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OBSERVATION OF MULTIPION RESONANCES AT 1630 AND 1720 MeV IN HIGH-ENERGY π^+p COLLISIONS*†

C. Baltay,‡ H. H. Kung, and N. Yeh
Columbia University, New York, New York

and

T. Ferbel and P. F. Slattery§
University of Rochester, Rochester, New York

and

M. Rabin‖
Rutgers, The State University, New Brunswick, New Jersey

and

H. L. Kraybill
Yale University, New Haven, Connecticut
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A number of recent experimental papers have reported the possible existence of new boson resonant states in the mass region from 1600 to 1800 MeV.[1] We present here the results of a bubble-chamber investigation of multipion production in π^+p collisions at incident pion momenta of 6.95 and 8.5 BeV/c. These data provide strong support for the existence of two isospin-1 resonances: (1) a negative G-parity state at 1630 ± 10 MeV with a width of 70 ± 40 MeV; (2) a positive G-parity state at 1720 ± 15 MeV having a width of 100 ± 35 MeV. These resonances are produced peripherally with observed production cross sections of the order of 50 μb.

The data were obtained from approximately 120 000 exposures of the 80-in. Brookhaven National Laboratory hydrogen bubble chamber to pions from the high-energy electrostatically separated beam at the alternating-gradient synchrotron.[2] The 6.95-BeV/c data were analyzed as a Rochester-Yale collaboration,[3] while the 8.5-BeV/c film was studied by groups at Columbia and at Rutgers.[4] The present results are based upon the analysis of 6959 events of Reaction (1) and of 5744 events of Reaction (2):

$$\pi^+p \to p\pi^+\pi^+\pi^- \qquad (1)$$

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

A total of 2293 events of Reaction (1) and 2942 from Reaction (2) were analyzed at 6.95 BeV/c while 4666 events of Reaction (1) and 2802 from Reaction (2) were studied at 8.5 BeV/c. The different relative amounts of Reactions (1) and (2) in the two samples of events reflect the fact that at the higher energy only events with at least one heavily ionizing positive track were measured, while no such selection was made at the lower momentum. The two samples of data, however, exhibited similar structure in the regions pertinent to the present investigation.

Figure 1(a) displays the effective-mass distribution of $\pi^+\pi^+\pi^-$ mass triplets from Reaction (1), and Fig. 1(b) shows the invariant-mass distribution of $\pi^+\pi^+\pi^-\pi^0$ mass combinations from Reaction (2). Both of these distributions exhibit con-

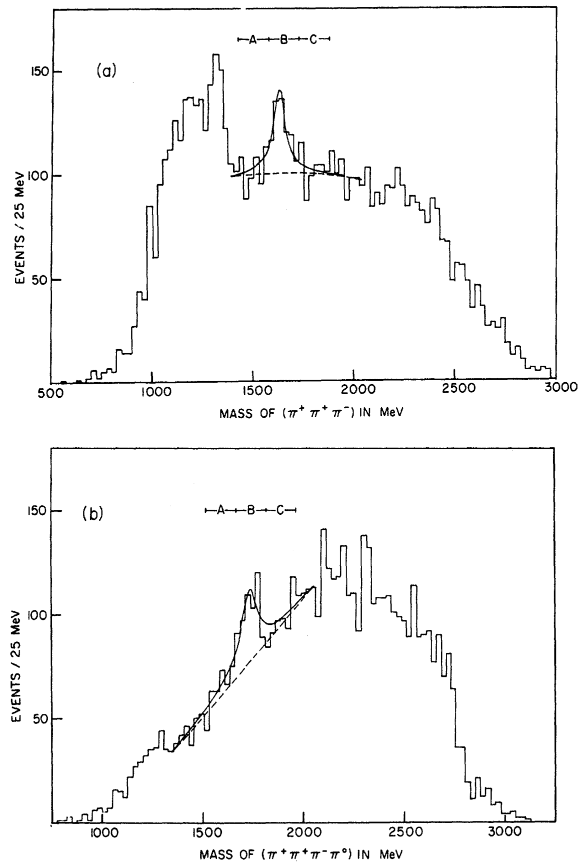

FIG. 1. (a) Effective-mass distribution of $\pi^+\pi^+\pi^-$ triplets in Reaction (1). (b) Effective-mass distribution of $\pi^+\pi^+\pi^-\pi^0$ mass combinations from Reaction (2).

siderable fine structure. We will, however, restrict our attention to the two indicated mass enhancements.[5] The smooth curves represent the results of a maximum likelihood analysis. The mass distributions were assumed to be adequately described in the regions of interest by the superposition of polynomial backgrounds and simple Breit-Wigner forms for the resonances. A quadratic polynomial was used to represent the background in Fig. 1(a), while a linear function was found to be sufficient in the case of Fig. 1(b). Both the polynomial coefficients and the resonance parameters were allowed to vary in the fit. The resulting masses and widths determined for the two enhancements are presented in Table I.

We also investigated the decays of these two resonant states. Three classes of events were distinguished corresponding to multipion masses occurring below, within, or above the immediate vicinity of the resonant mass values—these regions are labeled A, B, and C, respectively, in Figs. 1(a) and 1(b). The decay mass distributions for events in region B were analyzed and compared with the corresponding spectra for events in regions A and C, with the difference between these spectra being attributed to the excess of resonant events in region B. Representing the secondary resonances involved in the decays by the most recently compiled set of resonance parameters,[6] we obtained the decay rates presented in Table I.[7]

The decay modes into $f^0\pi^+$ and $\omega^0\pi^+$ for the states of 1630 and 1720 MeV, respectively (see Table I), imply that both states have isospin 1. We have tested our data against the hypothesis that all of the f^0 or ω^0 events in the appropriate decay distributions came from the nonresonant events alone. We found that we could reject this

Table I. Summary of results.

Mass (MeV)	Width (MeV)	Decay	Rate[a] (%)
1630 ± 10	70 ± 40	$\frac{\pi^+(1630)\to\rho^0\pi^+;\ \rho^0\to\pi^+\pi^-}{\pi^+(1630)\to\pi^+\pi^+\pi^-}$	<20
		$\frac{\pi^+(1630)\to f^0\pi^+;\ f^0\to\pi^+\pi^-}{\pi^+(1630)\to\pi^+\pi^+\pi^-}$	35 ± 20
		$\frac{\pi^+(1630)\to\eta^0\pi^+;\ \eta^0\to\pi^+\pi^-\pi^0}{\pi^+(1630)\to\pi^+\pi^+\pi^-}$	<2
1720 ± 15	100 ± 35	$\frac{\rho^+(1720)\to\omega^0\pi^+;\ \omega^0\to\pi^+\pi^-\pi^0}{\rho^+(1720)\to\pi^+\pi^+\pi^-\pi^0}$	25 ± 10
		$\frac{\rho^+(1720)\to A_2{}^0\pi^+;\ A_2{}^0\to\pi^+\pi^-\pi^0}{\rho^+(1720)\to\pi^+\pi^+\pi^-\pi^0}$	40 ± 20[b]

[a]The errors quoted are statistical only.
[b]Isospin conservation requires that the decay rate for $\rho^+(1720)\to A_2{}^+\pi^0$, $A_2{}^+\to\pi^+\pi^+\pi^-$ be one-half that of $\rho^+(1720)\to A_2{}^0\pi^+$, $A_2{}^0\to\pi^+\pi^-\pi^0$. Our data are consistent with this prediction.

hypothesis for the 1630-MeV state ($f^0\pi^+$ decay) with a confidence level of better than 90%, and for the 1720-MeV state ($\omega^0\pi^+$ decay) at better than a 99% confidence level. Consequently, we regard the isospins of these two states as having been determined to be one with these same levels of confidence.

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†The authors all have guest appointments at Brookhaven National Laboratory, Upton, N. Y.

‡Alfred P. Sloan Foundation Fellow.

§U. S. Atomic Energy Commission Postdoctoral Fellow.

‖Present address: Lawrence Radiation Laboratory, Berkeley, Calif.

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[5]If mass intervals of approximately three full widths centered at the peak position in Figs. 1(a) and 1(b) are considered, and if the observed peaks are interpreted as statistical fluctuations in the estimated backgrounds indicated, then these peaks would correspond to unlikely fluctuations of ~5 standard deviations in Fig. 1(a), and of ~6 standard deviations in Fig. 1(b).

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[7]We also investigated the reactions $\pi^+p\rightarrow p\pi^+\pi^+\pi^+\pi^-\pi^-$ and $\pi^+p\rightarrow p\pi^+\pi^+\pi^+\pi^-\pi^-\pi^0$ and obtained the following upper limits: $[\pi^+(1630)\rightarrow\pi^+\pi^+\pi^+\pi^-\pi^-]/[\pi^+(1630)\rightarrow\pi^+\pi^+\pi^-]$ $< 10\%$ and $[\rho^+(1720)\rightarrow\pi^+\pi^+\pi^+\pi^-\pi^-\pi^0]/[\rho^+(1720)\rightarrow\pi^+\pi^+\pi^-\pi^0]$ $<15\%$. The reaction $\pi^+p\rightarrow p\pi^+K^+K^-$ in these data was studied at Rutgers (R. Ehrlich, private communication) and the upper limit: $[\rho^+(1720)\rightarrow\varphi^0\pi^+;\ \varphi^0\rightarrow K^+K^-]/[\rho^+(1720)\rightarrow\pi^+\pi^+\pi^-\pi^0] < 5\%$, was obtained. From the published data of the Aachen-Berlin-CERN Collaboration on the reaction $\pi^+p\rightarrow p\pi^+\pi^0$ at 8 BeV/c [M. Deutschmann et al., Phys. Letters 18, 351 (1965)], we obtained the upper limit $[\rho^+(1720)\rightarrow\pi^+\pi^0]/[\rho^+(1720)\rightarrow\pi^+\pi^+\pi^-\pi^0] < 8\%$. Finally, we found evidence for a nonzero $\rho^0\rho^+$ decay rate for the $\rho^+(1720)$ state, but a reliable quantitative rate could not be estimated for this decay mode.