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High-Energy Photoproduction of $\rho'(1600)$

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A resonance is observed in the diffractively photoproduced two-pion final state with a mass of ~1600 MeV and a width of ~300 MeV. The four-pion distribution is characterized by a width of ~ 600 MeV and peaks around 1500 MeV.

The $\rho'(1600)$ meson has been observed as an enhancement in the four-pion final state both in e^+e^- collisions[1] and in photoproduction experiments.[2-5] Estimates of the mass vary from 1430 to 1620 MeV, while estimates of the width vary from 310 to 650 MeV. A nonresonance interpretation of the photoproduction data as a purely kinematic enhancement in the $\rho\pi\pi$ production amplitude also appears to describe these data adequately.[6] Indications of the existence of the two-pion decay mode have come from two photoproduction experiments[5,7] and from a phase-shift analysis of the reaction $\pi^-p\rightarrow\pi^+\pi^-n$.[8] It has been assumed that the branching ratio of $\rho'(1600)$ into two pions is small, although no published measurement of this number exists.

We report here on a study of high-mass two- and four-pion final states photoproduced in the wide-band neutral beam at Fermilab.[9] Our exposure consisted of approximately 6×10^{11} photons with energies greater than 50 GeV incident on a 2-cm-long (5% of a radiation length) scintillator target. The products of the interactions in the target were detected in the multiparticle spectrometer system described in Ref. 9. Two Cherenkov counters with pion thresholds of 6 and 12 GeV were used for particle indentification. A large lead-glass array detected γ rays accompanying the charged particles. Two-pion events were recorded under a trigger designed to accept e^+e^- pairs. The trigger had a finite efficiency for $\pi^+\pi^-$ pairs; however, uncertainties in the calculation of this efficiency result in a relatively large uncertainty in the absolute normalization for $\pi^+\pi^-$ states. Four-pion events were recorded under a trigger requiring at least three tracks in the spectrometer and a minimum energy deposition of 40 GeV in the hadron calorimeter. Approximately 25% of the data were taken with 6 radiation lengths of lead inserted into the neutral beam, enabling us to measure the contribution of K_L^0- and neutron-induced backgrounds.

The results presented here are based on a sample of 20 000 diffractively produced two-pion events with a mass >1 GeV and 150 000 diffractively produced four-pion events. Pions are identified by the two threshold Cherenkov counters. Any particle not positively identified as either a kaon, proton, or electron is assumed to be a pion. In order to ensure that we are looking at exclusive final states, the data are subjected to several cuts: (1) The number of tracks must be either two or four and the total charge zero; (2) there must be less than a total of fifteen unused hits in the fifteen proportional chamber planes and no visible tracks not originating at the production vertex; and (3) there must be no evidence for γ rays present in the lead glass. All events analyzed carry visible energy in the range 50 to 200 GeV.

To calculate the cross sections for the photoproduction of diffractive two- and four-pion states we correct the measured mass and transverse momentum distributions for geometrical acceptance, triggering efficiency, track reconstruction efficiency, absorption in the target, and electronics deadtime. In addition, the measured K_L^0- and n-induced background have been subtracted from all distributions presented here. This background subtraction amounts to a 15% correction for both the two- and four-pion samples. The errors shown in the figures are statistical only. We estimate an absolute normalization error of ±50% for the two-pion final state and ±15% for the four-pion final state. All cross sections are quoted per nucleon, i.e., assuming an $A^{1.0}$ dependence.

In Fig. 1 we display the P_T^2 distribution for two-pion events which have a mass greater than 1 GeV. The distribution shows the very strong forward peaking characteristic of diffractive photoproduction off carbon. The solid curve is the best fit by the sum of two exponentials. The best-fit value of the forward (coherent) slope is 59.0 ± 1.4 GeV^{-2}. The incoherent contribution is

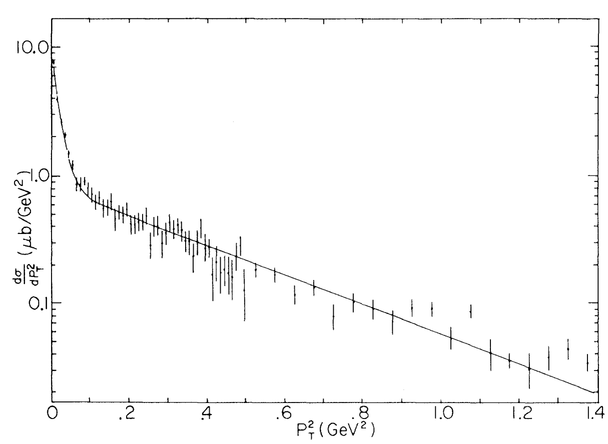

FIG. 1. The P_T^2 distribution for exclusively produced two-pion final states with masses > 1 GeV.

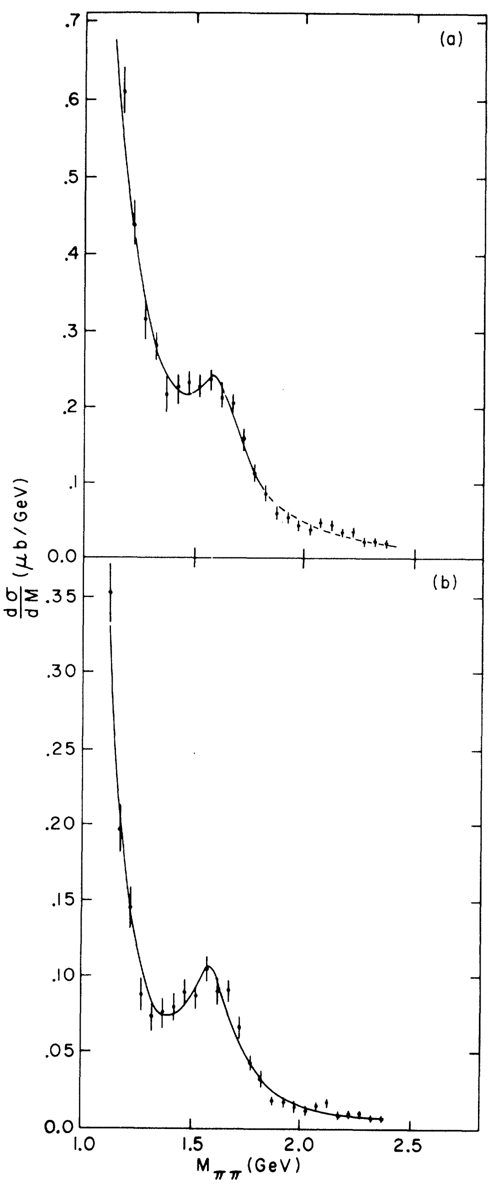

FIG. 2. The two-pion mass spectrum for (a) all events; (b) those events having $P_T^2 < 0.05$ GeV^2. The fit is described in the text.

measured to have a slope of 2.71 ± 0.04 GeV^{-2} although we consider this number to be meaningless since it contains a large contribution from three-pion events with the π^0 missing the lead glass. The shape of the P_T^2 distribution is observed to be independent of the two-pion mass. In Figs. 2(a) and 2(b) we show the mass distributions for all two-pion events and for the subset of those events lying in the region $P_T^2 < 0.05$ GeV^2. A two-pion resonance is clearly present at a mass of ~1600 MeV. The fits shown are the incoherent sum of a monotonically decreasing background plus a Breit-Wigner resonance shape. The fit values of the two curves are

$$M = 1600 \pm 10 \text{ MeV}; \quad \Gamma = 283 \pm 14 \text{ MeV}.$$

The errors quoted are statistical only. We estimate that there is an additional 40-MeV uncertainty in both the mass and width due to the choice of the form used for the background. The total integrated cross section is

$$\sigma(\gamma + \mathrm{C} \to \rho' \to \pi^+\pi^-) = 67 \pm 33 \text{ nb/nucleon},$$

where the error is entirely systematic. Approximately half of the cross section appears to be coherently produced. A J^P assignment for the resonance through a study of the helicity-angle distribution is not possible because of the large triggering biases.

In Fig. 3 we display the P_T^2 distribution for the four-pion final state. The shape is very similar to Fig. 1. The fit shown is the sum of three exponentials. The coherent slope is 64.6 ± 0.6 GeV^{-2} and the incoherent contribution is described by the sum of two exponentials with slopes of 9.93 ± 0.15 GeV^{-2} and 2.79 ± 0.02 GeV^{-2}. As in the two-pion final state we attach no significance to the incoherent slopes. Figure 4 shows the four-pion final-state mass distribution both with and without a P_T^2 cut. The distribution cannot be described by a single Breit-Wigner shape of arbitrary mass and width. The curves shown in Fig. 4 are Breit-Wigner shapes with the same mass and width as the observed two-pion resonance and are intended to demonstrate our conclusion that there are significant additional sources of four-pion events besides the $\rho'(1600)$. This conclusion remains unchanged even if we select only those four-pion events which appear to consist of $\rho\pi\pi$ since only 20% of the events in Fig. 4 fail to satisfy this criterion. The four-pion final state appears to be dominated by the production of a low-mass pion pair accompanied by a ρ meson. In Fig. 5 we show the mass distribution for the lowest $\pi^+\pi^-$ pair within the event [5(a)], and the mass distribution for the pion pair opposite this low-mass pair [5(b)]. The total cross section

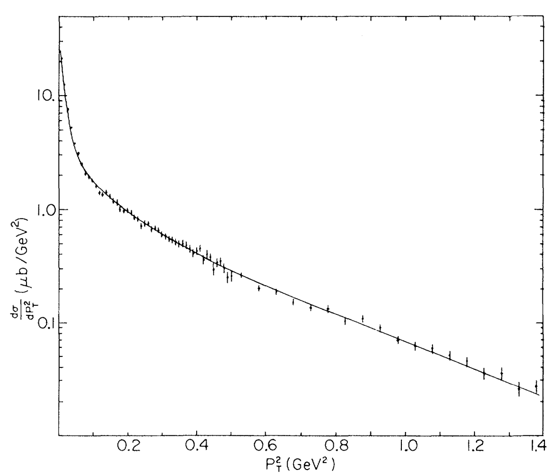

FIG. 3. The P_T^2 distribution for exclusively produced four-pion final states.

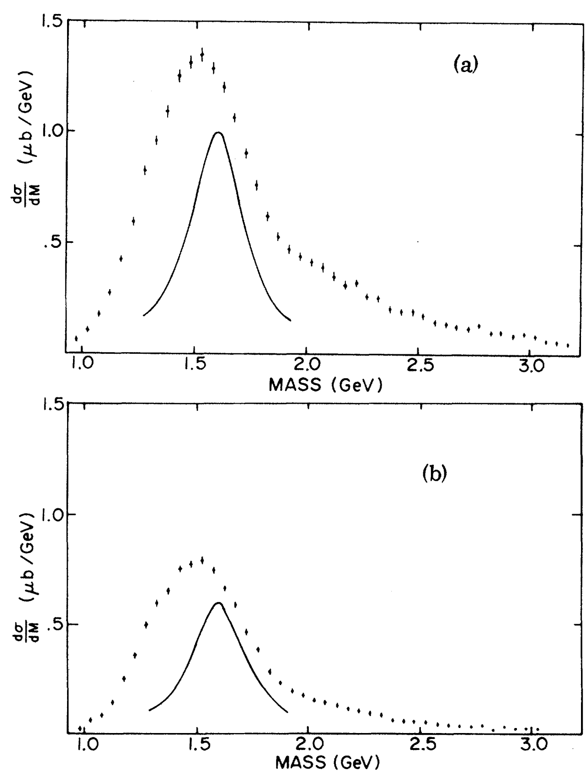

FIG. 4. The four-pion mass spectrum for (a) all events; (b) those events having $P_T^2 < 0.05$ GeV^2. The solid curves are Breit-Wigner shapes with mass 1600 MeV and width 283 MeV.

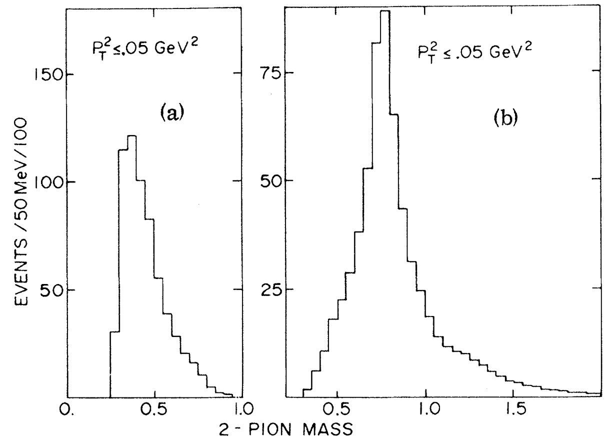

FIG. 5. (a) The distribution of the lowest mass $\pi^+\pi^-$ pair within the four-pion events shown in Fig. 4(b). (b) The mass disbribution of the pion pair opposite the pair entered into (a).

obtained by integrating the four-pion distribution over all masses is

$$\sigma(\gamma + C \to 4\pi \text{ exclusive}) = 1.02 \pm 0.15 \ \mu\text{b/nucleon}.$$

In conclusion, we have observed the diffractive photoproduction of a two-pion resonance with a mass of 1600 MeV, a width of 280 MeV, and a cross section of 67 nb. If the true width of the $\rho'(1600)$ is assumed to be given by the two-pion data, then the four-pion distribution observed indicates the presence of major contributions from other than this resonance.

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