FIRST OBSERVATION OF $\gamma\gamma \to K^{*+}K^{*-}$

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The final states $K^0_S K^0_S \pi^+\pi^-$ and $K^0_S K^\mp \pi^0 \pi^\pm$, produced in two-photon reactions, have been studied using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY. The reaction $\gamma\gamma \to K^{*+}K^{*-}$ has been observed for the first time. Its cross section is about eight times larger than that for $\gamma\gamma \to K^{*0}\bar{K}^{*0}$, but it has a similar $W_{\gamma\gamma}$ dependence.

The two final states $K^0_S K^0_S \pi^+\pi^-$ and $K^0_S K^\mp \pi^0 \pi^\pm$ have been used to study the reaction $\gamma\gamma \to K^{*+}K^{*-}$. These two channels account for one third of the possible decay modes of a $K^{*+}K^{*-}$ pair. The closely related reaction $\gamma\gamma \to K^{*0}\bar{K}^{*0}$ has recently been reported [1] to have a cross section of about 6 nb at a $W_{\gamma\gamma}$ invariant mass of around 2 GeV/c^2. Theoretical predictions for both these reactions are made using $q\bar{q}q\bar{q}$ models [2,3] and a QCD calculation [4]. The $q\bar{q}q\bar{q}$ models predict peak values for the $K^{*+}K^{*-}$ cross section of about 5 nb [2] and 1 nb [3] at $W_{\gamma\gamma} \approx 1.8$ GeV/c^2, with the $K^{*0}\bar{K}^{*0}$ mode being suppressed by factors of about 4 and 8 respectively. The QCD model predicts a maximum $K^{*+}K^{*-}$ cross section of about 7 nb at $W_{\gamma\gamma} \approx 2.4$ GeV/c^2, with the neutral mode being approximately a factor 8 smaller. Thus the maximum of the measured $K^{*0}\bar{K}^{*0}$ cross section [1] is about an order of magnitude larger than the different model predictions.

This paper reports the first measurement of the production of charged K*(892) pairs in two-photon reactions, $\gamma\gamma \to K^{*+}K^{*-}$. The study was made using a data sample corresponding to 234 pb^{-1} collected with the ARGUS detector at the e^+e^- storage ring DORIS II at DESY. The beam energies varied between 4.7 and 5.3 GeV. ARGUS is a universal magnetic detector with cylindrical symmetry and described in detail elsewhere [5]. This analysis depends strongly on the good momentum resolution and identification capabilities of charged particles, together with the good energy resolution and high sensitivity for photons. The momentum and ionization energy loss (dE/dx) of a charged particle are obtained from the drift chamber [6] measurements, and the time-of-flight (TOF) is measured by an array of scintillation counters [7] 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 [8] covering 96% of 4π, used for photon detection, as well as to reject events containing particles which deposit large amounts of energy.

Candidate events for the reactions

$$\gamma\gamma \to K^0_S K^0_S \pi^+\pi^- , \quad (1)$$

$$\gamma\gamma \to K^0_S K^\mp \pi^0 \pi^\pm \quad (2)$$

were selected by requiring at least two charged particles from the main event vertex and a total number of charged particles in the whole detector of six in reaction (1) and four in reaction (2). For both reactions, the total charge was required to be zero. A K^0_S was identified by its decay into a $\pi^+\pi^-$ pair, either by forming a decay vertex separated from the main event vertex, or by originating from the main event vertex if this contained at least four charged particles. The invariant mass of the $\pi^+\pi^-$ pair was required to lie between 0.48 and 0.52 GeV/c^2, which is within 4σ of the mass resolution, and it was adjusted to the standard value for the K^0_S mass by performing a constrained fit. The charged particles were identified by requiring the likelihood ratios, for the respective particle hypotheses, to exceed 5%. The charged kaons in reaction (2) were, in addition, not allowed

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to have a likelihood ratio for the pion hypothesis of more than 5%. This requirement reduces the background below the K_S^0 signal and assures exclusive final states due to strangeness conservation. The π^0 was identified by its decay into two photons. These had to have an energy larger than 50 MeV and form an invariant mass between 60 and 220 MeV/c^2. A constrained fit was applied to the π^0 mass. Event candidates for reaction (2) had to contain exactly two photons and no photons with energies larger than 50 MeV/c^2 were allowed for reaction (1).

The event selection was done using the same techniques as in our earlier work on vector-meson pair production in two-photon reactions (see e.g. ref. [1]). The scalar momentum sum of the final state particles had to be less than 3.5 GeV/c for both reactions. Their total transverse momentum, p_T^2, distributions were fitted with functions derived from the p_T^2 distributions of the respective Monte Carlo generated events. A term, assumed to be constant, was added to each function to allow for background. The background was found to be negligible for both reactions and the p_T^2 distribution could be described well by the Monte Carlo derived curves alone. Requiring the p_T^2 to be less than 0.02 (GeV/c)^2 assured background free event samples. After all selection criteria, there remained 13 events from reaction (1) and 45 events from reaction (2).

The sensitivities for the detection of the two reactions were derived using a Monte Carlo simulation to generate the collisions between two transverse photons according to QED [9]. The events were generated with a constant cross section and isotropic phase-space was used for the final state particles. A full detector and trigger simulation was also performed. The sensitivities are expressed in units of events per nb and per 200 MeV/c^2 of $W_{\gamma\gamma}$. In the $W_{\gamma\gamma}$ range between 1.6 and 3.5 GeV/c^2 the sensitivities are rather constant with values between 0.6 and 1 for both reactions. These values have been corrected for $\mathrm{Br}(K_S^0 \to \pi^+\pi^-)$. The sensitivities for the reaction $\gamma\gamma \to K^{*+}K^{*-}$ are smaller, due to the $K^{*\pm}$ branching ratios, by factors of $\frac{1}{9}$ and $\frac{2}{9}$ for the two final states respectively. This includes the K^0 meson being an equal mixture of K_S^0 and K_L^0. The systematic uncertainty of each sensitivity is estimated to be $\pm 13\%$ for isotropic final states and $\pm 17\%$ for the $K^{*+}K^{*-}$ final state. They are composed of Monte Carlo event generation and detector simulation ($\pm 10\%$), trigger simulation ($\pm 5\%$), and experimental luminosity ($\pm 5\%$). The effect on the acceptance from non-isotropic angular distributions, arising from different possible spin-parities of the $K^{*+}K^{*-}$ system, is estimated to give an additional systematic uncertainty of $\pm 10\%$ for this final state.

The invariant $K_S^0\pi^\pm$ mass distribution from reaction (1) is shown in fig. 1. A clear $K^{*\pm}$ signal is seen on top of a smooth background. The spectrum was fitted with a Breit–Wigner shaped function for the $K^{*\pm}$ signal, plus a polynomial multiplied by a threshold square-root expression to describe the background. The functional form for the background was fixed from a fit to the phase-space $K_S^0\pi^\pm$ mass distribution in the Monte Carlo generated events. The width of the K^* meson was determined from Monte Carlo to be 52 MeV/c^2 in its $K_S^0\pi^\pm$ decay mode. The fitted $K^{*\pm}$ mass was (882 ± 9) MeV/c^2, consistent with the accepted value of 892 MeV/c^2, and their number was found to be 28.9 ± 7.7.

The invariant $K_S^0\pi^\pm$ and $K^\mp\pi^0$ mass distributions from reaction (2) are shown in figs. 2a and 2b respectively. The spectra were fitted with the function described above. The width of a K^*, decaying into $K^\mp\pi^0$, is somewhat wider than for the other decay mode, due to the broadness of the π^0 signal, and was determined from Monte Carlo to be 60 MeV/c^2. The fitted masses of the $K^{*\pm}$ signals were consistent with

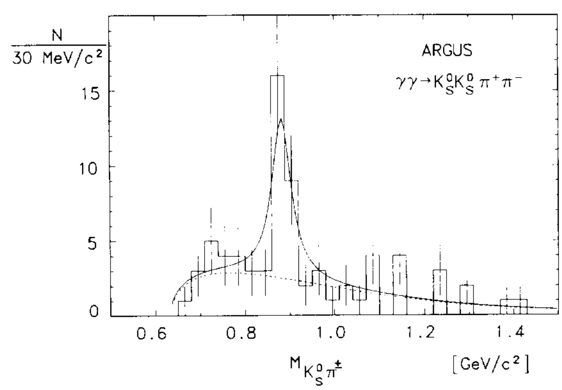

Fig. 1. Invariant $K_S^0\pi^\pm$ mass spectrum for the events of reaction (1), $\gamma\gamma \to K_S^0K_S^0\pi^+\pi^-$. The curves are the result from a fit to the data points consisting of a Breit–Wigner function for the $K^{*\pm}$ signal plus a background shape derived from the $K\pi$ phase-space. The full line curve represents the total fit and the broken line curve the combinatorial background.

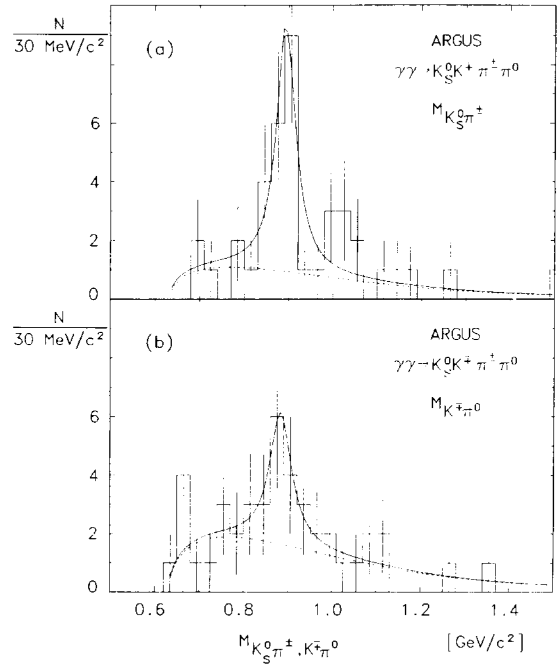

Fig. 2. Invariant Kπ mass spectra for the events of reaction (2), $\gamma\gamma\rightarrow K_S^0K^\mp\pi^0\pi^\pm$. (a) $K_S^0\pi^\pm$ and (b) $K^\mp\pi^0$. The curves are the result from fits to the data points consisting of a Breit–Wigner function for the $K^{*\pm}$ signal plus a background shape derived from the Kπ phase-space, the full line curves represent the total fit and the broken line curves the combinatorial background.

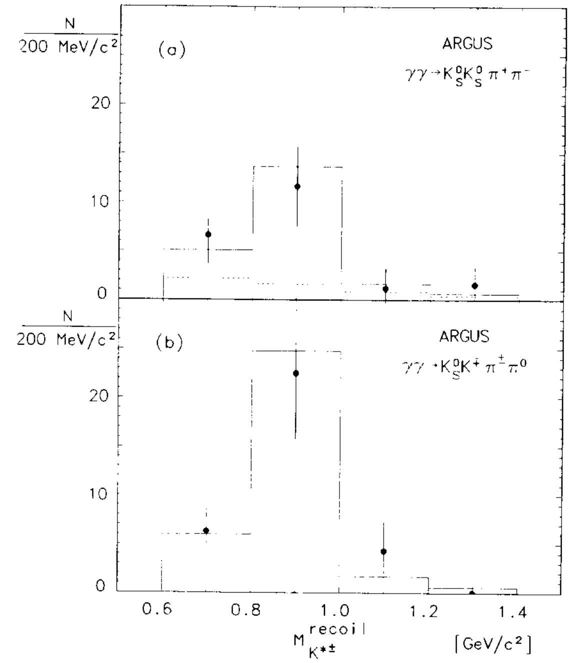

Fig. 3. $K^{*\pm}$ recoil mass spectra. (a) for reaction (1), $\gamma\gamma\rightarrow K_S^0K_S^0\pi^+\pi^-$, and (b) for reaction (2), $\gamma\gamma\rightarrow K_S^0K^\mp\pi^0\pi^\pm$. The full histograms show the result from the χ^2 fit (see text). The broken line histogram in (a) shows the contribution for reaction (1) due to $\gamma\gamma\rightarrow K^{*\pm}K_S^0\pi^\mp$.

the accepted mass value, and their numbers were found to be 22.9±6.6 and 14.1±6.3 in the $K_S^0\pi^\pm$ and $K^\mp\pi^0$ decay modes respectively.

The production of $K^{*+}K^{*-}$ was measured from the $K^{*\pm}$ recoil mass spectrum for each reaction separately. The $K^{*\pm}$ recoil mass spectra were derived from the scatter plots of $M_{K_S^0(1)\pi^\pm}$ versus $M_{K_S^0(2)\pi^\mp}$ for reaction (1), and of $M_{K^\mp\pi^0}$ versus $M_{K_S^0\pi^\pm}$ for reaction (2). Projections onto both axes of a scatter plot were performed for different mass intervals of the other, and for each mass interval the two Kπ mass spectra were added and fitted. The resulting number of $K^{*\pm}$ mesons in each mass interval was then plotted and is shown in fig. 3a for reaction (1) and in fig. 3b for reaction (2). Each $K^{*\pm}$ recoil mass spectrum was compared to a linear combination of a Breit–Wigner distribution with parameters of the $K^{*\pm}$ meson and a Kπ phase-space distribution. The resulting χ^2 distributions had minima for $K^{*+}K^{*-}$ contributions of 8.0±2.5 events for reaction (1) and 18.6±6.2 events for reaction (2) respectively. The errors correspond to the 1σ interval. The relative $K^{*+}K^{*-}$ contribution from the two reactions is consistent with expectations from the respective branching ratios and sensitivities. The simultaneously determined $K^{*\pm}K\pi$ contribution was 5.0±2.5 events for reaction (1) while being consistent with zero for reaction (2).

For reaction (2) we expect a contribution from $\gamma\gamma\rightarrow K^{*0}\bar{K}^{*0}$. In the reaction $\gamma\gamma\rightarrow K^+K^-\pi^+\pi^-$ [1] about 40 $K^{*0}\bar{K}^{*0}$ events were found. The branching ratio for $K^{*0}\bar{K}^{*0}$ into this final state is $\frac{4}{9}$, while being $\frac{2}{9}$ into the final state of reaction (2). The sensitivity for reaction (2) is only about 10% of that for $\gamma\gamma\rightarrow K^+K^-\pi^+\pi^-$. We therefore expect to see about two $K^{*0}\bar{K}^{*0}$ events in reaction (2). A fit to the sum of the invariant mass distributions for the $K^\mp\pi^\pm$ and $K_S^0\pi^0$ combinations yielded a total number for the K^{*0} plus $\bar{K}^{*0}$ mesons of 8.5±6.0. This means that there are at most 4.3±3.0 $\gamma\gamma\rightarrow K^{*0}\bar{K}^{*0}$ events in reaction (2). This shows the consistency between the two analyses.

The topological cross section for reaction (1) is shown in fig. 4b, and that for reaction (2) in fig. 4c.

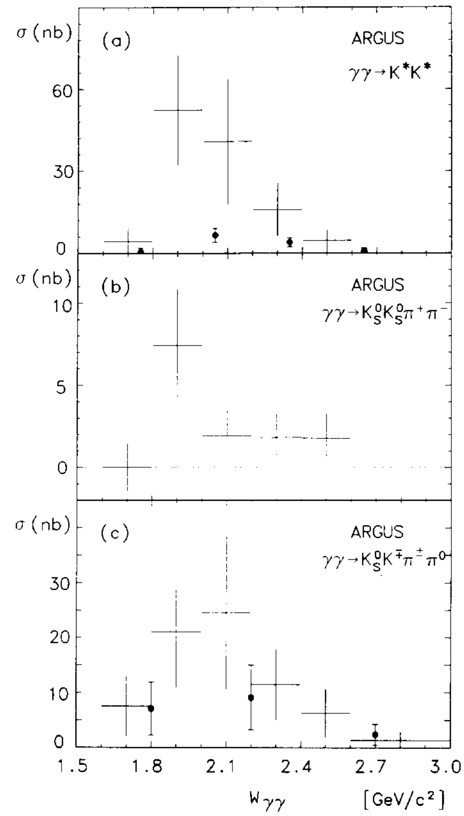

Fig. 4. Cross sections versus $W_{\gamma\gamma}$. Systematical errors are not included. (a) $\gamma\gamma\to K^{*+}K^{*-}$ (crosses) compared with $\gamma\gamma\to K^{*0}\bar{K}^{*0}$ (dots) from ref. [1]. (b) Topological $\gamma\gamma\to K^0_S K^0_S \pi^+\pi^-$. (c) Topological $\gamma\gamma\to K^0_S K^\mp \pi^0\pi^\pm$ (crosses) together with non-resonant $\gamma\gamma\to K^0_S K^\mp \pi^0\pi^\pm$ (dots).

Both have maxima for invariant $W_{\gamma\gamma}$ masses around 2.0 GeV/c^2. The systematic uncertainties in the cross sections of ±13% are not included in the figures.

The cross section for the reaction $\gamma\gamma\to K^{*+}K^{*-}$ shown in fig. 4a, was derived by combining both reactions. The systematical uncertainty in the cross section of ±17% is not included in the figure. For reaction (1) the events with $M_{K^0_S\pi^+}$ and $M_{K^0_S\pi^-}$ both laying between 800 and 1000 MeV/c^2 were used, normalized to the observed number of $K^{*+}K^{*-}$ events for this reaction. Similarly for reaction (2), those events with both the $K^0_S\pi^\pm$ and the $K^\mp\pi^0$ combinations having an invariant mass between 800 and 1000 MeV/c^2 were used. The resulting $M_{K^0_S K^\mp \pi^0 \pi^\pm}$ distribution was corrected for the non-resonant background, which was represented by the corresponding distribution resulting from wrong-charge Kπ combinations fulfilling the same $M_{K\pi}$ requirements, and normalized to contain the observed number of $\gamma\gamma\to K^{*+}K^{*-}$ events in reaction (2).

The average ratio, assuming equal shapes, between the cross sections for $\gamma\gamma\to K^{*+}K^{*-}$ and $\gamma\gamma\to K^{*0}\bar{K}^{*0}$ [1] is $7.8\pm3.1\pm2.0$, where the first error is statistical and the second systematical. A dominance of this order of the charged mode over the neutral was predicted by the models [2–4], but the observed absolute scale of the cross sections is much larger than predicted. The cross section for the non-resonant reaction $\gamma\gamma\to K^0_S K^\mp \pi^0 \pi^\mp$, finally, is shown together with the topological cross section of this reaction in fig. 4c. Its systematical uncertainty of ±13% is not included.

In conclusion, the reaction $\gamma\gamma\to K^{*+}K^{*-}$ has been observed for the first time and the measured cross section is about eight times larger than that for $\gamma\gamma\to K^{*0}\bar{K}^{*0}$. A ratio between the two cross sections of this order is expected within $q\bar{q}q\bar{q}$ and QCD models, but the observed absolute scale is much larger than predicted.

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