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FURTHER EVIDENCE FOR A POSSIBLE $I=\frac{5}{2}$ N^* RESONANCE AT 1580 MeV

G. Alexander, O. Benary, B. Reuter, A. Shapira, E. Simopoulou, and G. Yekutieli
Nuclear Physics Department, The Weizmann Institute of Science, Rehovoth, Israel
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In a study of the reaction $\pi^+ + p \rightarrow p + \pi^+ + \pi^+ + \pi^-$ at 3.65 GeV/c, Goldhaber et al.[1] have reported on an enhancement seen in the $p\pi^+\pi^+$-invariant mass distribution at 1.56 ± 0.02 GeV with a width of $\Gamma = 0.20 \pm 0.02$ GeV, selecting small-momentum-transfer events of $\Delta^2(p\pi^+\pi^+) \leq 15 m_\pi^2$. It was pointed out by the same authors that this enhancement, which may be due to the formation of an $I=\frac{5}{2}$ N^* resonance, could also be explained through the peripheral production of $\pi^+ + p \rightarrow N^{*++}(1238) + \rho^0$, taking into account the Bose symmetry of the two π^+-mesons in the final state.

In the present work a search has been done in p-p collisions at 5.5 GeV/c at different final-state channels, looking for a possible formation of an $I=\frac{5}{2}$ N^* resonance. The work was carried out with 30 000 pictures taken with the 81-cm hydrogen bubble chamber at CERN exposed to a secondary beam of protons at 5.52 GeV/c. An unbiased sample of 1020 four-prong and 159 six-prong events have been measured and analyzed kinematically. A total of 1014 events yielded at least one kinematical fit, and most ambiguous events were resolved by the ionization method. The p-p reactions used in the present work, together with their cross-section values, are given in Table I.

The data have been analyzed in terms of resonance production as a function of their momentum transfer Δ^2. As the initial state has two identical particles, two values for the momentum transfer Δ^2 may be computed for each particle. However, the angular distribution of the final-state nucleons and nucleon-pion systems show a marked forward-backward peaking (see Fig. 1). We have therefore chosen from the two possible Δ^2 values the smaller one to represent the actual momentum transfer. This procedure is equivalent to a fold in the angular distribution through 90°.

The relative production rate of the different charge states of a possible $I=\frac{5}{2}$ N^* resonance and their subsequent $N\pi\pi$ decay configurations may be uniquely determined by isospin consideration in the reaction $p+p \rightarrow N_{5/2}^* + N + \pi$; $N_{5/2}^* \rightarrow N + \pi + \pi$. These relative production rates are given in Table II for Reactions (1) and (2). Final states of $NN\pi\pi\pi$ involving more than one neutral particle could not be identified in the present work. As seen from Table II, the formation of an $I=\frac{5}{2}$ N^* resonance should mostly occur in the $p\pi^+\pi^+$ configuration of Reaction (1) and the $p\pi^+\pi^0$ configuration of Reaction (2). These two configurations have further the advantage that they cannot be in an $I=\frac{1}{2}$ state, and hence have no contribution from the two $I=\frac{1}{2}$ N^* resonances at 1.518 and 1.688 GeV. The invariant-mass distribution of $p\pi^+\pi^+$ and $p\pi^+\pi^0$ using all events shows some enhancement around 1580 MeV [Fig. 2(a)] which, however, is much more pronounced by using events with

Table I. Cross-section values for five- and six-body final states in pp collisions at 5.5 GeV/c.

	Reaction	No. of events	σ (mb)
(1)	$p+p \rightarrow n+p+\pi^+ +\pi^+ +\pi^-$	333	2.84 ± 0.15
(2)	$\rightarrow p+p+\pi^+ +\pi^- +\pi^0$	226	1.93 ± 0.13
(3)	$\rightarrow p+p+\pi^+ +\pi^+ +\pi^- +\pi^-$	74	0.63 ± 0.08

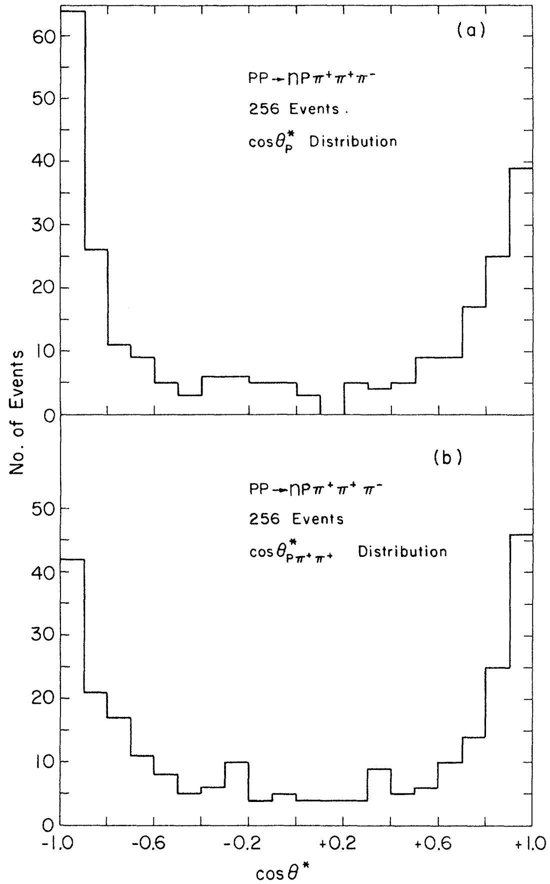

FIG. 1. Angular distribution in the production c.m. system of the reaction $p+p \rightarrow n+p+\pi^++\pi^++\pi^-$. (a) Of the proton; (b) of the $p\pi^+\pi^+$ configuration.

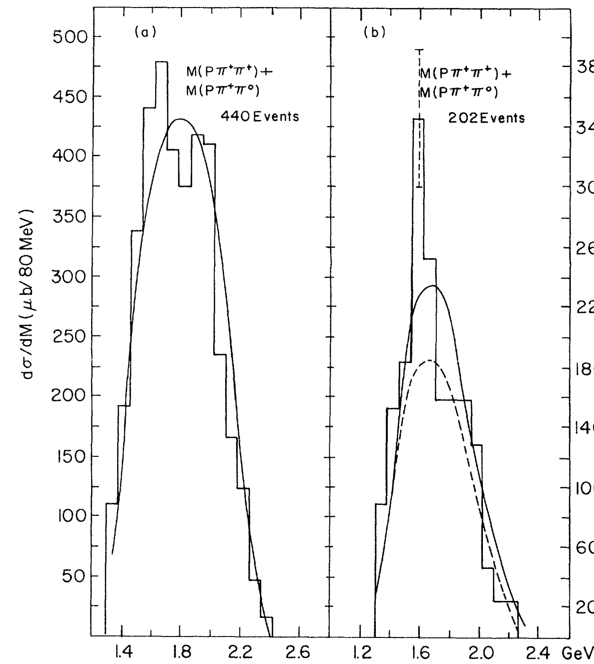

FIG. 2. Effective mass distribution of the $p\pi^+\pi^+$ and $p\pi^+\pi^0$ configurations in Reactions (1) and (2) (a) for all events, and (b) for events with $\Delta^2(p\pi\pi) \leq 0.8$ GeV^2. Full curves are $N^*\pi$ phase-space normalized to all the events, dashed curve normalized to 80% of the events.

momentum transfer of $\Delta^2(p\pi\pi) \leq 0.8$ GeV^2 [Fig. 2(b)] corresponding to a cutoff in the production angle of about $|\cos\theta| \geq 0.8$. In order to determine the expected background for the distribution $p\pi^+\pi^+$ and $p\pi^+\pi^0$ in Fig. 2 we have evaluated the amount of $N^*(1238)$ formation

Table II. Relative production rate of an $I=\frac{5}{2}$ N^* resonance in interactions $p+p \rightarrow N+N+\pi+\pi+\pi$ having only one neutral particle in the final state.

$I_z(N\pi\pi)$	Configuration	Reaction	Relative $N_{5/2}^*$ production
$+\frac{5}{2}$	$p\pi^+\pi^+$	(1)	0.50
$+\frac{3}{2}$	$p\pi^+\pi^0$	(2)	0.08
	$n\pi^+\pi^+$	(1)	0.02
$+\frac{1}{2}$	$p\pi^+\pi^-$	(2)	0.02
	$p\pi^+\pi^-$	(1)	0.01
$-\frac{1}{2}$	$p\pi^-\pi^0$	(2)	0.02
	$n\pi^+\pi^-$	(1)	0.01

in the $p\pi^+$ configuration using the same events of Reactions (1) and (2) shown in Fig. 2. For this evaluation we have used a linear combination of $N\pi$ phase space and $N^*(1238)$ mass distribution, taking properly into account the cutoff in Δ^2 and the various reflection effects.[2] It was found that the percentage of $N^*(1238)$ in the $p\pi^+$ invariant mass is above 80% and consistent with 100%. The 100% $N^*(1238)$ content has then been used in calculating the background curves in Fig. 2, the smooth curve is normalized to all the events in the plot, and the dashed curve was drawn so as to fit the data outside the enhancement mass region of 1.48 to 1.68 GeV. As seen from Fig. 2, neither curve reproduces the peak at 1.58 GeV, neither its height nor its shape. Best values for the position and width of the peak as obtained from the data were $m = 1.58 \pm 0.20$ GeV and $\Gamma = 0.20 \pm 0.02$ GeV, in very good agreement with the values given by Goldhaber et al.[1]

We have investigated the possibility that this 1.58-GeV enhancement is due to interference effects such as those coming from double production of resonances. Careful analysis of the data shows that double formation of isobars like $p+p \to N_a^* + N_b^*$; $N_a^* \to N+\pi$, and $N_b^* \to N+\pi+\pi$ is very small. There is some evidence for the reaction $p+p \to N_a^* + N_b^* + \pi$; $N_a^* \to N+\pi$, $N_b^* \to N+\pi$; however, it is seen from the data that the two pions in the $p\pi\pi$ configuration of the 1.58-GeV enhancement do not belong to the two different N^* isobars. Monte-Carlo-type calculation shows that the addition of the nonresonating pion to one of the N^* does not create an enhancement of 1.58 GeV. The production of boson resonances such as η, ω, and ρ are essentially absent in the 5.5-GeV/c reactions $p+p \to N+N+\pi+\pi+\pi$. Finally, we have looked into the possibility that the 1.58-GeV enhancement is due to a kinematical effect of the decay of higher N^* resonances such as $N_{3/2}^*(2360)$ into $p\pi\pi\pi$.

Attributing the 1.58-GeV peak to the formation of an $N_{5/2}^*$ resonance, we may proceed to evaluate from the data the relative production rates of the $I=\frac{5}{2}$ isobar in the different $N\pi\pi$ configurations for comparison with the expected values given in Table II. The invariant-mass distributions of $p\pi^+\pi^+$, $p\pi^+\pi^0$, $p\pi^+\pi^-$, and $p\pi^-\pi^0$ for events with a momentum-transfer cutoff $\Delta^2(p\pi\pi) \leq 0.8$ GeV^2 are given in Fig. 3 together with a phase-space curve of $N^*(1238)\pi$. The smooth phase-space curves in Fig. 3 are normalized to all the events, and the dashed curves normalized to all events minus the estimated events in the 1.58-GeV peak, that is, to ~75% of the events in Fig. 3(a) and to ~90% of the events in Fig. 3(b). Invariant-mass plots of both $p\pi^+\pi^+$ (pure $I=\frac{5}{2}$ state) and $p\pi^+\pi^0$ (mixture of $I=\frac{3}{2}$ and $\frac{5}{2}$ states) show an enhancement around 1.58 GeV. The small peak around 1.9 GeV seen in the $p\pi^+\pi^+$ mass plot is due to the formation of $N^*(1238)$ in the $n\pi^-$ configuration of Reaction (1). The small peak at 1.9 GeV seen at the $p\pi^+\pi^0$ mass plot is probably due to the formation of $N_{3/2}^*(1920)$ decaying into $p\pi^+\pi^0$. Estimation of the relative production cross section of the possible $N_{5/2}^*(1580)$ in the $p\pi^+\pi^+$ and $p\pi^+\pi^0$ configuration yields a value of 0.60 ± 0.35, where the error is statistical only and does not include the background uncertainties. This value is within one and one-half standard deviations from 0.16 predicted from isospin consideration (see Table II). The effective mass distribution of $n\pi^+\pi^+$ configuration (mixture of $I=\frac{3}{2}$ and $\frac{5}{2}$ states) is described well by a phase-space distribution of $N^*(1238)\pi$. The configuration $p\pi^+\pi^-$ and $p\pi^-\pi^0$, given in Figs. 3(c) and 3(d), also have contributions from the $I=\frac{1}{2}$ N^* resonances, namely, $N_{1/2}^*(1518)$ and $N_{1/2}^*(1688)$, which hinder the detection of a possible small enhancement in the 1.58-GeV region.

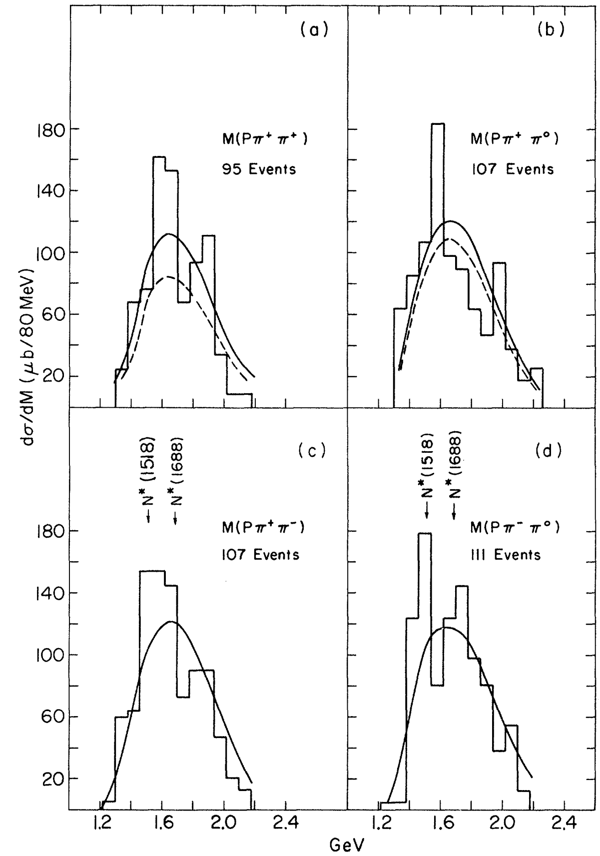

FIG. 3. Effective mass distribution for events with $\Delta^2(p\pi\pi) \leq 0.8$ GeV^2. (a) $p\pi^+\pi^+$ of reaction (1); (b) $p\pi^+\pi^0$ of Reaction (2); (c) $p\pi^+\pi^-$ of Reaction (2); (d) $p\pi^-\pi^0$ of Reaction (2). Full curves represent $N^*\pi$ phase space normalized to all events, dashed curve normalized to all events minus estimated events in the 1.58-GeV enhancement.

Finally, we have looked for the formation of the possible $N_{5/2}^*(1580)$ in the six-body state of Reaction (3). In this reaction the c.m. production angular distribution of the nucleons and nucleons-pions system are less peaked in the forward-backward directions than in Reactions (1) and (2). Analysis of the invariant-mass distribution of the $p\pi^+\pi^+$ configuration without momentum-transfer cutoff and using the two possible $p\pi^+\pi^+$ combinations of each event shows a small peak in the 1.58-GeV region. This peak, however, is less significant than the one seen in the five-body final states. Selecting events with small Δ^2 values does not improve the relative height of the 1.58-GeV peak.

In the framework of the SU(3)-symmetry model an $I = \frac{5}{2}$ N^* resonance may be classified in the 35 representation.[3] Recently it has been pointed out by Harari et al.[4] that in the extreme SU(12)-symmetry particle classification, where no orbital angular momentum between the quarks exists, the parity of an $I = \frac{5}{2}$ N^* resonance is negative if the decay mode $N_{5/2}^* \to N_{3/2}^*(1238) + \pi$ exists, and is a non-symmetry-breaking interaction. We have looked for the decay mode $N_{5/2}^*(1580) \to N_{3/2}^*(1238) + \pi$ in our data by plotting $m_{p\pi_1^+}{}^2$ versus $m_{p\pi_2^+}{}^2$ for events having $1.48 \leq m_{p\pi\pi} \leq 1.68$ GeV in the $p\pi^+\pi^+$ and $p\pi^+\pi^0$ configurations. Although there is some indication for the $N^*(1238) + \pi$ decay mode, the data is too meager for final conclusion.

We would like to express our gratitude to CERN and to the hydrogen bubble chamber crew for enabling us to have the p-p exposure.

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[2]By reflection effects we mean, for example, the contribution to the background in the $p\pi^+\pi^+$ invariant-mass distribution from the existence of the $N^*(1238)$ resonance in the $p\pi^-$ configuration in the reaction $p + p \to n + p + \pi^+ + \pi^+ + \pi^-$. These types of reflection effects were calculated through a Monte-Carlo-type phase-space calculation.

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HIGH-ENERGY PHOTOPRODUCTION OF NEUTRAL RHO MESONS*†

L. J. Lanzerotti, R. B. Blumenthal, D. C. Ehn, W. L. Faissler, P. M. Joseph, F. M. Pipkin, J. K. Randolph, J. J. Russell, D. G. Stairs,‡ and J. Tenenbaum

Harvard University, Cambridge, Massachusetts
(Received 7 June 1965)

Measurements were made of the photoproduction of charged pion pairs in a mass range from 0.300 to 1.500 BeV using a 5.5-BeV bremsstrahlung beam produced by the Cambridge electron accelerator.[1] Copious production of neutral rho mesons was observed in the forward direction. The dependence of the rho photoproduction cross section on gamma-ray energy, production angle, and atomic number of the target nucleus indicates that a diffraction-like mechanism is dominant.

The spectrometer arms from the previously reported electron-pair experiment were modified and used to detect pion pairs.[2] The circular bending magnet was removed and the single-momentum counters were replaced by an array of angle and momentum counters. The total angular acceptance of each of the two channels on one arm was 1.5°, and the full width at half-maximum of the total momentum acceptance was 8.2%; these combine to give a total mass acceptance of 21%. The angle and momentum counters divided the total acceptance into angle bins of 0.21° and momentum bins of 1.4%; these combine to give mass bins with a full width of 2.8%. The outputs of the angle and momentum counters were fed on-line to a PDP-1 computer, which analyzed each event and calculated the invariant mass of the two-pion system. All charged particle pairs were assumed to be pion pairs; the electron-pair contamination was less than 0.1%. The mass of the dipion system was varied by keeping both the synchrotron energy and the opening angle between the spectrometer arms fixed and varying the momentum in each spectrometer.

Figure 1 shows the dipion mass spectra for dipions produced at 0° from hydrogen and carbon targets. Similar spectra were obtained at laboratory angles of 3.5° and 6°. The only significant structure observed was a peak around a mass of 740 MeV; it was assumed that this peak was due to the rho meson. An analysis of the data with fine mass resolution gave for the rho a full width of 150 ± 10 MeV and a mass of 740 ± 10 MeV. Excitation curves suggested that the rho production was due predominantly to elastic production in which the recoil particle was an unexcited proton.