THE OPERATION OF A PRESSURIZED ULTRAVIOLET PHOTOIONIZATION THRESHOLD CHERENKOV COUNTER *

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We have successfully tested an ultraviolet photoionization Cherenkov counter in a 10 GeV/c pion beam. The counter has been tested to 11 atm pressure for use as a π–K separator. The design and operation of the counter is described.

1. Introduction

The importance of kaon identification over a large solid angle at e^+e^- storage rings has long been realized at PEP and PETRA energies. The identification of a kaon can be the signature for charm decay which in turn can lead to reconstruction of the B meson. It can also prove invaluable in any detailed jet physics study. However, despite high machine energies, high multiplicities imply that the large majority of particles have low to medium energies. A large fraction are in the 1–2 GeV/c momentum range. Unfortunately this is the very range that is difficult for time-of-flight and dE/dx techniques. The tight bunching of particles in jets compounds the difficulty of identification.

A useful device to fill this gap would be a pressurized threshold Cherenkov counter. However, the need to keep the phototubes of a conventional counter outside any magnetic detector makes a light guide system difficult if not impossible to design, especially for a highly segmented system. For this reason, Cherenkov counters which employ the far ultra-violet part of the Cherenkov spectrum (1150–1350 Å) have been studied [1,2]. To detect the light a proportional chamber doped with a small amount of benzene is used. The benzene has a high photoionization probability in this wavelength range. Tests showed that highly efficient counters (operating at atmospheric pressure with argon or nitrogen radiators) can be built [1] which provide excellent π–e separation up to 4 GeV/c momentum. A pressurized counter

using this same principle of operation should allow pion identification in the important 1–2 GeV/c momentum region.

The present paper describes tests of a prototype cell of an ultra-violet threshold Cherenkov counter system which we plan to construct for the High Resolution Spectrometer (HRS) at PEP. The counters will consist of 13 tori placed around the beam as shown in fig. 1. The design allows for high segmentation (64 azimuthal sections) and will at the same time minimize the amount of material contributing to multiple Coulomb scattering. The Cherenkov radiator will be an argon–nitrogen mixture at 16 atm pressure which gives a π threshold of 1.1 GeV/c and will allow π/K separation from 1.1 to 3.9 GeV/c. Time of flight counters will be used for particle identification at lower momenta.
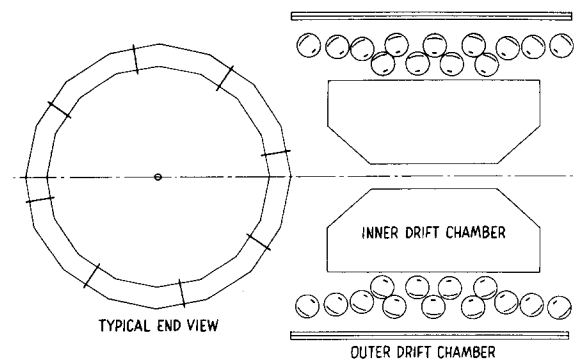

Fig. 1. End and side view of planned Cherenkov counter system for the HRS.

2. Choice of radiator

The number of photons per unit length of Cherenkov radiator is given by the expression

$$d\phi/dl = 370 \int\epsilon \sin^2\theta \, dE ,$$

where l is the particle path length in cm, θ is the Cherenkov angle, E is the photon energy in eV and ϵ is the photon detection efficiency. ϵ is dependent on the benzene photoionization efficiency, MgF_2 window transmission and mirror reflectance, all of which vary with photon energy [1]. Also affecting ϵ is the percentage of CO_2 which is used as a quenching gas in proportional chambers since it is absorbing below 1160 Å. A further possible factor is the absorption of photons in the Cherenkov radiator which could reduce the photon yield, especially in a pressurized system.

There is no gas which has a high enough refractive index to allow π/K separation down to 1 GeV/c at atmospheric pressure. In fact the only gases known to transmit within the desired wavelength range are nitrogen and the noble gases. It is well known that argon is transparent to photons in the 1150–1350 Å wavelength range and this makes it a natural choice for use as a Cherenkov radiator. However the refractive index of argon is such that a 16 atm Cherenkov counter must be constructed for the desired particle

separation. Also argon is known to scintillate at these wavelengths so a suitable quenching gas must be found. Another possible candidate is nitrogen. Although this has a similar refractive index to argon, it is known to absorb ultra-violet photons weakly [3]. Although the absorption length is large (187 cm), the effect is significant for a high pressure counter. Other possible candidates are krypton and xenon which by extrapolation from the visible probably have higher indices of refraction than argon and nitrogen [4] although they have not been measured at these wavelengths. They both have excited states and hence absorption lines in the region of interest.

We have measured the transmission of xenon and krypton with an ultraviolet spectrometer at moderate pressures. The results are shown in fig. 2. It can be seen that xenon is transparent between 1320 and 1440 Å and krypton is transparent above 1250 Å. Note however, the broadening of the absorption lines even at 4 atm. This will undoubtedly become worse at higher pressures. Triethylamine has a high photoionization efficiency around 1500 Å [5] and therefore might be a suitable chemical to use with xenon. However we decided not to pursue the use of xenon as we believe the photon yield would be inadequate. Krypton would give an adequate photon yield however the disadvantage of its high cost outweighed the advantage over argon of its slightly higher refractive index. In addition the krypton scintillation light was difficult to handle. We therefore decided that argon, doped with a small amount of nitrogen to quench scintillation light was the most suitable radiator gas.
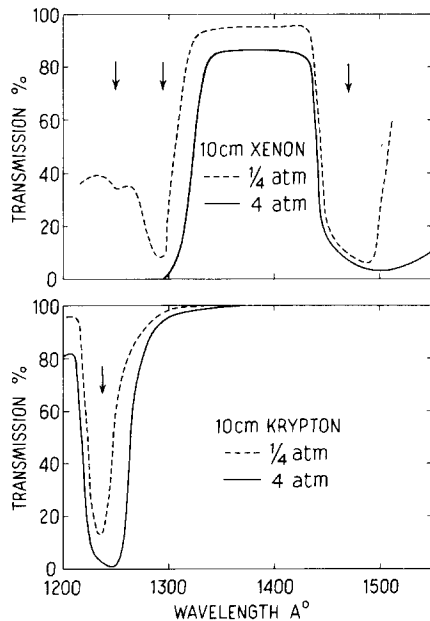
3. Experimental setup

A prototype of the cell geometry to be used in the HRS was built. This geometry is shown in fig. 3. The test section consisted of a 25.4 cm diameter aluminum tube of 0.32 cm thickness. Contained inside the tube was a 22.9 cm wide by 17.8 cm long elliptical mirror with a cylindrical cross section. The proportional chamber was placed 15 cm from the mirror at its first focus. The second focus would correspond to the e^+e^- intersection point, 200 cm away.

The structure of the proportional chamber is shown in fig. 4. The chamber was 15.2 cm long and contained six cells, each 0.5 cm wide. The dead region between cells was 0.5 mm. Two 1.75 cm wide MgF_2 windows, 5 mm thick were epoxied together lengthways. The epoxy joint between them caused a

Fig. 2. Absorption spectra of xenon and krypton. Arrows represent position of spectral lines.
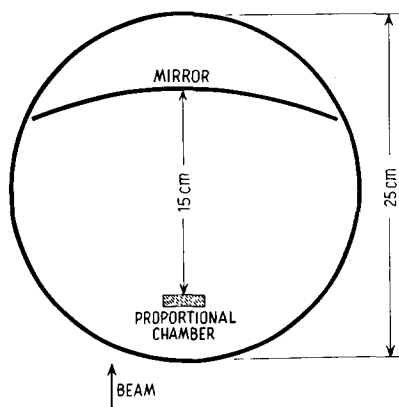
Fig. 3. Cross sectional view of Cherenkov counter test vessel.

loss of photons, however these windows were the only ones available to us at that time. A single 2 mm thick window has been tested and is being used in the final design. The six cell structure was chosen for two reasons. The proportional chamber runs at atmospheric pressure and the outside medium is at 16 atm. Hence the chamber structure must support the MgF_2 window. Also the chamber presents a dead region to particles since if a particle goes through the proportional chamber it will fire regardless of whether the particle was above threshold or not. If the chamber has discrete cells, the cell the particle went through can be ignored and the particle idenitified by looking for Cherenkov light in the other 5 cells.

The design of the proportional chamber has gone through a variety of stages. We have tested a two stage chamber proposed by Charpak et al. [6] but concluded the design was too complicated and costly
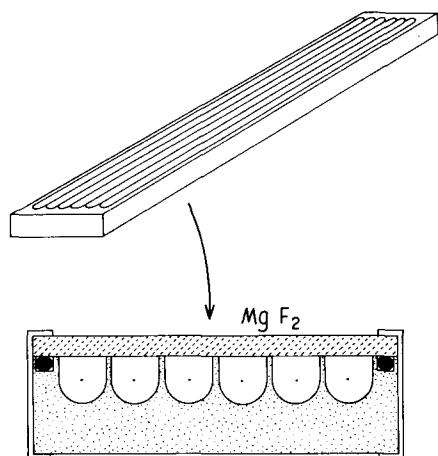
for our proposed system. We eliminated the wire grid just under the window used previously to shape the electric field in the proportional chamber [1]. The grid made the construction of the chambers more complicated, intercepted some photons and had negligible effect on the single photon detection efficiency.

We found that adding benzene as a photoionizing chemical tends to destabilize the proportional chamber. When a proportional avalanche occurs many argon atoms are excited. The argon emission spectrum is centered around 1000 Å. These photons can photoionize the benzene causing further avalanches. A suitable quenching agent must absorb these photons while transmitting UV light in the 1350–1150 Å region. CO_2 has a short absorption length below 1160 Å and a "window" at the desired wavelengths [7]. We experimented with a number of gas mixtures — argon with 1% C_6H_6 and 5%, 10%, 20%, and 30% CO_2. We have found that more CO_2 is needed than for a standard proportional chamber, a useful mixture being 1% benzene, 20% CO_2 and 79% argon. It was found that 30% CO_2 raised the operating voltage by 100 V but did not affect the chamber stability or improve the single photon detection efficiency. The 1 mol% benzene was chosen so that there are several mean absorption lengths for the UV photons in the chamber. The sense wire (38 μm diameter gold-plated tungsten) was positioned 2.4 mm from the window.

An interesting feature of the proportional chamber was its ability to detect visible photons as evidenced by its sensitivity to an overhead room light. We attributed this to the photoelectric effect of the aluminum oxide layer on the chamer walls. Silvering the proportional chamber surface eliminated the effect.

One worry was that the proportional avalanches would affect window transmission. The transmission of the MgF_2 window was measured to be 50% using a Lyman alpha (1216 Å) hydrogen discharge lamp. The chamber was run for 10^{10} counts just below breakdown and the MgF_2 transmission was remeasured. No noticeable difference was observed indicating that breakdown products formed by counter avalanches do not degrade the window transmission.

The mirror reflectivity has been measured to be 75% at 1216 Å. The mirror was made of glass, 2 mm thick. It was slumped in a graphite form which had the desired elliptical curvature. The glass was then vacuum aluminized with a MgF_2 overcoating to prevent oxidation [8].

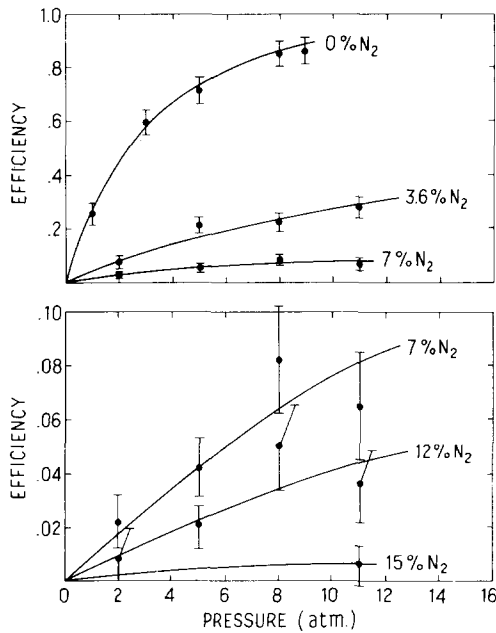Fig. 4. Structure of proportional chamber.

Fig. 5. Efficiency for detecting scintillation light as a function of pressure and nitrogen percentage.

The preamplifier is a crucial element in the system because it must have low noise $(3 \times 10^{-16} \text{ C})$ to detect single photoelectron avalanches efficiently. However since linearity is not required the preamp can be of very simple design.
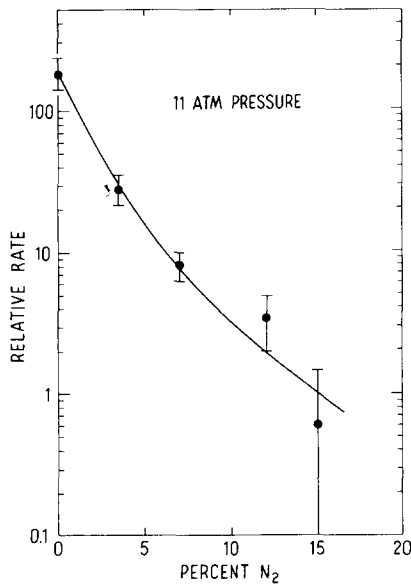
Scintillation light can be produced by a particle

Fig. 6. Scintillation efficiency as a function of nitrogen percentage at 11 atm pressure.
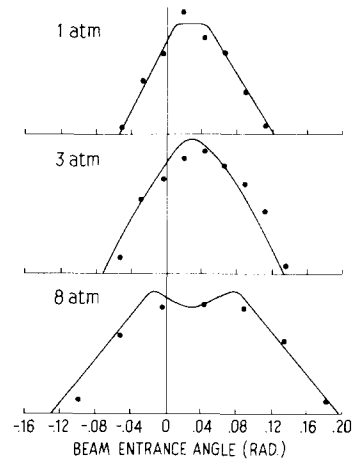

Fig. 7. Measured values and expected values (solid lines) of relative efficiency for detecting Cherenkov radiation as a function of beam direction.

below its Cherenkov threshold destroying the usefulness of the counter for particle identification. Tests were made to determine the scintillation properties of argon—nitrogen mixtures as a function of nitrogen percentage and pressure. We have found that the addition of nitrogen to the argon gas will cause the argon atoms to de-excite before they scintillate. Tests were made to determine what fraction of nitrogen was necessary to keep scintillation light down to an acceptable level. Particles, defined by scintillation counters, went through the Cherenkov radiator at 45° to the mirror. Under these conditions no Cherenkov light could be reflected from the mirror into the chamber. These tests were made with cosmic rays because of the large μ-meson halo in the test beam.
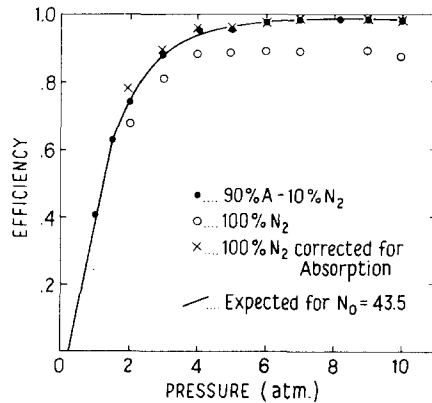

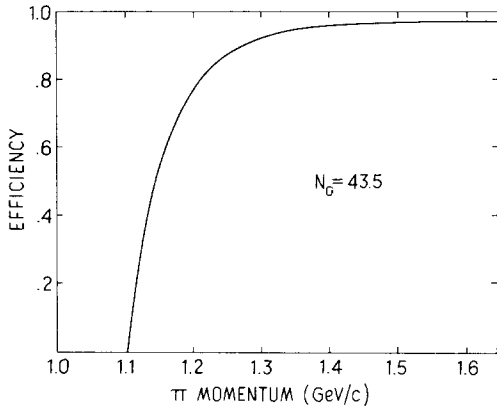Fig. 8. Efficiency of counter as a function of pressure for various gas mixtures.

Fig. 9. Expected efficiency of a system of counters as a function of π momentum.

those expected and confirm that we were observing Cherenkov light. The fact that these distributions drop to zero also confirms that scintillation light is minimal with this gas mixture.

4. Results

The Cherenkov counter was tested in a 10 GeV/c negative pion beam at SLAC. The threshold behavior of the counter is shown in fig. 8. Here the efficiency is shown as a function of Cherenkov gas pressure for a 90% argon—10% nitrogen and a 100% nitrogen radiator. The efficiency rises to 98.4% for the 90% argon—10% nitrogen mixture. The small inefficiency is consistent with the antiproton contamination in the beam. Unfortunately there was no low energy beam available at SLAC with which to measure the momentum dependence. The effect of nitrogen absorption is clear. If the nitrogen curve is corrected for absorption in order to agree with the argon curve, the resulting value obtained for the absorption length is within 10% of the published value [3]. The argon and nitrogen gas used, both had purities of 99.999% which were sufficient to make absorption by gas impurities unimportant.

Neglecting variation of refractive index with photon energy, the number of photons per unit length of Cherenkov radiator is characterized by the expression

$$\mathrm{d}\phi/\mathrm{d}l = N_0 \sin^2\theta \ ,$$

where θ is the Cherenkov angle. The solid curve in fig. 8 which is a fit to the data shows the efficiency expected for $N_0 = 43.5$ based on Poisson statistics. Using this value of N_0 we can deduce the efficiency of a 16 atm system proposed for the HRS. Taking into account bending in the magnetic field, finite beam crossing size etc and incorporating the geometry of fig. 1, the efficiency as a function of momentum was evaluated using Monte Carlo techniques. The results of this study are shown in fig. 9. A satisfactory counter can be built with $N_0 = 43.5$. Any improvement in this value will give a steeper threshold behavior.

A calculation based on the efficiency of the system components gives an expected value of $70 \sin^2\theta$ photons per unit length [1]. Although the experimental value of 43.5 is less than expected, fig. 9 demonstrates that a practical system can be built. We believe the difference in measured and expected values to be largely due to the failure to detect small

Fig. 5 shows the efficiency for detecting particles via scintillation light as a function of pressure for various nitrogen fractions. The values at 11 atm are shown in fig. 6. It can be seen that an 85% argon, 15% nitrogen mixture keeps the scintillation light level below 1%. Although the addition of more nitrogen would further reduce the amount of scintillation light it would also absorb a greater percentage of Cherenkov photons.

We made tests to check the optics of the system using a narrower proportional chamber 1.75 cm wide. The efficiency of the counter was measured as a function of beam entrance angle with the beam hitting the mirror 5 cm off axis. The results are shown in fig. 7 at 1, 3, and 8 atm pressure. The distributions agree with
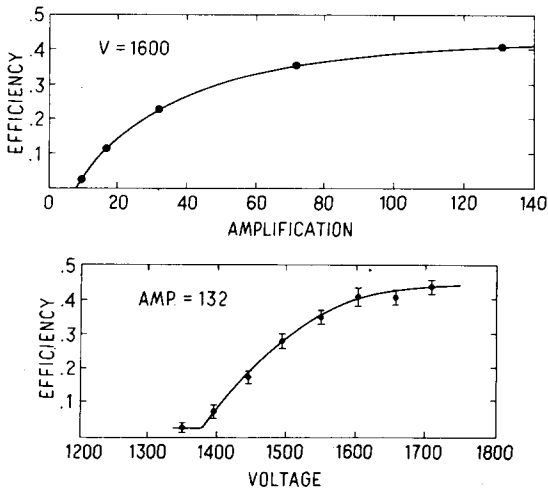
Fig. 10. Relative efficiency as a function of amplification and voltage on the proportional chamber.

pulses associated with single photoelectrons. In a limited test with a lower noise preamplifier and better designed chamber we have attained a voltage plateau for single photoelectrons as shown in fig. 10. This should allow us to attain an N_0 close to the predicted value in tests which we plan for the near future.

References

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