Fermi National Accelerator Laboratory

FERMILAB-Conf-93/148

A Fast Ring-Imaging Cherenkov Counter for a Fixed-Target Heavy-Quark Experiment

D.M. Kaplan

Northern Illinois University
DeKalb, Illinois 60115

L.D. Isenhower

Abilene Christian University
Abilene, Texas 79699

M. Atac and C.N. Brown

Fermi National Accelerator Laboratory
Batavia, Illinois 60510

C.W. Darden

University of South Carolina
Columbia, South Carolina 29208

June 1993

Presented at the *1st Workshop on Rich Detectors*, Bari, Italy, June 1-5, 1993

A FAST RING-IMAGING CHERENKOV COUNTER FOR A FIXED-TARGET HEAVY-QUARK EXPERIMENT

D. M. KAPLAN
Northern Illinois University, DeKalb, IL 60115, USA

L. D. ISENHOWER
Abilene Christian University, Abilene, TX 79699, USA

M. ATAC[1] and C. N. BROWN
Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

C. W. DARDEN
University of S. Carolina, Columbia, SC 29208, USA

We present a design for a fast ring-imaging Cherenkov counter operating in the visible. The Cherenkov photons are imaged on an array of small Winston cones and read out with optical fibers and VLPCs. The design is optimized for $\pi/K/p$ separation in the range $10 < p < 100$ GeV/c.

1. Introduction

For the proposed fixed-target heavy-quark experiment Fermilab P865 [1], we have designed a novel ring-imaging Cherenkov counter (RICH) optimized for the momentum range $10 < p < 100$ GeV/c. To achieve the desired charm and beauty sensitivities, P865 proposes to operate with large acceptance at $\approx$50 MHz interaction rate, imposing on the RICH the requirements of high speed and granularity. Since many decay modes of charm and beauty yield strange particles, a RICH is particularly advantageous for this physics: in particular, identified charged kaons can be used to reduce combinatoric backgrounds, and to tag the charm or beauty quantum number in the case of an incompletely-reconstructed decay. A series of threshold Cherenkov counters could serve this purpose, but a RICH can identify hadrons over a larger momentum range and with shorter counter length, thereby reducing the total cost of the spectrometer. In addition, a RICH is better able to cope with the high density of particles produced at small angles.

2. Ring-imaging Cherenkov counter

Optimization of the design is still under study, but we have sketched a possible solution. The counter is to be located 4.5 m downstream of the target and to instrument the aperture $|\theta_x| < 0.2$, $|\theta_y| < 0.16$. Figure 1 shows the proposed layout. The counter is $3 \times 2.4 \times 2\,\text{m}^3$ in size ($x \times y \times z$). The Cherenkov radiator is 1.9 m of gas at 1 atmosphere, consisting of 80% C_4F_{10} mixed with 20% argon. This gives a Cherenkov angle of 50 mr for a $\beta = 1$ particle, and $\pi/K/p$ momentum thresholds of 3/10/19 GeV/c. Sixteen rectangular mirrors,

[1] also at University of California at Los Angeles, Los Angeles, CA 90024

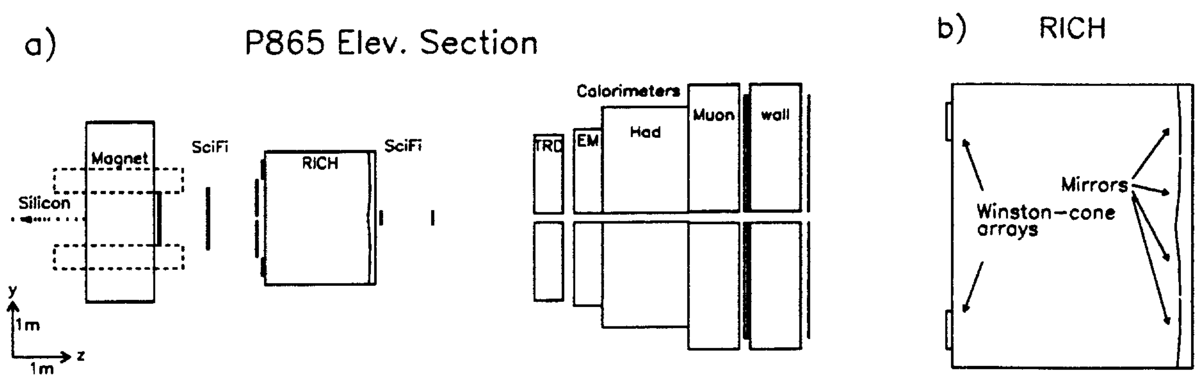

Figure 1: a) elevation of P865 apparatus; b) elevation of proposed RICH

each $70 \times 55\,\text{cm}^2$ and of 1.9 m focal length, focus the Cherenkov light on two 64-by-64-element hexagonal arrays of Winston cones [2] on 5 mm centers, located at the ring foci outside the active aperture. The cones concentrate the Cherenkov photons onto clear optical fibers of 1 mm diameter, which transport the photons to 8,192 solid-state low-temperature "visible-light photon counters" (VLPCs) [3] external to the radiator volume. The VLPCs will detect ≈ 100 photoelectrons per ring at $\beta = 1$ (spread over ≈ 120 cells), determining the Cherenkov-ring radius to ≈ 0.2 mm RMS. This will allow π/K separation to about 85 (100) GeV/c at 3 (2) σ, and K/p separation to 145 (175) GeV/c at 3 (2) σ. In this estimate, we have taken into account expected contributions from off-axis and spherical aberrations, coma, and astigmatism; we expect astigmatism to dominate over the other aberrations, contributing ≈ 1 mm RMS per detected photon.

The optical fibers could be of the "multiclad" type developed by the Kuraray Co. for SDC. These have a polystyrene core, a PMMA inner cladding, and a fluorinated outer cladding, giving an acceptance-angle range of $\pm 26°$ and an attenuation length of ≈ 9 m at a wavelength of 500 nm [4]. Since the Winston cones increase the angular divergence of the incident light by a factor of 6, Cherenkov photons are accepted by the fibers over a range of $\pm 4°$. Attenuation in the polystyrene causes a significant loss of photoelectrons, amounting to some 30% for 1 m fiber length. We are therefore investigating whether glass fibers could be employed, with a minimum length of polystyrene fiber (≈ 15 cm) retained inside the VLPC cryocassettes to suppress infrared noise.

VLPCs have been under development for some years by a Fermilab/UCLA/Rockwell International Science Center collaboration (led by M. Atac), with the goal of detecting light from scintillating fibers [5]. A second application of VLPCs to high-energy physics, the detection of Cherenkov light from an optical impact-parameter triggering device for heavy-quark decays, has recently been proposed [6]. We here propose a third application: VLPCs are highly suitable for Cherenkov ring imaging due to their high quantum efficiency, low

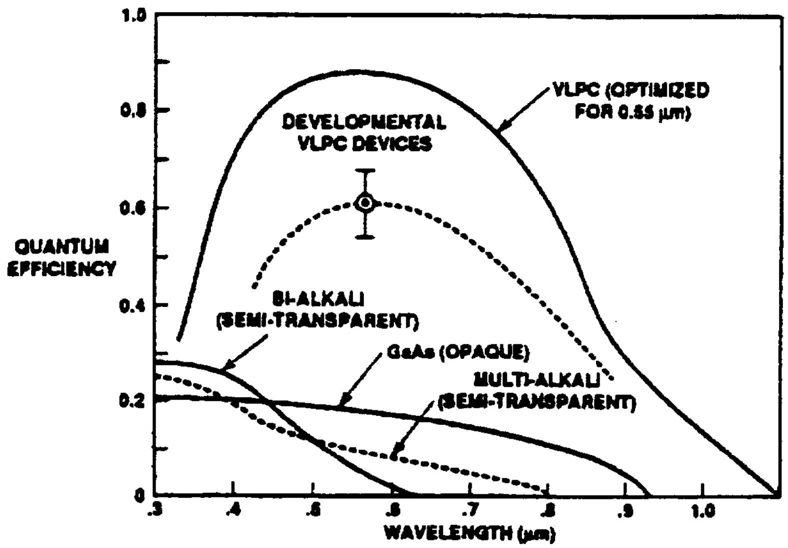

Figure 2: Quantum efficiency vs. wavelength for various photodetectors (from [7]).

noise, and high speed. Quantum efficiency as high as 85% for green light has been achieved [7] (see Figure 2), and 30-MHz rate capability has been demonstrated, with single-electron noise rates of several kHz [3]. Working in the visible portion of the Cherenkov spectrum rather than the UV has several advantages:

- The optical fibers can enter the radiator-gas volume, so that no additional windows are required.
- The mirrors do not have to work in the UV part of the spectrum.
- Requirements for radiator-gas purification are substantially eased.
- Partial instrumentation is easy, so that a phased construction plan can be followed.
- The shape of the detector plane can be optimized to reduce aberrations and astigmatism.

The photoelectron yield estimate given above is based on the assumption of 1-m-long polystyrene fibers and VLPCs having 60% peak quantum efficiency. Since VLPCs are still in a developmental stage, their fabrication yield vs. quantum efficiency and noise rate remains to be established. However, Rockwell is confident of achieving $> 65\%$ quantum efficiency routinely in future production runs [8]. This issue will be clarified in upcoming tests of large numbers of channels by the D0 [9] and SDC collaborations.

References

[1] L. D. Isenhower *et al.*, "P865: Revised Letter of Intent for a High-Sensitivity Study of Charm and Beauty Decays," D. M. Kaplan, spokesperson, April 2, 1993.

[2] H. Hinterberger and R. Winston, Rev. Sci. Instr. **37** (1966) 1094; R. Winston, J. Opt. Soc. Am. **60** (1970) 245.

[3] M. D. Petroff and W. G. Stapelbroek, IEEE Trans. Nucl. Sci. **NS-36** (1989) 158.

[4] M. Atac, C. N. Kim, M. Mishina, and R. Ruchti, in preparation.

[5] M. D. Petroff and M. Atac, IEEE Trans. Nucl. Sci. 36 (1989) 163; M. Atac *et al.*, Nucl. Instr. & Meth. **A314** (1992) 56; M. Atac *et al.*, Nucl. Instr. & Meth. **A320** (1992) 155.

[6] G. Charpak, L. M. Lederman, and Y. Giomataris, Nucl. Instr. & Meth. **A306**, 439 (1991); D. M. Kaplan *et al.*, "Test of Principle of an Optical Trigger for Beauty," FERMILAB-Pub-93/002, to appear in Nucl. Instr. & Meth. (1993); G. Charpak *et al.*, "Experimental Study of an Impact-Parameter Optical Discriminator", CERN-PPE/93-14, submitted to Nucl. Instr. & Meth. (1993).

[7] M. G. Stapelbroek, M. D. Petroff, and R. Bharat, "Visible Light Photon Counters for Astronomy," to appear in *Proceedings of an ESA Symposium on Photon Detectors for Space Instrumentation*, ESA/ESTEC, Noordwijk, The Netherlands, 10–12 November 1992.

[8] P. Besser and M. D. Petroff, Rockwell International Science Center, private communication.

[9] See e.g. M. Wayne, "A Scintillating Fiber Detector for the D0 Upgrade," presented at the *7th Meeting of the American Physical Society Division of Particles and Fields (DPF '92)*, Fermi National Accelerator Laboratory, Batavia, Illinois, November 10–14, 1992.