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THE FORWARD DETECTOR OF THE ANKE SPECTROMETER. SCINTILLATION AND CHERENKOV HODOSCOPES

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The scintillation and Cherenkov counter system of the forward detector of ANKE, magnetic spectrometer at the internal beam of the accelerator COSY in Jülich, is described. The timing and amplitude characteristics are presented as well as the capabilities to select physical processes of interest.

Описывается система сцинтилляционных и черенковских счетчиков переднего детектора ANKE, магнитного спектрометра на внутреннем пучке ускорителя COSY в Юлихе. Приведены их временные и амплитудные характеристики, а также возможности их применения для выделения интересующих физических процессов.

INTRODUCTION

The experimental facility ANKE [1] is in operation at COSY, the COoler SYnchrotron at the Forschungszentrum Jülich, Germany. It is used for study of proton- and deuteron-induced processes at intermediate energies of up to 2.8 GeV. The ANKE setup (Fig. 1) consists of a three-dipole magnet system installed in the accelerator ring, an internal target and a set of detector groups which select the interaction products in various kinematical regions. One of these groups is the forward detector (FD) which provides detection of fast forward-emitted particles with momenta from 30 to 130 % of the beam momentum in the polar angle range $0^\circ < \phi < 12^\circ$.

The FD acceptance covers a significant part of the phase space of secondaries produced in nuclear interactions at COSY energies. Therefore, being used alone or in coincidence with the other detector groups, the FD allows one to investigate a wide range of processes, including the cumulative deuteron breakup, the ω and ϕ meson production, the subthreshold kaon production and others.

The forward detector comprises a set of fast multiwire proportional chambers and hodoscopes of scintillation and Cherenkov counters. We describe here the design and performance of these hodoscopes used for triggering and particle identification in experiments with ANKE.

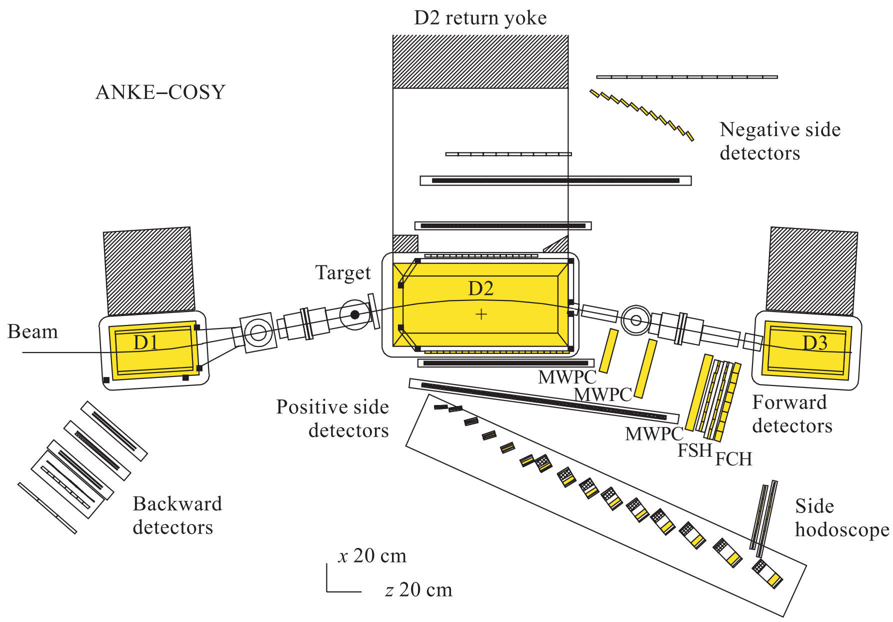

Fig. 1. Scheme of the ANKE setup

1. SCINTILLATION HODOSCOPE

The forward scintillation hodoscope (FSH) consists of two planes (A and B) with eight and nine vertically oriented counters in the planes A and B, respectively (Fig. 2). The counters in the plane B are half-width shifted with respect to the A-plane counters. The length of all scintillators is 360 mm, the width is 80 mm for most counters and gradually decreases to 40 mm for the counters in the high-momentum region near the beam pipe, where their occupancy increases. The scintillator thickness is 20 mm for the counters 80 mm wide and 15 mm for the others. The scintillators are viewed from both ends via lightguides with photomultipliers (PM) of the types XP4222 and XP2972 for the 20-mm and 15-mm counters, respectively. The counters, designed as independent units, are assembled on a common frame.

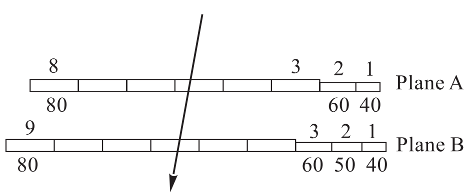

Fig. 2. Schematic top view of the forward scintillation hodoscope. The numbers above the planes are the counter numbers, those below the planes give the widths in millimeters

The front-end electronic channel for each counter (Fig. 3) includes a linear fan-out and a constant fraction discriminator/meantimer (CFD/MT) [2]. Hence, from each counter two analog signals (from the upper and lower PMs) and three logical signals (two from CFDs of the upper and lower PMs and one from MT) are available for further digitization in ADC and TDC and recording as well as for triggering purposes [3].

The time resolution of the counters measured in real beam conditions is in the range $\sigma = 100 \div 150$ ps, the lower value being for the counters with thicker scintillators. This provides the time-of-flight (TOF) measurements if the FSH is used together with one of other detector groups or if two particles hit different counters of the FSH. (As a matter of fact, in both cases not the TOF is measured but the relative timing of two detected particles which may have quite different trajectories. Nevertheless, this delivers information for the off-line particle identification which is equivalent to the TOF.)

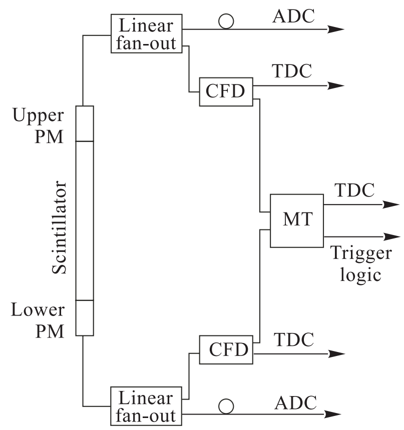

Fig. 3. Scheme of the electronic channel of an FSH counter

Using the timing information from the CFD channels of the upper and lower ends of a counter, one can find the value of the vertical coordinate y of the detected particle. The spatial resolution along the y direction obtained with this method is in the range $\sigma_y = 1.5 \div 2.2$ cm. The accuracy of the x-coordinate measurement in the hodoscope is defined by the counter widths. Taking into account the shift between the planes A and B, the uncertainty of the x-coordinate is close to a half of the counter width if the both plane signals are used (or slightly more for the inclined tracks). The x and y coordinates obtained in this way are used at the first step of the track reconstruction procedure in the forward detector proportional chambers. The achieved coordinate resolution of the FSH is sufficient to define a limited track search corridor and thus to exclude most of the spurious tracks.

The amplitude information from the FSH is used in the off-line analysis for particle identification and event selection of the processes under study. At intermediate energies the energy losses in the counters depend considerably on the particle type and momentum. For this reason a special amplitude calibration procedure has been developed [4]. The aim of this calibration is to obtain for each counter the relation between the measured amplitude in ADC channels and the real energy losses ΔE in the units MeV/cm.

The amplitude calibration procedure is the following. Events from several binary processes (i. e., when all the momenta are well defined) are identified and the most probable (m. p.) values of the corresponding peaks in the amplitude distributions are calculated. The processes used are the $pp \to d\pi^+$ reaction at a beam energy of 0.5 GeV with detection of the forward or backward emitted deuteron (in the c. m. s. frame) and the elastic pp scattering at a beam energies of 0.5, 1.0 and 2.0 GeV. The m. p. values can be related to the energy losses in MeV as the particle's type and momentum are defined and hence the energy losses are well known. These sets of the five m. p. values for each counter (independently for the signals of the upper and lower photomultipliers) are fitted with polynomial functions of ΔE, and corrections for the dependence of the amplitude on the coordinate are applied. The final calibration function for a counter is an average of the two functions obtained from independent fits for both counter amplitudes.

In Fig. 4 an example of the energy loss distribution in the counter A-3 and the corresponding counter B-4 is shown. The data were collected for a hydrogen target at a beam energy of 0.5 GeV. Among the three intensive peaks in the spectrum the lower losses correspond to

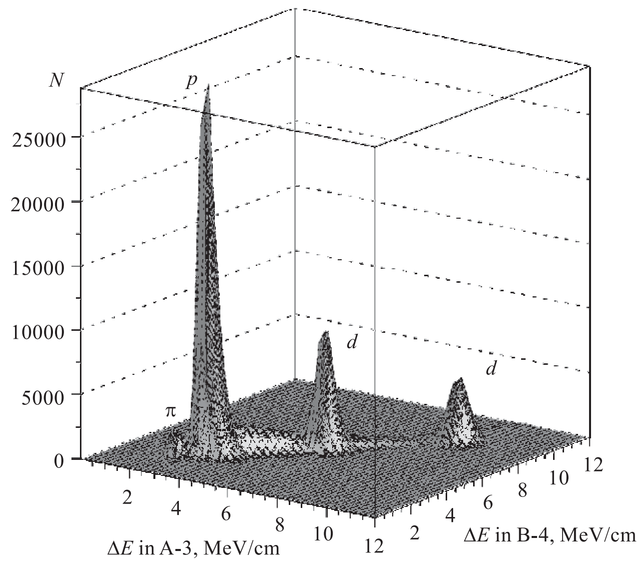

Fig. 4. Energy loss distribution in two matching counters of the scintillation hodoscope measured at a beam energy of 0.5 GeV with a hydrogen target

protons from the pp elastic scattering, while the medium and the rightmost peaks correspond to deuterons from the two kinematical branches of the process $pp \to d\pi^+$ (the forward and backward deuteron emission in the c. m. s. frame, respectively). A small peak at the left of the distribution is due to pions which have lower ΔE. The spectrum contains also the continuum caused by detection of protons from the pion production processes in which the protons are widely distributed over energy. So, the energy loss distribution as a whole reflects fairly well the dominant physical processes for the given conditions. The widths (FWHM) of the peaks in the ΔE distribution vary from 11 to 17 % for deposited energies from 9.6 to 2.8 MeV/cm, respectively.

2. CHERENKOV HODOSCOPE

Cherenkov counters in the forward detector help to distinguish between the particles of different velocities, especially in the high-momentum region where ΔE and TOF methods become less efficient. The counters in the forward Cherenkov hodoscope (FCH) make use of the total internal reflection of the Cherenkov light inside the radiators. The prototype of such counters for ANKE was tested in [5].

The counter radiator made of lucite is oriented at a predetermined variable angle to the direction of the particle flux. Particles of the same momentum but of different masses have different velocities and, as a result, radiate Cherenkov light at different angles. Hence, one can choose the value of the counter inclination angle such that the Cherenkov light for one of the particles leaves the radiator, but for another one, of less mass and hence faster, part of the light is «trapped» inside the radiator due to the total internal reflection and reaches the photomultiplier at the counter end. This is illustrated in Fig. 5 for the case of protons and deuterons. To absorb any but the total internal reflection light, the radiator is wrapped with a black paper.

The FCH consists of 16 identical counters assembled as two groups placed symmetrically with respect to the median plane of the forward detector (like in Fig. 5). Each counter has a lucite radiator of cross section 8×5 cm ($w \times t$) and length 30 cm. The counter is viewed by a photomultiplier XP2020 at the radiator end. The inclination angle can be set independently for any counter. The counters are mounted behind the forward scintillation hodoscope on a common supporting frame and cover approximately the same solid angle. For each counter the amplitude and the timing information are measured. The FCH signals are not used for triggering, so the particle identification is made in the off-line analysis.

The efficiency of the FCH to protons was investigated in a wide momentum range from 0.5 to 2.7 GeV/c (to cover this range the measurements were done at three beam energies). From these data the efficiency to deuterons can be easily deduced, since deuterons with twice higher momenta have the same velocity as protons and hence radiate the Cherenkov light identically.

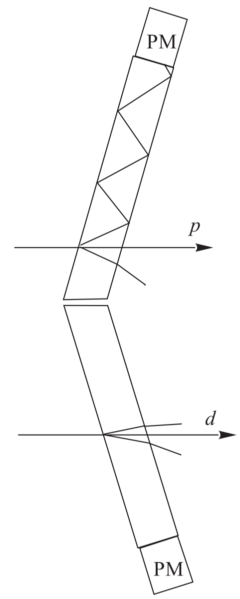

Fig. 5. Cherenkov light propagation in the total internal reflection counters. With a proper inclination angle the light from a deuteron leaves the counter, while part of the light caused by a proton is detected in a photomultiplier

The FCH performance with respect to proton/deuteron separation was obtained in an experiment on $\omega(782)$-meson production in the process $pd \to p_{\rm sp} d\omega$ (here $p_{\rm sp}$ is a slow spectator proton) at a beam energy of 2 GeV. The deuterons from this reaction, detected in the FD, have momenta in the range $1.7 \div 2.3$ GeV/c and should be separated from the background of protons. The FCH detection efficiency of deuterons in this momentum interval is equal to that of protons with momenta of $0.85 \div 1.15$ GeV/c. The counters' inclination angle was set at 10°. This angle, according to Monte-Carlo simulation, provides the best separation between the deuterons and protons at these momenta.

Note that the efficiency obtained in the off-line analysis depends on the applied software cut. The Cherenkov counter amplitude is compared with a software threshold and, depending on whether the amplitude is above or below this threshold, the event is classified as «signal is present» or «no signal». For protons the lower the threshold, the higher the efficiency, but simultaneously the efficiency for deuterons increases and the proton/deuteron separation becomes worse. For this reason the threshold is chosen as a reasonable compromise between efficiency and separation capability. The events of the type «signal is present», which include background protons as well as misidentified deuterons, are rejected in the analysis of the experimental data.

The dependence of the proton detection efficiency on the momentum measured with various software thresholds $Q_{\rm th}$ for one of the FCH counters is shown in Fig. 6. For each event the track in the forward detector proportional chambers is reconstructed and the value of momentum is obtained. The efficiency is defined as the ratio $N_{Q>Q_{\rm th}}/N$, where $N_{Q>Q_{\rm th}}$ is the number of entries in the spectrum with an amplitude above the threshold $Q_{\rm th}$ and N is the total number of entries. The efficiency plateau is reached between 1.5 and 1.8 GeV/c

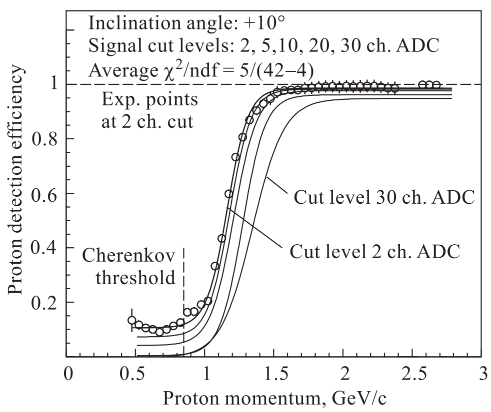

Fig. 6. Proton detection efficiency as a function of the momentum for various values of the software thresholds

and its level varies from 98.6 to 94.8 % for threshold setting between 2 and 30 ADC channels, respectively. This efficiency corresponds to a proton rejection factor from about 70 to 20. The maximum deuteron momentum in the process of the ω production under study is 2.3 GeV/c, and such deuterons are detected in FCH with the same probability as protons with a momentum of 1.15 GeV/c. Hence, the efficiency to detect deuterons in the whole momentum range $1.7 \div 2.3$ GeV/c is estimated from Fig. 6 to be $\leq 10\,\%$. These deuterons with an amplitude above the threshold are treated as protons and rejected.

The obtained results show that the Cherenkov counters of the forward detector provide a significant suppression of protons at rather small deuteron losses.

CONCLUSION

The performance of the scintillation and Cherenkov hodoscopes of the forward detector meets the requirements of the experiments at ANKE. The developed procedure for the hodoscope data analysis provides the particle identification and the event selection of the processes under study.

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