Nuclear Physics B58 (1973) 31–44. North-Holland Publishing Company

THE REACTION $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$ AT HIGH ENERGY AND PHOTON DISSOCIATION INTO FOUR PIONS *

M. DAVIER, I. DERADO **, D.E.C. FRIES ***, F.F. LIU ‡,
R.F. MOZLEY, A. ODIAN, J. PARK **, W.P. SWANSON,
F. VILLA and D. YOUNT ‡‡
Stanford Linear Accelerator Center,
Stanford University, Stanford, California 94305

Received 20 March 1973

Abstract: The reaction $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$ has been studied using the SLAC 2-meter streamer chamber placed in an 18 GeV bremsstrahlung beam. We find evidence for a broad enhancement (ρ') in the 4π mass spectrum at a mass of 1620 MeV with a width of about 300 MeV. This state is produced peripherally with a cross section consistent with being energy independent. I-spin = 1 ($C = -1$) is deduced from the dominant $\rho\pi\pi$ decay mode and $J \neq 0$ from the observation of a polarization phenomenon. Assuming quantum numbers $J^P = 1^-$, s-channel helicity is conserved at the γ–ρ' vertex. Further support for the J^P assignment is gathered when comparing our results to data from e^+e^- colliding-beam experiments.

1. Introduction

A well-known feature of the photon interacting with hadrons is its strong coupling to the neutral vector mesons. Indeed, for hadronic masses up to 1 GeV, the low-lying mesons, ρ^0, ω and ϕ essentially dominate the interaction. However, there is no such clear picture for higher masses. There is evidence from the e^+e^- colliding-beam experiments at Frascati [1] that multipion final states are copiously produced in the mass range from 1.4 to 2.4 GeV. Obviously the study of the photon coupling to hadronic states of high mass is quite fundamental since it could reveal new vector mesons or show interactions no longer mediated by vector mesons.

A direct way of studying the $J^P = 1^-$ hadronic spectrum is the e^+e^- annihilation process through one-photon exchange (fig. 1a). However, another approach is through diffractive photoproduction with real photons

* Work supported in part by the U.S. Atomic Energy Commission.
** Max Planck Institut für Physik und Astrophysik, Munich, Germany.
*** Institut für Experimentelle Kernphysik, Karlsruhe, Germany.
‡ Physics Department, California State College, San Bernardino, California 92407, USA.
‡‡ Department of Physics and Astronomy, University of Hawaii, Honolulu, Hawai 96822, USA.

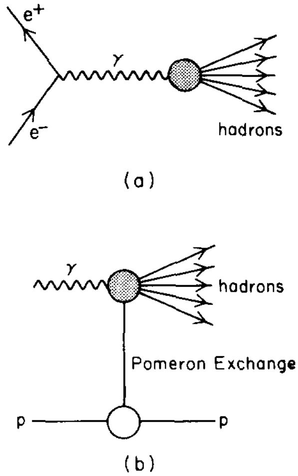


Fig. 1. (a) Hadron production in e^+e^- annihilations. (b) Diffractive photoproduction of hadrons.

$$\gamma p \to (\text{hadrons}) + p\,,$$

where the hadrons connected to the photon will appear at high energy and small momentum transfer (fig. 1b). While the $\pi^+\pi^-$ hadronic state has already been studied extensively [2, 3] with no convincing evidence for an isovector vector meson of mass higher than 1 GeV, searches in the higher multiplicity states have been almost non-existent. In this paper we present such a search in the photoproduction of four charged pions

$$\gamma p \to \pi^+\pi^-\pi^+\pi^- p\,. \tag{1}$$

Preliminary analyses of a limited fraction of our data have already been presented [4, 5]. The present work is based on the complete data of our experiment. Recently new results have become available on this reaction from the Berkeley-SLAC bubble chamber collaboration [6], showing good agreement with our findings.

2. Characteristics of the data

The two-meter SLAC streamer chamber was exposed to an 18 GeV bremsstrahlung beam and data were taken under a very loose trigger. Details on our experimental technique and the analysis procedures may be found elsewhere [7].

Our sample for reaction (1) amounts to 1667 events from photon energies between 4.5 and 18 GeV, where the lower energy cutoff is imposed by the falloff of our geometrical acceptance. General features of reaction (1) have been previously studied with the longitudinal phase-space method [8].

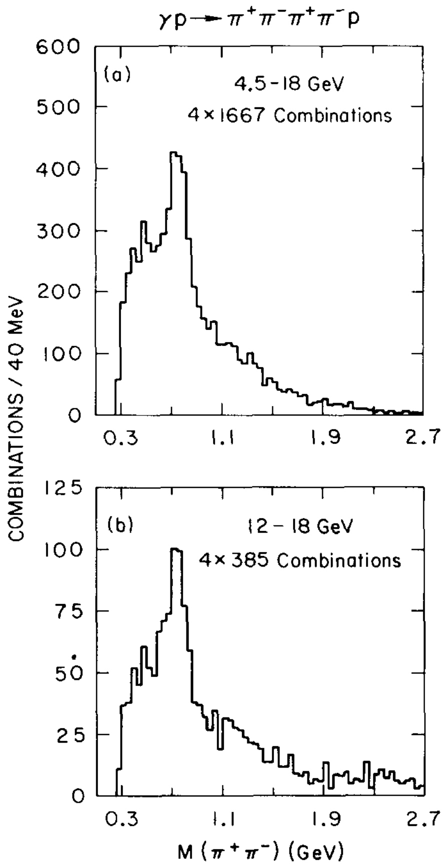


Fig. 2. $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$. $\pi^+\pi^-$ invariant mass distribution. (a) $4.5 < E_\gamma < 18$ GeV. (b) $12 < E_\gamma < 18$ GeV.

We find that reaction (1) is strongly dominated by ρ^0 and Δ^{++} production as seen in figs. 2a, 2b and 3a, 3b; the effect is particularly clear at the highest energies we have studied (figs. 2b and 3b). Above $E_\gamma = 10$ GeV such production accounts for about 70% of the complete channel. We have fitted the fractions of ρ^0 and Δ^{++} using hand-drawn background curves in order to study the energy dependence of the various subchannels. Fig. 4 and table 1 give the energy dependence of the cross sections for reaction (1) and the reactions

$$\gamma p \to \rho^0 \pi^+ \pi^- p \, , \tag{2}$$

$$\gamma p \to \pi^+ \pi^- \pi^- \Delta^{++} \, , \tag{3}$$

$$\gamma p \to \rho^0 \pi^- \Delta^{++} \, . \tag{4}$$

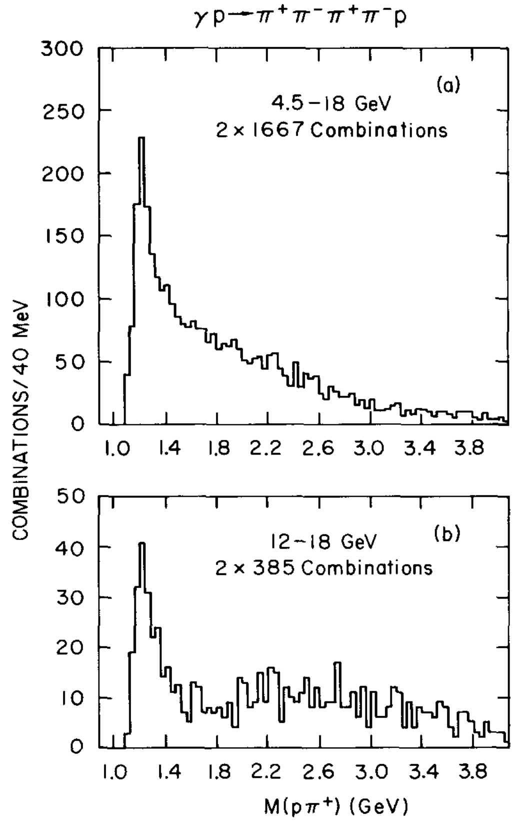


Fig. 3. $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$. $p\pi^+$ invariant mass distribution. (a) $4.5 < E_\gamma < 18$ GeV. (b) $12 < E_\gamma < 18$ GeV.

Since we are interested in the photon coupling to the 4π system we wish to remove events produced by exchange processes, such as reaction (3). Fortunately at high energy, where we primarily look for a diffractive phenomenon, the Δ^{++} peak is very clear with a relatively small background. Therefore we do not bias the 4π system too severely by removing events with a $p\pi^+$ mass combination in the Δ^{++} band (1.16–1.32 GeV).

3. The four-pion mass spectrum

Fig. 5a shows the 4π mass distribution for all events above $E_\gamma = 6$ GeV where some peaking is apparent around 1.6 GeV. When events with Δ^{++} are removed (fig. 5b) the effect appears as a more prominent broad peak centered at about 1.6 GeV.

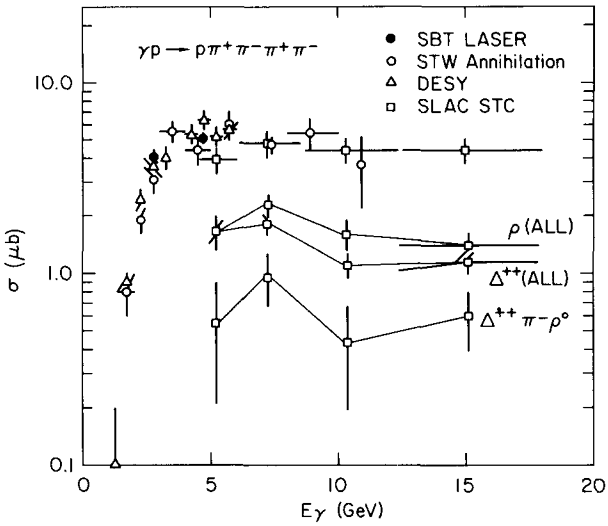


Fig. 4. $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$. Energy dependence of partial cross sections.

Since about half of the events with no Δ^{++} contain a ρ^0, it is interesting to look for a correlation between the 2π and 4π mass distributions. This is done in fig. 6 where it is seen that a large fraction of the produced ρ^0 contribute to the 4π bump. Conversely, almost all the events in the 4π peak have one $\pi^+\pi^-$ combination in the ρ^0 band (0.68–0.84 GeV). Fig. 5c then shows the $\rho^0\pi^+\pi^-$ mass distribution where the peak at 1.6 GeV is now very clear.

To study the behavior of our results as a function of incident energy, we divide our sample into two energy bins, E_γ = 6–12 GeV and 12–18 GeV. We see the enhancement in both cases, but the effect is more apparent in the high-energy sample since more phase-space is available in this case (figs. 7a and 7c). On the other hand, if we require that no ρ^0 be produced there is no evidence for an excess of events, thus confirming the strong correlation (figs. 7b and 7d).

Table 1
Channel cross sections

Photon energy (GeV)	4–6	6–8	8–12	12–18
$\sigma(\gamma p \to \pi^+\pi^-\pi^+\pi^- p)$	4.0 ± 0.5	4.8 ± 0.5	4.5 ± 0.6	4.4 ± 0.6
$\sigma(\gamma p \to \rho^0\pi^+\pi^- p)$	1.65 ± 0.3	2.3 ± 0.3	1.6 ± 0.3	1.4 ± 0.3
$\sigma(\gamma p \to \pi^+\pi^-\pi^-\Delta^{++})$	1.65 ± 0.2	1.8 ± 0.2	1.1 ± 0.2	1.15 ± 0.2
$\sigma(\gamma p \to \rho^0\pi^-\Delta^{++})$	0.55 ± 0.35	0.95 ± 0.25	0.43 ± 0.25	0.6 ± 0.2

Errors quoted include both systematic and statistical uncertainties.

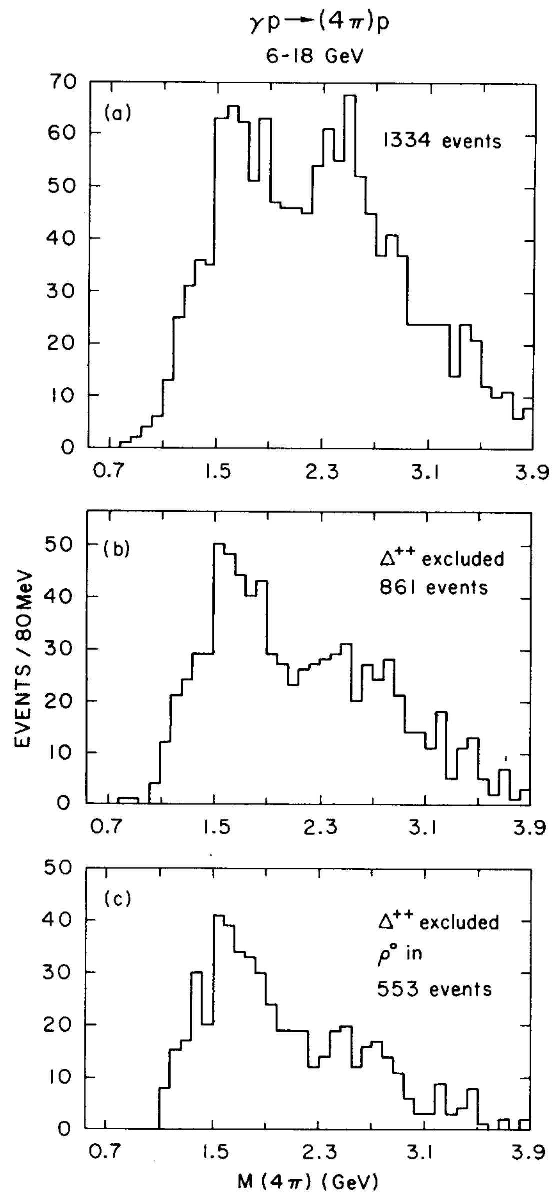


Fig. 5. $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$. Four-pion invariant mass distribution for $6 < E_\gamma < 18$ GeV. (a) All events. (b) Events not containing a Δ^{++}. (c) Events not containing a Δ^{++} and including a ρ^0.

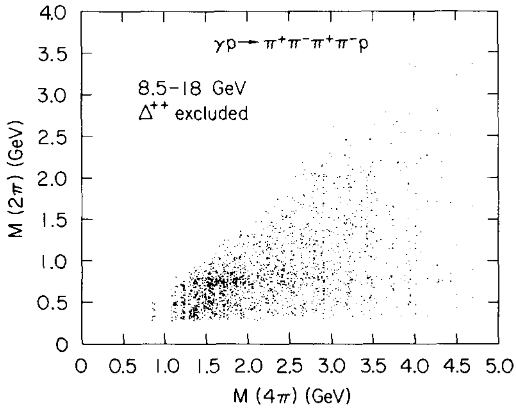


Fig. 6. $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$. Scatter-plot of the $\pi^+\pi^-$ invariant mass *versus* the four-pion invariant mass for $8.5 < E_\gamma < 18$ GeV for events with Δ^{++} excluded.

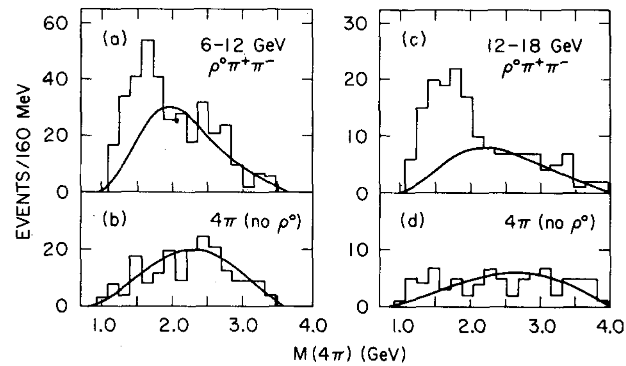


Fig. 7. $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$. Four-pion invariant mass distributions with Δ^{++} excluded. (a) $\rho^0\pi^+\pi^-$ mass distribution for $6 < E_\gamma < 12$ GeV. (b) 4π mass distribution for $6 < E_\gamma < 12$ GeV for events excluding a ρ^0. (c) $\rho^0\pi^+\pi^-$ mass distribution for $12 < E_\gamma < 18$ GeV. (d) 4π mass distribution for $12 < E_\gamma < 18$ GeV for events excluding a ρ^0.

To ascertain whether we are seeing a genuine effect not artificially produced by the ρ^0 cut, we have generated "peripheral" phase-space Monte Carlo events with exponential falloff in pion transverse-momenta squared [9] and in momentum transfer to the proton. These events have been subjected to the same cuts we have applied to the real data. We are unable to reproduce the 4π peak at 1.6 GeV whereas the higher mass part of the 4π mass distribution is well reproduced (solid line in figs. 7a, 7c). Furthermore, the 4π mass distribution with no ρ^0 is well described (solid lines in figs. 7b, 7d). We take this as evidence that the enhancement in the $\rho^0\pi^+\pi^-$ system is not a kinematical reflection of other gross features of data, nor is it an artifact generated by the cuts.

Table 2
Results from the fit to the $\rho\pi\pi$ spectrum; the minimum momentum-transfer effect has been taken into account

Photon energy (GeV)	6–12	12–18
Mass (MeV)	1622 ± 20	1624 ± 50
Width (MeV)	265 ± 90	433 ± 100

Using the Monte Carlo generated events to determine the shape of the background, we have fitted the 4π mass spectrum to a non-relativistic Breit-Wigner form in order to determine the parameters of the peak. The values we have found for the mass and width are shown in table 2 for the two E_γ selections considered: the values agree well between the two bins, although the width is rather poorly determined in both. To compute cross sections we have fitted the distributions in the ranges $E_\gamma = 6-12$ GeV and 12–18 GeV simultaneously using the same mass and width. The results are

(a) apparent mass $M = (1620 \pm 30)$ MeV and width $\Gamma = (310 \pm 70)$ MeV;

(b) a cross section roughly energy independent *:

(0.85 ± 0.3) μb for $E_\gamma = 6-12$ GeV,

(0.95 ± 0.3) μb for $E_\gamma = 12-18$ GeV.

Although the fitted values of "mass" and "width" do provide an adequate parameterization of our data, they depend strongly on assumptions made for the actual shapes of the resonance and background curves. This situation is aggravated by the observed enhancement being broad and lying close to the $\rho\pi\pi$ threshold where the shape of the phase space is crucial [10]. Using reasonable estimates for this phase space, we have obtained fitted mass values as low as 1.2 GeV. Therefore the values quoted should be taken with some reservation.

The $\rho\pi\pi$ events in the peak have a peripheral momentum-transfer distribution (fig. 8) which can be parameterized in the form $e^{(5.8 \pm 0.4)t'}$ where we define $t' = t - t_{\min}$. In contrast to this the ρ^0 in this reaction are produced with a much flatter t-distribution $e^{(1.4 \pm 0.6)t'}$ which is indicative of their secondary origin.

We have looked for possible two-body structure in the 4π decay. There is no evidence for a $\rho^0\rho^0$ channel which would of course violate charge conjugation invariance if we are really observing a diffractive process. We have also looked for possible structure in the $\rho^0\pi^\pm$ spectra (fig. 9): although they are substantially enhanced at low mass – as expected, since the $\rho\pi\pi$ spectrum itself peaks at low mass – we are unable to identify known structures.

Assuming that only $l = 0$, 1, or 2 waves can be present in the $\rho\pi\pi$ system, even

* The cross-section values, corrected by using the observed t-dependence and extrapolating at $t = 0$ – averaging over $M(4\pi)$ and E_γ – are

(1.23 ± 0.43) μb for $6 < E_\gamma < 12$ GeV,

(1.07 ± 0.34) μb for $12 < E_\gamma < 18$ GeV.

These values are used in the last section for the discussion on coupling constants.

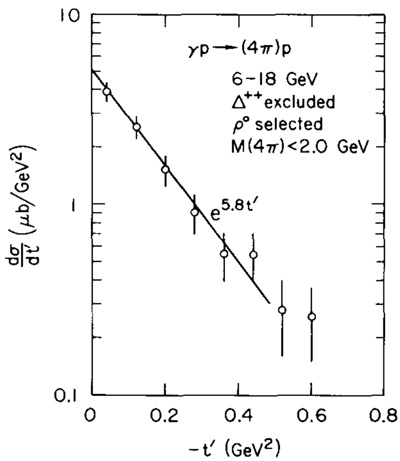


Fig. 8. $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$. Differential cross section *versus* momentum-transfer ($t' \equiv t - t_{min}$) for $6 < E_\gamma < 18$ GeV for events in the ρ' region.

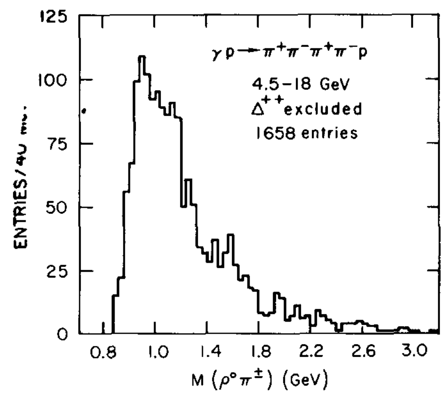


Fig. 9. $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$. $\rho^0\pi$ invariant mass distribution for $4.5 < E_\gamma < 18$ GeV for events excluding Δ^{++}.

I-spin states are excluded as they require either no ρ^0 or double ρ^0 production. This leaves only $I = 1$ and therefore $C = -1$.

4. Angular analysis of the decay

For an ($I = 1, J^P = 1^-$) state decaying into $\rho^0\pi^+\pi^-$, the following decay matrix element can be written:

$$M_D = \epsilon \cdot A = \epsilon \cdot \sum_{i=1}^{4} q_i \, \mathrm{BW}(m_i) \, ,$$

corresponding to the lowest angular momentum state, i.e., an s-wave dipion pair and an s-wave between the ρ^0 and the dipion system. ϵ is the 1^- polarization vector, q_i the momentum vector in the ith $\pi^+\pi^-$ center-of-mass frame, m_i the corresponding $\pi^+\pi^-$ invariant mass and $\mathrm{BW}(m)$ the ρ^0 Breit-Wigner form. For not too high a 4π mass it can be shown [16, 6] that a simple approximation for the vector A may be used

$$A \simeq A' = p_1 + p_2 \, ,$$

where p_1, p_2 are the momentum vectors of the two π^+ in the 4π rest frame. The quality of the analyzer A' is expected to become worse as the 4π mass increases and useful analysis using A' must be restricted to the lower part of the 4π peak. Fig. 10 shows the distribution of A' in the helicity system (defined by the direction of flight of the 4π in the overall center-of-mass): for $M(4\pi) < 1.6$ GeV one observes a rather pure $\sin^2\theta_{\mathrm{H}}$ distribution which is characteristic of s-channel helicity conservation for a $J^P = 1^-$ object. Since we know that this is a property of ρ^0 photoproduction, it gives strong indication that the 4π peak has the quantum numbers $J^P = 1^-$. The observation of this polarization phenomenon conclusively excludes a state of $J^P = 0^{\pm}$.

Conversely, we can use the property of s-channel helicity conservation to enhance the 4π peak without selecting on ρ^0. This is shown in fig. 11 for low momentum-

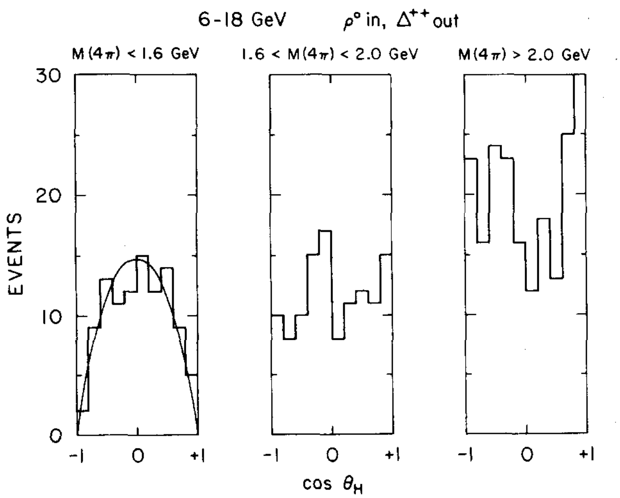


Fig. 10. $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$. Helicity polar angle distribution as a function of the 4π mass for $6 < E_\gamma < 18$ GeV for events including ρ^0 and excluding Δ^{++}.

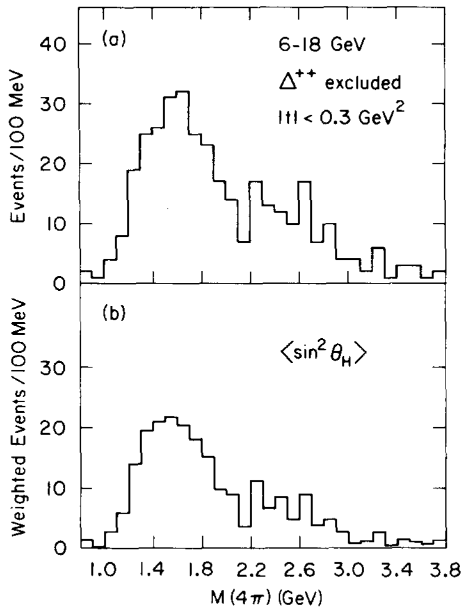


Fig. 11. $\gamma p \to \pi^+\pi^-\pi^+\pi^- p$. 4π mass distributions for $6 < E_\gamma < 18$ GeV for low momentum-transfer events ($|t| < 0.3$ GeV^2) excluding Δ^{++}. (a) Raw spectrum. (b) Spectrum weighted by $\sin^2\theta_H$.

transfer events ($|t| < 0.3$ GeV^2) and excluding events with Δ^{++}: the 4π mass spectrum weighted with $\sin^2\theta_H$ is displayed together with the raw spectrum. It is however difficult to estimate the mass and width of the enhancement in this way since the projection using the approximate analyzer A' distorts the original peak.

5. Discussion and results

Since our preliminary results have been presented [4, 5], a four-pion enhancement with quite similar parameters ($M \sim 1.6$ GeV, $\Gamma \sim 0.35$ GeV) has been found in e^+e^- collisions [11]. It is then quite tempting to assume that the two experiments are indeed seeing a new vector meson ρ'; if so, the coupling constant to the photon, as derived from the two experiments, should agree. Unfortunately, in the case of photoproduction, this is not directly accessible: assuming "generalized" vector meson dominance of the electromagnetic current, one is led to consider two possibly dominant diagrams (figs. 12a and 12b). If we assume that the amplitude corresponding to diagram (b) is negligible compared with that corresponding to (a) and that the amplitudes for ρp and ρ'p elastic scattering are comparable, we can derive a coupling constant $f_{\gamma\rho'}$ from the relationship

$$\frac{\sigma(\gamma p \to \rho p)}{\underset{\hookrightarrow 4\pi^\pm}{\sigma(\gamma p \to \rho' p)}} = \left(\frac{f_{\gamma\rho}}{f_{\gamma\rho'}}\right)^2 \frac{\Gamma_{\rho'}}{\Gamma(\rho' \to 4\pi^\pm)} \,. \tag{5}$$

Analogously, the peak cross sections for e^+e^- production are related by

$$\left[\frac{\sigma(e^+e^- \to \rho)}{\underset{\hookrightarrow 4\pi^\pm}{\sigma(e^+e^- \to \rho')}}\right]_{\text{peak}} = \left(\frac{f_{\gamma\rho}}{f_{\gamma\rho'}}\right)^2 \frac{\Gamma^2_{\rho'}}{\Gamma_\rho \Gamma(\rho' \to 4\pi^\pm)} \,. \tag{6}$$

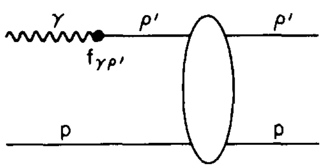
Using the measured photoproduction cross sections for ρ (from ref. [12]), for ρ' (from this experiment), and the ρ colliding-beam cross section [13], eqs. (5) and (6) would predict

$$\sigma_{\text{peak}}(e^+e^- \to \rho' \to 4\pi^\pm) = (17 \pm 6)\text{ nb}\,,$$

consistent with the measured value of (28 ± 12) nb of ref. [11].

From our experiment alone we cannot say anything about the coupling constant $f_{\gamma\rho'}$ since we do not know the branching ratio for $\rho' \to 4\pi^\pm$. However, other decay modes can be considered:

(i) the $\pi^+\pi^-$ mode seems to be quite suppressed, although two experiments [3]



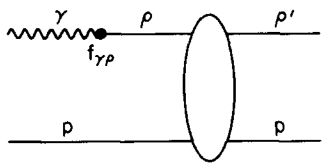


Fig. 12. Two relevant diagrams in ρ' photoproduction.

have shown some indication for a structure in $M(\pi^+\pi^-)$ near 1.5 GeV. Using the mass and width we have determined, we estimate *

$$\frac{\Gamma(\rho' \to \pi^+\pi^-)}{\Gamma(\rho' \to 4\pi^\pm)} < 0.14 . \tag{7}$$

(ii) the decays involving π^0 such as $\omega\pi^0$ and $\rho\pi^0\pi^0$ can be estimated [16] from the data of refs. [6, 14] to be

$$\frac{\Gamma(\rho' \to \pi^+\pi^-\pi^0\pi^0)}{\Gamma(\rho' \to 4\pi^\pm)} < 1.0 .$$

We finally find

$$0.15 < \left(\frac{f_{\gamma\rho'}}{f_{\gamma\rho}}\right)^2 < 0.30 .$$

Finally, we compare our results with data on $\bar{\mathrm{p}}\mathrm{p}$ annihilations at rest. Although the mass is somewhat higher (1876 MeV), it is interesting to make a comparison since 80% of the annihilation into four charged pions proceeds through the $^3\mathrm{S}_1$ $\bar{\mathrm{p}}\mathrm{p}$ state [15] which has the same quantum numbers as the isovector electromagnetic current. It is found that $\rho^0\pi^+\pi^-$ is the dominant (83%) final state in the $^3\mathrm{S}_1$ annihilation into $4\pi^\pm$. Taking the total annihilation into $\pi^+\pi^-$ (which is a pure $^3\mathrm{S}_1$ state) we find

$$\frac{\bar{\mathrm{p}}\mathrm{p}\,(I=1, J^P=1^-) \to \pi^+\pi^-}{\bar{\mathrm{p}}\mathrm{p}\,(I=1, J^P=1^-) \to \pi^+\pi^+\pi^-\pi^-} = 0.07 ,$$

consistent with our result (7), bearing in mind that the ($\bar{\mathrm{p}}\mathrm{p}$) mass is significantly higher than the ρ' mass.

6. Conclusion

We have studied the photoproduction of four charged pions between 4.5 and 18 GeV and have found evidence for an enhancement in the 4π mass spectrum at a mass of about 1.6 GeV. Since (a) the enhancement is produced peripherally, (b) the cross section is consistent with being energy independent, (c) the isospin and charge conjugation are $I = 1$, $C = -1$, (d) a similar effect is observed at the same mass in e^+e^- collisions and (e) some evidence exists for a broad structure at the same mass in the photoproduced $\pi^+\pi^-$ spectrum, we tentatively identify this structure with an

* Since these $\pi^+\pi^-$ photoproduction experiments are done on complex nuclei, we have corrected for the minimum momentum-transfer effect which considerably distorts the resonance peak in the case of nuclear production.

$I = 1$ vector meson ρ' although we have not proved the resonant nature of the enhancement. Assuming $J^P = 1^-$ we have shown that s-channel helicity is conserved at the γ–ρ' vertex and have determined limits on the γ–ρ' coupling constant.

We wish to thank the streamer-chamber technical staff and our scanning, measuring and data-analysis staff for their essential contributions to this work. It is a pleasure to thank the accelerator and computer operating groups and the machine shop personnel for their assistance.

References

[1] B. Bartoli, B. Coluzzi, F. Felicetti, V. Silvestrini, G. Goggi, D. Scannicchio, G. Marini, F. Massa and F. Vanoli, Nuovo Cimento 70 (1970) 615.
[2] G. McClellan, N. Mistry, P. Mostek, H. Ogren, A. Osborne, A. Silverman, J. Swartz, R. Talman and G. Diambrini-Palazzi, Phys. Rev. Letters 23 (1959) 718.
[3] F. Bulos, W. Busza, R. Giese, E.E. Kluge, R.R. Larsen, D.W.G.S. Leith, B. Richter, S.H. Williams, B. Kehoe, M. Beniston and A. Stetz, Phys. Rev. Letters 26 (1971) 149;
H. Alvensleben, V.J. Becker, W.K. Bertram, M. Chen, K.J. Cohen, R.T. Edwards, T.M. Knasel, R. Marshall, D.J. Quinn, M. Rohde, G.H. Sanders, H. Schubel and S.C.C. Ting, Phys. Rev. Letters 26 (1971) 273.
[4] M. Davier, I. Derado, D.C. Fries, F.F. Liu, R.F. Mozley, A. Odian, J. Park, W.P. Swanson, F. Villa and D. Yount, Report No. SLAC-PUB-666 and contribution to the 4th Int. Conf. on electron and photon interactions at high energy, Liverpool, September 14–20, 1969.
[5] M. Davier, I. Derado, D.C. Fries, F.F. Liu, R.F. Mozley, A. Odian, J. Park, W.P. Swanson, F. Villa and D. Yount, contribution to the 5th Int. Conf. on electron and photon interactions at high energies, Cornell University, August 23–27, 1971.
[6] G. Smadja, H.H. Bingham, W.B. Fretter, W.J. Podolsky, M.S. Rabin, A.H. Rosenfeld, G.P. Yost, J. Ballam, G.B. Chadwick, Y. Eisenberg, E. Kogan, K.C. Moffeit, P. Seyboth, I.O. Skillicorn, H. Spitzer and G. Wolf, LBL-991 (1972);
H.H. Bingham, W.B. Fretter, W.J. Podolsky, M.S. Rabin, G. Smadja, A.H. Rosenfeld, G.B. Yost, J. Ballam, G.B. Chadwick, Y. Eisenberg, E. Kogan, K.C. Moffeit, P. Seyboth, I.O. Skillicorn, H. Spitzer and G. Wolf, Phys. Letters 41B (1972) 635.
[7] D.C. Fries, M. Davier, I. Derado, F.F. Liu, R.F. Mozley, A.C. Odian, J. Park, W.P. Swanson, F. Villa and D. Yount, to be published in Nucl. Instr.
[8] F.F. Liu, M. Davier, I. Derado, D.C. Fries, R.F. Mozley, A.C. Odian, J. Park, W.P. Swanson, F. Villa and D. Yount, Nucl. Phys. B47 (1972) 1.
[9] W. Kittel and L. Van Hove, CERN preprint D. Ph. II/Phys. 70–8 (1970).
[10] D. Mortara, University of Illinois preprint (October 1972).
[11] G. Barbarino, M. Grilli, E. Iarocci, P. Spillantini, V. Valente, R. Visentin, F. Ceradini, M. Conversi, L. Paoluzi, R. Santonico, M. Nigro, L. Trasatti and G.T. Zorn, Nuovo Cimento Letters 3 (1972) 689.
[12] J. Park, M. Davier, I. Derado, D.C. Fries, F.F. Liu, R.F. Mozley, A.C. Odian, W.P. Swanson, F. Villa and D. Yount, Nucl. Phys. B36 (1972) 404.
[13] G. Parrour, doctoral dissertation, Université de Paris, LAL-1257 Orsay (1971).
[14] G. Bacci, R. Baldini-Celio, G. Capon, C. Mencuccini, G.P. Murtas, G. Penso, G. Salvini, M. Spinetti, B. Stella and A. Zallo, LNF 72-68 (1972).
[15] J. Diàz, Ph. Gavillet, G. Labrosse, L. Montanet, W.P. Swanson, P. Villemoes, M. Bloch, P. Frenkel, C. Ghesquière, E. Lillestøl and A. Volte, Nucl. Phys. B16 (1970) 239.
[16] M. Davier, Review presented at the 14th Int. Conf. on high energy physics, Chicago, 1972, to be published.