THE E771 RING IMAGING CHERENKOV DETECTOR

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Abstract

The preliminary design of the ring imaging Cherenkov detector proposed for Fermilab beauty experiment E771 is described. It is designed with a 2 m length of C_4F_{10} radiator gas. The Cherenkov rings will be detected with MWPC's with pad readout using TMAE. Discrimination between π's and K's up to $\approx$ 160 GeV/c should be feasible.

Introduction

A ring imaging Cherenkov (RICH) detector is proposed for E771 to perform π/K separation in the study of $B \rightarrow J/\psi + X$ decays. RICH detectors have been built and run in E605 at Fermilab[1] and in the Omega Spectrometer at CERN[2]. New experiments which are building RICH detectors are the SLD experiment at SLAC[3], the DELPHI experiment at LEP[4], and E665 at Fermilab[5].

The basic equations for Cherenkov radiation are now well known (see Ref. 6 and 7 for various formulations). The threshold Lorentz factor γ_{th} for a gas of index of refraction n is given by

$$\gamma_{th} = \frac{1}{\sqrt{1-\frac{1}{n^2}}} \approx \frac{1}{\sqrt{2(n-1)}} .$$

The Cherenkov angle θ is given by

$$\theta = \arccos\left(\frac{1}{n\sqrt{1-1/\gamma^2}}\right) \approx \frac{1}{\gamma_{th}}\left(\frac{\gamma^2-\gamma_{th}^2}{\gamma^2-1}\right) .$$

The maximum Cherenkov angle θ_∞ (when $\gamma = \infty$) is given by

$$\theta_\infty \approx \frac{1}{\gamma_{th}} .$$

If a spherical mirror of focal length f is used to focus the Cherenkov light the radius r of the Cherenkov ring at the focal plane is given by

$$r = f \tan\theta \approx f\theta .$$

The number of photoelectrons N is given by

$$N = N_0 L \sin^2\theta \approx N_0 L\theta^2 .$$

The maximum number of photoelectrons N_∞ (when $\gamma = \infty$) is given by

$$N_\infty \approx N_0 L\theta_\infty^2 \approx \frac{N_0 L}{\gamma_{th}^2} .$$

L is the length of the gas radiator and N_0 is a quality factor which includes factors such as transmission of the radiator gas, the reflectivity of the mirrors, the transmission of the windows, and the quantum efficiency of the detector gas. Design values of N_0 have ranged from 90 cm^{-1} [2] to 150 cm^{-1} [7]. We will use a value of $N_0 = 90$ cm^{-1} throughout the remainder of this report.

Description of Detector

We propose to build a RICH detector with a 2 m length of radiator gas. For the momentum range of interest C_4F_{10} should perform well as a radiator gas. C_4F_{10} has a $\gamma_{th} \approx 20$. If a higher γ_{th} is needed, then a gas such as N_2 can be used.

Within the radiator gas there will be a 4×2 array of spherical mirrors covering an area of $120" \times 60"$. Each of the 8 mirrors will be $30" \times 30"$ and have a 3 m focal length (6 m radius of curvature). The mirrors will be placed 4.5 m downstream from the center of the analysis magnet (called Rosie) and will be tilted so that the Cherenkov rings will be focussed onto a chamber outside of the aperture of the experiment. The mirrors will have a region of $\approx$ 12 cm radius around the beam removed so that Cherenkov rings from the non-interacting 800 GeV/c proton beam will not be detected. The portion of the radiator gas vessel within the experiment aperture and the mirror supports must be kept thin to reduce loss of photons from the interactions and to minimise multiple scattering of charged particles.

An MWPC using TMAE is proposed as the detector of the Cherenkov rings. There will be two MWPC's on the East and West side of Rosie. Each MWPC will have an active area of $30" \times 30"$ and will have a design similar to that tested by E665[5]. Each chamber will have an anode wire spacing of 2 mm and will have cathode pads of size 2 mm $\times$ 50 mm positioned perpendicular to that anode wires. The two chambers together will have $\approx$ 12200 channels to be read out. CaF_2 windows covering the active area of the chambers will be used to separate the radiator gas from the detector gas and allow transmission of the Cherenkov photons.

Fig. 1 shows the isometric view of the experiment. Fig. 2a shows the number of photoelectrons from 2 m of C_4F_{10} vs momentum. Fig. 2b shows the radius of the Cherenkov rings (using a 3 m focal length) vs momentum. Fig. 3a is from Ref. 5 and shows the chamber design we are considering. Fig. 3b show the geometry of the cathode pads and anode wires. Fig. 4 shows the quantum efficiency of TMAE and the transmission of CaF_2 windows.

Expected Performance

The RICH detector is to be used to separate π's and K's from $B \rightarrow J/\psi + X$ decays. The limit on resolving π's and K's at high momentum is due to chromatic dispersion in the radiator gas and the resolution of the chamber. The chromatic dispersion of C_4F_{10} is characterized by $\frac{\Delta\theta_\infty}{\theta_\infty} \approx 4 \times 10^{-3}$. At a given momentum P the quantity[7]

$$n_\sigma = \frac{\theta_\pi - \theta_K}{\sqrt{\Delta\theta_\pi^2 / N_\pi}}$$

represents the number of standard deviations n_σ to discriminate against a pion being identified as a kaon. Now

$$\Delta\theta_\pi^2 = \Delta\theta_{chrom}^2 + \Delta\theta_{geom}^2$$

where $\Delta\theta_{chrom} = \frac{\Delta\theta_\infty}{\theta_\infty} \frac{1}{\gamma_{th}\sqrt{1 - \gamma_{th}^2/\gamma^2}}$ is the chromatic dispersion due to radiator gas and $\Delta\theta_{geom} = \frac{s}{\sqrt{12} f}$ is the geometric resolution due to chamber wire spacing s and focal length f.

Fig. 5a shows n_σ vs momentum for 1 m, 2 m, and 3 m of C_4F_{10} with a 2 mm chamber wire spacing. Fig. 5b shows n_σ vs momentum for 1 mm, 2 mm, and 3 mm chamber wire spacing with 2 m of C_4F_{10}. Table I shows some of the properties of N_2 compared to C_4F_{10}. The proposed detector having 2 m of C_4F_{10} and a 2 mm chamber wire spacing should be able to identify π's from K's at a 2σ level over a momentum range of 3 to 165 GeV/c.

The average charged multiplicity within the acceptance of the RICH is $\approx$ 4.1 . So the problem from overlapping Cherenkov rings is not expected to be serious. In the case where there are overlapping rings we will use the rejection techniques of Ref. 8 which involve rejecting hits in overlapping rings and rejecting hits in supercells (which are 5 cm $\times$ 76 cm in our case). Ref. 8 finds good π/K separation in an SSC environment where the momenta are similar to those expected in E771 but where the multiplicities are much greater.

Table I
Comparison of Properties of N_2 and C_4F_{10}

	N_2	C_4F_{10}
$(n-1) \times 10^6$	310	1510
γ_{th}	40	17
$\frac{\Delta\theta_\infty}{\theta_\infty}$	10×10^{-3}	4×10^{-3}
N_∞ (in 2 m of gas)	11	62
Maximum P for 2σ π/K separation (in 2 m of gas)	155 GeV/c	165 GeV/c

Conclusion

In order to study B meson production and decay, E771 requires a RICH detector to perform π/K separation on the B meson decays. The RICH we propose here has a 2 m C_4F_{10} gas radiator ($\gamma_{th} \approx 20$) covering our aperture. The rings are focussed by 3 m focal length mirrors through CaF_2 windows onto an MWPC running on TMAE. The MWPC has $\approx$ 12200 channels of anode wires and cathode pads to be read out. The Cherenkov rings observed have maximum radii of $\approx$ 15 cm and contain $\approx$ 45 photoelectrons. With these parameters a 2σ discrimination between π's and K's up to $\approx$ 160 GeV/c should be feasible.

References

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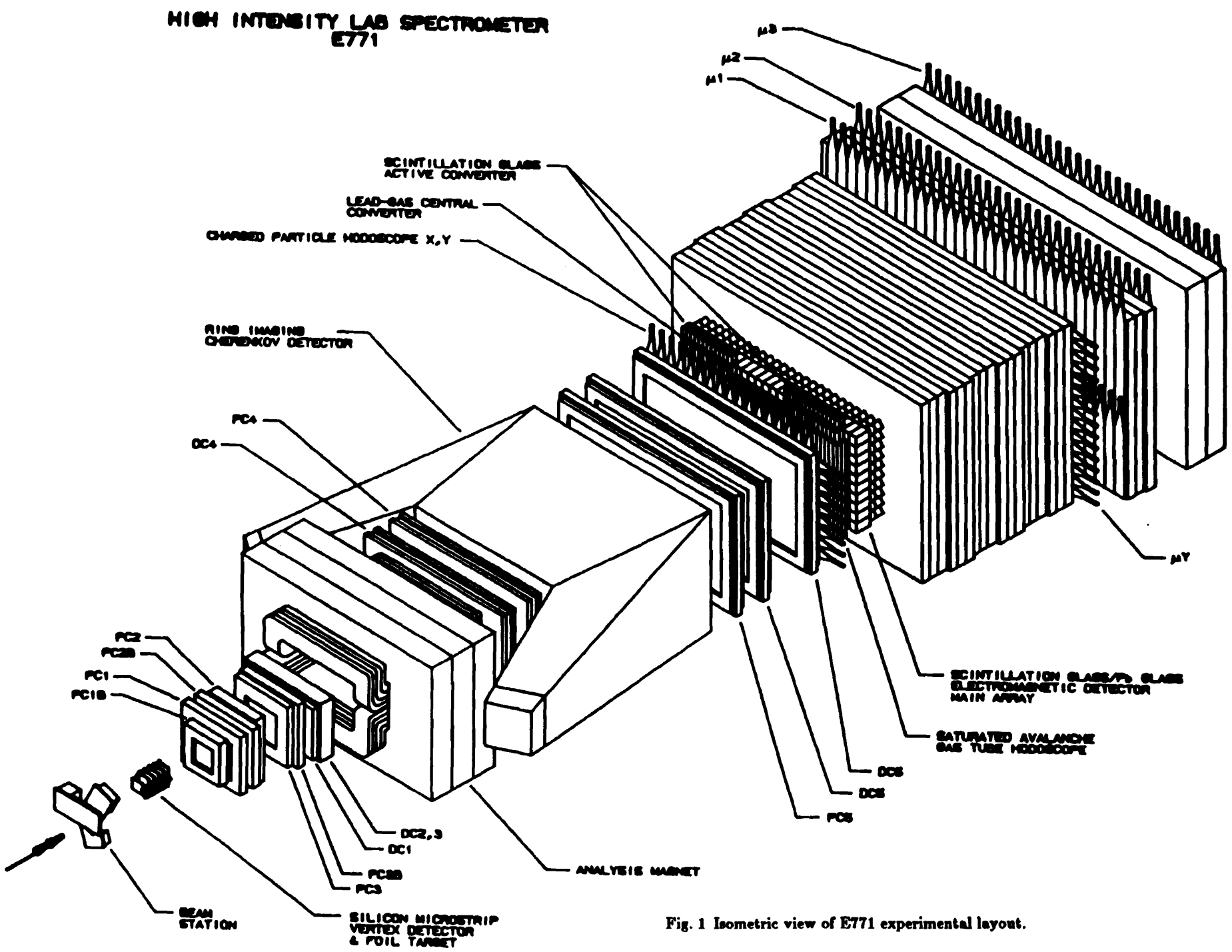

Fig. 1 Isometric view of E771 experimental layout.

Fig. 2 a)

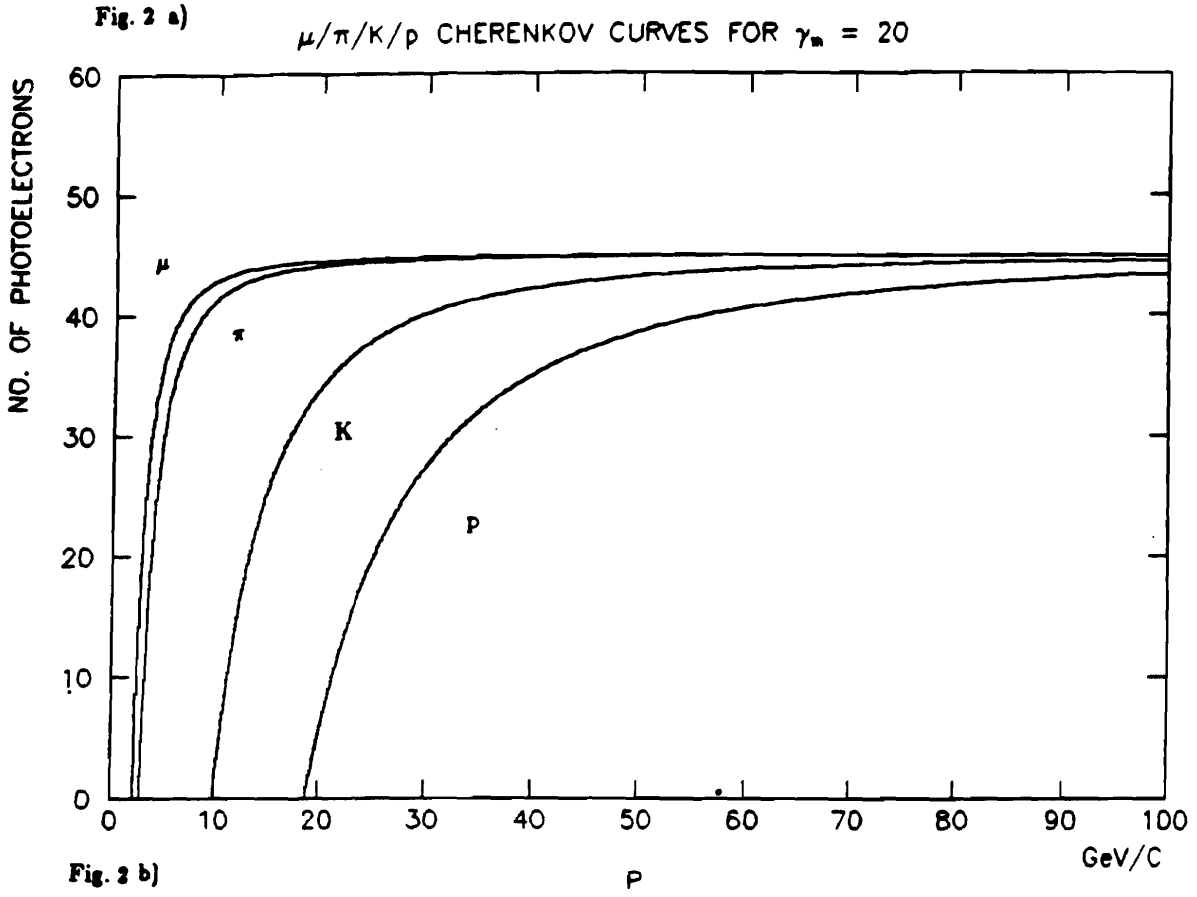

Fig. 2 b)

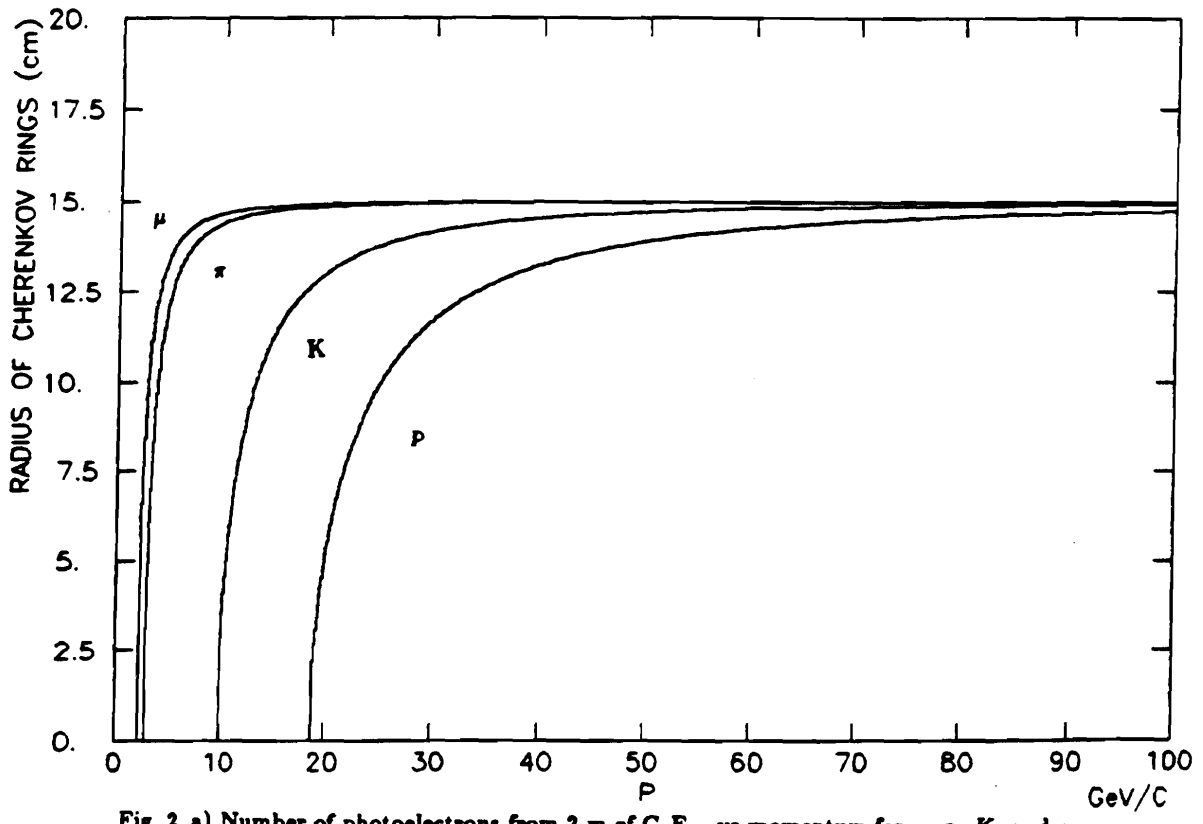

Fig. 2 a) Number of photoelectrons from 2 m of C_4F_{10} vs momentum for μ, π, K, and p.
b) Radius of Cherenkov rings (with a 3 m focal length) from C_4F_{10} vs momentum for μ, π, K, and p.

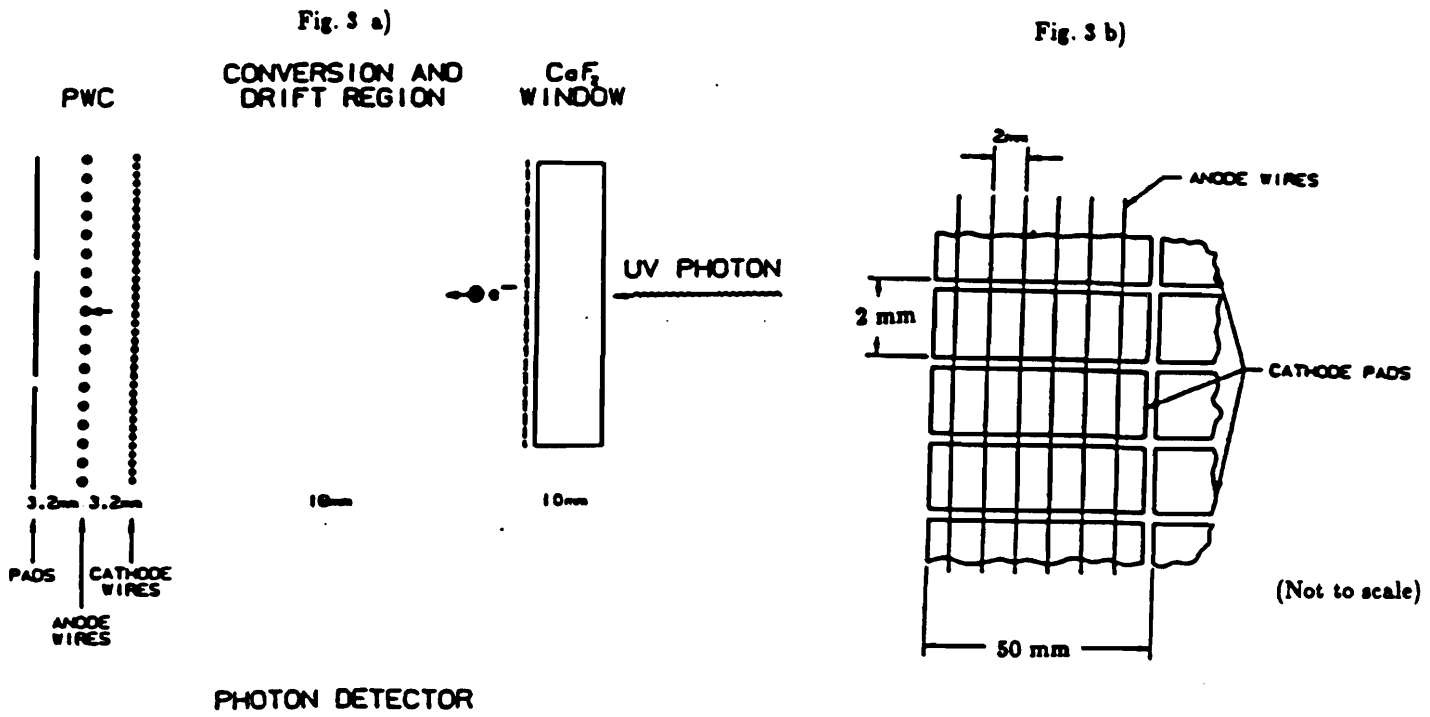

Fig. 3 a) Schematic of RICH MWPC photon detector[5].
b) Geometry of anode wires and cathode pads in E771 RICH MWPC photon detector.

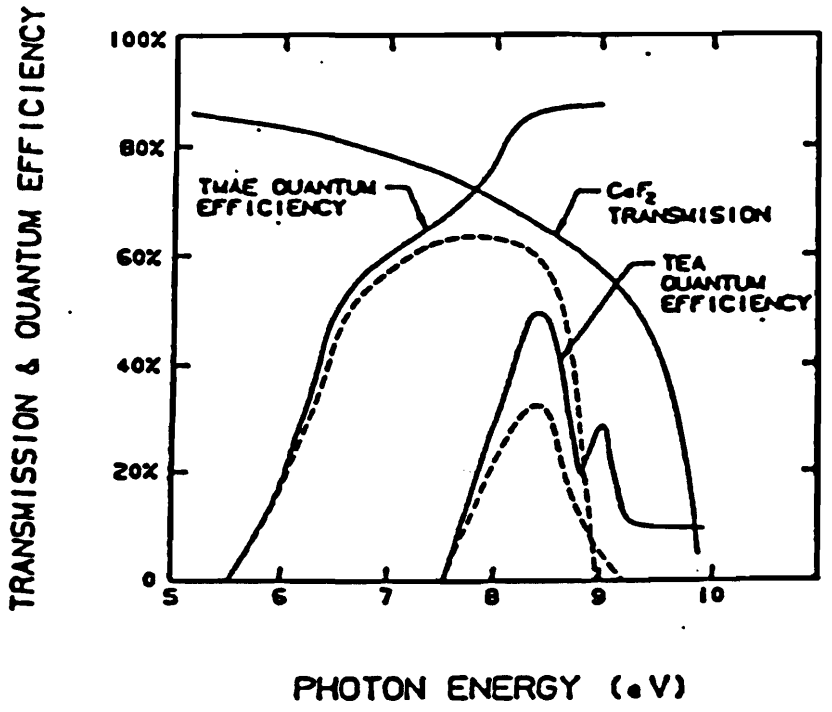

Fig. 4 Quantum efficiency of TMAE and TEA and transmission of CaF_2 [5].

Fig. 5 a)

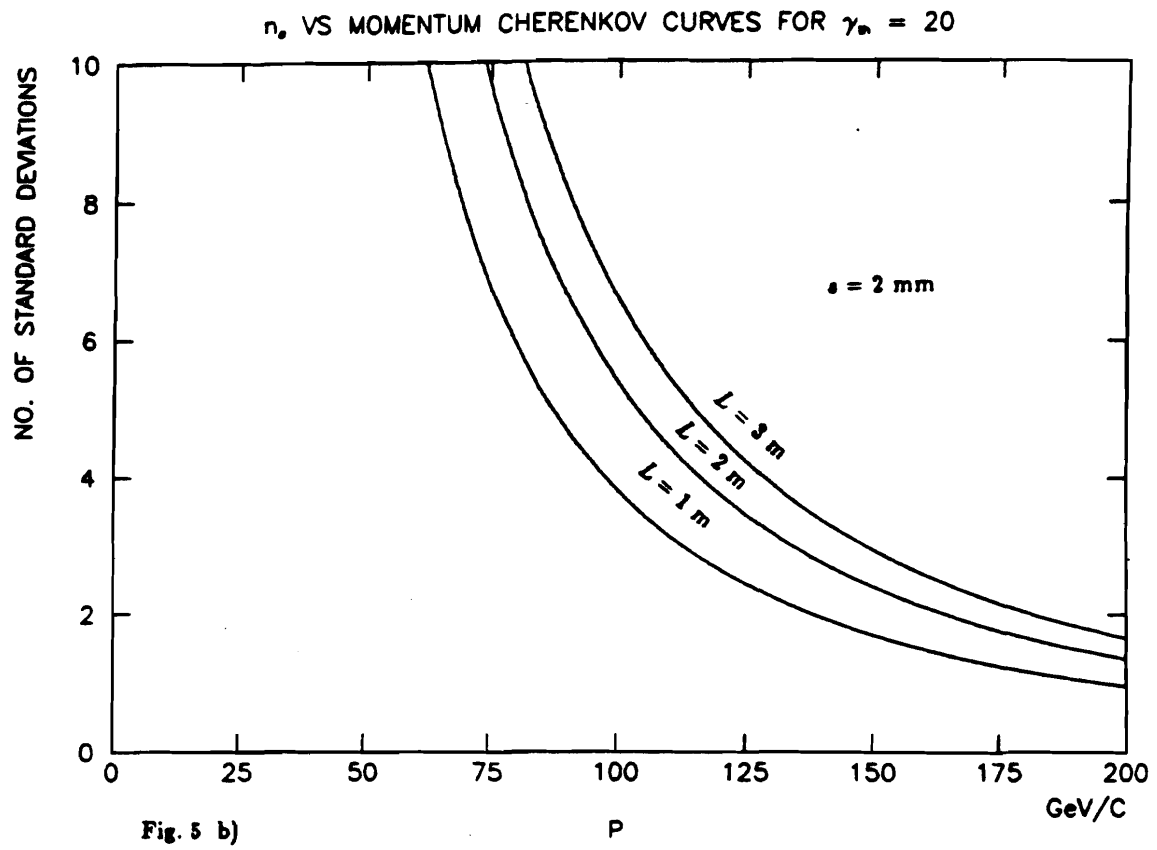

Fig. 5 b)

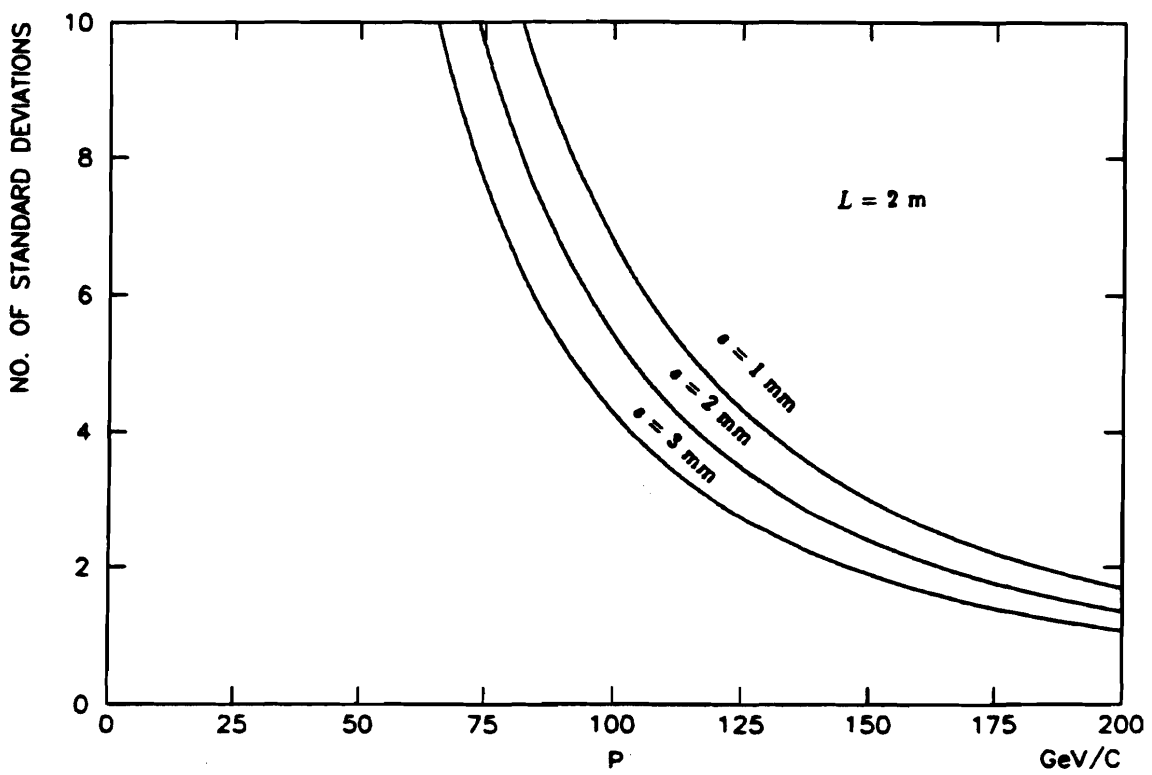

Fig. 5 a) Number of standard deviations for π/K separation vs momentum for 1 m, 2 m, and 3 m of C_4F_{10} radiator gas with a 2 mm chamber wire spacing.
b) Number of standard deviations for π/K separation vs momentum for 1 mm, 2 mm, and 3 mm chamber wire spacing with 2 m of C_4F_{10} radiator gas.