PRODUCTION AND ASYMMETRIC DECAY OF THE ρ^0 AND ITS RELATION TO THE PROPOSED ϵ^0 SCALAR MESON*†

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(Received 6 May 1965)

We have studied 550 events of the type

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

at 4-GeV/c incident pion momentum in the 80-cm Saclay hydrogen bubble chamber.[1] The results of the analysis are in very good agreement with a model of Durand and Chiu[2] which incorporates a $T=0$ scalar di-pion ϵ^0, $M_\epsilon = 0.73$ GeV. Direct evidence for the existence of such a meson has been recently reported by the Pennsylvania group.[3]

In the original experiment, 3828 two-prong events were measured. A total of 550 events were identified as being of type (1) and 390 events of type

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

The cross section for Reaction (1) is (3.16 ± 0.13) mb, and for (2) is (2.21 ± 0.10) mb.[1]

For the type-(1) events we fitted the di-pion effective-mass distribution with noninterfering Breit-Wigner amplitudes for the ρ^0 and f^0 plus a background arbitrarily calculated from phase space. Figure 1(a) shows the experimental data together with the fit. The parameters of the best fit are $M_\rho = 0.763$ GeV, $\Gamma_\rho = 0.15$ GeV, $\sigma_\rho = 1.1$ mb, $M_f = 1.270$ GeV, $\Gamma_f = 0.15$ GeV, $\sigma_f = 0.5$ mb, $\sigma(\text{background}) = 1.56$ mb.

Two features of ρ^0 production,

$$\pi^- + p \rightarrow \rho^0 + n, \qquad (3)$$

have been observed by many authors: (a) production cross section peaked at small angles, i.e., peripheral production, and (b) a large forward-backward asymmetry in the ρ^0 decay, e.g., $(F-B)/(F+B) = 0.28 \pm 0.09$ in this experiment. The latter feature does not seem to characterize the decay of the charged ρ.[4] Several models have been proposed to explain these facts. Here we wish to compare our results with the model of Durand and Chiu.[2] The essential features of this model are (a) the introduction of a $T=0$ scalar di-pion ϵ^0, (b) one-pion-exchange mechanism with no form factors, and (c) the inclusion of absorption effects in the initial and final states.

A sample of 131 events from Reaction (1) was selected with di-pion mass in the interval $0.60 \leq M \leq 0.90$ GeV and with the cosine of the production angle in the over-all rest frame in the interval $0.90 \leq \cos\Theta \leq 1.00$. At our energy this range of production angles corresponds to t

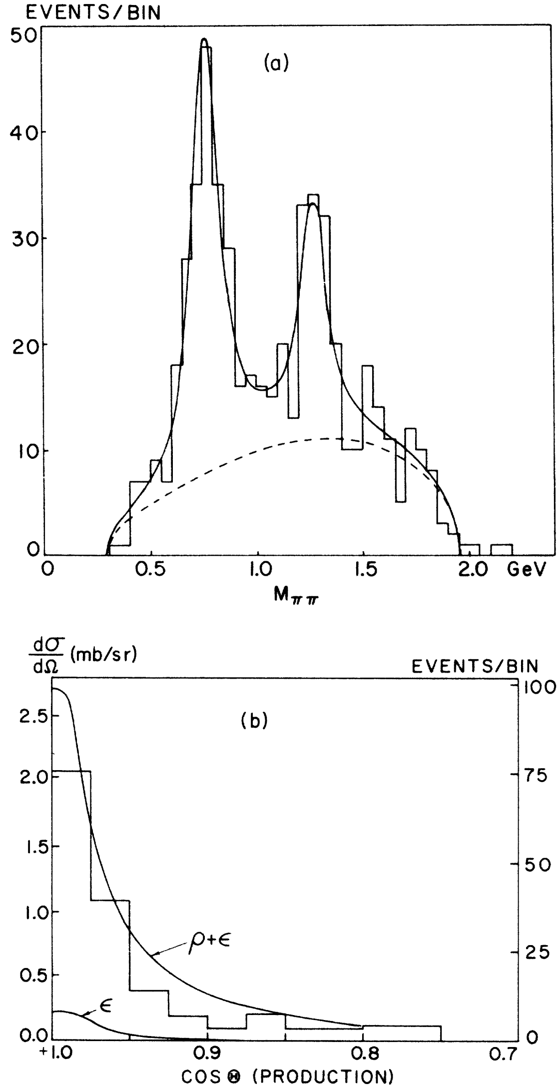

FIG. 1. (a) Effective mass distribution of $\pi^+\pi^-$ from the reaction $\pi^- + p \rightarrow \pi^+ + \pi^- + n$ at 4 GeV/c. (b) Differential cross section for production of the ρ^0 in the same reaction.

less than about $15m_\pi^2$.

Figure 1(b) shows the experimental ρ^0 production angular distribution. The integrated value of this cross section was normalized to 80% of the total ρ^0 production cross section to correct for our "slice" of the ρ^0 mass. We assume that the presence of the background does not appreciably change the shape of the distribution. The upper solid line is the prediction of the model for the same mass slice for $\rho^0+\epsilon^0$ production. The lower line is the ϵ^0 contribution, which is less than 10% of the total. The predictions of the model are absolute, with no free parameters. The constants used in the calculations are $G_{\pi\pi\rho}{}^2/4\pi=2.1$, $G_{\pi\pi\epsilon}{}^2/4\pi=0.356$, $G_{\pi NN}{}^2/4\pi=14.0$, $M_\epsilon=0.73$ GeV, $\Gamma_\epsilon=0.09$ GeV, $M_\rho=0.76$ GeV, and $\Gamma_\rho=0.12$ GeV.

The ρ^0 decay angular distributions have been fitted to an equation of the form

$$dN(\theta,\varphi)/d\Omega=\{\langle a_1a_1\rangle+(\langle a_0a_0\rangle-\langle a_1a_1\rangle)\cos^2\theta-2\sqrt{2}\langle a_1a_0\rangle\sin\theta\cos\theta\cos\varphi-\langle a_1a_{-1}\rangle\sin^2\theta\cos2\varphi\}3/4\pi$$
$$+\{-2\sqrt{2}\langle a_1b_0\rangle\sin\theta\cos\varphi+2\langle a_0b_0\rangle\cos\theta\}\sqrt{3}/4\pi+\langle b_0b_0\rangle/4\pi.$$

The $\langle a_ia_j\rangle$, $\langle a_ib_j\rangle$, and $\langle b_0b_0\rangle$ are the spin-density matrix elements, with trace equal to 1.0. The absolute values of these matrix elements averaged over the "mass slice" and "production-angle slice" of the experiment are predicted by the model. The above expression was used to construct a likelihood function for fitting the data. In fitting the matrix elements the over-all normalization is set equal to 1, which reduces the free parameters by one. Also there exists an ambiguity in this expression in that there are two isotropic terms. The value of $\langle b_0b_0\rangle$ was therefore constrained to be 0.072. Table I shows the calculated value of the matrix elements compared with the fitted values. The errors are only those due to statistics and correspond to one standard deviation.

Table I. Spin-density matrix elements for the decay of the ρ^0.

Matrix elements	Theoretical predictions	Experimental fits
$\langle a_1a_1\rangle$	0.139	0.202 ± 0.084
$\langle a_1a_0\rangle$	-0.151	-0.166 ± 0.043
$\langle a_1a_{-1}\rangle$	0.033	-0.034 ± 0.049
$\langle a_0a_0\rangle$	0.650	0.524 ± 0.084
$\langle a_1b_0\rangle$	-0.046	-0.052 ± 0.026
$\langle a_0b_0\rangle$	0.191	0.184 ± 0.043
$\langle b_0b_0\rangle$	0.072	0.072

Figure 2 is the scatter plot of our 131 events; $\cos\theta$ is the angle between the incident π^- and decay π^- in the di-pion center of mass, and φ is the Treiman-Yang angle. The solid lines represent contours of constant probability as predicted by the model. The projection of the data on the φ axis is shown above the scatter plot; the projection of the data on the $\cos\theta$ axis is shown to the right. The solid lines in the two projections are a maximum-likelihood fit with the expression (4). Table II shows a comparison of the experimental data with the predictions of the model. Theoretical values are calculated by integrating the probability over the various regions indicated in Fig. 2. A correction is applied assuming that the 33% background in the ρ region is isotropic,[5] and the results are compared with experiment.

In view of the large number of parameters and the limited statistics of the data, we fitted the ρ^- data at the same energy with the same likelihood function in order to see the signifi-

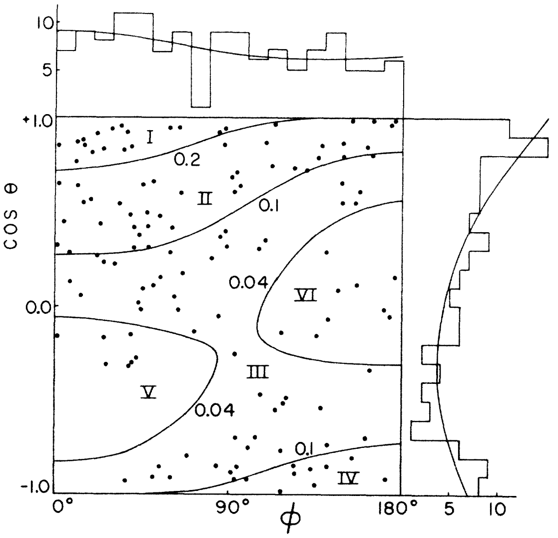

FIG. 2. Scatter plot for the decay angles in the center of mass of the ρ^0. The angle φ is the Treiman-Yang angle, and $\cos\theta$ is the cosine of the angle between incident and decay π^- in the di-pion rest system.

Table II. Comparison of the numbers of events observed and predicted for the regions on the contour plot of Fig. 2.

Region	Theory	Theory with background correction	Experiment
I	17.9	14.2	17
II	45.8	38.3	39
III	46.3	50.1	50
IV	9.2	8.4	9
V	5.9	10.0	7
VI	5.9	10.0	9

cance of the interference terms $\langle a_1b_0\rangle$ and $\langle a_0b_0\rangle$. We find that in the ρ^- data the fitted values of these two terms are both consistent with zero (21% confidence level). In the ρ^0 fit, they are inconsistent with zero (99.9% confidence level), and in full agreement with the predictions of the model.

Finally, we looked at events of the type

$$\pi^- + p \to p + \pi^- + n\pi^0 \tag{4}$$

where $n \geqslant 2$. There is no significant peaking in the missing-mass distribution at the mass of the ϵ^0. Because of the obvious difficulties with missing-mass distributions, and the fact that even the neutral decay of the f^0 is not seen in these data, it is not surprising that we do not see the ϵ^0 in the type-(4) events.

While an analysis such as this does not, in itself, prove or disprove the existence of a neutral scalar di-pion, it does demonstrate that the observed ρ^0 decay asymmetry can be explained in terms of such a particle.

We wish to thank our colleagues in the Aachen-Birmingham-Bonn-Hamburg-London (I.C.)-Munich collaboration for their cooperation in assembling the data on which this analysis is based. We are indebted to L. Durand, III, Y. T. Chiu, and F. A. Selleri for illuminating discussions on the subject, and to J. B. Annable and J. W. Andrews for valuable assistance.

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*Research supported in part by the National Science Foundation.

†Accepted without review under policy announced in Editorial of 20 July 1964 [Phys. Rev. Letters 13, 79 (1964)].

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[3] J. Halpern and M. Nussbaum, private communication.

[4] I. Derado, V. P. Kenney, and W. D. Shephard, Phys. Rev. Letters 13, 505 (1964).

[5] Of the selected 131 events, those with $M_{\pi n}$ in the isobar region show no asymmetry in φ. There is, in fact, no evidence for production of the $N_{33}{}^*$ isobar in the events of Reaction (1).

MESON COUPLING IN A RELATIVISTIC SU(6) SCHEME*

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(Received 16 April 1965)

Several phenomenological approaches to a relativistic SU(6) theory have recently been proposed.[1] The particular scheme used here is that of Sakita and Wali[2] (SW), in which the basic fields are tensors of $M(12)$, the interactions being invariant under transformations of $M(12)$ and space reflections, while the equations of motion for the fields are not covariant under $SL(6,c)$. This note will consider some consequences of trilinear and quadrilinear meson couplings[3] incorporating the spin-dependent and SU(3) spin-dependent mass splittings. The decays considered are $K^* \to K+\pi+\pi$ and $\omega \to 3\pi$ using both trilinear and quadrilinear interactions with mass breaking. The decay $X^0 \to \eta + \pi + \pi$ is also calculated using a quadrilinear interaction Lagrangian.

The second-rank mixed spinor $\Phi_A{}^B \equiv \Phi_{j\beta}{}^{j\alpha}$, with $i,j=1$ to 4 and $\alpha,\beta=1$ to 3 represents the meson field and transforms like the product of the fundamental quark fields Q and $\overline{Q}$. This 144-component field satisfies the Duffin-Kemmer[4] equation

$$\tfrac{1}{2}[\gamma_\mu, \partial_\mu \Phi] + m\Phi = 0, \tag{1}$$