Request to the

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Development of Detectors for the Superconducting Super Collider

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Executive Summary

We seek **$200k** from the TNRLC in FY1994 to continue our ongoing program of detector R&D for the Superconducting Super Collider. Matching funds of $18k will be provided by Princeton University and $xx by U. Pennsylvania. Emphasis will be placed on development of fast ring-imaging-Čerenkov detectors with CsI photocathodes for particle identification. Thin CsI will also be incorporated in time-of-flight detectors. We will also develop custom VLSI electronics for these pixel detectors.

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1 Description of the Research

1.1 Introduction

Particle identification is essential for experiments that plan to study CP violation in the B-meson system. The Superconducting Super Collider is the ultimate 'B factory,' offering the best combination of high rates ($\gtrsim 10^{12}$ B's per year) and good signal to noise (roughly 1 event in 50 at the SSC is expected to contain a B particle. However, improved detector elements are required to profit from this splendid physics opportunity.

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 $B \to J/\psi K_S^0$. 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 $b \to c \to s$ will tag with high efficiency the conjugation of the parent B meson. Čerenkov detectors provide a method of separating charged π's from K's and will therefore be important in the tagging process.

Several others methods have been proposed to measure CP-violating phases in B-meson decays that are also free of ambiguities due to strong interactions [1]. Most of these involve decays to non-CP eigenstates that contain D^0 mesons. The latter decay to final states containing a charged Kaon with high probability, so Kaon identification is also vital for these additional measurements of CP violation.

The Ring Imaging Čerenkov (RICH) detector [2] provides π 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 [3] and Delphi [4], 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 [5, 6]. 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 photosenstive layer [5, 6, 7].

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 [8], and it is established under certain circumstances they deliver high quantum efficiency, but their performance is readily degraded by absorption of water vapor [9].

In the last two years the work of the Anderson group at Fermilab [10, 11, 12], the Charpak group at CERN [13, 15], the Ypsilantis group at Collège de France [14], and the Breskin group in Israel [16, 17] indicates great promise for RICH detectors using high-quantum-efficiency CsI photocathodes. The fast time response of the solid photocathode [10, 15] 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. Futhermore, there is little loss of photoelectrons due to backscattering onto the cathode [19], 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 π/K separation.

In FY92 we built and tested a parallel-plate, low-pressure RICH detector with a CsI photocathode evaporated onto cathode pads [18]. We believe this constitutes the first observation of Čerenkov rings in a detector with a CsI photocathode. This proposal is for continuation of that research program in FY93.

1.2 Proposed Research

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 the viability of semitransparent CsI photocathodes.
5. Study of possible gain in quantum efficiency by use of a LiF substrate.
6. Investigation of spray technology for production of photocathodes.
7. Construction of prototype atmospheric-pressure RICH detectors with CSI photocathodes.
8. Study of low-density CsI cathodes for use in time-of-flight counters.
9. Testing of various photocathode detectors at BNL in summer '93.

1.2.1 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° after exiting the liquid. Recall that

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

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 π'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.

1.2.2 Preparation of High Quantum-Efficiency Photocathodes

As remarked in section 3, 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 (item A1 of the Budget Explanation Page) along with an ion-gauge controller to monitor the operating pressure (item A4).

1.2.3 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^2, 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 (item A2). The mechanical design of these chambers is sketched in Fig. 1, 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

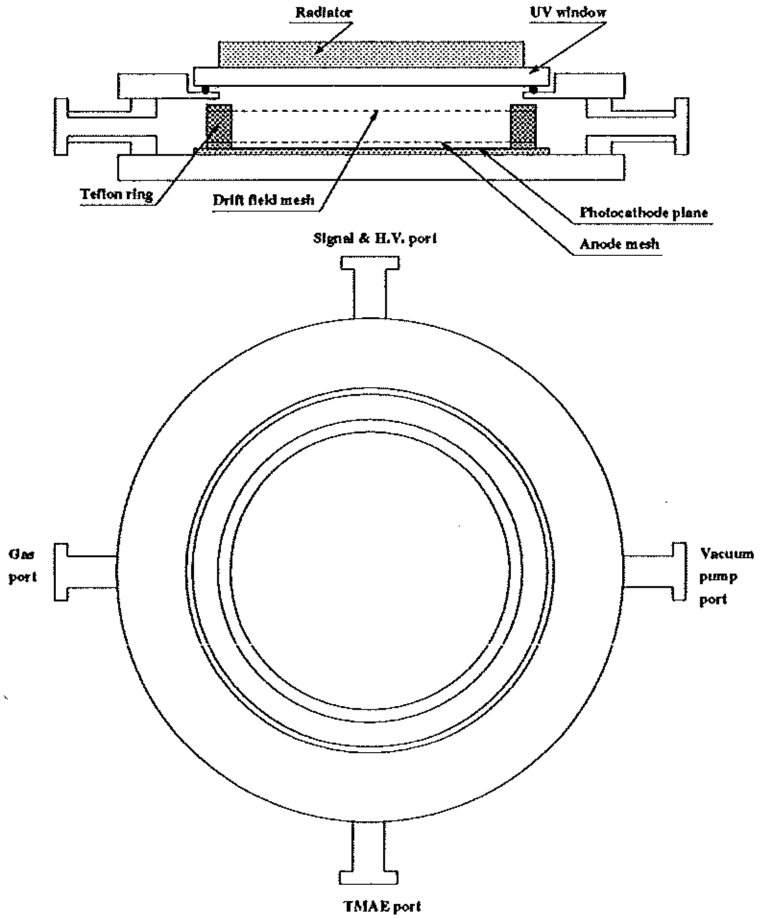

Figure 1: Sketch of the proposed test chambers for studies of Čerenkov yield and of time-of-flight at Princeton U.

photocathode.

1.2.4 Semitransparent Photocathodes

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.

1.2.5 LiF Substrate

In present CsI photocathodes many of the photoelectrons are lost as their momentum points away from the surface. Some of these are likely recovered by scattering in a thick CsI layer. Although the photoabsorption depth in CsI is only a few hundred Angstroms, there is a slow rise in quantum efficiency for thicknesses up to 1 μm, possibly due to favorable backscattering.

We plan to try an alternative method of obtaining backscattering: use of thin CsI layers on a thin LiF (or NaF) substrate. Lithium flouride has the largest bandgap energy ($\approx$ 11 V) of any alkali halide, which is much larger than the energy of photoelectrons of interest in RICH detectors. Hence we expect photoelectrons from CsI to be reflected back at a CsI-LiF interface.

If this hypothesis proves correct, the gain in quantum efficiency could be especially useful for semitransparent cathodes.

1.2.6 Spray-on Photocathodes

We would like to explore the viability of spraying CsI dissolved in methanol onto the cathode, rather than evaporating it as presently done. The spraying could be performed in a glove box (item A9) with a dry-N_2 atmosphere, avoided any exposure of the cathode to room air. Small-scale spraying tests at Fermilab are quite encouraging [12].

We propose to purchase a precision spray nozzle and controller (item A7), and construct an automated x-y stage (item A8) to move the nozzle over the cathode in a controlled pattern. Past efforts using an air brush have not provided sufficient uniformity of the cathode thickness, and a better technique must be achieved.

1.2.7 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 $\approx 25\%$ 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.

The new test chambers should have an associated oil-free pump (item A3) and ion-gauge controller (item A4).

1.2.8 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 will also extend our work on low-density CsI films, discussed in section 3.3, which have better electron transport properties than bulk-density material. The goal is to obtain 30 or more secondary-emission electrons from passage of a minimum-ionizing particle, which is not possible in full-density films. We must achieve greater control over the density of the films (~ 0.03 gm/cm^3 is desirable), for which the improved vacuum system of our evaporator (items A1 and A4) will be important.

1.2.9 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.

1.2.10 Infrastructure Support

As discussed further in sec. 2.7, an important part of our use of TNRLC funding in FY91 and FY92 has been toward infrastructure improvements. We wish to devote part of prospective FY93 funding in this manner.

In particular, we have hired an electrical engineer who has helped us establish a strong electronics CAD capability based on Mentor Graphics software running on Sun workstations. We propose 5 months of this engineer's salary in FY93 (item D1) to be funded by the present grant renewal. The use of the CAD workstations has been highly successful with both students and the electronics-group staff (five FastBus boards designed, fabricated and tested in the last 6 months) that we propose to add two more workstations (item B1).

We also propose to purchase several items of electronics (items B2-4 and C1-4) in support of the development of the fast RICH detectors. A PC computer, data acquisition system, power supplies, and trigger electronics will be used to establish the cosmic-ray test stand discussed in sec. 2.2.3. The fast pulser and oscilloscopes are needed to characterize the high-rate performance of the detectors.

1.3 Research Personnel

The proposed R&D program on particle identification will be pursued full-time by C. Lu, and part-time (in order of decreasing fraction of their time) by K. McDonald, E. Prebys, and D. Marlow. Two graduate students, V. Balasubramanian and Y. Zhu participate in the program at present. Participation by Princeton U. technical staff is mentioned in sec. 2.6.

1.4 Methodology

The clear test of success of detectors of elementary-particles is their successful operation in a high-energy particle beam. So our efforts in FY91 and FY92 have both included beam tests of prototype devices, and we anticipate further beam tests in FY93.

In preparation for these tests (in which the national accelerator labs contribute beam time and modest technical support free – a kind of matching funds!) we first maximize our understanding of the detectors on the test bench, using radioactive sources of charged particles, and photon sources (lamps).

1.5 Relevance to the SSC

As discussed in sec. 2.1, hadron identification is of particular interest to a possible B-meson physics program at the SSC. The high multiplicities and high rates at the SSC require detectors for particle identification with good segmentation and high-speed operation. RICH counters are well suited to high particle multiplicity, but past implementations have use readout schemes unsuitable for high rates. Hence new technologies must be developed, which is the motivation for the present proposal.

1.6 Institutional Commitment and Sources of Additional Support

Princeton U. and the DoE provide salary support for all physics researchers associated with this proposal. In addition the DoE high-energy-physics grant to Princeton provides salaries for a staff of a mechanical engineer, four mechanical technicians, and three electronics technicians; they work part-time in support of the R&D funded by the TNRLC at no direct cost to the Grant.

Princeton U. has provided three kinds of matching funds for the TNRLC grants in FY91 and FY92: funds from the Physics Department endowed research fund; funds from the Provost's office, and contribution of indirect costs on the salary (+ benefits) for the electrical engineer supported in part by the TNRLC grant. In FY93 only matching funds in the form of indirect costs will be available from Princeton U. for this proposal.

In addition we wish to note that the TNRLC funding has given us great leverage in obtaining special discounts from equipment vendors. These can properly be considered as industry-sponsored matching funds for our R&D program. The largest 'discount' in the past was from Mentor Graphics who awarded us a software grant of $309k (list price) of CAD software in FY91. We receive free software upgrades from Mentor Graphics on a continuing basis. Sun Microsystems has extended us 50% matching funds ($30k in FY91 and $12k in FY92) on the purchase of the workstations to run the CAD software as one of us (P.D. Meyers) is a Presidential Young Investigator. We anticipate an additional $30k discount from Sun in FY93.

1.7 Impact on Infrastructure of Science and Engineering

The TNRLC grants to Princeton in FY91 and FY92 have had an enormous effect in enhancing the technical infrastructure for high-energy physics at Princeton. We have purchased several major pieces of equipment that are extremely difficult to obtain (at universities) via historical funding trends by the DoE (our main source of support): a clean room, a (used) coordinate measuring machine, two lathes, three milling machines, a logic analyzer, a spectrum analyzer, a 20-GHz sampling oscilloscope. In addition, many smaller equipment items were purchased that are more typical of those obtainable via DoE HEP support, but which could not have been otherwise purchased under present funding restrictions.

These items represent an investment in infrastructure that will benefit our physics program for 10-15 years. The horizons for students entering our field are much broader because of this, and their future contributions as mature physicists will be one to the greatest payoffs of the initiative of the TNRLC.

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3 Resumé of Kirk T. McDonald

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1972	Caltech	Ph.D. (Physics)

Professional Employment:

1972-74	CERN	Research Scientist
1975-76	U. Chicago	Enrico Fermi Fellow
1976-80	Princeton U.	Assistant Professor
1980-85	Princeton U.	Associate Professor
1985-	Princeton U.	Professor

Recent publications:

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