Final-state interaction due to deuteron breakup by π mesons

L. G. Dakhno, A. V. Kravtsov, M. M. Makarov, V. I. Medvedev, G. Z. Obrant, V. I. Poromov, V. V. Sarantsev, G. L. Sokolov, and S. G. Sherman
B. P. Konstantinov Insitute of Nuclear Physics, USSR Academy of Sciences

(Submitted 7 August 1979)
Pis'ma Zh. Eksp. Teor. Fiz. **30**, No. 7, 467–470 (5 October 1979)

A final-state interaction due to deuteron breakup was observed in the reaction $\pi^- d \to \pi^- pn$ at π^- meson momentum of 438 MeV/*c*. The differential cross section for the $\pi^- d \to \pi^- d^*$ process was measured.

PACS numbers: 13.75.Gx

The final-state interaction in the *pn* system (FSI) due to splitting of a deuteron by intermediate-energy hadrons was observed recently in the $pd \to ppn$ reaction at energies of 585 and 800 MeV.[1] A strong interaction between a neutron and proton at zero relative energy produces sharp peaks observed in the nucleon-momentum spectra at certain kinematics of a two-branch experiment. The main result of this work was the observation of the FSI effect. In addition, the dynamics of the FSI due to deuteron splitting by high-energy hadrons has remained unclear. In this work, the FSI effect was observed in the process $\pi^- d \to \pi^- pn$ at momentum of 438 MeV/*c* and the angular distribution of the π^- mesons accompanying the FSI was measured, i.e., the differential cross section of the $\pi^- d \to \pi^- d^*$ reaction in the laboratory system.

The experiment was performed using in the 35-cm bubble chamber filled with deuterium and exposed to a π-meson beam from the synchrocyclotron of the LIYaF of the USSR Academy of Sciences. The momentum spread in the π^- meson beam was 35 MeV/*c* (FWHM) and the lepton-component addition was $5 \pm 1\%$. In all, 120,000 stereophotographs were obtained, and after measurement and identification the total statistics for the $\pi^- d \to \pi^- pn$ reaction were 7197 events. A serious experimental limitation was the fact that protons with a pathlength of less than 1.5 mm in the chamber were not detected. The experimental technique was described in detail in Ref. 2.

Figure 1 shows the experimental distribution of the relative kinetic energy T_{pn} in the two-nucleon system. At small relative energies the spectrum exhibits a sharp peak; ~ 1300 events occur in the region of the peak ($T_{pn} < 6$ MeV). The inset in Fig. 1. shows the low-energy region. The distribution has a distinct maximum at ~ 1 MeV and decreases rather slowly with increasing energy. To understand whether or not this peak is the result of the basic physical mechanism for the deuteron breakup, namely the scattering of a π meson by individual nucleons, we compare the obtained data with the calculation in the plane-wave momentum approximation. In the calculation we used the amplitudes from the CERN phase analysis,[3] and the Hulthen wave function. In addition, we took into account in the calculation the experimental limitation for the slow protons. The results of the calculation are represented by a solid line in Fig. 1. We can conclude from a comparison of the experiment with the calculation that the sharp

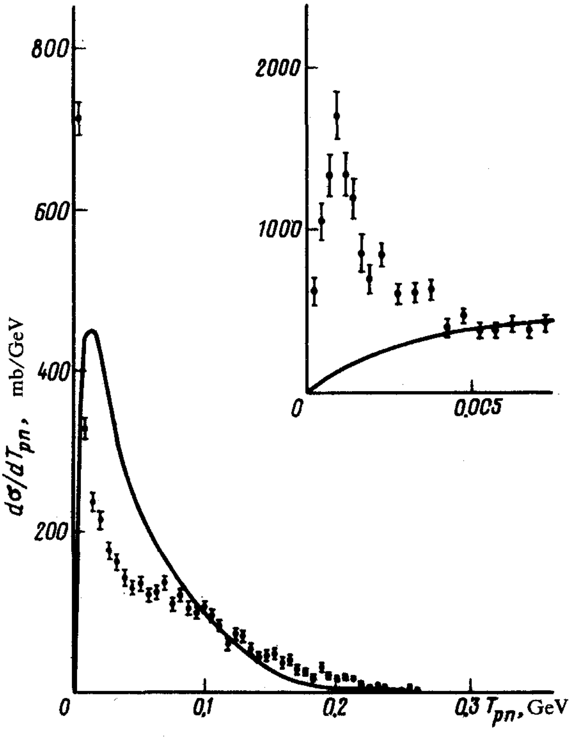

FIG. 1. Relative kinetic-energy distribution in the *pn* system. The inset illustrates separately the region of low energies. The curve represents the calculation in the plane-wave momentum approximation.

peak at $T_{pn} \sim 1$ MeV cannot be the result of the conventional mechanism for scattering of a π meson by a proton and a neutron but apparently indicates the existence of FSI. In addition, Fig. 1 shows that this calculation reproduces only qualitatively the situation in the region $T_{pn} > 6$ MeV. A large difference between the theoretical curve and the experiment could possibly indicate a strong destructive interference between the polar mechanism and the FSI. (At zero momentum transfer such interference occurs due to orthogonality of the states of the discrete and continuous spectra in the *pn* system).

In order to understand the dynamics of the FSI in the process $\pi^- d \rightarrow \pi^- d^*$, we shall examine the differential cross section for this process, i.e., the angular distribution of π^- mesons at small relative energies in the *pn* system ($T_{pn} < 6$ MeV). This distribution is shown in Fig. 2, along with the differential cross section for the elastic $\pi^- d$ scattering (dashed line), which was obtained for the same energy in Ref. 2. It can be seen that the FSI is dynamically analogous to the elastic πd scattering, although the slope of the differential cross section for the elastic scattering is somewhat larger. The rapid decrease of the differential cross section with increasing momentum transfer q can be qualitatively explained as follows. After the momentum is transferred to one of the nucleons of the deuteron, the relative momentum $\mathbf{p}$ between the nucleons in the intermediate state increases with increasing momentum transfer. The amplitude of the deuteron transition to the *pn* system with a small relative momentum $\mathbf{k}$ is

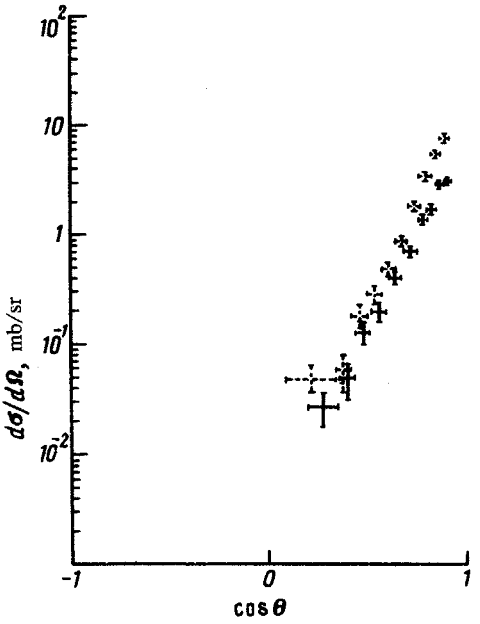

FIG. 2. Angular distribution of π^- mesons in the $\pi^- d \to \pi^- pn$ reaction at low relative energies in the pn system, and for the $\pi^- d \to \pi^- d$ reaction (shown by dashed line).

proportional to $\Psi_{\mathbf{k}}^{(-)}(\mathbf{p})$, the wave function in the pn system, which can be expressed in the following way in terms of the pn-scattering amplitude $t(\mathbf{k};\mathbf{p})$ outside the energy surface:

$$\Psi_{\mathbf{k}}^{(-)}(\mathbf{p}) = (2\pi)^3 \delta(\mathbf{p} - \mathbf{k}) + \frac{m t^*(\mathbf{k};\, \mathbf{p})}{p^2 - i0 - k^2},$$

where m is the nucleon mass. We can see that for small k a part of the wave function responsible for the FSI decreases sharply with increasing momentum p, which decreases the differential cross section with increasing q. The final explanation of the FSI mechanism can be given only after a theoretical analysis and comparison with the experimental data.

[1] R. D. Felder, *et al.*, Nucl. Phys. **A280**, 308 (1977).
[2] A. V. Kravtsov, *et al.*, Preprint LIYaF-426, Leningrad (1978).
[3] A. Donnachie, R. G. Kirsopp, and C. Lovelace, Phys. Lett. **26B**, 161 (1968).