Rescattering by a nucleus of ($N\pi$) and (3π) beams after their coherent formation

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The coherent processes of diffractive dissociation $NA \to (N\pi)A$ and $\pi A \to (3\pi)A$ are analyzed within the framework of the Drell-Hiida-Deck model, which was modified by taking into account the rescattering effects. It is shown that the scattering cross section of a ($N\pi$) beam has a "normal" value, whereas the scattering cross section of a (3π) beam is anomalously small. The small cross section is attributable to the small pomeron vertex function of the ρ mesons.

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1. The diffractive dissociation (DD) of a nucleon into a $N\pi$ system[1,2] and of a pion into a 3π system[3–5] was investigated experimentally using nuclear targets

$$NA \to (N\pi)A, \tag{1}$$

$$\pi A \to (3\pi)A. \tag{2}$$

The main result of these investigations, which was obtained after analyzing the experimental data in terms of the Glauber approach,[6] reduces to the following conclusion: the total cross section for rescattering of a particle beam by a nucleon, in which a hadron h dissociates into this beam, is independent of the beam composition and is equal to approximately σ^t_{hN}. Specifically, we obtained the equalities $\sigma^t_{N\pi,N} \approx \sigma^t_{N,N}$, and $\sigma^t_{3\pi,N} \approx \sigma^t_{\pi,N}$. It should be emphasized that the simplifying assumptions used to obtain these equalities in terms of the Glauber approach cast doubt on the validity of these results, as was noted many times in the literature.[7-10]

In this paper we examine the coherent part of the DD processes (1) and (2), which is dominant in the region of smallest momentum transfer, and use an approach which generalizes the traditional Drell-Hiida-Deck model[11] by taking into account the rescattering processes. This approach was used successfully earlier in describing the diffractive dissociation of a nucleon into a $N\pi$ system in a nucleon target.[12,13] Since it is convenient to regard a nucleus as a structureless object in the dispersive approach used by us, we selected as the unknown parameter the cross sections for scattering of individual beam components (consistent with the Deck model) by a nucleus, rather than the cross section for scattering of a particle beam by an individual nucleon.

This approach is correct in the region of small masses of the excited system (in the region of the so-called "Deck" maximum), in which the effects of rescattering of particles that form the beam on each other are small. With regard to the reaction (2), we further assumed on the basis of the experimental data that the produced 3π beam consists of ρ and π mesons, i.e., the reaction (2) in our approximation is equivalent to the reaction

$$\pi A \to (\rho\pi) A \ . \tag{3}$$

In contrast to the standard Glauber approach,[1-6] our analysis shows that the small effects produced as a result of scattering of the beam are present only in the reaction (3) [or (2)] and are missing in the reaction (1).

2. Like the DD reaction, we determine the amplitude of the reaction (1) using the nucleon target

$$NN \to (N\pi) N \ . \tag{4}$$

The amplitude of this process was determined previously[12,13] by summing the multipomeron diagrams. A simplified version of this amplitude is graphically illustrated in Fig. 1a. The T diagram is a single-pion, polar diagram while the TI and TN diagrams take into account the rescattering in the initial and final state. The lower horizontal lines in the diagrams in Fig. 1 represent a nucleon in the reaction (4) or a nucleus in the reaction (1). The wavy lines correspond to the elastic NA or πA scattering amplitudes. To record them, we used the standard Glauber formalism[14] in the approximation of heavy nuclei (optical approximation). The loops in Fig. 1 correspond to the integrals over the phase volume of two particles in the intermediate state with the coefficient $i/2$ $[i/2 \times \int d\tau_2 \ (\ldots)]$.

We write the amplitude of the process (1) in accordance with the diagrams in

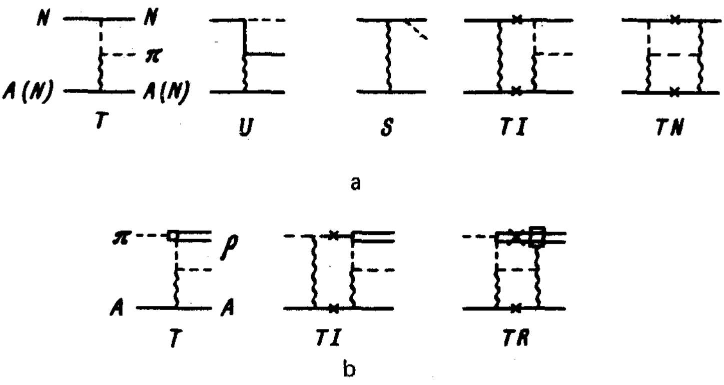

FIG. 1. Diagrams describing (a) the process (1) and (b) the process (2).

Fig. 1.

$$A_{N\pi} = T + C_{N\pi}\,(TI + TN) \qquad (5)$$

(the same symbols are used for the amplitudes and for the diagrams).

The $C_{N\pi}$ coefficient in Eq. (5), which is a free parameter, is called upon to take into account phenomenologically a possible production of showers in the intermediate state in the *TI* and *TN* diagrams. Note that the data for the reaction (4) were satisfactorily described at $C_{N\pi} \approx 1$ (Refs. 12 and 13) when a nucleon target was used.[1)]

In determining the amplitude (5) in accordance with the diagrams in Fig. 1a in order to record the πA and NA scattering amplitudes we used the energy-independent, invariant amplitudes which are related to the standard Glauber amplitudes F by the relation $M_{hA}(q) = 4\pi/K \cdot F_{hA}(K; q)$ (q is the transferred momentum and κ is the laboratory momentum of the beam).[2)]

$$A_{N\pi}(q) = \beta\left[M_{\pi A}(q) + C_{N\pi}\, 2i \int M_{\pi A}(q_1)\, M_{NA}(q_2)\, \frac{d(q_1^2)\, d\phi}{32\,\pi^2}\right]. \qquad (6)$$

Here β is a parameter that characterizes the average vertex of the dissociation $N \to N\Pi$ and the integration is performed over the transverse momentum q_1 and over the azimuthal angle ϕ that characterize the intermediate state in the *TI* diagram [Fig. 1a]. The transverse momenta q, q_1, and q_2 are related to each other in the following way $q^2 = q_1^2 + q_2^2 - 2q_1q_2 \cos\phi$. The second term in Eq. (6) was calculated by using a numerical integration.

Because of the parameter β, we did not normalize the result of the calculation; this is the main shortcoming of the simplified approach.

The imaginary part of the amplitude $A_{N\pi}$ (β = 1 GeV) and its separate parts (6) are shown in Fig. 2 for the DD into Pb (all the amplitudes are purely imaginary). The solid curve pertains to the total amplitude and the dashed and dot-dash curves describe the elastic amplitude $M_{\pi A}(q)$ and the double contribution of the *TI* diagram,

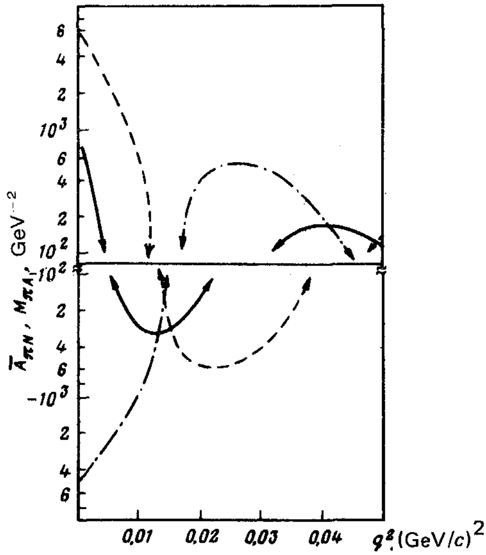

FIG. 2. Analysis of the dependence of the amplitude of DD of a nucleon in lead (6) on momentum transfer.

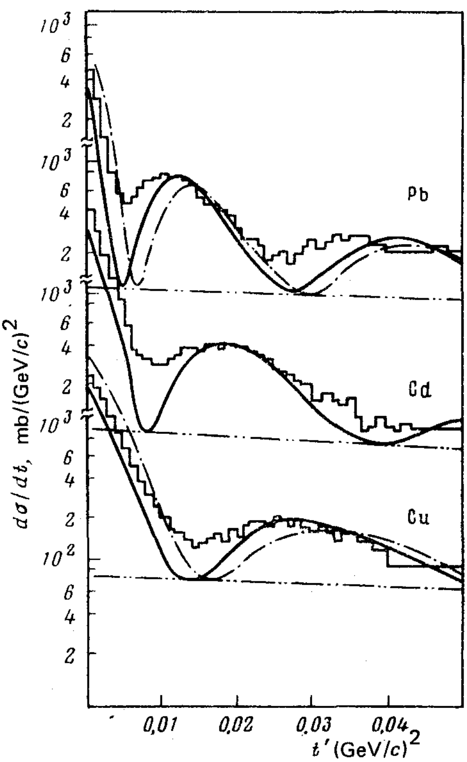

FIG. 3. A comparison of the model with the data for the DD process of a nucleon (1), which were obtained for the following conditions: $P_{\rm lab} = 12$ GeV/c, $\cos\theta_t > -0.2$, $1.35 < M^*_{N\pi} < 1.45 \times$ GeV.[1]

respectively. After subtracting the contribution of the *TI* diagram from that of the polar diagram, we obtain a zero at $t \approx 0.005$ $(\mathrm{GeV}/c)^2$ and the extrema that coincide with the zeros of the polar amplitude.

The amplitude (6) is compared in Fig. 3 with the date for the t' distribution ($t' = |t| - |t_{min}|$) in the $DDn \to p\pi^-$ process induced by Cu, Cd, and Pb nuclei at 12 GeV/c momentum.[1] The parameter β was determined in the description of the data obtained with Pb, so that the model gives absolute predictions for the remaining two nuclei. The dot-dash curves with two dots, which correspond to the contribution of the incoherent processes, were obtained by linearly extrapolating the data in the region $t' > 0.05$ $(\mathrm{GeV}/c)^2$.[1] The calculations showed that a satisfactory description is obtained when the parameter $C_{N\pi} = 0.9$–1 (the dot-dash curves and the solid curves in Fig. 3). The most sensitive functions of the parameter $C_{N\pi}$ are: the ratio of the t distributions in the regions of the first and second maximum d (for lead $d = 7, 20$, and 0.7 at $C_{N\pi} = 1, 0.9$, and 1.1, respectively, for the experimental value $d_{\exp} \approx 6$) and the location of the first minimum t_0 of the t distribution [for lead $t_0 = (5,7,2) \times 10^{-3}$ $(\mathrm{GeV}/c)^2$ for the same values of $C_{N\pi}$ at $t_{0\ \exp} \approx 5.5 \times 10^{-3}$ $(\mathrm{GeV}/c)^2$].

3. The amplitude of the process (3) [or (2)] is determined analogously. According to the diagrams in Fig. 1b, we derive the following expression for it:

$$\bar{A}_{\rho\pi} = \bar{T} + C_{\rho\pi} (\bar{T}I + \bar{T}R).$$

$$A_{\rho\pi} = \beta_1 \left[M_{\pi A}(q) + C_{\rho\pi} 2i \int M_{\pi A}(q_1)\, M_{\pi A}(q_2) \frac{d(q_1^2)\, d\phi}{32\pi^2} \right]. \qquad (7)$$

The only important difference between Eq. (7) and Eq. (5) is the substitution of the πA scattering amplitude for the NA scattering amplitude. In deriving Eq. (7), for specificity, we assumed that $M_{\rho A} = M_{\pi A}$ and allowed for the fact that the $C_{\rho\pi}$ coefficient may contribute to a deviation from this equality. The amplitude (7) squared is compared in Fig. 4 with the data for the t' distribution in the reaction (2), which were obtained at 23 GeV/c momentum.[3] The parameter β_1 was determined by comparing it with the data obtained with lead. The calculations using the different values of $C_{\rho\pi}$ showed that the value $C_{\rho\pi} = 0.7 \pm 0.05$ (solid curve in Fig. 4) is the preferred value. The results of a calculation for $C_{\rho\pi} = 0.9$, which diverge systematically from the experimental data, are illustrated in Fig. 4.

The obtained result corresponds to two physical realities:

a) $M_{\rho A} \approx M_{\pi A}$ and $C_{\rho\pi} \approx 0.7$. The negative contribution of the intermediate inelastic states in the *TI* and *TR* diagrams [Fig. 1b] accounts for the fact that $C_{\rho\pi}$ does not equal to unity. This is consistent with the result of Ref. 9.

b) $M_{\rho A} \approx 0.4 M_{\pi A}$ and $C_{\rho\pi} \approx 1$. This conclusion seems preferable to us, since it is consistent with the results obtained by Verebryusov and Ponomarev[15,16] who predicted an anomalously small pomeron vertex function of a ρ meson during its production in the $DD\pi \to 3\pi$ process induced by a nucleus.

We emphasize that if the possibility (a) is realized, then it would be reasonable to expect that the value of $C_{N\pi}$ will also be small, which contradicts our analysis of the reaction (1) in Sec. 2 of this paper.

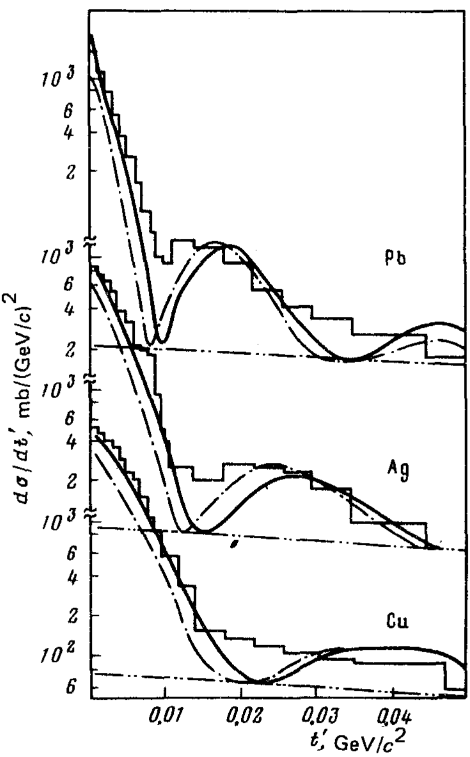

FIG. 4. A comparison of the model with the data for the DD process of a pion (2), which were obtained for the conditions: $P_{\text{lab}} = 23$ GeV/c, $1 < M^*_{3\pi} < 1.2$ GeV.[3]

4. Summarizing our discussion and using the standard language, we maintain that the $N\pi$ beam in the reaction (1) is scattered with a "normal" cross section, whereas the rescattering cross section of the $\rho\pi$ beam is anomalously small. The first point contradicts the standard Glauber treamtent,[1-6] whereas the second point is in qualitative agreement with it. The main difference between our approach and that used in Refs. 1-5 lies apparently in the fact that the produced $N\pi$ and $\rho\pi$ beams in the standard treatment remain tightly coupled after scattering, whereas the beam components are scattered independently of the beam in the examined (Fig. 1).

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[1)]The calculations with the exact amplitude confirm that the introduced simplifications are correct. We remind that, according to Refs. 12 and 13, none of these simplifications is correct for a nucleon target (4).

[2)]In determining (6) we disregarded the nucleon spin and averaged the amplitude over the mass of the excited system and over the angle variables of its decay. The calculations with the exact amplitude confirm that the induced simplifications are correct.

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