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SIMULATION OF K^+K^- PAIR PRODUCTION AT THE ANKE SETUP

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Introduction . The spectrometer ANKE is a general purpose detector under construction at COSY accelerator (KFA, Jülich) to study the proton-nucleus reactions at medium energies. One of important tasks is investigation of particle production below the corresponding threshold for nucleon-nucleon interactions. Production of mesons in nucleon-nucleus interactions at energy below the threshold for nucleon-nucleon interaction requires either high values of the internal momentum of nucleons (if the meson is produced in a quasifree collision with a single nucleon) or participation in the process of the effective target subsystems consisting of few nucleons in nuclei. Since high Fermi momenta are caused by short-distance correlations of nucleons, the both cases mean some kind of cooperative interaction of a projectile with few-nucleon subsystems in nuclei. Such cooperative interaction is obviously distinctive from free interaction with a single nucleon and becomes an actual task of nuclear reaction study at present.

Kaon subthreshold production attracts attention foremost because of rather high mass of the produced hadrons and generation of strangeness in the process. Therefore, K^+ subthreshold production in proton-nucleus collisions is the aim of some recent experimental programs [1],[3],[4].

The investigation of the K^- production is a useful extension of the proposed research program for the K^+ subthreshold production [1]. The physical motivations of this investigation and the conceptual design for the K^- detection system are given in [2]. In this experimental program a study of the subthreshold production of K^+K^- -meson pairs in the reaction:

$$p + {}^{12}C \rightarrow K^+ + K^- + X \qquad (1)$$

is planned.

Study of the K^+K^- pair production gives the new opportunities compared to the K^+ production in some aspects:

- Investigation of the process caused by creation of at least two quark pairs ($s\bar{s}$ and $u\bar{u}$) for the direct K^+K^- production;
- Comparison of the direct pair production with the production via $\phi(1020)$ generation;
- Investigation of final state interaction of the produced particles with a nuclear medium at the condition of significant difference of mean free path in the nuclear matter for the components of the pair.

The main goal of the Monte-Carlo simulation performed is the investigation of: (a) background accompanying K^+K^- pair production, (b) counting rates and efficiencies, and (c) background suppression with Cherenkov counters of total internal reflection. K^+K^- and $K^+\pi^-$ events calculated with the Rossendorf Collision Model (ROC model) [6] have been used to find the performance of the whole detection system.

Detector systems. The scheme of the ANKE setup supplemented with the K^- meson detection system is presented in Fig.1. It consists of four detection systems:

Forward detector (FD), Backward detector (BD), Positive and Negative side detectors. The basic geometrical parameters of the detector systems are given in [2].

K^+ mesons will be detected in the Positive side detector consisting of TOF start counters and telescopes of TOF stop, Cherenkov, ΔE and veto counters as well as of two wire chambers MWPC #1,2. The high momentum positive particles (up to $1100\,MeV/c$) will be detected in the Side scintillation hodoscope consisting of 6 modules.

For the Negative side it is difficult to develop telescope system similar to the Positive side detector because of the following reasons:

• very inclined negative particle trajectories to the focal surface at the 'negative' side of the magnet;

• serious limitations of space available for detector arrangement inside the magnet yoke gap.

Therefore, a more simple system of a hodoscope type for K^- meson detection is suggested [2]: Negatively charged particles (K^-, π^-) will be detected in the Negative side detector (naturally with lower K/π separation power) consisting of TOF start, TOF stop and ΔE scintillation counters (20 modules) as well as of two wire chambers MWPC #6,7. Then a question arises to what extent the measurement conditions may be improved by inserting additional counters into the Negative side detector.

Measurement Conditions . The ANKE spectrometer will allow to measure simultaneously positively and negatively charged particles emitted under forward angles $\vartheta < 10°$. To estimate the background conditions for the K^+ K^- pair detection a Monte–Carlo simulation was performed. For event generation the ROC model [6] for pC-interaction was used at the incident proton energy $T_p = 2500\,MeV$. A code GEANT [8] was used to describe the setup and to trace particles. The other generation conditions were the same as in [9].

Only the events where K^+ meson was detected and negative ejectiles (K^- or π^-) reached the TOF-stop counter were analyzed. The considered phase space was restricted to particle emission angle $\vartheta < 10°$, the size of the D2 gap and the momentum ranges $150 \div 1100\,MeV/c$ for K^+-mesons and $170 \div 1100\,MeV/c$ for K^--mesons.

Cross sections and background level. Since there are no data available on K^- production in pA reactions at energies $T_p \leq 2500\,MeV$, we used the cross sections calculated in the frame of the ROC model.

The ROC model belongs to a class of models, which take into account the projectile quasifree interactions both with single nucleons and also with few-nucleon subsystems in nuclei. The nucleons and the few-nucleon groups are considered as moving with normal distributions of Fermi-momentum, and a relative probability of the projectile interaction with 'elementary targets' of different baryon numbers is calculated on base of the Glauber theory. Empirical matrix elements are used to describe simultaneously all open reaction channels. It provides a possibility to study the reaction of interest and all the background channels. Further detailes concerning the ROC-model can be found in ref.[6]

The energy dependence of the K^- production cross section as expected from the ROC model is given in ref.[2],[7].

The first line of Table 1 lists the inclusive differential cross sections $\sigma_i(\Delta\Omega)\,mb$, integrated over the angle ($\vartheta < 10°$), obtained within the ROC model for the reaction:

$$p + {}^{12}C \rightarrow hadron + X \qquad (2).$$

The second line lists the cross sections ($\Delta\sigma_i$) for the production of π^- and K^-, detected in the Negative side detector and positive charged hadrons (p,π^+, K^+) detected in the Side hodoscope counters.

Table 1. ROC model differential cross sections for the production of hadrons from the reaction $p + {}^{12}C \rightarrow hadron + X$ at $T_p = 2500\,MeV$.

$hadron\,(i)$	p	π^+	π^-	K^+	K^-
$\sigma_i(\Delta\Omega)\,mb$	82.0	4.0	1.7	$5.0 \cdot 10^{-2}$	$5.0 \cdot 10^{-4}$
$\Delta\sigma_i(mb)$	1.6	0.8	1.0	$6.0 \cdot 10^{-3}$	$3.0 \cdot 10^{-4}$

Table 2 lists the differential cross sections integrated over the angle ($\vartheta < 10°$), for (K^+K^-) and ($K^+\pi^-$) pair production for various incident energies T_p for the reactions:

$$p + {}^{12}C \rightarrow K^+ + K^-(\pi^-) + X \qquad (3).$$

Table 2. ROC model differential cross sections for (K^+K^-) and ($K^+\pi^-$) pair inclusive production.

$T_p,\,MeV$	2500	2000	1500
$\sigma_{k^+k^-}(\Delta\Omega)\,mb$	$8.0 \cdot 10^{-5}$	$4.3 \cdot 10^{-6}$	$1.0 \cdot 10^{-9}$
$\sigma_{k^+\pi^-}(\Delta\Omega)\,mb$	$2.3 \cdot 10^{-3}$	$6.5 \cdot 10^{-4}$	$5.7 \cdot 10^{-6}$

From the table 2 the relations between the cross sections of the measured K^+K^- and the background $K^+\pi^-$ pair are seen. The table show some significant features of the kaon production in the energy range of interest. This high level of the background particles is the main difficulty of the kaon detection. For K^+ production the difficulty may be overcome by use of the sophisticated detector system, described in ref. [10], [11]. On the other hand, it is seen that the ratio of K^+K^- to $K^+\pi^-$ pair production is higher than the ratio of 'single' K^-, π^- production. Therefore, detection of K^- in coincidence with K^+ significantly diminishes requirements to K^-/π^- separation.

The momentum spectra of particles from the reaction $p + {}^{12}C \rightarrow (\pi^-, K^-) + K^+ + X$ and distribution of particles detected in the whole Negative side detector are presented in Fig.2. The ratio $N_{K^-} : N_{\pi^-} \approx 1 : 10^2$ (at about 300 MeV/c) decreases with increase of momentum (up to 1:1). The momentum spectra of 'detected' K^- or π^- mesons are presented in Fig.3 (upper windows) for some separate elements of the Negative hodoscope ($\#15, 18, 20$).

To extend the kinematic region for study of the K^+K^- pair production into the K^+ momentum range of $600 \div 1100\, MeV/c$ the possibility of high momentum particle identification by the Side hodoscope was investigated. The pion background level in this momentum range is somewhat higher than for the Negative arm. The kaon to pion ratio equals approximately to $N_{K^+} : N_{\pi^+} \approx 1 : 10^2$ in each module of the Side hodoscope, consisting of scintillation counters only.

Feasibility of background suppression. The negative pion background at the selection of the associated K^+K^- pair in the pC interaction was considered in [5]. It has been shown that the background suppression more than two orders of magnitude can be reached at the trigger level up to momentum of $600\, MeV/c$ using the TOF system and the ΔE information from the TOF stop counters. However, at higher momenta the K^-/π^- separation is worse and an additional pion suppression is necessary.

The TOF spectra at 600 and $1000\, MeV/c$ are presented in Fig.4. It is seen that at $1000\, MeV/c$ particle separation by TOF method is embarrassed. The corresponding ΔE spectra are even more harder for separation. The same problems arise for the K^+/π^+ detected in the Side hodoscope in the momentum range of $600 \div 1100\, MeV/c$.

The K^+K^- detection at momenta up to $1100\, MeV/c$ on both sides allows: (a) the K^+K^- pair investigation at high invariant masses, i.e. far from the kinematical threshold and (b) significantly increases the setup acceptance (the K^+K^- accepted phase space).

Cherenkov counter. To improve the K/π separation we propose to use the Cherenkov counters of total internal reflection in the Negative side detector (modules $\#13-20$) as well as in the Side hodoscope ($\#1-6$).

The proposed Cherenkov counter has been described recently in papers [12]. In this type of Cherenkov counter the light propagates via the total internal reflection in the radiator. The idea is to make use of total internal reflection for the Cherenkov light collection for particles with higher velocity by selection of a proper angle for radiator orientation. Therefore, the detection threshold can be easily tuned by counter inclination relative to the particle direction. The proposed Cherenkov counter characteristics were studied by Monte-Carlo simulation. Detailed description of the simulation procedure can be found in [12]. The PM output pulse heights are obtained for various momenta of K and π mesons. It has been assumed that $\Delta p/p = 10\%$ and the particle entrance angle varies in the range $\delta \in [0^\circ, 4^\circ]$. Photoelectron number in the stage photocathode – first dinode has been dispersed by the fluctuations with Poisson distribution. In Fig.5. pion detection efficiency is plotted at fixed 'kaon loss probability'. (The 'kaon loss probability'means that some of the kaons are misidentified as pions and therefore are rejected in the trigger scheme.)

The Cherenkov counter prototype had a plane parallel radiator ($35 \times 10 \times 5\,cm^3$) made of lucite ($n = 1.49$) polished on all sides except the side opposite to the PM ($FEU - 143$) and wrapped up into black paper to suppress the diffusion reflection. The prototype was tested in the $1500\,MeV/c$ beam (containing protons and pions) at the ITEP accelerator. A dependence of the PM anode pulse amplitude on the angle relative to the beam direction was clearly observed. The performed studies of the Cherenkov counter prototype show that such detectors can be successfully used for K and π separation up to momenta $p = 1100\,MeV/c$. It may be used for fast suppression of the pion background at the first level trigger. The pulse amplitudes from Cherenkov counters written in ADCs can be used also in **off-line** data processing, when the particle momentum and direction are already obtained. Therefore, the particle type can be defined with a higher confidence level.

Background suppression with Cherenkov counters. The Monte–Carlo simulation of the process (1) was carried out with addition of the Cherenkov counters behind the negative TOF stop modules from the 13-th element up to the 20-th element.

The dimensions of Cherenkov counter radiators were taken the same like for the scintillation stop counters ($10\,cm$ width). The counters cover the momentum range $600 \div 1100\,MeV/c$. In Fig.3 there are shown the momentum spectra of 'detected' K^- and π^- mesons **without** (the upper windows) and **with** (the lower windows) the Cherenkov counters. It is seen that with the proposed Cherenkov counters one can obtain a significant background suppression.

The addition of the Cherenkov counters to the Side hodoscope leads to reduction of the pion background for more than an order of magnitude. The momentum spectra of π^+ mesons **with** and **without** Cherenkov counters are shown in Fig.6.

Hence, by using the Cherenkov counters of total internal reflection one can significantly improve the ratio $N_K : N_\pi$ in the high momentum range $p > 600\,MeV/c$.

Additional pion suppression. At the above mentioned background level of $N_{K^+} : N_{\pi^+} \approx 1 : 10^2$ a reliable K^+ identification with Cherenkov counter alone is impossible. The distance between the Start and Stop counters in the high momentum range of the Side hodoscope is not enough for good K^+/π^+ separation at the trigger level by TOF method. Therefore, the additional background suppression during the **off-line** data processing with TOF system was considered.

In Fig.7. the time of flight distributions for the Side hodoscope elements are presented. The flight time has been calculated between the target and a separate Stop counter. The starting time at the target can be obtained using the off-line reconstructed K^- time of flight and its momentum. We assume that the interaction time moment can be reconstructed with an accuracy of 300 ps. The momentum dispersion in one counter results in a time variation equal to $500 \div 700\,ps$. An intrinsic time resolution of $200\,ps$ for scintillation counters was assumed. So the total TOF resolution is defined mainly by the momentum dispersion.

In Fig.7 there are also shown the values of 'figure of merit':

$$\mathbf{f} = \frac{t_K - t_\pi}{\sigma_K + \sigma_\pi},$$

which characterizes the quality of K/π separation. The background suppression is presented with respect to **f** in Fig.8. This factor is defined as $B = (1-\varepsilon)/\varepsilon$, where ε is the useful event detection probability. In these calculations $\sigma_K = \sigma_\pi$ was assumed and the middle point between the peaks for π and K was taken as a rejection threshold. The pion suppression factors B_{Cher} and B_{TOF} resulting from use of Cherenkov counters and TOF analysis, respectively, are presented in Table 3. The relation $N_{K^+} : N_{\pi^+}$ is presented before and after selection with Cherenkov counters and TOF system as well as the total suppression factor (last row).

Table 3. The relation N_{K^+}/N_{π^+} and π^+ suppression factors for individual modules of the Side hodoscope.

Count.No	#1	#2	#3	#4	#5	#6
P,Mev/c	670 ± 25	720 ± 35	780 ± 50	850 ± 65	950 ± 95	1050 ± 115
$N_{k^+} : N_{\pi^+}$	1 : 100	1 : 134	1 : 137	1 : 156	1 : 177	1 : 201
B_{Cher}	1.3%	1.6%	2.0%	4.0%	6.0%	9.0%
B_{TOF}	0.15%	0.6%	1.2%	2.4%	4.2%	7.2%
$N_{k^+} : N_{\pi^+}$	1 : 0.002	1 : 0.013	1 : 0.033	1 : 0.15	1 : 0.45	1 : 1.30

It is seen that the pion background can be suppressed essentially in the Side hodoscope. That provides reliable detection of K^+ mesons in the high momentum range (up to $1100\, MeV/c$). However the suppression factors for TOF analysis were obtained at the assumption of the time of flight distributions of strictly Gaussian shape. Real behaviour of the distributions should be found experimentally.

Conclusion. K^+K^- pair production at the ANKE set-up has been simulated using K^+K^- and $K^+\pi^-$ events calculated with the Rossendorf Collision Model. Background conditions for the K^+ K^- pair detection have been examined.

The main conclusions are the following. K^- identification can be essentially improved at the trigger level by use of the Cherenkov counters. The same is true for K^+ selection in the Side hodoscope. High efficiency for π^+ suppression by the TOF system at the off-line data analysis can be expected for the Side hodoscope. Therefore, the acceptance for K^+K^- pair detection can be significantly enlarged.

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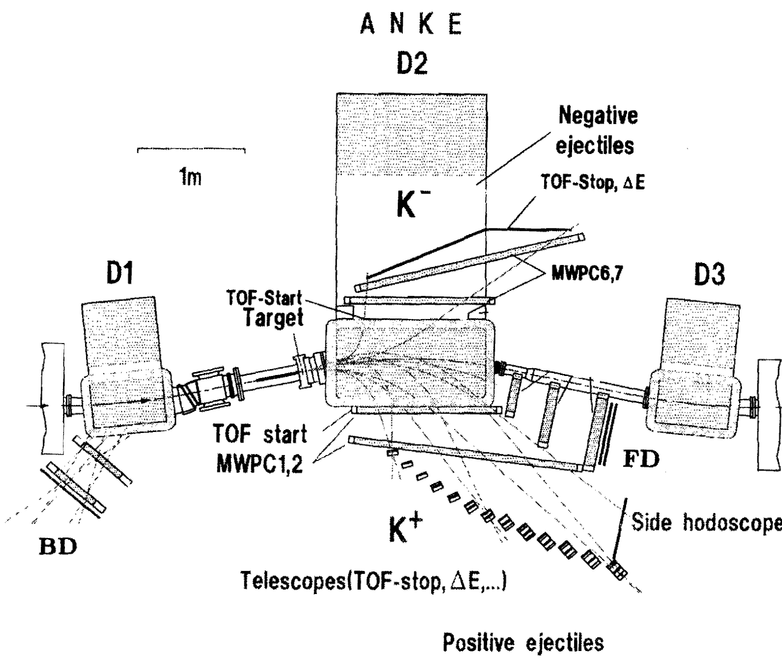

Fig.1. Layout of the experimental setup.

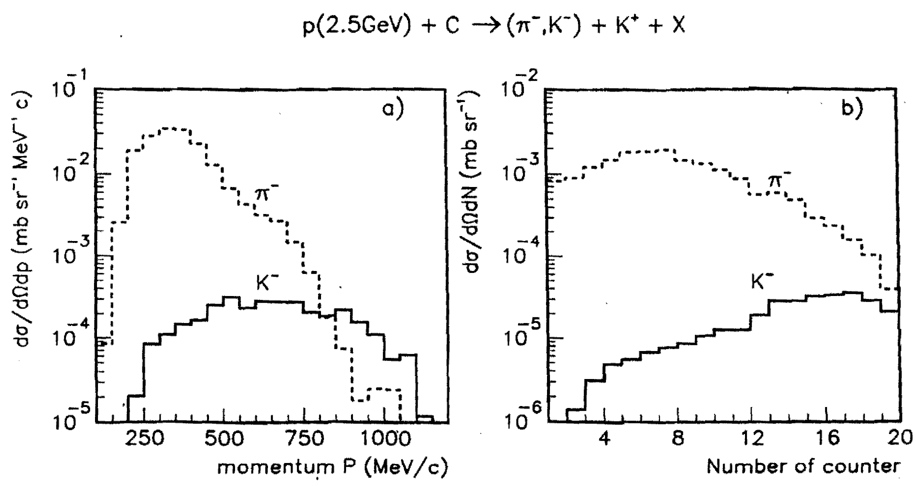

Fig.2. Simulation of negative particle distributions from the reaction $p(2500\,MeV) + {}^{12}C \rightarrow K^+ + K^-(\pi^-) + X$. (a) Momentum spectra of detected particles and (b) distribution of particles detected in Negative side hodoscope vs the module number.

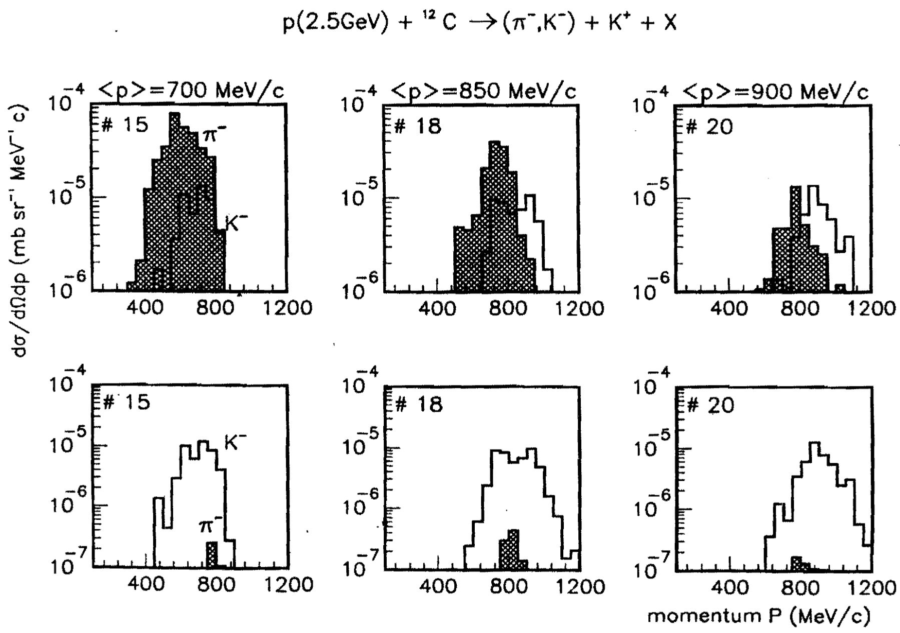

Fig.3. Momentum spectra of π^- (shaded histogram) and K^- detected in the individual counters of the Negative side hodoscope. Upper windows: without Cherenkov counters, Lower windows: with Cherenkov counters.

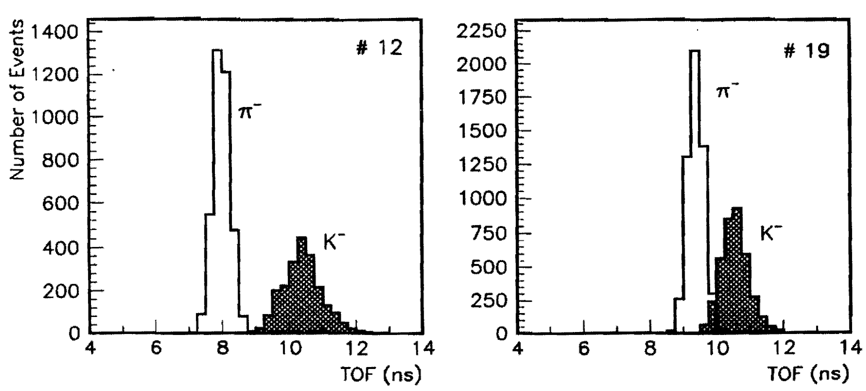

Fig.4. Time of flight spectra for the Negative side hodoscope modules.

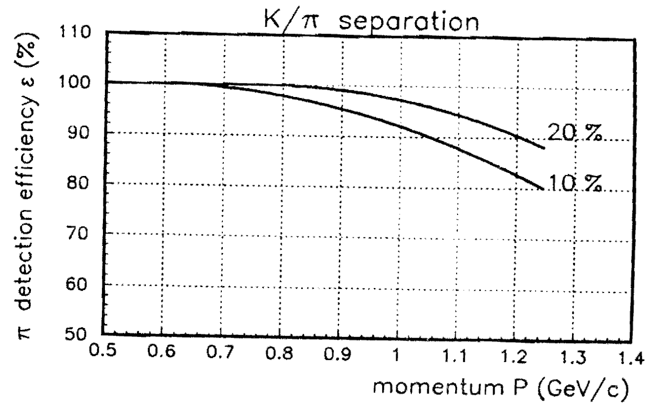

Fig.5. Pion detection efficiency (at 10% and 20% of misidentified kaons) vs momentum.

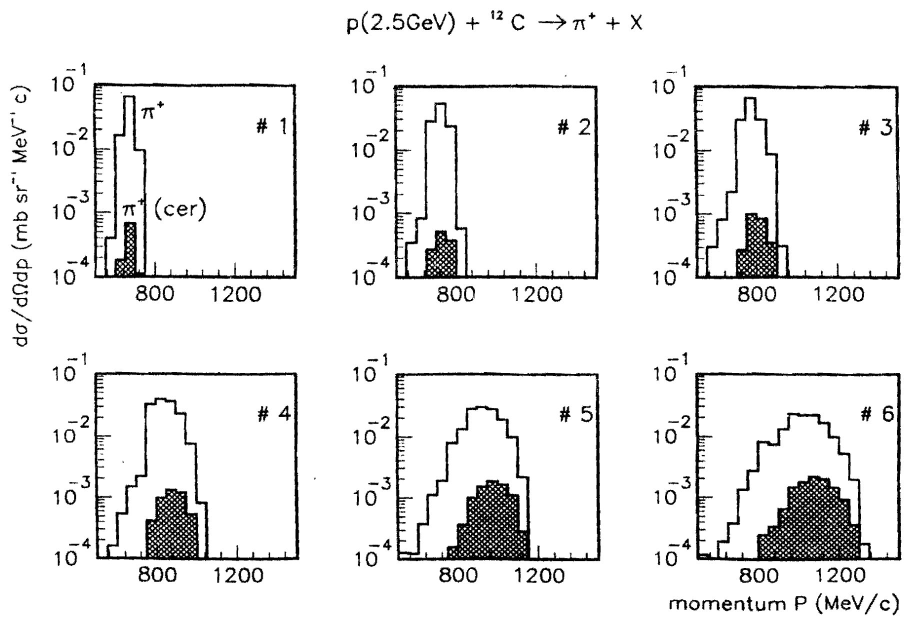

Fig.6. Momentum spectra of π^+ mesons detected in the counters of the Side hodoscope. Shaded histogram corresponds π^+ mesons with Cherenkov counters in trigger.

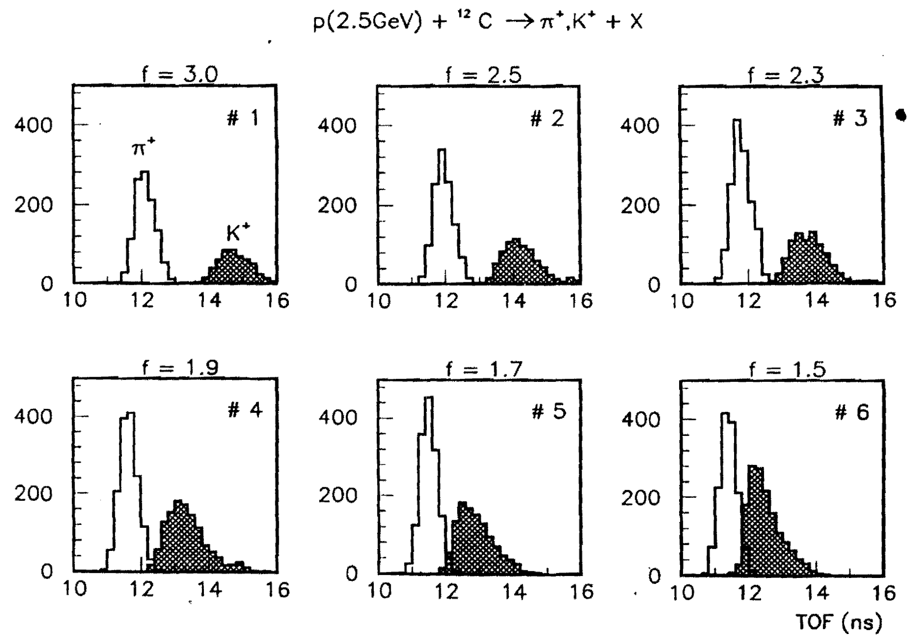

Fig.7. π^+ and K^+ (shaded histogram) time of flight spectra for different counters ($\#1-6$) of the Side hodoscope.

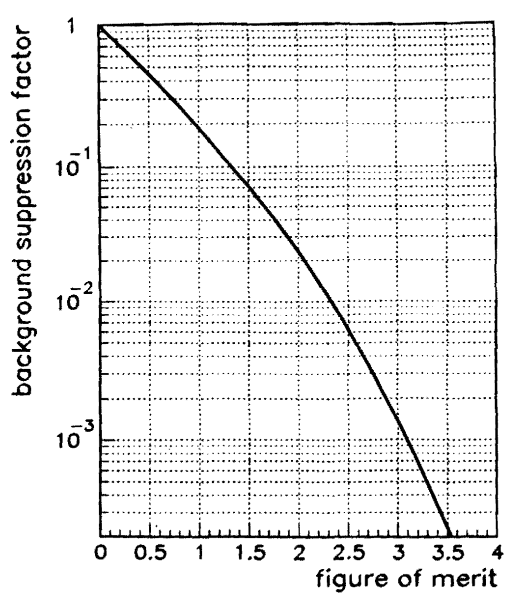

Fig.8. The background suppression factor vs 'figure of merit' **f**.

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Бюшер М. и др. E1-96-505

Моделирование процесса рождения K^+K^--пар на установке ANKE

Проведено моделирование условий измерения процесса рождения K^+K^--пар на установке ANKE с использованием события pC-взаимодействий, генерированных в рамках ROC-модели при энергии $T_p = 2500$ МэВ. Для подавления пионного фона на уровне быстрого триггера рассмотрена возможность использования черенковских счетчиков полного внутреннего отражения.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 1996

Büscher M. et al. E1-96-505

Simulation of K^+K^- Pair Production at the ANKE Setup

The mesturement conditions for the K^+K^- pair production at the spectrometer ANKE are simulated on the basis of pC interaction events generated within the ROC model at the energy $T_p = 2500$ MeV. The possibility of background suppression using Cherenkov counters of total internal reflection at the trigger level is examined.

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

Communication of the Joint Institute for Nuclear Research. Dubna, 1996