

October 1, 1992

# Development of a Fast RICH Detector with a Solid Cesium-Iodide Photocathode: Proposed Research in FY93

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## Abstract

We propose to continue development of prototype RICH detectors based on solid cesium-iodide photocathodes in parallel-plate chambers. In FY92 we demonstrated a small device with 332 channels that observed Čerenkov rings with 5 photoelectrons on average. In FY93 we will concentrate on improvements in the quantum efficiency (a factor of 4-5 may be possible), and explore the possibility of operation at atmospheric pressure. The very fast response time of the detector may make it suitable for time-of-flight measurements, which prospect will also be investigated. We seek a budget of \$236k to be allocated for equipment \$112k and operating \$88k at U. Pennsylvania, \$30k for operating at Princeton U., and \$6k at U. Puerto Rico.

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# 1 Executive Summary

Hadron identification is a critical component of any  $B$  detector at the SSC designed to study  $CP$  violation. Kaon identification is particularly efficient for tagging the particle-antiparticle nature of the other  $B$  in  $CP$ -violation studies. High-rate Ring Imaging Čerenkov detectors (RICH) provide the solution. We have been pursuing a breakthrough in solid-photocathode technology developed by us; low-pressure operation of a solid, roughly  $1\text{-}\mu\text{m}$ -thick, cesium-iodide (CsI) photocathode with or without a monolayer of adsorbed TMAE. This photocathode has extremely fast time response and can be coupled to a relatively simple parallel-plate chamber with instrumented cathode pads for readout. In the past year we have:

- Studied the basic properties of thin CsI + TMAE photocathodes including the aging rate, quantum efficiency, and time response.
- Designed, constructed, and tested the first full-prototype RICH detector using a solid photocathode inside a low-pressure parallel-plate chamber with VLSI readout.
- Observed Čerenkov rings from minimum-ionizing particles in a testbeam at BNL.

In FY93 we propose to continue and extend these studies with the following goals:

- Achieve a yield of 20 photoelectrons per Čerenkov ring by identifying which sealants and adhesives are contaminating the photocathodes and improve the vacuum system (U. Penn).
- Rebuild the quantum-efficiency test stand to give quicker and more reliable results (U. Penn).
- Build SVX Faraday cage and isolation electronics (U. Penn).
- Construct a small straw-tube tracker for pointing tracks (U. Penn).
- Measure position resolution of Čerenkov counter and width and radius of Čerenkov ring (U. Penn).
- Search for radiators with good transparency at 170 nm (Princeton U.).
- Systematic study of preparation of photocathodes (Princeton U.).
- Study CsI photocathodes for time-of-flight counters (Princeton U.).
- Test detectors at BNL in summer of 1993 to demonstrate separation of  $\pi^\pm$  from  $K^\pm$  (U. Penn, Princeton U. and U. Puerto Rico).

## 2 Introduction

Particle identification is essential for experiments that plan to study  $CP$  violation in the  $B$ -meson system. There are many  $B$ -meson decay modes that should exhibit  $CP$  violation, but the most precise information will come from the class of neutral  $CP$ -self-conjugate decay modes, such as  $B \rightarrow J/\psi K_S^0$ . The analysis of  $CP$  violation in such decays requires knowledge of whether a  $B$  or  $\bar{B}$  produced the final decay products, and consequently the other  $B$  in the event must be ‘tagged’ as a  $\bar{B}$  or  $B$ . The charge of the  $K$  meson from  $B$  decays with the quark decay chain  $b \rightarrow c \rightarrow s$  will tag with high efficiency the conjugation of the parent  $B$  meson. Čerenkov detectors provide a method of separating charged  $\pi$ ’s from  $K$ ’s and will therefore be important in the tagging process.

The Ring Imaging Čerenkov (RICH) detector [1] provides  $\pi$  and  $K$  identification over a greater momentum range than any other technique available. However, large RICH systems are difficult to build and operate at high rates and with high yields of photoelectrons.

RICH detectors using photomultiplier tubes perform well but are expensive to implement on a large scale, and insert a significant amount of material in the particles’ path.

The largest and most ambitious existing RICH systems, such as those at SLD [2] and Delphi [3], use a readout based on the photosensitive gas TMAE. For operation at atmospheric pressure a buffer gas is present, which typically is overly sensitive to minimum-ionizing particles and renders the detectors unstable at high gas gains. To achieve good quantum efficiency the TMAE gas volume is large, leading to long collection times for the photoelectrons. The photoabsorption length, and hence the collection time can be shortened by raising the temperature of the TMAE gas [4, 5]. However, the obvious operational and mechanical difficulties are such that at present no large system is proposed using this approach.

A variation on the TMAE gas detector employs a multistep-avalanche chamber where several stages of gain achieve high amplification while minimizing instabilities to photon feedback. These detectors still require heated TMAE gas to achieve a high quantum efficiency with a thin photosensitive layer [4, 5, 6].

In the present work we explore the use of low-pressure gas chambers with a solid cesium-iodide (CsI) photocathode. Such cathodes have been studied since the 1950’s [7], and it is established under certain circumstances they deliver high quantum efficiency, but their performance is readily degraded by absorption of water vapor [8].

In the last two years the work of the Anderson group at Fermilab [9, 10, 11], the Charpak group at CERN [12, 14], the Ypsilantis group at Collège de France [13], and the Breskin group in Israel [15, 16] indicates great promise for RICH detectors using high-quantum-efficiency CsI photocathodes. The fast time response of the solid photocathode [9, 14] enables a RICH detector to be designed with a pad-chamber readout which will be appropriate for use at high-luminosity hadron colliders and

*B* factories. Low-pressure operation renders the detector almost blind to minimum-ionizing particles, so they can be operated at very high gas gain. Furthermore, there is little loss of photoelectrons due to backscattering onto the cathode [18], and ion collection times are minimized as the mean free path is long. CsI cathodes coupled to low-pressure chambers show good quantum efficiency for wavelengths up to  $\approx 210$  nm, so can be used with relatively inexpensive quartz windows. The resulting narrow sensitivity in wavelength (170-210 nm) minimizes chromatic dispersion as needed for good  $\pi/K$  separation.

In FY92 we built and tested a parallel-plate, low-pressure RICH detector with a CsI photocathode evaporated onto cathode pads. This proposal is for continuation of that research program in FY93.

### 3 Review of Results from FY92

We constructed and tested a low-pressure, parallel-plate pad-chamber with a cesium-iodide solid photocathode and 332 pads read out with SVX chips, sketched in Fig. 1. This detector is blind to minimum-ionizing particles, and sensitive to Čerenkov photons of wavelengths 170-210 nm. We observed an average of 5 photoelectrons per Čerenkov ring were detected using a 2-cm-thick radiator of liquid  $C_6F_{14}$  [17].

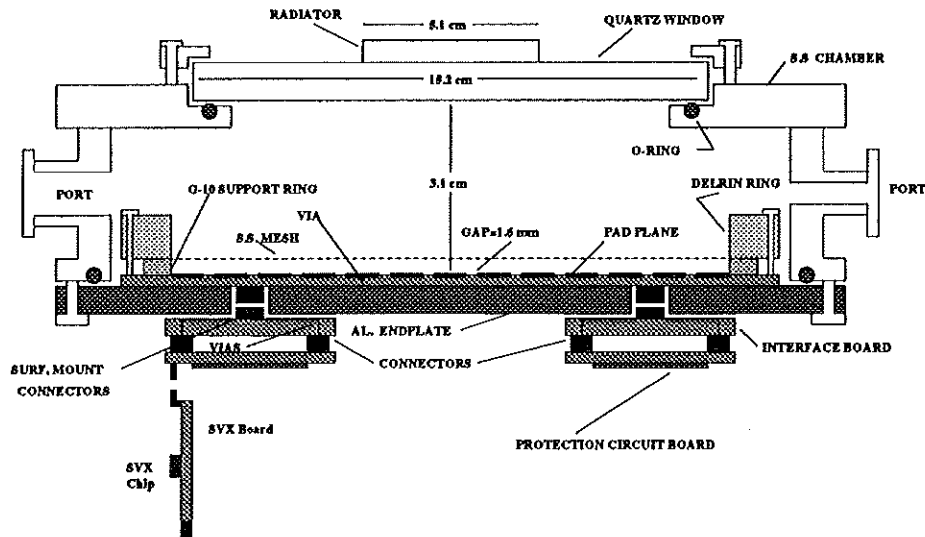


Figure 1: Schematic view of the prototype RICH detector showing the radiator, low-pressure gas volume, semitransparent steel-mesh anode, pad-plane cathode, and configuration of printed-circuit boards on which the SVX readout chips are mounted.

We are very encouraged with these results obtained in a BNL beam test. Three single-particle events are shown in Fig. 2 with struck pads indicated as squares. Each

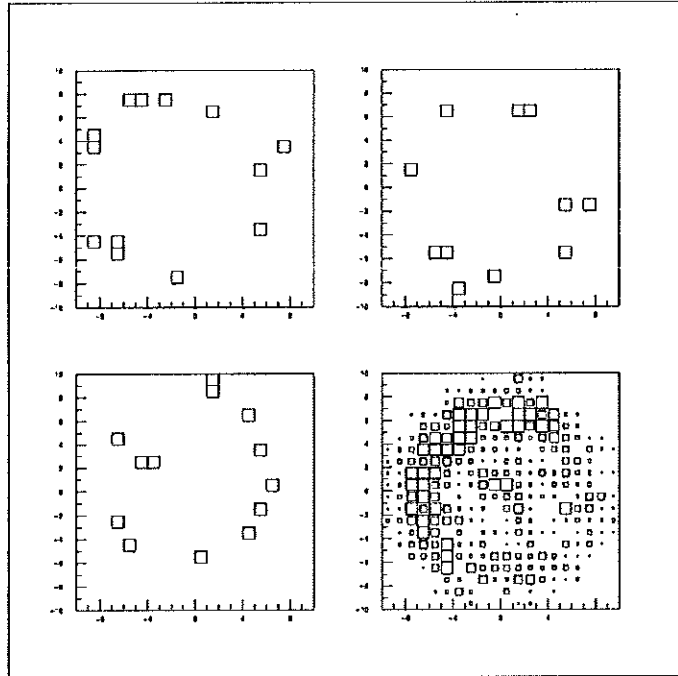


Figure 2: Three plots are single-particle events displaying obvious rings. The fourth plot shows a sum of events from a short run.

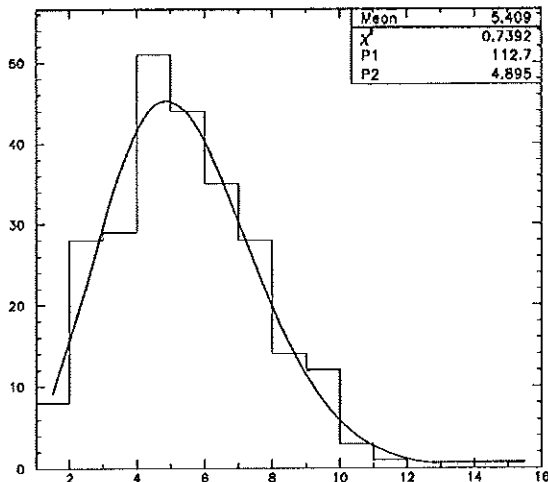


Figure 3: The spectrum of the number of detected photoelectrons per event from minimum-ionizing particles, fit to a Poisson distribution of mean 4.9.

photoelectron typically excites one pad, and the ring is easily identified. Shown in the lower-right of Fig. 2 is the sum of hits over a short run. The area of each bin reflects the summed number of hits. The general outline of the rings are seen to be enhanced, although there is smearing due to the transverse size of the radiator. The nonuniform density of hits around the ring is possibly due to uneven gain across the surface of the pad plane which resulted from a warping of the anode support ring during heating. Note that roughly 10% of the rings have a hit in their center, which corresponds to the probability that a minimum-ionizing particle is detected.

We observed an average of 5 photons per Čerenkov ring as displayed in the histogram of the multiplicity of hits per ring in figure 3. We calculate the number of photoelectron per ring would be twenty if we had our photocathode had the high quantum efficiency reported by Anderson *et al.*[11]. The prospect of a factor of four improvement is the prime motivation of our research program in FY93.

The gas gain in the low-pressure parallel-plate chamber can be as high as  $10^6$ , but we typically operate at  $10^5$  gain. The wire mesh plane was easy to construct and the chamber operates even with small defects in the wire mesh caused by months of handling during the many photocathode evaporations. The data-acquisition system [19, 20] worked well during the test run.



## 4 Proposed Research

### 4.1 Plan of Work at U. Pennsylvania

The goal for FY93 is to increase the number of detected photoelectrons per Čerenkov ring from 5 to  $> 20$ , to measure the position resolution of the chamber and hence the ring radius and width, and to test the improved chamber in a  $\pi^\pm$  and  $K^\pm$  beam at Brookhaven.

There are seven areas of work we plan to continue or initiate in FY93:

1. Identify which sealants and adhesives are contaminating the photocathode and improve the vacuum system.
2. Rebuild the quantum-efficiency test stand to give us quicker and more reliable results.
3. Build a  $N_2$  box that permits installation of the photocathode into the chamber without prolonged exposure to air and water vapors.
4. Design and build a Faraday cage for the SVX electronics.
5. Measure the position resolution of the chamber and determine the ring radius and width. We will build a small drift chamber telescope which points tracks into the RICH prototype.
6. Study atmospheric operation of the prototype chamber.
7. Test the improved prototype at BNL to demonstrate the separation of  $\pi^\pm$  from  $K^\pm$ .

#### 4.1.1 Contaminants

We have found that during the heating process, adhesives outgas at a high rate and destroy the quantum efficiency of the photocathode. We need to improve the quantum efficiency and still maintain good vacuum seals. Presently we use RTV-162 sealant between the interface board and chamber to provide a good vacuum seal with low electrical resistance. We have now determined that this one-component RTV has poor outgassing properties. We will test several new two-component adhesives.

#### 4.1.2 Improved Quantum-Efficiency Test Stand

We presently use the large prototype chamber to test new photocathodes. This is slow and cumbersome. We propose to build a small dedicated test stand which is shown in figure 4. There are tests to be performed that determine the gases, sealants, and conditions which deliver the highest quantum efficiency.

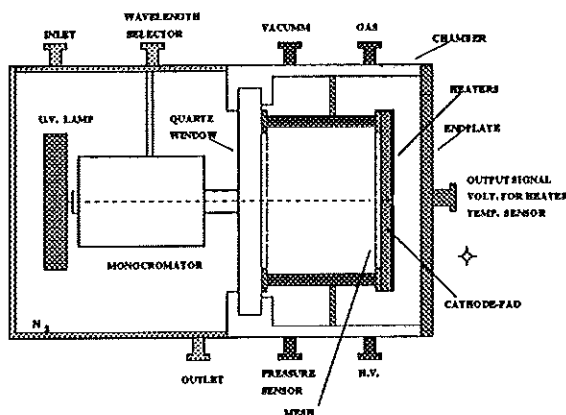


Figure 4: Sketch of the improved quantum-efficiency test stand.

### 4.1.3 N<sub>2</sub> Assembly Box

The photocathode quantum efficiency is reduced by up to a factor of three during the ten minutes exposure to air during the process where we remove the pad-plane from the evaporator and install it in the chamber. We propose to reduce the amount of time the photocathode is exposed to the air by performing the installation and assembly of the pad-plane inside a dry atmosphere. We propose to design and purchase a system.

### 4.1.4 Faraday Shield for the SVX Chips

The present readout is done with 8 SVX chips mounted on SVX Carrier printed-circuit boards which in turn are mounted on the chamber endplate. The 50-pin connectors and flat-ribbon cable are wrapped in aluminum foil, and the Port-Card is located inside an aluminum box. This system, which works well in the laboratory at U. Penn, did not perform as well in the testbeam at Brookhaven. We propose to build a complete Faraday cage that will consist of an aluminum shielding structure that clamps to the endplate. Inside the output lines from the SVX will enter a printed-circuit board which contains optical isolation and power-supply filtering. In addition, we propose to use flat-ribbon cable that has an internal ground plane.

### 4.1.5 Position Resolution

We propose to measure the width of the Čerenkov ring with the present pad-chamber prototype. This information will allow us to calculate the expected momentum dependence of  $\pi^\pm$  and  $K^\pm$  separation. We propose to build a small tracking chamber cosmic ray telescope that allows us to point the cosmic ray track into the pad chamber. We plan to build four  $x$ - $y$  planes of 1"-diameter brass straw tubes, 8 per row,

giving a total of 64 tubes. A resolution of  $200\mu\text{m}$  is adequate for this measurement. A sketch of the proposed experimental setup is shown in figure 5

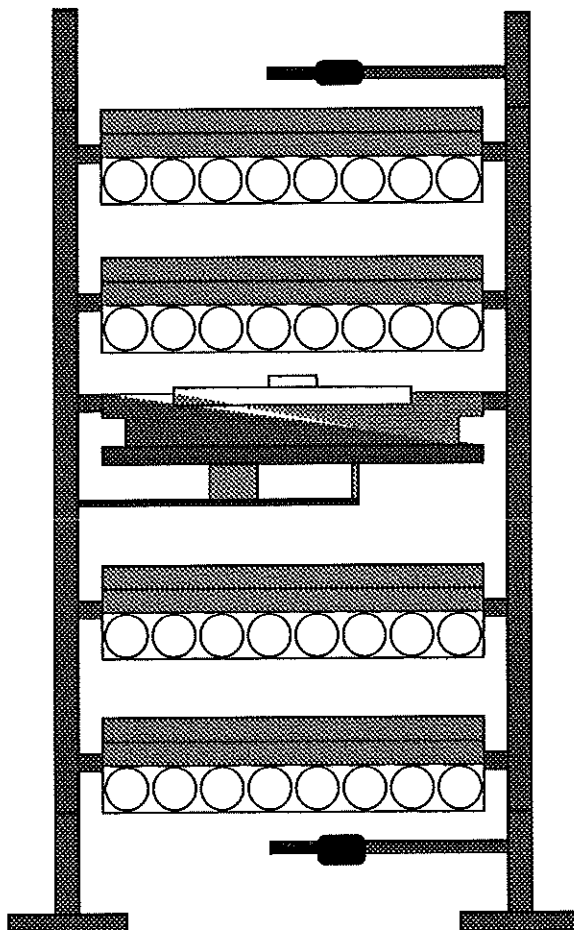


Figure 5: Sketch of the RICH detector located between 4 sets of straw-tube tracking chambers.

#### 4.1.6 Atmospheric Operation

A RICH detector that operates at atmospheric pressure will be easier and cheaper to build. However, compared to low-pressure operation the anode voltage must be much higher and the helium buffer gas will reduce the quantum efficiency by about a factor of two. To compensate for the latter, we will explore the use of improved radiators such as  $\text{C}_8\text{F}_{18}$ . We propose to buy a gas-mixing system to study various mixtures of buffer and gain gases.

## 4.2 Proposed Plan of Work at Princeton in FY93

We will continue our work in progress on various aspects of the RICH detector, and inaugurate several new programs of study. In brief these are:

1. Search for radiators with good transparency at 170 nm.
2. Systematic study of preparation of photocathodes with high quantum efficiency.
3. Construction of a pair of large-area single-pad test chambers for use with cosmic rays.
4. Study of CsI photocathodes for use in time-of-flight counters.
5. Construction of prototype atmospheric-pressure RICH detectors with CSI photocathodes.
6. Testing of various photocathode detectors at BNL in summer '93.

### 4.2.1 Radiators Transparent at 170 nm

Thus far RICH detectors with liquid radiators have used  $C_6F_{14}$  for the radiator, as this has good uv transparency and the lowest index of refraction of any reasonably stable liquid at room temperature. A low index is considered desirable to keep the Čerenkov angle from approaching  $90^\circ$  after exiting the liquid. Recall that

$$\sin \theta_{\text{vacuum}} = n \sin \theta_C = \sqrt{n^2 - 1},$$

so that for  $n > \sqrt{2}$  the Čerenkov light is internally reflected at the liquid-window-vacuum interface. Furthermore,  $n$  should not be too close to  $\sqrt{2}$  to limit chromatic dispersion. Also, a higher index leads to a lower maximum momentum at which  $\pi$ 's and  $K$ 's can be separated by the RICH technique.

However, RICH detectors seldom have too much signal, and some compromise on the value of  $n$  may be in order if another liquid is significantly more transparent. A large variety of fluorinated hydrocarbon liquids of excellent purity are available from the 3M Fluorinert Products Division. In particular they recommend that  $C_8F_{18}$  (called FC-104 by 3M) be considered if uv transparency is critical. The index of  $C_8F_{18}$  is quoted as being only 1.29, 0.02 larger than that of  $C_6F_{14}$ , and so seems still safely below  $\sqrt{2}$ .

We have evaluated a sample of  $C_8F_{18}$  with our spectrophotometer and it is indeed more transparent than  $C_6F_{14}$  down to 190 nm, the operating limit of our instrument. We are presently unable to address the critical issue of whether  $C_8F_{18}$  is transparent down to 170 nm, the cutoff of quartz windows. For this we propose to purchase a vacuum spectrophotometer to study the transparency of this and other liquids, as well as that of the windows for RICH counters.

### 4.2.2 Preparation of High Quantum-Efficiency Photocathodes

As remarked in the Progress Report, only recently have we been able to produce CsI photocathodes at Princeton with extremely high quantum efficiency. Continuing efforts will be required to insure that these high efficiencies can be reproduced on a routine basis.

Various improvements to our vacuum-deposition system will no doubt be needed. We have certainly benefited from our recent conversion from an oil-diffusion pump to an oil-free molecular-drag/diaphragm pump combination. However, the oil-free pump has a rather low pumping speed and is more appropriate for our test chambers than for the relatively large volume of bell jar of the evaporator. We propose to purchase a Balzers TSH180H turbomolecular/molecular-drag/diaphragm pump combination for use with the vacuum evaporator.

### 4.2.3 Cosmic-Ray Test Chambers

There are no test beams available in the U.S. until summer 1993, when we will return to BNL. In the meanwhile cosmic ray can be used as test particles, albeit at a rather low rate. Our present test chambers at Princeton have cathodes of area only about 4 cm<sup>2</sup>, which leads to cosmic-ray event rates of only a few per hour when some directionality is required.

We therefore propose to construct a pair of test chambers with 20-cm-diameter cathodes. The mechanical design of these chambers is sketched in Fig. 6, and is based on the general features of the prototype chamber we tested at BNL earlier this year. Initially we will read each chamber out as a single large pad. We can easily calibrate the test chamber for single photons using our pulsed hydrogen lamp. Then the total number of Čerenkov photons can be measured even though rings are not resolved.

The test chambers will then be used to verify the improvements in Čerenkov-photon yield due to increased transparency of the radiator and enhanced quantum efficiency of the photocathode.

### 4.2.4 CsI Photocathodes for Time-of-Flight Counters

Parallel-plate chambers with CsI cathodes have excellent timing properties in principle: time resolutions of better than 100 ps should be achievable. Some effort was made at Fermilab in the last year to explore the use of these chambers as time-of-flight counters, but that work was not carried to a conclusion. We propose to pursue this topic further in the next year, using the new test chambers discussed in the previous section with cosmic rays as the test particles.

We wish to explore a variation on cathode construction, in which a semitransparent CsI cathode is deposited on a thin transparent conducting film which is in turn deposited on a quartz window. In this case the anode plane could be continuous, rather than a wire mesh as in present chambers.

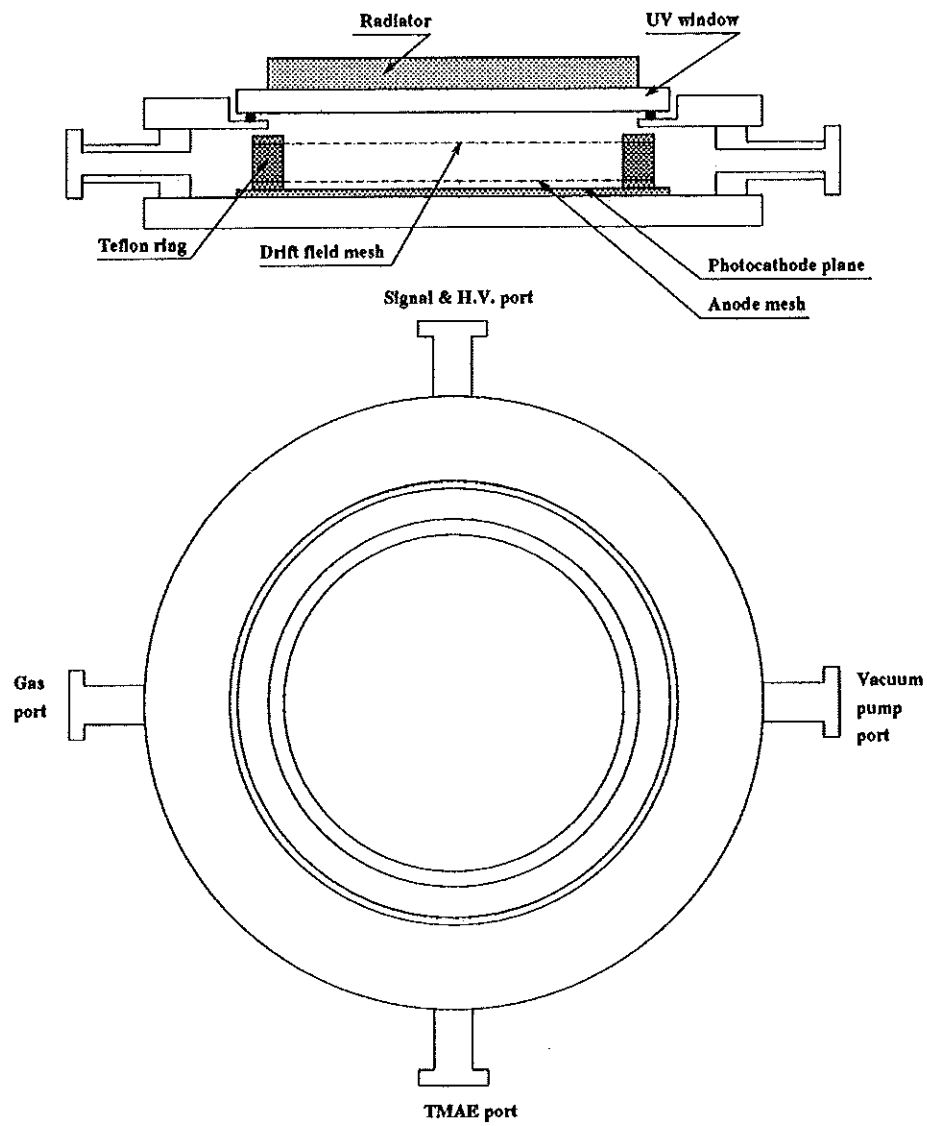


Figure 6: Sketch of the proposed test chambers for studies of Čerenkov yield and of time-of-flight at Princeton U.

#### 4.2.5 Atmospheric-Pressure RICH Detectors with CsI

All chambers constructed with CsI photocathodes thus far have been built as vacuum vessels for low-pressure operation. If the transparency of the radiator can be extended down to 170 nm and very high quantum efficiencies achieved, there will be sufficient light that we can afford to pay the factor-of-two penalty for operation at atmospheric pressure. This would greatly simplify the construction of large RICH detectors based on CsI photocathodes.

We will construct a prototype detector for atmospheric-pressure operation only, *i.e.*, it will not be a vacuum vessel. The first version would have only a single readout pad, as the main purpose is to explore construction techniques. Later versions would implement an array of pad for detection of Čerenkov rings.

We plan to explore the use of semitransparent photocathodes. These are standard in photomultiplier tubes, but have not yet been studied in the parallel-plate RICH detectors. A device with a semitransparent photocathode deposited on the quartz window would not need a wire-mesh anode. Thus we could avoid the  $\approx 25\%$  loss of light in the mesh, and also the problem of stretching the mesh uniformly over large areas.

#### 4.2.6 Beam Tests

We will return to the BNL test beam in summer 1993 to test the various chambers described above the we have built this winter. We anticipate that in these tests we will demonstrate devices with 15-25 photoelectrons per ring, which would be fully viable as detectors in high-energy-physics experiments.

## 5 Budget Proposal for FY93

### 5.1 U. Penn

In FY93 we will continue studies of the present prototype RICH detector. We envision several improvements to the present design that will improve the performance of the detector. The goal is to increase the number of detected photoelectrons from 5 to 20. This will require improvements to the chamber vacuum system and better transfer procedures between the evaporator and the chamber. We will measure the position resolution of the pad chamber and hence the ring size and width. This requires a small cosmic ray tracking system. Finally we plan to go back to the Brookhaven testbeam next summer and try to distinguish  $\pi^\pm$  from  $K^\pm$  with the prototype RICH detector.

#### 1. Permanent Equipment

1. Turbopump (Balzers TSH180H).....\$12k
2. 16-CFM vacuum pump, Leybold Model-D16B ..... \$2k

3. Nitrogen Box .....	\$3k
4. Two pressure transducers (Edwards 600A).....	\$2k
5. Hydrogen lamp (Hamamatsu) .....	\$2k
6. Two positive high-voltage power supplies (Bertan 377).....	\$4k
7. NIM electronics: Power Supply for crate, quad discriminator, quad coincidence, gate generator, quad BCD scalar .....	\$10k
8. CAMAC electronics: 4 TDC's and 4 discriminators, 12-channel ADC, Dataway Display, I/O Register.....	\$20k
9. Ortec 147PC preamp, 570 shaping amplifier, MCB916 multichannel ana- lyzer.....	\$5k
10. Digital scope, cart and printer Tek TDS620).....	\$15k
11. Two 6-digit DMM (HP 34401A).....	\$2k
12. Pulse generator (Lecroy 9210/9211/9212).....	\$10k
13. Gas Mixing System (MKS 147/250/1250/1239).....	\$10k
14. Moisture sensors (Kahn Cermet) .....	\$4k
15. Postscript Printer.....	\$3k
16. Workstation for Camac data-acquisition system.....	\$8k

**Total Permanent Equipment.....\$112k**

**2. Materials, Supplies, and Travel**

1. Material for drift chambers .....	\$2k
2. Material for small Čerenkov test chamber .....	\$3k
3. Electronics for Isolation Circuits and ribbon cable.....	\$5k
4. Stainless-steel fittings, tubing, valves, <i>etc.</i> .....	\$5k
5. High-purity chamber gases .....	\$2k
6. Oxisorb Cannisters .....	\$2k
7. Operating funds for travel, publications, and miscellaneous supplies	\$10k

**Total Materials, Supplies, and Travel .....** \$29k

**Indirect Costs of 62% on Materials, Supplies, and Travel.....** \$18k

**3. Salaries**

1. J. Millan (Electrical Engineering Ph.D. candidate) 50% Tuition ....	\$10k
2. J. Millan (EE) \$1.6k stipend per month .....	\$19k



Total Salaries.....	\$29k
Indirect Costs of 62% on Salaries .....	\$12k
Total University of Pennsylvania.....	\$200k

## 5.2 Princeton U.

We seek no funds for equipment in the present proposal, as a separate proposal for equipment will be submitted by Princeton U. to the Texas National Research Laboratory Commission. Here we seek only operating funds, which are not readily available through the TNRLC who will not fund indirect costs.

Table 1: Proposed budget for Princeton U. in FY93.

1. Materials and supplies for chamber construction	\$15k
2. Travel	\$4k
3. Indirect costs on items 1 and 2	\$11k
<b>Total</b>	<b>\$30k</b>

## 5.3 U.Puerto Rico

We seek funds to participate in the beam tests at Brookhaven next summer. We request funds for one summer student and travel expenses to BNL.

Table 2: Proposed budget for U. Puerto Rico in FY93.

1. Salaries	\$2k
2. Travel	\$2k
3. Indirect costs on items 1 and 2	\$2k
<b>Total</b>	<b>\$6k</b>

## References

- [1] J. Séguinot and T. Ypsilantis, *Photo-ionization and Čerenkov Ring Imaging*, Nucl. Instr. and Meth. **142** (1977) 377.
- [2] D.W.G.S. Leith, *Status of Čerenkov Ring Imaging Systems*, Nucl. Instr. and Meth. **A265** (1988) 120.
- [3] R. Arnold *et al.*, *A Ring Imaging Čerenkov Detector for the Delphi Barrel RICH Prototype* Nucl. Instr. and Meth. **A270** (1988) 255, 289.
- [4] A. Breskin *et al.*, *In Beam Performance of a Low-Pressure UV RICH Detector*, IEEE Trans. Nucl. Sci. **35** (1988) 404.
- [5] V. Vasileiadis *et al.*, *Development of a RICH Detector for Ultrarelativistic Heavy Ion Collisions*, Nucl. Instr. and Meth. **A289** (1990) 618.
- [6] G.B. Coutrakon, B. Biggs and S. Dhawan, *Ring Imaging Čerenkov Detector Prototype Results*, IEEE Trans. Nucl. Sci. **33** (1986) 205.
- [7] A.H. Sommer, *Photocmissive Materials*, Wiley (New York, 1968).
- [8] L. Heroux, W.J. McMahon and H.E. Hinteregger, *The Influence of Cathode Thickness and Aging on the Photoelectric Yields of LiF and CsI in the xuv*, Appl. Opt. **5** (1966) 1338.
- [9] B. Hoeneisen, D. F. Anderson and S. Kwan, *A CsI-TMAE Photocathode with Low-Pressure Readout for RICH*, Nucl. Instr. and Meth. **A302** (1991) 447.
- [10] S. Kwan and D.F. Anderson, *A Study of the CsI-TMAE Photocathode*, Nucl. Instr. and Meth. **A309** (1991) 190.
- [11] D.F. Anderson *et al.*, *Properties of CsI and CsI-TMAE Photocathodes*, Fermilab-Conf-92/13 (June 1992), accepted for publication in Nucl. Instr. and Meth.
- [12] V. Peskov *et al.*, *Liquid and Solid Organic Photocathodes*, Nucl. Instr. and Meth. **A269** (1988) 149.
- [13] J. Séguinot *et al.*, *Reflective UV Photocathodes with Gas-Phase Electron Extraction: Solid, Liquid, and Adsorbed Thin films*, Nucl. Instr. and Meth. **A297** (1991) 133.
- [14] G. Charpak *et al.*, *Investigation of Operation of a Parallel-Plate Avalanche Chamber with a CsI Photocathode Under High Gain Conditions*, Nucl. Instr. and Meth. **A307** (1991) 63.
- [15] V. Dangendorf *et al.*, Nucl. Instr. and Meth. **A289** (1990) 322.

- [16] V. Dangendorf *et al.*, *Progress in Ultrafast CsI-Photocathode Gaseous Imaging Photomultipliers*, Nucl. Instr. and Meth. **A308** (1991) 519.
- [17] N.S. Lockyer *et al.*, *Observation of Čerenkov Rings Using a Low-Pressure Parallel-Plate Chamber and a Solid Cesium-Iodide Photocathode*, UPR-0217E, Princeton/HEP/92-08 (Sept. 1992).
- [18] D.F. Anderson *et al.*, *Coupling of a BaF<sub>2</sub> Scintillator to a TMAE Photocathode and a Low-Pressure Wire Chamber*, Nucl. Instr. and Meth. **217** (1983) 217.
- [19] S. Kleinfelder *et al.*, *A Flexible 128 Channel Silicon Strip Detector Instrumentation Integrated Circuit with Sparse Data Readout*, IEEE Trans. Nucl. Sci. **35** (1988) 171.
- [20] F.A. Kirsten and C. Haber, *A Versatile, Programmable Control and Data Acquisition System for Complex Integrated Circuits*, IEEE Trans. Nuc. Sci. **37** (1990) 288.