# EVIDENCE FOR THE EXISTENCE OF AN $I=0$ MESON STATE OF 1610-MeV MASS*

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An $I=0$ meson state at 1610 MeV has been observed in an examination of 20 000 pictures taken with the Brookhaven National Laboratory 20-in. hydrogen bubble chamber exposed to a 2.7-BeV/$c$ beam of antiprotons. Approximately 3000 four-prong events with vertices restricted to a limited fiducial volume of the chamber were measured.

In these 3000 events the reaction

$$\bar{p}+p\rightarrow\pi^{+}+\pi^{+}+\pi^{-}+\pi^{-}+\pi^{0} \qquad (1)$$

has been investigated. Events were accepted as (1) if they satisfied the following requirements: (1) The missing mass (before fitting with GUTS) was within three standard deviations of the $\pi^0$ mass. (2) There were no other constrained fits. (3) The $\chi^2$ of the one-constraint fit to five pions was less than 9.0. With these requirements a sample of 320 five-pion events was obtained.

Analysis of the two- and three-pion effective-mass spectra shows a significant $\rho$ contribution and a very small $\omega$ contribution, respectively. Neither of these dominates the data. In addition, there are no apparent $\rho$-$\omega$ coincidences.

Analysis of the four-pion effective-mass spectra for the charged combinations $(\pi^+\pi^+\pi^-\pi^0)$ and $(\pi^-\pi^-\pi^+\pi^0)$ shows no significant deviation from phase space [Figs. 1(a), 1(b)]. The neutral combination $(\pi^+\pi^+\pi^-\pi^-)$ [Fig. 1(c)], however, deviates significantly at a mass value ~1600 MeV with a width ~150 MeV. A fit of phase space to this distribution, omitting the region 1550-1750 MeV, yields an expected number of 28 events in the omitted region. This is to be compared with the 51 observed events in this range. Subtraction yields an excess of 23 events with a combined statistical and phase-space-fit uncertainty of ±7.3 events.

The requirement of no other constrained fits must be eliminated as a possible cause of this effect. To this end 240 events which have multiple fits to $5\pi$'s and to $K\bar{K}3\pi$ have been studied. Estimates based on the unique $K\bar{K}3\pi$ events indicate that the majority of these multiple-fit events belong to the $5\pi$ final state. Doing an equivalent analysis on the $5\pi$ fits from these events shows a significant enhancement in the 1550- to 1750-MeV mass range for the combination $(\pi^+\pi^+\pi^-\pi^-)$ and no enhancement in this region for the other four-pion combinations.

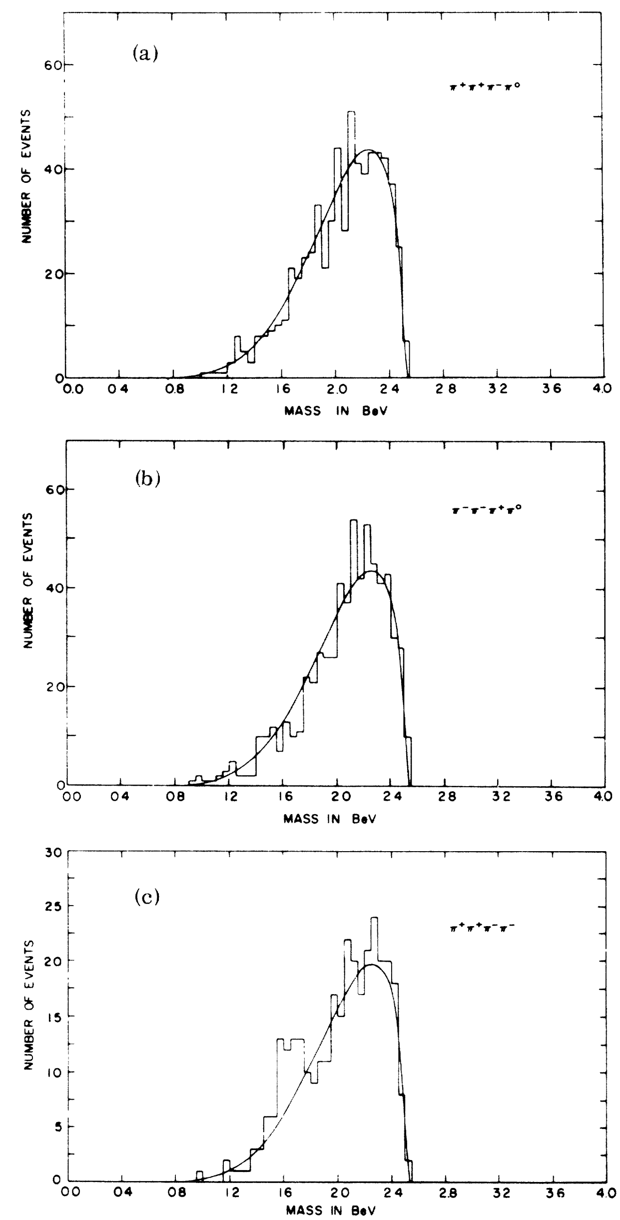


FIG. 1. Four-body effective-mass plots. The smooth curve is the best fit of phase space to the data. Each plot contains 320 events.

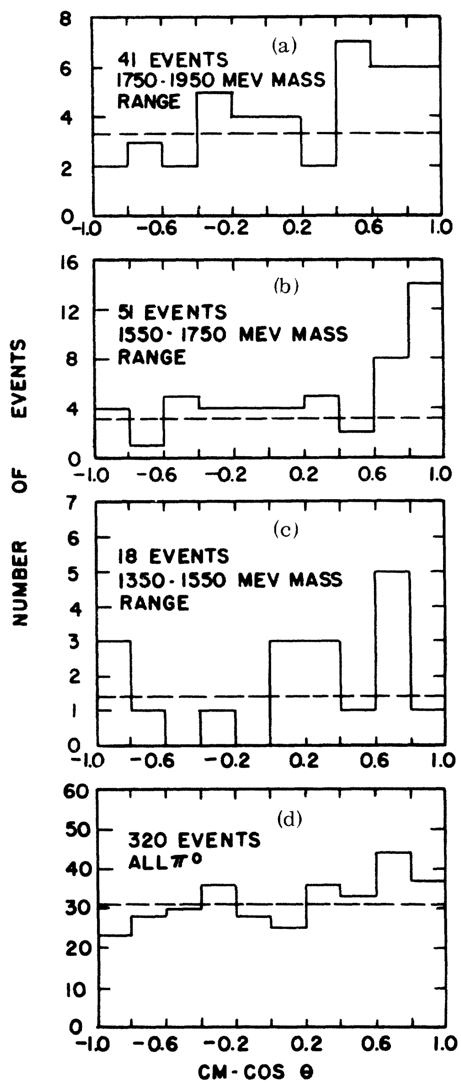


FIG. 2. Center-of-mass angular distribution of $\pi^0$. $\theta$ is angle between $\bar{p}$ and $\pi^0$. The horizontal lines represent the best fit of the data to an isotropic distribution. The fits are obtained by minimizing $\chi^2$ for an isotropic fit without requiring the total number of events and the number of events represented by the fit to be identical. The $\chi^2$ for the fits are (a) 7.8, (b) 18.7, (c) 9.7, (d) 11.2.

Figure 2 shows for the unique $5\pi$ events c.m. angular distributions of the $\pi^0$ for special ranges of the $(\pi^+\pi^+\pi^-\pi^-)$ effective mass. Charge-conjugation invariance requires a symmetric distribution of the $\pi^0$; however, the dominant features of the 1550- to 1750- MeV plot [Fig. 2(b)] are its anisotropy and asymmetry.

The apparent asymmetry can be shown to be an experimental bias by examining the class of events which have multiple fits to $5\pi$'s and to $K\bar{K}3\pi$. The c.m. angular distribution of the $\pi^0$'s for these events in the mass range 1550-1750 MeV is shown in Fig. 3. The appearance of the backward peak means that the selection criteria result in a bias which excludes those events with $\pi^0$'s in the backward direction in the c.m. system. The conclusion is that the observed anisotropy is real, but the asymmetry is a bias effect.

Preliminary attempts to fit the data to phase space plus a Breit-Wigner distribution led to a value of $1610 \pm 40$ MeV for the mass of the resonance. The data are not very sensitive to variations in $\Gamma$, but the fitted value of $\Gamma$ is $155 \pm 85$ MeV.

With the present data we observe a three-standard-deviation effect in the $(\pi^+\pi^+\pi^-\pi^-)$ mass spectrum, and at the same mass value a 2- to $2\frac{1}{2}$-standard-deviation change in the c.m. angular distribution. In addition, preliminary results from the analysis of

$$\bar{p} + p \rightarrow 3\pi^+ + 3\pi^- + \pi^0 \qquad (2)$$

in our experiment show a statistically significant enhancement in the 1550- to 1750-MeV range of the $(\pi^+\pi^+\pi^-\pi^-)$ effective-mass spectrum.[1]

Two separate experiments carried out at CERN and published jointly[2] have each seen an effect, with approximately the same statistical validity, in the effective-mass distribution of $(\pi^+\pi^-)$ with the following results:

$$M = 1660 \pm 40 \text{ MeV}, \quad \Gamma = 170 \pm 40 \text{ MeV},^3$$

$$M = 1675 \pm 35 \text{ MeV}, \quad \Gamma = 200 \pm 50 \text{ MeV}.^4$$

From the $\pi^+\pi^-$ mass data one would assign

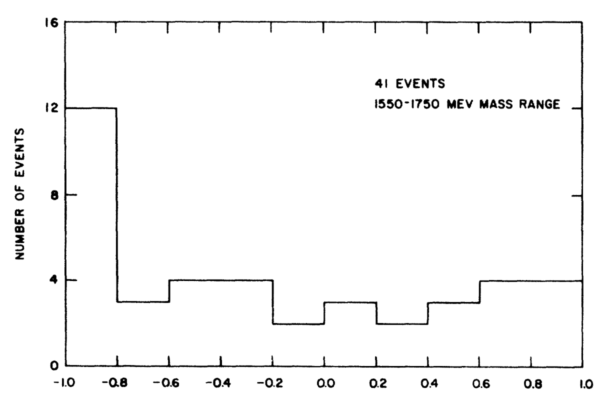


FIG. 3. Center-of-mass angular distribution of $\pi^0$ for ambiguous events. $\theta$ is angle between $\bar{p}$ and $\pi^0$.

a value of $1670\pm25$ MeV for the mass and a width of $180\pm30$ MeV. The mass value of the four-pion system reported here differs from 1670 MeV by only 1.5 standard deviations. Thus it seems at least possible that these are different decay modes of the same state. If the data on the four-pion mass distribution is refitted without using the bin 1550 to 1600 MeV, the central value of the mass increases significantly, but this effect is, of course, accompanied by a corresponding decrease in the statistical validity of the entire resonance effect, since one-fourth of the contribution of the resonance is not being used in the fitting procedure then.

The detailed arguments on the quantum numbers are built on the assumption that the experiments of references 3 and 4 and of this experiment are observing different decay modes of the same state.

An analysis of events in the resonance region gives some tentative conclusions on the branching ratio $\rho^0+2\pi$ to $4\pi$ in the decay of the resonance. Difficulty in making an accurate determination of the ratio arises in estimating the contribution of $\rho$'s from the background. The data indicate that this ratio is 1:4 or less. There is no evidence for a $\rho\rho$ decay mode.

The experiments of reference 2 were unable to determine the isotopic spin of this state. In the present experiment the lack of an effect at this mass value in the charged four-pion combinations for the unique $5\pi$ events [Figs. 1(a), 1(b)], as well as for the ambiguous class, leads immediately to the assignment $I=0$. The $G$ parity of a state of $N$ pions is $G=(-1)^N$. Hence, the two- and four-pion decays both have $G=+1$. The observation of only these two decay modes is a reasonable basis for assuming $G$ conservation in the decay, so $G=+1$ for the resonance. Then the relation $G=C(-1)^I$, which is valid for neutral meson states, gives $C=+1$. The two-pion state is an eigenstate of $CP$ with eigenvalue +1. This implies that $P=+1$, also. The parity of the two-pion system is given by $P=(-1)^J$, so a positive parity for this state restricts $J$ to even integer values.

The $A$ parity of the resonance is +1, since its two observed decay modes have $A=+1$.

The data reported here were obtained from examination of about a fourth of the pictures available from this exposure. The work will continue with the remaining pictures.

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[1]W. J. Kernan and D. E. Bohning, Ames Laboratory Internal Report (unpublished).

[2]M. Goldberg et al., Phys. Letters 17, 354 (1965).

[3]This experiment observes the reaction $\pi^++d\to p+p+\pi^++\pi^-$ for 6.0-BeV/$c$ incident $\pi^+$.

[4]This experiment observes the reaction $\pi^-+p\to n+\pi^++\pi^-$ for 8.0-BeV/$c$ incident $\pi^-$.

## LIMIT ON $d/f$ RATIO FROM $\Xi^-$ ASSOCIATED PRODUCTION*

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The most striking feature of the associated production of $\Xi^-$ by a $K^-$ beam is the very pronounced backward peaking of the $K^+$ mesons which are produced.[1] This is presumably the result of the fact that there exists no doubly charged vector meson to be exchanged in the $t$ channel.[2] Thus, the reaction should be dominated by nearby singularities in the $u$ channel, and the amplitude should be peaked in the backward direction.

There are several nearby singularities in the $u$ channel. The sigma and lambda hyperons give rise to the singularities nearest to the physical region (1192 and 1115 MeV, respectively). The exchange of the $Y_1^{*0}$(1385 MeV) 3-3 resonance produces the next singularity. There is also a pole due to the exchange of the $Y_0^*$(1405 MeV) $K^-p$ bound state. Calculations have shown that, due to the fact that the $Y_0^*$ is weakly coupled, it will have only a small