NEW AND UNTHINKABLE IDEAS

Summary Report of Working Group*

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1. Introduction

Colliding protons at 200-400 GeV each provides an initial state with a fantastic excitation energy--so far removed from our experience as to encourage the widest degree of speculation as to what new phenomena may now take place. Since a great deal of thought has already gone into extrapolations of "conventional" HEP to 400 GeV, it seemed appropriate to invest some time in thinking about processes that have, until now, not been investigated and described in the rich literature of ISABELLE, POPAE, and the European proton storage (LSR) ring study groups. We set out to study the reaction

$$p + p \rightarrow \text{something new.}$$

To give this process its largest possible rate, we should seek the inclusive channel:

$$p + p \rightarrow \text{something new + anything.}$$

In a well attended preliminary session, many suggestions were made[1]:

* W. C. Carithers, C. Y. Chang, L. M. Lederman, U. Nauenberg, C. Rubbia, and N. P. Samios.

1. Under the theorem that all truly novel ideas are totally obvious, no credit (or blame) will be given to physics ideas presented below.

A. New Symmetry Violations

e.g. 1. $p + p \rightarrow$ nothing.

This implies a search for violations of baryon number, charge, or both. Again, the inclusive channel is preferred:

$$p + p \rightarrow \text{nothing} + \text{anything}.$$

2. It is conceivable that the old symmetry violations could, in the intense fields of the 400 GeV collision, change their character, the $K^o - \bar{K}^o$ particle mixture could show interference effects of opposite sign.

3. Other properties of particles may change due to the environment at birth, e.g., mass, charge, etc.

4. Lorentz invariance breakdown at very small distances should be suspected.

B. Search for New Objects

1. Particles of high mass that are stable, perhaps because they are the ground states of new families carrying new conserved quantum numbers.[2] A particular example of this would be a sudden vast increase in the production of antiparticles perhaps suggested by some cosmological problems.

2. Particles that have very long lifetimes, that require: i) a K_L^o-type detector or ii) search for high-energy decay products after the machine is off (or before

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2. Quarks, monopoles, etc., are defined as old, familiar objects for this discussion.

it's turned on) or iii) search for neutral massive leptons through thick shields.

3. Particles of very high mass and short lifetime which decay hadronically could be sought via the unique signature of $\Sigma P_{\perp} \approx M/2$.

The burden of the study would be to think of the instrumental things that would bear on these "totally obvious" problems. Clearly what is done in this study will surely be improved by the relentless advance of instrumental technology. In the following sections, we present some approaches to the problems presented above.

2. Baryon Conservation

(Analysis contributed by U. Nauenberg, University of Colorado)

One might dare to ask the question whether baryon number is conserved in very high energy collisions. This question becomes somewhat reasonable when you note that conservation laws of this type may exist not only as a basic law of nature, but also as a result of the existence of a very strong binding force which keeps the basic baryon core from being dissociated in medium energy collisions. For example, the fact that strangeness is an element in elementary particle interactions did not become apparent until enough energy was available in the collisions to produce these new states.

Once we embark on such an experiment we must determine which is one of the most likely final states that may be produced in a baryon non-conserving collision. Here we must separate two possible types of non-conservation:

1. Baryon non-conservation that occurs because of the dynamics of a collision and hence may only occur when there is a "quark, antiquark annihilation." In such cases any number of final states may occur without a baryon in the final state. These may contain lepton pairs in addition to a large number of mesons, or just a large number of mesons.
2. Baryon non-conservation that occurs because the actual baryon core is disintegrated in the collision and the element of the core that carries the baryon number disappears. Then conservation of angular momentum requires the final state derived from the disintegration must have half integer angular momentum and hence an odd number of leptons must be present (the only fermion with baryon number zero). Of course this or these leptons can be accompanied by any number of mesons.

An experiment for ISABELLE that tries to observe such a reaction must be able to determine that two baryons are missing. As far as we can determine there is no detector that at these energies can distinguish a pion or kaon from a proton sufficiently well. Hence such an experiment must be designed to determine that the reaction occurred with no strongly interacting particles (charged or neutral) going through the detector. Hence all particles going through the detector must be either leptons or photons (either by themselves or from pi-zero decay). In addition we must determine that no baryons are escaping along the beam direction. Hence the detector must be capable of measuring the electromagnetic (muons excluded) energy deposited in the detector to such accuracy to determine that less than 1.88 GeV is missing. This implies measuring the energy deposition to better than 2 out of 400 or ½%. Such an accuracy cannot be achieved on an event-by-event basis. Hence the signal must consist of a statistically convincing number of events all with energy depositions in the detector within a few percent of 400 GeV and all indicating that no hadrons were present in the final state.

Possible Detecting Arrangement. A good device to detect the presence of electrons is a transition detector.[3] Hence we would surround the interaction region with two stacks of transition radiators like the inner region of the "W Search Device" described in the lepton detector summary report.[4] It is shown in Figs. 1 and 2. Each stack would consist of 500 Li foils ($\sim 1\frac{1}{4}$ mils thick) with 20 mils spacing between foils. This set would give a π/e separation of better than 10^{-2}. Hence if our trigger is the requirement that no charge track be a hadron, we get a very good discrimination against typical events. This arrangement is then surrounded by an array of lead counters to measure the electromagnetic energy generated in the collision. The lead glass arrangement is shown in Fig. 3.

The central region would consist of 30 transition radiator units and 180 lead glass counters. Each of the end pieces would

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3. J. Fischer, S. Iwata, V. Radeka, C.L. Wang, and W.J. Willis, BNL 20063. Submitted to Nuclear Instruments and Methods.

4. R. Burnstein, W. Carithers, M. Duong-Van, R. Imlay, M. Kreisler, U. Nauenberg, C. Rubbia, G. Snow, L. Sulak, H. Williams, E. Paschos, M. Sakitt, C.L. Wang and L.L. Wang, "Design of a Lepton Detector for ISABELLE", these Proc.

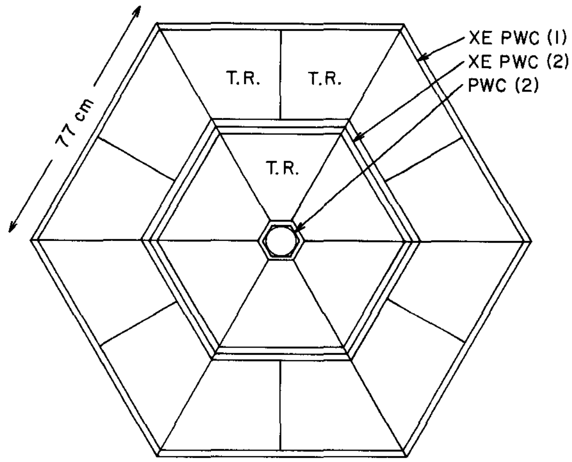

Fig. 1. Transition radiation detector system, cross-section through central region, view along beam direction.

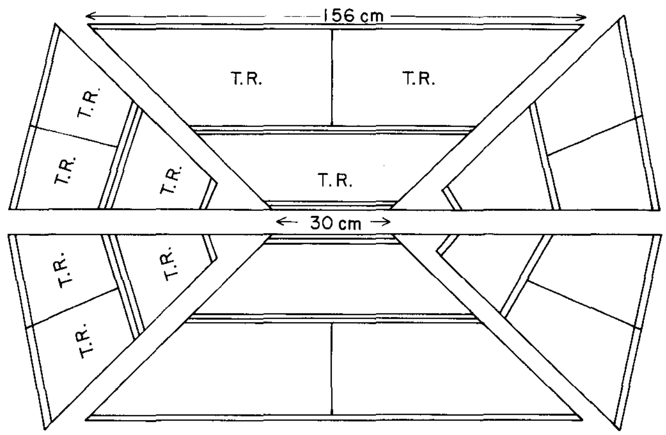

Fig. 2. Transition radiation detector system, vertical section through central region and end pieces.

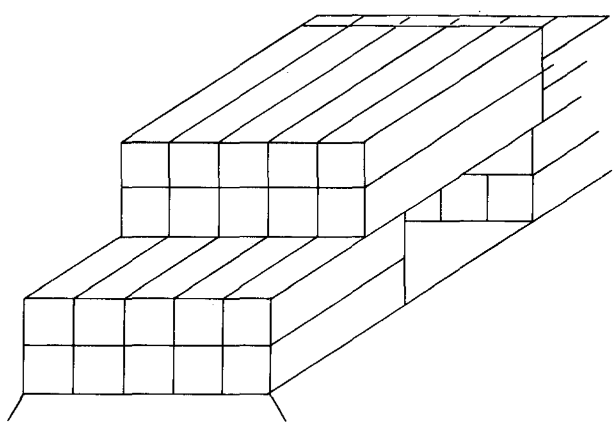

Fig. 3. One unit of lead glass arrangement for the central region.

have five transition radiators and about 10 lead glass counters. The number of MWPC wires is about 15,000 at a cost of about \$15.00/wire. We could read wire combinations by tying wires/readout reducing the price substantially. The cost of the lead glass counters is about \$800.00/unit. Roughly the cost of this device is about \$400 K.

Rates. Because of the high counting rates, this experiment would not use the full luminosity of 10^{33} sec^{-1} cms^{-2}. A luminosity of 10^{32} sec^{-1} cms^{-2} leads to a counting rate in the forward modules of $\sim 10^5$ counts/sec/module which is manageable.

3. New Object Detector

(Analysis contributed by L. M. Lederman, Columbia University)

Consistent with the introductory charge to the "New Ideas" group, we outline here the conceptual design for a new object detector (NOD) with the following desired properties:

1. Wide angular acceptance.
2. High rate capability.
3. High mass resolution over a large range of masses.
4. Flexible triggering arrangement.
5. Measure charges of all objects.
6. Study interaction and decay properties of new objects.

We must keep in mind the fact that an ISA with 10^{33} luminosity will produce no more than $\sim 5 \times 10^{13}$ interactions per year. Any detector which can define a signal at say one event per 20 hours of high luminosity running is sensitive to no less than $\sigma \sim 4 \times 10^{-36}$ per one percent of overall efficiency.

The NOD makes use of many ideas picked up in the corridors of the ISA summer study, principally the new gas Cerenkov counter ideas of Sandweiss and Fitch, hadron calorimeter ideas of Willis, etc., etc.

We divide the system into its subsystems proceeding from the interaction ring outward. We refer to Fig. 4. We opt for 90° CM as the place where background to signal may be optimum--certainly the most favorable, geometrically.

A. <u>Gas Cerenkov Counter</u>

This makes use of the old idea that the observation of the Cerenkov angle θ_c via the radius of illumination in the focal plane of a spherical mirror is a sensitive measurement of β. Since for $\beta \approx 1$, this is the most difficult part of the problem, we note that, for negligible error in Δp,

$$\frac{\Delta m}{m} = \gamma^2 \frac{\Delta\beta}{\beta} = \gamma^2 \frac{\Delta\theta_c}{\theta_c} \quad .$$

We adopt a momentum range of 1 - 20 GeV/c and argue that new objects of low mass are adequately searched up to $P_\perp \lesssim 10$ m, i.e., $\gamma \lesssim 10$. Thus, if we insist that the <u>worst</u> mass error is $\leq 10\%$, we need

$$\frac{\Delta\theta_c}{\theta_c} \lesssim 10^{-3}$$

(very ambitious!).

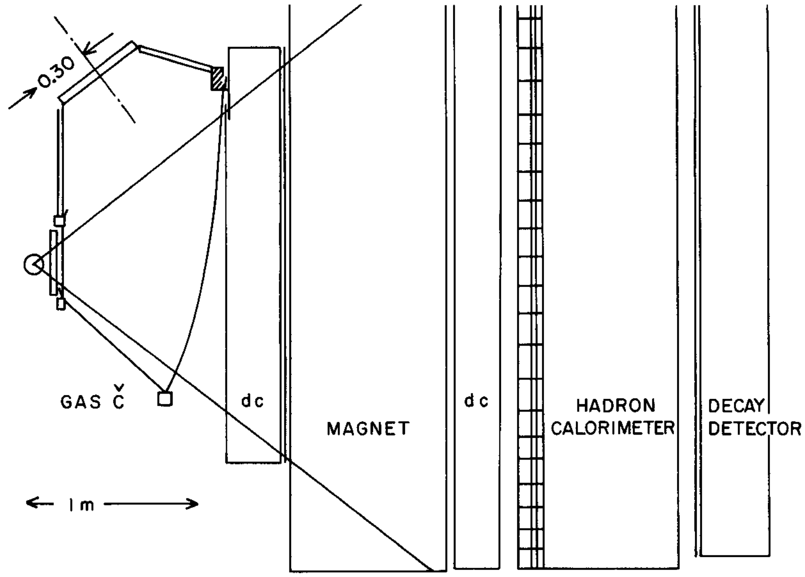

Fig. 4. Overall arrangement of the New Object Detector.

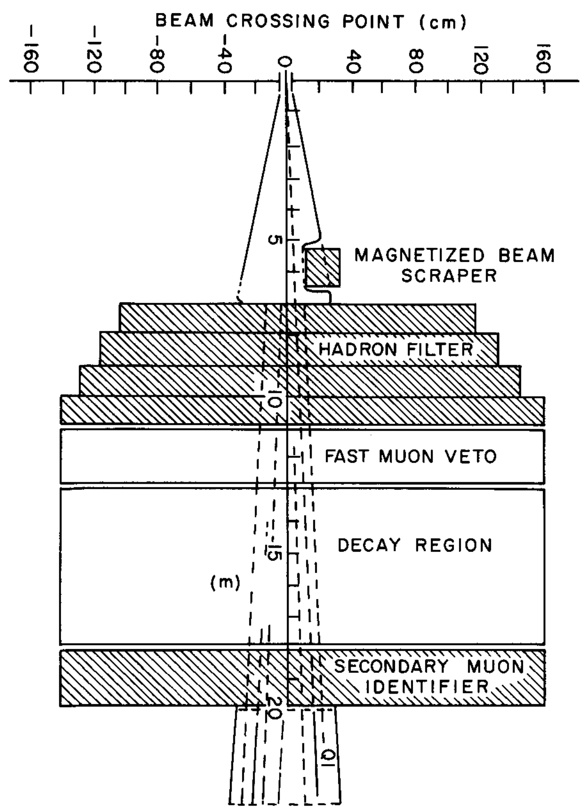

Fig. 5. Overall detector arrangement for K^o_L - type experiments to search for heavy leptons.

Radii may be measured by a Channel Electron Multiplier array (Sandweiss), by calculations from PM sampling of various sections of the focal plane (Fitch), perhaps by Xenon MWPC. We require $\gtrsim 5$ photoelectrons for good averaging--and a spatial resolution obtained from the following:

$N_{phe} \approx 100\ L\theta_c^{\ 2}$ Photoelectrons

$\theta_c \gtrsim .03$ in order to have ~ 10 photoelectrons in one meter of gas

$f \sim$ one meter

Radius $R_c = f\theta_c \gtrsim 3$ cm.

(For a lethargic object of $\beta = .95$, $\gamma^2 = 10$ the radius is 30 cm which we take as an absolute upper limit for the Cerenkov aperture.)

Thus for $\Delta\theta/\theta \sim 10^{-3}$, we need a Δr of 30 μ. The total area of the photoconverter will be $60 \times \sim 100 = 6000\ \text{cm}^2$. If all of this were to be subdivided into 30 μ cells, would require:

$$\frac{6000}{\pi(.003)}\ 2 = 2 \times 10^8\ !$$

Since this is probably too much, we note that the larger radii require less detail--but we are left with about 10^7 elements and the need for a clever serial readout system which does not require the location of 10^7 preset addresses as in PWC's.

The optics are probably such as to focus the line source of the interaction region into a line. Dispersion and aberrations, etc., are assumed correctable to the required precision.

(Several suggestions for improvements have been made: i.e., i) clever optics that would convert the "DISC"--a zero acceptance Cerenkov that measures $\Delta\beta/\beta \sim 10^{-5}$ to a wide acceptance device,

ii) use a laser-driven shutter in synchronism with laser induced bunching in the machine for time-of-flight with picosecond resolution. In view of this, we believe a wide acceptance device at $\Delta\beta/\beta \lesssim 10^{-3}$ is in the bag.)

B. Magnet System

This is a simple track-magnet-track system. We are dealing with momenta from 0 to $\sim$20 GeV/c and we are backed up by a hadron calorimeter. Thus, we set a criterion of negligible contribution to the mass error:

$$\left(\frac{\Delta m}{m}\right) = \frac{\Delta p}{p} \lesssim .05 \quad .$$

A one-meter 10^4 gauss bend gives $p\theta = 0.3$ GeV

i.e., 10 GeV/c bends 30 mr .

In general for ≥ 4 on hits per track $\Delta p/p \sim \delta/L(0.3)\,p$ where δ is the resolution and L the track length. We chose L = 20 cm, $\delta = 0.2$ mm and have

$$\frac{\Delta p}{p} = 3 \times 10^{-3}\, p \quad .$$

The biggest problem in this system is the rate in the PWC system which may go to $\sim$100 kcps per wire.

C. Hadron Calorimeter

This has several functions: to confirm the momentum measurement for hadrons, identify non-hadrons, hopefully improve the energy measurement at very high $P_\perp$, act as a mass measurer for shorter lived neutral objects which decay hadronically via the effective mass of the secondaries.

Calorimeters of the Willis type using uranium and liquid argon have resolution

$$\Delta E \sim \frac{0.20}{\sqrt{E}}$$

but the integration time may pose a serious problem at the ISA rates. Nevertheless, at an integration time of ~ 30 ns, this would be a powerful addition. We visualize this as subdivided finely soon after the evolution of the electromagnetic part of the cascade in order to separate fairly small angle γ's. This might be done with PWC after ~ 1 rad length of uranium plates. In this way, π^o's could be identified up to ~ 5 GeV, η^o's to 8 GeV, etc.

D. Decay Detector

This is a large device, perhaps a streamer chamber or optical spark chamber (magnetized plates?), which looks, for ~ 2 m, at decays of long-lived objects. Candidates are heavy neutrinos or new K_L^o-type objects. This device is duplicated so that the one behind the hadron calorimeter looks at leptons or other non-hadrons. The duplicate sits on the far side of the vacuum pipe. See the K^o detector of Carithers for details.

E. Scintillation Counters, Triggering System and Charge Measurement

This is used for making roads in the track chambers at nanosecond resolution, for providing a fall back time-of-flight system for low β objects, for providing the trigger logic. The triggering problem is difficult but will rely on the Cerenkov counter which, when blind to pions, will have a manageable intensity. We should also be aware of the possibility of fractional charge and include, if possible, a charge measurement to ±10%. This could most straightforwardly be done by a series of pulse height recordings, perhaps 4 in scintillation counters and also 6 in the PWC gas, acting in the proportional mode. After all, it makes no sense to measure a strange mass via β and p without verifying charge.

F. Summary

The main new point here is a fast, large acceptance mass spectrometer. The conceptual design tries to measure mass via β and p to $\gamma \cong 10$, to check or look for curious masses via the decay modes and to study the interaction properties of the new objects.

4. Search for Heavy Leptons via K_L^o-Type of Experiments at ISABELLE

(Analysis contributed by C. Y. Chang, University of Maryland, and N. P. Samios, Brookhaven National Laboratory)

Searching for new particles produced in a new energy region of PP collisions is of fundamental theoretical interest. In this note we propose to look for the production of long lived heavy leptons via K_L^o-type of experiments in the fragmentation region of PP collisions at ISABELLE. The new particle which we have in mind, might be characterized by:

1. Lack of strong interactions.
2. With a mass bigger than a few GeV/c^2 (e.g., > 5).
3. Possessing new quantum number, hence, a long lifetime.

4. Having a "0" or integral charge (M^o, $M^{\pm}$).

5. Decaying into ordinary leptons on the lowest leptonic states of its own kind, and some hadrons.

As shown in Fig. 5, the detecting system is located at the down stream end surrounding one of the crossing beams. It consists of a hadron filter, a fast muon veto device, and a decay region for the heavy leptons. The design is supposedly optimized to the following facts: i) covering the smallest possible P_t and highest $X = 2P_\ell/\sqrt{S}$ region for the new particles, ii) largest possible solid angle, iii) smallest decay path for high energy π's and K's into muons, and iv) largest decay probability of the heavy lepton.

The hadron filter is mainly a four meter deep Fe block. It provides more than twenty absorption lengths for the hadrons to interact. We assume that the $\lambda_\pi \simeq 130$ to 150 gm/cm^2, hence, the probability of hadron punch-through is $\simeq 10^{-9}$. For weakly interacting particles, such as muons and heavy mass charged leptons, dE/dx is $\simeq$ a constant due to ionization alone, essentially all of them should penetrate through the absorber with 6 - 7 GeV energy losses. Figure 6 shows the expected $\mu^{\pm}$ spectrum from the $\pi^{\pm}$ and $K^{\pm}$ decay in flight in the intersection region where 6 GeV energy loss into the four meter Fe block stopping material has also been taken into account.

Since muons are unwanted, they must be efficiently vetoed. For M^o, the fast muon veto device can simply be a scintillation counter which vetoes all charged particles that penetrate the hadron filter. For charged heavy lepton search, we can either use a gas threshold Cerenkov counter or some transition radiation detectors to veto the particle of high γ.

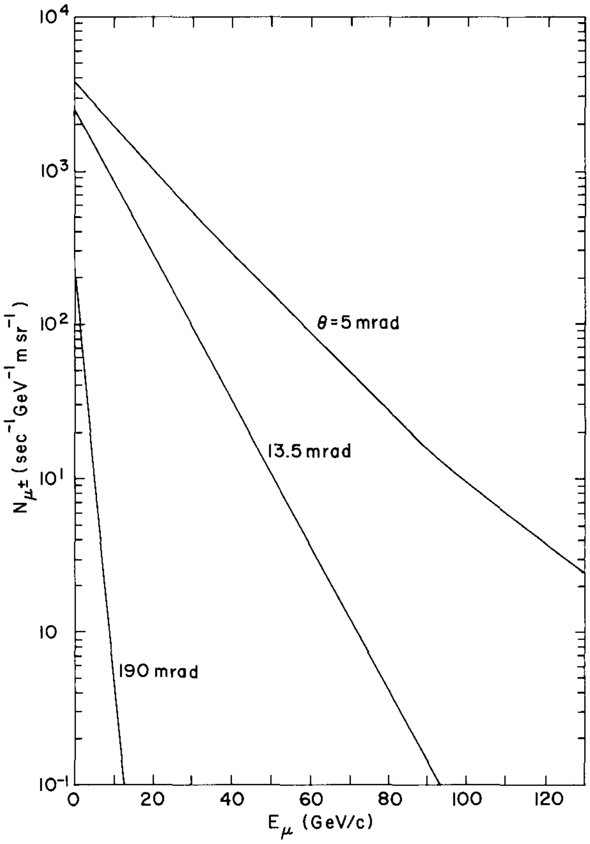

Fig. 6. Expected muon spectra after hadron filter, at various angles to the beam. θ is the angle between the muon and the primary beam direction.

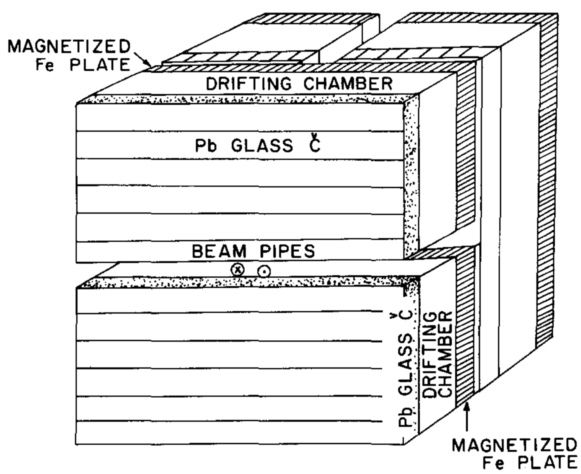

Fig. 7. Detector module arrangement for the decay region, which consists of five secondary particle detection modules, three in horizontal planes and two in vertical planes.

The decay region consists of five secondary particle detection modules. Each module, as shown in Fig. 7, consists of an array of Pb-glass Cerenkov counters (~ two radiation lengths thick), a drift chamber, and a magnetized Fe plate. The Pb-glass Cerenkov counters serve two purposes: i) making sure that the incoming $M^{\pm}$ has a muon pulse shape, and ii) serving as a π^{o} converter and e,μ identifier after the heavy particle decays. The drift chamber measures the decay vertex and the tracks of the decay particles of the heavy mass particle. The magnetized Fe plates provide a momentum analysis for the charged secondaries and also identify the μ's and π's, because pions may shower through the Fe plates. In order to cover smaller P_t regions, the detection modules are symmetrically located in all sides of the beam pipe. In addition, a magnetized beam scraper in the upper stream of the absorber is also under consideration. Such a scraper may serve as an ∞ aperture septum to the heavy leptons, but a beam scraper to the hadrons.

Behind the decay region, we may put a five interaction length μ-identifier there. Hence, the decay leptons can be identified.

Summarized below, the main features of this detection system are:

1. $\Delta\Omega \sim 0.0314$ str.
2. Smallest $P_t \simeq 0.28$ GeV/c or much lower if the magnetized scraper works,

   $X \simeq 0.25$ assuming $(P_L) \simeq 50$ GeV/c.
3. The decay detection efficiency is $\simeq 0.128$.
4. The most sensitive life time of the heavy particle depends

on the M/P ratio, i.e., $\simeq 48/\gamma$ for this particular arrangement. Therefore, it is sensitive to a 5 GeV/c^2 particle of momentum ranging from 10 to 100 GeV/c and life time ranging from 25 to 5 nsec. (proper life time), where for a 50 GeV/c^2 particle, the sensitive life time would be ~ 230 to 50 nsec.

5. Since $\Delta\Omega^*$ decay detection efficiency $\simeq 4 \times 10^{-3}$, for luminosity = 10^{32} cm^{-2} sec^{-1}, we obtain: $10^{32} \times 4 \times 10^{-3} \times 10^{-33}$ event/nb-sec = 4×10^{-4} event/nb-sec ≈ 400 event/nb-300 hr.
6. Triggering rate and background.

5. Identifying Super-Massive Particles Decaying Solely into Very Many Hadrons

(Analysis contributed by C. Rubbia, Harvard University)

Assume that new particles exist with masses in the order of many tens or even hundreds of GeV/c^2. Except in some fortunate circumstances, like in the case of weak vector mesons ($W^{\pm}$, Z^o) where the two-body leptonic decay might be detectable, a standard multihadronic decay in many prongs is expected. Since these particles are likely to be produced with a very tiny cross section and with a large associated inelasticity, the question of how to separate between the decay prongs and the remaining particles, it is not completely trivial.

We shall define "massive particle" an object having the following basic properties:

i) a mass M comparable to the center-of-mass energy, $\sqrt{s}$,

ii) a lifetime longer than the collision time,

iii) definite quantum numbers, and in particular a (small) spin value,

iv) multihadronic decay with $\sim \log M$ type of multiplicity. This law is approximately verified by almost all multihadron final states with no leading particles.

Since the mass of the particle is comparable with the available center-of-mass energy, the particle will generally be very slow. In a first approximation we shall assume that it is actually at rest. The multiplicity assignment (iv) specifies the average momentum of the decay particles:

M (GeV/c^2)	$\langle n \rangle$	$\langle p \rangle$ (GeV/c^2)
50	15.2	3.27
100	18.0	5.5
150	19.7	7.6
200	21.0	9.65

Now, the basic idea is that because of assignments (ii) and (iii), there is no way by which the particle can "remember" (to an order $\cos^s \theta$) the direction of the incoming particles. Therefore, with respect to this direction, while the ordinary debris is strictly limited in $P_\perp$, this cannot be the case for the decay fragments of the particle, for which one expects:

$$\langle P_\perp \rangle \simeq \frac{1}{\sqrt{2}} \langle p \rangle \quad .$$

Therefore, the production of the new particles will be characterized by an unusual "firework" of prongs which have all an "apparent" very large transverse momentum with respect to the incident beam line. This offers both an effective way of selecting for such events and a first crude handle on the mass, since large p particles carry the leading contribution in the expression of the invariant mass.

A way of illustrating the ideas is via a Peyrou plot, where $P_{\parallel}$ is plotted versus $P_{\perp}$. While ordinary fragments are expected to be confined to a very narrow region around $P_{\perp} \simeq 0$, the decay products of the massive particle are invariant with respect to rotations over the Peyrou plot. In such a plot it is also easy to see the effect of the slow motion of the decaying particle. The circle just becomes an ellipse.

Finally this method must not be confused with the "rapidity cluster" which is often suggested as a way of identifying massive objects since this last method, which works on "longitudinal" variables is very sensitive to particles produced with very large cross sections.

Likewise, this object is not a "fireball" or a jet which is characterized by a large conspiracy of particles in a given direction.

This is just one more of those unthinkable ideas.

6. Production of Anti-Nuclei at ISABELLE

(Analysis contributed by W. C. Carithers, University of Rochester)

As often noted, ISABELLE offers a considerable extension of the central plateau in rapidity (about 4 units). We have a high energy density with no orientation toward particular quantum numbers. It is intriguing to identify this energy density as a microscopic model of the primordial "big bang," and to contemplate the possibility of cosmological experiments probing the hadronic era of the universe.

One particular model will serve to illustrate the possibility. There is as yet no cosmological model which can account for the observed non-homogeneous matter distribution in the universe on the basis of statistical fluctuations. A universe that begins as a homogeneous sphere will not evolve into the observed galaxies and clusters of galaxies as the result of statistical density fluctuations. Omnes has pointed out that this problem might be overcome by introducing a matter-antimatter phase transition near the end of the hadronic era of the universe. Crudely the idea is that antimatter (and matter) would "condense" locally like small droplets. The droplets are stable in the sense that if antimatter drops collide, they coalesce as do matter droplets. However, if a matter droplet approaches an antimatter droplet, the annihilation pressure pushes them apart. The model has the additional esthetic advantage of producing a universe which is charge conjugation symmetric.

Could one hope to observe a matter-antimatter phase transition? A naive approach might be simply to look for unexpectedly large production of light anti-nuclei $\overline{He}$, $\overline{Li}$, $\bar{C}$. Of course light nuclei would also suffice except for the background from nuclear spallation from beam-gas interactions or interactions in the wall of the vacuum chamber.

We present a simple argument based on quark-counting for calculating the expected yields of antinuclei. Consider the quark content of π^-, $\bar{P}$ (antiproton), and $\bar{D}$ (antideuteron):

	Quark Content	
π^-	$n\,\bar{p}$	$\bar{u}\,d$
$\bar{P}$	$\bar{n}\,\bar{p}\,\bar{p}$	$\bar{d}\,\bar{u}\,\bar{u}$
$\bar{D}$	$\bar{n}\,\bar{p}\,\bar{p}\quad \bar{n}\,\bar{n}\,\bar{p}$	$\bar{u}\,\bar{u}\,\bar{d}\quad \bar{d}\,\bar{d}\,\bar{u}$

The $(\bar{P}/\pi^-)$ ratio is a crude measure of the probability of picking up an extra antiquark. Call this probability x. Then the $\bar{D}/\bar{P}$ ratio should be proportional to x^3. Then

$$\left(\frac{\bar{D}}{\bar{P}}\right)\Bigg/\left(\frac{\bar{P}}{\pi^-}\right) \approx \frac{x^3}{x} = x^2 = \begin{cases} (5.0 \pm 1.2) \times 10^{-3} & \text{ISR} \\ (4.0 \pm 1.0) \times 10^{-3} & \text{Serpukhov} \end{cases}$$

$$x \approx 0.07$$

(The double ratio was chosen since it is the same at ISR and Serpukhov.)

We can then calculate the individual ratios

	Calculated	Measured (ISR)	p = 0.7 GeV
$\bar{P}/\pi^-$	.07	.10	
$\bar{D}/\pi^-$	2.4×10^{-5}	$5 \pm 1 \times 10^{-5}$	
$\bar{H}_3/\pi^-$, $\overline{He}_3/\pi^-$	8×10^{-9}		
$\overline{He}/\pi^-$	3×10^{-12}		
$\overline{Li}/\pi^-$	1×10^{-22}		

The cross section for large angle $\overline{He}$ production is then roughly:

$$\sigma_2 = 4(40 \text{ mb}) \; (3 \times 10^{-12}) = 4.8 \times 10^{-37} \text{ cm}^2$$

$$\text{Counting rate} = (10^{33} \text{ cm}^{-2} \text{ sec}^{-1}) \; (4.8 \times 10^{-37} \text{ cm}^2) \; \Delta\Omega/4\pi$$

$$= 41 \; (\Delta\Omega/4\pi) \text{ counts/day}$$

Thus we might hope to detect $\overline{He}$ through ordinary production mechanisms. Detection of heavier antinuclei (e.g. $\overline{Li}$) would be strong evidence for a new process.

7. Metastable Neutral Particle Arm

(Analysis contributed by W.C. Carithers, University of Rochester)

A. Scope

Along with other bizarre objects which lack compelling theoretical motivation, one might contemplate a new neutral object which is stable enough to travel macroscopic distances before decaying. It might be a singlet ground state of a new quantum number such that it could decay only weakly. Even though possibly massive, it may have a substantial branching ratio to leptons, either exclusively, or along with a large number of hadrons. The basic signature would be the appearance of an n-prong vee whose vertex was a meter or more from the interaction region. One might also see large angle, high momentum muons from such a vertex. Secondaries in the forward direction (90° with respect to the interaction region) would be measured precisely in a traditional K^o spectrometer. One could obtain crude measures of the mass and hence lifetime from the secondary particle momentum spectrum. Known objects such as Ξ^o, Λ, K^o, $\bar{K}^o$ provide convenient calibrations.

Implicit in all of the "novelty shop" proposals is the hope that the regime of large s, large $P_\perp$ is indeed a new territory full of new physics. We should not presume that even familiar objects retain their standard properties when born in such an unusual environment. The $(K^o,\bar{K}^o)$ system has proven to be an extremely sensitive interferometer capable of measuring miniscule effects. For example, the CP violating parameter ε might go to zero, or grow, or reverse its sign as a result of a different production mechanism for $K^o,\bar{K}^o$. Perhaps even Δm, the $K_L - K_S$ mass difference, will change as a result of tampering with the higher order weak process at production. By repeating the K^o interference experiments at ISABELLE we could check the stability of effects as small as $\Delta m/m = 10^{-14}$.

B. <u>Detector</u>

The apparatus is intended to search in $P_\perp$ collisions for:

1. Production of new and probably massive neutral, metastable objects.
2. Symmetry violations or changes in known symmetry violation in the $(K^o,\bar{K}^o)$ system.

The detector is situated at 90°. It should provide a sweeping field to remove soft charged particles, a decay region, large angle chambers to detect n-prong vees, and a forward spectrometer for the K^o studies. Moreover the detector should be compact in order to maintain a reasonable solid angle. One approach to the problem is shown in Fig. 8. Here the same superconducting coils provide both sweeping and momentum analysis for the forward arm and large angle muons.

The design parameters can best be fixed by considering the minimum requirements for the K^o experiment, known in the trade as a "vacuum regeneration" experiment. Neutral K^o ($\bar{K}^o$) produced as eigenstates of strangeness decay as coherent combinations of K_L and K_S. Because of CP violation, the K_L and K_S decays interfere in the 2π channel. The 2π intensity as a function of the proper time, t, is a typical interference pattern:

$$I_{2\pi}(t) \propto \left(e^{-\Gamma_s t} + |\eta_{+-}|^2 + 2S(p)\,|\eta_{+-}|\,e^{-\frac{1}{2}\Gamma_s t}\cos(\Delta m t - \phi_{+-})\right)$$

Γ_s, η_{+-}, ϕ_{+-}, Δm have the usual meanings. S(p) is the momentum-dependent "dilution factor."

$$S(p) = \begin{cases} +1 & \text{for pure } K^o \text{ production} \\ -1 & \text{for pure } \bar{K}^o \text{ production} \\ \dfrac{\sigma(K^o) - \sigma(\bar{K}^o)}{\sigma(K^o) + \sigma(\bar{K}^o)} & \text{for incoherent production of both } K^o,\ \bar{K}^o. \end{cases}$$

Note that the experiment covers the 2 - 10 GeV K^o momentum range and is thus identical to our decade of experience at AGS and PS energies. Estimates of resolutions, detection efficiencies, and measurement errors are directly transferable. The one exception is the dilution factor, S(p). Because of the egalitarian production of particles in the central region, we should expect S to be substantially smaller at ISABELLE and our sensitivity to the interference term will diminish.

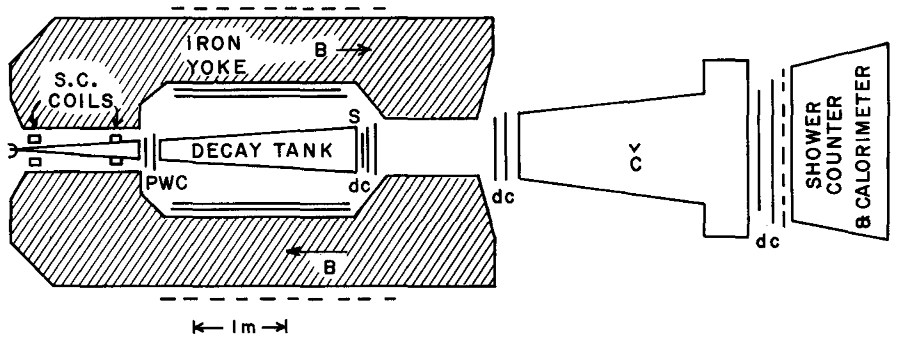

Fig. 8. Overall detector arrangement for metastable neutral particles such as the (K^o, $\bar{K}^o$) system.

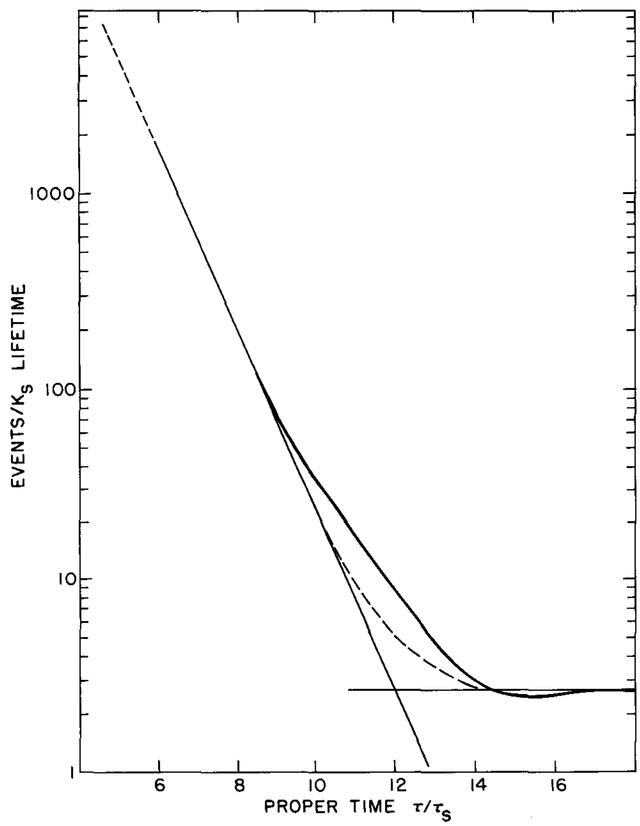

Fig. 9. Number of $K \rightarrow \pi^+ \pi^-$ events expected for a 100 hour experiment for typical dilution factors.

The superconducting coils provide approximately 1 GeV of bending power to sweep out soft charged particles. The length of the decay tank is fixed by the size of the interference region. The maximum sensitivity to the interference term occurs when interfering terms have equal amplitude. This occurs in the middle of the vacuum tank in Fig. 8 for a 5 GeV K_S, (i.e., 12 K_S lifetimes). The broad K^o momentum spectrum then sweeps out the interesting region in proper time.

PWC's precede the decay tank to tag remaining charged particles. Drift chambers just downstream of the decay tank measure the trajectory angles before entering the analyzing magnet. Drift chambers after the magnet complete the momentum analysis. A gas Cerenkov counter separates (π, μ, e) from heavier particles. Electrons are identified in the high z, thin plate front end of the shower counter/calorimeter. Muons are identified by their ability to penetrate the calorimeter while depositing minimum energy in the calorimeter. The detailed lepton identifications are important for measuring the leptonic charge asymmetries from K decays. The charge asymmetry gives an independent measure of Δm, S(p), and the $\Delta S = \Delta Q$ rule.

The decay tank is surrounded by drift chambers to detect an n-prong vertex. Since any long-lived object must decay weakly, one might expect a reasonable branching ratio to muons. Muons are bent in the magnetized iron of the return yoke. The muon momentum could be determined to about 25%.

C. Rates

Rates are based on the CCR parameterization of pion inclusive cross section at 90°:

$$\frac{d\sigma}{dP_\perp \, d\Omega} = \frac{1.5 \times 10^{-26}}{(P_\perp)^{7.24}} e^{-26.1 \, P_\perp/\sqrt{s}} \quad \frac{cm^2}{GeV \, .sr} \quad .$$

Figure 9 shows the number of detected $K \to \pi^+\pi^-$ events expected for a 1000-hour experiment. The easiest way to characterize the sensitivity is to note that we expect

$$3 \; K_L \to \pi^+\pi^- \text{ events}/K_S \text{ lifetime} \quad .$$

This should result in a 25% measurement of $|\eta_{+-}|$. The phase of η_{+-} is less well determined because of the dilution factor. One could probably do no better than localizing the phase to a quadrant.

The singles rates in the front PWC will be less than 10^6/sec which could be easily tolerated. The detector of Fig. 8 is sensitive to new metastable neutral objects with lifetimes greater than 10^{-8} sec. If we assume that the object is produced with transverse momentum = 5% of its mass, then a limit at 90% confidence of 3.7 x 10^{-33} cm^2 could be placed on the production cross section if the lifetime were 10^{-8} sec.