Study of the reaction $\pi^- + d \rightarrow p + \pi^- + n$ with large momentum transfer to the proton in the primary-momentum interval from 1.25 to 2.64 GeV/c

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The differential cross section of the reaction $\pi^- + d \rightarrow p + \pi^- + n$ (at a c.m.s. proton emission angle close to 0°) was measured in the momentum interval from 1.25 to 2.64 GeV/c. The measured cross sections turned out to be equal, within the limits of statistical accuracy, to the cross section of elastic $\pi^- p$ backscattering at the investigated energies. The result confirms the important role played in this process by the interaction in the final state.

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Scattering of hadrons by nuclei and their substructures (nucleons, clusters) at large angles is a little-investigated branch of high-energy physics. The paucity of experimental material, particularly at large momentum transfers, limits the possibilities of ascertaining the mechanisms of similar processes. For example, there are practically no data on the quasielastic process at large momentum transfers and energies above 1 GeV. An appreciable amount of research on this process was carried out only at small scattering angles.

The three-meter spectrometer of our institute[1] was used to investigate the reaction

$$\pi^- + d \rightarrow p + X^- \qquad (1)$$

with large momentum transferred to the proton, at initial momenta 1.25, 1.48, 1.68, and 2.64 GeV/c. To register the fast protons emitted forward, a Cerenkov counter was incorporated in the master system at momenta 1.68 and 2.64 GeV/c.[2] At smaller momenta, we used a system in which p, d, and π were separated by time of flight.[3]

To study the reaction (1), we used the missing-mass method. We measured the momenta and angles of the fast protons emitted forward. Figure 1 shows the distribution of the events with respect to the square of the proton missing mass (M^2_{XN}), calculated under the assumption that the target is a nucleon ($P_{\pi^-} = 1.68$ GeV/c). In the region $M^2_{XN} = 0$ there is observed a peak from the reaction

$$\pi^- + d \rightarrow p + \pi^- + n. \qquad (2)$$

Analogous distributions were obtained at other energies.

The proton spectra were described by an incoherent sum of a term of Gaussian form for the peak at $M^2_{XN} \approx 0$ and the statistical background of the production of two pions. It should be noted here that the process (2), at large momenta transferred to the proton, obviously includes quasielastic backscattering[1)] (diagram "a" of Fig. 2),

$$\pi^- + d \rightarrow p + \pi^- + n_s, \qquad (3)$$

the production of the isobar $\Delta(1236)$, which was inves-

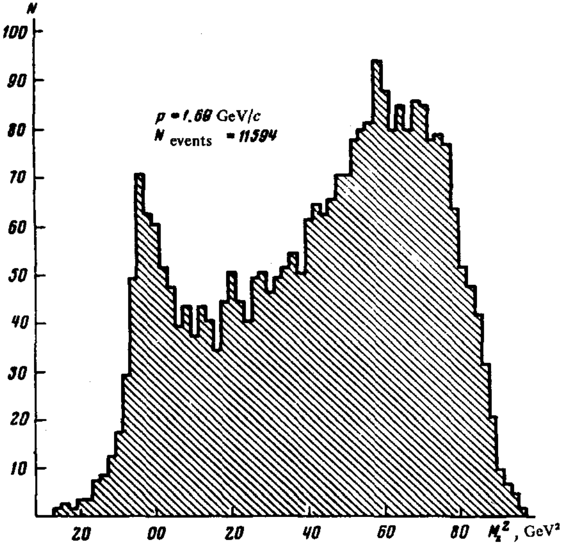

FIG. 1. Distribution with respect to M^2_{XN} in the reaction $\pi^- + d \to p + X^-$ at a π^--meson momentum 1.68 GeV/c.

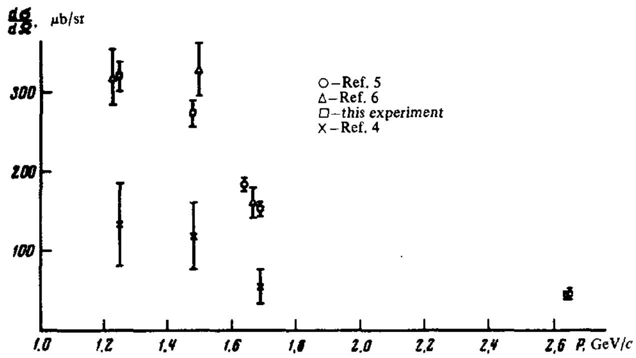

FIG. 3. Dependence of the differential cross section of elastic $\pi^- p$ backscattering, of the reaction $\pi^- + d \to p + \pi^- + n$ with large momentum transfer to the proton, and of the production of the isobar $\Delta(1236)$ backward in the reaction $\pi^- + d \to p + \Delta^-$, on the primary momentum.

tigated by us earlier[4] (diagram "b" of Fig. 2)

$$\pi^- + d \to p + \Delta^- \qquad (4)$$

and possibly some contribution from rescatterings of higher order. The spectra of the protons from the reactions (3) and (4) are concentrated in the form of peaks at $M^2_{XN} \sim 0$.[4] The contribution from reactions (3) and (4) in the region $M^2_{XN} \gtrsim 0.1$ GeV² is small. We thus arrive at the conclusion that the method chosen by us to describe the spectra gives the correct cross section of the process (2), accurate to rescatterings of higher order.

The obtained differential cross sections for the emission of a proton at a given angle in the reaction (2) are plotted in Fig. 3. The figure also shows values of the differential cross section for elastic $\pi^- p$ backscattering,[5,6] with allowance for the angle subtended by the spectrometer. At momenta 1.68 and 2.64 GeV/c, the angular aperture for the proton, in the c.m.s., lies in the range $1.0 \geqslant \cos\theta \geqslant 0.985$, while at 1.24 and 1.48 GeV/c we have $1.0 \geqslant \cos^*\theta \geqslant 0.93$. A comparison of the results shows that at each energy the differential cross sections for the emission of the proton in the process (2) and for the elastic $\pi^- p$ backscattering (from a free nucleon) are equal within the limits of statistical accuracy.

The result may seem paradoxical at first glance. Indeed, for the primary-energy interval investigated by

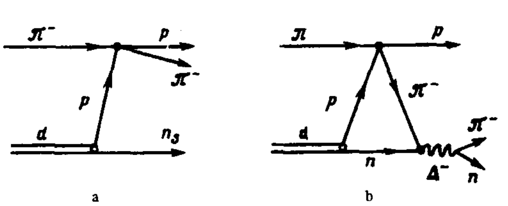

FIG. 2. Diagrams for the description of the reaction $\pi^- + d \to p + \pi^- + n$.

us, the momentum of the π^- meson in the final state in the reaction (3) is close to the resonant one, and the probability of the $\pi^- n$ rescattering is large. This was confirmed by us earlier[6] in measurements of the cross section of the reaction (4), which amounts to 0.3–0.4 of the cross section for elastic $\pi^- p$ backscattering. How is it that at such large a rescattering in the final state the cross sections of the reaction (2) and of the elastic $\pi^- p$ backscattering can be close to each other with an approximate accuracy 10%? A way out of this seeming contradiction is indicated in[8], in a theorem concerning the final-state interaction in the disintegration of the deuteron.

The gist of the statement made in[8] is the following: if particles that can experience only elastic rescattering are not detected (i.e., if integration takes place over all the possible states of these particles), then this rescattering cannot change the value of the cross section. As applied to reaction (2), this statement is formulated in the following manner (in the laboratory frame)

$$\int \frac{d^2\sigma_d}{dp\,d\Omega}\,dp = \frac{d\sigma_p}{d\Omega}, \qquad (5)$$

where the integration with respect to p is carried out within the limits of the quasielastic peak, and $d\sigma_p/d\Omega$ is the differential cross section of elastic $\pi^- p$ backscattering from a free proton. Formula (5) is the consequence of the unitarity condition for the amplitude of the $\pi^- n$ scattering, and generally speaking is valid in that range of $\pi^- n$-system masses where the inelastic $\pi^- n$ scattering cross section is small in comparison with the elastic cross section. Of course, it is necessary to include in the right-hand side of (5) the Glauber shadow corrections for the absorption of the initial pion and the final proton. However, the contribution of these corrections does not exceed 5–10%, which lies within the limits of the accuracy of the present experiment.

Thus, our result confirms formula (5). The importance of this result lies in the fact that it can be subsequently used to determine the cross sections for the interaction of elementary particles with a neutron in a number of other processes.

[1)]The reaction (3) was investigated at a negative-pion momentum 3.6 GeV/c in[7].

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