Mechanism of Δ-isobar production in $\pi\ d$ interactions at high energies

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(Submitted August 7, 1974)
ZhETF Pis. Red. **20**, No. 7, 510–513 (October 5, 1974)

A mechanism corresponding to backward elastic scattering of a π^- meson by a proton, with subsequent formation of the Δ^- isobar on a neutron, is proposed for the description of the reaction $\pi^- d \to p\Delta^-$ (1) with forward emission of a fast photon. It is shown that $d\sigma_d/du$ for the reaction (1) is proportional in this case to $d\sigma_p/du$ for backward elastic $\pi^- p$ scattering.

Scattering of high-energy hadrons by nuclei is an interesting but still relatively little investigated problem. Two important questions overlap here: the mechanism of processes with large momentum transfer and, apparently, the appreciable dependence of the cross sections of these processes on the behavior of the nuclear wave functions at short distances. Separation of these questions, whenever possible, would lead to appreciable progress in the understanding of the physics of these phenomena.

The question of the behavior of nuclear wave functions at short distances is connected with the admixture P_{N^*} of excited nucleon states in these wave functions. As shown in[1], P_{N^*} can reach the rather appreciable value ~1%. To obtain information on the isobar admixture $P_{\Delta\Delta}$ in the deuteron, it was proposed in[2] to measure the cross section of the reaction

$$\pi^- d \to p\Delta^- \tag{1}$$

with forward emission of fast protons. According to[2], the cross section of this reaction is determined at high energies by Δ-isobar exchange in the u channel, and consequently by the value of $P_{\Delta\Delta}$. The cross section of reaction (1) is then ~10–100 μb at an incident pion energy 1 GeV and at $P_{\Delta\Delta}$ ~1%.

In this paper we describe the reaction (1) within the framework of the triangular mechanism (Fig. 1a), when the pion is scattered backward by a proton and then interacts resonantly with a neutron.[3] In contrast to the mechanism used in[2], it is not assumed that Δ isobars are present in the deuteron. The cross section in our case does not depend very strongly on the behavior of the wave function at short distances, and is determined by an integral over the entire volume of the deuteron.

A similar mechanism was used successfully in[4,5] to describe the elastic backward pd scattering. The applicability of this model seems to be more justified in our case, owing to the resonant character of the πn interaction.

Within the framework of the triangular mechanism (Fig. 1a), the differential cross section of the reaction (1) is expressed in terms of the differential cross section of the elastic $\pi^- p$ scattering backward

$$\frac{d\sigma_d(s,u)}{du} = F(u)\frac{d\sigma_p(s_1,u)}{du}, \tag{2}$$

where $u=(p_\pi - p_p)^2$ and $s_1=(p_d/2+p_\pi)^2$. The function $F(u)$ is determined by the triangular diagram of Fig. 1a. Figure 2 shows plots of $f(u)$ for three variants of the deuteron wave function, those of Hulthen[6] (curve 1) and Moravcsik[6] (curve 2), and in the form of Gaussian parametrization[7] (curve 3).

The main source of the background is quasielastic scattering, which makes it possible for the invariant mass of the πn system to fall in the region of the Δ-isobar mass (diagram 1b). To weaken the background one can use a special selection of events with pion emission in the rear hemisphere in the c.m.s. of the πn system relative to the direction of motion of this system.[8] In the lab. system, the pion moves forward. In such events, the neutron has the largest momentum, and the contribution of diagram 1b is suppressed by the smallness of the deuteron wave function at large values of the momentum. Estimates of the quasielastic background remaining after such a selection of the events shows that it does not exceed several per cent.

Let us compare the theoretical cross section of the reaction (1) with the experimental value[8] at an incident pion momentum $p = 1.7$ GeV/c and $u = 0.181 \pm 0.025$, namely $(d\sigma_d/du)_{\text{theor}} = 0.32-0.52$ mb/GeV^2 as against $(d\sigma_d/du)_{\text{exp}} = 0.24 \pm 0.08$ mb/GeV^2. The uncertainty in the theoretical value of the cross section is connected with the different parametrizations of the deuteron wave function. Within the limits of errors, the theoretical and experimental values of the cross section agree. We emphasize that an experimental check on the predicted energy dependence of the cross section at a fixed value $u = u_0$, which should duplicate the energy dependence of the $\pi^- p$ scattering cross section at $u = 0$, would be of decisive significance for the proposed mechanism.

On the other hand, if the reaction (1) were to be described within the framework of the mechanism with Δ-isobar exchange in the u channel, the reaction cross section would be

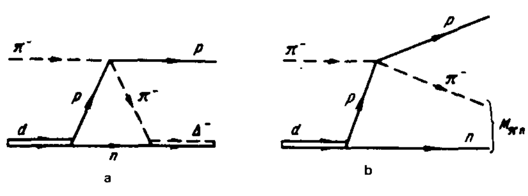

FIG. 1.

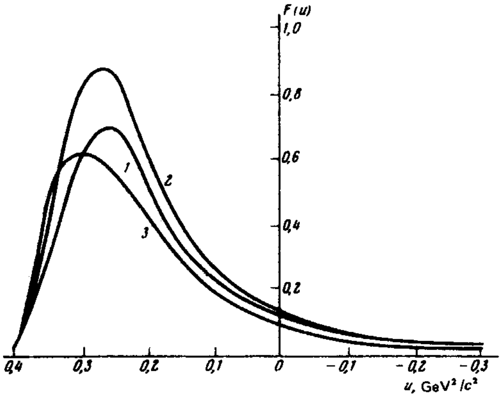

FIG. 2.

$$\frac{d\sigma_d}{du} = 180\, F(u) E \text{ mb/GeV}^2 \qquad (3)$$

where E is the pion energy in the lab. system in GeV. At $E=1.7$ GeV, the value of $d\sigma_d/du$ calculated from formula (3) is 180 mb/GeV^2 and differs radically from the experimental data. In addition, formula (3) leads to an incorrect energy dependence of the cross section.

The agreement between the experimental data and the calculation performed by formula (2) indicates that the considered triangular mechanism makes the predominant contribution to the cross section of reaction (2). At the same time it evidences that the reaction (1) cannot be used to determine the admixture of the ΔΔ state in the deuteron wave function, as suggested in[2].

The authors thank I. A. Dukhovskiĭ, V. V. Kishkurno, V. M. Kolybasov, and I. S. Shapiro for useful discussions.

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