

A THRESHOLD GAS ČERENKOV COUNTER FOR A 200 GeV/c BEAM*

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Received 12 March 1971

A test of a prototype gas Čerenkov counter is described. The emphasis was on testing various photomultipliers with extended quantum efficiency in the ultraviolet.

1. Introduction

The relative simplicity and economy of gas threshold Čerenkov counters as compared to the more complicated and costly differential type is particularly important when designing particle identification schemes for use at "high" energies (50 to 500 GeV). The most striking aspect of such threshold counters is that their lengths (tens of meters) are comparable to the drift spaces available in conventionally designed secondary beams. Any improvement that can be made in the collection or detection of the Čerenkov light allows one to shorten the counters thus making it possible to install several in one beam line which is required if several kinds of secondary particles are to be identified. A group at Serpukhov¹⁾ recently described a helium filled threshold counter with a very good light collection efficiency which was operated up to 50 GeV/c. We are reporting here the test of a prototype threshold gas counter of similar design. Our aim was to investigate

practical light collection and detection efficiencies which could be realized with various available photomultipliers.

The number of photoelectrons collected by the photomultiplier is given by

$$\bar{n} \text{ (photoelectrons)} = N_0 \sin^2 \theta_c \cdot L, \quad (1)$$

where L is the length of gas radiator in cm, θ_c a Čerenkov light cone angle and N_0 a number which depends on the light collection efficiency of the optical arrangement and the effective quantum-efficiency of the photocathode.

For highly relativistic particles, the length of a counter is determined from:

$$L = \frac{\bar{n}_1}{N_0} \frac{(P/c)^2}{(M_2^2 - M_1^2)}; \quad (2)$$

M_2 and M_1 are the masses of the two particles one wishes to identify, P is the momentum of the beam,

* Work supported by the U. S. Atomic Energy Commission.

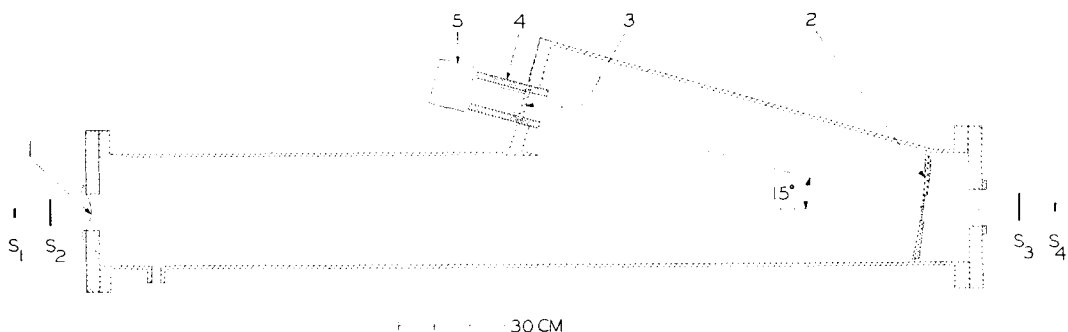


Fig. 1. Čerenkov threshold counter. 1 - Thin mylar windows. 2 - Front aluminized spherical mirror. 3 - Quartz window. 4 - Soft iron magnetic shield. 5 - Photomultiplier base, S_1 , S_2 , S_3 , S_4 - Plastic scintillator counters used in the test (see text).

c velocity of light and \bar{n}_1 is the number of photoelectrons produced by particles of mass M_1 . Under these conditions particles of mass M_2 are not counted while particles of mass M_1 are detected with the efficiency: $\varepsilon = 1 - \exp(-\bar{n}_1)$. For example, if one wishes to resolve pions and kaons at $P = 200$ GeV/ c and detect the pions with at least 95% efficiency i.e. $\bar{n}_1 = 3$, then relation (2) gives using $N_0 = 100/\text{cm}$, a required length of counter $L = 52.8$ m. The empirical number N_0 which appears in relation (2) can in principle be calculated from the well known Čerenkov relation

$$N(v)dv = (4\pi^2 e^2 / hc^2) \sin^2\theta dv, \quad (3)$$

the manufacturer's data on the quantum efficiency of photomultipliers, the reflectivity of aluminized mirrors and the transmission through quartz windows. In practice, N_0 calculated by this method can be overestimated by as much as a factor of two presumably because of the difference between the effective quantum efficiency and the manufacturer's value. Recent measurements of Meunier et al.²⁾ have shown, that the photoelectron collection efficiency is quite sensitive to the incident photon energy and that there are substantial differences between the manufacturer's data and the numbers obtained experimentally. We have therefore measured directly in a Čerenkov counter, the overall quantum efficiency of several photomultipliers currently available all having quartz windows and extended photo-efficiency in the ultraviolet. The experimental values of N_0 thus obtained are presented below.

2. Experimental method

The counter is shown in fig. 1. It is a 30 cm diameter aluminum pipe, painted black³⁾ inside. The spherical mirror is front coated with aluminum⁴⁾ and had a layer of MgF_2 as a protective coating. The focal length of the mirror is 100 cm and it is arranged to reflect the Čerenkov light back at a 15° angle through a quartz window (1.2 cm thick) which has an antireflection coating⁵⁾ on both sides. No light coupling grease is used between the photomultiplier and the window. The radiator length of the counter is 230 cm. The center portion of the mirror is 6 mm thick and the entrance and exit windows of the counter are 0.2 mm thick mylar windows 7.6 cm in diameter.

We have conducted our measurements in an extracted electron beam of the Cornell synchrotron. The 9.8 GeV beam was 7 mm in diameter with a divergence of less than ± 3 mrad and no observable halo. Counting the beam were 4 plastic scintillators. S_1 and S_4 being 2.5×2.5 cm and S_2, S_3 7.6×7.6 cm. S_1S_4 and S_2S_3

coincidences were counted separately to determine possible beam motion or halo. No beam motion or any halo was observed. The instantaneous beam rate was measured to be less than 1 Mc and the accidental coincidences were measured to be less than 1%. The momentum spread of the beam was less than 3% $\Delta p/p$ and was of no consequence to our measurements. The counter was evacuated and its counting efficiency compared to scintillators was measured as the counter was pressurized with helium. The threshold pressure of He for 9.8 GeV electrons is 3.57×10^{-5} atm and on the scale of our measurements is equivalent to vacuum. Thus the observed efficiency curves show effects which are solely due to photostatistics. One such efficiency curve is shown in fig. 2. The measured points agree very well with the expected relation

$$\varepsilon = 1 - e^{-\bar{n}}, \quad (4)$$

where \bar{n} is the mean number of photoelectrons obtained from relation (1). The relation between \bar{n} and pressure is given by

$$\bar{n} = N_0 2\alpha p L, \quad (5)$$

where p is the pressure in atmospheres at 0°C and

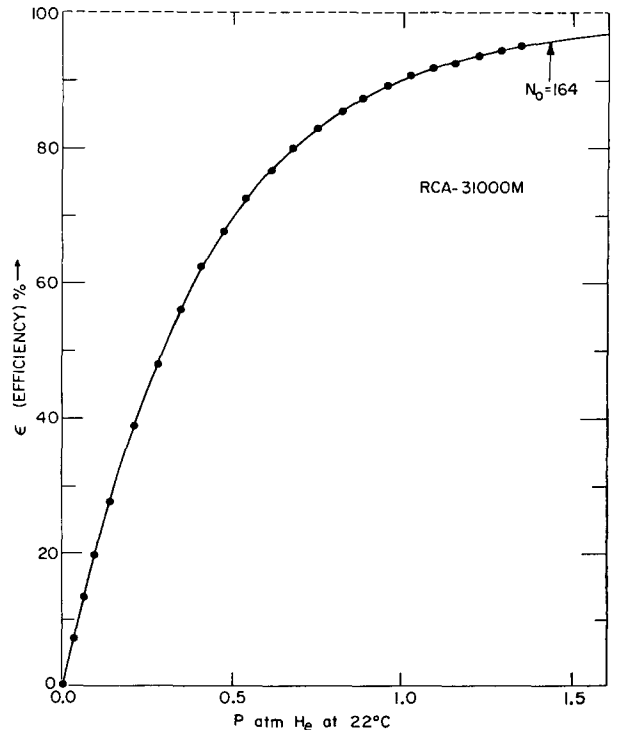


Fig. 2. Efficiency curve obtained with a RCA-31000M photomultiplier shows the percentage counting efficiency of the Čerenkov counter versus scintillators as a function of gas pressure. Statistical errors are smaller than the indicated points.

$\alpha = 3.55 \times 10^{-5}/\text{atm}$, which is the pressure coefficient of the known index of refraction of helium at 1 atm and 0°C. N_0 is obtained from the curve using this formula.

3. Results of the measurements

Five photomultipliers were measured. For each photomultiplier the efficiency-curves were measured several times and found to be reproducible. Each phototube was held under spring tension against the

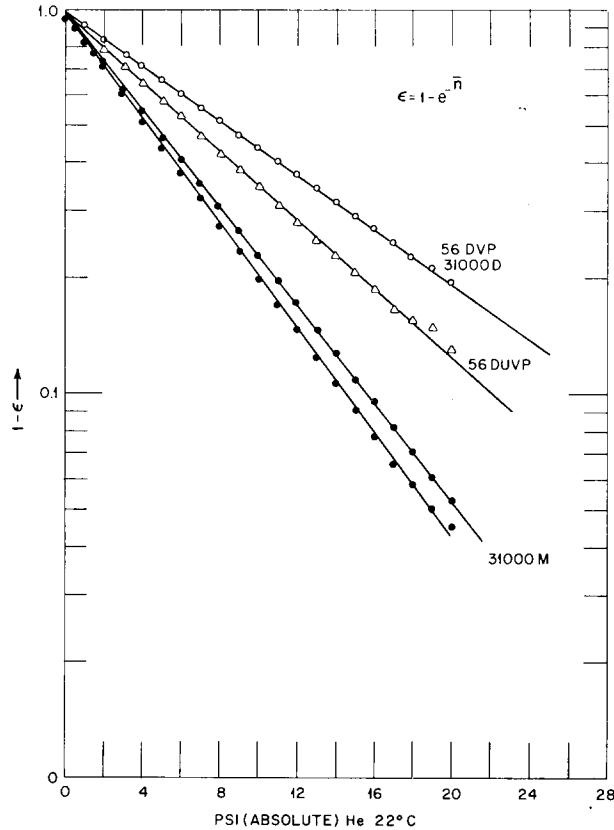


Fig. 3. Measured curves for various photomultipliers. The indicated exponential behavior agrees well with the expected expression (4) described in the text.

quartz window, and its electrical focusing adjustments were optimized. All photomultipliers were operated with grounded photocathodes. Each measured curve agreed very well with the expression (4), as shown in fig. 3. Table 1 lists N_0 as measured for several photomultipliers available to us. The 56 DUVP available to us was manufacturer's selected sample. During the measurement we took particular care that the discriminator threshold was set well below the single photoelectron pulse height. It was particularly easy to

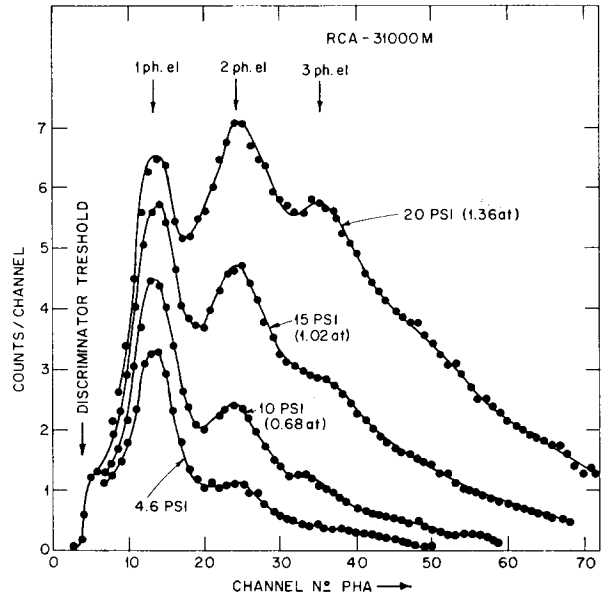


Fig. 4. Pulseheight spectra obtained with a RCA-31000M photomultiplier at various gas pressures measured with a 400 channel pulseheight analyzer. The peaks correspond to the single, double etc. photoelectron response of the photomultiplier.

establish this condition with the RCA photomultipliers because all had a galliumphosphide first dynode. Fig. 4 shows the pulseheight spectra obtained with RCA-31000M at various pressures. Single, double and triple

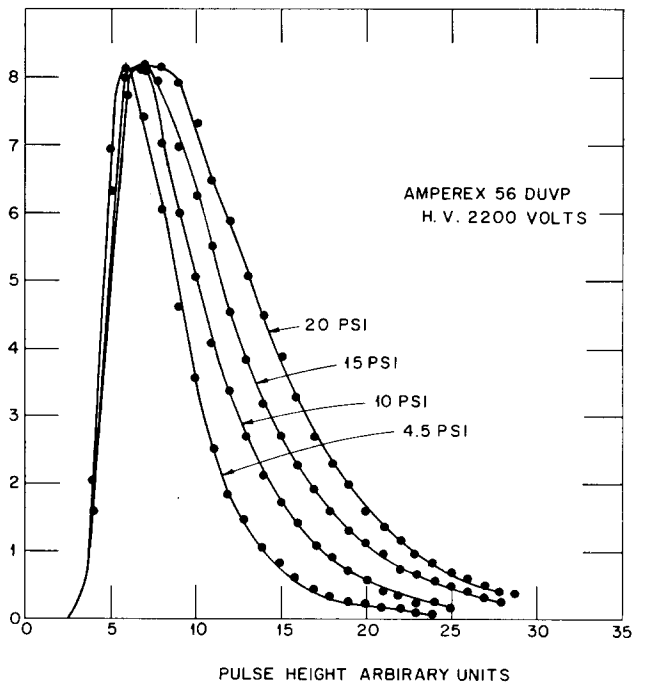


Fig. 5. Pulseheight spectra obtained with an Amperex 56 DUVP under the same conditions as those of fig. 4.

TABLE I

Photomultipliers	Serial no.	50% point	N_0
31000 M	RCA D22731	4.20 PSI	164 ± 3
31000 M	RCA P22733	4.70 PSI	146 ± 3
8850	RCA C10463	8.4 PSI	82 ± 2
56 DUVP	Amperex, 41903	7.0 PSI	101 ± 2
56 DVP	Amperex, 27961	8.4 PSI	82 ± 2

photoelectron peaks are clearly visible. The unfolding of these pulseheight spectra was in excellent agreement with a predicated Poisson distribution for a given measured average photoelectron number \bar{n} , at all pressures. Fig. 5 shows the pulseheight spectra obtained under the same condition with a 56 DUVP. In this case, lacking resolved photoelectron peaks, the photomultiplier high voltage was varied over a wide range to assure us that the discriminator threshold was well below the one photoelectron equivalent pulseheight.

The pressure was measured with a Bourdon tube gauge⁶⁾ calibrated to $\pm 1\%$ absolute by the manufacturer. The operating temperature was 22°C . The counter was vacuum tight and would maintain 10^{-4} torr pressure for several days without being pumped.

Finally, one test was made which assured us that no scintillation light from the He gas was observed in these measurements. The counter was rotated by 180° so that the beam now entered from the mirror end. Scintillation light being isotropic would have been collected by the same optics system but no Čerenkov light could reach the photomultiplier. We observed no counts even at a pressure of 1.35 atm He.

4. Conclusions

We feel that $N_0 = 150$ could be safely used as a design parameter for other Č-counters. Using $N_0 = 150$ a counter which could π 's with 95% efficiency at the K threshold at 200 GeV/c would have to be 35.2 m long. This conclusion is in good agreement with measurements of the Serpukhov group¹⁾. The differences observed between various types of photomultipliers are quite significant particularly at higher energies where counter length can be reduced by many meters by employing the more efficient photomultipliers.

We would like to thank the Director and staff of the Wilson Synchrotron at Cornell for letting us use their test beam in these measurements, and for their assistance in providing the beam of high quality. The help and expertise of P. Yoder of Argonne Central Shops who made the mirror was greatly appreciated.

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- 2) P. Duteil, J. P. Garron, R. Meunier, J. P. Stroot and M. Spiegel, CERN 68-14 (1968).
- 3) *Velvet coating*, no. 101-C10, Minnesota Mining and Manufacturing Co.
- 4) The company which performed the coating was: Dudley Leroy Clausing Co., 8038 Monticello Ave., Skokie, Illinois. The aluminizing was performed under 5×10^{-7} torr vacuum for 28 sec. MgF_2 coating was $\frac{1}{4}$ wavelength thick at 300 nm. Finally the mirror was sprayed with pure oxygen for several minutes.
- 5) Infrasil, grade A, Amersil Inc. Hillside, N. J. Same as ref. 4, MgF_2 coating was $\frac{1}{4}$ wavelength thick at 350 nm. Coating performed under 1×10^{-7} torr.
- 6) Heise Bourdon Tube Co., Newton, Connecticut.