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SIMULATION OF DEUTERON BREAK-UP AT $T_p = 2.5$ GeV FOR ANKE FACILITY

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Introduction. The setup ANKE is under construction at the COSY accelerator (KFA, Jülich) to study a wide class of proton-nucleus reactions [1]. The present paper deals with one item of the ANKE research programme, namely the deuteron experiment [2], [3] aimed at systematical studying the deuteron break-up reaction in the internal proton beam of COSY in the energy range $T_p = 1.0 \div 2.5\,GeV$. The operating conditions of the detectors designed for the deuteron break-up investigation are examined, the counting rates and background conditions are estimated.

Earlier these estimations [4] have been done for the deuteron break-up reaction at the proton beam energy $T_p = 1.0\,GeV$, i.e. at the lower boundary of the energy range of interest. The background was estimated by simulation with real experimental data from 1-m HBC (Hydrogen Bubble Chamber). The energy range $T_p = 1.0 \div 2.5\,GeV$ is a near-threshold one for many reactions, therefore the values of partial cross sections vary rather fast, for example, the pion production cross section significantly increases with energy [9] and the pion momentum spectrum becomes harder. The present paper is a continuation of [4] and deals with the above processes at the maximum beam energy $T_p = 2.5\,GeV$.

There are no experimental data for $T_p > 1.0\,GeV$ similar to those we used in [4]. That is why the event generator based on the ROC (ROssendorf Collision) model [5] - [8] is used instead of real experimental data. This model well describes hadron spectra for a variety of processes in a wide energy range, which allows it to be a generator of initial events in the simulation process.

Basic assumptions of the ROC model. A detailed description of the ROC model can be found in [8]. In the present paper only the basic assumptions of the model are reminded.

The model is based on the use of the empirical matrix elements and reproduces some main features of the processes caused by the quark structure of hadrons. It also exploits a concept of excited intermediate subsystems and includes the calculation of modified statistical weights of various final states. This approach allows to describe simultaneously all open reaction channels in a wide energy region (presumably from several hundreds MeV up to several GeV). The quasifree interaction of a projectile with nucleons of a target nucleus takes into account their Fermi-motion corresponding to commonly used nuclear wave functions. (For the deuteron, the well known Paris deuteron wave function is used.) More complicated mechanisms including excitation and rescattering of hadrons in intermediate states are described in a phenomenological way as excitation and subsequent decay of hadronic subsystems. Several free parameters of the model are fixed to suit the wide range of existing experimental data on proton-proton and proton-nucleus collisions [5] - [8]. The model is realized in a form of the computer code, resulting in calculation of three-momenta of all final-state particles for each event. Therefore, the model is especially useful as an event generator for the Monte-Carlo simulation of a process to be studied at an experimental facility, since it produces both the events of the process under study and the events of the accompanying "background" processes in the same approach.

Measurement Conditions. The experimental setup is shown in Fig.1. The main part of the setup is the achromatic system of three dipole magnets D1, D2, D3 arranged along the internal beam of the storage ring. Two of the magnets are used as spectrometric ones: D1 for backward ejectiles and D2 for forward ejectiles coming from the target placed in the accelerator internal beam between D1 and D2. The D2 gap restricting the acceptable phase space in the forward direction is equal to $20\,cm$. The strength of the equivalent homogenous magnetic field of D2 was taken to be $1.58\ T$. D1 and D3 are identical with a gap of $9\,cm$ and with the same magnetic field strengths. For particle detection in the forward and backward directions the forward (FD) and backward (BD) detector systems will be used.

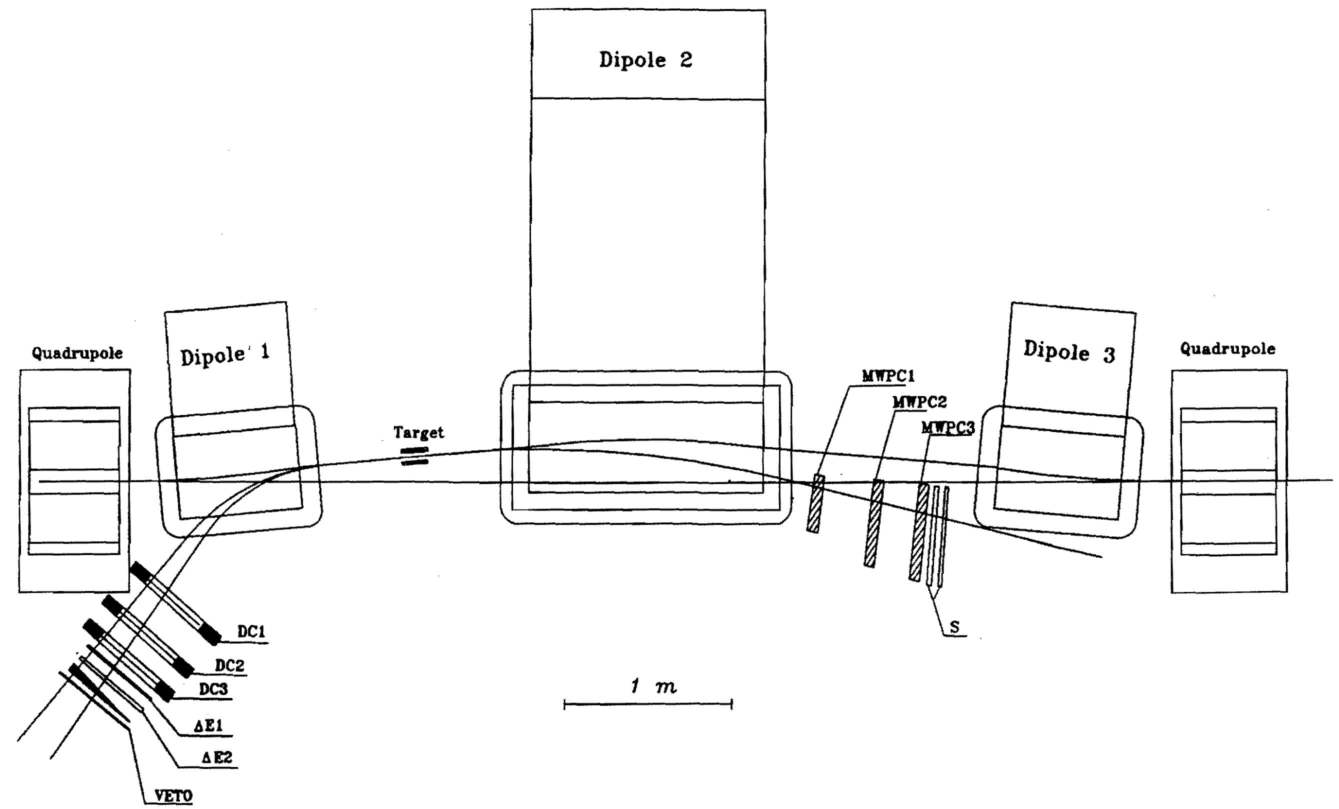

Fig.1. Scheme of the detectors arrangement for deuteron break-up study at ANKE.

The basic geometrical parameters of the detector systems are given in [4]. It is only worth adding that the forward scintillation hodoscope (S) of size $68(W) \times 36(H)cm^2$ and consisting of 10 counters 2.0 cm thick, was used for the simulation. The transverse dimensions of the hodoscope counters were different. The first 4 counters that are closer to the vacuum chamber of the accelerator are of 3.5, 4.5, 5.5, 6.5 cm width respectively. The other six counters are 8 cm wide each.

A code GEANT [10] was used to describe the setup and to trace particles. The generation conditions were the same as in [4].

A particle was considered as detected if it passed through all coordinate detectors in the FD or BD arm and reached the second plane of the scintillation hodoscopes. Three sets of 'detected' particles were considered, i.e. particles detected only in the FD, only in the BD, and simultaneously in the $BD\&FD$. The emission angle of all particles in the forward cone (FD) was limited to $\vartheta < 10°$. The latter condition was not used in [4].

Initial Data. The generated events are grouped into three data sets:

f - with at least one positive charged particle in the final state emitted into the forward cone $\vartheta < 10°$,

b - with at least one positive charged particle in the final state emitted into the backward cone $\vartheta > 165°$,

c - with simultaneous emission of a positive charged particle into the cone $\vartheta < 10°$ and another one into the cone $\vartheta > 165°$.

Table 1 lists the differential cross sections derived within the ROC model and integrated over the above-mentioned solid angles, $\sigma_i(\Delta\Omega)\,mb$, for the most significant pd interaction reactions at $T_p = 2.5\,GeV$.

The reactions given in Table 1 were regarded as background ones in relation to the deuteron break-up reaction $pd \longrightarrow ppn$, and a possibility of separating the process from this background was examined.

Table 1. ROC model cross sections $\sigma_i(\Delta\Omega)\,mb$ of different pd interaction channels at $T_p = 2.5\,GeV$.

$pd \to \ldots$	$\sigma_i(\Delta\Omega)(\mathbf{f})\,mb$	$\sigma_i(\Delta\Omega)(\mathbf{b})\,mb$	$\sigma_i(\Delta\Omega)(\mathbf{c})\,mb$
pd	7.94	$< 10^{-5}$	$< 10^{-5}$
ppn	**13.18**	**0.204**	**0.121**
$ppn\pi^o$	2.52	0.074	0.025
$pnn\pi^+$	3.12	0.075	0.007
$ppp\pi^-$	0.87	0.023	0.019
$pd\pi^+\pi^-$	0.21	0.004	0.001
$ppn\pi^+\pi^-$	2.46	0.050	0.024
$ppn\pi^o\pi^o$	1.42	0.028	0.009
$pnn\pi^+\pi^o$	1.49	0.022	0.004
$ppp\pi^-\pi^o$	0.76	0.013	0.010

Applicability of the ROC Model. To check the reliability of the data derived by the ROC model, the calculations were compared with the experimental hydrogen chamber data. The initial data for the code GEANT were the pd interaction events generated by the ROC model at $Tp = 1.0\,GeV$. Momentum spectra of the particles detected in the forward detector (FD) were obtained. Then the spectra were compared with those from [4] obtained with the HBC data.

In Fig. 2a,b there are the momentum spectra of particles from different reactions detected by the forward hodoscope. They were derived by simulation for two versions of the initial data: a) for the events obtained by the ROC model, b) for the real experimental HBC data. Unlike the HBC data, the simulated data include the elastic channel without losses. (The spectrum of particles from the elastic channel is not shown in Fig. 2.) The ROC model spectra at $Tp = 1.0\,GeV$ agree with the experimental data [4] well enough to find the acceptance and other characteristics of the setup.

Spectra of Secondaries . Identification of particles in the BD hodoscope was already discussed in [12], [11], [4], therefore in this pa-

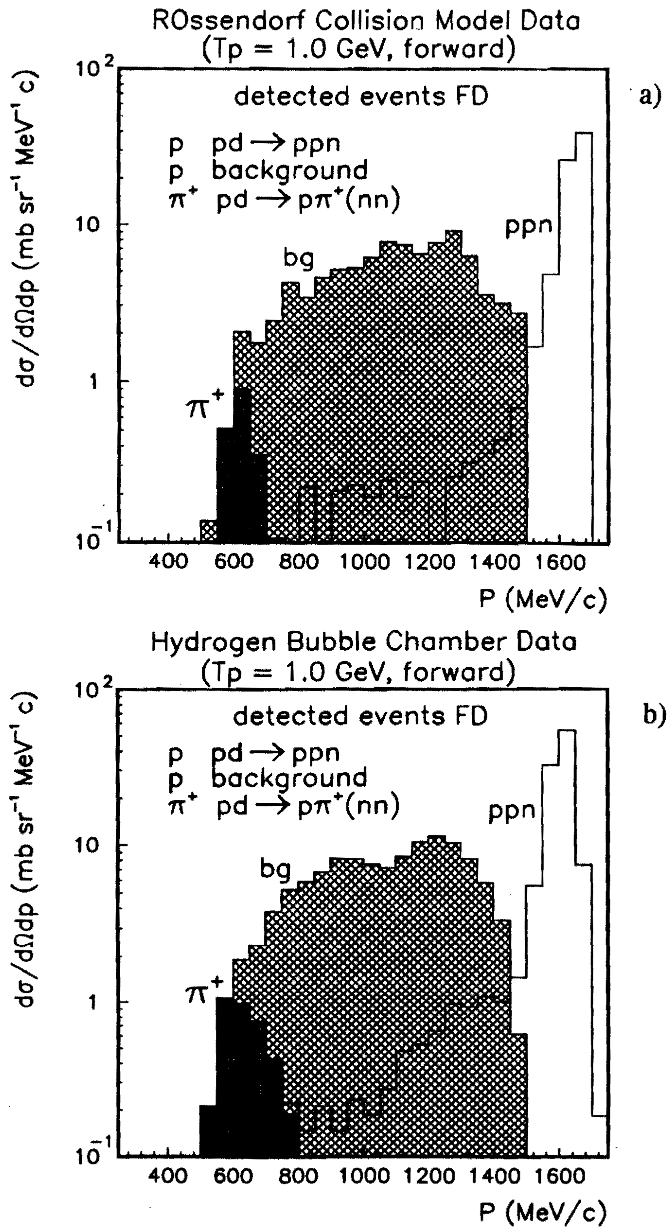

Fig.2. Momentum distribution of particles from the $pd \to ppn$ reaction and background processes detected in the FD hodoscope at $T_p = 1.0\,GeV$: a) ROC model, b) HBC data.

per we speak in more detail about spectra of particles detected in the forward detector.

The distribution of all detected particles along the hodoscope transverse axis is presented in Fig. 3. The shaded area corresponds to background events.

Table 2. Inclusive integrated cross sections (mb) for particles detected in the FD hodoscope counters. The number of the counter increases with increasing distance from the beam.

$N_{counter}$	$\Delta\sigma_{bg}\,(p)$	$\Delta\sigma_{ppn}\,(p)$	$\Delta\sigma_{bg}(\pi)$
#1	0.532	0.248	0.0027
#2	0.608	0.316	0.0068
#3	0.652	0.376	0.0060
#4	0.631	0.426	0.0086
#5	0.555	0.466	0.0186
#6	0.384	0.353	0.0152
#7	0.328	0.214	0.0162
#8	0.248	0.0057	0.0187
#9	0.109	0.0004	0.0193
#10	0.037	0.0002	0.0185
Total	4.08	2.40	0.14

Table 2 lists relative counting rates through the forward hodoscope (FD) counters expressed in mb as cross sections integrated with regard to detection probability $\varepsilon_i(\vec{p})$;

$$\Delta\sigma_i = \int_{\Delta\Omega} \frac{d\sigma}{d\vec{p}}\,\varepsilon_i(\vec{p})\,d\vec{p}.$$

The relative counting rates are given separately for protons from the deuteron break-up reaction $\Delta\sigma_{ppn}\,(p)$, background protons $\Delta\sigma_{bg}\,(p)$ and π^+-mesons $\Delta\sigma_{bg}(\pi)$ from all other reactions detected by the forward hodoscope at $T_p = 2.5\,GeV$. At the luminosity $L = 1.0 \cdot 10^{30}\,cm^{-2}\,s^{-1}$ the integral absolute counting rate in the forward hodoscope is $R = 6.5\,mb \cdot L = 6500\,s^{-1}$.

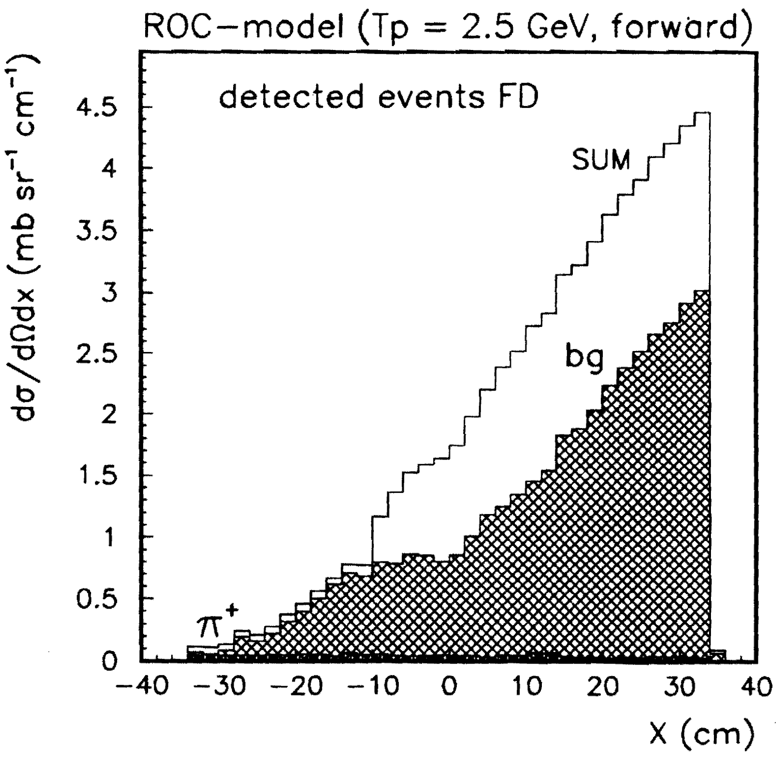

Fig.3. Distribution of all detected particles along the transverse axis of the FD hodoscopes. The point $x = 0$ corresponds to the hodoscope center. The shaded area corresponds to the background events.

In Fig. 4a,b there are shown the momentum spectra of particles in the forward hodoscope. As compared with $T_p = 1.0\,GeV$ [4], the cross section for production of pions ($\Delta\sigma_{\pi^+} = 0.02\,mb$) increased by about an order of magnitude ($\Delta\sigma_{\pi^+} = 0.14\,mb$) and their momentum spectrum became wider (overlapping the momentum spectrum of protons from different channels up to 2 GeV/c).

Figure 5 displays momentum spectra of $pd \to ppn$ reaction protons detected by coincidence in the forward (a) and backward (b) hodoscopes. The counting rate for these events at the above luminosity is $R = 0.4\,s^{-1}$. (At $T_p = 1.0\,GeV$ it equals to $R = 1.2\,s^{-1}$ [4]).

In figure 6 there are shown the inclusive momentum spectra of pions (from background processes) and protons from the deuteron break-up reaction in the forward hodoscope. In the upper left window there are total spectra, in the others there are spectra for individual counters which number increases with increasing the distance between the counter and the internal proton beam. The spectra in the first two counters are the same as in the 3rd one, and they are not shown in Fig. 6. It is evident from the spectra and Table 2 that in some hodoscope counters, especially in the three most distant from the vacuum pipe, the pion background becomes strongly dominating over the protons from the deuteron break-up. To illustrate, for the reaction in study the ratio $\Delta\sigma_{ppn}(p)\,:\,\Delta\sigma_{bg}(\pi)$ in these counters is 1:10. This relation in the momentum range $1.0 \div 2.0\,GeV/c$ becomes nearly equal 1:1 for the events detected in coincidence. Momentum spectra of protons in the forward hodoscope, from the reaction $pd \to ppn$ and π^+ mesons from the background pion production processes (presented in table 2), are shown in figure 7. It is seen, comparing with inclusive spectrum (see fig.6), pion background is decreased in absolute value. But for the separation of the deuteron break-up reaction in the momentum range $1.0 \div 2.0\,GeV/c$, it seems necessary to suppress pion background in the forward detector.

This is important, since the forward protons from this momen-

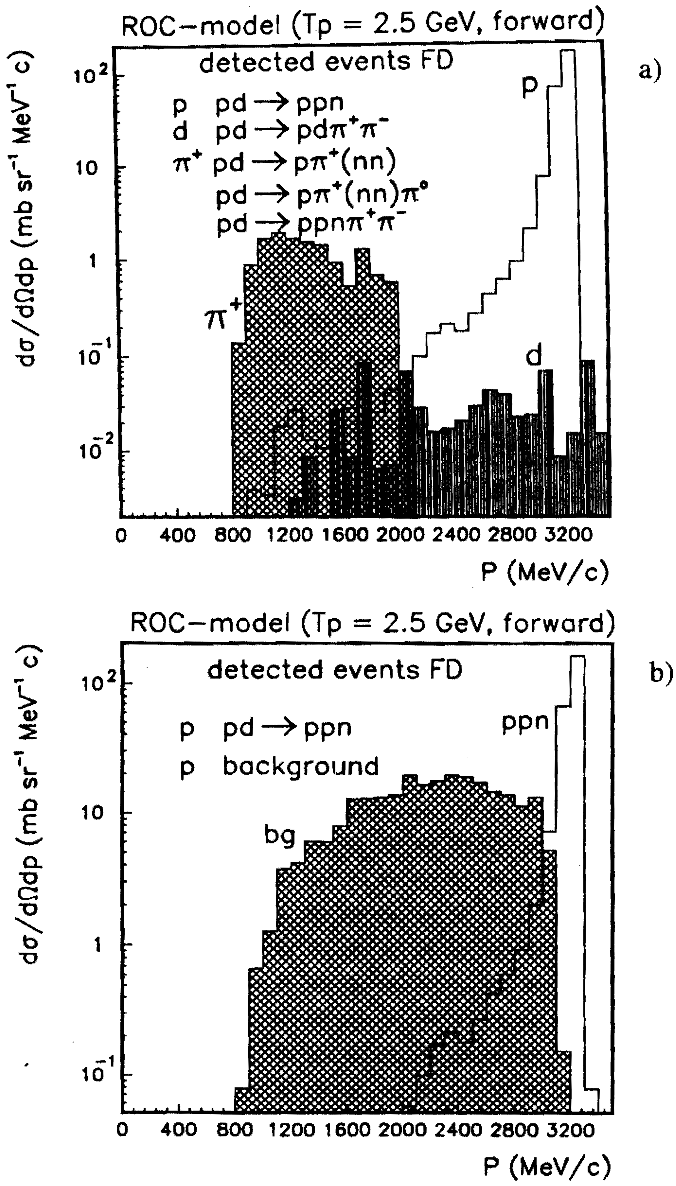

Fig.4. Momentum distribution of particles from the $pd \to ppn$ reaction and background processes (shaded) detected in the FD hodoscope at $T_p = 2.5\, GeV$.

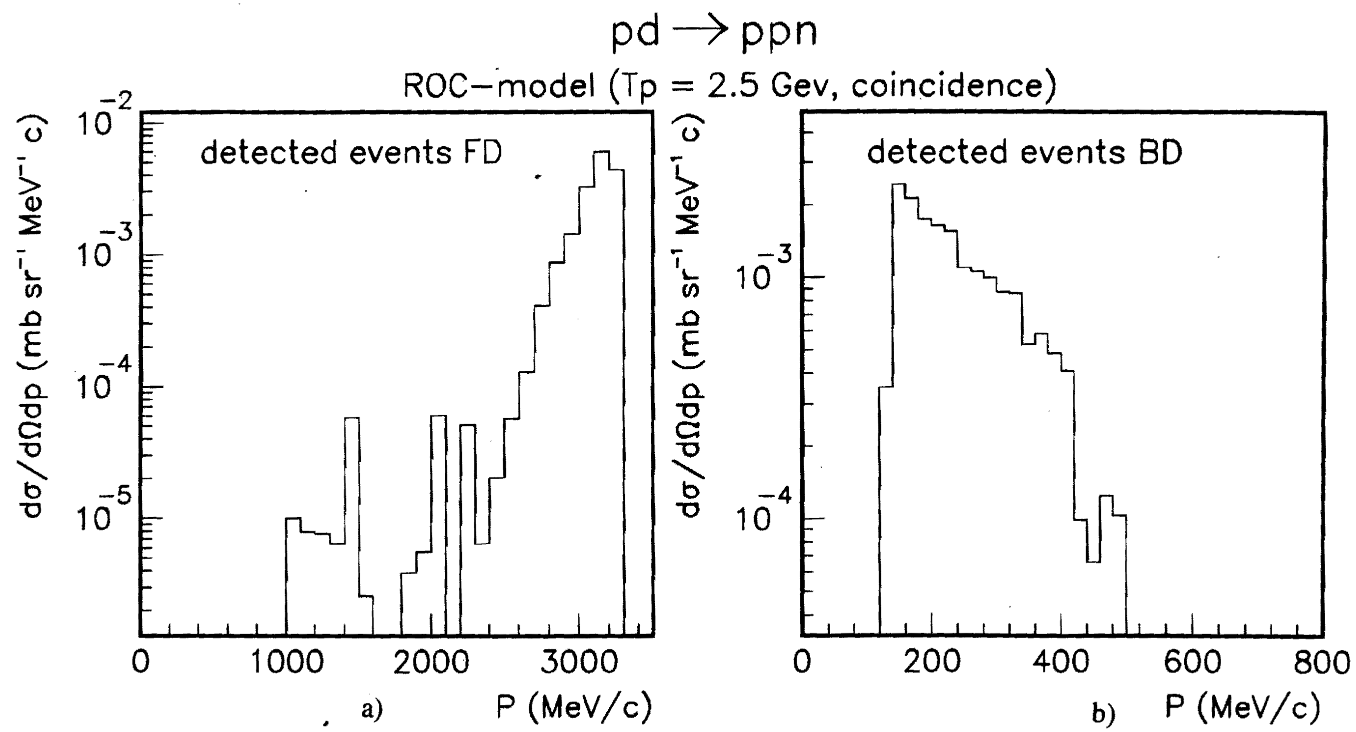

Fig.5. Momentum spectra of particles from the events detected in BD and FD coincidence.

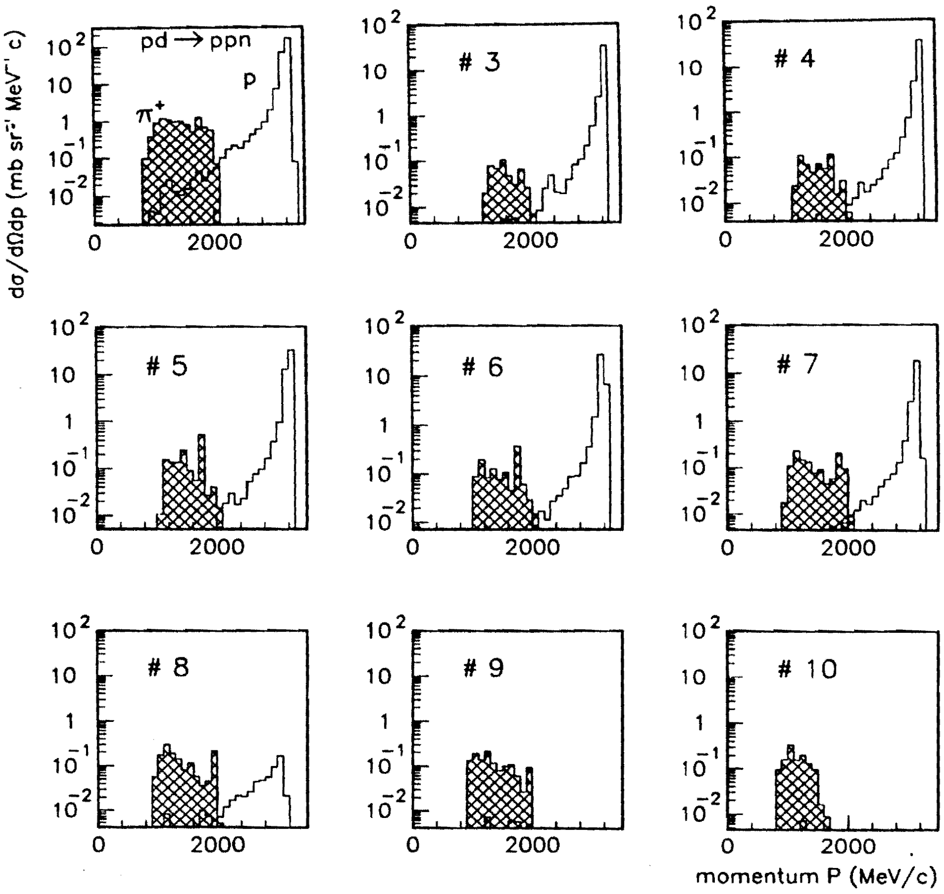

Fig.6. Momentum distribution of protons from the $pd \rightarrow ppn$ reaction and π^+ mesons (shaded) from the background processes recorded in the FD hodoscope at $T_p = 2.5\,GeV$. The upper left window is for the hodoscope as a whole, the others are for separate counters (the number of the counter increases with increasing the distance from the beam).

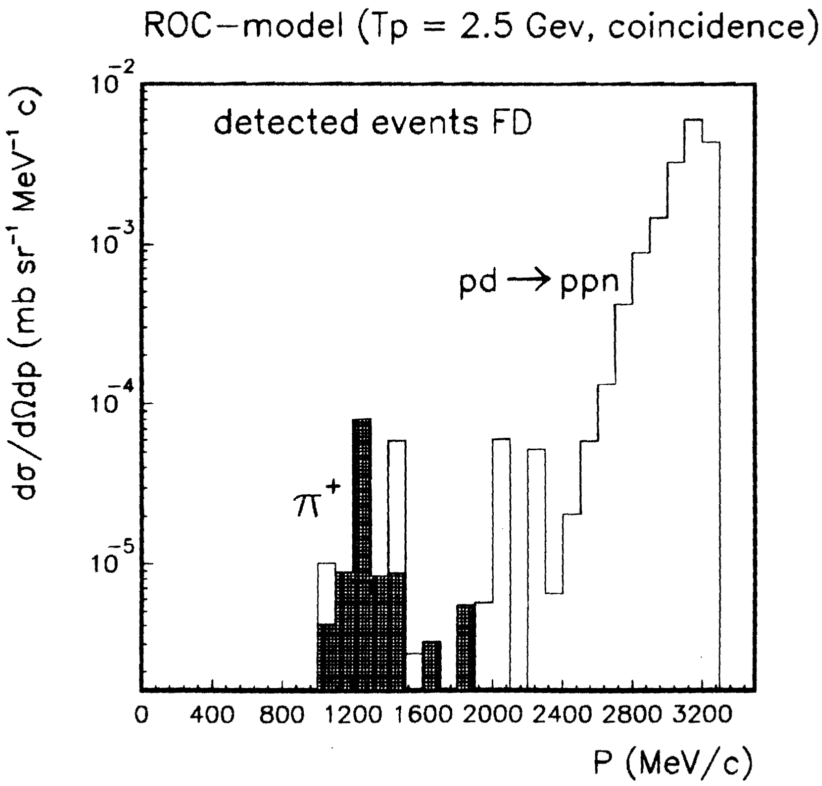

Fig.7. Momentum spectra of protons in the forward hodoscope from the reaction $pd \to ppn$ and π^+ mesons (shaded) from the background pion production processes.

tum interval detected in coincidence with the backward protons correspond the pd interaction with high value of Fermi momentum in the deuteron involved. From the physical point of view just these kinds of interactions are the most interesting [3].

Possibility of Background Suppression. As it was mentioned above, the momentum range of the particles detected by the FD hodoscope is $1.0 \div 3.3\, GeV/c$ at the beam energy $2.5\, GeV$. The momentum range in the backward BD hodoscope is $0.15 \div 0.50\, GeV/c$ and is only slightly dependent on the initial energy. Because of different kinematic conditions for particle detection, the identification methods will be different in the forward and backward detectors. The problems of the background suppression and particle identification in the backward hodoscope were studied in [4]. The pion background suppression in the FD hodoscope by ΔE counters and a TOF system is obviously of poor efficiency.

The possibilities of the separation of the $pd \longrightarrow ppn$ reaction from the pion production processes were considered in [13]. It has been done with the simulation on the basis of the pd interaction events generated by the ROC model at $T_p = 2.5\, GeV$. It was shown that at the 'off-line' data processing it is possible to identify unambiguously the studied process, using missing-mass spectrum calculated for two protons detected in coincidence. At these calculations the proton identification was supposed as perfect and the expected missing-mass resolution was taken into account.

The missing-mass spectrum for a case of pion misidentification as protons was calculated in present paper. The main source of π^+ mesons in the forward detector is the $pd \longrightarrow p\pi^+nn$ reaction. Calculated missing-mass spectra for the mesonless break-up and break-up with π^+ production are shown in figure 8. The events are taken from the class of coincidence (**c**) in the momentum range $1.0 \div 2.0\, GeV/c$. It is seen that the background of such type is rather low and cannot distort the $pd \longrightarrow ppn$ data even if the expected resolution (FWHM = 60 MeV for the neutron peak in the missing-mass spectrum) were taken properly in account.

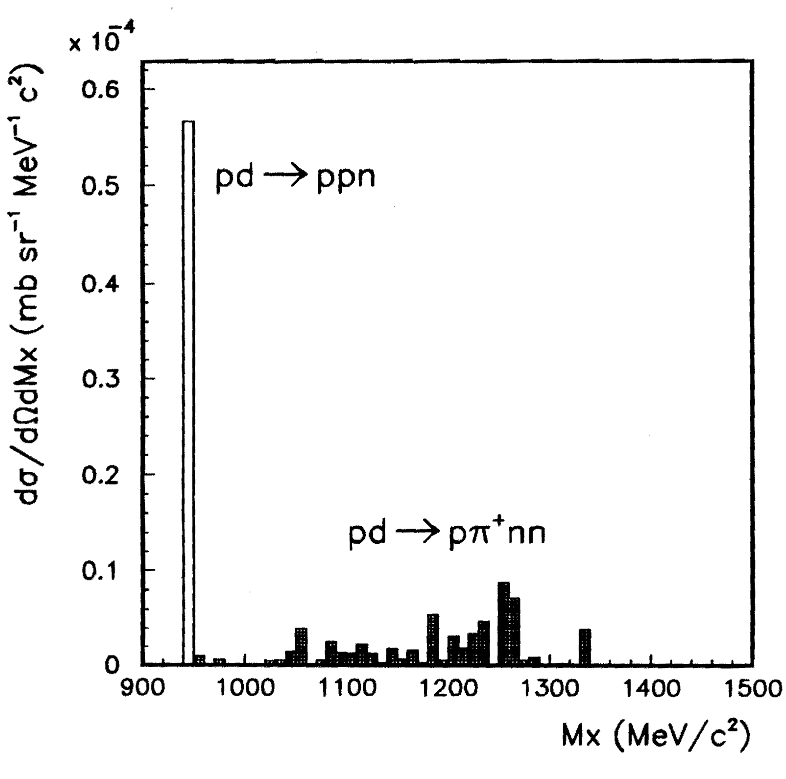

Fig.8. Calculated missing-mass spectra for the mesonless break-up and break-up with π^+ production.

Conclusion. To optimize the experimental setup, the measurement conditions for the deuteron experiment are simulated with pd interaction events generated by the ROC model at $T_p = 2.5\,GeV$. The background conditions for the break-up reaction $pd \rightarrow ppn$ are studied. Comparison of the model calculation and the experimental data from the 1-m HBC confirms the validity of the ROC model under the conditions in question.

The main conclusions are the following.

- Counting rates are estimated (in absolute value) for different particles in separate counters of the forward hodoscope. The event rate for the break-up reaction at the luminosity $L = 1.0 \cdot 10^{30}\,cm^{-2}\,s^{-1}$ with a trigger being the coincidence of the forward and backward hodoscopes is $\approx 0.4\,events \cdot s^{-1}$, that differs but slightly from that at $T_p = 1.0\,GeV$.
- It is shown that the pion background may be significant in the low momentum region $1.0 \div 2.0\,GeV/c$ of the FD hodoscope. However, using the missing mass spectra analysis the π^+ background can be minimized substantially and therefore should not distort the break-up data.

Thus, as was expected, the conditions for study of the pd interaction processes become more complicated with increasing the beam energy above $T_p = 1.0\,GeV$. For example, the counting rate of charged particles through the forward detector increases by several times and the pion background becomes substantial at the low momenta of particles. Yet, these factors cannot hinder the investigation of the mesonless deuteron break-up at the ANKE spectrometer even at the maximum energy of the COSY beam.

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Качарава А.К. и др. E1-96-270

Моделирование процесса развала дейтрона для установки ANKE при энергии T_p = 2.5 ГэВ

Проведено моделирование условий измерений эксперимента по изучению развала дейтрона на основе событий *pd*-взаимодействия, сгенерированных по ROC модели при энергии T_p = 2.5 ГэВ. Изучены фоновые условия для выделения реакции развала $pd \to ppn$ при этой энергии.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 1996

Kacharava A.K. et al. E1-96-270

Simulation of Deuteron Break-Up at T_p = 2.5 GeV for ANKE Facility

The experimental conditions for studying the deuteron break-up are simulated on the basis of *pd* interaction events generated by the ROC model at the energy T_p = 2.5 GeV. The background conditions for separation of the break-up reaction $pd \to ppn$ at this energy are examined.

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

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