INVESTIGATION OF THE $\pi^- + p \rightarrow p + \pi^- + \pi^+ + \pi^-$ REACTION AT 2.8 BeV

V. K. GRIGOR'EV, A. P. GRISHIN, V. V. VLADIMIRSKIĬ, K. A. TROSTINA, I. A. EROFEEV, and G. D. TIKHOMIROV

Institute of Theoretical and Experimental Physics

Submitted to JETP editor January 29, 1964

J. Exptl. Theoret. Phys. (U.S.S.R.) **47**, 400-403 (August, 1964)

The mass distribution of the three mesons in the $\pi^- + p \rightarrow p + \pi^- + \pi^+ + \pi^-$ reaction is obtained. The irregularity of the distribution in the 0.9—1.0 BeV/c^2 range indicates the possibility of three-pion resonance with T = 1 or T = 2.

An investigation [1] of the reaction

$$\pi^- + p \rightarrow p + \pi^- + \pi^0 + \pi^0 \tag{1}$$

at 2.8 BeV/c primary pion momentum disclosed a maximum in the mass spectrum of the three-pion system near 1.00 BeV/c^2. This maximum can be interpreted as a manifestation of a new resonance with negative G-parity and isotopic spin 1 or 2. In this connection, it was deemed of interest to investigate, using the same material, the analogous reaction with charged pions in the final state:

$$\pi^- + p \rightarrow p + \pi^- + \pi^+ + \pi^-. \tag{2}$$

To this end, approximately 30,000 photographs were scanned, i.e., 70% of the material used in[1]. This material was obtained with a 17-liter bubble chamber without a magnetic field [2] in a beam of 2.8 (±4%) BeV/c pions from the accelerator of the Institute of Theoretical and Experimental Physics. The chamber was filled with a mixture of 42.7% propane and 57.3% xenon (by weight; mixture density 0.84 g/cm^3).

We selected for the analysis four-prong stars not accompanied by γ pairs, where the proton track with increased ionization had to terminate in the working medium of the chamber to permit determination of the proton momentum from its range. Some 550 such cases were selected. Measurement of the cases (i.e., determination of the length of the track with increased ionization and of the directions of all the tracks relative to the track of the primary pion) was carried out in part with a stereo projector (150 cases) and in part by a coordinate method, using the automatic measuring equipment of the Institute of Theoretical and Experimental Physics (400 cases), with subsequent mathematical reduction with the M-20 computer. The angles were determined accurate to 1°. The error in the determination of the track lengths was 1 mm, making it possible to determine a 300 MeV/c proton momentum accurate to 3 MeV/c.

To separate the events occurring on the free protons from the "nuclear" background, which predominates in this case, the kinematics of the events were reconstituted from the angle measurements. The measured directions of the three pions and the proton momentum were used to calculate the absolute values of the momenta p_1, p_2, and p_3 of all three pions. This was done by using the equation

$$\mathbf{p}_1 + \mathbf{p}_2 + \mathbf{p}_3 = \mathbf{p}_0 - \mathbf{p}_p. \tag{3}$$

Here $p_{1,2,3}$—pion momenta in the final state, p_0 and p_p—momenta of the primary pion and the proton. This was followed by determination of the sum

$$\Sigma = E_1 + E_2 + E_3 + T_p. \tag{4}$$

($E_{1,2,3}$—total pion energies calculated from their momenta $p_{1,2,3}$, and T_p—kinetic energy of the proton). The reaction (2) was identified by the value of Σ. If the reaction occurred on a proton and no unregistered particles were produced in addition ["pure" reaction (2)], then Σ is equal to the total energy of the primary pion E_0, i.e., 2.8 BeV in our case. The reliability of such an identification depends on the errors in the measurements of the directions of all the particles and on the accuracy with which the proton momentum is measured. In most cases the accuracy of this criterion is not worse than 20—30 MeV, although in individual unfavorable geometries the error can reach 100 MeV. The distribution of the four-prong stars with respect to the value of Σ in the 2.7—3.5 BeV interval is shown in Fig. 1. The absence of events with $\Sigma < 2.7$ BeV on the histo-

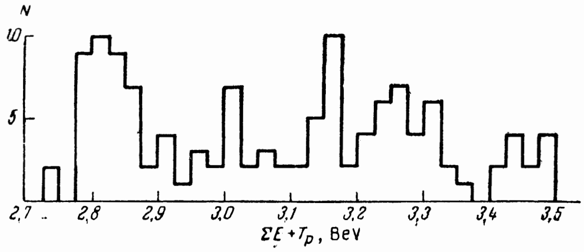

FIG. 1. Distribution of events relative to the value of Σ for those cases when $\Sigma \leq 3.5$ BeV.

gram corresponds to the fact that the momentum is carried away by the nucleus or by the unregistered particles, in the mean, into the forward hemisphere.

Out of the 550 events in the interval $2.75 < \Sigma < 2.9$ BeV, 38 were classified as "pure" and the mass spectrum of the three-pion system was constructed for them (Fig. 2) from the known values of the proton momentum and of the angle between the direction of its emission and the direction of the primary pion (in the laboratory frame). The inaccuracy in the determination of the mass did not exceed 25 MeV/c^2 at M = 1000 MeV/c^2.

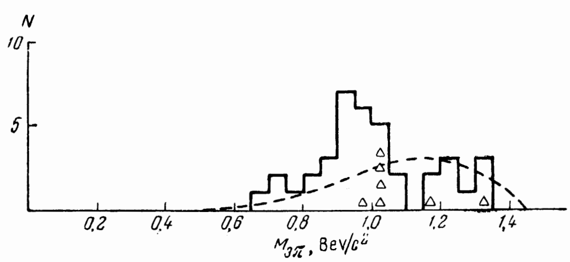

FIG. 2. Distribution of events relative to the 3π mass for the interval 2.75 BeV $< \Sigma <$ 2.90 BeV. The phase curve (dashed) is normalized to events with mass M < 900 and M > 1050. The triangles denote the events satisfying the hypothesis $\pi^- + p \rightarrow \Delta^0 + \rho^0 \rightarrow p + \pi^- + \pi^+ + \pi^-$.

Figure 2 shows also the curve of the phase volume of the reaction (2) for a momentum transfer 0.2—0.5 BeV/c to the proton (0.2 BeV/c—minimum proton momentum at which measurement of the direction of its emission is possible, 0.5 BeV/c—maximum momentum effectively registered in the chamber). A maximum, amounting (together with the background) to 22 events, is seen near 0.95 BeV/c^2. For comparison, Fig. 3 shows the $M_{3\pi}$ spectrum for all the events for which Σ exceeds 2.9 BeV. No maximum is seen on this histogram in the 0.95 BeV/c^2 region.

The maximum at 0.95 ± 0.02 BeV/c^2 on Fig. 2 can be naturally interpreted as a three-pion resonance with width $\Gamma \leq 70$ MeV/cm^2, and can

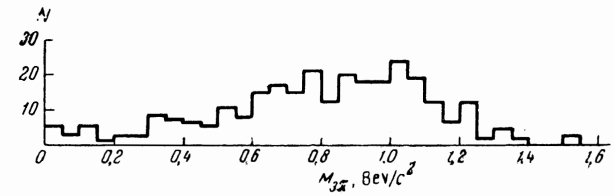

FIG. 3. Distribution of events relative to the 3π mass for $\Sigma >$ 2.90 BeV.

be assigned an isotopic spin T = 1 or T = 2. Such an interpretation is not perfectly unique, since reaction (2), like reaction (1), proceeds with a appreciable probability via formation of a ρ meson and an isobar $\Delta_{1/2,3/2}$:

$$\pi^- + p \rightarrow \Delta^+ + \rho^- \rightarrow p + \pi^0 + \pi^- + \pi^0, \qquad (1a)$$

$$\pi^- + p \rightarrow \Delta^0 + \rho^0 \rightarrow p + \pi^- + \pi^+ + \pi^-. \qquad (2a)$$

In this case the phase volume has an irregularity[1] precisely in the 1.0 BeV/c^2 region, so that some fraction of the events at the maximum of Fig. 2 may be connected with the reaction (2a). It is possible to compare the cross section of the reactions (1a) and (2a) by using isotopic relations. For the reaction with π^- mesons, two isotopic states of the total system, T = $^3\!/_2$ and T = $^1\!/_2$, are possible. If the interference of the amplitudes with the different isotopic states is not significant, then if reactions (2) and (1) proceed via a ρ meson and an isobar, the ratio of their cross sections lies in the range

$$R\left(\frac{3}{2}\right) = \frac{1}{16} < \frac{\sigma(2)}{\sigma(1)} < 1 = R\left(\frac{1}{2}\right). \qquad (5)$$

Here R($^3\!/_2$) and R($^1\!/_2$)—cross section ratios for the pure isospin states of the summary system. This ratio turns out to be equal to $^1\!/_4$ if the model of one-meson exchange (Fig. 4) is used to describe reactions (2) and (1) proceeding via a ρ meson and isobar. Thus, we should expect the irregularity of the phase value near the threshold for the production of $\Delta + \rho$, to be appreciably suppressed in reaction (2) compared with reaction (1).

In the case when the reactions (2) and (1) proceed via a three-pion resonance X^-, the cross section ratio depends on its isotopic spin. At $T_X = 1$ we have

$$1 < \sigma(2) / \sigma(1) < 4, \qquad (6)$$

and if the spatial spin is equal to zero, then $\sigma(2)/\sigma(1) = {}^4\!/_1$. For $T_X = 2$ we have

$$\sigma(2) / \sigma(1) = 1. \qquad (7)$$

The experimental cross-section ratio was

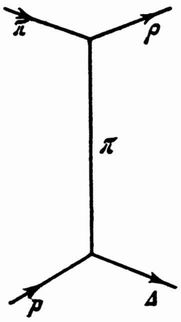

FIG. 4. Diagram for the production of an isobar and a ρ meson.

obtained by comparing the number of events above the normalized phase curve, obtained in our investigation, with the corresponding part of the statistics (70%) of [1], for the same momentum-transfer interval. After introducing corrections for the efficiency of γ-quantum registration in reaction (1) and for the possible loss of 20% of "pure" cases as a result of our selection (the latter figure was obtained by comparing the mass spectra for the interval $2.7 < \Sigma < 2.9$ BeV (Fig. 2) and the neighboring Σ intervals), it turns out that

$$\sigma(2) / \sigma(1) = 0.8 \pm 0.4. \quad (8)$$

This result is in better agreement with (6) or (7) than with the estimates presented for the reaction proceeding via ρ and Δ production. The insufficient statistical accuracy of (8) does not enable us to state with assurance that the three-pion resonance at $M_{3\pi} = 0.9-1.0$ BeV/c^2 exists, but it can be stated that new arguments have been obtained in favor of this hypothesis.1)

In conclusion, the authors are grateful to V. A. Shebanov, Yu. S. Krestnikov and V. V. Barmin for supplying the material, Yu. V. Trebukhovskiĭ for participating in the work during an earlier stage and for interesting discussion, to E. M. Landis, V. M. Polyakova, and V. N. Lyakhovitskiĭ for guidance of the mathematical processing of the measurement results, and to the accelerator and computer crews for cooperation.

1 Trebukhovsky, Yerofeyev, and Tikhomirov, Phys. Lett. 6, 190 (1963).

2 Blinov, Lomanov, Meshkovskiĭ, Shalamov, and Shebanov, PTÉ No. 1, 35 (1958).

3 L. Bondar et al, Nuovo cimento **31**, 485 (1964).

Translated by J. G. Adashko
59

1)Reaction (2) was recently investigated in[3]. The authors see no noticeable number of cases of simultaneous production of the isobar Δ^0 and the ρ^0 meson. In the reaction $\pi^- + p \to p + \pi^- + \pi^- + \pi^0 + \pi^+$, an irregularity is observed in the mass spectrum of three pions with charge -2 near 1000 MeV. If this result is confirmed, then the isospin of the resonance is equal to 2.