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SPACE CORRELATIONS IN THE REACTION pd → ppn

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Пространственные корреляции в реакции pd → ppn

Угловые распределения и корреляции вторичных частиц в реакции развала дейтрона протоном при импульсе 1,67 ГэВ/с исследованы на экспериментальном материале, полученном на 100 см водородной пузырьковой камере, облученной дейтронами. Показано, что в области импульса нуклона-спектатора, кинематически запрещенной для квазидвухчастичного взаимодействия /КЗО/, механизм процесса может быть описан треугольной диаграммой с возбуждением изобары $\Delta(3,3)$ в промежуточном состоянии. Проведено сравнение экспериментальных данных с предсказаниями модели перерассеяния. Выяснено, что выход вторичных частиц в КЗО связан с жесткими кинематическими ограничениями на механизм реакции. Обнаружена корреляция между азимутальными углами нуклонов, согласно которой в КЗО оптимальным оказывается расположение импульсов всех частиц в одной плоскости.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1979

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Aladashvili B.S. et al.

Space Correlations in the Reaction pd → ppn

The angular distributions and correlations of secondary particles in the reaction of deuteron breakdown at a momentum of 1.67 GeV/c have been investigated using the experimental data obtained from the 100 cm hydrogen bubble chamber exposed to deuterons. In the region kinematically forbidden for quasi-two-particle interaction (KFR), the mechanism of the process can be described by the triangular diagram with the excitation of the $\Delta(3.3)$ isobar in the intermediate state. The experimental results are compared to rescattering model predictions. It has been found that the by-product of secondary particles is due to hard kinematical restrictions on the reaction mechanism. According to the correlation between the azimuthal angles of nucleons, the disposition of the momenta of all particles at the same plane is optimal in KFR.

The investigation has been performed at the Laboratory of High Energies, JINR.

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Recently the processes of producing on nuclei particles with momenta, kinematically forbidden for interaction with a single nucleon of the nucleus,have aroused interest in the hope of obtaining information on the behaviour of nuclear matter at small distances. The case of the simplest nucleus-deuteron is particularly important when theoretical interpretations are connected with the description of many-particle states of heavier nuclei. A theoretical search for new approaches to the description of many-particle interactions has led to the fact that a study of inclusive processes with secondary particle production in the kinematically forbidded region (KFR) /1,2/ is assumed to associate with the hypothetical mechanism of amalgamation of a few nucleons in the cluster formed in the process of interaction /3-5/ or existing in a ready form in the nucleus. In the latter case by the cluster is meant both the superdense state of nuclear matter (fluctuons) /6-8/ and the anomally rigid correlation between nucleons in the nucleus /9-12/. From anothe point of view these processes are connected with the existence of the relativistic state of nucleons in the nucleus /13,14/. The division of models into categories is conventional enough. As an illustration, it is possible to observe in paper /11/ the evolution of theoretical interpretation of the results obtained by the authors.

As it follows from the representation of colliding "parton jets" /15/. the reaction under study of the deuteron break-down is convenient since the cluster mass is fixed, i.e., both nucleons are united to one 6-quark cluster (Fig. I.1).

From the traditional point of view of the nucleus as a system of weakly bound nucleons, the particle production in KFR is explained by the gradual rescattering of nucleons or particles produced on nucleons of the nucleus /16-22/.

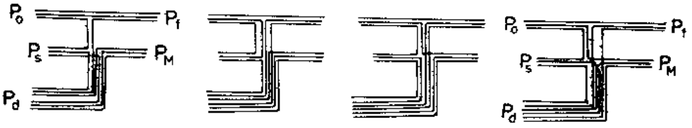

Fig. 1.1. Diagrams of the model of "parton jets".

a.) б.)

Fig. 1.2. Diagrams of the rescattering model: a) elastic interaction, b) interaction with isobar production in the intermediate state.

The diagrams for the reaction $pd \to ppn$ are given in Fig. 1.2. Figure 2 presents the experimental data[23], published elsewhere* , together with the theoretical curves calculated according to the model of rescattering [20]. The accuracy of such calculation is limited by a poor knowledge of necessary information on elementary amplitudes, mainly on relative signs of amplitudes in various spin states or, as in papers[24,25], on the hypothetical off-mass shell dependence of the amplitudes. Estimating the created situation when the class of reactions with particle production in KFR is studied, one should agree with the opinion [26] that the question concerning the mechanism of these processes cannot be solved by investigating inclusive spectra, and it is of special importance to obtain all information on the reaction, in particular by means of track chamber experiments. The performed studies of the Treiman-Yang angle (TYA) correla-

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* Paper[23] presents the experimental spectra integrated over the angular intervals $\Delta\Omega = 2\pi \Delta Z$, where ΔZ is the interval of cosine of the flight angle of nucleon-spactator.

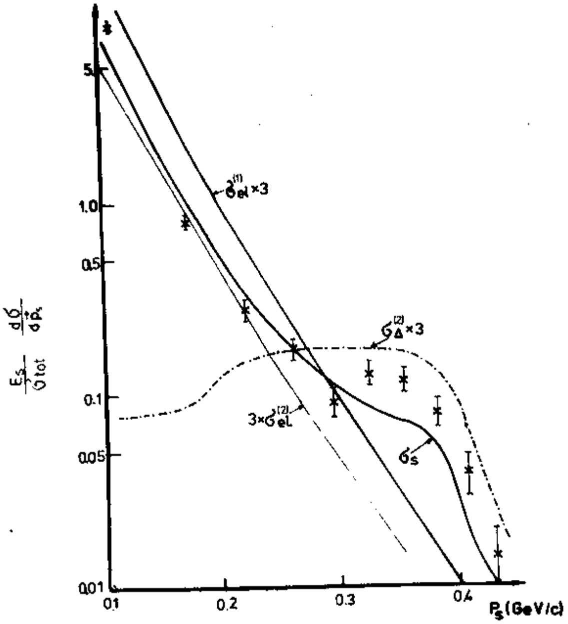


Fig. 2. Spectrum of the proton emitted backward in the interval $-1 \leq Z < -2/3$, where $Z = \cos\theta_S$; σ_{el} is the process with single and double interaction; σ_Δ is the process with the production of isobar Δ (3.3). The theoretical curves are taken from paper /16/.

tions of secondary particles in the reaction of deuteron break-down/27/ show a good agreement between theory and experiment in the region of quasi-two-particle interactions ($p_s \leq 0.2$ GeV/c, where p_s is the momentum of nucleon-spectator). In that region where the contribution of the triangular diagram (Fig. 1.2) is significant, a sharp increase of the TYA-asymmetry is predicted by the model of rescattering /28/. In the relativistic case this correlation converts to the correlation between azimuthal angles of secondary particles/29/. The indicated asymmetry means that momentum vectors have a tendency to be at the same plane. Such a situation, as shown in paper /19/, is typical for any nucleus with particle production in KFR due to gradual rescattering. In the same paper it is shown that in the process of elastic rescattering the optimal rotation angle in a separate act, $\Delta\theta$, must be near θ_s/n, where θ_s is the flight angle of the spectator in KFR and n is the interaction multiplicity. The resonance excitation in the intermediate state leads to decreasing the rotation angle in that act which the resonance is produced. Consequently, typical maxima corresponding to processes with different scattering multiplicity must be observed on light nuclei in angular distributions. The secondary interaction camouflages this effect on heavier nuclei when nucleons leave the nucleus.

In studies of space correlations one should take into account the circumstance that on the kinematical boundary each many-particle reaction converts to quasi-two-particle reaction so that all the particles, except for the separated one, fly in the direction opposite to the latter, and their relative momenta are close to nought.

The space correlations, predicted by the model of rescattering, are due to rather rigid kinematical limitations on the transfer of energy and momentum in a row of successive collisions which are necessary for particle ejection in KFR so that the energy is transported with minimal losses. The optimal trajectory of the nucleon, scattered in the nucleus, is a plane convex broken line. One of the consequences of the model should be the decrease of π -meson production with increasing the nucleon momentum in KFR. The formation of free mesons should be suppressed in the process of resonance excitation in the intermediate state [19], kinematically profitable for particle emission in KFR, when the energy of excitation is absorbed. The radiation of free mesons is possible in the first act. The region of secondary particle momenta, beginning with which the suppression occurs, shifts to the kinematical boundary with increasing the primary particle energy. In the region of high energy (p_B 10 GeV/c) at small rescattering multiplicities the production of mesons, associated to nucleons in KFR, is possible not only in the first act, and, consequently, it can exceed the production of pions in the elementary process. It is worth noting that on nuclei heavier than the deuteron the picture is complicated by the effect of resonance meson absorption.

In the models [3-5] the production in KFR must be accompanied by higher associative multiplicity of π -mesons.

The important role of triangular diagrams with resonance excitation in the intermediate state in the mechanism of elementary particle scattering on nuclei has been determined in pages [16-25,30-36].

One can observe the peculiarity, presented in Fig. 2, in the inclusive spectra of nucleons [16,26,37] flying out of nuclei in KFR at the same energy ($E_0 \simeq 80$ MeV). As shown in papers [17,19-22], such peculiarities are the result of resonance excitation. The same peculiarity is observed in the spectra of π -mesons [23,38] which is shifted with respect to its position in the nucleon distribution. The fact that the ratio of the production of mesons to that of protons [2,39,40] is slightly larger than 10^{-2} agrees with the assumption of the predominance of the mechanism, which corresponds to the diagram in Fig. 1.2, with subsequent resonance decay. From the same diagram it is easily seen that in KFR the production of neutrons in the studied reaction of deuteron breakdown amounts to the experimentally confirmed value which is equal to 1/5 of proton production.

As noted in paper [20] the investigated three-nucleon mechanism forms the basis of many interaction processes involving nuclei with particle production in KFR.

II. The data given below have been performed in an exposure of the 100 cm hydrogen bubble chamber to deuterons with a momentum of 3.33 ± 0.08 GeV/c which corresponds to the proton momentum in the deuteron rest system (d -system) at 1.67 GeV/c. About 5×10^4 dp interactions were taken, and among them 21700 $pd \to ppn$ events were identified. The slowest nucleon in the d -system is regarded as a spectator. In the d -system, two slow nucleons are formed with strongly different angular distriburions (Fig. 3). The angular distribution of spectators (s) in the region of small momentum transfers is almost isotropic and in KFR it is anisotropic.Anisotropy increases with increasing the spectator momentum. The decrease of the production of particle-spectators is specific to the angular distribution as emission angle increases [40].

The angular distribution of m- and f-nucleons indicates a quasi-elastic nature of interaction. The angular disrtibutions of the f-nucleon is sharply stretched forward and weakly dependent on momentum transfer.The bell-shaped angular distribution of the second slow nucleon (m) also weakly changes with momentum transfer but the maximum position shifts to the region of small angles with increasing the spectator kinetic energy T_S .

The division of nucleons into categories f, m and s does not become single-valued in those cases when two nucleons are emitted with relatively close momenta.

The dimensionless variable $x = T_S / T_{max}(\theta_s)$, where T_{max} is the maximum kinetic energy of the particle flying out at

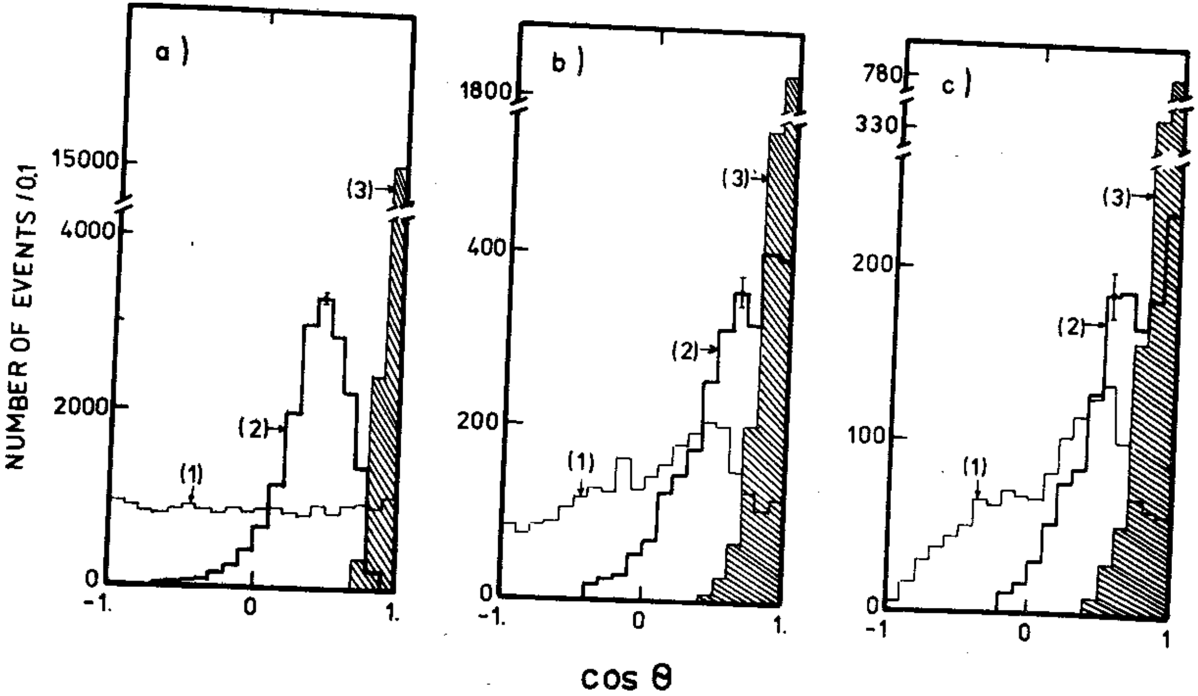


Fig. 3. Angular spectra of nucleons f(3), m(2) and S(1) in the d-system for kinetic energy intervals: a) $T_S \le 0.2$; b) $0.4 \le T_S < 0.6$; c) $0.6 \le T_S$.

angle θ_s to incident proton momentum p_B, is convenient as the inclusive spectra over this variable are independent of the emission angle of particles, and the simple condition ($x > 1/2$) can be compared with the production in KFR to a good approximation. Accuracy of this condition is limited by the fact that the inclusive spectra are overlapped in KFR and in the region permitted for the quasi-two-particle reaction.

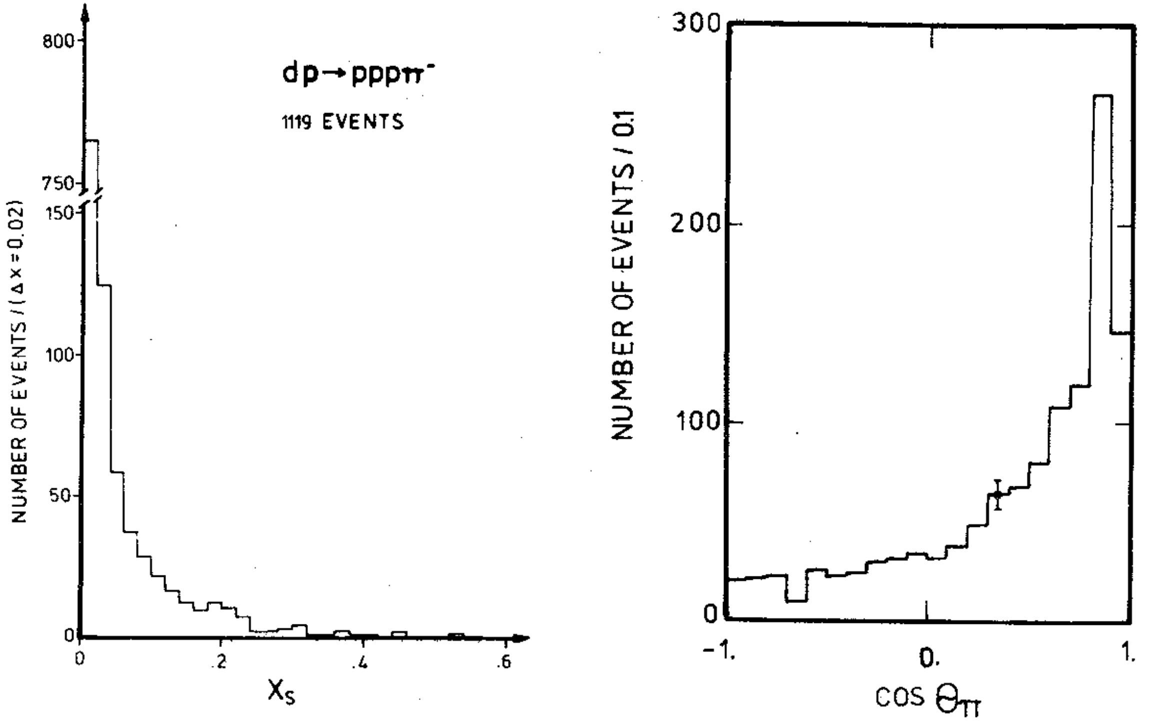
The production of π-mesons versus x of the spectator (the data for the reaction $pd \to pp p\pi^-$ are shown in Fig.4) supports the above-mentioned prediction of the rescattering model, and the sharply forward-streched angular spectrum of mesons (Fig. 4b) corresponds to that of the binary reaction.

Paper /17/ presents the effective mass distribution of m- and s-protons in the charge exchange reaction $pd \to n(pp)$ for the quasi-elastic region and outside it. In the latter case the effective mass spectrum is concentrated in the region of formation of the Λ-isobar, and at the same time the two-particle correlation is found between the emission angles of protons: they are emitted in opposite directions.

The distribution over mass $M_x^2 = (E_m + E_s - m)^2 - (p_m + p_s)^2$, presented in Fig. 5, can be a direct confirmation of the mechanism of the investigated reaction (see Fig. 1.2). The spectrum maxima are clearly seen at $M_x^2 \approx m^2$ and $M^2 \approx m_\Lambda^2$ in KFR. The formation of the Λ-isobar in the reaction $pd \to ppn$ leads to the mechanism of the diagram in Fig. 1.2b in the only manner.

The two-dimensional scatter plot of the nucleon azimuthal angles (Fig. 6), presented in Figs. 7,8,9, show three-particle correlations for various intervals at the variable x. In the presented data the plane of the reaction is determined through two vectors (p_B, p_s). The azimuthal angles of particles f and m are counted relative to the spectator s. As our studies have shown, the determination of the reaction plane through the couple (p_B, p_f) leads to identical results.

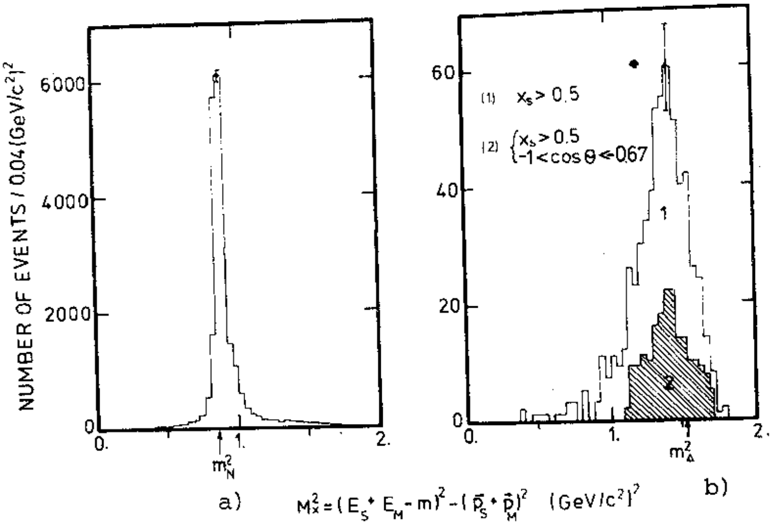
The correlation, which is typical for the binary interaction, is observed in the region $x \leq 0.2$ (Fig. 7). As is seen from Figs. 8,9, the picture in KFR is changed. Nucleons f and m are emitted mainly at large angles relative to the spectator. At the same time the momentum of relative motion (Fig. 10) of f and m is still large (~ 1 GeV/c) and, consequently, the greater part of events is far from the kinematical boundary of the reaction.



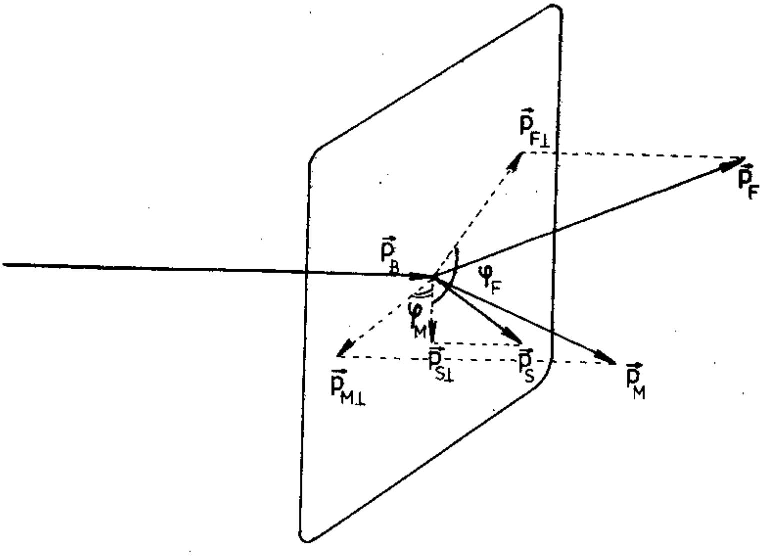
a)

b)

Fig. 4. Spectrum of π -mesons as a function of a) $x = T_S/T_{max}(\theta_s)$, b) emission angle of mesons in the d-system relative to the primary proton momentum.



<u>Fig. 5</u>. $M_x^2 = (E_m + E_S - m)^2 - (p_m + p_s)^2$ distributions for intervals: a) $x \le 0.5$; b) $x > 0.5$.



<u>Fig. 6</u>. Determination of azimuthal angles ϕ_f, ϕ_m and ϕ_s.

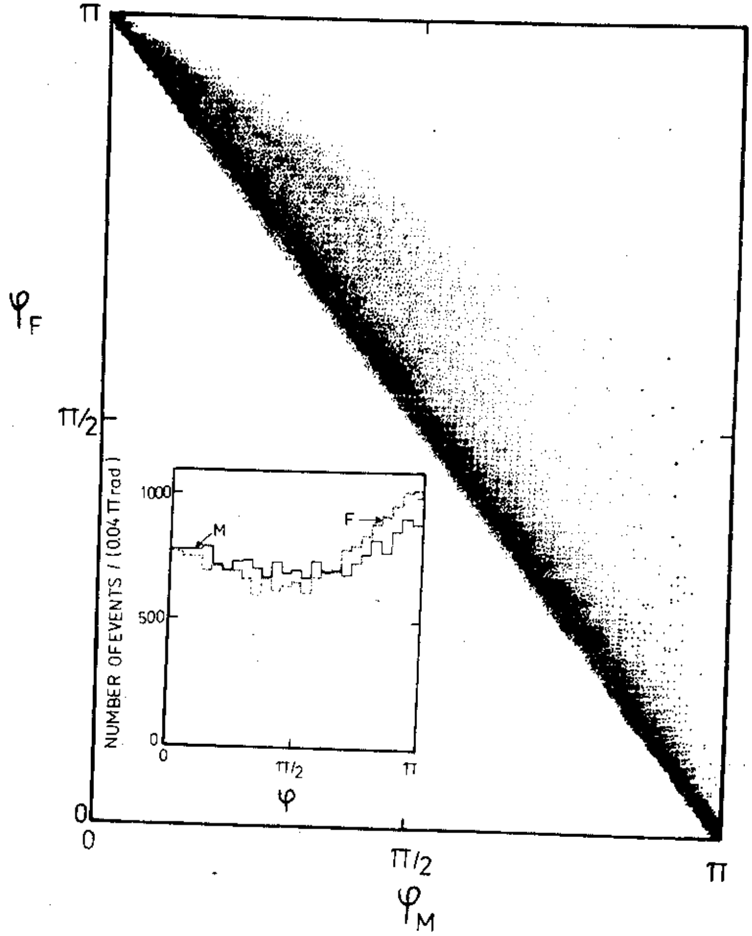


Fig. 7. Two-dimensional distribution against angles $\phi_F=\phi_f-\phi_s$, $\phi_M=\phi_m-\phi_s$ for the interval $x \leq 0.2$.

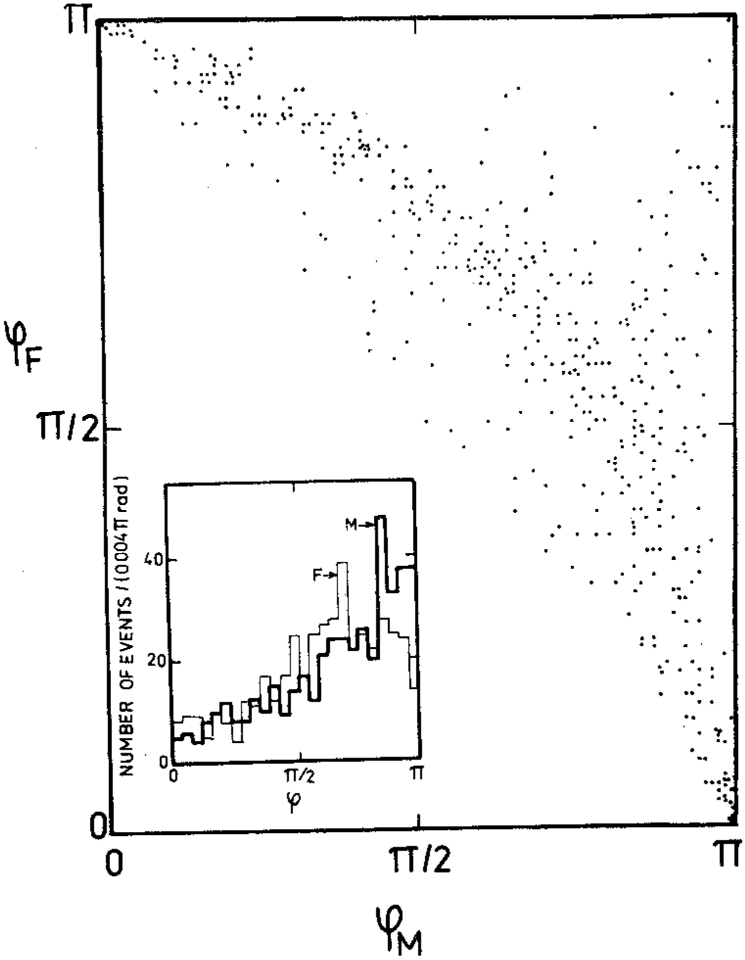


Fig. 8. Two-dimensional distribution for $0.4 \leq x < 0.6$.

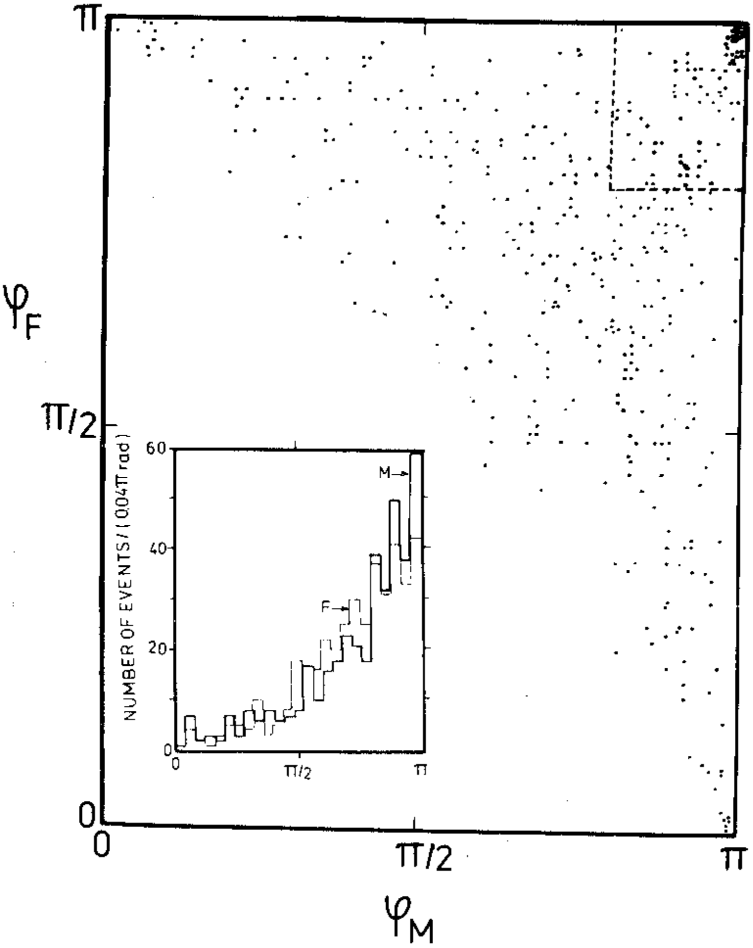


Fig. 9. Two-dimensional distribution for x ≥ 0.6.

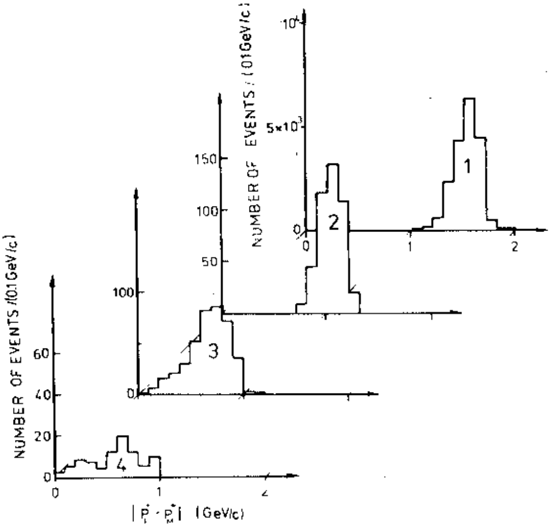


Fig. 10. $p = |\vec{p}_f - \vec{p}_m|$ distribution for intervals: 1) $x \leq 0.2$; 2) $0.4 \leq x < 0.6$; 3) $x \leq 0.6$; 4) in the region denoted by the dotted line in fig. 10.

The particular case of two-particle correlations has been recently investigated /41,42/. These results are in agreement with our data.

The angular distributions of events between the plane (p_f, p_m) and the reaction plane are presented in Fig. 11. The correlation, observed at $x \leq 0.2$, corresponds to the previously investigated TYA-correlation /27/ presented in the d -system, and demonstrates the planar correlation /19/ at $x > 1/2$. The determination of the reaction plane loses the sense for the spectator emission angle equal to 180° , and, as is seen from the presented data, the correlation decreases near this angle. Two other effects, predicted in paper /19/ and discovered experimentally /40,43,44/, are related to the investigated effect of planar correlations. One of them is "the effect of focusing" /19,20/ consisting in that the inclusive cross section in KFR ceases to decrease /40/ with

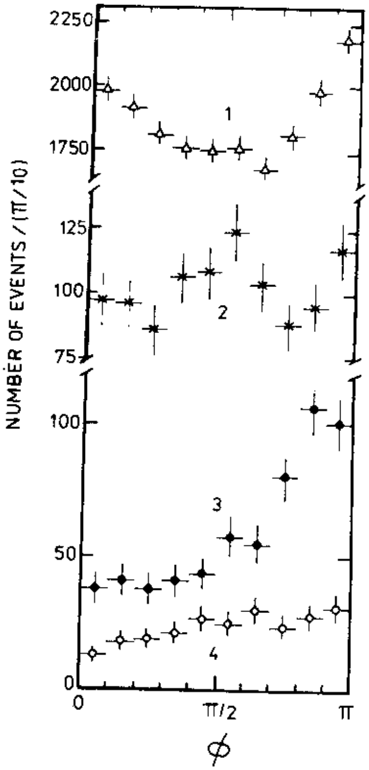


Fig. 11. ϕ-distribution between the planes (p_B, p_s) and (p_f, p_m). Asymmetry $A = \frac{N^+ - N^-}{N^+ + N^-}$, where $N_\pm$ is the number of particles to the right (to the left) of $\phi = \pi/2$.

The distributions are given for intervals:
1) $x \geq 0.2$; 2) $0.4 \leq x \leq 0.6$;
3) $x > 0.6$, $-2/3 \leq z_s \leq 1$;
4) $x > 0.6$, $-1 \leq z_s \leq -2/3$.

increasing the angle in the region of angles 160°- 180° as at the same time the region of permissible azimuthal angles of particles, associated with the spectator, increases. The second effect is the increase of the polarization of secondary nucleons with increasing their momenta /43,44/ that is in contradiction to the prediction of the model of local interaction /45/.

III. The correlation, described in this paper, has been studied at a high energy (p_B = 1.67 GeV/c) of the primary particle, i.e., in that region where the compton wave length is much smaller than the distance between nucleons in the deuteron.

The investigation of the processes of interaction of elementary particles with nucleus gives the basis for the conclusion that the mechanism of rescattering is very important in the reaction with particle production in KFR.

The results, presented in this paper, show that the properties of the observed correlation are not so simple as one could expect from the orthodox model of elastic multiple interactions[19]. To elucidate the peculiarities of the mechanism of interaction of relativistic particles with nuclei, it is required to perform both experimental studies in the region of high energy of particle-spectators (in particular, in the case when the resonance production cross section is small) and numerical calculations in the framework of the picture of multiple interactions. The divergence with the predictions of this picture is of particular interest.

Experiments with polarized nucleons and nuclei are of particular importance.

The processes of the type, being studied in our paper, could give valuable information on the high-momentum component of the wave-function in the case of a detailed calculation of all the properties of elementary amplitudes composing separate acts of rescattering. Unfortunately, a poor knowledge of information on the amplitudes of elementary processes largely makes the implementation of this possibility difficult.

In conclusion the authors would like to express their gratitude to A.V.Efremov and V.B.Kopeliovich for useful discussions and to M.Filipkowski for her help in performing the illustrations.

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