FIRST OBSERVATION OF $\gamma\gamma \to K^{*0}\bar{K}^{*0}$

ARGUS Collaboration

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The final state $K^+K^-\pi^+\pi^-$ has been studied in $\gamma\gamma$ interactions using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY. Production of the vector meson pair $K^{*0}(892)$ $\bar{K}^{*0}(892)$ is observed for the first time. The cross sections for $K^+K^-\pi^+\pi^-$, $K^{*0}K^-\pi^+$ + c.c. and $K^{*0}\bar{K}^{*0}$ are all found to be of the order of a few nb. In the $W_{\gamma\gamma}$ range accessible, a mean upper limit of 0.5 nb at 95% CL is derived for $\phi\rho^0$ production.

Previous observations of vector meson pair production in $\gamma\gamma$ reactions include $\rho^0\rho^0$ [1], $\omega\rho^0$ [2] and $\omega\omega$ [3], and upper limits have been found for the cross sections for $\rho^+\rho^-$ [4], $K^{*0}\bar{K}^{*0}$, $\phi\rho^0$ and $\phi\phi$ [5,6]. There are two main types of models for vector meson pair production in $\gamma\gamma$ reactions: $q\bar{q}q\bar{q}$ models [7] and a t-channel factorization model [8]. The $q\bar{q}q\bar{q}$ models predict cross sections for $K^{*0}\bar{K}^{*0}$ of about one nb and for $\phi\rho^0$ of several nb, while the factorization model predicts a $\phi\rho^0$ cross section of around 0.5 nb. In addition, a recent calculation of $\gamma\gamma\to K^{*0}\bar{K}^{*0}$ has been performed in the QCD frame [9], where a cross section of about 1 nb is predicted.

This paper reports on a study of the final state $K^+K^-\pi^+\pi^-$ produced in $\gamma\gamma$ reactions. $K^{*0}\bar{K}^{*0}$ production is observed for the first time and its cross section has been measured. An upper limit for $\phi\rho^0$ production is also derived. The study was carried out using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY. The data corresponds to an integrated luminosity of 234.3 events/pb collected at beam energies between 4.7 and 5.3 GeV.

ARGUS is a universal magnetic detector with cylindrical symmetry described in detail elsewhere [10]. Its most important features for the present study are good momentum resolution and charged-particle identification. The momentum and ionization energy loss (dE/dx) of a charged particle are obtained from the drift chamber [11] measurements, and the time of flight (TOF) is measured by an array of scintillation counters [12] surrounding the drift chamber. Each of these systems cover 94% of 4π. A charged particle is identified on the basis of the dE/dx and TOF informations. Surrounding the drift chamber and TOF systems is an array of electromagnetic calorimeter modules [13] covering 96% of 4π. The sensitivity for photons down to low energies and the high degree of hermeticity make the calorimeter a powerful tool for the rejection of events containing photons and charged particles with large deposited energy.

In $\gamma\gamma$ reactions the scattered leptons are at such small angles that they predominantly stay inside the beam pipe and thus never reach the detector. The candidates for the reaction $\gamma\gamma\to K^+K^-\pi^+\pi^-$ were therefore selected by requiring four charged particles with net charge zero originating from a common event vertex. Each of the four particles was required to be separately identified as a kaon or a pion with a likelihood ratio larger than 5% [10]. One kaon had to be uniquely identified but the other three particles were allowed to have more than one acceptable identity hypothesis. This strongly suppresses events with four pions and, together with the event cuts described below, enhances fully reconstructed events with two kaons due to strangeness conservation. No activity was allowed in the electromagnetic calorimeter, except for the expected ionization by the four charged particles, and for a background consistent with calorimeter noise. A cut on the scalar momentum sum of the four particles, $P^{\text{sum}} = \sum|\boldsymbol{p}_i| \leqslant 4.0$ GeV/c, was applied to enhance $\gamma\gamma$ events relative to incompletely reconstructed annihilation events and τ pair events. The square of the total transverse momentum, $P_T^{\text{tot}} = |\sum \boldsymbol{p}_{T,i}|$, is shown in fig. 1 for the events remaining after these selection criteria, together with a fit to the data points. This distribution exhibits the behaviour expected for exclusive $\gamma\gamma$

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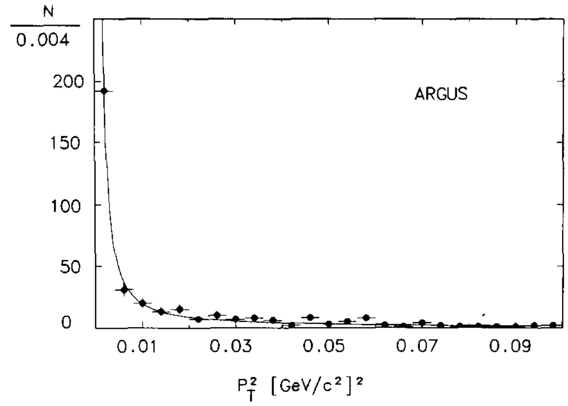

Fig. 1. $(P_T^{tot})^2$ distribution. The fit consists of a term determined from Monte Carlo $\gamma\gamma \to K^+K^-\pi^+\pi^-$ events, plus a constant to describe the background.

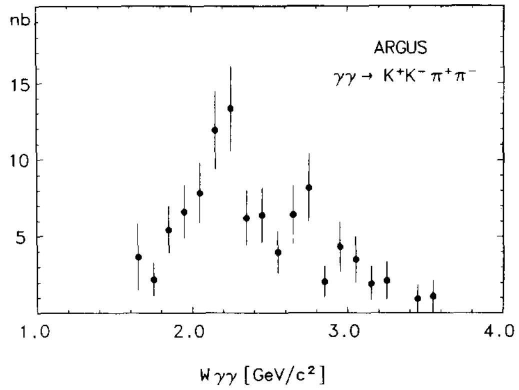

Fig. 2. Topological cross section for $\gamma\gamma \to K^+K^-\pi^+\pi^-$ versus $W_{\gamma\gamma}$. The error bars are statistical only.

events, namely momentum balance in the plane transverse to the beam axis. The $(P_T^{tot})^2$ spectrum was fitted to an expression derived from a Monte Carlo simulation of $\gamma\gamma \to K^+K^-\pi^+\pi^-$ events, plus a constant for the background. τ pair events and incompletely reconstructed events have to good approximation a flat $(P_T^{tot})^2$ distribution for small $(P_T^{tot})^2$. The fit to the data is consistent with zero background level. For the final selection, a requirement that $P_T^{tot} < 100$ MeV/c was applied to assure that background is negligible. This results in a clean sample of 237 $\gamma\gamma \to K^+K^-\pi^+\pi^-$ events. Only seven of these have two possible identification assignments. No K_S^0 signal is visible in the $\pi^+\pi^-$ invariant mass distribution, even when assigning the pion mass to all particles, hence no events of the kind $K_S^0K^+\pi^-$ are contained in the data.

To determine the acceptance, $\gamma\gamma$ reactions were generated according to the exact QED expression for collisions of two transverse photons [14]. Isotropic phase space was used to simulate the final states $K^+K^-\pi^+\pi^-$, $K^{*0}K^-\pi^+$, $K^{*0}\bar{K}^{*0}$ and $\phi\rho^0$. The $K^{*0}(\bar{K}^{*0})$ and ϕ were generated with Breit–Wigner shaped mass distributions using standard parameters [15], and were decayed to $K^+\pi^-(K^-\pi^+)$ and K^+K^-, respectively. The Monte Carlo events were passed through a full detector [16] and trigger simulation before being subjected to the same selection criteria as the data.

The sensitivity, expressed as number of events per nb of the $\gamma\gamma$ cross section and per 100 MeV/c^2 of the $W_{\gamma\gamma}$, was calculated for all final states investigated. They all turned out to have similar shapes and magnitudes: zero for $W_{\gamma\gamma}$ below 1.6 GeV/c^2; rising to a maximum of about 3 events/(nb·100 MeV/c^2) at 2.0 GeV/c^2; and with a slow fall-off with increasing $W_{\gamma\gamma}$. The systematic uncertainty is estimated to be $\pm 12\%$ for the topological $K^+K^-\pi^+\pi^-$ cross section. It consists of the following components: Monte Carlo and detector simulation 10%; trigger simulation 5%; and luminosity measurement 5%. The other cross sections have an additional systematical error of 15% due to the background subtractions needed for their derivation, leading to a total systematic uncertainty of $\pm 20\%$.

The topological cross section for $\gamma\gamma \to K^+K^-\pi^+\pi^-$ is shown in fig. 2. It reaches a maximum of about 12 nb at 2.2 GeV/c^2, and is lower over the whole $W_{\gamma\gamma}$ range than the cross sections published by the TPC/Two-Gamma Collaboration [5] and by the TASSO Collaboration [6].

The invariant K^+K^- mass distribution contains 7 ± 3 ϕ mesons, out of which five have a mass of the associated $\pi^+\pi^-$ pair below 1.2 GeV/c^2, consistent with coming from a ρ^0 meson. Thus at most five $\phi\rho^0$ events are observed. This leads to a mean upper limit for $\gamma\gamma \to \phi\rho^0$ of 0.5 nb at 95% CL in the $W_{\gamma\gamma}$ range 1.8–3.4 GeV/c^2. For the $W_{\gamma\gamma}$ range 1.8–2.2 GeV/c^2 the limit is 1.0 nb. This agrees with the estimate from the t-channel factorization model [8], but puts severe constraints on the $q\bar{q}q\bar{q}$ models [7].

To study the production of K^{*0} and $\bar{K}^{*0}$ mesons, events with a ϕ candidate, that is with a K^+K^- mass

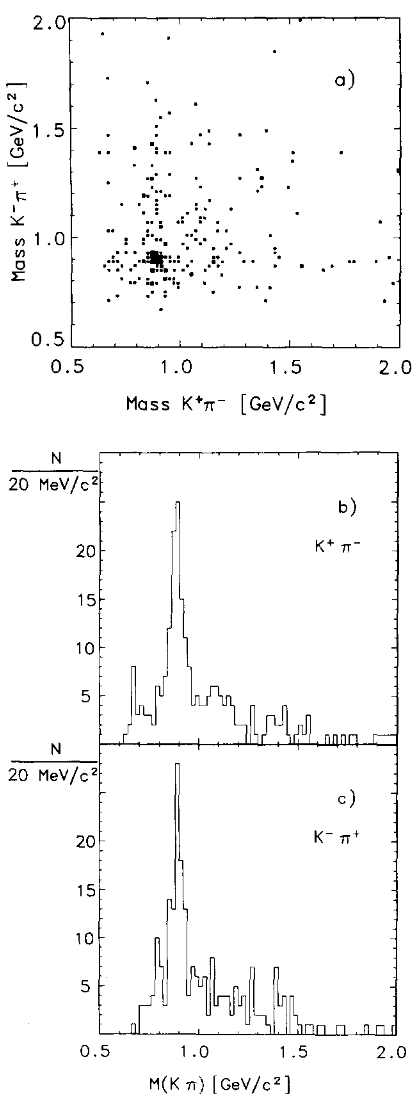

Fig. 3. (a) Scatter plot of the invariant $K^+\pi^-$ mass on the horizontal axis and the invariant $K^-\pi^+$ mass on the vertical axis. (b) Invariant $K^+\pi^-$ mass distribution. (c) Invariant $K^+\pi^-$ mass distribution.

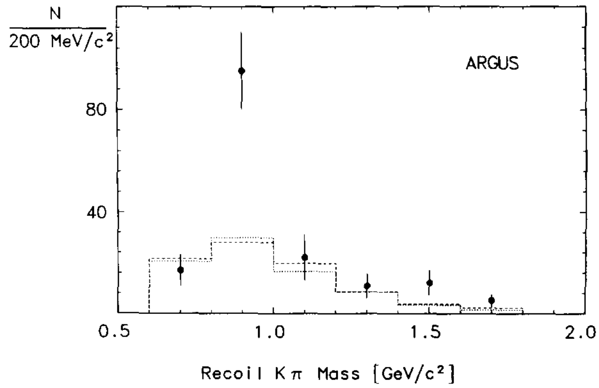

Fig. 4. Invariant mass of the $K\pi$ system recoiling against a K^{*0} or $\bar{K}^{*0}$ meson. The contribution due to $K^{*0}K^-\pi^+$ + c.c. is shown as histograms for the methods 1 (dashed) and 2 (dotted) as described in the text.

below 1.03 GeV/c^2, were removed. To demonstrate K^{*0} and $\bar{K}^{*0}$ production, fig. 3a shows a scatter plot with the invariant $K^+\pi^-$ and $K^-\pi^+$ masses along the horizontal and vertical axes, respectively. A clear clustering appears in the $K^{*0}\bar{K}^{*0}$ region. The projections onto the $K^+\pi^-$ and $K^-\pi^+$ axes are shown in figs. 3b and 3c, respectively. The number of K^{*0} and of $\bar{K}^{*0}$ mesons is found by fitting a signal plus a smooth background function. This signal was represented by a Breit–Wigner distribution, centered at 892.1 MeV/c^2 and with a width of 53 MeV/c^2 which inlcudes the detector resolution. The data contain 88 ± 15 K^{*0} and 86 ± 15 $\bar{K}^{*0}$ mesons, respectively. A fit to the sum of the spectra from figs. 3b and 3c yields a total number of K^{*0} and $\bar{K}^{*0}$ mesons of 175 ± 21.

To establish the presence of a $\gamma\gamma \to K^{*0}\bar{K}^{*0}$ signal, one must show that the enhancement in fig. 3a contains an excess over the contribution due to $\gamma\gamma \to K^{*0}K^-\pi^+$ + c.c. This was done by making projections of the scatter plot onto the $K^+\pi^-$($K^-\pi^+$) axis for different intervals in the $K^-\pi^+$($K^+\pi^-$) mass. For each mass interval the spectra of the two charge conjugate combinations were added. By fitting each of these spectra, the mass distribution of the $K\pi$ pair recoiling against the K^{*0} and $\bar{K}^{*0}$ mesons was obtained (fig. 4). Note that $K^{*0}\bar{K}^{*0}$ events enter twice while $K^{*0}K^-\pi^+$ + c.c. events enter once in fig. 4.

Two methods were used to estimate the shape of the non-resonant $K\pi$ mass distribution. The first method used like-sign $K\pi$ combinations in the data. The second method used Monte Carlo generated $\gamma\gamma \to K^{*0}K^-\pi^+$ events. To simulate the kinematics of the data, the $W_{\gamma\gamma}$ distribution was scaled to the observed number of K^{*0} plus $\bar{K}^{*0}$ mesons in bins of 200 MeV/c^2, obtained from data by fitting the sum of the $K^+\pi^-$ and $K^-\pi^+$ mass spectra for each $W_{\gamma\gamma}$ bin. The

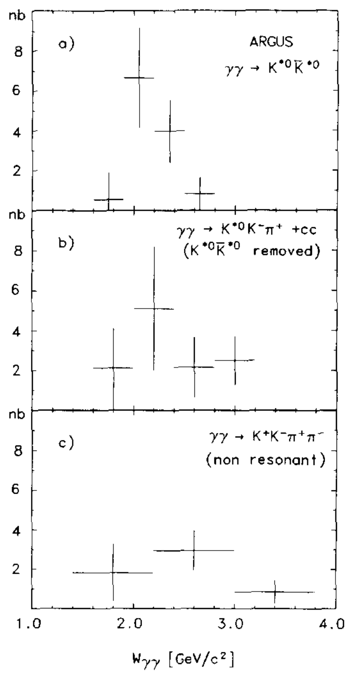

Fig. 5. Cross sections for the reactions (a) $\gamma\gamma \to K^{*0}\bar{K}^{*0}$; (b) $\gamma\gamma \to K^{*0}K^-\pi^+$ + c.c.; and (c) $\gamma\gamma \to K^+K^-\pi^+\pi^-$ (non-resonant).

number of $K^{*0}\bar{K}^{*0}$ events was determined by fitting the distribution in fig. 4 to linear combinations of $K^{*0}\bar{K}^{*0}$ and $K^{*0}K^-\pi^+$ + c.c. contributions. The χ^2 distributions have pronounced minima for $K^{*0}\bar{K}^{*0}$ contributions of 83.6 ± 20.3 and 80.0 ± 20.3 for the two methods, respectively. Note that these numbers are twice the number of $K^{*0}\bar{K}^{*0}$ events. The simultaneously determined $K^{*0}K^-\pi^+$ + c.c. contribution from each of the two methods is also shown in fig. 4. The number of $K^{*0}\bar{K}^{*0}$ events is derived from the mean of the value from the two methods, assigning the difference between them to the systematic uncertainty. This yields $40.9 \pm 10.2 \pm 1.0$ events in the $\gamma\gamma \to K^{*0}\bar{K}^{*0}$ channel.

To derive the cross section for $\gamma\gamma \to K^{*0}\bar{K}^{*0}$, the total $K^+K^-\pi^+\pi^-$ mass distribution was plotted for events with the $K^+\pi^-$ and the $K^-\pi^+$ combinations both having a mass in the range 800–1000 MeV/c^2. The background shape was represented by the $K^+K^-\pi^+\pi^-$ mass distribution for events with the like-sign $K\pi$ combinations fulfilling the same cuts. The part of this distribution that is due to $K^{*0}\bar{K}^{*0}$ events was extracted by subtracting the background, which was normalized to make the difference equal to the number of $K^{*0}\bar{K}^{*0}$ events. After correcting for the sensitivity, $Br(K^{*0} \to K^+\pi^-) \cdot Br(\bar{K}^{*0} \to K^-\pi^+)$ and the mass cuts, the cross section for $\gamma\gamma \to K^{*0}\bar{K}^{*0}$ is derived (fig. 5a). It is considerably larger than the predictions by both the $q\bar{q}q\bar{q}$ models [7] and the QCD calculation [9].

The cross section for $\gamma\gamma \to K^{*0}K^-\pi^+$ + c.c. (fig. 5b) was derived by subtracting the $K^{*0}\bar{K}^{*0}$ mass distribution from the previously mentioned $W_{\gamma\gamma}$ distribution of the total number of observed K^{*0} plus $\bar{K}^{*0}$ mesons.

The non-resonant $\gamma\gamma \to K^+K^-\pi^+\pi^-$ events were extracted by subtracting the sum of the $K^{*0}\bar{K}^{*0}$ and $K^{*0}K^-\pi^+$ + c.c. mass distributions from the total $K^+K^-\pi^+\pi^-$ mass distribution. Its cross section (fig. 5c) is found to be about 2 nb in the $W_{\gamma\gamma}$ range 1.6–3.5 GeV/c^2. Table 1 summarizes the results.

To conclude, the reaction $\gamma\gamma \to K^+K^-\pi^+\pi^-$ has been studied, where the production of K^{*0} and $\bar{K}^{*0}$ mesons was seen to be significant. The cross section for $\gamma\gamma \to K^{*0}\bar{K}^{*0}$ has been measured for the first time. It was found to be much larger than predicted by both the $q\bar{q}q\bar{q}$ models [7] and the QCD approach [9].

Table 1
Event decomposition. Only statistical errors are given. Systematic errors of ± 20% are not included. σBr is the mean cross section without correction for branching ratios.

Final state	Events	Event fraction	σBr (nb)
$K^+K^-\pi^+\pi^-$	95.9 ± 34.8	0.40 ± 0.15	2.4 ± 0.9
$K^{*0}K^-\pi^+$ + c.c.	93.2 ± 29.3	0.39 ± 0.13	2.0 ± 0.7
$K^{*0}\bar{K}^{*0}$	40.9 ± 10.2	0.17 ± 0.04	1.3 ± 0.4
$\phi\pi^+\pi^-$	7 ± 3	0.03 ± 0.01	0.2 ± 0.1
all	237	1.00	5.9 ± 0.5

The upper limit on $\phi\rho^0$ production is considerably lower than the $q\bar{q}q\bar{q}$ prediction but agrees with the estimates from a *t*-channel factorization model [8].

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