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Observation of the $\rho'(1600)$ in the channel $\gamma p \to \pi^+\pi^- p$

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ABSTRACT

A dipion enhancement of mass 1.59 GeV and width 0.23 GeV is observed in the channel $\gamma p \to \pi^+\pi^- p$. The spin-parity of the enhancement is consistent with being 1^-.

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The 2π decay of the $\rho'(1600)$ is of interest since only through observation of the ρ' in several final states can the possibility that the state is a non-resonant threshold effect be excluded. Evidence for this decay mode of the $\rho'(1600)$ has been previously found in $\pi\pi$ phase shift analyses and in photon-carbon and photon-beryllium interactions(1,2).

We report here the first observation of the $\rho'(1600)$ in the channel

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

The data presented here originate from a general study of the photoproduction of multiparticle final states carried out at the CERN SPS using the Omega Spectrometer with a tagged photon beam. The beam gives photons over an energy range 20 - 70 GeV with an intensity of $\sim 2 \times 10^5$ photons/burst. A Cerenkov counter was used for charged particle identification. The trigger for channel (1) required two particles to traverse the spectrometer and hit a hodoscope behind the Cerenkov counter. Electromagnetic background was reduced by a veto counter in the electromagnetic plane. A full description of the apparatus is given elsewhere(3).

Channel (1) was selected from events with two or three charged tracks which originated from a vertex within the hydrogen target. The two charged tracks that passed through the Cerenkov counter had to be consistent with being a $\pi^+\pi^-$ pair. To eliminate residual electromagnetic background the pions were required to make an angle greater than 7mr with the electromagnetic plane.

Fig. 1 shows the (missing mass)^2 distribution calculated from the $\pi^+\pi^-$ pair and the beam. A clear recoil proton peak is present. The final selection of channel (1) was made by requiring that $|(\text{missing mass})^2| < 5.0\ (\text{GeV})^2$.

The $\pi^+\pi^-$ mass spectrum is given in Fig. 2. The figure shows that the channel is dominated by rho production. There is also an enhancement of $\sim$ 300 events at

$\sim$1.6 GeV. This can be seen in Fig. 3 where the $\pi^+\pi^-$ mass distribution is shown on a logarithmic plot together with an insert giving the mass region 1.0 - 2.5 GeV on a linear scale. On Fig. 3(a) a smooth curve has been drawn through the data points on the high mass side of the rho and through the 2 - 3 GeV mass region. A broad enhancement above this curve is evident at a mass of $\sim$ 1.6 GeV.

To determine the mass, M, and width, Γ, of the enhancement we have fitted a relativistic Breit-Wigner and second-order polynomial background to the mass region 1.1 - 2.4 GeV (the result of the fit is shown dotted on Fig.3(a) and as solid lines on Fig. 3(b)). We have taken the width to be mass independent and have obtained $M = 1.59 \pm 0.02$ GeV and $\Gamma = 0.23 \pm 0.08$ GeV.

We consider now the spin of the enhancement. To investigate the spin we have calculated the spherical harmonic sums $\Sigma\, Y_l^0\,(\theta)$ where θ is the polar angle of the π^+ in the two pion rest frame; the z axis is given by the direction of the two pion system in the overall γp system and the sum is over all events within a given range of two pion masses. Only $\Sigma\, Y_2^0$ gives a significant peak in the region of the enhancement. The quantity $-\sqrt{20\pi}\ \Sigma\, Y_2^0$ is shown in Fig. 4. For an s-channel helicity conserving 1^- state this quantity would be equal to the numbers of events in the mass plot in the absence of significant biases. We have verified that acceptance biases are unimportant for the Y_2^0 moment. The dotted curve on Fig. 4 is the result of the fit to the mass spectrum (described below) superimposed on a smooth handrawn background (solid curve); the dotted curve describes well the distribution of $-\sqrt{20\pi}\ \Sigma\, Y_2^0$. We conclude that the enhancement is consistent with being due to an s-channel helicity-conserving 1^- state.

The mass of the enhancement is in good agreement with that observed for the photoproduced $\rho'(1600)$[4,5]. The mass, together with the spin being consistent with 1^-, leads us to identify this enhancement as the 2π decay mode of the $\rho'(1600)$. We remark that the spin-parity analysis cannot rule out spin 3 for the enhancement, but that identification of the enhancement with the g(1680) is made unlikely by the $\sim$ 100 MeV difference in mass. The width found here is lower than that obtained from the 4π decay mode of the $\rho'(1600)$ in both photoproduction and e^+e^- annihilation[4,5,6]. We shall return to this point following a discussion of the ρ' branching ratio.

From the fit, after correcting for the difference in ρ^0 and ρ' acceptance, we obtain $\sigma(\rho' \rightarrow \pi^+\pi^-) / \sigma(\rho^0) = 0.01 \pm 0.002$. Taking a ρ^0 cross section of 10μb[7], and using our $\sigma(\rho' \rightarrow \pi^+\pi^+\pi^-\pi^-)$ of 0.8 ± 0.3μb (determined by taking all 4π events in the mass region 1.2 - 1.8 GeV to be ρ′(1600)), we obtain a branching ratio, R, $\rho' \rightarrow \pi^+\pi^- / \rho' \rightarrow \pi^+\pi^+\pi^-\pi^-$ of 0.13 ± 0.05. This value is in agreement with the upper limits found in photoproduction experiments and in the analysis of e^+e^- data[4,8]. If it is assumed that the ρ′(1600) decays into ρε this value of R gives a branching ratio, B, $\rho' \rightarrow 2\pi / \rho' \rightarrow$ all of ∿ 0.1. We now compare our result for B with that obtained in phase shift analyses.

Phase shift analyses of the CERN-Munich experiment[9] have lead to ambiguous solutions[10,11]. In recent attempts to constrain the solutions further, Frogatt et al.[1] require a ρ′(1600) while Martin et al.[12] do not. A partial wave analysis of the $\pi^+\pi^-$ data from an experiment using the CERN Omega Spectrometer favours a solution without a ρ′(1600), implying $B < 0.1$[13]. In those phase shift analyses where the ρ′(1600) is required, a branching ratio B ∿ 0.25 is obtained.

If we assume that all 4π events are ρ′(1600), our results favour those phase shift analyses which require $B < 0.1$. However our data cannot exclude larger values of B. This follows from the suggestion that there is a large non-resonant background under the ρ′(1600) in the 4π final state[14] and from the possibility that the $\rho' \rightarrow 2\pi$ mass spectrum could be distorted through interference with the tail of the ρ. Both these backgrounds could result in B being underestimated in photoproduction experiments; the backgrounds could also explain differences between the ρ′ widths in the 2π and 4π channels.

We are grateful to the Omega Group at CERN for their help in running the spectrometer and providing online and offline software. The work of the technical support staff in our home institutions has been invaluable. We thank the Science Research Council (UK), the BMFT (W. Germany) and IN2P3 (France) for their generous support.

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Figure Captions

1. $(\text{Missing mass})^2$ distribution for $\gamma p \to \pi^+\pi^-$ (missing mass).

2. $\pi^+\pi^-$ mass distribution for the channel $\gamma p \to \pi^+\pi^- p$.

3. $\pi^+\pi^-$ mass distribution for the channel $\gamma p \to \pi^+\pi^- p$.
   (a) The smooth curve is a handrawn background curve. The dotted line is from the fit described in the text.
   (b) The two curves are from the fit described in the text. The upper curve gives the fitted Breit-Wigner + polynomial background while the lower curve shows the background only.

4. $-\sqrt{20}\pi \; \Sigma \; Y_2^0(\theta)$ for the channel $\gamma p \to \pi^+\pi^- p$. The solid curve is a handrawn background curve. The dotted line is from the fit described in the text.

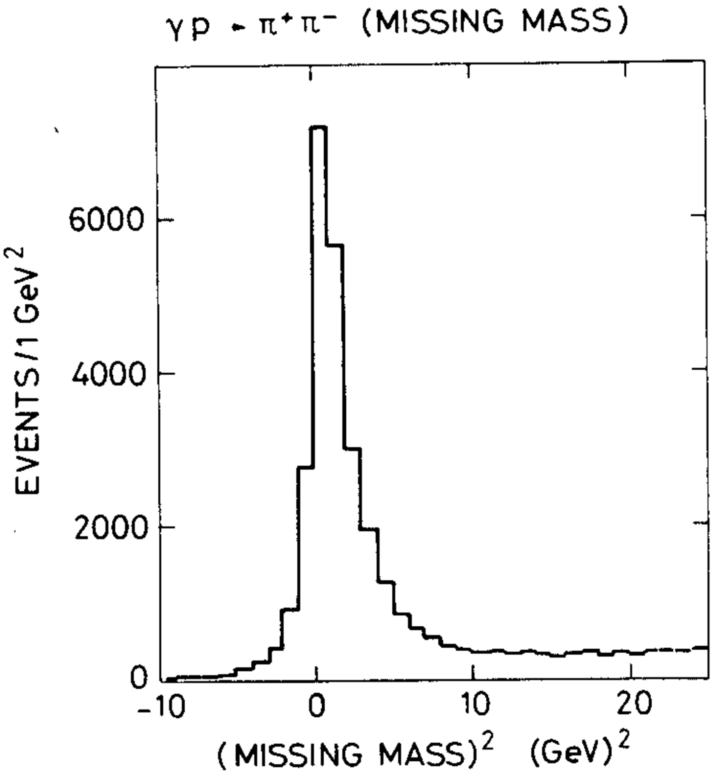
γp → π⁺π⁻ (MISSING MASS)
EVENTS/1 GeV²
6000
4000
2000
0
−10
0
10
20
(MISSING MASS)² (GeV)²

Fig. 1

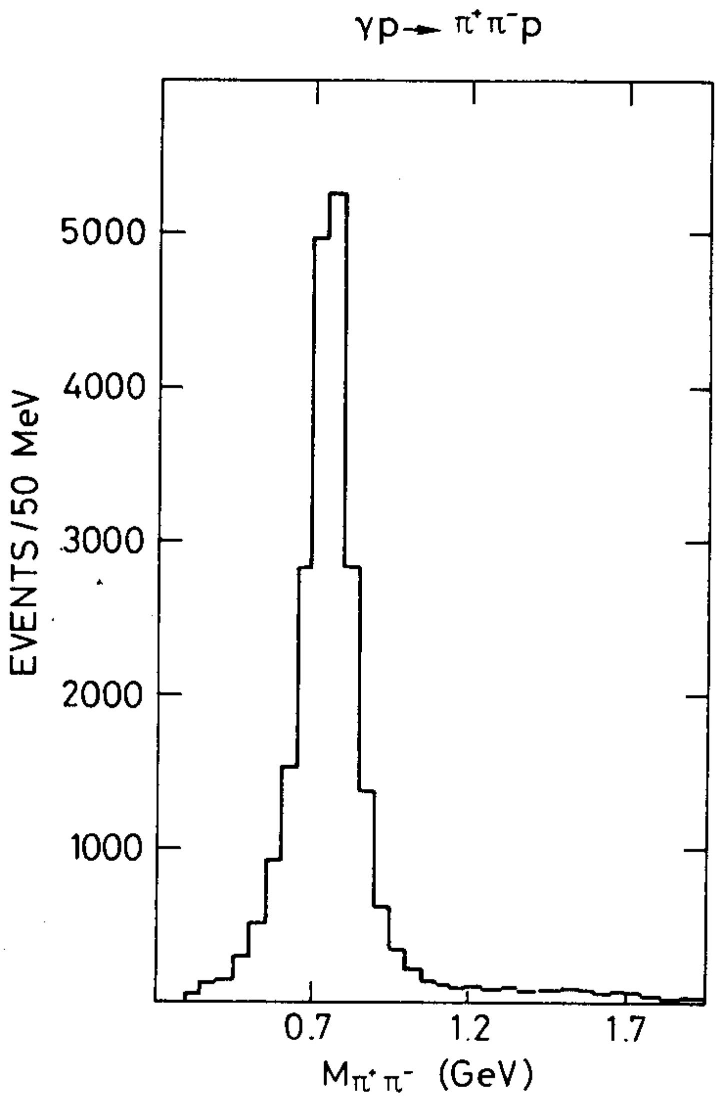

Fig. 2

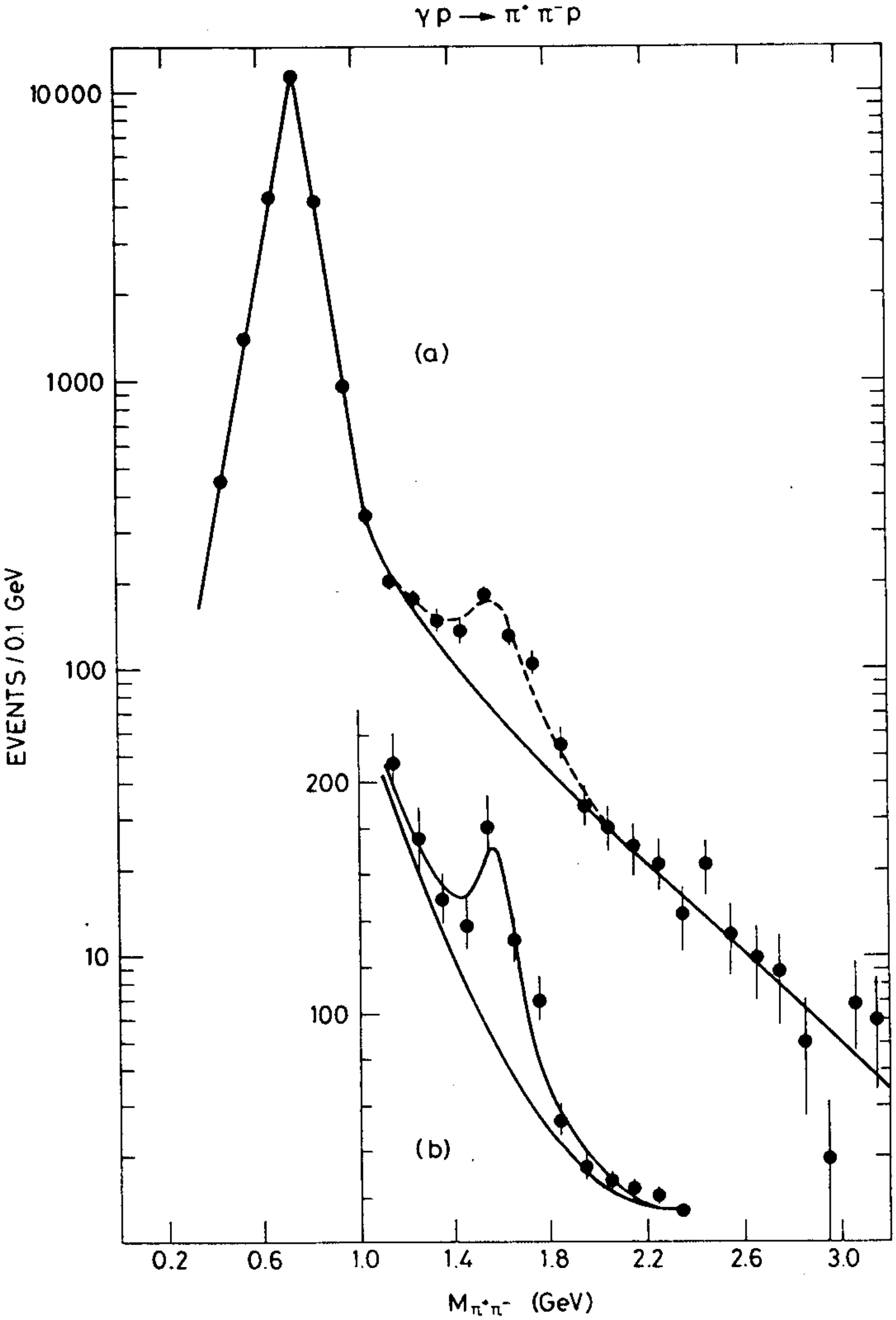
γp → π⁺π⁻p
10000
1000
100
10
(a)
(b)
200
100
EVENTS / 0.1 GeV
0.2
0.6
1.0
1.4
1.8
2.2
2.6
3.0
$M_{\pi^+\pi^-}$ (GeV)

Fig. 3

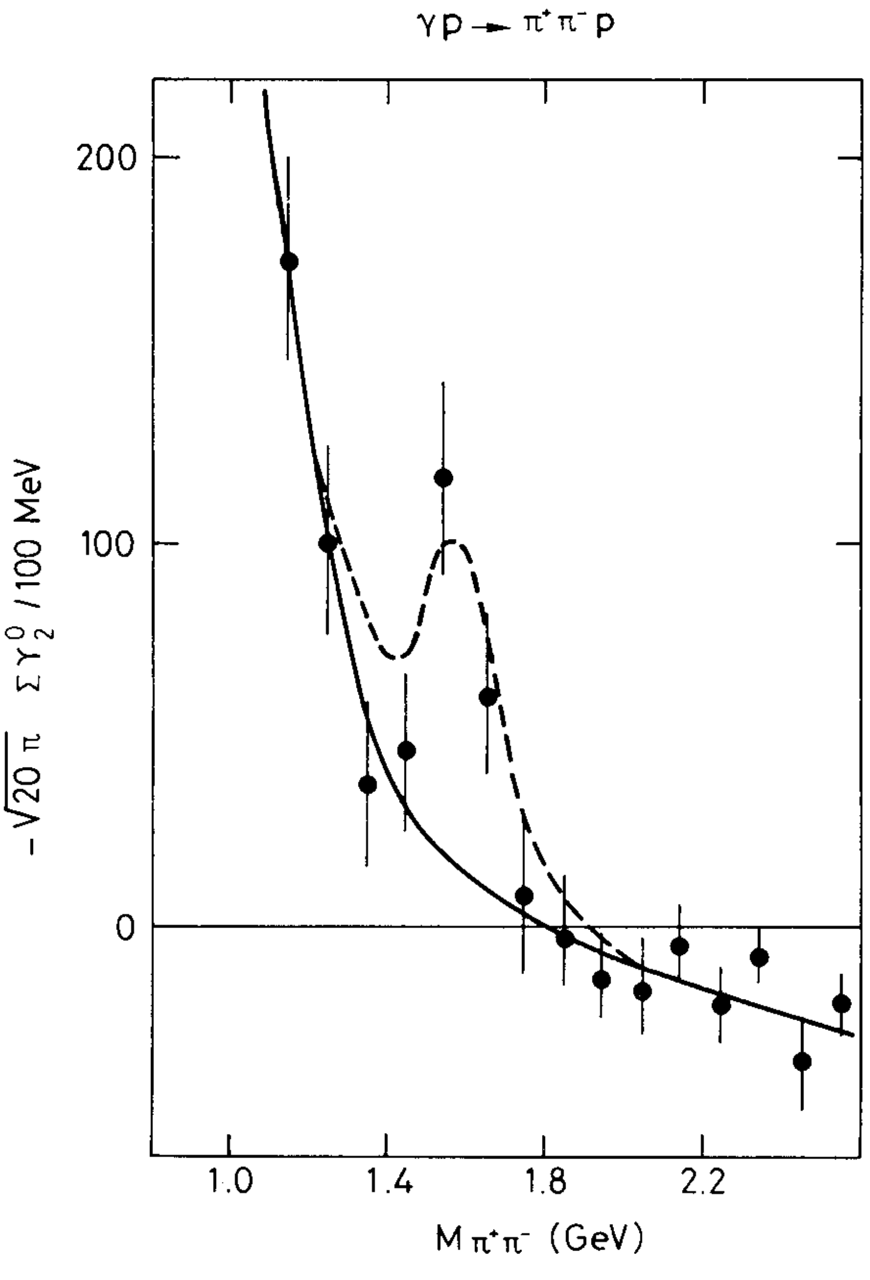

Fig. 4