TWO-PION STRUCTURE WITHIN THE A MESON*

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In this Letter we present a study of the distributions of two-pion effective masses from the decay of the A^+ meson,[1] now resolved into two peaks,[2,3] A_1 and A_2. These distributions show evidence against the spin and parity assignments 1^- and 2^+ for the lower mass peak, A_1, and against 0^- and 1^+ ($l=2$) for the upper mass peak, A_2.

After analyzing about 5500 four-prong events produced by 3.5-BeV/c π^+ in the Brookhaven National Laboratory 20-inch hydrogen bubble chamber, we identified

$$1918 \text{ events as } \pi^+ + p \rightarrow \pi^+ + p + \pi^+ + \pi^-.$$

The details of the analyzing methods have been described elsewhere. The $M(\pi^+\pi^+\pi^-)$ enhancements of these events have been shown to be associated both with ρ^0 production and low momentum transfer, Δ^2, to the proton. The data of Fig. 1(c) in which the selection required at least one ρ and $\Delta^2 < 36\ \mu^2$, as well as no N^*, suggest two peaks in agreement with the previous work of references 2 and 3. The solid curve is the expected phase-space distribution for $\pi + p \rightarrow p + \pi + p$, averaged over the ρ mass, including the effect of the selection $\Delta^2 < 36\ \mu^2$. It has been normalized to the number of events above 1.53 GeV. We take the region 1040 MeV to 1210 MeV to represent the A_1 peak and 1210 MeV to 1380 MeV to represent the A_2 peak. Figure 1(a) is a Dalitz plot of those events in the A_1 peak (dropping the ρ requirement). Figure 1(b) is a similar Dalitz plot for the events in the A_2 peak. The events have been plotted twice, once above the diagonal and once below it. This has the advantage of presenting the ρ band as a straight line rather than having it make a 90° bend at the diagonal. Of course, the significance of the data must be judged on one-half of the plot only. The solid lines outline a band 0.2 GeV^2 wide and centered on the ρ.

The observed distribution of Fig. 1(c) is presumably a mixture coming from $\pi^+ + p \rightarrow A^+ + p$, $\pi^+ + p \rightarrow p + 3\pi$ phase space, and $\pi^+ + p \rightarrow p + \rho^0 + \pi^+$ without A^+ formation. The last process is neglected in the following, since we do not observe it outside the A^+ region. Boson symmetrization requirements modify the two-pion effective-mass spectrum from the decay of the A^+ meson depending on the spin and parity (J^P) of the A^+. These calculations have been made assuming that the A_1 or A_2 decays 100% of the time to $\rho^0 + \pi^+$.[4] The effects are displayed by a curve representing the profile of the Dalitz plot along the center of the ρ band. This profile has been calculated by taking the decay amplitude to be a sum of the two terms, $A^+ \rightarrow \rho^0 + \pi_1^+$ and $A^+ \rightarrow \rho^0 + \pi_2^+$. The resulting density distribution has been averaged over the A^+ mass region, corrected for the finite experimental resolution (estimated full-width−half-maximum = 25 MeV), and integrated over the 0.2-GeV^2 wide band in the Dalitz plot. Figures 2(a) and 2(b) show the density distribution of events along the bands of Figs. 1(a) and 1(b), respectively. Care has been taken to avoid duplication of points in the crossover region. These theoretical curves contain no background. Using the 3π effective-mass distribution for events with $\Delta^2 < 36\ \mu^2$ and no N^* we estimate the background under the A peaks to be $\gtrsim 25\%$. Table I shows the χ^2 probabilities obtained assuming no background and also assuming 25% 3π phase-space background. Figures 2(c) and 2(d) show the projections of the two Dalitz plots along with the theoretical curves for the more likely J^P choices.

The data of Chung et al.[2] require (because of their KK decay mode) 2^+ as the lowest assignment for the A_2, and favor 0^- for the A_1. We note that our data are consistent with these assignments, although for the A_1 the 1^+ ($l=0$), 2^- assignments with 70% probability are favored over the 0^- assignment (9%).

Aderholtz et al.[3] present evidence for $\eta\pi$ enhancements at ~1080 MeV and ~1300 MeV. If these enhancements are alternate decay modes of the A_1 and A_2 then they require $J^P = 1^-, 2^+, 3^-, \cdots$. We note that our data disagree rather strongly with the assignment 1^- or 2^+ for the A_1.

It has been pointed out[5] that the $\rho\pi$ enhancement at 1080 MeV may be the result of a Peierls singularity and, if so, would not have a definite angular momentum.[6] In that case, our analysis would not apply. More detailed calculations,[7] however, suggest that this singularity would, in fact, not be observable. Although these recent calculations make it difficult to associate the A_1 with the Peierls mechanism, the absence[8] of the $\rho^+\pi^0$ decay mode of the A_1, if substantiated, would mean the A_1 is not an "ordinary" reso-

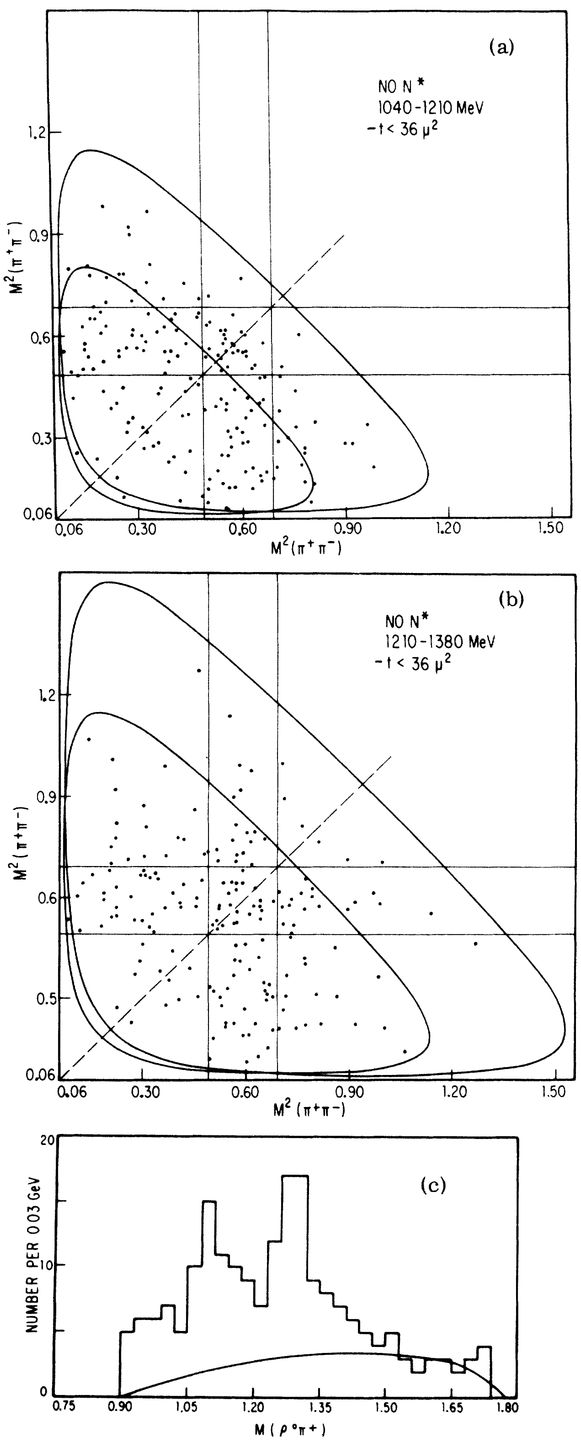

FIG. 1. (a) Dalitz plot of the three pions from the events with no $N^*(1120\text{-}1320)$, $-t(p,p) < 36\ \mu^2$, and $1040\ \text{MeV} < M(\pi^+\pi^+\pi^-) < 1210\ \text{MeV}$. (b) Similar to 1(a), but with $1210\ \text{MeV} < M(\pi^+\pi^+\pi^-) < 1380\ \text{MeV}$. (c) Effective-mass plot of those events with no $N^*(1120\text{-}1320)$, $-t(p,p) < 36\ \mu^2$ and a $\rho(\pi^+\pi^-)$ present.

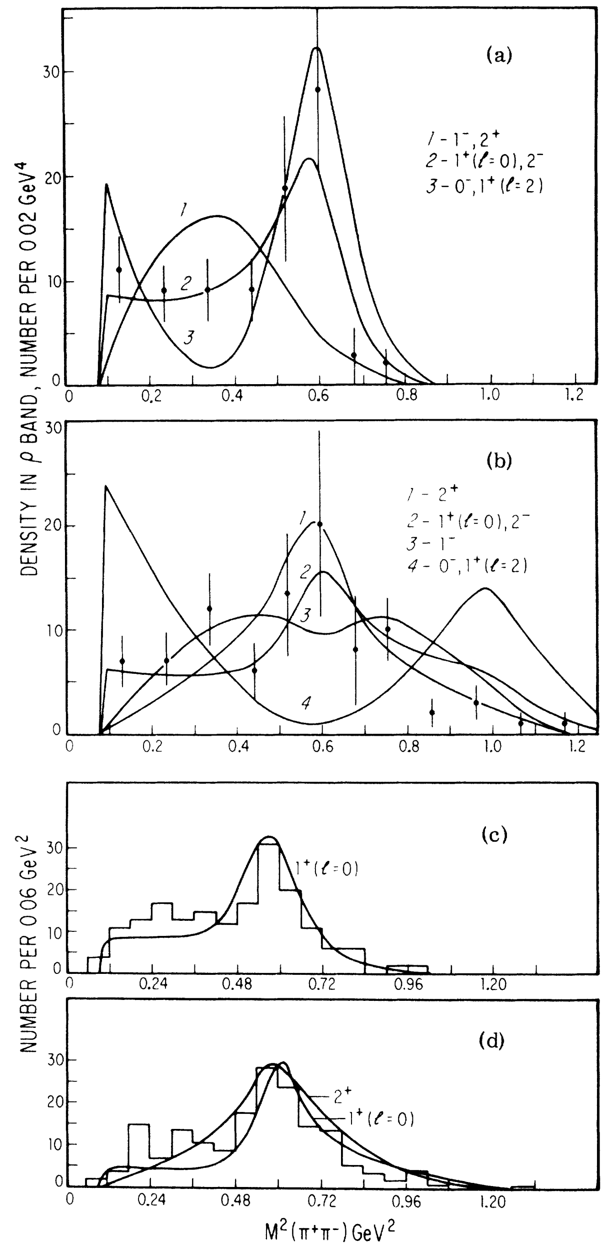

FIG. 2. (a) Distribution of the density of points on the Dalitz plots of Fig. 1(a) within a band centered on the ρ and 0.2 GeV^2 wide. The curves are theoretical expectations assuming $A \rightarrow \rho + \pi$ without background. (b) Similar to (a), but for the data of Fig. 1(b). (c) Projection of the Dalitz plot of Fig. 1(a). (d) Projection of the Dalitz plot of Fig. 1(b).

Table I. χ^2 probabilities for various J^P choices for A_1 and A_2 mesons, first assuming no background, and then with 25 % 3π phase-space background added.

	J^P	Percent 3π phase space 0	25
A_2^+	1^-	0.005	0.01
	2^+	0.008	0.10
	1^+ $(l=0)$, 2^-	0.07	0.10
	0^-, 1^+ $(l=2)$	<0.001	<0.001
A_1^+	1^-, 2^+	<0.001	<0.001
	1^+ $(l=0)$, 2^-	0.70	0.70
	0^-, 1^+ $(l=2)$	<0.001	0.09

nance. We cannot decide this question here, but merely remind the reader of its existence.

The Bronzan-Low A-parity[9] for $\rho\pi$ state is -1, while for a $K\bar{K}$ it is $+1$. Thus the $K\bar{K}$ mode reported for the A_2 meson would violate the conservation of A-parity in strong interactions. The ratio $(A_2^+ \rightarrow K^+ + K^0)/(A_2^+ \rightarrow \rho + \pi)$ is an indicator of this violation. The ratio predicted by phase space is about 1.0. Figure 3 shows the distribution in effective mass of the $K^+K_1^0$ pairs from the $\pi^+ + p \rightarrow p + K^+ + K_1^0$ events of this same experiment. We cannot say we observe the K^+K^0 peak at the region of the A_2, but we can set an upper limit of 15 μb. This value, combined with the lower limit of 100 μb for $A_2(\rho^0\pi^+)$ scaled by a factor of two to include the $\rho^+\pi^0$ mode, gives

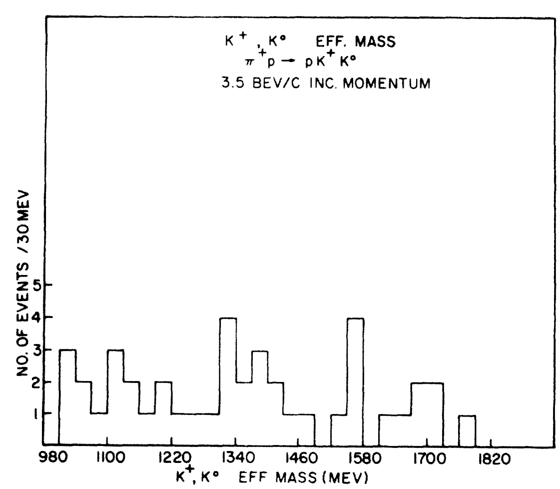

FIG. 3. Plot of the effective mass of the $K^+K_1^0$ pair from events of the type $\pi^+ + p \rightarrow K^+ + K_1^0 + p$.

an upper limit ~1/13 for the $(K^+\bar{K}^0/\rho\pi)$ branching.

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[5]M. Nauenberg and A. Pais, Phys. Rev. Letters 8, 82 (1962).

[6]R. J. Oakes, Phys. Rev. Letters 12, 134 (1964).

[7]C. Goebel, Phys. Rev. Letters 13, 143 (1964); G. Chew and F. Low, private communication.

[8]We have looked at the reaction $\pi^+ + p \rightarrow p + \pi^+ + \mathrm{MM}$ at 3.5 GeV/c, where MM means two or more π^0 mesons, and plotted the effective mass $M(\pi^+, \mathrm{MM})$ of the π^+ and the missing mass and observe the $A_2(1310)$, but not the $A_1(1090)$, in agreement with the prediction of the Peierls mechanism. On the other hand, our observations disagree with the predicted (R. J. Oakes and A. Pais, private communications) distribution in the π-ρ scattering angle for the A_1 events in this paper. See D. Carmony et al., Proceedings of the International Conference on High-Energy Accelerators, August 21-27, 1963, Dubna (Atomizdat, Moscow, 1964).

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