SSC SUBSYSTEM R&D PROPOSAL

DETECTORS FOR THE IDENTIFICATION OF ELECTRONS, PIONS, KAONS AND PROTONS

D. F. Anderson and J. G. Morfín*
Fermilab

M. Adams
University of Illinois/Chicago

Y. Onel
University of Iowa

M. S. Alam, A. Deogirikar and W. M. Gibson
State University of New York/Albany

D. Kaplan and G. Kalbfleisch
University of Oklahoma

D. Marlow
Princeton University

A. Lopez, A. Mendez and J. Palathingal
Universidad de Puerto Rico/Mayaguez

B. Hoeneisen, C. Jimenez, C. Marin and F. Pasmay
Universidad San Francisco de Quito, Ecuador

D. Errede and M. Sheaff
University of Wisconsin

P. Karchin and A. J. Slaughter
Yale University

* Contact person

I INTRODUCTION

Although the techniques which the proponents will attempt to develop through the proposed research can be applied generally to any SSC detector, the proposed Bottom Collider Detector (BCD) will be used to illustrate possible applications of the technology. The well known main goal of the BCD Experiment is the study, as opposed to simply the detection, of CP Violation in the B-System. To accomplish this, the strength of the CP-Violating component must be measured in as many different decay channels as possible. Among other physics topics that BCD will investigate, both the rate/upper-limit of rare decays and a determination of the low-x_{Bj} behavior of the gluon distribution function either require or are enhanced by detailed knowledge of the final state. For this reason, particle identification is a major aspect of the BCD program both in its Fermilab and SSC phases. Identification will be accomplished through a combination of Time-of-Flight, Transition Radiation and Ring Imaging Cerenkov techniques. Although these techniques are not new, the resolution and speed that the detectors must attain to function in a hadron collider environment are still beyond present technology. It is for this reason that we submit this SSC Sub-system R&D Proposal to request support for research directed toward expanding the technology to our required limits.

II OVERVIEW OF THE PARTICLE IDENTIFICATION SYSTEM

The particle identification system of BCD consists of a transition radiation device (TRD) for the prompt identification of electrons and an ensemble of ring imaging Cerenkov (RICH) and time-of-flight (TOF) counters for hadron identification as illustrated in Figure II-1.

In the barrel region the momentum spectra of the B decay products is quite low even at SSC energies. Figure II-2 shows the momentum distribution of the decay products from 2-body decay modes. Even the most energetic particles (from the 2-body decays) are distributed such that 90% have momentum less than 8 GeV. To cover the lower end of this range, an array of TOF counters will be installed at about 1.5m radius for hadron identification. With this lever arm and a time resolution of $\leq$ 50 picosec the TOF system will be able to distinguish π from K up to 2.5 GeV/c. At this point a RICH could take over to allow the separation of π/k/p up to 20 GeV/c. In the forward region a combination TOF and liquid plus gas RICH counters could provide π/k separation from < 1 to several hundred GeV/c which would cover over 80% of the most energetic decay products.

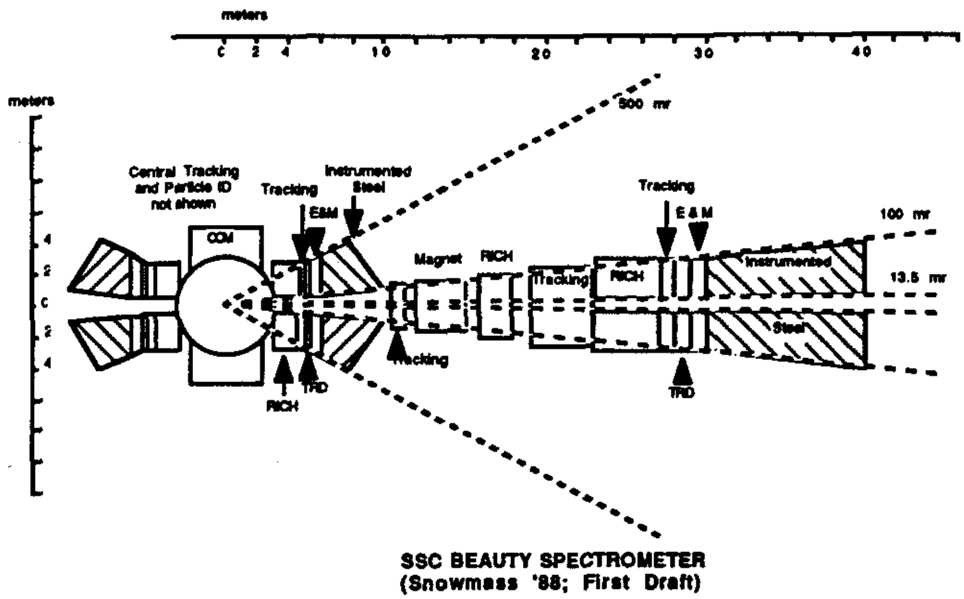


Figure II-1 Possible configuration of an SSC Beauty Collider Detector

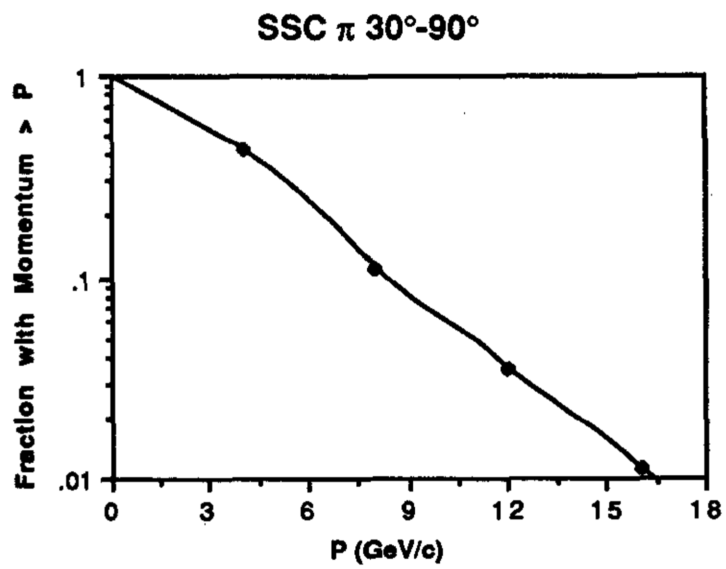


Figure II-2 Momentum spectra of π's from 2-body B decays

The same research program must cover the development of a fast, fine sampling TRD which will have a rejection factor of ≥100 for pions and an electron acceptance of >90%. In the barrel region this must be done in a total depth of 30 cm which is possible due to the low momentum range (<20 GeV) of the pions and electrons. Current ideas focus on adapting the straw tube technology, developed for the tracking part of BCD, as the TRD detectors.

III SOFTWARE DEVELOPMENT

Universidad de Puerto Rico, Mayaguez: A. Lopez, A. Mendezand J. Palathingal
Universidad de San Francisco de Quito, Ecuador: B. Hoeneisen, C. Jimenez, C. Marinn and F. Pasmay

In addition to the design, building and testing of prototype hardware systems, a significant effort will be required to develop a software package for the RICH. The main objective will be to simulate performance with sufficient accuracy to determine the effect of alternative designs on the ability of the RICH to contribute to the achievement of the physics goals of the BCD program. The simulation will consist of predicting the eventual hits on the RICH detector followed by the reconstruction of pattern recognized rings.

The initial work will utilize the GEANT package and existing BCD physics simulation programs to develop a basic simulation which can provide answers to fundamental questions in a relatively short period of time (1 year). Of particular interest is the geometry and number of readout elements. A question which must be answered is how the efficiency of detection and ability to identify particles is affected by these parameters. More sophisticated simulation will be incorporated later. At that time we will also study the possibility of using simulation techniques which may be more efficient in their use of computer time.

This work will require close collaboration with other institutions which will undertake other aspects of the RICH R&D. On the one hand, those developing the software must keep abreast of the most promising geometries, materials and detector schemes, while on the other hand, the simulation results will be helpful for the hardware development in pointing out what are the desirable detector characteristics in terms of achieving specific physics goals.

To achieve these goals at the University of Puerto Rico/Mayaguez, PR and the University of San Francisco/Quito, Ecuador, the purchase of a VAX workstation for each campus is imperative. The workstation will be dedicated entirely to BCD work and will be used not only for simulation studies of the RICH and analysis of TRD R&D, but for other aspects of the BCD effort such as analysis of data from the 1990 test run in the fixed-target beam and the 1991 C0 test run.

BUDGET

		Puerto Rico	Ecuador
I. Salaries per year			
A. Faculty	(2 @ 25% time)	16K	10K (50%)
B. Post Doc		24K	15K
C. Grad students (3)		26K	10K (2)
	TOTAL	$66K	$35K
II. Other costs			
Materials/Supplies		$2K	same
Workstation		11K	
	Software	2K	
	400 Mb disc	5.3K	
	Tape drive	8.8K	same
	Printer	1.0K	
	Terminals	2.0K	
	DECnet	2.1K	
	Tax	2.0K	
	SUM	$35K	same
Maint.		1K	3K
Travel		15K	10K
	TOTAL	$53K	$48K
Grand Total (with overhead)		$158K	$105K

IV-1 DETECTOR DEVELOPMENT: TIME-OF-FLIGHT / PRE-TRACKER SYSTEM

State University of New York at Albany: M. S. Alam, A. Deogirikar, and W. M. Gibson
University of Oklahoma: D. Kaplan and G. Kalbfleisch
Yale University: P. Karchin and A. J. Slaughter

1 INTRODUCTION

In this proposal we seek support to initiate a research and development program aimed at designing, building and testing a combined 50 to 100 picosecond resolution time-of-flight (TOF) system with tracking and preshower detection capability for use in experiments at the SSC. Of particular interest is the deployment of such a system in the Beauty Collider Detector (BCD) at the SSC.

Our initial intention is to develop and test prototypes of several different time of flight systems with the goal of making a detailed comparative evaluation for suitability at the SSC. Such systems would include those utilizing thin scintillator bars doped with a number of new and promising chemical compositions, plastic scintillating fiber (PSF) based systems, and systems based upon crystals. Several fast readout options also need to be evaluated. Our ultimate goal is to design, build, test and calibrate a fully operational large area time of flight/tracking system for the SSC.

To date, a number of U.S. groups have separately accumulated a variety of experiences with time of flight and plastic scintillating fiber (PSF) techniques. Our intention is to eventually form a U.S. collaboration of all groups interested in extending and combining these techniques for use at the SSC. With joint financial support and a sound research and development plan we intend to coordinate the multiple research efforts.

At the moment three groups can commit themselves to this approach: the University of Oklahoma group (which would be co-led by D. Kaplan and and G. Kalbfleisch), the Yale University group co-led by P. Karchin and A.J. Slaughter, and the New York group led by M.S. Alam (State University of New York at Albany). Both the New York and the Oklahoma groups have considerable experience with time of flight techniques. The New York group designed and built both the MARKII barrel and CLEOII endcap time of flight systems, while the Oklahoma group was involved in the design and construction of the FNAL E653 time of flight system. A.J. Slaughter, from Yale, has played a leading role in the physics and detector simulation for the Bottom Collider Detector (BCD) Group. This past summer, she and a summer student from Puerto Rico completed a Monte Carlo study of SSC particle identification with RICH counters as well as continuing work on tracking simulation. These efforts can naturally be extended to time-of-flight studies.

Both the Oklahoma and New York groups have considerable experience with plastic scintillating fibers as well. One member of the Oklahoma group, while at Northeastern

University, was heavily involved in the design and construction of a PSF tracking detector that has been installed in L3 at CERN to calibrate the central Time Expansion Chamber (TEC)[1]. This work represented an intermediate step in a program whose ultimate goal is the design of a PSF based microvertex detector for the SSC. On this project experience with multianode microchannel array photomultipliers and associated VLSI readout electronics was gained. He has also been involved in other PSF research, including a program to understand the causes of attenuation in fibers[2] and in collaborative PSF research[3] with the Washington University Cosmic Ray group led by M. Israel, J. Klarman and W.R. Binns, one of the pioneering groups in the PSF technique. The New York Group was involved in building prototypes for the CLEOII endcap TOF counters using 1 mm and 2 mm scintillating fibers which were then evaluated for their potential usefulness for time-of-flight.

The funds that we are requesting in this proposal are for the first phase of the work and would be used mostly to facilitate two initiatives: to allow us to develop a time-of-flight test setup at Oklahoma and update the existing setup at New York. Our initial plan is to learn how to build 50 to 100 ps resolution TOF counters using scintillating bars at both places. We plan to develop detailed Monte Carlo simulation programs to understand how the best timing resolution can be achieved. In this regard, Arvind Deogirikar, presently of Sun Microsystems, has volunteered to contribute to this effort with his considerable programming, graphics and artificial intelligence expertise. In a parallel effort, equivalent counters using PSF will be studied to investigate the relative merits of the two types of systems. On a third front, W.M. Gibson, Distinguished Service Professor of Physics at SUNYA has volunteered to investigate fast scintillator and crystal possibilities. Professor Gibson is as much a material scientist as he is a physicist. The information gained from the experimental study of these systems and from Monte Carlo simulations will fix the design of our final time-of-flight system for B physics at the SSC.

2 Time-of-Flight Technique

As is well known, the time-of-flight T of a charged particle for a flight path L is related to its velocity $\beta = v/c$ according to the equation

$$\beta = \frac{L}{c \cdot T}$$

For a relativistic particle we have

$$\beta = \frac{p}{\sqrt{p^2 + m^2}}$$

where p and m are the track momentum and mass respectively. Therefore

$$T = \frac{L}{c}\sqrt{1 + \frac{m^2}{p^2}}$$

The time difference between two particles having masses m_1 and m_2 is given by

$$T_1 - T_2 = \frac{L}{c}\left(\sqrt{1 + \frac{m_1^2}{p^2}} - \sqrt{1 + \frac{m_2^2}{p^2}}\right)$$

The time difference between pion and kaon and pion and proton for different flight paths and different momenta is shown in Table 1 below:

Table 1.

Momentum GeV/c	$\Delta te\pi$ (ns)	$\Delta t\mu\pi$ (ns)	$\Delta t\pi K$ (ns)	$\Delta t\pi p$ (ns)	ΔtKp (ns)
Time Differences for Flight Path = 1.0 meter					
0.500	0.128	0.054	1.224	3.630	2.405
1.000	0.032	0.014	0.352	1.206	0.854
1.500	0.014	0.006	0.162	0.584	0.423
2.000	0.008	0.003	0.092	0.341	0.249
2.500	0.005	0.002	0.059	0.222	0.163
3.000	0.004	0.002	0.041	0.156	0.114
Time Differences for Flight path = 1.5 meter					
0.500	0.191	0.081	1.836	5.444	3.608
1.000	0.048	0.021	0.528	1.809	1.281
1.500	0.022	0.009	0.242	0.877	0.634
2.000	0.012	0.005	0.138	0.511	0.373
2.500	0.008	0.003	0.089	0.333	0.244
3.000	0.005	0.002	0.062	0.234	0.172

One sees that for a 1 meter flight path, we get 2σ separation up to 2.0, 3.5 and 3.0 GeV/c for $\pi - K$, $\pi - p$ and $K - p$ for a timing resolution of 50 ps. A 1.5 meter flight path achieves 2σ separation in momenta up to 2.5, 4.0 and 3.5 GeV/c for the above pairs and the same timing resolution.

3 The Need For Time Of Flight at the SSC

There are several potential applications of a time-of-flight system at the SSC. We list them below:
(a) hadron identification,
(b) multiple interactions in the same bunch,
(c) multiplicity trigger,
(d) longitudinal space information,
(d) search for quarks, monopoles, etc..
We discuss these applications in the subsections that follow.

3.1 Hadron Identification

Having established that kaons and protons can be separated from pions up to momenta of the order of 2 to 3 GeV/c, we now show why this is important for the study of B meson reconstruction at the SSC. The CLEO and ARGUS collaboration have presented the first generation of results on the physics of B mesons[4]. After nearly ten years of operation, the total number of fully reconstructed B mesons produced in e^+e^- collisions is only of the order of two hundred. $B^0 - \overline{B^0}$ mixing has been observed by both collaborations[5] with the mixing parameter $r = 0.20 \pm 0.07$. With this discovery the exciting possibility of studying CP violation in the B meson systems is opened. Several methods have been proposed for doing this[6], all of which involve reconstructing (tagging) large samples of both charged and neutral B mesons due to the expected smallness of the effect. Since B mesons decay almost 100% of the time into either charmed mesons or baryons which decay predominantly into final states with kaons or protons, and since the decay sequence involves two vertices, secondary vertex reconstruction alone may not provide clean, unambiguous tags. Thus kaon and proton identification becomes essential.

The first evidence that the $b \to uW^-$ transition is non-zero has been reported by both the collaborations[7]. Direct observation of exclusive charmless final states would provide convincing corroboration for this; however, the branching fractions into specific charmless exclusive states may turn out to be of the order of 10^{-6} to 10^{-5}. Another very important area is that of B meson decays which proceed through QCD and electroweak penguin diagrams giving rise to few-body states rich in kaons. The branching fractions for these states are predicted to be of the order of 10^{-4} to 10^{-5} and are sensitive to the mass of the top quark and the number of quark-neutrino generations[8]. Reconstruction of these states in the midst of large numbers of background tracks, predominantly pions, can only be achieved with good kaon and proton identification over the whole momentum range.

Another area of physics where kaon identification is very important has to do with B_s decays which proceed primarily through a pair of $s\bar{s}$, thus mostly leading to final states with two kaons. Also bottom baryons remain to be seen convincingly; since they decay through charmed mesons and baryons, they give rise to kaon and proton rich final states.

From the short discussion above, we see there is a very rich field of B meson physics waiting to be explored. The interesting physics can only be reached with large samples of B mesons, of the order of 10^{10} B mesons. For this reason, B factories have been proposed for the SSC and elsewhere. For a variety of reasons, however, the SSC is probably the only logical place to successfully implement this study.

Now, while several of the two body decay modes of the B mesons are of interest in a B factory experiment, so far it has been found experimentally (see Figure 1) that most of the decays of B mesons involve considerably higher final state multiplicities, with the mean charge multiplicity being somewhere between five and six. Since they are so predominant, the identification and reconstruction of such decays must necessarily be of importance for future CP experiments.

The rather high mean value for the final state multiplicity has the net effect of softening the momentum spectrum of B decay products considerably. For example, in Figures 2 and 3 we show Monte Carlo histograms of the momenta of pions (kaons) resulting from the decay of B mesons produced at the SSC with track angles within the central ($30\,\text{deg} < \theta < 90\,\text{deg}$) and forward ($\theta < 30\,\text{deg}$) regions of a "B Collider Detector". It is interesting to note, for example, that in the central region about 89% of the pions have momentum less than 2 GeV. Figure 3 shows that even in the forward region almost a third of the pions have momentum less than 3 GeV. The kaon spectrum from B meson decays is only slightly harder than that of the pion.

As mentioned above, for the efficient reconstruction of events involving the decays of B mesons, good particle identification of all decay products becomes much more important than it is for the decay of, for example, charmed mesons, due to the considerably more complex double vertex structure. This will be especially true in the high multiplicity SSC environment.

The need for high quality particle identification and the softness of the expected momentum distributions underscore the importance of utilizing time of flight techniques at the SSC. Since RICH systems are generally complex and optimized for pion - kaon separation for momenta above 2 GeV/c, the time-of-flight system should be optimized for the momentum range up to 2.5 GeV/c; the range of overlap with the RICH system allowing for cross-calibration of the two systems. From Table 1, we see that for flight paths of the order of 1.0 to 1.5 meters, a 2σ $\pi - K$ separation up to momenta of 2.0 to 2.5 GeV/c is only possible with timing resolution of the order of 50 ps. Thus we have set this as our goal.

3.2 Multiple Interactions

The present design of the SSC stipulates bunch crossings separated by 16 ns. The tracking chamber system will not be able to resolve tracks from interactions in different bunches, a task which a TOF system with even very modest timing resolution can achieve. The more difficult case is that of multiple interactions in the same bunch. At SSC design luminosities we expect about 1.5 interactions per bunch crossing. The projected bunch length of 7 cm corresponds to 230 ps. Multiple interactions in the same bunch will be separated in both space and time. According to a study[9], about 47% of the tracks in double events can be separated at the 2σ level for a timing resolution of 50 ps even if they cannot be separated by the tracking device .

3.3 Multiplicity Trigger

The TOF system is the fastest system in most particle physics experiments and has always played a very important triggering role in e^+e^- collider experiments. The total cross-section is dominated by low multiplicity minimum bias QCD type events. A TOF system with good segmentation could provide fast information on charged track multiplicities which together with triggers based on transverse momentum and/or electron identification could be used for managing the high triggering rates expected at the SSC[9].

3.4 Longitudinal Spatial Information

A timing resolution of 50 ps corresponds to a spatial resolution of about 0.8 cm along the counter longitudinal direction. This information may be used to match inner detector charged tracks with outer calorimeter hits.

3.5 Search for Free Quarks

Heavy quarks may have velocities in the range that can be measured accurately by TOF systems. With dE/dx information from the tracking device this will yield identifiable non-integral charge signatures.

4 General Parameters of an SSC Time of Flight/Tracking System

In this section we discuss general notions about an SSC time of flight/tracking system. Such a system might consist of both central ("barrel") and forward ("endcap") elements. For concreteness, our discussion will apply to the time of flight requirements of a proposed SSC B factory ("Bottom Collider Detector" (BCD) experiment). Monte Carlo studies of the optimal geometry of such an experiment are currently in progress; here we assume an approximately 4π coverage.

4.1 Central Detector

For the central region we plan to construct a cylindrical detector at radius (r) $\approx$ 1.5m composed of a number of layers . One of these layers is shown schematically in Figure 4.

This would cover the range of, for example, $-45\,\text{deg} < \theta < 45\,\text{deg}$ so that the counter length would be 3 m. Designs with lengths up to 5 m have been considered to cover wider angles. Layers of elements running along z (beam direction) and at an angle could provide z as well as azimuthal (ϕ) track information to compliment the central tracking. The system would also serve as a preshower detector and might usefully be implemented as the innermost layer of an electromagnetic calorimeter.

In view of the relatively high multiplicities expected at the SSC, a transverse (ϕ) segmentation of the order of 1000 to 2000 may be necessary. At r=1.5 m a segmentation of 1000 to 2000 implies an (azimuthal) width for each "module" of mm order. This option is discussed briefly in the next section.

4.2 Forward Detectors

The current design for Bottom Collider Detector experiments at the SSC assumes a forward detector coverage for (pseudo-) rapidity range of about 1 – 4 on each side of the beam axis (+ and - θ) for each of the two detectors (forward and back). We plan a pair of disklike time of flight detectors, each with a central "beam hole" and with "strips" running in the transverse x and y direction. At a distance of 3 meters from the interaction point, this implies detectors of radius several meters.

Assuming a mean of about 6 particles per unit rapidity at the SSC implies desired segmentation of about 400 in each of the x and y directions. (6x3=18 particles for each of positive and negative angular range. We assume a mean of 10% occupancy for a reasonable detector). In at least the small θ region of this range this again implies elements of mm order width, which again suggests the use of scintillating fibers.

5 The Scintillator Bar Option

All large TOF systems have been implemented using scintillating slabs. Several large TOF systems have been built in the last decade, such as those inside the MARKII, MARKIII and CLEOII detectors. The lengths of the counters used in these systems are about 2.5 to 3.0 meters with long ($\sim$ 1.5 meter) light guides. The thickness of the scintillator is 2" in all cases. The CLEOII TOF system has achieved a timing resolution of 120 ps[10], based on prototype tests. Actual timing resolutions obtained by working systems such as MARKII and MARKIII are more of the order of 150 – 200 ps. For slab counters, the basic parameters are the length, width and thickness of the counter and the design of the light guide which couples the scintillator to the photomultiplying device.

5.1 Length of the Counter

The length of the counter is determined by the radius of the inner detector and the solid angle coverage desired. We list the polar angle coverage for various counter lengths and inner detector radii in the table below:

Polar Angle Coverage for Different Configurations

Radius (m)	length1 3.0 m	length2 4.0 m	length3 5.0 m	length4 6.0 m
1.0	$\pm18^0$	$\pm14^0$	$\pm11^0$	$\pm10^0$
1.5	$\pm27^0$	$\pm21^0$	$\pm17^0$	$\pm14^0$
2.0	$\pm34^0$	$\pm27^0$	$\pm22^0$	$\pm18^0$
2.5	$\pm40^0$	$\pm32^0$	$\pm27^0$	$\pm23^0$

We are currently preparing detailed Monte Carlo programs to determine the optimal rapidity range.

5.2 Azimuthal Segmentation and Radial Segmentation

The azimuthal segmentation is matched to multiplicities expected at the SSC. Multiplicities of up to 250 charged tracks are expected which would stipulate segmentations of the order of 5000 elements. This has to be decided by a careful Monte Carlo of the physics goals of the experiment. To achieve $\pi - K$ separation up to 2 to 3 GeV/c, we need timing resolutions of the order of 50 ps. The best timing resolution claimed for a large system is 120 ps for the CLEOII barrel counters which are 2" thick. Since the timing resolution improves with the number of direct photons reaching the PMT device, one way to improve it is by increasing the thickness of the counter. However, this approach will work only if one corrects for the travel time for the particle in the counter, which demands that we segment the counter radially. A thickness of 30 cm corresponds to 1 ns. The travel time of a particle in a 10 cm thick counter will be about 333 ps which must be corrected for.

6 The Scintillating Fiber Option

For a number of reasons, scintillating fibers present themselves as a potentially attractive option for use in an SSC time of flight system. Some of the potential advantages are:

1. Scintillating fibers offer a natural means of achieving accurate positional resolution. As such, a PSF system offers a natural complement to a large radius electromagnetic calorimeter positioned just outside the time of flight/tracking layer. Such a system can also provide, for example, transverse energy information for a trigger.

2. The intrinsically good resolution also makes the PSF technique particularly suitable to jet studies or for providing a quick "multiplicity trigger". As we have remarked above in this regard, it is interesting to note that Monte Carlo studies indicate that events of interest may tend to have relatively high multiplicities as compared to "ordinary" interactions. However, cross sections for interesting events will likely be many orders of magnitude

lower than those for minimum bias events. In the extremely high interaction rate environment of the SSC it becomes crucial to have certain selective triggers available for implementation so that the trigger rate is manageable.

3. For a highly segmented system where narrow elements of several meters length are required, scintillating fibers become easier to fabricate to size than accurately machined very thin bars. In addition, the flexibility of long fibers makes them less fragile and less susceptible to breakage than long, very thin bars.

4. Accurate timing information requires the collection of as much light as possible. With long active elements, efficient light collection depends on total internal reflection and hence on maintaining a high quality polished surfaces. For very long, very thin bars this becomes difficult, very labor intensive, and hence very expensive. With fibers we have been able to routinely achieve reflection coefficients on the order of .9999 at no additional expense since the almost perfect reflective surface is formed automatically during manufacture when the cladding layer is heat fused to the core.

5. We have been able to both manufacture and purchase scintillating fibers coated with a special extramural layer of absorber and/or reflector. This can consist, for example, of a thin layer of aluminum that is vacuum deposited onto the fibers during manufacture. (It is interesting that, in addition to preventing cross talk and providing light tighting, such a reflective layer can potentially provide an increased light output). Thus, with scintillating fibers the light tighting can be made intrinsic to the fabrication process. Hence, in a highly segmented system with a very large number of readout channels there is no need to individually light tight each of many thin bars.

6. The spread in arrival times of photons at the readout device is potentially considerably reduced with fibers as compared to bars due to the fact that all of the light is confined to be within the critical angle for total internal reflection. As an example, it has been shown in a recent Monte Carlo simulation that at at 1 meter distance from the readout device it is 3.76 ns. for a typical sized bar counter and 0.24 ns for a counter composed of scintillating fibers (see Figure 5).

7. As is well known, the nature of the physics that we are interested in exploring requires that modern collider experiments be instrumented

very densely. Almost every square cm of space must be used, either for the detectors themselves, or for the very large number of cables necessary. Detectors must thus be implemented using a minimum of space.

For a number of tracking applications it is useful to implement at least two layers of elements inclined at an angle with respect to each other (stereo). The inherent flexibility of plastic fibers makes them particularly suitable for this in detectors where space is at a premium, since they can be wrapped "flat" on the surface of a cylinder even if they must run at an angle with respect to the cylinder axis.

It is interesting that for these and other reasons, PSF has been proposed for and/or implemented in a number of tracking applications in high energy physics, including high resolution microvertex detection at the SSC. Such high resolution applications, especially in collider geometry where large area coverage is important, depend crucially on the very accurate alignment (to a few tens of microns or better) of long elements. This is difficult. A large radius time of flight/tracking detector, on the other hand, does not require such accurate alignment since the tracking resolution need only be to mm order. This sort of alignment is certainly currently achievable.

For reasons such as these, the PSF technique appears promising. However much research needs to be done to fulfill this promise. Some of these areas of necessary investigation include the following:

i) Research must be done on improving attenuation lengths. This becomes especially important in applications such as time of flight in an SSC experiment where the elements must be long and where spatial and other considerations limit the radial thickness of the detector, but where as many photons as possible must be collected.

The Oklahoma group has been involved in a program to investigate the causes of attenuation and to investigate different composition fibers to improve the attenuation lengths. (We also now know that cooling seems to improve the attenuation length). This research must be continued in collaboration with industry. New dyes must be carefully investigated.

ii) While the overall light output curve may be tighter for fibers than for bars (smaller sigma - point 6 above), it needs to be determined experimentally whether this in fact does lead to a better time of flight resolution. For this purpose we must carefully compare the resolution from scintillator bars with modules composed of fibers that are read out in common.

7 Example of a TOF System – CLEOII

We describe the CLEOII time-of-flight system as it has the latest design and will form the starting point of any further R and D studies.

The CLEOII TOF system consists of a barrel and an endcap part. The barrel part consists of 64 counters with width = 10 cm, thickness = 5cm and length = 2.7 meters with 1.3 meter long light guides at each end and viewed by Amperex XP2020 tubes which are placed in a magnetic field free region (see Figure 6). The timing resolution achieved for each counter in prototype tests is about 120 to 150 ps. This is better than those achieved by other systems of comparable length. The endcap part consists of 28 counters on each side of the barrel. Each counter is a radial sector of length about 58 cm, top width about 18 cm, bottom width 5cm and thickness 5cm. The scintillator is viewed at the narrow end at right angles by the 2" diameter Hamamatsu R2490 photomultiplier tube that is not sensitive to the magnetic field. The tube is glued directly to the scintillator which has been cut at 45^0 to provide the reflecting surfaces. The magnetic field at the tube will be 1.5 Tesla and axial (see Figure 7). The design eliminates the need for long light guides required to transmit the light out of the magnetic field. The timing resolution achieved for this varies from 150 to 200 ps from counter to counter as found by measuring every counter in a lab test setup (see Figure 8). The corresponding timing resolution for a prototype with long light guides was measured to be 450 to 500 ps.

The Hamamatsu R2490's are transmissive mesh dynode tubes with 10^6 gain in zero field and are very comparable to other fast tubes of conventional dynode design (see Figure 9). We measured about 30 tubes in a 1.5 Tesla axial magnetic field and found that the gains of the tubes decreases by about 150 – 250 relative to that at zero field (see Figure 10). Our measurements are confirmed by similar measurements at HERA (see Figure 11). We also found no decrease in the timing resolution at 1.5 Tesla. Further, we found the tube to behave about the same or better for axial alignments up to 25^0 away from the direction parallel to the field.

For the 5 cm thick counters, we get output pulses of average peak height 5 to 10 volts at 0 field and 20 to 50 mV at 1.5 Tesla. For triggering purposes, it was necessary to design fast preamplifiers with gain of 75, band width of 40 to 800 MHz, rms noise of $\pm 5\mu V$ and saturating at output pulse heights above 3 volts. These were designed at Cornell University.

8 TOF Readout at the SSC

The BCD detector design calls for magnetic fields of the order of 1.0 to 1.5 Tesla transverse to the direction of the beam. We would like to avoid long light guides to put the photomultiplier outside the region of the magnetic field, since the corresponding attenuation of light causes decrease of the timing resolution. Instead we propose to read both ends of each layer with the new transmissive mesh dynode Hamamatsu R2490 which is relatively insensitive to an axial magnetic field. The properties of this PMT have been discussed in the earlier section describing the CLEOII endcap TOF system. Hamamatsu is planning to produce a 64-anode version of this tube which would match our preferred segmentation. We would have to put right-angle prisms at the end of the barrel counters so that the PMT's when glued to the ends appear axial with respect to magnetic field.

The output from the photomultipliers are used to trigger discriminators which mark the time of arrival of the signal. Since the output pulses vary both in height and risetime, there is a contribution to the timing resolution due to this. The conventional approach has been to use leading edge discriminators and to record the output pulse charge and to correct for the contribution to the timing resolution due to varying pulse charge offline. We would like to explore if this can be improved by using constant fraction, risetime compensated and multiple threshold triggering discriminators.

The signal from the discriminator is used to stop a time-to-digital converter (TDC). The start signal is obtained from the bunch crossing. To the present TDC's with least count of 50 ps have been adequate. Our SSC aim is to measure timing resolutions of the order of 50 ps. Thus, we have to design TDC's with least count of 10 to 20 ps.

9 Program of Hardware Research and Development

We intend to carry out an intensive program of research and development. A detail study of all possible hardware options will be undertaken. As our first effort, at Albany we will concentrate on a system based on scintillator bars while at Oklahoma we will concentrate on scintillating fiber based systems.

9.1 Scintillating Material

Scintillating materials are characterized by four parameters, the total emission of light and its frequency spectrum in response to a charged particle, the risetime and decay width of the output light pulse, the attenuation length of the light and finally the resistance to crazing with time. There are three major suppliers of scintillating plastic, Bicron in U.S.A., Nuclear Enterprise in England and Kyowa Gas Chemical Co. Ltd. in Japan. The parameters for two of the fast plastics are listed in the table below:

Comparison of Fast Scintillators

Brand Name	Light Output % Anthracene	Rise Time (ns)	Decay Width (ns)	Attenuation Length meter
BICRON408	60	1.0	~ 2.5	3 - 4
BICRON418	67	0.5	~ 2.5	1

The timing resolution depends on the amount of light arriving in the first or second nanosecond. The probability of emission of a photon from a scintillator may be expressed to a first approximation as

$$P(t) = \frac{1}{\tau} e^{-t/\tau}$$

where τ is the decay width. For long counters, as will be necessary at the SSC, the attenuation length will be important. We intend to work with the manufacturers to explore faster scintillators with long attenuation lengths.

9.2 Photomultiplier Devices

We need to consider the different options for photomultiplier devices such as (a) conventional PMT's, (b) microchannel plate multipliers, (c) Hamamatsu R2490 PMT's which are not sensitive to the magnetic field, (d) multianode version of R2490 PMT's, (e) solid state photocathode and (f) fast avalanche photodiodes.

9.3 Fast Preamplifiers

For designs which call for placing the PMT's inside the magnetic field, we need fast preamplifiers to make up for the gain decrease inside the magnetic field. We need to design cheap, broad band (40 to 1 GHz), high gain (100 to 200), low noise (5 to 10 μV) and wide output range (3 to 5 volts).

9.4 Signal Triggering

The most tricky and time-consuming part of the time-of-flight system is correcting for the time-walk due to variations in risetime and pulse charge. Conventionally, one triggers at some optimum threshold above the noise using a leading edge discriminator and records the pulse charge using an ADC; the time-walk is then taken out offline. We would like to explore corrections using the pulse peak to correct for the time-walk. We intend to carry out a careful study at the Monte Carlo and hardware level to understand this correction. Studies with different kinds of discriminators are also planned such as with (a) leading edge discriminators, (b) risetime compensated discriminators, (c) constant fraction discriminators and (d) multiple threshold discriminators.

10 Monte Carlo Studies

We plan to perform Monte Carlo studies using ISAJET and the detector program GEANT to optimize the TOF system geometry and parameters with respect to the physics goal. We also plan to develop a complete TOF system Monte Carlo for all the processes involved in determining the time resolution such as (a) ionization loss inside the scintillator material with proper Landau distribution, (b) time and photon spectrum of the emitted light, (c) propagation of light inside the slab or fiber, (d) light guide, (e) transit time difference and transit time jitter for the PMT and (f) the triggering used in the discriminator.

11 Schedule and Landmarks

Physics Monte Carlo Studies	Month 1 to 3
Device Monte Carlo Studies	Month 1 to 3
First Bar and Fiber Prototype Fabrication	Month 3 to 4
Timing Studies with the Prototype and R2490	Month 4 to 6
Design System with Segmented PMT	Month 4 to 6
Construct System with Segmented PMT	Month 6 to 8
Timing Studies with Above System	Month 8 to 10
Proposal for System Design	Month 10 to 12

References

[1] A. Grimes, et. al., "Calibration of a Central Time Expansion Chamber and Applications of Plastic Scintillating Fibers to Tracking Problems in High Energy

Physics", Northeastern University Preprint No. 2953, in preparation, to be submitted to Nucl. Insts. Meths. (1989); H. Akbari, et. al., "Multi-Anode Readout of Scintillating Fibers for L3 Vertex Chamber Calibration", proceedings of Scintillating Fiber Workshop at Fermilab, Nov. 1988; see also The L3 Collaboration, Technical Description of L3 Experiment (title approximate) to be submitted to Nucl. Insts. Meths. (1989).

[2] See references 3. and also A. Grimes, et. al. "Some Aspects of the Theory of Plastic Based Scintillating Fibers", Northeastern University preprint No. 2943, March, 1988.

[3] A.J. Davis, et. al., "Scintillating Optical Fiber Trajectory Detectors", Nucl. Insts. Meths. A276, 347 (1989), D.H. Kaplan, et. al.,"Attenuation Effects and Temperature Dependence in Plastic Scintillating Fibers", Proceedings of the Scintillating Fiber Workshop at Fermilab, Nov. 1988, A.J. Davis, et. al., "Attenuation and Effective Efficiency in Small Fiber Waveguides", Proceedings of the Scintillating Fiber Workshop at Fermilab, Nov. 1988, D.H. Kaplan, et. al.,"The Effect of Cooling on the Light Yield of Polystyrene Based Fibers", in preparation, to be submitted to Nucl. Insts. Meths. (1989)

[4] "B meson Decay", B. Gittelman and S. Stone, High Energy Electron-Positron Physics, World Scientific,1988, page 275.

[5] (ARGUS Collab.) H. Albrecht et al., Phys. Lett., 192B, 245 (1987) (CLEO Collab.) R. Fulton et al., CBX 88-13, submitted to the International conference in High Energy Physics, Munich (August, 1988).

[6] " Report of the B-Factory Group: I. Physics and Techniques", G. Feldman et al., Contributed to the DPF Summer Study: Snowmass '88.

[7] (CLEO Collab.) S. Behrends et al., Phys. REv. Lett. 59, 407 (1987).

[8] "Loop Induced Rare B Decays", G. Hou and A. Soni, University of Pittsburgh preprint PITT-87-05.

[9] "Study of Scintillating Fibers for a High Resolution Time of Flight System at the SSC", M. Kuhlen, CALT-68-1547, Presented at the International Industrial Symposium on the Super Collider, New Orleans, Feb., 1989.

[10] R. Giles et al., Harvard University Preprint, 1985

Figure Captions

Figure 1: Modes and branching fractions of B mesons. (From R. Cass, Proceedings of the XXIVth Recontre de Moriond, Les Arcs-Savoie, France (1989).

Figure 2: Monte Carlo (Isajet) histogram of the momentum distribution for pions from the decays of B mesons produced at the SSC with polar angle theta between 30 and 90 degrees (central region). The distribution is summed over currently known decay modes according to currently known branching fractions.

Figure 3: Monte Carlo (Isajet) histogram of the momentum distribution

for pions from the decays of B mesons produced at the SSC with polar angle theta between 0 and 30 degrees (forward region). The distribution is summed over currently known decay modes using currently known branching fractions. Provided by L. Roberts.

Figure 4: View of barrel time of flight system for central region. Figure is schematic only and not to scale. Each detector module is shown in the inset as segmented both radially and transversely. Each segment would consist either of a scintillating "bar" or of a number of scintillating fibers read out in common.

Figure 5: Time Spectrum of photons from 2 cm thick scintillator bar and scintillator fiber counters at a distance of 1 meter from light source(Kuhlen).

Figure 6: Design of the CLEOII barrel TOF counter.

Figure 7: Design of the CLEOII endcap TOF counter.

Figure 8: Measurement of timing resolution of CLEOII endcap TOF counters.

Figure 9: Spec sheet on Hamamatsu R2490 PMT properties.

Figure 10: Change in gain of R2490 PMT's in 1.5 Tesla relative to that in 0 field.

Figure 11: Measurement of the effect of varying magnetic fields on the gain of the Hamamatsu R2490 PMT as done at HERA.

12 Personnel

12.1 University of Oklahoma Personnel

The Oklahoma high energy physics group consists of four faculty members, 2 postdoctoral fellows and 5 Ph.D. students

12.2 SUNYA Personnel

At Albany, the particle physics group consists of two faculty members, two postdoctoral (one to be hired) staff members, six graduate students and one technical staff member. Our second postdoctoral staff member has just left the group to take another job. We are in the process of advertizing his position. Mr. Zoeller and Mr. Wang are advanced graduate students already working on their Ph.D. thesis. They both have played a major role in building the CLEOII endcap TOF system. Jing Su is starting the testing of an advanced version of the CLEOII barrel TOF counters and this will be the topic for her Masters thesis.

13 BUDGET

13.1 Yale University Budget

The Yale Group will continue simulation studies using existing funds from the HEP division of the DOE. No further funds are requested in this proposal.

13.2 University of Oklahoma Budget

Proposal to Dept. of Energy Oct. 1989

O.U. Principal Investigator: David H. Kaplan, Assistant Professor of Physics
soc. sec. no. 065-44-9646

Other O.U. faculty on proposal: George R. Kalbfleisch, Professor of Physics
(co-principal investigator)

Oklahoma budget - tentative: (April 1, 1990 - March 31, 1991)

Equipment:

IBM PC 386 with 40 Megabyte hard disk drive + "mouse" + modem	-----$3.5K
CAMAC bin	-----$2.5K
NIM bin	-----$3K
CAMAC to PC interface (Kinetics Corp. 3922 crate controller + 2926 interface card)	-----$2.5K
PC-Camac Driver Software	-----$0.25K
25 ps resolution TDC	-----$2.5K
Peak Sensing ADC (LeCroy 2259)	-----$3K
ADC/TDC Calibration Module (Phillips Scientific 7120)	-----$2.5K
NIM Discriminators:	
Constant Fraction (Phillips Scientific 714)	-----$2.2K
Rise Time Compensated (Phillips Scien. 730)	-----$1.5K
Fast Logic Coincidence mods (4 modules, LeCroy)	-----$4K
Digital Scaler	_____$1.5K
HV power supplies (Lecroy HV 4032 A/M mainframe	-----$4.3K
4 channel pods HV4032a1n (2)	-----$1.29K
HV to Camac Interface (LeCroy 2132)	-----$1.24K
Scintillators and scintillating fiber ribbons	-----$5K
Fast photomultiplier tubes (Hamamatsu R2490) (4)	-----$6K
PMT preamps (Fast, broad.band, 50-200 gain, high output saturation. Phillips Scien. 6954) (10)	-----$3K
Fast Multianode PMT (under development by Hamamatsu Photonics, Inc.)	-----$15K
Scintillators (bars)	-----$5K
Scintillating Fiber Ribbons	-----$5K
Fiber Polishing Equipment	-----$1K

TOTAL EQUIPMENT	$75.78K

Personnel: 1 graduate student 50% time for 12 months @12K/yr -----$12K

1 undergraduate research assist. 25% time 12 months -----$5K

Travel: 10 trips per yr @$0.6K (five trips to Albany and five to Fermilab (Chicago) -----$6K

Total Direct Cost Personnel and Travel	$23K
Indirect Cost (45% of direct cost Personnel+Travel above)	$10.35K
TOTAL EQUIP., PERSONNEL, TRAVEL:	$109.13K

13.3 SUNYA Budget

At Albany, we have a test setup for measuring the absolute resolution of time-of-flight counters. It is based on the LeCroy3500 Data Acquisition system, which uses the Intel8085 8-bit microprocessor and $8\frac{1}{2}$ floppy drives. The system has limited memory and can record data only at a few kilohertz. Further, the available software is very limited. In fact, the system is a major bottleneck in our setup. We would like to update to a PC-based system but also desire portability so that we can carry the setup to different accelerator laboratories for testing purposes.

An important part of our study would be to examine how the risetime of the output pulses from the photomultiplying devices relate to the timing resolution. This can be done very conveniently with fast digital scopes with the ability to record transient wave forms. This will allow us to tune our Monte Carlo simulations to actual data.

We need to set up a small plastic polishing shop with an oven for forming light guides.

The details of the equipment budget we request are presented below:

Proposal to Dept. of Energy Oct. 1989

SUNYA Principal Investigator: M.S. Alam, Associate Professor of Physics
soc. sec. no. 305-66-5290

Co-PI's on the proposal: Dr. W.M. Gibson,
Distinguished Service Professor of Physics

(co-principal investigator)
Dr. Arvind Deogirikar),
Manager (Networking), Sun Microsystems
(co-principal investigator)

SUNYA budget - tentative: (April 1, 1990 - March 31, 1991)

Equipment

A. Data Acquisition

1. Laptop PC-386 system with VGA, $5\frac{1}{4}$ and $3\frac{1}{2}$ disk drives, 40 MB Hard disk drive, Mouse, Modem	$ 3500
2. PC-to-CAMAC Interface. Kinetics Corp. 3922 Crate Controller and 2926 IBM PC Interface Card	$ 2500
4. PC CAMAC driver software	$250
Total	$ 6250

B. CAMAC Instrumentation

1. LeCroy 8013A Benchtop 13 slot CAMAC Power Bin	$ 2450
2. TDC with 25 picosecond least count (Modified LeCroy 2228A)	$ 2450
3. Peak Sensing ADC. LeCroy 2259B	$2945
4. ADC/TDC Calibration Module. Phillips Scientific 7120	$2250
Total	$ 10095

C. NIM Instrumentation

1. High Power NIM bin and power supply. LeCroy 1403	$ 2830
2. Quad two-fold logic unit. LeCroy 622	$ 995
3. Triple 4-fold logic unit. LeCroy 465	$1195
4. Two-channel four-fold logic majority unit. LeCroy 365AL	$1045
5. Digital Readout Visual Scaler (BNC)	$1500
Total	$7565

D. Special Timing Instrumentation

1. Constant Fraction Discriminator. Phillip Scientific 714	$2150
2. Amplitude and Risetime Compensated Discriminator. Phillips Scientific 730	$1475
3. NIM pocket pulser	$65
4. Fast broad band (DC – 800 MHz) 50 – 200 gain, low noise, high output saturation preamplifiers for PMT output pulses. Phillips Scientific 6954	$ 3000
Total	$ 6690

E. Photomultiplier Devices

1. Magnetic field insensitive photomultipliers. Hamamatsu R2490 x 4 tubes	$ 6000
2. Segmented anode versions of the above to be developed in collaboration with Hamamatsu	$10000
3. 3.3 KV high voltage mainframe. LeCroy HV4032A/M	$ 4295
4. HV4032A1N 4-channel pods x 2	$1290
5. HV to CAMAC interface. LeCroy 2132	$1240
Total	$ 22825

F. Scintillator Materials

1. 5 x 10 x 300 cm^3. BICRON408	$ 1500

2. 5 x 5 x 300 cm^3 x 2 BICRON408	$ 1500
3. 5 x 5 x 100 cm^3 x 2 BICRON418	$ 700
4. 5 x 10 x 400 cm^3 BICRON408	$ 2000
Total	$ 5700
G. Scintillating fibers	
1. 5 x 10 x 400 cm^3 bundle from 1mm diameter fibers	$ 2500
2. 5 x 10 x 400 cm^3 bundle from 2mm diameter fibers	$ 2500
Total	$ 5000
H. Plastic Shop	
1. Buffing wheel	$ 500
2. Forming Oven	$ 500
Total	$ 1000
J. Miscellaneous	
1. Cables, connectors, glues, wrapping paper, etc.	$2500
K. Oscilloscope	
1. LeCroy9450 Fast waveform digitizing scope	$ 18900
EQUIPMENT TOTAL	$ 86525

Travel

A. Travel to Collaborators	
1. 6 trips x $ 500 each	$ 3000
B. Travel for In - Beam Tests	
1. 2 trips x $ 1000 each	$ 2000
C. Instrumentation Conferences	
1. 1 x $ 1000 each	$ 1000
TRAVEL TOTAL	$ 6000

Salaries

Graduate Students	
1. 2 Full time students x $ 11500 each	$23000
2. 1 Summer student	$ 5000
Total	$ 28000
TOTAL DIRECT COSTS	
Equipment + Travel + Salaries	$ 120525
TOTAL INDIRECT COSTS	
(Travel + Salaries)$\times$ .521	$ 17714
TOTAL BUDGET	$ 138239

Table III-B Branching Ratios (%)

Mode	CLEO 1987	CLEO 1985[37]†	ARGUS[37]†	Bauer, et al. Model[2]
$B^- \to D^0\pi^-$	$0.30 \pm 0.06 \pm 0.04$	$0.54 \pm 0.17 \pm 0.11$	$0.21 \pm 0.11 \pm 0.07$	$0.48(a_1 + 0.73a_2)^2$
$B^- \to D^{*+}\pi^-\pi^-$	< 0.4	$0.23 \pm 0.15 \pm 0.07$	$0.7 \pm 0.3 \pm 0.4$	
$B^- \to \psi K^-$	$0.08 \pm 0.02 \pm 0.02$	$0.10 \pm 0.07 \pm 0.2$	0.08 ± 0.04	$1.01a_2^2$
$B^- \to \psi K^{*-}$	$0.13 \pm 0.09 \pm 0.03$			$4.33a_2^2$
$B^- \to \psi K^-\pi^+\pi^-$	$0.12 \pm 0.06 \pm 0.03$		0.12 ± 0.08	
$B^- \to \psi' K^-$	< 0.05		0.24 ± 0.19	
$B^- \to \psi' K^{*-}$	< 0.35			
$B^- \to D^0 D_s^-$	3.7 ± 1.9			$0.73a_1^2$
$\bar{B}^0 \to D^+\pi^-$	$0.27 \pm 0.08 \pm 0.05$	$0.51 \pm 0.27 \pm 0.14$	$0.28 \pm 0.12 \pm 0.09$	$0.48a_1^2$
$\bar{B}^0 \to D^{*+}\pi^-$	$0.33 \pm 0.09 \pm 0.06$	$0.27 \pm 0.13 \pm 0.08$	$0.32 \pm 0.16 \pm 0.12$	$0.37a_1^2$
$\bar{B}^0 \to D^{*+}\rho^-$	$1.9 \pm 0.9 \pm 1.3$			$1.18a_1^2$
$\bar{B}^0 \to D^{*+}\pi^-\pi^+\pi^-$	$1.5 \pm 0.4 \pm 1.0$	< 4.0	$3.9 \pm 1.1 \pm 1.8$	
$\bar{B}^0 \to D^{*+}a_1^-$	$1.8 \pm 0.5 \pm 1.2$			$1.63a_1^2$
$\bar{B}^0 \to \psi \bar{K}^0$	$0.06 \pm 0.03 \pm 0.02$			$1.02a_2^2$
$\bar{B}^0 \to \psi \bar{K}^{*0}$	$0.11 \pm 0.05 \pm 0.03$	$0.35 \pm 0.16 \pm 0.03$	0.30 ± 0.16	$4.36a_2^2$
$\bar{B}^0 \to \psi K^-\pi^+$	$0.10 \pm 0.04 \pm 0.03$			
$\bar{B}^0 \to \psi' \bar{K}^0$	< 0.15			
$\bar{B}^0 \to \psi' \bar{K}^{*0}$	$0.14 \pm 0.08 \pm 0.04$			
$\bar{B}^0 \to D^+ D_s^-$	2.1 ± 1.1			$0.67a_1^2$
$\bar{B}^0 \to D^{*+} D_s^-$	3.2 ± 1.7			$0.30a_1^2$

†The ARGUS and previous CLEO results have been renormalized for equal charged and neutral B production on the $\Upsilon(4S)$.

Figure 1

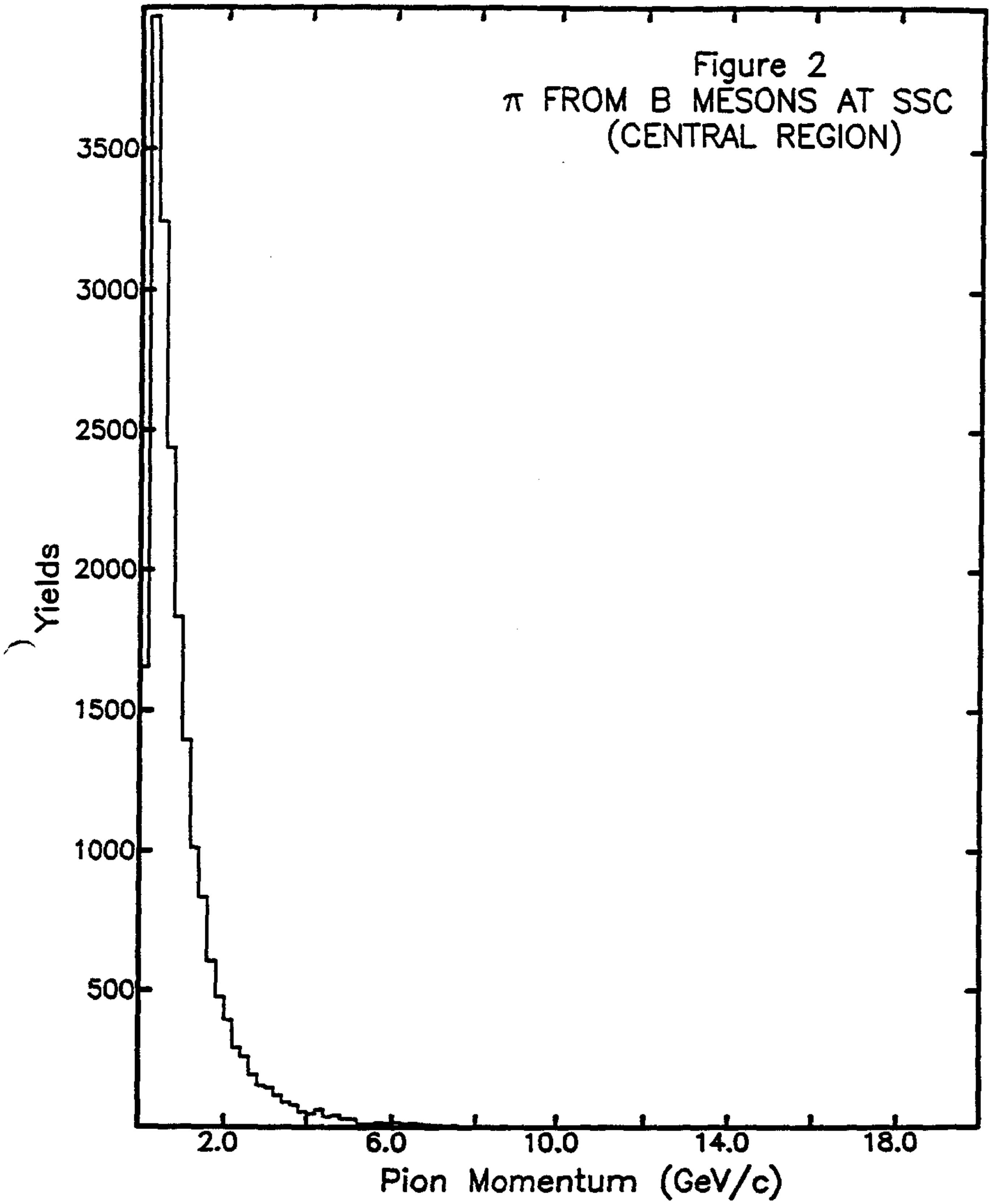


Figure 2
π FROM B MESONS AT SSC
(CENTRAL REGION)
Yields
3500
3000
2500
2000
1500
1000
500
2.0
6.0
10.0
14.0
18.0
Pion Momentum (GeV/c)

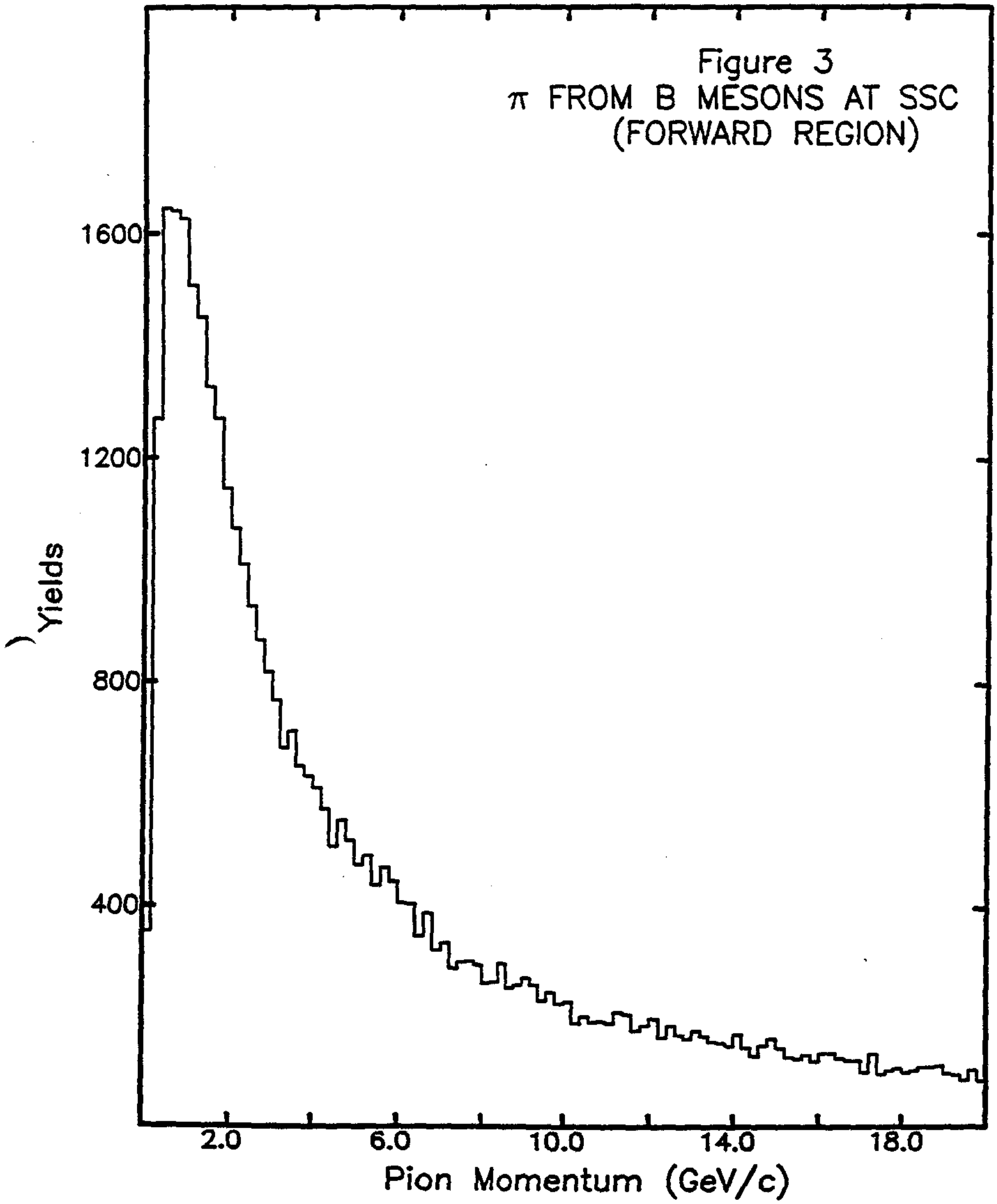
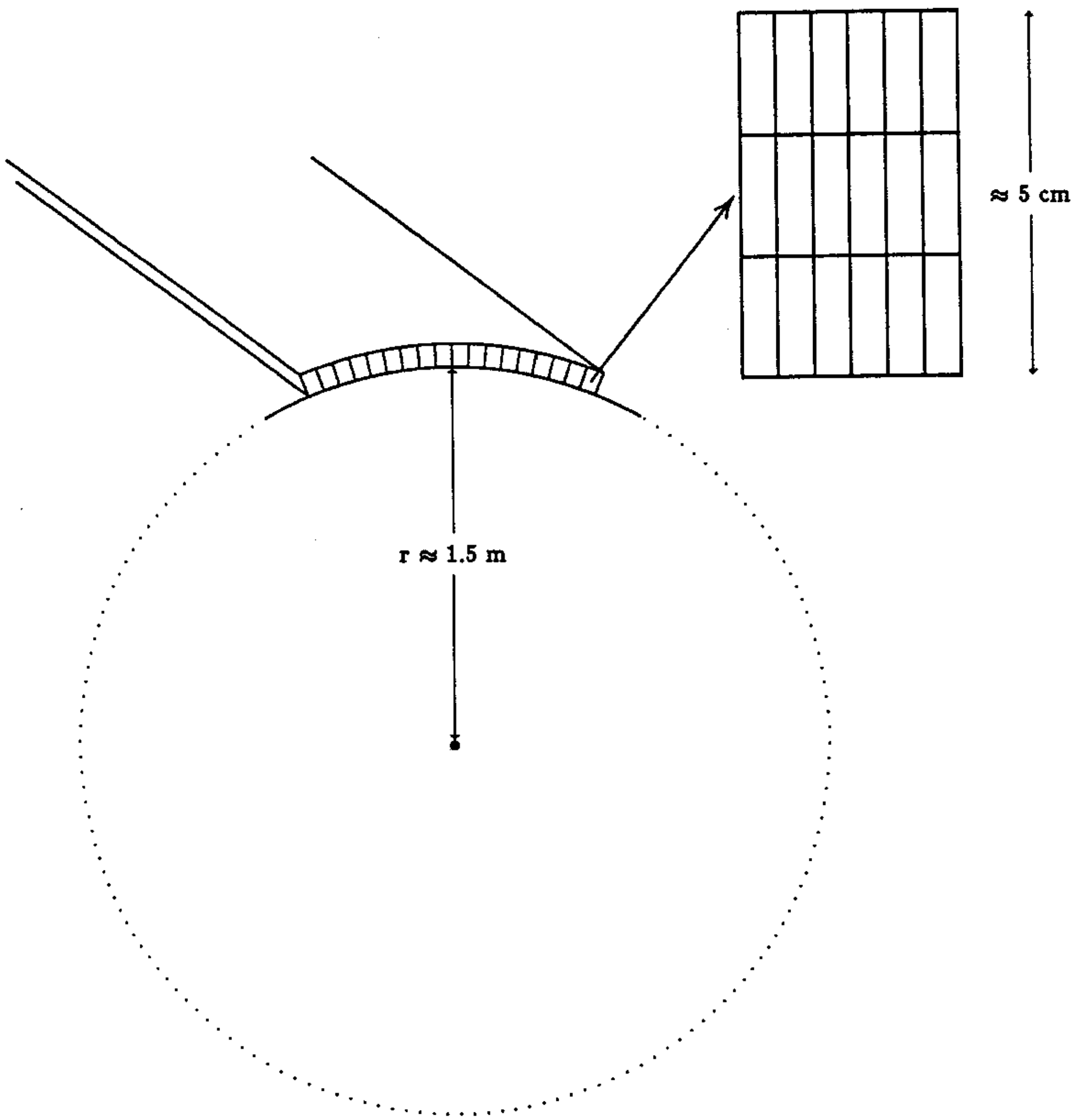
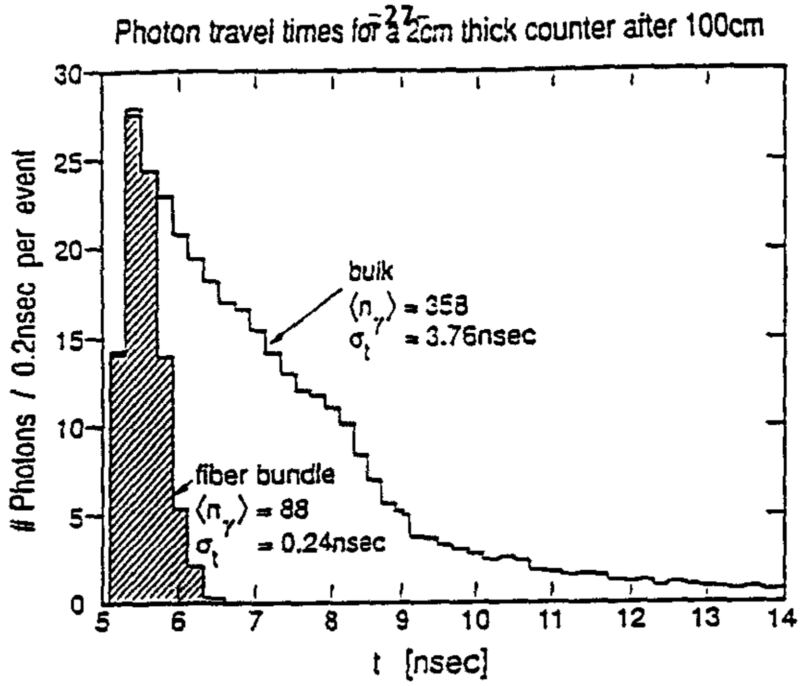


Figure 3
π FROM B MESONS AT SSC
(FORWARD REGION)
1600
1200
800
400
Yields
2.0
6.0
10.0
14.0
18.0
Pion Momentum (GeV/c)

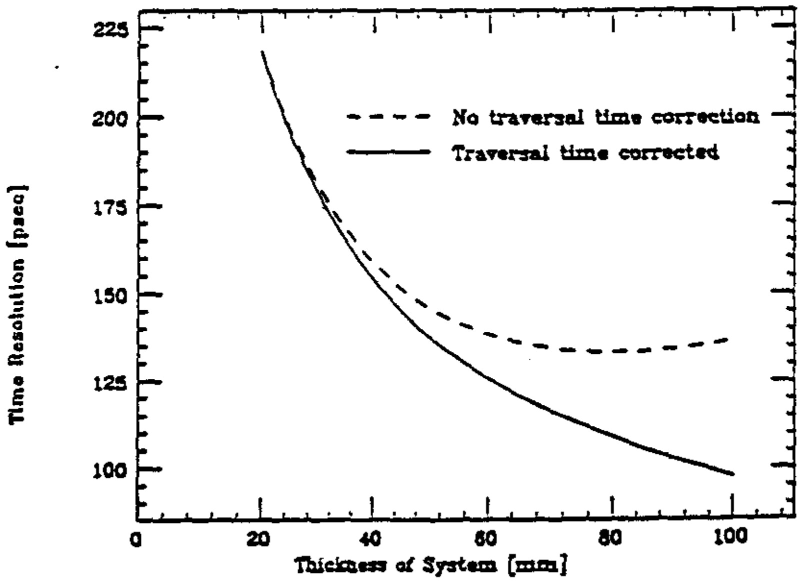


SSC TOF SYSTEM

Figure 4



Photon travel times in scintillating fibers and bulk scintillators



Time resolution with and without radial segmentation.

Figure 5

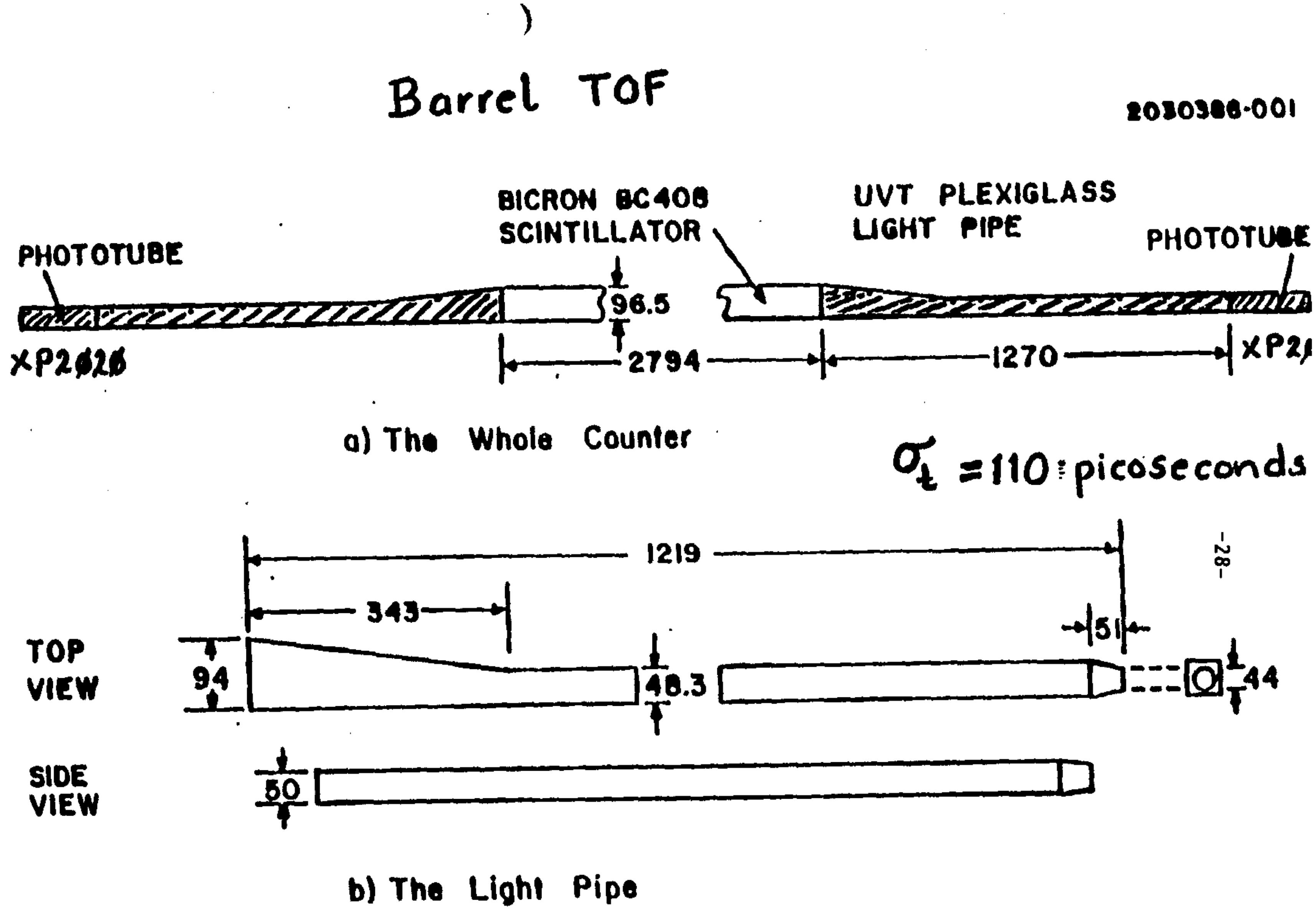

Barrel TOF
2030388-001
PHOTOTUBE
XP2020
BICRON BC408
SCINTILLATOR
UVT PLEXIGLASS
LIGHT PIPE
PHOTOTUBE
XP2
96.5
2794
1270
a) The Whole Counter
σt = 110 picoseconds
1219
343
51
TOP
VIEW
94
48.3
44
SIDE
VIEW
50
b) The Light Pipe

Figure 6

Figure 7 ECTOF Side-View Inside CLEO II

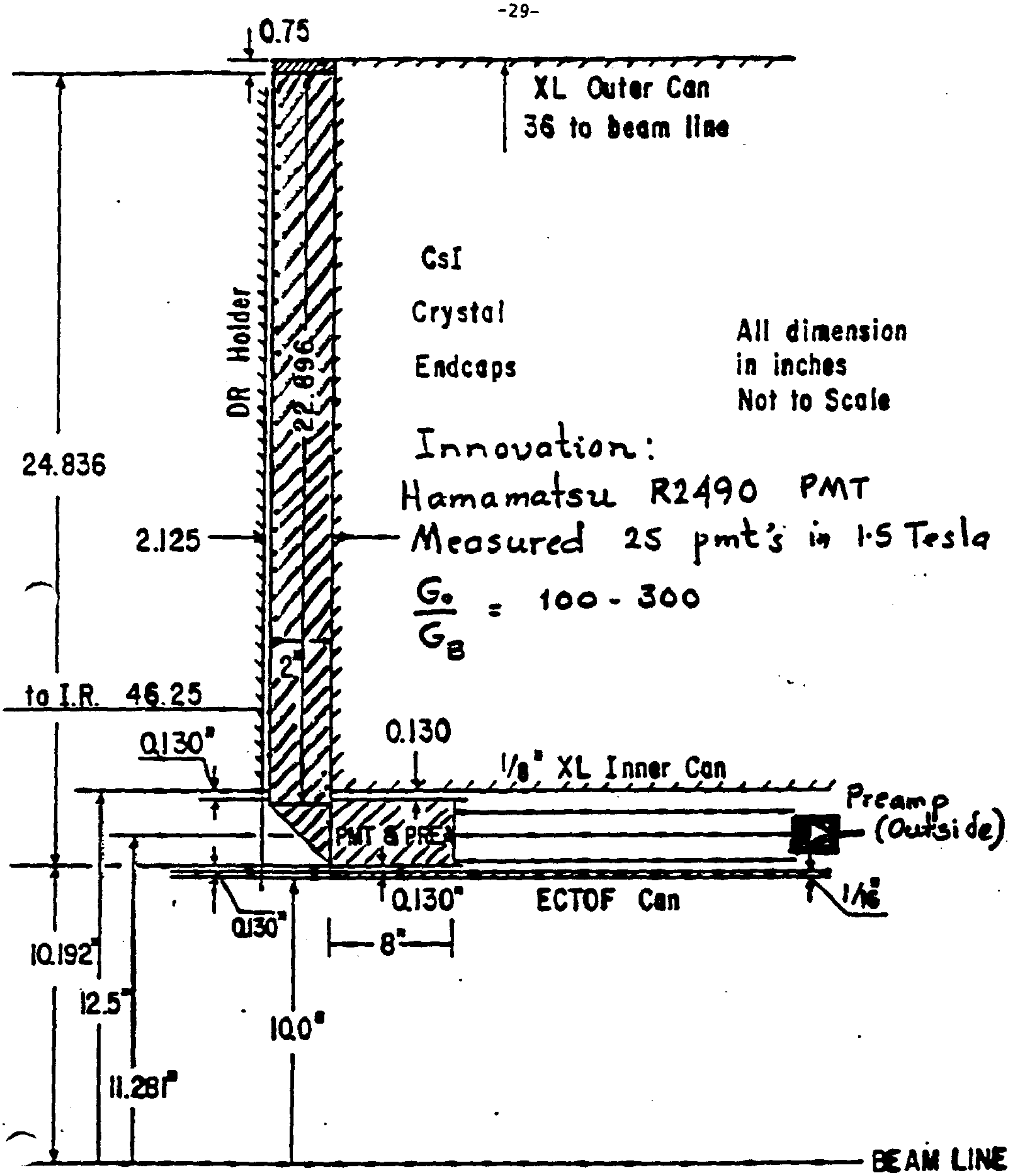


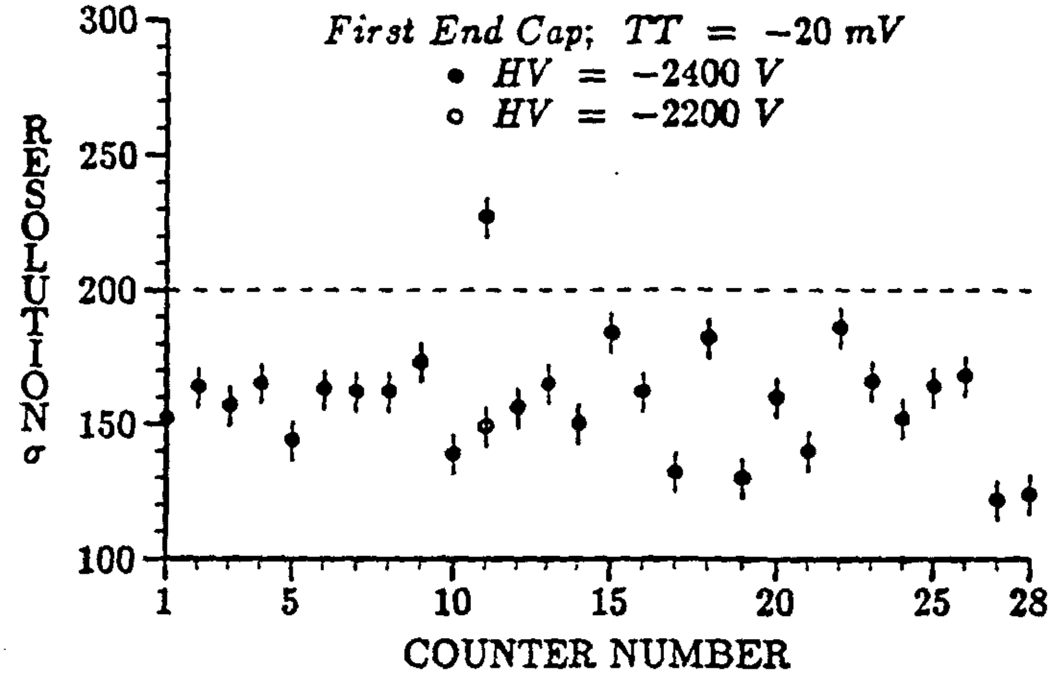
Figure 5

FINAL TEST FOR END CAP TOF COUNTERS

High Energy Group

SUNY at Albany

Preamp Gain = 75



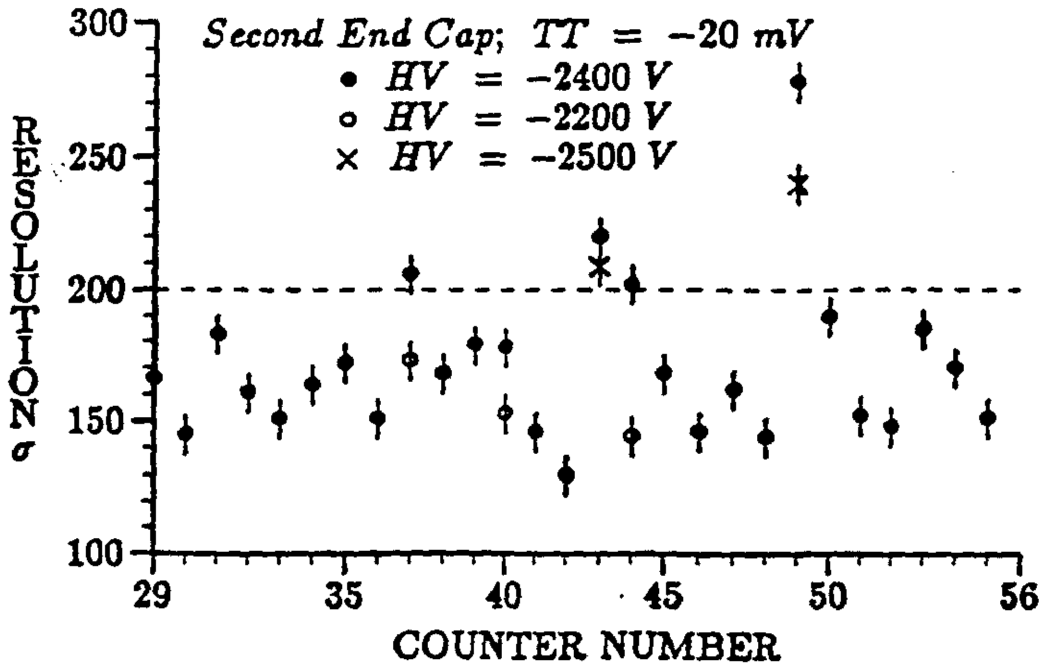


Figure 2: Typical Gain vs. Supply Voltage (at 0 gauss)

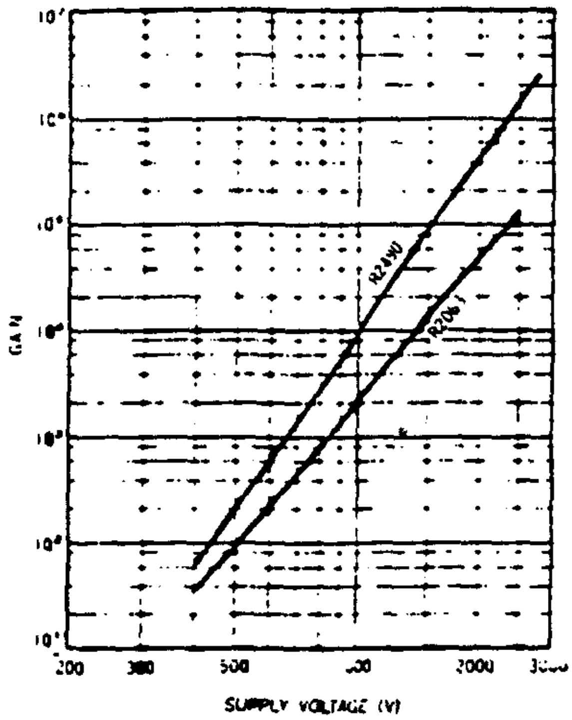


Figure 3: Typical Gain and Dark Current in Magnetic Field (Parallel to Tube Axis)

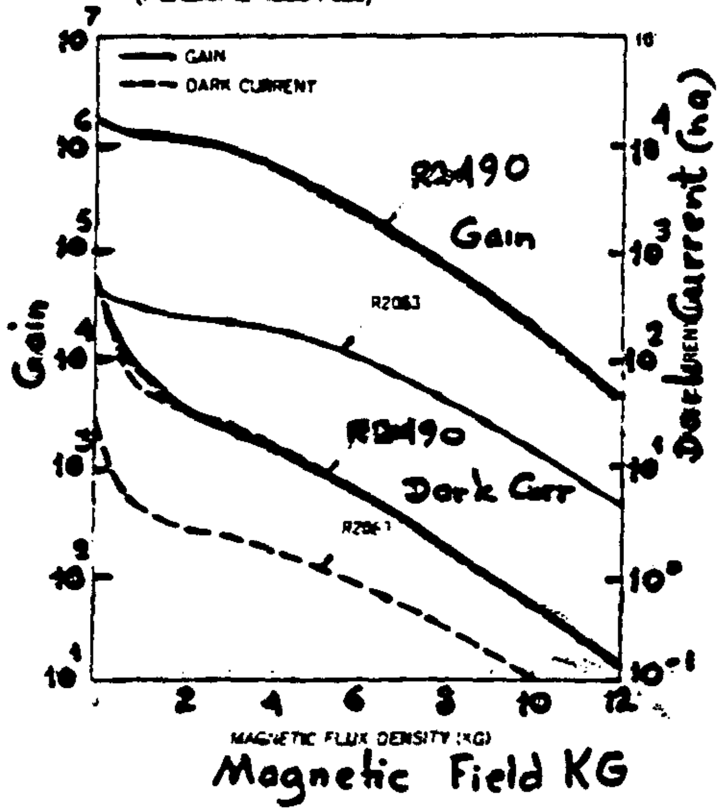


Figure 4: Typical Gain vs. Magnetic Flux Direction

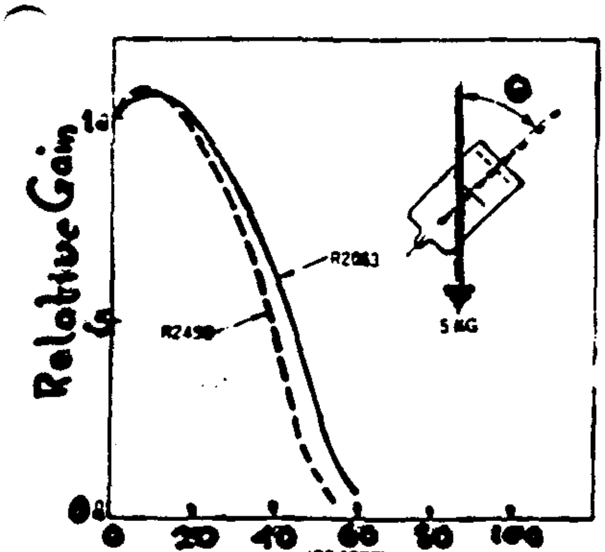


Figure 5: Typical Time Response vs. Magnetic Flux Density

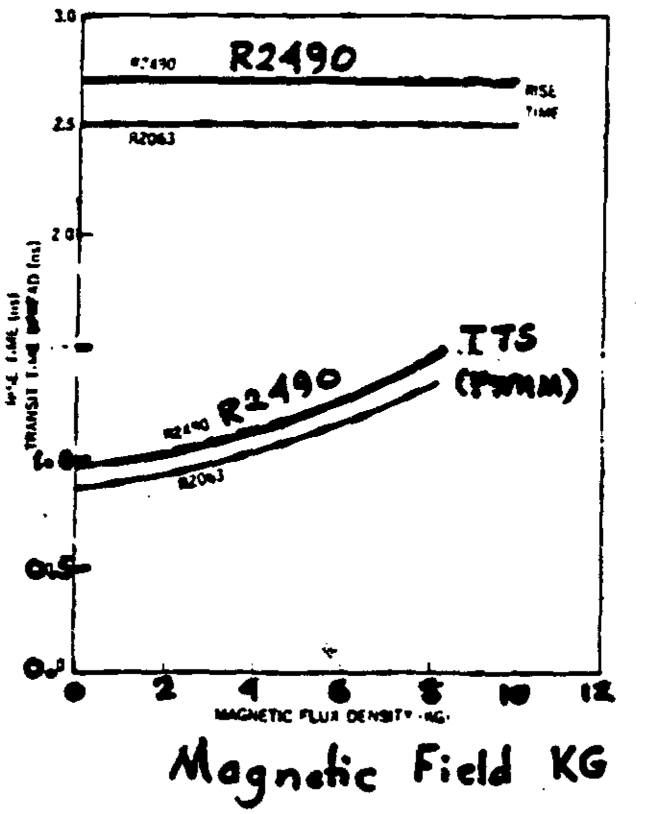


Figure 9

FINAL TEST FOR END CAP TOF COUNTERS

High Energy Group

SUNY at Albany

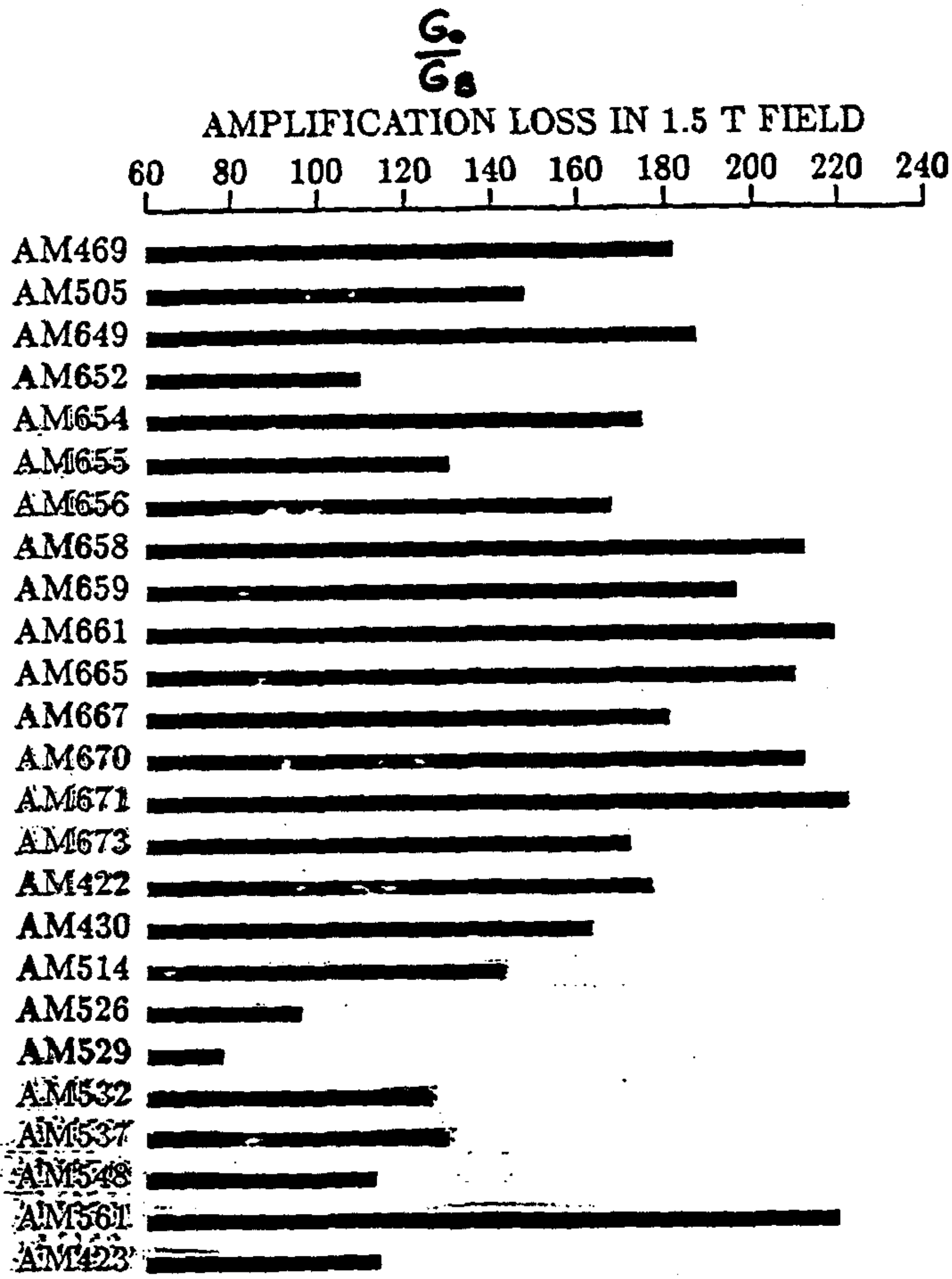


Figure 10

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HERA Results:

Figure 11

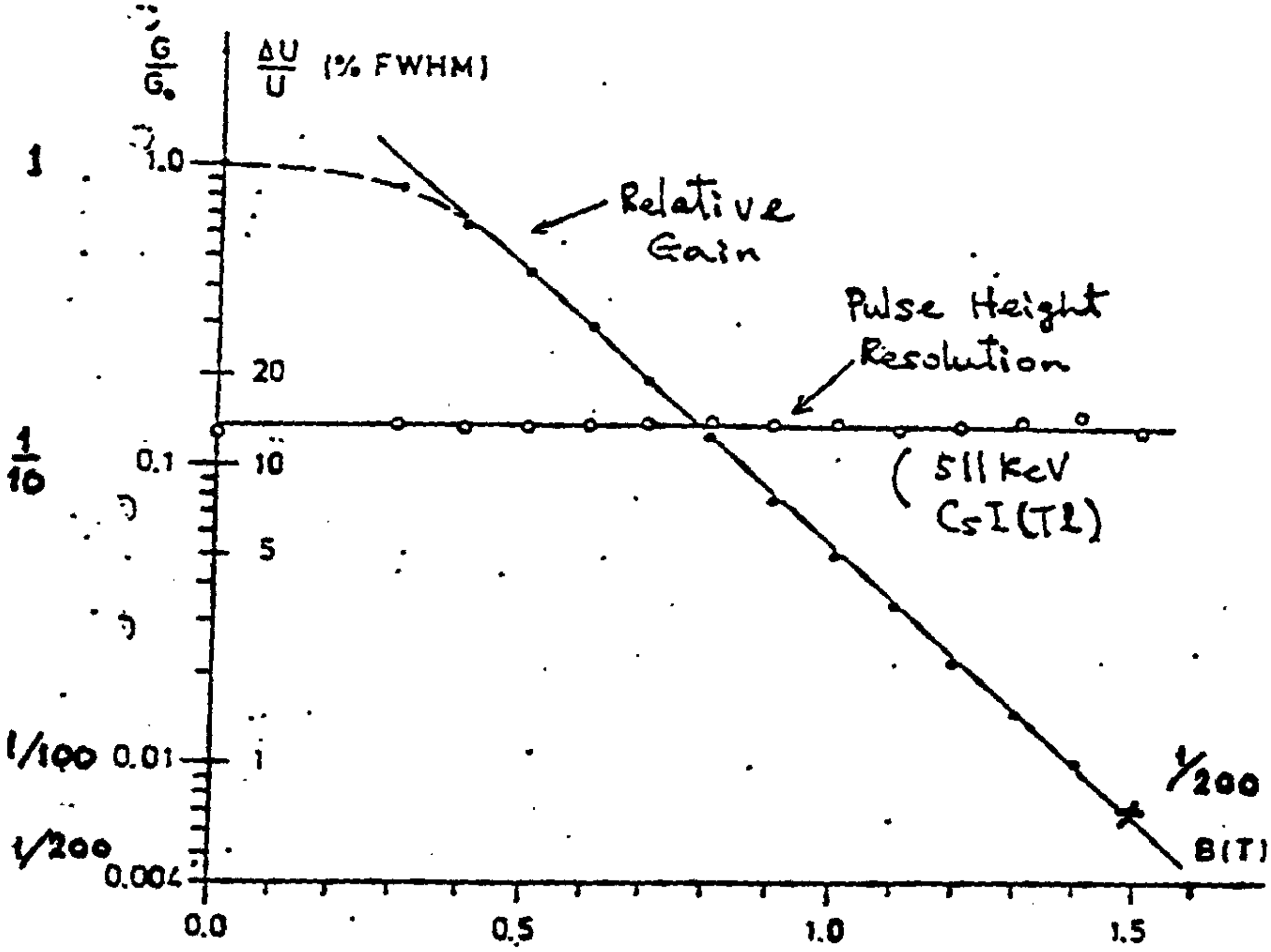

Fig. 2: Relative position G/G_0 (•) and amplitude resolution $\Delta U/U$ (o) for the 511 keV-photopeak vs. B for an axial field (source: ^{22}Na; scintillator: CsI[Tl]; photomultiplier: HAMAMATSU Type R 2490).

Reported by S. Mordhorst, H. Duhm, R. Langkau of Univ of Hamburg / H1 at HERA.

Tested with 17 x 48 x 137 cm³ Gap. Magnet.

IV-2 DETECTOR DEVELOPMENT: RICH DETECTOR PROPERTIES

Fermilab: D. F. Anderson and J. G. Morfín
University of Illinois/Chicago: M. Adams
Princeton University: D. Marlow

INTRODUCTION

The viability of the Ring-Imaging Cerenkov (RICH) technique, which was proposed by Ypsilantis and Sequinot[1], has been established by a number of groups[2,3] who have successfully built and tested devices for use in high-energy physics experiments. The central problem to be faced in designing a RICH counter for use at the SSC is obtaining stable operation in the anticipated high-rate high-multiplicity environment. The RICH detector must be sensitive to the single-photoelectron pulses from Cerenkov light, but insensitive to the ionization trails of through-going charged particles. Furthermore, it must be possible to extract signals using a narrow timing gate so as to minimize confusion from out-of-time events.

SUMMARY OF THE FAST-RICH DETECTOR PROPOSAL

The BCD group is proposing a fast RICH detector to detect UV Cerenkov photons up to an event rate of 50MHz, allowing 20ns event separation. The detector is envisioned as a multistep avalanche chamber (MSAC) operating at low pressure. UV photons will be converted to electrons using a narrow gap of hot (80 C) photosensitive TMAE. The two amplification stages will be separated by a gate to allow high-rate operation. We will investigate several methods of readout, focussing mainly on smart pads. Much work has established the ability to operate low pressure RICH counters at lower rates[4,5]. We intend to build on this work by performing the research and development needed to construct RICH counters with mechanical properties suitable for the large aperture coverage necessary for SSC detector geometries, and to determine the limits imposed by chamber memory time and by spatial resolution. The R&D of the detector will be a joint effort led by David Anderson at Fermilab, Dan Marlow at Princeton, and Mark Adams at the University of Illinois at Chicago.

FURTHER DETAILS

All RICH counters consist of a radiator (liquid or gas, depending on the momentum range to be covered) and a system of optics that images the Cerenkov rings onto a photodetector. The photodetector is generally some sort of multi-wire proportional counter (MWPC) variant, which is filled with a gas that doubles as a photocathode, usually TEA or TMAE plus a carrier gas. The photodetector must be separated from the radiator and optics by a UV-transparent window such as quartz or CaF and must be read out in such a way that two-dimensional images (the rings) can be extracted on an event-by-event basis. Since the time scale for emission of Cerenkov light is instrinsically very short, most of the research needed to develop a fast RICH counter will be focussed on the photodetector.

In most devices built thus far, an intrinsic jitter in photoelectron detection time arises because the absorption length of the photosensitive gas is long enough that the photoelectrons are produced at varying distances from the amplification region and therefore arrive at varying times. For example, the absorption length of TMAE at 30 degrees is about 15 mm, resulting in a 200-300 ns variation in pulse arrival time, depending on the carrier gas. Since this is several SSC bunch-crossing times, a faster solution must be developed.

Solid or liquid photocathodes offer a simple solution to the arrival time problem, since all photoelectrons are produced in a thin layer and drift for the same distance. However, if the photocathode is placed on the quartz window as in a PMT, it must be deposited on a UV-transparent conductive substrate and the window must be cooled. If the photocathode is placed on a second surface, the electrons must drift back towards the window and the readout pads must be transparent. Furthermore, in the case of a solid photocathode, the efficiency is very sensitive to the thickness of the cathode layer. Even if the readout problems of solid/liquid photocathodes can be solved, none have been developed that compete with photosensitive gases. Nonetheless, it is too early to abandon this approach, and we plan to devote some effort to developing a suitable solid/liquid photocathode along with a suitable readout scheme. In view of the difficulties, however, we plan to primarily pursue gaseous photodetectors of the (MSAC) variety, operating at low pressure and elevated temperature. Exploratory work on this type of device has been carried out by Majewski[4] et al. and by Breskin[5]. Fig. 1 shows the electrode structure of a typical MSAC.

At high temperature (60-80 degrees), the vapour pressure of the TMAE increases to the point where its absorption length drops to a few mm or less, reducing the spread in photoelectron transit times to about 20 ns. Even so, the total chamber pressure can still be kept low enough (a few torr) that the amount of primary ionization from charged particles is greatly reduced, rendering the chamber insensitive to throughgoing hadrons. Since almost any gas can be used, one can achieve a high gain at low voltages with minimal photon feedback from the amplification process. The latter feature eliminates the need for elaborate screens to isolate secondary photons from the main gas volume. One disadvantage of low pressure operation is that one must mechanically support the quartz window against a 1 atmosphere differential pressure. Two mechanical designs will be pursued. Mosaics of small (10cmx10cm) chamvers will be compared with larger aperature devices (50cmx50cm) constructed with internal deadening support posts.

Multistage operation provides the high gain needed for the detection of single photoelectrons and further reduces the amount of photon feedback. Moreover, the parallel plate geometry can easily accomodate a gating electrode, allowing one to operate in a mode where only pulses of interest are passed to the second stage of amplification. Such operation simplifies the electronic readout of the chamber and reduces the average current drawn by the final stage, thereby reducing aging effects. Finally, by placing a drift region between the first stage of amplification and the gating electrode, one can build in an economical trigger delay of several hundred ns. We plan to investigate the operation of such a gate and to explore how narrow a gate pulse can be achieved. Our initial goal is a 100 ns or less.

Readout of RICH counters operating in an SSC environment presents the technically demanding challenge of extracting inherently two-dimensional images in a high-rate high-multiplicity environment. The position coordinates of a series of amplified single-photoelectron hits must be measured and fitted to a circle. The approach employed in some existing designs[3] extracts one of the two position coordinates through measurement of the drift-time interval between the passage of the particle and the arrival of the charge at the photodetector's sense plane. Although this technique affords precision position measurements and allows a single wire plane to cover a large photodetector area, the several-microsecond long drift times makes it inappropriate for high-rate applications. Analog readout of stereo wire cathodes was used at a higher rate, with several hundred nanosecond charge collection times, but in a low multiplicity environment[10]. We have thus elected, at least initially, to concentrate on two-dimensional pixel-type schemes, such as cathode pad readout.

In a typical SSC detector, the area to be covered is several square meters (25 m**2 in the case of the BCD barrel RICH). One could achieve the desired 1-mm position resolution in a straightforward way by dividing the cathode plane into 2-mm square pads, each instrumented with a simple amplifier-discriminator combination. However, the resulting number of channels (6 x 10**6) is impracticably large. Furthermore, in the case of cathode readout, the ``footprint" of the image charge will extend over an area whose transverse dimensions are comparable to the spacing between the anode and cathode planes, typically several millimeters.

One is immediately led, therefore, to consider more economical approaches based on determination of the center-of-gravity of the cathode image charge (the techniques to be described can also be applied to anode plane readouts). In the simplest such scheme, the cathode surface is divided into larger squares and each square is instrumented with an amplifier and an ADC. To avoid significant differential non-linearities in the relationship between the induced charge centroid and the true position[6], the pad size is limited to a value no larger than the cathode-anode gap, or about 5x5 mm**2. By increasing the gap, and/or by correcting for the differential non-linearities offline, the pad size might be increased to 1x1 cm**2, thereby reducing the required number of channels by a factor of twenty-five to the (somewhat) less daunting value of 250,000. We plan to investigate just how far this can be reasonably pushed.

There are, however, other intriquing possibilities that can potentially reduce the channel count even further. For example, the "wedge and strip" (W&S) approach [4,7,8], employs the repetitive three-electrode pattern shown in Fig. 2 to extract position coordinates via the simple relations

$$X = 2S / (S + W + Z) \text{ and } Y = 2W / (S + W + Z)$$

where S, W, and Z are the charges collected on the three electrodes. Since spatial resolutions considerably better than 1% of the overall linear dimensions of the W&S pad are possible, very large pads can be employed. In fact, in the absence of other considerations, large pad sizes are preferable since the W&S scheme tends to break down toward the edges of the pads. (In such cases, one reverts to the centroid-finding algorithms described above.)

In RICH counter applications, the maximum pad size will be driven not by resolution requirements, but by the need to minimize the number of cases where two or more photoelectrons produce avalanches landing on the same pad. Since the W&S method yields a value corresponding to the center-of-gravity of the charge distribution rather than the center-of-gravity of the space points, and since the dynamic range of the pulses is large, the relative "weight" of the low pulse-height hit will tend to be diminished. In the pessimistic limit that only the largest pulse height hit counts, one concludes that the pad size should be chosen so that the probability of two or more hits on a given pad is less than roughly 10%, corresponding to a expected number of hits per pad of about .5. Assuming

Cerenkov rings of R=20 cm radius and No=20 photoelectrons per ring, this limits the linear dimensions of the pad size to

$$d = 2*pi*.5*R / No = 3 \text{ cm}$$

Another limitation comes from the observation that for two hits on the same pad the center-of-gravity lies not on the common circle to which they belong, but rather to the chord connecting them, as shown in Fig. 3. In the worst case of a pair of points at either end of the W&S pad the effect introduces an error in the radius (for the pair) given by

$$dR = R(1 - \cos(theta)) = d**2 / 8*R = .6 \text{ mm}$$

Although for 3 cm pads this effect is small, it is not completely negligible and deserves further study. The pad size should also be small enough that the level of confusion in the high-multiplicity environment is not too great. The charged particle density varies with angle so that an optimization will likely result in an angle-dependent pad size. At angles close to the beam direction, the simple square pad solution may be best. Table I summarizes the charged-particle rates and expected pad occupancies in various rapidity regions for a detector (BCD) operating at a luminosity of 10**32 /cm**2/sec. The column labeled area gives the total area of the photodetector, the column labeled rate gives the rate of charged particles per unit area (including those below threshold), and the last two columns give the expected occupancy of 25 x 25 mm**2 pads for all bunch crossings and for bunch crossings where a typical interaction occurs. The former occupancy gives an indication of the severity of the general rate problem, while the latter indicates the extent to which the Cerenkov rings from the same interaction illuminate the detector. The situation appears tolerable in all parts of the detector, except the largest rapidity bin, where smaller pad sizes are clearly needed. Since the total area to be covered in this rapidity bin is small, the effect on the overall channel count is also small.

Although we believe that the W&S approach appears to be the most promising, we will also devote further study to the readout scheme presented at the Vienna Wirechamber Conference by Charpak et al. where the electrons are drifted through a gate and then at 90° into a TPC type readout. If this were to work well it would greatly reduce the number of channels that are needed and might be particularly advantageous for covering large areas with low to moderate rates. One of the key requirements is the development of a very fast gate.

At this writing we have not settled upon a scheme for electronic readout of the pads. However, a number of groups[9] are engaged in generic R&D on schemes that could be adapted to RICH counters. Since the details of the readout will to some extent be driven by the conclusions from our detector studies it is reasonable to postpone a decision on this question.

Finally, we recognize and plan to address the difficult engineering problems associated with building a RICH system of SSC dimensions. These problems include the need to support the quartz window of the photodetector in such a way that it can withtand the 1 atmosphere pressure differential, the need to maintain the detector volume at an elevated temperature without local "cold spots", and the need to minimize the area of dead regions and the amount of dead material presented to the incident particles. The effects of aging will also be studied.

TIMESCALE AND MANPOWER

The research will be carried out jointly by Fermilab, UIC, and Princeton. Fermilab and UIC will concentrate mainly on the questions of chamber design, construction, and operation; while Princeton will work on schemes for pad readout. We will concentrate initially on assembling fixtures such as the TMAE handling system and a suitable test setup as well as the design and testing of small-scale prototypes, temporarily avoiding some of the engineering problems associated with larger modules. Early studies of pad readout schemes will proceed in parallel at Princeton using conventional MWPC's. In the longer-term (after one year), we plan to progress to more realistic prototypes with complete readouts, culminating in the construction of a full-scale prototype module suitable for use as part of a larger system. We estimate that construction of the full-scale module could begin after two years of research with smaller devices.

We expect this research to provide a number of excellent opportunities for graduate students to gain practical experience with detector technology and plan to rely heavily on their contributions to this work. Although the students will do much of the research, they will be supported by the technical staffs at Fermilab, UIC, and Princeton and guided by the research staff and faculty at those institutions.

SUMMARY OF FAST RICH RESEARCH AND DEVELOPMENT

Mechanical: large aperture
how big can individual chambers be?
dead regions

material in particle paths
large chambers with internal supports
small chamber mosaics
window construction Quartz with TMAE or CaF2 mosaics with TEA

Timing limits: conversion gap size
dispersion of carrier gas + TMAE
conversion gap-preamplification gap interaction

Gating: investigate limits to amplification stage separation due to chamber capacitance
Readout scheme pioneered by Charpak using a Drift Chamber instead of pads

Gas System hot TMAE handling
purification system
carrier gases: optimization of hydrocarbons

Materials Needed
Prototype detector
2 sets of Quartz windows
MSAC planes
Power supplies
Crates
UV lamp
Gas system
Radiator vessel + Mirror
Loan from another group of the E605 radiator is possible

Test electronics : absorption measurements require PMTs, scintillator planes, CAMAC ADCs and TDCs.
Data acquisition computer (microVAX II with Jorway to CAMAC) exists. Trigger electronics and crates also exist at the UIC lab.

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[8] O. Siegmund et al., IEEE NS-30, 503 (1983).
[9] see e.g. L. Callewert et al., IEEE NS-36, 446 (1989). J. Alsford (RAL), talk at BCD workshop, Desoto TX, May (1989).

BUDGET REQUIREMENTS: FERMILAB

Post Doc	$50K
Gas System	20K
Machine Shop	30K
Quartz Windows	20K
Chamber Hardware	15K
Electronics	40K
Engineering Support	15K
Travel	8K
TOTAL	$198K

BUDGET REQUIREMENTS: UNIVERSITY OF ILLINOIS AT CHICAGO

Vacuum vessel machining	8K
Temperature Controls	6K
Chamber Construction	20K
Electronics for test	20K
Post Doc	50K
1/2 graduate student	12K
Travel	5K

TOTAL	$121K

PRINCETON BUDGET REQUIREMENTS

Graduate student full-time	$ 15 K
Shop and Technician time	$ 10 K
Travel to FNAL and RICH con	$ 10 K
Materials and supplies for chamber construc.	$ 10 K
Princeton University overhead ``67% X (A-D)	$ 30 K
CAMAC test electronics	$ 20 K
Total	$ 95 K

Charged Particle Rate Summary				
Region	Area m^2	Rate MHz/m^2	Occupancy (all BX)	Occupancy (Event BX)
$0 < \|y\| < 1$	25	4.8	.001	.006
$1 < \|y\| < 2$	32	1.9	.0004	.0023
$2 < \|y\| < 3$	3.1	20	.004	.024
$3 < \|y\| < 4$	.43	140	.029	.17

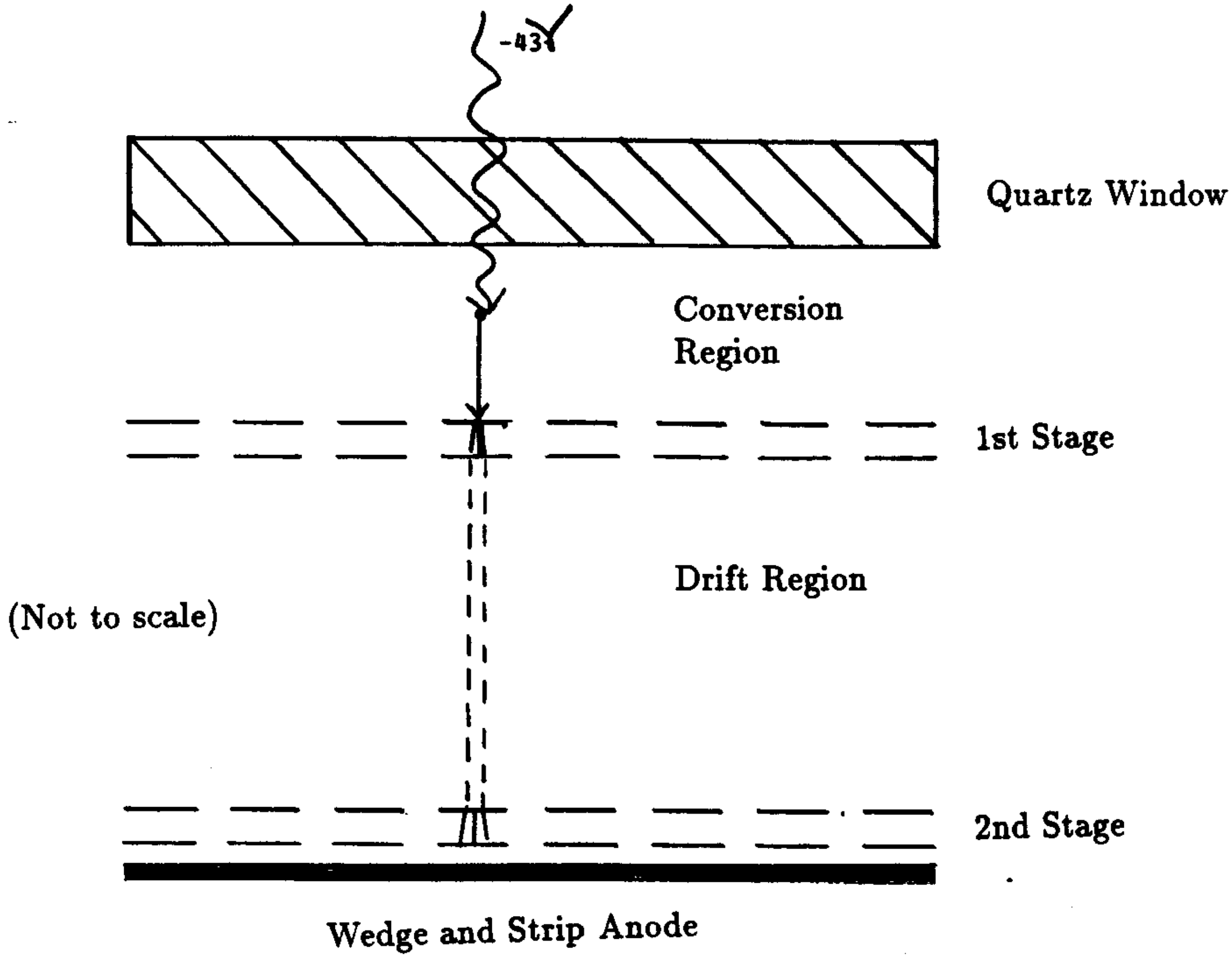
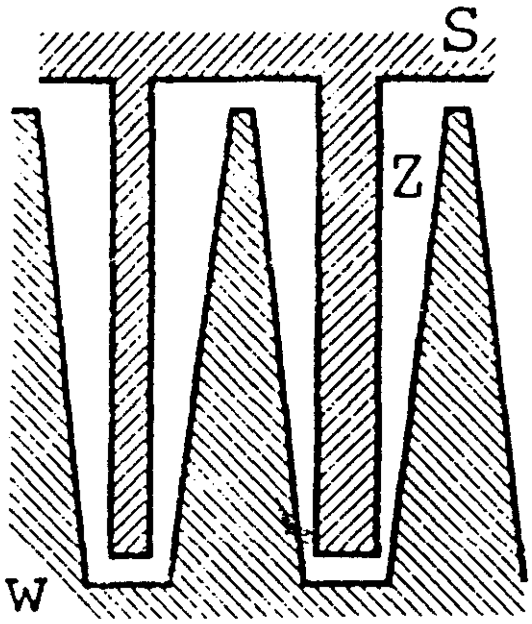


Fig. 1. Schematic of a typical MSAC.



$$x = \frac{2S}{W + S + Z}$$

$$y = \frac{2W}{W + S + Z}$$

Fig. 2 Wedge and Strip "Smart" Pad

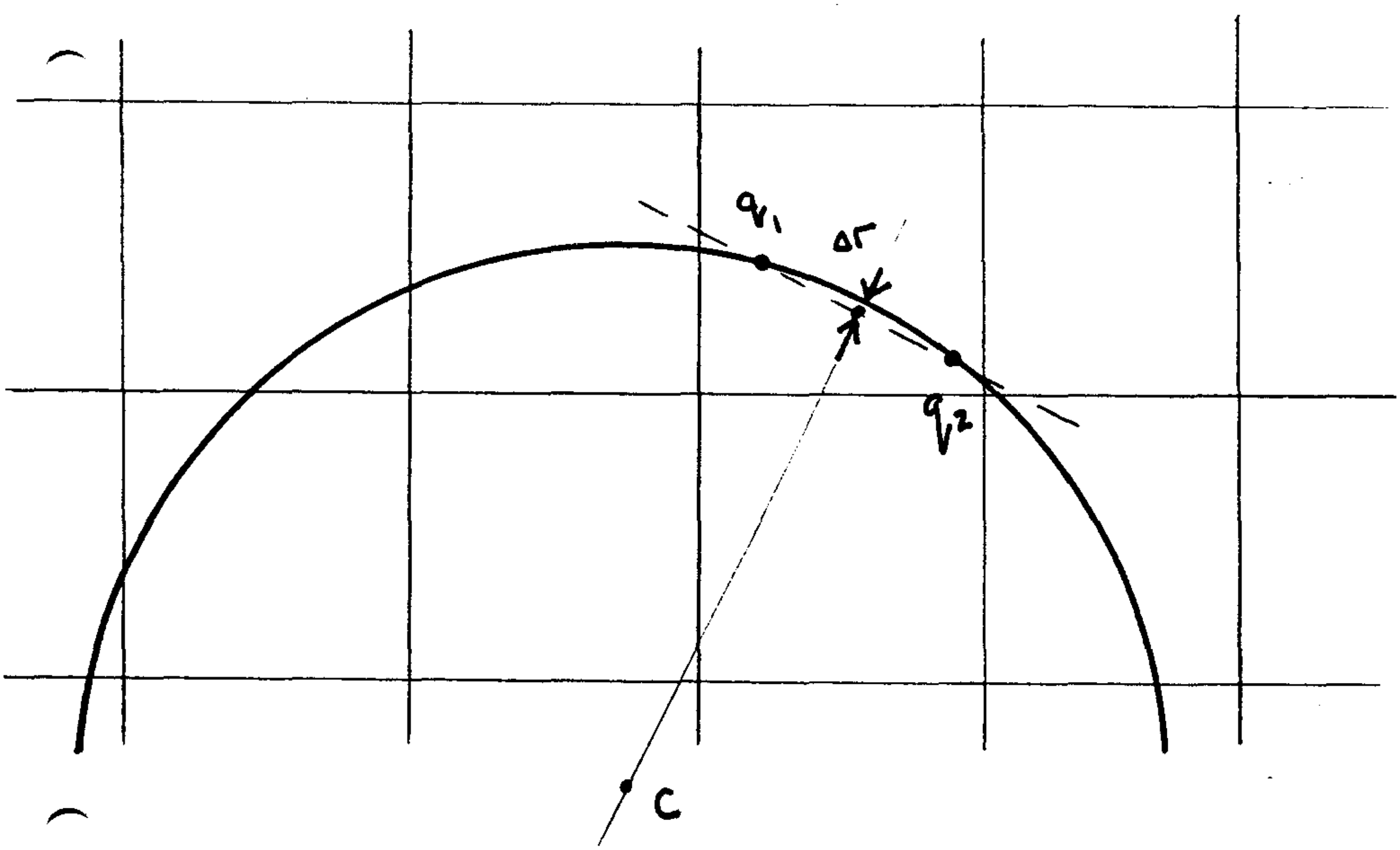


Fig. 3 Center-of-gravity with two hits on same pad

IV-3 DETECTOR DEVELOPMENT: TRANSITION RADIATION DEVICES

University of Wisconsin: Marleigh Sheaff, Deborah Errede

INTRODUCTION

The large branching fractions of B mesons and daughter D mesons to leptons make electron identification at the first level trigger, i. e., within 2 μsec, an essential element in the overall design of the BCD spectrometer. This is to be achieved by Transition Radiation Detectors (TRD's) which provide full coverage over the spectrometer. The design goals are for a rejection factor of at least 100 for pions and for an electron efficiency of at least 90% over the barrel, intermediate, and forward regions. The need for electron identification beyond that provided by the electromagnetic calorimeter alone is evident in studying single electron triggers for the CDF experiment at the luminosity of the present collider, which is two orders of magnitude below the planned luminosity for BCD at the SSC. Even with the support of a prompt stiff track calculation, the single electron trigger threshold is limited to ~10 GeV/c in transverse energy. For the BCD experiment, where the study of high statistics B decays to look for CP violation is the primary Physics goal, the electron thresholds required are ~1GeV/c.

DESCRIPTION OF THE PROPOSED DETECTOR

The TRD will be made up of modules containing "standard cells". The modules will be constructed to conform to the overall mechanical design structure in each region of coverage. The basic TRD "standard cell", radiator plus xenon-filled proportional chamber or chambers, will be approximately 2 cm deep. Thus 15 such cells are expected to comprise the central TRD, which is planned to be of 30 cm total depth, filling the region from 130 to 160 cm in transverse dimension from the interaction region. (See Figure 1) The overall design structure in the central region is square when viewed along the beam direction. The TRD chamber wires for all the cells on a given side of the square will be aligned along the same direction and will be perpendicular to the beam direction. There will be at least three cells which will have fast 3-dimensional readout. This could be effected by etching cylindrical pads on the outside of resistive plastic straws which would be read out in addition to the wires[1]. Alternatively, if this turned out not to be technically feasible, two additional chamber planes aligned along other directions could be added on these layers to allow fast vector tracking. In this case, special logic circuits would be required to do the hit matching in time for the first level trigger. In either scheme, the 3-dimensional coordinates will provide a "road" along which the count of TR hits will be required to be above some threshold. This prompt TRD trigger can be matched to either the fast track trigger from the central straws or to an electromagnetic calorimeter tower trigger or both.

All cells of the TRD may use amplifier-shaper-discriminator cards with two discriminators to allow the use of two different thresholds, one for the detection of the large signal due to capture of a TR x-ray and the other for the smaller signal due to passage of a minimum ionizing particle through the chamber. Thus they may also be used in an overall tracking algorithm[2]. The need for this will be studied using Monte Carlo simulations. The same philosophy will apply in the design for the intermediate and forward regions. More layers, or "standard cells", are required in these regions because of the higher momenta of the pions to be rejected. The estimated numbers are 20 cells or 40 cm in the intermediate region where pions up to 40 GeV/c must be rejected and 50 cells or 100 cm in the forward region where the maximum pion momenta are more like 200 Gev/c. As in the central region, three or more planes will have special provisions to allow a prompt TRD trigger.

This relatively "compact" design for the TRD's is achieved by "fine sampling"[3], which means that detector planes are interspersed with radiators containing a small number of foils to minimize the deleterious effect of foil self-absorption. Previous design efforts have concluded that TRD's made from radiators containing of order 20-50 foils followed by single xenon-filled chamber planes of depth 2-6 mm make optimum use of the allowed space[3,4]. The exact number of foils (or density of fibers) and the depth of the straw chambers which best meet the requirements of this experiment will be determined using Monte Carlo simulations. Preliminary Monte Carlo runs have indicated that the combined goals of a factor of at least 100 rejection for pions and of high efficiency for acceptance of electrons, ≈90%, can be realized in a total depth of 30 cm. using a TRD with 15 layers, each with 50 12.7 micron polypropylene radiator foils followed by a chamber 6 mm deep filled with 90\% xenon. This simulation was carried out for the barrel of the BCD and therefore it was assumed that the momenta of the signal electrons and background pions range from 1-20 GeV/c. For the BCD intermediate and forward regions, more depth can be allowed and more is needed because of the higher momentum of the pions that must be rejected by the TRD.

While the BCD is designed to operate in a relatively low luminosity region, the short time between bunch crossings, expected to be 16 ns, dictates that the TRD be fast to keep the range of bunches over which overlapping hits may occur as small as possible. Thus, the detector cell size must be small and the gas must have a reasonably high drift velocity. Drift times of 30-40 ns/mm are typical for drift spaces filled with Xe-CH_4 or Xe-methylal[5,6]. This is probably fast enough if the average cell occupancy is not too high (say, a few percent), but tests will be carried out using these gases in various ratios with a small admixture of CF_4. Previous studies by others have shown that a factor of 1.5 to 2 speed-up in drift velocity (at least) can be achieved by this addition[7]. A modest fraction of CF_4 in the TRD gas would thus be expected to significantly improve the rate capability of the device. The other properties of any gas mixture to be used to detect TR x-rays must also be determined. E. g., it is important that it manifest stable operation in the proportional region and thus linearity of gain.

The current plan is to use straw tube chambers as detectors[8]. Not only are the cell sizes small, but this design eliminates the need for large area windows at the interface between the xenon-filled chambers and the helium-flushed radiators. Since the density of xenon is so much greater than that of helium, large windows made from materials like aluminized mylar which are thin enough not to attenuate the TR photons severely can not be stretched tightly enough to keep them from deforming at the bottom of the cells. In the case of planar cathodes, where these windows are the cathodes, the cathode-anode separation increases toward the bottom of the cells which results in lower gains in this region. To overcome this problem, previous experiments have used thin interface volumes filled with CO_2 or N_2 and have added helium or a larger fraction of CH_4 to the chamber gas to make the weight of the gases in the two volumes the same[5,9]. This doubles the number of windows, which results in a larger attenuation of the TR x-rays, and also reduces the amount of xenon in the chamber gas, which makes it necessary to increase the depth of the detector cells to keep the x-ray absorption efficiency high (thus increasing the maximum drift times). By using wire cathodes, the gain can be made uniform throughout the cell. But in this case, the windows bow out at the bottom of the cell creating a non-active volume filled with xenon outside the cathode wires, so that x-rays are absorbed where they can not be detected[10].

Straw drift tubes have been wound which are capable of withstanding pressure differentials of up to 10 atmospheres [11]. Thus it should be relatively easy to construct a cell array that is gas tight at least as far as the xenon mixture leaking out of the tube. Whether this is true for helium which might leak into the tubes is not known and must be studied. If this turns out to be a problem, a buffer gas volume with barrier windows will have to be added. A double-walled box structure is envisioned in which the tubes could be mounted. The inner volume would be filled with helium and the outer (both ends) volumes with the xenon mix. The gas inlet and outlet ports to the straws would be open to these outer volumes. Mechanical design is one of the most difficult challenges to be faced. Not only must the system be gas-tight, but solid electrical connections must be made and the signals carried out in an orderly way for the very large number of channels involved. Because of the large area to be covered, ease of construction and relatively low construction costs are important to the mechanical design. Also, because of the large number of straws in the system, the gas volume will be significant. This makes a recirculating gas system for the xenon mixture imperative, since xenon is a relatively expensive gas, ~$4/liter.

The fact that the cells of a straw detector are electrically isolated so that one broken wire is not potentially lethal to an entire region of the detector make this the preferred design choice. However, the radiation hardness of a straw tube detector has not yet been studied so it is not known whether a TRD built in this way could survive in the high particle flux at an SSC collision region. Beam tests will be carried out to investigate this. Alternative designs for the chambers will be considered which might be easier to construct and therefore relatively inexpensive. Planar chambers with walls made from Rohacell bonded to kapton would appear to be an attractive possibility.

The electronics must be fast and integration times short to allow for the use of ``cluster counting" techniques [12,13] in discriminating the signal due to capture of a TR x-ray from the typical signal due to passage of a minimum ionizing particle through the cell. Suitable circuits using discrete components already exist at the lab for use in early prototype tests[6]. The entire TRD detector system has a sufficiently large number of channels to require use of large-scale integrated circuits containing amplifiers, shaping circuits, discriminators, and sufficient storage capability to hold the signals until the experiment trigger is received. Since there is already at least one initiative in the community to develop I. C.'s of this type suitable for use in the BCD straw chambers[14], it is not planned to duplicate this effort as part of the TRD design effort but to use the existing chip design, modifying the parameters as appropriate for this application. Tests will be carried out on the feasibility of using pad readout in the trigger by etching cylindrical pads on the outside of resistive straws. Whether the signal shaping required to discriminate x-rays from typical track ionizations by "cluster counting" can be maintained in a pad readout scheme is a question of interest and will be studied.

Since the light output at each interface between two media of differing dielectric constants is small, of order alpha, it is important to construct the radiators from materials which have been optimized to produce TR photons in the region of the x-ray spectrum where absorption in xenon is highest. Significant use will be made of existing Monte Carlo programs in this part of the design effort. Ease of construction favors the use of matting constructed of polypropylene (CH_2) fibers. A recent report indicates that such radiators are almost as efficient in producing TR x-rays as stacks of regularly spaced foils[15]. Both types of radiator will be tested. The foils will be "dimpled" to separate them for the stacked foil radiator[16}. Another possibility is to grade the foils, putting the thicker foils, which produce a stiffer photon spectrum than the thinner foils and which, because of their thickness, absorb more of the TR x-rays, upstream of the thinner foils. Since the absorption cross section for x-rays is larger at the low end of the spectrum, this choice of foil placement means that the lower energy photons produced by the thinner foils traverse as little material as is possible.

SCOPE OF THE PROJECT

The scope of the project is as follows:

Simulations - includes event simulation for both signal and background as well as detector simulation.

Prototyping -includes design of the mechanical structure to hold the tubes, gas and electrical connections to the tubes and volumes holding the tubes, and the preliminary design study for a recirculating gas system. It does NOT include straw design which is being done by others (although the TRD may well put special requirements on the conductive material with which the tubes are to be coated) or development of the readout I. C.'s.

Testing - includes studies of "fast" gas mixtures both to investigate the speed-up in drift velocity and the properties of operation in the proportional region (linearity of gain). Also, whether the tubes are impervious to helium must be determined. The pad signals that result from x-ray capture will be compared to those due to minimum ionizing particles. In addition to the above bench tests, prototypes will be exposed to test beams. The radiation hardness of the detector will be studied as part of these tests.

MANPOWER

Post Doc - 1/2 time for 2 years

Students (preferably undergraduate) - 2 for 10-20 hours/week during the school year and full time in the summer for 2 years

Engineer or Experienced Technician - 1/2 time for 2 years

MILESTONES

1 Modest scale prototype finished for testing at end of 1990 fixed target run using existing electronics.

2 Full-scale prototype to be tested during 1992 fixed target run using prototype large scale I. C.'s if possible.

BUDGET (1990)

Salaries -	$60K
Materials -	$20K
TOTAL	$80K

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[16]D0 TRD, e. g.

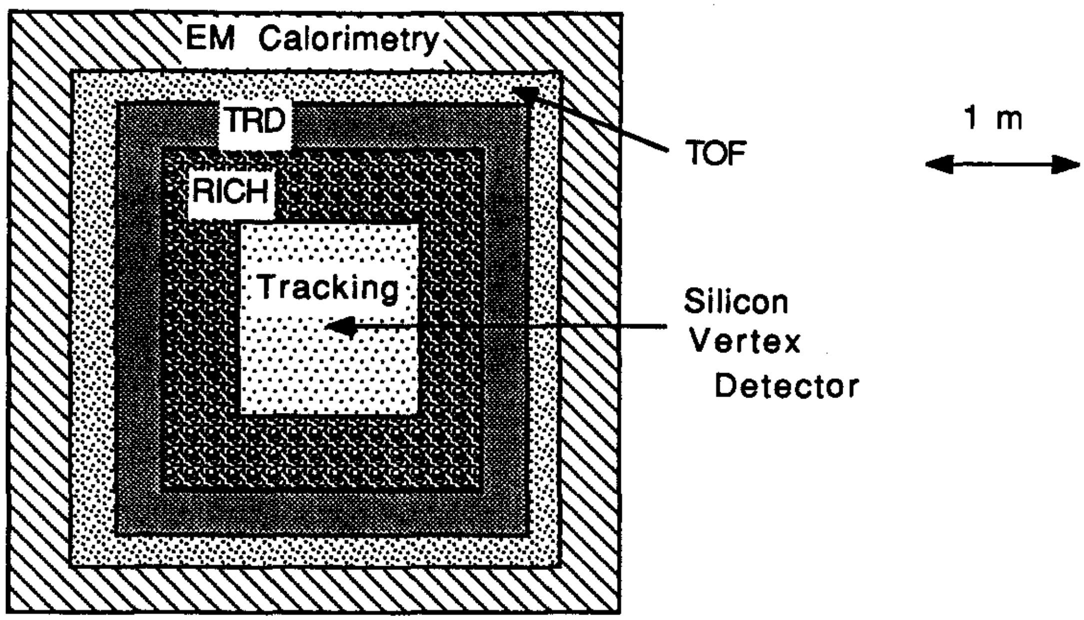

Fig. 1 Transvers cut of a typical B detector showing the position of the TRD

Following is a summary of the budget requests for the research described in this proposal. All figures include the respective institutions overhead charges where applicable.

	Salaries & Travel	Equipment & Services	TOTAL
SOFTWARE			
Univ. of Puerto Rico	$94K	$64K	$158K
Univ. San Francisco / Quito	$64K	$41K	$105K
TIME-OF-FLIGHT			
Univ. of Oklahoma	$33K	$76K	$109K
SUNY A	$51K	$87K	$138K
RING IMAGING CERENKOV			
Fermilab	$58K	$140K	$198K
Univ of Illinois/Chicago	$67K	$54K	$121K
Princeton Univ.`	$42K	$53K	$95K
TRANSITION RADIATION			
Univ of Wisconsin	$60K	$20K	$80K
		TOTAL	**$1004K**