THRESHOLD CERENKOV COUNTERS AT NAL

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ABSTRACT

Design features of threshold Cerenkov counters at NAL are discussed and a possible set of counters for identifying pions, kaons, and antiprotons up to 200-GeV/c beam momenta are presented.

Recent experience at Serpukhov has shown that threshold Cerenkov counters can be of use at the new accelerators (IHEP, NAL).[1] The 5-meter long Serpukhov threshold counters were able to separate K's from π's at 50 GeV/c. Figure 1 shows that the same counters would be able to separate π's and K's from protons up to about 150 GeV/c. They were able to achieve this resolution by extending the spectral response for Cerenkov light into the near-ultraviolet down to 1800 Å.

In designing a threshold counter, one can use a single equation to scale from previous counters. This is

$$N_{\text{photoelectrons}} = N_0 \sin^2 \theta_c \ell$$
$$= 2\, N_0 \frac{(\eta^2 - m^2)}{2p^2} \ell ,$$

where $N_{\text{photoelectrons}}$ is the number of photoelectrons knocked out of the photocathode, ℓ is the length of the radiator in cm, $\eta = n - 1$ where n is the index of refraction of the radiator and N_0 is a constant which can be determined either by calculation or from the threshold curve of an existing counter. It includes the light collection efficiency of the counter as well as the photocathode response. Many counters have been made with a value for N_0 between 60 and 70. The Serpukhov threshold counters have an N_0 of 100 to 110 using 56 UVP phototubes. R. Meunier has estimated that using 56 DUVP phototubes will lead to values of N_0 25% higher than that for 56 UVP (SS-170). The current state of photocathode development is such that it may be possible to get phototubes giving somewhat higher values for N_0 by the time NAL counters are built; however, for the present we must continue to use available tubes in the design.

We consider first the task of producing a pion tag. If we adjust the pressure in the threshold counter so that it is just below the threshold for kaons producing light, then

$$n_{\pi \text{photoelectrons}} = 2N \frac{m_K^2 - m_\pi^2}{2p^2} \ell$$
$$= 125 \times 0.225 \times \frac{\ell}{p^2}$$
$$= 28.1 \frac{\ell}{p^2}.$$

Since we are scaling N_0 from a value deduced from pressure curves for the Serpukhov counters, it includes the effect of a finite discriminator threshold. The efficiency for counting the pion is then

$$\text{eff} = \left(1 - e^{-n_{\text{photoelectrons}}}\right).$$

Table I shows the pion efficiency of a 40-m long counter set to not detect kaons.

The probability of detecting δ rays from kaons or protons has been calculated before and found to be quite small.[2] Thus, 40 m of radiating gas is sufficient to provide a pion signal up to 200 GeV/c. This gas must be enclosed in a cylindrical container with an inside diameter of at least 18 inches at the downstream end so as to be able to collect light with a Cerenkov angle of 6 mrad emitted at the upstream end of the counter without the light having to be reflected from the walls of the container. This container must be able to be evacuated but should not need to be pressurized for beam momenta above 25 GeV/c. The Cerenkov light is focused by an optical-quality spherical mirror at the downstream end of the container onto the photocathode of a photomultiplier tube. This tube might be placed inside the radiating gas since the counter does not need to be pressurized, thereby eliminating any possible absorption of the Cerenkov light in a window, as well as the cost of an ultraviolet transmitting window.

In order to get a kaon tag with threshold counters, one must have at least two threshold counters, one of which is set to detect both kaons and pions, while the other, set to detect pions only, acts as a pion veto upon the first. In order to have a clean kaon signal, it is necessary that the veto counter have very high efficiency (> 99.99%) for detecting pions and that the pion + kaon counter not see many δ rays from protons. A 15-m long counter with its refractive index just below threshold for protons has about the same efficiency for detecting kaons as the 40-m long counter for detecting pions but not kaons. Table I shows that 80 m of radiating gas is needed to detect pions with high enough efficiency to obtain a 150-GeV/c K beam with less than 1% pion contamination if the π^-/K^- ratio in the beam is 100.

It is very desirable to have at least two counters detecting kaons so as to further reduce background from accidental coincidences in intense beams.

In order to get a proton tag, one can simply require that none of the Cerenkov counters detect any light. It is harder to rely on this for antiprotons, however, since the π^-/p^- ratio is so large ($\sim 10^3$). Theoretically, two 40-m long counters set just below kaon threshold and two 15-m long counters set just below antiproton threshold should give a clean signal (less than 1% pion or kaon contamination assuming production ratios do not vary greatly from Serpukhov to here). It is unfortunate, however, to have such a high rate in a veto channel. Prokoshkin[3] has suggested two other methods of operating threshold counters which should be tested at NAL. The first is to discriminate on the pulse height of a threshold counter set to just be able to detect antiprotons. This was found at Serpukhov to give a $\bar{p}$ signal with a 1% π^- contamination at 50 GeV/c where the flux ratio $\bar{p}/\pi = 10^{-3}$. This still has the unfortunate feature of a high rate veto channel but is able to give pion and proton signals with only one threshold counter. For the phototube used (56 UVP) this method gave a velocity resolution a factor of three wider than when the counter was used in the threshold mode. This can be improved by using one of the new RCA Quantacon tubes with a high photoelectron resolution capability (Fig. 2).

The second Prokoshkin suggestion was to put a mask on the threshold counter's photomultiplier window and thus convert it into a differential counter which accepts only very small Cerenkov angles. Since $\Delta\theta_{chrom} = \theta/2V\ (1 + 1/\gamma^2\theta^2)$, (where $\Delta\theta_{chrom}$ is the variation in Cerenkov angle due to the variation of the index of refraction of the gas with wave length, and V is the relevant Abbe number $\approx$ 20 for CO_2, as long as $\gamma \gtrsim 1/\theta$, one can reduce $\Delta\theta_{chrom}$ while increasing the difference in Cerenkov angles between two particles by going to smaller Cerenkov angles. For example, for 200-GeV/c $\bar{p}$'s with $\theta = 5$ mrad, the pion and kaon Cerenkov angles are 6.8 and 6.4 mrads respectively while $\Delta\theta_{chrom} = 0.25$ mrads for pions and 0.17 mrads for protons. Therefore, no chromatic corrector is needed. This method, however, requires an optical-quality spherical mirror (spherical aberrations can easily be made less than 0.1 mrad by making the focal length ~2.5 meters). This method has the advantage of not requiring a high-rate veto although the influence of accidentals or off-axis particles on the purity of the $\bar{p}$ signal may be a problem.

In conclusion, a system of two 40-m long counters set to count pions but not kaons, and two 15-m long counters set to count both pions and kaons but not protons would satisfy the needs of most experiments in the NAL 200-GeV/c area.

REFERENCES

[1]J. V. Allaby, IHEP (Serpukhov)-CERN Experiments, CERN (published in Particle Reactions at the New Accelerators, University of Wisconsin); Yu P. Gorin, High Resolution Cerenkov Counter, Serpukhov IHEP 69-63.

[2]R. Ely, Lawrence Radiation Laboratory Report UCRL-16820, April, 1966, p. 170; J. A. Poirier and T. Romanowski, Threshold Cerenkov Counters in Secondary Beams at NAL, National Accelerator Laboratory 1968 Summer Study Report C.1-68-15, Vol. III, p. 107.

[3]Yu D. Prokoshkin, Differential-Threshold Cerenkov Counter, Serpukhov IHEP 69-7.

Table I. Pion Counting Efficiency
for 40 Meter Long Threshold Counter Set to Not Count Kaons.

p	eff
200	94%
175	98.7
150	99.3
125	99.92
100	99.998

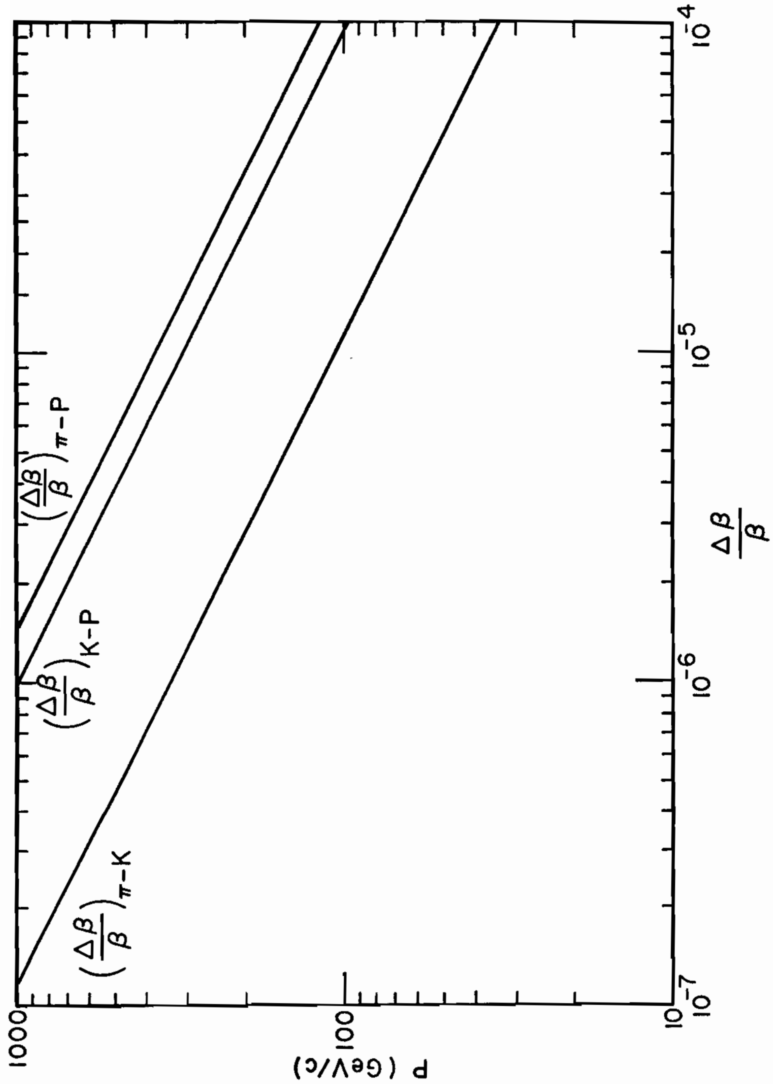
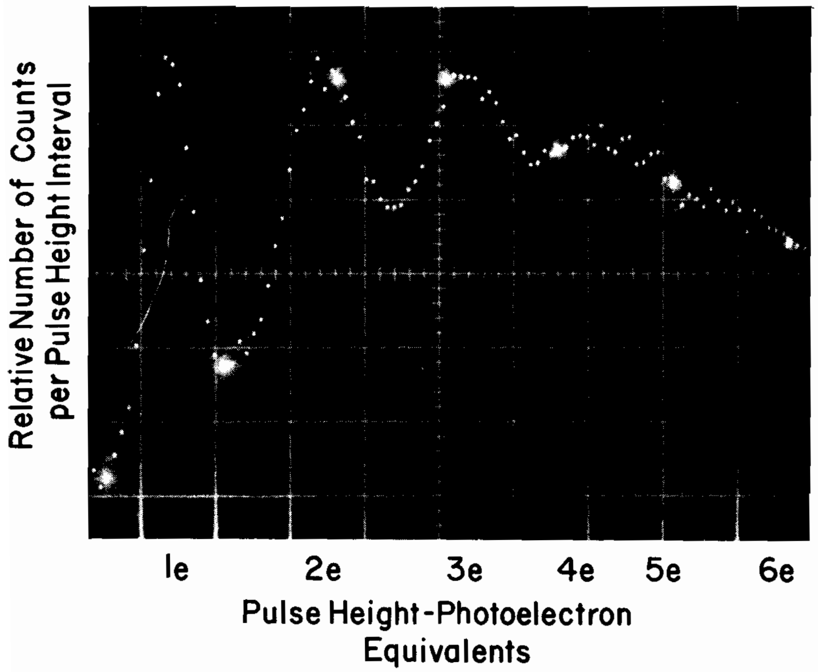


Fig. 1. $\Delta\beta/\beta$ as a function of momentum for L.



(photograph courtesy of RCA)

Fig. 2. Example of photoelectron resolution capability of Quantacon type photomultiplier tube.