all particles that comprise the neutral $K\bar{K}\pi$ system are observed and measured. To check for systematic mass shifts, we examined the effective-mass ideogram for each momentum interval separately; within statistics no mass shifts were observed.

[3]Phenomenological matrix elements for three-particle systems are discussed systematically by C. Zemach, Phys. Rev. 133, B1202 (1964).

[4]Events in the peak are produced over a large range of momentum transfer to the neutron. Since the relative phase space available for low-mass $K\bar{K}\pi$ systems is reduced at higher incident π^- momentum, background is reduced by rejecting events with $p_\pi < 2.7$ BeV/c.

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[7]Since no effect was observed in the corresponding $K_1K_1\pi^0$ events, Armenteros et al.[1] have suggested that the $K^\pm K_1$ peak has $I^GJ^P = 1^+1^-$. In this case, the peak represents a resonant state with allowed decay into $\pi\pi$ and, consequently, production in π^-p interactions. Although an anomalously small coupling to the $\pi\pi$ system could account for the absence of this effect in π^-p interactions, interpretation as an $I=1$ S-wave enhancement appears consistent with the $\bar{p}p$ data. Since both the $I=0$ and $I=1$ $K\bar{K}$ combinations contribute to the $K_1K_1\pi^0$ events, the expected K_1K_1 enhancement may be reduced by a partial cancellation in the two strongly interacting S waves.

It is not possible to determine whether these S-wave interactions are strong enough to produce either an $I=0$ or $I=1$ bound state of the type discussed by R. Dalitz, Phys. Rev. Letters 6, 239 (1961).

[8]It is interesting to note that should the possible $I^GJ^P = 0^+1^+$ assignment be verified in subsequent experiments, a strong $I=1$ S-wave $K\bar{K}$ interaction together with the P-wave $K\pi$ interaction provides a possible dynamical basis for such a state. An $I=0$ $K\bar{K}\pi$ system requires $I=1$ for all $K\bar{K}$ pairs; the $J^P=1^+$ configuration permits the maximum interaction in the $K\pi$, $\bar{K}\pi$, and $K\bar{K}$ pairs simultaneously. If the strong $K\bar{K}$ interaction were in the 1^+1^- state (reference 7), this model would lead to a 0^+1^- $K\bar{K}\pi$ state in complete analogy with the ω meson. The observed decay correlations are in strong disagreement with this assumption.

[9]The possibility that the D meson is part of an SU(3) octet may be considered. The $A_1(1080)$ remains the only $I^G=1^-$ enhancement reported in this mass region. Although there is little direct evidence that this enhancement represents a meson state with definite J^P, use of the Gell-Mann–Okubo mass formula leads to the expectation of an $S=\pm1$ state at ~1230 MeV. Whether the $K\pi\pi$ enhancement in this mass region reported by Armenteros et al.[1] is to be identified with such a state remains to be determined.

INDICATION OF A 0^+, $T=0$ 2π RESONANCE AT 720 MeV*

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(Received 15 April 1965)

Recent theoretical work has resulted in important methods of grouping strongly interacting particle states according to various symmetry groups. It is a further problem to relate groups with different spin and parity numbers. In this connection, it is of considerable interest to identify meson states or multiplets with low values of spin, J. Although nine pseudoscalar mesons are known at present, no scalar mesons have yet been clearly identified.

A 0^+ meson state, if of zero strangeness and even G parity, should show itself as a resonance in $\pi\pi$ scattering. The single-pion-production process, using pions incident on nucleons, has been extensively studied as a means of obtaining information on $\pi\pi$ scattering and resonances.[1-5] In the study of the $\pi^-\pi^+$ system, through this reaction, a strong forward-backward (F-B) asymmetry has been found in the "$\pi\pi$ scattering angle" distribution, in the ρ mass region ($M_{\pi\pi}$ ~ 650 to 850 MeV).[6-9] At sufficiently high beam energies, this asymmetry is clearly not due to final-state π-nucleon isobar effects,[5,10] and it was suggested by Hagopian and Selove, and by Baton and Reignier,[11] that the asymmetry could be explained by a large phase shift in the $T=0$ s-wave $\pi\pi$ scattering, possibly a resonance, near the ρ.

Halpern et al. have recently observed a peak in the neutral meson mass spectrum at about 700 MeV, and have strong evidence that this peak occurs in the $2\pi^0$ system.[12] These results, and the recent calculations of Patil and of Durand and Chiu,[13] have stimulated us to examine the combined data from π^-p experiments at 2.75 and 3.0 GeV/c[14] carried out by the Pennsylvania[7] and S.O.B.B.[5] groups. We find an indication of a $T=0$ s-wave $\pi\pi$ resonance, at about 720 MeV, with width $\Gamma\sim 50$ MeV. The data on which this conclusion is based are reported here; our belief in the existence of this resonance comes from the fact that three independent sets of data are all consistent with this interpretation.[12,8,14]

The data for the reactions

$$\pi^- + p \to \pi^- + \pi^+ + n \tag{1}$$

and

$$\pi^- + p \to \pi^- + \pi^0 + p \tag{2}$$

are shown in Figs. 1 and 2, for the indicated values of $M_{\pi\pi}$, Δ^2, and $\cos\theta_{\pi\pi}$. (Δ is the four-momentum transfer to the nucleon, and $\theta_{\pi\pi}$, or θ, is the scattering angle in the $\pi\pi$ c.m. system.)

In Fig. 1(a), the mass spectrum is shown both for all $\cos\theta$, and separately (cross-hatched) for $\cos\theta$ near zero. In the region of small $|\cos\theta|$, the strong p wave—i.e., the ρ—should give relatively little intensity. If an even-l resonance is present in addition to the ρ, and if the even-l resonance energy is appreciably different from the ρ energy, then the small $|\cos\theta|$ selection should peak at a different mass.

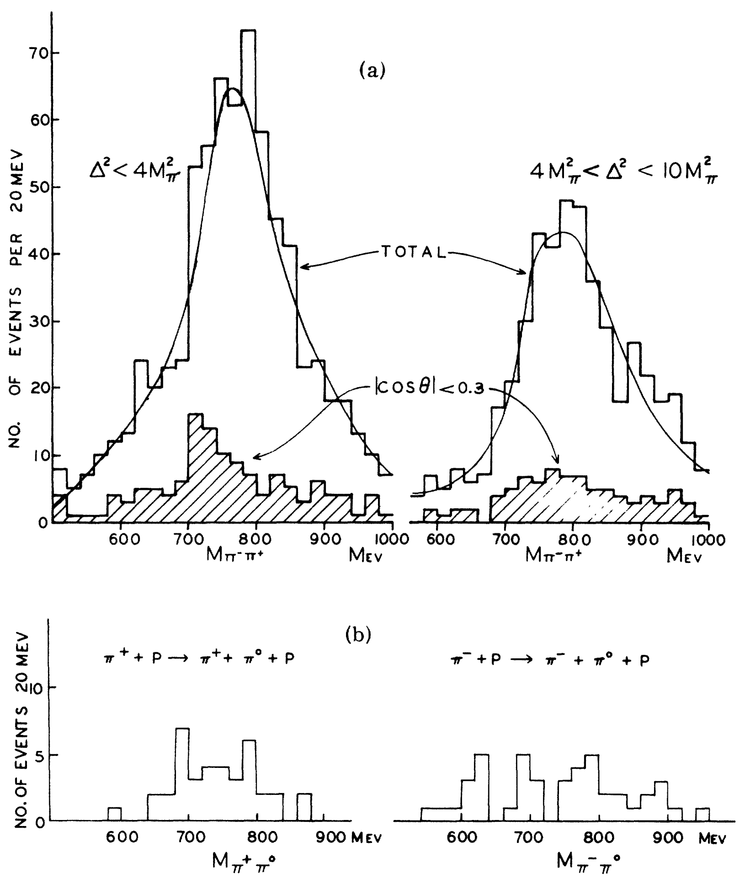
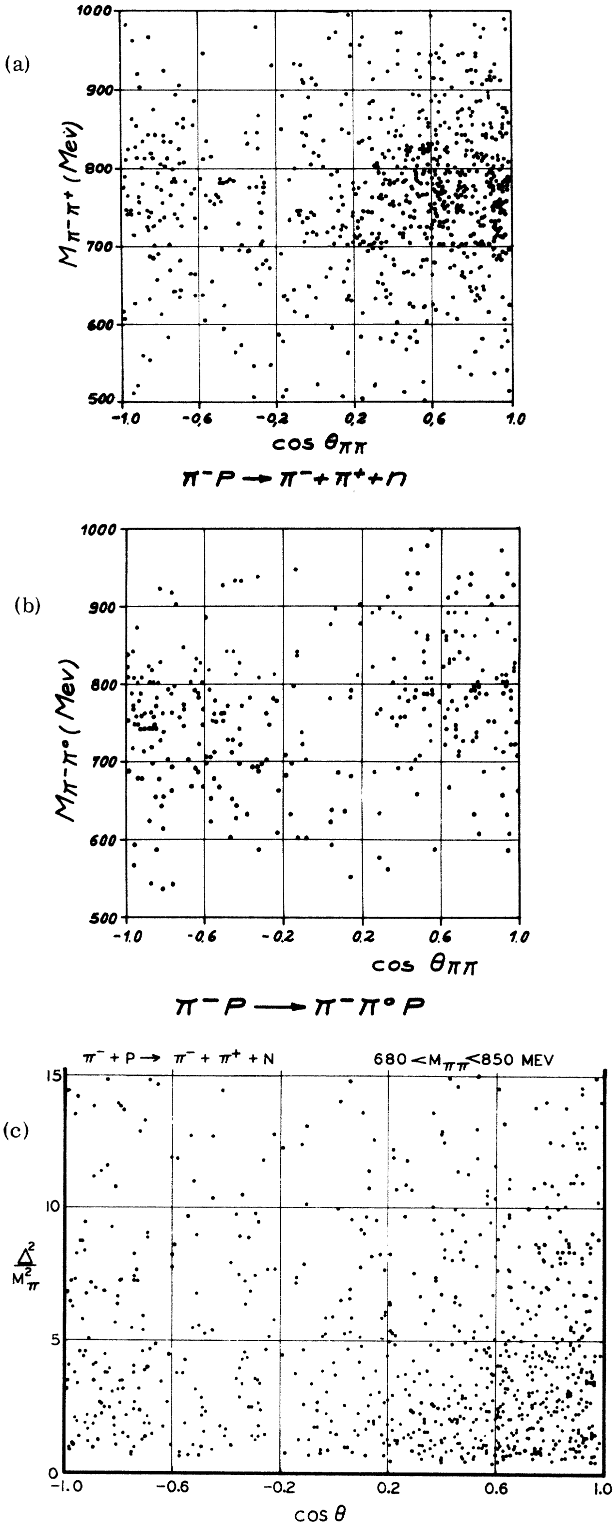


FIG. 1. (a) Mass histogram, $\pi^-\pi^+$ system. The curves are simply smooth curves drawn through the data. (b) Mass spectra for $\pi^+\pi^0$ (2.75-GeV/c $\pi^\pm p$ data, Orsay-Bari Collaboration, private communication) and $\pi^-\pi^0$,[14] for $\Delta^2 < 4M_\pi^2$ and $|\cos\theta| < 0.3$.

In Fig. 1(a), one sees that for low $|\cos\theta|$ and low Δ^2, there is a distinct peak in the $\pi\pi$ mass spectrum at about 720 MeV, at a position clearly different from that of the over-all "ρ^0" peak. (Even summed over all $\cos\theta$, the mass spectrum at low Δ^2 peaks at a mass significantly lower than for larger Δ^2. This effect has been observed previously.[15]) Moreover, it is seen in Fig. 2(a) that the F-B asymmetry shows a sudden variation at the same mass, 720 MeV.



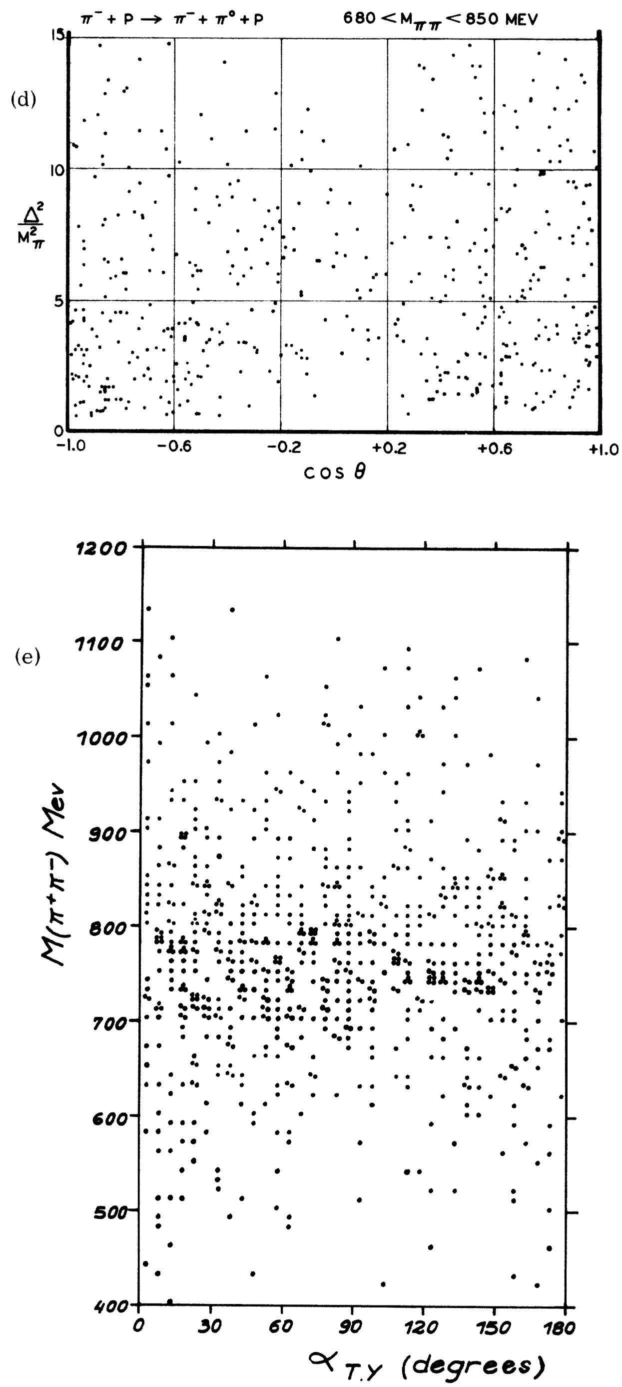


FIG. 2. (a) and (b) Scattergrams for $\Delta^2 < 4M_\pi^2$. (c) and (d) Scattergrams for $M_{\pi\pi} = 680$ to 850 MeV. (e) Scattergram, Treiman-Yang angle versus $M_{\pi\pi}$, for $\pi^-\pi^+$ system, $\Delta^2 < 4M_\pi^2$.

It is important to note that very good agreement with the F-B shift around 720 MeV is found in similar data previously reported at 1.59-GeV/c beam momentum.[16]

It should be noted that no peak at ~720 MeV is observed in the charge = 2 $\pi\pi$ state,[17] nor in the charge = 1 $\pi\pi$ state [see Fig. 1(b)]. Figure 2(b) shows the scatter plot of the $\pi^-\pi^0$ events with $\Delta^2 < 4M_\pi^2$ and shows no significant effect in the angular distribution at about 720 MeV.[18]

In terms of $\pi\pi$ scattering, this shift in the F-B asymmetry, together with the mass peak for events with small $|\cos\theta|$, is a strong indication of an even-l resonance; the asymmetry shift is due to interference with the large p-wave $\pi\pi$ phase shift already present at 720 MeV. (The F-B asymmetry shift tends to be masked by the strong increase in forward $\pi\pi$ scattering as $M_{\pi\pi}$ increases toward the ρ peak. The F-B asymmetry shift is very much clearer if one uses only events with $-1.0 < \cos\theta < 0.3$ to 0.5, for example.)

We next comment briefly on why we believe the data can be interpreted in terms of $\pi\pi$ scattering. (For a fuller discussion, see reference 14.) Gottfried and Jackson[19] and Durand and Chiu[13] have recently calculated the angular distribution of "ρ decays"—i.e., the angular distribution of what we call "$\pi\pi$ scattering" at the ρ—using a one-pion-exchange (OPE) model with absorption effects included (OPEA). Their calculations agree well with all major features of ρ^- production and decay, both in our data and in other similar data. It is this result which gives us confidence in the OPEA model.

The calculation of Durand and Chiu also includes the effect of an s-wave resonance. They find that the OPEA model predicts results which again, as for the p wave, correspond roughly to the results expected on a $\pi\pi$ scattering model. The absorptive damping of the s-wave resonance and the p-wave resonance are found to be comparable.[20]

It is one feature of the OPEA model that the ρ, although of angular momentum $l = 1$, gives a decay distribution which is not pure $\cos^2\theta$, but which also includes a $\sin^2\theta$ term. The relative magnitude of the $\sin^2\theta$ term should decrease as Δ^2 decreases. Figure 2(d) shows that for $\pi^-\pi^0$ events in the ρ mass region, the $\sin^2\theta$ term does in fact become smaller as Δ^2 decreases; Fig. 2(c) shows that this is not the case for $\pi^-\pi^+$ events. This difference is in good agreement with the interpretation that a strong even-l ($T = 0$) $\pi\pi$ interaction is present.

We have considered whether these data are clearly consistent with an s-wave resonance, or with a d-wave resonance. The d-wave interpretation is completely inconsistent with the data, as we shall explain. First, we note that the widths of the mass peak and of the backward cancellation [see Fig. 2(b)] at ~720 MeV are greater than our resolution. Consequently, we expect the over-all mass histogram (Fig. 1, all $\cos\theta$) to show the true height of the 720-MeV peak. If the resonance were d wave, then the height of the 720-MeV peak in $\Delta N/\Delta M_{\pi\pi}$ (Fig. 1) would be about $\frac{3}{4}$ the height of the $l = 1$ ρ peak.[21] (A factor of 5/3 enters from the spin factor $2l + 1$, and a factor of 4/9 enters from isotopic-spin Clebsch-Gordan coefficients.) The over-all $\pi^-\pi^+$ mass spectrum is completely inconsistent with such a peak. On the other hand, an s-wave resonance would be expected to have a peak height only about 1/7 that of the ρ, and this is consistent with the mass spectra of Fig. 1.

We note that, again on the conclusion that the width of the 720-MeV peak is greater than our resolution, the angular distribution ($\Delta N/\Delta\cos\theta$, see Fig. 2) also rules out a d-wave interpretation.[7,11]

It should be mentioned that Keefe et al. have noted an apparent distinct bump at about 720 MeV, in the over-all $\pi^-\pi^+$ mass spectrum, for small Δ^2, in a spark-chamber study of Reaction (1).[22]

Next we remark on the value of the s-wave "resonance energy," E_γ, which we take for present purposes as the energy at which the s-wave phase shift equals 90°. This energy can, in principle, be determined from our data, from the combined behavior of the mass distribution and the (forward-backward) angular distribution. These data give a resonance energy near 720 MeV. The data are too meager to make a precise analysis, and there is also some uncertainty in the exact nature of interference effects which may be influencing the mass spectrum near $\cos\theta = 0$. For these reasons we cannot give very precise values for the resonance energy, E_γ, or for the width Γ. As preliminary values, we quote 720 MeV for E_γ, and 50 MeV for Γ.

Finally, we note that a sudden change is apparent in the Treiman-Yang[23] versus $M_{\pi\pi}$ plot at ~720 MeV in the $\pi^-\pi^+$ system [Fig. 2(e)].

This change occurs just at the position of the 720-MeV mass peak and F-B anomaly, and is presumably associated with the 720-MeV resonance. We have no explanation for this effect. We have checked that the effect, and in fact the entire 720-MeV resonance effect, is not associated with any π-nucleon isobar effect.

We express our strong appreciation to Professor J. Halpern for information on his results, to Professor A. Berthelot, Professor L. Durand, Professor K. Gottfried, Professor J. D. Jackson, and Professor J. Reignier for very useful comments, and to Mr. R. Van Berg for assistance in the analysis of the data.

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*Work supported in part by the U. S. Atomic Energy Commission.

†On leave of absence from Istituto di Fisica dell'Università, Bari, Italy.

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[16]Reference 8—see particularly p. 536.

[17]S.O.B.B. Collaboration, Nuovo Cimento 35, 1 (1965); C. Ouannes, thesis, Orsay, 1964 (unpublished); Aachen-Berlin-Birmingham-Bonn-Hamburg-London-Munchen Collaboration, M. Aderholz et al., to be published.

[18]The events occurring at small $|\cos\theta|$ will include a contribution from ρ mesons with such polarization as to produce a $\sin^2\theta$ instead of $\cos^2\theta$ distribution—i.e., from nucleon spin-flip effects. Such spin-flip effects can arise either from absorption or from non-one-pion exchange. However, we can see no simple way in which such processes could give the shifted mass peak and the forward-backward asymmetry change, which occur in the $\pi^-\pi^+$ data but not in the $\pi^-\pi^0$ data.

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[21]This assumes two things: (1) that $\pi\pi$ scattering at this mass region is purely elastic (as is indicated by all existing data); and (2) that absorptive damping effects for a d-wave resonance, as well as for an s-wave resonance, would be similar in magnitude to those for the p wave.

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