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BEAM TEST OF ČERENKOV COUNTER PROTOTYPE FOR ZDF SETUP

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Качарава А.К. и др. E1-95-380
Испытание на пучке черенковского счётчика для установки ZDF

В работе рассматривается черенковский счётчик полного внутреннего отражения, предназначенный для разделения частиц в области импульсов выше порога черенковского излучения. Прототип счётчика был испытан на вторичном пучке ускорителя ИТЭФ (Москва). Наблюдалась зависимость выходного сигнала от ориентации радиатора относительно направления входа пучка.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1995

Kacharava A.K. et al. E1-95-380
Beam Test of Čerenkov Counter Prototype for ZDF Setup

In this paper we describe a Čerenkov counter of total internal reflection for particle separation in the momentum range where all types of particles radiate Čerenkov light. The Čerenkov counter prototype with the lucite radiator was tested on the secondary beam of the ITEP (Moscow) accelerator. Dependence of the photomultiplier pulse height on the particle entrance angle was clearly observed.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1995

Basic Remarks

In this paper we consider the Čerenkov Counter of total internal reflection proposed for π/K and p/d separation and background suppression at the trigger level in the momentum range above the threshold. We plan to use this type of the Čerenkov counter in the forward detector of the Zero Degree Facility (ZDF) at the COSY synchrotron (Jülich). The ZDF is a general purpose detector under construction. It is intended for investigation of the K^+-subthreshold production [1] and to study the exclusive deuteron break-up process [2].

We have well known expression for the Čerenkov photon number reaching the photocathode:

$$\frac{dN_{ph}}{dL} = \frac{\alpha}{\hbar c} \sin^2 \vartheta_C \int_{\Delta E} \varepsilon(\delta, E)\, dE$$

where $\vartheta_C = \arccos(1/\beta n)$ is the Čerenkov cone half opening angle and $E = 2\pi\hbar c/\lambda$ is the energy of the irradiated photon. We have assumed that $\varepsilon(\delta, E)$ is the factorizable light collection efficiency, uniform over E and equal to the fraction of the light reaching the photodetector $\varepsilon(\delta, E) = \varepsilon_T \Delta\phi(\delta, \vartheta_C)/2\pi$ with constant light propagation efficiency ε_T. $\delta \in [\delta_o, \delta_o + \Delta\delta]$ is the particle entrance angle, with δ_o radiator inclination angle and the angular spread $\Delta\delta$ of uniform distribution.

The number of generated photoelectrons in the photomultiplier (PM) with the conversional efficiency ε_{PM} is equal to

$$N_{pe} = \frac{dN_{ph}}{dL} \frac{\Delta_z}{\cos\delta} \varepsilon_{PM},$$

where $\Delta_z/\cos\delta$ is the particle path length in the radiator with thickness Δ_z.

Simulation

The idea is to make use of the total internal reflection (the angle of total internal reflection: $\vartheta_R = \arcsin(1/n)$) for the Čerenkov light collection for particles with higher β through the radiator inclination angle selection [3]. The proposed Čerenkov counter characteristics were studied by Monte-Carlo simulation using GEANT3 package [4] for particle tracing. The particles were generated at the pointlike target and traced straightly to the counter. We used lucite for the Čerenkov radiator in the simulation program. The Čerenkov counter consisted of a plane parallel radiator connected with PM on one side. Radiator dimensions were $50\times10\times5 cm^3$.

For each event we calculated the amount of Čerenkov light fraction that reached PM. For the light fraction detected by PM we used a simplified algorithm for the arc $\Delta\phi$ estimation in each generated event (instead of ray tracing). The 'arc active fraction' (or detectable part of Čerenkov light) was defined as:

$$\Delta\phi = 2\ \arccos\left(\frac{\tan(\vartheta_R+\delta)}{\tan\vartheta_C}\right).$$

If $\vartheta_R+\delta > \vartheta_C$, total internal reflections do not occur and $\Delta\phi = 0$. The photocathode conversional efficiency ε_{PM} was taken equal to 0.2 and the light propagation efficiency $\varepsilon_T = 0.4$. $\Delta E = 1.2\,eV$ for lucite. The inclination angle $\delta = 0°$ corresponds to perpendicular particle entrance direction and $\delta = -90°$ to the entrance from the free side of the radiator.

The following factors influencing the particle detection efficiency were taken into account:

- The particle momentum spread for one counter in the acceptable range, because of kinematical and geometrical fluctuations and due to energy losses. It gives:

$$\Delta\vartheta_C[deg] = \frac{0.52}{(\beta\gamma)^2}\frac{\Delta p}{p}[\%]$$

$$\frac{\Delta p}{p} = 3\% \quad \text{at } 1.5\,\text{GeV/c gives } \Delta\vartheta_C = 1°.$$

- Variations of the particle entrance angle and position due to the acceptable angular range and multiple Coulomb scattering. In the simulation program we have used most unfavorable geometry: the entrance angle spread was taken equal to $\Delta\delta = 5°$.

- The number of calculated photoelectrons has been undergone to the gauss fluctuations on the stage photocathode– first dinode with $\sigma = \sqrt{N_{pe}}$.

The factors such as radiator optical dispersion, light attenuation, energy losses and multiple scattering inside the radiator were not considered. It is evident that these factors are not significant (maybe except the light attenuation).

In fig.1 the particle detection efficiencies (expressed as 'arc active fraction' $\Delta\phi$) for various radiator orientation angles (δ_o) are shown for K and π mesons in the momentum range $0.8 \pm 0.02\,GeV/c$.

The corresponding pulse heights for the lucite radiator are presented in fig.2. In the simulation program 1000 input events were generated for each particle type. In the presented results pulse heights from PM are expressed in the photoelectron number, but, as is evident from the assumptions listed above, these numbers were estimated approximately. On the other hand, they reflect the pulse height relative values correctly.

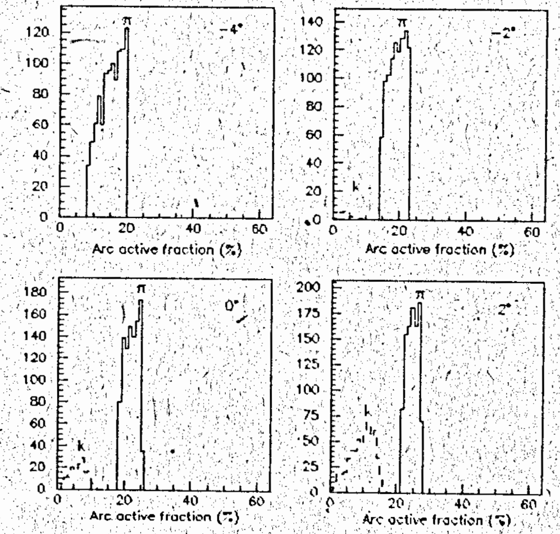

fig.1 Arc active fraction at 0.8 GeV/c for various inclination angles(δ_o).

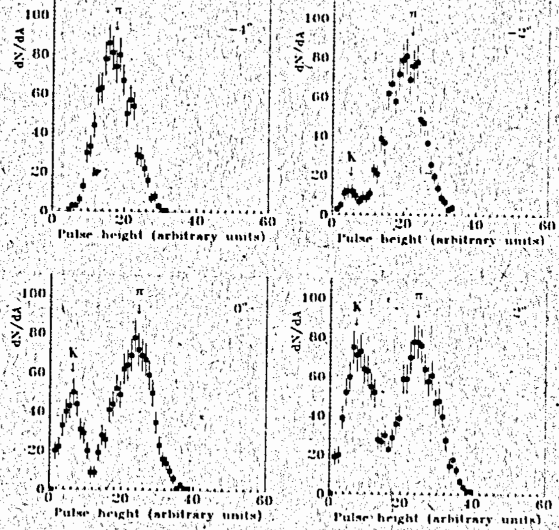

fig.2 Pulse heights at 0.8 GeV/c for various inclination angles(δ_o).

Experimental Testing

The Čerenkov counter prototype was a plane parallel radiator made of lucite ($n = 1.49$) with a 2" PM FEU-118 glued on the one end of it. A voltage divider of the PM was optimized for output signal in the linear range. The anode signal duration was about $100ns$. The radiator was polished on all sides except the opposite side of the PM and wrapped up in black paper to suppress the diffusion reflection. Dimensions of the radiator were $36 \times 10 \times 4cm^3$.

The counter was placed on the plane that allowed placing it at angles from $-45°$ to $+45°$ relative to the beam direction.

Measurements were carried out on the secondary beam of ITEP accelerator. Tuning the operation mode of the beam channel elements allowed choosing the particles of a given momentum and type. The intensity of the positive particle beam with momentum $1.5 GeV/c$ (with $\Delta p/p = \pm 3\%$) containing protons and pions was $(3 \div 5) 10^4$ for a $1s$ spill duration of $1s$ and acceleration cycle of $5s$. The beam spot on the Čerenkov counter was approximately $4cm$ in diameter.

The PM anode pulse was recorded in an ADC (10 bit LeCroy 2249A) placed in the CAMAC crate and analyzed on-line by IBM-PC/AT. The ADC and data acquisition were triggered by the beam signal obtained by coincidence of three scintillation counters. These triggering counters were located at a distance of about $20m$ and the delay selection allowed choice of both protons and pions in the beam.

Measurements proceeded mainly for the beam hitting of about $25cm$ from the PM. Investigation of the scintillation was done at the beam momentum $0.8 GeV/c$ (that is the threshold for protons). The scintillation in the radiator was not observed.

Dependence of the Čerenkov counter signal on the beam entrance angle was investigated with the beam containing both protons ($\beta = 0.85$) and pions of momentum $1.5 GeV/c$. Protons with this momentum radiate Čerenkov light equivalent to deuterons at $3.0 GeV/c$ and K mesons at $0.8 GeV/c$. At this momentum the angle of Čerenkov radiation in the radiator with a refractive index $n = 1.5$ is 36° for protons while for pions it equals 48° and total internal reflection angle equals 42°.

Results of measurements for protons and pions are presented in fig.3. As is seen from this figure, dependence of the PM anode pulse height on the angle relative to the beam direction is clearly observed. With rotation in the direction of negative angles the pulse height from π mesons rises earlier than for protons. As mentioned above, the cone of Čerenkov radiation for protons is narrower, therefore the increase in the amplitude for protons is sharper. At $\delta_o = 0°$ a decrease in the amplitude is stipulated in the same way the signal is well extinguished by multiple reflection.

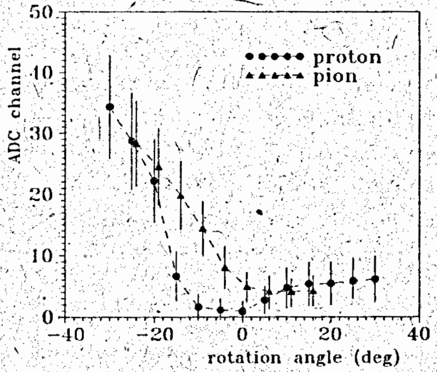

fig.3 Measured pulse heights for protons and pions vs the rotation angle at $1.5 GeV/c$. Error bars correspond to the output signal spread.

At the positive angle disposition a decrease in the reflection number occurred and it also included the reflections from the free side of the radiator. That caused some increase in the signal. For pions the total internal reflection takes place even at the perpendicular disposition of the radiator and an increase in the signal at negative angles is more gentle. In the case when both protons and pions radiate Čerenkov light the possibility of discrimination is well demonstrated in fig.4 corresponding to the disposition angle −10°. For the given conditions 98% of pions can be suppressed at 15% of lost protons.

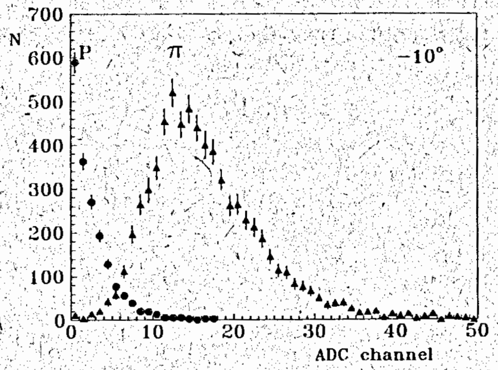

fig.4 Pulse-height distributions for protons and pions at $1.5 GeV/c$, corresponding to the rotation angle −10° in fig.3

Conclusion

The advantages of the proposed Čerenkov counter are the possibility of operation at high Čerenkov radiation intensity (it means good timing properties and high detection efficiency with respect to the threshold Čerenkov counters, e.g. Silica Aerogel) and the threshold tuning with variation of the rotation angle. The proposed Čerenkov counter is compact and does not require complicated engineering, can be easily standardized, requires less space than a conventional threshold Čerenkov counter for particle separation in the momentum range above the threshold.

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