CONF-8710107--

BNL--52114

DE88 008012

BNL 52114
UC-28
(Particle Accelerators and
High Voltage Machines — TIC-4500)

Proceedings of the 1987 ICFA Seminar on Future Perspectives in High Energy Physics

October 5-10, 1987
Brookhaven National Laboratory

Editor: P.F. Dahl

Sponsored by
Particles and Fields Commission of IUPAP
and
International Committee for Future Accelerators

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Brookhaven National Laboratory
Associated Universities, Inc.
Upton, Long Island, New York 11973
Under Contract DE-AC02-76CH00016
United States Department of Energy

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes:
Printed Copy: A20; Microfiche Copy: A01

Preface

A Seminar on Future Perspectives in High Energy Physics was held at Brookhaven National Laboratory, USA, on October 5-10, 1987. The Seminar was organized jointly by the International Committee for Future Accelerators (ICFA) and by Brookhaven National Laboratory. This is the second such occasion in the recent past, the first one having taken place at KEK in Japan on May 14-20, 1984. It brought together many leading practitioners in the field of high energy physics from all parts of the world to review progress in the construction of the facilities which will serve the field in the future, and to have an exchange of information and opinion on international and interregional cooperation in the development, construction, and exploitation of future facilities.

The first two days of the seminar were mainly devoted to a general overview of future prospects in theoretical and experimental physics, to the review of construction projects begun since the last meeting, and to a preview of future construction initiatives, either approved or in the development stage. Beginning on the second day there were two panel discussions on future cooperation in accelerator construction, and after a review of the work of the ICFA subpanels, a discussion on the role of these panels and on future cooperation in accelerator and detector R&D work.

In these Proceedings we have collected written versions of most of the invited talks. In many cases the written papers are more extensive and complete than the spoken versions. For the two panel discussions on accelerator construction, formal statements were given by the panel members during the first session, and comments made from the general audience were invited in the second session. The general discussion has been summarized by the editor and the session chairman. The activities of the four ICFA Subpanels over the last three years were described by their Chairman. The account of the panel discussion on future cooperation in accelerator and detector R&D and the role of the ICFA Panels has been similarly prepared by the editor and the session chairman.

As Local Chairman of the Organizing Committee, I am grateful for the partnership of Mrs. Pat Tuttle, Dr. W. Owen Lock, the ICFA Secretary, and Ms. Helga Schmal (CERN), and the guidance of Prof. Yoshio Yamaguchi, ICFA Chairman, in the preparations for this event. The Local Committee organized the technical arrangements (Per Dahl), the laboratory tours (Art Greene and Sam Aronson, assisted by Gene Kelly and his staff), external administrative arrangements (Herb Kinney), and the entire database of information and budgets (Penny Bagget and Pat Tuttle). Pat Tuttle and her able staff of assistants controlled all the organizational details before, during, and after the event. Per Dahl has served as Editor of these Proceedings, as he has so ably done before on other occasions. The many photographs which lend a touch to the Proceedings were taken by Mort Rosen and Peter Horton. These are the people who have made this seminar run as smoothly as possible.

Brookhaven National Laboratory and ICFA also acknowledge the support and the financial contributions of the US Department of Energy, of IUPAP and of its Particles and Fields Commission, and of UNESCO. It was because of the support of these agencies that a number of the participants from the Fourth Region were able to attend this Seminar. The US National Science Foundation has financed the initial publication and distribution of these Seminar Proceedings.

Horst W.J. Foelsche
Local Chairman of the Organizing Committee

Background Information

ICFA Seminar on Future Perspectives in High Energy Physics
5-10 October, 1987 • BNL, Upton, NY, USA

1. ICFA

ICFA is the International Committee for Future Accelerators, set up by the Particle and Fields Commission of IUPAP in 1976*. (The present membership is given in Annex 1). ICFA meetings have been held once or twice a year. The aim of ICFA as redefined in 1985 is as follows:

> "To promote international collaboration in all phases of the construction and exploitation of very high energy accelerators.
>
> To organize regularly world-inclusive meetings for the exchange of information on future plans for regional facilities and for the formulation of advice on joint studies and uses.
>
> To organize workshops for the study of problems related to super high-energy accelerator complexes and their international exploitation and to foster Research and Development of necessary technology."

ICFA has been active in many ways. Firstly, it has organized three workshops, viz:
two on "Possibilities and Limitations of Accelerators and Detectors" (Fermilab, USA, October 1978 and Les Diablerets, Switzerland, October 1979);
and one on "Possibilities and Limitations for Superconducting Accelerator Magnets" (Protvino, USSR, October 1981).

It should be stressed that it was at these ICFA Workshops that the prototypes of LEP and SSC were formulated and the idea of linear colliders born and first discussed.

In view of developments of planned and projected accelerators in different regions of the world (e.g. BEPC in China, HERA at DESY, LEP at CERN, SLC and SSC in the USA, Tristan in Japan and UNK in the USSR), ICFA organized a Seminar on "Future Perspectives in High Energy Physics" at KEK, Japan, in May 1984. There the current status of high energy physics as well as how to promote international cooperation were reviewed and discussed. The new guidelines of ICFA, quoted above, were formulated on this occasion.

Another outcome of this Seminar was to set up four ICFA Panels to stimulate worldwide cooperation in R&D relevant to high energy physics:

(1) ICFA Panel on Superconducting Magnets and Cryogenics
Chairman: G. Brianti (CERN)
(2) ICFA Panel on Future Instumentation, Innovation and Development
Chairman: T. Ekelof (Uppsala)
(3) ICFA Panel on Beam Dynamics
Chairman: N.S. Dikansky (Novosibirsk)
(4) ICFA Panel on New Acceleration Schemes
Chairman: A. Sessler (Berkeley).

Each Panel has about 16 members from 4 regions (CERN Member States, JINR Member States, USA and other regions of the world). Each ICFA Panel has met several times a year to discuss relevant issues, organized workshops or collaborated on existing conferences/symposia. Panels (2) and (3) have begun to publish respectively an Instrumentation Bulletin and a Beam Dynamics Newsletter.

ICFA considers it appropriate to organize the type of seminar held at KEK in May in 1984 at intervals of 3 or 4 years. Meanwhile, the progress of hadron colliders, especially the proposal to build a hadron collider in the LEP tunnel at CERN and the design study of the SSC project in the USA and increasing worldwide interest in R&D on linear colliders, led ICFA to decide at its meeting held in LBL in July 1986, to organize the next seminar at BNL, USA, in October 1987.

2. The 1987 Seminar

To draw up the scientific programme for this Seminar, ICFA held a special "extended" meeting in Balatonaliga, Hungary, on 13 and 14 April 1987, to which a number of senior scientists were invited (see Annex II for a list of participants). The programme that they drew up is attached. The basic aim of the Seminar was to conclude with some specific recommendations being formulated by ICFA to lead to more international and interregional collaboration, not only in carrying out experiments (where it is well developed), but also in accelerator research and development work and in accelerator design and construction.

The Seminar was limited to about 130 participants, being 20-25 per region, chosen by the ICFA members of the region concerned and meant to include theoretical and experimental physicists, accelerator specialists, laboratory directors and a few appropriate officials. It was hoped that a number of the participants would be under 40 years of age.

* For details of the early history, see E.L. Goldwasser, Proceedings of the 19th International Conference on High Energy Physics, p. 961 (1978), Tokyo.
For more recent activity, see Y. Yamaguchi, Proceedings of the International Symposium on Lepton and Photon Interactions at High Energies, p. 826 (1985), Kyoto.

ANNEX I

Membership of ICFA (as of January 1987)

Chairman: Y. Yamaguchi	**Secretary:** W.O. Lock
CERN Member States:	J. Sacton, H. Schopper, V. Soergel
JINR Member States other than USSR:	D. Kiss
USA:	B.D. McDaniel, L. Pondrom, N. Samios
USSR:	Yu. Ado, E. Myae, A.N. Skrinsky
China:	Fang Shou-xian
Japan:	Y. Yamaguchi
Fourth Region:	J. Tiomno
Chairman of IUPAP Particles and Fields Commission (ex officio):	I. Mannelli

ANNEX II

Participants in "Extended ICFA Meeting" Held at Balatonaliga on 13-14 April, 1987

ICFA Members and Panel Chairmen:	Y. Yamaguchi (Chairman), Yu. Ado, G. Brianti, N. Dikansky, T. Ekelof, Fang Shou-xian, D. Kiss, B.D. McDaniel, E. Myae, L. Pondrom, J. Sacton, N. Samios, H. Schopper, A.N. Skrinsky, V. Soergel, K. Strauch*, W.O. Lock (Secretary)
Invited:	J. Ellis, H. Foelsche, J. Sandweiss, D.V. Shirkov, V.L. Telegdi, A.P. Vorobiev

* Representing Chairman, IUPAP Particles and Fields Commission.

ANNEX III

Organizing Committee

Horst W.J. Foelsche (Local Chairman) **W.O. Lock** (ICFA)
Pat Tuttle (Seminar Secretary) **H. Schmal** (CERN)

Penny Baggett
Per Dahl
Arthur F. Greene
Herbert L. Kinney

Seminar Program

MONDAY, OCTOBER 5

10:00 a.m.-10:00 p.m.
REGISTRATION - Berkner Hall

ALL PROGRAM SESSIONS AT BERKNER HALL

TUESDAY, OCTOBER 6

8:45 a.m. OPENING SESSION
Chairman: G-Z Zhou

Welcome	N.P. Samios,
Opening Remarks	Y. Yamaguchi
Keynote	V.F. Weisskopf

10:00 Coffee Break

10:20 Updates of Ongoing Major Accelerator Construction Projects

BEPC	S-X Fang	15 min
HERA	F.J. Willeke	15 min
LEP	C. Wyss	15 min
SLC	R.D. Ruth	15 min
TEVATRON	H. Edwards	15 min
TRISTAN	S. Ozaki	20 min
UNK	N.E. Tyurin	20 min

12:30 p.m. Lunch

2:00 PHYSICS AS A FUNCTION OF ENERGY AND LUMINOSITY
Chairman: J. Tiomno

THEORY

New Physics in High Energy e^+e^- and Hadron-Hadron Collisions — J.R. Ellis — 40 min

Post-Fermi Scale Physics and Future Accelerators — S.S. Gershtein — 40 min

3:20 Coffee Break

3:40 EXPERIMENTS

Experimental Problems at Multi-TeV Hadron Colliders and TeV e^+e^- Linear Colliders — D. Froidevaux — 40 min

Detector Strategies and Questions for High Luminosities and Energies — R.F. Schwitters — 40 min

6:00 RECEPTION/BUFFET DINNER - Brookhaven Center (Hosted by BNL)

8:30 LECTURE
John M. Rowell
Bell Communications Research, Inc.
"The Science and Applications of High Temperature Superconductors"

WEDNESDAY, OCTOBER 7

9:00 a.m. FUTURE FACILITIES
Chairman: N.E. Tyurin

SSC	M. Tigner	30 min
PROJECTS UNDER DESIGN		
LHC	G. Brianti	30 min

10:10 Coffee Break and Photograph

10:45 Linear Colliders

CERN	W. Schnell	15 min
JAPAN	M. Yoshioka	15 min
USA	R.D. Ruth	15 min
USSR	V.E. Balakin	15 min

12:00 Lunch

2:00 p.m. PANEL DISCUSSION:
FUTURE COOPERATION IN
ACCELERATOR CONSTRUCTION (I)
Chairman: W.K.H. Panofsky

S-X Fang	15 min
L.M. Lederman	15 min
J.H. Mulvey	15 min
T. Nishikawa	15 min
B. Richter*	15 min
H.F. Schopper	15 min
V. Soergel	15 min
M. Tigner	15 min
N.E. Tyurin	15 min

8:30 CONCERT - The Composers String Quartet
Berkner Hall

L. van Beethoven Quartet Op. 18 #3
L. van Beethoven Quartet Op. 130
(with Grosse Fuge)

THURSDAY, OCTOBER 8

9:00 a.m. SURVEY OF THE WORK
OF THE ICFA PANELS
Chairman: V. Soergel

Superconducting Magnets
and Cryogenics
G. Brianti 30 min

Beam Dynamics
N.S. Dikansky 30 min

10:10 Coffee Break

10:40 Future Instrumentation,
Innovation and Development
T.J.C. Ekelof 30 min

New Acceleration Schemes
A.M. Sessler 30 min

12:00 Lunch

2:00 p.m. PANEL DISCUSSION:
FUTURE COOPERATION IN
ACCELERATOR CONSTRUCTION (II)
Chairman: W.K.H. Panofsky

S-X Fang
L.M. Lederman
J.H. Mulvey
T. Nishikawa
B. Richter
H.F. Schopper
V. Soergel
M. Tigner
N.E. Tyurin

BANQUET - Berkner Hall (Hosted by BNL)

6:30 p.m. Cocktails
7:15 p.m. Dinner

FRIDAY, OCTOBER 9

9:00 a.m. PANEL DISCUSSION:
FUTURE COOPERATION IN
ACCELERATOR AND DETECTOR R&D
WORK AND THE ROLE OF THE
ICFA PANELS
Chairman: U. Amaldi

G. Brianti
N.S. Dikansky
T.J.C. Ekelof
H. Hirabayashi
E. Keil
R. Leiste
R.B. Palmer
A.M. Sessler

12:00 Lunch

1:45 p.m. CLOSED ICFA MEETING

1:45 TOUR OF BNL SUPERCONDUCTING
MAGNET FACTORY (2 hours)

SATURDAY, OCTOBER 10

9:00 a.m. CLOSING SESSION
Chairman: I.M. Mannelli

Summary	J. Sacton
Recommendations	Y. Yamaguchi
Closing Remarks	N.P. Samios
Acknowledgements	I.M. Mannelli

* Represented by R.D. Ruth for this session.

In front of Berkner Hall - a relaxing sunny day.

ICFA Meeting on October 9, 1987.

Berkner Hall, site of Seminar

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Opening Session

WELCOME

N.P. Samios

Brookhaven National Laboratory
Upton, New York, U.S.A. 11973

Good morning. On behalf of Brookhaven I welcome the participants to this ICFA Seminar on the Future Perspectives on High Energy Physics. As we all know, this is a follow-up to the meeting which we held three years ago in Japan. Just a few weeks ago, we also had the occasion to celebrate the Fortieth Anniversary of AUI-BNL in this very auditorium. This we did with a symposium lasting two days, featuring six distinguished presentations on a variety of fields that are pertinent to Brookhaven's activities. We are equally pleased to host this Seminar on high energy and accelerator physics.

As one looks at the progress of the field over the years, one is impressed by two things. One, the international nature of our field. In an operational sense we are truly international. As one contemplates the gathering in this room, as one thinks back over the years, one sees examples of this. One sees Satoshi Ozaki - he helped build TRISTAN, but spent twenty years at this Laboratory. One thinks of T.D. Lee in the context of U.S.-China negotiations. I think he's on the American side, but I don't know that for certain. My thesis advisor, Steinberger, spent many years at Columbia, and for the last twenty years has been a distinguished member of the CERN experimental group. And lastly, of course, Carlo Rubbia, who is truly international; I think he's a Harvard professor but I believe that for the next six months he is going to insist on his Italian lineage.

I also note great progress that the international community has made in accelerators. TRISTAN in Japan has been operational for a year - a very beautiful machine that was brought in on time -- exactly on time -- and has operated smoothly from the start. It is the highest energy e^+e^- machine in the world. The TEVATRON, the $p\bar{p}$ collider, came into operation last year and has a full experimental program. Again, it is the highest energy hadron machine in the world. Parenthetically I would note that at CERN and at Brookhaven, we successfully accelerated light ions of atomic number 30 to high energies. Under construction, awaiting imminent start-up, is the SLC. The

SLC is the first venture into e^+e^- linear colliders in the United States. BEPC in China is a high luminosity e^+e^- machine which will come into operation in October of next year. LEP at CERN is a real gangbuster machine, expected to be operational in the Summer of '89. HERA under construction in Germany - a very high energy electron-proton collider -- is a very ambitious project. UNK in the Soviet Union is a machine which will have both TeV fixed target and collider capability. We look forward to hearing about these exciting projects over the next few days.

We in the United States are particularly gratified by the decision of the President of the United States to proceed with the SSC. In this regard, I am pleased to read excerpts from a letter sent to this Seminar from the Secretary of Energy, John Herrington:

> I would like to extend a warm welcome and greeting to those of you assembled for the International Seminar on Future Accelerators. I am especially pleased that you have chosen Brookhaven, one of our great National Laboratories, in partnership with the Department of Energy as your meeting site. We share a common belief that basic science is the foundation for future technological progress for all mankind and that frontier fields like high energy physics stimulate frontier technologies. President Reagan's recent decision to support construction of the SSC represents the opportunity to continue your exploration to the next century within one of the greatest frontier technologies ever conceived. We believe that the facility holds a vast potential for all mankind to begin a new revolution in science, education, technology, and commerce. Although Congress has not yet authorized construction of the SSC, I am working closely with them to convey this message and build the understanding of this revolutionary project.

But of course, we don't stand still there; there are future plans for the LHC, a $p\bar{p}$ collider at CERN, and, as you will hear, plans for many linear colliders in Europe, the USSR, Japan and the U.S. And then, of course, there's the ELOISATRON, a one-man international laboratory. Quite a lot of activity.

I welcome you again and look forward to a lively and enlightening few days. Thank you.

OPENING REMARKS

Yoshio Yamaguchi
Department of Physics, Tokai University
Kitakananie 1117
Hiratsuka-shi, 259-12 Japan

Distinguished Guests, Dear Hosts and Dear Colleagues:

It is my great honor and pleasure to present this address on behalf of ICFA, the organizing body of this Seminar at Brookhaven.

First of all I express my sincere acknowledgments to Brookhaven National Laboratory, particularly its Director, Dr. Nick Samios, and to the host organizer, Dr. Horst Foelsche and his secretaries, whose marvelous preparation and hospitality made it possible to hold this seminar in such excellent surroundings.

Secondly, many thanks to the ICFA Secretary, Dr. Owen Lock; without him I cannot serve as ICFA Chairman. I acknowledge with gratitude the U.S. Department of Energy, the National Science Foundation, Associated Universities which operate BNL, UNESCO, IUPAP and the IUPAP Commission on Particles and Fields for their generous financial support of this Seminar.

Now let me go on to explain a little bit about ICFA, though some of you know already, as there are perhaps many who may not be familiar with it. ICFA stands for International Committee for Future Accelerators, set up by the Particles and Fields Commission (C11) of IUPAP in 1977. It actually stemmed from East-West meetings, starting in 1967, for the purpose of organizing collaboration between CERN and CERN member countries and JINR (Dubna) and its member states, an effort which the USA subsequently joined, culminating with the world-wide Seminar on Future Perspectives in High Energy Physics organized by Prof. Viki Weisskopf in 1975 at New Orleans.

At New Orleans, leading physicists, accelerator experts and people from funding agencies were gathered from East and West Europe, North and South America, Asia and Oceania. There the idea to form ICFA was born. Then, a Serpukhov-Moscow meeting paved the way to ICFA and finally C11, following discussions at Tbilisi in 1976, set up ICFA in 1977 at its meeting at Hamburg.

ICFA has organized workshops, and made great contributions to the high energy physics communities. More importantly, it formulated the ICFA guidelines for the Interregional Utilization of Major Regional Experimental Facilities for High Energy Particle Physics Research, which were approved by all directors of major high energy labs in the World.

An ICFA Seminar with the same title as the present one was held at KEK in 1984, whose Proceedings are available from KEK. I shall skip the details of activities of ICFA which are described fully in the Proceedings of the International Seminar on Lepton and Photon Interactions at High Energies in 1985 (Kyoto) and 1987 (Hamburg) by myself. It suffices to note that four ICFA Panels were set up by ICFA as a result of the 1984 Seminar, whose reports are scheduled at this Seminar.

Lastly, an important remark is in order. I notice, and many of you also must be aware, that there is an increasing tendency to boost applied physics, or physical engineering rather than basic physical research, such as high energy physics. This is not only in governmental agencies for science and/or technology and industrial strata but also even in scientific communities, as evidenced by the recent creation of vice chairmen from industry in IUPAP Commissions on specific subjects.

This implies that we, high energy physics communities, are facing a rather hard environment in most parts of the world, at least in the near future, in spite of the obvious need to go to even higher energies in search of ultimate micro-structures and laws of nature which necessitates increasing manpower and financial/material resources. Accordingly, we have to be wise enough to utilize our potential, possibilities and resources with the greatest possible efficiency.

Here today from all regions of the world are gathered leading senior physicists, active physicists, accelerator experts, as well as persons in charge of financing the high energy research programs. I urge that we do our utmost to ensure the success of this Seminar. Though discussions here might be heated, I wish very much that a general consensus can be formed so that the outcome of the Seminar --conclusions, recommendations, on whatever we can agree on-- will be of maximum usefulness for the future of high energy physics and that the next generation will appreciate the outcome of this ICFA Seminar.

Now I call on Professor Weisskopf to deliver the Keynote Address. I respect Viki Weisskopf enormously as a physicist. In all respects he is the Father of ICFA. Without his enthusiastic initiative for international cooperation/collaboration ICFA would not have been born.

KEYNOTE ADDRESS

Victor F. Weisskopf
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

My dear friends and colleagues: I was deeply honored to be asked again to be the Keynote Speaker at this ICFA meeting. I accepted with pleasure, although I do no longer follow high energy physics in detail. I look at it from a distance which may be an advantage for an introductory speech. I also would not turn down an invitation to speak before an international body like this, since I devoted a good part of my life to further international collaboration in science.

Let us look at the last 15 years of high energy physics in order to see where we have to go from here. Our field can be divided into three parts: 1. Accelerator construction; 2. Experimental physics; and 3. Theory. Accelerator construction went through a decisive change from fixed-target machines to colliders, both of proton with protons or antiprotons, and of electrons with positrons. I feel a personal pride of having taken part in planning and realizing the first p - p collider, the ISR. We called it at that time "a window to the future." But that future is here! Almost all machines under construction, planned or studied, are now colliders.

A striking development in experimental physics was the introduction of new kinds of detectors, wire chambers, drift chambers and other devices that allow direct electronic registering and immediate computer evaluation. Bubble chambers became obsolete; there are no scanning girls anymore (it had some sociological consequences as to the choice of spouses by young experimentalists). The experimental results were impressive. They are well known to this audience. I mention only a small section: the third electron, two new quarks, the discovery of neutral currents, of the W and Z boson and other confirmations of the electro-weak theory, the deep inelastic scattering by nucleons of electrons, neutrinos, and x-rays, which gave us direct evidence of the existence of quarks and a deeper insight into the inner structure of hadrons.

What did theory achieve? We saw the development of the standard model.

It consists of the electro-weak theory that establishes a connection between electromagnetism and weak interactions, and quantum chromodynamics, the theory of strong interactions. Both developments represent ingenious generalizations of gauge-field theory. Attempts were made toward a unification of these two developments in the form of a Grand Unification Theory, which is not yet in its final form. The earlier attempts predicted a finite lifetime of the proton, much shorter than the lower limit determined by experiment.

But let us not forget that the standard model is a "phenomenological" theory. It contains a large number of constants not determined by the theory, such as the masses of the particles, coupling constants and mixing angles. It is not a complete theory. However, all predictions of that standard model that were testable with present day machines have been confirmed. This is an overwhelming success which may have some negative consequences, to which I will come later on. Another important feat of theory was the establishment of connections between particle physics and cosmology, in particular with the processes supposedly going on shortly after the Big Bang. This has given high energy physics a deeper significance. We can be justifiably proud of replicating in our laboratories the processes that probably happened during the first fraction of a second after the beginning of the Universe.

Nevertheless, the spotless confirmation of the standard model is disappointing to me. There is no evidence of trouble in this incomplete theory that may give a theorist a point of departure to improve and complete the theory. Therefore their attempts to do so hang in the vacuum (perhaps suspended on superstrings). I am not well acquainted with the details of those new attempts but I am worried that they are based upon assumptions that, so far, have no confirmations whatsoever by experiment. No new particles required by sypersymmetry have been identified; the weakest part of the standard model--the Higgs' sector--is basic to their attempts, but no Higgs' particle has been seen so far. The new theories are attractive since they seem to avoid the awkward divergences and anomalies of the standard model and, last but not least, since they include gravity which so far has been outside the theoretical models.

Will the great success of purely theoretical reasoning be repeated that we witnessed with Einstein's general relativity, or even with the electro-weak unification? How long can the success of theoretical speculation last? There is only one way to find out: we must transgress the limits of energy, luminosity and detection ability that we encounter in our present facilities. There we will enter into new realms of phenomena which, probably, will be richer and more surprising than any theoretical speculation has foreseen.

Energy is always the most important barrier to transgress. We are now at the TeV limit. I use this term also for electron-electron (or positron) colliders up to 0.1 TeV; lepton collisions are expected to yield similar results as proton colliders at a tenth of the energy, since they are probably pure particles and not composites of quarks and gluons like the protons. However, new results can and should be searched for also with machines at presently used energies by employing higher beam intensities and luminosities and by developing more accurate detectors. New unexpected phenomena may well be discovered also by facilities with newly constructed accelerators below the TeV limit, as for example, Tristan at KEK in Japan or HERA at DESY, and by improving the performance of existing facilities. This is true in particular of certain "low-energy" hadron phenomena below 0.1 GeV where the results of QCD are hard to get at, since perturbation theory does not work. We may expect in the near future new theoretical predictions in that region which must be tested by experiment.

We have reached the TeV limit at the Tevatron at Fermilab with almost 2 TeV in the center of mass and the LEP electron collider under construction that will reach 0.2 TeV in a few years. We must try to transgress it. I expect that we will find a new world as we always did when an important limit is transgressed. Whether they agree with theoretical expectations or not is of no importance. It may even be more interesting if they do not. There are already many activities around the world for reaching higher energies. We were given a list by Nick Samios in his introductory talk. Some are under construction, such as the UNK program in the USSR which may reach 6 TeV in the center of mass. Then we have the SSC in the USA with 40 TeV, a project that is discussed and developed in detail, not only among physicists and engineers; it has serious support in the US Government and in Congress. Its construction is not yet approved, but there is a reasonably good chance that it will be. In Europe serious studies are going on about constructing the LHC, a hadron collider in the LEP tunnel reaching 15-20 TeV. Furthermore, there are intensive studies underway about the feasibility of a linear electron collider of several TeV. This is a difficult technical problem which requires much research and development. Such studies are carried out at CERN, in the USSR, in Japan and in the USA. It would be a new way of getting particle collisions. New ways are highly desirable. It was successfully pioneered at SLAC with the construction of colliding linear electron beams at 100 GeV in the center of mass. However, the problems of reaching the TeV region are not easy to solve.

The difficulties of breaking the TeV barrier are manifold. Some are political and some are technical. The former usually are more difficult to overcome than the latter. None of the machines beyond the barrier are approved with the exception of the UNK complex in the Soviet Union. The European plans are under study by the physicists and engineers but they are not yet considered by the governments. We don't know whether the SSC will be approved and how much time it will take.

I can and will say little about the technical difficulties. They will be discussed at length at this meeting. In very short terms, I believe I am right to say that p - p colliders do not offer great technical difficulties; we know in principle how to build them, but some serious hurdles will have to be overcome in building detectors to find specific processes, since the amount of "junk" produced by high energy proton collisions is enormous. We will have to find needles in haystacks. In contrast, the e - e colliders present serious difficulties in construction; we really don't know yet how to build them, but the detector problems will be much simpler since considerably less "junk" is produced by electron collision.

Let me now proceed to problems that are of special importance for ICFA. Particle physics is an international enterprise. I would have liked to use the term "supernational" since the interest and the driving forces are beyond any national, regional or cultural concerns. But the word "super" has been overused in this field. We must ask the question: Is there enough international collaboration; is there enough international spirit in our undertakings? I am not convinced that it is so.

At present and in the near future, the construction of large facilities will be mainly national. (Some people use the word "regional" since Western Europe isn't one nation. I would like to stick to "national." I always considered CERN as the first step to a new nation: "The United States of Europe" at least as far as science is concerned. This is probably one of the greatest achievements of CERN apart from its scientific successes. Today we have more such organizations: EMBO for Europe Molecular Biology, ESO for the European Southern Observatory, and ESA for the European Space Agency.) The construction of new accelerators is planned on a national scale, without excluding technical and financial help from other nations. However, the exploitation of national facilities is to a great extent international.

Unfortunately, I sense a nationalistic trend in the latest developments. I believe there was not enough mutual understanding and discussion between the nations about their future plans. This did lead to a certain degree of misunderstanding, especially between Western Europe and the USA in regard to the SSC versus the LHC project. There were indications of a spirit that should not be present in our work community. Here are a few examples. There is a sub-panel on high energy physics of the Economic Summit Committee which deals with questions of international collaboration. That sub-panel contained a number of physicists of other nations but none from the USA. That panel may be an excellent body to establish important international collaboration between physicists and government representatives. Why do the USA physicists neglect this opportunity?

Another example is what I read and hear about the reasons given for the SSC. To my mind, and I hope to the mind of all of us here, the purpose of the supercollider is to widen the frontiers of knowledge, and to be exploited internationally. In other words, to widen the frontiers for all high energy physicists in the world; and not as I read and hear too often, to put the United States again as the leading nation in high energy physics. First of all, the United States was and is still a leading nation in that field. The whole idea of one leading nation is something that goes extremely against my grain. The United States will be a leading nation not because of the facilities within their frontiers but because of the excellence of their physicists. This excellence shows up whenever they do their work, for example when Sam Ting does his experiments at LEP. Furthermore, why was a Canadian offer rejected out of hand to locate the SSC at or across the Canadian border, with active Canadian participation, including delivery of cheap Canadian power?

I hasten to add that these remarks are not arguments against the SSC. There is no question in my mind that the SSC will be a great boon for high energy physics all over the world, if it will be approved and constructed in due time. First of all, because it is a good and useful machine reaching a most interesting energy region. The high cost is an advantage! It will show, if approved, the great value that the US assigns to high energy physics. It will encourage other countries to emulate the US and support large projects. It will raise the esteem for particle physics all over the world. Unfortunately, the reverse is also true. If the SSC is turned down, it would have a strong damping effect on the world efforts to transgress the TeV barrier. I believe, therefore, that the realization of the SSC is important for the world of high energy physics. It needs international support. All regions should support it in words, deeds, with technical help and, whenever possible, with financial contributions. World interest should be shown by expressing willingness to participate in the exploitation, by proposing experiments and detector systems which would be brought in if and when the machine is ready. The studies to construct the LHC should by no means stop. After all, we are not sure as to whether the SSC can be approved within a reasonable time period. If that period is too long, it might well be sensible to build the LHC, but not for the sake of European predominance, but for the sake of an earlier insight into the new world of phenomena in that energy region.

In the future, we certainly will have a distribution of different facilities in different regions of the world. International distribution of machines is desirable because of two reasons. First because of the high cost of these facilities, but also because it will express the international character of the field. We will have realized the much talked about World Laboratory of Particle Physics, but not at one place. Parts of it will be distributed all over the world.

It will function only if international exploitation is well organized. So far it has functioned reasonably well. Sure, there were frictions and sometimes unnecessary restrictions but we have Europeans, Soviet citizens and Japanese working in the USA and many international guests working at CERN and at DESY. It will have to be improved in order to make good use of large facilities placed in different regions. If international exploitation is well organized, there should be no reason against working at a facility in another continent. After all, the distances of New York to Geneva and New York to California are comparable.

Nevertheless, international exploitation of large unique facilities will bring about a number of problems. Teams from abroad must have similar access as local teams. We must guard against the tendency of favoring teams from the country that has built the machine. Perhaps we may need international selection committees for experiments and some international body to check whether international exploitation worked satisfactorily. It should not control or supervise it, but it should act as an advisory body to point out weaknesses and abuses.

Let me finally express a serious warning. High energy physics has become less popular than it was. Unfortunately, other branches of the physics community are increasingly opposed to the support of particle physics because they fear that money is siphoned away from them. I don't think this is the case. On the contrary, large amounts for one branch of science will increase the support for all sciences. The US Government proposed the doubling of the budget of the National Science Foundation together with the support of the SSC. I believe in what I like to call "Bose Statistics" in science budgeting. A large sum for one branch has an effect on the visibility of science in general and will in the long run bring more support for all sciences.

We also need the support of the public in general. We need it more than before since we are asking for more support. It is the public opinion that influences governments and Congress in the USA, and corresponding authorities in other countries. Not enough effort is spent to study how to make high energy physics fascinating to the public. The intimate connection with cosmology and the origin of the world helps a lot. Somehow the stars and the story of the beginning of everything remain fascinating subjects.

In my opinion, we should put less stress on the search of the fundamental laws of nature, but more on the fact that we are looking for new modes of behavior of nature, for new processes, way beyond what was ever expected. We are after the very processes of creation that are yet mostly unknown.

I would propose to ICFA to create an International Public Enlightenment Center that brings together the attempts in that direction that have been made in the different countries. It should study how to improve these efforts—how to make them more effective. It could organize press conferences, media events, comic books, exhibitions, translations of publications, and similar activities. Many of these activities in one region are not known in other regions, such as the exhibition "The Dance of the Universe" made in France with great success. Also, more stress should be given to the educational value of working in our field. It teaches the students attitudes that are useful in so many other human enterprises, such as team work, the science-technology relation, managing large technical enterprises, looking for unconventional solutions, and readiness for new ideas.

In order to proceed successfully as in the past, we will have to work harder during the next 15 years, not only in physics and technology, but we also must be more aware of our role in society since we ask more from society.

But I am optimistic about our success. I wish I could see, hear and enjoy what wonderful new things you will find in the next 15 years. If all nations work together and not against each other, and if I stay healthy, maybe I will indeed be able to do so.

Current Status of BEPC
(The Beijing Electron Positron Collider)

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Introduction

BEPC (Beijing Electron Positron Collider) is the first high energy particle accelerator to be built in China. It consists of four main subsystems: a 1.4-1.55 GeV electron positron linac, a 2.2-2.8 GeV storage ring, a magnetic spectrometer for high-energy experiments, and synchrotron radiation facilities. The designed luminosity is 1.7×10^{31} cm^{-2} sec^{-1} . The total budget is 240 million Chinese Yuan (RMB), which is equivalent to about 80 million US dollars in 1984. It was approved by the government in April 1983 and is scheduled to be completed by the end of 1988.

There are two purposes for building such a collider. The first one is to do particle physics research, such as charmed particle physics and lepton physics; the second one is to provide synchrotron radiation in VUV, soft X-ray and hard X-ray for scientific research and applications in other sciences.

So far the tunnels for the electron linac and the storage ring and the experimental halls have all been completed. The experimental halls for synchrotron radiation will be available for installation at the end of this year. Most of the conventional facilities have been installed and put into operation. As to the components of the collider, great progress had been made in developing the prototypes in 1985 and batch production in 1986. Up to now, most of them have been fabricated with the exception of the R.F. cavity. Tests showed that their performances have reached the designed requirements. The 1.4 GeV electron linac was installed at the end of August, this year, and its sub-system is under commissioning. Beam adjustment was carried out of the first 250 MeV section last February and a positron beam was produced last May with a beam intensity of 2.5 mA and an energy of 100 MeV obtained. The installation of the transport line was finished last June. All the magnets and some of the vacuum chambers for the storage ring have been put in place. Most of the I&C hardware has been tested and is being assembled. Besides, most of the software has been debugged. All its cables have been laid, and the system assembly and connection to equipment are underway. The BES coil and magnet were fabricated last February and were successfully assembled in the experimental hall last March. The central drift chamber, the main drift chamber and the barrel part of TOF and the shower counter have all been assembled. They are now being tested. Measurement of the magnetic field of BES cannot be finished until the end of this year and its general assembly has to be postponed by about 4 months because of the delay of civil engineering construction and the unavailable water system. General assembly of the electronic systems of detectors has started. As to the front ends of synchrotron radiation, the main components have been fabricated. They are now under installation. The main optical equipments of the third beam line have also been manufactured. Tests showed that their performances were fine.

Civil Engineering

Figure 1 is a layout of the BEPC project which involves a total building floor space of 24,000 square meters. Since the ground was broken on October 7, 1984, the construction of the collider housing has been proceeding well. So far 16,000 square meters have been completed, including the tunnel for the electron linac, the klystron gallery, the tunnel for the beam transport line and the storage ring, the experimental halls of the first and second interaction point, the buildings for R. F. transmitters and power suplies of the storage ring. The experimental halls for synchrotron radiation are expected to be finished at the end of this year and the building of the computer center in the middle of 1988. Generally speaking, civil engineering has been progressing rapidly, but still cannot meet the requirement of the overall schedule of BEPC project. Compared with the original plan, some items were delayed by one or two quarters, which brought some difficulties to the installation and commissioning of certain components.

Linac

Table 1 shows the main parameters of the electron linac. Compared with the data published in 1983 [1], the major modification according to paper [2] lies in the shift of the positron production target from 340 MeV to 150 MeV with the total length of the linac unchanged. Besides, thanks to the successful developemnt of the 30 MW klystron, the output energy of the electron linac can reach 1.4--1.55 GeV, thus full energy injection may be possible when physics is done in the region of 1.55 GeV.

a. Main Components of the Linac

All components of the linac are ready. 56 disk-loaded wave guides were fabricated in-house. A dedicated production line was established in 1985 with a special large hydrogen furnace. A 3.05 m long disk-loaded wave guide can be brazed in full length in the furnace. The monthly output is 6. By the end of 1986, all the accelerating tubes had been finished and adjusted. Test showed that only 3 did not meet the designed parameters. In a 3.05 m long accelerating tube, the maximum phase shift between cavities is < 2.5 , attenuation constant is < 5db, and the standing-wave ratio is < 1.2 when the band width is 4.5 MHz. The 1A electron gun has also been fabricated and is being used. The pre-buncher, the four-cavity buncher with a phase speed of Ø.75c and the focusing coil for the first accelerating tube are all available. 14 pieces of the energy doublers were fabricated in-house with Q<95ØØØ.

All the 16 klystrons have been manufactured with the output power of each reaching 3Ø MW. For main parameters, see Talbe 2. All the modulators have been put in place and tested with dummy load of water and the first 4 modulators used at the 25Ø MeV section are in a combined operation which show good performance.

b. Installation

In order to find out problems that may emerge from the key components by putting them under system integration test and checking positron production and positron acceleration, installation of the linac was conducted in two steps. The first step was to install the first 25Ø MeV section and at the same time, to set up the auxiliary equipments necessary for the commissioning of the 25Ø MeV section, such as water, electricity, heating and ventilation. The second step was to carry out in turn the commissioning of the 25Ø MeV section and the installation of the rest of the linac which started from the way back to the 25Ø MeV section.

The installation of the 25Ø MeV section started from May last year and soon a lot of difficulties were encountered. The first one was the high humidity in summer in the tunnel that forced the installation to discontinue for more than two months. The second one was the TIG welding between flanges of the accelerating tubes, which took us three months to solve. Besides, the installation of some components took a long time because of the lack of a detailed installation layout and our inexperience during the initial stage of installation. It was just because of this that the installation of the 25Ø MeV section was not finished until the end of last year. And it was not put in trial operation until last February because the conventional facilities were unavailable.

Thanks to the experience obtained in installing the 25Ø MeV section, the remaining part of the 1.4 GeV linac has been proceeding well. The installation of the whole linac was completed at the end of August, this year. Now its sub-system integration test is underway. It is expected that the 1.4 GeV linac will produce a beam in November.

c. Commissioning of the 25Ø MeV Section.

One of the main function of the 25Ø MeV section is to produce positron beams. It consists of one ns electron gun, one pre-buncher, one buncher, one positron converter, eight accelerating tubes, one energy doubler and four klystron amplifiers. The first five accelerating tubes can accelerate the electrons to an energy of 15Ø MeV which bombard the tungsten target to produce positron beams while the last three accelerating tubes are used to accelerate the positrons to 1ØØ MeV collected by the magnetic focusing system. As we did not have enough standby klystrons, the maximum power of klystrons had to be limited to <20MW in the initial phase of commissioning. When the above energy of electron and positron was reached, the maximum output power of four klystrons each was betweem 14 MW and 17 MW and the highest working voltage of the coresponding modulator was 230 KV. In the beginning, the modulators interferred the control circuits greatly with a level of over 100V. After the shielding of the modulator was improved, the interference was decreased to 1V. One energy doubler works normal with Q>95000. The microwave drive system can meet the requirements. The only problem lies in the travelling wave tubes whose lifetime is too short. Better travelling wave tubes are being procured.

The vacuum system has met the designed parameters with 2×10^{-7} Torr obtained in accelerating tubes and 7×10^{-8} Torr in the rectangular wave guides.

Temperature control of the cooling water system has preliminarily met the requirement. The temperature of the cavity can be controlled within 45° 0.2°C. But the gases in the water system cannot be totally excluded, thus causing instability of the water pressure and great noise.

The positron source is composed of one target, one pulse flux concentrator and one pulse power supply. The maximum pulse current can reach up to 6000 A and the magnetic field 28000 Gs which basically meets the needs of focusing.

Since the installation of the computer control system cannot be finished until the end of 1987, only the manual control system is available in the local control station for the 250 MeV section. Operations showed that the monitoring of all the devices, adjustment of the current and voltage, the interlock protection of the components and the synchronous trigger system all work well.

The beam diagnostic system of the 250 MeV section consists of five beam intensity monitors, three profile monitors, two energy spread monitors, six beam loss monitors, a set of data acquisition system and the corresponding electronic interface circuits. They all work well. Particular mention should be made of the beam intensity monitors which can detect the positron beams with a current of 40μA. Undoubtedly, this will be very helpful to the testing of the positron beams.

The 250 MeV section has been commissioned four times which amount to sixty days and nights. The main parameters obtained so far are shown in Table 3.

The above values showed that the commissionings, R&D and installation of the 250 MeV section are successful and that the conventional facilities are also fine. The commissionings, however, did reveal some problems. The principal one is that the linac vacuum system is seriously contaminated. Repeated checks showed that the tapered load has not thoroughly been cleaned. The only solution to this problem found so far is to conduct prolonged baking of the tapered load in a separate vacuum system. Efforts are being made in this regard. In order to increase the positron production, a new high current electron gun with 5A is being developed.

Storage Ring

The main parameters of the Storage Ring are given in Table 6.

More than 95% of the non-standard components of the storage ring have been delivered and are being tested except the RF cavities.

a. The Magnet systyem

The storage ring consists of 40 dipoles, 60 quadrupoles and 8 insertion quadrupoles. All the cores are made of stacked laminations. Each lamination is 0.5 mm in thickness. The cross-section of a dipole is of C type. For easier fabrication, the curved core has been changed to a straight core, and thus the horizontal aperture is 150 mm, 30 mm is sagitta and the vertical aperture is 70 mm. The bending magnets were manufactured by a factory in Shanghai. By using 5 long coils existent in parallel in the air gap, the integral field distribution of the dipole can be obtained along the radial direction. The integral field discripancy between bending magnets ($\Delta Bl/Bl \leqslant 3\times10^{-4}$) is better than what theory requires.

The first die for making quadurpole laminations was manufactured by US industry with the arrangement of FNAL, and the second one was made by our machineshop. The quadrupoles were fabricated in-house. Measurements show the discrepancy is $\Delta Gl/Gl \leqslant \pm 0.6\times10^{-4}$, which is also better than the requirements. 8 insertion magnets were manufactured by Hitachi with the arrangement by KEK, and its field measurement and shimming were made in KEK with the help of our Japanese friends. Now they have been sent to our institute and are being re-tested and re-shimmed. The dipoles & quadrupoles for the transport line have also been delivered & measured. Testing of the wiggler magnet is underway.

b. The RF System

Owing to the available technology in China at the time of designing (1982-1983), 200 MHz had to be chosen for the RF system. It consists of two cavities, each of them is powered by four 30 KW RF transmitters. In developing the RF system, we have encountered a lot of difficulties. In the begining, the anti-multipactor coating technique was not adopted on the ceramic window. When 50 KW was transmitted into the cavity, the multipactor occurred and the ceramic window was broken. Later, the technique adopted was to sputter the side of the ceramic window facing the vacuum with 100Å TiN. Since the technologies and test equipments were backward, the efficiency was so slow that it was not until last June was the first ceramic window sputtered with TiN. It is now being tested. The second window made of 99.5% ceramic was finished last July.

In order to quicken R&D of the ceramic windows, a special group was set up to tackle this problem and at the same time, SLAC was asked to help manufacture two ceramic windows.

The first RF cavity was finished last August and it is under aging test. The second one will be finished at the end of this month.

Eight RF transmitters have already been in place, but the test of them one by one did not start until last June because of unavailable electricity and cooling water. Combining test of the four RF transmitters on the west side is being made and that of the RF transmitters on the east side will be finished in January next year.

Besides, the conditions for testing the RF cavities have been improved, including the setting-up of the automatic tuning loop and photoelectric protection system, etc.

c. The Vacuum System

After the Al vacuum chambers extruded by a U.S. manufacturer were shipped to China, the pumping hole,the bending and the welding were done by Chinese industry. When the cleaning of these chambers was finished in-house, the distributed ion pumps made of stainless steel and Ti pieces were installed in the DIP chamber, and the beam position monitors and synchrotron radiation masks were welded in the beam chamber. So far, more than half of the chambers have been finished and pumped down to 10^{-10} Torr. One section of 7m long vacuum chamber has been installed inside the dipole gap. Pumping speed test with the distributed pumps showed that the vacuum has reached 2×10^{-10} Torr when the magnetic field was between 5000 to 9000 Gs, and that the pumping speed could reach 200l/s.m which has met the designed specification when the vacuum was 10^{-8} Torr.

d. The Injection System

The main components of the injection system, such as the Lambertson magnet, the electrostatic separators and kickers have all been delivered and measured. The field uniformmity in the good field region of the Lambertson magnetsis better than 2×10^{-3} and the leakage field is about 1×10^{-5}. The thickness of the Lambertson septum is less than 7mm. The current stability of its high precision power supply has reached 1×10^{-4}.

High vacuum test of 5 electrostatic separators has been made, which showed that the vacuum has reached 6×10^{-10} Torr. Analysis of the residue gas indicated that it was in full agreement with the requirement of the high vacuum of the storage ring. High voltage applied has reached $\pm$ 60KV. The current stability of the power supply for electrostatic separators during long time operation has reached 5×10^{-4}/24 hours.

Six kickers have undergone high vacuum test and pulse field measurement. High vacuum test showed that the vacuum has reached the same level as that of the electrostatic separators. Field measurement showed that the field uniformity is $\pm\, 2\times10^{-2}$ within 50mm of the median plane of the deflection plate. The discharging circuit of the pulse power supply has been adjusted. The rise time of the rectangular wave form is 200ns, the fall time 400ns and the top width 300ns.

e. Installation

The installation of the transport line and the vacuum chamber has completely finished and the subsystem test is underway.

Measurement of the survey network of the circular tunnel has been finished, and the precise coordinate of each control point provided.

The installation of the storage ring was carried out in two steps. With the co- girder structure used, magnets were pre-aligned relatively and precisely cell by cell outside the tunnel and then moved into the tunnel. This has greatly shortened the time for installation of the storage ring. It is expected to be finished in October this year, followed by subsystem integration test. If everything turns out to be all right, the first beam running in the ring will be tested by the end of this year.

f. Instrumentation and Control

The design of the BEPC contyrol system was developed on the basis of the SPEAR new control system. One VAX 11/750 was used as the main control computer with a 6 MByte memory, a 912 MByte disk and 3 control consoles. Each consol is composed of graphics dispaly, touch panels and programmable control knobs. A VAX-CAMAC Channel(VCC) with data transmitted by serial optical fibresis used in this data acquisition and processing system. The VCC is an interface designed by SLAC and used at VAX computers for the CAMAC system. There are about 350 CAMAC modules and 700 interface modules connected to about 900 components of the collider, such as the magnet power supply, the vacuum system,the RF transmitter and the beam diagnositics system.

The VAX-VCC-CAMAC system had been established by the end of 1986. The technologies concerning hardware or software of the serial optical fibre communication, the console graphic processing, the large timing data-base and the schedule of the BEPC operating system were basically solved. Computer controlled on & off operations of 172 power supplies of various kinds were conducted and the synchronous RAMP simulation with an accuracy of 2×10^{-4} and 8000-16000 steps made. System integration test of the actual power supplies was also carried out. Thus, a set of software system for BEPC power supplies has been established.

The closed orbit measurement has been made and the display system of BPM debugged. This system can collect data, sample ns signals from 128 buttons of 32 position monitors, correct the errors quickly and then display on screen the deformation of the closed orbit of the beam.

In addition, all the control racks, crates and consoles in the local station and the main control room have been in place. All the special controllers and interface modules and the control subsystems have been accomplished and all the control cables and the optical fibre laid. System assembly and connection to equipments are in progress. According to schedule, combining test of hardware and software system and on-line debugging of the sybsystem control are expected to be finished in November this year. A working control station with minimum control function will be provided for the commissioning of BEPC at the end of this year.

The timing system was designed on the basis of that for the storage ring at KEK. With the help of KEK's experts, 150 kinds of modules and interfaces were purchased and jitter was measured at KEK. The jitter time is <200 PS which met the requirement of timing during the operation of the collider. Its installation will be finished in November this year.

As for the beam diagnostic system, all the 32 BPM for the storage ring have been TIG welded to the vacuum chambers with mapping test made. The measuring system of the synchrotron radiation light, DCCT monitor and beam scrapper have been fabricated. The Q measuring monitors and the fluorescent targets in the ring are being manufactured.

The beam diagnostic system is now under commissioning and system integration test will start following the installation of the monitors.

Beijing Spectrometer(BES)

The main parameters of the spectrometer are given in Table 5.

a. The Central Drift Chamber

The fabrication of the central drift chamber was finished in the middle of this year. Test showed that its performances have met the designed specifications.

b. The Main Drift Chamber

For the main drift chamber, beam test of the prototype of multi-layer cell was made at KEK in 1986 with dE/dX, position resolution, etc. measured. The test confirmed the advantages of such a structure. Wire stringing began at the end of 1986. By the end of last July, 19380 wires have been strung. Sealing and leakage detection are in progress.

c.The Time of Flight Counter

All the 48 cells of the barrel part of the time of flight counter have been made and test showed that their performances can meet requirement. It is expected that all the 48 end caps will be finished before November, this year.

d. The Shower Counter

The assembly of the shower counter was accomplished last March, but dislocation was found from layer 4 to layer 8. Following the modification of the technology of clamping the segments together with circumferential bands, the barrel shower counter was reassembled and finished at the end of last July. The fabrication of the four end caps has been finished and wire stringing are in processing.

e. The Muon Identifier

Al extrusions arrived at IHEP at the end of last year. Two prototypes of the muon counter were made in the begining of this year. Test showed that they are up to standard. Now the muon counter has been put in batch production. The fabrication of all the muon counters and the muon identifier are expected to be finished respectively in March and August of 1988.

f. The BES Magnetic Coil and Iron Yoke

The BES magnetic coil and iron yoke were accomlished last February and installed in the experimental hall last March. Acceptance test showed that the insulating resistance of the coil has reached 1000 M . The installation of the magnetic coil power supply did not start until last May because of the delayed civil engineering construction. As the deionized water for testing the power supply was only available in early September this year, measurement of the magnetic field cannot be finished until the end of this year. In a word, the general assembly of BES has slipped the schedule by more than four months.

g. Readout Electronic Data Acquisition and Analysis System

The readout system adopts the following scheme: the signal from the detector, after it has been amplified or discriminated, is to be kept in a sample-and-hold circuit or converted (i.e. time signal converted into analog signal), and is to be read out later by a multiplexed intellegent ADC (i.e. the BADC of SLAC). The total number of readout channels of BES is 19964. A VAX 11/785 computer will be used for on-line data acquisition. We follow the SLAC MARK III on-line system with a VAX-CAMAC Channel (VCC).

Four read-out electronic subsystems have been established and tested, including a 576-channel subsystem for the drift time readout of the drift chamber, 2 subsystems of 288-channel each for the charge division readout of the shower counter and two small subsystems: one is for the time of flight readout of the scintillation counter and the other one is for the charge division readout of the muon counter. The on-line correction and measurement of these subsystems showed that their performance can meet the requirements.

Most of the PC boards, hybrid chips, modules, power supplies and non-standard CAMAC crates have been finalized and put in batch production. With the help of SLAC experts, some electronic parts fabricated by U.S. manufacturers have been delivered. We wish to get all the hardware by the end of this year and then start the assembly and measurement.

The VCC system and CAMAC modules have been tested. Integration test of VCC with VAX 11/785 has been successfully carried out. Integration test and calibration of VCC and BADC-ADC are now underway. The system structure of the BES on-line data acquisition programme and the frame have been basically determined and the BES on-line programme established.

As for the off-line analysis, the development of the track reconstruction programme of charged particles in the main drift chamber, one event display and Monte Carlo simulation of BES physics have been accomplished.

H. The Trigger System

Modules for the logic circuits of TOF and the shower counter and the drift chamber track finding circuits have all been accomplished. Level 1 of the trigger system is expected to be completed at the end of this year.

Synchrotron Radiation

Synchrotron radiation research programmes are planned for both the parasitic mode and the dedicated operation mode. The characteristic parameters are listed in Table 4.

The synchrotron radiation facility consists of three beam ports, five beam lines and eight experimental stations.

The front ends of the three beam ports are now being fabricated. They will be available in the fall of this year.

BL-1 is a white beam line from the wiggler beam port. The mechanical design is close to completion. An X-ray topgraphy station has been designed to exploit this beam line and the white beam topography camera ordered.

BL-2 is an unfocused monochromatic beam line from the wiggler beam port for EXAFS and diffuse scattering experimental stations. The optical design of the beam line was completed last year. The mechanical design of the monochromator is near completion. The beryllium window technique has been developed and is now being tested for its compatibility with UHV conditions.

BL-3 is an X-ray beam line for diffraction station and small angle scattering station. The optical and mechanical designes have been completed. The cylindrical mirror has been fabricated and tested. Most components for the beam line are available with the exception of the orders being placed for the diffracometer and the small angle scattering camera.

BL-4 is a VUV/soft X-ray beam line. The optical design was completed last spring while the mechanical design is close to completion. Apart from the spherical gratings and the toroidal mirror, most components for this beam line are available. A two level photoemission spectrometer with two preparation chambers has been designed.

BL-5 is a soft X-ray beam line for lithography. It is being designed by the Changchun Insititute of Fine Optical Mechanics, and R&D work on the stepper is being performed at Chengdu Institute of Optical Instrument.

The safety interlock system of the Synchrotron Radiation Laboratory is being designed and some independent units are under test. General purpose facilities, such as chemistry lab, biology sample preparation room, dark rooms and working rooms for users are under construction.

Conclusion

Since 1984 when the detailed design was approved, about 3 years have passed, and the BEPC project has progressed quite well. It is expected to be completed on schedule and within budget.

Acknowledgements

We appreciate very much all the helps given by the world high energy physics community. The PRC/US Joint Committee for High Energy Physics has made a big contribution to the progress of our project. We would like to thank ANL, BNL, FNAL, LBL and SLAC. Since BEPC is similar to SPEAR and BES to MARK III, SLAC is much involved in the collaboration. Particular thanks should go to SLAC for all the valuable helps given to us by its staff members.

We would also like to express our gratitude to CERN, KEK, DESY, and other institutes. CERN has been training a lot of engineers and physicists for us and providing much techical assistance. KEK has kindly provided us with the beam for the testing our prototype drift chamber, shower counters and luminosity monitor, etc.

Professor T. D. Lee of Columbia University has made very valuable and great contributions to our project--without his painstaking efforts this project could have hardly moved. Special thanks also go to Professor W.K.H.Panofsky, who has been giving us much important help and advice.

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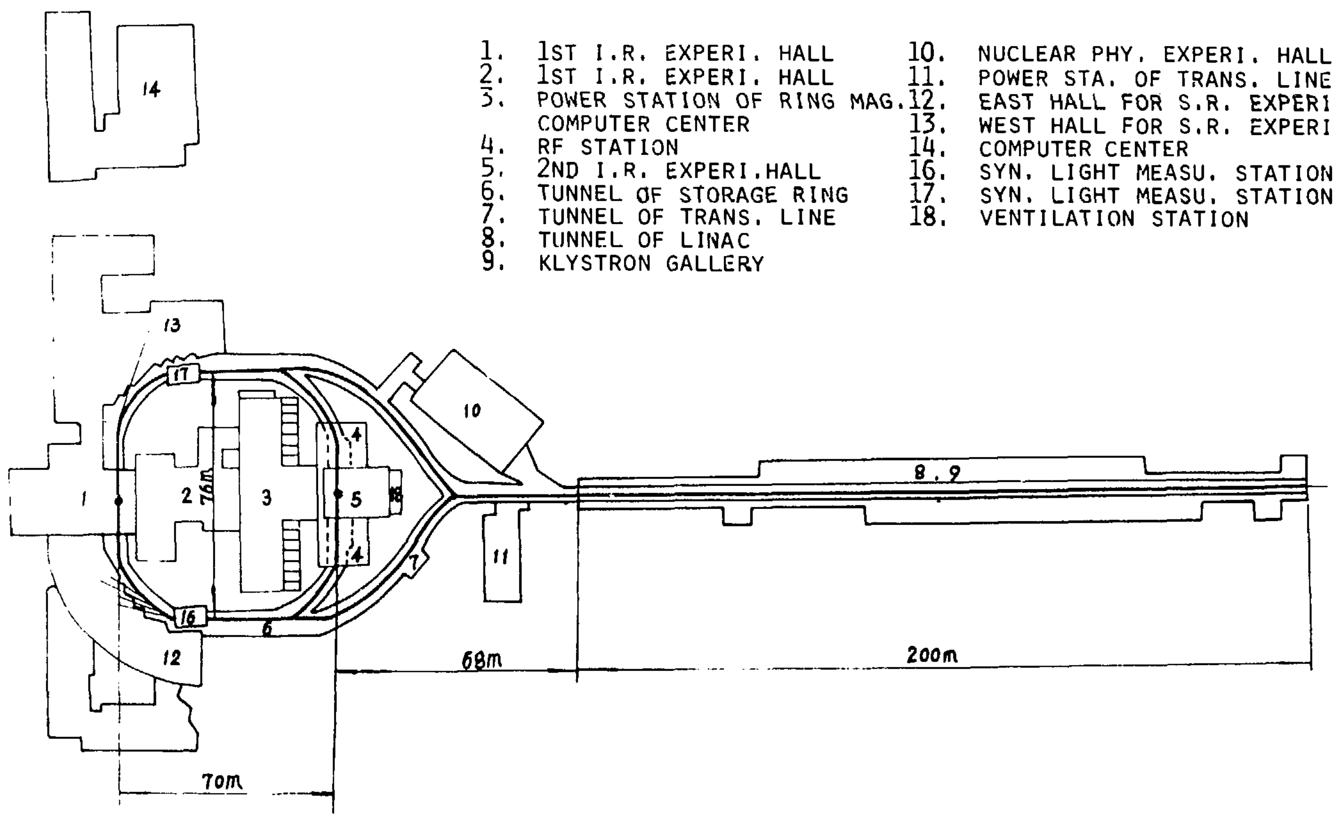
FIGURE 1



1. 1ST I.R. EXPERI. HALL
2. 1ST I.R. EXPERI. HALL
3. POWER STATION OF RING MAG. COMPUTER CENTER
4. RF STATION
5. 2ND I.R. EXPERI.HALL
6. TUNNEL OF STORAGE RING
7. TUNNEL OF TRANS. LINE
8. TUNNEL OF LINAC
9. KLYSTRON GALLERY
10. NUCLEAR PHY. EXPERI. HALL
11. POWER STA. OF TRANS. LINE
12. EAST HALL FOR S.R. EXPERI.
13. WEST HALL FOR S.R. EXPERI.
14. COMPUTER CENTER
16. SYN. LIGHT MEASU. STATION
17. SYN. LIGHT MEASU. STATION
18. VENTILATION STATION

Table 1

e energy	1.4-1.55 GeV
pulse electron current	2A (for positron production) 0.2A(for injection of electron)
pulse width	2.5 ns
pulse repetition rate	50 times/sec
number of klystrons	16
klystron power	>20 MW
number of accelerating tubes	56
working frequency	2856 MHZ
energy spread E/E	0.6%
bunch phase spread	5°
energy of preinjector	30 MeV
bombarding energy for positron production	150 MeV
thickness of positron production target	5 mm
emittance of positron beam	0.22 MeV/c.cm
positron production rate	0.02 e+/e- GeV

Table 2. Measured Result of Sampled Klystron Parameters

pulse voltage	250 KV
pulse current	265 A
perviance	2.14 P
pulse drive power	164 W
average output power	3.78 KW
pulse output power	30.6 MW
gain	52.76 db
efficiency	45.7%

Table 3

Main parameter	Designed value	Experimental value
pulse beam current of electron gun	1A	0.92A
bombarding electron beam current	500mA	785mA
bombarding electron energy	150MeV	148MeV
bombarding beam diameter	2-3mm	<2.5mm
positron beam current	1.5mA	2.5mA
positron beam energy	100MeV	99MeV
electron beam energy	250MeV	250MeV
positron production rate	0.02(e^+/e^- GeV)	0.021(e^+/e^- GeV)

Table 4 Main Parameters of the Storage Ring

Item	Parasitic Mode	Dedicated Mode
Energy	1.6-1.8 GeV	1.-2.8 GeV
Circumference	240 m	240 m
Luminosity at 2.8GeV	1.7×10^{31} $cm^{-2}.s^{-1}$.	
Current	37-65 mA	150 mA
Particles/Beam	3.3×10^{11}	7.4×10^{11}
Free length for experiment	5 m	
Number of I.R.	2	
Revolution frequency	1.274 MHz	1.274 MHz
No. bunches/beam	1	1-160
No. of bending mag.	40	40
No. of quardrupoles	68	68
Max. magnetic field	9028 Gs	9028 Gs
Bending radius	10.345 m	10.345 m
Frequency of acc. field	199.53 MHz	199.53 MHz
Total RF power	200 KW	200 KW
Peak RF voltage	1.35 MV	1.0 MV
Syn. rad. power/beam	2-34 KW	1.9-78 KW
Syn. rad. loss/turn	522 KeV	522 KeV
Hori. & verti. tune	6.18-7.12	7.76-6.76
Hori. & verti. chromaticity	-11.2- -17.7	-10.6- -7.9
Hori. & verti. emittance	0.66 mm.mrad	0.03-0.12 mm.mrad
Max. momentum dispersion	3.9 m	1.4 m
Coupling coef.	0.027	0.316
Trans. damping time	8.6 ms	8.6 ms
Overall beam lifetime	6.7 hr	7 hr
I.R. hori.& verti.beta	1.3 m, 0.1 m	
Max. hori.& verti beta	49.7 m, 71 m	17.4 m, 15.4 m
Hori. & verti. I.R. r.m.s. beam size	0.89 mm, 0.069 mm	
r.m.s. energy spread	7.4×10^{-4}	7.4×10^{-4}
r.m.s. bunch length	5.8 cm	1.8-4.5 cm
Central brightness $B_z(\lambda_c)$	10^{11} -10^{12} (photons/s.mm.mrad.1% BW)	4.3×10^{13}
Characteristic wavelength	14.1-2.63 Å	43.7-2.63 Å

Table 5 Main Parameters of BES

Dimension of beam pipe (1xdxw)	150cm x 15cm x 0.3mm A1 2mm carbon fiber
Dimension of central drift chamber($1 \times d_{in} \times d_{out}$)	110 x 18.8 x 29.6 cm^3
Solid angle of c.d.c.	96% x 4π
Layer and cell of c.d.c.	4, 4
Total sense wire of c.d.c.	192
Spatial resolutiion of c.d.c.	$\sigma_x = 150 \mu m$ $\sigma_z = 2cm$
Dimension of main drift chamber ($1 \times d_{in} \times d_{out}$)	$220 \times 31 \times 230 cm^3$
Solid angle of m.d.c.	96% x 4π
Layer and cell of m.d.c.	10, 702
Total wires of m.d.c.	19380
Spatial resolution of m.d.c.	$\sigma_x = 200 \mu m$ $\sigma_z = 3-4mm$
Monmemtum resolution of m.d.c.	($\Delta p/p$) space = 0.7% ($\Delta p/p$) multipole scattering =1.2%
Counter dimension in barrel TOF(1xwxt)	$284 \times 15 \times 5.0 cm^3$
Solid angle of TOF	95% x 4π
No. of counter in bar. TOF	48 (NE110)
Resolution counter in bar. TOF	200ps
No. of counter in two end cup TOF	48 (NF102A, 2.5cm thick)
Resolution of counter end cup TOF	<250ps
Dimension of barrel shower counter ($1 \times d_{in} \times d_{out}$)	$385 \times 27 \times 338 cm^3$
Layer and cell of bar. s.c.	24, 13400
Spatial resolutiion of bar.s.c.	$\sigma_z = 2cm$
Energy resolution of bar. s.c.	$\sigma_E / E = 15\% / E$
Field of magnet coil	4.5 KGs
Diemnsion of magnet coil ($1 \times d_{in} \times d_{out}$)	$360 \times 348 \times 414 cm^3$
Dimension of muon identifier module (1x cross section)	$(426-460) \times 29.4 \times 11.2 cm^3$/layer
Layer, module, cell of muon identifier	3, 190, 1520
Cell cross section of muon identifier	$60.9 \times 50.8 mm^2$
Spatial resolution of muon iden.	$\sigma_z = 5cm$ $\sigma_\varphi = 3cm$
Solid angle of muon iden.	$0.65 \times 4\pi$
On-line computer	VAX 11/785
Off-line computer	2 x DEC 8550

PROGRESS ON HERA

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Abstract

The present paper is a progress report on the $30GeV/820GeV$ electron/proton colliding beam facility HERA which is being built at DESY in Hamburg, Germany. It includes a short presentation of the HERA design. The current stage of the project is described for the various systems. Considerable progress has been made in civil construction. Tunneling is completed. During summer 1987 the cryogenic plant was successfully commissioned. More than a quarter of the dipole magnets of the electron ring have been installed in the tunnel. Mass production is going on or is imminent for the components of the proton ring. A string of three superconducting dipoles and two quadrupoles has been tested successfully at field levels corresponding to $1TeV$ operation.

Introduction

The HERA electron-proton collider under construction at DESY will be a new tool to study collisions between protons and longitudinally spin-polarized electrons in the next decade.

Design goals are the collisions of $820GeV$ protons with $30GeV$ electrons at three collision points. The particles will be stored in two rings arranged on top of each other in the same underground tunnel. The protons will be deflected by superconducting magnets. The ring for the electrons is designed with conventional magnet technology.

The luminosity is expected to be $L = 1.6 \cdot 10^{31} s^{-1} cm^{-2}$. This requires an electron intensity of $3.9 \cdot 10^{10}$ particles and a proton intensity of $9.3 \cdot 10^{10}$ particles in each of the 210 bunches respectively.

Simulations show that the degree of longitudinal electron spin polarization which is an important design goal of the electron ring can be as high as 87%.

Being a rather large project, HERA was made possible by an international collaboration. Many different countries contribute a considerable part of the project. Table I gives an overview of the HERA collaboration.

Construction of the machine around the site of the high energy physics laboratory DESY in Hamburg started immediately after the project's authorization by the German government in April 1984.

TABLE I The HERA International Collaboration

Canada	52 Mhz rf systems for PETRA III and HERA-p; H^- transport system
China	Work on H^- linac, DESYIII rf system, p-beam dump, cryogenics, vacuum, quench protection, magnet measurements, radiation protection
France	Design of the superconducting quadrupoles; construction of 50% of these magnets
Israel	Super conducting current leads; work on HERA-p controls
Italy	Construction of 50% of the superconducting dipoles
Netherland	Design and construction of the superconducting correction magnets
Poland	Work on HERA-p vacuum, p-beam dump, controls, DESY III, H^- Linac, magnet measurements, cryogenics
U.K.	Design of rf systems for the proton ring; design, work on DESY III, septa and beam dump
U.S.A.	Short sample measurements of superconducting cables; cryogenic equipment

Short Design Review

The HERA storage rings are situated in a 6.34 km long tunnel about 15m below ground level. They are composed of four 1224m long 90 degree arcs which are separated by 360m long straight sections. Three of these **straight sections** are designed for head on collisions whereas the fourth one is preserved for utilities like proton beam dump, injection and rf cavities. The arcs consist of regular FODO structures. The lattice design in the straight sections is more complex. It includes not only the low-β insertion and the horizontal and vertical beam separators but also the electron spin rotator magnets and a region with small beam envelopes which accommodates the conventional electron rf cavities. All of these require special beam optics properties. A detailed description of the lattice design is contained in references /1-4/. The layout of the HERA storage rings is sketched in fig.1. The major design parameters of HERA are listed in table II.

Design studies of the **superconducting magnets** led to the so called hybrid type magnet. It is characterized by a two layer superconducting coil which is clamped with a laminated collar of aluminum alloy. The iron yoke is inside the cold part of the cryostat as is the quench protection circuit with cold diodes. This design combines some of the advantages of both the warm and cold iron designs of TEVATRON and CBA type magnets respectively. The superconducting cable is made from 24 strands of 0.83 mm diameter. Each strand contains 1200 $Ni-Ti$ filaments of 14μm diameter in a copper matrix (copper/NiTi ratio = 1.8). Superconducting magnets are described in references /5-7/. Each of the eight cryogenic circuits contains 53 dipole magnets and 28 quadrupole magnets.

For the **normal conducting magnets** of the electron ring the concept of a magnet

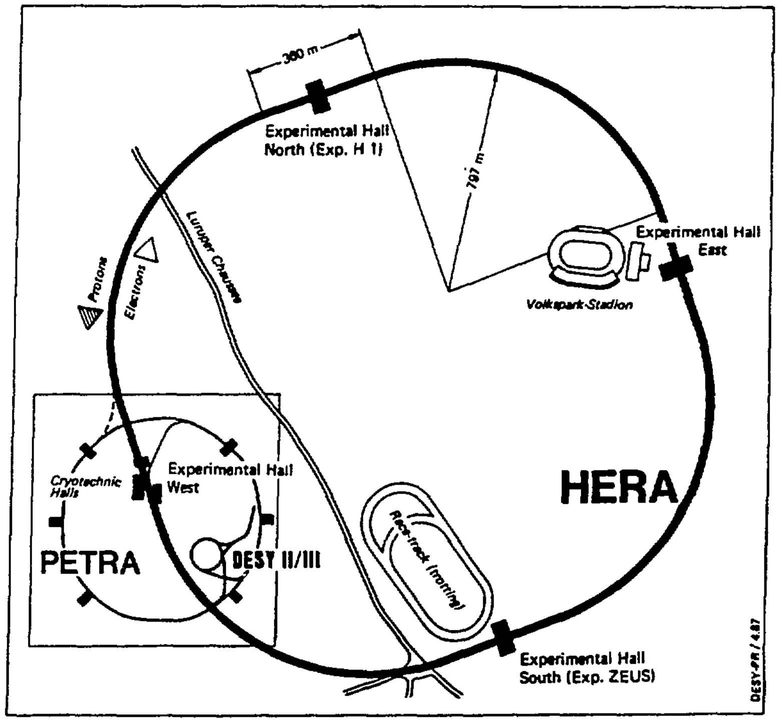

Fig 1) Layout of the HERA Storage Rings

module was developed (ref /8/) which is described in section (4).

In the straight sections, the magnets for the proton ring are also built using normal conducting techniques.

The conventional 500 Mhz **rf system for the electron ring** is carried over from PETRA. It provides a circumferential voltage of $U = 150MV$ which allows for an electron beam energy of $26.5GeV$ with a beam intensity of $60mA$. In order to raise the energy beyond that, it is planned to install superconducting rf cavities in addition which provide an accelerating field of $5MVm^{-1}$(ref/9/). Eight cavity units containing $2 \times 4 - 500Mhz-$cells are sufficient to achieve the $30GeV$ design energy.

The HERA **proton ring** has two **rf systems**. The $52Mhz$ system provides a circumferential voltage of $26.4kV$ with two cavities. It accommodates the $52Mhz$ bunches from PETRA. After adiabatic compression by raising the voltage to $280kV$, the bunches are captured in a $208Mhz$ bucket generated by four $CERN - SPS$ type cavities providing a voltage of $2400kV$.

The **injection system** for the protons includes the acceleration of H^- ions starting from the H^- source and the rf quadrupole. They are followed by a $50MeV$ $CERN$ type Alvarez linac. Details about H^- acceleration are described in ref/10/. The ions are foil

TABLE II Parameters of the HERA storage rings

	Electron-Ring	Proton-Ring
Maximum energy/GeV	30	820
Injection energy/GeV	14	40
Circumference/m	6336	6336
Number of interaction points	3 (4)	3 (4)
Length of straight section/m	4× 360	4× 360
Bending field /T	0.185	4.53
rf frequency /Mhz	500	52/208
Harmonic number	10560	1100/4400
Circumferencial voltage/MV	165	0.3/2.4
Number of bunches	210	210
Beam current/mA	60	150
Horizont. beam size/mm at IP	0.27	0.24
Vertical beam size/mm at IP	0.06	0.07
Longitud. Spin Polarization	87%	-
Polarization Time/min	24	-

$$\text{Luminosity/interaction point} \quad = \quad 1.6 \cdot 10^{31} cm^{-2} s^{-1}$$

stripped at injection in the DESY III synchrotron which is built using the magnets of the old DESY synchrotron (see ref/11/). Protons are then accelerated up to $8GeV$. After transfer to the PETRA storage ring which acts now as an intermediate accelerator /12/, they are accelerated to $40GeV$ and then injected on axis in the HERA proton ring in the straight section WEST. The electron injection chain includes two linacs, a 200 MeV e^--linac or a $450MeV$ positron linac plus accumulator ring, the new DESY II electron synchrotron, the PETRA electron accelerator which accelerates electrons from $7GeV$ to the HERA injection energy of $14GeV$. The layout of the HERA electron injection system includes the possibility of beam accumulation, though this is not intended for routine electron-proton operation.

The proton ring **vacuum system** has a stainless steel pipe. In the arc it is copper coated and at liquid helium temperature. The room temperature vacuum pressure of $10^{-6}mb$ is sufficient to achieve a necessary "cold" vacuum pressure of $10^{-11}mb$. Details about the proton vacuum systems are described in refs/13/,/14/. The electron ring vacuum system is made from extruded copper alloy profiles which absorbs 90% of the synchrotron radiation power. Integrated ion getter pumps will maintain gas pressures as low as $10^{-9}mb$.

In both vacuum systems great care has been taken to keep discontinuities in the beam pipe smaller than $1mm$.

At present two **colliding beam experiments** are being designed by the $H1$ and $ZEUS$ collaborations. These experiments will be installed in the north and south straight sections respectively.

The **schedule** of HERA calls for start of commissioning of the electron ring in July 1988. The proton ring will be completed during the year 1989 so that colliding beams will be available in 1990.

HERA Status

Civil Construction: The HERA tunneling was completed on August 19, 1987. In October 1987 the last of the four underground experimental halls (the East one) will be handed over to DESY. Most of civil construction will be finished by the end of 1987.

Cryogenic Plant: The cryogenic plant was commissioned during summer 1987. The screw compressors providing He gas at $180bar$ with a mass flow rate of $870gs^{-1}$ have an efficiency of 52%. Two of the three cold boxes are in operation now. They provide more than $6.5kW$ cooling power each at the $4.6K$ level which corresponds to the specification. The efficiency is $\frac{1}{277}$ (25% of the carnot efficiency). The $6.3km$ long liquid helium transfer line was ordered on July 1, 1987. From this order a $50m$ long prototype is scheduled for delivery to DESY in November 1987. Series production and installation of transfer line feed- and end-boxes will start in April 1988.

Normal Conducting Magnets: Of the 400 dipole magnet modules required for the electron ring 250 have been manufactured and about 200 are equipped with quadrupole, sextupole and correction dipole magnets. The 318 standard quadrupoles are already available for installation and about 60% of the 246 stronger quadrupole magnets which go in the straight sections have been completed. All those completed magnets have been found to be within the specified tolerances for field strength and field quality. About 25% of the electron ring magnets are already installed in the HERA tunnel. Some 50% of the 440 sextupole magnets for the electron ring are available for installation, as are about 75% of the correction dipoles.

Superconducting Magnets: Five prototypes of the superconducting magnets have been built and have been delivered to DESY. The maximum dipole field exceeds $6T$ (at a temperature of $4.6K$) which is well above the $4.65T$ required to reach the proton design energy of $820GeV$. The field quality measured in these prototypes is quite satisfactory. The largest multipole component is the sextupole which exceeds (with $\frac{\Delta B}{B} = 3 \cdot 10^{-4}$ at $25mm$, at high field) the other components by more than a factor of 3. The measured static heat load improved from prototype to prototype and has reached the excellent value of $P = 4.5W$ at the $4.6K$ level for a shield temperature of $60K$. The order for half of the dipoles (242), which will be contributed by Italy to the HERA collaboration, was placed at the Italian company Ansaldo in December 1986. Delivery of a preseries of ten magnets will start in November 1987. Mass production will start by June 1988. The second half of the dipoles will be built by BBC, the order for which was placed in April this year.

A preseries of 5 magnets is scheduled for delivery in February 1988. Two prototypes of superconducting quadrupole magnets which have been developed at Saclay have arrived at DESY. The maximum gradient is with $G = 126Tm^{-1}$ which is comfortably above the value of $G = 91.4Tm^{-1}$ needed for the 90° optics at $E = 820GeV$. Half of these magnets will be contributed by France, the order having placed with the French company Alsthom in December 1986. The other 120 quadrupole magnets will be built by the companies KWU/Interatom and Noell in Germany. A preseries of 7 quadrupoles from each production line is expected to arrive at DESY by the end of this year. Series production will start in May 1988. Mass production of the superferric window frame correction dipole magnets is underway. About 100 of these magnets have been delivered and meet the specification. This is also the case for the sextupole and correction quadrupole windings which are mounted on the beam pipe. About 300 of a total of 440 magnets have been already manufactured. The correction dipoles, quadrupoles and sextupoles are contributed by the Netherlands. Production has started at DESY of the strong superferric correction quadrupole magnets which will be installed at the end of the arcs.

Rf Systems: The normal conducting rf system for the electron ring is already available. Installation of normal conducting cavities, wave guides and klystrons has started with the first of the six conventional rf sections already completed. A prototype of the superconducting cavity (2×4 cells in one bath cryostat) has been built and successfully tested at DESY. An accelerating gradient of $6.2MVm^{-1}$ has been achieved. This cavity is being installed in PETRA where beam tests are scheduled for November 1987. The $208Mhz$ system for the HERA proton ring consisting of four, tetrode powered cavities is being manufactured. They will be delivered by the end of 1987. The 52 Mhz systems for HERA-p and PETRA II, a contribution from Canada, are in the design phase. The DESY III rf system is complete and is being installed.

Injection Systems: The injectors for the HERA electron ring, namely the DESY II synchrotron and the PETRA II (the modified PETRA) accelerator have been recently commissioned and are ready for operation. Installation of the DESY III proton synchrotron will be completed by the end of 1987. In March 1988 the proton linac with H^- source and rf quadrupole injector will go into operation. The bypass around the electron rf section in PETRA for proton acceleration is changing from the design to construction phase. The transport lines for protons/positrons and electrons between PETRA and HERA were comissioned in April 1987 and July 1987 respectively. The injection elements for the electron/positron transport to HERA are ready or in the final stage of manufacturing and some of them are tested with beam. The elements for proton beam transfer have passed the design stage. Construction has started on some components.

Vacuum Systems: Measurements on the cold and insulating vacuum systems on prototype cryostats are described in section (5). Orders have been placed for the components of the stainless steel vacuum system for the warm parts of the proton ring. The electron ring vacuum pipe made from extruded copper profiles is brazed by the DESY vacuum group. In the initial stage of production there were some problems having to do with the reduced stiffness of extruded copper after reheating. These problems have been solved and mass production of the $3m$, $9m$, and $12m$ long beam pipe elements is going on.

Installation of Components in the Tunnel: In all four quadrants of the HERA tunnel installation of components is underway. The largest progress has been made in the south-west which quadrant is already equipped with the magnet modules for the electron ring. In this section, the beam pipe is the last missing major component of the electron ring. In the north-west section, injection elements and electron ring modules with vacuum pipe are at present being installed. Cooling water supplies, quench gas pipes, current leads and magnet girders are being installed in the north-east section.

Experience with the Magnet Module Concept

In order to facilitate installation of magnets in the HERA tunnel, the concept of a magnet module was developed. Besides dipole, quadrupole, sextupole and correction dipole magnets a complete magnet module also includes the vacuum pipe (Fig 2). The "backbone" of the module is a $9.1m$ long slotted square tube which surrounds the iron yoke of the dipole magnet. The dipole itself is stacked with $5mm$ thick laminations. The advantage of the module concept is apparent. The module can be assembled outside the tunnel where enough room and equipment is available and where there is no interference with the installation of other components in the tunnel. Furthermore the survey of module components relative to each other can be done in advance so that final adjustments in the tunnel are reduced to the alignment of the module as a whole and control measurements. This concept was expected to significantly speed up the installation of magnets in the tunnel.

To date more than half of the bare magnet modules (carrying the dipole magnet only) have arrived from the manufacturer to be completed at DESY. The field of the dipole magnet of all the modules is measured upon arrival at DESY. The rms variation of $\int Bdl$ is quite acceptable beeing $2 \cdot 10^{-4}$. The nonlinear field inhomogeneity is as small as $2 \cdot 10^{-4}$ at the horizontal aperture limit of $40mm$ and varies in the range of $6 \cdot 10^{-5}$ from magnet to magnet. A somewhat stronger variation is observed in the somewhat large quadrupole component of the dipole (corresponding to $3 \cdot 10^{-3}$ of the strength of a standart quadrupole) which is the reason for installation of ordered sequences of magnet modules in the tunnel. Survey of installed modules has shown that they are very sensitive to shocks which might occur during the transport into the tunnel. At some modules a twist of the order of several milliradians has been observed on installed magnets. As a consequence additional reinforcement has had to be installed and great care is taken during the module transport. The installation of the electron ring magnets in the tunnel section south-west progressed rapidly. All the magnets of the south-west quadrant were installed within eight weeks demonstrating a clear advantage with respect to conventional procedures.

System Test

The system test is a comprehensive measurement program of major components of the proton ring combined into a unit which is comparable to a cryogenic circuit in HERA.

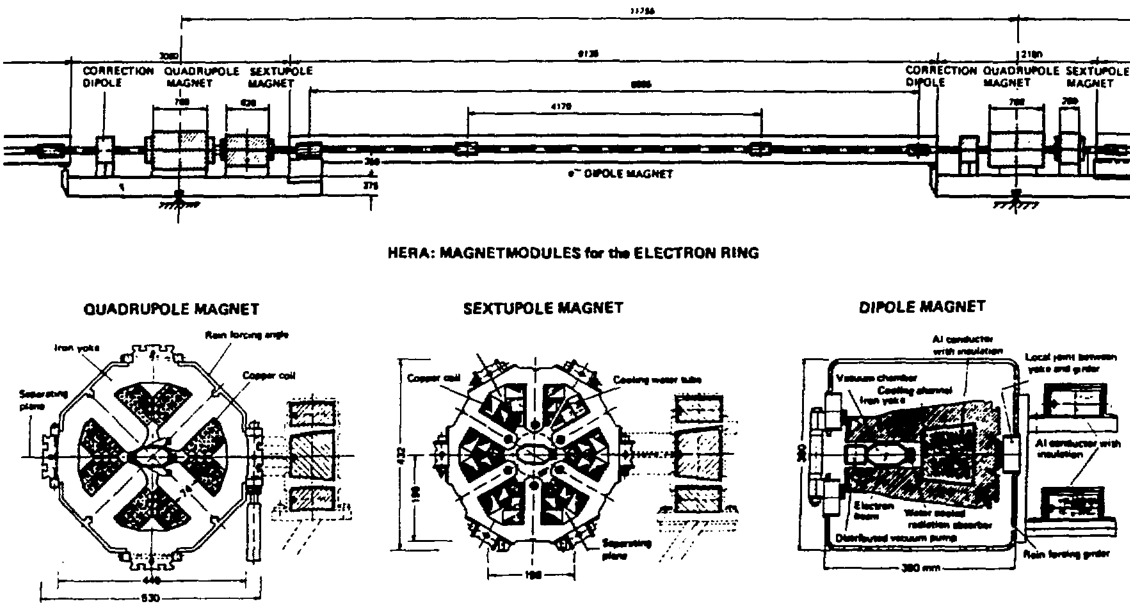

Fig 2) The Magnet Module for the HERA Electron Ring

The test set up includes three dipole magnet- and two quadrupole magnet cryostats, a feed box and an end box. The axis of the system has a one degree slope with respect to the horizontal plane to simulate the slope of the HERA ring due to terrain following. Fig 3 shows a sketch of the set up.

For the cryogenic system, information about cooldown procedures, operational stability, heat load and also the effect of the slope of the system were the main concern of the test.

The quench protection group wanted to test the cold diode and magnetic amplifier quench protection circuitry and to study quench propagation.

The vacuum group has an opportunity to test design and equipment before the components go into mass production.

The results of the system test are very encouraging: the maximum exitation of magnetsachieved during the string test corresponds to a proton beam energy of $1000 GeV$. Deliberate quenches of the magnets are initiated routinely. The cold diodes, the quench detection system and the heaters work reliably (ref/15/).

Helium pressure and temperature during cooldown developed as precalculated. The counter flow heat exchange, by which the one phase helium is cooled by the two phase

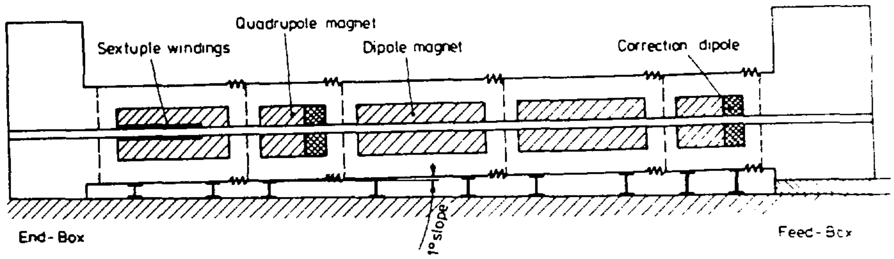

Fig 3) Sketch of the System Test Set Up

helium return flow, works as expected. No influence of the slope of the set up on heat exchange was observed. Static heat load measurements of the system as a whole correspond very well with the heat load measured at single components. Extrapolating these data for the full proton ring yields a total heat load of the magnets of $6kW(4.5K)$. Including AC and rf losses the total heat load of HERA can be estimated as $11kW$.This cooling power is developed by the liquid helium plant operating with two of the three cold boxes as planned (ref/15/).

No surprises were discovered in the vacuum system. The cold beam vacuum pressure was measured to be $p = 5 \cdot 10^{-14}$ $mbar$. The leak rate l is below the measurable threshold ($l < 10^{-16} mbar \cdot l \cdot s^{-1}$). In the insulating vacuum only a pressure of $10^{-6} mbar$ is achieved which is the result of spurious water in the system (ref/15/).

Evaluation of the measurements made during the last six months is still in progress. So far one can conclude that all components work as expected. Nothing has been discovered which would delay series production of components.

Summary

Work on HERA proceeds very well for all subsystems. Prototypes of all major components have been examined and tested. No principle problems have been discovered so far.

All systems for the electron ring are in the mass production stage. The electron injection system is completed. First injection of an electron beam into a part of the HERA electron ring is planned for November 1987.

Most of the cryogenic infrastructure now available. Mass production is imminent for the main components of the proton ring.

The next milestone to be achieved is completion of the HERA electron ring in July 1988.

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STATUS REPORT ON LEP

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INTRODUCTION

This report describes the state of advancement of the LEP (Large Electron-Positron) project at CERN, as reached in September 1987. This collider will have an initial beam energy of up to 60 GeV, which will later be raised to nearly 100 GeV by the stepwise addition of superconducting acceleration cavities and by upgrading various machine systems.

Four large experiments are in an advanced stage of construction and are expected to be ready for the first machine test in early summer 1989.

1. THE LEP PROJECT - A REMINDER

The study of the LEP project [1], an e^+e^- collider able to reach a centre-of-mass energy of 2×100 GeV (with an ultimate capability of 2×125 GeV), was completed in 1981, and the first stage of its construction (Phase I) was approved by the CERN Council at the end of the same year.

The first phase of the LEP project includes:

- the construction of two Linacs and an Accumulator Ring to be added as e^+e^- preinjectors to the Proton Synchrotron (PS) - Super Proton Synchrotron (SPS) accelerator complex, upgraded to enable its operation also as 20 GeV injector for LEP;
- the construction of the LEP Main Ring, sufficiently equipped to reach a beam energy of at least 50 GeV with enough luminosity for initial research;
- the construction of four experimental areas.

Table I shows a number of parameters for LEP Phase I.

Two main options have been kept open in the design of the LEP Main Ring:

a) the tunnel cross-section is large enough to accommodate later a superconducting hadron collider;

b) the position of the Main Ring is such that it would later be possible to perform hadron-lepton collision experiments by transferring hadrons from the SPS through a bypass.

Table I. LEP Phase I - Main Machine Parameters

Reference circumference (including sagitta)	26658.883376 m
Slope of the median plane of the machine	1.42 %
Lattice type	FODO
Phase advance/period	60° or 90°
Number of bunches per beam	4
Number of interaction points	4 + 4
Equipped experimental areas (P2, P4, P6, P8)	4
Ratio horizontal/vertical beta values at int. point	25
RF frequency	352.209042 MHz
Revolution time	88.92446 μs
Nominal klystron output power (total)	16 MW
Active RF structure length (copper cavities)	272.377 m
Injection energy	20 GeV
Beam energy with nominal luminosity (copper cavities)	55 GeV
Maximum energy (zero luminosity, copper cavities)	∿ 60 GeV
<u>Data for 60° / period lattice at 55 GeV:</u>	
Luminosity in physics interaction region	$1.7\ 10^{31}\ cm^{-2}\ s^{-1}$
Beam-beam tune shift (maximum possible value)	0.032
Circulating current per beam (assumption)	3 mA
Particles per bunch	$4.16\ 10^{11}$
Natural bunch length (J_e = 2)	15.6 mm
Relative r.m.s. energy spread with design damping	$0.98\ 10^{-3}$
Synchrotron energy loss	263 MeV/turn
Quantum lifetime (assumption)	1440 min
Required circumferential RF voltage	364 MV
Synchrotron power (two beams)	1.6 MW
Momentum compaction factor	$3.866\ 10^{-4}$
Horizontal betatron wave numbers (tunes)	70.35
Vertical betatron wave numbers (tunes)	78.20
Space between quadrupoles at interaction points	± 3.5 m
Vertical β-function at experimental interaction points	0.07 m
Horizontal dispersion at interaction points	0.0 m

The 26.6 km long LEP tunnel, consisting of eight arcs and eight straight sections containing the beam-collision points, is excavated for 90 % of its circumference through sedimentary rock ("molasse", well known to CERN) and for

10 % through limestone strata under the Jura. The tunnel is situated on an inclined median plane (maximum slope 1.4 %) at a depth below surface varying between 50 to 150 m.

Experimental zones in the form of about 21 m wide and 70 m long caverns and auxiliary tunnels housing machine services, such as power distribution, cooling, controls, etc., are located at the collision points labelled P2, P4, P6 and P8.

At P2 and P6, so-called klystron galleries are designed to house RF equipment; the excavation of this type of gallery could possibly be required at a later stage at points P4 and P8 if the installation of cavities there turned out to be necessary for raising the beam energy to near 100 GeV.

Injection tunnels to allow particle transfer from the SPS system are located on either side of P1; a total of 18 shafts connect the tunnel and experimental areas with the surface. Figure 1 shows the layout of the various tunnels and shafts of the LEP underground work.

Auxiliary surface buildings for power distribution, power conversion, cooling, cryogenics, gas storage, etc., are located near the access shafts.

The accelerating structure for LEP Phase I consists of 128 copper cavities, each one containing a five-cell accelerating structure, side coupled to a low-loss spherical storage resonator (Figure 2). The coupled system is

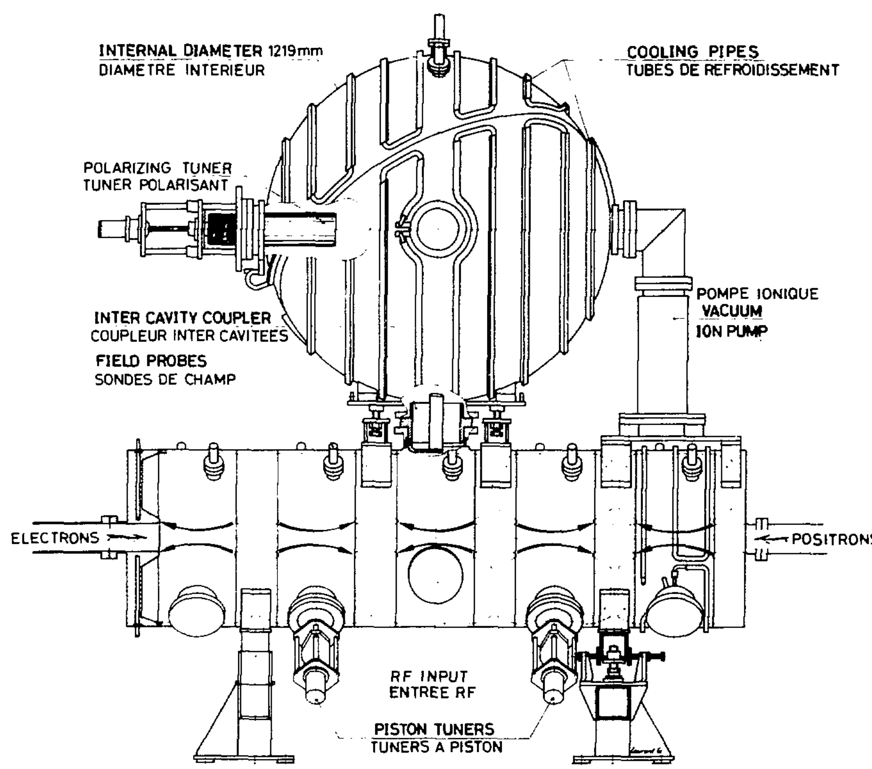

Figure 2. Cavity assembly.

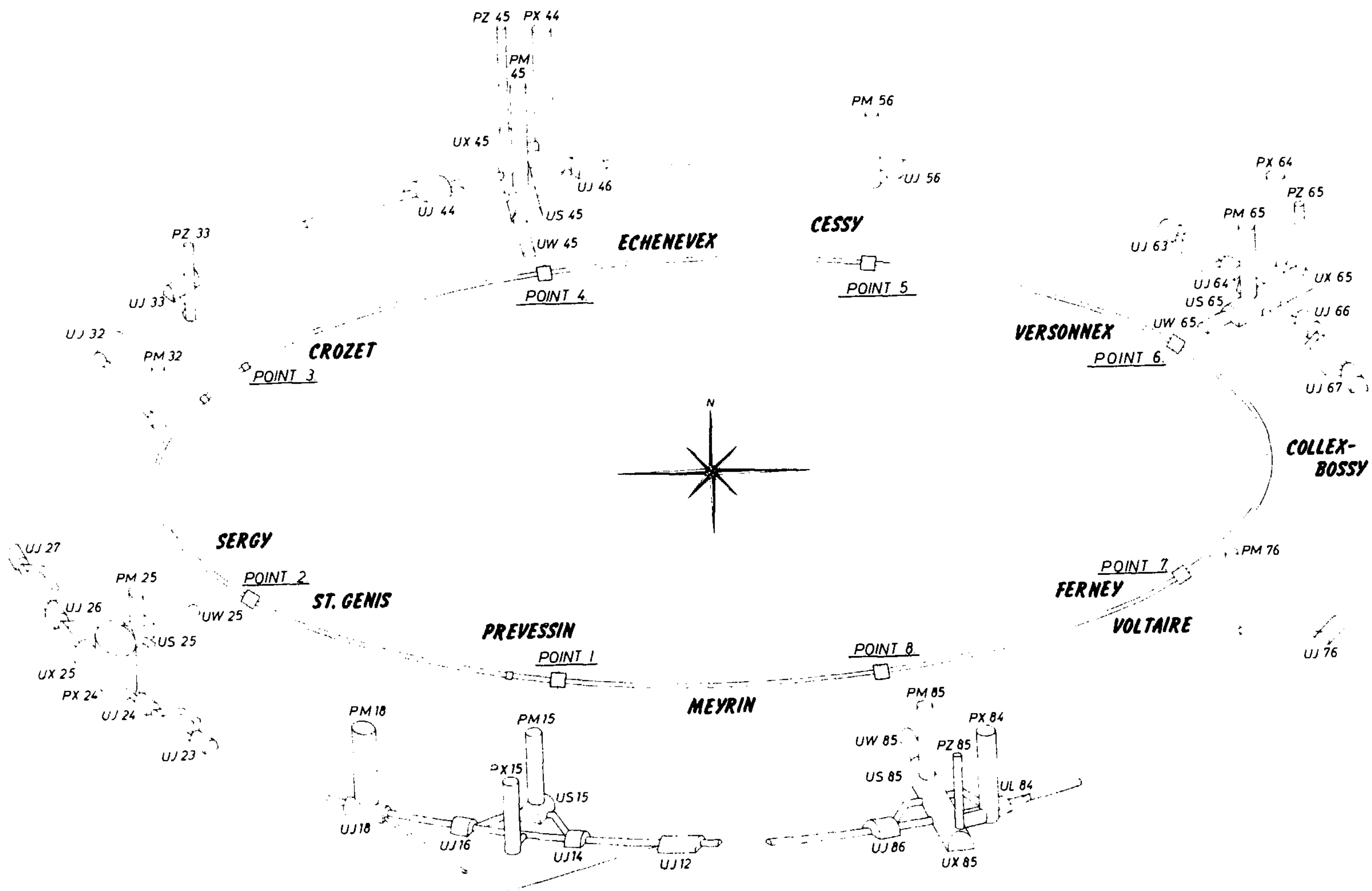

Figure 1. LEP underground work.

excited with its two resonant frequencies so that the maximum of the accelerating field coincides with the passage of a pair of e^+e^- bunches, and the stored energy spends half the time in the low-loss cavity [2]. This scheme reduces the energy lost to the cavity walls by a factor 1.6. The accelerating structure is powered by a total of 16 klystrons, each having a 1 MW nominal continuous-wave output power.

As regards the magnetic system, a very low bending field (about 0.1 T) is required to contain synchrotron-radiation losses within acceptable limits. Considering that classical dipole cores would have contained an unnecessary mass of poorly used magnetic steel, a novel design [3] with an optimum steel filling factor of only 0.27 has been adopted. These cores are composed of a stack of laminations, separated by 4 mm gaps filled with cement mortar; four prestressing rods act on two end plates and compress the core which then behaves like prestressed concrete beam (Figure 3). Compared to classical cores, about 40 % savings in cost and weight have thus been achieved.

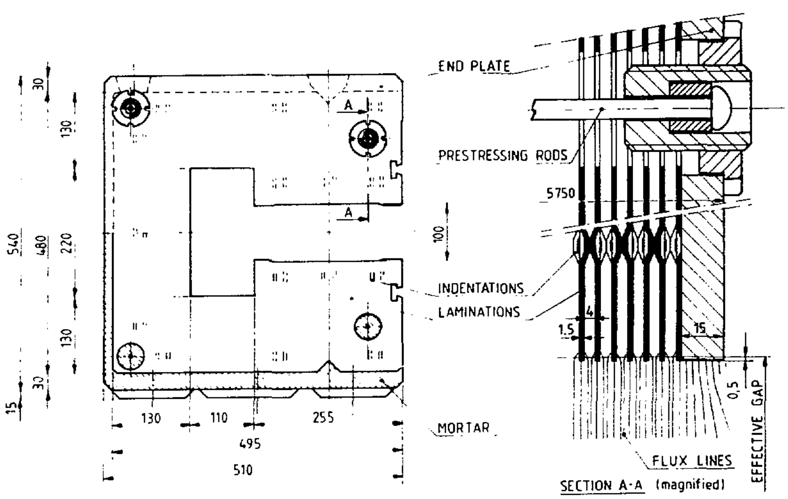

Figure 3. Dipole core structure.

Synchrotron radiation and low bending fields have strongly influenced the design of the standard LEP vacuum chamber which is made of an extruded aluminium profile covered with a lead radiation shield (Figure 4).

The strong desorption, particularly during early operation, of gas from the vacuum chamber walls hit by synchrotron radiation requires a distributed pumping system, achieved in other lepton storage rings by linear sputter-ion pumps operating in the field of the bending magnets.

In LEP, even at 50 GeV operation, the bending field is below the threshold of efficient operation of such pumps and, therefore, the main pumping system [4] is based for the first time on the non-evaporable getter (NEG) strip, installed in pumping channels running along most of the vacuum chambers. In the presence of stored beams, the base pressure is expected to be about 4 10^{-7} Pa in the arcs and 10^{-8} Pa in the experimental regions.

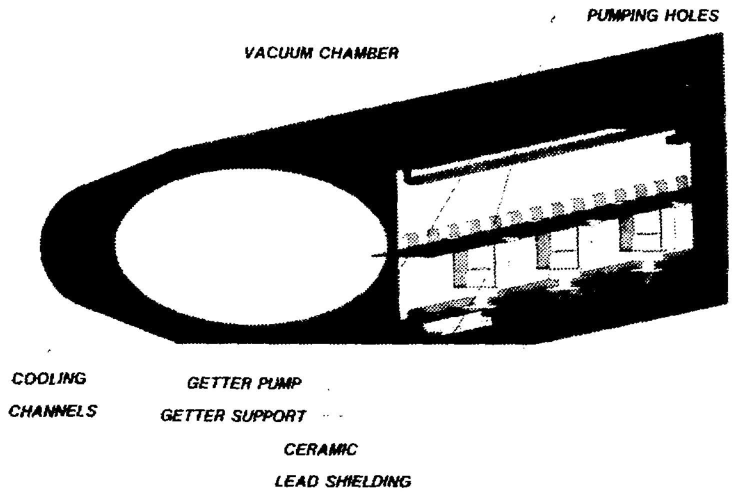

Figure 4. LEP dipole vacuum chamber.

Ironless superconducting quadrupoles, immersed in the solenoidal magnetic fields of the experiments, provide the final vertical focusing of the beams in order to achieve nominal luminosity at the four experimental interaction points.

Electrostatic separators are used to keep the beams separated vertically at all interaction points during injection and acceleration to avoid harmful beam-beam effects.

After acceleration, the beams are brought into head-on collision at the experimental collision points only, where the separators are designed such as to permit a vertical adjustment of the beams with a resolution of a few µm.

2. PRESENT STATUS

2.1 Civil engineering

The excavation of the tunnel in the molasse rock (about 24 km), of the 18 shafts and of all underground experimental and service areas is finished; already 86 % of the excavated volume has received its final concrete lining. Three octants (1-2, 1-8 and 4-5) have been handed over by the contractor to CERN, and the installation of infrastructure and machine components is under way.

Octants 8-7 and 2-3 will be handed over in the course of October 1987 and the remaining two octants in the molasse (6-5 and 7-6) will be available by April 1988.

Regarding octant 3-4, which is mainly situated in the Jura limestone, 150 m remain to be excavated. Since August 1986, the excavation work has entered a 400 m long zone of permeable, fractured limestone and a four-month stop was necessary to master a first water inflow (100 l s^{-1}, 10 bar) from a karstic phenomena. Work was resumed in January 1987 and about 230 m have been excavated until encountering a second water inflow at the end of July 1987, which was throttled one month later.

Excavation work is now progressing again at a pace of about 8 m per week, with still 50 m of poor rock lying ahead.

Systematic injection of resin and cement into the rock faults ahead of the working face and the reinforcement of the tunnel with steel lining are required. It is expected that the excavation work will be finished by mid-February 1988 and that the octant will be handed over in summer 1988.

The experimental caverns, the underground service areas and 12 shafts have received their concrete lining; that of the experimental shafts PX45, PX65 and PX85 will be completed by December 1987 and that of the remaining three machine shafts at points 3, 5 and 7 by summer 1988.

2.2 Machine components

2.2.1 Radiofrequency system. All 128 five-cell accelerating cavities and spherical storage cavities required for Phase I of LEP have been delivered; 121 cavity assemblies have undergone adjustment, bakeout and conditioning to full power and are ready to be installed. Out of the 16 klystrons required, 15 have been delivered and tested to full power with a very satisfactory efficiency of about 68 %. All wave guides are at CERN; four out of the 16 ferrite circulators, which are required to protect the klystrons from reflected power because of mismatches in the cavities, have been delivered.

Concerning the electronic units for driving and controlling the RF system, 75 % of them are at CERN and two groups of preassembled racks have already been installed in their "klystron gallery" at point 2.

The installation of 32 cavities in the RF straight sections of octant 1-2, near point 2, will start in November 1987, and it is expected to have one fourth of the RF system working in the LEP tunnel as from March 1988. (A string of 16 cavities assembled as in the machine has already been operated at full power in an auxiliary building.)

2.2.2 Magnetic system. The 3304 steel-mortar dipole cores have all been delivered and are stored at CERN; about 90 % of them have undergone the core straining required to relieve the stresses induced by the mortar shrinkage and the final magnetic measurements.

The 24 injection dipoles are assembled, 42 low-field dipoles out of 64 have been delivered.

About 50 % of the dipole excitation bars are stored in the magnet assembly hall and their delivery will be completed by summer 1988.

As regards the lattice magnets, the delivery of the 524 regular arc quadrupoles, the 508 sextupoles (two types) and the 624 correcting dipoles (four types) will all be terminated by February 1988; 160 out of 290 straight-section quadrupoles are at CERN and the remainder will be delivered by summer 1988.

The prototype superconducting quadrupole for the low-beta insertions has been successfully tested (quenches at 1950 to 2000 A, nominal operating current 1625 A in an external field of 0.7 T); the first series magnet has been delivered and is being tested.

Two out of the eight wiggler magnets, required for controlling beam size and damping, are at CERN; their manufacture will be completed by January 1988.

The assembly of the so-called straight-section units, which generally consist of a quadrupole, a sextupole and a corrector with their vacuum chamber mounted on a common girder, has started at the beginning of September 1987, and about 20 such units have already been installed in the octant 1-2.

The assembly of dipole magnet pairs with their excitation bars and vacuum chambers is also under way and their installation will start in the course of October 1987.

2.2.3 Vacuum system. More than 60 % and 70 % of the standard dipole and quadrupole vacuum chambers, respectively, have been delivered.

About 50 % of the total number of chambers is now ready for installation, after having undergone leak checking, bakeout and final pumping down to the vacuum limit below 3 10^{-9} Pa.

The manufacture of special vacuum chambers for the RF straight section and the low-beta insertions is progressing as planned, and it is expected that the vast majority of all vacuum chambers will be ready before the end of 1988.

Other main components of the vacuum system have been delivered: 100 % of the non-evaporable getter (NEG) pumping strip with performances twice as good as those specified, 100 % of the sector valves and 85 % of the ion pumps. The manufacture of bellows is also in good progress: more than 20 % have been delivered and their production will be completed by the end of 1988.

The next important milestone for the vacuum system will be reached in February 1988 when the major part of octant 1-2, from the e^+ injection point down to the RF cavities, is expected to be under vacuum.

2.2.4 Power conversion. As concerns the power converters for the magnets, those for the main dipoles, the injection dipoles and the two circuits of the rizontally focusing and defocusing arc quadrupoles are on the CERN site.

The series prototypes of the switched mode power supplies (82 % of the total number of power converters) have been accepted, their manufacture has started and will be completed by the end of 1988, as will be the manufacture of all other power converters for the magnets.

The prototype 100 kV, 40 A power converter for the klystrons has also been accepted (8 are required for the 16 klystrons), the series production has started and is expected to be finished by October 1988. The prototype will be installed in the rectifier building at point 2 in January 1988 in view of the RF tests in the LEP tunnel scheduled for March 1988.

2.2.5 Other machine components. The deliveries of the items necessary to assemble, install and operate other major machine systems, such as beam electrostatic separators, beam orbit measurement equipment and beam instrumentation, cryogenics, controls, cooling and ventilation, power distribution, are progressing on schedule, and it is not possible to give a detailed account in this brief report.

2.2.6 Machine installation. As already mentioned, installation of octant 1-2 with accelerator components has already started and is planned to be completed by February 1988.

Installation of infrastructure equipment (electrical distribution, cooling and ventilation, and monorail) is well advanced in octant 1-8 and has begun in octant 4-5. The equipment of the machine shafts and service areas is completed at points 1 and 2 and is in good progress at points 4, 6 and 8. The peak of activity will be reached in 1989, when accelerator components will be installed simultaneously in three different LEP octants.

From the handing over of an octant by the civil engineering contractor to full installation and testing of the collider elements, 12 to 16 months are required to perform more than 100 different activities, from marking the components' position to putting the accelerator under vacuum.

2.3 Injectors

The two Linacs (200 MeV - 600 MeV) and the 600 MeV EPA accumulator were already able to deliver e^- in the course of 1986, which were successfully accelerated to 3.5 GeV by the PS at the end of 1986 [5].

The progress in 1987 was such that by April EPA could store 2.5×10^{10} e^+/bunch (nominal figure), the PS accelerated positrons at the end of June and 10^{10}/bunch were accelerated to 14.8 GeV (limit set by the SPS travelling wave cavities) in the SPS on September 10. The electron transfer line from the PS to the SPS has also been commissioned.

The SPS is already running with a 14 to 450 GeV proton cycle followed by 3.5 to 20 GeV cycles for e^+ and e^-; next goals will be the acceleration of e^+ and e^- on successive cycles using six of the dedicated standing wave cavities, and the testing of a future LEP superconducting cavity, presently installed in the SPS. Further standing wave cavities will be installed during the SPS winter shutdown.

As regards the transfer lines from the SPS to LEP, the ejection equipment in the SPS has already been installed; during the winter shutdown, the installation of the e^+ injection line into LEP will be completed and ready by February 1988 (at present, 60 % of the magnets are already installed).

3. RUNNING-IN AND DEVELOPMENT

As a result of the status of advancement summarized in Chapter 2, the next important step will be the full installation of octant 1-2, from the injection point to the RF straight sections, by February 1988 (octant under vacuum). This will make it possible to check equipment and systems in view of beam injection tests and studies in July 1988 before the SPS $p\bar{p}$ run. Furthermore, the experience gained in the installation at a rapid pace of this first octant will be very valuable for the installation in the other octants.

The whole LEP collider is expected to be completed and ready for the first beam tests in summer 1989; the completion of the excavation of the main tunnel under the Jura and the experience gained with the installation of octant 1-2 will allow the determination of the final target date.

As regards the developments undertaken for a later upgrading of the LEP beam energy, very encouraging results have been obtained with prototype superconducting RF cavities.

Two four-cell prototype cavities made of niobium sheet material and equipped with all coupling ports needed for operation in LEP have consistently exceeded the design values (an accelerating field of at least 5 MV m^{-1} and a quality factor of 3 10^9 at 4.2 K). One of these cavities is being tested in the SPS as mentioned above.

Two other cavities of this type have been ordered from European industry, and it is intended to install as soon as possible at least four four-cell superconducting cavities in LEP in order to gain experience with their operation and to start a smooth upgrading of the LEP beam energies, for which different scenarios have already been considered [6,7].

Development work is also being pursued on the deposition by sputtering of a niobium layer, a few microns thick, on copper cavities; a four-cell cavity with the same geometry as those made of pure niobium has already shown performance beyond the design values [8]. The sputtering approach, besides offering excellent thermal stabilization and substantial savings in niobium material, is also very interesting for a future application of high T_c superconductors.

4. THE EXPERIMENTS

The delivery and assembly of the major elements for the four LEP experiments are progressing rapidly and the present situation is briefly summarized below.

4.1 Magnets

L3 : all 28 coil pancakes are finished; all steel elements are on site; assembly at pit UX25 has started on August 17, 1987.

ALEPH : the full steel yoke and superconducting coil are assembled; the nominal current of I = 5000 A has been reached; the quench protection system has been tested and field mapping is being made; installation at pit UX45 is foreseen for March 1988.

DELPHI : the steel yoke is fully assembled and the superconducting coil has been tested at liquid nitrogen temperature (at RAL); liquid helium tests at CERN will start beginning 1988; installation at pit UX85 is scheduled for April 1988.

OPAL : all steel elements are on site; coil winding is completed and finishing is progressing; coil testing with current will start beginning 1988; installation at pit UX65 is planned for May 1988.

4.2 Detectors and calorimeters

- Tracking detectors: all tracking detectors are under construction and/or assembly; some parts are already under test (TPC for ALEPH, JET for OPAL).
- EM calorimeters:
  - half a barrel (3840 crystals) of the BGO calorimeter of L3 is installed for test purposes in a SPS beam line.
  - The lead/gas calorimeters of ALEPH and DELPHI are being assembled; beam tests are being performed on the first modules.
  - The Pb-glass calorimeter for OPAL is ready; its elements are being calibrated.
- Hadron calorimeters:
  - For ALEPH, DELPHI AND OPAL, these calorimeters are incorporated in the magnet yoke assemblies.

. For L3 (uranium/gas calorimeter), the modules are under construction and preassembly.

- Other major detectors:
  . the main components for the Ring Imaging Cerenkov detector for DELPHI have been delivered and the completion of their assembly is scheduled for end 1987.
  . L3 muon chambers are under assembly at CERN.

4.3 Other equipment

- The counting rooms for the four experiments are available and partly already in use for testing and calibrating the various detectors.
- All gas storage equipment has been ordered and delivery is expected as planned.

ACKNOWLEDGEMENTS

The author would like to thank E. Picasso for his encouragement and F. Bonaudi for his help in gathering relevant information concerning the experiments. Thanks are also due to the many colleagues who have provided the material for this report.

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THE STATUS OF THE SLC*

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1. INTRODUCTION

On October 10, 1987, the SLC ceased commissioning activities to move the Mark II detector into the beam line for the spring physics run. The planned shutdown is for a period of 13 weeks. In this paper, the various subsystems and their status as of October 10, 1987 are briefly discussed. For a more extensive but not as up-to-date review, the reader is referred to Refs. 1 and 2.

In Fig. 1, you see a schematic layout of the SLC. Before beginning the discussion of the subsystems, it is useful to trace the e^+e^- beams through the SLC. At the beginning, two 20 cm long bunches are emitted from a thermionic gun and accelerated to 160 KeV. These bunches are compressed in two stages to an rms bunch length of 2 mm each and then accelerated in a linear accelerator at 2.8 GHz to 200 MeV. At this point, the electrons join a positron bunch which was created on the previous pulse. All three bunches are then accelerated to 1.2 GeV.

At the 1.2 GeV point, a D.C. magnet deflects the electron bunches north into the north damping ring while the positrons are deflected south into the south damping ring. After a storage time longer than about 5.5 msec, the low emittance positron bunch is extracted from the south damping ring and re-injected into the linac. About 60 nsec later, the first low emittance electron bunch is extracted and 60 nsec after that the final low emittance electron bunch is extracted.

The positron bunch and the first electron bunch are accelerated in the linac up to 51 GeV and separated at the end of the linac where the electron bunch travels in the north arc and the positron bunch travels in the south arc. After transport in the arcs, they are

* Work supported by the Department of Energy, contract DE – AC03 – 76SF00515.

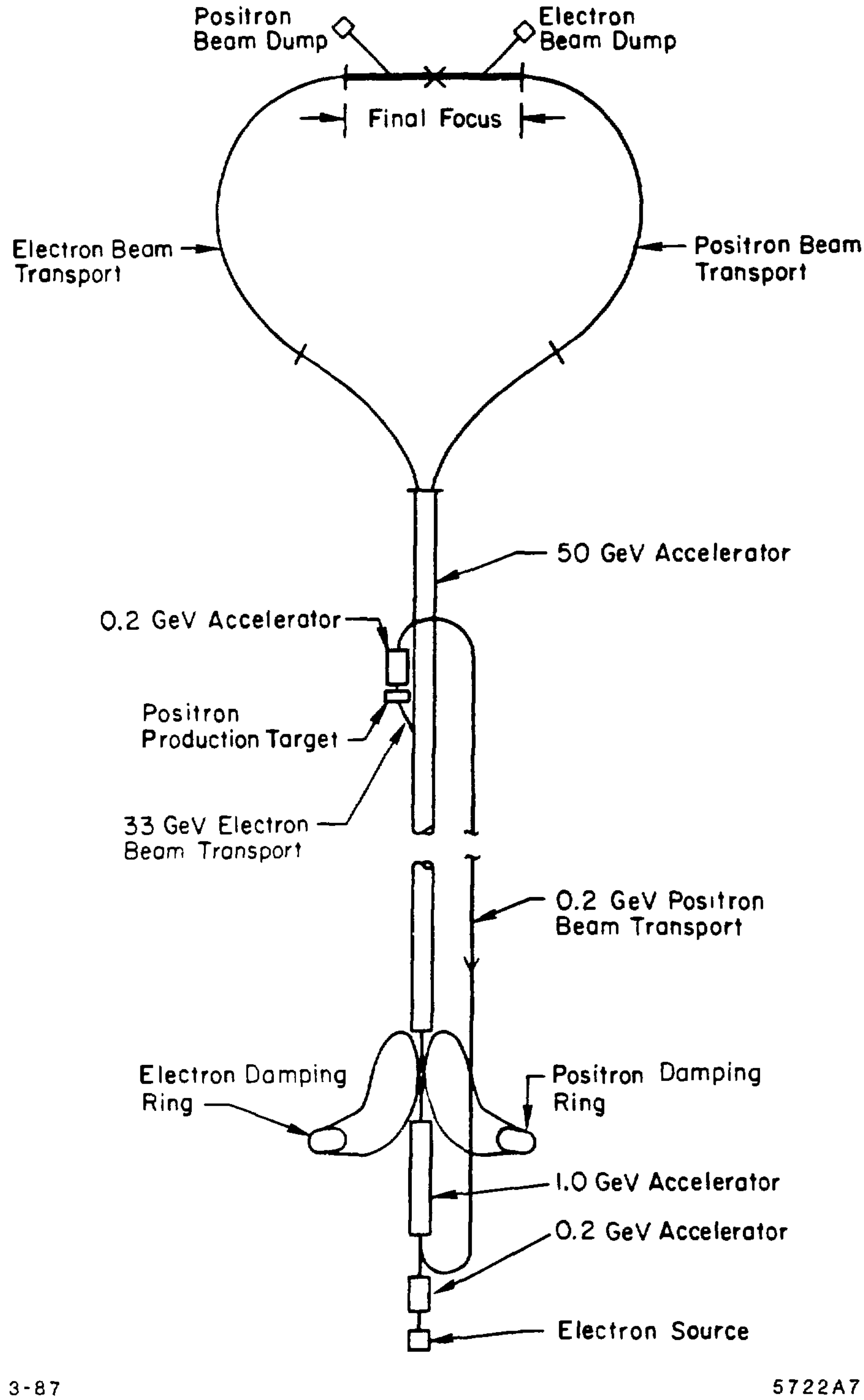


Fig. 1 The overall layout of the SLC

focussed to a small spot by the final focus system for a collision at 2×50 GeV and then finally they are deflected into beam dumps.

The second electron bunch, the third bunch in the train, follows the first two up to the 2/3 point of the linac where it is extracted at an energy of 33 GeV. It is then used to produce positrons which are accelerated to 200 MeV and then transported back to the injector to be injected and to start the whole process over again.

To put the next few sections into perspective, in Table 1 you see a list of parameters of the SLC which distinguishes the design goals of the SLC from the initial performance goals. The initial goals are those for the spring 1988 physics run and yield a luminosity of $6 \times 10^{27}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$. This will produce about 15 Z°'s per day.

Table 1. BASIC PARAMETERS FOR THE SLC

	Design Goal	Initial Goal	Achieved	Units
Beam energy at IP	50	46	46	GeV
Beam energy at end of linac	51	47	53	GeV
Electrons at entrance of arcs	7×10^{10}	10^{10}	3.5×10^{10}	
Positrons at entrance of arcs	7×10^{10}	10^{10}	0.6×10^{10}	
Repetition rate	180	60	5	Hz
Normalized transverse emittance at end of linac (electrons)	3×10^{-5}	10×10^{-5}	$3 - 20 \times 10^{-5}$	rad-m
Spot radius at IP	1.6	2.8	5.0	μm
Luminosity	6×10^{30}	6×10^{27}	–	$\mathrm{cm}^{-2}\mathrm{sec}^{-1}$

2. DAMPING RINGS

2.1 STATUS

The SLC damping rings provide an emittance of $\epsilon_N = 3 \times 10^{-5}$m at 1.2 GeV. Both the electron and positron rings operate routinely and reliably to provide low emittance beams for the linac, arcs and final focus commissioning effort. Both rings have achieved the design emittance. The north ring has achieved an intensity of $4.5 \times 10^{10} e^-$ while the south ring has achieved 1.0×10^{10}. Both of these are limited by upstream intensity and thus they are not hard limits.

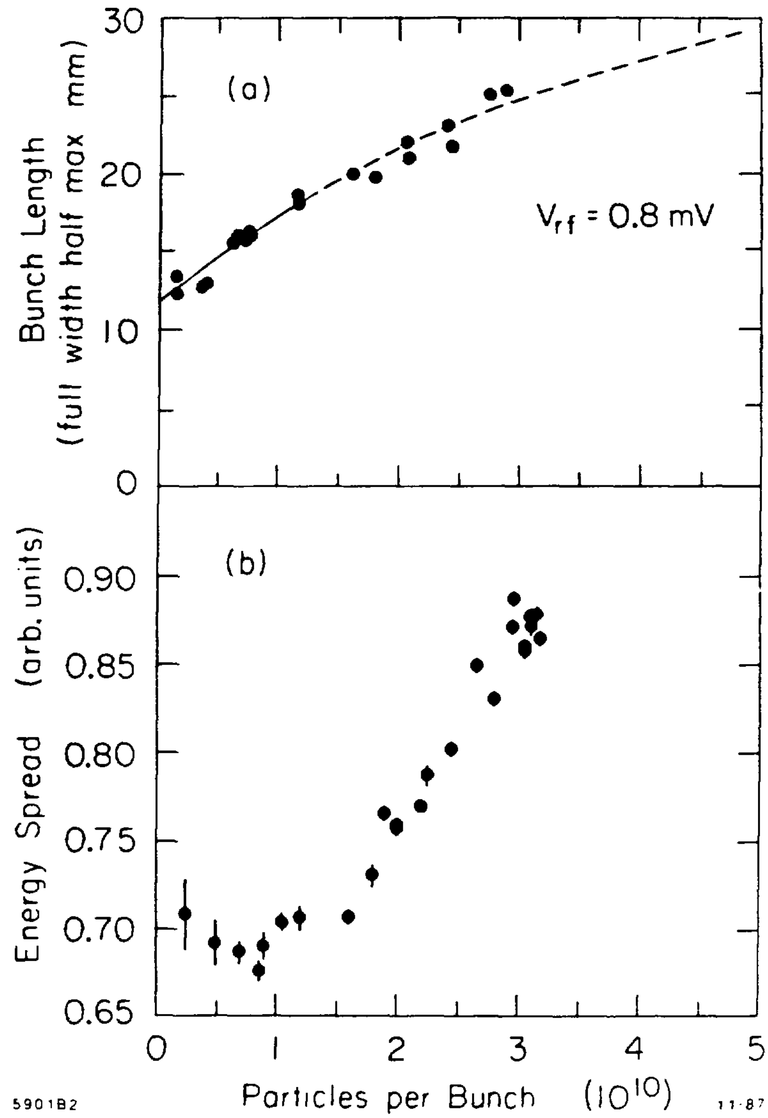
2.2 OUTSTANDING ISSUES

Bunch lengthening has been observed in the north damping ring and has limited the intensity which can be injected into the linac. Since the two rings are essential identical, the south ring is expected to have the same problem although at the present lower intensity it is not a problem. The lengthening is caused by a combination of potential well distortion and turbulent bunch lengthening. The lengthened bunch, after passing through the compressor, has a larger than nominal energy spread. Due to finite aperture in the ring-to-linac transport line, this results in beam scraping and intensity losses. Thus far, this has limited routine running to $2 \times 10^{10} e^-$/bunch.

The data for the increase in bunch length and energy spread are shown in Figs. 2a and 2b. Notice that the energy spread starts increasing at around 1.5×10^{10} which signals the start of turbulent bunch lengthening. The bunch lengthening at lower currents is entirely due to potential well distortion.

Both of these effects are due to an excess longitudinal impedance from discontinuities in the vacuum chamber. The wake fields of all the discontinuities have now been calculated, and the theory is plotted on top of the data in Fig. 2a. From the excellent agreement, we believe we understand in detail the source of the bunch lengthening.

We are taking a stepwise approach to curing the effects of bunch lengthening in both rings. First, during the fall shutdown 1987, we will open the aperture in the ring-to-linac transport line. Next we will use the RF in the ring to induce a quadrupole oscillation in order to pre-compress the bunch. This has been tested and works well. After testing these two modifications, we will determine the extent of the vacuum chamber modifications and/or RF power increases necessary to achieve the design current.



(a) Bunch length (b) Energy spread *vs.* current in the Damping Ring.

3. POSITRON SOURCE

3.1 STATUS

At 33 GeV in the linac, electrons are targeted on a W-Re target to produce positrons. These are captured by a high gradient acceleration section immersed in a high solenoidal field. After acceleration to 200 MeV, they are transported 2 km back to the beginning of the linac to be injected and accelerated to 1.2 GeV for injection into the south damping ring. Due to a sequence of small losses in the entire system, the yield of the system is only 50%; 2 electrons on target yield one positron out of the south damping ring.[3]

3.2 OUTSTANDING ISSUES

The key problem in the positron system is to increase the yield to 100%. There are several improvements which should accomplish this.

First, the septa will be replaced by one with a larger aperture to eliminate losses at extraction from the linac. The high gradient capture séction was initially designed to operate at 40 MeV/m. Due to initial vacuum problems associated with a leak in the rotating target, the section was damaged and so has been commissioned at the reduced field of 20 MeV/m. A new acceleration section will be installed during the fall shutdown 1987 to bring the field back up to 40 MeV/m. Finally, the high field solenoid has had some problems with turn-to-turn shorts which limit its performance to about 4 kG. This is being replaced by a new solenoid which will produce a field of 5.8 kG.

The combination of all these improvements is expected to increase the yield by about a factor of 2. This will bring the entire positron system (including the positron damping ring) up to the design value of 1 positron per electron on target.

4. LINAC

4.1 STATUS

The linac at SLAC has been upgraded with over 200 new 67 MW klystrons. Thus far, beam energies of 53 GeV have been measured, but commissioning and initial running will be at 47 GeV since this yields an energy at the interaction point corresponding to the Z° mass.

Positrons and electrons are routinely accelerated on the same RF pulse without significant emittance increase. The energy spectrum for both beams is 0.2–0.3%, and the routine intensity is typically $2 \times 10^{10} e^-$ and $5 \times 10^9 e^+$.

The single beam trajectory has been corrected to 150 μm. Two beam steering has yielded about 300 μm for both beams; however, this number is improving as hardware is debugged. The linac dilutes the emittance of the beam by about a factor of two. This is complicated by matching into the linac and bunch lengthening.

4.2 OUTSTANDING ISSUES

The two most important issues for the linac are stability and trajectory correction. As for stability, there is ongoing work on both slow and fast feedback for position and angle in both planes, energy, and energy spread. Much of this work is complete.

To aid the trajectory correction, the linac is being realigned and hardware checks on faulty beam position monitors are continuing.

To control the beam matching, a system is being finished to automatically measure the emittance and beta function. The klystron replacement program which controls the scaling of the lattice as klystrons cycle on and off is very nearly working.

5. ARCS

5.1 STATUS

Both the north (e^-) arc and south (e^+) arc routinely supply beams to the final focus now. However, due to large systematic errors, the arcs have introduced coupling and magnification of the betatron oscillations.

5.2 OUTSTANDING ISSUES

In Fig. 3a, you see measurements of the phase advance per cell showing the systematic errors. The procedure to correct these errors involves moving magnets and adjusting the backlegs to achieve the proper dipole and quadrupole field on the orbit. (The arcs magnets are combined function dipole-quadrupole-sextupoles.)

In Fig. 3b, you see measurements taken after the "phase fix" described was applied. This required a movement of all magnets by values which were typically around 200 μm. After these corrections, the optical functions are matched much better in the arcs, but there is still residual coupling and some residual magnification.

Work is ongoing to locate the sources of the residual errors and to calculate small modifications to the arc lattice to render it less sensitive to errors.

6. FINAL FOCUS

6.1 STATUS

Due to the problems mentioned in the arcs, the final focus has had limited commissioning time with a good input beam. In spite of this, a spot size of about 5 μm has been achieved in the north final focus (see Fig. 4), and a spot size of 20 μm has been achieved in the south final focus. In addition, the location of the collision point was measured with a streak camera and found to be 1 mm south of the surveyed point.

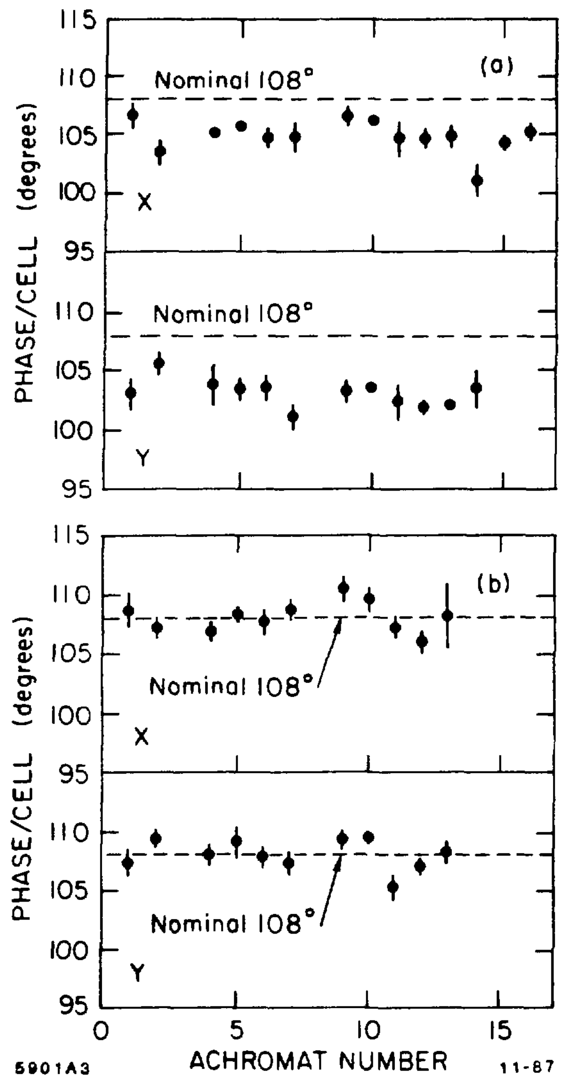


Fig. 3 Phase advance per cell (a) before and (b) after 'phase-fix'.

6.2 OUTSTANDING ISSUES

In spite of the fact that 5 μm spots have been achieved several times; it is not routine. A key effort in the final focus commissioning will be to reliably make small spots. This is greatly influenced by the upstream conditions and puts heavy demands on the linac and arcs. Once 5 μm spots are routine, the second order chromatic correction needs to be commissioned in order to go from 5 μm to 2 μm.

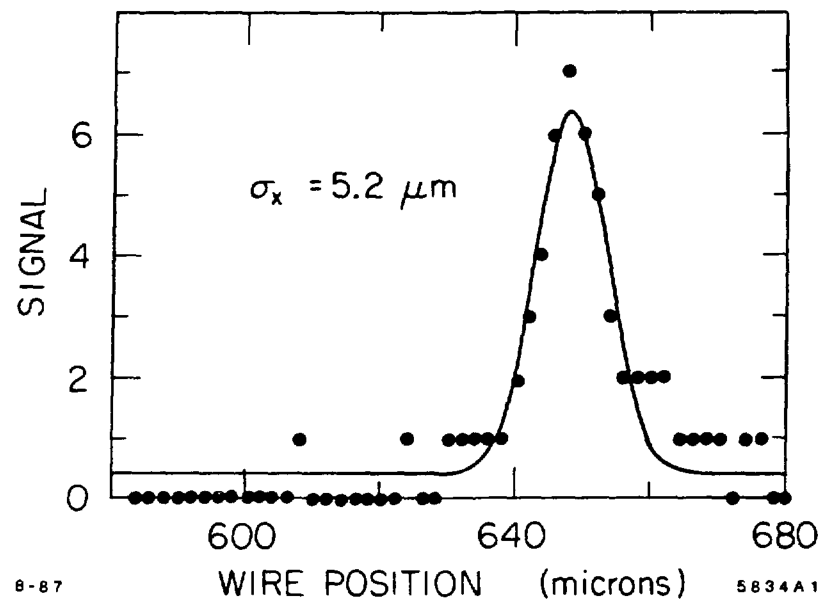


Fig. 4 Measurement of the Final Focus spot size.

In the area of beam-beam monitoring and control, the beamstrahlung radiation monitor is not yet complete and the beam-beam deflection monitor to aid steering must be commissioned.

7. CONCLUSION

As noted in the introduction, the SLC began a 13-week shutdown to move the Mark II detector and to upgrade various subsystems on Oct. 10, 1987. During that time, as the various subsystems are finished, they will be re-commissioned. The north damping ring will be turned on in late November followed by the positron system and south damping ring. Finally around mid January, beams are scheduled to pass through the final focus.

At this point, commissioning of the final focus and arcs will resume to prepare the SLC for the spring physics run.

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THE FERMILAB TEVATRON OPERATION AND UPGRADE PLANS*

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INTRODUCTION

The Tevatron is now being operated year round with alternative fixed target and collider runs of about six months' duration interrupted by two-month changeover and maintenance periods. This pattern is expected to continue if funding is sufficient. Statistics for the presently achieved fixed-target and collider operation are given in Tables I-III and Fig. 1. We are now in our second extended run for fixed-target physics at 800 GeV, the first run having taken place in 1985. The first collider run took place in the winter/spring of this year and achieved a peak luminosity of 10^{29} and an integrated luminosity of ~$70nb^{-1}$ at 900-GeV beam energy. The second collider run will beginning in the winter/spring of 1988. The goal is to achieve an integrated luminosity of ~7 times that obtained during the first run, or $1/2pb^{-1}$ (Table IV).

The long range Fermilab program requires maintaining a viable physics program into the mid to late 1990's when the SSC will begin operation. The program calls for doubling the integrated luminosity with each succeeding run until peak luminosity of a few $\times 10^{31}$, or an integrated luminosity per run of greater than $10pb^{-1}$ is achieved. No major new accelerator initiatives are contemplated because of their obvious interference and competition with the SSC funds and human resources. Rather, a highly challenging upgrade of the present Tevatron proton accelerator and proton-antiproton collider will be undertaken. Thus, the program outlined here clearly would not be considered an optimum plan for Fermilab or the U.S. High Energy Physics if the SSC were not to begin operation within the next 10 years.

*Operated by Universities Research Association, Inc. under contract with the U. S. Department of Energy.

Table I. TEV Fixed Target Operation

	Design	87
Energy (GeV)	800-1000	800
Intensity $\times 10^{13}$ ppp	>2	1.8
Rep rate	1-2 cyc/min	1
Extraction duration	1-10 sec	20 sec
Booster record intensity	4.6×10^{13} ppp (13 Booster batch)	
Main Ring record intensity	3.2×10^{13} ppp	

TABLE II. TEV Collider Missing Factors and Goals for First Run (87)

	Design	Apr 87	Missing Factor	Goals Winter 86-87
$\bar{p}$ extracted from accumulator bunch		2.6E10		2.7E10
$\bar{p}$ MR transmission		0.77		3/4
$\bar{p}$ coalescing efficiency		0.70		1/2
$\bar{p}$ transmission from MR to TeV low-β		0.64		1
$\bar{p}$ overall transmission		0.35		0.37
$\bar{p}$ stored/bunch	6E10	0.91	6.6	1E10
p extracted from Booster		1.5E11		
p MR transmission		0.75		3/4
p coalescing efficiency		0.62		1/2
p transmission from MR to TEV low-β		0.8		1
p overall transmission		0.37		0.37
p stored/bunch	6E10	5.6E10	1.07	4E10
Number of bunches	3x3	3x3		3x3
Transverse emittance 95% normalized ($\pi\times 10^{-6}$m)	24	20-25 (p) 30-40 ($\bar{p}$)		24
Bunch length luminosity reduction		0.85	1.2	0.9
Luminosity	E30	10^{29}	10	E29
$\bar{p}$ accumulation rate	11xE10/hr	1.2E10	9.2	1.5xE10/hr
Average minimum storage time required from $\bar{p}$ production rate	2 hr	6.5 hr		5-6 hr

Table III. Pbar Source stacking rate.
Missing factor breakdown for first run (87)

Stage	Design Report	Apr 87	Missing Factor Apr 87	Factor Goal 87
1. MR intensity on target	2×10^{12}	13×10^{11}	1.54	1.33
2. Pbar production collection to debuncher	7×10^{7}	14.6×10^{6}	3.11	2.5
3. Pbars after bunch rotation in 0.2% $\delta p/p$	7×10^{7}	12.3×10^{6}	1.19	1.1
4. Pbars in accumulator on injection orbit	7×10^{7}	10.4×10^{6}	1.18	1.1
5. Pbars on stacking orbit	7×10^{7}	9.9×10^{6}	1.05	1.1
6. Stacking efficiency	80%	88%	0.9	1.0
7. Cycles/hr	1800	1400	1.29	1.5
Stacking rate (10^{10}/hr)	10	1.23	8.2	6.7

TABLE IV COLLIDER GOALS FOR 88

	Design (TEV I)	Apr 87	Goal 88	Factor Improvement 88/87
Collider				
Energy (TeV)	0.8-1.0	0.9	0.9	
Number of bunches	3x3	3x3	3x3	
p stored/bunch (10^{10})	6	5	6	
$\bar{p}$ stored/bunch (10^{10})	6	1	3	3
95% emittance ($\pi 10^{-6}$ M)	24	25x35	<20	2
β^* (M)	1	2/3	1/2	
Peak luminosity (10^{30} cm^{-2}sec^{-1})	1	0.1	1/4	2 1/2
Integrated luminosity				
week (NB^{-1})	-	15	33	2 1/4
run (NB^{-1})	-	69*	500	7

*absolute luminosity uncertain to about 25%.

	Design (TEV I)	Apr 87	Goal 88	Factor Improvement 88/87
$\bar{p}$ Production				
Proton intensity/batch (10^{12})	2	1.3	1.8	1.4
Booster batch/cycle	1	1	3	
MR target cycles/hr	1800	1400	630	1.3
Protons on target/hr (10^{15})	3.6	1.8	3.4	2
$\bar{p}$ accumulation/hr (10^{10})	10	1.2	2.4	2
$\bar{p}$ transmission to low-β	-	0.35	0.5	1 1/2
Average minimum storage time required from production rate (hr)	2	7	7.5	

In the near term, minor improvements will help us to achieve the design goals of the present Tevatron project (2×10^{13} ppp, 10^{30} luminosity) and the completion of a second interaction region, the DØ detection region. However, more and more extensive upgrades need to be planned for in the 1990 time scale in order to sustain the required ever-increasing luminosity per run. Such a plan, by necessity, has improvements in almost all areas of the acccelerator as the present system is already reasonably optimized. Therefore, changes in many areas may be necessary in order to make gains of one specific type or another.

The Upgrade places emphasis on collider operation. This is because collider physics demands a continual increase in integrated luminosity with each run to productively search new physics domains. Fixed-target physics intensity improvements are also planned and are part of the overall consideration. Intensity increases of a factor 2-3 do seem possible and will aid in antiproton production as well as substantially benefit the fixed-target program.

TABLE V. TENTATIVE UPGRADE PARAMETERS

N_p	$5\text{-}6\times10^{10}$
N_p	$2\ 1/2\text{-}3\times10^{10}$
ϵ_T (95%)	$12\pi\times10^{-6}$m with growth to 20 π
ϵ_L	0.5-1.0 eV-s with growth to 3 eV sec
σ	20-30 cm with growth to 60 cm
Bunches B	96
β^*	1/2 m with possibly 1/4 m
L/hit (10^{25}cm^{-2})	1 max.-reduction with growth
L (10^{30} cm^{-2} sec^{-1})	44-64 peak-reduction with growth
Design goal L (10^{30})	50
Bunch spacing	132 ns
Harmonic number	1113/7=159
BNp (10^{12})	6
BNpbars (10^{12})	3
$\bar{p}$ accumulation rate	$2\text{-}3\times10^{11}$/hr
Accumulator intensity	10^{12} max.
Depository Ring fill interval	3-5 hours
TeV fill interval	10-15 hours
Beam-beam tune shift head-on 3 crossings per IR	0.022

The goal of the design study for the Tevatron Upgrade is a peak luminosity of 5×10^{31} cm^{-2} sec^{-1}. This goal is ambitious and may not be achievable but it forces us to investigate and determine what the real limitations may indeed be. Typical parameters under consideration are given in Table V.

Major ingredients of the Upgrade are in the following areas:

1) The Tevatron must be made to work with multibunches of protons and antiprotons and two low-β regions (BØ = CDF and DØ) by using separated beams produced by electrostatic deflectors in both horizontal and vertical planes.

2) In the p-bar Source, the antiproton production rate should be increased to $2\text{-}3\times10^{11}$/hr from a present 1.2×10^{10}/hr. This can be accomplished by a combination of increased proton-targeting flux, antiproton-collection efficiency, and more efficient stochastic cooling. This latter requires the development of higher frequency and more powerful cooling systems, with lattice modifications in both the Debuncher and Accumulator to utilize the higher frequency.

3) Proton intensity increase will benefit both fixed-target physics and antiproton production. This increase can best be realized by increasing the Linac energy from 200 MeV to 400 MeV in order to reduce space-charge tune-shift limitations in the Booster. A higher intensity, brighter beam (intensity per unit emittance) can then be injected and accelerated through the Main Ring. Minor modifications to the Main Ring which will improve lifetime at injection and transmission will continue to be incorporated as our understanding of the problems and their possible solutions develop.

4) Finally the advantages of construction of two new rings of intermediate energy (~20 GeV) are being evaluated. The role of one of these rings would be to provide 20-GeV injection energy for protons into the Main Ring which presently operates at 8 to 150 GeV. The 20-GeV injection from a post-Booster is attractive for a number of reasons, including the following: field quality in the magnets should be better at 20 GeV than at 8 GeV; injection would take place above transition in the Main Ring so losses and longitudinal emittance blowup associated with it would be precluded; transmission of high intensity, large normalized emittance beams (~25π) should be possible at the higher energies.

The second ring would serve as a "depository ring" for antiprotons. It becomes attractive at a luminosity where the number of antiprotons required in the Tevatron exceeds the number that can be stacked in the antiproton Accumulator, and still maintain peak stacking rate. We expect this saturation level to come at about 10^{12} antiprotons. When the stacking rate becomes inefficient, one option is to decelerate in the Tevatron, replace a fraction of the antiprotons, then reaccelerate and restore the beam. The beam would then consist of an old and just-replaced new fraction. This is a complex operation and subtracts from the time when data-taking would be going on. The other option is to use a new "depository ring" to unload the antiprotons whenever the accumulator becomes full. A number of Accumlator loads could be transferred and held in the depository ring while waiting for the appropriate time to refill the Tevatron.

A second possible use of the depository ring is to recover and recool antiprotons from the Tevatron when a store is terminated because the beam emittance degradation has caused reduction in luminosity. The proton Post-Booster and antiproton Depository rings would be built in the same tunnel and have a circumference not much longer than the present Booster or Accumulator rings. Preliminry parameters for these rings are given in Tables VI and VII and Figs. 2 and 3.

THE TEVATRON

Crucial to any major luminosity upgrade is the ability to operate the Tevatron with separated beams. This is required so that many bunches of protons and antiprotons can be collided at the detectors, but miss each other elsewhere. Minimization of the beam tune shift, intrabeam scattering, and the number of interactions expected per crossing in the detectors all push for the desirability of numerous bunches (~100) with low intensity per bunch ($\sim 3\times 10^{10}$).

It appears that electrostatic beam separators can be placed in the interaction region of the lattice just outboard of the $\beta *$ focusing triplet on either side of the IR's. These would provide for separation of all but three crossings per IR at bunch spacing of (130-230 ns).

Table VI. Post-Booster Machine Parameters

Circumference	513.7	meters
Injection Energy	8.9	GeV
Peak Energy	20.0	GeV
Harmonic Number (@53 MHz)	91	
Horizontal Tune	7.41	
Vertical Tune	7.41	
Transition Gamma	7.1	
Number of Bunches	84	
Protons/Bunch	8.6×10^9	
Transverse Emittance (Normalized)	8π	mm-mr
Longitudinal Emittance/Bunch	0.09	eV-sec
Momentum Spread (Max, full width)	0.3	%
Transverse Acceptance (Unnormalized)	5π	mm-mr
Momentum Acceptance	0.6	%
β_{max} (Arcs)	21	meters
β_{max} (Straights)	29	meters
Maximum Dispersion	2.3	meters
Number of Straight Sections	12	
Total Length in Straight Sections	60	meters
RF Frequency (Injection)	52.8	MHz
RF Frequency (Extraction)	53.0	MHz
Number of Dipoles	76	
Dipole Length	4.1	meters
Dipole Field (Max)	13.5	kGauss
Number of Quadrupoles	88	

Table VII. Antiproton Depository Parameters

	Ring 1	
Circumference	474.2	meters
Accumulation Energy	8.9	GeV
Peak Energy	20.0	GeV
Harmonic Number (@53 MHz)	84	
Horizontal Tune	6.61	
Vertical Tune	6.61	
Transition Gamma	6.9	
η @ Low Energy	.010	
η @ Peak Energy	.019	
Maximum No. of Antiprotons	4×10^{12}	
Transverse Emittance (Normalized)	10π	mm-mr
Full Momentum Spread	20	MeV
Longitudinal Emittance	29	eV-sec
Cooling System Bandwidth	8-16	GHz
Transverse Acceptance (Unnormalized)	10π	mm-mr
Momentum Acceptance	1.8	%
Number of Straight Sections	6	
Length of Zero Dispersion SS	10.1	meters
Length of High Dispersion SS	6.0	meters
Number of Dipoles	42	
Dipole Length	6.5	meters
Dipole Field (Max)	15.4	kGauss
Number of Quadrupoles	66	
Magnet Style	TeV I	

In order for collisions not to take place elsewhere, the separators must produce helical spiral orbits of protons and antiprotons about one another in the x,y plane. The crucial issue for separators is whether the beams with large orbit distortions can be stored with reasonable lifetime. There are two parts to the problem. First, there is the single-beam question of whether magnetic fields and corrections are, or can be made sufficiently satisfactory and flexible to provide for good single beam lifetimes for both beams with their relatively large orbit distortions. This issue may be especially important at the 150 GeV injection energy where separation of $\pm 2\ 1/2\ \sigma$ requires a large fraction of the aperture at the high dispersion points.

Acceleratior studies are underway to investigate tune, chromaticity, and lifetime changes at injection and storage energies for a single beam as a function of orbit distortion amplitude. So far, results have been obtained only for the change in tune resulting from an orbit distortion. These results agree well with what is expected from magnetic measurement data.

The other question about separated beams with many bunches is that of the long-range beam-beam interaction (bunches passing each other at a distance). Theoretical studies have been initiated to study the expected effect of these long-range passings for the specific geometries involved.

For the Tevatron upgrade, the question of whether the magnet aperture can sustain long beam lifetimes for the separated orbits is crucial. There are, however, a number of other problems and engineering developments which must also be addressed. Intrabeam scattering (coulomb collisions of particles within a bunch) will be a fundamental limitation to the achievable integrated luminosity. Many of the parameters that can be decreased to increase the peak luminosity, e.g. β^*, bunch length, and emittance, also decrease the luminosity lifetime through increased growth of transverse and longitudinal emittances. Fortunately, longitudinal emittance which has the shortest growth lifetime affects the luminosity only to second order.

So far, there seems to be no feasible technical way around the intrabeam scattering problem. Bunch-beam cooling, for the bunch lengths needed at the planed β^* of 1/2 - 1/4 m, appears to be just beyond reasonable technical expectations. We appear to be stuck with accepting the luminosity degradation with stored beam time and with filling the Tevatron as often as possible. This brings up the fundamental logistics problem of the Upgrade which can be expressed as follows:

1) The luminosity lifetime in the Tevatron will become shorter as the peak bunch luminosity is increased.

2) Though, in a sense, protons are unlimited, antiproton production is finite. If possible, antiprotons should be conserved.

3) The number of antiprotons needed in a store in the Tevatron will exceed the number that can be held in the stack in the p-bar Source Accumulator and still maintain high stacking efficiency. The p-bar Source cannot stack efficiently when it has more than $\sim 10^{12}$ particles or ~1/3 of what the Tevatron might use in a complete fill. The Accumulator must then be emptied every 3-5 hours if it has a production $2\text{-}3 \times 10^{11}$/hr, whereas to get sufficient numbers of antiprotons in the Tevatron, storage times must be of the order of 12 to 18 hours.

It is just these points which force us to consider the benefits of an 8-20 GeV Depository ring, and of recovery and re-cooling of antiprotons from the Tevatron in that ring, as well as holding antiprotons from the accumulator until they are required for a Tevatron fill.

PROTON INTENSITY AND EMITTANCE IMPROVEMENTS

We believe that the Booster performance is limited by space-change tune spread at injection time. Evidence for this is given in Fig. 4 where it can be seen that the transverse emittance out of the Booster grows linearly with intensity. Analysis shows that this is consistent with the Booster being able to sustain a tune spread of $\Delta\nu = 0.37$. That the Booster is a fast cycling machine (15 Hz) probably is a help in achieving this rather large $\Delta\nu$ value.

The space-change tune shift scales as $1/\beta\gamma^2$, so injecting at 400 MeV would substantially increase N/ϵ as indicated in Fig. 4. The Booster intensity at which its aperture would begin to a limiting factor is also increased by 50%. Thus, the Booster with 400-MeV injection should be able to accelerate considerably higher intensity as long as collective instabilities can be controlled.

LINAC

A proposal has been developed and R&D is underway to upgrade the Linac to 400 MeV. This upgrade calls for replacing the downstream half of the present 200-MHz drift-tube linac with an 800-MHz side-coupled cavity structure operating at 7 MeV/m. Specifications are listed in Table VIII. R&D has been started to evaluate both side-coupled and disk and washer cavity structures. Conceptual design of a matching section between the 200 and 800-MHz sections is also being developed.

TABLE VIII. LINAC UPGRADE SPECIFICATIONS

A. General Linac Upgrade Parameters	
Energy range (MeV)	116.5-400
RF frequency (MHz)	805
Particle accelerated	H^-
Beam intensity (mA)	50
Number of modules	7
Number of klystron power supplies	7
Available power per klystron power supply (Mw)	10
Average accelerating gradient (Mv/m)	7-7.5
Pulse repetition rate (pulses per second)	15
RF pulse length (μsec)	125
Duty factor (%)	0.2
Total length available, approximate (m)	59
Stable phase angle (from peak)	-32°
B. Prototype parameters	
Bore tube radius (cm)	1.5
Cell length (cm)	8.506
Accelerating mode frequency (MHz)	805
Separation between sections, cell to cell (cm)	25.518

The new cavity structure would fit in the same length as is presently used and connected to the transport line to the Booster. Certain elements of this line will require replacement.

R&D work has also been initated to develop an RFQ (2 MeV) and new first drift-tube tank to replace the present 750-kV Cockcroft-Walton preaccelerator. We believe that smaller linac emittance and a less complicated preaccelerator system will result. The small emittance will only be of use at low-bunch intensities ($1\text{-}2\times10^{10}$), however there is a considerable space saving and a substantial amount of antiquated hardware can be retired.

MAIN RING

With the Linac Upgrade, higher intensity and brighter beams can be injected into the Main Ring. Main Ring transmission should be improved for the higher intensities. Referring to Fig. 4, this might be simplistically indicated by a horizontal translation of the present typical operating point to the 400-MeV dashed line and result in, for example, a fixed-target Tevatron intensity of 3×10^{13}. This is almost a factor of 2 gain, though collective effects and $\Delta p/p$ acceptance still need to be factored in.

POST-BOOSTER

A 20-GeV post-Booster between the present Booster and Main Ring and injection into the Main Ring above transition at 20 GeV would considerably increase its acceptance. The Main Ring acceptance would be increased by a factor of 2, both for transverse emittance and momentum spread (Δp). In addition, the magnet field quality probably is considerably better at this excitation

High intensity beams ($>5\times10^{13}$) could be contemplated at large transverse emittances, if we can learn to control the instabilities throughout the accelerator chain. Injection into the Main Ring at 20 GeV (above transition) should reduce the problems of collective phenomenon (space charge and instabilities) in the accelerator.

ANTIPROTON SOURCE

The $\bar{p}$ Source accumulation rate was 1.2×10^{10}/hr in the last run with 1.8×10^{15} proton on target/hr ($0.67\times10^{-5}\bar{p}$-/p). This stacking rate is a factor of 8 below the TeV I design value of 10^{11}/hr (see Table III) and was produced with an average targeting cycle time of 2.6 sec. at a proton intensity of 1.3×10^{12} per cycle. This missing factor of 8 from design was made up primarily of a factor of 2 from proton flux on target, and a factor of 2.5 apparently in the antiproton production cross section. Considerable effort must now be put into increases in targeting flux and into source improvements if this cross section reduction is to be overcome and antiproton accumulation rates of $2\text{-}3\times10^{11}$/hr are to be achieved for the upgrade operation.

A factor of ~20 improvement over present operation can be contemplated. In the upcoming collider run, we will attempt to decrease the effective targeting cycle time by simultaneously accelerating three booster batches (instead of one) in the Main Ring and then sequentially extracting them to the antiproton production target. This should improve the average cycle rate from 0.4 to 1/2 Hz. In the longer term, if six batches can be accelerated and targeted without beam dilution, an average targeting rate of 1 Hz can be achieved (1.35 Hz instantaneous). This will give a factor of 2.5 improvement

With the Linac Upgrade and minor improvements in the Main Ring transmission, batch intensities can be expected to increase from a typical value during the last run of 1.3×10^{12} to 3.2×10^{12} for a factor of 2.5 improvement. Additional gains would be expected with the construction of the 20-GeV Post-Booster.

If the Antiproton Source Debuncher ring's rf capture voltage is increased by 1.75, momentum acceptance will be increased from 3 to 4% for a gain in collection efficiency of 1.25. Further collection improvement of ~1.5 is possible if the aperture in the Debuncher ring and injection transport line is increased from 20 to 30π acceptance. The aperture increase in the Debuncher ring can be implemented by increasing the gap of the cooling electrodes. Consequently, cooling system power will need to be increased by a factor of 2. Together, longitudinal and transverse acceptance improvements may result in a factor of 1.9-2 improvement in antiproton efficiency.

Focusing of the proton beam to a smaller spot size on the production target will increase the effective yield into the debuncher's acceptance. A factor of 1.5 can be obtained by reducing the rms size from 0.38 mm to 0.14 mm. This reduction alone with increased flux and rep rate will force a redesign of the lens and target systems, including a possible beam-sweeping system in order to prevent thermal failure.

The factors listed above: 2.5 from rep rate; 2.5 from proton intensity; 1.5 from spot size; and 2 from acceptance improvements; when combined can provide for a production rate of 2×10^{11} antiprotons per hour. This increased rate will in turn require cooling-system improvements in both the Debuncher and Accelerator rings. Table IX indicates what those improvements might include. R&D is presently underway on 4 to 8 GHz systems.

Table IX. Pbar Source Cooling Improvements

Debuncher Cooling
Δf (GHz) P (watts)

		Transverse H, V		Longitudinal	
		Δf	P	Δf	P
Present		2	800	-	-
87-88		2	800+		
88-89		2	1600+		
Long term	1)			4	~1000
	2)	4	~1600		

+With optical notch filter.

Accumulator Cooling
Δf (GHz) P (watts)

		Stack tail		Core			
		Longitudinal		Transverse		Longitudinal	
		Δf	P	Δf	P	Δf	P
Present		1	1500	2	10	2	30
87-88							
88-89				4	10	4	30
Long term	1)						
	2)	4	1500				
	3)			8	10	8	30
	4)	Precooling					

CONCLUSIONS

In order for the Tevatron Collider program to remain viable into the 1990's, luminosity increases are required. In the near term, these increases can be obtained by improved operation and optimization of the present complex, and minor modifications. In the long range, increased proton intensity must be obtained in order that antiproton production can be increased. Two steps are contemplated, an upgrade of the Linac energy to 400 MeV and the construction of a Post-Booster. Both of these steps will lead to increased fixed-target intensity. At some point when antiproton production is sufficiently large, a Depository ring for holding the antiprotons between Tevatron fills will be required.

ACKNOWLEDGEMENTS

A large number of Accelerator Division people have contributed ideas to the Upgrade Program. In particular, thanks are due S. Holmes, J. Marriner, G. Dugan for their Report of the New Ring Study Group (Fermilab FN to be published), to D. Young for The Tevatron Linac Upgrade Conceptual Design, to G. Dugan and J. Peoples for the Source Upgrade, and to T. Collins, E. Malamud, K. Koepke, and D. Finley for DØ low-β and separator design work.

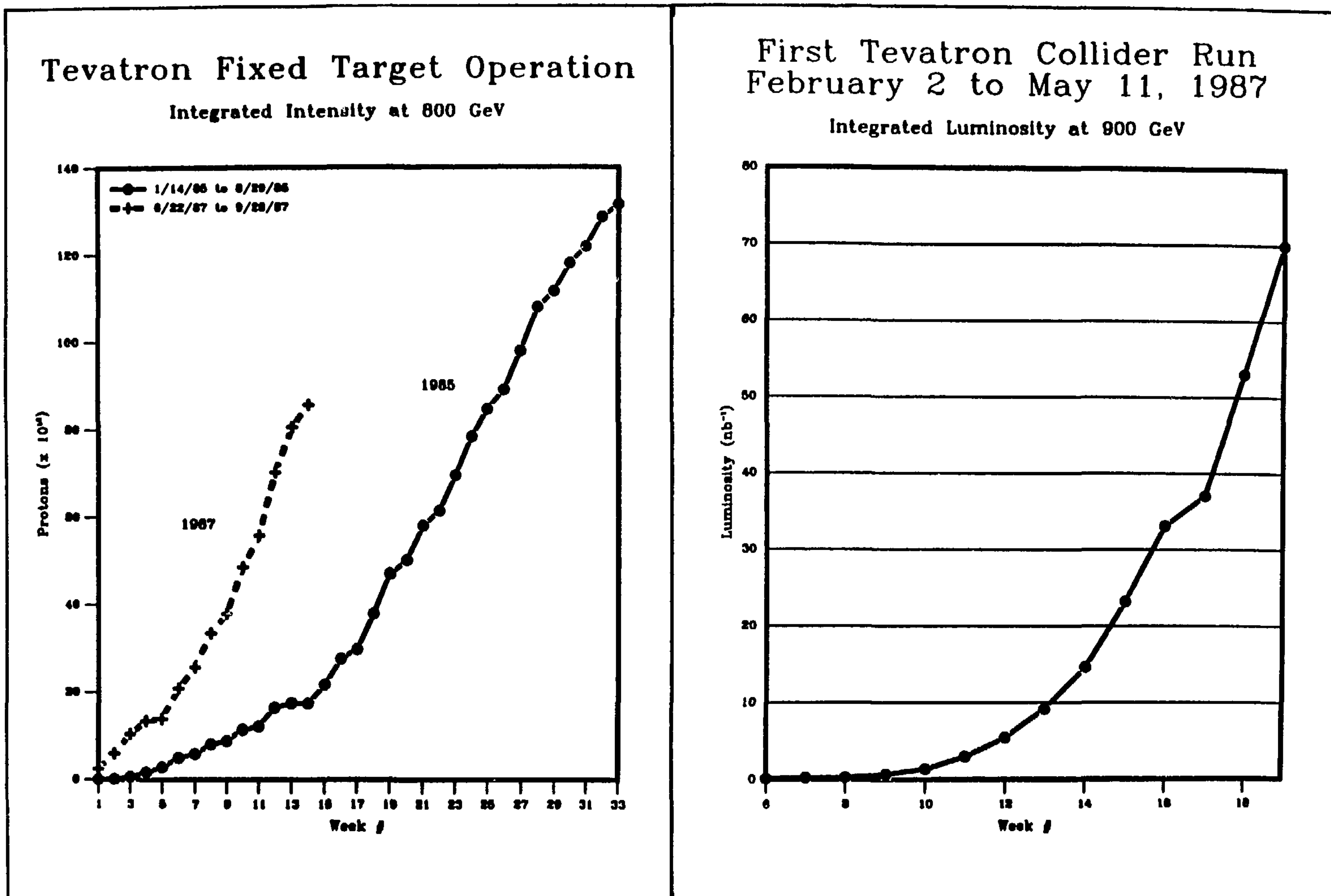
Tevatron Fixed Target Operation
Integrated Intensity at 800 GeV
1967
1985
Week #
First Tevatron Collider Run
February 2 to May 11, 1987
Integrated Luminosity at 900 GeV
Luminosity (nb⁻¹)
Week #

FIGURE 1

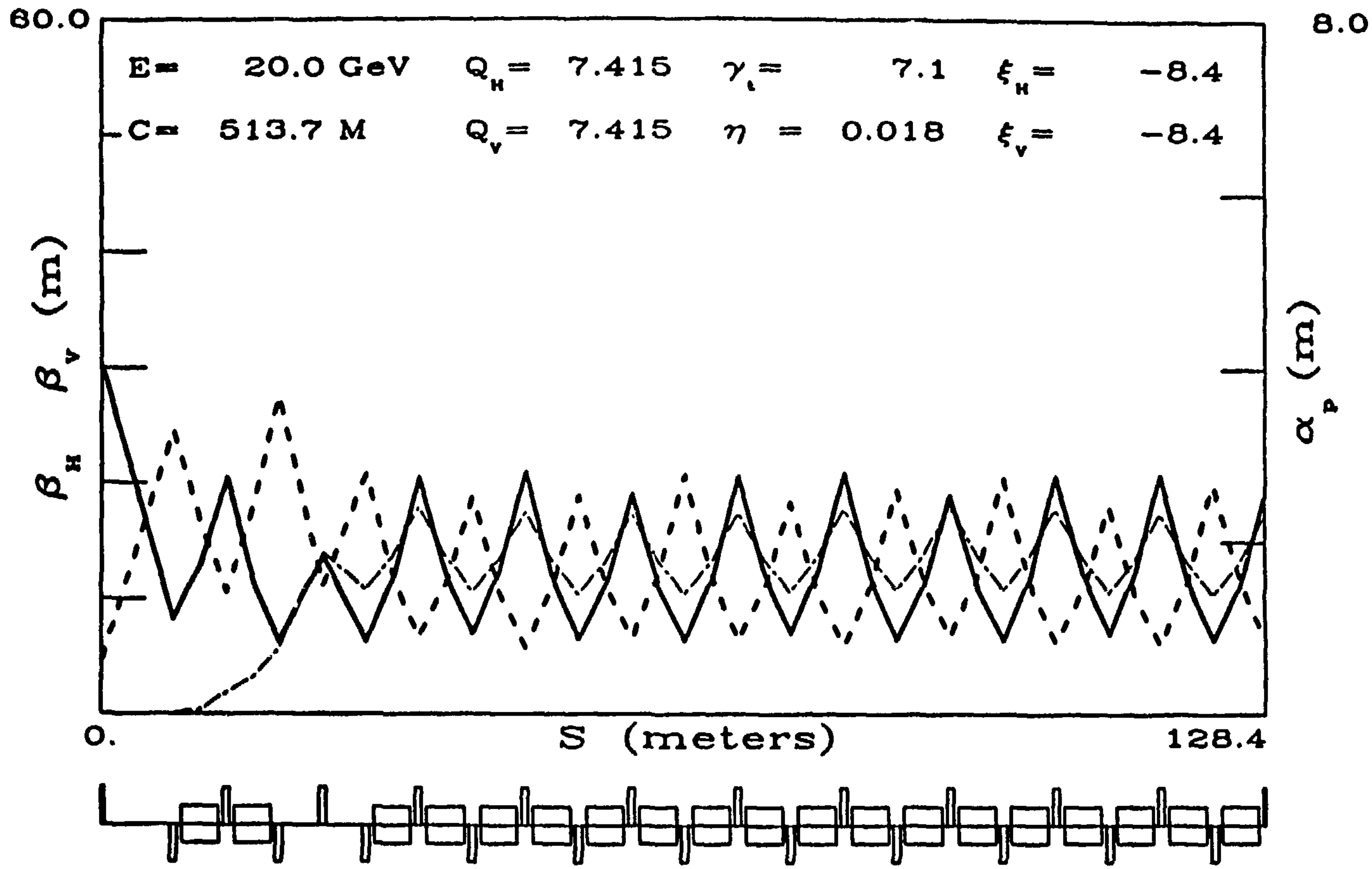

Figure 2. 20 GeV Post-Booster.

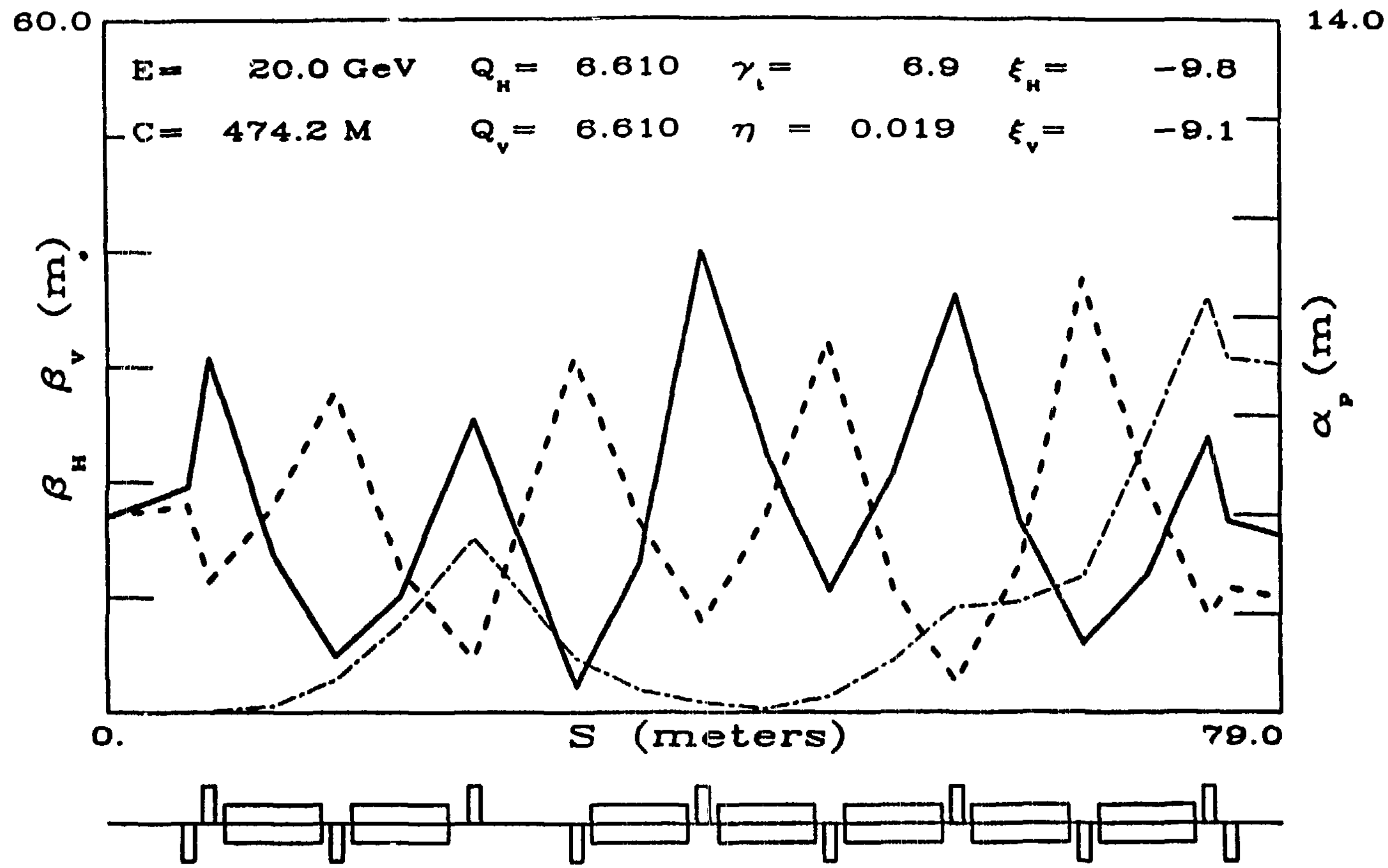

Figure 3. 20 GeV Pbar Depository.

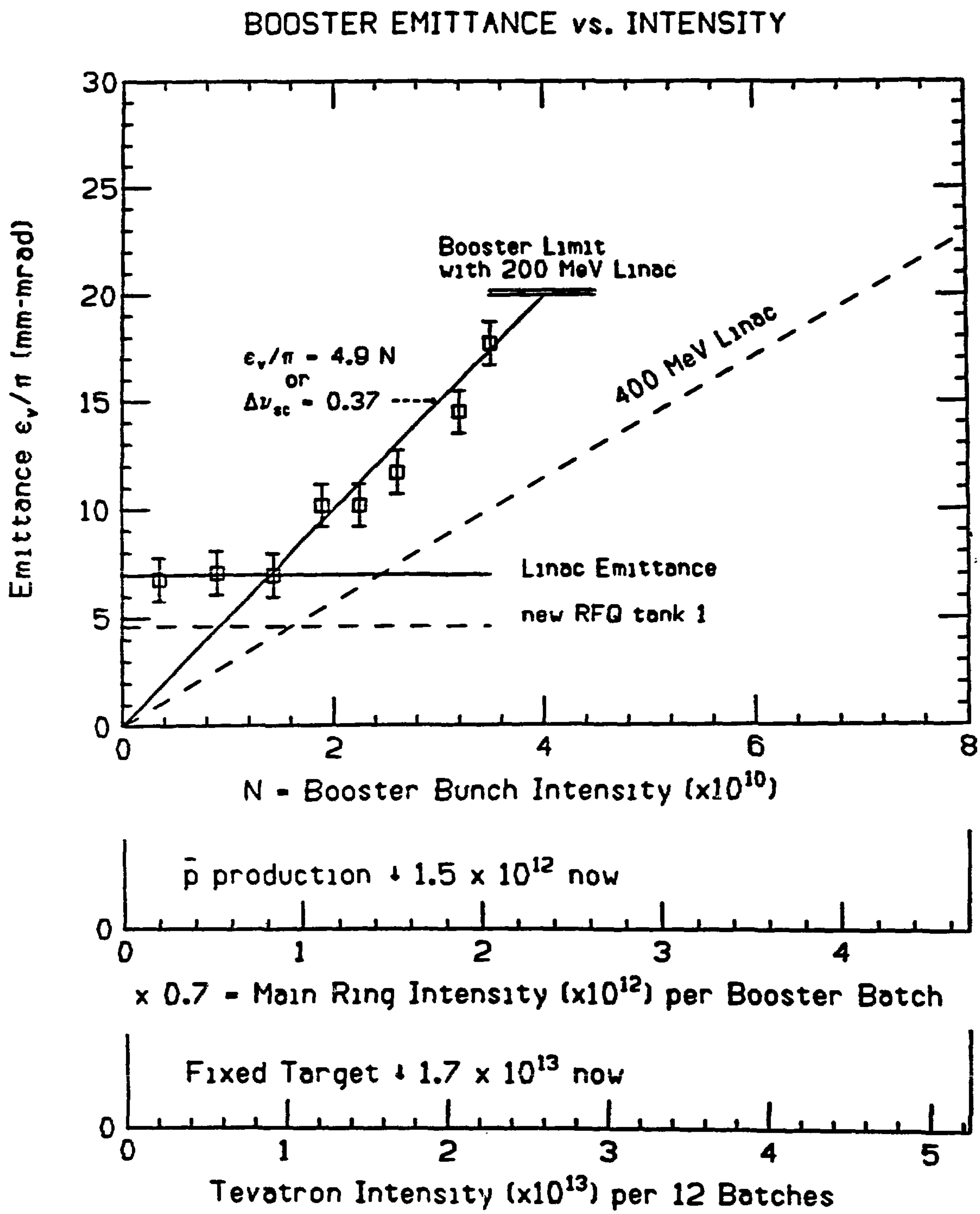
BOOSTER EMITTANCE vs. INTENSITY
Emittance ϵ_v/π (mm-mrad)
Booster Limit
with 200 MeV Linac
ϵ_v/π = 4.9 N
or
$\Delta\nu_{sc}$ = 0.37
400 MeV Linac
Linac Emittance
new RFQ tank 1
N = Booster Bunch Intensity ($\times 10^{10}$)
$\bar{p}$ production ↓ 1.5 x 10^{12} now
x 0.7 = Main Ring Intensity ($\times 10^{12}$) per Booster Batch
Fixed Target ↓ 1.7 x 10^{13} now
Tevatron Intensity ($\times 10^{13}$) per 12 Batches

Figure 4

CURRENT STATUS OF TRISTAN e^+e^- COLLIDER AT KEK

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Ibaraki-ken, 305 Japan

About three years ago, when 1984 ICFA Seminar on "Future Perspectives in High Energy Physics" was held at KEK,I reported on TRISTAN e^+e^- colliding beam facility[1], the construction of which was in progress. Now, in this 1987 Seminar on the same title, I am reporting on the facility which was completed, at least in its initial form, and was commissioned in November of the last year. In fact, I am quite happy to say that TRISTAN not only has started to run on schedule but also the first physics results at $\sqrt{S}$ = 50 GeV and 52 GeV was analyzed and reported on the last July 27 at the "International Symposium on Lepton and Photon Interactions at High Energies (Hamburg, July 27-31, 1987)" and on August 25 at "Physics in Collision (Tsukuba, Aug. 25-27, 1987)".

INTRODUCTION

This presently world highest energy e^+e^- colliding beam facility is the second major high energy physics accelerator installation in Japan, the first one being 12 GeV proton synchrotron which became operational in 1976. We hope that TRISTAN will allow Japan to join others in high energy physics research at the *bona fide* energy frontier. The idea of the TRISTAN in a form of three-storage-ring complex was born during 1973[2]. Construction of TRISTAN in the present form was approved and funded by the Japanese Government as a five-year project starting in the Japanese fiscal year 1981. The actual construction began on November 19th of that year with a ground breaking for the TRISTAN accumulation ring. Five years later, TRISTAN achieved e^+e^- collision at the world's highest center-of-mass energy of 50 GeV on November 14th, 1986, and on November 19th, exactly five years from

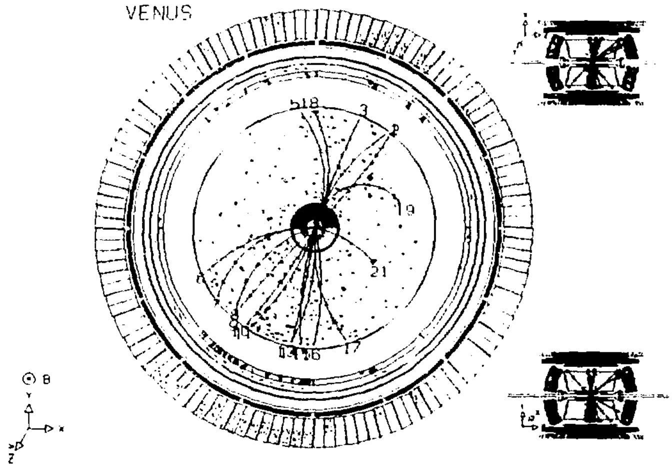

Figure 1. The first hadronic event obtained by VENUS on Dec. 13, 1986.

the date of the ground breaking, one of the TRISTAN detectors, VENUS, which had been at the collision point since the beginning of the commissioning run has succeeded in observing a clean large angle Bhabha scattering at the collision energy of 48 GeV, then the world's highest collision energy. On December 13, the first hadronic event (Fig. 1) was observed also by VENUS. It is interesting to note that a $q\bar{q}$ event at this energy indeed give a jet-like appearance on the event display. Another TRISTAN detector, AMY, by a collaboration of groups from the USA, China, Korea and Japan was rolled into the collision point on November 23, and started to observe collision events also in the subsequent commissioning and engineering runs.

THE TRISTAN ACCELERATOR COMPLEX

The TRISTAN accelerator complex[3] involves four connected accelerators as shown in Fig. 2; Namely, a pair of short LINACs for e^+ generation, 400 m long electron LINAC, an accumulation ring with a circumference of 377 m, and the main ring with a circumference of 3 km. The main ring consists of four long straight sections, each ~200 m long, and four quadrants of arc, each ~550 m long. These long straight sections are designed in the overall

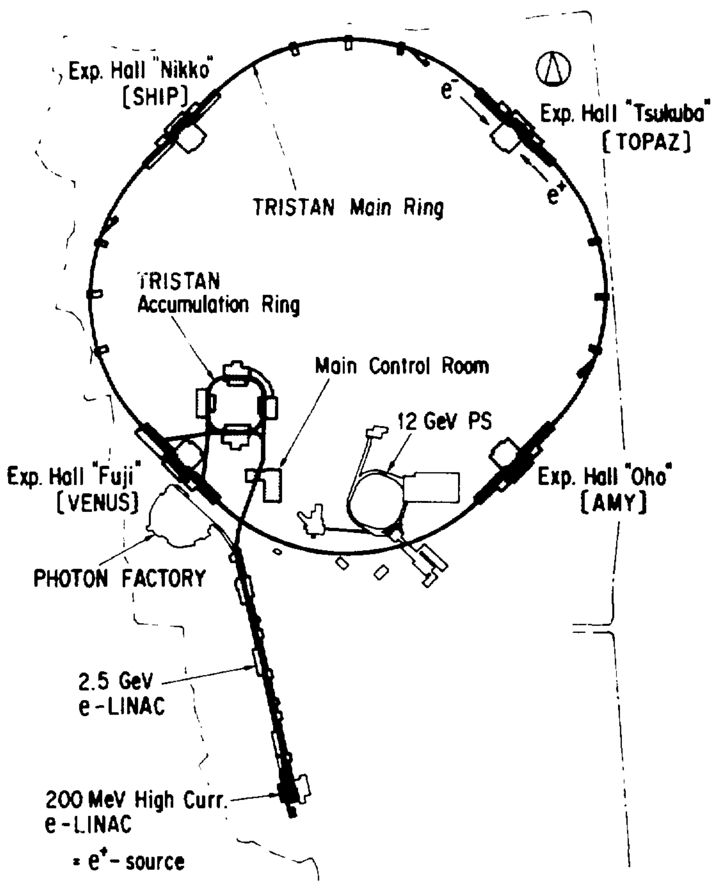

Figure 2. Layout of TRISTAN Accelerators

geometry of the accelerator, sacrificing the bending radius of the arc, for an extensive installation of radio-frequency acceleration cavities needed to replenish the enormous energy lost by the synchrotron radiation emission at these high energies. The r-f power prepared for 28 GeV operation is about 25 MW, delivered to 104 units of room temperature 9-cell Alternating-Periodic-Structure (APS) cavity assemblies distributed in three of the four long straight sections of the main ring. For the commissioning runs, however, only two out of four straight sections were filled with the cavities. The fourth straight section is set aside for an installation of superconducting r-f cavities which will be discussed later. Photographs of a curved section of the main ring tunnel with magnets and a straight section

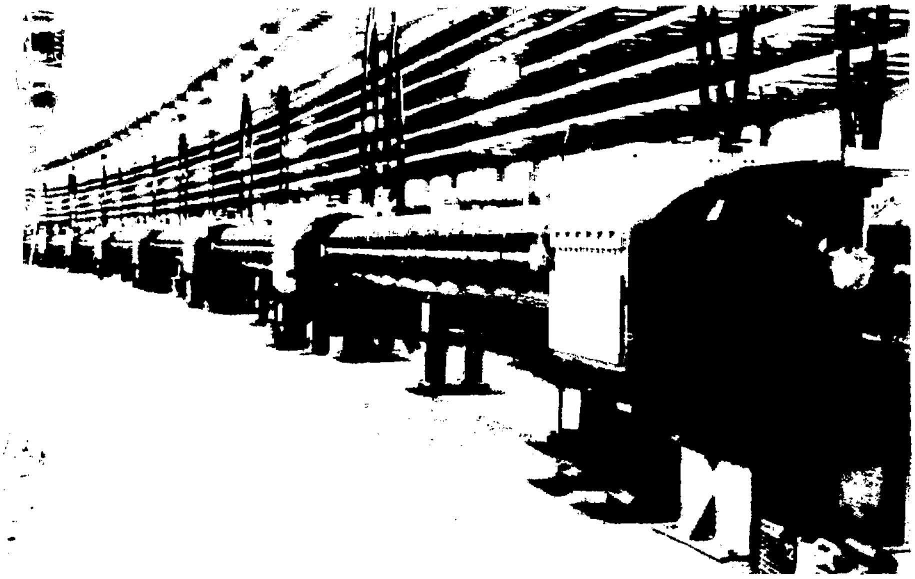

Figure 3. An arc section of the main ring tunnel with ring magnets.

Figure 4. A straight section of the main ring with APS r-f cavities.

with r-f cavities are shown in Figs. 3 and 4, respectively. Important design parameters for the accumulation ring and main ring are given in Table 1.

Table 1 PRINCIPAL PARAMETERS OF THE TRISTAN

	MAIN RING	ACCUM. RING
Circumference	3018.1 m	377.0 m
Ave. radius of curved sec.	346.7 m	47.7 m
Length of long straight sec.	4 × 194.4 m	2 × (19.5 m+19.1 m)
Total length of r-f sec.	509.4 m	38.1 m
r-f Frequency	508.6 MHz	508.6 MHz
Injection energy	6 - 8 GeV	2.5 - 3 GeV
Max. energy	25 - 30 GeV	6 - 8 GeV
Number of Int. points	4	2
Max. design luminosity (optimum coupling)	$8\times10^{31}cm^{-2}s^{-1}$	$8\times10^{31}cm^{-2}s^{-1}$

Incidentally, the accumulation ring is also a storage ring with a circumference of 377 m, and, therefore, can also be used as a synchrotron radiation source at the beam energy of ~6.5 GeV as well as an electron-positron collider at the center-of-mass energy of ~13 GeV for B-physics.

Two bunches of electrons and two bunches of positrons circulate around the main ring clockwise and counter-clockwise, respectively, and come to meet each other at the middle of four straight sections. Experimental halls, built at these locations are named, counting clockwise from the southwest hall, Fuji, Nikko, Tsukuba and Oho, after a well known landmark in respective direction. Incidentally, Oho is the name of the town in which KEK is located.

THE FIRST PHYSICS RUN

After the commissioning run of November and December of the last year and the engineering run of 6 weeks in January-February of this year, TRISTAN was operated for the first full-scale physics run from May 13 through July 25. All four experiments at TRISTAN participated in this run. The operation was broken up into three cycles as follows:

Cycle 1	May 13-May 23,	Mostly the machine start-up and study
Cycle 2	May 27-June 15,	25+25 GeV colliding beam operation.
Cycle 3	June 23-July 25,	26+26 GeV colliding beam operation.

The performance of the machine has rapidly improved since the commissioning run and reached to have the beam life of about 2 hrs and 3 hrs by the end of the cycle 2 and in the latter part of the cycle 3,

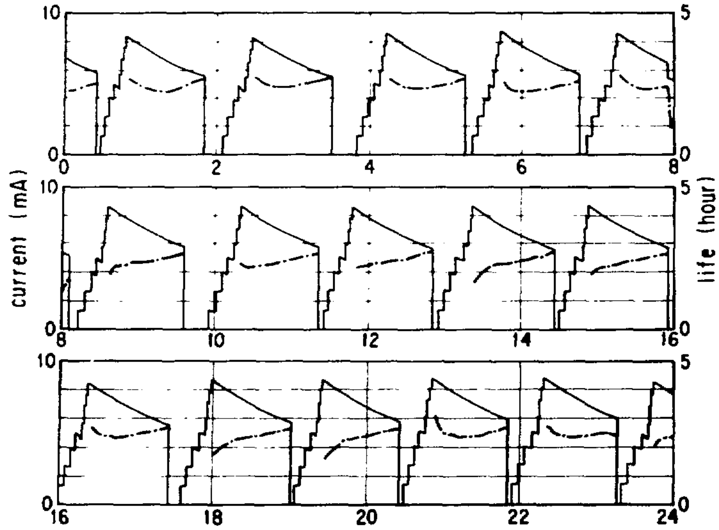

Figure 5. Operation cycles of the main ring on a typical day (July 21, 1987). Shown are the cyclic change of stored beam current (solid line) and the beam lifetime as a funcution of time (broken line).

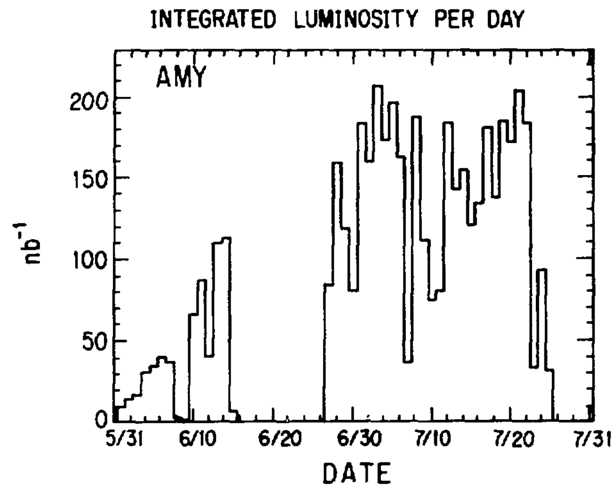

Figure 6. Daily integral of the liminosity for May 31~July 25 period as accumulated by AMY.

respectively. The highest peak luminosity obtained was 0.6×10^{31} $cm^{-2}sec^{-1}$ for the cycle 2 and 0.8×10^{31} $cm^{-2}sec^{-1}$ for the cycle 3. These improved peak luminosity and life time resulted in a very rapid improvement of the daily luminosity integral which reached to 100 nb^{-1}/day by the end of the cycle 2 and 200 nb^{-1}/day in the latter part of the cycle 3. A record of the main ring operation cycle on a typical day, shown in Fig. 5, indicates a reliable repetition of the fill-acceleration-storage(collision)-dump cycles. A growth of the daily luminosity integral is shown in Fig. 6. TRISTAN accelerator performances achieved are compared with design values in Table 2.

Table 2 TRISTAN MAIN RING Performances

	Design	Achieved (July '87)	Expected (Oct '87)
E_{beam}	~30 GeV	26 GeV	~28 GeV
$E_{injection}$	8 GeV	7.4 GeV	7.6 GeV
# of RF units	52×2	40×2	52×2
I_{beam} (Total)	15 mA	9.5 mA	
I_{beam} / bunch	4 mA	3.5 mA	
τ_{beam}	4~5 hrs.	2~3 hrs.	3~4 hrs.
$(L)_{peak}$	1×10^{31} $cm^{-2}s^{-1}$	0.8×10^{31} $cm^{-2}s^{-1}$	
$\Delta\nu_h$ / $\Delta\nu_v$	0.03 / 0.03	0.02 / 0.03	
β^*_h / β^*_v	1.6 m / 0.1 m	1.8 m / 0.1 m	
Coupling Ratio	4.4 %	2~3%	
σ_h / σ_v	520 μm / 32 μm	350 μm / 12~14 μm	

TRISTAN DETECTORS

Four experiments, VENUS*, SHIP**, TOPAZ*** and AMY**** were set in their respective experimental hall, i.e. Fuji, Nikko, Tsukuba and Oho. The SHIP experiment is a specialized and simple experiment by a small collaboration of physicists from the USA and Japan that Searches for Highly Ionizing Particles, such as Dirac magnetic monopoles, using a small polyhedral box made out of laminated plastic sheets of CR-39 and Lexan. The other three are big experiments with colliding beam detector of more-or-less standard cylindrical configuration. All of them use solenoidal magnet with superconducting coil. Of these, the VENUS and TOPAZ experiments are by collaborations of mostly Japanese university groups and KEK groups, while the AMY experiment is a major international collaboration of physicists from the USA, China, Korea and Japan. Principal detector parameters of VENUS, TOPAZ and AMY are compared in Table 3, and a photograph of each detector is shown in Fig. 7, 8 and 9, respectively.

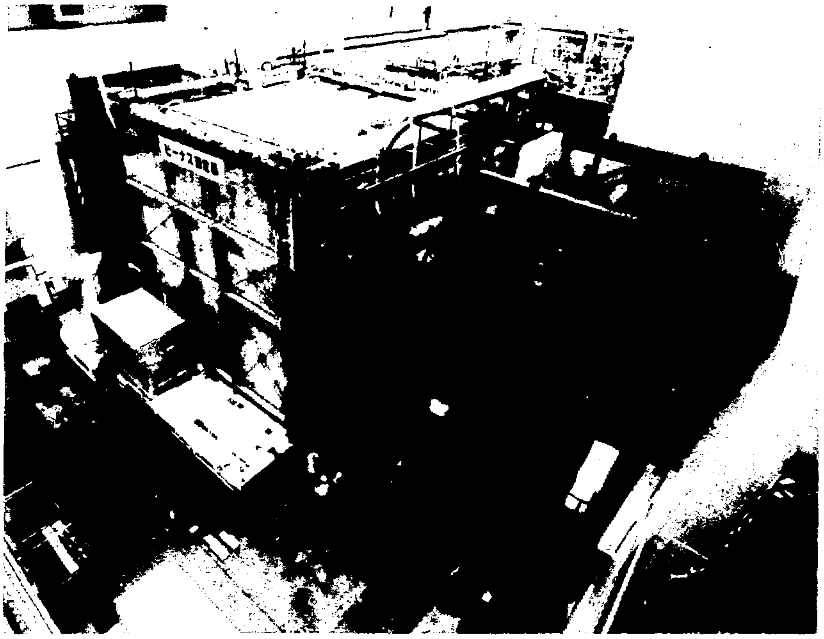

Figure 7. The VENUS detector

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* VENUS Collaboration
Tohoku U., KEK, U. of Tsukuba, Tokyo Met. U., Hiroshima U., Wakayama Med. Coll., Tokyo U. of Agri. and Tech., Osaka U., Kyoto U., Tohoku-Gakuin U., Kobe U., Meiji-Gakuin U. and Fukui U.
** SHIP Collaboration
Harvard U., U. of Calif. Berkeley, Inst. for Space and Astro. Sci., Gifu U.and KEK
*** TOPAZ Collaboration
KEK, U. of Tokyo, Inst. of Nucl. Study U. of Tokyo, Tokyo U. of Agri. and Tech., Nagoya U., Nara Women's U., Osaka City U., and Kobe U.
**** AMY Collaboration
KEK, Louisiana State U., IHEP Beijing, Virginia Polytechnic Inst., U. of South Carolina, Ohio State U., Chungnam Nat'l U., U. of Calif. Davis, Rutgers U., Niigata U., Nihon Dental Coll., U. of Rochester, Saga U., Korea U., Kyungpook Nat'l U., Chuo U., Tokyo Inst. of Tech and Saitama U.

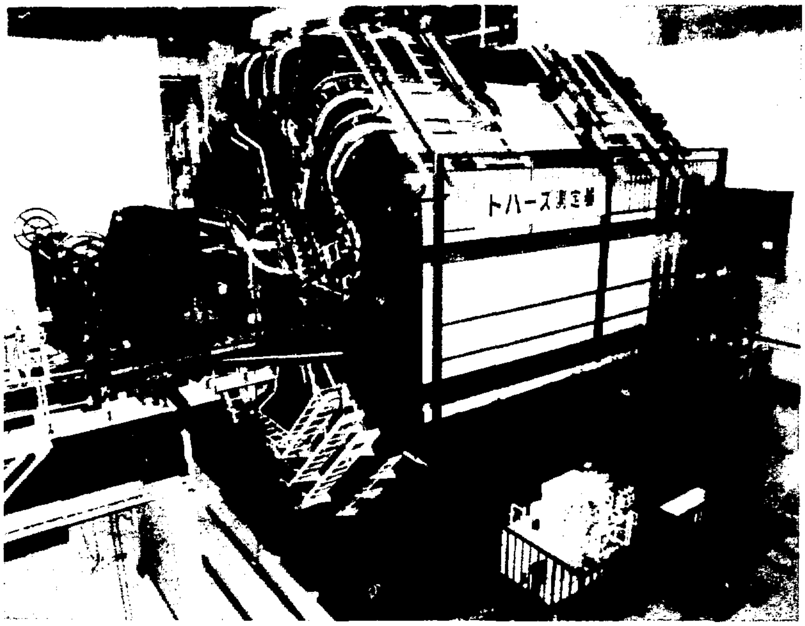

Figure 8. The TOPAZ detector

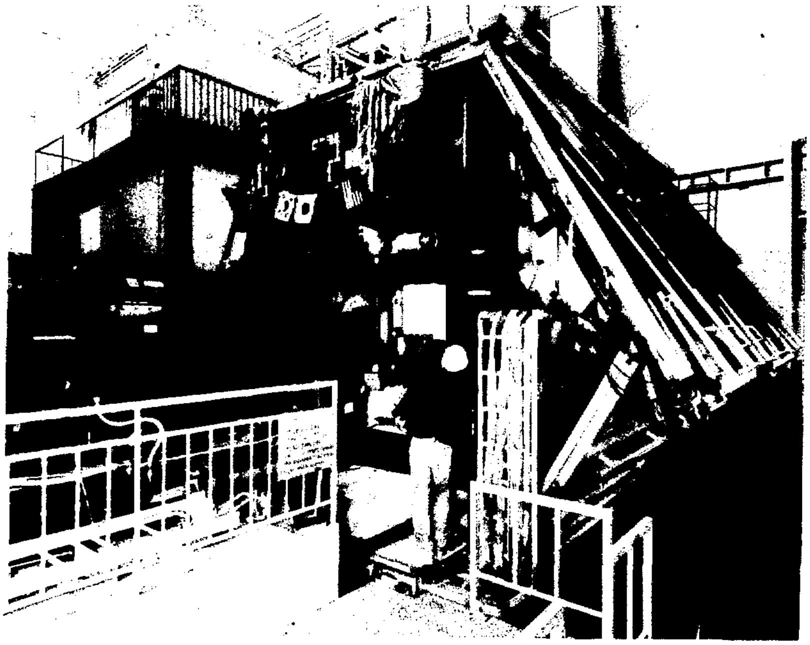

Figure 9. The AMY detector

Table 3: Principal parameters of the TOPAZ, VENUS and AMY detectors.

Compornent	TOPAZ	VENUS	AMY
Inner chamber	Cyl. drift ch. Cathode delay lines 1600 channels	Cyl. drift ch. (Cathode pad r. o.)	Straw chambers
Central tracking chamber	TPC with dE/dX (4 atm) ID=70 cm OD=250 cm 11000 r. o. channels	Cylind. drift ch. ID=50 cm OD=252 cm ~7104 r. o. channels	Cylind. drift ch. ID=30 cm OD=134 cm ~9000 r. o. channels
Time-of-flight	64 elem. ($13\times4.2cm^2\times4m$)	96 elem. (10.5cm×4.2cm×4.66m)	Scint. counters outside μ detectors
Magnet coil	Supercond. solenoid B=1.0 T	Supercond. solenoid B=0.75 T	Supercond. solenoid B=3.0 T
Mag. field volume	2.27mφ×5.08m	3.4mφ×5.48m	2.4mφ×2.2m*
Barrel drift ch.	Limited steamer tubes Cathode strip r.o. 4300 channels	Limited streamer tube Cathode strip r.o.	None
Barrel electro-magnetic cal.	Lead glass. cyl. array 4320 units ($20X_0$) Coverage 35°-145°	Lead glass. radial array 5160 units ($18X_0$) Coverage 37°-143°	Lead/ conductive tube 4 longitudinal segm'ts 11K r.o. channels Coverage 42°-138°
Muon detector	3 iron slab layers Prop. drift tubes 2400 channels	2 iron slab layers Drift tubes	single iron layer 4 layers (2x-2y) Drift tubes
End cap drift ch.	Limited streamer tubes Cathode strip r.o.	None	None
End cap electro-magnetic cal.	Pb-prop, tube sandwich($18X_0$) 2300 channels	Liq. aragon shower detector 3840 r.o. channels	Lead/scinti. shower counter with 1-layer cond. plastic tubes Cathode Strip r.o.
Luminosity monitor	Pb-scint. sandwich	Pb-scint. sandwich	lead-scintillator
Other detectors		Outer drift tubes 1144 channels	Xe drift chamber

*coil length 1.5m

THE FIRST PHYSICS RESULTS

All four experiments at TRISTAN had fully engaged in data taking through out the physics machine time of the cycle 2 ($\sqrt{S}$ = 50 GeV) and the cycle 3 ($\sqrt{S}$ = 52 GeV). The luminosity integrals accumulated by each experiment are;

$\sqrt{S}$	VENUS	TOPAZ	AMY	SHIP
50 GeV	0.71 pb^{-1}	0.46 pb^{-1}	0.69 pb^{-1}	0.7 pb^{-1}
52 GeV	2.97 pb^{-1}	3.554 pb^{-1}	3.98 pb^{-1}	3.88 pb^{-1}.

In spite of the fact that the most of data were collected during the month of July, the data analyses which had been carried out in parallel with data taking allowed us to present the first physics results from TRISTAN on July 27[4] at the International Symposium on Lepton and Photon Interactions at High Energies (Hamburg 7/27-31, 1987), and also on Aug. 25[5] at the International Conference on Physics in Collision (Tsukuba 8/25-27, 1987). In addition several papers are already submitted for publication.[6]

The results from three large TRISTAN detectors are based on the following numbers of events in each categories;

		VENUS		TOPAZ		AMY	
$\sqrt{S}$ = 50 GeV							
$\int Ldt$ Collected		0.71 pb^{-1}		0.43 pb^{-1}		0.69 pb^{-1}	
e^+e^-	$\to e^+e^-$	306	$\|\cos\theta\| < 0.74$	–		264	$\|\cos\theta\| < 0.73$
	$\to \gamma\gamma$	36	$\|\cos\theta\| < 0.74$	–		26	$\|\cos\theta\| < 0.7$
	$\to \mu^+\mu^-$	22	$\|\cos\theta\| < 0.7$	–		–	
	$\to q\bar{q}$	96		59		87	
$\sqrt{S}$ = 52 GeV							
$\int Ldt$ Collected		2.96 pb^{-1}		3.54 pb^{-1}		3.98 pb^{-1}	
e^+e^-	$\to e^+e^-$	1193	$\|\cos\theta\| < 0.74$	1654	$\|\cos\theta\| < 0.77$	1616	$\|\cos\theta\| < 0.73$
	$\to \gamma\gamma$	159	$\|\cos\theta\| < 0.74$	181	$\|\cos\theta\| < 0.80$	177	$\|\cos\theta\| < 0.70$
	$\to \mu^+\mu^-$	65	$\|\cos\theta\| < 0.7$	54	$\|\cos\theta\| < 0.75$	74	$\|\cos\theta\| < 0.74$
	$\to q\bar{q}$	399		483		478	

In the electro-weak interaction sector, VENUS, TOPAZ and AMY data on processes with significant statistics, such as $e^+e^- \rightarrow e^+e^-$, $e^+e^- \rightarrow \gamma\gamma$, $e^+e^- \rightarrow \mu^+\mu^-$ are altogether consistent with QED and the standard model a la Weinberg, Salam and Glashaw. As an example, the differential cross sections obtained by VENUS for $e^+e^- \rightarrow e^+e$ process is compared with the lowest order QED prediction in Fig. 10. In Fig. 11, the angular distribution of $e^+e^- \rightarrow \mu^+\mu^-$ from AMY is compared with that obtained from the standard model. Here one clearly sees a marked foward-backward asymmetry, indicating a strong interferance of γ and Z° exchange in this energy region as predicted by the model.

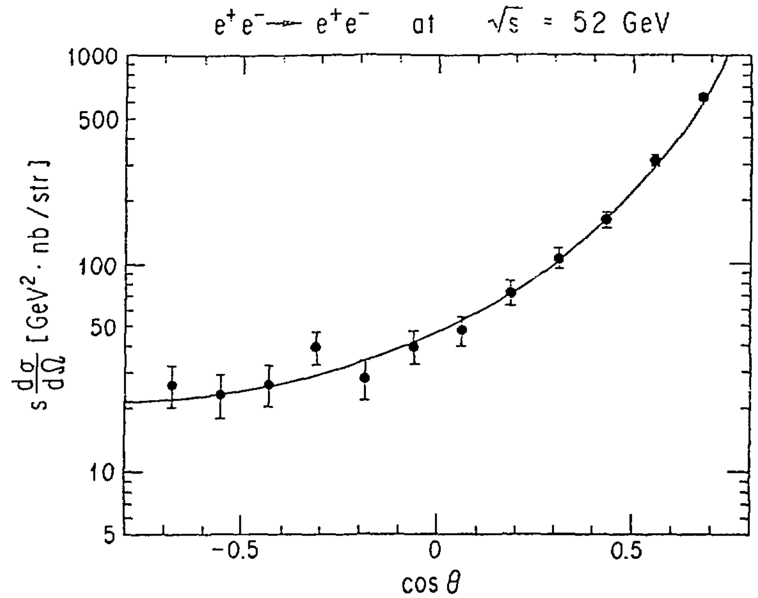

Figure 10. $e^+e^- \rightarrow e^+e^-$ differential cross section at $\sqrt{s}$ = 52 GeV obtain by the VENUS experiment.

Many features of hadronic final states can be discribed quite well by a quark fragmentation model. Here, the comparsions are made with the Monte Carlo simulation based on the LUND 6.3[7] fragmentation model. From the number of observed hadronic events, each experimental group has caluculated the R ratio, the hadronic total cross section normalized by QED point-like cross section using the equation;

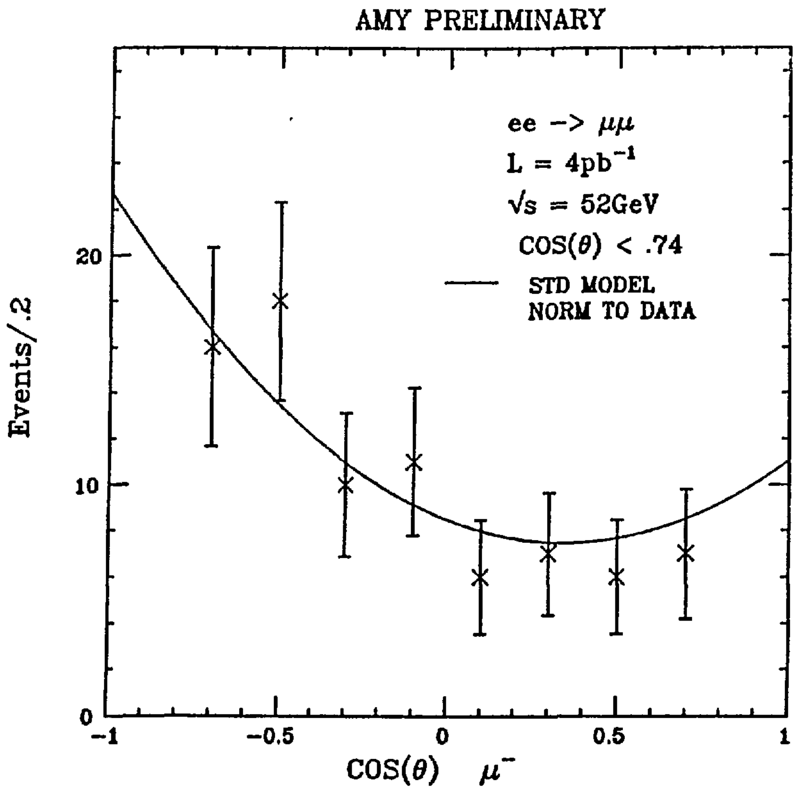

Figure 11. The angular distribution of $e^+e^-\to\mu^+\mu^-$ obtained by the AMY experiment.

$$R = N_{obs} \,/\, L \cdot \varepsilon \cdot (1+\delta) \,/\, \sigma(e^+e^-\to\mu^+\mu^-)_{pt}$$

where N_{obs} is the number of hadronic events, L is the luminosity integral, E is the acceptance of the detector, δ is the radiative correction factor, and $\sigma(e^+e^-\to\mu^+\mu^-)_{pt}$ is the point-like QED cross section. The values of R ratio obtained are summarized below;

$\sqrt{s}$	VENUS	TOPAZ	AMY	Average
50 GeV	$4.3\pm0.5\pm0.5$	$4.0\pm0.4\pm0.4$	$4.3\pm0.5\pm0.3$	4.2 ± 0.3(atat. only)
52 GeV	$4.6\pm0.3\pm0.6$	$4.4\pm0.3\pm0.2$	$4.4\pm0.2\pm0.4$	4.5 ± 0.2(atat. only)

H · the first errors attatched are statistical and the second errors systematic. In taking the avarage values, only the statistical errors are taken into account. These values are to be compared with the values that are predicted with the quark contribution of 5 flavors, 5 flavors + top(t) and 5 flavors + 4th-generation bottom(b') as below;

$\sqrt{s}$	5 flavors	5f+t	5f+b'	TRISTAN Average
50 GeV	4.31	5.79	4.76	4.2±0.3
52 GeV	4.43	5.93	4.91	4.5±0.2

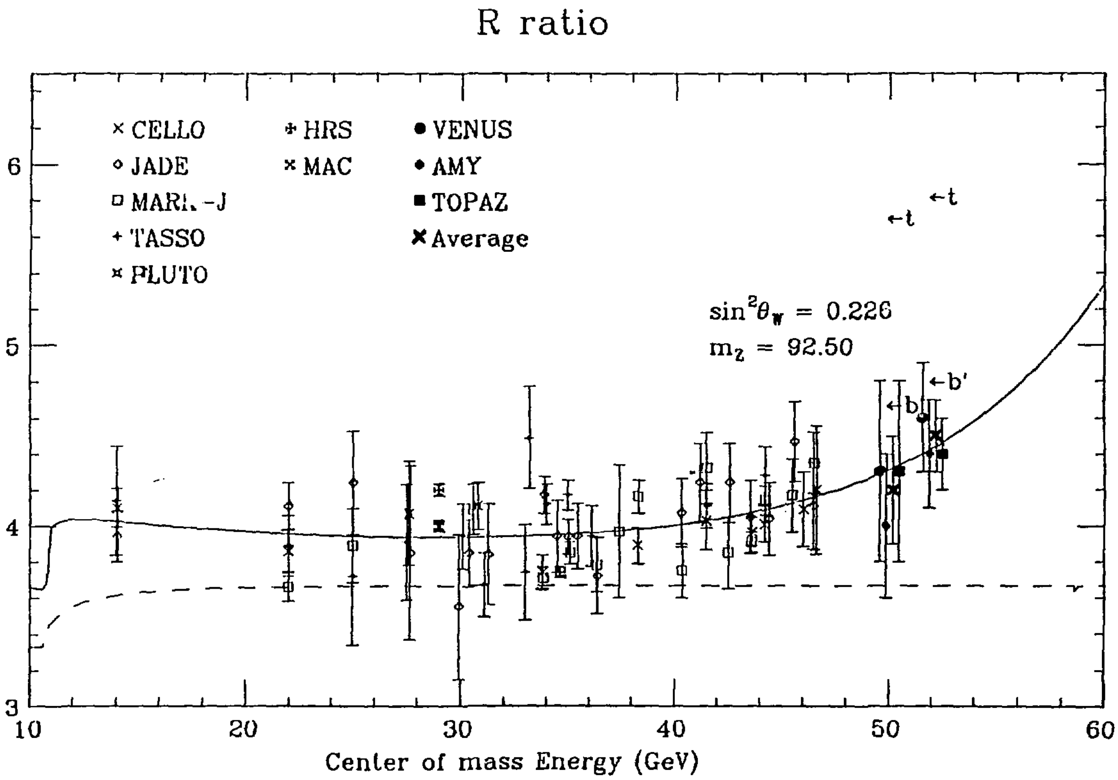

Figure 12. The results for the measurement of R-ratio from TRISTAN experiments (closed symbols) and TRISTAN average (thick cross) together with previously reported results at lower energies. Solid line is the Standard Model prediction. ←t and ←b' indicate the prediction with fully contributing additional top quark and 4-th generation bottom quark.

Here, M_{Z°= 92.5 GeV, $\sin^2\theta_W$ = 0.226 and α_s = 0.17 were used and a full contribution of new quark flavor to R ratio was assumed at each energy. R ratios from these experiments are also shown in Fig. 12 together with low energy data[8] and the prediction from the standard model (solid line) with parameters above. The comparison indicates that the production of t-quark is excluded up to 52 GeV. As to the b′-quark, further study is needed, though its production at 52 GeV is unlikely. The topological analysis of hadronic events also gives a negative conclusion on the production of t-quark at 52 GeV (see Fig. 13).

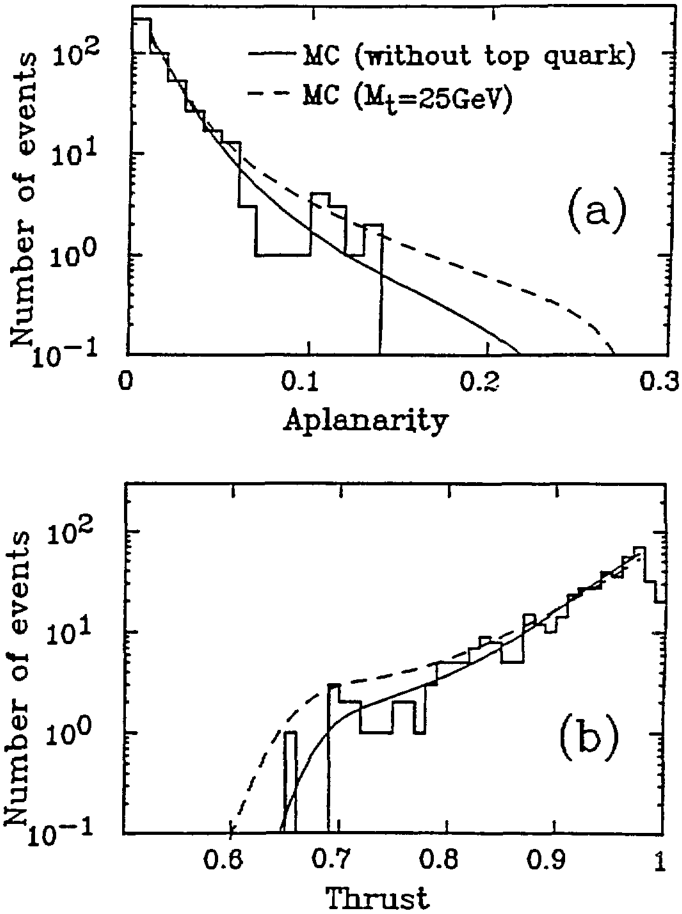

Figure 13. The aplanarity distribution and thrust distribution of hadronic events obtained by TOPAZ at $\sqrt{s}$ = 52 GeV. Lines shown are the Monte Carlo similation based on the LUND 6.3 fragmentation model.

The MARK-J group at PETRA found an excess of hadronic events with relatively low-thrust accompanying isolated muons at $\sqrt{S}$ = 46.3~46.8 GeV.[9] This effect was also observed by the JADE group.[10] Although situation was not clear with this effect not being observed in isoleted electron final state[10,11] nor by other PETRA detectors[11], and also with limitted statistics, it could have been an on-set of new phenomena. The result of an investigation of this effect by the VENUS group is listed below together with other results from PETRA.

	$\sqrt{S}$	$\int L(pb^{-1})$	Acceptance	N_{obs}	$N_{T<0.8,\cos\sigma<0.7}$
μ-candidate					
VENUS	52	2.9	0.31	18	1
MARK J	46.3~46.8	2.9	0.50	28	7
JADE	46.3~46.8	1.8	0.58	32	5
TASSO	46.3~46.8	2.1	0.29	9	1
CELLO	46.3~46.8	2.1	0.57	25	1
e^-candidate					
VENUS	50,52	3.6	0.376	23	0
JADE	46.3~46.8	1.8	0.76	11	0
CELLO	46.3~46.8	2.1	0.70	6	0

VENUS data clealy do not support such excess events. AMY, though preliminary, reported also similar lack of the effect in their data.

In other area of physics, VENUS reported 25.0 GeV as the low-mass bound for a higher mass sequential lepton, and SHIP reported the upper limit for

$$\sigma(e^+e^-\rightarrow MM) < 7.7 \text{ pb } (95\ \%\ \text{CL}) \text{ for } M< 23.2 \text{ GeV} / c^2.$$

FUTURE PLAN AND SUMMARY

Principal mile stones in the course of five-year construction and months that followed are listed in Table 4. As indicated in the table, the plan is to increase the beam energy to about 28 GeV for the colliding beam experiment in the fall period with fully installed room temperature APS cavities in the Fuji, Tsukuba and Oho straight sections. In order to obtain the beam energy in excess of 30 GeV, 500 MHz superconducting cavities and a 4.5 kW He refregirator are being developed. A test of the first two 5-cell units designed for the main ring gave a promissing result of E_{acc} = 6~10 MV/m and $Q>3\times10^9$ at E_{acc} = 5 MV/m. The present plan calles for an installation in the Nikko straight section of 32 such cavity units, half of which are to be installed in the summer 1988. This should provide sufficient r-f power to reach 30 GeV or higher beam energy for the operation in the fall of 1988.

Table 4 MAJOR MILESTONES OF THE TRISTAN PROJECT

1981	April	:The TRISTAN Project approved by the Government.
	Nov. 19	: The ground breaking for Accumulation Ring.
1982	April	: Construction of Main Ring and e^+ generator began.
1983	March	: The VENUS and TOPAZ experiment approved.
	Nov. 19	: Succeeded in accelerating electrons to 4.8 GeV in Accumulation Ring.
	Dec.	: The AMY experiment approved.
1986	March	: The SHIP experiment approved.
	Sep.	: VENUS detector rolled-into the collision point.
	Oct.-Dec.	:Main Ring commissioning.
	10/16	: Electrons injected into Main Ring.
	10/24	: Accelerated electrons to 25.5 GeV.
	11/14	: First e^+e^- collisions in Main Ring at $\sqrt{s}$ = 50 GeV. Peak luminosity $\sim2.6\times10^{29}$ $cm^{-2}sec^{-1}$.
	11/19	: The first-large angle Bhabha scattering observed by the VENUS detector.
	11/23	: The AMY detector rolled-into the collision point.
	12/13	: The first $q\bar{q}$ event observed by VENUS. The first large angle Bhabha scattering by AMY.
1987	Jan.-Feb.	:Engineering run. peak luminosity $\sim1\times10^{30}$ $cm^{-2}sec^{-1}$; $(\int Ldt$ / day$)_{max}\sim10$ nb^{-1} / detector. Total $\int Ldt$ ~80 nb-1 / detector.
	March 14	:The TOPAZ detector rolled-into the collision point.
	May-July	:The first physics run
	5/13~5/23	: Cycle 1 Machine studies and TOPAZ test.
	5/27~6/15	: Cycle 2 Run at E_{beam} = 25 GeV. Peak luminosity 0.6×10^{31} $cm^{-2}sec^{-1}$. $(\int Ldt$ / day$)_{max}\sim100$ nb^{-1} / day. Total $\int Ldt$ ~600 nb^{-1} / detector.

6/27~7/23 : Cycle 3 Run at E_{beam} = 26 GeV
Peak luminosity 0.8×10^{31} $cm^{-2}sec^{-1}$.
$(\int Ldt$ / day$)_{max}$ ~ 200 nb^{-1} / day
Total $\int Ldt$ ~4000 nb^{-1} / detector.

Future plan
1987 Oct. :E_{beam} to 27~28 GeV (Room temperature cavities).
1988 Oct. :E_{beam} to over 30 GeV (Superconducting RF cavities).

In order to optimize on the highest attainable energy for a given site of KEK, a new concept was introduced in the design of TRISTAN storage ring. Namely the main ring is more like four long linear accelerators connected by four quadrants of arc with a relatively short bending radius. This geometry presents operational difficulties arising from the strong beam-cavity interactions and an enormous energy loss by the synchrotron radiation. Never-the-less, the main ring was commissioned on schedule and its performance improved to close to the design values in a relatively short time. This must have been due to a careful choice of the accelerator design which included the use of APS type r-f cavities, an introduction of wigglers for quick damping of instabilities, extensive use of beam monitoring devices, and fully computerlized control system. In addition, all four detectors have been assembled also on schedule and the physics results from them reported in about 8 months of commissioning. The TRISTAN complex, as a running entity, will undego steps of up-grading in energy and, hopefully, in luminosity in coming years, the first one being the upcoming physics operation starting on coming Oct. 15 at the beam energy of ~28 GeV.

In closing, the author expresses his appreciation to Professor T. Nishikawa, the Director-General of KEK, who has lead the unified support of the entire laboratory behind the TRISTAN Project. His appreciation is due also to the accelerator and physics members directly involved in this project under an excellent leadership of Professors J. Tanaka, G. Horikoshi, Y. Kimura and K. Takahashi, and the entire supporting members of the laboratory. He, on behalf of the laboratory, acknowledges with thanks, the

valuable support and contribution of the national and international high energy physics communities and of those concerned with this project.

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ACCELERATING AND STORAGE COMPLEX (UNK). EXPERIMENTAL RESEARCH PROGRAMME

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BASIC CHARACTERISTICS OF UNK

The project of the IHEP Accelerating and Storage Complex (UNK)[1] envisages the following operational modes:

1. Acceleration of protons up to 3 TeV at the intensity $6\cdot10^{14}$ ppp for fixed target experiments.
2. Proton-proton colliding beams with energy $\sqrt{S}$=6 TeV and luminosity $4\cdot10^{32}$ $cm^{-2}sec^{-1}$.

The presently existing 70 GeV proton accelerator (U-70), whose intensity is planned to be raised up to $5\cdot10^{13}$ ppp (now it is $2\cdot10^{13}$), will be the injector for UNK. The beam from U-70 is injected into the 1st stage of UNK (UNK-1) which is a conventional accelerator. The UNK circumference is 14 times that of U-70. The beam is stacked by multiple injection, 12 injection pulses during 71.5 s. After stacking of $6\cdot10^{14}$ protons and acceleration in UNK-1, the beam is transferred into the 2nd, superconducting stage, by single-turn injection where it is accelerated to 3 TeV. The cycle of the superconducting stage is as follows: 40 s field rise, 40 s flattop and 40 s field drop. In the future, an additional superconducting ring (UNK-3) will be constructed to realize pp-collisions at $\sqrt{S}$=6 TeV. Figure 1 shows the cross section of the main tunnel and location of the magnets of the three stages, fig. 1a shows the magnetic lattice.

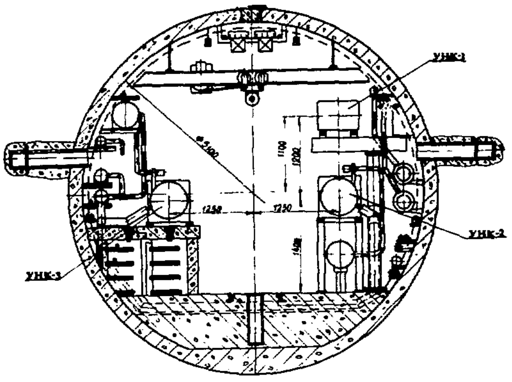

Figure 1. Cross-section view of the UNK tunnel.

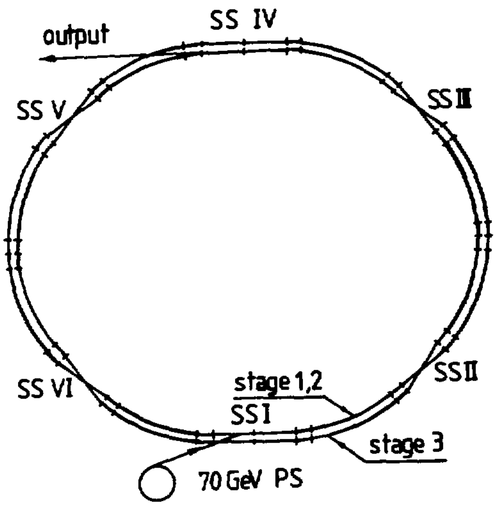

Figure 1a. The scheme of the UNK magnet structure.

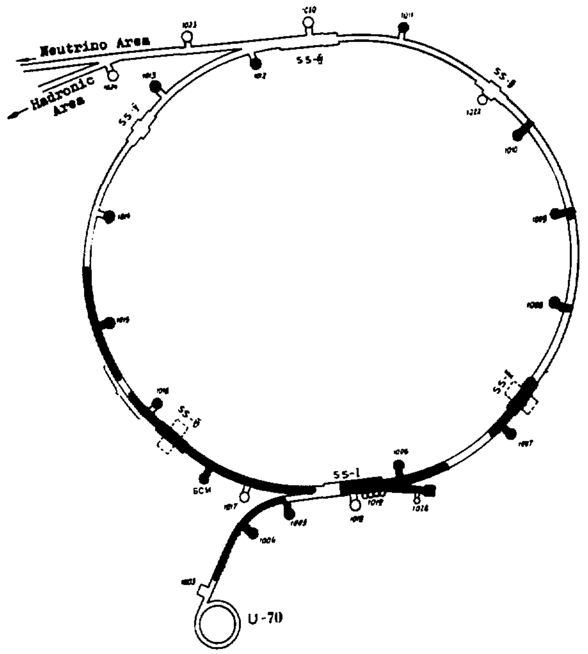

Figure 2. The layout of the basic structure of the ring tunnel and injection channel.

Figure 2 presents the layout of the basic UNK structures. The machine is located in stable limestones at a depth varying from 15 to 60 m depending upon the terrain relief. The diameter of the main tunnel is 5 m. To inject the beam, 3.5 m in diameter tunnels are foreseen. The power supply and monitoring systems of the technological equipment are placed in surface buildings connected with the underground tunnel through vertical shafts and communication tunnels 40 m long. The refrigerators of the cryogenic system are put in 12 underground buildings distributed uniformly along the ring.

Table 1 presents the basic parameters of UNK. For the chosen parameters of the magnetic cycle the mean power consumed by the complex is 120 MW.

STATUS OF UNK

Prototype work on the basic components of the machine systems will be over this year and the superconducting magnet design will also be chosen. Orders for manufacturing various systems have been put into industry. The construction of a special workshop for production of superconducting magnets at IHEP will be over very soon.

The construction work is carried out over the whole territory of the complex. Out of 26 vertical pits, 11 are ready completely and 3 more are under completion. Tunneling is now done from 6 pits in 11 directions. Figure 2 presents the status of construction work. Beginning from 1989, sections of the ring tunnel will be commissioned for installation of the equipment. In 1988-1989, a chain of 100 superconducting magnets will be put into the tunnel for large-scale tests.

The construction of the 3 TeV machine is planned to be completed in 1993.

Table 1. Basic Characteristics of UNK

Parameter	Unit	1st stage	2nd stage
Circumference	m	20771.8	20771.8
Maximum energy	GeV	600	3000
Injection energy	GeV	70	400-600
Critical energy	GeV	42	42
Maximum field	T	1	5
Maximum injection field	T	0.116	0.67÷1
Number of technological sections		2	2
Length of technological section	m	800	800
Number of sections for colliding beams		4	4
Length of section for colliding beams	m	490	490
Number of dipoles		2176	2176
Dipole length	m	5.8	5.8
Number of quadrupoles		454	438
Quadrupole length	m	3.7	3.6
Gradient-field ratio	m^{-1}	17.06	17.415

THE UNK EXPERIMENTAL FACILITIES

For carrying out the research programme, the following experimental facilities are designed:

1. Underground hall for experiments in the internal beam (in straight section III).
2. Hadron and neutrino areas.
3. Halls for colliding beam experiments (in straight sections II, V, VI).

For fixed-target experiments the proton beam will be extracted from the 3 TeV machine with the help of slow (40 s) and simultaneous fast resonance (every 4 seconds, 1-2 msec duration each) extraction. The total duration of the accelerator cycle is 120 seconds. The design beam intensity is $6 \cdot 10^{14}$ ppp. The slowly extracted beam is intended for both hadron and neutrino areas, while the fast extracted beam is designed for neutrino experiments.

The hadronic area of UNK envisages a wide set of moderate and high intensity conventional hadron beams, a hyperon beam, electron and photon beams as well as beams of polarized protons and antiprotons produced from decays $\Lambda \to p\pi^-$, $\bar{\Lambda} \to \bar{p}\pi^+$.

Figure 3 shows the scheme of forming extracted proton beams and the beams in hadron and neutrino areas. The proton beam for hadronic area after being transported to the surface is splitted into two parts and guided onto two targets TH1 and TH2. Target TH1 is used to form beam line H1 and target TH2 - for beam line H2. The fraction of the proton beam which has not interacted with the target TH2 is transported onto target TH3 from which two beam lines H3A and H3B are formed.

The basic characteristics of the beam lines are enlisted in Tables II and III. Beam H1 is designed to form high intensity hadron (and electron) beams on two operating in turn experimental setups placed in $18x240\ m^2$ expe-

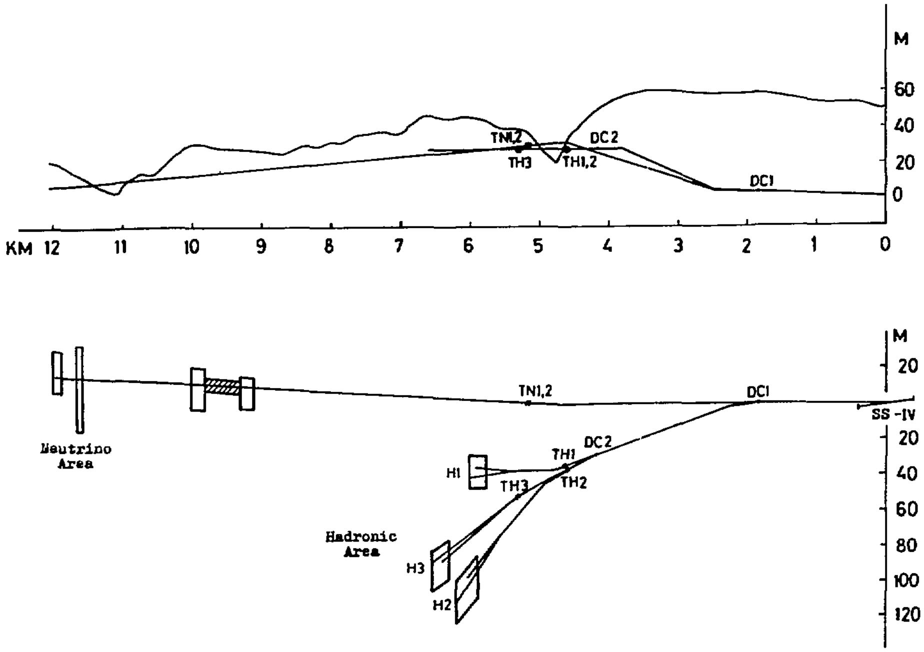

Figure 3. The general layout of the beam lines of the UNK and experimental halls.

rimental hall No 1 (high intensity hall). In this hall, a short well-focused, almost pure hyperon beam may also be formed. The beam channel is 80÷100 m long, its design focal size is $\sigma_x = \pm 2$mm, $\sigma_y = \pm 0.6$ mm, the expected intensity is $3 \cdot 10^7$ Σ^-/s, the content of Σ^--hyperons should be more than 80%.

Beam line H2 is to form moderate-intensity beams in 24x300 m^2 experimental hall No 2. Two operating in turn setups will be located in this hall. Beam lines H3A and H3B have a common initial part and will provide beams for two operating also in turn setups located in the 24x240 m^2 experimental hall. The optical scheme of H3A line is optimized to obtain polarized proton (antiproton) beams from $\Lambda(\bar{\Lambda})$-decays. The intensity of polarized proton beam is (3÷6) 10^7 p/s at a mean transverse polarization of about 40%. Beam H3B as well as beam H1 is designed to form high intensity beams. Its small bending angle will allow to obtain electron beams at the maximum momentum.

The following types of neutrino beams are planned to be formed at the neutrino area:

- wide band neutrino beam formed with the help of lithium lenses operating in pulsed mode;
- dichromatic neutrino beam;
- a tagged neutrino beam, obtained from reconstruction of the kinematics of $K_{\mu 2}$ and K_{e3} decays in a dichromatic beam;
- a beam of prompt neutrino from semileptonic decays of short-living particles.

Table II. Basic Parameters of the Beam Lines

Beam line	H1	H2	H3A	H3B
Length, m	1260	1265	1070	1000
Acceptance, μ ster	0.50	0.25	0.10	0.35
Maximum momentum, GeV/c	3000	3000	2400	3000
Maximum momentum of positive secondaries, GeV/c	1500	1800	1100	1100
Selected momentum interval				
$(\Delta p/p)_{min}$	$\pm 1.5\%$	$\pm 1.0\%$	$\pm 0.7\%$	$\pm 2.5\%$
$(\Delta p/p)_{max}$	$\pm 9.0\%$	$\pm 4.0\%$	$\pm 15.0\%$	$\pm 8.0\%$

Table III. Intensities of UNK Extracted Beams [2]

Beam line	Momentum, GeV/c	π^+	K^+	π^-	K^-	e
	500	$2.8\cdot10^{10}$	$2.3\cdot10^{9}$	$2,0\cdot10^{10}$	$1,3\cdot10^{9}$	$3,9\cdot10^{9}$
	1000	$3.4\cdot10^{10}$	$3.6\cdot10^{9}$	$1.6\cdot10^{10}$	$1.1\cdot10^{9}$	$6.6\cdot10^{8}$
H1	1500	$1.6\cdot10^{10}$	$2.4\cdot10^{9}$	$7.9\cdot10^{9}$	$3.4\cdot10^{8}$	$3.3\cdot10^{7}$
	2000	-	-	$1.9\cdot10^{9}$	$4\ 0\cdot10^{7}$	-
	2500	-	-	$1,3\cdot10^{8}$	$7.0\ 10^{5}$	-
	500	$1.9\cdot10^{9}$	$1,5\cdot10^{8}$	$1.1\cdot10^{9}$	$7.2\cdot10^{7}$	$9.7\cdot10^{8}$
	1000	$2.9\cdot10^{9}$	$2.9\cdot10^{8}$	$1.0\cdot10^{9}$	$6.3\cdot10^{7}$	$2.9\cdot10^{7}$
H2*	1500	$1.9\cdot10^{9}$	$2.5\cdot10^{8}$	$5.2\cdot10^{8}$	$2.2\ 10^{7}$	-
	2000	-	-	$1.4\cdot10^{8}$	$2.8\cdot10^{6}$	-
	2500	-	-	$1.0\cdot10^{7}$	$5.5\cdot10^{4}$	-
	500	$5.7\cdot10^{9}$	$4.5\cdot10^{8}$	$5.6\cdot10^{9}$	$3.6\cdot10^{8}$	$2.0\cdot10^{9}$
	1000	$5.9\cdot10^{9}$	$5.8\cdot10^{8}$	$5.0\cdot10^{9}$	$3.1\cdot10^{8}$	$3.8\cdot10^{8}$
H3A	1500	-	-	$2.7\cdot10^{9}$	$1.1\cdot10^{8}$	$3.3\ 10^{7}$
	2000	-	-	$7.3\cdot10^{8}$	$1.5\cdot10^{7}$	-
	2500	-	-	$5.4\cdot10^{7}$	$2.8\cdot10^{5}$	-
	500	$1.9\cdot10^{10}$	$1.5\cdot10^{9}$	$1.4\cdot10^{10}$	$9.3\cdot10^{8}$	$2.9\cdot10^{9}$
	1000	$2.1\cdot10^{10}$	$2.3\cdot10^{9}$	$1.2\cdot10^{10}$	$7.8\cdot10^{8}$	$5.6\cdot10^{8}$
H3B	1500	-	-	$6.0\cdot10^{9}$	$2.6\cdot10^{8}$	$5.8\cdot10^{7}$
	2000	-	-	$1.5\cdot10^{9}$	$3.1\cdot10^{7}$	$1.0\cdot10^{6}$
	2500	-	-	$1.1\cdot10^{8}$	$5.7\cdot10^{5}$	-

Intensity is given for 10^{13} incident protons (500 mm long Be target).

*For a 0.1 ℓ_{int} target.

The maximum intensity of the proton beam spilled onto the neutrino targets may be as high as $3 \cdot 10^{14}$. A possibility of both slow and fast resonance extractions ($\tau \sim 2$ ms, 10 times during the flattop) is foreseen.

The neutrino energy spectra under different conditions are presented in Figs. 4 and 5. Large neutrino fluxes $2 \cdot 10^{-3}$ $\nu/m^2 \cdot p$ are expected at UNK. Focusing will be done with the help of a triplet of lithium lenses.

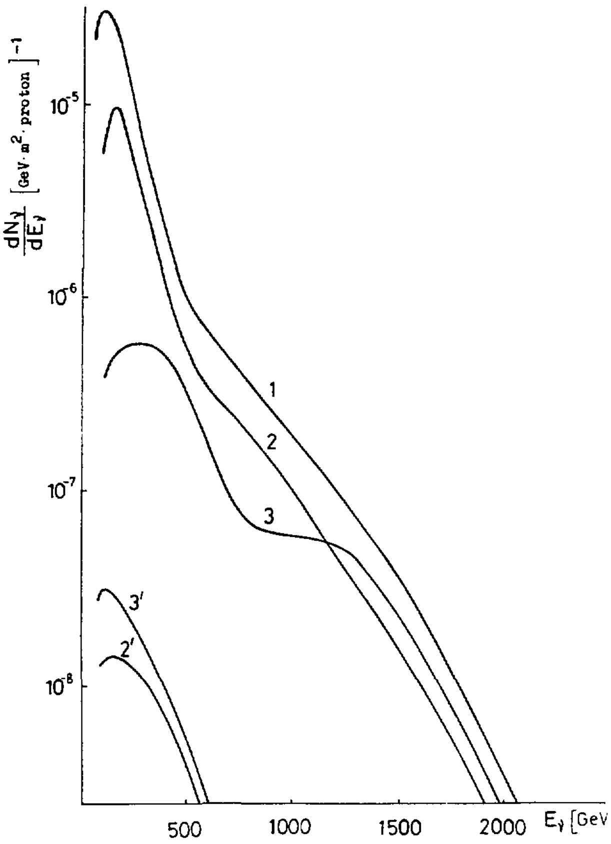

Figure 4. The energy spectra of wide band neutrinos for the case of ideal focusing (1), with use of focusing systems of three (2) or one (3) lithium lenses. Curves 2', 3' show antineutrino contamination.

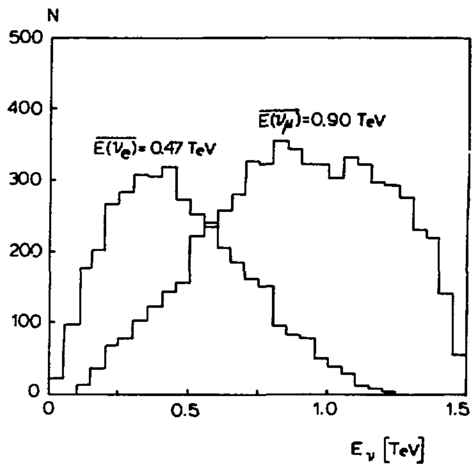

Figure 5. ν_e and ν_μ spectra for tagged beams, P_{K^+}=1.5 TeV.

The contamination of $\tilde{\nu}(\nu)$ in the neutrino (antineutrino) beam will be 0.3% and 1.5%, respectively. The project envisages a possibility to place the detectors at a distance of 50 km from the beginning of the muon shielding.

The layout of the neutrino area is shown in Figure 6.

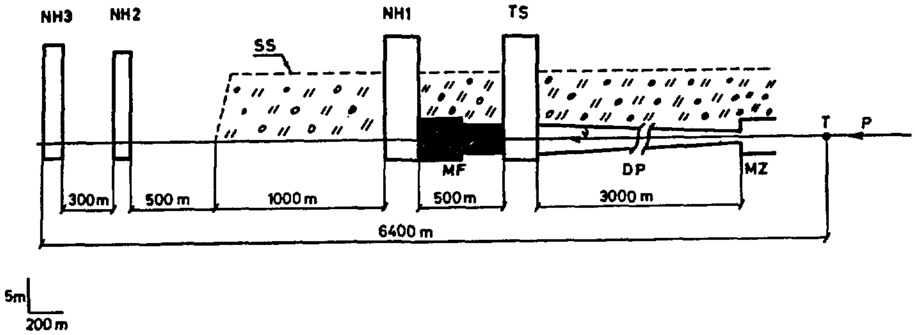

Figure 6. The general layout of the neutrino area.

THE PHYSICS PROGRAMME

When discussing and working out the experimental programme for UNK the main task is to specify the priority directions where the parameters of the machine and its experimental facilities could result in a new step in physics.

Among such directions are:

1. Study of B-particles.

Considerably larger yields of heavy particles produced in hadronic collisions are expected at UNK in comparison with TEVATRON (Fig. 7). With the energy increased from $\sqrt{S}$=44 GeV (TEVATRON) up to $\sqrt{S}$=77 GeV (UNK), the largest increase takes place for beauty particle production. The calculated fluxes of charmed, beauty particles and τ-leptons ($F \to \tau\nu_\tau$) will be 10^{10} c, $10^7 \div 10^8$ b, $10^7 \tau$, respectively. These fluxes are by 2-3 orders of magnitude larger than those expected at e^+e^--colliders.

2. Experiments with Pure Hyperon Beams

UNK presents a possibility to realize working conditions in the $x \geqslant 0.85$ kinematic region, when $I(\Sigma^-) \gg I(\pi^-)$, and an almost pure 2700 GeV Σ^--hyperon beam may be obtained (Fig. 6). The intensity of this beam is expected to be $\sim 3 \cdot 10^7$ Σ^-/s. These parameters of the hyperon beam are unique. Hyperon beams are the best sources of B_s^0-mesons, therefore one gets a possibility for direct study of $B_s^0 \rightleftarrows \bar{B}_s^0$ oscillations, search for mixing and CP-violation effects, especially those of going beyond the frames of the standard model (new currents, low energy manifestations of new families of fundamental particles, etc.).

3. Search for and study of the central production of glueballs, study of the mechanism of the total cross section growth.

4. Experiments with high energy polarized proton beams.

5. Systematic study of the universality of ν_μ, ν_e and ν_τ-interactions.

The physics problems to be studied at the UNK pp-colliding beams will be treated separately.

At present on the basis of the proposals obtained, the programme of primary experiments is formed:

1. Experiments with Internal Beam of UNK(NEPTUN Project)

It is the only experiment to be performed at the 1st stage of UNK at 600 GeV. Later it will be extended to the 3000 GeV ring. Thus, this setup may

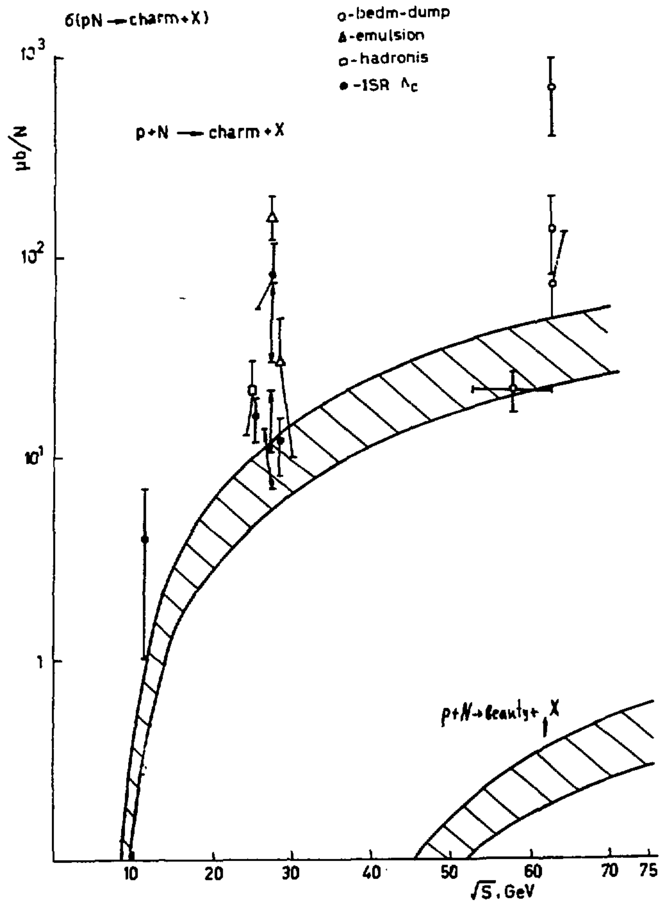

Figure 7. The energy dependence of the production cross sections for c- and b-particles in hadron collisions.

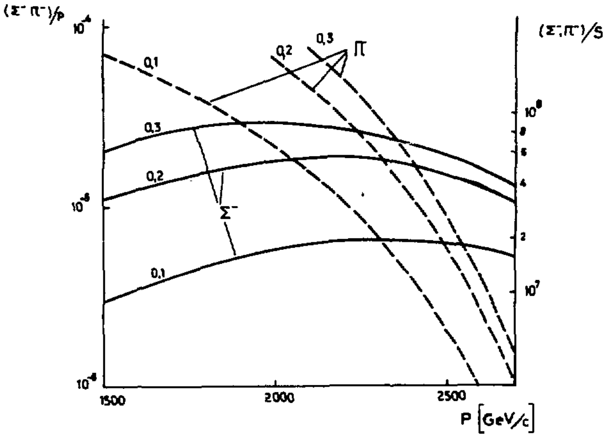

Figure 8. The absolute yields of Σ^--hyperons and π^--mesons in the beam channel (per one interacting proton, left scale) and the fluxes of these particles at 2700 GeV/c at a distance of 100 m from the target forming the hyperon beam (right scale); $I_o=3\cdot 10^{12}$p/sec, the acceptance angles are 0.1; 0.2;0.3 mrad.

cover the 600÷3000 GeV energy range. Luminosity of experiment is the following:

$L=10^{33}\div 10^{35}$ cm^{-2} s^{-1} for molecular jets (H_2,...Ar, Xe) and film targets (Be, Cu,...Au);

$L=5\cdot 10^{30}$ for atomic polarized jets p(↑) and d(↑), the polarization is about 80%.

The research programme includes:

- study of polarized effects in elastic pp-scattering;
- study of asymmetry in the production of neutral and charged mesons, of direct γ's in hard processes at polarized target;
- study of asymmetry in $\ell^+\ell^-$-production;
- measurement of polarization parameters in inclusive hyperon production; analysis of spin transfer at the constituent level;
- study of the mechanism of the total cross sections growth.

The layout of the setup and its location in the experimental hall in straight section III are shown in Figure 9.

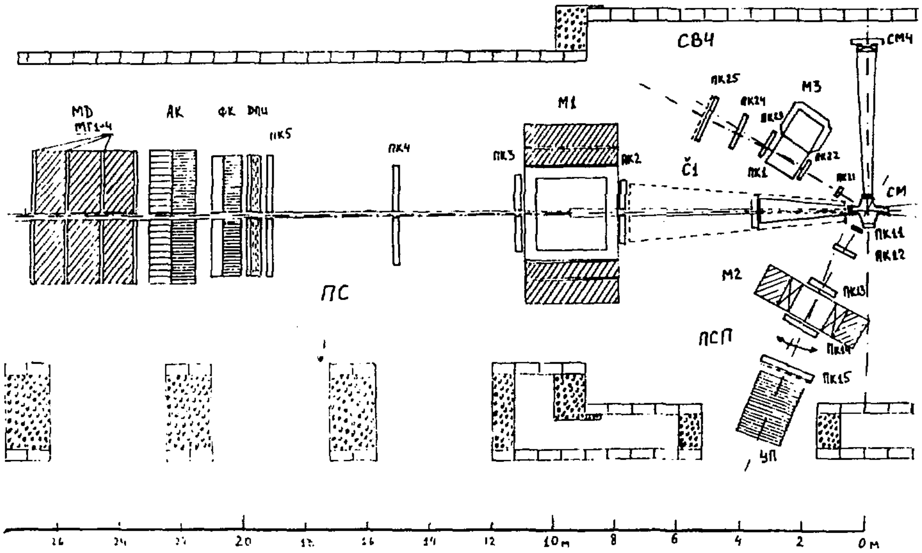

Figure 9. The layout and location of the jet target setup **NEPTUN** in the underground hall of SS-III at the internal beam of UNK.

2. Experiments with hyperon beam (HYPERON).

The experimental programme includes the following directions:

- heavy quark and rare decay physics, production of strange-charmed and strange-beautiful baryons and mesons and study of their weak decays;
- search for heavy exotic baryonic and mesonic states with s-, C- and b-quark.
- study of $B_s^o \rightleftarrows \bar{B}_s^o$ oscillations and of CP-violation.

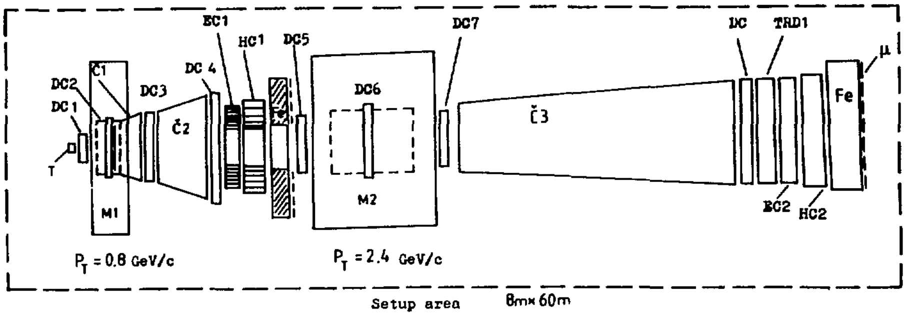

Figure 10. The scheme of the setup "Multiparticle spectrometer" (beam H3B).

3. Investigation of Multiparticle Reactions in h-, γ-Beams at UNK.

The "Multiparticle spectrometer" setup is schematically shown in Figure 10.

The programme includes the following studies:
- heavy quark physics;
- precise measurement of the K-M matrix parameters;
- study of the structure of weak currents;
- investigation of resonances containing heavy quarks;
- search for CP-violation effects in the systems with C- and b-quarks.

4. Investigation of Gluon Interactions and Production of Glueballs (GLUON Project).

Investigation of the processes

$$h+N \longrightarrow h+N+M^{o} \quad ; \quad h= \pi^{\pm}, K^{\pm}, \ p, \ \bar{p},$$
$$\hookrightarrow \eta\eta, \eta'\eta, \eta'\eta'$$

is planned with a view to study:
- mechanism of the total cross sections growth;
- inclusive production of ($c\bar{c}$) and ($b\bar{b}$) states;
- systems with masses up to 10 GeV which are produced in the central region (glueball production and decays). The setup scheme is shown in Figure 11.

5. Polarization Studies at High Energies (POLEX).

The research programme covers almost the whole field of high energy spin physics and will be defined more precisely as soon as the results on E-704 experiment are available.

6. The Programme of Neutrino Experiments Incorporates:
- study of the universal nature of ν_μ, ν_e, and ν_τ, interactions;
- study of the structure of nucleons and properties of final hadron states in the new range of Q^2;
- verification of the standard model within the new neutrino energy range.

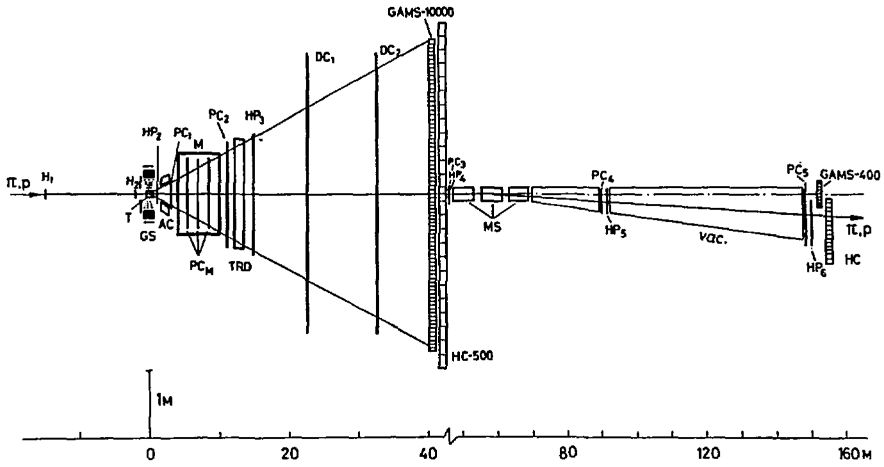

Figure 11. The scheme of GAMS-10000 (beam H2).

ON THE UNK COLLIDING BEAMS

The construction of the second superconducting ring in the UNK tunnel is planned to be over in 1995. This will allow to realize pp-colliding beams with energy $\sqrt{S}$=6 TeV and luminosity L=$4\cdot10^{32}$ $cm^{-2}.s^{-1}$. The experimental area in straight section SS-II will be constructed before the 3 TeV accelerator is put into operation. This will make it possible to carry out preparations for colliding beam experiment. In the region of SS-V the tunnel will be enlarged to perform another experiment at the colliding beams, though its programme will be more limited than that for SS-II. As to the underground halls in SS-VI, they will be constructed later on.

Now draft design is ready for the setup termed Universal Calorimeter Detector (UCD) to be positioned in SS-II. The detector should meet the following requirements:

- 4π geometry;
- high resolution in E_t;
- precise μ, e-identification;
- high accuracy in determining the energy of single particles and jets.

The research programme discussions are concentrated on:

- verification of the basic features of the standard model;
- study of "hard" collisions (hadron jets, the mechanism of hadronization of quark-gluon fields);
- study of "soft" hadron interactions (the dominating role of gluons, glueball production, measurement of cross sections);
- search for supersymmetric particles.

Figures 12 and 13 show the cross section of the ring tunnel and the test facility for superconducting magnets.

Figure 12. View of the UNK ring tunnel.

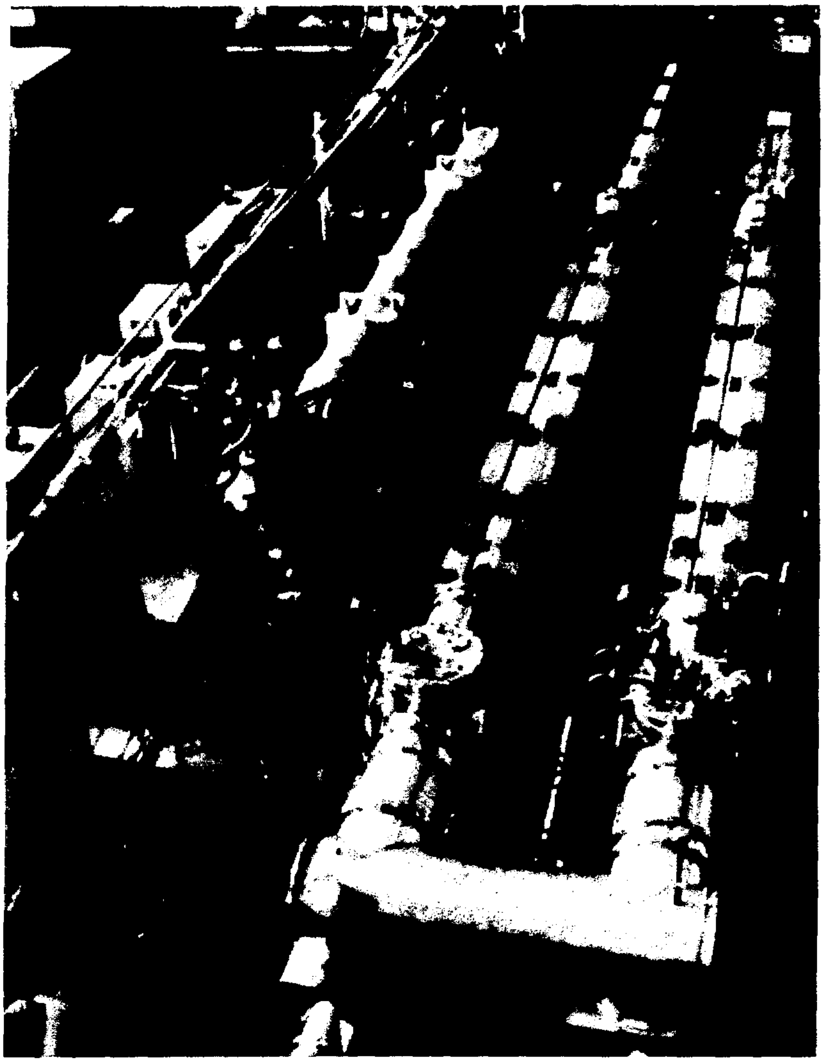

Figure 13. Test facility for superconducting magnets.

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Physics as a Function of Energy and Luminosity

115/116

NEW PHYSICS IN HIGH ENERGY e^+e^- AND HADRON-HADRON COLLISIONS

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INTRODUCTION

Studies of e^+e^- and pp colliders

In this talk I will compare the physics capabilities of possible future e^+e^- and pp colliders [1]. For reasons of time, ep colliders will be discussed only briefly: more about their capabilities can be found in Ref. [1]. As requested by the organizers, I will also discuss how the physics reaches of e^+e^- and pp colliders vary as functions of the centre-of-mass energy and luminosity.

Again for reasons of time, only a very limited range of physics topics will be discussed. Searches for Higgs bosons [2] -- perhaps the most important topic for future colliders -- are discussed here by Froidevaux [3]. I will concentrate on searches for supersymmetric particles and for a new neutral gauge boson Z'. Leptoquarks, composite models, etc., are consigned to what Einstein described as the theorists' most valuable tool, the waste-paper basket. The studies I will report were mainly done in the context of the La Thuile workshop [1] and of a subsequent study of pp physics at high luminosity [4].

The pp colliders which have been studied are the LHC ($\sqrt{s} \sim 17$ TeV) [5] in comparison with the SSC ($\sqrt{s} = 40$ TeV) [6]. Initially, luminosities of 10^{33} $cm^{-2}s^{-1}$ have been assumed for both machines, but the high-luminosity LHC study [4] has also considered luminosities up to 5×10^{34} $cm^{-2}s^{-1}$ and higher luminosities could undoubtedly be considered for the SSC as well. The LHC also has an ep option [5] with $\sqrt{s} = 1.4$ to 1.8 TeV and a luminosity of 10^{32} $cm^{-2}s^{-1}$ to 10^{31} $cm^{-2}s^{-1}$. There would also be the possibility of making heavy ion collisions in the LHC, which I will not discuss at all. On the

e^+e^- side, studies at CERN have focused on a collider with $\sqrt{s}$ = 1 to 2 TeV and a luminosity of 10^{33} $cm^{-2}s^{-1}$ to 4×10^{33} $cm^{-2}s^{-1}$, called CLIC [7]. These studies can of course be carried over directly to other projects such as the UNK e^+e^- collider [8] or the NLC proposed here by Richter [9].

Energy and luminosity

For purposes of general orientation, Fig. 1 compares the differential parton-parton luminosities in e^+e^- and pp collisions. The e^+e^- peak luminosity at CLIC is spread out by beamstrahlung. Note that the $W_L^+W_L^-$ luminosities at CLIC and the LHC are very comparable. Figure 2 compares parton-parton luminosities at the LHC and the SSC. Clearly the SSC always wins over the LHC if both machines have the same luminosity, and this is why a high-luminosity option for the LHC has been considered. If the SSC had a luminosity of 10^{33} $cm^{-2}s^{-1}$ and the LHC had 5×10^{34} $cm^{-1}s^{-1}$, the rate at the SSC would still be higher than at the LHC for systems weighing more than 4 or 5 TeV (e.g., a massive Z'). Rates at the LHC would be higher for lighter objects, but in some cases the signal-to-background ratio would be lower. It is presumably also possible to increase the luminosity of the SSC, so as to retain its advantage in $\sqrt{s}$, but this has not yet been studied in detail.

Physics issues

What physics issues does one wish to study with these machines? The success of the Standard Model leaves open three major categories of problems, those of Unification, Flavour and Mass. The Unification Problem is that of finding a unified field theory of all the particle interactions, most likely based on some big gauge group G $SU(3)_C\times SU(2)_L\times U(1)_Y$. Estimates put the scale of this grand unification above 10^{15} GeV, making it difficult to test at TeV accelerators, except by indirect means such as precision measurements of $\sin^2\theta_W$ [10]. The flavour problem is that of understanding the multiplicity of quark and lepton flavours and the ratios of their masses. Some physicists believe the quarks and leptons are composite. Searches for the corresponding new contact interactions, form factors and excited states

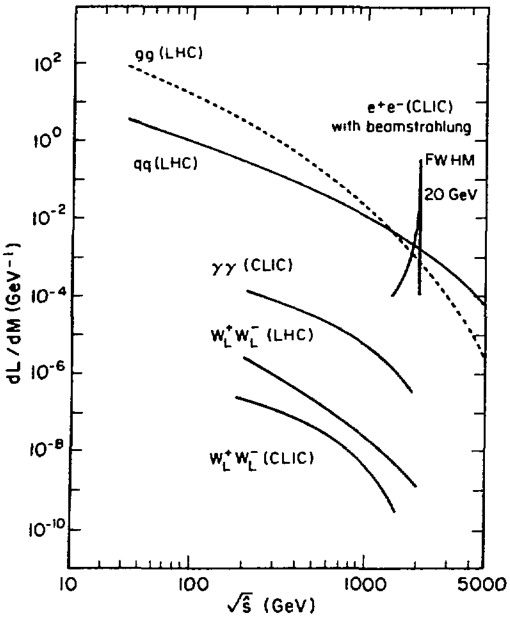


Fig. 1 : Comparison of effective parton-parton luminosities at the LHC and CLIC.

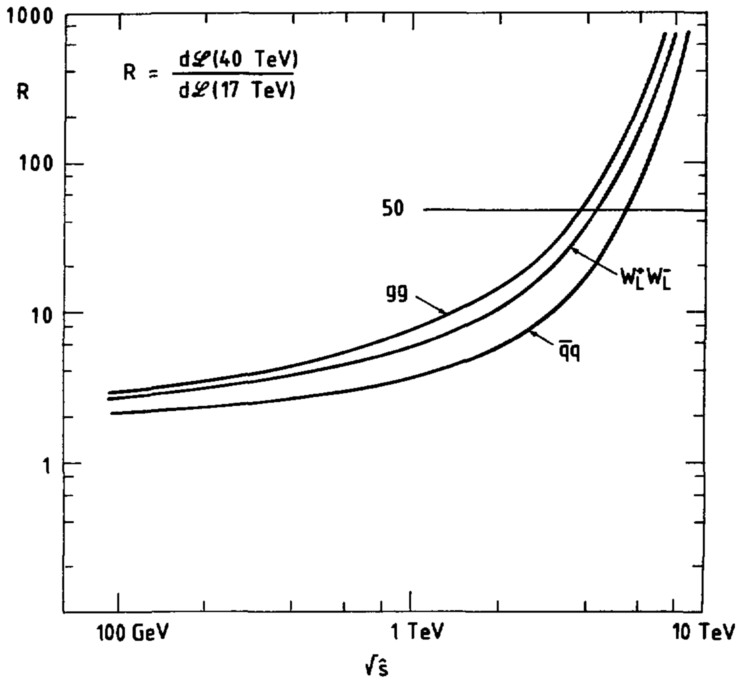


Fig. 2 : Comparison [4] of effective parton-parton luminosities at the LHC and SSC.

already push the scale of compositeness above (1 to 10^2) TeV [1]. I do not much like such composite models, and consign them to Einstein's favourite tool for the purposes of this talk. The Mass Problem is that of understanding the origins of quark, lepton and W masses, and why they are so much smaller than the only plausible candidate for a fundamental scale in physics, namely $m_P \sim 10^{19}$ GeV. It is generally thought that particles get their masses from a Higgs boson which must weigh $\lesssim 1$ TeV [2,6]. The Higgs mass may well be stabilized by supersymmetric particles which also weigh $\lesssim 1$ TeV [1,6]. This line of thought offers the richest prospects for physics with the next generation of accelerators, and probing it will be the primary focus of this talk. Beyond these immediate problems lies that of finding a Theory of Everything (TOE) which also includes gravity, reconciles it with quantum mechanics and explains the origin of space-time. The superstring is a prototype TOE, and some phenomenological treatments of it suggest a new neutral gauge boson Z', searches for which I will also discuss.

Detector characteristics

The working groups [1,4] whose work I describe here contained a majority of experimentalists, who also did most of the work. The following detector characteristics have been assumed in their simulations. Energy resolutions were taken to be

$$\left.\begin{array}{ll} e,\gamma: & \dfrac{\delta E}{E} = \dfrac{10\%}{\sqrt{E}} \oplus 1\% \\ \text{hadrons}: & \dfrac{\delta E}{E} = \dfrac{50\%}{\sqrt{E}} \oplus 5\% \end{array}\right\} \text{or} \left\{\begin{array}{l} \dfrac{15\%}{\sqrt{E}} \oplus 2\% \\ \dfrac{35\%}{\sqrt{E}} \oplus 2\% \end{array}\right. \tag{1}$$

and momentum resolutions

$$\mu: \frac{\delta p}{p} = 10^{-4}p \ (\text{tracker}) \ \text{or} \ 0.1 \ (\text{magnetized Fe}) \tag{2}$$

Granularities were taken to be

$$e, \gamma, \text{hadrons} : \delta\eta = \delta\phi = 0.05 \tag{3}$$

and the angular coverages in pp collisions:

$$|\eta| < 5 \tag{4}$$

and in e^+e^- collisions

$$10^\circ < \theta < 170^\circ \tag{5}$$

for e and μ detection and for calorimeter elements, with the possibility of a luminosity monitor down to 2°.

When a pp collider is run at a luminosity above 10^{33} cm^{-2}s^{-1}, it is assumed [4] that one does no tracking. Muon detection is relatively easy, at least with a closed geometry. Calorimetry would have to be very fast -- the LHC at 5×10^{34} cm^{-2}s^{-1} would have on average 25 events every 5ns -- and our working group [4] has discussed ideas for achieving this which appear feasible. A fine-grain transition radiation detector appears to be a promising technique for electron detection in this environment [4]. The major concern at high luminosity is radiation damage. The radiation levels depend quite sensitively on the polar angle and the centre-of-mass energy. For example, the radiation level at $|\eta| = 5$ at $\sqrt{s} = 17$ TeV is comparable to that at $|\eta| = 4$ at $\sqrt{s} = 40$ TeV, if the luminosities are the same, and the radiation level at $|\eta| = 5$ at $\sqrt{s} = 40$ TeV is about six times worse [4].

PHYSICS STUDIES

Supersymmetry

Present mass limits on strongly-interacting sparticles are [11]

$$m_{\tilde{q}} \gtrsim 45\ \text{GeV} \quad , \quad m_{\tilde{g}} \gtrsim 53\ \text{GeV} \tag{6}$$

and for electroweakly-interacting sparticles are [11,12]

$$m_{\tilde{l}} \gtrsim 20\,GeV\ ,\ m_{\tilde{W}} \gtrsim 22\,GeV \tag{7}$$

In the near future, the best limits for squarks and gluinos are likely to come from the FNAL Tevatron collider [13]:

$$m_{\tilde{q}}\ ,\ m_{\tilde{g}}\ \gtrsim\ 200\,GeV \tag{8}$$

and the best limits for sleptons and winos are likely to come from LEP 2 [14]:

$$m_{\tilde{l}} \gtrsim 90\,GeV\ ,\ m_{\tilde{W}} \gtrsim 80\,GeV \tag{9}$$

How much better can we do with the next generation of colliders, bearing in mind that we expect the sparticle masses to be below 1 TeV?

Strongly-Interacting Sparticles in pp Collisions

We consider [1,4] the production processes $pp \to \tilde{q}\bar{\tilde{q}}+X$ and $\tilde{g}\tilde{g}+X$, and the favourable decay modes $\tilde{q} \to q\tilde{\gamma}$, $\tilde{g} \to q\bar{q}\tilde{\gamma}$. We realize that this scenario is idealized and perhaps unlikely [15], but it serves us as a useful bench- mark for comparing different accelerators. If you cannot detect these decay modes, you probably cannot detect more complicated (realistic?) decay modes. I will discuss here studies [1,4,16] at $\sqrt{s}$ = 17 TeV, first with an integrated luminosity of 10^{40} cm^{-2} = 10 fb^{-1}, which would give $\sim 10^4$ $\tilde{g}\tilde{g}$ events if $m_{\tilde{g}}$ = 1 TeV. This study can then be scaled to other luminosities and centre-of-mass energies. Other studies [13] comparing the LHC and the SSC at 10^{33} $cm^{-2}s^{-1}$ give similar results.

Shown in Fig. 3 are the main physics backgrounds [16]: QCD production

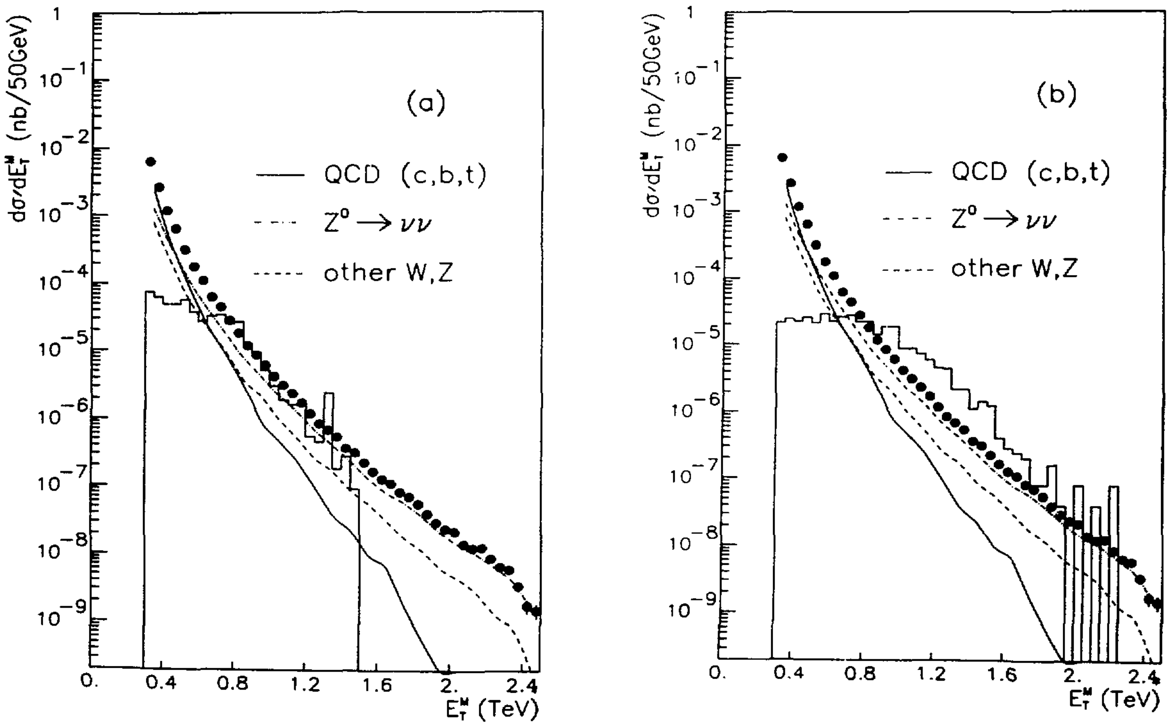


Fig. 3 : Supersymmetric signals and backgrounds [16] at the LHC: (a) for $\tilde{g}\tilde{g}$, and (b) for $\tilde{q}\bar{\tilde{q}}$ production. In these and all subsequent distributions it is assumed that either (a) $m_{\tilde{\gamma}} \ll m_{\tilde{g}} = 1$ TeV $\ll m_{\tilde{q}}$, or (b) $m_{\tilde{\gamma}} \ll m_{\tilde{q}} = 1$ TeV $\ll m_{\tilde{g}}$.

of heavy $\bar{q}q$ pairs (c,b,t) which is dominant for missing transverse energy E_T^M < 500 GeV, and $W \to e\nu$, $\mu\nu$, $\tau\nu$, $Z \to \bar{\nu}\nu$, $\tau^+\tau^-$ events which are dominant for E_T^M > 500 GeV. The background from weak boson pair-production is negligible, and the background at large E_T^M is independent of m_t in the range 40 GeV to 200 GeV. There is also an important instrumental background due to fake E_T^M from particles passing through the beam holes. Figure 4a shows [17] that at $\sqrt{s}$ = 16 TeV this is negligible for E_T^M > 50(200) GeV if one has calorimeter coverage out to $|\eta|$ = 4.7 (3.1). Figure 4b shows that at $\sqrt{s}$ = 40 TeV a calorimeter with coverage to $|\eta|$ = 4.7 (3.1) has negligible fake E_T^M background for E_T^M > 100 (500) GeV. For fixed $|\eta|$ coverage, the fake E_T^M scales roughly as the centre-of-mass energy.

To reject the physics background [16], one first removes events containing a visible μ or e, which we assume to be any μ or isolated e in $|\eta| < 5$ with P_T > 15 GeV. One must then use the event topology: number of jets, differences in azimuthal angles between jets and the missing transverse energy vector, and circularity:

$$C = \frac{1}{2} \min \frac{\left(\sum \underline{E}_T \times \underline{n}\right)^2}{\sum \underline{E}_T^2} \tag{10}$$

which is the analogue of the familiar sphericity variable in e^+e^- collisions. Two event selections have been made; one for gluinos: N_{jet} > 3, c > 0.25; and one for squarks: N_{jet} = 2, $\Delta\phi$ (jet_1, jet_2) < 130°; As can be seen in Tables 1 and 2 respectively, in both cases a conservative estimate of the physics reach is

$$m_{\tilde{q}} \text{ or } m_{\tilde{g}} \sim 1 \text{ TeV} \tag{11}$$

and an optimist might expect that one could reach masses of 1.5 TeV. Similar conclusions are reached in Ref. [13].

What would happen if the LHC luminosity were increased to 5×10^{34} $cm^{-2}s^{-2}$? In this case one expects on average 25 events per bunch crossing,

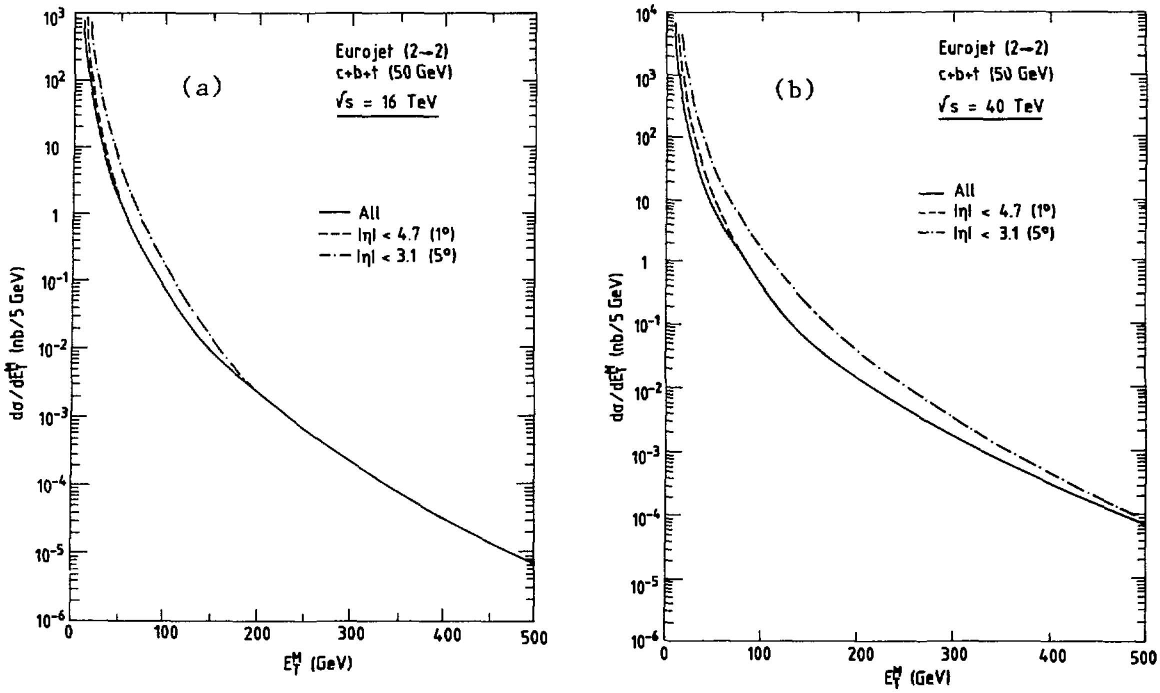


Fig. 4 : The instrumental E_T^M background [4] due to beam holes: (a) at $\sqrt{s}$ = 16 TeV, and (b) at $\sqrt{s}$ = 40 TeV.

with consecutive bunch crossings separated by 5ns. This situation has been modelled [17] by superimposing on pp $\rightarrow \tilde{g}\tilde{g}$+X events a Poisson distribution of overlapping events with $\langle n \rangle = 25$, each one containing a pair of minijets in the range 10 GeV < p_T < 100 GeV. Remarkably, the E_T^M spectrum is almost unchanged, whilst the event topology (N_{jet}, E_T^{jet}) does change, as seen in Fig. 5. A new event selection was made, removing now events with a μ: p_T^{μ} > 50 GeV or an isolated electron: p_T^e > 50 GeV, discarding all tracking information and changing the jet definition as described in the caption to Fig. 6. In this way, one arrives [17] at very similar event topologies to those found previously in the absence of overlapping events, as seen in Fig. 6b. One assumes that the same would be true when background events are combined with overlapping events, although constraints on computer time prevented detailed checks on this belief from being made. Applying the new cuts and jet definition to the background cocktail, one arrived at the results shown in Figs. 7 and in the last columns of Tables 1 and 2. The signal-to-background ratio is not significantly reduced by the overlapping events [17]. We therefore believe that it would be possible to exploit for sparticle searches the full luminosity of any pp collider such as the LHC or SSC.

What happens at the SSC? The larger cross-sections for pp $\rightarrow \tilde{q}\bar{\tilde{q}}$+X or $\tilde{g}\tilde{g}$+X largely compensate for any attempt at the LHC to gain a luminosity advantage. Indeed, if $m_{\tilde{q}}$ or $m_{\tilde{g}} \gtrsim 2$ TeV the SSC would have a larger rate even if the LHC had a factor 50 more luminosity. Although the study discussed in the previous paragraphs has not been extended to the SSC, we assume that optimized cuts would enable physicists there also to extract a significant signal from the same number of events, especially since the signal-to-background ratio is likely to be more favourable at the SSC [6]. This is supported by the comparative analysis in Ref. [13]. Therefore, with the same degree of optimism for each accelerator, namely that a signal could be extracted from 10^4 events, one obtains the following physics reaches for $m_{\tilde{q}}$ or $m_{\tilde{g}}$:

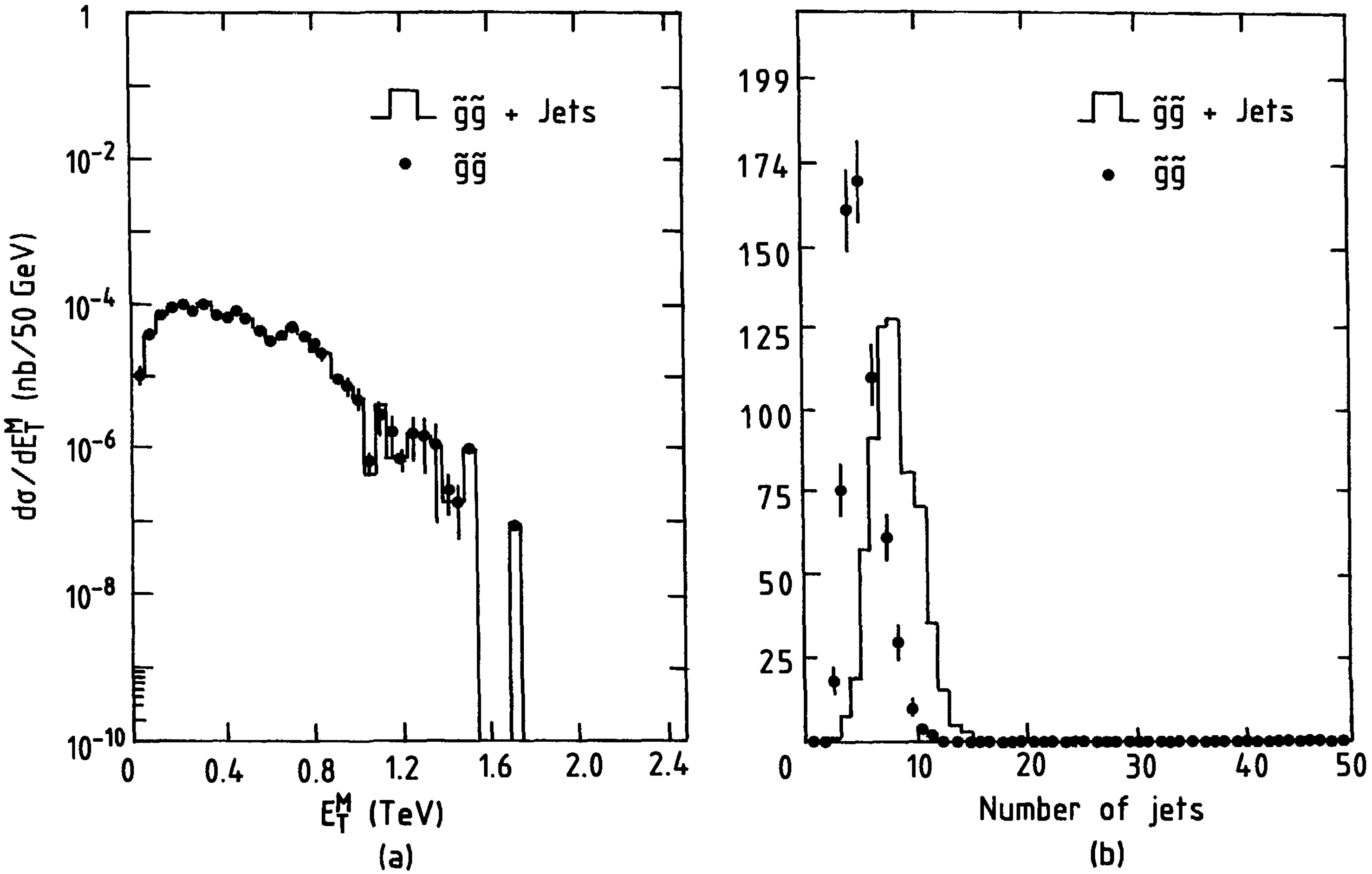


Fig. 5 : When ⟨n⟩ = 25 background events are superimposed on sparticle production events, (a) the E_T^M distribution does not change, but (b) the number of jets does change. In this figure a UA1-type algorithm was used to define jets: $E_T^{jet} > 10$ GeV in $\Delta R < 1$ [16].

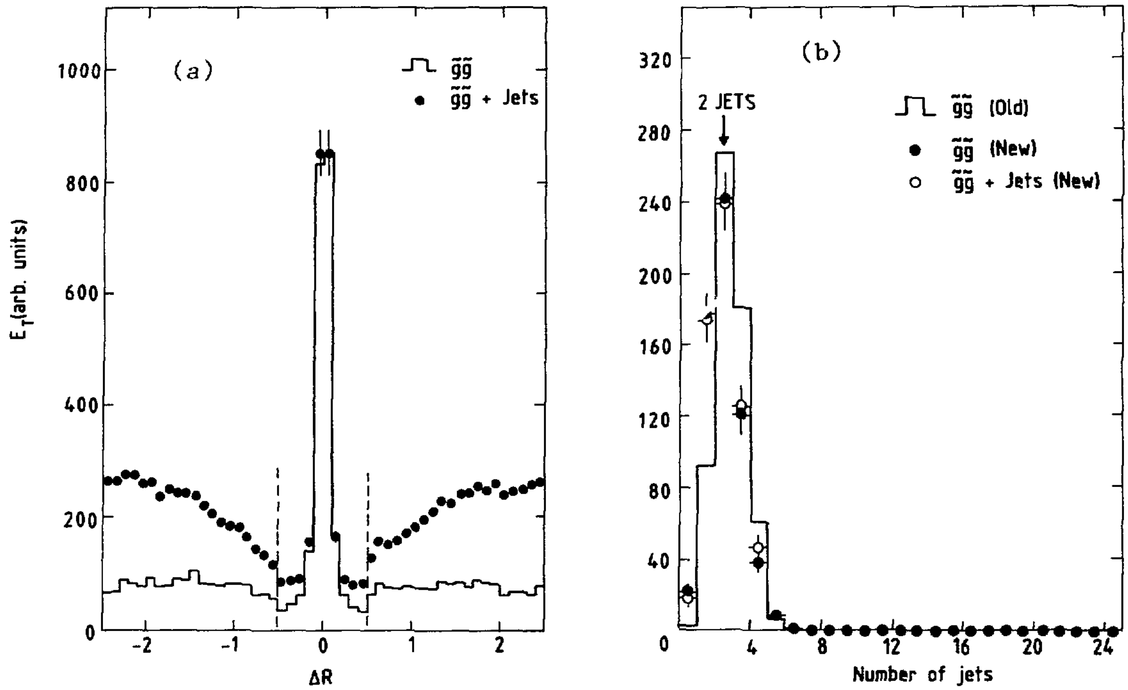


Fig. 6 : (a) The jet profile [4] for 250 GeV < E_T^{jet} < 500 GeV in events with $\langle n \rangle$ = 25 background events superimposed, as a function of $\Delta R = (\Delta\theta^2+\Delta\eta^2)^{\frac{1}{2}}$. (b) The distribution [4] in the number of jets with E_T^J > 250 GeV and measured E_T^M > 300 GeV, after removal of events with any μ or isolated e with p_T > 50 GeV. Here "new" jets are defined by E_T^{jet} > 50 GeV in ΔR = 0.5 with a cell threshold of 5 GeV [17], whilst "old" jets are defined as for Fig. 5.

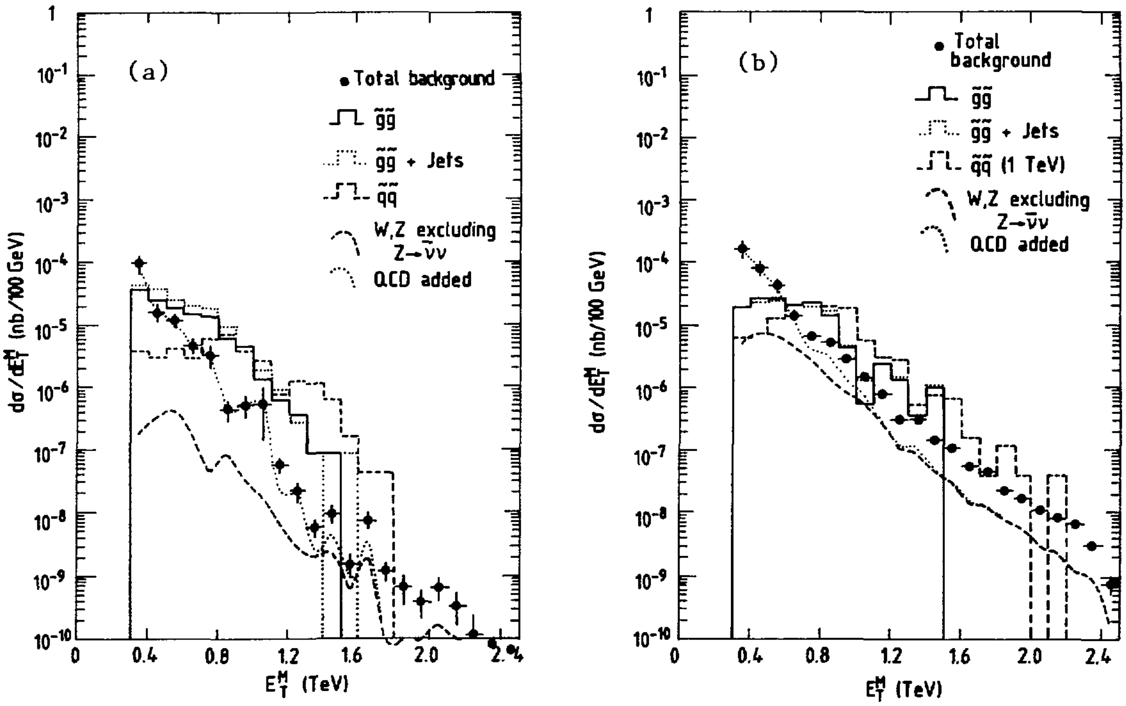


Fig. 7 : Comparisons [4] of signals and backgrounds in high-luminosity running: (a) for E_T^{jet} > 250 GeV, $N_{jet} \geq 3$, c > 0.25, and (b) for N_{jet} = 2, $\Delta\phi(jet_1,jet_2) < 130°$.

Table 1

Event rates for $\tilde{g}\tilde{g}$ production after selection cuts ($E_T^M > 800$ GeV, $E_T^{jet} > 250$ GeV, $N_{jet} \geq 3$, $c > 0.25$) for a total integrated luminosity of $10 fb^{-1}$.

		Overlapping events?	
		without	with
backgrounds	QCD (m_t = 40 GeV)	10±5	13
	QCD (m_t = 200 GeV)	6±2	
	$Z \rightarrow \bar{\nu}\nu$	2±1	2
	$W \rightarrow \tau\nu$	2±1	1
	Total (m_t = 40 GeV)	15±5	16
	(m_t = 200 GeV)	11±2	
signals	$m_{\tilde{g}}$ = 800 GeV	87±19	
	1000 GeV	160±29	133
	1500 GeV	45±4	
	2000 GeV	5±1	7

Table 2

Events rates for $\tilde{q}\tilde{\bar{q}}$ production after selection cuts ($E_T^M > 800$ GeV, $E_T^{jet} > 250$ GeV, $N_{jet} = 2$, $\Delta\phi(jet_1, jet_2) < 130°$) for a total integrated luminosity of $10 fb^{-1}$.

		Overlapping events?	
		without	with
backgrounds	QCD (m_t = 40 GeV)	15±6	25
	QCD (m_t = 200 GeV)	9±4	
	$Z \rightarrow \bar{\nu}\nu$	60±6	57
	$W \rightarrow \tau\nu$, $e\nu$, etc.	29±4	34
	Total (m_t = 40 GeV)	103±9	116
	(m_t = 200 GeV)	98±8	
signals	$m_{\tilde{q}}$ = 800 GeV	640±76	
	1000 GeV	565±44	519
	1500 GeV	149±8	
	2000 GeV	35±2	37

$$\left.\begin{array}{lll} \text{LHC}\ (10^{33}\ \text{cm}^{-2}\text{s}^{-1}) & : & 1\ \text{TeV} \\ \text{SSC}\ (10^{33}\ \text{cm}^{-2}\text{s}^{-1}) & : & 1.7\ \text{TeV} \\ \text{LHC}\ (5\times10^{34}\ \text{cm}^{-2}\text{s}^{-1}) & : & 1.8\ \text{TeV} \end{array}\right\} \tag{12}$$

Several comments on these numbers are in order. (1) The only detailed analysis has been for the LHC at 10^{33} $\text{cm}^{-2}\text{s}^{-1}$ and the other two figures are extrapolations. (2) Truly conservative limits for the SSC at 10^{33} $\text{cm}^{-2}\text{s}^{-1}$ and the LHC at 5×10^{34} $\text{cm}^{-2}\text{s}^{-1}$ would be $1\frac{1}{2}$ TeV. (3) This also means that no significance should be attached to the apparent small difference between the SSC and high-luminosity LHC numbers. (4) This is particularly true in view of the greater difficulty of experiments at the LHC with high luminosity. (5) Presumably it would also be possible to run the SSC at higher luminosity to improve its physics reach.

$e^+e^- \to$ sparticle pairs

One should always remember that these cross-sections are small [1,18]. The reference cross-section

$$\sigma_{pt} \equiv \sigma(e^+e^- \to \gamma^* \to \mu^+\mu^-) = \frac{87\ \text{fb}}{(E_{cm}\ (\text{TeV}))^2} \tag{13}$$

corresponds to 220 events per year of 10^7s at a luminosity of 10^{33} $\text{cm}^{-2}\text{s}^{-1}$ at E_{cm} = 2 TeV. Many interesting supersymmetric cross-sections are smaller:

$$R_0 \equiv \frac{\sigma(e^+e^- \to \gamma^* \to (J=0)(\overline{J=0}))}{\sigma(e^+e^- \to \gamma^* \to \mu^+\mu^-)} = \frac{1}{4} Q^2 N_{colours} \beta^3 \tag{14}$$

which means that

$$R_{\tilde{\mu}} = \frac{1}{4}\beta^3 : \beta^3 = 0.65(0.22) \text{ for } \frac{m}{E_{beam}} = 0.5(0.8) \quad (15)$$

To do some reasonable physics one needs the equivalent of 10^3 $\mu^+\mu^-$ per year, corresponding to a luminosity

$$\mathcal{L} = 10^{33}\left(E_{cm}/1\,\mathrm{TeV}\right)^2 \quad (16)$$

or 4×10^{33} $cm^{-2}s^{-1}$ at E_{cm} = 2 TeV. If this were not obtained, there would be a significant reduction in the physics reach for supersymmetric particles [18], and the loss of much other good physics [1].

The typical process which has been studied is $e^+e^- \to \tilde{X}\tilde{\bar{X}}$ followed by $X \to X\tilde{\gamma}$, with $m_{\tilde{\gamma}}$ = 0 to 50 GeV. Such events have missing energy E^M, missing momentum p^M, are acollinear and acoplanar. The missing transverse momentum P_T^M is independent of beamstrahlung, whilst the signal for missing longitudinal momentum P_L^M is not greatly affected by it. In general, sparticle cross-sections are only a few fb, so losses must be avoided, whilst the backgrounds of a few tens of fb are not overwhelming, so relatively loose cuts should, and can, be used to pick signals out from the backgrounds.

Consider as an example the search foı smuons via $e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^-\tilde{\gamma}\tilde{\gamma}$. First one selects events with both a μ^+ and a μ^- inside the detector ($|\cos\theta|$ < 0.87) with momenta above 30 GeV. The possible backgrounds are $e^+e^- \to \mu^+\mu^-(\gamma)$, $\tau^+\tau^-(\gamma) \to \mu^+\mu^-\nu\bar{\nu}(\gamma)$ and $W^+W^- \to \mu^+\mu^-\bar{\nu}\nu$. However, these all give events where the $\mu^+\mu^-$ pair are either back-to-back in the transverse plane, or else contain a visible γ as seen in Fig. 8, and in the last case are also sharply peaked forward-backward. Relatively loose cuts remove the backgrounds while retaining 50 to 60% of the signal. Therefore we conclude [1,18] that one can see

$$m_{\tilde{\mu}} \sim 850\ \mathrm{GeV} \quad (17)$$

at E_{cm} = 2 TeV with an integrated luminosity of 50 fb^{-1}. The physics reach is reduced in proportion at E_{cm} = 1 TeV with an integrated luminosity of

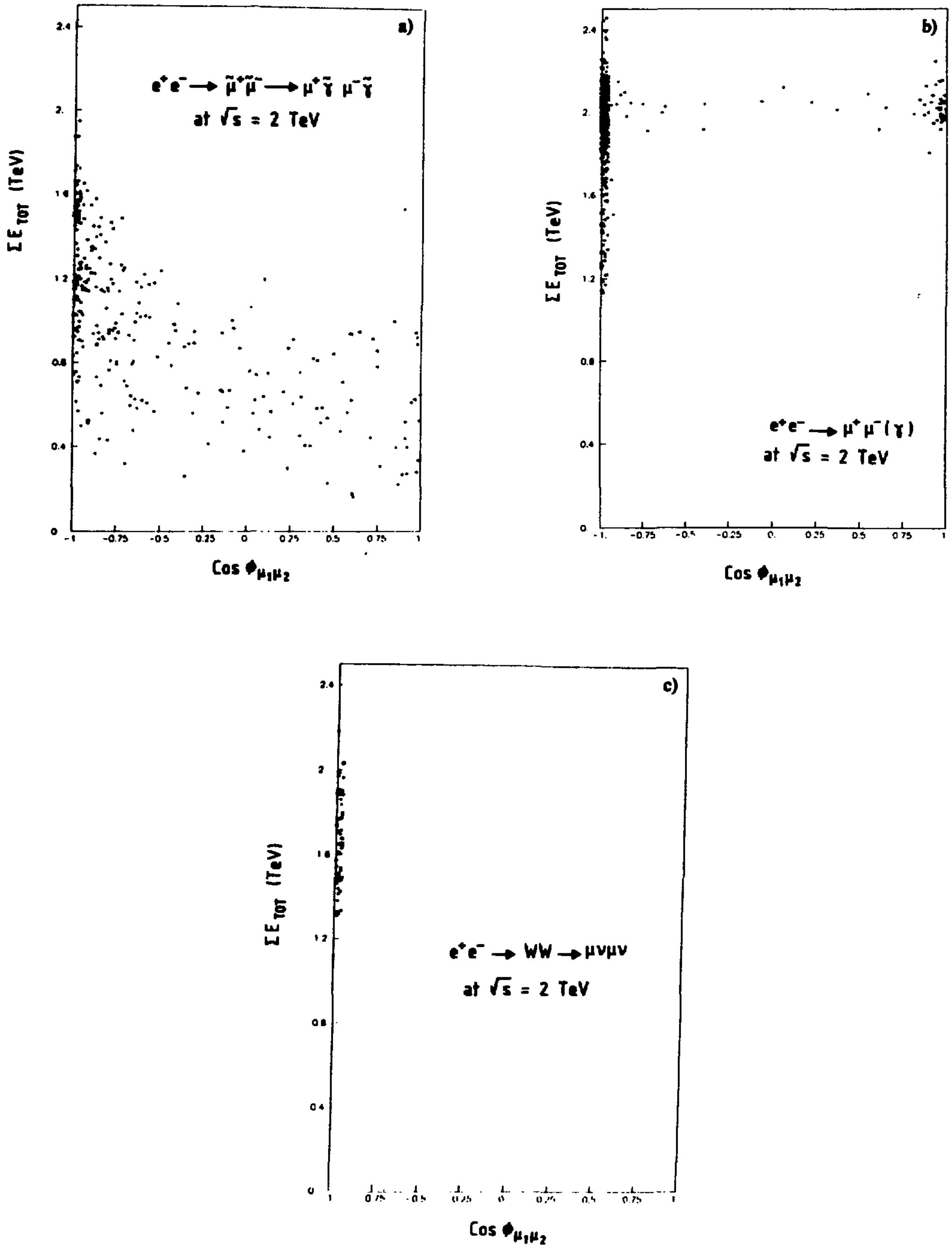


Fig. 8 : Scatter plots [18] in ΣE_{TOT} and $\cos\phi_{\mu_1\mu_2}$ for (a) $\tilde{\mu}^+\tilde{\mu}^-$ production, (b) $\mu^+\mu^-(\gamma)$ and (c) $W^+W^- \to \mu^+\mu^-\nu\bar{\nu}$.

$10\ fb^{-1}$, and much sensitivity is lost if only $10\ fb^{-1}$ are available at $E_{cm} = 2$ TeV. Similar conclusions apply to searches for $\tilde{e}^+\tilde{e}^-$ and for $\tilde{W}^+\tilde{W}^-$.

If one is lucky enough to find a sparticle in e^+e^- collisions, it is possible to determine its mass and spin with high precision [1,18]. Figure 9a shows the average angular distribution of muons from $e^+e^- \to \tilde{\mu}^+\tilde{\mu}^-$ with $m_{\tilde{\mu}} = 0.5$ TeV at $E_{cm} = 2$ TeV, contrasted with that from a conjectural spin-$\frac{1}{2}$ parent particle. Figure 9b shows the threshold behaviour of the cross-section for $e^+e^- \to \tilde{\mu}^+\tilde{\mu}^-$ if $m_{\tilde{\mu}} = 0.5$ TeV, together with the likely statistical errors in measuring it. A sequence of measurements at different energies above threshold should [1,18] enable $m_{\tilde{\mu}}$ to be measured with an error of 2%.

Z' physics

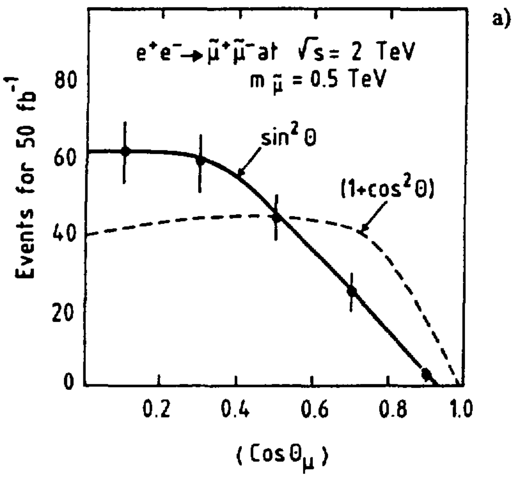
There are many alternative Z' models with different couplings. Just to have something definite to use as a bench-mark, we choose one particular superstring-inspired Z'. Maybe the world is described by a ten-dimensional heterotic string with an $E_8 \times E_8{}'$ gauge group, and maybe E_8 is broken to E_6 during Calabi-Yau compactification which then might be broken down to the minimal rank-5 gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_E$ (but probably not!). In this particular case, the extra hypercharges of all particles are specified [1]:

$$Y_E\left(\nu_L, e_L, d^c_L\right) = -\frac{1}{6}\ ,\quad Y_E = \left(e^c_L, u_L, d_L, u^c_L\right) = \frac{1}{3} \qquad (18)$$

and the overall coupling strength is fixed:

$$\alpha_E = 0{\cdot}010 \qquad (19)$$

What is unknown is the mass of the Z', which could be anywhere up to 10^{19} GeV, although there are arguments [19] favouring a mass in the TeV range. Another uncertainty is the amount of its mixing with the conventional



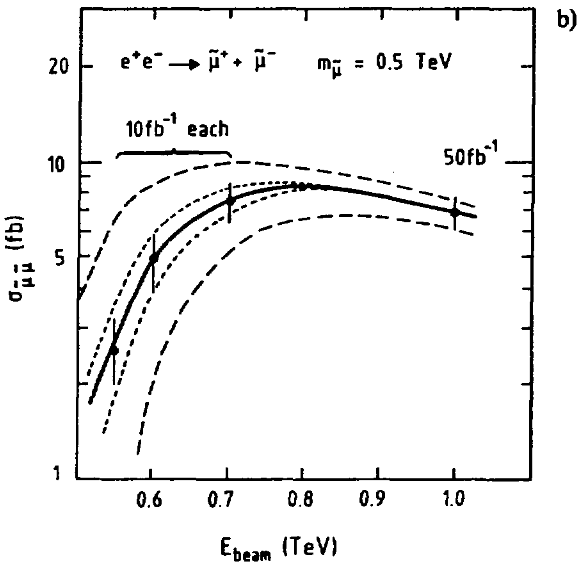


Fig. 9 : (a) Angular distribution [18], and (b) threshold cross-section rise [18] for $e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\tilde{\gamma}\mu^-\tilde{\gamma}$.

Z^0, which we will not discuss here [20]. The present lower mass limit on this Z' is [10]

$$m_{Z'} \gtrsim (130 \text{ to } 500)\ \text{GeV} \tag{20}$$

with the precise value depending on extra model-dependent assumptions.

$$pp \to Z' + X$$

<u>$Z' \to e^+e^-$</u> As can be seen in Fig. 10, one has an observable rate at E_{cm} = 17 TeV with an integrated luminosity of 10 fb^{-1} up to

$$m_{Z'} \lesssim 4\ \text{TeV} \tag{21}$$

with the precise limit depending on the branching ratio $B(Z' \to e^+e^-)$ which is assumed [20]. The detector does not have a large influence: cutting to $p^e_{T_1} > 20$ GeV, $p^e_{T_2} > 10$ GeV and polar angles $25° < \theta < 155°$ reduces the observable cross-section by a factor of 2 [21]. The resonance width is broadened by the detector resolution (1), but should still be measurable if $\Gamma/m_{Z'} > 0.01$. <u>$Z' \to \mu^+\mu^-$</u> The main difference here in the influence of the detector is the much worse mass resolution: about 100 GeV for $m_{Z'}$ = 1 TeV [21]. There are apparently no significant backgrounds to searches for $Z' \to \ell^+\ell^-$, but this is not the case for <u>$Z' \to \bar{q}q$</u>. Detection above the large QCD two-jet background does not appear to be very feasible. One may have more luck with <u>$Z' \to W^+W^-$</u>, which is expected [20] to have a branching ratio similar to that for $Z' \to \ell^+\ell^-$ in many models. It seems to be possible to find this signal, both above the electroweak W^+W^- background, and also above the QCD W+jet background.

Figure 10 shows the cross-sections for E_{cm} = 40 TeV as well as 17 TeV, from which we infer the following physics reaches assuming 10^7 s of running at the nominal luminosity:

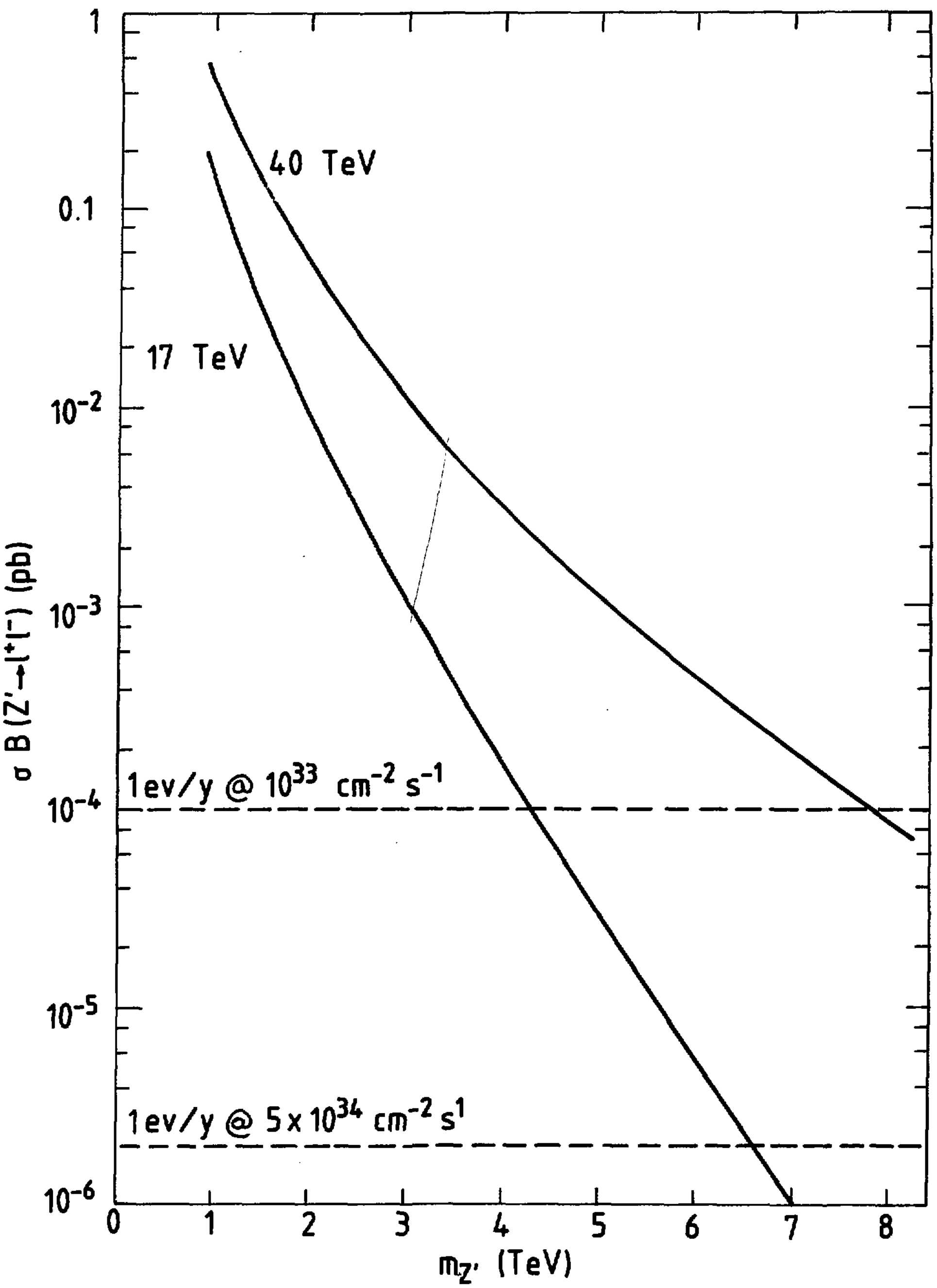


Fig. 10 : Cross-sections [4] times maximal $\ell^+\ell^-$ branching ratio for the Z' in a minimal rank-5 superstring-inspired model [20], at $\sqrt{s}$ = 17 TeV and 40 TeV.

$$\left.\begin{array}{ll} \text{LHC } (10^{33}\,\text{cm}^{-2}\text{s}^{-1}) & : 4\text{ TeV} \\ \text{SSC } (10^{33}\,\text{cm}^{-2}\text{s}^{-1}) & : 7\text{ TeV} \\ \text{LHC } (5\times10^{34}\,\text{cm}^{-2}\text{s}^{-1}) & : 6\text{ TeV} \end{array}\right\} \qquad (22)$$

In this case the mass advantage of the SSC is real, and probably could be improved by running at higher luminosity. There is no obvious obstacle to a "beam-dump" type of experiment looking for $Z' \to \mu^+\mu^-$ at the highest luminosity a collider can reach.

Z' in e^+e^- collisions

A high-energy e^+e^- machine such as CLIC could be a good Z'factory [1,22], perhaps after discovery of the Z' at the LHC or SSC. The peak cross-section is determined by unitarity to be

$$\frac{\sigma(e^+e^- \to Z' \to X)}{\sigma_{pt}} = \frac{9}{\alpha^2} B(Z' \to e^+e^-) B(Z' \to X) \qquad (23)$$

For typical Z' models, one has $B(Z' \to e^+e^-) = (0.6 \text{ to } 6)\%$. Taking $B(Z' \to e^+e^-) = 1\%$ in (23), one has at the Z' peak

$$\sigma(e^+e^- \to Z' \to \text{all}) = 0.13\,\text{nb} / (m_{Z'}(\text{TeV}))^2 \qquad (24)$$

Typical examples for a luminosity of 10^{33} cm^{-2}s^{-1} and $m_{Z'} = 1(4)$TeV are one event every 8 s (2 min), and more examples [22] are given in Table 3. However, typical natural widths

$$\Gamma_{Z'}/m_{Z'} \sim (0.6 \text{ to } 4)\,\% \qquad (25)$$

may be rather narrower than the beam energy spread, which would lead to reductions in the expected event rates.

This has been studied [23] for CLIC at a conjectured Z' peak including beamstrahlung, non-chromatic bunches with a Gaussian energy spread $\sigma_E = 1\%$, a Breit-Wigner resonance with natural width $\Gamma/m_{Z'} = 0.02$ and $B(Z' \to e^+e^-) = 1\%$.

By comparison with Table 3, the beam energy spread reduces the peak event rate by a factor between three and four [23], but still leaves sufficiently many events ($\sim 10^4$ to $\sim 10^5$) to make detailed measurements on the peak and to look for rare Z' decays. In this particular case, even a luminosity lower than 10^{33} $cm^{-2}s^{-1}$ could be interesting.

CONCLUSIONS

As is shown in Fig. 11, high energy pp colliders with E_{cm} = 17 to 40 TeV have a comparable physics reach to e^+e^- colliders with E_{cm} = 2 TeV. This holds not only for the small range of new physics topics studied here, but also for the wider range studied in Ref. [1]. Although the mass ranges which can be explored with pp colliders may be larger for strongly-interacting particles such as squarks and gluinos, e^+e^- colliders have larger physics reaches for weakly-interacting particles, which are equally interesting. In addition, e^+e^- colliders offer more possibilities for follow-up studies, fixing for example the mass and spin of any new particle discovered. In some cases, very detailed studies can be made, for example in the exploration of rare Z' decays. For these reasons I would stress the complementarity between e^+e^- and pp colliders, rather than any competition between them. Therefore one should use caution and intelligence in comparing the physics reaches shown in Fig. 11.

The same is also true for the comparison between different pp colliders. In the two cases studied, the ratios of the physics reaches of the LHC and the SSC at 10^{33} $cm^{-2}s^{-1}$ are in the ratios of the 0.6 powers of the centre-of-mass energies. The centre-of-mass advantage of the SSC could largely be recaptured by running the LHC at 5×10^{34} $cm^{-2}s^{-1}$, if one could do any experiments at such a high luminosity [4]. Studies [4,17] indicate that having O(25) overlapping events is not an obstacle to searching for squarks, gluinos, or a Z'. However, life would clearly be easier at a higher-energy machine. Presumably the SSC luminosity could also be increased if this was deemed desirable to restore its advantage in physics reach for some particular new particle search, although this possibility has apparently not been studied in detail.

<u>Table 3</u>

Z' properties and event rates for $m_{Z'} = 1$ TeV: no energy spread included.

Model	A		B		C	
Available decay modes	minimal	maximal	minimal	maximal	minimal	maximal
$\Gamma(Z' \to \text{all})/m_{Z'}(\%)$	0.65	3.8	1.2	3.8	0.65	3.8
$BR(Z' \to e^+e^-)(\%)$	3.6	0.6	5.9	1.8	5.4	0.9
$\sigma(e^+e^- \to Z' \to \text{all})$	0.46	0.077	0.76	0.23	0.69	0.12
Mean time between events*(s)	2.2	13	1.3	4.3	1.4	8.7

The superstring models are defined in Ref. [20].

*Calculated assuming $L = 10^{33}$ $cm^{-2}s^{-1}$ and neglecting the effects of beam energy spread.

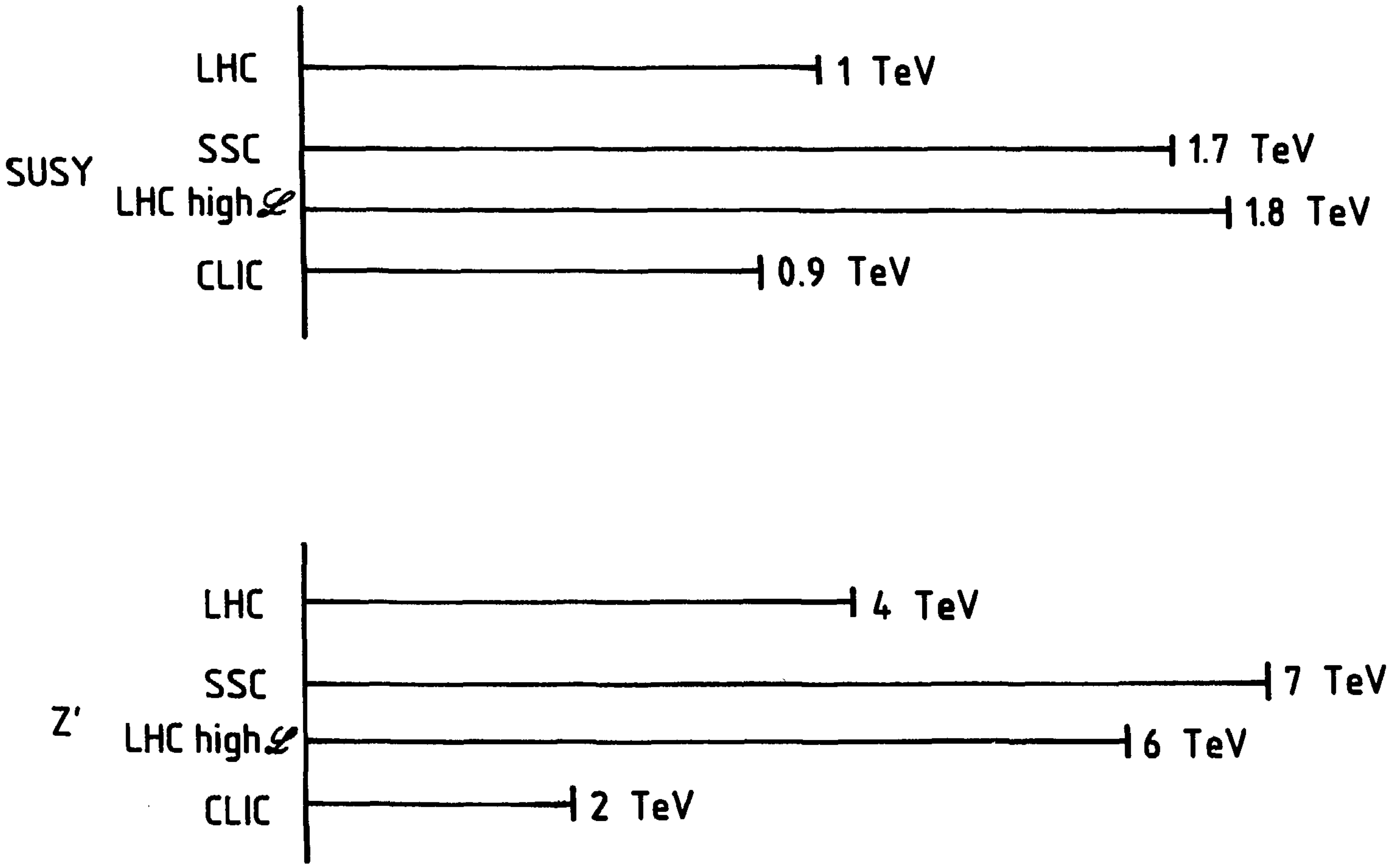


Fig. 11 : Comparisons of the discovery limits for supersymmetric particles and a Z' at the LHC, the SSC, the LHC high-luminosity option, and CLIC. These comparisons do not take into account the relative cleanliness of e^+e^- experiments, nor the relative dirtiness of high-luminosity pp experiments.

ACKNOWLEDGEMENT

It is a pleasure to thank Felicitas Pauss for her help in convening the Working Group on New Particles at La Thuile, and for many valuable conversations about the studies summarized in this report.

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POST-FERMI SCALE PHYSICS AND FUTURE ACCELERATORS

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1. INTRODUCTION

The possibility, or most probably, the inevitability of a "new" physics to exist at energies of elementary subprocesses of $\sqrt{s}\simeq 1$ TeV has been under detailed discussions for a long time. Such discussions can be found in various reports, reviews and summary reports of working groups (see, for instance [1,2]).

We do not think that the ideas of "new" physics in the TeV energy range need to be advocated too much because the decisions on the construction of the proper colliders either have already been approved (UNK) or, one may hope, will be approved in the nearer future (SSC, LHC). Such machines will undoubtedly be constructed in the nearer decade and the TeV energy range will be, in the main, studied by the beginning of the next century. The question arises: what is to be done further?

The discovery of high-temperature superconductivity as well as the ideas of new acceleration techniques imbue one with the hope that by the beginning of the next century real technical and economical opportunities for the construction of higher energy accelerators, up to energies of $\sqrt{s}\sim 1$ PeV (10^3 TeV), will have opened up.

As experience shows, the energy increase factor with a change-over to accelerators of next generation is 20-25 for hadron machines (30 GeV$\rightarrow$(500--900) GeV$\rightarrow$20 TeV). If this factor is taken as a guide for the future, then the advance from the SSC to a 500x500 TeV hadron collider, with high-temperature superconductivity applied, will require technical progress comparable with that already made or to be made for the machines of the nearer future. For example, with 20 T superconducting magnets, which are apparently within the reach of the strength of materials, the circumference of such a 500x500TeV hadron collider will be about 520 Km. In this case, the intensity of synchrotron radiation per particle, $I\sim p^2H^2/m^4$, $p\sim HR$ (p being the particle energy, m-its mass, R - the accelerator radius), will be 6 times less than that of the LEPII. However, the required increase of luminosity may result in a substantial increase of integral loss.

The technical problems do not allow to raise appreciably the energy and luminosity of the future machines (see, for example [3]) using traditional techniques. Therefore new R & D which will take a decade at least, are required. Bringing to light the physical problems whose solution necessitates advance into the PeV energy range may stimulate this R & D. Therefore we believe that to put the problem of a PeV collider ("Pevatron") right now is not premature, especially if one takes into account that advance to energies of the order of 1 PeV can apparently be a real possibility with high-temperature superconductivity applied.

It should be pointed out that with the intensity of synchrotron radiation being limited by the value of, say, the one accepted for the LEPII, a (0.5-1) PeV ring hadron accelerator will utilize high temperature superconductivity to the best advantage. This is clearly seen in Figure 1.

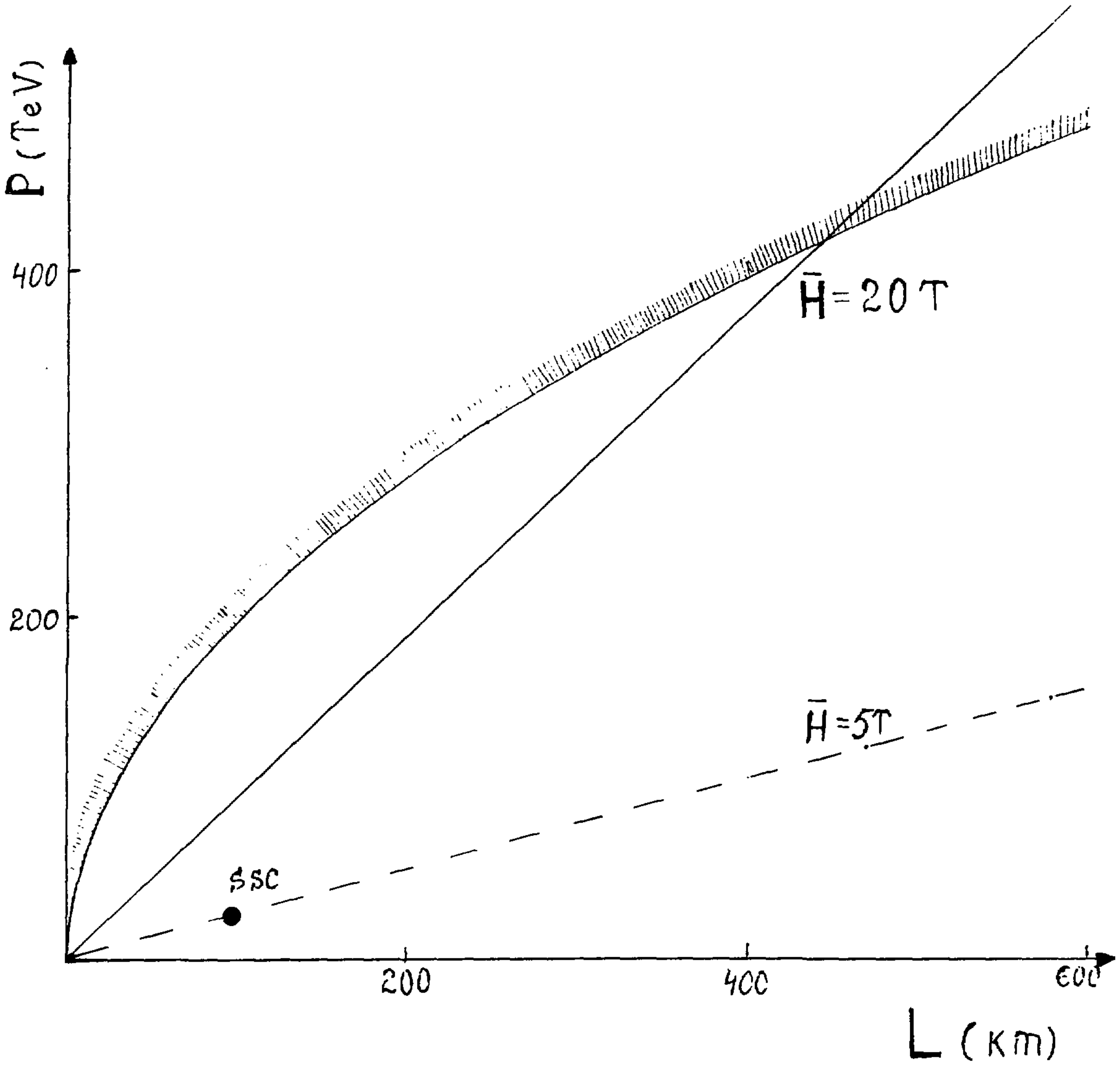

Figure 1. Limitations imposed by an admissible intensity of synchrotron radiation. The curve with the dashing bounds the region in which the synchrotron radiation loss is less than 0.1 of the relevant one at the LEPII. L is the proton accelerator length, p is particle momentum, $\bar{H}$ - the mean magnet field ($\bar{H} \simeq 0.9H$).

Setting the admissible ratio of intensities of synchrotron radiation per particle for proton and electron machines, I/I_e, we obtain the following limitation on the momenta of accelerated protons: $p \leq p_\ell (R/R_\ell)^{1/2} (I/I_\ell)^{1/4} (m/m_\ell)$ (the curve with the dashing in the figure corresponds to $I/I_\ell = 0.1$, $p_\ell = 100$ GeV, $R_\ell = 4.5$ Km). From here we obtain $p \leq 420$ TeV for $\bar{H} = 20$ T magnets. As seen from the figure, advance to higher energies with the I/I_ℓ fixed, requires that the magnet field be reduced and the machine radius be increased essentially. So, (0.5-1) PeV is the limiting energy for ring proton accelerators, similarly as an energy of the order of 100 GeV is the limit for electron ones.

Possibilities for new physics to exist in the (10^2-10^3) TeV energy range were discussed, for example, in the Grand Unification frames in the report of Salam [4]. We would like to discuss these possibilities within the frames of the problems left unanswered by the Standard Model. In Section 2 we highlight two classes of the problems. The solution to the 1st class of the problems should be related to the Fermi scale, $\Lambda_F = O(1$ TeV), while the solution to the 2nd one may point to a new, "post-Fermi", scale $\Lambda_{PF} = (10^2 \div 10^3)$ TeV. In Section 3, we touch upon the physics of the Fermi scale as well as new prospects for studying it which PeV machines offer as compared with TeV ones. In Section 4, we try to substantiate the value of Λ_{PF} to be expected and to outline a set of new phenomena inaccessible for study at TeV machines. In Section 5, we discuss additional possibilities to obtain indirect information on a possible nature of the post-Fermi scale with the help of the TeV machines (or lower-energy ones) as well as astrophysics.

2. EXTENSIONS TO THE STANDARD MODEL

The Standard Model (SM) of strong and electroweak interactions, confirmed brilliantly by the experiment, actually has a number of inherent imperfections which impel one to treat it as an effective manifestation of a more fundamental theory rather than the fundamental one.

It is expedient to divide the problems of the SM, requiring its extension, into two categories:

i) the problems related to the inconsistency of the SM and necessitating its nearby extension;

ii) the problems related to the incompleteness of the SM which may signify the presence of a further extension.

2.1. The Nearby Extension

The weakest point of the SM or, more precisely, of its electroweak part, is the Higgs mechanism of spontaneous electroweak symmetry breaking with an elementary scalar field. This mechanism, firstly, does not substantiate the mean vacuum expectation value $(G_F 2\sqrt{2})^{-1/2} \approx 0.175$ TeV as compared with, say, $M_{P\ell}$ (the "hierarchy" problem) and, secondly, what is the most important, is "unnatural", i.e. unstable with respect to the quadratically diverging vacuum fluctuations of bosonic fields (the "naturality" problem). These fluctuations should have given $(G_F 2\sqrt{2})^{-1/2} \simeq 10^{-1} \Lambda_F$, where Λ_F is the cut off scale (the scale of "new" physics). In accordance with the experimental value of G_F, the scale Λ_F (the Fermi scale) should be in the range of $O(1$ TeV).

This situation is very similar to the paradox of small $\Delta m_{K_L K_S}$ value and suppression of $K_L \rightarrow 2\mu$ decay, which had existed before the c quark was discovered. The theoretical estimates based on perturbation theory demanded that the divergent integrals should be cut off at the scale of 0 (1 GeV) and regardless of the specific mechanism of this cut off. And the number of the mechanisms offered was large. It should be noted that some people viewed the arguments based on the cut off perturbation theory not adequate enough. And still, just these arguments encouraged the experimental studies which culminated in the discovery of the c quark whose mass proved consistent with the theoretical expectations.

Similarly, one may anticipate, regardless of the specific mechanism called for the solution to the naturality problem, the existence of an extension to the SM at energies of $\Lambda_F = 0$ (1 TeV) ("nearby" extension). This is required by the self-consistency of the theory. The solution to the naturality problem should lie in the region of the Fermi scale, $\Lambda_F = 0$ (1 TeV).

2.2. The Far-away Extension

In addition to the naturality problem testifying to the inconsistency of the SM, the theory also faces a number of other problems which are indicative of its incompleteness.

First of all, these are the problems related to fermions.

1) Incomprehension of the reason for the existence of identical generations and of their number.

2) Lack of understanding of quark-lepton analogy within the generations.

3) Difference in the masses of fermions within the generations and between them as well as the problem of fermion mixing. It is manifested in the complete arbitrariness of the Yukawa couplings of the Higgs boson to fermions. The total number of the SM parameters is 26, its larger part being related to fermions.

4) Incomprehension of the CP-violation mechanism. In the SM this violation is introduced into the quark mass matrix in a pure phenomenological manner, with the help of a nonzero phase.

There is one more problem which is related to gauge fields, i.e. the arbitrariness in the electroweak mixing angle $\sin \theta_W$.

The solution to these problems apriori seems independent of the one to the naturality problem, and this prompts seeking for a "far-away" extension to the SM. Of course, the nearby extension actually may be a consequence of the far-away one. However, in a certain approximation they may be independent. This would point to the existence of some new physical scale, in addition to the Fermi scale.

3. THE FERMI SCALE

3.1. The TeV Manifestations of the Fermi Scale

A number of mechanisms have been offered for the solution to the naturality problem of the SM. They are actually reduced to the following options:

1) Strong interaction in the scalar sector and, consequently, in that of the longitudinal W and Z bosons, which leads to the effective cut off due to unitarization at momenta $p \sim \Lambda_F \sim 0(1 \text{ TeV})$.

2) Extended gauge symmetry with a fermion and scalar set selected in a special manner.

3) Low-energy supersymmetry with the breaking scale $\Lambda_S \sim \Lambda_F$ in the sector of usual particles.

4) Dynamic electroweak symmetry breaking (technicolour interaction of techniquarks at the $\Lambda_{TC} \sim \Lambda_F$ scale or the ordinary colour interaction of new quarks in high-dimension colour representations).

5) "Nearby" compositeness of the vector W and Z bosons as well as of leptons, quarks and Higgs bosons (hyperstrong interaction with $\Lambda_{HC} \sim \Lambda_F$).

It is essential that, regardless of the specific mechanism of the naturality restoration, the scale corresponding to new physics should lie in the TeV energy range. Possibilities of studying the expected new physics at the future colliders SSC, LHC, UNK, LEPII, VLEPP are examined fairly well and therefore we shall not discuss them here.

These expectations are based much on the use of the fairly well understood perturbative part of the SM. However, there should also exist nonperturbative effects, understood at present incompletely, which may lead to "prolonged" manifestations of the Fermi scale in the multi-TeV energy range. We would like to treat some of them in more detail.

3.2. The Multi-TeV Manifestations of the Fermi Scale (Nonperturbative Scale)

In the SM, as in any other non-Abelian gauge theory, there may be various gauge-nonequivalent configurations of gauge and scalar fields with the lowest energy. These states correspond to various topological numbers $n=0, \pm 1, \ldots$, the vacuum having the periodic structure (the so-called θ-vacuum). Different states are separated by the energy barriers $\Lambda_{NP} = (m_W/\alpha_W) \cdot B(m_H/m_W)$ high, where $B(m_H/m_W)$ is a smooth function of the Higgs boson mass so that $\Lambda_{NP} \sim$ ~ 10 TeV is actually independent of m_H. The field configuration corresponding to the top of the barrier is a saddle point in the energy functional, the so-called "sphaleron"[5]. Λ_{NP} is a new nonperturbative scale of the electroweak theory, in addition to perturbative scale $(G_F \sqrt{2})^{-1/2}$ (Figure 2).

Under usual conditions, for the transition between states with different topological numbers n to occur, the physical system should tunnel through the potential barrier, the amplitude of this transition being suppressed exponentially, $\exp(-2\pi/\alpha_W) \sim 10^{-85}$[6]. Physical vacuum corresponds in essence to a fixed n, and the baryon number is practically conserved.

However, with energies of elementary subprocesses as high as $\sqrt{\hat{s}} \gtrsim \Lambda_{NP}$, there is a possibility of transition above the barrier rather than under it. As a result, the probability of the transition proves not to be suppressed and this presents an opportunity to study the topological structure of the electroweak vacuum. What are possible manifestations of this structure? Not pretending to elucidate the problem completely, we shall point just to two of them[7,8].

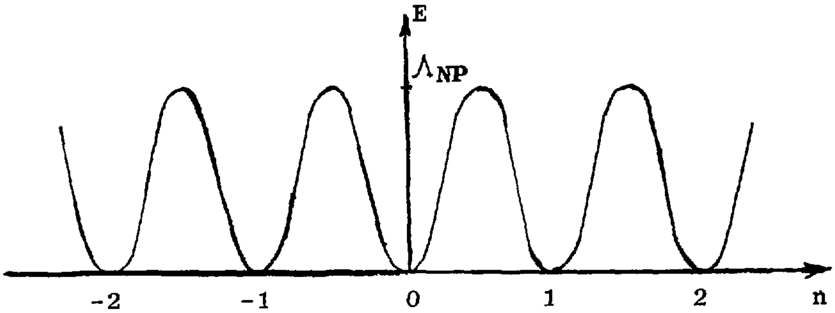

Figure 2. Schematic of the electroweak θ-vacuum, E being energy, n - topological number. $\Lambda_{NP} \sim m_W/\alpha_W$ corresponds to a new nonperturbative scale of the electroweak theory.

With transition made between different topological states, both baryon and lepton numbers are not conserved due to the axial anomaly in corresponding currents. In this, the selection rule, that the whole set of the weakly intereacting fermions $(3q_1+3q_2+3q_3+\ell_1+\ell_2+\ell_3)$ appear simultaneously, should be satisfied in the standard electroweak theory. Here any member may be selected from the weak doublets q_i, ℓ_i of each generation, i=1,2,3. This may result at high energy in the following striking many-fermion subprocesses: $qq \to (7\bar{q})(3\bar{\ell})$ or $WW \to 9q3\ell$ with $\Delta B \neq 0$.

If superheavy particles, $M > m_W/\alpha_W$, for example, a techibaryon B_T, do exist then for an even number of technicolours the following subprocess

$$q\bar{q} \to B_T\bar{B}_T \to 9q3\ell, \quad \to 9\bar{q}3\bar{\ell}$$

with the extremely clear signature is also possible. In this one has $\Gamma_{B_T} \sim m_W$ at $M_{B_T} \gtrsim \Lambda_{NP}$. Besides, the processeses of the electroweak violation of the baryon number are expected to be accompanied by the multiple emission of W/Z bosons, photons and H bosons.

The study of the topological structure of the electroweak vacuum is undoubtedly of the paramount importance both for particle physics and cosmology. Since such a study is apparently beyond the reach of the TeV colliders, it should be the highest-priority problem for the multi-TeV or PeV colliders.

4. THE POST-FERMI SCALE

Though at present we know little about a possible nature of the Fermi scale, still we may judge about its value, $\Lambda_F \sim 0$ (1 TeV), fairly confidently. As to the post-Fermi scale, we have at our disposal only some guiding ideas about the value of Λ_{PF}, to say nothing of its nature. The physical arguments associated with the post-Fermi scale may be broken roughly into two categories: "unavoidable" and possible ones.

To the first category we may attribute everything in any manner related to the problem of fermion masses (the presence of the replicating families of fermions, the values of their masses and also quark mixing and angles phase).

1) Flavour Changing Neutral Currents

Here we have the following lower experimental bound: $\Lambda_{FCNC} \gtrsim (10^2 \div 10^3)$ TeV.

2) Superweak CP-violation

Setting $G_{CP}=\alpha\Lambda_{CP}^{-2}$ one obtains $\Lambda_{CP} \sim 10^3$ TeV from $G_{CP}=10^{-9}G_F$.

3) Extended Technicolour

If the nature of the Fermi scale is related to technicolour, then the nature of the fermion masses is possibly related to the extended technicolour, i.e. to a broken gauge symmetry transforming fermions into technifermions. If this is so, $m_f \approx \left(\frac{\Lambda_{TC}}{\Lambda_{ETC}}\right)^2 \cdot \Lambda_{TC}$ therefore for $\Lambda_{TC} \sim \Lambda_F = 0(1$ TeV$)$ we have $\Lambda_{ETC} \approx$ $\approx (10^2 \div 10^3)$ TeV.

4) "Horizontal" Symmetry

It is a broken gauge symmetry introduced just with the purpose of describing transitions between fermions of different generations. The scale to be expected is $\Lambda_H \geq \Lambda_{FCNC} \geqslant (10^2 \div 10^3)$ TeV.

5) Compositeness of Leptons and Quarks

The previous two approaches do not solve the problem of the nature of fermion generations. The most natural solution to this and to all other related problems would be the idea of the common composite nature of all fermions (leptons, quarks and, possibly, technifermions). In this case the compositeness scale to be expected is $\Lambda_C \simeq \Lambda_{ETC} \simeq (10^2 - 10^3)$ TeV. If this scale is $\Lambda_C \sim$ $\sim \Lambda_{TC} \sim 0$ (1 TeV), then suppression of nondiagonal neutral currents necessitates introduction of an additional mechanism whose nature may be related to Λ_{PF}.

The second category of arguments may include phenomena related to the gauge and Higgs sectors of the Grand unified gauge symmetries.

1) Electroweak Mixing

The Grand unified models of strong and electroweak interactions should substantiate, in particular, the value of the electroweak mixing angle $\sin\theta_W$ which is arbitrary within the frames of the Standard Model. Despite the widespread belief that Grand Unification of these interactions should take place at a large scale, $\Lambda_U=(10^{11}-10^{12})$ TeV (within the frames of SU(5) group or other groups containing it, SO(10), E_6,...), the "nearby" unification of these interactions is also possible for $\Lambda_U \geqslant 10^3$ TeV[9]. An example of the corresponding unified symmetry is $SU(8)_L \times SU(8)_R$[10]. The necessary condition for the nearby unification within the frames of this symmetry is the presence of the broken chiral colour symmetry $SU(3)_L^{(C)} \times SU(3)_R^{(C)}$. Its breaking scale is related to the axial gluon mass, $\Lambda_A \simeq 10^2$ GeV.

2) Baryon Number Violation

The Higgs sector of the unified models is very complicated. In particular, it may be responsible for the processes of baryon number violation. For example, within the frames of the $SU(8)_L \times SU(8)_R$ symmetry, where (left-handed) fermions and antifermions are unified into independent multiplets, the baryon number violating processes like $3q \to \bar{\ell}$ with $\Delta(B-L)=0$ are forbidden, while the processes like $3q \to 3\ell$, not violating the fermion number $\Delta F \equiv \Delta(3B+L)=0$, are possible. This six-fermion interactions do not lead to conflict with the experimental bound on proton stability for $\Lambda_B \geqslant 10$ TeV/11/.

In addition to the above fairly possible manifestations of the post-Fermi scale physics, we may specify a number of more "fantastic" possibilities such as

- "shadow" world related to supersymmetry breaking;
- nearby compactification, etc.

The capabilities of a hypothetic PeV collider surely require a more detailed and thorough investigation. Here we give only some representative ideas.

If one proceeds from the requirement that a new hadron collider should be capable of studying the same relative share $M/\sqrt{s}$ of the available energy scale as, say, the SSC, then the required luminosity should be $L \sim s$. (The same relation is apparently valid for e^+e^- colliders). Consequently, for $\sqrt{s}=$ =1 PeV the luminosity required should be $L=6\cdot 10^2 L_{SSC}$. Attaining such a high luminosity and processing of the relevant information pose new challenging problems. But still, there is a possibility to advance into larger M without an essential luminosity increase.

In scaling approximation, the relationship $M \sim s^{p/2} L^{(1-p)/2}$ holds true, where the power $p<1$ is related to the specific process [3]. If the requirement on M is less stringent, i.e., M accessible for study should grow, though slower than $\sqrt{s}$, the requirement imposed on L may also be made weaker and basically the luminosity may be left at the level of the SSC. Though the physical efficiency of energy utilization will be lower, this still will make it possible to attain almost an order of magnitude larger M than that attainable at the SSC at the same luminosity.

5. THE RELICS AND RESIDUAL INTERACTIONS ("PALEONTOLOGY")

When leaving the realm of the Fermi scale, we anticipate to find ourselves not in a "desert" but in an area populated with unusual "beasts" imaginable. Findings of such "beasts" may bring us much closer to the understanding of the general construction of the world. However, one should regretfully realize that despite fast progress in accelerator engineering, we will never attain the energies of the Grand Unification, 10^{14}-10^{15} GeV, to say nothing of the Planck scale, 10^{19} GeV. To study phenomena proceeding in these energy ranges, we will have to apply the approach of paleontology and reconstruct from individual bones and imprints the appearance of the beasts of this world, thus trying to verify this or that theory of the world "evolution". These paleontologic methods require that various branches of physics should be involved such as the following ones:

1) Search for proton decay and neutron-antineutron oscillations.

2) Search for relic objects, for example, monopoles, in the earth environment and cosmic rays.

3) The study of the nature of hidden mass of galaxies by the classical astrophysical methods, the study of cosmic rays, for example, low-energy antiprotons, applications of γ and ν astronomy, etc.

4) Refinement of the cosmologic and geochemical observations (the Hubble constant, the time of the Big Bang, the chemical composition of the Universe, the He^4/p, d/p ratios, etc.). The study of the large-scale Universe structures and attempts to bring all facts into the unified scenario with account of events occuring at energy scales as large as the Planck mass.

5) Attempts to establish whether the neutrino mass is nonzero and whether there exist the following related processes: double β-decay and oscillations of neutrinos including solar ones (the Wolfenstein-Mikheev-Smirnov effect).

6) Gravimetric studies (search for the "fifth" force).

"Paleontology" may seem to be related to the methods of non-accelerator physics only. However, this is not so. First of all, some objects associated with the superstring theory, i.e. with the Planck scale, may be found in the energy range which is within the reach of accelerators. Such objects may be Z'-bosons whose existence is expected in the TeV energy range. With the accessible observational range extended, the probability to discover such objects may be increased, especially if one takes into account that hierarchy may have a few levels.

Physics at supersmall distances may lead to superrare processes in decays of strange and charmed particles, for example, to $K_L \to \mu \bar{e}$ decays and other ones due to nondiagonal neutral current interactions. The need to search for such superrare processes is a basic motivation for the development and construction of kaon facilities. It would be extremely important to have such facilities for charm and beauty.

Precision study of states with c and b (and, possibly, t) quarks allows one to measure the parameters ($\sin \theta_W$, mixing angles, strengths of the nondiagonal neutral currents, etc.) which, one may hope, will be explained by the future theory. Of a great importance is the study of CP-violation effects for states with heavy quarks, for example, B_S. Such an investigation will help establish the dependence of CP-violating interactions on the quark masses and may bring us closer to the understanding of the nature of these forces.

6. CONCLUSIONS

1) "New" physics should necessarily manifest itself at the Fermi scale $\Lambda_F \sim 0$ (1 TeV).

2) Investigations carried out at energies $\sqrt{\hat{s}} \sim 0$ (1 TeV) will apparently be unable to solve a number of outstanding problems inherent in the Standard Model.

3) The next scale of new phenomena ("supernew" physics) may be expected to lie in the (10^2-10^3) TeV energy range (the post-Fermi scale). It is necessary to examine more thoroughly the feasibilities of experiments in this energy range and of constructing the multi-TeV or PeV accelerators with the new technologies applied.

4) Precision measurements carried out at lower energies, $\sqrt{\hat{s}} \lesssim 0$ (1 TeV), may help obtain additional indirect information on the objects and phenomena related to the larger scale. Low-energy facilities of new particles, (B,K,..), are an additional, to multi-TeV or PeV machines, tool for the study of "super-new" physics.

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DETECTOR STRATEGIES AND QUESTIONS FOR HIGH LUMINOSITIES AND ENERGIES*

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INTRODUCTION

In this talk, I shall cover much of the same ground as the preceding talks, but from a slightly different point of view. As we have heard, the central question for experimental particle physics for the remainder of this century is to find what lies beyond the Standard Model. There is general agreement on the program. We would like to find the mass spectrum of new states of matter that are unknown at the present time. These have various names associated with them: Higgs, heavier Z's and W's, super-symmetry, preons, and so on. The general experimental program is much the same as it has been in the recent past: find new mass bumps if we are very lucky, or find new event configurations that are clearly distinguishable from the old physics. When such new structures are found, the next and even more difficult task will be to measure the detailed properties of these particles and the new force laws they imply.

I would like to outline here the general problem for the experimentalist. We have already heard much about this in the previous talks and there is a vast literature on this topic in proceedings from the SSC summer studies, LHC workshops, and ICFA reports. This talk cannot begin to review this work; it should be viewed as one person's study guide for examining the written record of experimental plans for the next generation of collider experiments.

The basic strategy for planning a new detector system can be broken down as: 1) decide on the fundamental physics goals, 2) assess available accelerator and detector technology, 3) determine the "real-world" resources of money and people, and 4) make the necessary choices for the detector design. Typical choices to be made include: the overall acceptance of the detector, the granularity of the detecting elements, the relative importance of particle identification (to resolve leptons and jets, for example), the materials and techniques to be employed as they relate to detector resolution and mechanical design, the bandwidth of the electronics system, and on and on. The collider study reports mentioned previously give many instructive examples of this process of arriving at detector hardware configurations from differing sets of physics priorities.

* Work supported in part by the U.S. Department of Energy

When the basic detector layout is settled, additional issues must be addressed. These are in the areas of data taking and analysis and include such major topics as triggering the apparatus, strategies for reconstructing events for subsequent analysis, software management, data summary formats, and data bases for the many parameters needed to describe fully the detector performance. Much of what follows pertains both to electron-positron colliders and to hadron colliders although there are significant differences. For example, the very high interaction rate at a hadron machine places special demands on triggering and event analysis strategies.

UNIFYING THEMES

There is broad agreement that experimental investigation of the 1 TeV mass scale is crucial to making progress in high energy physics. The justification for this energy scale will not be considered here. Rather, its adoption determines the basic scope of the detectors that will be required and the accelerator luminosities needed to collect enough events of interest. Most of the following discussion assumes that hadron colliders are the vehicles for achieving this energy scale, but many of the points also hold for electron-positron or electron-proton machines.

The second general theme is that the basic observables will be what they are at today's colliders, namely leptons, quarks, photons, and gluons. We argue that lepton and photon identification will become relatively more difficult in future colliders, while measurements of quarks and gluons should become somewhat easier.

The three kinds of charged leptons, e, μ, τ, are routinely identified and measured in various collider experiments. Establishing lepton signals is often crucial for separating rare signals from large QCD backgrounds. Rather standard and effective methods have been developed for identifying and measuring electrons and muons. They rely on precise tracking of the single charged particles in conjunction with information on the relative responses of layered detectors such as shower counters, hadron calorimeters, transition-radiation detectors, etc. Tau leptons are identified principally by their low-multipliciy, low-mass decay topologies. The key point here is that several different kinds of detector information must be combined to give positive lepton identification. This information can be compromised by overlapping particles, thus placing a high premium on excellent granularity and time-resolution. Because events are expected to become more complicated with increasing energy and because higher luminosities, with attendant higher collision rates, are required, we expect that single lepton identification will become very difficult in future colliders and will probably have to play a diminishing role in general-purpose detectors.

Single photon detection similarly becomes relatively more difficult as the energy and event complexity increase.

Neutrinos cannot be observed directly and indirect methods that seek an apparent imbalance in observed momenta are well developed. Clearly, such an approach is most effective when only one neutrino carries a large transverse-momentum relative to typical momenta in the event. The requirement to detect the presence of such neutrinos by measuring carefully the momenta of as many as possible of the other particles in an event can be a major factor in choosing the overall acceptance and detailed mechanical design of detectors. It would appear that these "missing-energy" techniques will remain viable at the next generation of colliders, but of limited usefulness because there are no practical longitudinal constraints and interpretation in the case of more than one energetic neutrino is difficult.

A major advance in high energy experimentation is the clean detection of quarks and gluons by hadron jets. While identities are virtually impossible to determine, the kinematic properties of jets become much easier to measure with increasing energy. An example of an ordinary two-jet event as observed by CDF at the Tevatron collider is shown in Figure 1. This figure displays the "natural" variables for describing jets, namely the energy detected in individual calorimeter cells or towers, weighted by $\sin\theta$ (the "transverse-energy"), plotted above the rapidity-azimuthal angle ($\eta-\phi$) coordinate of the cell. With this choice of variables, jet kinematics and fragmentation are quite simple. For example, jets are expected to be circular structures in $\eta-\phi$ space with typical radii that are approximately independent of the jet's rapidity, polar angle and energy. On average, the jet energy falling outside an $\eta-\phi$ radius of 1/2 - 1 units is of order a few GeV; the additional energy of higher energy jets tends to fall at ever smaller radii. Meanwhile, the average transverse energy coming from the underlying event in hadron collisions is typically a few GeV per unit area in $\eta-\phi$ space. Thus, when dealing with jets of energy of order 100 GeV or greater, the uncertainties introduced by fragmentation and the underlying event become of order a few percent, which is comparable to or less than the errors in the energy measurement, itself. One can imagine situations where energetic jets can be well measured even if several "minimum-bias" events are superimposed on the event of interest. Another way to visualize the clean emergence of high energy jets is to note that the invariant mass of observed jets scales roughly as $\sqrt{E_t}$. Relative to their energy, the invariant mass of a real jet diminishes with increasing energy so that it will appear more like the ideal massless jets of the theorists!

The third general theme to consider in planning future detectors is the tremendous advance taking place in the understanding of basic detector technologies. Perhaps the most significant illustration of this is the recent work on sampling calorimeters taking place at several laboratories.

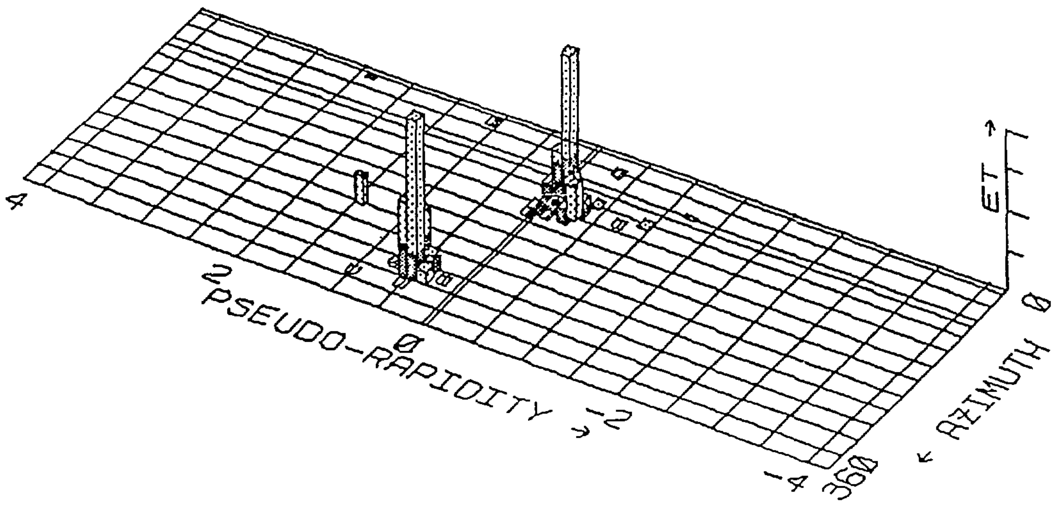

Figure 1. Example of a 2-jet event observed by CDF at the Tevatron. Calorimeter energies weighted by sin θ are plotted vertically over the corresponding η–φ coordinate. The transverse energy of each jet is about 100 GeV.

Hadron calorimeters have been very important experimental tools for over 15 years, but they have traditionally presented technical difficulties related to differing responses to pions and electrons of the same energy. This has led to relatively large uncertainties in measurements of hadron jets because of the inherently large fluctuations in the composition of jets between charged hadrons and neutral pions. The situation has changed dramatically in recent years through the deep understanding of the role of neutrons and other transport phenomena that has come about with the development of detailed simulation codes and careful test-beam studies. The relative electron-pion response depends, in detail, on the selection of materials in the calorimeter. Now one can confidently engineer the relative amounts of ionization sampling materials and the heavy, absorbing materials in a given calorimeter configuration. An overall system can be optimized even though other factors such as mechanical requirements, radiation resistance, charge collection time, and cost may dominate the design. Thus, what was once a black art has been raised to engineering practice.

In a similar way, great advances have taken place in tracking chambers. With the introduction of new electrode geometries, "image" chambers of various configurations are able to distinguish and measure precisely tracks in extremely complicated events. As with calorimeter design, much more elaborate and accurate computer modeling of tracking chambers now takes place before even prototypes are constructed; chambers are really being engineered! However, we must project a relatively more limited role for tracking chambers in future hadron collider detectors simply because of the overwhelming number of charged tracks that will be present in typical events recorded by general purpose detectors, especially at the highest luminosities. This is one of the principal reasons for the earlier comments on the relative difficulty of identifying leptons in future detectors.

Another area of detector technology that is seeing dramatic advances is in electronics. Custom designed integrated circuits are proving to be a very effective way to cope with the demands of very high performance in both analog and digital systems with very large numbers of channels. In several detector applications, powerful computer-aided design tools have been used successfully to develop new integrated circuits. These tools have actually reduced the development time for new systems even though the complexity and performance specifications are increasing substantially. The compact packaging provided by such large-scale integration often can solve what traditionally would be a mechanical and topological nightmare to connect detector components to the electronics and data acquisition systems. It is clear that "designing in silicon" will become even more important for future detectors.

SCOPE OF FUTURE DETECTORS

As demonstrated by the similarities between the various SSC and LHC studies, the themes outlined here lead to a fairly consistent picture for the scope of detectors that will be needed at future high energy colliders.

The first choice is overall acceptance. From general phase-space considerations, the heaviest systems that will be produced at measurable rates in either hadron collisions or through fusion processes in electron-positron collisions will have a spread in longitudinal motion corresponding to roughly 3-5 units of rapidity. Thus, to detect decay products of such objects with high efficiency, the detector should extend to within approximately 1° of the beam line. Full azimuthal coverage has been crucial in most collider experiments and will continue to be so.

The choice of granularity has enormous impact on costs and complexity because it largely determines the total number of channels and it can strongly influence the mechanical design. Granularity in the calorimetry is usually determined by the desire to isolate jets and leptons. Because of the approximate scaling in jet fragmentation, the granularity required of future calorimeter systems for jet studies will not differ significantly from present detectors. 400 cells per unit $\eta-\phi$ space is a typical, albeit somewhat luxurious choice that is made in the various studies. With something like 8π units of total acceptance, one is dealing with of order 10,000 total cells, each of which will have several channels of different detector information. Granularity in the tracking is largely determined by track multiplicity and will, therefore, grow considerably for future detectors if tracking goals remain as they are today. The electrostatic stability of wires may limit attainable granularities.

The scale size of a detector will probably be set in most instances by the physical size of calorimeter cells. It is pointless to build calorimeter cells that are much smaller in transverse dimension than the characteristic absorption length of the calorimeter material because of showers spreading to adjoining cells. When combined with the granularity, this determines the inner radius from the beam line of the calorimeter system. Typical radii are 1-2 meters. Clearly, there is a premium on using very dense materials in calorimeters so that the scale size can be minimized. If magnetic analysis is required, then this inner radius could grow. For example, to maintain the same relative momentum measurement error, the scale size of the tracking system must grow as the square root of the mass scale being studied. The problem is that the detector volume grows as the cube of the scale size! The thickness of the calorimeters must grow with increasing mass scale in order to contain hadron showers. This dimension also strongly affects the overall volume and, hence, the cost of the detector.

The point of this discussion is that from very general considerations of kinematics and the basic properties of materials, one can predict with reasonable precision the scope of detectors needed for the future large colliders. They will be somewhat larger and more complex than current detectors. The detailed studies indicate that typical linear dimensions will be roughly twice those of current devices. The problem is that the mass and volume will grow by an order of magnitude! While there will certainly be some economies of scale, the costs of these detectors will several times those of today's detectors.

Can we actually build these huge devices? Table 1 represents an attempt to address this question by looking at the historical progress in collider detectors. The "first" generation represents the first general purpose, large solid angle collider detectors. It is interesting to note that the time between when they were built and first operated to today's generation of detectors is approximately the same as that projected from now to first running of the SSC or LHC. ("Second" generation refers to PETRA and PEP detectors.)

Table 1. Comparison of Different Generations of Collider Detectors

Category	"First Generation"	"Third Generation"	"Fourth Generation"
Examples	Mark I, Pluto	UA-1,2 ,CDF, D0 LEP, TRISTAN	SSC, LHC
Year	~1973	~1985	~1997
Mass	few x 10^2 t	few x 10^3 t	few x 10^4 t
# Channels	10^3	10^5	10^6
Int. rate	1 Hz	10^4 Hz	10^8 Hz
Cost	m x 10^6 \$	m x 10^7 \$	m x 10^8 \$
Size of Collaboration	n x 10^1	n x 10^2	??!!

The principal message of this table is that we have come about as far from the first collider detectors to the present generation as we have to go in planning for the next generation of colliders. Note that the total costs have scaled with weight, while the single channel costs have diminished. As will be discussed, the scaling of interaction rate is not a simple matter. Also the sizes of collaborations implied by the Table give one reason to pause! Nevertheless, we can be reasonably confident about our projections of future detector needs and about our abilities to construct and operate successfully the new instruments. This is not to say, however, that there are no remaining challenges!

CHALLENGES FOR FUTURE DETECTORS

The huge event rates that are an inevitable part of experiments on hadron colliders present very real and serious experimental difficulties. It is believed that this problem can be mitigated by various technical means, but there will be costs. Attention will have to be paid to using radiation resistant materials. Very sophisticated electronics is needed. In some cases, the detector granularity can be increased to reduce instantaneous rates. In other cases, performance will have to be lowered if it is not absolutely required by the physics goals. R&D and operating experience are required to learn how to deal with these rates. Tracking systems are likely to be severely compromised by the very high rates.

Much more thought has to be put into planning for the overall data handling, event reconstruction, and offline analysis at the time the hardware is being designed. The software burden to analyze collider data is enormous; by thoughtful design of the apparatus, it must be possible to reduce this effort. For example, in most systems today, much of the detector information starts out as electric charge stored on capacitors distributed over the apparatus. The spatial relationships of these capacitors and charges is similar to the parent event. Then, those charges are digitized and placed into computer lists with similar information from the rest of the detector. The spatial relationships have been lost! Later, a complex computer program sorts through the lists and attempts to reestablish the relevant spatial relationships. This can be very costly in terms of software development and computer time. It would be very nice to preserve the spatial relationships by careful design of the detector hardware and electronics systems. This is an area of detector R&D that deserves attention.

System complexity is a very important challenge for detector builders. These are big, complicated devices. There is a fundamental problem of how to be sure the apparatus is working properly and, when it is not working, how to fix it. Failures directly impact the detected luminosity and can easily requires days to isolate and repair. Pedestals are a simple example; do they really reflect the quiescent state of the experiment? As more electronics is installed on these devices, the potential grows for subtle cross talk problems where asynchronous digital signals flow near very sensitive analog electronics. Calibration is always difficult, especially at hadron colliders where there are no natural calibration signals. Can more clever ways be found to use the underlying data to help with calibration? Data acquisition and online systems are notoriously complex. Usually only two or three experts really understand these systems; if they are out of town, it can be frightening to be on shift!

Perhaps the biggest challenge facing us is in the area of sociology. Consider the author page on the discovery paper of the W; it has more than 100 names on it and, today, it is considered to be a small experiment! For the CDF we managed to come up with a word processor that puts twice as many names in the same space, hardly a satisfactory solution! What concerns me here is not how we function ourselves, but how we are viewed by our scientific colleagues. I am convinced that the processes by which individuals do physics within these large collaborations are working quite well. In some sense, these detectors are laboratories, themselves. They address many different physics topics with a diverse group of people having a broad range of strengths and capabilities. Typically, detector collaborations are organized in such a way that different institutes assume particular hardware and software responsibilities. Then individuals from those institutions pursue physics topics of interest to them, often joining like-minded colleagues from other institutions. There is usually a very lively literature in the internal notes of the collaboration. This is a good system. However, there is a problem in our relationship with other scientists. When we present our work outside high energy physics, we have not been able to convey the true working relationships and individual contributions. We must do better.

A related issue is the small number of large detectors. We all depend on the success of these devices. What is a little disappointing is that we lose the possibility to fail; we become too conservative. The definition of an expert is the one who has made the most mistakes. We need experts to build the future detectors! Perhaps, in detector R&D studies we can be much more aggressive and take the chances required to become experts.

Another very difficult problem, both technical and social, is how to insure proper access to the data. This involves subtle and difficult communication problems related to software management, quality control of the data, and calibration data bases. It is exacerbated by the broad geographical distribution of large detector collaborations and computing resources.

The next point concerns critical review of experimental results. It is extremely difficult for physicists outside a collaboration to make critical assessments of new results. Fortunately, there is still sufficient overlap in the capabilities of detectors so that when a startling result is announced, several other groups will soon attempt to confirm it. This fundamental system of checks and balances cannot be sacrificed in the move to small numbers of large detectors. On the other hand, the conservatism inherent in this system of large authorships may inhibit individual creativity and we might lose a radical new discovery. Here, again, we need to devise mechanisms for individuals to extend themselves and have the chance to fail (honestly!).

I would like to end with a modest suggestion on how we might modify the way we acknowledge contributions to these large detector experiments. It is intended to promote discussions in the community; I do not expect to see it actually implemented in this form. First, we must recognize that insuring the quality of the data is of paramount importance. For this reason, individuals who are principally responsible for the apparatus will always be central to any experimental analysis and it is altogether fitting that they be authors even if they are not able to defend completely the details of a particular analysis. Where I would suggest modifying the current practice of listing all authors alphabetically, would be on papers that involve "follow-up" analyses of data that have been reported on previously. The group could declare a period of "initial use" of new data (say two years) where all authors are automatically listed on all papers using the new data. Following the period of initial use, the group could go over to the system used by a few groups of "lead authors", where the individuals primarily responsible for the particular analysis are listed at the beginning of the author list. I would further suggest that other persons desiring to be on the author list of a paper published after the period of initial use would have to request it; authorship would no longer be automatic. It would be important to guarantee that any qualified collaboration member requesting to be placed on the author list would be listed without question. On the other hand, I would hope that senior members not directly involved with the analysis being reported would refrain from being listed as an author. In this way, individuals knowledgeable in the detailed analysis can be identified by outside readers and we can reduce the size of some of our papers. There are strong feelings on these issues; each collaboration will have to deal with them in their own way. I think it is a mistake to ignore these issues, however.

Future Facilities and Projects under Design

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SSC PROJECT STATUS

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INTRODUCTION

The expectation that new phenomena crucial to understanding the fundamental interactions must occur at the 1 TeV energy scale [1] motivates the proposed SSC, a proton-proton collider with 20 TeV beams and $10^{33}cm^{-2}s^{-1}$ luminosity. Three years of research and development—on the basic dipole magnets, quench protection, correction elements, superconductor strand and cable, cryogenics, accelerator physics, and conventional facilities—culminated in March 1986, in a detailed conceptual design. This demonstrated the technical feasibility of the venture and provided the basis for the decision to proceed with the SSC by the United States Department of Energy and, subsequently, by the President of the United States. Research and development of the magnet system has been pursued vigorously. Both short and long model magnets have been built to test design modifications. The first three long model magnets to be tested met thermal, mechanical, electrical, and quench protection criteria, and showed encouraging field strength results. Further work on beam dynamics led to the decision to change from a 60° phase advance per cell to 90°. To support the evolution of detector technology, an international advisory panel has been formed to evaluate proposals and keep track of progress on those that have been funded. More than thirty qualified sites have been proposed and are being evaluated. In addition to the Administration's appropriations requests, an authorization bill with 254 co-sponsors, HR 3228, has been reported out of the House Space, Science and Technology Committee.

The Department of Energy has announced that it will seek to share the cost of the SSC with all interested countries.

CHRONOLOGY

The germ of the SSC formed at the ICFA Workshops on Future Accelerators of 1978 and 1979, where several ideas for higher energy accelerators were discussed. The idea was further developed at the Division of Particles and Fields of the American Physical Society Workshop in 1982, where it became clear that to go beyond the Standard Model required hard collisions with sub-energies greater that 1 TeV, and that a multi-TeV hadron collider could be built using the superconducting magnet technology that had been newly won at the Tevatron.

In 1983, workshops at LBL, Cornell University, and the University of Michigan addressed the physics, accelerator, and detector issues associated with such a collider. In the summer of the same year, the High Energy Physics Advisory Panel, which advises the United States Department of Energy (DOE) on particle physics research, unanimously recommended to the DOE that research and development begin immediately, with the goal of realizing multi-TeV hadron collisions at high luminosity as soon as possible. In response, the DOE reprogrammed FY84 funds into SSC magnet research and development.

The following year, a group sponsored by DOE and the directors of the national high-energy physics laboratories prepared a Reference Designs Study, in which three possible designs for the SSC were developed and compared. The completed report was described at the first of these ICFA Seminars, held at KEK. Based on the conclusions of the Reference Designs Study, the DOE contracted the SSC research and development program with the Universities Research Association, a consortium of 56 research universities. The SSC Central Design Group was established, accepted the hospitality of the Lawrence Berkeley Laboratory, and began work on a conceptual design. It is a great pleasure to acknowledge the significant contribution of European, Japanese, and Canadian individuals and institutions, both to the conceptual design, and to the research and development that supported it.

The completed Conceptual Design Report [2], some 700 pages with another 2000 pages of attachments, details the scientific, technical, and cost aspects of the SSC. It was issued in the spring of 1986, and it became one of the bases for President Reagan's approval of the SSC project in January of 1987.

BRIEF DESCRIPTION

The SSC is conceived as a proton-proton collider with 20 TeV protons in each beam and a luminosity of $10^{33} cm^{-2} s^{-1}$. Magnets 16.6 meters long, with niobium-titanium superconducting coils, provide the magnetic bending field of 6.6 T. The circumference of the main ring is about 85.7 km. Because the tunnel (3 m inside diameter) is 10 m or more underground for reasons of radiation protection and thermal stability, the only surface evidence of the facility around most of the circumference will be refrigeration/power service units every 8.4 km and much smaller ventilation and emergency personnel exits in between them.

Major facilities are clustered in two regions, an advantageous arrangement with respect to beam optics and convenience of access to experimental areas. The total length of experimental and utility regions is almost 11 km.

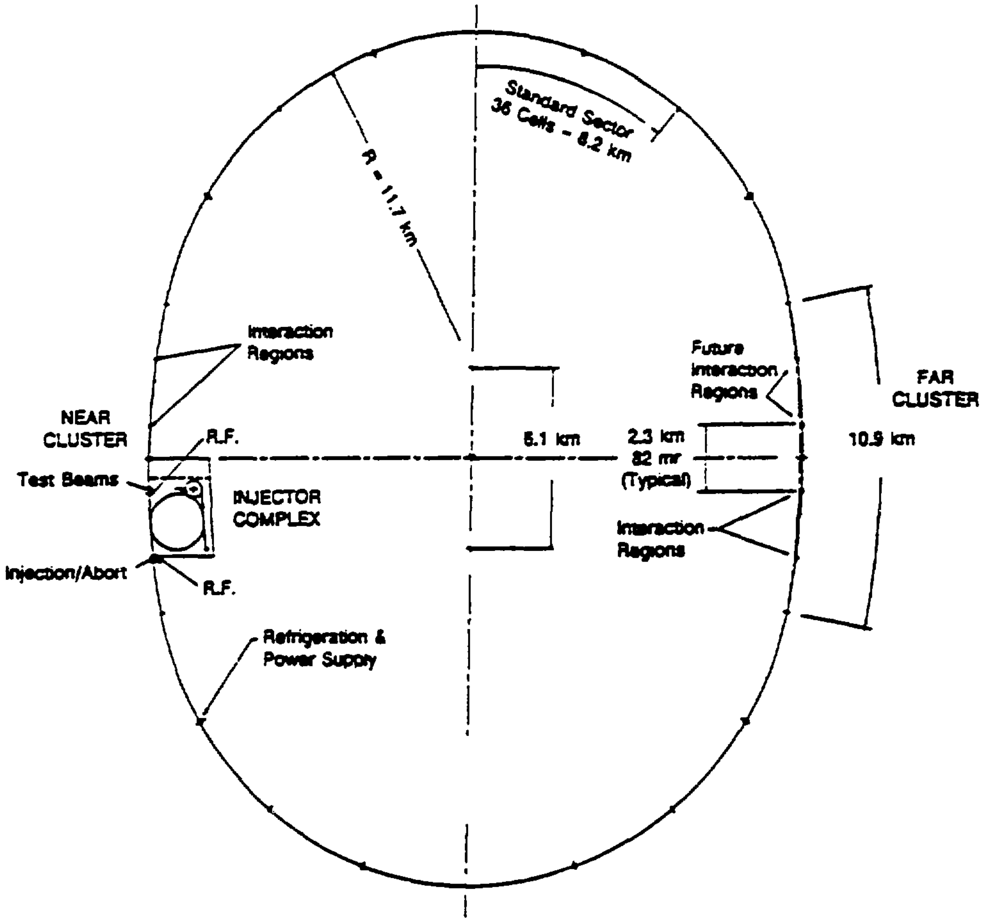

Figure 1. Schematic layout of the SSC.

The near cluster (left side in Figure 1) comprises two low-beta interaction regions, two straight regions for injection and abort equipment, and the rf system. The campus area is planned nearby. The cascade of four accelerators that make up the injectors will be adjacent to the straight sections. Negatively charged hydrogen ions are accelerated to 600 MeV at 10 Hz in the first part of the injector complex, a linear accelerator. An 8-GeV synchrotron pulses at the same rate. From there the protons are injected into a 100-GeV ring with a 4-second cycle. The protons are then fed into the large injector with a 60-second cycle that boosts the beams to 1 TeV, with a circulating beam current of about 87 mA, and finally are sent to the main ring.

Four interaction regions, set 2.3 km apart, make up the far cluster (right side in Figure 1). A relatively large bend angle (87 mr) prevents particles produced in the forward direction in one interaction region from entering adjacent regions. Two of the four interaction regions will initially be developed (with medium beta).

The cryogenic system is divided into ten sectors. A refrigeration plant in the center of each sector circulates liquid helium and nitrogen in a continuous path, 4 km in each direction. Each plant is connected to the adjacent systems to provide redundancy in case of a malfunction.

CONCEPTUAL DESIGN STATUS

Since March, 1986, when the Conceptual Design Report was published, the design has changed from a phase advance of 60° per cell to 90°. The design of the lattice has been revised accordingly. The low-beta interaction regions have $\beta^* = 0.5$ m with ±20 m free space; the medium beta interaction regions have $\beta^* = 10$ m and ±120 m free space.

The machine provides about 10^8 events per second at the high-luminosity interaction areas, achieved through an inelastic collision rate of about 1.7 per bunch-bunch encounter. Each bunch, which contains 8×10^9 protons, is 14 cm long and has an approximately circular cross section of $10\,\mu$ diameter as it passes through an interaction region. In the present design, the 20,000 bunches in the machine are separated by 5.1 m, although this distance could be made smaller or much larger. The stored beam energy is 405 MJ per beam. The small required emittance is commensurate with existing technology. Each beam radiates a synchrotron power of almost 10 kW, which gives a damping time for synchrotron oscillations of 12.5 hours. It is believed that this will actually be useful in maintaining the luminosity lifetime of the machine. Beam lifetime is determined principally by proton loss from inelastic collisions at the interaction regions.

MAGNET STATUS

The superconducting magnet program has dominated the research and development effort. In FY85 a high-field, conductor-dominated magnet was selected for future development into the SSC magnet. The cross section of the conceptual design of the SSC magnet is shown in Figure 2.

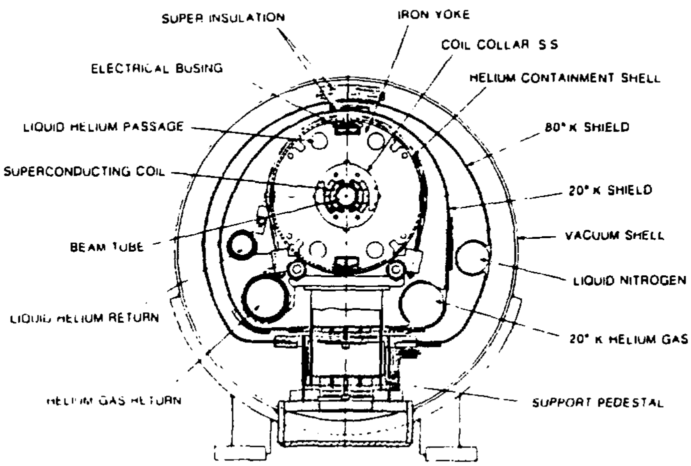

Figure 2. Cross section of the SSC dipole magnet and cryostat assembly.

The beam tube, two-layered coils, collars (which might be aluminum or stainless steel), and iron yoke can be seen in the upper center. The diameter of the iron yoke is approximately 27 cm. It is surrounded by the 20 K shield, the 80 K shield, and the outer stainless steel vacuum shell, which measures 61 cm in diameter. The re-entrant support post uses graphite fiber composite material and a special design to minimize the heat leak into the system. Running the refrigeration system compressors requires about 30 MW, comparable with the operating power of today's major laboratories.

Both short and long model magnets have been built (1 m at LBL, 1.8 m, 4.5 m, and 17 m at BNL) and tested at LBL, BNL, and Fermilab. The first three full-scale magnets and cryostats to be tested met thermal, mechanical, electrical, and quench protection criteria. The first two long models achieved 85 percent of full field. The third long magnet, with improved coil clamping, reached a stable plateau field above 6.8 T, albeit with twelve training quenches.

An intense program of magnet construction and testing is planned for FY88. Among the issues to be focused on are training and magnet stability as influenced by conductor stabilization, coil end support, and overall coil prestress. Test results will provide information that will be used in magnet assembly modifications.

Other major efforts include production improvement of the support system for the "cold mass" (beam tube, collared coil assembly, and iron yoke; see Figure 2) within the cryostat and the detailed design of the cryogenic system.

STATUS OF OTHER EFFORTS

The influence of synchrotron light on beam tube design continues to be investigated. The backgrounds of neutrons and other radiation in the tunnel are being studied at Fermilab. The effect of radiation on quench-protection diodes is being investigated at TAC.

Accelerator physics efforts include experiments with the Tevatron to check some of the aperture calculations of the conceptual design study. Improvements to the interaction region optics have been developed, and changes in the lattice to allow bypasses to be constructed are also being examined.

To allow laboratories and universities to pursue detector ideas independently, yet preserve a sense of direction toward goals necessary for the SSC to succeed, a coordinating office at the SSC and an international advisory panel have been established. A group with a proposal for detector research and development pertinent to the SSC submits it to the usual funding agencies. The proposals are then forwarded to the coordinating office for assessment and recommendation by the advisory panel. The panel held its first meeting in April 1987 and recommended that work on basic detector technologies, integrated circuit development (for drift chambers, calorimeters, and silicon strip devices), signal processing (drift chambers and calorimeters), scintillating fibers, pixel detectors, radiation damage, and simulation techniques be funded.

SITE SELECTION AND FUNDING STATUS

While the Central Design Group's research and development program proceeds, the DOE is moving ahead with site selection and the Congressional budget process.

The publication of an Invitation for Site Proposals on 1 April 1987 marked the beginning of the site selection process.

The schedule published at that time is shown in Figure 3.

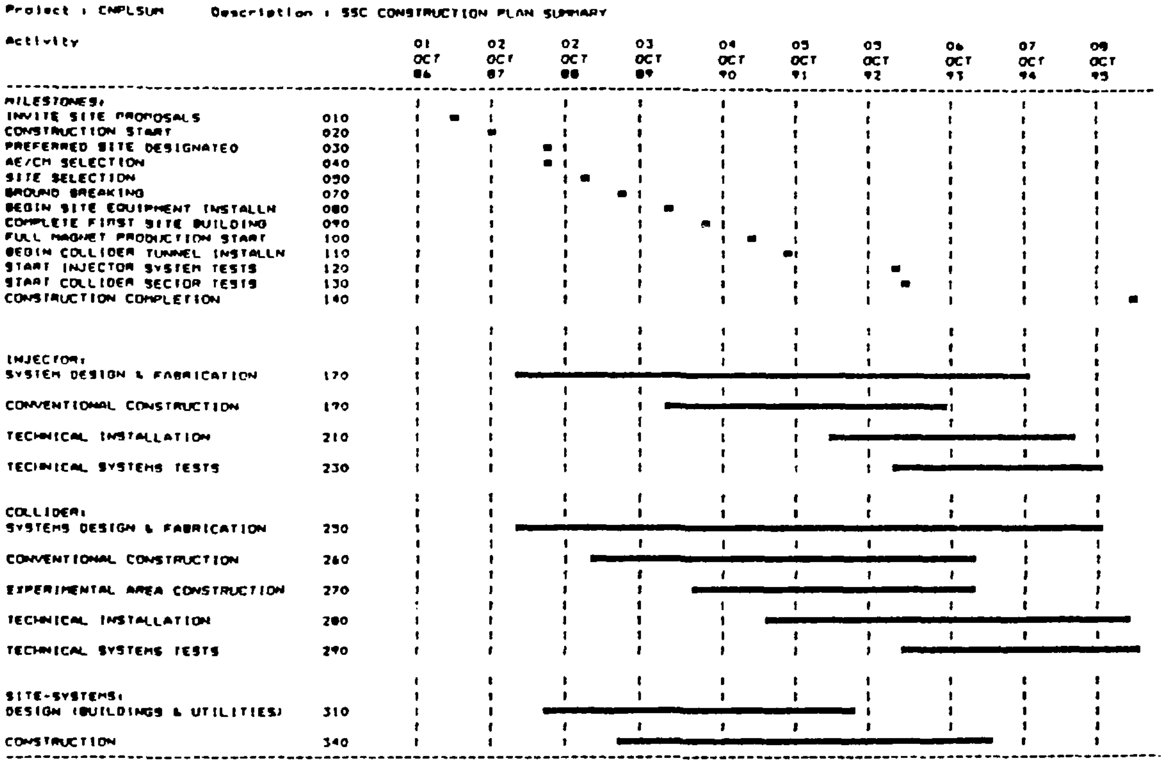

Figure 3. SSC construction schedule as proposed by the United States Department of Energy on 1 April 1987.

The DOE has determined that the proposals for the more than 30 sites shown in Figure 4 meet the minimum requirements. A distinguished panel appointed by the National Academies of Sciences and of Engineering is scheduled to evaluate the proposals this fall and to list, without ranking, an unspecified number of the best qualified sites. DOE reviews of this short list, designation of the preferred site, and environmental reviews are to take place in calendar year 1988. It is hoped that the final

Figure 4. Locations of proposed SSC sites that meet minimum requirements.

site will be announced in January, 1989.

As a consequence of the President's endorsement, funds for research and development and for construction were included in the Administration's FY88 budget request to Congress. In addition, 254 members of the House of Representatives have co-sponsored an authorization bill for $35 million for the FY88 SSC program ($25 million for research and development and $10 million for initial construction activities) and "such sums as may be necessary for fiscal year 1989 and subsequent fiscal years." Two hundred eighteen is just more than half of the membership of the House of Representatives, so that if the bill comes to the floor and all the co-sponsors vote for it, its passage is assured.

A detailed cost estimate was part of the conceptual design effort. The total cost of civil and technical construction of the accelerator and its laboratory is $3 billion in 1986 currency. That amount is allocated as shown in Table I. The technical components (magnets, cryogenics, the injector, interaction regions, power supplies, etc.) represent about $1.4 billion, just less than half. Conventional structures (tunnels, service buildings, the central laboratory, roads, etc.) come to slightly less than $600 million. Engineering for both technical and conventional systems is estimated to be about $288 million, and management and administrative support come to just under $200 million. $530 million has been added to cover contingencies.

Table I. Projected construction costs of the SSC machine and laboratory in thousands of 1986 U.S. dollars.

SSC Component		Projected Cost (Thousands of U.S. FY86 Dollars)
Technical components		1,424,161
injector systems	189,252	
collider ring systems	1,234,909	
Conventional facilities		576,265
site and infrastructure	85,433	
campus area	42,860	
injector facilities	39,758	
collider facilities	346,803	
experimental facilities	61,412	
Systems engineering and design		287,607
EDI	195,404	
AE/CM services	92,203	
Management and support		192,334
project management	114,749	
support equipment	52,635	
support facilities	24,950	
Contingency		529,951
Total		3,010,318

INTERNATIONAL PARTICIPATION IN THE SSC

The international aspect of the SSC, as contemplated by the Administration, was announced by the DOE on 10 February 1987:

> The Department of Energy will seek cost sharing for the Superconducting Super Collider with all interested countries. Such cost sharing could take the form of in-kind contributions such as magnets or detectors. International interest in the possibility of contributing to the super collider has been expressed specifically in the on-going discussions with the seven other Nations of the Economic Summit. It also has historical precedents....
>
> A statement from the Summary conclusions of the Economic Summit Working Group meeting in 1983 concerning the super collider is significant:
>
> "Participation of other countries in the construction of [this] accelerator could be envisaged. As is the usual practice in high energy physics, it is anticipated that scientific research will be open to qualified scientists from all countries, with the different countries contributing to the cost of the experimental detectors."

ACKNOWLEDGMENT

The essential help of K. Metropolis in preparing this report is gratefully acknowledged.

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THE LARGE HADRON COLLIDER IN THE LEP TUNNEL

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INTRODUCTION

At its session of June 1987, the CERN Council received preliminary conclusions of two important Committees whose tasks were to define the medium and long-term future of CERN.

The CERN Long Range Planning Committee chaired by Prof. C. Rubbia, having to deal with the future of High Energy Physics, pointed out that new physics can be expected in collisions involving energies of the order of 1 TeV at elementary constituent level. It recommends the construction of a Large Hadron Collider of 2x8 TeV protons in the existing LEP tunnel allowing also electron-proton collisions with a centre-of-mass energy $\sqrt{s}$ = 1.3 to 1.8 TeV [1].

The CERN Review Committee chaired by Prof. A. Abragam, whose task was to make a full in-depth examination of CERN, noted that 'for the next ten years CERN seems well set to provide the majority of its users with first-class facilities' and that ' there is broad agreement within CERN-linked scientific community .... on the long-term interest of planning the construction of a machine with an energy of the order of 1 TeV at the constituents level' [2].

Therefore this paper gives a summary and an up-dated version of the studies for the CERN Large Hadron Collider (LHC), as presented last June to the CERN Council [3]. It first outlines the main interesting features of LHC and gives the performance predictions; then the three major items, the lattice, the superconducting magnets and the cryogenics are briefly described; finally one considers if possible limitations could come from the existing injector or from collective effects and if LEP and LHC are compatible with an efficient exploitation of the two machines.

* Also presented at the CERN Accelerator School, Berlin 14-25 September, 1987

LHC MAIN INTERESTING FEATURES

One of the most interesting features of LHC is certainly the fact that the energy and luminosity requested by such a new machine can be reached by using important facilities already existing at CERN.

CERN is building LEP, a 27 km ring for electron-positron collisions, initially at 50 GeV per beam, to be later increased to 100 GeV.

The same basic infrastructure (tunnel, injectors, conventional facilities, etc.) can be used for the addition of a twin aperture proton ring made of superconducting magnets.

The tunnel circumference was chosen in 1981 as large as possible, compatible with local geological structure, not only to reach an electron beam energy of ~ 100 GeV under optimal conditions but also the highest possible energy for the proton beam.

The existing CERN complex of accelerators (Linacs, Booster, PS and the 450 GeV Super Proton Synchrotron - SPS) is already the injector chain of LEP. It will also become the injector for LHC. Since it can fill both LHC rings in a few minutes and since the ramping time of LHC is only 20 minutes, frequent fills of LHC are possible, resulting in an average luminosity very close to the peak luminosity.

LHC in the same tunnel as LEP allows collisions between different types of particles : proton-proton collisions up to 16 TeV in the centre-of-mass would become available in the LEP tunnel. In addition it would be possible to collide one of the proton beams with the electron beam of LEP at centre-of-mass energy between 1.3 to 1.8 TeV.

The SPS can also provide ions as well as protons, where they can be accelerated to an energy per nucleon equal to half the energy of the protons, which would open up a new field of research. For example, the luminosity for O^{8+} collisions is expected to be $L = 2.5 \times 10^{26}$ $cm^{-2}.s^{-1}$ at a centre-of-mass energy of 128 TeV. This estimate is based on the present performance of the injector chain, but substantial improvements may be expected in the years to come, resulting eventually in a much increased ion-ion luminosity in LHC with a possible extension to heavier ions.

LHC can operate at different high luminosities depending on the needs of the experiments. Its nominal luminosity (1.42×10^{33} $cm^{-2}.s^{-1}$) is based on a bunch spacing of T = 25 ns and on the number of protons per bunch $N_p = 2.6 \times 10^{10}$, so that the beam-beam limit is just reached. With this luminosity the average number of events per crossing is <n> = 3.55. For those experiments which cannot operate with such a value of <n>, the luminosity can be reduced by a factor 4 by increasing the β at the relevant crossing points. To reach lower values, the machine must be operated at reduced beam intensity.

For special experiments that can cope with a higher number of events per bunch and/or a smaller bunch spacing, a luminosity of 10^{34} $cm^{-2}.s^{-1}$ can be expected. Indeed the compactness of the machine and its aperture ensure that very high luminosities can be obtained.

Since the circumference of the LHC orbit is fixed by the LEP tunnel, one must obtain in the guiding dipoles a magnetic field as high as possible because it determines the top energy. Therefore the nominal field is chosen to be 10 T. For p-p collisions it allows two proton beams of 8 TeV circulating in opposite direction in two separate magnetic channels, distant horizontally by 180 mm and 0.9 m above the median place of LEP (Fig. 1).

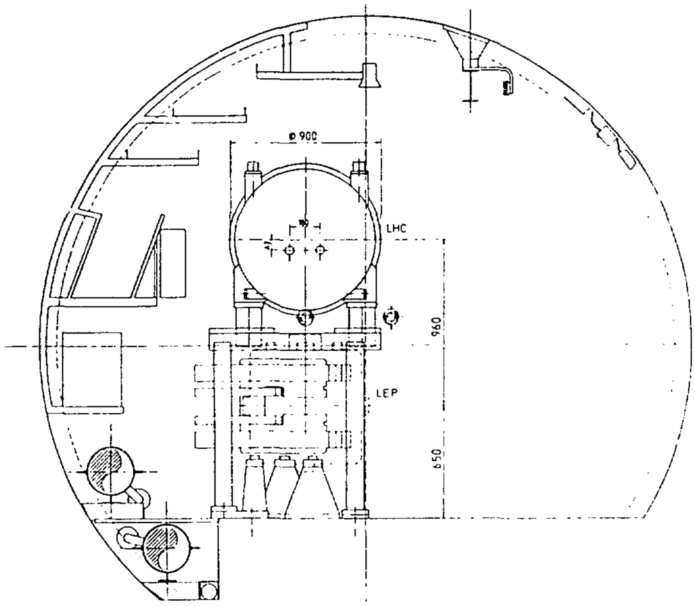

Fig. 1. Regular LEP tunnel cross-section with an LHC dipole cryostat above LEP

The superconducting coils providing equal but opposite magnetic fields have a common iron yoke and force-retaining structure, the whole being housed in one cryostat. This 'two-in-one' solution (Fig. 5) allows the highest possible field in the restricted space above LEP, which has not only the advantage of compactness but also of low cost, compared with that of two independent rings with separate cryostats. The required current density and magnetic field of 10 T can be reached either by a NbTi conductor operating at 2 K and cooled by superfluid He II or by a Nb_3Sb conductor operating at 4.2 K, both technologies seeming attainable and economically feasible provided a vigorous R&D programme is undertaken. A close look is also given at the rapid evolution of the high T_c superconductors.

PERFORMANCE PREDICTIONS

Proton-Proton performance

Apart from the beam energy, the most important parameter from the user's point of view is the luminosity L given by :

$$L = N_p \; f \; k_b/4\pi\sigma^2 \qquad (1)$$

Here N_p is the number of particles per bunch, f is the revolution frequency, k_b is the number of bunches in each beam and σ is the r.m.s. beam radius at the crossing points.

Experience at the CERN SPS has shown that an upper limit for N_p is given by the beam-beam tune-shift, where betatron resonances of order 12 or less produce a significant diffusion of large-amplitude particles into the tails of the beam distribution. This leads to losses which decrease the useful beam life-time and create background in the interaction regions. It can be avoided only if the tune spread ΔQ in the beam is smaller than about 0.02. For k_x interaction regions, the total tune-shift experienced by low-amplitude particles is $\Delta Q = k_x\xi$, while large-amplitude particles suffer almost no tune-shift. ξ is called the beam-beam tune-shift parameter. Dividing the total permissible tune spread equally between the beam-beam effect and all other phenomena causing a tune spread, and assuming that there will be 4 pp interaction regions, the maximum permissible beam-beam tune shift becomes

$$\xi = 0.01/4 = 2.5\times10^{-3} \tag{2}$$

which will be used as the standard design parameter.

For round beams at crossing point $\xi = N_p r_p/\varepsilon$, where r_p is the classical proton radius and ε is the normalized emittance defined by

$$\varepsilon = \gamma\ 4\pi\ \sigma^2\ /\ \beta^* \tag{3}$$

β^* being the beta value at the crossing point and γ being the usual relativistic factor.

Combining these equations, the luminosity becomes :

$$L = f\ k_b\ \gamma\ \varepsilon\ \xi^2\ /(r_p^2\ \beta^*). \tag{4}$$

However the average number of events $\langle n\rangle$ in a single beam-beam collision and the bunch spacing in time units T_x are also parameters of considerable interest for the experiments. They are related to the total pp cross-section, $\Sigma = 100$ mb, by the following equation which shows that it is impossible to impose conditions simultaneously on L, $\langle n\rangle$ and T_x :

$$\langle n\rangle = \Sigma\ L\ T_x = \Sigma\ L/(k_b\ f) = \Sigma\ \gamma\ \varepsilon\ \xi^2/(r_p^2\ \beta^*)\ . \tag{5}$$

The lower limit of the emittance given by the injector chain is $\varepsilon = 5\pi$ μm. The corresponding beam-beam tune-shift limit with 4 interation regions is obtained with $N_p = 2.56\times10^{10}$. Choosing $T_x = 25$ ns, $\beta^* = 1$ m, $k_b = 3564$ (maximum number compatible with the LHC, SPS, CPS circumference ratios), one gets $L = 1.42\times10^{33}$ $\mathrm{cm^{-2}s^{-1}}$ and $\langle n\rangle = 3.55$. These values are now considered as the basic parameters of LHC and correspond to a stored energy of 117 MJ for one beam of 8 TeV and a synchrotron radiation of 3.93 kW for both beams.

The upper limit of the emittance is given by the dynamic aperture of LHC which has been fixed as 20 πμm for ep performance. By increasing N_p accordingly, L and $\langle n\rangle$ are increased. A substantial increase in luminosity is also conceivable for special experiments that can cope with a higher $\langle n\rangle$ and/or a smaller T_x; β^* can be smaller than 1 m, T_x can be reduced for special runs and N_p could be correspondingly increased. It appears reasonable to assume that a luminosity of 10^{34} $cm^{-2}.s^{-1}$ can be achieved in runs for special experiments by applying a suitable combination of the measures enumerated above.

Electron-proton performance

With two machines in the same tunnel, it will be possible to collide the electrons of LEP with the protons of one of the LHC rings. The electron beam is deviated upward and made to collide head-on with the proton beam of 8 TeV.

Adequate RF power is available from the LEP RF system to compensate the synchrotron radiation losses for an average circulating current of 5 mA at 100 GeV. This corresponds to the highest centre-of-mass energy of 1.8 TeV. Assuming that the electron beam current scales as E^{-4}, it would lead to 80 mA at 50 GeV where the centre-of-mass energy is reduced to 1.3 TeV ($E^{0,5}$ scale).

The smallest bunch spacing must be a multiple of the LEP and the SPS RF wave-lengths. This is possible to a maximum of 540 bunches in both beams where the bunch spacing becomes 164.8 ns (49.4 m). With 3 interaction regions the beam-beam tune-shift limit is not reached for a number of electrons per bunch $N_e = 8.2 \times 10^{10}$ and a number of protons per bunch $N_p = 3.0 \times 10^{11}$ with an increased normalized proton emittance $\varepsilon = 20$ πmm.mrad. In these conditions with a proton energy of 8 TeV and an electron energy of 50 GeV, the nominal luminosity is 2.7 10^{32} $cm^{-2}.s^{-1}$.

LATTICE

The design of LHC in the LEP tunnel imposes several constraints :

- both machines must have a periodicity 8 (8 arcs and 8 straight sections),
- the average curvature of LHC and LEP must be very similar in order to avoid radial translations of more than a few tens of mm between the orbits of the two machines,
- because of the two-in-one magnet design with horizontal beam separation in the arcs, and because the colliding beams are bunched, the circumference of the two LHC rings must be rigorously the same. This is achieved by changing from the outside arc to the inside arc (and vice-versa) 8 times around the

circumference, thus maximizing the number of possible interaction points (Fig. 2),

- the insertions are designed for round beams with equal values of the horizontal and vertical β-functions at the interaction points.

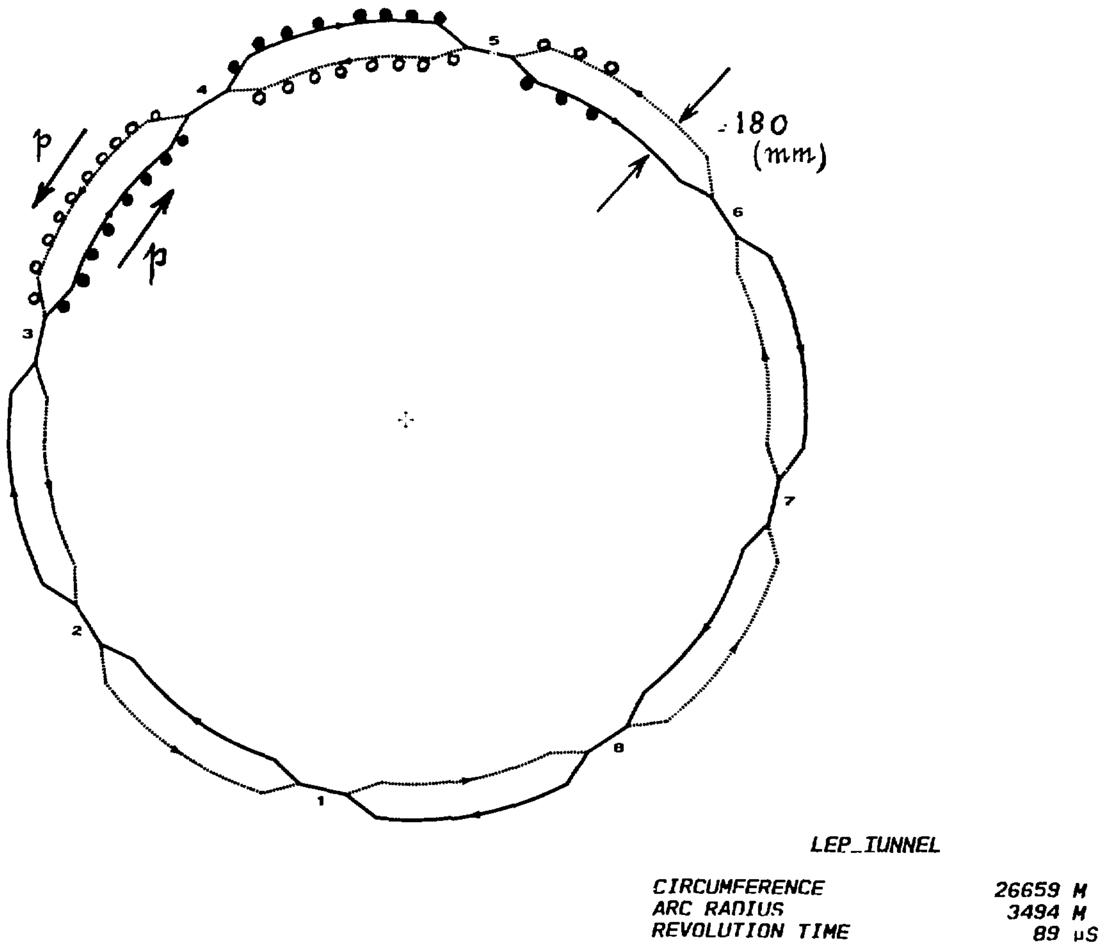

Fig. 2. Schematic layout of pp collider with two magnetic channels.

An antisymmetric design has been chosen with 49 half-cells per octant. A phase advance of 90° per cell has been chosen because, at a given cell length, the dynamic aperture is higher than with 60°. A cell length of 100 m results from a compromise between the dynamic aperture decreasing with the cell length, mainly when the high-order multipole components of the bunching magnets are added, and the maximum beam energy which increases with the dipole length for a given dipole field.

The low-β insertions for pp collisions contain a drift space of $\pm$ 20 m for the detectors, a triplet for focussing the beams down to $\beta^* = 1$ m in both planes, and groups of separating magnets to obtain the horizontal separation of 180 mm between the two beams. A sequence of drift space and four quadrupoles allows for adjusting the phase advances through the insertions, and finally the dispersion suppressors match the orbit parameters to the values at the entrance of the arcs. (Fig. 3).

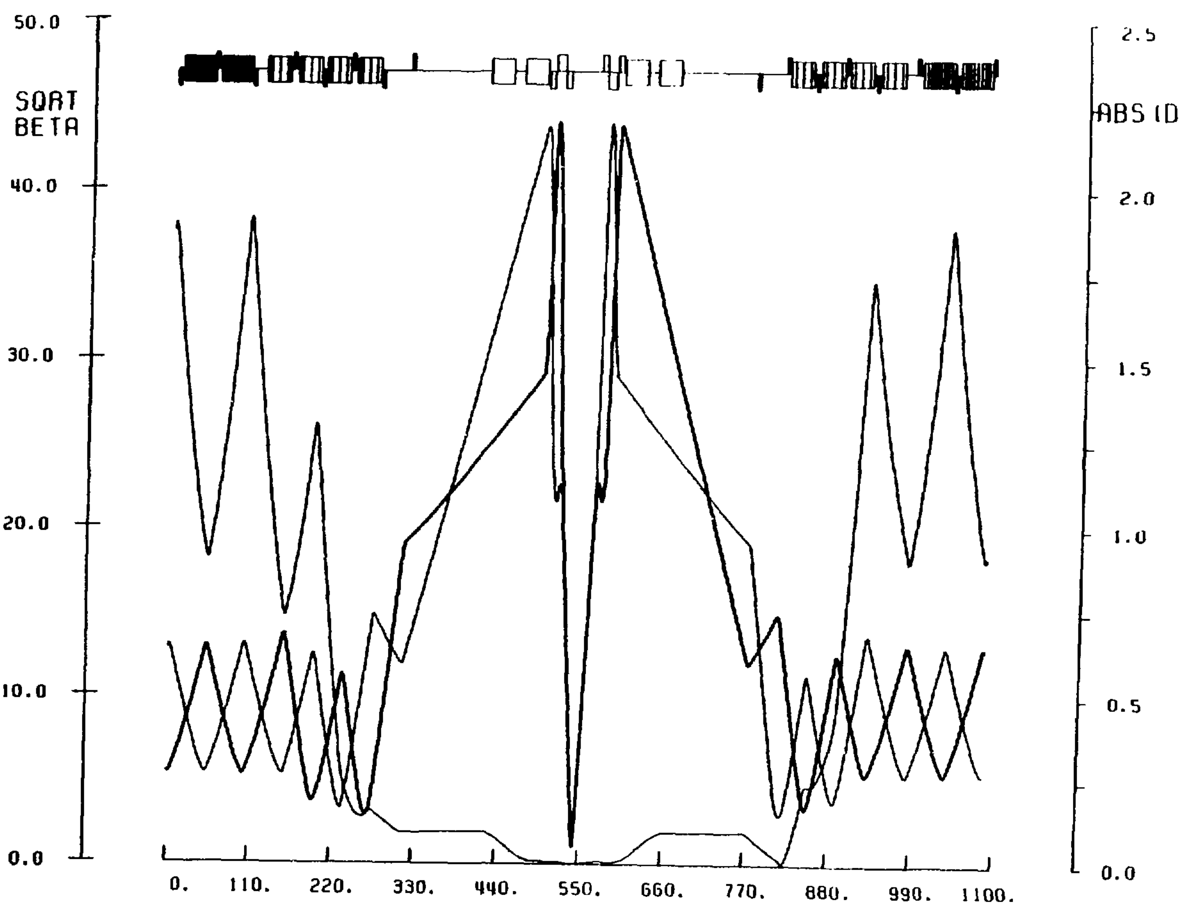

Fig. 3. Schematic layout and optics of low-β insertion providing $\pm$ 20 m free space; $\beta^* = 1$ m.

About 24 km out of the 27 km long LHC ring, will be occupied by superconducting magnets of various types, and the so-called machine "regular cells" are repeated periodically around the ring covering approximately 20 km of the circumference. One half of a regular cell (Fig. 4) consists of four ~ 10 m long, dipole magnets (D), a focusing quadrupole magnet (Q), a tuning quadrupole (TQ), a combined sextupole/dipole corrector magnet (S+DC) and a beam observation station.

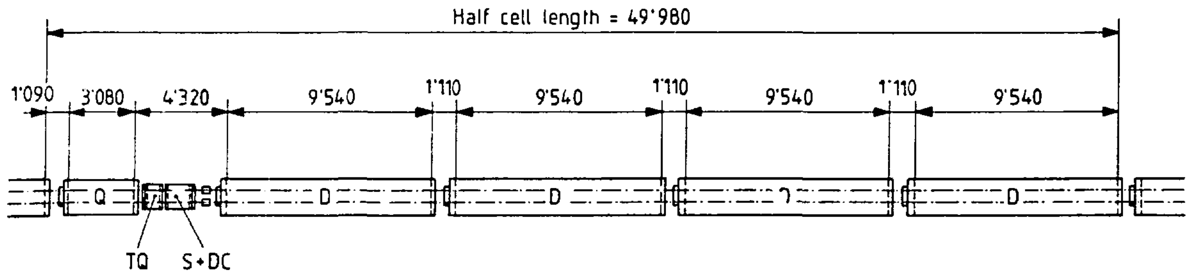

Fig. 4. LHC regular cell

All these magnets are superconducting. Their approximate number and main characteristics are given in Table 1.

Table 1 - General characteristics and number of magnets

	Strength	Length		Number of magnets
Dipoles	95.4 Tm	10 m	$B_0 = 10$ T	2 x 1760
Quadrupoles	770 T	3.5 m	$G = 250$ T/m	2 x 568
Tuning quadrupole	86 T	0.9 m	$G_2 = 120$ T/m	796
Sextupole	4000 T/m	1.3 m	$\frac{d^2B}{dx^2} = 3640$ T/m^2	796
H corrector dipole	1.5 Tm	1.3 m	$B_0 = 1.36$ T	398
V corrector dipole	1.5 Tm	1.3 m	$B_0 = 1.36$ T	398

The most significant and technologically difficult elements are the dipoles, of which a cross-section can be seen in Fig. 5, showing the 10 T, NbTi, 2 K version. The superconducting coils, providing equal but opposite field in the two beam channels are mounted inside a common iron yoke and force retaining structure, the whole being housed in one cryostat. This solution results in a compact and economical construction.

The present design is based on the following :

- Field range : 8 to 10 T
- Inner coil diameter : 50 mm - Inter-beam distance : 180 mm
- Use of NbTi conductor at 2 K, or of Nb_3Sn at 4.5 K
- Two-shell coils with graded current density.

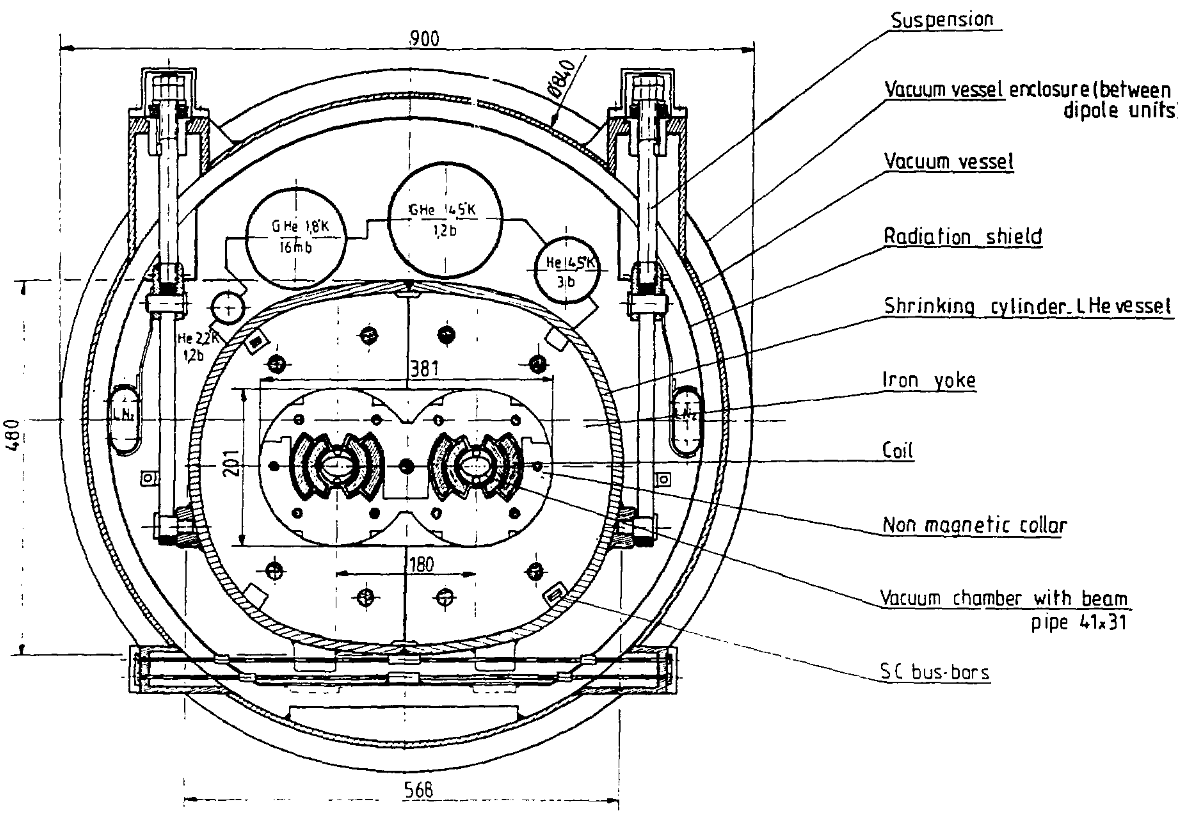

Fig. 5. Cross-section of the 10 T twin-aperture dipole (2 K variant)

The main parameters of the dipole magnet are given in Table 2.

Table 2 - Dipole parameters

Nominal field B_0	10 T	Coil inner diameter	50 mm
Excitation per dipole	1158 kA	Distance between beams	180 mm
Operation current	15650 A	Coil outer diameter	122 mm
Stored energy for both channels combined	684 kJ/m	Length	10 m
		Weight	~ 18 t

Table 3. Multipole errors due to design limitations and fabrication tolerances

Systematic multipole components (Absolute values) (normalized for R = 1 cm, in 10^{-4} units)	Random variation of multipoles (r.m.s. for R = 1 cm, in 10^{-4} units)
	a_1 = 5.0 b_1 = 5.4
a_2 = 0.6 b_2 = 1.6	a_2 = 1.7* b_2 = 1.2*
a_3 = 0.1 b_3 = 0.35	a_3 = 0.50 b_3 = 1.5
a_4 = 0.03 b_4 = 0.05	a_4 = 0.20 b_4 = 0.15
a_5 = 0.03 b_5 = 0.05	a_5 = 0.07 b_5 = 0.20
a_7 = 0.01 b_7 = 0.03	a_7 = 0.04 b_7 = 0.02
a_9 = 0.001 b_9 = 0.01	a_9 = 0.002 b_9 = 0.005

* without correction

The field quality is determined by the multipole components defined by :

$$B_y + iB_x = B_o \sum_1^{\infty} (b_n + ia_n) \left(\frac{Z}{R_r} \right)^{n-1} \qquad (6)$$

where B_o = magnitude of dipole field in the y(vertical) direction.

b_n = normal multipole coefficient.
a_n = skew multipole coefficient.
n = 1, 2 3, ...
$Z = x + iy$
R_r = reference radius (R_r = 1 cm in this report)

A summary of the systematic and random components due to design limitations and fabrication tolerances is given in Table 3.

CRYOGENICS

Conventional-helium (4.5 K) and superfluid-helium (1.8 K) options are possible schemes of LHC cryogenics. Only the superfluid option, the most complex one, is summarized here (Fig. 6).

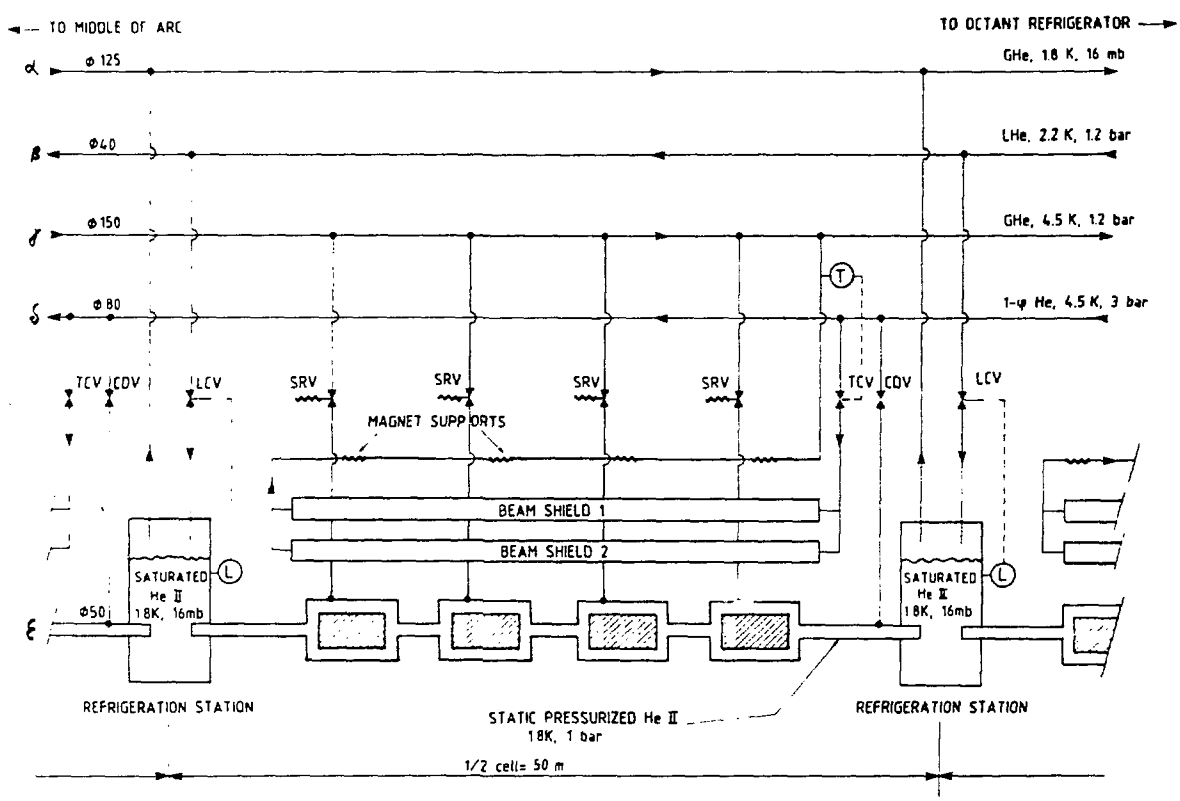

Fig. 6. Details of the cooling scheme of one half-cell

Superfluid helium has an extremely high thermal conductivity. This property can be used to cool elements located at some distance from the cold source simply by heat conduction through a static column of helium. In steady operation, magnet coils, collars, iron yoke, and shrinking cylinder are immersed in static superfluid helium at temperatures of 1.8 to 2.0 K and atmospheric pressure, through which heat is transported by conduction to local refrigeration stations (one per half-cell). Each station consists of a cryostat where sub-cooled liquid helium at 2.2 K, 1.2 Bar produced by the octant refrigeration (line β) is throttled down to the saturation pressure at 1.8 K (16 mBar). The cold helium vapour, produced by the throttling process and the refrigeration load is returned to the octant refrigerator via a low-pressure line (line α).

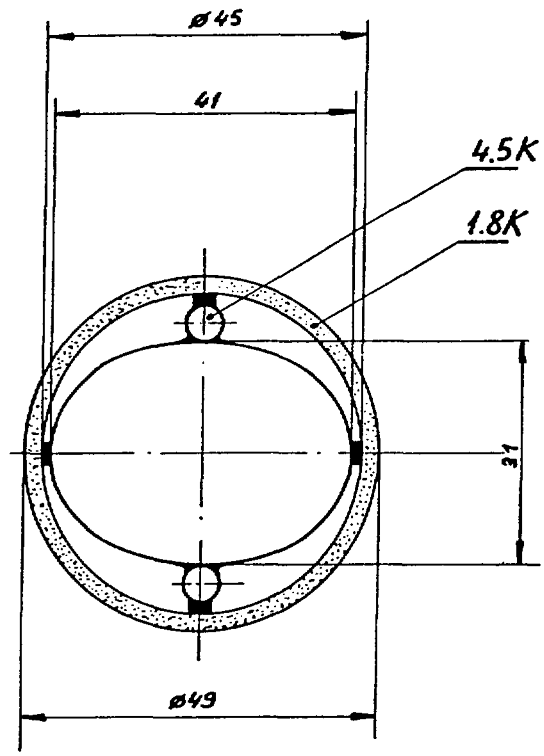

Fig. 7. Vacuum chamber with heat shield forming beam pipe
($41 \times 31\ mm^2$)

Monophase helium at 4.5 K, 3 Bar (line δ) coming from the octant refrigerator is expanded through the cooling channel of the inner radiation shield installed in the beam pipe to intercept synchrotron radiation produced by the beam in the ultra-violet range (71 eV is the critical energy at 8 TeV) (Fig. 7). The same helium flow intercepts the heat conducted along the magnet supports before returning to the octant refrigerator (line γ). The same return line is also used to recover helium discharged from the magnet cryostats in the case of a quench. Cool-down and warm-up of a magnet string are achieved by forced circulation of gaseous helium using the same distribution.

A third temperature level consisting of circulating liquid nitrogen at 90 K allows to cool the outer radiation shield of the magnet cryostat, with the purpose of reducing the radiation losses between the elements at 1.8 K and the vacuum vessel at room temperature.

The other systems like vacuum, radio-frequency, beam dumping, are more conventional and described elsewhere [3]. It is more relevant here to point out that the use of an important existing facility such as the injector and collective phenomena inside LHC itself do not limit the beam performances. Similarly it is worth noting that the construction of LHC in the LEP tunnel is compatible with the exploitation of LEP.

INJECTION

The injection into LHC uses the CERN complex of existing accelerators : Linacs, Booster, 28 GeV PS, 450 GeV SPS. The LHC performances are then determined by the beam characteristics given by the injector chain.

<u>In pp mode</u>, the PS and SPS are limited in intensity to respectively $2x10^{13}$ and $4x10^{13}$ circulating protons essentially by the RF power available and by beam instabilities. With the LHC nominal bunch spacing of 25 ns and $2.56x10^{10}$ ppb, the bunch train is formed at top energy in the PS by a dedicated RF system operating at 40.1 MHz, and the 84 PS bunches (= $2.2x10^{12}$ protons circulating in the PS) are compressed in length to fit into the 200 MHz buckets of the SPS. After box-car stacking of 10 PS pulses in the SPS, the

beam containing a maximum of 924 bunches (gaps ignored) and $2.4x10^{13}$ protons is accelerated to 450 GeV and is then transferred to LHC. This is repeated four times for filling one LHC ring.

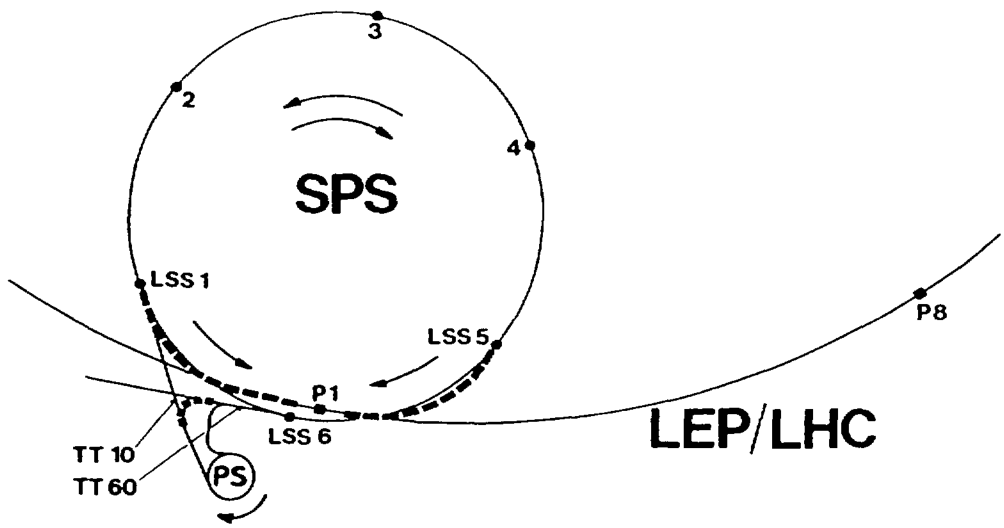

Fig. 8. Proton beam transfer through the injector chain

To minimize the transfer tunnel length, it is proposed to reverse the SPS polarity for filling the other LHC ring, also with 4 SPS cycles (Fig. 8). There is no limit in intensity in this process and the normalized emittance is mainly determined by the beam injected by the Booster into the PS, namely $\varepsilon = 4\pi\gamma\ \sigma^2/\beta = 5\pi$ mm.mrad.

In ep mode, the number of bunches is reduced to 540 but the intensity in the bunch is higher, thus increasing the danger of beam instabilities. To reach the nominal performances, the $8.2x10^{10}$ electrons per LEP bunch need multi-turn injection from the SPS limited to ~ $0.8x10^{10}$ epb.

The $3x10^{11}$ protons per LHC bunch can be achieved by increasing the emittance to 20 πmm.mrad. This intensity is only a factor 2 above the value currently used during the present $p\bar{p}$ operation. As for the pp mode, four SPS cycles of 135 proton bunches each can fill LHC, but the bunch spacing of 164.8 ns imposed by the different frequencies of LEP and LHC cannot be produced by the PS. Hence the PS must accelerate each bunch separately to 26 GeV/c and the SPS must wait at this energy until all the 135 bunches are injected. The time needed for injection of one proton beam is 20 mn. This is considerably longer than in the pp mode, but the electron injection into LEP and the acceleration in LEP will be done during the ramping of LHC and will not influence the total filling time.

COLLECTIVE EFFECTS

The last main item which could limit the LHC performances is the collective effects, important for high-intensity beams.

The electro-magnetic field generated by the beam can interact on the beam itself independently of its surroundings. Amongst these effects in the pp mode, the space charge tune shift amounts to 10^{-3} at the 450 GeV injection energy and 5×10^{-6} at 8 TeV; these values are small enough not to cause any problem. The intra-beam scattering produces a growth of both transverse and longitudinal emittances. Whilst the transverse emittance is fixed by luminosity, the longitudinal emittance can be chosen to ensure a sufficiently small growth rate. A 1 eV.s emittance at injection provided by the SPS is amply sufficient at this energy, while an increase by a factor 2.5 is needed during acceleration.

However, most of the effects result from the interaction of the beam with its surroundings. This produces collective instabilities and energy loss which heats up the vacuum chamber and contributes to the cryogenic load in the cold parts. To estimate both these effects, the longitudinal Z_l and transverse Z_t coupling impedances have to be calculated. Both Z_l and Z_t are complex numbers; their real parts give instability growth rates, whilst their imaginary parts cause frequency shifts of the coherent modes of oscillation. The real part of Z_l also determines the parasitic energy loss. Table 4 gives Z_l/n for the main contributing elements where n is the frequency divided by the revolution frequency.

Table 4. LHC coupling impedance Z_1/n (in Ω)

Broad-band	RF cavities	0.3	
	Bellows (unshielded)	0.6	
	Monitors	0.15	
	Kickers	0.1	
	Total	1.15	
Resistive wall at $\omega/2\pi$ = 3.3 kHz	$0.7(1 + j)\Omega$	at	450 GeV/c
	$2.7(1 + j)\Omega$	at	8 TeV/c

Table 5 shows the power losses from the two beams averaged over the machine circumference, and expressed in dissipated power per unit length. The broad-band impedance contribution comes from the bellows and the monitors.

Table 5. Power lost by the beam per unit length (mW/m)

Resistive wall	4.5
Broad band	0.7
Synchrotron radiation	234
Total	249.2

Among the most dangerous longitudinal instabilities, the microwave instability affects single bunches and is induced by the broad-band impedance. For LHC it has a threshold intensity of 7×10^{11} ppb, well above the nominal value. The coupled-bunch instabilities driven by the high-order longitudinal modes of the RF cavities can be dangerous mainly above a threshold of 5.6×10^{10} ppb. Below this level, Landau damping is effective and only a limited number of modes can be unstable and must be damped with an active feedback.

In the transverse plane, the dominant single-bunch instabilitiy is the mode-coupling instability, which fortunately has a threshold at $2x10^{11}$ ppb in LHC. Transverse-coupled mode instabilities can be induced by the resistive-wall effect which can be counteracted by a tune spread of ~ $3x10^{-3}$. They can also be created by transverse modes of the RF cavities. In spite of the Landau damping a few of these modes may induce instabilities, and have to be suppressed by feedback systems.

Therefore in the nominal pp mode, all the instabilities seem well under control. For higher luminosities, detailed studies have still to be made.

In the ep option, problems are more crucial since the proton bunch density ($3x10^{11}$ ppb) is more than 10 times higher than in the pp version. This will not affect the intra-beam scattering rates since the phase space density is about the same in both cases, due to the larger transverse emittance in the ep mode. The threshold of the microwave instability is still high enough not to pose any problem. But the inductive-wall effect produces frequency shifts which suppress the Landau damping in both the longitudinal and transverse cases. As a consequence the coherent longitudinal modes are instable; the dipole and quadrupole modes can be damped by feedback systems, and the effect of higher modes can be reduced by increasing the longitudinal emittance which requires the addition of a few single-bore RF cavities on the proton beam used for ep collisions. In the transverse case the head-tail mode m = 0 can be easily damped with a feedback system. Higher modes should be suppressed by Landau damping. This can be achieved with the help of octupoles. In order to reduce the necessary tune spread to a value which is tolerable (around $6x10^{-3}$), the transverse coupling impedance must be reduced by shielding the bellows from the beam.

COMPABILITY BETWEEN LEP AND LHC

Two phases can be distinguished. A first phase of progressive installation of the LHC, in the years when LEP is the only operational collider in the tunnel, and a second phase when both colliders (LEP and LHC) are operational.

During the first phase LEP will operate approximately 4000 hours per year and, therefore, the installation of the LHC, which takes place primarily in the arcs at considerable distance from the LEP experiments, could be carried out during the rest of the time (also approximately 4000 hours). In this context, it is worth noting that the magnet cryostats contain also the pipes for the cryogenic fluids, making the installation in the tunnel more rapid than in the case of a separate He distribution system.

During the first phase, the construction of additional pp or ep experimental areas could also proceed, even during LEP operation, except for the part involving the tunnel and its immediate surroundings. In fact this was done around the SPS for the UA1 and UA2 experimental areas.

Once the LHC is fully installed and commissioned, one could divide the year in two operational periods of approximately 5 months each, one devoted to LEP operation and the other to LHC operation, with a period of two to three weeks in between for the change over of the experiments. When LEP is operating the corresponding experiments would be in the data-taking position and the LHC experiments in their garages and vice-versa. As far as pp collisions are concerned, it is in principle possible to produce them in 7 out of the 8 interaction points symmetrically arranged around the LEP circumference; the straight section around insertion point 3 is reserved for the dump system of both LHC beams.

CONCLUSIONS

As seen above, the nominal performances of LHC can be reached without limitations with the high quality injectors and excellent machine optics, which satisfy all requirements of beam stability. Comfortable margins do exist to increase the luminosity for experiments which can deal with a higher average number of events or with a smaller bunch spacing.

The exploitation of LEP and LHC in the same tunnel is not only compatible, but is of considerable interest for collisions between protons and electrons. Furthermore, the current CERN experience in accelerating ions allows one to envisage collisions between ions in LHC.

The superconducting magnet system with a dipole field of 10 T can be built, but requires a vigourous development programme for materials and cryogenics (1.8 K) and for the construction of magnet prototypes. Nevertheless experience in European industry exists and if LHC could be scheduled just after the completion of HERA, skilled teams could be available by the end of 1989.

At that date, LEP phase 1 will also be completed and CERN trained teams could start the construction of LHC while LEP phase 2 is being achieved.

In these conditions, with the availability of the existing injectors and of the general CERN facilities (infrastructure, offices, wokrshops, general services), and with the know-how of CERN staff, considerable savings can be made in the cost of LHC. A cost estimate of the basic machine structure for the pp mode, which consists essentially of the superconducting magnet system and of the cryogenics, has been worked out [4]. This cost is ~ 1315 MSF (for 10 T) and represents as much as 85% of the new investment. Adding ~ 15% of contingency the total amounts to 1500 MSF.

ACKNOWLEGEMENT

The authors are indebted to all the contributors to the report CERN-87-05 of the same title, who have made the studies and furnished the basis of this contribution.

They also wish to thank the CERN Long Range Planning Committee, chaired by Professor C. Rubbia, for the constant encouragement and guidance.

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RESEARCH AND DEVELOPMENT FOR A CERN LINEAR COLLIDER

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1. INTRODUCTION

Up to about 1985 work on linear colliders in Europe was mainly based in national laboratories and universities and was primarily concerned with novel methods of acceleration. Much stimulation and impetus was given to this work by international meetings jointly organized by ECFA, the European Committee for Future Accelerators, and CAS, the CERN Accelerator School. The first of these meetings was held at Oxford in 1982,[1] and a second one at Frascati in 1984.[2] A third meeting of this kind was held in June this year at Orsay.[3] Outstanding examples of substantial development work resulting from these early initiatives are the experiments on wake field acceleration at DESY,[4] on plasma beat waves at the Rutherford laboratory[5] and on lasertrons at LAL Orsay.[6]

At CERN work on linear colliders rapidly gained momentum from 1985 onwards. Indeed, a Long Range Planning Committee initiated by the CERN Council and chaired by C. Rubbia had decided on its first meeting that one of its three advisory panels was to explore the possibility of an e^+e^- collider at TeV energies, the two other panels being concerned with the Large Hadron Collider (LHC) in the LEP tunnel (chaired by G. Brianti) and the physics issues (chaired by J. Mulvey).

The panel on e^+e^- colliders (under the chairmanship of K. Johnsen) adopted the name of CERN Linear Collider (CLIC) for the subject of its study, made the tentative choice of 2 TeV for the centre of mass energy and proceeded to initiate its own study work - at CERN and in collaboration with other laboratories - in addition to reviewing the results obtained elsewhere. The panel issued its report in May 1987. As part of the Long Range Planning Committee's report[7] this "Report from the Advisory Panel on the Prospects for e^+e^- Linear Colliders in the TeV Range"[8] was submitted to the CERN Council in June w ere it was very positively received. Much encouragement is coming from ECFA and from the high-energy physics community at large who examined the physics potential of future accelerators - LHC and CLIC - at a workshop in La Thuile[9] in January 1987.

Following the conclusions[8] of the Advisory Panel the CERN-based study now continues. The aim is to be assured of basic feasibility and to gain clear ideas of the main parameters and design features of a TeV linear collider in a few years' time so as to create the option of a project. Clearly, only the most fundamental problems can be studied for the time being. The following paragraphs give an overview.

2. GENERAL PARAMETERS

The greatest difficulty with e^+e^- linear colliders is the generation of the necessary luminosity which should increase with the square of particle energy and exceed 10^{33} $cm^{-2}s^{-1}$ at 1 TeV per beam. This is more than an order of magnitude above the performance of present-day circular colliders and it has to be obtained in the much more difficult situation where each accelerated particle makes only a single passage through the collision region. In order to aim at such values of luminosity the collider has to be designed from the collision point outwards within the constraints imposed by the close relations existing between luminosity, beam power, disruption by electromagnetic beam-beam interaction and beam-beam radiation. In all but superconducting accelerating structures the required high efficiency of energy transmission to the beam severely limits stored energy. Other constraints are imposed by limitations to the strength of the final focus system and to beam emittance, by beam-induced wakefields and by severe dimensional tolerances of all kinds.

The strong interrelation between all collider parameters resulting from these fundamental constraints is now well understood.[10] It leaves only very limited freedom of choice if the final aim of providing adequate luminosity is not to be abandoned from the start. Very low values of transverse beam emittance have to be obtained in the injector and maintained throughout the linear accelerator with correspondingly stringent requirements on alignment tolerances. The final focus system must be very strong and contain a system of chromaticity correction so as to produce a final spot size below

100 nm - possibly much below that value - at least in one direction, in spite of the inevitable energy spread in the beam. Beam disruption by electromagnetic beam-beam interaction and beam-beam radiation ("beamstrahlung") impose constraints on the combination of final spot size and bunch charge. Fortunately, the onset of quantum effects in the radiation[11] helps to make these constraints less severe than originally believed.

A large bunch charge is desirable for good energy transmission to the beam. The bunch charge is limited, however, by beam-induced wake fields which tend to lead to intolerable degradation of beam emittance or even beam loss. The effect of transverse deflecting wake fields has to be controlled by "Landau damping", obtained by creating a large spread of transverse focusing wave numbers within the bunch.[12] This may be done by creating (or tolerating) a large energy spread. The spread must then be compensated as best as can be done in the final part of the linear accelerator before the final focus is reached. Radio-frequency focusing[13] may be an alternative way to create strong Landau damping. In either case, however, the short coherence length of transverse oscillations concomitant with a large spread in wave numbers tends to aggravate the problem of alignment tolerances along the linac.[14]

In our first tentative sets of parameters, given in Table I, we have put much emphasis on high efficiency of energy transfer to the beam and, hence, on high beam power. Another course of action, followed elsewhere[15], would be to reduce beam power and Landau damping at the price of much reduced values of vertical emittance and vertical final spot size.

3. DAMPING TO SMALL EMITTANCE AND FINAL FOCUS

At least the positrons have to spend a certain time in a specially designed damping ring system before they can be injected into the main linac. In principle the required values of normalized transverse emittance (a few micrometre-radians) are within reach of known designs of ring lattices (e.g. those used for synchrotron radiation sources). The choice of energy (a few GeV) has to balance quantum excitation against intrabeam scattering and damping rate for minimum equilibrium emittance. Several special lattice types have been proposed and it is as yet unclear which type is the best, or indeed feasible at realistic tolerances. Production rate of damped particles is a problem and the required total circumference of damping rings depends on our ability to inject and extract isolated bunches (or trains of bunchlets) without disturbing adjacent bunches.

The final focus system must focus each beam to less than a tenth of a micrometre r.m.s. radius and superimpose these sub-microscopic focal spots within a small fraction of the spot size. With feasible values of transverse emittance the first requirement asks for a value of the amplitude function β^* of a few millimetres. This is comparable to SLC nominal values but it has to be achieved at 20 times higher energy. There are basically two approaches to this. Either extremely short values of focal length are obtained by means of plasma, beam-induced space charge in a gas or beam-beam focusing. Or the long focal length of a more conventional quadrupole system is made acceptable by precise "chromaticity correction", i.e. by compensating the variation of focal length with particle energy within the bunch. At this time neither approach has led to a completely satisfactory solution yet and the problem is further complicated by beam-beam interaction which tends to direct a destructive spray of "disrupted" beam on to the opposite half of the focusing system, by the extreme tolerance problem stated above and by the required repetition rate.

The hope that very strong focusing - and simultaneous focusing in all directions - might be achievable by means of plasma devices gives strong incentive to a continuation of the basic research on plasma-generated fields, in spite of the undeniable shift of emphasis towards the classical principles of RF acceleration in the main linear accelerator.

At this time, however, there is growing confidence [16] that a satisfactory final focus system may yet be built on classical principles, using strong, small aperture quadrupoles for focusing and a combination of dipoles and sextupoles for chromaticity correction.

4. METHODS OF HIGH-GRADIENT ACCELERATION

During the last decade several novel methods of particle acceleration were proposed. It was hoped that practical accelerating gradients approaching, if not exceeding, gigavolt per metre values might be achievable, while the classical RF linear accelerator then appeared to be limited to values substantially below 100 MV/m. These new acceleration methods included plasma beat-wave acceleration,[17] plasma wake-field acceleration,[18], acceleration by wake fields in a metal structure[4] and the "switched power linac" excited by opto-electrical switches.[19]

Basic research on the switched power linac is being pursued jointly by BNL and CERN. At CERN, a scale model of the accelerating structure has been studied.[20] This structure has the form of a stack of circular discs with a central beam aperture. The structure forms a radial line transformer excited by laser-driver switches distributed around the circumference. The predicted transformation ratio has been verified and the effect of imperfections in the drive has been measured. At BNL an extensive study of the switches is under way.

Experiments with CO_2 lasers (10 μm wavelength) at UCLA and Quebec,[21] together with computer simulations, have shown that the basic principle of plasma beat-wave acceleration is valid. CERN is participating in an experiment at Rutherford Lab. and Imperial College aiming at producing beat waves at the more suitable wavelength of 1 μm. A first result[22] was the successful production of a high-uniformity plasma column using multi-photon ionization by a laser beam. Experimental tests on the plasma wake field method are being performed by an Argonne/Wisconsin group[23] while theoretical work has been done in several places, including CERN.

Given the expertise on superconducting RF cavities developed at CERN for LEP it is not surprising that linear colliders based on such cavities are being very seriously considered. Parameters for fully superconducting main linacs have been proposed at CERN[24] and at Cornell.[25] This solution is a tempting one because of its potential of very high efficiency and beam power, making it relatively easy to envisage luminosities in the 10^{34} $cm^{-2}s^{-1}$ range. Unfortunately, the limited accelerating gradient and high cryogenic loss associated with proven materials (niobium, possibly niobium tin) tend to make this solution unattractive (e.g. 100 km total length for 2 × 1 TeV even under quite optimistic assumptions), although the dramatic advent of high-temperature superconductors in recent months may lead to developments which could reverse such a negative conclusion.

In parallel with all the work on novel acceleration methods much worldwide effort has been devoted to adapting the principles of the well-known normal-conducting travelling-wave linac to the requirements of a linear collider (see for instance refs. [3], [10] and [26]). This has been very successful and a large consensus has now developed that RF acceleration - "classical" in principle but not at all in choice of parameters and technology required - is the most promising approach to linear colliders known at this time. The CERN Advisory Panel has come to the same conclusion and its final report contains specific proposals and parameters for CLIC which have now become the basis of our ongoing work, as explained in the next section.

Radio-frequency linear accelerators consist of two main parts: the accelerating structure and the source of rf power. The first topic includes all questions of type of structure, choice of frequency, wake fields, alignment tolerances, transverse focusing and the choice of basic collider parameters. In this field the CERN work advances completely in parallel with work done elsewhere. Our tentative choice of wavelength - generally considered close to a lower practical limit - emphasizes high RF-to-beam efficiency and beam power at the expense of problems with transverse wake fields and tight transverse tolerances along the linac. Our work related to wake fields[27] leads us to believe that these problems may be overcome.

The second main part of an RF linac, the power source, presents a fundamental problem because of the terawatt level of total peak power required. Several types of d.c. to RF power converters and two-beam schemes have been proposed to solve this problem (see for example ref. [3]). In this area CERN pursues its own specific proposal featuring a fully relativistic auxiliary drive beam , a superconducting drive linac and a travelling wave transfer structure.

The next section gives a description of our proposed scheme for CLIC and the ongoing work.

5. A 30 GHZ LINAC POWERED BY A SUPERCONDUCTING DRIVE LINAC

It is now established that, at sufficiently high frequency, normal-conducting radio-frequency structures accelerating gradients of several hundred megavolts per metre are possible in principle. In practice, maximum attainable gradients are given by considerations of efficiency and limitations of peak power more than by electrical breakdown. Another fundamental problem is presented by self-deflection and self-deceleration due to the electromagnetic wakefields left behind by the particles.

Travelling wave structures offer the important advantage of presenting a matched load to a short pulse of RF power at a single feed point per section. It is proposed, therefore, that the accelerator be made of travelling wave sections, each one of length L, group velocity v and fill time $\tau = L/v$ for electromagnetic energy. The well-known disc-loaded guide is still a good choice of structure at the high frequency considered here. Fabrication may be by electroforming or by brazing techniques.[28] Assembly from radial, comb-like, segments spanning the full length of a section has also been proposed.[29] Special variants of the disc-loaded structure, for damping higher modes and for RF-focusing will be mentioned below.

The enormous dissipation per unit length associated with accelerating gradients E_0 of the order of 100 MV/m or more, requires the RF power to be applied in the form of very short pulses with low duty cycle. The duration of each power pulse is made approximately equal to the fill time τ and a beam pulse (consisting of a bunch of particles or a train of several bunches) is made to pass at the end of the power pulse. As the decay time of stored energy will be much shorter than the repetition period, any energy not extracted by the beam is lost. Therefore, the efficiency of transferring power from the RF feed point to the beam approaches, at best, the fraction η of energy extracted. On the one hand this extraction efficiency is limited to about 10% at most by the concomitant energy spread (roughly $\eta/2$) which must remain correctible before the final focus system is reached. On the other hand η is proportional to the charge per beam pulse, the square of the resonant frequency and the inverse of the accelerating gradient. The charge per bunch of particles is limited by the wake fields and by beam-beam radiation in the final focus. Therefore, the price for reaching a high value of accelerating gradient at acceptable efficiency is a very high frequency, much higher than the customary 3 GHz of present-day electron linacs. A value of about 30 GHz, corresponding to 1 cm wavelength, appears to be a limit imposed by transverse wake fields and by constructional problems of travelling wave accelerating structures. Test structures for about 1 cm wavelength have, indeed, been manufactured and tested at high gradient.[28] It is proposed, therefore, that about 1 cm wavelength should be used in spite of the considerable extrapolation from present-day technology implied by this choice.

If the RF to beam efficiency is to approach the energy extraction η, dissipation **during** the fill time has to be made as small as possible. The only way to do this is to make the fill time very short in spite of the concomitant increase of peak power. A reasonable compromise may be a choice of fill time that makes the peak power per metre of section length twice the classical minimum. The corresponding dissipation during the structure fill time amounts to 28% of the input energy. With the typical Q-factor of a copper structure at 1 cm wavelength this fill time amounts to only 11 ns.

Column A of Table I represents a relatively conservative choice of parameters[8] resulting from the arguments outlined above. There is only one bunch of electrons or positrons per pulse, extracting 8% of the stored energy. The accelerating gradient is 80 MV/m giving the accelerator a total active length of 2 × 12.5 km for 2 × 1 TeV. The efficiency of energy transfer from the RF input to the beam is a little over 6% yielding 5 MW beam power (and a luminosity of 10^{33} $cm^{-2}s^{-1}$) for 80 MW average RF power per linac. Beam power and luminosity may be doubled or the input power halved if the electromagnetic energy reappearing at the output end of each accelerating section after the beam passage can be recovered. The superconducting drive system described below appears to permit just this but the details remain to be studied.

Table I. Main linac parameters for two accelerating gradients. Parameters for one linac.

Case	A	B	
Final energy eU	1	1	TeV
Frequency f	29	29	GHz
Average accelerating gradient E_0	80	160	MV/m
Total active length L_{tot}	12.5	6.25	km
Shunt impedance per unit length R'	170	170	MΩ/m
Attenuation constant for power α	0.5	0.5	
Fill time τ	11.4	11.4	ns
Peak power per unit length $\hat{P}_L/L$	96	384	MW/m
Bunch population N	5.35	5.35	$\times 10^9$
Energy extraction per pulse η	0.08	0.08	
Number of bunches per pulse	1	2	
Repetition rate f_{rev}	5.8	5.8	kHz
Average RF power $\langle P_{RF}\rangle$	80	80	MW
Beam power $\langle P_b\rangle$	5	5	MW
Beam radius at collision σ_r^*	65	65	nm
Disruption D	0.91	0.91	
Pinch enhancement H	3.5	3.5	
Beam-beam radiation loss δ	0.19	0.19	
Bunch length σ_z	0.3	0.3	mm
Luminosity	1.1	1.1	$\times 10^{33} cm^{-2} s^{-1}$
Fractional average critical energy Υ	0.28	0.28	
Normalized emittance $\varepsilon_n(\beta^* = 3$ mm$)$	2.8	2.8	$\times 10^{-6}$ rad m

The accelerating gradient could be doubled and the total active length reduced to 2 × 6.5 km if two bunches per beam pulse could be used (Column B of Table 5.1). Moreover, at the price of a 20% reduction in average accelerating gradient, an RF to beam efficiency of as much as 30% may be reached by using a larger number of bunches, whose interval is adjusted so as to make the fresh influx of RF power cancel the bunch to bunch depletion of energy due to beam loading. In known accelerating structures this multibunch operation is probably precluded by multibunch wake field effects (regenerative beam break-up). To overcome this effect the proposal has been made[29] to equip the accelerating structure with longitudinal slits in the outer wall, so as to let transverse deflecting modes be propagated away. Transverse Q factors will have to be depressed to values of a few tens at most, but this does not seem impossible. The longitudinal slits might be created by assembling an accelerating section from precision machined comb-like segments. Experimental tests are in preparation.

Each bunch induces longitudinal and transverse-deflecting wake fields as it passes through the accelerating structure. The wakes left behind by downstream particles act on the upstream part of the same bunch. Longitudinal wakes lead to energy loss and energy spread. Dipole wakes may amplify accidental transverse oscillations (due to misalignment of accelerating structures or quadrupoles) so as to cause severe emittance blow-up or even beam loss. For given structure geometry longitudinal wake potentials scale with ω^2, transverse ones with ω^3.

Up to at least 30 GHz - generally considered an upper practical limit for the choice of frequency - the effects of transverse wakes can be cancelled by the introduction of a large spread in transverse wave number ("Landau damping"). This spread is most naturally obtained via the natural chromaticity of the focusing lattice by creating or tolerating an energy spread. A large spread might also be obtained directly, without requiring a concomitant energy spread, by rf focusing. Such RF quadrupole focusing[13], produced by means of asymmetric RF apertures being placed alternately vertically and horizontally at suitable period lengths, might obviate the need for precision quadrupoles and provide their own diagnostics for transverse alignment in the form of beam-induced higher modes. The main feature would be an essentially linear spread in phase advance per period which could be as large as three to one (say) over $\pm 2\ \sigma_z$, if so desired. Although this turns out to be very effective in stabilizing the wake fields the objection has been raised[14] that the short coherence length associated with such large spreads would lead to unacceptably small tolerances for transverse alignment. Recent computer simulations[30] indicate, however, that a suitable choice of parameters will make this tolerances of the order of 10 μm (roughly ten times the beam size) which may be achievable with the help of active, pulse-to-pulse, feedback for steering the beam. The fast repetition rate of several kilohertz will be helpful in this respect.

The main remaining problem is the generation of the enormous peak power required. All known d.c. to RF power converters contain space charge limited electron guns limiting the current density of the beam of electrons which is used to transfer energy from d.c. to RF. It follows that the output power rapidly decreases with the wavelength if a given design is scaled. The kilohertz repetition rate poses another very serious problem. No suitable power converter at 1 cm wavelength is available at present and if it could be developed the very large number of units required is likely to make this solution economically unattractive.

Instead of the multitude of d.c. to RF power converters a continuous drive beam running along the main linac may be employed.[31] The drive beam supplies energy to the main linac at regular intervals via transfer structures. The drive beam energy is restored by accelerating structures forming a "drive linac". Free electron lasers[28,31,32] and direct RF deceleration sections[33,34] have been proposed as transfer structures, induction units[31,35] and superconducting RF accelerating cavities[32,34] as drive linacs.

A drive linac formed by superconducting cavities, combined with decelerating RF transfer structures, opens the possibility of a fully relativistic drive beam, thus eliminating all phasing problems and this is the scheme we propose for CLIC. It is shown schematically in Fig. 1. The mains input is converted to RF power at UHF frequency by large CW klystrons. Such klystrons of over 1 MW output and nearly 70% transfer efficiency are available[36] to-day. The CW operation of the drive linac, made possible by the high Q-factor of the superconducting cavities, means that the main linac repetition rate is limited by pre-injector considerations only.

Drive beam pulses of a duration equal to the main linac fill time τ have their energy periodically restored by being passed through the superconducting cavities. Energy conservation along the drive beam demands that the "transformer ratio", i.e. the ratio of the accelerating gradient E_0 in the main linac to that, E_1, in the drive linac be proportional to the ratio of frequencies. The resulting choice of drive linac frequency in the low UHF range is quite suitable for superconducting cavities. In fact, the 350 MHz superconducting cavities[37] developed for the second stage of LEP could already be used at their present state.

Table II gives parameters of superconducting drive linacs. The first column is for the main linac of column A, Table I. The corresponding drive linac parameters (E_1 = 6 MV/m and $Q_1 = 5 \times 10^9$ at 350 MHz) are present-day performances. The second and third column correspond to E_1 = 15 MV/m, a development that is expected to occur in a few years' time. In case B 2 × 6.25 km of main linac are powered by only 2 × 800 m of superconducting drive linac. In case C (admittedly an extreme example) the entire installation is compressed to only 2 × 2.24 km active length, main linac and drive linac alike. This would, however, require multiple bunches from the start.

Table II. Superconducting drive linacs for three main linac gradients. Parameters for one linac

Case		A	B	C	
Main linac energy	eU	1	1	1	TeV
Main linac frequency	f	29	29	29	GHz
Main linac accelerating gradient	E_0	80	160	445	MV/m
Main linac active length	L_{tot}	12.5	6.25	2.24	km
Drive linac voltage gain	U_1	15	12	33.6	GV
Drive linac frequency	f_1	350	350	350	MHz
Drive linac R over Q parameter	r'_1	270	270	270	Ω/m
Drive linac accelerating gradient	E_1	6	15	15	MV/m
Drive linac active length	mL_{tot}	2.5	0.8	2.24	km
Drive linac quality factor	Q_1	5×10^9	5×10^9	5×10^9	
Cryogenic input power (η_{cr} = 0.2%)	$\langle P_1\rangle/\eta_{cr}$	33	67	186	MW

Energy transfer to the main linac may be by RF deceleration in short sections of travelling-wave structures, each one coupled to the input of a main section via a short run of waveguide. This scheme requires the drive beam to be tightly bunched at the main linac frequency. It has, however, the great advantage of permitting drive beams of several GeV energy. This assures rigid drive bunches and the absence of any phase slip between the beams, thus eliminating all phasing problems for the tens of thousands of main linac sections. The required impedance of the transfer structure is very low. This will permit a design with a large enough aperture to cope with the longitudinal and transverse wake f'.elds due to the intense drive beam. The required drive charge is rather large. For the parameters of the first columns of Tables I and II each drive bunch has to contain 4×10^{11} electrons and there are 40 such bunches per main linac pulse. Generation and acceleration to relativistic energies of these drive bunches appears to be the main difficulty with this scheme. At least this difficulty is confined to the injector.

If the output of each accelerating section is conncted to an input of the following transfer section a suitably timed and phased recovery pulse, following the drive beam pulse, permits transfer of the energy left after the beam passage back into the superconducting cavities. This means a factor two in power economy for single bunch operation at the cost of extra complication but little additional cost of hardware.

The 350 MHz superconducting cavities which are being developed[37] at CERN for LEP 2 would be immediately usable for the superconducting drive linac outlined above. This new potential application leads, however, to increased emphasis on higher gradients, higher Q-factors and low-cost fabrication methods in our ongoing development program on superconducting RF structures.

Work on the development of a suitable transfer structure has started[38] with low-power model measurements and 3-D computations. Figure 2 shows a scale model used for the determination of dispersion diagrams and impedance values. As a next stage it is planned that a scale model will be tested in the beam of the 3 GHz LEP injector linac. Finally, it is intended that a dedicated test set-up - containing a high-current laser gun, bunch compressor and pre-accelerator for the generation of a full-intensity drive beam - will be built so as to permit high gradient demonstration tests of actual accelerator modules at 1 cm wavelength.

6. CONCLUSIONS

During the last few years impressive progress has been made in understanding the requirements and interconnected parameter constraints of TeV linear colliders. The conclusion has emerged that one approach holds the promise of leading to a real project in the foreseeable future. This approach is based on a normal conducting radio-frequency linear accelerator with a resonant frequency substantially above that of present-day linacs.

Outstanding fundamental problems, for which practical solutions have yet to be demonstrated, although promising proposals exist, are the efficient and economic generation of peak RF power, the generation and preservation of very small transverse beam emittance and the final focus system, including its alignment. In addition, a very large number of engineering problems have yet to be analysed. The picture, nevertheless, emerges that a 1+1 TeV collider is approaching potential reality and the CERN work is directed towards this goal.

Specific features of the tentative parameters on which most of our work is centred are the relatively short wavelength of about 1 cm, strong Landau damping (possibly obtained by RF focusing) and an auxiliary beam of a few GeV energy, which receives energy from superconducting cavities and transmits it to the main linac via travelling wave transfer structures. We hope to be able to demonstrate the viability of this concept - including all changes that may emerge from the study - in a few years' time, so that an actual CLIC design study could then begin, if so desired.

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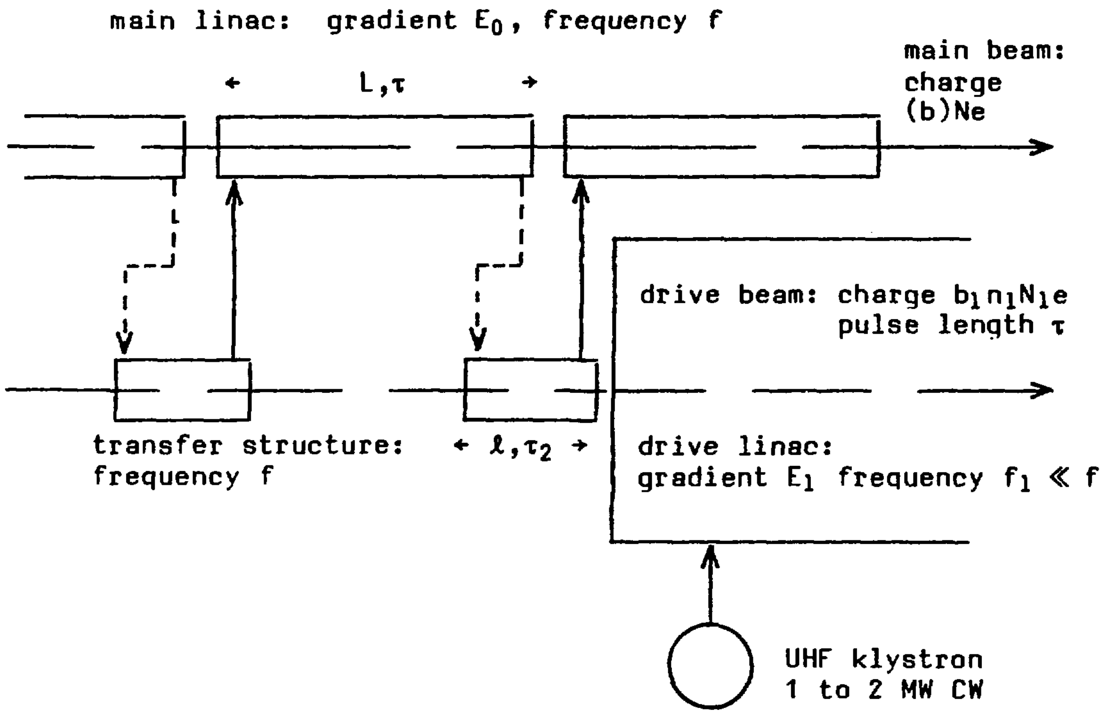

Fig. 1. Two-stage linear accelerator composed of a superconducting CW drive linac at UHF frequency and a microwave main linac.

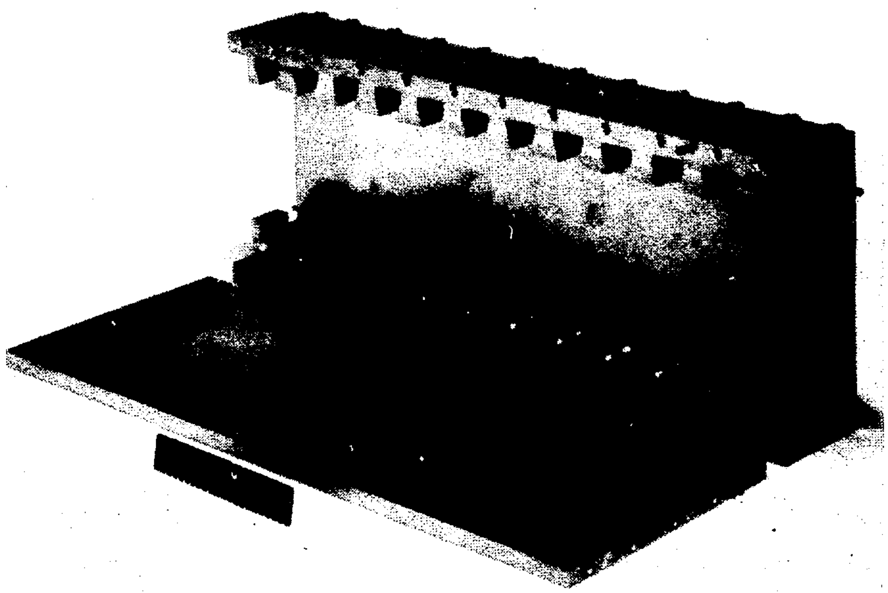

Fig. 2. Scaled-up model of transfer structure

ELECTRON-POSITRON LINEAR COLLIDER R&D PROGRAM AT KEK

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INTRODUCTION

It is generally recognized that the study of elementary particle interactions should be extended to the multi-TeV region for penetration of the frontier described by the Standard Model. This necessarily demands development of new accelerators, both hadron colliders and lepton colliders, of energies a few to tens of TeV. In Japan, the High Energy Committee, high energy scientist's organization in Japan, showed in 1986 the directions in which we should go after TRISTAN to pursue physics in the new energy frontier. Those are summarized as follows.

1. Immediate initiation of R&D efforts to investigate a possible construction of an electron-positron linear collider of the beam energy 0.5 - 1 TeV as a home-based facility.
2. Promotion of the international collaboration which will lead to the participation in experiments to be done by super-high energy hadron colliders as SSC and LHC.

Responding to this High Energy Committee's proposals, KEK has organized a group to do a coherent R&D work on the linear collider this year. The tasks imposed on this group are to make and execute an R&D program to determine the feasibility of a TeV class linear collider in approximately five years. It should be noted, however, that the R&D work required will be far beyond the scope of one institute and should be done in a frame of an international cooperative program.

OUTLINE OF THE R&D PROGRAM

In order to grasp technical difficulties inherent to TeV class linear colliders, we present in Table 1 the general parameters of a 0.5 TeV + 0.5 TeV linear collider which is tentatively designed. Investigations of those parameters generally specify areas which the present R&D program should encompass as follows.

1. Theoretical works on (a) system design including injection damping rings, linacs, and final focuses, and (b) beam dynamics such as beam-beam disruption, beamstrahlung, and instabilities of an intense bunch accelerated in linacs.

2. Development of high gradient accelerating structures which can attain the accelerating field higher than 100 MV/m in practical operations.

3. Development of high power sources of an output power larger than that presently realized by an order of magnitude.

4. Development of final focussing devices.

5. Investigation of ground motion and development of static and dynamic methods to install and align accelerator structures with an accuracy better than submicron meters.

A major experimental R&D program planned at KEK is to build a test accelerator facility as described below. The facility will be a multipurpose one and expected to offer means for developments of high gradient accelerating structure and high power RF sources as well as studies of interactions between beam and accelerating structures.

Recently the superconducting cavity R&D group of KEK has begun an experimental study to investigate a possible application of newly discovered oxide superconducting materials to RF cavities. If a cavity which generates an accelerating field as high as 50 MV/m at liquid nitrogen temperature can be developed, the superconducting linac will also become a strong candidate for the TeV class linear collider.

In parallel with the experimental work, considerable efforts are also to be directed to design studies of not only a TeV class linear collider but also a fairly lower energy one. Construction of such a prototype accelerator might become necessary preceding the TeV one. At the moment no guidance exists as to the energy of the prototype. It will be influenced both by future progress of R&D works including the operation of SLC and by require-

Table 1 Parameters of a linear collider tentatively designed at KEK

Beam related parameters

Beam energy, E_0	0.5 TeV
Luminosity, L	1×10^{33} $cm^{-2}sec^{-1}$
Beam power, P_b	7.5 MW/beam
Disruption parameter, D	0.45
Aspect ratio, σ_y^*/σ_x^*	1
Enhancement factor, H	5.7
Beamstrahlung parameter, δ_{cl}	0.1
Number of particles per bunch, N	4.8×10^{10}
Bunch frequency, f_B	2×10^3 sec^{-1}
Normalized emittance, $\gamma\varepsilon$	1.8×10^{-5} m•r
Final focus parameter, β^*	1 cm
Bunch length, σ_z^*	0.6 mm
Bunch radius, σ_r^*	0.43 μm

Linac parameters

Length per linac, L_ℓ	5 km
RF frequency, f_{rf}	10 GHz
Accelerating gradient, G	100 MV/m
Attenuation parameter, τ	0.65
Filling time, T_f	140 ns
RF and structure efficiency, $\eta_{rf} \cdot \eta_s$	0.25
Energy extraction efficiency, η_b	0.06/bunch
Total wall plug power, P_{ac}	100 MW/linac

ments of physicists, provided that the prototype will also be used to produce physics outputs.

TEST ACCELERATOR FACILITY

Numerous new ideas on the linear collider have been proposed to solve such technical problems as mentioned above. On a relatively short time scale, however, the solutions should be sought among the fairly conventional approaches. As one of such approaches we are going to build a test accelerator facility as depicted in Fig. 1. The main ingredient of the facility is a 1 GeV S-band linac with an accelerating field as high as 0.1 GeV/m. The linac is about 10 m long and will be composed of three sections of a 3.3 m structure unit. For a conventional $2\pi/3$-mode constant impedance structure with the beam aperture 22 mm in diameter, the group velocity would be approximately 0.011c and the shunt impedance 55 MΩ/m. Hence the required peak RF power per unit section would be 840 MW for the average accelerating gradient 0.1 GV/m. If we assume klystrons of output power exceeding 100 MW are available, eight such tubes should be employed for each unit. One of the candidates will be the SLAC 50/45 type 60 MW klystron which is expected to generate an output power of about 100 MW for pulse width less than 1 μs. The output power from those eight tubes will be combined straight forwardly by a series of 3 dB hybrids. The input coupler of each structure will have two or four input ports for the sake of field symmetry on the beam axis and also to reduce the number of the 3 dB hybrids.

A high gradient S-band accelerating structure has already been tested at KEK.[1] The structure is composed of three regular cells and two coupler cells at each end and operated in the $2\pi/3$ traveling wave mode. Main parameters of the regular section are summarized in Table 2. The structure was tested by inserting it in a resonant ring as shown in Fig. 2. The klystron output power of 30 MW with a pulse width 2 μs was fed into the ring through 6 dB coupler to give a maximum circulating power inside the ring of about 120 MW. After about five-hundreds hours of integrated microwave conditioning, an accelerating field gradient of 104.5 MV/m was stably achieved ex-

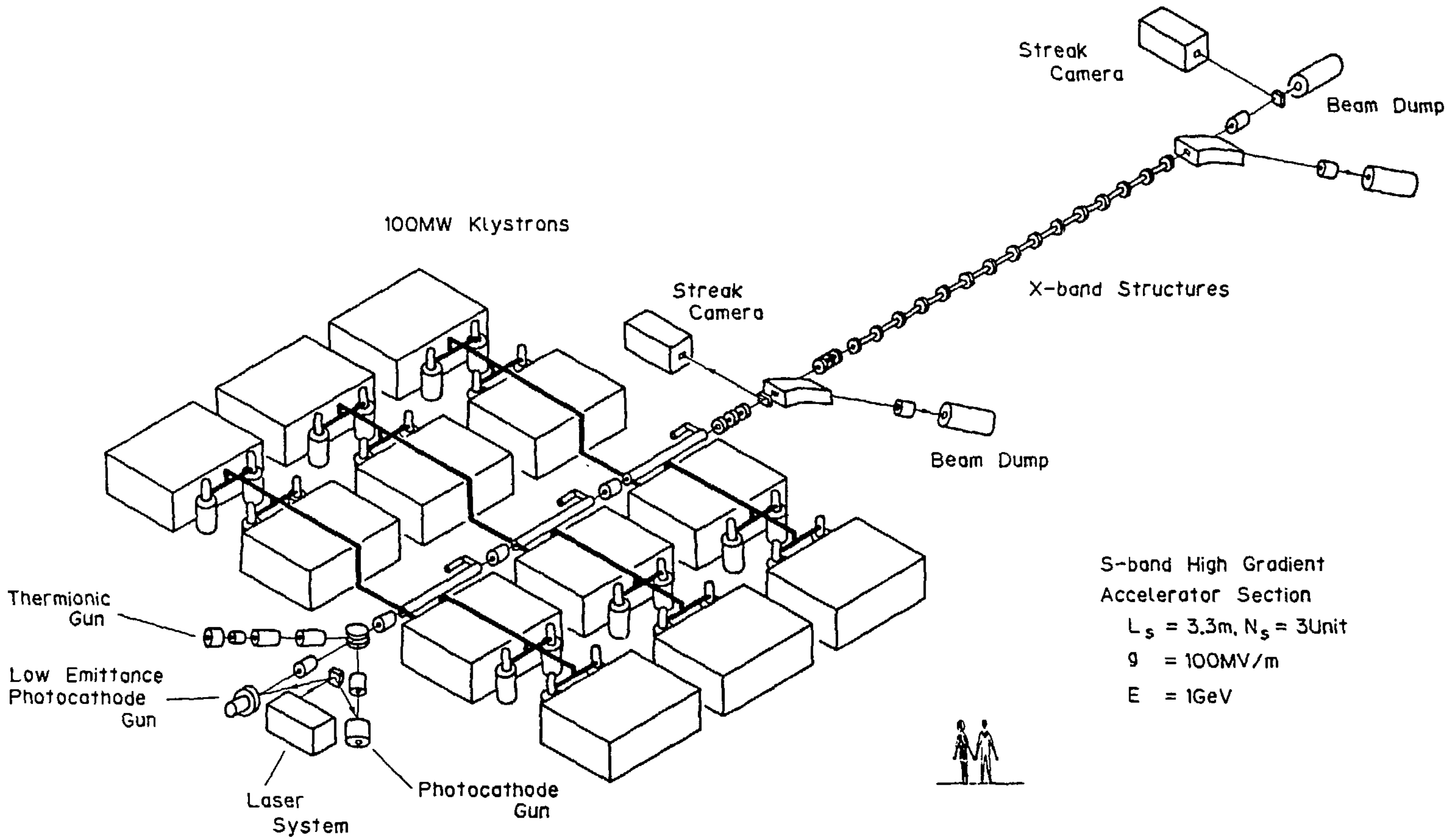

Fig. 1 KEK test accelerator facility.

Table 2 Parameters of the accelerating structure

Phase shift/cell	$2\pi/3$
Structure length	17.5 cm
Beam hole diameter	1.6 cm
Cavity diameter	8.132 cm
Resonant freqeuncy	2856.15 MHz
Q	13330
Shunt impedance	63.1 MΩ/m
Attenuation	0.7017 Neper/m
Group velocity	0.0032 c

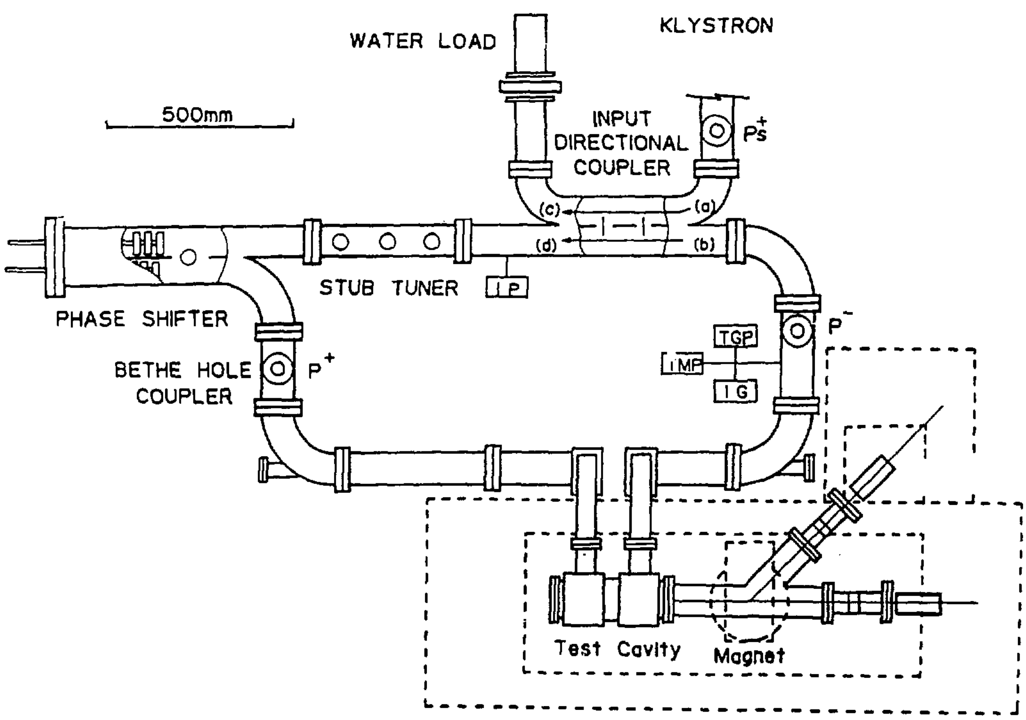

Fig. 2 Experimental set-up for high accelerating field generation.

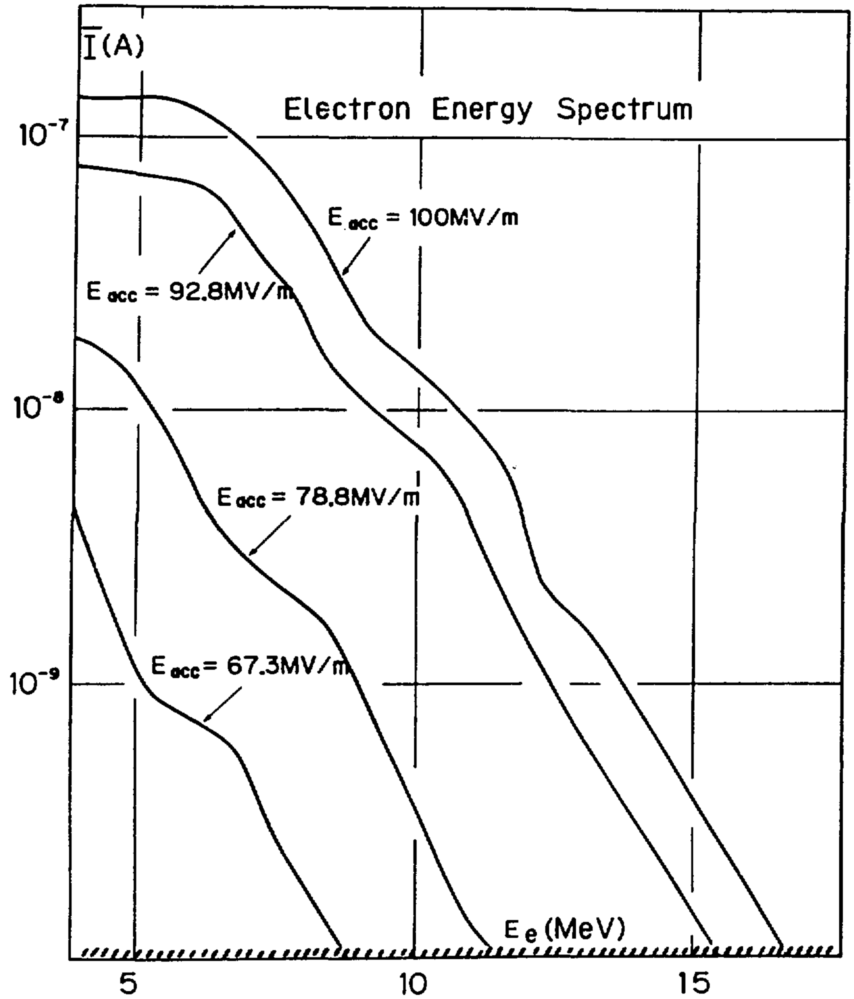

Fig. 3 Energy spectra of field emitted electrons for various accelerating field.

tending for more than ten hours. This was experimentally proved by measuring energy spectra of the field emitted electrons as shown in Fig. 3.

As illustrated in Fig. 1, we will install a long section of X-band structures to transmit electron bunches accelerated by the 1 GeV test linac. For the moment it is very difficult to say what frequency range will be best suited to TeV class linear colliders. Recent progress in the theoretical design studies, however, seems to show a preference of considerably higher frequencies than S-band, 10 GHz the lowest. In such a case, serious problems will arise from beam induced transverse wake fields, which scale as the third power of the operating frequency. Unless errors on jittering of the injected bunch position, misalignment of structures and Q-magnets etc. are minimized enough, effects of this wake would make stable transmission of a high current bunch extremely difficult. Therefore, with the present facility we plan to investigate a transverse emittance growth due to the wake by constructing a transmission line made of the X-band structures with a total length corresponding to several betatron wave lengths or 10 to 20 m.

With regard to the RF source, there is no available X-band high power tube. If we scale from the S-band case, to obtain an accelerating gradient of 0.1 GeV/m for the X-band structure will require an RF power of around 65 MW per 0.5 m long unit structure with a pulse width about 0.2 μs.

In the past few years, an experimental development of a lasertron is underway at KEK.[2] The purpose of this work are to study high RF power generation by lasertron and to investigate a possible application of the lasertron gun to a high current and low emittance electron source. Theoretical analyses show that compared with a conventional klystron the lasertron will have the potential merit of producing higher peak power with higher efficiency. The present lasertron has such a structure as drawn in Fig. 4 and is assembled together with a laser system, a modulator power supply, a coaxial cable to supply charge to the photocathode, and a beam collector as shown in Fig. 5. A cw mode-locked Nd:YAG laser produces a continuous train of 85 ps infrared optical pulses with 5.8 ns separation. After pulse modulated and waveform shaped, the output is converted by a second harmonic generator into green light of the wave length 532 nm, pulse width 60 ps, and optical power about 40 mJ. Then, a mirror system increases the frequency by a factor of 16 to form a 2856 MHz optical pulse train. A GaAs wafer with an active area of 20 mm in diameter is used as the photocathode. Its quantum efficiency is expected to be about 5 %. Results of the first experimental test of the present system are given in Fig. 6. The figure shows the beam current I and output RF power P_{rf} as a function of the

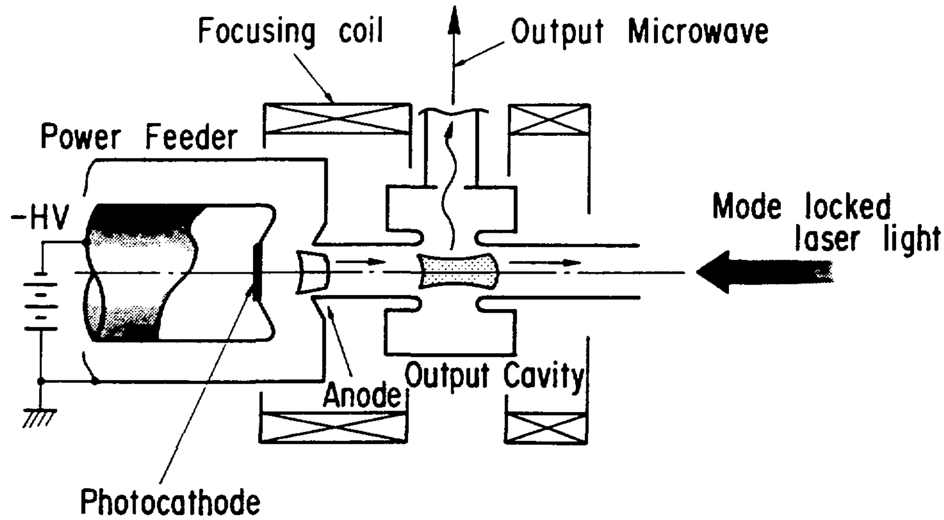

Fig. 4 A conceptual drawing of the lasertron.

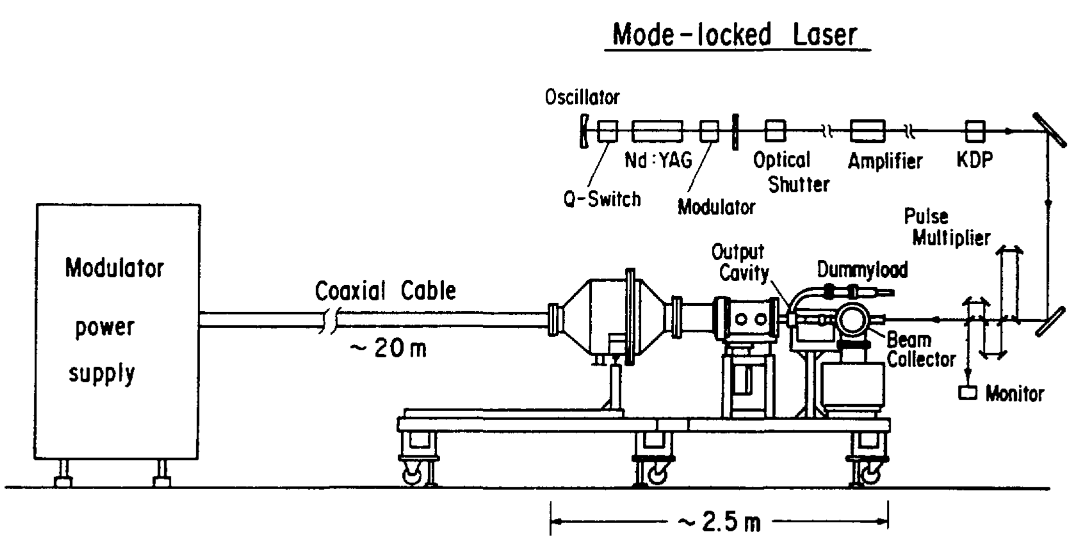

Fig. 5 Experi..ental arrangement of the KEK lasertron system.

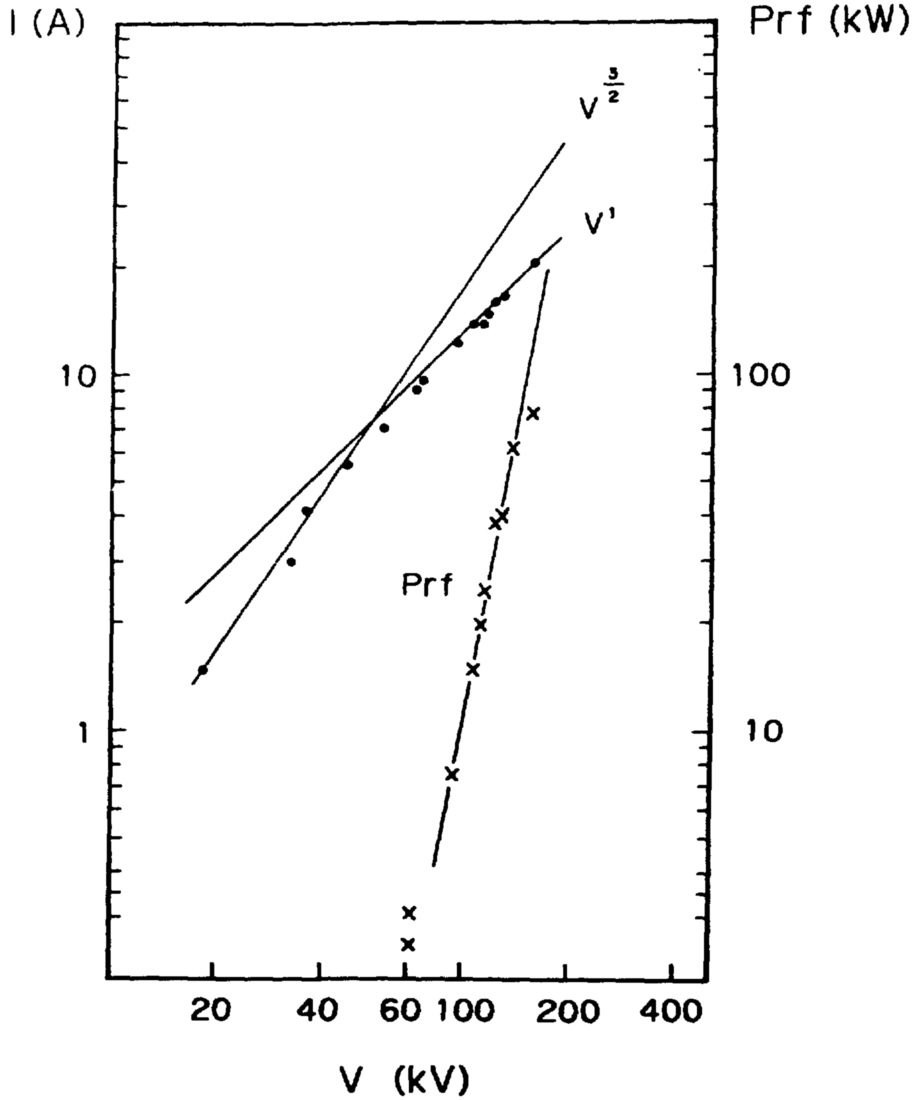

Fig. 6 Beam current and output RF power of the lasertron as a function of the accelerating voltage.

accelerating voltage V. Below 50 kV, I exhibits a normal behavior characteristic of a klystron. Above 50 kV, I is proportional to V and indicates a deviation from the normal diode characteristics. The maximum RF output power attained so far is about 80 kW with a peak current of 21 A and an applied pulsed high voltage of 150 kV. Efforts to improve the performance of the present system are in progress aiming at achieving an output power exceeding 1 MW.

OBSERVATION OF A REGULAR GROUND TREMOR

In connection with problems of the fine beam alignment required for linear colliders, we have tried to measure a regular ground tremor in the KEK site. A system of high sensitivity seismometers was set at the depth of 100 m underground at the site boundary about 100 m away from a main public road. The stratum on which the seismometers were placed is a hard sand layer with an n-value larger than 100. The seismometer system consists of three units to measure vibration amplitudes in three directions. Each unit has a sensitivity of better than 0.01 μm. The measurements were carried out through a week by using an automatic data recording system. Typical data measured are illustrated in Fig. 7 and 8. Figure 7 shows the tremor amplitudes in horizontal, North-South and East-West, and vertical, Up-Down, directions. Figure 8 shows frequency spectra of the tremor obtained by Fourier analysing the amplitude data. Case A and B denoted in the figures correspond to the data obtained in the night-time and day-time, respectively. As seen from Fig. 7, the peak to peak amplitudes of about 1 μm in the day-time are suppressed to about 0.2 μm in the night-time. Correspondingly, the frequency spectra of the day-time data contain far larger high frequency components than those of the night-time data indicating the dominant source of the ground tremor is vehicular traffic on the public road.

ACKNOWLEDGEMENTS

The authors wish to thank all of the KEK linear collider R&D group for helping them to prepare this manuscript.

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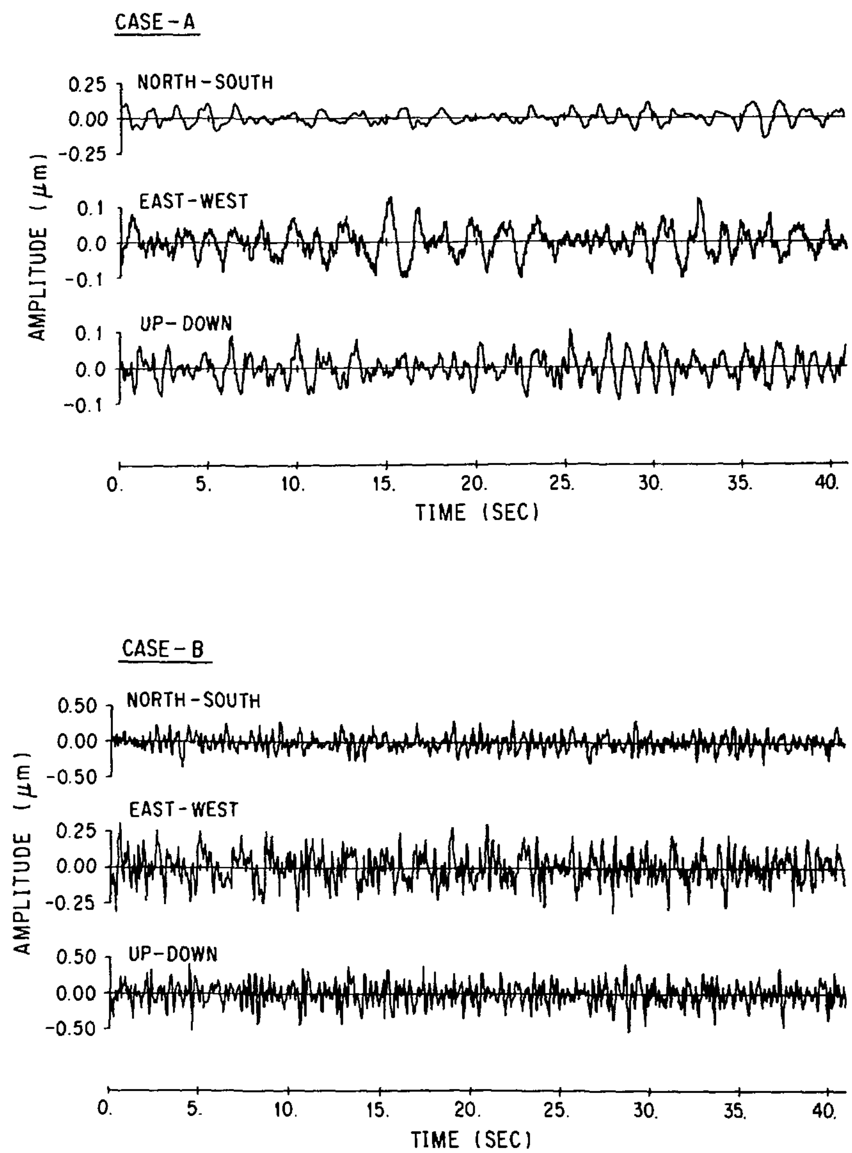

Fig. 7 Ground tremor amplitudes in horizontal, North-South and East-West, and vertical, Up-Down, directions. Case-A and B correspond to the data obtained in the night-time and the day-time, respectively.

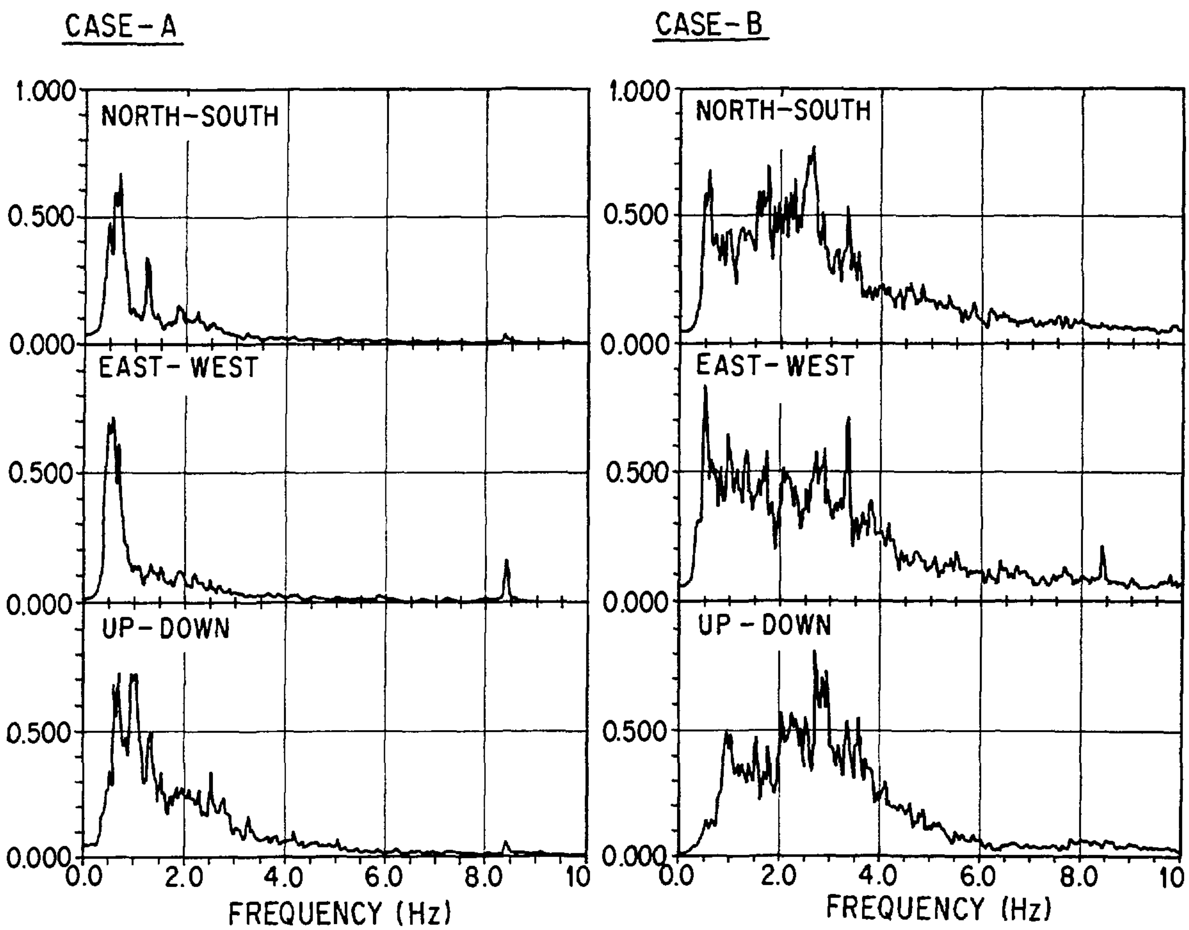

Fig. 8 Frequency spectra of the ground tremor as shown in Fig. 7.

LINEAR COLLIDER RESEARCH AT SLAC*

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1. INTRODUCTION

We, at SLAC, are in the process of preparing the SLC, the first linear collider, for the initial physics run in the spring of 1988. The present status of that process is covered in Ref. 1 and 2, and also in Ref. 3 which appears in these proceedings. Therefore, the time is ripe for initial investigation into the next generation of linear colliders.

Towards this end, Burt Richter has charged the Accelerator Department at SLAC to design a next generation linear collider by about 1990, so that the construction might start in the mid 1990's $\pm$ a couple of years. The general parameters of such a machine are listed in Table 1. The center of mass energy is taken to be about 1 TeV and the luminosity in the range $10^{33} - 10^{34}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$. These two parameters force the design to be a non-simple extension of the SLC.

The other requirements in Table 1 are somewhat arbitrary but allow the machine to be built on a Stanford site with "reasonable" wall-plug power. The technology used in the machine must be realizable by the early 1990's. A possible site for such a machine is shown in Fig. 1. The Tev Linear Collider (TLC) is about twice as long as the SLC; however, the site shown in Fig. 1 is entirely on Stanford land.

A linear collider can be divided into 4 main subsystems: *Damping Rings* provide low emittance beams with the appropriate intensity and repetition rate. Next, to prepare a short bunch for injection into a high gradient accelerator structure, we need a section for *Bunch Rotation and Pre-acceleration.* The *Linac* is then used to accelerate the beams to high energy while maintaining the emittance of the beam. Finally, the *Final Focus* is used to focus the beams to a small spot for collision. This must yield a luminosity consistent with constraints on beam-beam effects (disruption and beamstrahlung).

* Work supported by the Department of Energy, contract DE – AC03 – 76SF00515.

Table 1. GENERAL PARAMETERS

Energy	2×0.5 TeV $= 1$ TeV in center of mass.
Luminosity	$10^{33} - 10^{34} \mathrm{cm}^{-2}\mathrm{sec}^{-1}$, (preferably the latter).
Length	Each Linac $\lesssim 3$ Km.
Power	$\lesssim 100$ MW per Linac.
Technology	Must be realizable by 1990–92!

Before beginning the discussion of each of the subsystems, it is useful to present a possible parameter set for the next linear collider. This parameter set appears in Table 2 and was generated by Bob Palmer.[4] It is a self-consistent set in which there was an attempt made to optimize based on approximate formulae and scaling for the various subsystems. The repetition rate and number of particles per bunch are somewhat less than the SLC design. The accelerating structure for the example in Table 2 is at 4 times the SLC frequency and is powered to 10 times the SLC acceleration gradient. This leads to short filling times for the travelling wave structure and to quite high peak-power requirements. The final spot size is very much smaller than the SLC design. This is achieved by a combination of a much smaller emittance of the beam and a small beta function at the final focus. For this example the beamstrahlung parameter is about 1/3.

These self consistent solutions change depending upon the choice of frequency of the linac. Several other possibilities appear in Ref. 4. In this paper, this particular example is used to illustrate the general nature and scope of the various subsystems.

In the next section, we begin the discussions of the various subsystems at the final focus and interaction point since this is where we produce the physics. In subsequent sections, we work our way upstream to discuss qualitatively various features of each subsystem.

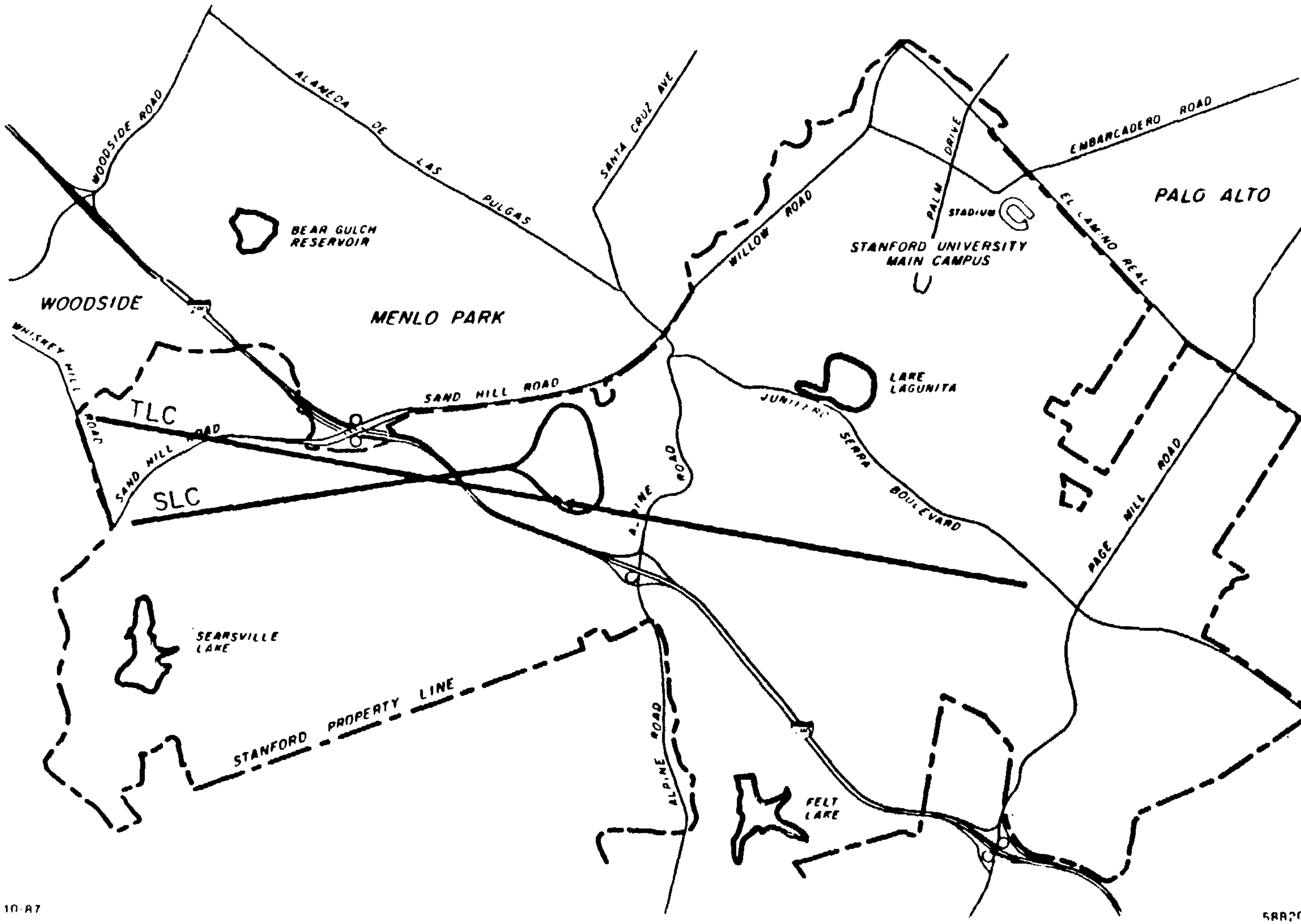

Fig. 1. A Possible Site for the TeV Linear Collider (TLC).

Table 2. SOME POSSIBLE PARAMETERS OF 1 TEV COLLIDER*

(Used in defining R&D Programs)

LUMINOSITY	
$\mathcal{L}$	$1.7 \times 10^{33} cm^{-2} sec^{-1}$
AC Power/Wall Plug	100 MW
Repetition Rate	100 Hz
Number of particles per bunch	1.8×10^{10}
RF POWER	
Frequency	11.4 GHz
Acceleration Gradient	186 MV/m
Group Velocity β_g	.08
Pulse Length	45 nsec
Distance between feeds	1.2 m
Watts per meter	1.2 GW
FINAL FOCUS	
β_y^*	.05 mm
β_x^*/β_y^*	300
Final Focus Pole Tip Field	1.4 Tesla
σ_y	1.5 nm
σ_x	270 nm
σ_z	.04 mm
Disruption	14
Beamstrahlung δ	.33
DAMPING RINGS	
Vertical emittance ϵ_y	3.5×10^{-8} m rad
ϵ_x/ϵ_y	100
Energy	1 GeV
Damping Time	2.3 msec
Average Radius	15 m

*Not necessarily optimum, but self-consistent.

2. FINAL FOCUS

The final focus design from Table 2 assumes that flat beams collide with a small crossing angle. Why should the beam be flat?

The purpose of a flat beam is to increase luminosity while controlling beamstrahlung and disruption. As we move from round beams to flat beams, the beamstrahlung from the beam-beam crossing becomes independent of the vertical size. Thus we can increase the luminosity without affecting the energy loss due to beamstrahlung.

Why should we have a small crossing angle? If we allow the beams to cross at angles less than σ_x/σ_z where σ_x is the horizontal (wide) dimension and σ_z is the bunch length, then the luminosity is changed very little when compared to head-on collisions since there is almost complete overlap of the two distributions. However, this has the great advantage of allowing the disrupted beam, after collision, to follow a different path than the entering beam. Therefore, one can design the final quadrupole to accept the incoming emittance of the beam, and thus it can have a very small aperture. This leads to the reasonable pole tip field shown in Table 2. The quadrupole shape can allow a separate channel for the disrupted beam.

To achieve the small spot in an aberration free way, it is necessary to provide some chromatic correction upstream of the final quadrupole doublet. Bends are used to disperse the beam horizontally, while sextupoles provide the different focussing forces for different energy particles. These bends cause the beam to emit synchrotron radiation. This chromatic correction section must be designed so that the total energy radiated by these bends is quite small, and in addition so that the transverse emittance is not diluted by the diffusion caused by emission of the discrete photons of synchrotron radiation.

Finally, to conclude this section, we may need to correct higher order chromatic effects for the vertical dimension. This may not, however, be needed horizontally because of the much larger horizontal size.

3. LINAC

3.1 Power Sources

The linac is envisioned to be similar to the SLAC disk-loaded structure with a frequency at least 4 times the present SLAC frequency. The irises will probably be relatively larger to reduce transverse and longitudinal wake fields. This would be driven by an RF power source with the capability of about 1 GW per meter of structure with a pulse length of about 50 nsec. The peak power can be reduced somewhat by using smaller irises in the structure and longer pulse lengths.[5] However, this increases the transverse wake fields and causes instability transversely. In either case this high peak power is difficult to obtain and is a key area for research.

Presently, the SLC klystrons produce 67 MW of power for about 3.5 μsec at 2.86 GHz. This is used to feed 12 m of structure. For the next linear collider, we are investigating two approaches.

RF Pulse Compression

In Fig. 2a, you see illustrated the basic principle of RF pulse compression. A long modulator pulse is converted by a high power, 'semi-conventional' klystron into RF power with the same pulse width. This RF pulse is then compressed by cleverly slicing the pulse and re-routing the portions through delay lines so that they add up at the end to a high peak power but for a small pulse width. This scheme was suggested by D. Farkas at SLAC and is presently under experimental investigation also.[6] With a factor of 16 in pulse compression, the method requires a 60 MW klystron with a 1 μsec pulse length for each meter of the accelerator.

The Relativistic Klystron

In Fig. 2b, you see the principle of the relativistic klystron illustrated. In this case, the pulse compression happens *before* the creation of RF. This technique makes use of the pulsed power work done at LLNL in which magnetic compressors are used to drive induction linacs to produce multi-MeV e^- beams with kiloampere currents for pulses of

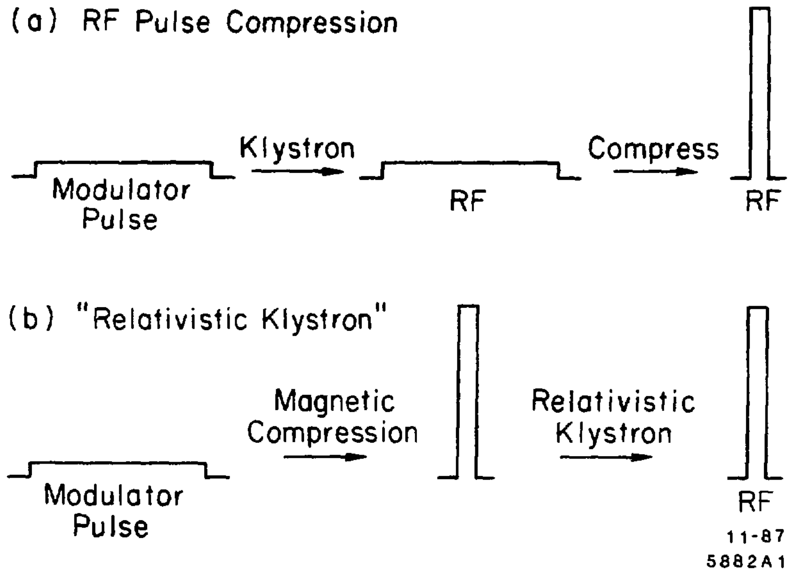

Fig. 2a. Illustration of RF Pulse Compression
2b. Illustration of the Relativistic Klystron With Magnetic Compression

about 50 nsec. These e^- beams contain gigawatts of power. The object, then, is to bunch the beam at the RF frequency to extract a significant fraction of this power. This can be done either by velocity modulation or by dispersive magnetic "chicanes". After bunching, the beam is passed by an RF extraction cavity which extracts RF power from the beam.

Presently, we are collaborating with LLNL on a relativistic klystron experiment which makes use of the ARC facility (e^- beams 1.2–4.5 MeV and 1–3 KA). This collaboration will continue on ETA II (e^- beams 7 MeV and 1–3 KA) later after it becomes operational. The present program has achieved 70 MW at 8.6 GHz in a test run at ARC. We hope to achieve about 500 MW at 11.4 GHz early in 1988. The purpose of these experiments is to first achieve significantly higher RF power than the SLC klystrons at a much higher frequency and secondly to drive an accelerator section to fields exceeding 200 MV/m to test breakdown and field emission.

A final power source along these lines might have a 10 GW beam (say 2 KA and 5 MV) which is RF modulated at some stage in the acceleration process. The RF might then be extracted with greater than 50% efficiency in 5 extraction gaps to drive about 5 meters of accelerator structure. Of course, there is a continuum of possible devices from a rather short relativistic klystron up to a full two-beam accelerator as envisaged by A. Sessler and S. Yu.[7]

3.2 TRANSPORT

Of course, the beam must be transported as well as accelerated in the linac. This is complicated by deflecting wake fields caused by the beam as it moves off axis slightly in the accelerator. For a single bunch, this leads to very tight tolerances on beam position measurement and on the alignment of quadrupoles. It also necessitates opening the irises of the structure to reduce the transverse wakefield to tolerable levels.

In order to obtain the highest luminosity, it will probably be necessary to have many bunches of particles per RF pulse. This allows a much more efficient transfer of energy and thus for little increase in wall-plug power, one can possibly increase the luminosity by a factor of 10 with about 10–20 bunches per pulse. Unfortunately, the transverse deflecting wakes are once again a problem. Each bunch induces a long-range wakefield which acts on many trailing bunches. This leads to the beam break-up of the bunch train. This is a very serious problem which so far has not been solved. However, for 2 or 3 bunches, the problem is not so severe, and indeed the SLC plans 3-bunch operation ($e^+e^-e^-$). For many bunches, one probably must damp the long-range transverse wake by clever cavity design.

4. BUNCH COMPRESSION AND PRE-ACCELERATION

In order to obtain the very short bunches necessary for the linac, it is necessary to perform at least two bunch compressions. A bunch length of 50 μm in the linac puts a tight constraint on the longitudinal emittance of the damping ring. In addition, during the bunch compressions, it is necessary to keep the energy spread small to avoid the dilution of the transverse emittance. If we assume that we can transport 1% energy spread without diluting either transverse emittance, then at least two bunch compressions are needed. For example if we consider a 1 GeV damping ring with energy spread $\Delta E/E = 10^{-3}$ and a bunch length of 5 mm, the two compressions are shown in Table 3. The first one decreases the bunch length by an order of magnitude. This is followed by a pre-acceleration section to decrease the relative energy spread in the beam by an order of magnitude. One must avoid an increase of energy spread due to the cosine of the RF wave (and also due to beam loading). If this pre-acceleration is done at the present SLAC frequency and if the bunch current is as shown in Table 1, then the additional energy spread induced is about 5×10^{-4}. Neglecting this small increase, the next bunch compression happens at 10 GeV and serves to reduce the bunch length to about 50 μm. This is suitable for injection into the high frequency, high gradient structure.

5. DAMPING RINGS

The damping ring emittances are shown in Table 1. For the horizontal, they represent a factor of 10 decrease in emittance (a factor of 3 in beam size) from the SLC. For the vertical, they reflect the fact that damping rings provide an asymmetrical emittance naturally.

This small vertical emittance will not, however, be trivial to achieve since it requires tight orbit tolerances and the control of coupling and the vertical dispersion. However, experience shows us that large emittance ratios are possible; PEP has achieved $\epsilon_x/\epsilon_y \simeq 100$, and the VUV ring at BNL has achieved $\epsilon_x/\epsilon_y \simeq 300$. Thus we expect these ratios to be possible also in the next damping ring.

In addition, we must control the longitudinal emittance, and thus, avoid bunch lengthening in the damping ring. This means that the impedance of the ring must be carefully

Table 3. BUNCH COMPRESSION

E	$\Delta E/E$	σ_z	Compress $\rightarrow$	$\Delta E/E$	σ_z
1 GeV	10^{-3}	5mm	Compress $\rightarrow$	10^{-2}	0.5mm
[pre-acceleration at long wavelength, $\lambda = 10.5$ cm]					
10 GeV	10^{-3}	0.5mm	Compress $\rightarrow$	10^{-2}	50μm

controlled.

To gain experience with asymmetrical emittance, we are planning an experiment at the SLC which has the goal of achieving $\epsilon_{ny} = 3 \times 10^{-7}$ (an emittance ratio $\epsilon_x/\epsilon_y = 100$).

Recently, ICFA sponsored a workshop on low emittance production.[8] The general conclusion was that the emittances shown in Table 2 seem to be possible with only modest extensions of present techniques.

6. TOLERANCES AND MEASUREMENT PROBLEMS

Many of the key issues for the next linear collider are related to the tight tolerances required. In both the linac and damping ring, it will be necessary to measure the orbit position very precisely in order to be able to correct it. This will require a beam position monitor (BPM) precision of less than 10μm. Presently at the SLC, we measure beam position to about $50-100\mu$m, and in some cases, we can measure relative positions to about 20μm. Therefore, the next generation of BPM's should be about an order of magnitude more precise than the present generation. With smaller apertures and low noise designs, this will probably be possible.

In addition to careful measurement, we must also align the magnets very precisely. For the design in Table 2, this alignment tolerance is less than 10μm for magnet to magnet misalignments. This will require more careful survey techniques, and perhaps more importantly, the precise determination of the magnetic centers of all the focussing quadrupoles.

The problem of position measurement and correction is helped somewhat by pulse to pulse stability since for a stable beam one can average many successive measurements. This pulse to pulse stability is another key requirement to maintain the collision of the beams. Slow variations of the beam position can be corrected with feedback systems, therefore, much of the ground motion can be cured since it occurs at low frequency. However, variations of the beam at the repetition rate are uncorrectable except by vibration isolation techniques and careful power supply regulation.

In addition to the beam position, one must also measure the beam spot size. These measurements are used to check the optics and to measure the emittance of the beam. At the end of the linac in the example shown in Table 2, the spot sizes are

$$\sigma_y \simeq 1\mu\text{m}$$
$$\sigma_x \simeq 8\mu\text{m} \quad .$$

Since these are typical throughout the linac, routine measurements of such spot sizes and aspect ratios must be addressed. Presently at the SLC, the final focus spot will eventually be about 1μm; and, in fact, 5μm spots have already been measured with flying wire techniques. The SLC system is designed for the 1μm level, so for a future collider there is at least one option for spot size measurements in the linac.

The final focus spot is a completely separate question. In this case the spot sizes for the example shown in Table 2 are

$$\sigma_y^* \simeq 1.5\text{nm}$$
$$\sigma_x^* \simeq 270\text{nm} \quad .$$

Thus far, there are no specific proposals for this measurement. It is certainly a challenging problem; however, it could be attacked with significant resources since it occurs only *once* in the entire linear collider.

7. OUTLOOK

What are the prospects for a linear collider with 1 TeV center of mass in the near future? We have briefly discussed a few of the problems in the previous sections to emphasize that the next linear collider will *not* be just a simple extension of SLC technology. In spite of this, experience with the SLC is an essential ingredient. Various topics for research and development have been specified and detailed studies on many of the subsystems are beginning. A key element is the power source. Just now the relativistic klystron seems to be a promising candidate; however, future experiments and cost studies will tell the true story.

In spite of the amount of work yet to be done, with the combined efforts of the various laboratories around the world we may see a detailed design of a TeV linear collider in the next 2 to 3 years.

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PHYSICAL FOUNDATIONS FOR LINEAR COLLIDERS

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The new principled solution of the high energy problem is the creation of a facility with colliding linear electron-positron beams. In this case synchrotron radiation is negligible and the cost of the facility is proportional to the ultimate energy. However, in spite of seemed simplicity of the proposal, there are many complicated problems to be solved. In particular, to achieve the equivalent luminosity it is necessary to accelerate high - intense beams of very small emittance, so to get the cross section area of the order of 1 mkm^2 at the collision point. Also the value of the accelerating gradient in linear accelerators should be very high; 100 MeV/m as the total facility length is determined by this value.

VLEPP-COLLIDING LINEAR ELECTRON-POSITRON BEAMS

The VLEPP project was first reported at the International seminar on problems in high Energy Physics and Thermonuclear Fusion which was devoted to the 60th anniversary of academician G.I.Budker in the April of 1978. The information about this seminar and the VLEPP project was published in CERN COURIER [1]. Later the project was published in the proceedings of the ICFA-2 (1979) [2] and the 12-th International Conference on High Energy Accelerators, which took place in Fermilab [4-6, 10, 14].

A lay-out of installation is shown in Figure 1. The main VLEPP facility elements are the two identical linear accelerators. Linacs are several kilometers long with an energy gain of

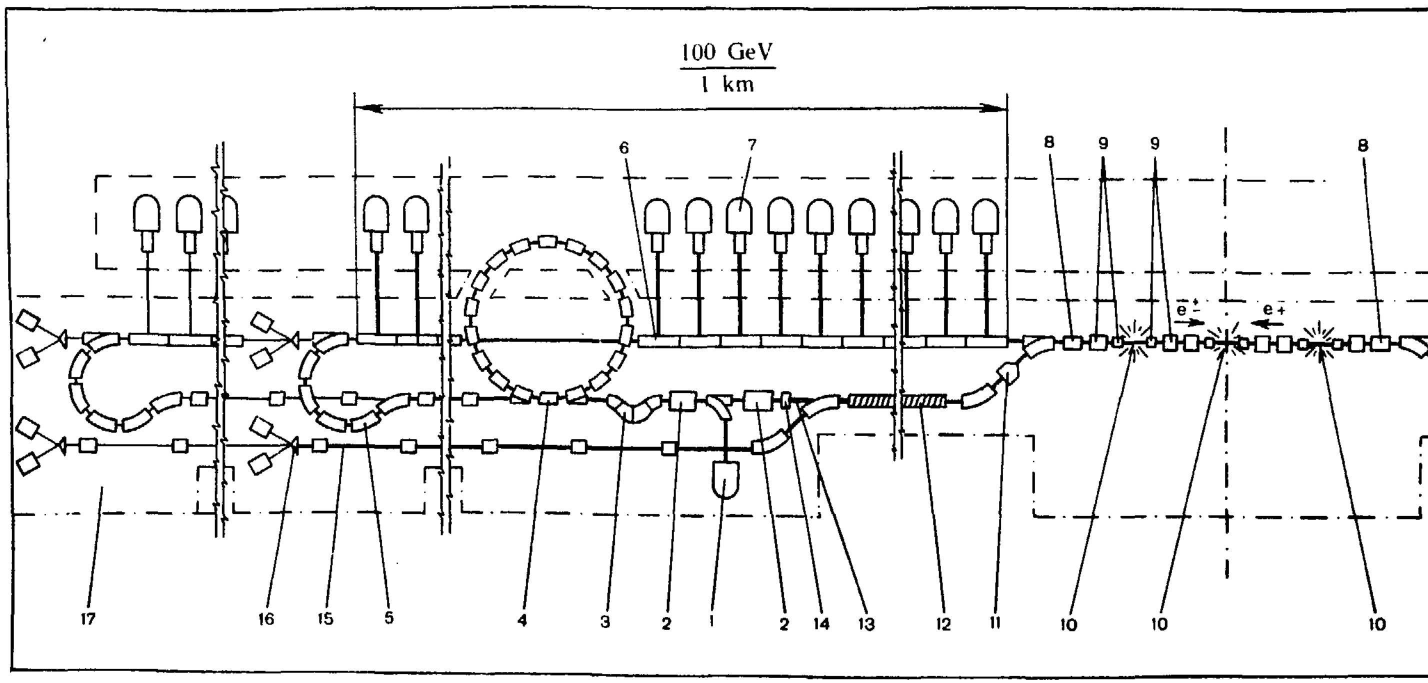

Figure 1. The general lay-out of the VLEPP facility:

1- initial injector; 2- intermediate accelerator ; 3- debuncher-monochromatizer; 4- storage ring; 5- buncher; 6- accelerating sections; 7- RF-generators; 8- pulse detector; 9- focusing lenses; 10- collision points; 11- spectrometer; 12- helical ondulator; 13- the beam of -quanta; 14- conversion target; 15- residual electron (positron) beam; 16- electron (positron) beam experiments; 17- the second stage.

about 100 GeV per one kilometer.

In one linac a single bunch of polarized electrons is accelerated and a bunch of also polarized positrons is accelerated in another one. The electron bunch moves in the direction to meet the positron bunch. Between the linacs a set of particle detectors are installed. Although electrons and positrons are collided only in one point, the position of the collision point can be varied, so that in different cycles different detectors can be in operation.

BEAM DYNAMICS IN LINEAR ACCELERATOR

The main problems in beam dynamics are connected with the realization of the acceleration of a single highly-intense electron or positron bunch with extremely low emittance in a linac. These problems were studied theoretically and successfully resolved. Results were first presented on the 6-th National Conference on Charged Particles Accelerators in Dubna in 1978 [3] . Later the results were published in the Proceedings of the 12-th International Conference on High Energy Accelerators [4-6] .

The efficient acceleration of a signle bunch in an accelerating structure is real when at the minimum energy spread, the bunch extracts a significant fraction of electro-magnetic energy stored in the structure. The main role in the single bunch acceleration is played by wakefield. In Figure 2 plots of electric force lines of a signle charged bunch moving in "empty" periodic iris-loaded waveguide at different time moments are presented. These plots were calculated by 1978 [1-3].

As the correct knowledge of wake fields was needed the method of numerical calculation of wakefields in an accelerating structure has been developed. The method is based on a time domain integration of Maxwell's equations [7] . Calculations for the VLEPP accelerating structure were carried out and the

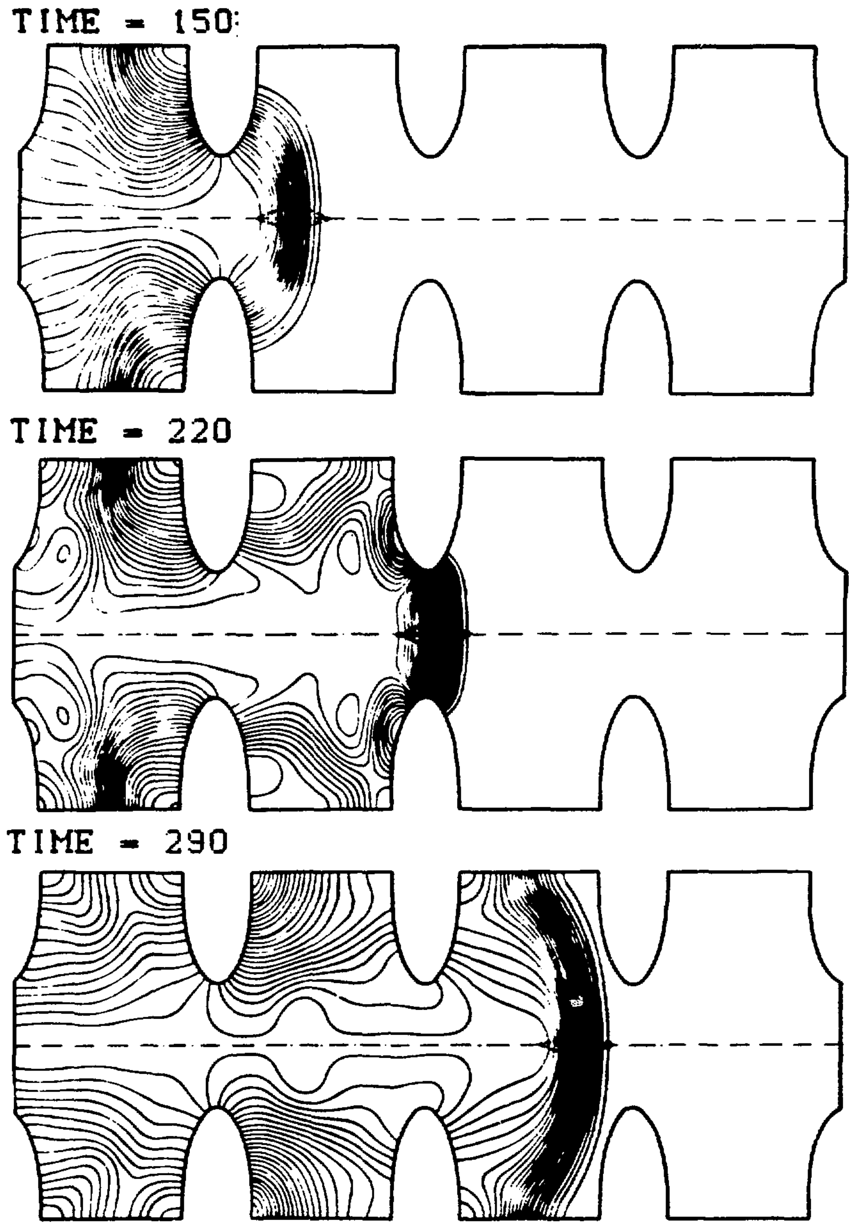

Figure 2. The dynamics of electric force lines of a charged bunch moving in "empty" periodic iris-loaded waveguide (1978).

results were presented at the National Conference in 1978 [3]. Later on also approximate analitical formulae for the amplitude values of the wakefield have been derived based on a physical diffraction model [4,9].

The net accelerating gradient is a superposition of the external generator field and the bunch wakefield. Energy gain as a function of a particle's position in the bunch is shown at Figure 3 for two bunches of different bunch length.

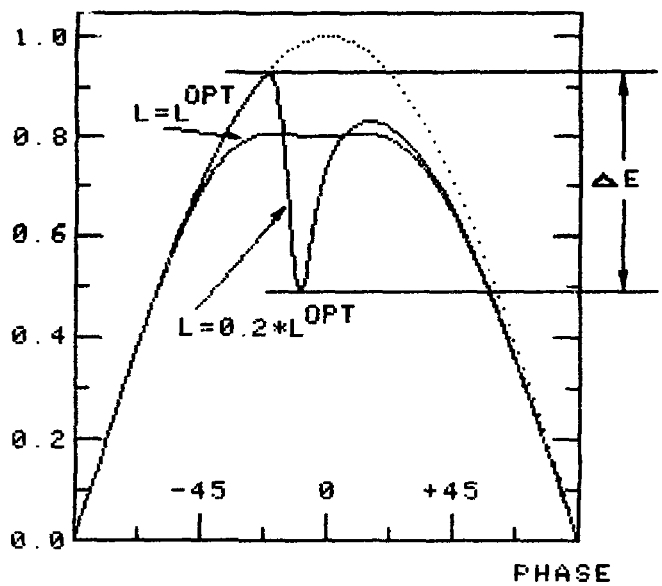

Figure 3. Net accelerating gradient for bunches of different length.

The results of calculations have shown that the optimum choice of the bunch and field parameters enables one to achieve a highly-efficient acceleration of a signle bunch and a sufficiently low energy spread simultaneously. Figure 4 demonstrates this fact. Here the distributions of particle's energy gain for bunches with different number of particles and optimized phase and bunch length are presented.

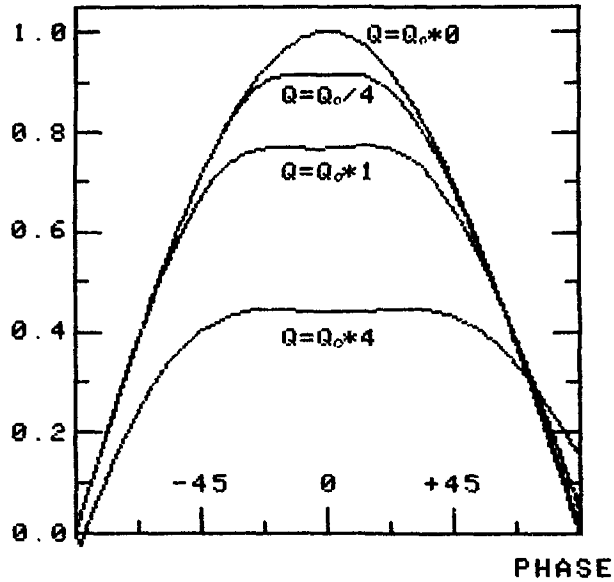

Figure 4. Net accelerating gradient for bunches of optimum length and phase. Optimum bunch length increases with the increasing of number of particles in a bunch.

Any deviation of bunch and field parameters from the optimum values leads to increasing the particle energy spread to some degree. The most stringent tolerance is for the stability of the phase. Phase deviation from the optimal value leads to a linear particle energy variation along the bunch. Net accelerating gradient for this case is shown in Figure 5.

The transverse dynamics of a single bunch is also determined mainly by the wakefields. When the bunch trajectory is shifted from axis, nonsymmetric fields are radiated and produce transverse forces upon the bunch particles. The specified feature of this force in the ultrarelativistic case is that the

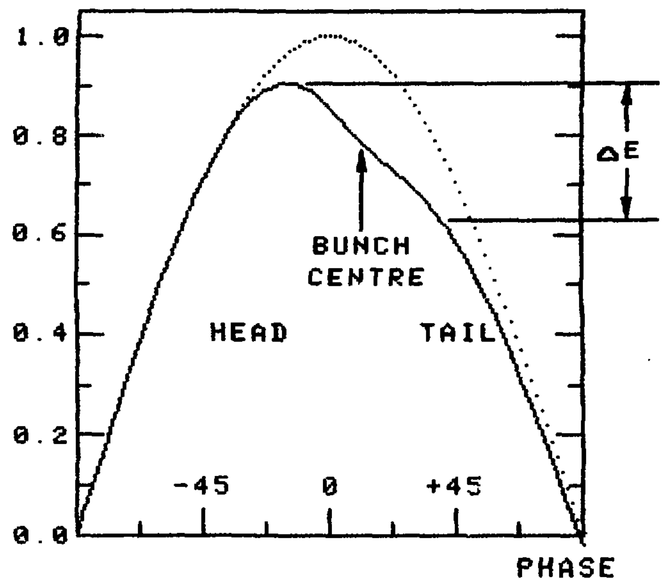

Figure 5. Net accelerating gradient for a bunch of optimum length but shifted phase.

field radiated by any particle acts only upon the trailing particles.

The action of this force leads to the growth of bunch emittance or in other words to the development of the transverse instability of a single bunch in a linac. In a linear accelerator with a periodic focusing system the transverse instability has a resonant character because the oscillation frequency of the driving particle and hence the force frequency is equal to the free oscillations frequency of a trailing particle.

The known methods of damping the transverse instability of a train of bunches in conventional linacs cannot be used for damping the single bunch instability.

In 1978 the method has been suggested of damping the single bunch transverse instability [3] . It's essence consists in introduction of a linear variation in particle energy along the bunch by a phase tuning of the accelerating field (Figure 5). The energy variation along the bunch leads to variation of frequencies of betatron oscillations and hence to damping the transverse instability. The dependence of the bunch effective emittance upon the sign and the value of energy variation along the bunch is shown in Figure 6.

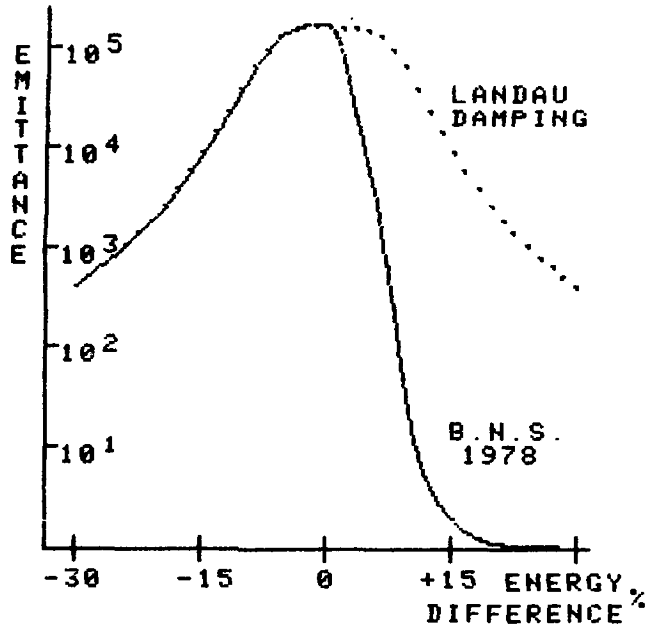

Figure 6. Final bunch emittance as a function of sign and value of the energy variation in the bunch.

This method of transverse instability damping is called Landau damping by several authors [10-12] , but it is not so. As it can be easily seen from the Figure 6, Landau damping is not so effective as our method.

Another mechanism of increasing an effective bunch emittance is due to an unstable position of the quadrupole lenses and accelerating sections, so called stochastic beam heating [3,6,8] . Figure 7 demonstrates the action of this mechanism. Fundamental result of the consideration of this mechanism is that the alignment of accelerating sections and quadrupole lenses must be done very carefully.

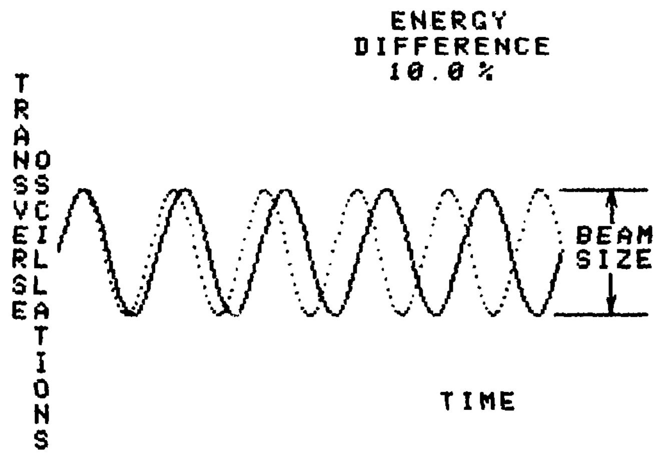

Figure 7. Stochastic beam heating.

BEAM-BEAM EFFECTS

The needed high luminosity of the linear colliders like VLEPP is achieved thanks to the focusing of the beams into extremely small spot of the order of square microns. Let's examine what happens in the collisions of such dense bunches. The electric and magnetic fields of bunches, of the intensity under discussion and micron transverse sizes, attain megagauss magnitudes. For ultrarelativistic particles the action of self-field is compensated, however, the action of electric and magnetic field of the opposite bunch is summed up.

The forces, which appear at the interaction point, become significant so that namely these determine the transverse beam-beam dynamics and most of the important characteristics of the accelerator, for example, luminosity, monochromaticity, final emittance of the bunches. etc.

Let us examine briefly two aspects of the influence of these fields.

1. Synchrotron radiation.

The particles moving in this fields emit synchrotron radiation. Consequently instead of collision of monochromatic electron-positron bunches, we obtain for round bunches a diffuse spectrum of e^+e^- reactions. The synchrotron radiation at the collision point leads to an additional energy spread in the beam.

$$\frac{\Delta E}{E} \simeq \frac{r_e^3 N^2 \gamma}{\sigma_z (\sigma_x+\sigma_y)^2}, \qquad r_e = \frac{e^2}{mc^2}$$

Here σ_x and σ_y are the transverse horizontal and vertical dimensions of the beam, σ_z is the length of the bunch, N is the number of particles in the bunch.

As we have seen, the fields and respectively the energy spread here decreases with increasing width of the bunch σ_x. Therefore one has to resort to flat bunches while conserving the cross section area to maintain the luminosity. For the first time to this fact the attention was paid in 1978 [1].

For the flat bunches the energy spread is proportional to 1/R, where $R = \sigma_x/\sigma_y \gg 1$; therefore the choice of the R is determined by the required monochromaticity [13,14].

2. The transverse beam-beam dynamics.

In collision of the bunches of the opposite sign (e^+e^-), their electric fields are compensated, and the magnetic ones are added. Therefore, the force is of attractive nature, and the particles will oscillate in the transverse direction. A clear parameter characterizing the force of a beam-beam interaction is the average number of plasma oscillations executed by the particles during their interaction. In each trans - verse direction this parameter is equal to

$$n_y = \frac{K}{2\pi}\left(\frac{r_e N \sigma_z}{\gamma \sigma_x \sigma_y} \cdot \frac{R}{R+1}\right)^{1/2}, \qquad n_x = n_y/\sqrt{R}$$

where K is the factor of the order of unity, dependent on the charge distribution inside the bunch. In the case of flat bunches , we have $n_y \gg n_x$, and consequently the motion occurs only in vertical direction. Let's examine briefly how the beam beam dynamics influences the luminosity. When the interac - tion between the bunches is negligible we have geometric luminosity:

$$L_0 = f\,\frac{N^2}{4\pi\sigma_x\sigma_y}$$

where f is the repetition rate.

It is important to get answers on two questions. The first is, where the oscillation is stable, and if it is not, then how large can the number of oscillations be before plasma instability increase the sizes of the beams during the collision and thereby reduce the luminosity. The second question is , what is the effect of the beam-beam dynamics on the luminosity.

The self-consistent problem of particle motion at the interaction point has been solved numerically using the method of "big" particles.

The analysis of computer results shows that if the number of oscillations is small enough $n_y < 1$, the pinch-effect is observed, which decreases the transverse size of the bunches , that leads to the increasing of the luminosity maximum 2.2 times compared to geometrical one. The results are presented in Figure 8.

Figure 9 shows the collision of two flat bunches with Gaussian charge distribution for $n_y = 0.6$, that is near to the value of that parameter for VLEPP.

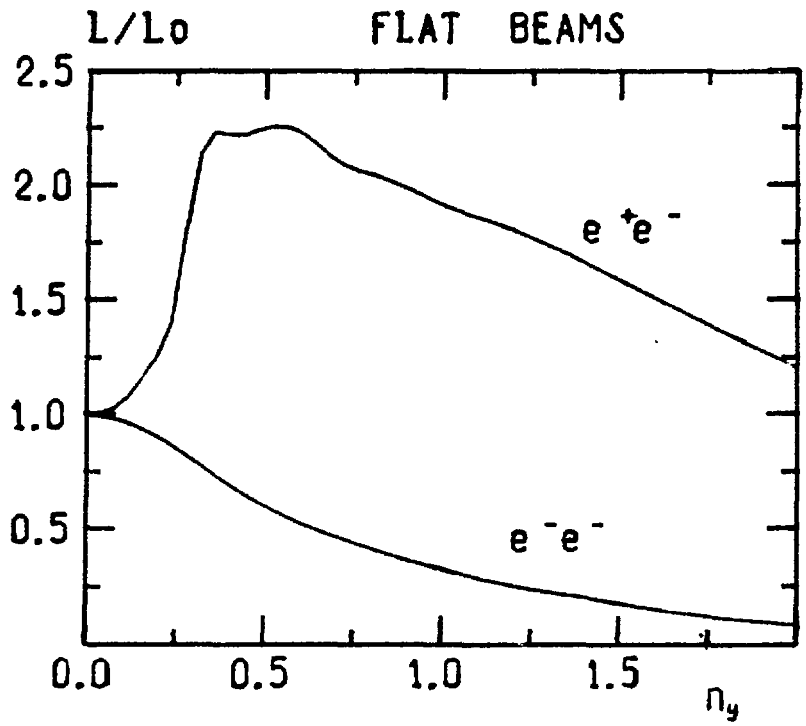

Figure 8. Luminosity as a function of the number of oscillations for e^+e^- & e^-e^- beams.

However, if the number of oscillations is greater then 2, the plasma instability developes, that gives as a result the considerable increasing of the transverse sizes of the bunches during the collisional time and thereby the luminosity degrades. This condition determines the ultimate density of the bunches. Note that the effect being discussed sharply diminishes the attainable luminosity of e^+e^- colliding beams.

Initial offset of the opposite charged bunches leads to decreasing in luminosity, but considerably slower than in the case of non-interacting bunches due to attraction between them. Figure 10 shows the beam-beam dynamics for bunches with uniform charge distribution when initial offset is equal $2\sigma_y$.

For equal charged beams the luminosity is always less than geometrical (see Figure 8).

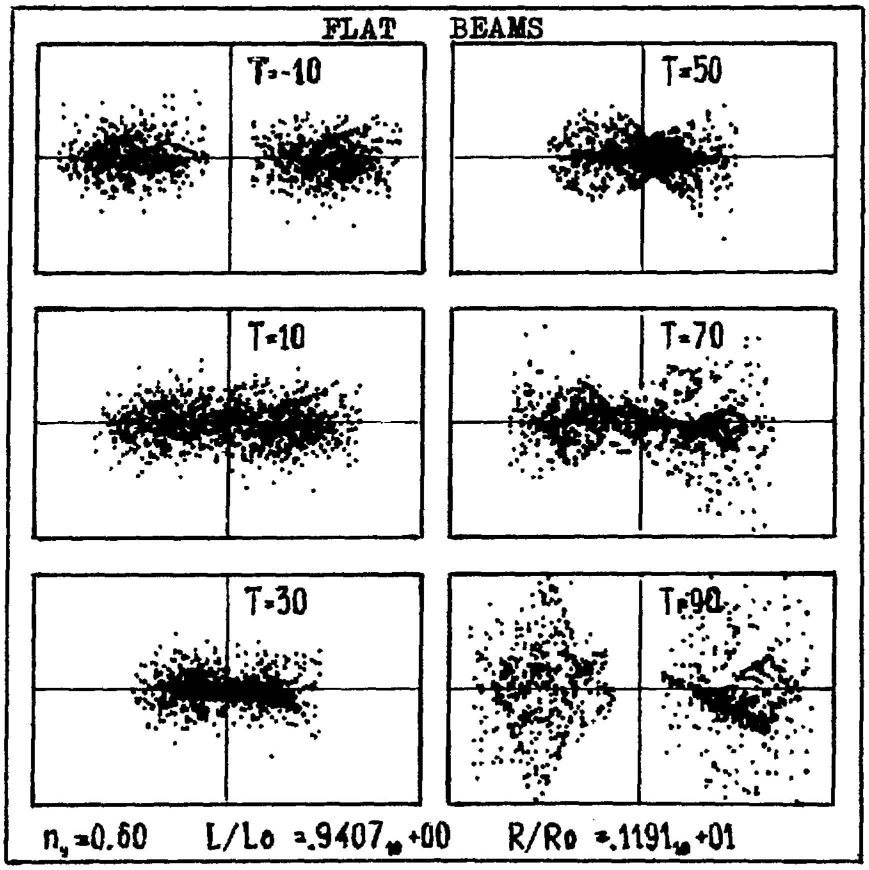

Figure 9. Central collision. Gaussian distribution.

INVESTIGATION OF THE MAXIMUM ACCELERATING GRADIENT

The main idea of studing a maximum attainable electric field at the copper surface is demonstrated in Figure 11.

The cavity consists of the testing plane surface and the foundation, which is manufactured from the bronze. The electric contact between the different parts of the cavity is achieved by powerful hydraulic clamp. The profile of the cavity is selected to obtain the maximum electric field at the centre plane surface. The tested plane surface of the cavity can be changed easily. The magnetic spectrometer is installed after a cavity

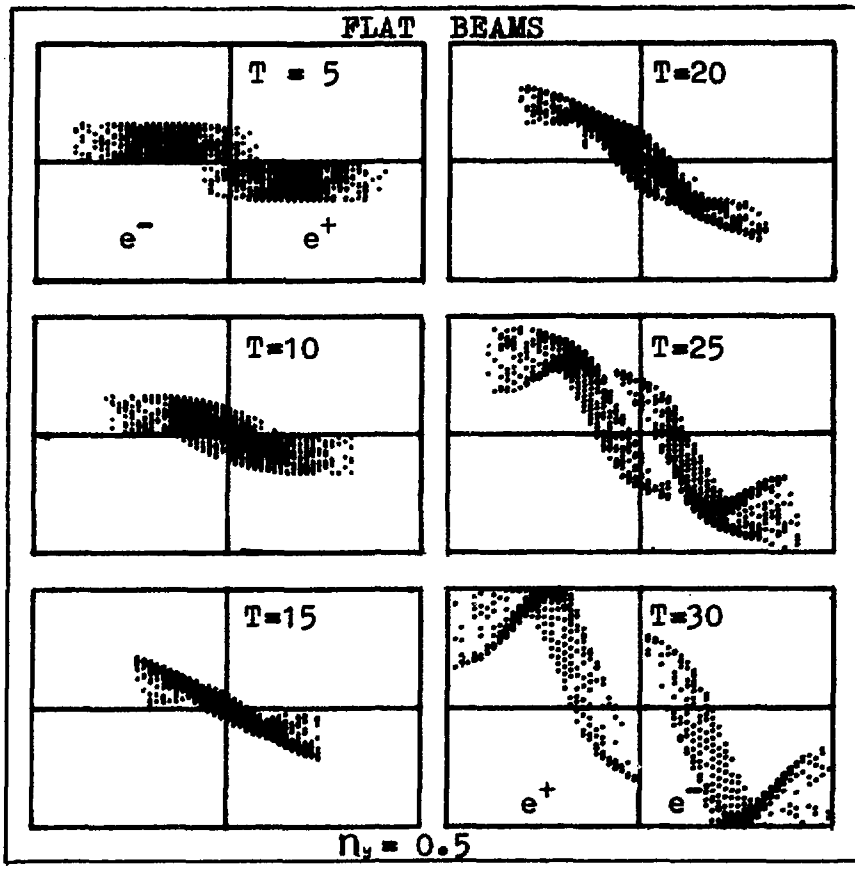

Figure 10. Off-central collision. Uniform distribution.

hole and used for energy measurements. The sensitive detector allows to measure the small autoemission current emitted from tested surface. The cavity is excited with the powerful RF-source. In 1978 [15] experiments were carried in 10 cm range.

The accelerating autoemission electrons emitted from the centre of the plane surface are analyzed with the spectrometer. This method allows to investigate the maximum attainable electric field and it's dependance of electrode material, quality and technology of surface preparation. Figure 12 shows typical autoemission electron spectrum of a cavity in 10 cm range. It can be seen that the electric field about 200 MV/m can be achieved.

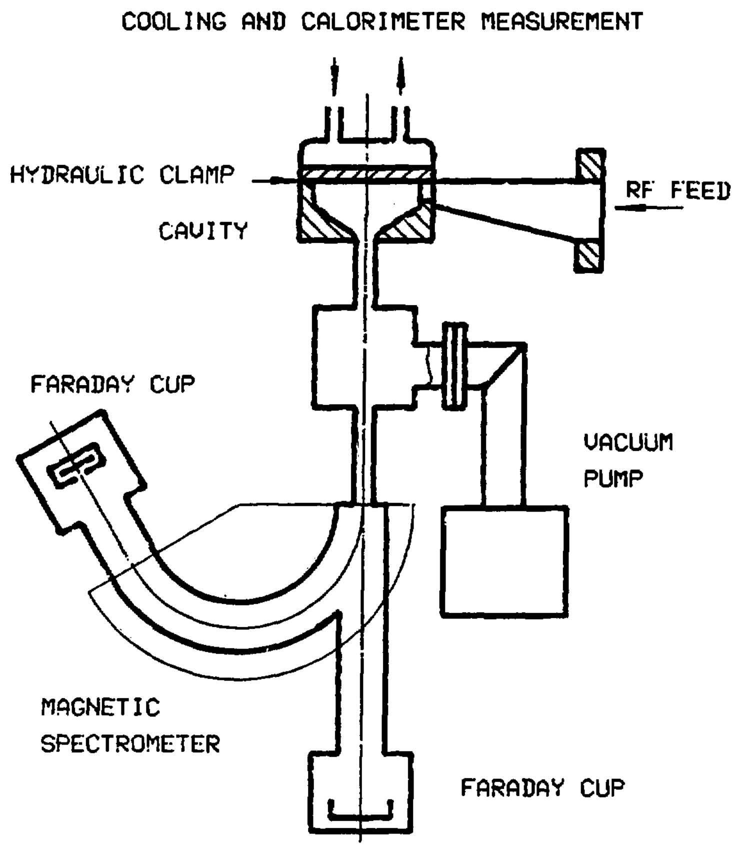

Figure 11. Lay-out of the installation for investigation of the maximum electric field.

CONVERSION SYSTEM

In September 1979 the new method had been proposed of obtaining highly polarized e^+ and e^- at the energy more than 100 GeV [16].

The general idea of the method is that the circular polarized photons are converted into positrons and electrons in a heavy material target, that provides high yields of longitudionally polarized e^+,e^- at the high boundary of the energy spectrum [16-17]. Circular polarized photons are radiated by the initial particles in the helical undulator. Nonpolarized

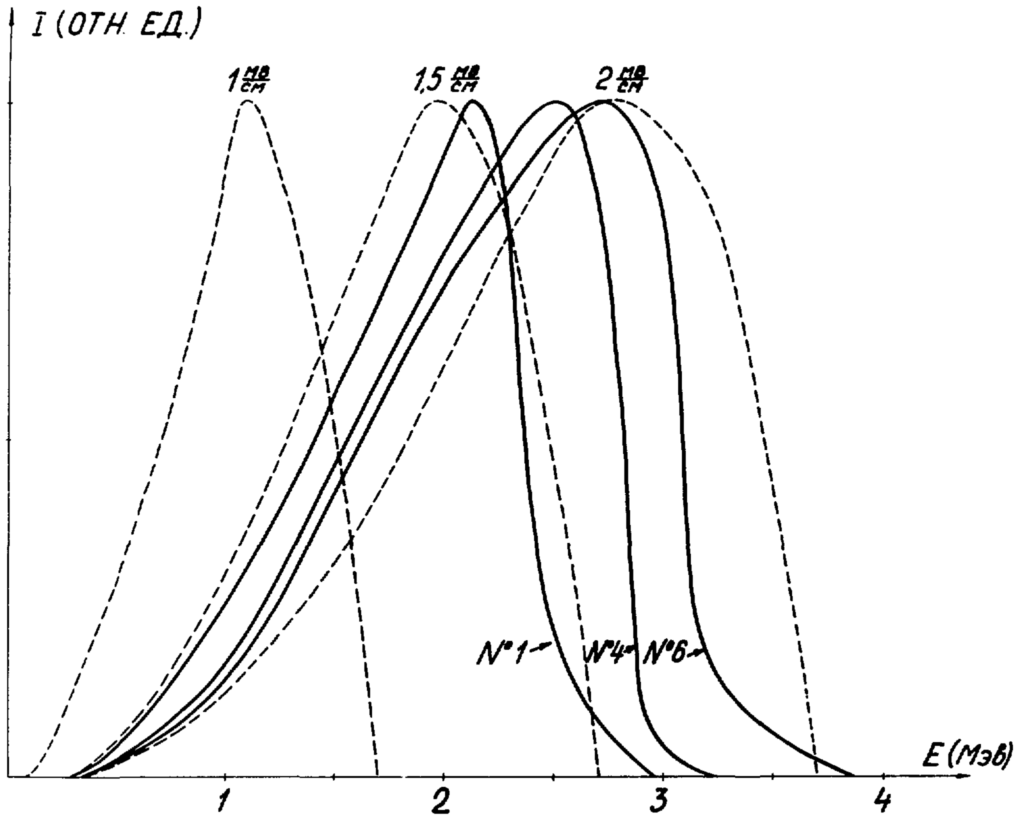

Figure 12. The spectra of autoemission current (solid lines) and the calculated spectra (dot lines).

bunches of e^+, e^- can be used as the initial ones and after their passage through the conversion system they are not lost.

The most interesting property of the interaction of high energy polarized photons is the correlation between polarization of initial photons ξ_γ and final electrons and positrons polarization $\vec{\xi}$ from the pairs and Compton betas [18,19,20]. Just near the high boundary of energy of created e^+, e^- the polarizations are equal. The behavior of polarizations $\zeta(E)$ as a function of the particle energy is shown in Figure 13 [18].

$$\vec{\xi} = \xi_\gamma \left[\vec{n}_\parallel F_1(E) + \vec{n}_\perp F_2(E) \right]$$

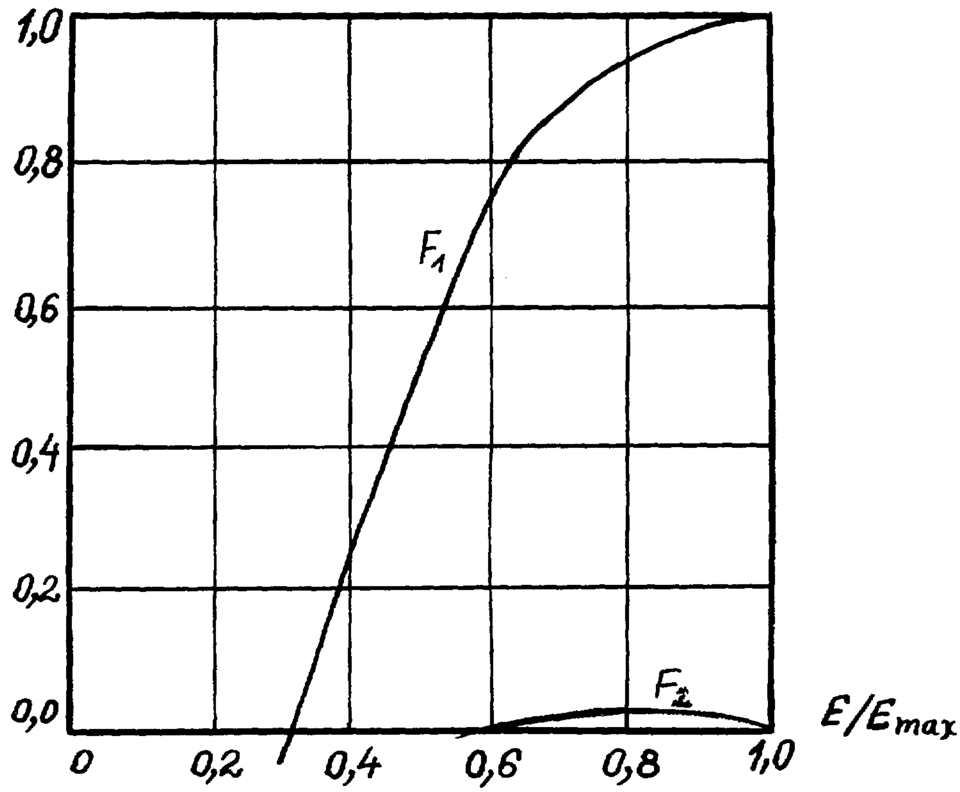

Figure 13. The longitudinal electron or positron polarization as a function of its energy.

The view of the graph is practically independent of the photon energy. That is why it is necessary to select the energy of final particles near the maximum of the energy spectrum. The differential cross-section of pair production is shown in Figure 14 [19] .

$$\frac{d\sigma}{dE_+}(E_\gamma, E_+) = \frac{4}{E_\gamma} Z^2 \alpha r_e^2 \ln\frac{183}{Z^{1/3}} f\left(\frac{E^+}{E_\gamma}\right) = \frac{A}{N_0}\frac{f(E^+/E_0)}{X_0 E_\gamma},$$

(for $f(E^+/E_\gamma)$ see Figure 14).

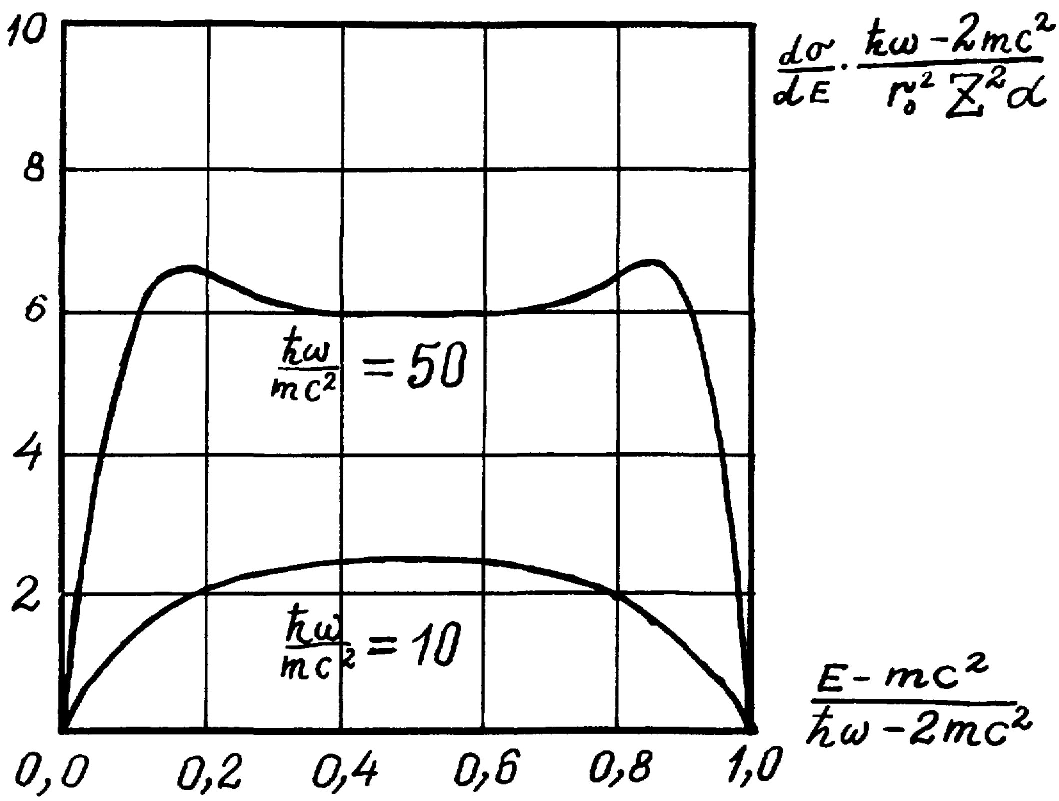

Figure 14. The differential cross-section of generated electrons and positrons.

The degree of polarization of e^+, e^- is limited by degree of polarization of the photons from the undulator, so it is desirable to have it as high as possible. It is clear that the number of photons radiated by each initial particle must be maximal for compensation of the non-full energy interval of collected particles and limited efficiency of conversion gammas into pairs. The total cross-section of production of pair after passage of target of thickness of T g/cm^2 is

$$\sigma_{pair} \cong 4 Z^2 \alpha r_e^2 \left(\frac{7}{9} \ln \frac{183}{Z^{1/3}} - \frac{1}{54} \right) \sim \frac{7}{9} \frac{A}{N_0} \frac{1}{X_0}$$

The mean degree of polarization of created particles for fully polarized photon radiation is

$$\langle \vec{\zeta} \rangle = \frac{\int_{E}^{E_{max}} \zeta (E^+) \frac{d\sigma}{dE^+} dE^+}{\int_{E}^{E_{max}} \frac{d\sigma}{dE^+} dE^+}$$

$\vec{\zeta}$ (E) see at Figure 13. And the total number of created positrons in full energy spectrum is

$$N^+ / N_\gamma = \frac{7}{9} \frac{t}{X_0}$$

and the density is

$$\frac{dN^+}{dE^+} \simeq \int \frac{dN^\gamma}{dE_\gamma} \frac{d\sigma(E_\gamma, E_+)}{dE_+} dE_\gamma$$

here $X_0^{-1} = \frac{4 r_e^2 \alpha N_0 Z^2}{A} \ln \frac{183}{Z^{1/3}}$ – is the radiational length of the target used and dN^γ / dE_γ is the spectral density of photons.

Let us consider the scheme of conversion system like that in Figure 15. While passing through the undulator 2, the beam 1 loses about 1-2 % oft their energy which depends upon the energy of the initial beams and the period λ_0 of magnetic field $H_\perp$ in the undulator [21]

$$E_{\gamma_K}^{max} = \frac{2.48\,(\gamma/10^5)^2 K}{(1+P_\perp^2)\,\lambda_0\,[cm]}\ [MeV] \quad , \qquad K = 1,2,3,\ldots$$

where $\gamma = E/mc^2$ is gamma factor, $P_1 = (eH_\perp\lambda_0)/(2\pi mc^2)$ is transfer momentum or factor undulatority. Full emitted energy $\mathcal{E}(X)$ on the length X is

$$\mathcal{E}(x) = \frac{8}{3}\ \frac{\pi^2 r_e X \gamma^2}{\lambda_0^2}\ P_\perp^2\, mc^2 \beta_\parallel^2$$

(r_e is the classical radius of electron = 2.818 x 10-13 cm)

The spectral density of the undulator radiation is [21]

$$\frac{dN_\gamma}{dE_\gamma} = \left(\frac{\alpha P_\perp}{\gamma}\right)^2 \frac{X}{r_e}\ \frac{1}{mc^2} \sum_K F_K\left(\frac{E_\gamma}{E_{\gamma K}^{max}}\right)$$

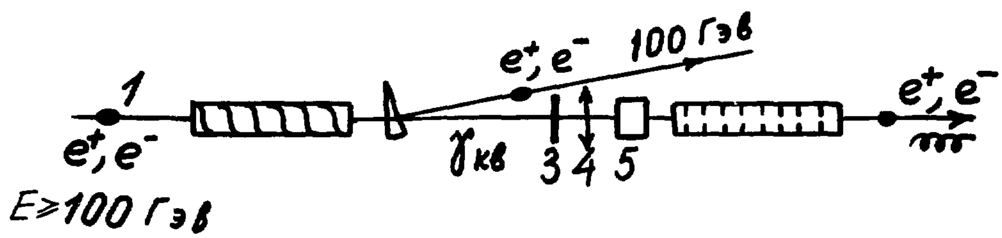

Figure 15. Testing convertion system
(the comments are in the text)

The particles of the initial beam are removed from the pho - ton propagation line and are directed to the beam collector or used for experiments with a stationary target. The photon beam produced in a target 3 electrons and positrons which are collected by a short focus lens 4 and are directed into accelerator 6 . The energy selector 5 can be made as transport system or additional RF cavity.

The final energy of the accelerator is equal 1.1 GeV , which is $2.5 \times E_{os}$, where $E_{os} = 0.44065$ GeV is the spin resonant energy. This is very useful for simplest spin operation for preparation the necessary type of polarization . After that the particles go to the storage-ring for cooling and preparation of necessary emittance.

The resulting conversion coefficient in this system is more than unity and the resulting degree of polarization is more than 0.65 with the simplest energy selection system as azimuthally symmetric lens and diaphragm.

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Panel Discussion: Future Cooperation in Accelerator Construction (I)

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Looking Beyond BEPC

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As you know, China is a developing country. The current policy of our country is to develop our national economy by making the best use of our limited resources. China cannot be expected to increase the fund for basic research in a short period of time. Therefore, we are not very clear about what to do next when the BEPC project is completed. However, it is certain that collaboration with the international community of high energy physics will be strengthened.

We have accumulated some practical experience in the course of BEPC construction. Some Chinese industries have improved their skills and technologies in fabricating the subcontracted components of the collider. What is more, quite a number of accelerator and experimental physicists and engineers were trained. All these have had a solid foundation for future international collaboration.

There is an old Chinese saying: "Contribute money if you have money. Contribute manpower if you have manpower". I am deeply convinced that the physicists and engineers trained in the course of BEPC construction will make their due contributions to the construction of accelerators and detectors in the next ten years.

PERSONAL VIEWS ON FUTURE COOPERATION IN ACCELERATOR CONSTRUCTION

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Personal Views

It will probably not come as a surprise that my views of world HEP in the next 10-15 years are dominated by the SSC.

As Director of Fermilab, I have the habit of discussing all science policy issues with Fermilab Senior Staff and back in 1981-82 there were many discussions about a multi TeV machine to address the issue of the 1 TeV mass scale. We were in the throes of building the TEVATRON but already felt that we knew what we were doing and that another generation of SC circular hadron machines was feasible. The news from CERN about the $p\bar{p}$ collisions in the $S\bar{p}pS$ was very encouraging too.

We also debated the politics and the inevitable question as to how SSC would impact on Fermilab. I remember one dramatic morning when we went around the table and discovered a remarkable consensus on two issues:

(1) SSC would make life very difficult for Fermilab and may ultimately be fatal.

(2) The field of HEP <u>must</u> be capable of exploring the 1 TeV mass scale before the end of the decade.

Well, time has passed and both issues have been brilliantly confirmed. SSC is like a black cloud on the fortunes of Fermilab and its TEVATRON and the more we know the more we realize that the 40 TeV in CM is a correct decision - if we were permitted to make any change I personally would make it a <u>60 TeV</u> machine - even if we had to sacrifice some luminosity. Thus although I think it will surely be too late, I'm glad that there is a program of developing 10T magnets. It's just what we need. (The higher energy makes everything easier in the signal to noise when you are looking for masses near 1 TeV.)

Let me elaborate for a minute on why SSC is causing problems for us ... and SSC is following a predictable and predicted course in its tortuous path towards reality.

(1) There is of course a competition for funds at this stage of SSC deployment ~ i.e. the R&D phase. This especially hurts as we are trying to operate a very complex array of machines.

(2) There is a steady and escalating depletion of key people to SSC.

This raises the very general question as to whether we, as a planet, or as individual regions, have thought through the problem of manpower to design, build and use the machines that we gaily talk about here.

The impact of SSC on TEVATRON foreshadows its impact on the rest of the planet. Most dramatically it will clearly influence the plans of our CERN, European colleagues. It must also impact on all regions in planning the future evolution of their own facilities.

One of the planning problems we have is that if we look at the needs of physics, we do not know enough about the accelerators to make a sensible plan. However let's look at an idealized set of facilities. Later we may try to "give them out" around the globe. In parentheses are the factors over existing or soon-to-exist facilities:

(20x)	SSC	p x p	40 TeV ~	2-4 TeV CM
(10x)	Super SLC	e^+e^-	~ 2 TeV	~ 2 TeV
(5x)	Super Hera	100 GeV-e x 10 TeV-p	2 TeV	
(10x)	Super TeV	Fixed Target	50 TeV	330 GeV

The closest approximation to this is:

CLIC	e^+e^-	CERN	1 TeV x 1 TeV	2 TeV
Super Hera	ep	CERN	100 GeV x 8 TeV	1.8 TeV
Fixed T	p x T	UNK	5 TeV (?)	100 GeV

Now what extensions of technology will permit all of this to happen?

(1) The e^+e^- is much studied and answers, it has been estimated, will be in 4-5 years.

(2) The ep can be either CERN or Japan where electrons $\geq$ 30 GeV are available. Protons of 10 TeV can be built in a ring of radius R=2km and 20T magnets.

(3) A fixed T single ring of 15 TeV could be built in the USSR's UNK tunnel with 20T magnets.

Assuming the technology of 20T magnets is secure (this is a big assumption!) then a new step in energy - say 100 TeV x 100 TeV collider could be built in a tunnel of radius of ~ 150 km circumference - this is Eloisatron scale. Now 20T magnets are a formidable challenge. To my knowledge, no one is working on them. Is this a well defined goal for high Tc materials? Is this a more difficult problem than Super SLC or Super CLICK?

Modes of Collaboration

CERN provides the quintessential collaborative mode. CERN-like. Truly international.

HERA provides a new mode - collaboration by many in the building of a machine in one country which pays > 60% of the costs..

HERA-Variation: Collaborative but with int'l agreements on management e.g. host country nominates director with approval of Science Policy Group. This Group consists of representatives of contributing nations. The degree of governance can be varied smoothly.

TEVATRON Collaboration in use only.

Questions: How does the Host nation go about organizing anything?

Comments on the World Lab + VBA

Recall the original definition of VBA: an accelerator so expensive that no nation or region could afford to build it alone. I wonder whether it will not be time soon to revive the idea for the ~ 10 TeV mass scale. Since none of us knows how to build it (yet alone why we need it) wouldn't this be the ideal time to address the world lab problems? Suppose we did devise a WLPC (World Lab Planning Committee) to design an R&D program, to design a political strategy etc. Normally the US, with SSC not 100% sure, would resist out of fear that this would show our financial leaders a way out. Our Soviet colleagues may feel the same way. But if we couch this in futuristic terms, I don't think it would damage SSC. The charge to the ICFA subcommittee (WLPC) could be:

"In order to plan a coherent program for HEP into the 21st century, we charge WLPC to investigate the technologies that would be needed in order to achieve ~ 500 TeV in the CM. A prototype R&D program to be shared among ICFA participants could be conceptually outlined. The political steps needed to form such a world consortium could be outlined and WLPC could we asked to report back to ICFA in one year's time."

I suspect that very few of the leading Labs will look with enthusiasm on a World Lab. But I should remind you that there are two very positive forces:

(1) The Economic Summit of Thatcher, Kohl, Mitterand, Reagan, etc. stressed international collaboration in the construction of new HEP facilities. Now that PRC and USSR are liberalizing their own economies, it is only a matter of time before we'll be ordered to build a VBA.

(2) We see here today the presence of Brazil, symbolizing, in my view a vast potential in the developing countries (not third world) - Mexico, Brazil, Argentina, Israel, Singapore, Taiwan, Korea, etc., etc. To couple these into our work is important. Of course we shouldn't wait for a world lab for that but ultimately - the World Lab with VBA, a World University, a central locality for Other Sciences, is a vision we must keep alive.

What are the candidates for VBA or indeed for any post-SSC accelerator? If we still have need for higher energy there are now two possibilities:

(1) Superlinear Collider or N^3LC to use Richter's notation $\geq$ 10 TeV

(2) New Technology Magnets $\geq$ 20T.

The success of a 20T magnet program could yield 120 TeV in the SSC tunnel or 500 TeV in one only 3 x larger, i.e. 200 km circumference.

Comment on Cost Effectiveness and the LHC/SSC Problem

We have heard many of our CERN colleagues extoll the cost-effectiveness of LHC. Here is my study.

According to G. Brianti, LHC with 10T magnets (not yet an engineering triviality) costs 1.6B SWF. To this we must add 0.2B for civil construction of new experimental halls etc. and 0.2B for labor, assuming 500 people for 4 years). This is 2.0B SWF and let's use 1.8 SWF per dollar (its now 1.4). This gives us 1.2B$ for 16 TeV. SSC is 3.1B$ for 40 TeV and if you do the ratios you come upon a theorem: "You Get What You Pay For." There are quibbles on contingency, salaries, the 10T magnet problem etc., but the basic fact is that an LHC machine in the U.S. using 6T magnets would cost about the same as the 10T magnets LHC in the LEP tunnel.

One problem I've had is the difficulty of using either of these machines at the design luminosity of $10^{33}cm^{-2}sec^{-1}$. Now our friends tell us they can make LHC superior by going to $5 \times 10^{34}cm^{-2}sec^{-1}$. This bold stroke gives rise to a philosophical point.

Our subject of HEP rests on three legs: Experimenters, Theorists and Machine Builders. When Experimenters talk to Theorists, that's good. When Experimenters talk to Machine Builders, that's good. But when Theorists talk to Machine Builders, that's terrible and should be forbidden!

Report of the CERN Long-Range Planning Committee

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Early in 1985 the CERN Council set up a committee (LRPC) under the chairmanship of C. Rubbia to consider the long-range future of CERN.

The Committee reported to CERN Council on 19 June 1987(CERN/1658) and I will summarize the main conclusions as my contribution to this Panel discussion. The existence of the LRPC has been extended by Council to the end of this year. Its members are: G. Brianti, P. Darriulat, G. Ekspong, A. Salam, S.C.C. Ting, S. van der Meer, and G.A. Voss. The chairman of ECFA, J. Sacton, is also an *ex-officio* member. As one of its first actions the LRPC formed three sub-panels to advise on:

1. The Feasibility of a Hadron Collider in the LEP Tunnel (LHC); chaired by G. Brianti.
2. The Feasibility of a Large e^+e^- Collider in the TeV Energy Range (CLIC); chaired by K. Johnsen.
3. The Physics Potential and Feasibility of Experiments at Multi-TeV Energies; chaired by J.H. Mulvey.

You have already heard reports on the LHC and CLIC studies from Giorgio Brianti and Wolfgang Schnell. Some of the work of the 'Physics' sub-panel has also been described in the talks of John Ellis and Daniel Froidevaux, however I will take a few minutes to outline the results of these studies, which culminated in a Workshop held at La Thuile in January this year.

For the first time a comparison has been made of the potential for discovery of experiments at three types of particle collider: *pp*, *ep*, and e^+e^-, with the basic parameters of centre-of-mass energy, $\sqrt{s}$, and luminosity, L, given in Table 1. As well as providing the opportunity of colliding protons with the electrons of LEP, the LHC could also be used as a collider for heavy ions but this option was not included in the La Thuile studies.

Table 1.

LHC and CLIC parameters.

Machine	Particles	$\sqrt{s}$ (TeV)	L ($cm^{-2}s^{-1}$)
LHC	*pp*	16	10^{33} to 10^{34}
	ep	1.4 to 1.8	10^{32} to 10^{31}
CLIC	e^+e^-	2	10^{33} to 10^{34}

To characterise the potential of a future machine in terms of 'discovery limits' is to confine its possibilities within the boundaries of today's knowledge, and to ignore the importance of serendipity. However, such estimates require an examination of the experimental feasibility, including the evaluation of backgrounds, and provide a means of comparing the strengths and weaknesses of experiments at different types of collider.

The La Thuile studies are fully reported in the Proceedings(CERN 87-07, Vols. 1 and 2) which have been used to compile the summaries of discovery limits for a selection of processes given in Tables 2, 3 and 4. Following the LRPC report in June a further study group was formed to extend to higher luminosity, up to 5.10^{34} cm^{-2}s^{-1}, the evaluation of the 'reach' of the LHC for Higgs, SUSY gluino and squark, and Z' searches. This study is still in progress and preliminary results are given in column 3 of Table 2; a report will be published by the end of the year.

Table 2.

Discovery Limits in TeV/c^2.

LHC *pp* 16 TeV.

	Luminosity cm^{-2}s^{-1}	
Physics	10^{33}	5.10^{34}
Higgs		
$ll\nu\nu$	0.6	-
$\mu\mu\mu\mu$	0.3	0.8†
$l\nu + jj + qq$tag	0.8	-
Z'	4	6
SUSY		
$\tilde{g}, \tilde{q}$	$1 \rightarrow 1.5$	$1.5 \rightarrow 2$
$Q \rightarrow Wq$	0.8	
W'	4.5	
Leptoquark	2	
Λ_{qq}	12	
$m(q^*)$	5	
$m(e^*)$	4	

† Adding the $2\mu^{\pm}2e^{\pm}$ channels should allow 1 TeV/c to be approached.

Table 3.

Discovery Limits in TeV/c^2.

LHC *ep* 1.4/1.8 TeV.

W_R	1.5	(e Pol. $\gtrsim$ 50%)
Leptoquark	1.6	
$\tilde{q}$	0.7	
$\tilde{e}$	0.3	
Λ_{eq}	$8 \rightarrow 13$	(e Pol.)

Table 4.

Discovery Limits in TeV/c^2.

CLIC e$^+$e$^-$ 2 TeV.

Higgs	
$M_z < M_H < 200$ GeV	YES
$M_H > 200$ GeV, $H \rightarrow 2W \rightarrow 4j$	0.8†
$H^\pm$	0.8
Heavy L, Q ($\rightarrow W\nu$ or Wq)	0.8
Z′ (factory)	2.0
SUSY	
$\tilde{q}$	0.8
$\tilde{e}, \tilde{\mu}, \tilde{\tau}$	0.8
$\tilde{W}$	0.8
Compositness	
Λ_{eq}	30 to 80
$\Lambda_{ee}, \Lambda_{e\mu}$	60 to 100

† Luminosity 10^{34}cm^{-2}s^{-1} would enable ~1 TeV to be reached.

The main conclusion is that there is a very clear complementarity in the strengths of the machines. Although, because of low $\sqrt{s}$, the reach of the ep collider is less impressive, this mode of the LHC nevertheless constitutes an important addition to the physics of the pp collider: using e-polarisation for W_R and Λ_{eq}, and giving a direct channel for leptoquark production.

One of the prime topics for study at a TeV collider is the $W_L W_L$ interaction. Figure 1 shows the cross section for $W_L W_L$ fusion as a function of Higgs mass for pp and e^+e^- colliders for a range of values of $\sqrt{s}$. This comparison demonstrates that for masses approaching 1 TeV, a 2 TeV e^+e^- collider with a luminosity reaching $\sim 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ would be very competitive with, as well as complementary to, a 40 TeV pp collider of $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, bearing in mind the much greater 'cleanliness'—freedom from background—in the e^+e^- case.

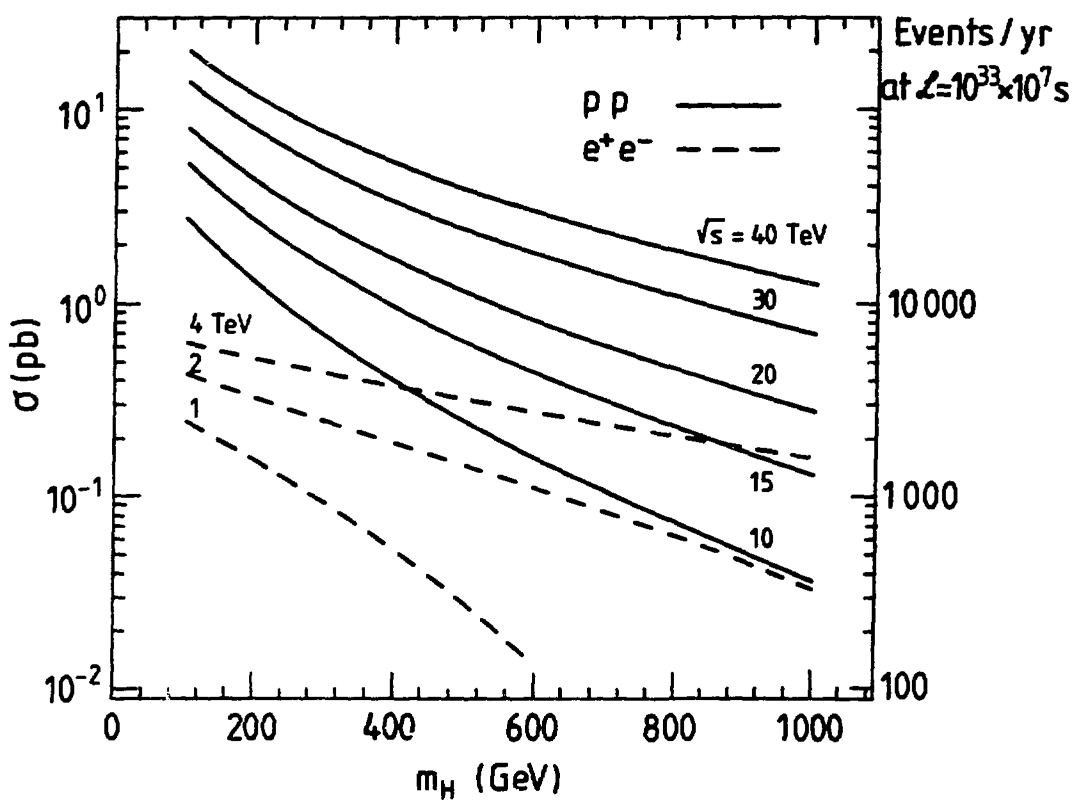

Fig. 1. Cross sections for $W_L W_L$ fusion as a function of Higgs mass in pp and e^+e^- interactions; from G. Altarelli (La Thuile, Vol. 1).

Turning now to the conclusions reached by the LRPC, as reported to Council in June, these can be summarized briefly as follows:

1. LEP should be completed to its design energy of ~200 GeV.
2. The existence at CERN of (i) a high-quality injector complex with record performance, and (ii) the LEP tunnel and related infrastructures, makes it extremely attractive to explore the 1 TeV energy domain with the LHC. The LRPC therefore unanimously supports the recent resolution of the Committee of Council (19th February 1987) and hopes that the world scientific community will respond positively to the invitation to join the project.
3. As the lower energy of the LHC compared to the SSC can be partially compensated with the help of higher luminosity, the LRPC concludes that the LHC offers the most cost-effective way for the world's high energy physics community to achieve early access to energies $\approx$ 1 TeV in the constituent centre of mass, one order of magnitude greater than is currently available.
4. CERN must intensify immediately its research and development on: (i) the possibility of attaining on a large scale 10 Tesla fields with existing superconductors at a lower operating temperature; (ii) the "two in one" magnet configuration; and (iii) detectors, to ensure that they can be operated efficiently at the highest luminosities.
5. Exploration of the 1 TeV energy domain requires both a hadron collider in the multi-TeV region and an e^+e^- collider with about 2 TeV in the centre of mass. The latter requires the development of an entirely new accelerator technology to which Europe, and CERN in particular, should contribute significantly. A full-time team and appropriate financial support are needed at once.

To complete this summary of the LRPC's conclusions, I will quote the last paragraph of the report to Council:

"The LRPC recommends that the R&D progress be periodically reviewed in order to enable Council to take a decision on which option to follow in 1989, taking into account the evolution of the world situation. If taken at this date, a decision to construct the LHC would allow collisions to be achieved by 1995. Conversely, by 1989, one should have better ideas on the technical problems involved in the construction of a linear e^+e^- collider if that option proves to be the most desirable."

A PERSONAL VIEW FOR FUTURE HIGH ENERGY PHYSICS FACILITIES

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I. INTRODUCTION

We, at KEK, have succeeded in the initial operation of TRISTAN as well as preliminary physics experiments with the new collider. As to the future high energy physics facilities, however, I have to say that we have not formulated a definite scenario as yet beyond TRISTAN. I personally have some possibilities or more properly, some hopes or dreams for future progress in this field which will be promoted by our excellent and active young fellows who have grown up in these decades through KEK activities.

Here, I will start with an introduction of a short summary of the report on future plans of Japan's high energy physics proposed by a subcommittee of the High Energy Committee that consisted of fifteen next generation scientists in this field.

Then, in addition, I will give personal comments on not so far future accelerator facilities. One mainly concerns the recent development of superconducting RF cavities, in particular a possible use of new high T_c superconducting materials including an inquiry on their high frequency properties. The other is the idea of a plasma accelerator not on the surface of our earth but in the ionosphere. For both plans, I, myself, have recently made a small contribution to the preliminary studies in cooperation with my colleagues, some of them in fields other than high energy physics. Of course, I can only give a description of these plans at the level of an imagination or a dream.

II. FUTURE PLANS OF HEC, JAPAN

With the notion that the inauguration of TRISTAN would be near in sight, a subcommittee of fifteen members who are expected to be active in the field of high energy physics in the succeeding years was formed in 1984 by the High Energy Committee (HEC), Japan. The charge was to make recommendations to the parent committee on future plans in this field in Japan, including the next accelerator plans after TRISTAN, international cooperative plans and non-accelerator experimental programs. The Subcommittee held thirteen meetings including a workshop, and heard presentations of prominent physicists and opinions from a broad spectrum of high energy physicists. A final report was submitted to the HEC meeting held on March 6, 1986 and favorably accepted.[1] It gave proposed plans, prevailing wishes of physicists, and placed priorities on general areas to which future efforts should be directed. The content of the report is summarized as follows:

"After TRISTAN, the highest priority should be placed on research to explore a new energy frontier, with the center of mass energy from a few hundred GeV to a few tens of TeV. In order to achieve this purpose, the Subcommittee proposes:

1. Initiate immediate research and development efforts for an electron-positron collider in the TeV region, which is to be constructed as a possible home-based facility.
2. Promote international collaborative experiments using facilities such as the SSC.

An essential ingredient in achieving the above goal is to build a foundation, on which we can maintain creative research activities and can educate young people. With due consideration not to disturb early realization of a new energy frontier, we also have to improve or enlarge on-going facilities, keeping in step with the progress of physics. Experiments in non-accelerator particle physics should be promoted independently. Since they can be performed without the use of accelerators, they are suited best to satisfy broad needs of physics research. In addition, experiments of varying scope outside the country, and international collaboration in developing accelerator technology should be continued and encouraged further.

Some projects of immediate concern are given here:

*a. After the completion of the current TRISTAN project, the energy of the main ring should be increased further. An effort should be made for a possible future operation of the TRISTAN complex as a low energy, high luminosity electron-positron collider.

b. The intensity of the 12 GeV KEK PS should be increased.

* Experiments in non-accelerator particle physics should be promoted."

We have a long way to go to achieve the above goals with steady efforts. We also have to consider possible influences on other fields of science.

Needless to say, it is not to be overemphasized that production of good physics results using TRISTAN is a must to make further steps. R & D efforts aimed at new accelerator technology for the twenty-first century should also be promoted. In this sense, an important style so far we have tranditionally followed is close collaborations with the scientists and engineers in other fields and in industrial sectors.

III. SUPERCONDUCTING LINEAR COLLIDER

I have just introduced a future plan on high energy physics facilities proposed by the HEC, in Japan. It mainly concerns the present-day general consensus based upon discussions on physics requirements and technical possibilities not only in our country but also in the world.

Now I wish to give a personal view on one of them, i.e. the R & D on electron-positron linear colliders in the 100 GeV $\sim$ TeV region aiming at its realization, probably by the end of this century or in the beginning of the next century.

The art of designing linear colliders, as discussed in yesterday's session, is in its infancy and many questions are yet to be answered. However, it became more comprehensible during these years what will be the problems to be solved by engineering and technical R & D for the accelerator complex, considering beam-beam effects, beam optics, beam-cavity interactions, and other beam dynamical problems. I have listed them in Table I together with the required important or desired performance of such a linear collider which has a sufficiently high luminosity at high energies as well as its stable and reliable operation.

A key-point among these requirements, I believe, is to obtain a

I. Problems

Beamstrahlung } D, δ, L
Final Focusing

Accelerating Structures (High Field, ---)

RF Sources (High Power, High Duty, ---)

Damping Ring (Small Emittance, ---)

Linac Beam Dynamics (Alignments : static and dynamic, Pulse to Pulse Changes, Emittance Blow-up, Instabilities---)

Detector Considerations ---

II. Requirements

High Luminosity, Low Emittance, Low Energy Spread, Low D, High Gradient Field, Low RF Loss, Low Peak Curr, High Duty Factor, Stable Operation, ---

Table I Problems and Required Performance for Future Linear Colliders

high duty factor, stable electron and positron beams with low emittance and low energy spread by reducing the peak beam intensity and the beam strahlung. This would be realized only by superconducting linacs instead of conventional linacs.

In this regard, here I will introduce a recent R & D study on superconducting RF cavities and high T_c superconducting materials done at KEK.

The beam energy of TRISTAN is planned to be upgraded up to about 33 GeV by adding a superconducting RF system. For this purpose, thirty-two sets of 5-cell niobium 508 MHz structures are now being prepared. Sixteen cryostats, each of which will contain two 5-cell structures and a refrigeration system to cool down to liquid helium temperatures are also being constructed. The typical Q_o-E_{acc} curves in the first cool down test of the 5-cell 508 MHz niobium cavities are shown in the Fig. 1.[2] These superconducting RF systems are expected to begin operation in summer 1989, though one half of the total system, i.e. sixteen sets of 5-cell structures are scheduled to be operated in summer 1988.

One prototype of the 5-cell structure was tested in the accumulation ring in February 1986 with the electron beam, and the results were quite encouraging. Two 5-cell structures which have essentially the same design as that for the TRISTAN main ring, are to be tested in the accumulation

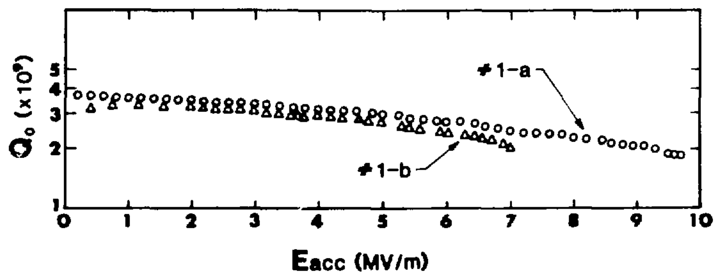


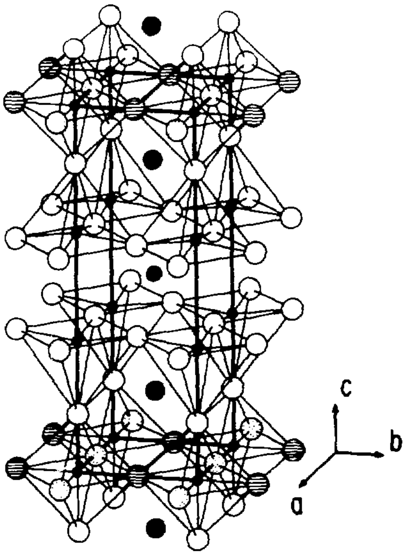
Fig. 1 Typical Results of 508 MHz 5-cell Niobium Cavities for TRISTAN

ring in this month. These two structures have already been tested in a vertical cryostat and showed satisfactory results, i.e. an accelerating field strength more than 5 MV/m and a Q_o value of greater than 2×10^9 at 5 MV/m were obtained.

During the past fifteen years, the performance of our niobium cavities has been progressively upgraded mainly due to improvements in diagnostic methods, the niobium material, the electron beam welding technique and the surface treatment. Among these techniques, electro-polishing of the niobium surface has been especially investigated at KEK. Nowadays, the complicated relationship between many parameters of the electro-polishing process has been understood and well controlled polishing is being adopted to the single cell and multi-cell structures.

Development of Nb-Cu cavities is also being investigated. RF magnetron sputtering of niobium onto copper has been adopted to obtain a thin film coating of Nb, which showed RF loss characteristics similar to those of bulk Nb at 6.5 GHz.

An alternative method for developing superconducting linear colliders would be to utilize recently developed high T_c superconducting materials. At KEK, the spallation neutron source using the booster synchrotron of the 12 GeV PS has taken an important role to determine precise crystal structures and oxygen occupation factors of these materials. An example of $Ba_2YCu_3O_{7-x}$ (BYCO) powders is shown in Fig. 2, for which we made the first observation of a large asymmetry of the oxygen occupation factor between the 1 b site and 1 e site in the orthorhombic form as 0.60 $\sim$ 0.85 and $\sim$ 0.05 respectively.[3] Similar study by neutron powder diffraction has been made for the material with its Y replaced by rare-earth elements, i.e. Lanthanoid-substituted compounds.[4] Further detailed structure



●:Ba, ●:Y, •:Cu, ○:O(1b), ⊜:O(1e), ○:O(2q,2r and 2s).

Crystal data for $Ba_2YCu_3O_{7-x}$

crystal system: orthorhombic
space group: Pmmm
cell dimensions: a = 3.880, b = 3.8122, c = 11.6264 Å

Fig. 2 Crystal Structure of $Ba_2YCu_3O_{7-x}$ (BYCO)

studies have also been made by using the Photon Factory at KEK, in particular on the valency of Cu ions in the orthorhombic and tetragonal phases of BYCO ($x = 0 \sim 4.8$) by means of the EXAFS method.[5] As a result, it was found that the nearly full occupation of oxygen ($x \leq 0.7$) of the 1 b site of the orthorhombic form is responsible for the high T_c superconductivity and that almost all compounds have the critical temperature T_c about 90 K when $x \leq 0.3$. These material studies on high T_c superconductors will bring about broad applications to future high energy accelerator and detector arts, e.g. development of a very high energy and high field undulator using the anisotropic property of single crystal layers.

In particular, running parallel with these material structure studies, we just started R & D of applying high T_c superocnducting materials for RF cavities. The method of RF magnetron sputtering of BYCO is being investigated to obtain a thin film coating onto glass, aluminium oxide and copper plate. Many problems are still to be solved to get a film of the expected composition. Various target materials and ambient gas compositions, etc. are now being tested. Emphasis is being put on exploring the controllable multi-targets sputtering method onto a Cu plate including treatment of the copper surface. Although we have not yet succeeded in obtaining superconducting films onto Cu, Al_2O_3, etc., we have made a study on the sputtered surface with X-ray photoelectron spectroscopy and Auger electron spectroscopy.[6] An RF loss measurement is planned using sputtered end plates for a TE mode niobium superconducting cavity.

Needless to say that the use of high T_c superconducting materials for RF cavities has many other problems, such as anisotropy of the materials, limit of the critical field, H_c, and so forth. However, if we recall that the first superconducting linac was proposed in the beginning of the 1960's and that it took a quarter century to attain an actual application of superconducting cavities for high energy accelerators, we may have our hope for further progress in making superconducting linear colliders around the beginning of the next century. I also would like to mention that such an R & D on the high frequency properties of high T_c superconducting materials could contribute to the development of future VLSI, a new type of RF power source etc., all of which will also be valuable for future high energy accelerator and detector facilities.

IV. IONOSPHERIC ACCELERATOR

Now, looking far ahead into the middle of the next century and the future, I wish to mention an idea nicknamed the "Ionospheric Accelerator". Consider the diameter of circular accelerators, which started from the order of 1 m for cyclotrons in the 1930's and increased one order of magnitude or so for every decade as the attainable energy increased. Then, a simple extrapolation predicts that such a diameter would exceed our earth's in the middle of the next century (Fig. 3).

At the 21st International Conference on High Energy Physics held at Paris in 1982, I commented at the Round Table Discussion on "The Accelerator after Next" that in order to achieve $\geq$ 100 TeV energy range, we should consider not only to stay on the surface of our earth but also to use manned space facilities in the ionosphere.[7] The idea was based on laser plasma acceleration originally proposed by T. Tajima and J. M. Dawson in 1979.[8] A preliminary consideration indicated that an accelerator in the 100 TeV energy region could be conceivable in the ionosphere, in particular using a laser self-trapping mechanism. Recently, after a

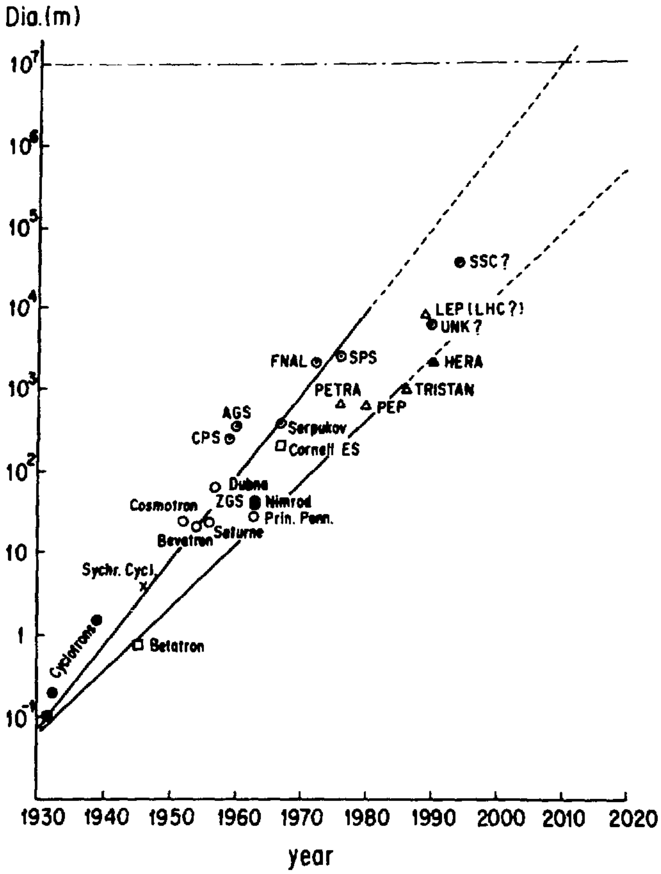


Fig. 3 Diameter of Circular Accelerators vs. Years

private discussion between Tajima and myself, he and his colleague made further investigations on the possibility of such an ionospheric accelerator and a paper will be submitted for publication. The essence of the paper is as follows.[9] Intense electromagnetic waves with a millimeter wave length or shorter in an ionospheric or magnetospheric plasma can be self-trapped above a certain threshold power. The self-binding property based upon the non-linear ponderomotive force, and the consequent self-induced transparency of the triple soliton structure of two electromagnetic waves and a plasma (accelerating) wave allow the propagation of an intense electromagnetic pulse without severe and wasteful (pump depletion) distortion that accompanies linear pulse propagation. For example, corresponding to a set of parameters such as 250 km in height, $n_e = 10^{10}$ cm^{-3} of the plasma density, and $\lambda = 3$ mm of the wave length of driving electromagnetic waves ($\omega_o/\omega_p = 100$), an acceleration of 10 TeV could be obtained between space facilities separated by about 1,000 km. Other choices of parameters would be obtained by alternative acceleration mechanisms like the use of a slow wave system.[10] A definite advantage of such an ionospheric accelerator is, of course, its tremendous size. If we could succeed in using a controllable chain of such facilities as is

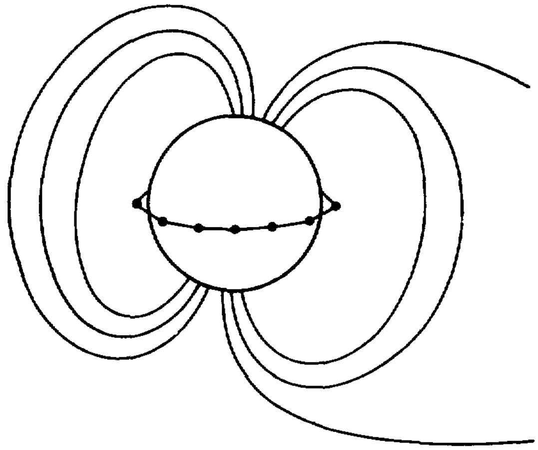


Fig. 4 A Conceptual Picture of "Ionospheric Accelerator"

shown in Fig. 4, an accelerator complex over 100 TeV energy region would deserve consideration. In addition, such an ionospheric accelerator may be useful for nitrogen, oxygen or other ion accelerations in the space plasma.

Preliminary studies on the plasma and beam stabilities, molecular effects etc. are being undertaken. So far, however, it has been shown that Rayleigh diffraction can be arrested by the self-focusing effect of the electromagnetic radiation in a plasma. In order to avoid various plasma instabilities, we have to make the pulse length of elctromagnetic waves short enough. The effect of magnetospheric fluctuations on the particle beam transport are also considered and the fluctuation seems to be within the margin of tolerance for useful beam transport and acceleration.

The most important problems necessary to be solved will be to obtain super high peak power electromagnetic waves and a sufficiently high magnetic field for controlling and stabilizing beam motions, as well as development of precisely controllable space facilities. For instance, a peak power of about 10^5 GW may be required to achieve the above tentative parameters. In addition, many outstanding problems to be investigated are remaining such as parameter optimization, attainable luminosities, fluctuations and inhomogeneities of space plasma, fiber rigidity, molecular effects and so forth. Therefore, such a space accelerator really is a dream of new science and technologies expected in the next century!

V. CONCLUSION

I just tried to give a comment based upon my personal view on future possibilities of high energy physics facilities. As our pioneers and ourselves have experienced in treading the path of progress in this field, one always needed the unforeseen development of new ideas, new innovations and new technologies in order to facilitate the large instruments for the study of the small particles in nature. Recalling such a history, we are not going too far in saying that the progress of pure academic science such as high energy physics and the development of human technologies in various fields are like the "chicken and egg" problem. Even from the above examples I have tried to mention a few possibilities, it is obvious that the international or interregional corporative effort should become more and more important for future high energy physics facilities as well as the cooperation among scientists, engineers and promoters in various sectors including governments and industries.

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A PERSPECTIVE ON FUTURE ACCELERATORS*

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I. INTRODUCTION

Ladies and gentlemen, let me begin with an apology for being late to this important meeting. I have a conflicting engagement, but I expect to arrive tonight and will be with you tomorrow. I appear in this virtual state by invitation of our chairman, Yoshio Yamaguchi, who flatters me by believing that my perspective is important.

I assume that you have already heard, or will soon hear, much about the future of proton machines and so I will not spend any time on that topic other than to say that the goal of achieving parton collision energies sufficient to produce particles of around 1 TeV mass is an important one for high energy physics. Proton machines are now the quickest way to get there. I will spend my time talking about the future of electron-positron colliders.

It is generally agreed that reaching collision energies much beyond the energy available from LEP II requires the construction of advanced linear colliders if these machines are to be built in a cost-effective fashion. It is interesting to note – especially on this occasion – that the modern, high energy, high luminosity

* Work supported by the Department of Energy, contract DE–AC03–76SF00515.

linear collider was born at the first ICFA workshop which was held at Fermilab nine years ago. That workshop brought together people from all over the world who were interested in advanced electron-positron colliders, and I believe it is fair to say that the work done there led directly to both the SLC and to the broad interests expressed by scientists in all of the regions of the world for still more advanced electron-positron colliders.

The high energy physics community is a relatively small one, and it is still possible for one person to know most of the people working it, and to have serious discussions with them. It is from those discussions that I know that my European, Japanese, and Soviet colleagues are as interested as I am in building the machine which, for ecumenical reasons, I call the NLC, or Next Linear Collider.

It is important to all of us to consider how to manage cooperation in this area without rousing interregional rivalries, or at least without rousing them prematurely. Toward this end I have a modest proposal to make, but before making that proposal I will briefly discuss some of the scientific and technical issues which must be resolved before such a machine can be built and then return to internationalism.

II. PHYSICS ISSUES

In principle, electron-positron colliders have two great advantages over proton colliders. These are:

1. Democracy – all cross-sections are of the order of one unit of R as long as the particles produced have electromagnetic or weak charge.
2. Cleanliness – lepton and hadron yields are comparable and peripheral processes are small at large P_T and distinguishable with simple cuts.

Unfortunately, the cross-sections of interest are small at high energies as is the case for proton colliders as well. Figure 1 shows the cross-section as a function of center-of-mass energy. The annihilation cross-section drops like E^2 and has a structure corresponding to the known narrow resonances. As about 100 GeV in the center of mass a new peripheral process involving W exchange appears and starts to rise, and this becomes comparable to the annihilation cross-section in region of the 1 TeV. I have marked the figure, which I borrowed from Ugo Amaldi, showing the region of the NLC which spans the range from 1/2 – 2 TeV in the center of mass.

Any machine that we build must have enough luminosity to produce sufficient events to study the physics that we are interested in, and I define that as about 1000 events per 10^7 seconds per unit of R. This implies that the luminosity required is

$$\mathcal{L} = 10^{33}\,(E^*[\mathrm{TeV}])^2\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1} \quad .$$

By this criteria a machine with a center-of-mass energy of 1/2 TeV requires a luminosity of about 3×10^{32}, while one of 2 TeV requires a luminosity of 4×10^{33}.

III. ACCELERATOR ISSUES

With this very crude collection of requirements as input Figure 2 gives our view at SLAC of the accelerator issues. One might build an NLC at the lower bound of interesting energies with moderate extensions of present technology, but machines with energies of 1 TeV or above are going to require new approaches. This is illustrated in Table 1 which compares the parameters of the SLC, a 1 TeV collider built using SLC technology, and a 1 TeV machine using one of several possible approaches to new technology; pulsed, high power rf sources . much higher frequency than the SLC. I think one can build the "SLC technology" machine, but I would hate to have to pay for 60 km of it, or to pay the operating costs for 1/2 gigawatt of power. New technology can shrink the length and shrink the power requirements.

Table 1

SLC Compared to "OLD" and New Technology 1 TeV NLC

	SLC	SLC Technology	New Technology
Energy (GeV)	100	1000	1000
Repetition Rate (Hz)	180	360	90
Luminosity (cm^{-2} s^{-1})	6×10^{31}	10^{33}	10^{33}
Accelerator Gradient (MV/m)	20	20	200
RF Frequency (GHz)	2.86	2.86	11.4
Peak RF Power per M. of Accelerator (MW)	20	20	1200
Length (km)	3	60	5
Wall Plug Power (MW)	50	500	100
$\sigma_x \times \sigma_y$	1.6×1.6	0.4×0.4	1×0.005

There is a great deal to do in accelerator R&D to create the technology base required for an economical and efficient NLC. There are four areas that need considerable work:

Theoretical studies

Low emittance sources

Efficient and stable accelerators

High precision final focus

While the largest amount of money will be involved in the accelerator and its power sources to drive the NLC, an enormous amount of work is required in all of these areas. It is very difficult for any one laboratory to do all the work required for one particular approach to this type of machine, and it is probably impossible for any one laboratory to afford the resources and manpower required to investigate many of the promising alternatives.

IV. A MODEST PROPOSAL

Our goal at SLAC is to complete the R&D required in time to start the construction of our version of the NLC in the mid-90's $\pm$ a couple of years. I believe the goals of our European, Japanese and Soviet colleagues are identical. Thus we ought to be able to work out a method to avoid duplication and to move the whole effort along faster and more economically than if one group tried to do it all.

My proposal is simply to do the R&D internationally. Make it a mix of coordinated and collaborative work, for we will all move faster that way and there are no secrets in accelerator physics anyway.

Governments and circumstances in the future will determine where and when a machine is built. We can argue about that later and cooperate now, for that cooperation will serve all of our best long-range interests.

Who knows? Perhaps if we get into the habit we can even get together on building such a machine.

V. ROLE OF ICFA

Is there a role for ICFA in all of this? I will be interested in hearing the panel discussion on accelerator R&D which is scheduled for later in the week. My own personal opinion is that ICFA is best at facilitating long-range R&D work, and so should probably concentrate its efforts on the R&D required to go beyond the NLC while leaving NLC to the actors in our drama.

As to the NLC program itself, we probably should all get together some time in the fall of '88 and have an extended workshop on where we are and where we are going. SLAC would be happy to host it.

FIGURE CAPTIONS

Figure 1: Cross-section versus center-of-mass energy for electron-positron reactions. The region between 0.5 and 2 TeV is the region of the NLC. The figure is from U. Amaldi, Proceedings of the Workshop on Physics at Future Accelerators, Le Thuile, Italy/ and Geneva, 7–13 Jan. '87, CERN 87-07, Geneva, 1987, Vol. I, p. 323.

Figure 2: A rough estimation of technology requirements for linear colliders in the Luminosity – Energy plane.

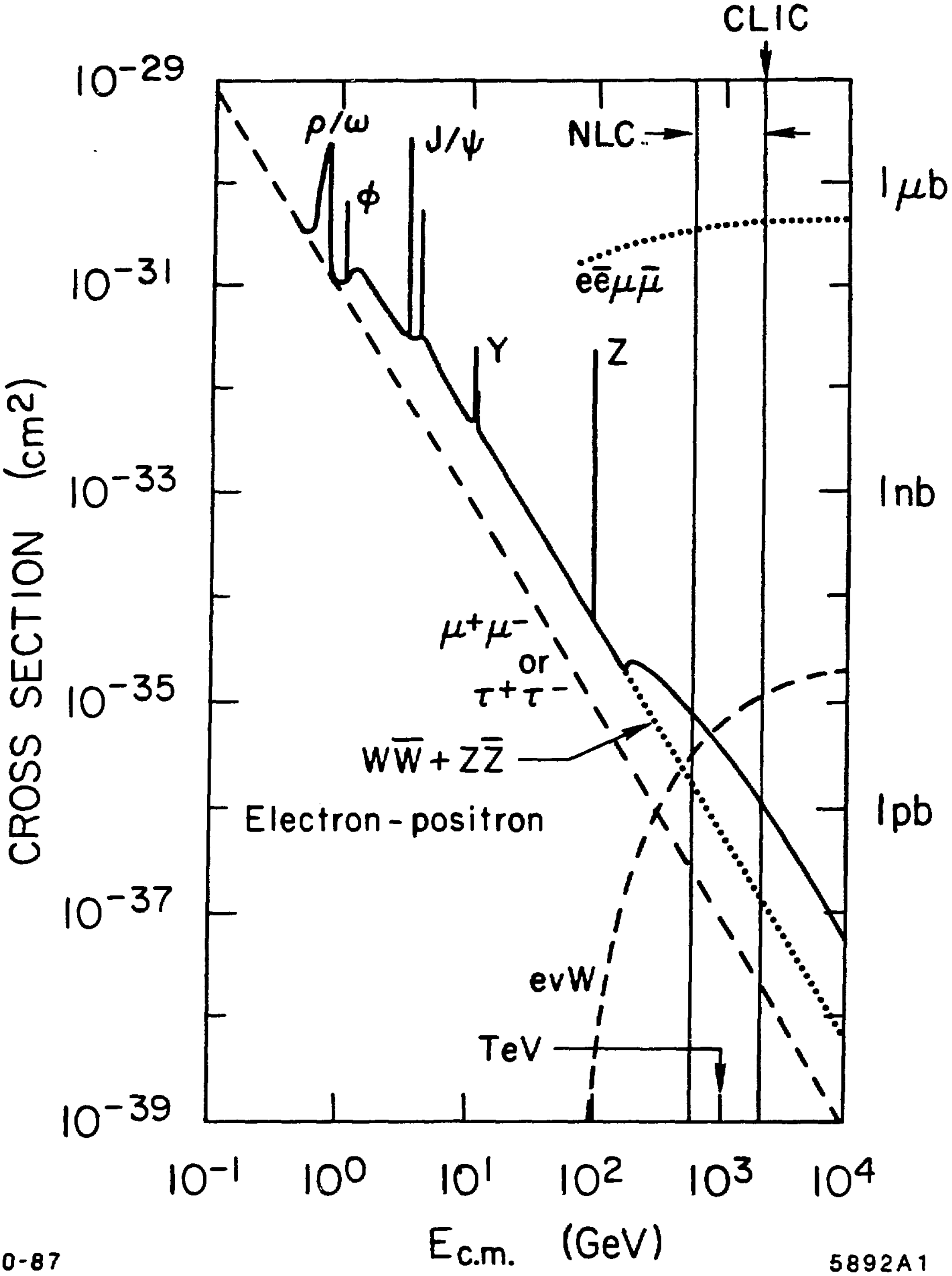

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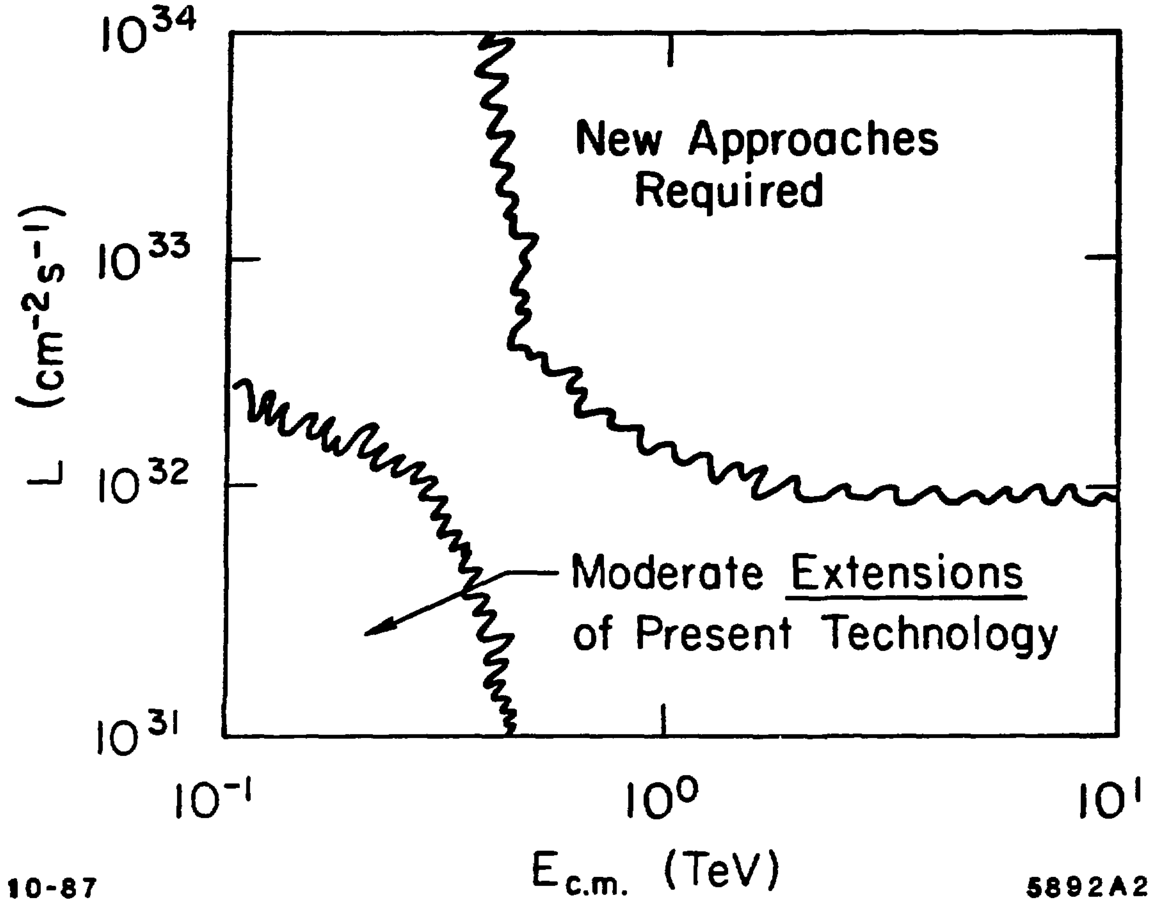
Fig. 1



10^{34}
10^{33}
10^{32}
10^{31}
L $(cm^{-2}s^{-1})$
New Approaches Required
Moderate Extensions of Present Technology
10^{-1}
10^{0}
10^{1}
$E_{c.m.}$ (TeV)
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Fig. 2

FUTURE COOPERATION IN ACCELERATOR CONSTRUCTION

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INTRODUCTORY REMARKS

When ICFA was founded some ten years ago, the main motivation was to prepare the construction of a Very Big Accelerator (VBA) which would require resources beyond the possibilities of one continent. It is my opinion that this objective should be abandoned, and indeed the activity of ICFA has become much broader in the recent past. By penetrating into higher energies we are exploring unknown territory, full of surprises, and it is this fact which contributes so much to the fascination of our field. Since in this adventure one cannot be sure where the keys to a deeper understanding of matter will be found, an approach from different directions seems to be necessary. This implies that a variety of machines with complementary potentialities are needed:

- $\bar{p}p$ colliders (high energies can be achieved, however "dirty" events);
- e^+e^- colliders (high energies difficult to achieve, but "clean" events);
- ep colliders (to continue previous programmes of electron-, muon-, and neutrino-scattering experiments at higher energies);
- fixed target p machines (for neutrino, hyperon beams, etc.).

To convince governments to finance such a varied programme and in order to demonstrate our drive to international collaboration it seems necessary to me that the HEP community presents a coherent world scenario. Such a scenario must not only take care of the different types of accelerators, but should include also time scales with proper staging. An extended interregional collaboration will very likely not only have to cover the construction of projects but also their common exploitation, including both operation of experiments and machines.

CRITERIA FOR FUTURE STEPS

In discussing future projects emphasis is given to reaching higher energies. However, besides energy luminosity (number of collisions per second) is as important a parameter. A third important parameter is the relative timing of projects in different regions.

In order to make a choice of these parameters for a new generation of high energy accelerators a number of criteria have to be taken into account. Physics motivation should of course be one of the most important arguments. Theoretical guidance is needed and different predictions may be put to experimental test. But the most exciting issue is to discover new phenomena, not predicted by theory in a newly accessible energy range. Therefore guidance by theory is limited.

For proton synchrotrons no immediate technical limit is in sight as far as energy is concerned. Between 10 and 100 TeV per beam synchrotron radiation is increasing rapidly but by designing the cooling system in a proper way one could go quite some way. At around 100 TeV synchrotron radiation losses will influence the beam dynamics and then the design principles for proton machines will be similar to those of present electron machines.

For electron machines LEP will very likely be the last circular machine. For higher energies linear colliders are much more favourable from an economic point of view. However, as is well known, a number of technical problems have to be solved.

Since the pointlike cross-section goes down with $1/E^2$ the luminosity should approximately increase with the square of the energy. If one looks back to the history of accelerators

(Figure 1) one notices that this increase was not achieved, but that rather for all colliders the luminosity remained rather constant with best values somewhat higher than $10^{31}cm^{-2}s^{-1}$. The main challenge for future proton colliders seems therefore to be rather luminosity than energy.

If higher luminosities can be achieved then one still has to learn how to build detectors for luminosities of $10^{33}cm^{-2}s^{-1}$ or more. It seems to be generally agreed today that for proton machines one knows how to build the collider but not how to design the detectors, whereas for electron machines it is rather the opposite. In deciding on the energy of proton machines it might therefore be wise to take into account the problems connected with high luminosities. A moderate step in energy

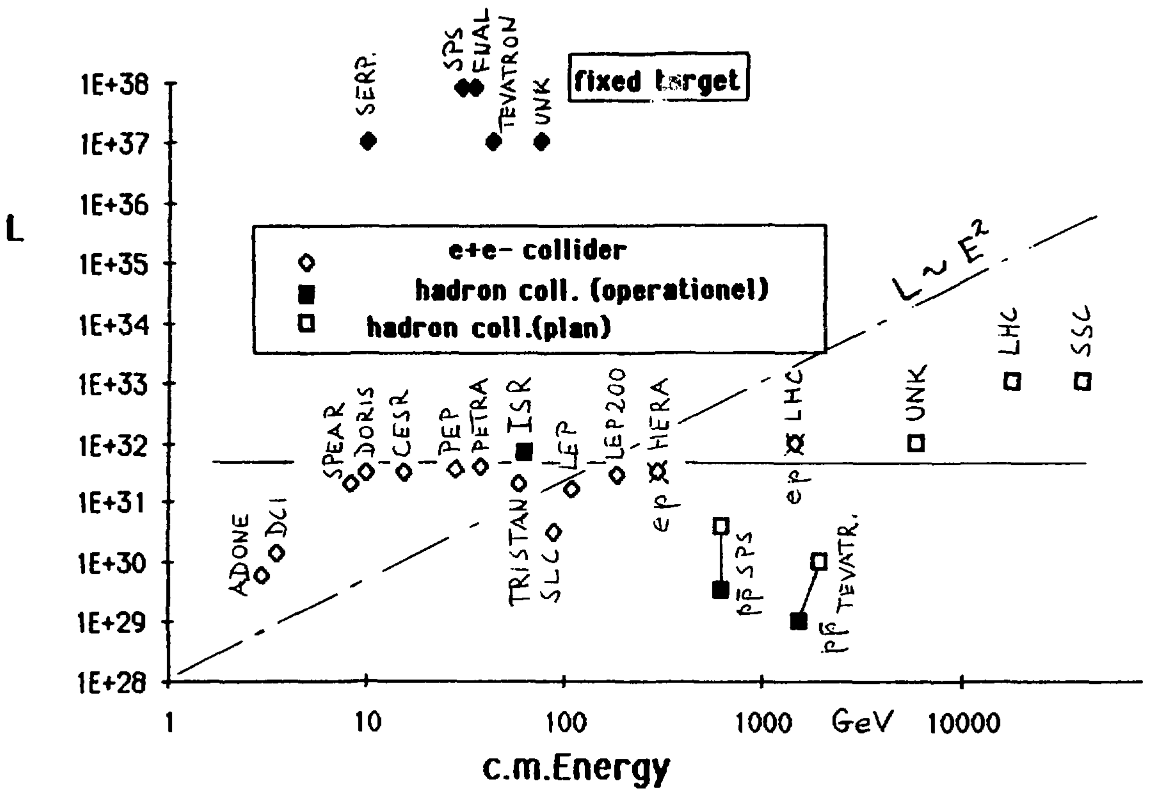

Figure 1. Luminosity versus centre of mass energy

might give a reasonable chance to learn how to build and operate a new generation of detectors.

Sociological aspects will also play a larger role, in particular in view of the long time constants both to build new accelerators and detectors. The survival of high energy physics will depend on whether we are able to attract excellent young people. One will therefore have to find ways to decouple the essential time constants of their careers from those of the technical projects (e.g. detector development as accepted topic for thesis). Travelling over long distances and time zones could perhaps be reduced by using modern communication means not only to analyse data but maybe even for remote control of experiments.

Certainly decisions in one region will have stronger consequences in the future also for the other regions. We are practically all sitting in the same boat and a consensus seems to be necessary.

INTERNATIONAL COLLABORATION VERSUS NATIONAL INTERESTS

Collaboration in high energy physics on a world-wide scale has worked so far very well for the common planning, decision making, financing, and staffing of experimental collaborations. The interregional exploitation of accelerators works so very well that it would seem to me as the next logical step to foresee also an interregional participation in the construction and operation of machines. A positive step in this direction has been taken for HERA at DESY but it is not certain that this very special model can be applied to larger projects. One might therefore ask the question why does it seem to be so difficult to agree upon an interregional scale for the planning and conception of a new generation of accelerators and for their common construction and operation?

The advantages of international collaboration may be counterbalanced however by national interests. These may stem from the expectation of technological developments and economic returns to the industry of a country; there may be specific interests to develop a local region, and there is the convenience for physicists using an installation which is in their own country or continent.

I should to like to make a few remarks concerning these arguments in favour of national interests. As far as the importance of the location of a machine has bearings on the national pride or the competition between countries or regions I believe that it is exaggerated. CERN may serve as an example in this respect. Since CERN was started as an international Laboratory from the beginning, the idea that CERN is a Swiss Laboratory and therefore all the credits should go to Switzerland never arose. The more distant Member States are as proud of CERN as the Host States. I believe therefore, that if a new accelerator is started as an interregional project from the beginning the location should not be a major issue.

As far as economic returns to the national industry are concerned again the location is of no major importance. The policy concerning either development or production contracts to industry seems to be more important. If industrial firms of all those countries which contribute to the project are accepted as partners the return is rather independent of the location of the project.

The benefits for the local area as far as the creation of jobs or the creation of local industrial firms is concerned is also rather limited. The construction of the project is limited in time and therefore only jobs and work linked to the operation of the installation can give some long lasting incentives to the local region. These are partly off-set by the infrastructure which has to be provided like schools, hospitals, roads, etc.

National pride is sometimes a very strong motivation for politicians. It might help to get a project approved but the enthusiasm of individual politicians might change quickly and is not a safe basis for a long-lasting project or Laboratory.

We are going through a secular development in which fast growth is turning over to more stability. High energy physics will not escape from this general trend. The fact that we will be forced to live within a certain ceiling of our resources will force us to answer a question which we have avoided so far: what is the total number of high energy physics laboratories that should be supported in the US, in Europe, in the USSR, and in other countries?

In view of the limited resources which will be available to high energy physics in the future, international and inter-regional collaboration will be more appealing and convincing to governments. A complementary coherent programme involving several regions will not only be easier to sell but in the end will be more economic or cost efficient. I believe therefore that it should be our aim to prepare a common planning and the presentation of such a coherent programme.

A POSSIBLE SCENARIO

If one considers different scenarios for the coming generation of accelerators, certainly the SSC has to play a major role. There I see three possibilities:

1. The SSC is approved and is built as planned, which means that it will come into operation in 1996.
2. The SSC is not approved.
3. The SSC is eventually approved and funded but starts operation not before the year 2000.

I sincerely hope that the SSC will become a reality because otherwise high energy physics in the whole world would lose. On the other hand for a number of reasons it is very unlikely that the SSC can come into operation in 1996. Therefore I shall base the following considerations on my last assumption, which might not be too far from reality.

The other important element for such a scenario is the possibility of adding a hadron collider to the LEP machine in the same tunnel. This would offer a number of advantages: CERN has many years of experience with hadron colliders, European industry has learnt how to build superconducting magnets (for HERA), there are later options, like colliding electrons in LEP with protons in LHC which would give about five times the centre of mass energies of HERA. Since relativistic ions have been accelerated in the SPS they could also be taken to the hadron collider.

As a result a hadron collider would be a very economic way to penetrate into the TeV mass range and it could be realized on a realistic time schedule.

The LHC is not yet a definite proposal. Its realization would require very likely interregional collaboration and indeed the Committee of Council of CERN has expressed itself in a press release on 19 February 1987 in the following way: "While such a project is being studied and before a definite proposal is worked out, a scientific and technical cooperation with the USA and other interested non-Member States should be sought, inviting such countries to participate in a wide international cooperation with the aim to optimize the use of the available global resources in the most cost effective way. Such discussions could open up the way to a world wide strategy with a possibility of European contribution to complementary projects in high energy physics in other continents." Hence other countries are invited to participate in the planning, in the R&D, and in the final parameter selection of such an option. Indeed there is a range of energies which one could consider. One extreme would be to use existing technologies (based in particular on the experience of HERA magnets) and try to achieve energies of about 6 TeV at an early time. The other possibility would be to dedicate some time to R&D, push the magnets to as high fields as possible (about 10 Tesla) and try thus to obtain the highest possible energies in the given tunnel.

Discussing proton machines, the UNK at Serpukhov is another project which has to be taken into account. My guess is that the UNK will start as a fixed target machine where it is unique and that its upgrading into a proton-proton collider will come, if at all, much later.

A possible scenario for pp and ep machines is shown in Figure 2.

In this scenario LHC would follow the Tevatron giving even at the lower energy range a factor of at least 6 with respect to the Tevatron. This seems to be an interesting factor, in particular in view of the fact that one will have to learn how to use

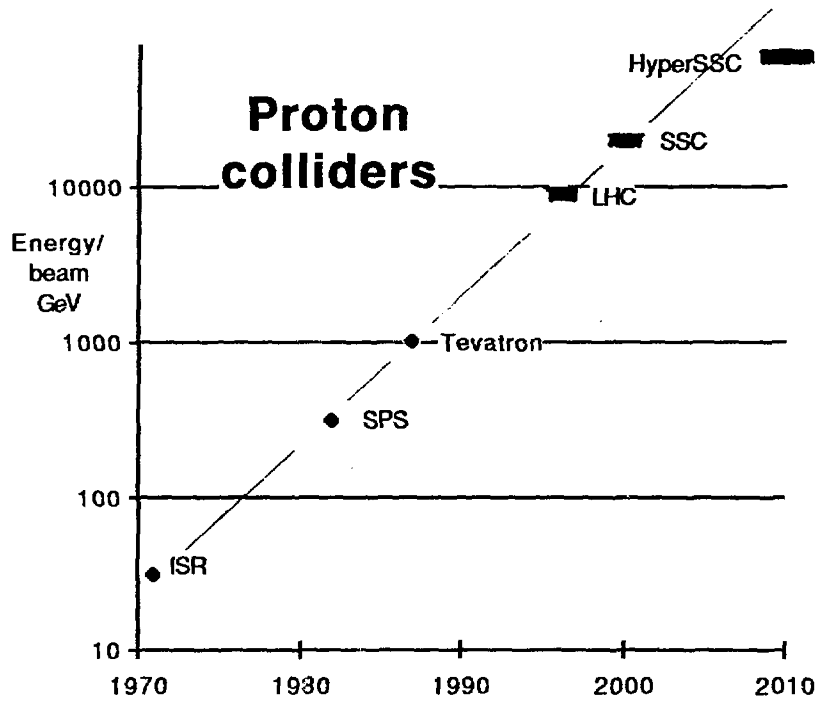

Figure 2. Livingston-plot for hadron colliders

the higher luminosities. Such energies would be sufficient to reach the 1-2 TeV mass region. The SSC would follow giving another factor of 3-5 in energy compared to LHC. If one uses the coming years to improve the magnet technology, the SSC energy probably could be increased without essential additional cost. As mentioned above, in principle there does not seem to be a limitation in energy for proton machines. Hence the SSC could be followed by another machine with energies up to about 100 TeV. Thus, several generations of proton machines are possible without having to use exotic acceleration techniques like plasma wave acceleration.

When the SSC comes into operation the LHC could be converted into an ep-collider at very little cost. This machine would provide about five times the centre of mass energies of HERA. Collisions of relativistic ions could be another interesting option. If one plots these future machines on a so-called Livingston-plot one finds out surprisingly that the LHC and the SSC would follow the trend of the past, whereas the Hyper SSC would fall somewhat below the extrapolation.

For electron colliders one might say that the upgraded LEP with the beam energy close to 100 GeV will certainly be the last circular machine. For a collider with energies at least four to five times higher linear colliders are much more favourable. In view of the enormous technical difficulties I believe that the next step after LEP would be a linear collider with a beam energy between 300 and 600 GeV. Only after that one could consider a linear collider with a beam energy of 1 TeV or higher (see Fig. 3).

As far as fixed target proton machines are concerned, it seems that there will be only one accelerator in the next generation, which is the UNK at Serpukhov giving about three times the energies of Tevatron. Since this machine will be unique it should, to my mind, be exploited at best in this mode of operation.

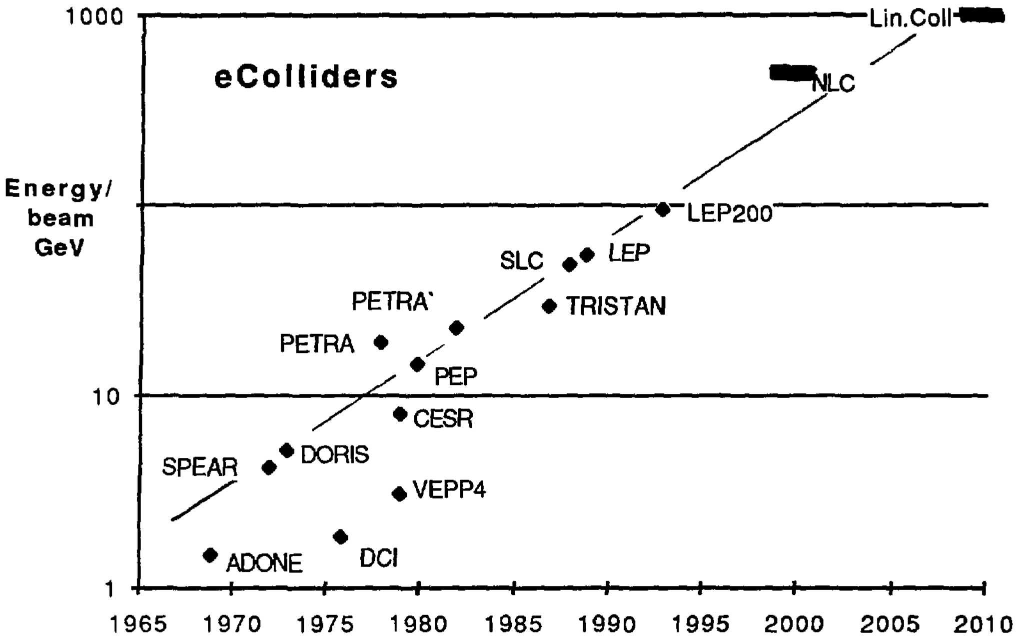

Figure 3. Livingston-plot for electron colliders

Of course this scenario should be considered as only one possibility. There might be many variations to it or scenarios based on completely different assumptions. All I wanted to show is that there exist scenarios and therefore the objective to come to an agreement on a scenario does not seem to be impossible.

International Collaboration in High Energy Physics Facilities

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Federal Republic of Germany

(Summary prepared by Editor; not reviewed by Speaker)

Soergel prefaced his remarks by noting the virtues of ep colliders, in view of HERA. They have a common virtue with e^+e^- colliders in producing very clean reactions -- between a quark and an electron -- and yet the virtue of a proton machine as well: providing high center-of-mass energy. Nevertheless, he felt the future must rely on a multiplicity of approaches, and not on the proverbial "world machine". International collaboration will be necessary on e^+e^-, pp, ep, and perhaps heavy ion colliders, as well as on detectors.

Assuming the various machines are technically feasible, how will we realize them from a political and financial point of view? First, large facilities can presumably only be realized by international collaboration. This must involve three kinds of partners: the Laboratory proper for constructing the facility, the host government, and the collaborating country (and Laboratory). For the constructing Laboratory international collaboration contributes money, helps to obtain approval from the government, and -- very important -- yields international contributions on the technical level. For the host government, money is important. Equally important, however, judging by HERA's experience, it must be convinced from the outset that the facility will be truly international in character. The principal role of the collaborating country and Laboratory is twofold: to serve their physicists and to promote technical interest in local industrial participation.

The above remarks assume future facilities are constructed along the "HERA model", not in the CERN tradition. Soergel feels that CERN represents a very special situation that arose after World War II and that its future replication is unlikely. Nowadays one cannot ignore the fact that national pride also provides an important incentive for governments to become the host for big international facilities. As an example of the HERA model, Soergel presented the following table listing countries participating in HERA and their area of contribution:

International Collaboration
in
HERA Construction

Canada	Proton transfer line, proton rf system
China	People
France	SC Quadrupoles (50%)
Israel	Warm-cold current leads
Italy	SC Dipoles (50%)
Netherlands	SC Correction magnets
Poland	People
USA (BNL)	Collaboration on SC cable measurements, cyogenics

Each of the countries listed has a strong incentive for collaboration from a technical/industrial point of view, not simply from the scientific viewpoint. Regarding the monetary contribution to HERA from the outside countries, it amounts to roughly 100 million marks out of 500 in the proposal, or roughly 20% of the overall materials budget for the machine (excluding civil construction, which adds 200 million marks). It is of interest to note that HERA represents roughly 10% of the SSC.

Soergel concluded by summarizing various factors which, in his opinion, are important in ensuring international collaboration in high energy facilities. First, one needs good collaboration on the project as a whole, both on the accelerator as well as on detectors. Second, the various components of the project must remain distributed over the various regions to maintain government responsibility. Next, referring specifically to the HERA experience, it seems wise to invite for collaboration and contribution primarily those countries which do not have their own major national facilities. Furthermore, it is desirable to obtain roughly equal volume of contribution to detectors and to the accelerator facility, and in an amount appropriate for each particular country -- small and large. Finally, and independent of the monetary contribution, a strong international collaboration on the technical R&D level is indispensable at all times.

Directions in Future Cooperation

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One way to gain a view of what our goals should be is to think about the impact of particle physics on human affairs, how the impact is applied, and from where the resources for its support come.

Basic research in general, and particle physics in particular, influences culture in at least three ways. Most importantly, the results of the research strongly affect our understanding and appreciation of the physical world and our place in it. The results of the research and the technology developments created to carry out the research increase economic wealth, inspire youth to devote themselves to scientific careers and train cadres of scientific and technical workers who will contribute to the technical economy. In addition, the pursuit of the science and accompanying technology creates a medium of cultural exchange which transcends barriers of language, ethnic culture and ideology.

For these benefits to be reaped with any efficiency by the citizens of a region, it is necessary that the scientific and technical practitioners among them have reasonably good access to facilities for doing the science. In addition, their students need even easier access, as does the general public.

The obvious inference to be drawn from these observations is that the number of research centers should expand as the number of regions for whom scientific and technical culture is important expands. Maintaining the intense international or interregional character of the users is also very important.

As we know from recent experience, expanding the number of centers now in existence is very difficult. Nevertheless one should be optimistic. The fraction of earth's people whose lives are touched by scientific culture is increasing. That will exert a pressure in a positive direction. In addition, the willingness of nations or regions to pool resources with others could increase the total resources available worldwide. This potential increase is to be sought after but is unlikely to, by itself, produce the desired results. The biggest leverage clearly comes from technology improvements which, as a glance at the Livingston chart shows, has enormous potential for enhancement of cost effectiveness.

Thus while collaborative construction of accelerators is something we should pursue as a way to enhance worldwide investment in our science, the really big leverage may be in cooperative technology development. This has traditionally been an area of chronic underinvestment. If we can find a way to enhance that investment through international cooperation, the dividends could be spectacular. Among the many difficulties which such an approach will face are visa and work permit problems, customs problems, and matters of national technology transfer. Another challenge, of course, is how to organize the best collaborations even if such barriers did not exist.

As has been so eloquently observed by Bill Wallenmeyer, High Energy Physics is a World Laboratory, located in many places. It is our privilege and obligaton to expand on that theme.

TOPICS FOR DISCUSSION OF COLLABORATION

IN CONSTRUCTING THE FUTURE GENERATION OF ACCELERATORS

N.E. Tyurin

Institute for High Energy Physics, Serpukhov, USSR

I. Future Facilities in the USSR

The construction of a 3 TeV accelerating storage complex (UNK) is in progress at the Institute for High Energy Physics. The project and our plans foresee the construction of:

- 3 TeV superconducting accelerator in 1993 for carrying out experiments on a fixed target; the design intensity is 6×10^{14}p/c;

- proton-proton colliding beams with $\sqrt{s}$ = 6 TeV and luminosity $\mathcal{L}$ = $4\times10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ in 1995.

Linear electron positron colliding beams (VLEPP) with the energy of 500×500 GeV and luminosity of $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ are to be constructed in the vicinity of Protvino in 1996. Later on the energy of e^+e^- collisions may be increased up to 1000×1000 GeV.

The corresponding design and construction of a 1 GeV model (a 10 m long module) will be the responsibility of the Nuclear Physics Institute of the Academy of Sciences of the USSR. The e^+e^- collider parameters will be detailed in the course of the technical design.

The electron accelerator (VLEPP) and the proton accelerator (UNK) being accommodated on the same site will allow one to consider possibilities to have in the future electron-proton beams with the energy $\sqrt{s}$ ≈ 3500 GeV (UNK+1000 GeV electrons). It is too early to discuss the parameters of such an ep collider and go into details of organizing ep collisions. Nevertheless we may assume that the luminosity $\mathcal{L} \geqslant 10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ will be attainable.

II. Collaboration in Constructing the Accelerators of Future Generation

In 1976 when ICFA was founded the expedience was stressed that there should be no duplication in the type of accelerators when different regions are constructing new facilities.

At present high energy physics is developing on the regional basis. New facilities are being designed and constructed in Western Europe, the USA, Japan and the USSR. The regional basis for the development of high energy physics assumes wide joint participation of physicists and experts from different regions in the regional projects, both at the stage of preparing and carrying out experiments and of machine design.

The physicists of the USSR take part in the experimental programmes at Tevatron, LEP, and HERA, including their contribution to the construction of experimental setups.

The USSR, in turn, always welcomes and supports participation of the other regions in the preparation and carrying out of experiments, in particular at UNK.

The USSR could participate in the research and development programme for the LHC and SSC, for CLIC and superconducting projects and, in turn, will be ready to receive experts to take part in the UNK and VLEPP projects.

In our opinion, there may be considered a question of reciprocal participation of regions in realizing regional projects with the aim to shorten their realization. Certainly, such integration of the efforts of the regions around the regional projects will require detailed consideration, but it inevitably favours a more definite division in the types of machines being constructed and more tight mutual collaboration in the field of high energy physics.

At present the programme on constructing high energy accelerators until the year 2000 has already been shaped in the world. Therefore, at the current stage the regional cooperation in construction should be treated in the frame of regional projects.

Perhaps later on at some further stage it will become possible for two or more regions to unite their efforts in the frame of a single project. No doubt this will require overcoming certain difficulties, improving mutual understanding and efforts in increasing the level of mutual confidence.

Survey of the Work of the ICFA Panels

SURVEY OF THE WORK OF THE ICFA PANEL ON SUPERCONDUCTING MAGNETS AND CRYOGENICS

G. Brianti
CERN, European Organization for Nuclear Research
1211 - Geneva, Switzerland

INTRODUCTION

The main activity of the Panel composed of

Europe (3)	G. Brianti (CERN) - Chairman
	C. Daum (NIKHEF)
	H. Desportes (CEN, Saclay)
USA (3)	P. Reardon (BNL)
	C. Taylor (LBL)
	A. Tollestrup (FNAL)
Japan (2)	H. Hirabayashi (KEK)
	S. Mitsunobu (KEK)
USSR (3)	K.P. Myznikov (Serpukhov)
	A.I. Ageev (Serpukhov)
	V.A. Titov (Efremov Inst., Leningrad)
+ (1)	I. Shelaev (Dubna)
Fourth Region (3)	Yan Lu-Gugan (Inst. Elec. Engineer., Beijing)
	Poh-Kun Tseng (Nat. Taiwan Univ., Tapei)
	P. Chadha (BARC, Trombay)

was to organize a Workshop on Superconducting Magnets and Cryogenics, primarely for accelerators and colliders, with a mixed participation of Laboratories/Universities and Industrial people.

It was very kindly and effectively hosted by the Brookhaven National Laboratory, which set up a Local Organising Committee composed of

A.F. Greene (Chairman)
D.P. Brown
P.F. Dahl
M. Garber
C.L. Goodzeit
W.J. Schneider
P.M. Tuttle, Workshop Secretary

and took place from 12 to 16 May 1986.

Proceedings, edited by P.F. Dahl, were promtly issued by BNL with the support of the United States Department of Energy under the Reference BNL-52006 and title : "ICFA - Proceedings of Workshop on Superconducting Magnets and Cryogenics, Brookhaven National Laboratory May 12-16, 1986".

The main features of the Workshop can be summarized as follow.

PURPOSE

The purpose of the Workshop was to review in depth the state of the art for the design and construction of accelerator magnets throughout the world, the prospects for future development of superconductors and various aspects of large systems and of cryogenics. A second goal was to decide on future activities of the Panel, which met on 14 May and took the decisions indicated under 5 below.

ATTENDANCE

The attendance, limited to about 130 people active in the field, was by invitation, organized on regional basis by the ICFA Panel members. A novelty was to open the Workshop to a large participation of technical people from industry.

The attendance was largely in accordance to expectation and can be summarized as follows :

Region/Country	Labs. & Univ.	Industry	Total
USA	35 (+6)*	13	48 (+6)*
Western Europe	16	16	32
USSR	8	0	8
Japan	5	12	17
Fourth Region	2	0	2
Totals	66 (+6)*	41	107 (+6)*

* 6 from BNL Local Organizing Committee.

The large participation of experts from USSR and Japan and the presence of representatives of China and India should be underlined.

It is particularly gratifying to report that, despite the heavy programme (eight to nine hours of presentations and discussions per day, for a total of about 40 hours) the participation in the sessions remained particularly full and very active for the entire Workshop.

PROGRAMME

Taking into account the large participation, the nature of the Workshop, the large quantity of information, and the specific request of some delegations, it was decided not to split in groups but rather to have a number of presentations, followed by an intensive discussion of one and a half hours, for each subject. The six discussion leaders summarized the discussion in short "rapporteur" talks at the end of the meeting. A few comments can be made :

Session A1 and A2

SUPERCONDUCTING ACCELERATOR MAGNETS GENERAL FEATURES AND PRESENT STATUS

It was devoted to the presentation of large projects or studies and of regional activities. It is remarkable to see that, since the commissioning of the Tevatron in 1983, two large projects are in the construction phase (HERA and UNK), two under very active preparation (SSC and RHIC) with the construction of full length prototypes, and one under intense study (LHC).

To-date, more than one thousand magnets have been built, and eventually up to fifteen thousand should be built over the next ten years.

It is also remarkable that the field considered goes from less than 4 T (Tevatron operation) to up to 10 T for LHC. This is made possible by the development of materials and techniques, as reviewed in the following sessions.

Session B1 and B2

SUPERCONDUCTOR DEVELOPMENT

After an overview of advanced materials, the spectacular progress of NbTi wires and cables over the last years were treated by various authors. The current density at 5 T increased by more than 50% since the Tevatron, while the filament size, which determines the magnetization currents and hence the field errors at injection, tends to be considerably decreased.

It is particularly encouraging to note that this progress is realized in the products of several industrial companies. For this reason the nominal dipole field now set for the SSC is 6.6 T (6 T before). Nb_3Sn and Nb_3Al superconductors also show considerable progress but development work on them is less than for NbTi. However, the interest for LHC stimulates further developments in these newer materials. There was general agreement that present or prospective superconductors should allow the construction of dipoles with fields up to 10 T (NbTi at ~ 2 K and Nb_3Sn/Nb_3Al at ~ 4.2 K).

The electrical properties of wires and cables, and the methods and procedures to measure them were eagerly discussed, and form the subject of one of the future activities of the Panel (see 5 below).

Sessions C1 and C2

MAGNET DESIGN AND CONSTRUCTION METHODS

The session opened with a very clear presentation of the basic requirements on magnet aperture and field uniformity for a good accelerator magnet system.

Then, specific designs and construction methods were presented by various authors, completed by the description of correcting magnet systems and of powering and quench protection schemes.

It is interesting to note that :

a) practically all designers of high field ($\geq$ 5T) magnets adopt the layout of two concentric collared coils, inserted in a cold iron yoke,

b) for pp colliders, both separate magnet and cryostat systems (SSC) and "two-in-one" combined systems (LHC) are considered,

c) 10 T appears to be the limit allowed by the present technology, due in part to the mechanical strenght of materials.

Session D1

CRYOGENIC SYSTEMS

The experience acquired with the cryogenic system of the Tevatron and the design and constructional features of various other large systems were reported and thoroughly discussed. Of particular interest was the discussion on systems operating with superfluid He (1.8 K) or at temperatures between 2 and 4.6 K.

Low temperature systems, pioneered in France in the tokomak Toresupra at 1.8 K, are of particular interest for reaching high fields (8 to 10 T) with well known and easy-to-fabricate NbTi conductors. They may become important for radio-frequency cavities, expecially at frequencies above 1 GHz. Presentations by industry were particulary appreciated.

Session E1 and E2

ACCELERATOR MAGNET MEASUREMENTS

The last two topical sessions were devoted to the measurement of complete accelerator magnets, which demands high accuracy (10^{-6}) in the determination of multipolar components up to high order, which are important for determining the performance of accelerators (especially for slow beam extraction) and of colliders (beams circulating and colliding for many hours).

Session F

CONCLUSIONS

Most of the session was devoted to six short "rapporteur" talks by the discussion leaders, namely :

A. Tollestrup (FNAL)	for Sessions A1 and A2
C. Taylor (LBL)	for Session B1
C. Walters (RAL)	for Session B2
R. Perin (CERN)	for Sessions C1 and C2
M. McAshan (LBL)	for Session D1
P. Mantsch (FNAL)	for Sessions E1 and E2

which will be inserted in the Proceedings.

The various technological aspects of importance for the construction of large accelerator/collider systems seem to be in a very healthy state and still developing fast. This is due to the considerable 'pulling' force represented by on-going projects or by some under preparation, which acts in the laboratories and in industry. The nominal field of NbTi magnets is moving up in the 6 to 7 T region for systems cooled at the normal liquid He temperature (< 4.5 K), and beyond 8 T, possibly up to 10 T, at lower temperature (~ 2 K), or with A15 conductors.

While the superconductors are currently produced by industry, there is no experience yet with the industrial production of hundreds or thousands of magnets. In the next few years this important event should occur, and should be beneficial not only to high energy physics but also to other applications (NMR, fusion, electro-technique).

GLOBAL ASSESSMENT OF THE WORKSHOP

- There was a large consensus of the participants that the Workshop was very useful at this time, when major projects are under construction or very actively prepared. The unity of the subject favoured a full treatment of all aspects of materials and engineering without falling into unduly long descriptions or unnecessary debates.
- The industrialists integrated very well with the laboratory people and made excellent presentations of their work. They repeatedly expressed their satisfaction for the opportunity offered to them of acquiring full informaiton on the world scale and of expressing their views on the industrial production of accelerator magnets.
- The Proceedings were published within three months and will constitute an excellent review of the state of the art.

FUTURE ACTIONS

It is intended to appoint a sub-apenl with the following tasks :

i) to work out a standard form of specifying superconducting wires and cables,

ii) to determine the parameters to be measured and the measuring procedures on superconducting wires and cables, and express them in a standard form.

This standardisation would facilitate the work of the laboratories and of the industrial firms, as well as the comparison of the results.

Other topics which could be tackled by the Panel could be :

i) Detector magnets (solenoids)

ii) RF superconductivity

iii) Use of high temperature superconductors.

I am passing now the Chairmanship to the very capable hands of Dr. H. Hirabayashi (KEK) and wish to thank all the Panel Members for their very effective collaboration.

A DESIGN STUDY ON HIGH ENERGY ACCELERATOR MAGNETS WITH COMPLETE ARCH COILS BY SPECIAL KEYSTONE CABLES

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Abstract: In the near future, superconducting magnets with a small aperture will be required for high energy storage accelerators. When coils are designed to arch of themselves over a small beam pipe, it simplifies the magnet construction both in the winding procedure and in the field quality control. Fabrication of these coils requires cables with large keystone angles. A new structure of "braid-in-strands" is devised to make these cables. A design study is performed to make clear the characteristics of the magnets that are wound by these cables. A magnet is designed in this study and the straight section of this magnet has been fabricated as a preliminary test before constructing a whole magnet.

1. Introduction

Dipole magnets with two-layer coils have been developed for TEVATRON at Fermilab[1,2]. The Rutherford type cables of keystoned shape were wound into the coils. They arched of themselves over the magnet aperture. This indicates that the keystone angle of the cable fitted the magnet aperture (full keystoned cable). In the magnet cross section, all cables were vertically directed to the center of the magnet aperture. This is a special feature of the self-arched coils. The structure of these coils was useful to simplify both the winding procedure and the field quality control. The basic simplicity of the structure made it possible to produce a great number of magnets which had an acceptable field quality.

A high energy proton accelerator in the energy region of 10 to 20 TeV will be built in the near future[3,4]. The dipole magnet for

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Presented at 1987 ICFA Seminar (BNL) Oct. 6∿10 '87.

Superconducting Super Collider (SSC), has been designed to possess the two-layer coils[5,6]. In comparison to that of TEVATRON, this magnet have the following characteristics: The coil aperture is reduced by about half in diameter. The cable is widen by about 20%. The cable has a smaller keystone angle by 20% (outer coil) to 40% (inner coil). If this cable is wound into a coil without use of wedges, the radius of its curvature becomes much larger than the design value of the aperture. This means that the keystone angle does not fit the smaller design aperture (partial keystone cable). This unfittness is a marked feature of the SSC magnet.

The SSC magnet then required many wedges. They were inserted into the coils to compensate the original curvature of the windings. Both the size and the position of the wedges were chosen carefully to achieve a good field quality[6]. The use of these wedges arched the coils as a whole. Unlike that of TEVATRON, this arch was not made in a completely self-arched manner. All cables were not vertically directed to the magnet center. Thus, the adoption of the partial keystone cable brought about complexity in the winding procedure and in the field quality control.

It is desirable that the magnet for the future accelerator will have the structure of the self-arched coils. A preliminary study[7] has been made by a KEK group to apply this structure to the magnet for the future accelerator. The magnet requires the cables with the larger keystone angle (full keystone cable) that fits the smaller coil aperture. It has been difficult to fabricate such cables. This is because the excess cable deformation causes their critical current to be degradated during the cable forming procedure. New technology is being developed in Japan to fabricate these cables. They are now available in a mass-production scale. We will present the development of the cable with the larger keystone angle. Both the design and the experimental studies will be described on the dipole magnet with the self-arched coils.

2. Full keystone cable

The full keystone cable has been developed by a Japanese Furukawa Industry. The cable is principally a Rutherford type, but contains a superconducting or pure aluminum braid inside the usual strands (braid-in-strands structure). The structure of the cable is illustrated in Fig. 1. The picture is shown in Fig. 2. The braid is put closely to one edge of the cable, so that it raises the cable thickness mainly on this side. The braid thus has an important role in the increase in the keystone angle. The keystone angles are 4.64 and 2.61 degrees for the inner and outer coils, respectively.. The angles for the corresponding coils are 1.61 and 1.21 degrees in the SSC magnet[6). The present values are about twice as large as that for the SSC magnet.

The specifications of the cables are shown in Table I. The nominal current is 6.37 kA for the central field of 6.5 T. The filament diameter is 5 $\sim$ 6 μm. The cables have different copper-to-superconductor ratios for the inner and outer coils. The overall current densities at 6.5 G are 370 and 450 A/mm^z for the inner and outer coils, respectively. The average cross sectional dimension of the cable is 10.0 × 1.72 mm for the inner coil and 10.0 × 1.42 mm for the outer. These values include the thickness of insulation layers, and they stand for the dimensions after collaring. The values in the table shows the dimension of bare cables. The cable is insulated by Kapton tape (thickness 2 × 0.025 mm) with small gap winding. B stage epoxy resin impregnated glass tape (thickness 0.10 mm) wraps the cable with a gap space of 1 mm.

The braid in the cable is made of a number of thin superconducting or pure aluminum wires of 0.1 mm diameter. It will be studied experimentally whether or not the coupling current through the braid produces an anominous effect on the magnet performance. If the effect is considerably large, the superconducting braid will be replaced by that made of surface insulated pure aluminum wires.

3. Design of the magnet with self-arched coils

In contrast to that of SSC, the magnet with the self-arched coils has the following characteristics.

(1) On a plane of the magnet cross section, all cables are vertically directed to the magnet center. Hence, mechanical properties of the coil such as elastic modulus are basically the same in the radial direction. This also applys to the azimuthal direction.

The cables are expected to be wound, cured and collared in a more uniform manner.

(2) There is less probability for locational errors of the cables for the reason in item (1). Better reproducibility of multipole characteristics may be expected for field homogeneity.

(3) All radial dimensions of coils are fixed to certain values. Then, the multipole characteristics are simply determined by the angular configurations of coils. The control of the field quality is easier because less parameters determine the field shape.

(4) Insertion of less wedges sufficiently achieves good field homogeneity. The use of less wedges simplifies the winding procedure.

A diameter of 4 cm is taken as the magnet coil aperture. The inner diameter of iron yoke is 5.56 cm. Such values are principally the same as that of the SSC dipole magnet[5,6]. The magnet specifications are listed in Table II. Two wedges are used for a quadrant. The cross section is illustrated in Fig. 2. The transfer function and the field homogeneity shown in Table II are similar to that of the SSC magnet.

Characteristics of the magnet design are summarized in Table III in the case of use of loss wedges. During the calculation, coil radii and current densities are kept basically the same as in Table II. When no wedge is used, the magnet design leads to considerably less number of turns in the outer coil. This produces the larger values of both 14 and 18 poles: $b_6 = -1.4$ and $b_8 = 0.5$ in the usual units of 10^{-4} at 1 cm. The transfer function decreases to an appreciable extent. In contrast, the TEVATRON dipole magnet having no wedge showed a negligible magnitude of 14 poles[1]. Whereas the coil aperture in the present design is about half of that in the TEVATRON magnet, the cable width is larger by a quarter in this design. Hence, the procont magnet has a larger ratio of cable width to its coil aperture than the TEVATRON magnet, and accordingly does relatively thicker shell coils for its coil aperture. This is the reson for the appearance of 14 poles in the case of no wedge design.

For use of one wedge, adjustment of the coil configuration leads to a negligible size of 14 poles, but the value of 18 poles still remains to be slightly large i.e. $b_8 = 0.4$. When another wedge is added, the values of both 14 and 18 poles become negligibly small by choosing a suitable coil configuration. Therefore, two wedge design is adopted in this study. The SSC magnet was designed by the partial keystone cables, and has four wedges for a quadrant[6]; half of them mainly serve to compensate the inadequate coil arch which is ascribed to the partially keystoned cables.

4. Fabrication of the straight section

For producing the magnet of good field quality, it is most important to settle the cables correctly into the design position. The coils are influenced on their cable position by such factors as winding accuracy, curing pressure, collaring pressure and collar deformation. The careful choice and control of these factors should lead to the successful construction of high quality magnets. Therefore, checking the cable positions is useful to find an adequate method of the magnet construction.

The straight section of the magnet was fabricated to obtain information on the actual cable positions. The length of this section was as short as 15 cm, which is about twice the transposition pitch of the cable. The short section was made under the same condition as in the real magnet construction. For the purpose of flexibility, a grow discharge wire cutting machine was used to make the collars in this test fabrication.

The cross section of the straight section is illustrated in Fig. 3. The field calculation based on the detailed positions of each strand should produce the magnetic field which would appear in the magnet constituted by this conductor configuration. The computed magnetic field is considered to be correct specially for a current around 2000 A. This is because neither the magnetization of superconductor nor the saturation of iron yoke appear significantly in this current region. Deformation of coils is still negligibly small at this current. Fabrication of this short straight section and its subsequent analysis serve to contract the high quality magnets in a controlled manner.

5. Conclusion

The magnet with the self-arched coils is desired for the future high energy accelerator. The magnet requires the cables with large keystone angle for them to make the self-arched coils. The new idea of "braid-in-strands" structure enabled us to successfully fabricate the special keystone cables. The magnet design shows that the good field homogeneity is achieved by inserting two wedges into a quadrant of magnet winding. Prior to construction of a whole magnet, its straight section was fabricated to obtain the detailed information on the cable position.

Acknowledgements

The authors express their thanks to Mr. S. Meguro of Furukawa Electric Co., Ltd. for fabrication of the full keystone cables, and to the staff of the machinery division of KEK for their constructing the straight section of the magnet.

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6) "SSC Conceptual Design - Magnet Design Details", SSC-SR-2020B (1986).

7) K. Ishibashi, H. Hirabayashi and others: Proc. of Workshop on Superconducting Magnet and Cryogenics (ICFA), BNL Report BNL-52006 (1986) 179.

Table I Specifications of the braid-in-strands cable

	Inner layer	Outer layer
Number of strands	26	30
Width (bare) (mm)	9.72	9.67
Thickness (bare) (mm)	1.17-1.96	1.06-1.50
Keystone angle (deg)	4.64	2.61
Transposition pitch (mm)	72	75
Strand diameter	0.748	0.648
Filament diameter (μ m)	6	5
Cu:SC ratio	1.71	1.69
No. of strands in braid	75	75

Table II Specifications of the magnet

	Inner layer	Outer layer
Radius (mm)	20.0-30.0	30.2-40.2
No. of turns (half)	6+7+4	19
Maximum angle (mm)	70.4	44.0
Wedge angle (deg)	23.9-25.9 53.5-58.2	none
Iron inner radius (mm)	55.7	
Iron outer radius (mm)	87.6	
Transfer function (G/A) at 2kA	10.4	
Current (kA) for 6T	5.8	
Harmonics (10^{-4} @1cm) at 2kA		
Sextupoles (b_2)	0.0	
Decapoles (b_4)	0.0	
14 poles (b_6)	0.0	
18 poles (b_8)	0.0	
22 poles (b_{10})	0.1	
26 poles (b_{12})	0.03	

Table III Design characteristics in the case of fewer wedges. Values for the magnetic field are shown at a current around 2 kA.

	No. of wedges for a quadrant	
	No wedge	One wedge
Number of turns (half)		
Inner coil	18	13+5
Outer coil	16	18
Maximum angle (deg)		
Inner coil	72.4	73.7
Outer coil	36.5	41.0
Wedge angle (deg)		
Inner coil	—	51.2-53.7
Transfer function (G/A)	10.0	10.5
Harmonics (10^{-4} @1cm)		
Sextupoles (b_2)	0.0	0.0
Decapoles (b_4)	0.0	0.0
14 poles (b_6)	-1.4	0.0
18 poles (b_8)	0.5	0.4
22 poles (b_{10})	-0.08	-0.1
26 poles (b_{12})	0.01	0.02

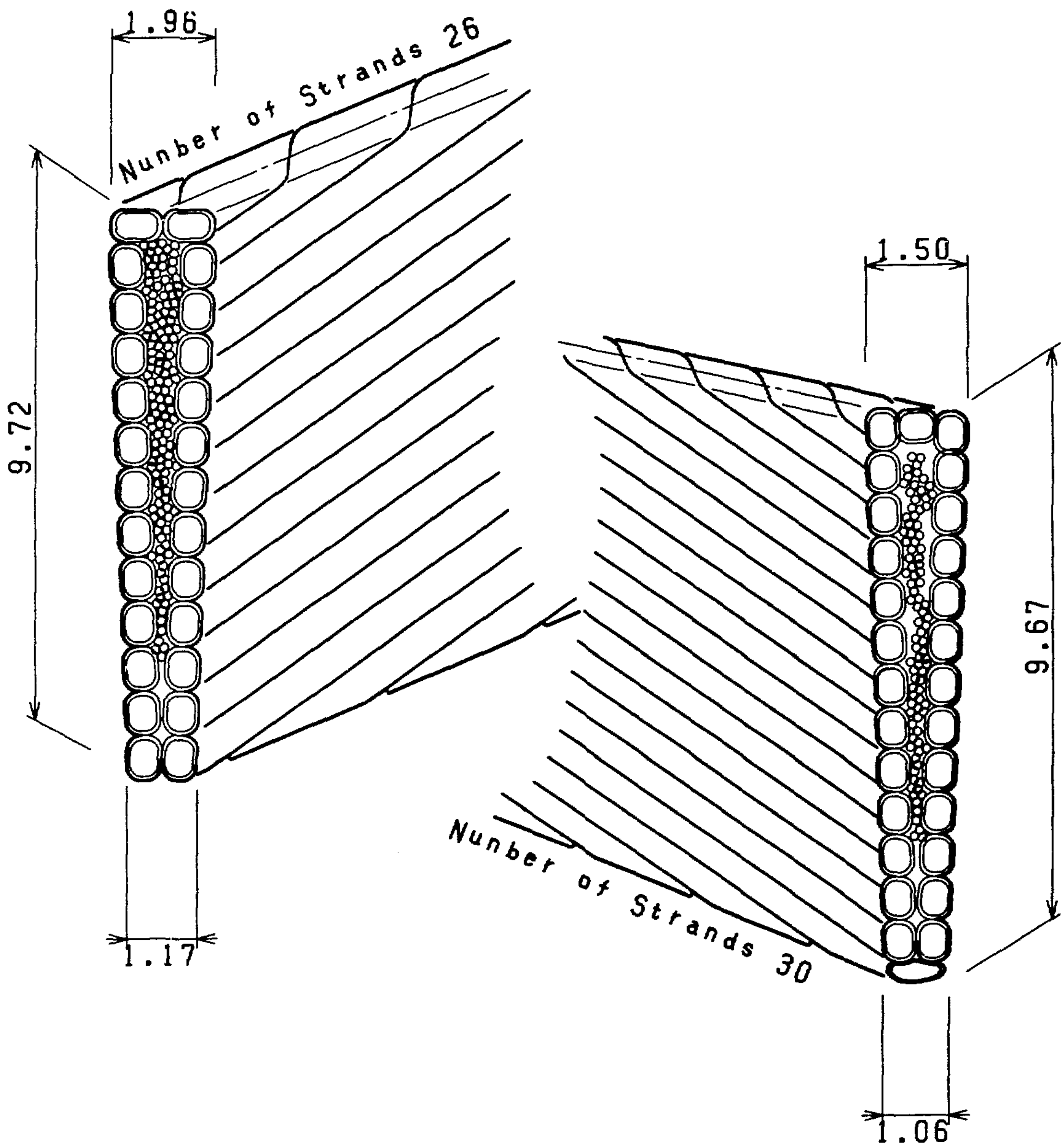

Fig. 1 Largely keystoned cable. The Rutherford type stranded cable contains an inner braid therein (braid-in-strands structure). The width is expressed in units of mm.

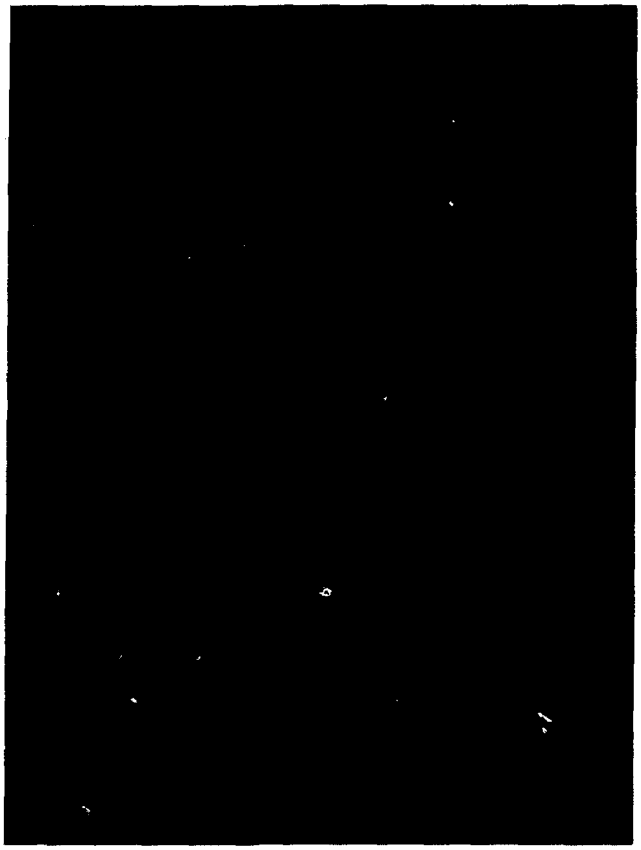

Fig. 2 Picture of the cable.

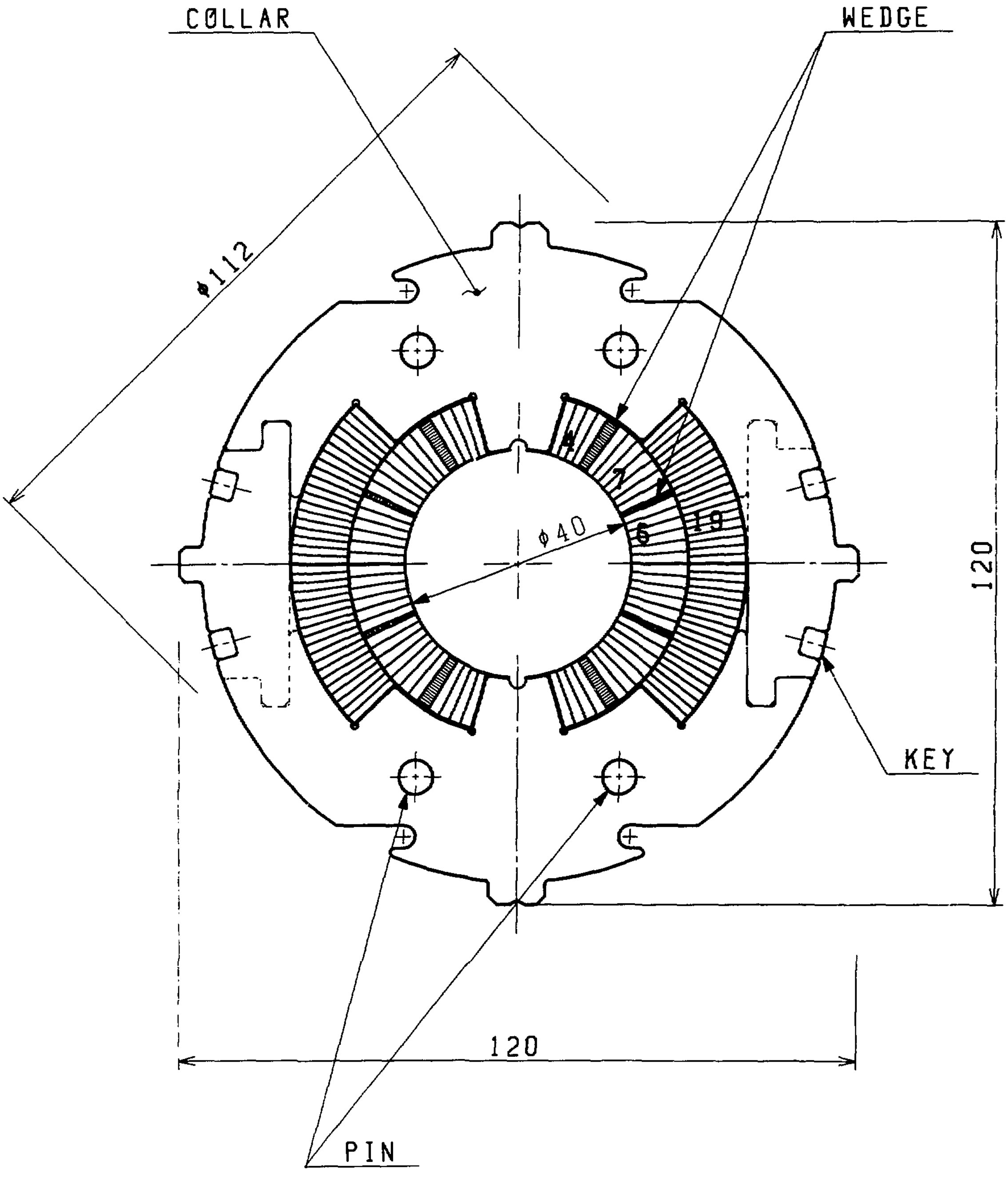

Fig. 3 Cross section of the magnet. Coils completely arch over the aperture. There are two wedges for a quadrant. The numbers are written in units of mm.

REPORT ON THE WORK OF THE ICFA PANEL ON BEAM DYNAMICS

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CERN, Geneva, Switzerland

1. INTRODUCTION

This report of the ICFA Beam Dynamics Panel to ICFA covers the period from November 1986 till October 1987. It contains brief summaries of two panel meetings, and a report on the first Advanced Beam Dynamics Workshop. The approval of ICFA is sought for two further workshops, to be held in 1988 and 1989, and for the creation of a Beam Dynamics School.

2. PANEL MEETINGS

2.1 Second Panel Meeting

The Panel had its second meeting from 3 to 5 November 1986 at DESY, Hamburg, Germany. The meeting was attended by 8 members, and 7 members were absent, among them all members from the Soviet Union. Because of his absence, N. Dikansky asked E. Keil to act as chairman.

The Panel heard presentations of ongoing and planned beam dynamics studies in the following laboratories and/or regions: CEBAF, CERN, Cornell, DESY, European synchrotron radiation sources, Fermilab, Italian laboratories, KEK, LBL, SLAC and SSC. The members present felt that this exchange was very informative and should be repeated in future panel meetings.

The Panel obtained the permission of ICFA to publish an ICFA Beam Dynamics Newsletter with reports on ongoing and planned beam dynamics studies, written by the Panel members, and a list of forthcoming beam dynamics events. None of the absent panel members submitted a contribution. The Panel considers that a wide circulation of the Newsletter will stimulate collaboration between regions.

The Panel compiled specifications for Advanced Beam Dynamics Workshops on the following topics:

- Aperture-Related Limitations of the Beam Lifetime in Storage Rings,
- Low Emittance Beams,
- Parallel Processing in Beam Dynamics,
- Beamstrahlung,
- Mechanical Vibration Effects.

The following topics were also considered for future Workshops: (i) Beam-beam effects, (ii) Polarized beams, (iii) Collective effects, (iv) Impedances and wakefields, (v) Application of chaos to beam dynamics.

2.2 Third Panel Meeting

The Panel had its third meeting, attended by 8 members, from 1 to 3 October 1987 at the SSC/CDG in Berkeley, USA.

The Panel heard presentations of beam dynamics activities at BNL, CEBAF, CERN, DESY, Fermilab, KEK, LBL, Novosibirsk, SLAC and SSC/CDG. As for the second Panel meeting, the presentations will be published as a Beam Dynamics Newsletter.

The Panel reaffirmed its commitment to organize one "Advanced Beam Dynamics Workshop" per year. It updated and slightly modified its specifications for workshops to be held in 1990 or later:

- Operations Simulation (Modeling)
- Final Focus and Beamstrahlung
- Mechanical Vibration Effects

Polarized beams, collective effects, impedances wakefields, parallel processing in beam dynamics, and beam cooling techniques were also considered as possible topics for future Advanced Beam Dynamics Workshops.

It was suggested that the knowledge of beam dynamics be spread into the third world in a fashion similar to the efforts of the ICFA Instrumentation Panel, in the form of a Beam Dynamics School at university level. The Panel considers that Beam Dynamics of Electron Storage Rings, addressing the basic physical and engineering principles, is a suitable subject for such a School. Sites and dates for such a School were also discussed.

2.3 Future Panel Meetings

Future Panel meetings are foreseen around the time of the Aperture Workshop in Lugano in April in 1988, and around the Beam-Beam Workshop in Novosibirsk in July 1989.

3. ADVANCED BEAM DYNAMICS WORKSHOPS

3.1 First Workshop

The first Advanced Beam Dynamics Workshop was held at BNL from 20 till 25 March 1987 on "Low-Emittance Beams". It was organized by C. Pellegrini. Some 45 people from 25 laboratories and companies attended the workshop, not counting BNL staff. The proceedings are ready for distribution at the ICFA Seminar in October 1987.

3.2 Second Workshop

Approval of ICFA is sought for a second Advanced Beam Dynamics Workshop, to be held from 14 to 20 April 1988 in Lugano, Switzerland. The members of ICFA have been asked to make this workshop known to interested physicists in their region.

The subject of the workshop is "Aperture-Related Limitations of Storage Rings". Its purpose is to survey and advance present knowledge, both experimental and theoretical, of those aperture-related effects which limit the performance of storage rings, and in particular the lifetime of the stored beams. Examples of elements contributing to such limitations are multipole elements, both intentionally and unintentionally present, and noise and ripple in power supplies. More specifically, the following topics will be discussed:

- Experiments on existing accelerators and the lessons to be learned for the planning of future experiments and the design of future machines.
- Analytical methods for determining amplitude limitations and diffusion rates in the tails of circulating beams.

- Criteria for the properties of the circulating beam, i.e. tune spreads, etc., and the resulting criteria for the quality of the magnetic field.
- Compensation schemes for field defects.

The organizing committee is chaired by E. Keil, its members are mostly the members of the Panel. During its first meeting at Berkeley, the committee adopted the list of topics above and a first list of participants.

3.3 Third Workshop

Approval of ICFA is also sought for a third Advanced Beam Dynamics Workshop on "Beam-Beam Effects and Stochasticity", to be held at Novosibirsk in July 1989. The exact date remains to be defined.

4. NEWSLETTER

The first Beam Dynamics Newsletter was printed and some 1100 copies were distributed by DESY early in 1987. The Panel is keen to have the opinion of the ICFA members whether the wide circulation intended was actually achieved. It is foreseen to publish Newsletters after all future Panel meetings. Their contents, style, and circulation were discussed at the Panel meeting, no changes were suggested. Organizations who would like to be put on the distribution list, may contact Dr. A. Piwinski, DESY, Notkestr. 85, 2000 Hamburg 52, Germany.

REPORT ON THE ACTIVITIES OF THE PANEL ON FUTURE INSTRUMENTATION INNOVATION AND DEVELOPMENT

Tord Ekelöf
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1. Introduction

The ICFA Panel on Future Instrumentation Innovation and Development since it was set up in 1985 has been operating with the following basic aims.

1. To create new channels of communication for information on High Energy Physics Instrumentation to stimulate new and more activity in this field in order to meet the experimental challenge of the planned future colliders and also of the forthcoming non-accelerator experiments.
2. To stimulate the involvement of all regions of the world in Experimental High Energy Physics for general reasons of scientific culture and in particular in order to increase the amount of human and material resources channelled to the field of High Energy Physics.

With these basic aims the Panel has organized the following activities which are now well under way:

1. The ICFA Instrumentation School
2. The ICFA Instrumentation Bulletin
3. The ICFA Review of Detector Properties

Lately a few other activities have been initiated. They are:

4. Facilitating international computer net-work mail communication
5. Publication of a list of HEP Instrumentation Workshops and Conferences
6. Assistance in redistribution of used HEP instrumentation from big to small labs.

The Instrumentation Panel has had 7 meetings (most of them two-day working meetings) since it was set up, four times in Europe, twice in the USA and once in the USSR. In table 1 is shown the attendance of the Panel members at these meetings.

Below accounts are given of the various activities of the Panel.

2. The ICFA Instrumentation School

The aim of the ICFA Instrumentation School is to teach the physics and technology of particle detectors for High Energy Physics experimentation. Emphasis is put on a didactic treatment of the basic principles of particle detectors and of the experimental requirements at the upcoming and planned accelerator facilities. Hands-on laboratory exercises constitute an important part of the School. PhD students or young PhD's qualify for participation in the School. The aim is to have about equal participation from industrialized and developing countries.

The first School was held at the International Centre for Theoretical Physics (ICTP) in Trieste, Italy, from 8th to 19th of June 1987. Two members of the Panel, Chris Fabjan and Jim Pilcher, acted as organizers of the School. The School was attended by 74 students, 45 of which were from developing countries. The participation of the students from developing countries was made possible through a very generous financial support from ICTP.

The names of the lecturers and the title of their lecture courses, as well as the names of the principal laboratory instructors and the theme of their laboratory exercises are listed in table 2.

The lectures were given in the morning and the laboratory sessions in the afternoon. There were also discussion sessions based on the morning lectures organized during the afternoon. There were four identical set-ups of each of the four laboratory experiments, i.e. in total 16 laboratory set-ups in operation. Two students, in most cases one from an industrialized country and one from a developing country, worked together during four half-afternoons on a given experimental station. Each student carried through two out of the four experiments. In addition to the principal instructor there were 2-3 assistant instructors per experiment and in consequence there was about one instructor for each of the 16 student pairs.

The students on average took a very active part in both the discussions and in the laboratory sessions. The spread in academic ability and experience within the student group was considerable but less than might have been thought. Many of the students from the developing countries had in fact had some experience with High Energy Physics and turned out as very active and motivated participants.

The School was financed to 90% by a very generous contribution from ICTP amounting to about $70 000. The major part of this budget was used to pay the travel and subsistence of the 45 students from the developing countries and also to cover some teaching-staff costs. About $10 000 of the contribution was used for the preparation of the equipment for the laboratory sessions, to which also CERN and INFN contributed with about 7000 SF each. The experimental equipment had been prepared at Fermilab, at Cornell, at Imperial College in London and at CERN, respectively and was brought to ICTP for the School. One set-up of each experiment was left at ICTP after the end of the School.

The School is generally agreed to have been a big success. This is not to say that there were not also some shortcomings in the organization. One was that the posters and the bulletins of the School which were channelled out using the ICTP mailing lists did not efficiently reach the HEP communities in the industrialised countries and we have received complaints from colleagues who said they only heard about the School when it was too late to apply.

In general, however, we have had very positive reactions to the School and the Panel has therefore decided to organize a Second ICFA Instrumentation School in 1989, also in Trieste. ICTP has offered to continue its generous support to the School. The Panel hopes that also the other institutions which sponsored the first School, as well as new ones, will support the continuation of this most useful and appreciated activity.

3. The ICFA Instrumentation Bulletin

The ICFA Instrumentation Bulletin is intended to be a periodical offering useful news-letter type communications on instrumentation issues to be distributed to the HEP community and also to industry. It contains information on the following items.

- Experience and ongoing work with new interesting devices, products and technologies.
- Discussions on proposed experimental set-ups in High Energy Physics.
- Reports on Working groups, Workshops and Conferences on the development of HEP instrumentation.
- Reports on projects with Industry and Other Sciences.

The first issue of the Bulletin was printed in 1500 copies and appeared in March 1986, the second in February 1987 with 2000 copies and the third at the time of the ICFA Workshop at BNL, also with 2000 copies. A member of the Panel, Heinrich Walenta, is acting as editor for the Bulletin. He has lately affiliated Dr Hans-Jürgen Besch as co-editor. The Bulletin is distributed free of charge to all persons interested.

In table 3 are listed the authors and the titles of the articles published in the three first issues.

These issues of the Bulletin have been edited and printed in Siegen in West-Germany and distributed by DESY following an initial list of workers in the field, set up by Walenta. To this list has successively been added many hundred new names of persons who since then have requested to be on the mailing list of the Bulletin.

The cost of the Bulletin per issue is about 4000 DM for the printing and 2000 DM for the distribution. To this should be added the need for secretarial assistance for typing, formatting, correspondence with authors and maintenance of mailing list. For the two first issues the printing costs were covered by the German Ministery for Research and Technology and the distribution costs by DESY. The secretarial assistance was found ad hoc at the University of Siegen. In the third issue commercial advertisments from six industrial companies were published. The name of these companies are listed in Table 4.

The charge for an advertisment was set to 800 DM per page as to having the income from advertisments cover the printing costs.

The aim will be to keep the amount of advertisments in the Bulletin to be not more than 40% of the contents. The advertisments are selected strictly on a first-come, first-served basis. The secretarial work for the third issue was made by Mrs Gäng, who will be working half-time for the Bulletin on a post at the University of Siegen.

On the basis of the more stable organization achieved with the third issue the Panel is now planning to issue a Bulletin every three months. The Panel wishes that the distribution of the Bulletin, which is presently done by DESY alone, be divided out on CERN, DESY and a laboratory in the USA in a manner similar to that for the CERN Courrier.

4. The ICFA Review of Detector Properties

The aim of the ICFA Review of Detector Properties is to create a compilation of such current scientific and technical information as is needed in High Energy Physics for work with innovation and development of new particle-detection techniques and for work with design, build-up and operation of experiments at existing and future accelerators. The Review should be made such that it will also be of use for the novice in the field.

To achieve this the Panel intends to invite front-line experts in the field as guest authors to summarize the information on current and future experimental techniques in High Energy Physics with the following guidelines.

The summary should set out by defining the basic principles of the experimental technique in question. The introduction should also contain a very short history of the development of the technique and outline the fields of application. The main subject should be to describe and analyze the current situation and the trends for the future development of the particular technique, referring to ongoing or planned High Energy Physics experiments using the technique. Unsolved problems and opportunities for the editors will help the authors to use available data bases like the International Nuclear Information System (INIS), the Energy Data Base (EDB) in the USA and others by setting up so-called Selective Dissemination of Information Searches. The instructions on how to use these data bases and the key-word combinations needed for retrieving data relevant to each subject treated will be included in the Review.

The next step now being undertaken is to invite the guest authors and to agree on the terms of publication with the editors of NIM. The Panel will try to have the first issue of the Review of Detecto... ...ties out by the end of 1988.

5. Summary and outlook

The Instrumentation Panel has met seven times since it was set up three years ago and it has launched three projects, the School, the Bulletin and the Review, which are now operating. Furthermore, the Panel will try to facilitate worldwide computer communication through networks, stimulate and inform about High Energy Physics instrumentation workshops and assist in the redistribution of used High Energy Physics instrumental devices. It also plans to offer its services for providing an international platform for the organization of instrumentation workshops to stimulate the utilization, by physicists from all regions, of the regional colliders that are planned or under construction to be the ready in the next decade, i.e. LHC, SSC and UNK.

Let me conclude by noting that many members of the Instrumentation Panel have worked with much enthusiasm and invested a great personal effort in our common work. Furthermore, several institutions, in particular ICTP, DESY, CERN, LBL, INFN and the University of Siegen are supporting our activities in a very generous way. This support is of decisive importance for the realization of our projects. It goes nearly without saying that it has been and is a great pleasure to chair the ICFA Instrumentation Panel under such circumstances and I wish to thank warmly all collaborators and contributers for the excellent collaboration we have together.

development should be discussed, pointing out priorities. The summary should also contain a number of data tables and curves intended to be of practical use for the workers in the field.

The status of this project is as follows. An index of current instrumentation methods and techniques in High Energy Physics has been compiled. This index is called the Catalogue of Instrumentation Issues and has been edited by a member of the Panel, Dave Nygren. Seven subjects have then been selected from this Catalogue to be treated in the first issue of the Review. These subjects are listed in Table 5. The list of subjects does not cover the whole field of High Energy Physics instrumentation and although the subjects selected are thought to be of high relevance for the future development, the selection does not a priori represent a judgement of priority with regard to other subjects not appearing on the list. The motivation for selecting a limited subsample was primarily to limit the initial effort required when starting up the Review.

The Panel has appointed two editors for the Review, Dr Heinrich Leutz of CERN and Dr Robert Kenney of LBL. Although the two editors are not nominally members of the Panel they will be invited to the meetings of the Panel to take part in all discussions and decisions on the Review. An agreement of support for the Review has been reached with CERN and LBL, who will each provide a 1/4-time secretarial assistant and a budget of 20 000 CHF per year for drafting, computing, printing, distribution, travel etc. to be used by the respective editors.

The plan is to publish the seven reports, each about 50 printed pages long, as a special issue of Nuclear Instruments and Methods (NIM) to be made available to the High Energy Physics community by distributing copies free of charge in a way similar to what is done for the Review of Particle Properties. Preliminary contacts with the editors for NIM have already been made on the subject. The plan is also to edit the contents of the Review as a computer text file accessible via computer links.

The task of the two Review editors is to make contact with the authors, to collect and edit the papers, to organize the printing and distribution and also to edit the computer-based text files. Furthermore,

Table I ICFA Instrumentation Panel Members and Meetings

		1985		1986			1987	
		Uppsala Feb	LBL Oct	Trieste June	LBL July	CERN Dec	Trieste June	Dubna Sept
China								
M.A. Ji-Mao	Beijing			x	x	0		x
Europe								
T. Ekelöf	Uppsala	x	x	x	x	x	x	x
C. Fabjan	CERN	x	x	x		x	x	
G. Hall	London	x	x	x		x	x	x
H. Walenta	Siegen	x		x		x		x
Fourth Region								
A. Santoro	Rio de Janeiro							
S.C. Tonwar	Bombay			x				
Japan								
S. Iwata	KEK	x				x		x
H. Okuno	Tokyo		x					
USA								
M. Breidenbach	SLAC		x		x	x		
D. Hartill	Cornell	x	x				x	x
D. Nygren	LBL	x	x		x			
J. Pilcher	Chicago	x	x				x	
USSR								
Yu. M. Antipov	Serpuknov			0				x
I.A. Golutvin	Dubna				x		x	x
V.A. Liubimov	ITEP			0				x
V. Sidorov	Novosibirsk							x

x = present; 0 = replacing person present.

Table II
Lecture courses and Laboratory sessions of the ICFA Instrumentation School

Lecture courses

W.H. Allison	Interaction of Charged Particles and Photons in Matter
B. Sadoulet	Drift and Detection of Charges
R. Schwitters	Accelerator Experiments in Elementary Particle Physics
V. Radeka	Detector Signal Processing
G. Yodh	Cosmic Ray Physics and Astrophysics
R. Wigmans	Energy Loss of Particles in Dense Matter - Calorimetry
J. Stone	Elementary Particle Physics Detectors for Non-Accelerator Experiments.
V. Perez-Mendes	Detectors in Medicin and Biology
R. Klanner	Drift and Detection of Charges in Solid Detectors
U. Amaldi	An Experimentalists Overview of Accelerators
Evening seminars	by G. Charpak and F. Bradamante

Laboratory Sessions

F. Sauli	Principles of MWPC Detectors
D. Christian	Drift Chamber Studies
D. Hartill	Measurements of the Life time of Cosmic Ray Muons
G. Hall	Signal Processing and Noise Studies

Table III
Contents of the three first issues of the ICFA Instrumentation Bulletin

Issue no 1, March 1986 - 20 pages

T. Ekelöf	The ICFA Instrumentation Panel
Zeus collaboration	Zeus, a detector for HERA
S.O. Flyckt	New Vacuum Photo Triods
D. Freytag D. M. Haller	VLSI-circuits for Research

+ Editorial, Short contributions, Who knows, Schools, Conferences, Workshops

Issue no 2, February 1987 - 32 pages

A. Wagner	Report of the task force on detector R & D for the SSC
H1-Collaboration	H1 - a Detector for HERA
J. Ellison G. Hall S. Roe	Silicon drift detectors: Recent work at Imperial College
J. Engler	TMS Ionization Chambers

+ Editorial, Short contributions, Who Knows, Schools, Conferences, Workshops.

Table III (cont.)

Issue no 3, September 1987 - 32 pages

K. Pretzl	Report of the Workshop on Low Temperature Devices for the Detection of Low Energy nerutrinos and Dark Matter.
Y.F.Gu & J.T.He	Study of Chinese-made BGO
A. Zichichi	The LAA Project
M. Gilchriese	SSC Establishes Detector R & D Coordinating Office

+ Editorial, Schools, Conferences, Workshops.

Table IV
Industrial companies advertising in the third issue ofthe ICFA Instrumentation Bulletin

STRUCK, FRG (VME crates)	1 page
CRISMATEC, France (BiGe)	1/2 page
GERO, FRG (High temperature ovens)	1/2 page
LAMRECHT, FRG (crystals)	1/2 page
DSG, FRG (Ge amd Si detectors)	1 page
PHILIPS, Netherlands (microchanel plates)	1 page

Table V
Subjects selected for the first edition of the ICFA Review of Detector Properties

1. Electron Drift in Gases
2. Large Scale Semiconductor Detectors
3. Ring Imaging Cherenkov Counters
4. Simulation of Hadronic Showers and Calorimeter Response
5. Application specific and Very Large Scale Integrated Circuits for HEP
6. Radiation Effects on Wire Chamber Gain
7. Scintillating Fibres and Associated Opto-electronics

Report of the New Acceleration Schemes Panel

Andrew M. Sessler
Lawrence Berkeley Laboraory
University of California
Berkeley, CA 94720

I Panel Members

R. Jameson ****
R. Palmer ****
P. Morton *
A Sessler ****
Y.Kamura (replacing Kamei *)
M.Yoshioka **

J. LeDuff ****
M. Erikson *
J. Lawson *
S. Ramanuthy

V. Balakin *
E. Laziev *
S. Sarantsev
A. Lebedev

I have placed stars next to the listed names indicating the number of Panel meetings attended. We held the following meetings, at the indicated locations:

January '85	Malibu (Informal, but with all four Americans attending)
July '85	CERN
August '86	Madison
July '87	Orsay
October '87	Brookhaven

Attendance at Panel meetings can be broken down by regions, which is shown in the following:

	USA	Europe	USSR	Japan	Other
July '85	4	3	0	1	0
Aug. '86	3	1	0	1	0
July '87	3	1	1	0	0
Oct.. '87	3	1	1	1	0

II Acceleration Schemes

Our panel has been concerned with the work outlined in Table 1, in which is also indicated the major places that are working on the various approaches. Perhaps just a few comments are in order. We can limit ourselves to just a few highlights since there have been recently -- in the last five years -- six conferences, each with lengthy proceedings, on the subject.

Table 1. Novel Accelerator Schemes

1. Plasma - laser	UCLA
	Paris
	RAL
	NRC
	LLNL
2. Plasma lens	SLAC
3. Wakefield	DESY
	Osaka
	ANL
	SLAC
	UCLA

4. Switched Linac	CERN BNL Rochester
5. I FEL	BNL NRL
6. Cherenkov	UCSB
7. Two -Beam	CERN LBL/LLNL
8. Photo-Cathodes	LANL BNL
9. Gradient Studies	SLAC LBL/LLNL KEK Novosibirsk
10. Collider Physics	SLAC CERN KEK Novosibirsk

11. Power Sources

a) Klystrons, Klystrinos, Gyrocons

SLAC
Novosibirsk

b) Lasertrons

KEK
SLAC
Orsay

c) Sheet-Beam Lasertron

Texas

d) Gyroklystrons

Maryland

e) FEL, CARM

LBL/LLNL
MIT
NRL
KEK

f) Relativistic Klystron

SLAC/LLNL

The interested reader can be reminded of the meetings at:

Los Alamos '82	Oxford ;83
Malibu '85	Frascati '85
Madison '86	Orsay '83

The Plasma-laser accelerator have achieved a gradient ~ 1. GeV/m and electrons have actually been accelerated. Furthermore a "long" uniform plasma has been created.

The principle of the wakefield accelerator has been demonstrated. A photo-cathode has been achieved with a peak current of more than 100 A, at 1 MeV, and with a rms normalized emittance of 20×10^{-6} π m rad.

Gradient studies have realized an accelerting field of more than 300 MV/m, while power source work has resulted in a 60 MW gyrocon at 7.5 GHz, a 70 MW relativistic klystron at 8.6 GHz, and a 1.8 GW FEL at 35 GHz.

Collider studies have begun to make the next linear collider (NLC) a "real thing", while the Two-Beam approach is being actively pursued, also, for the NLC.

III Panel Activities During the Last Two Years

While there has been very considerable progress in the physics, the Panel did very little. Why? A variety of reasons, which I want to report upon here:

1. Attendance: Attendance of Panel members at our meetings has been minimal. We have not been able to engage in any significant undertaking, and especially in anything which requires sustained effort.

2. Conferences: There are lots of conferences, as I mentioned above. We did not feel it would serve any useful purpose to have ICFA sponsor still another meeting. We explored have ICFA jointly sponsor one which was still (at that time) in a planning phase. We ran into a regional jealousy and our overtures were rejected.

3. Information Exchange: At our first meeting we decided this would be a significant activity for us, for we felt we could play an important role in this regard. We drew up a list of Coordinating Groups, Investigators (name, addresses, phone numbers), and a Bibliography (with emphasis upon pre-prints; ie still to be published works).

In subsequent years we corrected, updated, and added to our list. I tried to get Soviet participation, but was not successful. It has seemed improper to distribute a booklet in which half-of-the-world is not included and, consequently, we have never issued the booklet.

4. People & Equipment Exchange: We drew-up, at our very first meeting, a list of all those investigators who have spent extended times at other laboratories. We hoped, then, to facilitate further exchanges. In particular, we hoped to do this between the Soviet Union and the rest of the world. We were not successful, at all, in this regard.

5. Budget: We asked ICFA for a budget. With this we hoped to:

(a). Support the travel expenses of Panel members to meetings and, thus hopefully, have better attendance at our meetings.
(b). Sponsor research fellows (especially from the Third World).
(c). Sponsor research projects. (Modest, of course, but something ICFA could point to.)

These uses are in the order of increasing funds. We argued, that even a small budget would make the members of the Panel feel (quite correctly) that they were engaged in a significant enterprise. Thus we could expect better attendance at meetings and more interesting meetings.

We were told that ICFA has no funds.

6. Goals: We set ourselves the goal of listing novel schemes, describing them, and then -- most importantly -- evaluating them. In this last regard we have in mind discussing time scales (Some will take decades; some only a few years.), cost to develop (Many millions and much effort vs. just a bit.), and likelihood of contributing to HEP (Some things look very interesting, but only at low energies, etc.).

We didn't do this evaluation. Why? For two reasons:

(a). There were only a few of us at any meetings and hence we did not have a broad enough group to provide a proper perspective.
(b). We wondered if anyone was listening; ie what purpose would such an evaluation serve? It was felt that "important people"; ie, lab directors and funding agents have their own opinions and don't need ours.

IV. Future Panel Activities

For the future we have two activities planned:

1. Collider Conference: Although there have been a large number of conferences on novel acceleration methods, there has only been one conference focused upon colliders. It is proposed that ICFA sponsor a meeting on Collider Physics in June '88 (in Italy and just following the Rome Accelerator Conference). We have been fortunate to obtain INFN support of this proposal.

2. Soviet Visit: In order to better inform the ICFA Panel on Soviet work on novel accelerators, it is proposed that jointly with the Panel on Beam Dynamics a number of Panel members tour Soviet laboratories in October '88 (just after the National Accelerator Conference). It is expected that between 6 and 10 scientists will visit about for (say) 2 weeks. Of course the visitors would expect to give lectures as a quid-pro-quo.

Panel Discussion: Future Cooperation in Accelerator Construction (II)

PANEL DISCUSSION

FUTURE COOPERATION IN ACCELERATOR CONSTRUCTION (II)

(Text prepared by Editor with concurrence of Panel Chairman)

Panel Chairman: W.K.H. Panofsky

Panel Members: S-X Fang
L.M. Lederman
J.H. Mulvey
T. Nishikawa
B. Richter
H.F. Schopper
V. Soergel
M. Tigner
N.E. Tyurin

W.K.H. Panofsky, in his opening remarks, stated that the Panel Discussion was a continuation of the Panel Discussion on Future Cooperation in Accelerator Construction (I) of the previous day. The purpose of these discussions was to provide input to ICFA in its deliberations. Panofsky noted that in Round I of the Discussion a mixture of summaries of regional plans and views and of individual views was presented, which brought out points of agreement as well as disagreement. Full consensus was expressed on the need for international collaboration in communication, exchange of information, and so forth, and with Wallenmeyer's observation that high energy physics is a World Laboratory--albeit not in a single location. There appeared to be convergence of opinions on technical matters, among them on the expectancy of superconducting magnets and the new high-T_c superconductors, and on certain basic parameters for very large e^+e^- linear colliders. Differences in views were expressed on the timeliness of the VBA versus "simply letting regional laboratories run their course" (with the majority opting for the latter view), on the cost-effectiveness of different hadron colliders, and on the role of ICFA in coordinating research activities for the linear colliders. With that, Panofsky declared the session open for discussion, statements, or queries from the audience.

J. Sandweiss (Yale) agreed with the need for a wide diversity of machines and approaches, and with the need for a strong regional activity upon which to build an effective international collaboration. He addressed Schopper's caution on raising the energy of accelerators since its full utilization requires working in a very difficult luminosity regime. Jack noted that sometimes raising the energy to reach a higher cross section allows circumventing the luminosity problem. He then posed the question, given the scale and sophistication of projected detectors for the next generation of hadron colliders, whether a shortage of resources--human or financial--might arise if both the LHC and SSC were to proceed.

J. Mulvey (Oxford) replied that, in spite of the many detectors presently installed or under construction for the Tevatron, LEP, HERA, and SLC, a limited number of SSC or LHC-scale detectors could probably be accommodated on a time scale extending well into the mid-90's. John urged that a decision on the SSC be made as soon as possible. Personally, he felt that if the SSC were to move quickly, he would not support the LHC.

H.F. Schopper (CERN) stressed "luminosity as energy" and the concomitant need for R&D to exploit higher luminosity. This did not imply curtailing the SSC; speed of construction was a matter of cost optimization, something not possible with LEP, due to funding profile limitations.

The Chairman added that funds can be expected to become available as ongoing detector efforts wind down. The problem will be not so much manpower, as what to build, avoiding parallelism and multiplicity in interaction regions. Panofsky agreed with Schopper's comment on optimum scheduling, exemplified by the rather remarkable fact that, historically, the time to build machines has been nearly independent of machine size, implying a matching of effort and size. What is needed is continuity of commitment from R&D to construction.

R.B. Palmer (BNL) questioned the presumed assumption of ICFA that duplicate facilities are bad *a priori* while, in fact, the field from its inception has been driven by healthy competition (AGS vs PS, FNAL vs SPS, etc.). He also noted that the capital cost of new facilities is a small percentage of the Gross National Product when spread over the years necessary for construction. Moreover, the cost is small compared to the operating cost typically spread over several decades. Regarding more or less duplicate facilities, Bob quoted the ZGS vs AGS vis-a-vis their respective supposed and actual machine intensities. In the same vein, the SSC and LHC are technically quite different facilities. Finally, Bob warned against taking new facilities--e.g., the SSC--for granted and in so doing making premature judgements concerning other facilities, in this case the LHC. B. Richter (SLAC) endorsed Bob's point that duplication is healthy--a view, to be sure, which is a function of time and economy.

W. Kummer (Vienna) stated that national pride is a determining factor in decision making, but should be subjugated if possible. The "HERA Principle", even the model furnished by CERN, could be applicable in new regions, even those spanning the Atlantic.

G. Barbiellini (Trieste) echoed Lederman's, Tigner's, and Wallenmeyer's view of a World Lab, even if not in a single location. Every region must push for technological excellence. Guido saw several lines of research clearly demarcated: continuity in e^+e^-, with two new projects close to producing physics and more to come; pp colliders--specifically the SSC and LHC which as emphasized by Palmer, are not so incompatible. For now, no obvious ep successor to HERA is evident, but Guido asked Soergel whether a post-HERA machine has been considered. V. Soergel (DESY) replied in the negative; the question must await assessment of HERA's performance. Returning to the matter of duplication, Soergel suggested we can no longer afford duplication in machines, but the concept still seems appropriate for detectors. He concurred in the importance of national, or rather regional, pride in securing resources for future facilities; CERN and HERA are good examples of this.

Schopper drew attention to "competition" in high energy physics being something quite different from that in other fields: in high energy physics it implies shared, not withheld information. Coordinated competition, if you will. On another point, Schopper was less concerned about lump sum funding over a limited interval than about long term operating commitment, including people.

Mulvey agreed that competition is important, partly as an element in the process of selecting new accelerators. This he illustrated in terms of the

SSC and LHC, where we have the possibility of proceeding with two machines <u>or</u> choosing one over the other, making sure that in so doing we avoid the disastrous foreclosure of both. On luminosity, John stated that at CERN they have looked at $\mathcal{L} > 10^{34}$ in the context of a specialized detector, with 25 events per bunch crossing and bunch crossing at 5 nanosecond intervals. They conclude that calorimeters can see large signals, even in large backgrounds. Identification of isolated electrons should be possible, even in the presence of many overlapping events per bunch crossing. The importance of more detector R&D—e.g., radiation damage in electronics—cannot be emphasized too much, however. John presented a somewhat detailed comparison of the LHC and SSC in terms of performance and discovery potential, concluding that LHC represents "best value for money" and SSC is "of considerable worth but pricey".

Panofsky warned that such comparisons are apt to be very dependent on unknowns, and pointed to Lederman's observation that, in any case and within probable errors, the cost-per-energy ratio of the LHC vs SSC is roughly equal. Schopper disputed the productiveness of arguing at the 10% level but not the advantages of a 20 TeV machine over a 10 TeV machine from a purely physics point of view. Regarding the two colliders, he preferred to view the choice in terms of economy rather than cost <u>efficiency</u>—simply a matter of how much money is available. Panofsky, returning to energy vs. luminosity, noted that if the focus is on a specific process, higher energy can bring it within reach at lower luminosity because of the momentum distribution of the constituents. Palmer repeated his point that the LHC and SSC are very different in most every respect: ring size, aperture, current, terrain placement, ring options, cost—not merely with regard to energy and luminosity.

<u>T. Nishikawa</u> (KEK) observed that hadron colliders and linear e^+e^- colliders are fundamentally different machines in that the former have many interaction points, allowing a multiplicity of experiments per machine, whereas linear colliders provide only one IR. Thus, these machine types should be approached from quite different perspectives. Tetsuji likened linear collider studies, in particular those in the Fourth Region, to a "composer's quartet" promising beautiful harmony. <u>Richter</u> seconded this view on linear colliders, seeing good reasons for more than one such machine, especially if we are

limited to a single interaction point.

Mulvey drew attention to machines other than "frontier" machines including a single world accelerator ("the last act of really desperate men")--namely B factories, a relativistic heavy ion collider, perhaps top factories.

U. Amaldi (CERN) summarized what he considered three key points raised in the two Panel Discussions: 1) diversity, 2) the human aspect of accelerator science (Tigner), 3) national pride. He felt all three points were crucial in paving the way toward Mulvey's factories, akin to what happened to the field in the 1960's. In Europe, at that time, there was much talk of a pyramid of distributed accelerators with its apex centered on CERN. The apex remains, but the base never really developed and needs to be drastically widened, he argued. There are factories to be exploited for B's, for kaons, tops, and beauty--not simply leptons and quarks. KEK is moving in this direction, as are the Canadians and SIN; Italy and France are thinking about linear colliers in the same context. Ugo's point was that funding for one project may benefit others (Weisskopf), some people find slightly smaller experiments better to their liking, and this could widen the community of machine experts and that a diversity of facilities can only enhance prospects for solutions paving the way to the very big machines of the future.

C. Quigg (SSC/CDG) emphasized the unity and cooperative spirit that has prevailed in the field and remains a prerequisite for exploiting the new generation of machines. He questioned the need to have the ultimate detectors in place during machine start-up, and suggested a strategy of staged detectors as well as interaction regions.

F. Dydak (CERN) wished clarification as to the goals of ICFA and its audience, and questioned the language of its charter as being too narrow. His concern prompted Y. Yamaguchi (INS, Tokyo) to touch on several relevant points:

..It would be most desirable to have "World Laboratories" in different regions. They need not be "Big"--witness Bohr's Institute in Copenhagen.

..ICFA and IUPAP are engaged in improving the "visa situation" to further international exchange of scientists.

..Today high energy physics is no longer confined to the developed regions; witness synchrotron light sources, medical accelerators, spallation neutron sources in developing regions, and the promise of detector and accelerator R&D in smaller institutions.

..Utilization of industry; witness Japan's example.

The Chairman suggested the discussion now focus on R&D and technology issues underlying the new colliders and how to improve the international effectiveness of such R&D. To be sure, advances in technology has bought more economy than strictly financial benefits, but it is generally agreed that we are not doing enough, Panofsky noted. In addition, there is a strong symbiotic interdependence between technology and high energy physics.

Richter, replying to Sandweiss' query on the plan presented by R. Ruth the day before, was encouraged by the interest shown in R&D for future linear colliders in the various regions, there being far too much for any one region to handle alone: new RF sources, relativistic klystrons, superconducting cavities, etc. Potential subjects and common problems for workshops include machine tolerances, final focus systems, low emittance beams. Burt suggested a series of workshops in various places, with SLAC hosting the first in late 1988. A small group at SLAC, including Schnell and Palmer, will get the ball rolling by examining the matter in relation to the ICFA Seminar, attempt to form an organizing committee, define some serious topics, and communicate with the interested regions.

I. Mannelli (Pisa) made two points. First, is the limitation of one interaction region per LC really an absolute one, or can one visualize more than one, albeit not necessarily operating at the same Ecm or operating simultaneously? Second, re Palmer's point that since the SSC and LHC are very different machines they might both be justified, he noted that in Europe two even more disparate facilities (LHC and CLIC) are under study, but it is generally agreed that funding of both cannot be seriously contemplated. Concerning multiple interaction regions for LC's, Richter stated that presently only side-by-side IR's fed from alternate pulses have received much thought —a solution simply requiring doubling the machine power. Alternatively, serial IR's would require much weaker beam-beam interaction. Nobody has, as yet, any clear notion of how to rejoin the two beams. Panofsky noted that, so far, the only substantial laboratory work under way on linear colliders is on power sources. An enormous number of difficult problems --adjustable structures, asymnmetric couplers, fabrication methods--await experimental answers, but the work has not received adequate attention to allow intelligent selection of topics to be cooperatively pursued in the different regions.

M. Crawford (Science) asked Richter if he saw the U.S. government imposing any restraints on sharing technology information with the USSR or foresaw any, given DOE's position on fusion cooperation with the Soviets. Burt was not aware of any, other than on the actual transfer of hardware to the Soviet Bloc. This is another reason to get going on international collaboration, Panofsky added.

Richter, Schopper, Panofsky, Aronson and Yamaguchi agreed that there is a pressing need for a dialogue or workshop between the various interested parties, comparing shopping lists for LC R&D, identifying and possibly apportioning tasks. They would leave it for ICFA to determine the "best dynamic" to launch such a concerted effort.

J. Tiomno (Brazil) emphasized the importance of schools in the developing countries, and, citing the experience of Mexico and Brazil, collaborative programs involving groups in developing countries interacting with big labs such as Fermilab and Brookhaven. Experience has shown that undertaking high energy physics programs in the home nation, stimulated by such collaboration, often requires no more resources than, say, solid state physics as long as accelerators abroad are accessible, Finally, Tiomno described the new light source installation under construction in San Palo with a budget of 75 million dollars. First comes a 100 MeV electron linac, followed by a 2-3 GeV booster synchrotron, and finally a storage ring designed for low emittance, high briliance and capable of accommodating wigglers, undulators, beam lines and instrumentation for ultraviolet and x-ray radition.

Panofsky asked S-X Fang (IHEP, Beijing) for any comments he might have in the context of Tiomno's remarks on developing countries. Fang replied that discussions are taking place on the involvement of the Fourth Region in high energy physics; manpower might be available both in R&D for e^+e^- colliders and possibly for the SSC and LHC. C. Avilez (Mexico) expressed the willingness of his region to continue, even expand, its collaboration with high energy laboratories abroad, but guidance and better definition of specific tasks suitable for such collaboration are needed. S. Tovey (Melbourne) summarized a relatively recent (November 1985) report to the Prime Minister on Nuclear Science and Technology in Australia. It recommended the establishment of a center for high energy physics--a proposal still to be acted on, however. The first step would be the creation of a group which can play a viable role in one experiment or as an element in building the SSC or LHC in an arrangement similar to that instituted at HERA. Two obstacles to Australia's progress in this area are funding and Australia's remoteness from the active centers abroad. Yamaguchi sympathized with his colleagues from Mexico and Australia. Japan faced similar problems soon after WWII. They started small, concentrating on a modest cyclotron at the University of Tokyo, which gave rise to a new and gradually expanding Institute. The initiative did not prove easy for Japan, what with the language barrier, different traditions and, again, the distance barrier.

Soergel returned to the matter of coordinated R&D effort on linear colliders, asking if Richter had any concept of the resources necessary for such a world-wide collaboration. Burt replied that SLAC is currently investing roughly 5-10 million dollars per year, including manpower costs, on the advanced linear collider problem. This is obviously not enough; perhaps $40M might suffice, but the question would need serious study.

The Chairman solicited comments on this by Tyurin, in view of the long and pioneering effort on linear colliders in the USSR, particularly at Novosibirsk. Tyurin responded that a decision has been made to proceed with a large e^+e^- collider in the USSR. The USSR also intends to cooperate with other laboratories, and Tyurin endorsed both Richter's proposal for a meeting at SLAC and the necessity for a broad division of responsibility for R&D on linear colliders. Schopper added that CERN shares the interest in participating in such coordinated R&D, having recently formed an in-house group for the purpose under Schnell. Schopper could not offer an off-hand estimate of how much CERN is currently spending in this area, due to the difficulty of separating amounts being spent on long-range studies from spending on existing facilities. As an example, important elements for a future two-beam accelerator are superconducting cavities, which also play a strong role in upgrading LEP.

Richter felt that there is considerable room for contributions from outside the major laboratories as well; many smaller laboratories are quite capable in this area--e.g. Orsay. Schopper agreed; in his opinion workshop participation from the Third and Fourth Regions is especially important, regardless of the level of available technical expertise. Palmer first reiterated the lack of communication and collaboration between the different regions by stressing once again Novosibirsk vis-a-vis the West. Secondly, he argued that the fact that we do not currently possess the technology adequate to construct a "10 TeV e^+e^- linear collider with a luminosity of $10^{36}cm^{-2}s^{-1}$" should not preclude a vigorous R&D program being mounted, aimed well beyond the next linear collider. Third, apropos Schopper's point, he noted that Brookhaven is purchasing certain state-of-the-art linear collider elements from China--a most impressive achievement on China's behalf. The discussion concluded with brief remarks by N.S. Dikansky (Novosibirsk), echoing the importance, from their point of view, of collaboration, not only on linear colliders, but on other machines such as UNK, and by Schopper who stressed that groups pursuing high energy physics in developing countries must strive to stay in close touch with other home disciplines and institutions--industry, engineering schools, universities to properly exploit both accelerator and detector development.

The Chairman closed the session by thanking all contributors, and enumerating what he construed to be points of consensus:

..Technology must be pushed harder.

..The next technology on the horizon seems to be that of e^+e^- linear colliders, to be achieved through a focussed division of effort among the various regions.

..Much discussion centered on the virtues of multiplicity of approaches (mistakes are costly in high energy physics) including detectors, analysis, etc., but not necessarily to be construed as duplication of basic facilities.

..The developing regions can better participate in high energy physics, having many constructive ideas to offer, as repeatedly attested to in the Discussion.

..Active collaboration is sought for UNK, linear colliders; the SSC also welcomes participants from other regions, as would the LHC if and when it reaches the proposal stage.

..With all the emphasis on competitiveness the fact remains that, in the unity of science, high energy physics has always been in a particularly strong position of documenting that unity--strongly aided in this respect by ICFA.

Panel Discussion: Future Cooperation in Accelerator and Detector R&D Work and the Role of the ICFA Panels

PANEL DISCUSSION

FUTURE COOPERATION IN ACCELERATOR AND DETECTOR R&D WORK AND THE ROLE OF THE ICFA PANELS

(Text prepared by Editor with concurrence of Panel Chairman)

Chairman: U. Amaldi

Panel Members: G. Brianti
N.S. Dikansky
T.J.C. Ekelof
H. Hirabayashi
E. Keil
R. Leiste
R.B. Palmer
A.M. Sessler

U. Amaldi, in his opening remarks, stated that the purpose of the Panel Discussion was to examine R&D issues, take a look at the role of the various ICFA Panels, and discuss what the panels might be doing during the next several years. These Panels were established three years ago, and the present ICFA Seminar provides the first opportunity for non-members of the panels to review their accomplishments to date, and to hear points of views of the Panel Discussion Members. No consensus or decisions were expected--merely expressions of opinions.

Amaldi then read the main guidelines set in 1984 by ICFA for the ICFA Panels. These are as follows:

1. Each panel for a particular field should generally include not more than 16 members, with an effort toward an adequate balance among the regions.
2. ICFA will choose the panel chairmen from among the nominees of the regions.
3. The panels should encourage the exchange of information and coordinate the pertinent activities (e.g. exchange of personnel and/or equipment) of the regions represented in it. Panel members should act as representatives of their regions.
4. The regional work i a particular field should be organized by the participating institutions.

5. The panels should organize their meetings at least once a year to establish programmes and to analyze results. The times and places of these meetings should be agreed upon in advance.
6. The Panel Chairmen should report once a year to ICFA on the progress of their activities.

The major charges are those under points 3,4,5; viz., exchange of information and coordination of activities, organization of regional work in particular fields, and organizing of meetings.

A survey of the work of the ICFA Panels was presented in an earlier Survey session by the past Panel Chairmen. The present Panel Discussion has been organized around four basic themes; namely:

A. ICFA panels: Issues and programs.

B. Common issues.

C. Issues particular to each Panel.

D. General discussion.

In part (A), each present Panel Chairman will repeat and condense the earlier Survey presentation, underscoring two points: a) issues arising in each particular Panel, and b) programs that appear desirable to follow up in the forthcoming several years. Part (B) will deal with common issues, five issues in particular. They will be enumerated later in the Session. Next, in part (C), the discussion returns to issues particular to each panel, with the principal individuals involved focusing on points deemed of particular importance and fresh points of view solicited for discussion by the audience. Finally, part (D) will involve a general discussion, concentrating on the overall usefulness of the various ICFA Panels.

(A) ISSUES AND PROGRAMS

R. Palmer, present Chairman of the Panel on New Acceleration Schemes, opened this part of the Panel Discussion. He addressed two particular issues. The first was that of communication with the USSR. He reminded the audience that much of the new accelerator technology had its origin in the USSR--e.g., original work on linear colliders, power supplies, accelerator physics. Yet, awareness of these pioneering contributions is often sadly lacking in the West. There are many reasons for this, such as mail system, travel restrictions, language barriers, and monetary restraints. (Concerning the language problem, language translation in future ICFA meetings remains a possibility.)

Palmer's second issue was one of being useful. That is, his and the other ICFA Panels should not be competing with other initiatives, such as the various accelerator physics schools. Four areas, technical and pedagogical, seem particularly relevant to the Panel on New Acceleration Schemes: a) exotic acceleration schemes (a topic promoted by DOE, ICFA, and the various accelerator physics schools); b) physics pertaining to new linear colliders; c) a 10-TeV collider; d) the various schools organized in the US and by CERN. Expanding on some of these topics, Palmer noted that when the technology for advanced linear colliders first came under discussion, the problem was mainly seen as obtaining very high acceleration gradients. Thus, there was tremendous interest in lasers, plasmas, and other exotic acceleration schemes. More recently, we have become much more aware that this is far from the only problem: The physics will demand high luminosity; high luminosity demands very high beam power, among other things. All this has underscored the need for a detailed study of the linear collider, which brings us to the planned program.

First item in the program will be a Workshop on Linear Colliders, to be held in Capri during June 14-18, 1988, timed to follow the international accelerator conference in Rome the previous week. The Workshop will be sponsored jointly by INFN and ICFA, with Vaccaro the Local Organizer. Participation will be by invitation only. All sessions will be plenary in nature, with afternoons devoted to discussions. The tentative agenda is as follows:

Monday:	e^+e^- sources (incl. damping rings, polarized sources, etc.)
Tuesday:	Linac (incl. wake field, superconducting linacs)
Wednesday:	Power sources (incl. relativistic klystrons, gyrotrons, lasertrons)
Thursday:	Final focus (incl. plasma lenses, general scaling)
Friday:	Intersection (incl. disruption, beam strahlung, physics).

The possibility remains of a later meeting at one of the laboratories, as

Richter has suggested; or, again it might be attached to an international conference, partly to ease travel difficulties.

The second item in the planned program is a Panel Visit to the USSR, tentatively set for October 1988 in conjunction with the National Accelerator Conference there. The agenda would take the group around the various institutions of interest, with participators giving lectures on activities in the West and learning of corresponding progress in the USSR institutions; the visit would be followed by a report to be circulated to ICFA members.

Beyond that, future possible workshops include: new physics applicable to 10-TeV colliders; new superconducting cavities, in conjunction with the ICFA Panel on Superconducting Magnets and Cryogenics; new power sources; finally, perhaps more collider workshops at the various accelerator conferences.

E. Keil, next, covered issues and problems of concern to the Panel on Beam Dynamics, in terms of the forthcoming program. Meetings will be held once per year. One Panel meeting will be held in conjunction with a Workshop on Advanced Beam Dynamics. Soon after that, a Newsletter will be issued. A second Workshop will be held in Lugano, probably 10 or 11 to 16 April, 1988. Its theme is to be Aperture-Related Limitations in Storage Rings, grouped under roughly four headings: Experiments and lessons from them; Analytical methods for amplitude limits and lifetimes; Criteria on properties of beams, and resulting criteria on components; Schemes for compensating defects in components.

Roughly a year later, a third Workshop is provisionally foreseen in July of 1989 in Novosibirsk. The theme this time will be Beam-Beam Effects and Stochasticity. Subtopics will include: Experimental and theoretical studies for e^+e^-, ep and pp or $p\bar{p}$ machines; Coherent beam-beam effects; Long range forces, of particular concern for the large machines of today; Stochasticity in the accelerator context.

A report submitted to ICFA contains further workshop topics; it will be updated on a regular basis. One additional idea was discussed at the Panel's last meeting: A Beam Dynamics School, in contrast to the advanced level of the various workshops. It would serve to spread beam dynamics knowledge at the university level into all the ICFA regions. Beam dynamics of electron rings seemed a particularly appropriate topic, since virtually the only machines under active consideration in the Fourth Region are machines of this type. Trieste would appear to be a possible site, in view of Ekelof's success with his school there. Finally, the Panel's Newsletter should be continued as a main vehicle for stimulating collaboration, and oriented more toward work to be done, rather than toward work completed.

H. Hirabayashi followed, having just succeeded G. Brianti in heading the Panel on Superconducting Magnets and Cryogenics. A principal issue in this area is standardization of superconducting wire and cable; a subpanel on Standardization has been formed, Chaired by W. Sampson (BNL). Of chief concern is degradation from fine-filament NbTi wire to cable during cable compaction. Another problem encountered in predicting magnet performance is due to conductor self-field effects. This problem is particularly acute with large cables. These problems have been under continuous study since they were discussed during the Workshop on Superconducting Magnets and Cryogenics at Brookhaven in 1986 [Proceedings: BNL 52006]. Hirabayashi noted an interesting possibility explored in a recent design study by himself and colleagues on accelerator magnets with complete, arch coils formed by special keystone cables (paper enclosed). The new idea here is a large keystoned Rutherford-type stranded cable made possible with an internal support of superconducting or aluminum braid.

The new subpanel will have the tasks of: a) determining a standard form for specifying wires and cables, and b) determining the parameters to be measured, and the measuring procedures on wires and cables, as well as devising a standard form for expressing them. A prototype is the existing US National Bureau of Standards Publication 260-91 (1984) on Standard Reference Material. A good starting point would be wires of, say, 200 A capacity, and their subsequent cabling (6 kA), leading finally to a cable-in-cable (30 kA). Parameters to be measured include the critical current density and critical field, resistance ratio, etc., as a function of field. This program should include a new workshop in one to two years with mixed participation from laboratories and industry, as well as a proposal for an ICFA standard for superconducting wires and cables.

Speaking next, T.J.C. Ekelof covered issues and problems of concern to the Panel on Future Instrumentation, Innovation and Development. He began by recalling the basic aims of the Panel:

1. To create new channels of communication for information on High Energy Physics Instrumentation in order to stimulate new and additional activity in this field, to meet the experimental challenge of the planned future colliders and also of non-accelerator experiments.
2. To stimulate the involvement of all regions of the world in Experimental High Energy Physics for general reasons of scientific culture, but also in order to increase the amount of human and material resources channeled to the field of High Energy Physics.

With these basic aims, the Panel has opted for various particular activities—some already well launched, others just now being started. Projects already launched include:

ICFA Instrumentation School.

ICFA Instrumentation Bulletin.

ICFA Review of Detector Properties.

The school will fill a void in the sense that the subject is not generally covered by other established accelerator schools. The Bulletin looks forward, not backward, like the Newsletter on Beam Dynamics, and will also serve as a discussion forum. The review of Detector Properties is intended to provide a coherent treatment of the subject, beyond existing articles and compilations. Projects in the initiation stage are the following:

..Facilitate world-wide communication between HEP physicists via computer networks.

..Stimulate, support and inform on the organization of HEP.

..Instrumentation Workshops and Conferences in the different regions of the world.

..Assist in some way in the re-distribution of used HEP instrumental devices from the major laboratories to peripherally situated smaller laboratories.

Ekelof stressed that, regarding used instrumentation, the problem is not to find it, but to ensure that it is operational and making arrangements for its transportation. The judgment of what is useful must be left up to the receiver, not to the laboratories providing the equipment. In regard to the second point, above, conferences as opposed to workshops among working parties should focus on regions presently lacking initiatives. Note, however, that ICFA has no resources *per se*. Finally, Ekelof phrased a basic issue in terms of the question whether there might be services in the context of experimentation at the forthcoming hadron colliders that the ICFA Instrumentation Panel can provide and that would be in the mutual interest of the parties involved.

(B) COMMON ISSUES

With the first part of the program finished, Chairman Amaldi opened the second part which, as noted earlier, was structured around five common issues, mainly organizational issues, some of which the previous presentation (part A) has addressed in varying degrees. These five issues are:

1. Participation of panel members,
2. Sponsorships for travel by persons not supported by their home institutions,
3. Young people from developing countries: schools and fellowships in the major laboratories,
4. Newsletters and exchange of information,
5. Exchange of equipment and software.

Amaldi solicited opinions on these various points, first on point No. 1, and by the Panel Discussion Members.

A. Sessler observed that, in fact, very few members of his particular Panel participated actively in the various meetings; indeed, some never replied to the invitations. T. Ekelof concurred, having had a quite similar experience. Perhaps 16 panel members are too many for an efficient working group. Half that number might suffice, this in fact being about the number usually attending. Even then, problems remain with a) uneven rotation of individuals and b) under-representation of certain regions. R. Palmer stressed three reasons for the lackluster participation: a) some panel members are simply not interested; b) some have genuine financial problems; c) some may in principle have the financial means but are restricted, for one reason or another, from attending (perhaps some kind of ICFA appeal might help here).

Amaldi then turned to the floor for additional opinions on this issue.

Y. Yamaguchi encouraged individuals experiencing problems to contact ICFA which might possibly help, but only if it is informed. Possibly IUPAP could help as well. He pointed out a difficulty sometimes experienced when workshops are divided between several locations, particularly between two countries.

J. Haissinski (Orsay) agreed that large working parties obviously must meet jointly on occasion, but suggested that for smaller groups--e.g., 6-7 participants--there might be other effective ways of communicating mutually and exchanging information without having to travel abroad (e.g., BITNET, Fax, etc.).

Amaldi then turned to the next, closely-related issue No. 2 on travel by unsupported individuals.

T. Ekelof appealed to those who control the purse strings, i.e., laboratory directors and administrators, for some help if, in his view, ICFA is to serve a meaningful mission. Rather small sums would be at issue, if the burden were spread among the various major laboratories, intended for relatively few individuals. Amaldi agreed, noting that ICFA is "simply a prop or a screen" behind which reside the laboratory directors.

G. Kalmus (Rutherford) felt that an important role of ICFA must be in the involvement of the Fourth Region; in this context, both common issues 2 and 3 are very important. The short-term problem is how to involve people from the Fourth Region in the ongoing HEP programs, whereas the long-term problem is one of fostering self-contained activities *per se* within the Fourth Region. E.g., one more, minor, workshop might not have much impact at, say, SLAC or Novosibirsk, but it could be very important for Mexico City or Rio de Janeiro.

J. Sacton (Brussells) agreed, and suggested that Panel meetings might also be considered for the Fourth Region.

K. Ahmed (Pakistan) wished to emphasize Issue No. 3, pointing to young talent in Pakistan, some of which was recruited by Prof. Ting in 1980. While traditionally Pakistan has produced theoretical high energy physicists (Salam, Amadelli, etc.), unfortunately it has thus far not been possible to develop a national high energy experimental program. What seems to be lacking is incentive for the young people; perhaps an agency like ICFA could provide support or encourage recruitment of youngsters from Pakistan.

C. Pellegrini (BNL) explained that the Beam Dynamics Panel had discussed the possibility of organizing an introductory school exclusively for the Fourth Region, perhaps in Singapore or Brazil. However, there was nobody from these countries in attendance at the meeting where this possibility was raised, so the matter was not pursued further. Thus, input from the local community affected will be necessary if this possibility is to be actively pursued. On a second point, Issue No. 1 on participation, Pellegrini suggested that the problem might be alleviated by reducing the number of meetings to, say one Panel meeting per year in conjunction with a workshop. On a more general level, and returning to the matter of Fourth Region countries, Pellegrini pointed to the rapid development of synchrotron light sources in recent years; this has stimulated great interest in accelerator physics, and allowed new countries to become involved. Funds needed are relatively modest. From this point of view, organized schools on beam dynamics would be very useful. They could well be held in Latin America or Asia.

G. Barbiellini (Trieste) commented on the Institute for Theoretical Physics in Trieste and the role of Salam in its founding. A major aspect of its mission is dealing with the kind of Fourth Region problems under discussion here. Barbiellini also agreed on the importance of synchrotron radiation facilities in fostering and spreading accelerator technology.

W. Hoogland (Amsterdam) endorsed G. Kalmus' views, and stressed that laboratory directors must do more to ease the problem of travel support.

R. Sosnowski (Warsaw) stressed the importance of developing better electronic communication between eastern and western computer networks. He also commented on the problem of travel permission--that is, visas. This problem has generally eased in recent years, but still surfaces at times (e.g., most recently in France).

P.K. Malhotra (Bombay) stressed two points. First, in India recently, considerable resources have become available for fabricating equipment (e.g., for detectors) within the country, particularly if it involves some high technology element--even for importing missing components from abroad. However, it is much more difficult to obtain financial support for expenses of personnel who will use the equipment in collaborative experiments abroad. Part of this problem is due to the great difference between scales of expenses in India and in western countries. Second, he endorsed the importance of rotating conferences, schools and workshops in various Fourth Region countries, adding that these countries are also capable of taking certain initiatives. An example is a training school on detectors held in India in 1985, aided by experts from abroad.

H. Hirabayashi noted the need for Japan to import from abroad virtually all raw materials for superconductors: niobium from Brazil, titanium from Australia and India.

Y. Yamaguchi summarized briefly the structure of IUPAP, and the role of high energy physics and ICFA within this parent body. IUPAP consists of 105 world-wide societies, with an annual budget limited to a quarter of a million dollars. There are 18 different IUPAP Commissions, of which the IUPAP Commission on Particles and Fields is the 11th. It receives from IUPAP ten thousand dollars annually, mostly for support of IUPAP-sponsored conferences in this field. ICFA is a subcommittee, but without any funds, and so must rely on the good will of the HEP community. Indeed, contributions from the laboratories have grown steadily--as evidenced by proceedings of ICFA workshops (e.g., the 1986 Workshop on Superconducting Magnets and Cryogenics at BNL) and the Instrumentation Bulletin (supported by DESY and Univ. of Siegen). An acute problem remains on how to encourage participation from the Fourth Region; suggestions are most welcome.

G. Kalmus pointed out that fellowships are available, not only at the major laboratories, but at the smaller ones and at universities. Thus, at the Rutherford Laboratory there are typically 15-20 research associates on fellowships in residence at any given time--many from the Fourth Region. This is true to some extent for most institutes represented at this Seminar, and something young people from the Fourth Region should be aware of. A. Sessler explained that some of the fellowships established at the major laboratories (incl. LBL) were established specifically for non-competitive Fourth Region applicants, to ease the burden on the smaller laboratories and universities.

E. Lillestol (Bergen) suggested that ICFA approach the United Nations. He also pointed out that many governments have, through bilateral agreements, aid programs in the Fourth Region. Some time ago, in the course of attempting to launch an activity concerning a European network in particle physics through ECFA, considerable help was indeed secured from the European Community.

Amaldi declared the discussion of Issues 1,2, and 3 closed, and moved on to the fourth issue, Newsletters and Exchange of Information.

T. Ekelof was the only Panel member to express an opening statement on this topic, repeating his earlier point that a newsletter, as the term implies, must stress new developments. Amaldi then opened the subject to discussion from the floor.

J. Sacton agreed with Ekelof; while the early issues of the Instrumentation Bulletin contained perhaps excessive summaries and tables dealing with past events, this (Ekelof assured him) should be rectified in forthcoming issues. E. Keil asked to what extent the two present newsletters (Instrumentations, Beam Dynamics) are reaching libraries. J. Tiomno (Brazil) replied that he was not aware of them in his own institution. He urged that an effort be made to ensure that all issues are made available in Fourth Region centers; pre-knowledge of forthcoming issues via the newsletters would be very important in planning schools or other forms of activity in this region. F. Dydak (CERN) stressed that the newsletters should concentrate on truly long-range matters, not so much on present or near-term activities.

Y. Yamaguchi pointed out a newly launched publication titled Asia-Pacific Physics News (ASPAP), created by Prof. S.C. Lim of Singapore. Four issues per year are planned. The format is very similar to the CERN Courier, although it covers all fields of physics, basic and applied, in Asia and West Pacific regions. The first two issues contain substantial coverage of high energy physics.

R. Kajikawa (Nagoya) wished to see greater effort in data banks, BITNET and computer networks generally.

Amaldi suggested that perhaps ICFA should consider establishing a list of institutions--a white book--to which all newsletters should be sent. At this point, he suggested the discussion proceed to the last common issue, Exchange of Equipment and Software.

N.S. Dikansky recounted much effort in bringing lithium lenses to Fermilab; clearly exchanging high-technology equipment is a two-way problem. J. Sacton inquired if the problem, no doubt raised at the Summit working groups, had been followed up subsequently. G. Brianti confirmed that the subject has been addressed occasionally (including the exchange of people), but he was not aware of a real follow-up. H.F. Schopper added that only the industrialized, western countries were represented in the Summit discussions, so the matter of exchange of equipment did not touch on other regional blocks to any extent. Concerning used equipment, a point raised by Ekelof, CERN has such material in abundance, and has indeed contributed some to various Fourth World countries. This requires, however, that the countries desiring such equipment send people to select it and lend a hand in repairing and reassembling. In the longer run, it is imperative that hardware development be initiated in these countries as well.

B. Richter, in response to Amaldi's request for comments on software exchange, specifically, stated that he sees no problem here. The problem lies in hardware differences, something ICFA can do little about.

(C) ISSUES PARTICULAR TO EACH PANEL

R. Palmer reiterated briefly some of his earlier points: avoiding competition with established schools; to what extent the ICFA Panel should continue to be involved in meetings on linear colliders; the question of workshops on more exotic topics (i.e., superconducting RF cavities, lasertrons); should workshops be held in conjunction with international conferences, or are they better held in the national laboratories?

U. Amaldi readdressed the question of relative emphasis by the Panels on the next linear collider(s) vs long-range (10 TeV) colliders.

J. Sandweiss (Yale) recalled that the history of the existing efforts in colliders can be traced back to ICFA workshops, and admonished the Panels not to neglect addressing long range issues. B. Richter agreed: Once a project reaches the detailed design stage, ICFA's role vis-a-vis that particular activity ceases to be very useful. A. Sessler felt that, in this respect, the Panel on New Acceleration Schemes is unique in that its sole concern is with far-term aspects.

H.F. Schopper remarked that the question of long- vs short-term preoccupation depends on what one regards the main task of ICFA to be. If it is one of coordinating work between the US and Europe, then long-term considerations come to the forefront. If, however, a major concern of ICFA is with the Third and Fourth Regions, then very long-term thinking is clearly less relevant.

S. Ozaki's (KEK) opinion was that ICFA should be addressing fairly long-range matters; as to Schopper's concern, laboratories like KEK and Fermilab are already strongly involved with Fourth World regions. Ozaki also endorsed Weisskopf's warning of the importance of public enlightenment.

W. Schnell (CERN) felt that it should not be ICFA's task to coordinate ("police") research, but mainly to create forums for the exchange of information. Moreover, ICFA should not yet ignore relatively near-term linear collider studies at the 1 to 2 TeV level, since such machines are far from in hand yet. However, a major focus should be on far-ranging, say 10 TeV, possibilities; this has been the implicit aim for some time of the ongoing studies of new acceleration schemes.

E. Keil solicited the reaction of the audience in aiding ICFA to formulate a guideline on the range of sizes of circular machines to be included in beam dynamic studies. He phrased the problem in terms of the following considerations. Electron-positron rings for HEP range from the damping rings needed for linear colliders to storage rings for physics, such as LEP. The beam dynamics and machine sizes are very similar for damping rings, synchrotron radiation sources of the third generation now under discussion, and free electron laser machines. Thus it is natural to ask: should such machines be considered? Should B-factories be included? Similarly, a wide range in sizes exist for hadron machines, from kaon factories to the SSC and LHC, and beyond that toward the VBA. Again, the question arises: should all these machine types be included in beam dynamics studies?

With this introduction, Amaldi reiterated a related issue raised earlier: the desirability of the Panel organizing in a Fourth Region country a school on the dynamics of electron storage rings at the university level. The usefulness of such a school, focusing on the accelerator physics of synchrotron radiation sources, was emphasized by J. Tiomno. C. Avilez (Mexico) added that Mexico would be pleased to host such a school, noting that Mexico has hosted groups of this type in the past, in a variety of fields.

G. Brianti felt that, on the question of lepton vs. hadron machines, the former appear likely to become more widespread; thus, perhaps the ICFA Panels should concentrate on them. On the subject of schools, both the US and CERN schools are now firmly established, and more effort should be made to exploit them with participation from the Fourth Region or peripheral countries.

J. Sandweiss commented that from the point of view of high energy physics the study of B-factories is highly relevant, since the physics accessible with them bears on very fundamental issues, such as the nature of CP violation. Thus, if these machines are interesting from the viewpoint of beam dynamics, they should be pursued by all means.

E. Keil was pleased that so many countries have expressed interest in hosting schools on beam dynamics and other topics, but concerned that perhaps other countries would find it inconvenient to travel to, say, Mexico or Brazil compared to Trieste. Amaldi suggested that this question will have to be studied by the ICFA membership.

H. Hirabayashi addressed some particular issues of interest to the Panel on Superconducting Magnets and Cryogenics. The first of these will be one of following up on the new high- T_c copper-oxide superconductors, such as BaYCuO.

Among the questions to be pursued: Are they stable? Are they reproducible? How do we stabilize them? Critical current densities and critical fields must be determined, as well as the crystal structure and the mechanism itself. Potential applications include magnetic shields, solenoids, and (year 2000?) accelerator magnets.

A second issue is high-H_c, radiation resistant materials of the A15 type (e.g., Nb_3Sn). In spite of 15 years experience with these materials, no accelerator dipole utilizing them is yet in hand. The third issue concerns cryogenics for accelerators and detectors. This subject is closely related to new acceleration schemes--e.g., superconducting cavities--and strongly impacts on instrumentation, large solenoids and detectors. Thus, it will be a subject of concern for several ICFA Panels.

S. Ozaki agreed on the importance of pursuing the new superconducting materials vigorously. As T. Nishikawa had noted in his address earlier, work on these materials has already been initiated at KEK, with the hope of exploiting them in RF cavities.

The Chairman noted Hirabayashi's fleeting reference to large solenoids for experiments and solicited opinions on the importance of this subject for the ICFA Panels. Ekelof replied that the subject had been raised by Brianti two years earlier, and that the Instrumentation Panel does indeed consider it an appropriate subject for its consideration. R. Leiste (DDR) concurred, recommending that it be the subject of a joint meeting between the Instrumentation and Superconducting Magnet Panels.

L. Pondrom (Wisconsin), returning to an earlier point that perhaps ICFA Panels can at times "get in the way of ongoing work," asked Brianti, in particular, how he felt on this in conjunction with his own Panel on Superconducting Magnets and Cryogenics. Brianti replied that while he agreed that the Panel should concentrate on long-range developments, his Panel had nevertheless uncovered at least two "holes" in ongoing work in this area. One was standardization, the other the challenge of bringing in industry.

T. Ekelof, speaking on behalf of the Instrumentation Panel on the question of particular issues relevant to its mission, emphasized that the Panel considers one of its major responsibilities to focus on the Third and Fourth Regions and, hence, on shorter-range problems--the present which, of course, is also the key to the future.

M. Gilchriese (Cornell/SSC CDG), responding to Amaldi, spoke briefly on ICFA vis-a-vis detector R&D for hadron colliders. He felt that during the coming decade we might see 2-3 hadron colliders of varying sizes, and that a major limitation in their exploitation will be the detectors. While the detector R&D will be crucial in the decade ahead, it will be even more so in the next, say, subsequent 10 years if we are to exploit a further range of luminosities which will go hand in hand with even higher energies. Gilchriese encouraged ICFA to look closely at both the near-term and beyond. N. Tyurin (Serpukhov) agreed with Gilchriese on the importance of detector R&D for proton-proton colliders and suggested that a workshop on the subject might be appropriate in about a year, perhaps at Serpukhov.

H. Schopper, again responding to the Chairman, commented briefly on LAA. This is a special program at CERN, supported by Italy, with the aim to develop detectors for large hadron colliders. Its budget is roughly 20 million dollars. It is not an open source of money for R&D; the purpose is rather to pursue R&D at CERN in collaboration with outside institutions. In view of ongoing R&D in this area in the United States and the USSR as well, Schopper agreed that a workshop would be useful to assess the various efforts in an attempt to avoid needless duplication.

M. Gilchriese added that the Central Design Group is, in fact, intending to hold a meeting in mid-Summer of 1988 on future directions in detector R&D; it will be held at Snowmass, Colorado, in conjunction with the larger meeting there sponsored by the Division of Particles and Fields of the American Physical Society.

R. Leiste also agreed to the desirability of a workshop on detector R&D for hadron colliders, expressing the willingness of one of the Dubna member states to host such a meeting in the second half of 1988.

(D) GENERAL DISCUSSION

At this point, the Chairman opened for discussion the fourth and last part of the Session. Specifically, he asked for opinions on a) the usefulness of the present Panels, b) other Panel topics, and c) other matters of common interest.

A. Sessler reminded the attendees that the present four Panels were agreed upon at the 1984 ICFA Seminar, with the understanding that the matter of Panels be reassessed subsequently. Perhaps the time has come.

N. Tyurin expressed his strong support on behalf of the USSR, for the activities of the ICFA Panels. At the same time he stressed Serpukhov's willingness to host Panel meetings; the Laboratory may even be able to provide some assistance for individuals, if necessary. Tyurin also urged that such meetings be planned well in advance.

W. Hoogland warned about the major laboratories, e.g., CERN, SLAC, becoming "black holes" for accelerator and detector R&D. Perhaps ICFA can assist in seeing that some of this activity remains within the purview of the smaller laboratories and universities (including engineering faculties, as stressed by Brianti).

G. Brianti, responding to a question on the rule for selecting Panel members in view of the mixed participation, pointed out that, in accordance with the guidelines of 1984, members are nominated to ensure a balance between regions, laboratories, and so on. By now the Panels are mature enough that they can be organized "around the work," not simply to ensure some sort of democratic distribution.

Amaldi pressed for opinions on whether ICFA could cope with additional Panels, or indeed, whether any of the present Panels might have reached the end of their usefulness. J. Sandweiss suggested, rather, that the present Panels may well redirect their focus of interest in new directions--in effect creating new Panels quite naturally.

D. Froidevaux (Orsay) expressed concern about a plethora of instrumentation workshops in the next year. He was also uneasy about an earlier apparent statement that CERN R&D money is available exclusively for work carried out within CERN. Not necessarily, Schopper assured him, but the funds must be channeled through the normal CERN funding apparatus.

CHAIRMAN'S CONCLUDING REMARKS

The Chairman concluded the Session with a few of his own impressions of what were the principal points brought out in the discussion:

.. Participation of young people from the outlying regions must be encouraged, and the laboratory directors must do their best to help.

.. Organization of meetings in these regions is also very important, but can only succeed with active participation at the local level.

.. Trieste should not be overlooked as an appropriate place for such activities.

.. Numerous fellowships are available at the smaller laboratories; perhaps ICFA can help in spreading the information.

.. Newsletters: perhaps ICFA can also help in preparing a mailing list. Data banks should be explored. Concerning the contents of newsletters, the consensus appeared to be to stress future developments, not dwell on fait accompli.

.. ICFA Panels; primary issues:

New Acceleration Schemes--area of concern should not be limited to 1-2 TeV region, but should focus on exotic methods at very high energies.

Beam Dynamics--low energy electron machines are especially important.

Superconducting Magnets and Cryogenics--long-range attention must focus on the new oxide materials, on A15 materials, on cryogenics and superconducting RF cavities.

Instrumentation--should mix with detector R&D for colliders; ICFA must evaluate its stance with respect to the various workshops planned or suggested; note that detector construction takes about as long as the accelerator construction itself, and that one can design a proton-proton detector without knowing where the collider will be sited.

ICFA Panels must be more flexible vis-a-vis their areas of purview, and the membership selection process should be tailored accordingly. ICFA should make sure that the persons named are really interested. The pros and cons of organizing workshops at the major laboratories vs at exotic, Fourth World locations, must be weighed.

Closing Session

SUMMARY

J. Sacton
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In May 1984, ICFA organized at KEK its first seminar on "Future Perspectives in High Energy Physics". As a result of intense discussions it was agreed there to reformulate the mission of ICFA(*) in the perspective of improving the exchange of information on future plans for regional HEP facilities and of promoting international collaboration in all phases of the construction and exploitation of these machines. As a first step along these lines it was decided to set up four Panels to coordinate the activities in the following fields : Superconducting Magnets and Cryogenics, Beam Dynamics, New Acceleration Schemes and Instrumentation Innovation and Development.

During this week at BNL, our main tasks have been (i) to take stock of our programme of accelerator construction and to review future options, (ii) to survey critically the activities of the ICFA Panels and (iii) to discuss how to further improve international cooperation in our field and to widen it to the developing countries. To present a fully objective summary of all these discussions is

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(*) ICFA was set up in 1976 by the Particles and Fields Commission of IUPAP mainly to further the cause of the so called VBA (Very Big Accelerator) - a facility indispensable to the progress of our field but out of the reach of any individual region.

a difficult task. On some controversial matters conflicting views were expressed and I apologize beforehand if full credit is not given to all opinions.

Since the KEK Seminar, two new HEP facilities have come into operation. The TEVATRON, the first accelerator using superconducting magnets, has been working in the fixed target mode at the record proton beam energy of 800 GeV since 1985 and has experienced its first $p\bar{p}$ collider run at $\sqrt{s}$ = 1.8 TeV this year. Fine tuning is still needed to improve the luminosity but from now on a new member has joined the very restricted "Z, W physics club". TRISTAN which has produced its first physics results this summer, five years after ground-breaking, is presently the e^+e^- collider running at the highest energy - an impressive success, bearing witness to the "terrific" efficiency of our Japanese colleagues.

Among all the on-going construction programmes, SLC - the first e^+e^- linear collider - is the nearest to come into operation, its first physics run at $\sqrt{s}$ = 50 GeV being planned for Spring 1988. This challenging enterprise which has still to overcome various non-trivial technical difficulties carries a good part of our hopes for the long term future of our field.

Extensive "underground" activities are going-on both in Western Europe, at CERN and DESY, and in the USSR, at Serpukhov. In total some forty kilometers of tunnel have been excavated already and tens of shafts and halls are being digged in preparation for LEP, HERA and UNK. The CERN e^+e^- collider is expected to run at $\sqrt{s}$ = 50 GeV in 1989 and a programme to increase progressively the beam energy up to 100 GeV has recently been approved in principle. HERA should be operational in 1990, offering a new mean to investigate the structure of matter via the study of high energy e-p collisions. UNK, in a first stage to be completed in 1993, will run as a fixed target facility at a proton beam energy of 3 TeV; its transformation into a $\sqrt{s}$ = 6 TeV pp collider is foreseen for the second half of the nineties.

With the construction of BEPC our Chinese friends are making a step of the greatest importance for the promotion of particle physics in their country. This e^+e^- collider ($\sqrt{s}$ = 5.6 GeV, L = 1.7×10^{31} cm^{-2} s^{-1}) which will be used as a charm factory and a synchrotron radiation facility is expected to be running at the end of 1988. Despite its modest energy it has a large value for the whole of our community.

In closing this mini review of the on-going programme of accelerator construction I would like to emphasize the tremendous effort which, in parallel, has been devoted to the development and construction - in a truly international collaborative spirit - of the tools needed for an efficient and successful exploitation of these machines. In the last few years indeed, some thirteen "4π-multipurpose" detectors of various sizes and degrees of complexity have been or are being built in the world : AMY, TOPAZ and VENUS near TRISTAN, CDF and DO near the TEVATRON, SLD near SLC, ALEPH, DELPHI, L3 and OPAL near LEP, H1 and ZEUS near HERA and BES near BEPC ! Some of them are by now successfully taking data.

We may look forward to the important discoveries to be made by the experiments under preparation at the above facilities. However, they will not answer all the questions now posed and there is a general belief that the exploration of the energy region up to the order of 1 TeV at the constituent level will uncover a rich vein of new phenomena of fundamental importance for our understanding of the Standard Model. A new generation of colliding beam facilities is therefore needed to gain access to these energies.

In the last few years the discovery potential of high energy hadron colliders has been analysed in depth by the various SSC study groups and at the Lausanne LHC workshop. For the first time, early this year at the La Thuile workshop a comparison has been made of the physics interest and feasibility of experiments at pp, e^+e^- and ep colliders. Building upon this vast amount of material, J. Ellis and D. Froideveaux have illustrated at this meeting the case of e^+e^- ($\sqrt{s}$ = 1 to 2 TeV) and hadron colliders ($\sqrt{s}$ = 17 and 40 TeV) in searching for SUSY particles, new neutral gauge bosons and for the standard Higgs particle. It was clearly shown that both types of accelerators are highly complementary in their discovery potential. Lower level of backgrounds and the existence of additional kinematical constraints, however, are expected to make experimentation at electron machines cleaner and easier, provided that the beamsthralung effects do not flood the central part of the detectors with low energy photons. Hadron and e^+e^- colliders are not competitors and both are eagerly needed. High energy hadron machines can be built with present technology. They provide a powerful exploratory tool capable of locating new effects which would help to define more precisely the energy region to be investigated with e^+e^- colliders. The latter indeed have a greater potential in analysis strength but one has still to learn how to build them in a cost-effective way. The effective energy domain available for constituent collisions at hadron colliders was shown to be determined by both the beam energy and the luminosity; higher luminosities may, indeed, partly compensate for lower energies. However, the complexity of the phenomena to be studied at hadron colliders will make it very hard to work with luminosities of the order of 10^{33} cm^{-2} s^{-1} or 10^{34} cm^{-2} s^{-1}, as suggested for some dedicated searches. R. Schwitters has shown us that despite the enormous progress made in our understanding of basic detector science and engineering still major problems remain to be solved before one would be able to construct a practical detector capable of operation at such luminosities. Trigger selection, data acquisition and handling, on line equipment calibration, failure detection and repair constitute another set of areas where substantial progress and novel approaches will be needed. It is hard today to evaluate realistically how much this "complexity factor" might affect our comparison of the physics reach of machines operating at different energies with different luminosities.

How are we preparing this exploration of the 1 TeV energy range in practice ? As far as hadron colliders are concerned two machines have their enthusiastic supporters and were presented at this meeting. In the US a definite proposal exists to build the SSC, a p-p collider to reach $\sqrt{s}$ = 40 TeV with a luminosity around 10^{33} cm^{-2} s^{-1}. It has the support of the President and is presently in the pipeline to get Congress approval. If this approval is obtained in the forthcoming months, the machine could be operational early in the second half of the nineties. In Europe, the LHC project consists in the installation in the LEP tunnel of a p-p machine of maximum energy $\sqrt{s}$ = 17 TeV and luminosity reaching 10^{34} cm^{-2} s^{-1}. This machine is claimed by its proponents to offer the most cost-effective way for accessing the 1 TeV energy domain. In addition, operated with LEP it would allow the study of ep collisions at $\sqrt{s} \sim 1.5$ TeV with a luminosity around 10^{32} cm^{-2} s^{-1}.

Some international collaboration has existed during the elaboration of both these projects mainly through the exchange of experts, consultation activities and participation in seminars and workshops. It went on, however, more on an individual basis than as a coordinated effort. At this meeting, Americans and Europeans have reiterated their previous calls for international cooperation in constructing and exploiting these facilities. One may safely guess that, once built, the SSC and/or the LHC will be exploited by large international groups similar to the ones now working at the $Sp\bar{p}S$ collider, TEVATRON and TRISTAN or preparing the SLC, LEP and HERA experiments. The construction of detectors able to cope with the expected event rates and event complexity will require extensive R & D work in various areas. Some actions are being taken, in particular in the US, to organize this work, define priorities and avoid undue effort duplication. In a early phase these activities can be done with relatively little technical support and limited amount of money. In addition, sometimes calling for a multidisciplinary approach, they are well suited for university research laboratories. It was felt that ICFA, via its Panel on Instrumentation Innovation and Development, should promote such R & D work, in particular, by facilitating the involvement of groups from the developing countries.

How the construction of the machines themselves will proceed remains an open question which was only briefly discussed at this meeting. Nevertheless, it should be said that neither of the original HERA or CERN models could be applied "ne variatur" because the present projects have developed within a different context. Variants of such schemes, however, might be imagined.

The situation regarding e^+e^- linear colliders with energies around 1 or 2 TeV is quite different : as yet no firm proposals exist for the construction of such machines. In Europe, Japan, U.S. and USSR various groups are actively working on feasibility studies which, based on fairly conventional approaches, could lead to credible, well costed designs within the next few years. However, to create the technology base required for an economical and efficient machine, intense R & D work is needed in different crucial areas such as power sources, low emittance production and conservation, final focus, machine stability and efficiency, ... The needed effort exceeds by far the resources of a single laboratory. The time is appropriate to organize a collaborative approach to these various questions in order to move as efficiently as possible to our goals by selecting the best road(s). A proposal was put forward by B. Richter to convene in autumn of next year a working group of experts in the field who should define and distribute the work to be done and the responsibilities and set up the needed procedures to monitor the progress of the activities. The role of ICFA in this area was discussed. In particular, some participants were in favour to see ICFA concentrating its effort on the preparation of the long term future by facilitating and coordinating the R & D work required to develop and test more exotic approaches based on completely new concepts which would hopefully allow to go well beyond the 1 TeV energy region.

At the ICFA Seminar held at KEK in 1984 four Panels were set up to stimulate world-wide cooperation in R & D work in the following areas : superconducting magnets and cryogenics, beam dynamics, new acceleration schemes and instrumentation innovation and development. The review of the activities of these Panels, presented by their chairmen, has shown that various levels of success had been reached. Concrete tracks of these activities were the successful organization of two workshops respectively on "Superconducting Magnets and Cryogenics", with a strong participation of representatives of the industry attracted by the perspective of large-scale markets, and on "Low Emittance Beams". The first School on "Instrumentation" was also organized which has brought some 70 students, of which 50 % belonged to the "fourth region", in direct contact with technology in use to-day in our field. In an attempt to improve the exchange of information, new communication channels have been set up - the Instrumentation Bulletin and the Beam Dynamics Newsletter - or are under study - a Review of Detector Properties.

The organization, role and future plans of the ICFA Panels were critically discussed at this meeting. It was recognized that the success of the enterprise had been a function of the enthusiasm, motivation and personal involvement of the Panel members and depending on the support (financial, technical, manpower) that had been provided by some laboratories.

The overall insufficient participation of panelists from the USSR and the "fourth region" - mainly due to shortage of financial support or administrative limitations - was found to be a major problem for which however various solutions have been proposed.

Each Panel has an attractive programme of activities, in line with its mission as defined at KEK. It was felt, therefore, that all four panels should continue, being however encouraged to adapt their activities and set their priorities by taking account of the evolution of the needs. The activities should be focussed on the preparation of the long term future which for several participants remains the major objective of ICFA. Short-term issues not covered by other "bodies" should also be looked at because of their potential direct impact on the fourth region. All possible effort should indeed be made to promote the participation in our field of the young scientists from the fourth region with the long term goal of fostering there fundamental research and advanced technology. The Panels should therefore favour the organization of Workshops, Conferences and Schools in these countries where a local community, even small, already exists awaiting eagerly outside help for further development. A continuous effort should be made to improve the communication channels indispensable for a world-wide exchange of information. In this connection, the importance of an increased mobility of research workers was also advocated; it was suggested to better advertise the existence of the many fellowships offered both by large laboratories and universities. In recent years, some large laboratories have set up programmes of cooperation with institutes from developing countries. Further initiatives of this type should be welcomed.

What could be the future of our field after "the next step" that we are presently preparing ? In his talk, S. Gershtein has given us the opportunity to catch a glimpse on that question. It is quite possible that the careful investigation of the 1 TeV energy region will not solve all the problems faced by the Standard Model. The origin of CP violation, the exact number of lepton and quark generations, ... are some of the questions which might remain unanswered. According to Gershtein, Salam and others, interesting phenomena of relevance to these questions might be expected to occur in the 10^2-10^3 TeV energy range, thus requiring for their study the construction of a 10^{15} eV hadron collider (a Pevatron) ! Although there is today a wide consensus to abandon the notion of a world machine and to strongly favour a diversified world HEP research programme conducted in a collaborative spirit in different locations distributed over the regions, it is not inconceivable that the eventual construction of a Pevatron would re-open the debate about the VBA sometimes in the next century.

CONCLUSIONS AND RECOMMENDATIONS

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We have had very active and constructive discussions during this Seminar. On behalf of ICFA, I should like to thank all the speakers and participants for their efforts to make this meeting so successful.

Now I present to you the "Conclusions and Recommendations of ICFA" which were extensively discussed at the ICFA meeting held yesterday, October 9, 1987.

1. ICFA believes strongly that particle physics research needs to expand into regions of higher energy, and that this task is best accomplished by intensified collaborative efforts and cooperation between the different regions in the world.

2. It therefore welcomes the next generation of large hadron colliders in the multi-TeV region now being constructed, proposed or considered in the USSR, the USA and Europe (UNK, SSC, LHC) which are different in many respects, such as energy range, different options, etc.

3. For the longer-term future of this field of fundamental research, ICFA recommends that research and development studies of electron-positron linear colliders be encouraged in all the interested regions on a coordinated collaborative basis and that steps are taken to find technical solutions towards the realization of these accelerators.

4. ICFA further recommends that collaborative research and development work on both new detectors and new methods of particle acceleration be intensified. Detector developments are particularly needed to more efficiently utilize the higher intensity particle beams expected and envisaged. New methods of particle acceleration are needed to reach by the most economic

means higher energy regions than those currently accessible with present-day techniques and providing at the same time the luminosities necessary for proper physics exploitation of new facilities.

5. ICFA also welcomes the growing involvement of many of the developing countries in elementary particle physics research. ICFA recommends that the presently existing high energy physics laboratories as well as international organizations, such as ICTP and UNESCO, for example, should actively encourage and support activities in these countries, such as research and development work on detectors or new acceleration methods as well as participation in particle physics research in the main accelerator laboratories.

6. In order to enable the developing countries to expand their efforts in particle physics, ICFA recommends that appropriate Conferences, Workshops and Schools on various aspects of the subject should be organized in these countries, with the assistance of the existing major laboratories in the industrialized world.

7. ICFA has noted with satisfaction that the Panels set up at the KEK Seminar in 1984 have overall made significant contributions to the coordination and development of work in their respective fields. It congratulates the Chairmen and the members of their Panels on their achievements and encourages them to continue their activities. ICFA also notes with satisfaction the growing support of the major laboratories of activities such as Workshops, Schools, Bulletins and Newsletters, all of which promote and stimulate the exchange of information and coordination of effort throughout the world.

8. ICFA recommends that appropriate Conferences, Workshops and Seminars on forefront topics should continue to be organized by the respective Panels as, when and where the need arises.

9. ICFA also supports the continued organization of Schools such as that recently held on Instrumentation in collaboration with ICTP Trieste and that now envisaged for Accelerators. More specifically, it supports the organization of such Schools in the different regions with particular attention to the participation of the developing countries in order to help the emergence of high energy physics in these countries, especially in those areas with applications to other fields.

10. ICFA considers that International Seminars of the type held at KEK, Japan in 1984 and now at BNL, USA in 1987 appear to be a useful forum to exchange information and ideas on a world-wide basis, leading to a general consensus on the future steps to be taken in the field on a collaborative basis. ICFA therefore would propose to hold a further Seminar on Future Perspectives in High Energy Physics in 1990, possibly in Europe.

CLOSING REMARKS

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In closing I thought I would make just a few observations. First, it has become abundantly clear that the high energy community is an international fraternity. I made the same comment in my opening remarks and I believe the week's activity here has really underscored this fact. If ICFA has done one great thing, its not just the presentations that took place but the conversational interactions that took place this week in the corridors among very distinguished, sophisticated accelerator designers and builders. Second, I also note that we are more widespread than before. This is shown by the committees, in the sense that we've been able to obtain distinguished people from around the world whom the community respects as chairmen, not dominated by one region. Moreover, the number of regions that are contributing expertise, distinguished expertise, has increased and is still increasing dramatically.

Comments on accelerators: I believe in the free enterprise system for accelerators and ICFA can't and won't dictate to any region what accelerators to build and what not to build. What ICFA has done is to provide a forum for a clear exchange of information, eye to eyeball discussions between people who are pushing accelerators in various regions. The one thing that we cannot afford is to build a nonproductive machine for the wrong reasons. So, if there is anything that this community and these meetings hopefully can accomplish is to make people quite aware of what's going on in a deep way and to prevent irrational decisions from being made in some area of the world on some machine being built. I also agree with Vicki Weisskopf's comments in his address that success in one area of the world in high energy physics breeds success in another region and vice versa, so it is in all our interests that we all be successful.

If one looks at the future one can emphasize once again the complementarity of machines, and I think Sacton did a very nice job of pointing out the strengths and weaknesses of hadron-hadron and electron-positron machines. I agree with our theorist friends that the 1 TeV mass scale is the next exciting place to strive for. One can visualize several scenarios, including one which would not be very nice: namely one Higg's particle at a mass of 150 GeV and that's it. If so, we're all in trouble. None of us will build five, six machines; perhaps there will be one and we'll have a very hard time finding that Higg's particle if its mass is below two W's. On the other hand, I don't believe that. I believe that there will be a rich spectroscopy at the 1 TeV mass scale. We shouldn't trust our theoretical friends too strongly; they've led us astray many times. I'm reminded of the ISR, one of the great machines, where people would say there's no physics at large momentum transfer and -- sure enough -- that's where the great physics was! It also was a machine that provided higher luminosities than designed for, which was also very nice. So therefore, I think can I anticipate a rich spectroscopy at the 1 TeV mass scale; Mr. Ellis tells us it may even be below 1 TeV, which would also be nice. Therefore, one can visualize a scenario which will utilize the strength of a highest-energy hadron collider to map out the mass space, with a rich spectroscopy, and then one can easily visualize many e^+e^- colliders exploiting the particularly interesting masses that one finds in this mass interval. I believe we all agree that we now know how to build the hadron colliders, and as we see we have plans for doing just that. However, I also think we believe that there's a great opportunity for making major advances in accelerator R&D in the e^+e^- colliders, where one can possibly bring costs down even further. This rich variety of world-wide accelerators should be a very attractive situation for our community in years ahead.

My final remark has to do with the VBA. As I said the other day at dinner, ICFA has stated its opposition to duplication of the VBA, and now we are reaching a consensus for duplication without a VBA. Duplication I've commented on; we don't want to duplicate specific machines. We know that hadron physics is sufficiently rich and that duplication is not much of a problem, and that we certainly don't want to build them with the same energy when we could have a whole array of them. One VBA would be the end of the field. As Wallenmeyer said, we do have the VBA all over the world. On the other hand, there may come a time when there will be one particular machine we may need which is beyond the reach of any particular region; if that comes to pass, I think it can only be realized when accelerator people from one region approach accelerator people from another region and undertake joint workshops to build such a machine, being aware of their own limited resources. So again, I believe that will be a grass roots matter which comes from below and can't be forced in from above. Again, I would reemphasize, we shouldn't be thinking of one grand machine, because this field thrives by having many centers all over the world, and it is gratifying to see that our community is expanding.

CLOSING REMARKS AND ACKNOWLEDGMENTS

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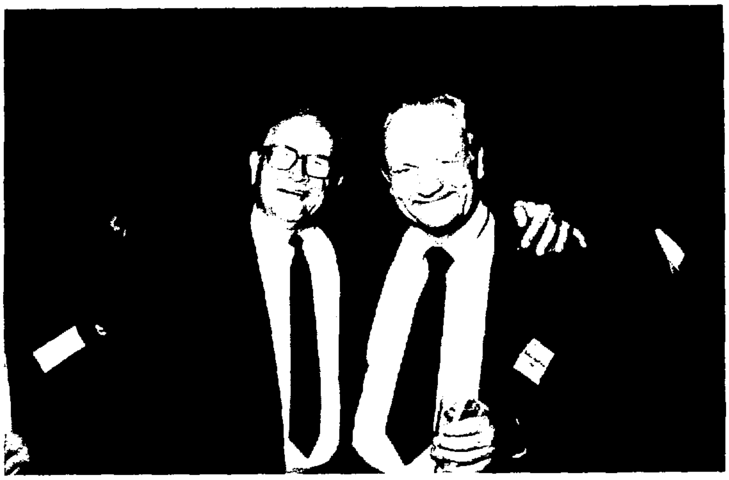
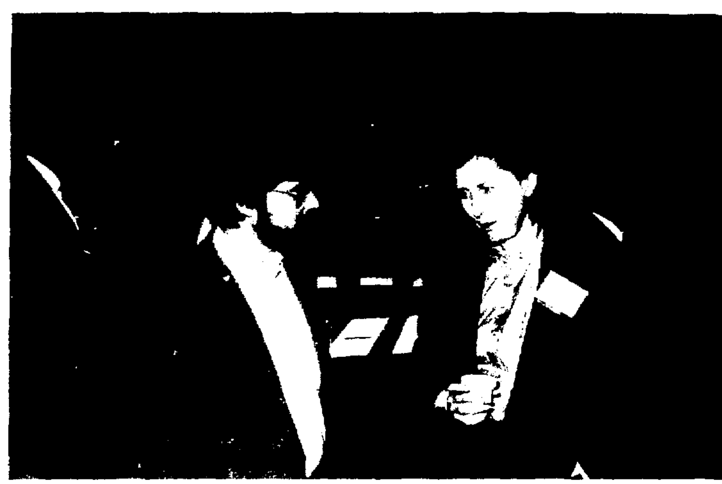
We are coming close to closing this Seminar and I thought I would do so by first giving you a little bit of information about the parent organization of ICFA, the International Union of Pure and Applied Physics. As you know, IUPAP has been in existence for about 60 years. Every three years a general assembly is held where the officers of the Union and the members and officers of its Commissions are nominated. This year the assembly took place in Washington, just the preceding week, and I would like you to know that the President of IUPAP for the next three years is **Larkin Kerwin** from Canada and the Secretary General is **Jan Nilsson** from Sweden. The IUPAP is organized in some nineteen Commissions, not all of which are active during the same period. You are certainly interested in at least two of them. One is Commission 11, the Commission of Particles and Fields, of which the Chairman for the next three years is **Professor K. Strauch.** The Vice-Chairman has been nominated as a physicist coming from industry. Although he retired from industry some time ago, it was thought that **Professor H.B.G. Casimir** has made such an important contribution to the field of particles and fields, and as he had been Director of Phillips Research Laboratory for some 26 years, he was emminently qualified to be Vice-Chairman of the Commission, especially from the point of view of his industrial background. The Secretary will be **Professor A. Donnachie.** There are several other members. There is also, in addition to the Commission on Astrophysics with which we have some close links, the Commission on Nuclear Physics which will be chaired by **Professor H. Feshbach.** I mention it explicitly, because following a statement by ICFA in Berkeley last year that ICFA was concentrating on the high energy frontier, rather than looking at all possible machines that can contribute to the advancement of the physics, the Commission on Nuclear Physics has now taken the initiative of creating a new committee which would have some analogy to ICFA. This will be an International Committee for Future High-Intensity Facilities, in particular kaon factories and the like. By the way, during the General Assembly the Commission on Particles and Fields was invited to stress in its tri-annual report on the status of the physics and on the activity of the Commission the activity of ICFA which emanates from this Commission.

Having given you this little piece of information I now come to the very pleasant task of giving some acknowledgment to the organizers of this fruitful Seminar. First of all, of course, Nick Samios worked very hard. He first traveled to Brussells; then he traveled to Washington, I am sure, to obtain some help from DOE; then he traveled again to Budapest to finalize matters with ICFA; and finally, he settled down back here and did a lot of work for all of us. I am sure it has been for me personally, and for all of us, a great pleasure to be here. It was said in opening the Seminar that Brookhaven National Laboratory is a great Laboratory. I really share this judgment and I believe that the Laboratory is justly proud of its scientific achievements. These achievements of course represent the most important assurance for its future continued prosperity. But I believe it is also a great Laboratory because it has contributed very much to a remarkable evolution that has taken place during the forty years of its existence in the sense of the adjective "National"; I have not consulted an updated dictionary for all the possible meanings for this word. I know that "national" has never been interpreted here in the narrow sense, of restricting something to physicists, or to something pertaining exclusively to the U.S.A. This Laboratory has been a host to physicists from all over the world, and it has been a beacon of international cooperation for the forty years of its existence. And so, it is also in this sense that it deserves the qualification of great. So in the name of IUPAP, in the name of ICFA and speaking for all of the participants of this Seminar, I would like first of all to thank Brookhaven National Laboratory and its Director Nick Samios.

Of course, although he worked very hard and he traveled extensively, he could not have done himself all the work that is needed to organize this Seminar, so he surrounded himself with very helpful and competent collaborators-- most of them from Brookhaven, and at least two of them from CERN. The first two of them, of course, that we have all interacted with are Horst Foelsche and Pat Tuttle; then Per Dahl, Arthur Greene, Herb Kinney, Penny Baggett, and a group of very able secretaries who have made life much easier for all of us. I have only been able to convince two of them to join us in the first row, but I hope that all of them are here, perhaps in the back rows. They are Pat Tuttle, Rae Bailey, and Pam Campbell. And then, as I have mentioned, there have been two very helpful organizers from CERN: Owen Lock, who is also the Secretary of ICFA, and Helga Schmal. I would really like to commend to future organizers the very synthetic but almost perfect way of putting together in a single sheet the program of a seminar like this. It simplifies also their work but is a very good example of foresight and thought.

Again, in closing the Seminar I would like to thank them all very, very much. It has been a pleasure.









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