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The Fast Strangeness Trigger of the CPLEAR Experiment

The CPLEAR Collaboration*

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Abstract

To measure the CP violation in the neutral kaon system with initially pure K^0 and $\bar{K}^0$ beams from the annihilation reaction $p\bar{p} \rightarrow \pi^\pm K^\mp K^0(\bar{K}^0)$ a good separation of pions and kaons is necessary. The properties of a particle-identification device making this separation possible and consisting of a scintillator Cherenkov scintillator sandwich are presented.

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1 Introduction

The CPLEAR group intends to measure various CP violation parameters in the decay of the neutral kaon system [1]. These parameters will be extracted from asymmetries of the form

$$A(t) = \frac{R(\bar{K}^0 \rightarrow f) - R(K^0 \rightarrow f)}{R(\bar{K}^0 \rightarrow f) + R(K^0 \rightarrow f)}$$

and

$$I = \frac{\int_0^{t_0} dt R(\bar{K}^0 \rightarrow f) - \int_0^{t_0} dt R(K^0 \rightarrow f)}{\int_0^{t_0} dt R(\bar{K}^0 \rightarrow f) + \int_0^{t_0} dt R(K^0 \rightarrow f)}$$

where f represents decay channels like $\pi\pi$, $\pi\pi\pi$ and $l\nu_l\pi$. t and t_0 are the decay eigentimes of the neutral kaons. To do so it is necessary to identify the strangeness of the the neutral kaon. This is done by identifying the charged particles in the annihilation reaction $p\bar{p} \rightarrow \pi^\pm K^\mp K^0(\bar{K}^0)$ ("golden" events). The sign of the charge is determined with the help of proportional and drift chambers in a magnetic field (fig.1) while the separation of pions and kaons is done in a threshold Cherenkov counter, which provides a fast trigger. As the branching ratio for $p\bar{p} \rightarrow \pi^\pm K^\mp K^0(\bar{K}^0)$ is only 0.004 and the expected rate of antiprotons at the Low Energy Antiproton Ring (LEAR) is $2 \times 10^6 s^{-1}$ a particle identification device with fast response (ns) is required in order to reduce the rates at the first trigger level. Cherenkov threshold counters fulfill these requirements. On the first trigger level a reduction in rate of a factor of 500 is required.

2 The Particle Identification Device

The particle identification device consists of 32 trapezoidal sectors of a scintillator Cherenkov scintillator sandwich (fig.2), placed on a cylinder with a radius of 65 cm (middle plane). The thickness of one sector is 12.5 cm. The thickness of the single components is 3 cm for scintillator 1 (S1) which is used for time of flight (TOF), 8 cm (Cherenkov) and 1.5 cm for scintillator 2 (S2)

which, seen from the target, is behind the Cherenkov detector to make sure that kaon-candidate really transverses it. Both scintillators are in the lateral size 1 cm smaller than the Cherenkov detector to avoid geometrical Cherenkov inefficiencies. The length of a sector is 310 cm without the light guides and the average width (middle plane) is 14 cm. The scintillators and the Cherenkov counter are equipped with light guides. The length of the light guides is 100 cm for S1, 90 cm for the Cherenkov and 75 cm for S2. The scintillators are at each end equipped with one photomultiplier (PM). The Cherenkov counter is equipped with two photomultipliers at each end in order to keep the useful cross section for the light collection as large as possible. The PM's for the Cherenkov counter and for S2 must be mounted perpendicular to the light guide to save space (fig.3). The optical contact is made with a small adaptor piece. For the Cherenkov counters XP3462/PA PM-tubes with a diameter of 7.5 cm are used. These PM's have a good single photoelectron resolution (fig.4) which makes it easy to set a clearly defined threshold by means of a discriminator. Each of the Cherenkov PM signals is split in two parts. One part is fed into a discriminator and used for the fast kaon-candidate trigger. The other part is fed into an ADC for the use at a later stage in the trigger, when the z-coordinate and the momentum of the particle are known. The z axis is defined as the length axis of the Cherenkov counter.

The Cherenkov counters are made of a tube of extruded UV transparent polymethyl methacrylate (PMMA) with a wall thickness of 2 mm. The ends are closed directly by light guides of the same material. Each of these sandwiches is hold in place by a frame made of 0.5 mm of stainless steel. The radiator is the liquid C_6F_{14} (FC72, Fluorinert) with a refractive index of 1.26 in the visible region of the spectrum and a very low dispersion down to a wavelength of 200 nm. Since the Cherenkov spectrum is proportional to $1/\lambda^2$, where λ is the wavelength of Cherenkov light, the efficiency of the Cherenkov counter can be largely improved by wavelength shifters. An extensive search has been done to find a suitable wavelength shifter which has been found in the form

of 2,5-diphenyl oxazole (PPO) which absorbs light between wavelengths of 200 and 350 nm. The maximum solubility of PPO in FC72 is 22 mg/l [2] at room temperature. At the used concentration of 20 mg/l the PPO absorbs more than 99% of the light per cm in the wavelength range of 280 to 310 nm [2]. Outside this range the absorption decreases continuously until it reaches 0 at the wavelength limits stated above. The absorbed light is reemitted between the wavelengths of 300 and 450 nm (peak at 340 nm) with a quantum efficiency of about 70% [2]¹. The emission peak is at a rather low wavelength compared with the transmission curve of UV transparent PMMA which makes thin counter walls necessary. The FC72 is practically transparent for wavelengths down to at least 200 nm.

Owing to the decay kinematics of "golden" events (fig.5) the ideal Cherenkov threshold is $\beta_t = 0.84$ corresponding to the maximum kaon velocity. This requires a refractive index of $n = 1/\beta_t = 1.19$. However, FC72 is the only liquid available in suitable quantities with a sufficiently low refractive index ($n = 1.26$). Owing to energy loss in the FC72, the effective threshold velocity of the incident particle is not given by $\beta_t = 1/n = 0.79$ but by $\beta_t = 0.81$ (fig.6) which is not too far from the required threshold of $\beta_t = 0.84$.

Tests with a prototype of such a Cherenkov counter have been carried out at the SIN/PSI in Villigen with a beam of unseparated pions, muons and electrons with momenta between 150 and 450 MeV/c. A gas Cherenkov counter and a time of flight system were used to separate pions, muons and electrons. Measurements of the z and angular dependence of the photoelectron yield have been done. These measurements show that the response of the Cherenkov counter could be improved significantly by painting the middle 80 cm of the detector on all four sides with white reflective paint (NE561). The Cherenkov light from the visible part of the spectrum cannot be totally internally reflected in

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the central region. The white paint acts as a diffuser and scatters this part of the Cherenkov light isotropically, resulting in a factor of two increase in the photoelectron yield. With this configuration the photoelectron yield per PM tube for pions of $\beta = 0.9$ incident perpendicular on the centre of the detector was 1.8. Measurements performed with pure FC72 as the radiator show that about half of these photoelectrons are due to the UV component of the Cherenkov light which is shifted by the PPO. Measurements of the z -dependence of the photoelectron yield with correlated angles (fig.7), simulating a pointlike target as an approximation to the final detector geometry, show a strong dependence of the photoelectron yield on the impact position. For 300 MeV/c pions the photoelectron yield varied between 0.29 photoelectrons per PM tube at $z = -40$ cm and 9.6 photoelectrons per PM tube at $z = 60$ cm (fig.8). The centre of the detector is at $z = 0$ cm, and positive z are counted towards the PM tube. The strong variation of the photoelectron yield with the impact position is not only due to the increased pathlength of the pions in the radiator but also to the fact that an increasing part of the visible light undergoes total internal reflection. The number of reflections for the shifted light which is still partially absorbed by the PMMA contributes to this dependence. This is demonstrated by a measurement comparing the added photoelectron yield of two Cherenkov detectors of a thickness of only 4 cm with one detector of 8 cm thickness, showing an increase in the photoelectron yield of a factor of two for the latter case.

On the other hand no effect has been found by moving the impact point across the width of the detector at least up to 0.5 cm from the wall. Information about the detector response for impact positions closer to the wall could not be obtained owing to the limited beam resolution. In the test run at the PSI the Cherenkov prototype was equipped with only one PM. Therefore, the information on the response of the Cherenkov counter, especially as far as background is concerned, is not complete. Up to now no information about the background correlations in the PM signals is available. The photoelectron yield from the centre of the detector, obtained with pions below threshold velocity,

was 0.1 photoelectrons per PM.

3 Simulation of the Detector Response

The data obtained from measurements with the prototype detector have been used to derive suitable parameters for a simulation of the Cherenkov detector that has been implemented in a simulation of the whole detector, based on the program GEANT [3].

In the following, a kaon-candidate is defined as a particle which has the pattern $S1 \bullet \overline{C} \bullet S2$ in one module of the particle identification device. The effects of different discriminator thresholds on pion and kaon tracks were simulated. The threshold is applied to the sum of all four PM's. The efficiency was defined as $\frac{S1 \bullet C \bullet S2}{S1 \bullet S2}$. The response of the Cherenkov counter as part of the trigger system was studied using this simulation. In addition to the kaon-candidate as defined above, a minimum cut on the transverse momentum [4] of roughly 300 MeV/c is required for particles giving no light in the Cherenkov counter. The cut on the transverse momentum is applied in order to prevent pions with a low momentum to fake kaons. This cut does not reduce the kaonic events because most of the kaons with a momentum lower than 320 MeV/c are stopped in the Cherenkov counter. The trigger for a "golden" event asks for more than 2 hits in S1 with at least one kaon-candidate that fulfills the condition on the transverse momentum. The Monte Carlo results obtained so far indicate that a rejection of pionic background by about a factor of 500 can be expected if a discriminator threshold of 2.5 photoelectrons is applied to the sum of the four PM signals.

A threshold of 2.5 photoelectrons means that the discriminator threshold is set between the second and the third photoelectron peak. This threshold is applied because of the strong z-dependence of the photoelectron yield and makes it possible to accept "golden" events also when the kaon transverses the Cherenkov counter near one of its ends. The low pionic background that is accepted because of this can later be reduced with a z-dependent threshold applied on the ADC contents

of the Cherenkov counter. With the above threshold only 20% of the golden events are lost owing to Cherenkov light produced by the kaons. The bigger part of the losses in the golden events is due to the solid angle covered by the detector (40%) and due to the number of kaons that stop in the Cherenkov counter (15%).

4 Conclusion

The tests of a Cherenkov prototype showed that for pions with a momentum of 300 MeV/c incident perpendicular on the centre of the Cherenkov counter a photoelectron yield of 7 photoelectrons per counter can be obtained. This is, geometrically as well as kinematically, the worst situation concerning the photoelectron yield. The Monte Carlo simulations, based on this measurements, indicate that the requirements on the Cherenkov detector have been fulfilled. The rejection of background by the fast kaon-candidate trigger, based only on information from the scintillators, the Cherenkov counter and the p_T -cut, is better than 1:500. At a later stage of the trigger, after some cuts on the tracks have been done, and the z-position and the momentum of the tracks are known, a cut on the ADC contents of the Cherenkov detector is applied. This gives a further reduction of the background of a factor of 5 to 10 depending on the annihilation channel. At the same stage a cut on the time of flight is applied which yields another factor of 3 [5].

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6 Figure Captions

Figure 1: A cross-section of the detector with a typical event is shown. The detector consists, moving from the centre outwards, of the target, two proportional chambers, six drift chambers, a streamer tube system, scintillators (S1) used for time of flight, the Cherenkov counter, a second layer of scintillators (S2), an electromagnetic calorimeter and the coil of the magnet. The beam axis is perpendicular to the plane of the figure. The overall diameter is 2 m and its length is 5 m.

Figure 2: The cross-section of the particle-identification device in its frame of stainless steel. From top to bottom the scintillator S2 which is hold in place by spacers, the Cherenkov detector and scintillator S1. The height is 12.5 cm and the width at mid height is 14 cm.

Figure 3: Scheme showing the outer part of the light guides with the PM tubes. The light guides of S2 and the Cherenkov counter are cut at an angle of 45 degree to reflect the light towards the PM tube. The connection between the light guides and the PM tubes is done with a small piece of UV transparent PMMA that makes the adaption to the cross section of the PM tube.

Figure 4: The photoelectron spectrum of a single PM-tube. The pedestal, and the first and second photoelectron peaks are clearly visible. The number of photoelectrons follows a Poisson distribution. The dashed line shows the spectrum obtained with an on-line threshold of 0.5 photoelectrons by a discriminator. A threshold of 0.5 photoelectrons means, that the threshold is set in between the pedestal and the first photoelectron peak. The spectrum shown corresponds to the photoelectron yield from the centre of the detector obtained with pions of 300 MeV/c. The mean number of photoelectrons is 1.8 .

Figure 5: The velocity distribution of the charged kaons and pions with a p_T of more than 200 MeV/c from "golden" events. The ideal threshold in order to accept most golden events and to separate kaons and pions is at $\beta = 0.84$ which is the maximum velocity of the kaons.

Figure 6: The velocity dependence of the photoelectron yield in the centre of the Cherenkov detector. The dashed line is the expectation of the yield according to $\langle nphe \rangle \sim 1 - 1/(n\beta)^2$, while the full line takes the energy loss according to the Bethe-Bloch formula into account. The vertical arrow is at $\beta = 0.84$ and indicates the maximum velocity of the kaons in "golden" events. If a p_T - cut of 300 MeV/c is applied to pions their minimal velocity is at $\beta = 0.91$.

Figure 7: Scheme explaining the meaning of the correlated angles ϑ . The z -coordinate and the impact angle ϑ of a particle coming from the target are not independent but follow approximately $\tan(\vartheta) = z/r$. There are, however, deviations due to the extension of the target.

Figure 8: The photoelectron yield for one PM as a functions of the impact position with its correlated angle for pions with a momentum of 300 MeV/c. The full dots correspond to the prototype painted white in the centre region while the open dots show the results for the unpainted box. The point a 60 cm is common to both situations. The error bars correspond to the sum of statistical and systematic errors. Painting the box results in an increase in the photoelectron yield of a factor of two in the centre of the Cherenkov counter.

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Fig. 1

S₂

> U

S₁

Fig 2

Fig 3

Fig. 4

Fig. 5

Fig 6

Fig 7

Fig. 8