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Evidence for a New Meson Resonance at 2340 MeV

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Evidence is presented for a new meson resonance at 2340± 20 MeV, with a width of 180± 60 MeV, decaying primarily into $\rho\rho\pi$. The resonance, which is observed in 15-GeV/c π^+p interactions, has isotopic spin 1 or 2 and odd G parity. The cross section for production of the $\rho\rho\pi$ state is 7.3± 1.7 μb. Branching ratios into $\rho\rho\pi$ and other decay modes are given.

We have found evidence for a new meson resonance at a mass of 2340 MeV, having a width of 180 MeV, and decaying primarily into $\rho\rho\pi$. The evidence comes from a study of 15-GeV/c π^+p interactions.[1] The experiment was performed at the Stanford Linear Accelerator Center using an rf-separated π^+ beam incident on the 82-in. bubble chamber filled with liquid hydrogen. An exposure of 866 000 pictures was taken and scanned, and all interactions were recorded. All interactions up to the highest multiplicity observed (fourteen outgoing charged prongs) were measured on the Columbia University Hough-Powell Device (HPD) operating in an automatic pattern-recognition mode. About 750 000 events were measured on the HPD independently in three views. The measurements were processed by an event-finding program that matched tracks from view to view, and determined which tracks corresponded to prongs of an event. Our versions of the programs TVGP and SQUAW were then used for three-dimensional geometrical reconstruction and kinematic fitting to specific final states.[2] This paper is based on about 520 000 events that successfully passed through all of the selection criteria.

The new resonance was observed in a sample of 7698 events which made four-constraint fits to the reaction

$$\pi^+p \to p3\pi^+2\pi^- . \tag{1}$$

Figure 1(a) shows the effective mass of the five pions, requiring that two distinct $\pi^+\pi^-$ mass combinations lie in the ρ^0 mass region (620–920 MeV). There were 4632 events which satisfied this requirement. In the vicinity of 2340 MeV, the $\rho^0\rho^0\pi^+$ mass distribution shows a 4.5-standard-deviation enhancement above a low-order polynomial fit to the data. The $\rho\rho\pi$ mass resolution (σ) at 2340 MeV is ~15 MeV.

We have performed a fit of the $\rho\rho\pi$ mass distribution to a polynomial background and a Breit-Wigner resonance shape for the enhancement. The best fit, which had a χ^2 of 55 for 63 degrees of freedom (this is an improvement of 13 in the χ^2 value over a fit to a polynomial without a resonance), is indicated by the solid line in Fig. 1(a), and the background is represented by the dotted

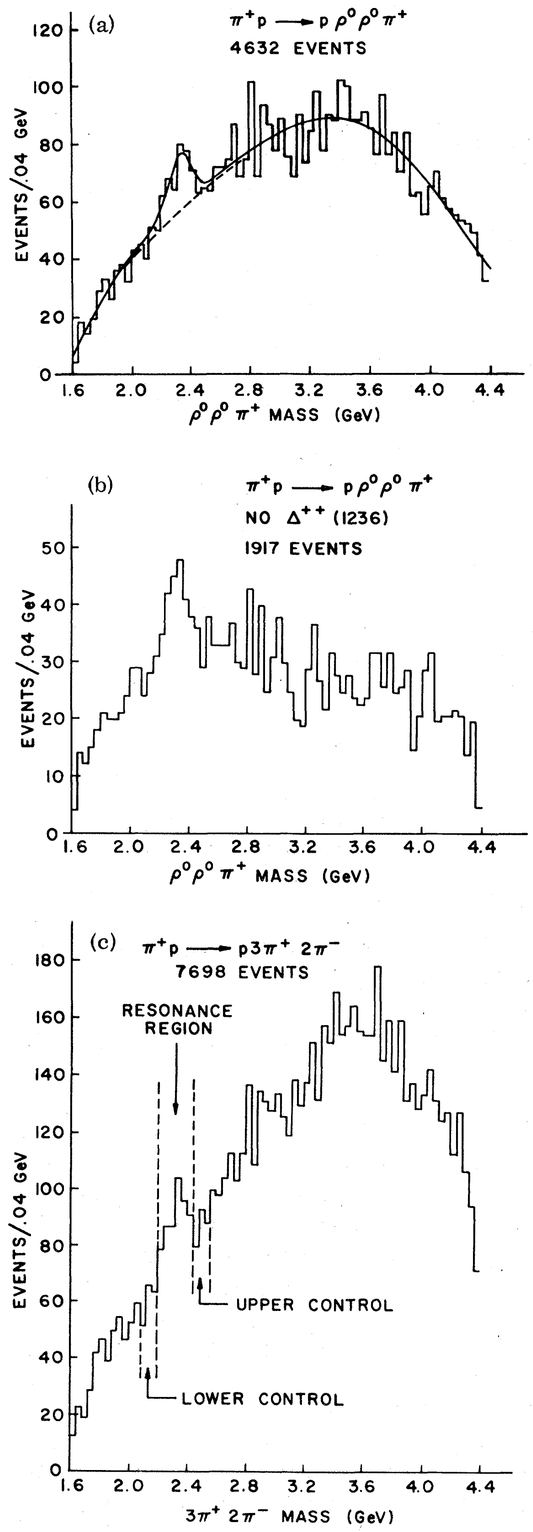

FIG. 1. (a) The $\rho^0\rho^0\pi^+$ mass distribution. The curve represents a fit by a Breit-Wigner plus a polynomial. (b) The $\rho^0\rho^0\pi^+$ mass, removing all events with any $p\pi^+$ mass combination below 1360 MeV. (c) The uncut $3\pi^+2\pi^-$ mass distribution.

line. This fit yielded the following resonance parameters: $M = 2340 \pm 20$ MeV, $\Gamma = 180 \pm 60$ MeV. There were a total of 126 ± 28 events in the resonance, corresponding to a production cross section of 7.3 ± 1.7 μb. This cross section was determined taking into account the efficiencies in the scanning, measuring, event-finding, and kinematic-fitting processes. The quoted error includes the uncertainties in these efficiencies and in our knowledge of the pion flux and liquid-hydrogen density in addition to the statistical error and the uncertainty in the shape of the background.

Reaction (1) is characterized by copious production of the $\Delta^{++}(1236)$ resonance. Figure 1(b) shows the $\rho^0\rho^0\pi^+$ mass distribution, removing all events with any $p\pi^+$ mass combination less than 1360 MeV. The mass plot still shows a clear signal for the 2340-MeV resonance, indicating that the effect is not a kinematical reflection of the Δ.

In view of the large background under the ρ meson, it is not clear from the $\rho\rho\pi$ mass plot alone that the resonant events truly represent a $\rho\rho\pi$ state. We have attempted to measure the $\rho\rho\pi$ branching ratio by the following technique. In Fig. 1(c), which shows the uncut 5π mass distribution from Reaction (1), we have defined a resonance region and a control band on either side. We have also performed a fit of this distribution using the same mass and width values for the resonance as obtained from the best fit of the $\rho\rho\pi$ plot. The fit yielded the numbers of resonant and background events in the signal and control regions of 5π mass. For events in the resonance region of 5π mass, we have made a scatter plot of one $\pi^+\pi^-$ mass combination against a different $\pi^+\pi^-$ combination from the same event. There are six entries for each event. We have drawn the two ρ bands on the scatter plot and counted the number of events in the overlap box. From the overlap region, we have subtracted events corresponding to background boxes around the overlap, and corrected for the tail of the ρ to obtain the number of true $\rho\rho\pi$ events when the 5π mass is in the resonance region. To make the subtraction of $\rho\rho\pi$ events due to the nonresonant background in the resonance region of 5π mass, we have used the control regions below and above the resonance. We have made similar scatter plots to obtain the number of true $\rho\rho\pi$ events when the 5π mass is in the control regions. Then, assuming that the amount of $\rho\rho\pi$ from the nonresonant background varies smoothly between the two control regions, a subtraction was made,

TABLE I. Decay branching ratios of (2340) resonance. (c.l. denotes confidence level.)

$\frac{(2340)^+ \to \rho^0\rho^0\pi^+}{(2340)^+ \to \text{all } 3\pi^+2\pi^-}$	1.05 ± 0.25
$\frac{\text{Background} \to \rho^0\rho^0\pi^+}{\text{Background} \to \text{all } 3\pi^+2\pi^-}$	0.16 ± 0.04
$\frac{(2340)^+ \to A_2{}^+\rho^0}{(2340)^+ \to \text{all } 3\pi^+2\pi^-}$	0.19 ± 0.27
$\frac{(2340)^+ \to \pi^+\pi^+\pi^-}{(2340)^+ \to 3\pi^+2\pi^-}$	<9% (68% c.l.)
$\frac{(2340)^+ \to 4\pi^+3\pi^-}{(2340)^+ \to 3\pi^+2\pi^-}$	<8% (68% c.l.)
$\frac{(2340)^+ \to f^0\pi^+\pi^+\pi^-}{(2340)^+ \to \text{all } 3\pi^+2\pi^-}$	<3% (68% c.l.)

taking into account the fact that the tails of the 2340-MeV resonance extend into the control regions. Table I summarizes our results. We obtain strikingly different numbers for the $\rho\rho\pi$ branching ratios of the 2340-MeV resonance and the background events. For the resonance, we get a branching ratio of 1.05 ± 0.25 into $\rho\rho\pi$ while for the background, we get 0.16 ± 0.04. Our data therefore indicate a dominant $\rho\rho\pi$ decay for the resonance.

With a dominant $\rho\rho\pi$ decay, we would expect, in addition to $\rho^0\rho^0\pi^+$, decays into $\rho^+\rho^0\pi^0$, $\rho^+\rho^+\pi^-$, and $\rho^+\rho^-\pi^+$. All three of the latter decays lead to a $p\pi^+\pi^+\pi^-\pi^0\pi^0$ final state, which is kinematically unfittable, and thus the 5π effective mass cannot be calculated. We have, however, examined the distribution of the missing mass opposite the proton in events which are consistent with $p\pi^+\pi^+\pi^-$ and two or more missing π^0's. We find a bump near 2340 MeV with a statistical significance of about 3 standard deviations. This bump is independent evidence for the existence of a resonance at 2340 MeV. It contains 480 ± 200 events above background when fitted by a Breit-Wigner shape centered at 2340 MeV with a width of 180 MeV, which is about 4 times the number of events in the $\rho^0\rho^0\pi^+$ peak of Fig. 1(a). This ratio is in principle sensitive to the isotopic spin of the 2340-MeV resonance; however, because of the large errors on the number of events in the peak in the missing-mass distribution (480 ± 200) and the complexity of the $\rho\rho\pi$ system, we can draw no conclusions.

We have examined our data further to see if the $\rho\rho\pi$ state is the decay of an $A_2\rho$ intermediate state. We have used the same technique as for the determination of the $\rho\rho\pi$ branching ratio, this time making a scatter plot of $\pi^+\pi^-$ mass against $\pi^+\pi^+\pi^-$ mass. Our analysis yields a branching ratio of 0.19 ± 0.27 into $A_2\rho$. We therefore do not have any clear evidence for an $A_2\rho$ decay mode.

We have also searched for 3π and 7π decay modes of this resonance, by examining the four- and eight-prong reactions

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

$$\pi^+p \to p4\pi^+3\pi^-. \tag{3}$$

A total of 25991 events made four-constraint fits to Reaction (2), and 1733 events made four-constraint fits to Reaction (3). We do not see an enhancement at 2340 MeV in either the 3π or the 7π mass distribution from Reactions (2) and (3), respectively. To place an upper limit on the relative rates, we fitted a polynomial to the mass plots and counted the number of events above the fit in a 240-MeV-wide interval around the resonance mass. To this number of possible resonant events, we added 1 standard deviation on the total number of events in the resonance region to obtain upper limits at the 68% confidence level. As shown in Table I, we obtained an upper limit of 9% for the 3π decay and 8% for the 7π decay. We also calculated an upper limit of 3% on the branching ratio for the $f^0\pi^+\pi^+\pi^-$ decay.

The observation of a charged state for the resonance implies that the isospin is at least 1. An upper limit of 2 can be placed on the isospin by observing that the initial π^+p state is a pure state of isospin $\frac{3}{2}$, and the resonance is produced with a proton in the final state. The G parity is odd, since the state decays into an odd number of pions.

We have studied the t' dependence of the production cross section for the resonance. t' is defined to be $t - t_{\min}$, where t is the square of the four-momentum transfer from the target to the outgoing proton, and $t_{\min}$ is the minimum value of t kinematically possible for the event under consideration. We have binned the data in t', plotted the $\rho\rho\pi$ mass separately for each t' bin, and fitted by a Breit-Wigner shape to determine the number of resonant events in each t' bin. Figure 2 shows the t' distribution. We have fitted the distribution to the form $\exp(at')$; the results of the best fit are indicated by the solid line in the figure, with a slope parameter of $a = 4.4 \pm 0.9$ GeV^{-2}.

We conclude that we have evidence for a new

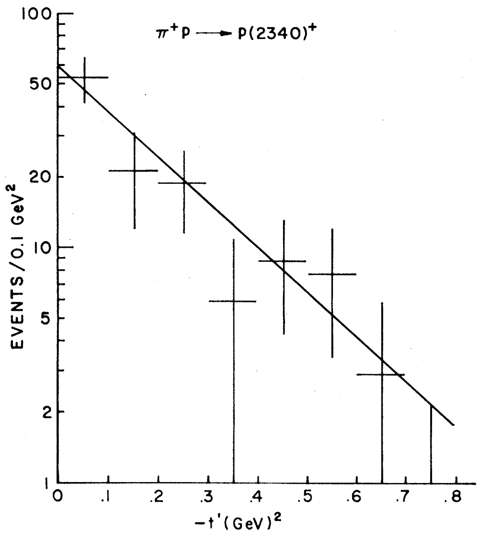

FIG. 2. The t' distribution for the 2340-MeV resonance.

broad meson resonance at 2340 ± 20 MeV, decaying primarily into $\rho\rho\pi$, with isotopic spin 1 or 2 and odd G parity. With a mass resolution of 15 MeV in this region, we find the width of the resonance to be 180 ± 60 MeV. The production of the resonance in Reaction (1) does not seem to be diffractive as indicated by the slope of the t' distribution. This resonance may be connected with an $I = 1$ enhancement in the nucleon-antinucleon total cross section observed by Abrams *et al.*[3] at a mass of 2350 ± 10 MeV with a width of 140 MeV. However, we feel that this resonance is not related to the so-called U meson that has been reported in missing-mass experiments[4] since the large width observed here is not compatible with the very small (< 30 MeV) width reported for the U meson.

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[1]For reports on other aspects of this experiment, see C. Baltay *et al.*, Phys. Rev. Lett. 34, 1118 (1975); C. Baltay *et al.*, Phys. Lett. 57B, 293 (1975).

[2]For experimental details, see M. Kalelkar, Ph.D. thesis, Columbia University, 1975 (unpublished).

[3]R. J. Abrams *et al.*, Phys. Rev. Lett. 18, 1209 (1967). See also J. Alspector *et al.*, Phys. Rev. Lett. 30, 511 (1973).

[4]G. Chikovani *et al.*, Phys. Lett. 22, 233 (1966).

Two-Component Model for Deep Inelastic Lepton-Nucleon Scattering

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A two-component model of deep inelastic lepton-nucleon scattering is presented in which the phenomena that the usual quark-parton model attributes to the presence of the core (wee) quarks are instead described by a generalized vector-meson-dominance model, modified to take into account a correction arising from the finite size of the nucleon and the uncertainty principle. The model predicts the core-quark distribution in satisfactory agreement with the results of neutrino experiments.

There are two popular models for deep inelastic electron-nucleon scattering. The generalized vector-dominance model (GVDM)[1,2] extends the successful treatment of photoproduction to deep inelastic electron processes, and is able to predict correctly the asymptotic value ($\omega \to \infty$) of the