COO-3072-119

CONF-801103--49

MASTER

RESULTS ON THE PERFORMANCE OF A BROAD BAND FOCUSSING CHERENKOV COUNTER*

R. Cester,† V. L. Fitch, A. Montag, S. Sherman,†† R. C. Webb,††† M. S. Witherell
Department of Physics, Princeton University, Princeton, N. J. 08544

Abstract

The field of ring imaging (broad band differential) Cherenkov detectors[1] has become a very active area of interest in detector development at several high energy physics laboratories. Our group has previously reported[2] on a method of Cherenkov ring imaging for a counter with large momentum and angular acceptance using standard photo multipliers. Recently, we have applied this technique to the design of a set of Cherenkov counters for use in a particle search experiment at Fermi National Accelerator Laboratory (FNAL). This new detector operates over the range $0.998 < \beta < 1.000$ in velocity with a $\delta\beta \sim 2 \times 10^{-4}$. The acceptance in angle is ± 14 mrad in the horizontal and ± 28 mrad in the vertical. We report here on the performance of this counter.

Introduction

A standard technique for identifying hadrons at high energy is to measure their velocity with a Cherenkov counter and to use this result and a momentum measurement to determine the mass of the particle. A threshold Cherenkov counter produces an output signal for any particle whose velocity is greater than c/n, where c is the speed of light in vacuum and n is the index of refraction in the radiating medium. Threshold counters can be used to identify particles over a large angular acceptance, but they are unable to measure the velocity much above threshold. A counter of this type can typically distinguish kaons from protons over a range of a factor of two in momentum, and cannot separate kaons from pions at all in this range. Differential Cherenkov detectors, on the other hand, measure the angle at which the light is emitted, $\theta = \cos^{-1}(1/n\beta)$ where β is the particle's velocity divided by the speed of light. These counters focus the emitted Cherenkov radiation from a given charged particle to a circle in the focal plane of the light-collecting system. A narrow annular ring in the focal plane defines the narrow range of Cherenkov angles which may be detected by this counter. Only particles within a limited angular acceptance and within a fixed velocity range are detected. A counter of this type is often used to tag particles in beam lines, where the angular divergence of the beam is small and the momentum band is narrow.

In many experiments one needs a device which can measure the Cherenkov angle, as in the differential counter, but over a greater range of particle velocity and angle. The Cherenkov angle is determined by measuring the diameter of the ring of light in the focal plane of the detector. Recently counters using segmented photomultiplier arrays with high quantum efficiency (microchannel plates)[3] or photosensitive ionization detectors with good spatial resolution[4] have been proposed to accomplish these measurements, but several technical problems complicate their application. In this paper we describe a broad-band focussing Cherenkov counter which represents an intermediate step in this direction. A coarse measurement of the Cherenkov angle is made with modest improvements to the standard threshold device. The counter extends the velocity range of a threshold counter, while maintaining a reasonably large angular acceptance.

Principle

In a differential Cherenkov counter the light emitted by the particles is focussed to a ring of light in the focal plane. The radius of this ring is approximately $f\theta_c$ where f is the focal length of the focussing system and θ_c is the Cherenkov angle. The center of this ring will be displaced from the focal point of the optical system by an amount $f\theta_p$ where θ_p is the angle the particle's trajectory makes with the axis of the counter. In the conventional differential counter the angular band accepted by the slit must be less than the difference in Cherenkov angles between particle types, but larger than the angular dispersion of the particle beam.

The basic principle of our counter, which has been described previously in reference 2, is to divide the focal plane into two regions and to measure the amount of light falling into these areas separately. The boundary between these regions is shown in Figure 1. The rosette pattern was formed by evaporating aluminum onto a quartz substrate. Two 5" diameter photomultiplier tubes detected the light from these separate regions, one observing the reflected light and the other the transmitted light. The amounts of light in the two tubes provide an analog measurement of the Cherenkov angle from threshold to the maximum Cherenkov angle. The fraction of the light falling into each region is remarkably insensitive to displacements of the ring image from the axis of the light-collecting system.

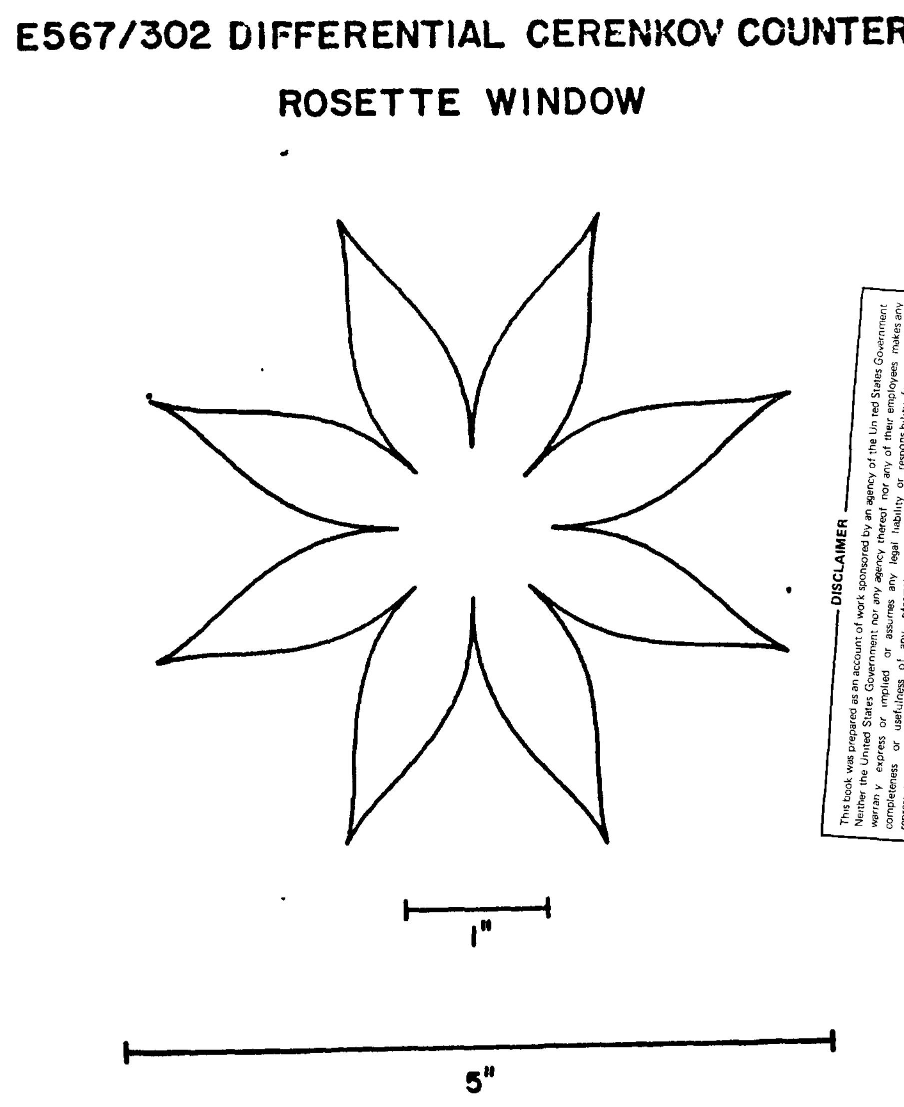

FIGURE 1. The outline of the reflecting mask which was placed on a quartz window in the focal plane of the Cherenkov counter.

DISCLAIMER
This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

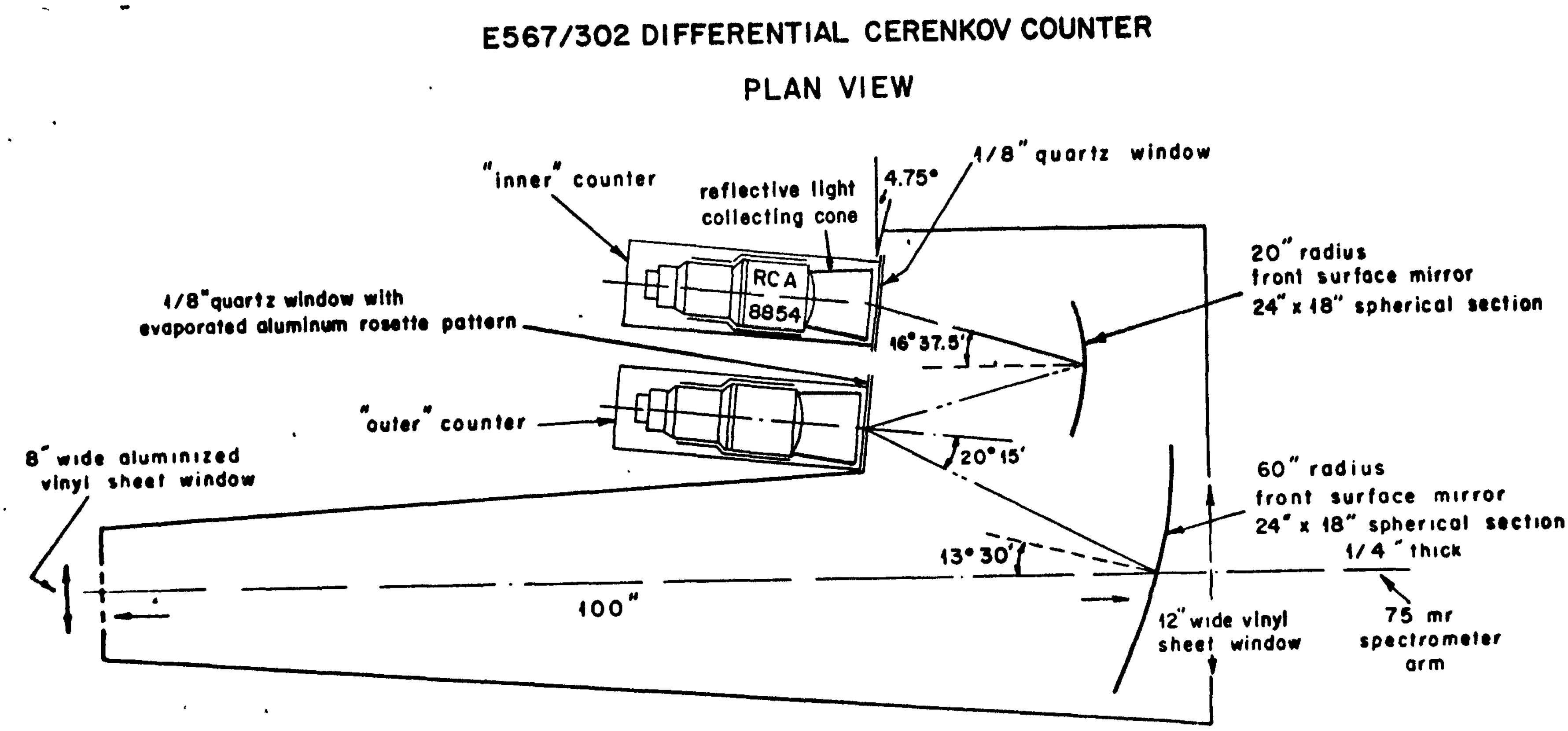

FIGURE 2. Schematic diagram of one half of the counter.

Hence the Cherenkov angle measurement is independent of the particle's angle, θ_p, providing θ_p is not too large.

Design

Two counters were built for the double-arm spectrometer used in a charm search experiment at Fermi National Laboratory (FNAL). Each arm had an angular acceptance of ± 14 mrad in the horizontal plane and ± 28 mrad in the vertical. The goal was to separate kaons and protons from a momentum of 10 GeV/c to the highest momentum possible. The counter was divided vertically into two identical cells, one of which is shown in Figure 2. The counter was filled with Freon 114, a gas with index of refraction n = 1.00135, which set the threshold for kaons at 9.5 GeV/c. The primary mirror, a section of a sphere with radius 60", was tilted horizontally enough to keep the optics sections out of the region of accepted particles. The light was focussed at a 1/8" thick quartz window upon which the mask of figure 1 was deposited with aluminum. Behind the window was the photomultiplier tube which collected the outer light. The light which struck the mask was reflected to a secondary mirror. This mirror, of 20" radius, focussed an image of the mask on a quartz window in front of a second photomultiplier tube which collected the inner light. Each of the tubes was an RCA 8854, with 5" diameter photocathode and a high quantum efficiency. There were therefore four photomultiplier tubes in each counter. The signal from each tube was recorded in an analog-to-digital converter (ADC) and stored for off-line analysis.

Analysis

In the simplest case a single particle passed through the counter sufficiently far away from the vertical midplane that all of the Cherenkov light struck a single mirror. There were then two tubes, "inner" and "outer", which gave output pulses of amplitude I and O, respectively. The total output, I + O, was proportioned to $\sin^2\theta_c$, the output from a similar threshold Cherenkov counter. The fraction of this light which fell into the outer region, R = O/(I+O), varied from 0 to 1 as the Cherenkov angle increased. For particles with $\beta = 1$ this ratio R was 0.6. To check the dependence of the observed signals on β, we selected a sample of kaons by using a threshold Cherenkov counter to reject pions. Figure 3 shows a plot of the total pulse height as a function of kaon momentum. It follows very closely the expected $\sin\theta_c$ dependence, which means the light collection efficiency does not depend strongly on the Cherenkov angle. Also shown is the level measured for $\beta = 1$ particles (pions). The error bars on the data points represent the standard deviations for a single event, not the error on the central value. Figure 4 shows separate plots of the light in each tube for the same kaons. As expected the inner tube collects most of the light near threshold, but the signal reaches the maximum value at relatively low momentum. The outer tube rises more slowly near threshold and is still increasing with velocity well above threshold. The $\beta = 1$ point is shown for comparison. To use all of the available information to measure β one should find the value of β for which the expected amounts of light in the two tubes best fits the measured values, O and I. In our case this problem is naturally divided into two cases. Near threshold the information is contained in the sum of the two tubes and the counter acts as a threshold counter. Above threshold the amount of light in the inner tube reaches its maximum value, since the amount of light lost to the outer tube as θ_c increases is just compensated for by the increase in the total light radiated. Thus simply using the outer tube gives the most sensitivity to β. Thus, although at 15 GeV/c kaons and pions are both well above threshold, they are separated because the kaons give only 1/2 as much light in the outer tube as the pions. The error on β increases slowly from 1.2×10^{-4} at threshold to 2×10^{-4} at $\beta = 1$.

The best measure of how much improvement was gained by adding the flower mask and second tube was how much higher in momentum particles could be separated compared to a similar threshold counter. If the differential information was ignored in this counter, and only the sum was used, 25% of the kaons were identified as pions at a momentum of 12.5 GeV/c. A similar level of misidentification was reached when using the outer tube at a momentum of 16 GeV/c. As a rough figure of merit, the extra information extended the upper limit by a factor 1.3, i.e. the

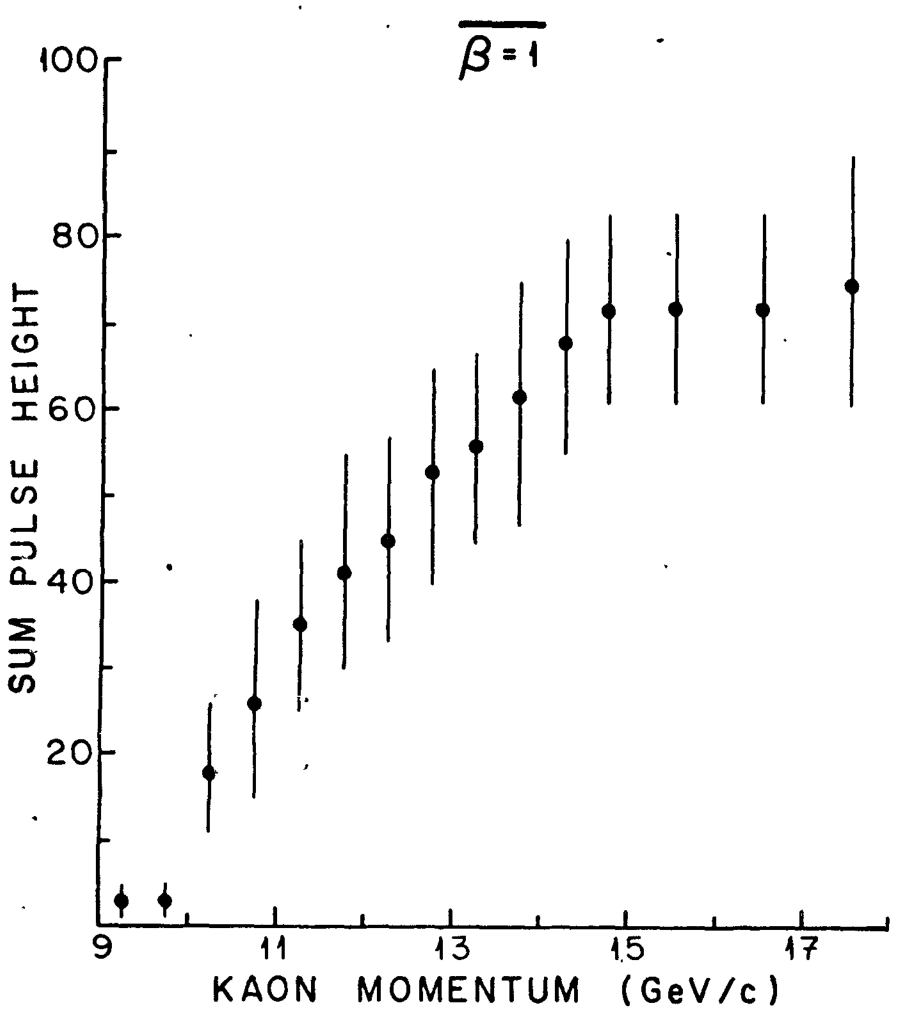

FIGURE 3. Sum of the pulse heights for the two tubes vs. kaon momentum. The β = 1 measurement comes from a sample of pions.

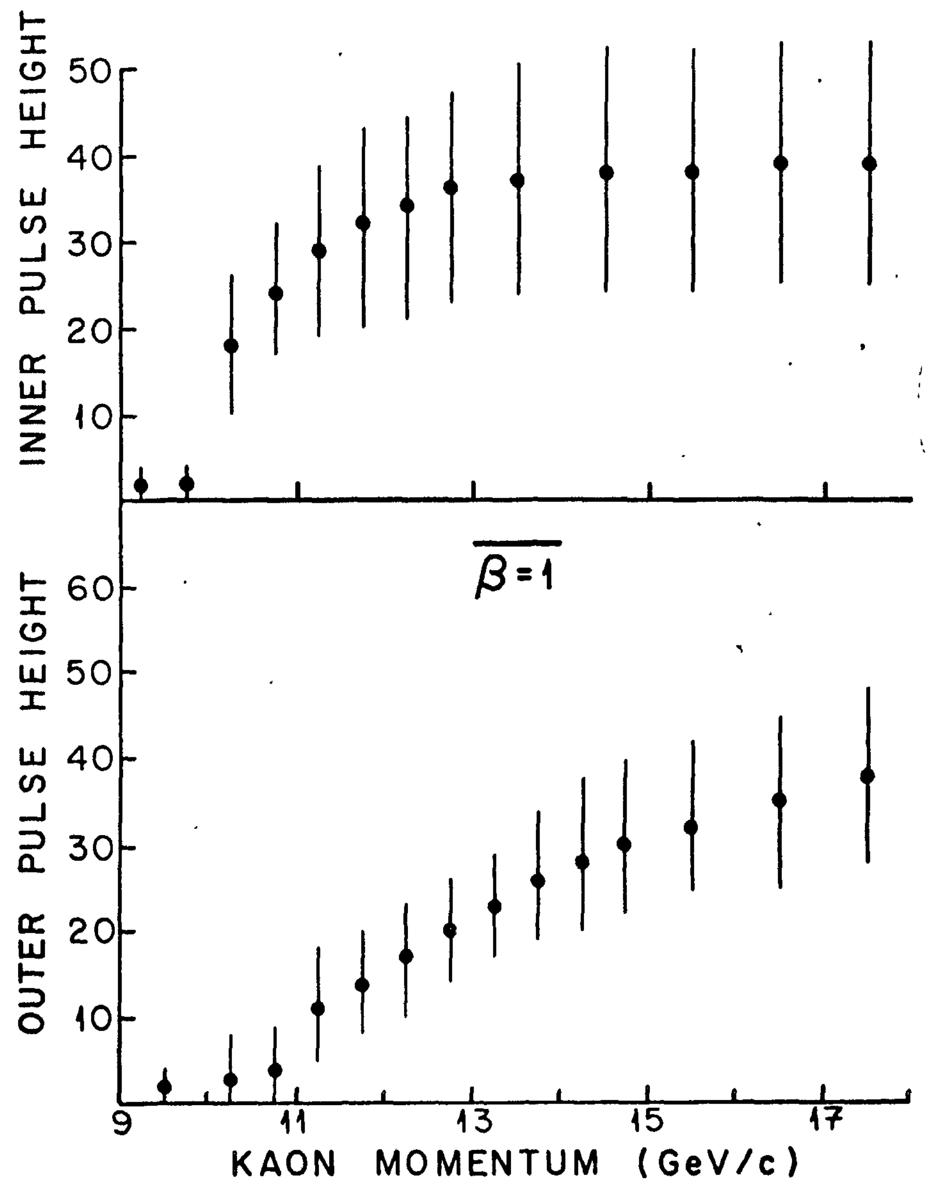

FIGURE 4. Pulse height for the inner (top) and outer (bottom) tubes vs. kaon momentum.

range of kaon-proton separation was extended from 10-20 GeV/c to 10-26 GeV/c.

Studies were made of how the measurements depended on the angle of the particle. The variations of the central value due to track angle were always much less than the statistical fluctuations. For a kaon momentum of 13 GeV/c, the Cherenkov angle of 36 mrad was measured to about ±4 mrad. For particles which were 12 mrad off-axis, the contribution to this error from the effects of the particle's angle was about ±1 mrad. Thus the pattern automatically corrects for almost all of this effect, and systematic corrections can be applied to reduce the contribution further.

Another feature of this scheme is the ability in certain cases to identify two particles which are in the same cell of the counter. As an example, if there were two particles, one of 6 GeV/c and one of 11.5 GeV/c, the total pulse height did not distinguish which particle was a pion and which was a kaon. However, most of the light from the kaon was in the inner tube if the kaon was above threshold, and it was thus possible to resolve the problem using the differential information. One problem in the use of this counter in the present experiment was the presence of extra tracks which give light in the Cherenkov counter but were not within the acceptance of the entire arm. These could have been either particles produced in the target which did not go through the magnet or particles produced in surrounding material. Since these particles could have had arbitrarily large angles the light they produced could not be handled in the same way as second tracks within the arm acceptance.

Applications

We can foresee a number of applications for this type of Cherenkov counter. The conditions which favor its use are a large momentum acceptance band and an angular acceptance which is large compared to the desired resolution in Cherenkov angle, but smaller than the Cherenkov angle itself. To illustrate the limitations of the technique, we list two situations in which it is not suitable. One is as a beam Cherenkov counter in a monochromatic beam. In this case, where one wants to decide between two fixed Cherenkov angles, one sets better separation with a circular boundary between inner and outer light, even if the angular spread is not negligible. The other situation in which a counter of the type described in this paper is not useful is when the angular spread seen by a single Cherenkov cell is large compared to the Cherenkov angle. In such a case the entire ring of light is displaced to one side of the pattern, and one loses the averaging effect of the pattern. One needs to measure the position of each photon and reconstruct the ring in this case.

An interesting application of the present technique is for a narrow band of momentum but a broad band of mass. A search for stable massive particles is being done at Fermilab using a counter of this type installed in a high momentum secondary beam line. A peak in the velocity spectrum would be a signal of particles with a fixed mass. Such a broad band counter allows the experimenters to search a broad mass range at one time. The primary application of the rosette counter is in situations similar to the experiment for which it was designed, where it is used to extend the momentum range of a Cherenkov counter of moderate acceptance. In designing the mask for such a counter the first step is to specify the quantity $R = O/(O+I)$ as a function of θ. The main design consideration is to keep $dR/d\theta$ as large as possible in the region just below θ_m, the maximum Cherenkov angle which corresponds to $\beta = 1$. The differential information is used when one tries to distinguish particles just above threshold from $\beta = 1$ particles. This optimization must be made under the constraint that the θ corresponding to $R = 1$ must be as large as the maximum angle of particles with the counter axis plus θ_m, or the averaging in azimuth does not work. Thus as the range of accepted particle angle is reduced, the resolution in Cherenkov angle is improved. For a threshold Cherenkov counter with threshold velocity β_o the error in measuring β above threshold is roughly $\delta\beta = (1 - \beta_o)/N^{1/2}$ where N is the number of photoelectrons observed for $\beta = 1$. For a rosette counter $\delta\beta \doteq \frac{[R(1-R)/N]^{1/2}}{dR/d\beta}$ and since $dR/d\beta$ is about $1/(1-\beta_o)$ and $[R(1-R)]$ is about 1/4, $\delta\beta = (1-\beta_o)/2N^{1/2}$, or a factor of two better than for the threshold counter. This gain is achieved at the cost of a minimal addition to the threshold device.

---

*This research was supported by the Department of Energy under contract #DE-AC02-76ER03072.

†Now at the University of Torino, Torino, Italy

††Now at California Institute of Technology, Pasadena, CA 91125

†††Now at Texas A & M University, College Station, TX 77843

References

1. A. Roberts, Rev. Sci. Instruments, 31, 579 (1960).

2. R. Cester, et al., IEEE Transactions, NS-25, 525 (1978).

3. K. Oba, et al., IEEE Transactions, NS-26, 346 (1979).

4. G. Charpak, et al., Nucl. Instrum. Methods, 164, 419 (1979).