

# Angular distributions of secondary pions in the reaction

$$\pi^- p \rightarrow \pi^- \pi^+ n$$

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Results are presented of the analysis of the angular distributions of the secondary pions in the reaction  $\pi^- p \rightarrow \pi^- \pi^+ n$ . The asymmetry of the angular distributions in the region of the  $\rho^0$  resonance is confirmed and the angular symmetry function  $R$  is calculated. Using the spin density matrix formalism, the experimental data are compared with the predictions of the one-pion exchange (OPE), one-pion exchange with form factor (OPEF), and the absorption (OPEA) models. Good agreement with experiment is obtained with the OPEA model.

This work was performed with the results of irradiating a 50-cm hydrogen bubble chamber (ZhVK-50) of the Institute of Theoretical and Experimental Physics (ITEP) by a beam of negative pions of momentum  $4.45 \pm 0.02$  GeV/c. The two-prong events were selected from the obtained stereo photographs. The selected events were measured with semiautomatic devices at the Kurchatov Institute of Atomic Energy (~65% of the events) and at the ITEP (~35% of the events). The ASP program<sup>[1]</sup> was used to reconstruct the geometry and to identify the events. The results for both parts of the statistics turned out to be identical. The procedure for the selection and identification of the two-pronged events is described in detail in<sup>[2]</sup>.

The reduction yielded 6263 events with two charged particles in the final state, pertaining to the channel

$$\pi^- + p \rightarrow \pi^- + \pi^+ + n. \quad (1)$$

The total cross section of this channel, with allowance for the corrections for the possible admixtures and missed counts turned out to be

$$\sigma_{\pi\pi n} = 2.60 \pm 0.20 \text{ mb}.$$

As shown by a number of studies, for example,<sup>[2,3,5-8]</sup> the reactions of the type  $\pi + N \rightarrow \pi + \pi + N$  proceed via a bound state with formation of a  $\rho$  resonance. Considerable interest attaches to the study of the angular characteristics of the production and decay of the  $\rho^0$

meson. Figure 1 shows the angular distribution of the secondary pions for the reaction  $\pi^- p \rightarrow \pi^- \pi^+ n$  in the Gottfried-Jackson system of coordinates for various intervals of  $\omega_{\pi\pi}$ . The angle  $\theta$  is the polar angle for the scattering of the  $\pi^-$  meson in the dipion system, and  $\omega_{\pi\pi}$  is the dipion mass. The entire analysis was carried out for  $|t| \leq 0.3$  (GeV/c)<sup>2</sup>, where  $t$  is the square of the four-momentum transfer. This separated the region where the one-pion interaction makes the decisive contribution. The solid curve in the figure is the result of approximating the experimental histograms by the function  $F = A + B \cos \theta + C \cos^2 \theta$ .

It is clearly seen from the figure that the angular distribution in the  $\rho^0$ -resonance region 750-850 MeV is strongly asymmetrical with the forward peak favored. The asymmetry in the  $\rho^0$ -meson decay is one of the interesting problems of the phase-shift analysis. It can be attributed to the interference of  $\delta_0^0$  and  $\delta_1^1$  ( $\delta_j^T$  is the phase shift, the superscript and the subscript label the isospin and angular momentum, respectively). The asymmetry is then evidence that the phase shift  $\delta_0^0$  goes through 90° in the region of the  $\rho^0$  meson. This can be accounted for by assuming the existence of a  $S_0$  meson with  $T=0$  and  $J=0$ , and with mass ~720 MeV. One cannot exclude, however, the possibility of interference of the  $\rho^0$  meson with a non-resonant background in a state  $T=0$  and  $J=0$ . Figure 3 shows the angular asymmetry function  $R = (F - B)/(F + B)$  as a function of  $\omega_{\pi\pi}$  ( $F$  and  $B$  are the number of events with  $\cos \theta > 0$  and

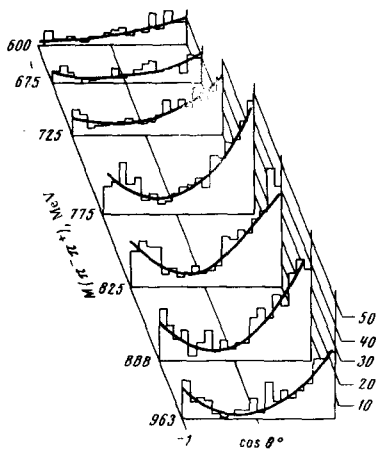


FIG. 1.

$\cos \theta < 0$ , respectively). For reaction (1),  $R$  has a maximum in the region of 600 MeV, and then falls off in the region of the  $\rho^0$  resonance, remaining at all times close to 0.4 and revealing no tendency to increase with increasing  $\omega_{\pi\pi}$ .

The dashed curve was calculated by Patil<sup>[4]</sup> assuming the existence of an  $S_0$  meson with mass 700 MeV. Our results do not seem to confirm this hypothesis. The solid curve is the average of the experimental data from a number of studies and is taken from<sup>[3]</sup>.

As is well known, at present there is no theoretical model describing the aggregate of the data on the inelastic processes. However, the one-pion exchange model (OPE), developed quite some time ago, provides a satisfactory description of certain characteristics of quasi-two-particle processes, which include the investigated reaction.

We have compared the experimental results with the predictions of the one-pion exchange model (OPE), of the Amaldi-Selleri one-pion exchange model with form factor (OPEF), and of the Jackson absorption model (OPEA). Figure 2 shows the theoretical predictions of these models with the experimental values of  $d\sigma/dt$ . The best agreement with experiment is given by the OPEA model.

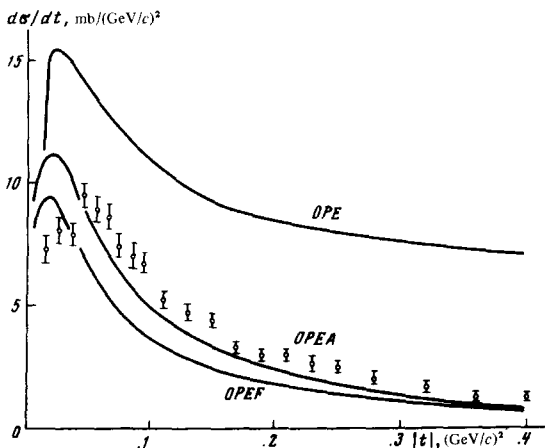


FIG. 2.

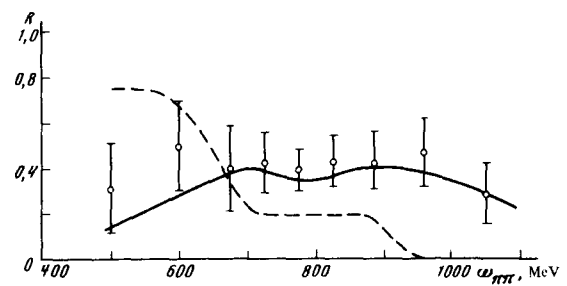


FIG. 3.

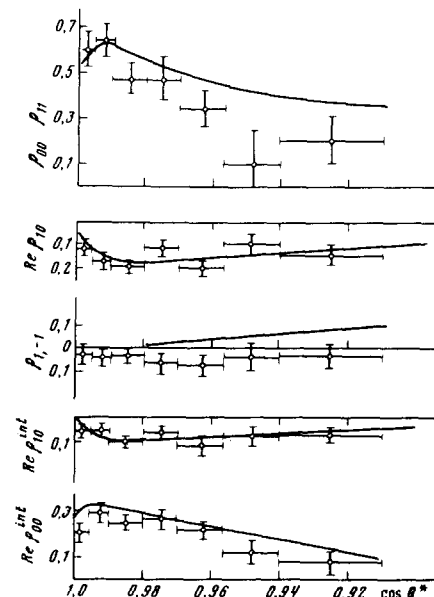
An investigation of the angular distribution of the secondary pions yields information on the  $\rho^0$ -meson production mechanism. To this end was used the spin density matrix formalism. For the reaction  $\pi^+p \rightarrow \pi^-\pi^+n$  in the region of the  $\rho^0$  meson, the density matrix can be written in the form<sup>[3]</sup>

$$\begin{bmatrix} \rho_{11} & \rho_{10} & \rho_{1,-1} & \rho_{10}^{int} \\ \rho_{10}^* & \rho_{00} & -\rho_{10}^* & \rho_{00}^{int} \\ \rho_{1,-1}^* & -\rho_{10} & \rho_{11} & -\rho_{10}^{int} \\ \rho_{10}^{int*} & \rho_{00}^{int*} & -\rho_{10}^{int*} & \rho^{T=0} \end{bmatrix}$$

where  $\rho_{ij}^{int}$  are elements of the S-P wave interference. The angular distribution of the decay products is described by the formula

$$\begin{aligned} W(\cos \theta, \phi) = & \frac{1}{4\pi} + \frac{3}{4\pi} \{ (\rho_{00} - \rho_{11})(\cos^2 \theta - 1/3) \\ & - 2\sqrt{2} \operatorname{Re} \rho_{10} \sin \theta \cos \phi - \rho_{1,-1} \sin^2 \theta \cos 2\phi \} \\ & + \frac{\sqrt{3}}{4\pi} \{ -2\sqrt{2} \operatorname{Re} \rho_{10}^{int} \sin \theta \cos \phi + 2 \operatorname{Re} \rho_{00}^{int} \cos \theta \}. \end{aligned}$$

To obtain the experimental values of  $\rho_{mj}$  as functions



or, more accurately, of  $\cos\theta^*$ , where  $\theta^*$  is the nucleon scattering angle in the c.m.s.), events with effective mass in the  $\rho^0$ -meson region were distributed over  $\cos\theta^*$  intervals, with approximately 200 events each. A three-dimensional angular distribution  $N_i = f(\cos\theta, \phi)$  was constructed for the selected events with respect to  $\cos\theta^*$  and with respect to  $\phi$ , and the function (3) was fitted to this distribution by least squares. The parameters obtained in this manner are shown in Fig. 4.

The OPE model predicts that the spin density matrix elements have the values  $\rho_{00} \approx 1$ ,  $\rho_{11} \approx \rho_{10} \approx \rho_{1,-1} \approx 0$  and  $\text{Re}\rho_{10}^{\text{int}} - \text{Re}\rho_{00}^{\text{int}} = 0$ , and are independent of  $\cos\theta^*$ . This prediction is not confirmed. Obviously, it is impossible to neglect the other mechanisms even for small  $|t|$  ( $\cos\theta^* \rightarrow 1$ ). The figure shows the theoretical OPEA-model curves taken from<sup>[5]</sup> at  $p_{\pi^-} = 4.16$  GeV/c. We see that the agreement of our experimental points with the theoretical curves is quite good. It should be noted, however, that while  $\rho_{1,-1}$  remains close to zero, it exhibits no tendency to increase with increasing  $|t|$  (with

decreasing  $\cos\theta^*$ ). The decrease of  $(\rho_{00} - \rho_{11})$  is faster than predicted by the theory.

It is possible that these discrepancies are due to the  $A_2$ -meson exchange mechanism, which should make a noticeable contribution at  $|t| \gtrsim 0.25$  (GeV/c)<sup>2</sup>.

In conclusion, we consider it our duty to thank I.I. Gurevich for a discussion of the results and to the group headed by Ya.M. Selektor for supplying the films and part of the statistical material.

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<sup>2</sup>A.A. Kartamyshev, K.N. Mukhin, *et al.* Preprint IAE, No. 2374 (1974).

<sup>3</sup>D. Miller, L. Gutay, *et al.*, Phys. Rev. 153, 1423 (1967).

<sup>4</sup>S. Patil, Phys. Rev. Lett. 13, 261 (1967).

<sup>5</sup>P. Johnson, L. Gutay, *et al.*, Phys. Rev. 163, 1497 (1967).

<sup>6</sup>S. Barish, W. Selove, *et al.*, Phys. Rev. 163, 1462 (1967); Phys. Rev. 184, 1375 (1969); Phys. Rev. D6, 1266 (1972).

<sup>7</sup>J. Bouches, L. Gutay, *et al.*, Nucl. Phys. B45, 205 (1972).

<sup>8</sup>B. Oh, A. Garfinkel, *et al.*, Phys. Rev. D1, 2494 (1970).