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17 February 1983PHOTOPRODUCTION OF AN ISOSCALAR 3π RESONANCE AT 1.67 GeVBonn¹-CERN²-Glasgow³-Lancaster⁴-Manchester⁵-Paris VI⁶-Rutherford⁷-
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ABSTRACT

A $\rho\pi$ enhancement with mass 1.67 ± 0.02 GeV and width 0.16 ± 0.02 GeV is observed in the channel $\gamma p \rightarrow p\pi^+\pi^-\pi^0$. Assuming an incoherent background, the cross section $\times$ branching ratio is 100 ± 20 nb. A spin-parity analysis favours $J^P = 1^-$. The enhancement is most simply interpreted as a radial recurrence of the ω meson.

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The search for radial recurrences of the ρ , ω , and ϕ vector mesons has so far produced only one well-established resonance, the $\rho'(1600)$ [1]. Recently, some evidence for a $\phi'(1680)$ state has been found in e^+e^- interactions at the DCI storage rings [2]. However, the interpretation of these data is complicated by the fact that several interference phenomena are required to give a consistent picture.

We report here on the observation of an enhancement of mass 1.67 GeV in the photoproduced $\pi^+\pi^-\pi^0$ mass spectrum. The enhancement has $I^G = 0^-$ and $C = -1$. A spin-parity analysis favours $J^P = 1^-$.

The data presented here are from a photoproduction experiment (WA57) [3] using the CERN SPS tagged photon beam [4] at the Omega spectrometer. The incident photons were partially polarized and were tagged in the energy range 20 to 70 GeV. The data for the reaction

$$\gamma p \rightarrow p \pi^+ \pi^- \pi^0 \quad (1)$$

come from a trigger which required between two and five forward charged particles together with a signal from the lead-glass array indicating the presence of one or more γ -rays. Pattern recognition and geometrical reconstruction were performed by the program TRIDENT [5].

Event selection for channel (1) required two or three charged particles to be reconstructed to a single vertex in the liquid hydrogen target. In addition, two γ -rays had to be detected by the photon detector. One-constraint fits were performed to reject pairs of photons which did not originate from π^0 's, and the $\gamma\gamma$ mass was required to be in the range 120–150 MeV. Final selection of reaction (1) required that the $|(missing\ mass)^2|$ to the 3π system and the beam be less than 5 GeV^2 . The inelastic background remaining after this cut is about 20% and the background from non- π^0 $\gamma\gamma$ pairs is about 5%.

The $\pi^+\pi^-\pi^0$ mass spectrum (Fig. 1a) shows that in addition to ω and ϕ meson production, there is a continuum of 3π states and a third enhancement at about 1.67 GeV which is seen more clearly in Fig. 1b. Some evidence for this state has been reported from an earlier photoproduction experiment [6] where the statistical significance was poor; we now confirm this

result. A detailed analysis of the reaction (1) over the whole 3π mass range will be published separately; in this letter, only the 1.67 GeV peak is discussed.

A fit of an incoherent sum of a cubic polynomial background and a simple Breit-Wigner function to the mass spectrum gives the following parameters for the resonance:

$$\begin{aligned} M &= 1.67 \pm 0.02 \text{ GeV} \\ \Gamma &= 0.16 \pm 0.02 \text{ GeV} . \end{aligned}$$

From the total number of events in the peak, we calculate a cross section times branching ratio of

$$\sigma \cdot B = 100 \pm 20 \text{ nb}$$

(this result is insensitive to assumptions about the production and decay mechanisms of the 3π system).

From consideration of the ρ , ω , ϕ vector-meson nonet and with the assumption that the peak is an isoscalar member of a nonet containing the $\rho'(1600)$, we would expect a $\sigma \cdot B$ of less than 20 nb for a $\phi'(1680)$ interpretation of the peak. We have made fits allowing interference between the Breit-Wigner and background to determine if $\sigma \cdot B$ can be reduced to a value compatible with that expected for a ϕ' . In a fit allowing interference with a real background a value of $\sigma \cdot B$ of 100 nb was again found, but with a mass of 1.62 ± 0.03 GeV for the resonance (dashed curve on Fig. 1b). This fit required 8% of the background intensity to interfere with the Breit-Wigner (a study of the Dalitz plot distributions in the mass region near the peak indicates that only about 25% of the background intensity is in a $J^P = 1^-$ state) and had a probability of 35% for 17 d.o.f., compared with a probability of 20% for the incoherent fit. It is possible to obtain a value of $\sigma \cdot B$ as low as 15 nb by allowing all of the 25% $J^P = 1^-$ component of the background to interfere with the Breit-Wigner amplitude and allowing this background to have a large imaginary part; such a fit with a quadratic polynomial background gives a $\sigma \cdot B$ of 15 ± 2 nb with a mass and width of 1.64 ± 0.02 GeV and 0.12 ± 0.01 GeV, respectively (dotted curve on Fig. 1b). This fit has a χ^2 of 25 for 17 d.o.f. corresponding to a

probability of 10%. We conclude that the observed resonance is unlikely to be due to a ϕ' vector meson and that the simplest interpretation of the data is that the peak is due to a major decay mode of an ω' vector meson. This interpretation is supported by our non-observation [7] of a narrow peak in K^*K [2].

Another possible interpretation of the peak is that it is due to the $J^P = 3^- \omega(1670)$ which is known to decay to 3π [8] and which could be diffractively photoproduced. However, assuming VDM, we would then expect diffractive photoproduction of $g(1700)$, its isovector partner, to occur in $\pi^+\pi^-$ and $\pi^+\pi^-\pi^+\pi^-$ with a total cross section which is 10 times that for $\omega(1670)$ production. In addition, the 5π decay mode of the $\omega(1670)$ would be observed in photoproduction. No such signals are seen [9-11]. The observed resonance is therefore considered not to be the $3^- \omega(1670)$, a conclusion which is reinforced by the results of the spin-parity analysis described below.

To investigate the spin-parity of the resonance, we have adopted two complementary approaches, the first being to study the moments of the 3π angular decay distribution in the helicity system, and the second being a maximum likelihood fit to the Dalitz plot using Zemach tensor decay amplitudes [12].

For the analysis of the moments of the decay distribution we consider the normal to the 3π decay plane in the helicity system; then θ and ϕ are the polar and azimuthal angles of this direction with respect to the helicity axis (as defined in Ref. [13]). All moments are found to be zero within errors thus giving no direct information on the spin of the enhancement.

Figures 2a and 2b show the 2π mass spectra for 3π masses from 1.6 to 1.75 GeV; strong ρ meson production is evident. The ratio $\rho^+:\rho^-:\rho^0$ is 1:1:1, as expected for an $I^G = 0^- 3\pi$ state decaying via $\rho\pi$. We have performed a maximum-likelihood fit to the Dalitz plot in bins of 3π mass using $\rho\pi$ decay amplitudes constructed with the Zemach tensor formalism. With all spin-parity states up to $J^P = 3^-$ allowed in the fit, only the intensity of the 1^- contribution was found to increase in the region of

the peak. Because the Dalitz plot density can be similar for several J^P assignments, the fit is poorly constrained; therefore, to obtain a good quantitative estimate of the cross section for production of $J^P = 1^-$ states, the fit was made in 70 MeV bins of mass with contributions allowed from 3π phase space, $J^P = 1^+(s\text{-wave})\rho\pi$, $J^P = 1^-\rho\pi$ and $J^P = 3^-\rho\pi$. The resulting cross section for 1^- production is shown in Fig. 3a together with the expected cross section (solid curve) for production of a simple Breit-Wigner resonance of intensity 100 nb plus an incoherent background (hand-drawn dashed curve). The errors are those given by the fitting program MINUIT [14]. A similar fit to the mass region from 1.6 to 1.75 GeV required 33% each of 3π phase space, $J^P = 1^+(s\text{-wave})\rho\pi$ and $J^P = 1^-\rho\pi$ with no $J^P = 3^-$ contribution. The distribution of the variable λ , given by

$$\lambda = \frac{(p_{\pi^+} \times p_{\pi^-})^2}{\frac{3}{4} \left[\frac{1}{9} \left(M_{3\pi} + m_{\pi^\pm} - m_{\pi^0} \right)^2 - m_{\pi^\pm}^2 \right]^2},$$

which measures the radial density of the Dalitz plot, is shown in Fig. 3b for this mass range. The solid curve is the expected distribution for the above result (similarly, the curves on Figs. 2a and b) and has a χ^2 of 33 for 20 data points. With half of the $J^P = 1^-$ contribution replaced by 3^- , the dashed curve is obtained; this has a χ^2 of 48 for 20 data points (in this mass range, 50% of the 1^- intensity is due to the peak and 50% to the background). We conclude that the favoured spin-parity assignment for the enhancement is 1^- .

To investigate the production characteristics of the state, we follow the procedures of Schilling et al. [12] for the analysis of vector-meson photoproduction by polarized photons. Figure 4 shows the distribution of $\cos \theta$, the polar angle between the normal to the 3π decay plane in the helicity system and the helicity axis, for 3π masses from 1.6-1.75 GeV. The solid curve ($\chi^2 = 28.6$ for 20 points) is the expectation for an isotropic decay distribution altered by acceptance; the dashed curve ($\chi^2 = 10.6$) shows the distribution expected assuming that the $J^P = 1^-$ enhancement is produced by an s-channel helicity conserving mechanism, as has been found for photoproduction of other vector mesons [1]. The data are consistent with this hypothesis, but the low peak to background ratio and limited statistics preclude a more detailed analysis.

In conclusion, we have observed an isoscalar vector meson which is most simply interpreted as a radial excitation of the $\omega(783)$ meson, rather than the ϕ' state reported from e^+e^- annihilation results [2]. Assuming an incoherent background, the mass and width are 1.67 ± 0.02 GeV and 0.16 ± 0.02 GeV, respectively, and the total photoproduction cross section $\times$ branching ratio to $\rho\pi$ is 100 ± 20 nb. The production mechanism of the resonance is consistent with s-channel helicity conservation.

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Figure captions

- Fig. 1 : a) Mass spectrum of $\pi^+ \pi^- \pi^0$.
b) Mass spectrum of $\pi^+ \pi^- \pi^0$; the curves are from fits described in the text.
- Fig. 2 : a) Mass spectrum of $\pi^+ \pi^-$ for 3π mass in the range 1.6 to 1.75 GeV.
b) Mass spectrum of $\pi^\pm \pi^0$ for 3π mass in the range 1.6 to 1.75 GeV.
The curves are from a fit to the Dalitz plot.
- Fig. 3 : a) Cross section for production of $J^P = 1^-$ states as deduced from maximum likelihood fit.
b) Radial density of the Dalitz plot for 3π mass in the range 1.6 to 1.75 GeV.
The curves are explained in the text.
- Fig. 4 : Distribution of the normal to the 3π decay plane in the helicity system for the mass range 1.6 to 1.75 GeV. The curves are explained in the text.

Fig. 1a

Fig. 1b

Fig. 2

Fig. 3

Fig. 4