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UVT-PMMA CHERENKOV COUNTER PERFORMANCE TESTS

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UVT-PMMA Cherenkov detectors have been tested in a particle beam at the Frascati electron linear accelerator. The scintillation light is 1/45 of the Cherenkov light. These counters have good uniformity, in spite of the strong angular dependence of the Cherenkov light.

1. Introduction

We have tested a prototype of the Cherenkov counters to be used in the Free Quark Search [1] experiment at the electron–positron colliding beam facility PEP (at SLAC-Stanford).

These counters are made of UVT-PMMA (ultra violet transparent polymethyl-methacrylate) by Polivar *.

The Cherenkov counter (fig. 1a) we have used consists of a UVT-PMMA (refractive index $n = 1.49$) slab 300 cm long, 21 cm wide, 5 cm thick with a 30 cm light guide of the same material glued on each side. Each end of the counter is viewed by a 9618R 5″ EMI photomultiplier. The coupling between the counter and the tube is realized by a UVT-PMMA cylinder, 11 cm long and with 5″ base diameter.

We have measured:

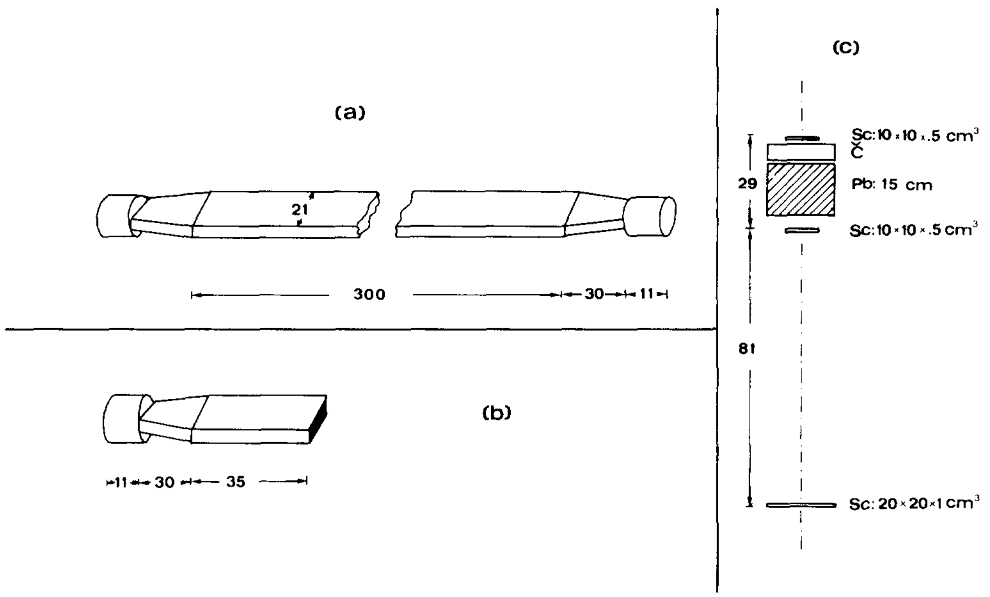


Fig. 1. (a) Cherenkov prototype used in our tests with cosmic rays. The thickness is 5 cm. (b) Cherenkov prototype used in our tests with the pion beam. (c) Telescope arrangement for our tests with cosmic rays.

* POLIVAR S.p.A., Via Naro, 72, P.O. Box 111, 00040 Pomezia, Rome, Italy.

(i) the light attenuation length;

(ii) the number of the collected photoelectrons as a function of the incidence angle and the position in the counter;

(iii) the ratio between the Cherenkov and the scintillation light collected.

In this paper we summarize the results obtained and give a short description of the techniques used.

2. Attenuation length measurement

For this measurement we have used a 5″ EMI photomultiplier at one end of the counter while the opposite end was blackened. We have measured the anodic current of the tube versus the position of a ^{60}Co source placed on the counter (fig. 2). The attenuation length was found to be $\lambda = 4.04 + 0.40$ m (χ^2/DOF = 4.26/13) after correcting for the non-uniformity of the counter's thickness (0.5 cm over the complete length). We notice that the attenuation length depends on the angle of the emitted light, which is isotropic in the case of a ^{60}Co source. We then expect a somewhat lower value in the case of particles hitting the counter at normal incidence.

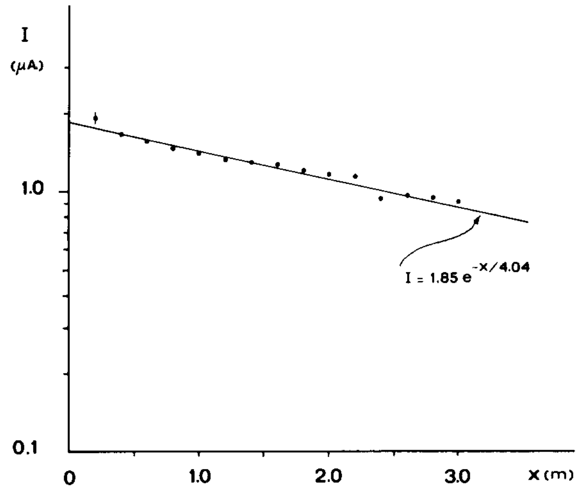


Fig. 2. Attenuation length measurement.

3. Cosmic ray tests

For this measurement we used a telescope of scintillation counters detecting cosmic rays. Fig. 1c is a sketch of this set-up; a lead absorber of 15 cm thickness was inserted in order to accept only particles

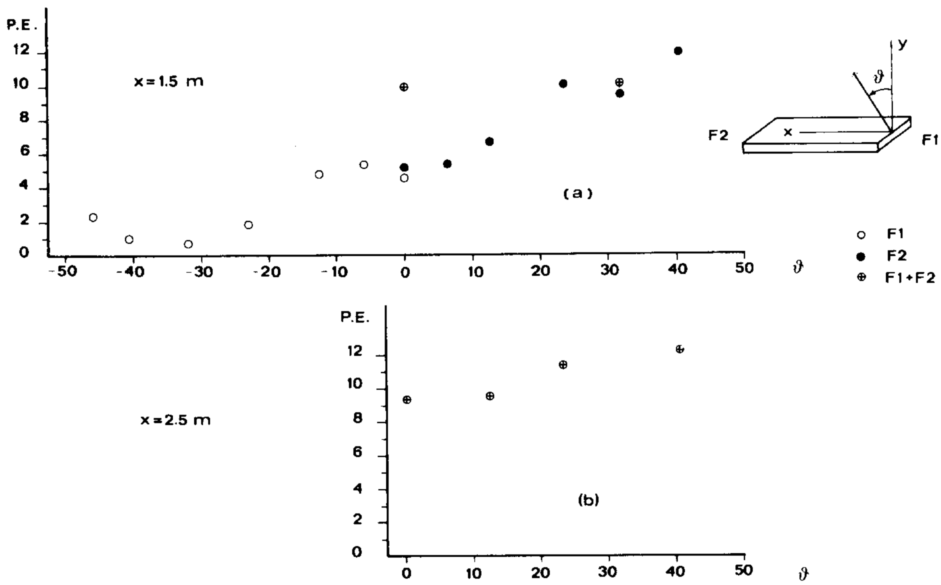


Fig. 3. Number of photoelectrons versus the incidence angle ϑ. F1 and F2 are the two photomultipliers at the opposite ends of the counter. F1 + F2 refers to the sum of the photomultiplier signals. (a) Telescope at center of the counter. (b) Telescope placed 1 m from the center.

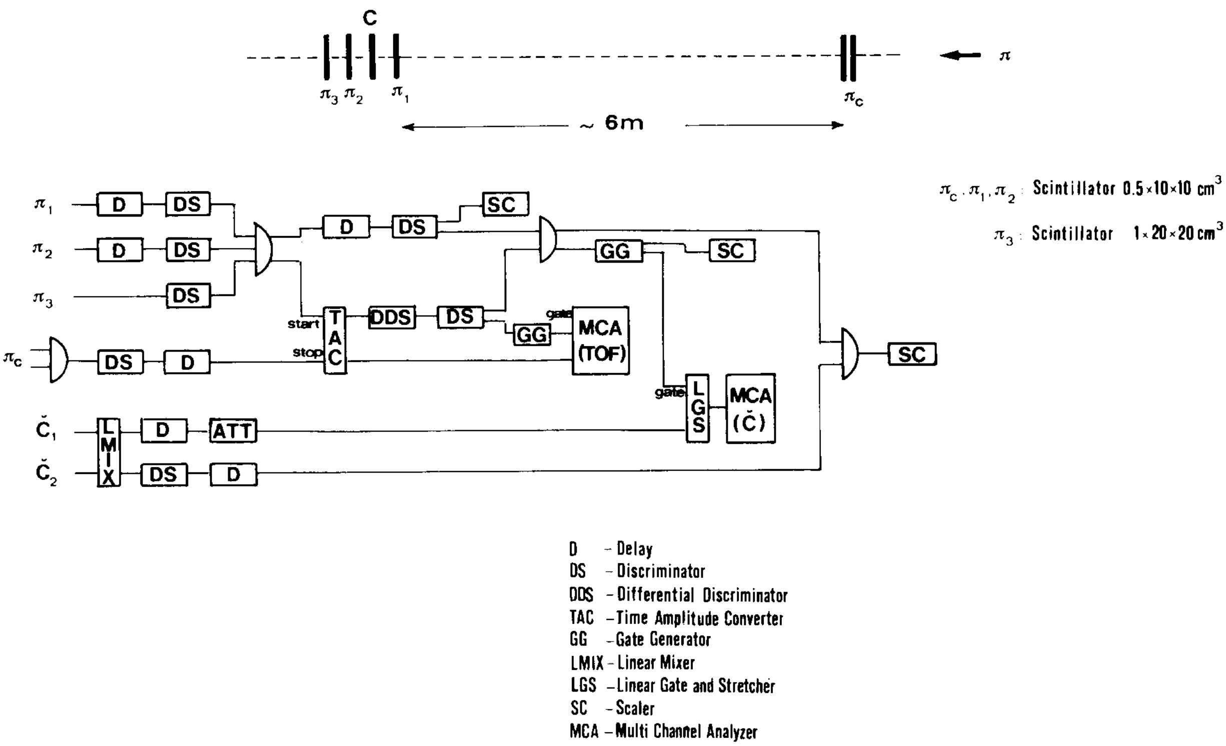


Fig. 4. Counter arrangement and logic for tests with pion beam.

with $\beta > 0.9$. For this β value the Cherenkov angle is greater than the critical angle so that the light undergoes total internal reflection. In fig. 3 we report the results obtained in terms of N_{PE}, the photoelectron number. We have

$$N_{PE} = \alpha\mu \tag{1}$$

where μ is the mean of the pulse height distribution and α is a scale factor determined at an N_{PE} value such that the statistics can be regarded as gaussian *. For this test the Cherenkov was viewed by two EMI phototubes one at each end; the HV was adjusted in such a way that the anodic current was the same when a ^{60}Co source was placed in the middle of the counter.

We have investigated the dependence of N_{PE} on the incidence angle (fig. 3a): we have found that the total number of photoelectrons seen by the tubes in several angular conditions is enough to allow high detection efficiency $[1 - \exp(-10) \simeq 1 - 5 \times 10^{-5}]$.

* The exact relation is [2]: $N_{PE} = (M^2/V)[\delta/(\delta - 1)]$, where δ is the secondary emission rate of the photomultiplier. The correction due to δ ($\simeq$20%) and other effects such as the cathodic quantum efficiency have been disregarded since we are interested in relative measurements.

We have also found that this number, in spite of the Cherenkov light directionality, does not show a strong dependence on the incidence angle and is about constant up to a distance of 1 m from the center of the counter (fig. 3b).

4. Pion/electron tests

In order to measure the ratio between the Cherenkov and the scintillation light collected in the counter we have used the LEALE pion beam facility at the LNF. The main parameters of the beam are: maximum kinetic energy $T = 170$ MeV (corresponding to $\beta = 0.9$), momentum spread 1%, duty cycle 5×10^{-4}; the muon and electron contamination of the beam is the order of 10% at lower energy and decreases substantially with the energy.

Due to the large environmental background and the lack of space for a good shield we could not use the 3.6 cm long counter for this measurement. We used a smaller prototype, of the same width and thickness but only 35 cm long, viewed by a phototube at one end only (fig. 1b).

Figure 4 shows the experimental layout for this

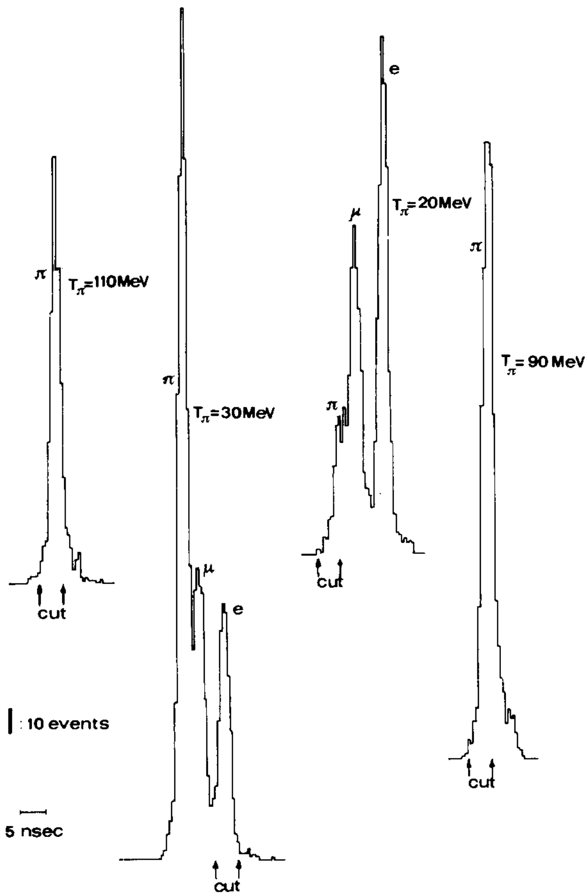


Fig. 5. Time-of-flight spectra; the sensitivity is 2 chs/ns, T is the kinetic energy of a pion at the exit from the Cherenkov counter; the cuts used to select different particles are also shown.

test and a flow chart of the electronics used.

The $\pi/\mu/e$ particle identification was obtained using time-of-flight measurements over a 6 m long path; typical TOF distributions obtained are reported in fig. 5. Fig. 6 shows some typical pulse-height distributions. In order to evaluate the background at each energy we also collected distributions with the gate signal delayed.

In order to determine the scale factor we have used the relation:

$$N_{PE} = \ln(N_{TOT}/N_{PED}) \tag{2}$$

where N_{TOT} is the total number of events and N_{PED} is the number of events in the pedestal channel. We have measured N_{PE} for electrons and found $N_{PE} = 5.8 + 0.8$. N_{PE} can also be determined using the mean value and the variance of the distribution (see

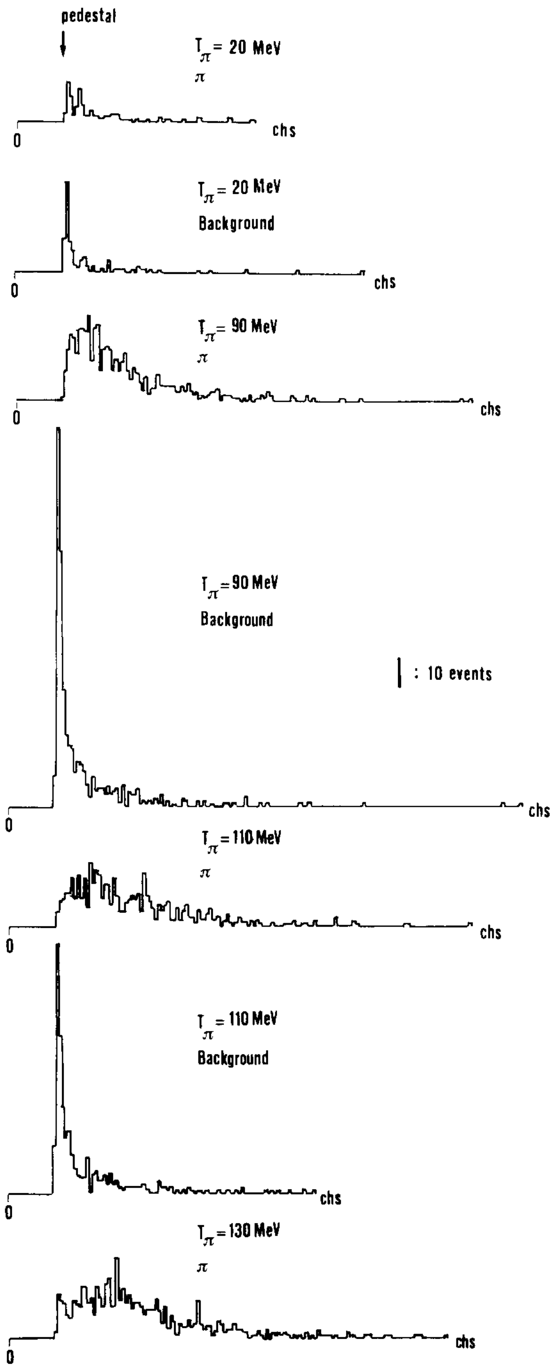


Fig. 6. Pulse-height spectra: "π" refers to spectra collected with gate in-time and "background" to spectra with gate out-of-time.

previous footnote and ref. [2])

$$N_{PE} = (M^2/V). \tag{3}$$

In order to determine M and V we have fitted our

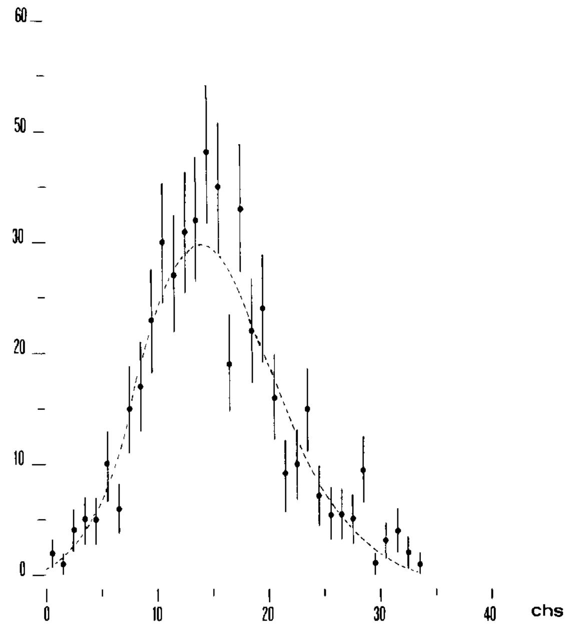


Fig. 7. Electron spectrum; the dotted line refers to a fit with an empirical distribution derived from the poissonian with a continuous formula for the factorial.

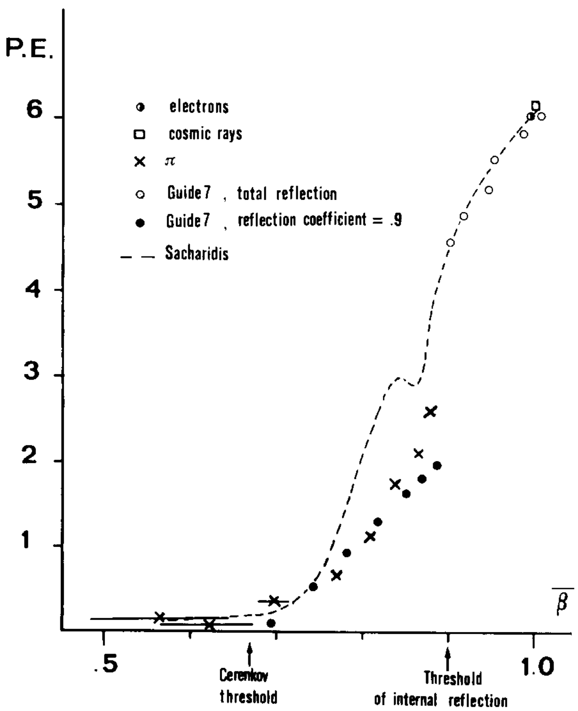


Fig. 8. Photoelectron number versus beta.

experimental distribution with a gaussian (χ^2/DOF = 94/74) and a poissonian with a continuous approximation for the factorial function (χ^2/DOF = 49/40) (fig. 7). We have obtained respectively $N_{PE} = 5.3 + 0.8$ and $N_{PE} = 5.75 + 0.75$. The results from the two techniques are in very good agreement; the value of the scale factor [see eq. (1)] that we derive is $\alpha = 8.7$ channels $\times$ PE.

When the number of photoelectrons is very small eq. (2) cannot be used because the position of the pedestal cannot be determined with high accuracy due to the high-level background, so we have used the equation

$$N = \alpha(\mu - \mu_{BG}) \tag{1a}$$

where μ and μ_{BG} are the mean values of the spectra respectively with the gate-in-time and out. Fig. 8 shows the results as a function of beta. The ratio $N_{PE}(\beta = 1)/N_{PE}$ ($\beta <$ Cherenkov threshold) is found to be 45. This result agrees with that obtained by Sacharidis [3] in 1972, although there is some difference between the Sacharidis curve and our results in the region of the critical angle where the geometrical effects are important.

Consistency has also been found between our experimental data and the results of a Monte Carlo simulation of the counter (GUIDE7 [4]). The results, also plotted in fig. (8), have been normalized for β = 1; for beta below the value that gives total internal reflection, the reflection coefficient has been assumed to be 0.9.

In order to evaluate the fraction of particles with beta below the Cherenkov threshold that gives a pulse-height in the counter above a fixed value we must first subtract from the $\beta = 0.62$ pion distribution, with gate-in-time and out, respectively. The subtraction of the background was carried out using the equation

$$G(j) = \left[F(j)/D - \sum_{i=0}^{j-1} G(i)H(j-i)\right]/H(0) \tag{4}$$

where i and j are bin indexes, 0 is the pedestal channel, D the bin width, H and F are the normalized distributions corresponding to the spectra of fig. 9 (see the Appendix). After this background subtraction the PE number at $\beta = 0.62$ calculated from eq. (3) is 0.12 [to be compared with 0.13 calculated from eq. (1a)]. Fig. 10 shows $G(j)$, as function of N_{PE}, compared with the normalized distribution of the $\beta = 1$ particles.

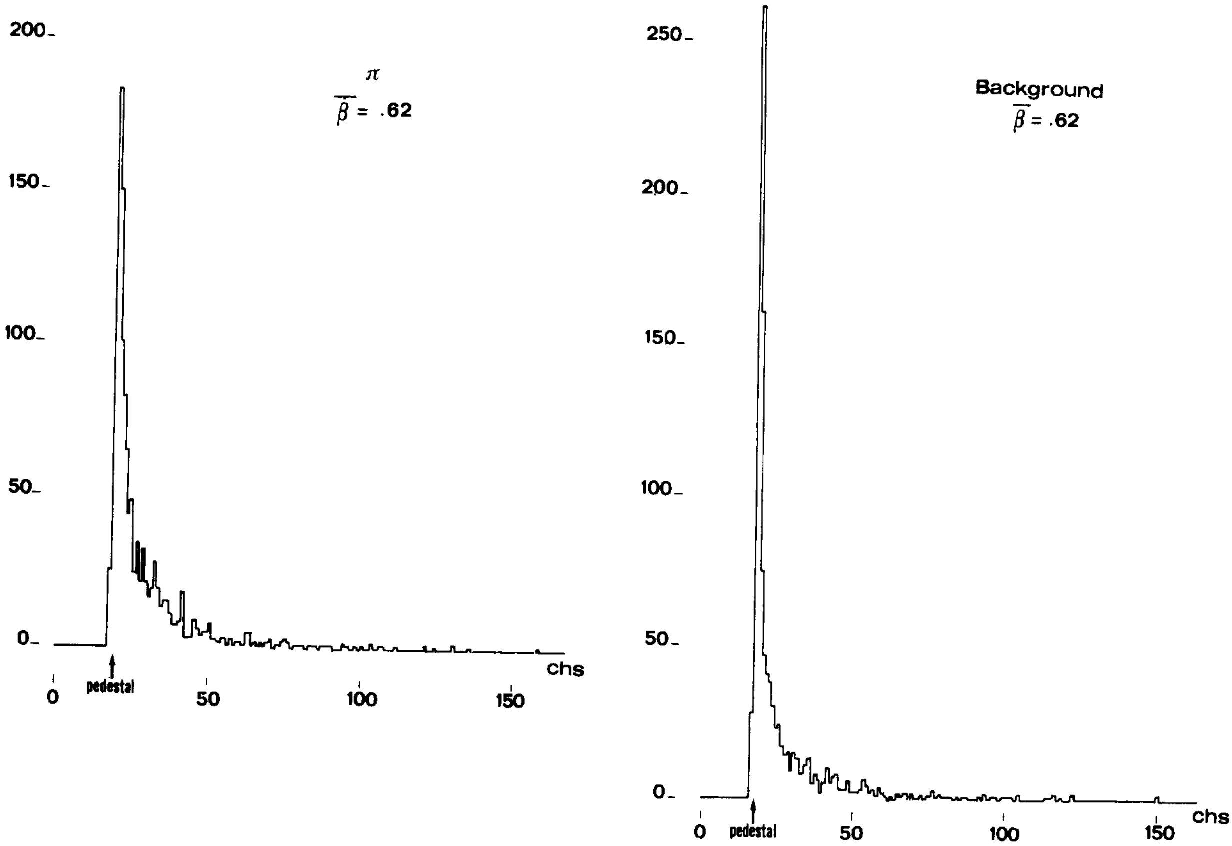
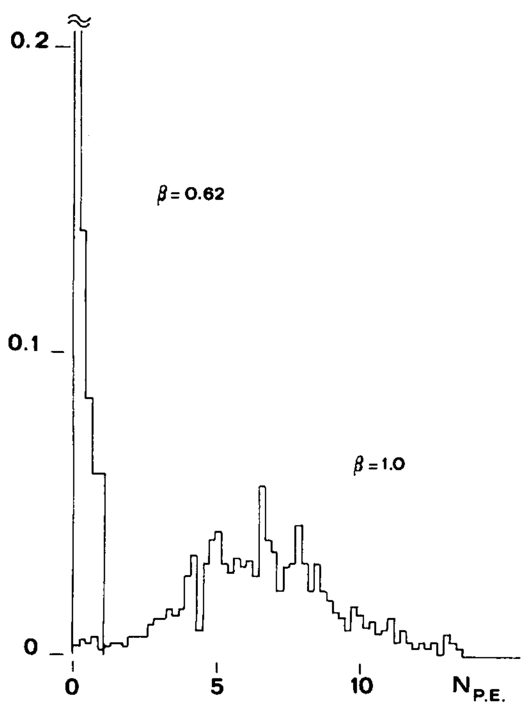


Fig. 9. Pion and background pulse-height spectra at β = 0.62.



The comparison of these two distributions shows that a suitable cut is at $N_{PE} = 1$: with this cut a β = 0.62 particle has a probability close to zero to be detected while the tagging efficiency for $\beta = 1$ particles is about 98%.

5. Conclusions

The main features of the counter we have tested are: it is very easy to build, is of low cost if compared with counters with wave-shifter and quencher, has good attenuation length and good angular uniformity. The angular dependence of the light seen by one phototube is well compensated when the signals of

Fig. 10. Normalized pulse-height distribution for β = 0.62 pions with the subtraction of the background and normalized pulse-height distribution for β = 1 particles.

both are summed. Scintillation light is rather low in comparison with counters of different kind [5]. The tagging efficiency when a cut at 1 photoelectron is applied is greater than 99% (extrapolating our result with one photomultiplier to the case of two).

We are grateful to Prof. C. Guaraldo, Dr. A. Maggiora and the whole staff of the LEALE group for their support during the test runs.

Appendix

Let $F(x)$, $G(y)$ and $H(z)$ be the distribution functions of x, y, z with the contraint $x = y + z$. We assume F and H known and G unknown. Then

$$F(x) = \int G(y)\, H(x - y)\, \mathrm{d}y\,. \tag{A}$$

If all the previous distributions are 0 for negative arguments, an approximation for (A) is

$$F(i) = \sum_{j=0}^{i} G(j)\, H(i - j)\, D \tag{B}$$

where D is the integration step. By inverting (B) it is possibly to obtain eq. (4).

References

[1] T. Pun et al., PEP Proposal PEP 14.
[2] E. Breitenberger, Prog. Nucl. Phys. 4 (1961) 56.
[3] E.J. Sacharidis, Nucl. Instr. and Meth. 101 (1972) 327.
[4] T. Massam, CERN 76-21 (1976).
[5] R. Bernabei et al., Nucl. Instr. and Meth. 155 (1978) 407.