Observation of a Threshold Enhancement in the Reaction

$$\gamma p \rightarrow K^+ K^- \pi^+ \pi^- p \text{ at } \gamma \text{ energies of } 20 - 70 \text{ GeV}$$

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ABSTRACT

An analysis is presented of the channel $\gamma p \rightarrow K^+ K^- \pi^+ \pi^- p$. Evidence is found for a $K^* K \pi$ enhancement of mass ~ 1.9 GeV and width ~ 0.4 GeV. The spin-parity of the enhancement is consistent with being 1^- .

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Radial excitations of quark-antiquark pairs with spin-parity 1^- have been observed for charmed quark pairs, namely the ψ' family⁽¹⁾. Similar states are expected for light quarks; however only one candidate, the $\rho'(1600)$, has been clearly established⁽²⁾. No radial excitations of the ϕ , which we refer to as ϕ' 's, have been observed. By analogy with the ρ' decay to $\rho\pi\pi$, a ϕ' may decay to $K^*K\pi$ and thus be observed in the channel

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

We report here on the characteristics of a $K^*K\pi$ enhancement in this channel which is consistent with having spin-parity 1^- .

High energy photon-proton interactions were studied at the CERN SPS using a tagged photon beam and a liquid hydrogen target in the magnetic spectrometer Omega⁽³⁾. The tagged photon facility gave a photon beam intensity of $\sim 2 \times 10^5$ photons/burst over an energy range 20-70 GeV. A threshold gas Cerenkov counter was used for particle identification. Approximately 5.1M triggers were recorded with the requirement that there be between 4 and 9 charged particles in the final state. About 70% of the data presented in this paper were obtained with only this multiplicity requirement, while for the remaining 30% we required one of the particles in the final state to be a charged kaon. Pattern recognition and geometrical reconstruction were carried out using the program ROMEO⁽⁴⁾.

Channel (1) was selected from events with 4 or 5 particles, net charge 0 or 1 respectively, which originated from a single vertex within the hydrogen target. Two of the tracks were required to be consistent with being kaons of opposite charge. Specifically both particles had momentum between ~ 5.9 and ~ 19 GeV/c and gave no signal in the Cerenkov counter.

The majority of recoil protons stopped in the target; consequently events were further selected using the (missing mass)² distribution, see Fig. 1, calculated from the 4-momenta of the incoming γ and the outgoing $KK\pi\pi$ system. The distribution shows a clear proton peak over a background. We have selected events with (missing mass)² less than 2.0 GeV² and have obtained 1565 events compatible with channel 1. From a polynomial + Breit-Wigner fit to the (missing mass)² distribution in the region of the peak, we estimate that the selected events include $\sim 30\%$ background due to events with missing particles. To reduce this background further, the four-momentum transfer squared, t , from γ to $KK\pi\pi$ was required to be greater than -0.4 GeV², giving 1142 events. In addition the channels $\gamma p \rightarrow \pi^+ \pi^+ \pi^- \pi^- p$ and $\gamma p \rightarrow p \bar{p} \pi^+ \pi^- p$ may simulate channel (1). Using 5-prong events we compared the total meson mass calculated from the recoil proton with the same quantity calculated from the final state meson 4-momenta assuming reaction (1). We deduced that there is a negligible background of $\gamma p \rightarrow \pi^+ \pi^- \pi^+ \pi^- p$ but that the reaction

$$\gamma p \rightarrow p \bar{p} \pi^+ \pi^- p \quad (2)$$

contributes a 20% contamination to the data sample.

The overall $KK\pi\pi$ mass spectrum is shown in Fig. 2(a). In contrast to the smooth rise from threshold expected from the phase space distribution of four bodies out of five, the mass spectrum shows a broad threshold enhancement peaking at ~ 1.9 GeV. The mass spectrum of $\pi^+ \pi^-$ given in Fig. 2(b) shows no significant ρ production. Fig. 2(c) and (d) giving $K^\pm \pi^\mp$ and $K^+ K^-$ mass spectra show that the channel is dominated by $K^*(890)$ and $\phi(1020)$. The fractions of events with a K^* and with a ϕ are $\sim 35\%$ and $\sim 10\%$ respectively. The $K^\pm \pi^\mp$ mass spectrum (not shown) is structureless.

We have investigated the $K^*K\pi$ component in the enhancement, and eliminated the background due to channel (2) by selecting events with

- (a) $K^\pm \pi^\mp$ mass combinations in the $K^*(890)$ region $0.83 < M_{K\pi} < 0.95$ GeV and
- (b) $K^\pm \pi^\mp$ mass combinations outside the $K^*(890)$ region, namely the regions $0.71 < M_{K\pi} < 0.83$ and $0.95 < M_{K\pi} < 1.07$ GeV.

The $K^*K\pi$ spectra for these selections are shown in Fig. 3(a), which shows that the enhancement in the $KK\pi\pi$ mass spectrum originates from the $K^*K\pi$ channel. Fig. 3(b) shows that the enhancement is not present in $\phi\pi\pi$. The smooth curves on Fig. 3 give the acceptance of the apparatus for $KK\pi\pi$,

derived from Monte Carlo calculations assuming a $1/E_\gamma$ photon energy spectrum and isotropic $K^*K\pi$ and $\phi\pi\pi$ decays. The data in Fig. 3(a) are consistent with the existence of a $K^*K\pi$ enhancement of mass ~ 1.9 GeV and width ~ 0.4 GeV, together with a smooth background. The total production cross-section of the channel $\gamma p \rightarrow K^*K\pi p \rightarrow K^+K^-\pi^+\pi^-p$ is 60^{+30}_{-20} nb.

The energy dependence of the cross-section and the peripheral t -distribution for channel (1) are consistent with a diffractive production mechanism for the $K^*K\pi$ system. If the channel is diffractively produced, the $K^*K\pi$ system would have a spin parity 1^- component. By analogy with the photoproduced $\rho^-(1600)$, a $1^- \phi'$ state would be expected to conserve s -channel helicity and decay into $K^*K\pi$ with the K^* in a relative s -wave with respect to the s -wave $K\pi$ system. Hence a K^* with a $\sin^2\theta$ decay distribution would be expected (θ is the polar angle of the K from K^* decay in the K^* rest frame and the z axis is defined by the direction of the $K^*K\pi$ system in the γp c.m.s.).

Decay angles for the region $1.8 < M_{K^*K\pi} < 2.1$ GeV are given in Fig. 4 with the acceptance-biased decay angular distributions to be expected from (a) an isotropic $K^*K\pi$ decay and (b) an s -channel helicity-conserving spin-parity 1^- state which decays into $K^*K\pi$ as described above. From the figure we conclude that the data are compatible with the enhancement having spin-parity 1^- . The assumption of an isotropic decay is also consistent with the data. Thus we are unable to exclude a mixed spin-parity state such as might arise from a Deck effect⁽⁵⁾.

In summary, we have observed an enhancement in the reaction $\gamma p \rightarrow K^*K\pi p$ the decay properties of which are indicative of a $1^- \phi'$ state of mass ~ 1.9 GeV and width ~ 0.4 GeV. However, within the limited statistics of the experiment we cannot exclude the possibility that the enhancement is non-resonant.

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References

1. See, for example, International Symposium on Lepton and Photon Interactions at High Energies, ed. F. Gutbrod (Hamburg 1977) and references therein.
2. H. Bingham et al., Phys. Lett. 41B (1972) 635.
M. Davier et al., Nucl. Phys. B58 (1973) 31.
M. Grille et al., Nuovo Cimento 13A (1973) 593.
3. For details of the Omega Spectrometer and the tagging system see D. Aston et al., Jet-like structure in the reaction $\gamma p \rightarrow \pi^+ \pi^- \pi^+ \pi^- \pi^+ \pi^- p$, CERN-EP/79-146, submitted to Nucl. Phys. B.
4. F. Bourgeois, H. Grote, J-C. Lassalle, Pattern Recognition Methods for Omega and SFM Spark Chamber Experiments, CERN/DD/DH/101.
H. Grote, M. Hansroul, J-C. Lassalle and P. Zaneella.
Identification of digitised particle trajectories, International Symposium 1973 (North-Holland, Amsterdam 1974).
5. R.T. Deck, Phys. Rev. Lett. 13 (1964) 169.

Figure Captions

1. (Missing mass)² for the channel $\gamma p \rightarrow K^+ K^- \pi^+ \pi^-$ (missing mass) for all events and for momentum transfer, $|t|, < 0.4 \text{ GeV}^2$.
2. Mass Spectra for the channel $\gamma p \rightarrow K^+ K^- \pi^+ \pi^- p$ with $|t| < 0.4 \text{ GeV}^2$.
 - (a) $K^+ K^- \pi^+ \pi^-$
 - (b) $\pi^+ \pi^-$
 - (c) $K^\pm \pi^\mp$
 - (d) $K^+ K^-$.
3. Mass spectra for the channel $\gamma p \rightarrow K^+ K^- \pi^+ \pi^- p$ with $|t| < 0.4 \text{ GeV}^2$.
 - (a) $K^* K \pi$ mass spectra for K^* peak and background selected as described in the text. The background is weighted by 0.5 to obtain the correct normalisation with respect to the peak.
 - (b) $\phi \pi^+ \pi^-$ mass spectrum.

The smooth curves show the acceptances for $K^* K \pi$ and $\phi \pi^+ \pi^- p$.
4. Polar decay angles for the $KK\pi\pi$ mass region $1.8 < M_{K^* K \pi} < 2.1 \text{ GeV}$ with $|t| < 0.4 \text{ GeV}^2$.
 - (a) The K from $K^*(890)$ decay in the $K^*(890)$ rest frame;
 - (b) The K^* in the $K^* K \pi$ rest frame;
 - (c) The K not originating from the $K^*(890)$ in the $K \pi$ rest frame.

The solid line shows the angular distribution expected for isotropic decay of the $KK\pi\pi$ system while the dotted line shows the distribution expected from the $\phi^-(J^P = 1^-)$ decay described in the text. The K^* was selected as described in the text. Events in the K^* peak and background are plotted with weights +1.0 and -0.5 respectively.

Fig. 1

$$\gamma p \rightarrow K^+ K^- \pi^+ \pi^- p$$

$$|t| < 0.4 \text{ GeV}^2$$

Fig. 2

$$\gamma p \rightarrow K^+ K^- \pi^+ \pi^- p$$

$$|t| < 0.4 \text{ GeV}^2$$

Fig. 3

$\gamma p \rightarrow K^* K^- \pi^+ \pi^- p$
 $|t| < 0.4 \text{ GeV}^2$
 $1.8 \text{ GeV} < M_{K^* K \pi} < 2.1 \text{ GeV}$

Fig. 4