EVIDENCE FOR A THREE-PION RESONANCE NEAR 550 Mev*

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A study has been under way of multipion resonances in $\pi^+ + d$ reactions observed in the Lawrence Radiation Laboratory 72-in. bubble chamber exposed to a 1.23-Bev/c pion beam from the Bevatron. A preliminary report on this research was given at the Aix-en-Provence Conference on Elementary Particles[1] where the existence of the ω^0 meson reported by the Berkeley group[2] was confirmed. Since then these data have been substantially increased, although the experiment is still in progress. The existence of a second neutral 3-pion resonance with a mass of approximately 550 Mev is indicated by this larger sample of events.

Many authors[3] have speculated on the existence of neutral, strongly interacting bosons of mass of the order of 3-4m_π, in order to fit the data for nucleon form factors obtained from electron scattering experiments. These bosons could be readily identified experimentally in the reaction

$$\pi^+ + d \rightarrow p + p + X^0. \qquad (1)$$

In order to observe the possible decay mode,

$$X^0 \rightarrow \pi^+ + \pi^- + \pi^0, \qquad (2)$$

we consider the reaction

$$\pi^+ + d \rightarrow p + p + \pi^+ + \pi^- + \pi^0. \qquad (3)$$

Only events where both protons are visible and at least one proton stops in the chamber with a range less than 15 cm were accepted for analysis.[4]

The events were measured with a digitized microscope and reconstructed by the Berkeley PANG program. A kinematic fit[5] was obtained for the assumed π^0 using the KICK program, and the effective mass of the fitted 3-pion system was then calculated. In order to check the identification of the π^0, we have calculated the missing neutral mass for events which fit our criteria. An ideogram[6] for this missing neutral mass is given in Fig. 1 for the first 199 of our events.

Figure 2 is a histogram of the effective mass of the 3-pion system for our 233 events. An average mass uncertainty on a given event is ~±20 Mev. The large peak near 770 Mev is clearly identifiable as the ω^0. Another large peak in the 3-pion mass plot of Fig. 2 is seen near 550 Mev, which strongly suggests the existence of a second 3-pion resonance (or particle). We shall hereafter refer to this particle as η.

In order to estimate the number of events in this peak which are reasonably due to the η particle, we make the following interpretation of our data. We believe the impulse approximation is reasonably valid because of the loose structure of the deuteron. Thus the basic reaction we are looking at is

$$\pi^+ + n \rightarrow p + X^0, \qquad (4a)$$

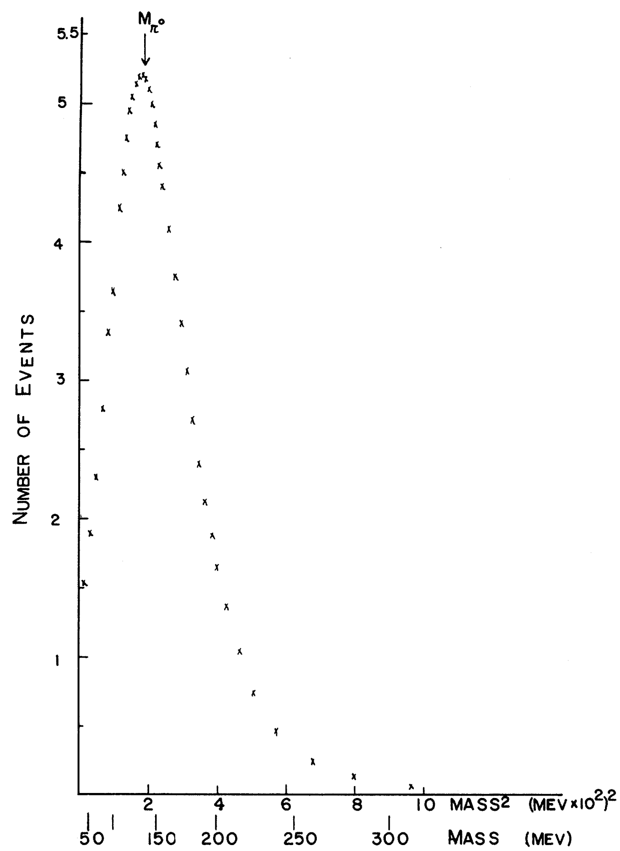

FIG. 1. Ideogram of the missing mass in the reaction ($\pi^+ + d \rightarrow p + p + \pi^+ + \pi^- +$ missing mass) for 199 events which meet the selection criteria.

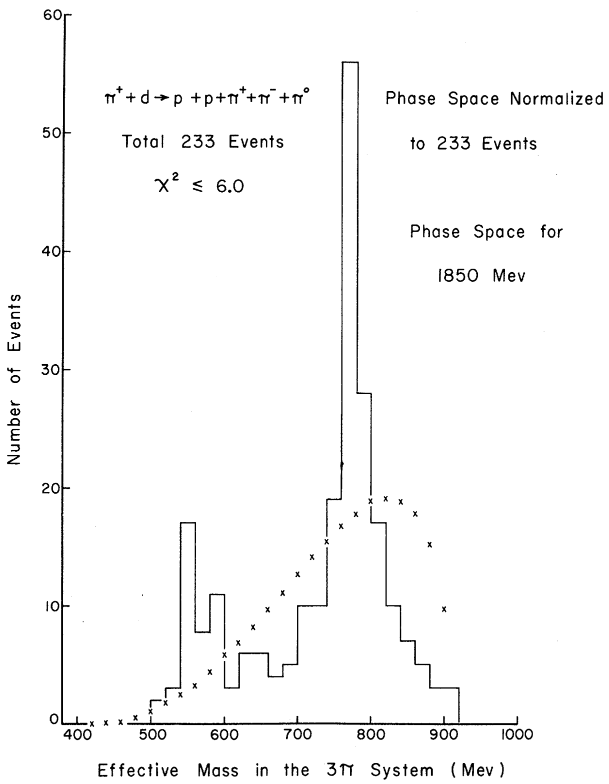

FIG. 2. Histogram of the effective mass of the three-pion system for 233 events.

where

$$X^0 \to \pi^+ + \pi^- + \pi^0. \qquad (4b)$$

We have calculated the Lorentz-invariant phase space[7] for the 3-pion mass from the background reaction to (4a), i.e.,

$$\pi^+ + n \to p + \pi^+ + \pi^- + \pi^0, \qquad (5)$$

using the experimental average of the total energy in the p-3π center-of-mass system (1850 Mev). This curve, normalized to the total number of events, is plotted in Fig. 2.

Clearly, because of the presence of the ω^0 particle at 770 Mev, such a normalization of phase space yields a gross overestimate of events expected near 550 Mev. Between 540 and 600 Mev there are 36 events in the experimental distribution, whereas the overestimated phase space would account for 12.

An analysis of the data, which takes into account the spread in errors on the individual events on the histogram, gives a mass of approximately 764 Mev with a half-width at half maximum of ≤ 20 Mev for the ω^0 and a mass of ~546 Mev with a half-width at half maximum of ≤ 25 Mev for the η.

An attempt is being made to determine the isotopic spin for both peaks by studing the reaction

$$\pi^+ + d \to p + \pi^+ + \pi^+ + \pi^- + n. \qquad (6)$$

Only 61 events were found in an analysis of one-half the film represented by Fig. 2. The low yield is probably indicative of the lack of any resonance in the isotopic spin states 1 and 2. This is in accord with the Berkeley assignment of $T=0$ to the ω^0.

A search for the $\pi^0 + \gamma$ decay mode of the ω^0 and η is being carried out by a study of events of the type

$$\pi^+ + d \to p + p + (\text{neutrals}). \qquad (7)$$

The results will be available shortly.

The proton form factor F_{1p} obtained from electron scattering experiments[8] cannot be fitted using only the ω^0 and ρ particles.[9] However, a three-pion resonance of mass $\leq 4m\pi$ having $T=0$ and spin 1^- would make a fit to the data possible.[10] With the film on hand we expect to more than double our statistics, so that a determination of the isotopic spin and spin of the η may be possible to see whether it fits these theories.

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[4]In a sample representing one-fourth of the film reported here, the requirement that one of the protons had to stop with a range ≤15 cm was removed. The results agree within statistics with those reported here.

[5]Events were accepted for analysis which fit the following criteria: (a) $\chi^2 \leq 6$ for the hypothesis $\pi^+ + d \rightarrow p + p + \pi^+ + \pi^- + \pi^0$. (b) $\chi^2 \geq 25$ for the hypothesis $\pi^+ + d \rightarrow p + p + \pi^+ + \pi^-$. (c) If the nonstopping proton had a momentum ≥700 Mev/c, where it becomes difficult to differentiate a proton from a π^+ by ionization in this chamber, then the χ^2 had to be greater than 15 for the hypothesis $\pi^+ + d \rightarrow p + n + \pi^+ + \pi^+ + \pi^-$, which is another background reaction under these circumstances.

[6]The ideogram was calculated in units of mass squared since our experimental errors are Gaussian in this representation. Each event was given a constant-area Gaussian distribution.

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EXPERIMENTAL STUDY OF THE K_{e3}^+ DECAY INTERACTION*

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Although the V-A theory has been used with considerable success to explain the observed features of the weak decays of nucleons, pions, and muons, only a few experimental tests have been made to determine if the same couplings apply to the leptonic decay modes of strange particles. Insofar as the two-body modes of K^+ mesons are concerned, the experimental upper limit to the K_{e2}^+ ($K^+ \rightarrow e^+ + \nu$) branching ratio (namely about 1%)[1] is certainly compatible with the value of 1.5×10^{-5} expected from the V-A coupling.[2] The interpretation of various features of the K_{e3}^+ ($K^+ \rightarrow e^+ + \pi^0 + \nu$) and $K_{\mu3}^+$ ($K^+ \rightarrow \mu^+ + \pi^0 + \nu$) decay modes in terms of possible couplings has been the object of considerable theoretical work. Pais and Treiman[3] have pointed out that the K_{e3}^+ mode leads to especially simple predictions and have obtained the following distribution functions of the pion momentum and pion-electron angular correlation:

For vector coupling,

$$F(P,\theta)dPd\cos\theta = \frac{P^4(W^2-P^2)^2 \sin^2\theta\, |f_v|^2}{E(W+P\cos\theta)^4} dPd\cos\theta; \qquad (1a)$$

for scalar coupling,

$$F(P,\theta)dPd\cos\theta = \frac{P^2(W^2-P^2)^2 |f_s|^2}{E(W+P\cos\theta)^2} dPd\cos\theta; \qquad (1b)$$

for tensor coupling,

$$F(P,\theta)dPd\cos\theta = \frac{P^4(W^2-P^2)^2(P+W\cos\theta)^2 |f_t|^2}{EM^2(W+P\cos\theta)^4} \times dPd\cos\theta, \qquad (1c)$$

where P and E are the pion momentum and total energy; M is the K-meson mass; $W = M - E$; θ is the angle between the pion and electron momenta; and the quantities f_v, f_s, and f_t are functions that depend only on the total pion energy, E. The lables vector, scalar, etc., are appropriate to a pseudoscalar K^+ meson and should be replaced by axial vector, pseudoscalar, etc., for a scalar K^+ meson, with no change in the functions (1). Thus the vector, axial-vector coupling leads to the distribution given in Eq. (1a), independently of the K-meson parity. It is clear that for any assumed form factors f_v, f_s, and f_t, the expressions (1) determine the energy spectra and angular correlations of any of the three secondaries