# A SEARCH FOR $\omega\phi$ AND $\phi\phi$ PRODUCTION IN THE REACTIONS $\gamma\gamma \to K^+K^-\pi^+\pi^-\pi^0$ AND $\gamma\gamma \to 2K^+2K^-$

ARGUS Collaboration

H. ALBRECHT, P. BÖCKMANN, R. GLÄSER, G. HARDER, A. KRÜGER, A. NIPPE, M. SCHÄFER, W. SCHMIDT-PARZEFALL, H. SCHRÖDER, H.D. SCHULZ, F. SEFKOW, J. SPENGLER, R. WURTH, A. YAGIL
*DESY, D-2000 Hamburg, Fed. Rep. Germany*

R.D. APPUHN, A. DRESCHER, D. KAMP, H. KOLANOSKI, U. MATTHIESEN, H. SCHECK, G. SCHWEDA, B. SPAAN, A. WALTHER, D. WEGENER
*Institut für Physik [1], Universität Dortmund, D-4600 Dortmund 50, Fed. Rep. Germany*

J.C. GABRIEL, T. RUF, K.R. SCHUBERT, J. STIEWE, K. STRAHL, R. WALDI, S. WERNER
*Institut für Hochenergiephysik [2], Universität Heidelberg, D-6900 Heidelberg 1, Fed. Rep. Germany*

K.W. EDWARDS [3], W.R. FRISKEN [4], D.J. GILKINSON [5], D.M. GINGRICH [5], H. KAPITZA [3], R. KUTSCHKE [5], D.B. MACFARLANE [6], W. McLEAN [6], A.W. NILSSON [6], R.S. ORR [5], J.A. PARSONS [5], P.M. PATEL [6], J.D. PRENTICE [5], J.D. SWAIN [5], G. TSIPOLITIS [6], T.-S. YOON [5]
*Institute of Particle Physics [7], Canada*

R. AMMAR, S. BALL, D. COPPAGE, R. DAVIS, S. KANEKAL, N. KWAK
*University of Kansas [8], Lawrence, KS 66045, USA*

B. BOŠTJANČIČ, G. KERNEL, P. KRIŽAN
*Institut J. Stefan and Oddelek za fiziko [9], Univerza v Ljubljani, YU-61111 Ljubljana, Yugoslavia*

L. JÖNSSON
*Institute of Physics [10], University of Lund, S-223 62 Lund, Sweden*

A. BABAEV, M. DANILOV, B. FOMINYKH, A. GOLUTVIN, I. GORELOV, V. LUBIMOV, V. MATVEEV, A. SEMENOV, S. SEMENOV, V. SHEVCHENKO, V. SOLOSHENKO, V. TCHISTILIN, I. TICHOMIROV, Yu. ZAITSEV
*Institute of Theoretical and Experimental Physics, 117 259 Moscow, USSR*

R. CHILDERS, C.W. DARDEN and R.C. FERNHOLZ
*University of South Carolina [11], Columbia, SC 29208, USA*

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The reaction $\gamma\gamma\to K^+K^-\pi^+\pi^-\pi^0$ has been observed for the first time, using the ARGUS detector at the $e^+e^-$ storage ring DORIS II at DESY. The cross section shows an enhancement for $W_{\gamma\gamma}$ close to 3 GeV/$c^2$. Searches for $\gamma\gamma\to\omega\phi$ and for $\gamma\gamma\to\phi\phi$ leading to this final state, as well as for $\gamma\gamma\to\phi\phi\to 2K^+2K^-$, have been performed. The derived upper limits for $\omega\phi$ and $\phi\phi$ production are compatible with $q\bar{q}q\bar{q}$ model predictions.

Vector-meson pair production in $\gamma\gamma$ collisions, $\gamma\gamma\to VV'$, has been suggested as one of the cleanest reactions to use in searching for exotic hadrons such as $q\bar{q}q\bar{q}$ states [1,2]. In addition, cross sections for $\gamma\gamma\to VV'$ have been estimated without involving the production of any exotic hadrons, using $t$-channel factorization [3,4], as well as QCD [5]. Measurements of VV′ production $\gamma\gamma$ interactions are also complementary to observations of the radiative $J/\psi\to\gamma VV'$ decays.

To enable the construction of reliable models for $\gamma\gamma\to VV'$, with or without exotic hadrons, experimental input on all possible VV′ channels is needed. So far cross sections have been measured for $\rho^0\rho^0$ [6–9], $\omega\rho^0$ [10], $K^{*0}\bar{K}^{*0}$ [11] and $\omega\omega$ [12], and upper limits have been derived for $\rho^+\rho^-$ [13], $\rho^0\phi$ [11,14] and $\phi\phi$ [14]. The models [1–3] are able to describe $\rho^0\rho^0$ production, although the calculation within the $t$-channel factorization model [3] is not unambiguous [4]. The channels $\omega\rho^0$ and $K^{*0}\bar{K}^{*0}$ cannot be described completely by the available models. For example, the QCD estimate [5] does not account for the threshold enhancement in $\gamma\gamma\to K^{*0}\bar{K}^{*0}$. Furthermore, $t$-channel factorization [3] does not describe $\omega\omega$ production, and the upper limit on $\gamma\gamma\to\phi\rho^0$ [11] is much smaller than the rate predicted by the $q\bar{q}q\bar{q}$ models [1,2].

In this paper a search for $\gamma\gamma\to\omega\phi$ and $\gamma\gamma\to\phi\phi$ is reported using the final states $K^+K^-\pi^+\pi^-\pi^0$ and $2K^+2K^-$. The reaction $\gamma\gamma\to K^+K^-\pi^+\pi^-\pi^0$ is observed for the first time and a data sample of 39 events is used to measure the cross section. The data, corresponding to an integrated luminosity of 234.3 pb$^{-1}$, were collected using 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 described elsewhere [15]. Besides its good momentum resolution and identification capability for charged particles, the most important features for the present investigation are the good energy resolution and high sensitivity of the ARGUS electromagnetic calorimeter [16] which covers 96% of the full solid angle.

Candidate events for the reactions

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

$$\gamma\gamma\to 2K^+2K^- \qquad (2)$$

were selected by requiring four charged particles with zero net charge originating from a common event vertex. The charged particles were identified, based on the $dE/dx$ and time-of-flight measurements [15], by requiring the likelihood ratios for the considered particle hypotheses to be greater than 5%. The kaons were subjected to the additional requirement that at least one kaon in reaction (1) and at least two kaons in reaction (2) did not have a likelihood ratio for any other particle hypothesis exceeding 5%. The distribution of $dE/dx$ versus momentum for the charged particles in the selected event sample for reaction (1) is shown in fig. 1. The background from $\gamma\gamma\to 5\pi$ is negligible.

For the event candidates for reaction (1) exactly two photons were required. A photon was defined as a separate neutral cluster extending over one or more neighbouring electromagnetic calorimeter modules with an energy larger than 50 MeV. The invariant mass distribution of the two photons is shown in fig. 2. For those events with an invariant mass of the two photons laying between 60 and 220 MeV/$c^2$ a constrained fit to the $\pi^0$ mass was performed. The charged

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[2] Supported by the German Bundesministerium für Forschung und Technologie, under the contract number 054HD24P.
[3] Carleton University, Ottawa, Ontario, Canada K1S 5B6.
[4] York University, Downsview, Ontario, Canada M3J 1P3.
[5] University of Toronto, Toronto, Ontario, Canada M5S 1A7.
[6] McGill University, Montreal, Quebec, Canada H3A 2T8.
[7] Supported by the Natural Sciences and Engineering Research Council, Canada.
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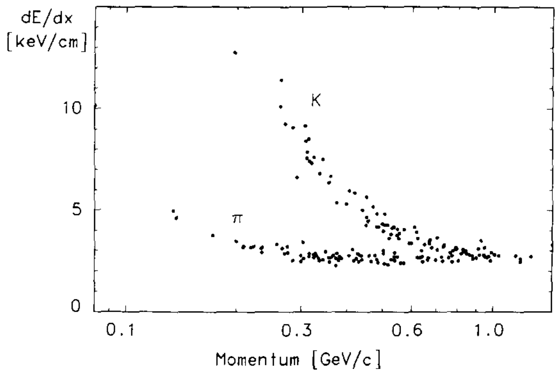


Fig. 1. Scatter plot of $dE/dx$ versus momentum for the charged particles of the selected $\gamma\gamma\to K^+K^-\pi^+\pi^-\pi^0$ events.

particles for this reaction had to have a total $p_T$ larger than 50 MeV/$c$, to eliminate possible background from $\gamma\gamma\to K^+K^-\pi^+\pi^-$ combined with noise in the electromagnetic calorimeter. For reaction (2) no separate neutral clusters extending over two or more neighbouring electromagnetic calorimeter modules and with energies larger than 50 MeV were allowed.

For both reactions a cut on the scalar momentum sum of all particles $\sum|\boldsymbol{p}_i|\leqslant 3.5$ GeV/$c$ and a cut on the total transverse momentum $p_T=|\sum \boldsymbol{p}_{T,i}|\leqslant 100$ MeV/$c$ were used to enhance $\gamma\gamma$ interactions and suppress background from $\tau$ decays and incompletely reconstructed events. The $p_T^2$ distribution of reaction (1) is shown in fig. 3. The curve is parametrized from a fit to the $p_T^2$ distribution of Monte Carlo generated events $\gamma\gamma\to K^+K^-\pi^+\pi^-\pi^0$, plus a term, assumed to

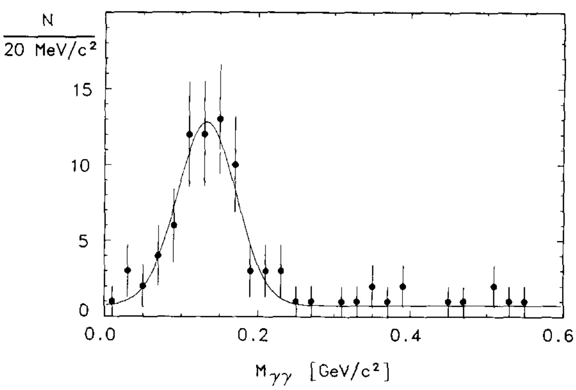


Fig. 2. Invariant mass of the two photons in $K^+K^-\pi^+\pi^-\gamma\gamma$ events with $p_T<100$ MeV/$c$. The curve is from a fit to the data using a gaussian for the $\pi^0$ signal plus a constant background.

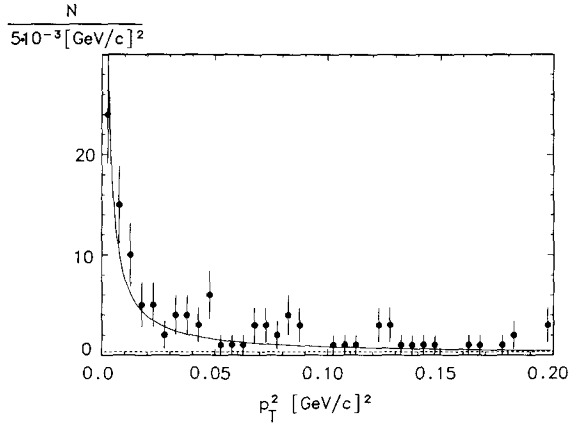


Fig. 3. $p_T^2$ distribution of $K^+K^-\pi^+\pi^-\pi^0$ events. The curve (full line) is a fit to the data using a parametrization derived from Monte Carlo generated $\gamma\gamma\to K^+K^-\pi^+\pi^-\pi^0$ events, plus a constant to describe the background (broken line).

be constant, to describe the background in the data. The background was found to be less than one event for $p_T<100$ MeV/$c$. After imposing these selection criteria, 39 events remained for reaction (1), while only three events were found for reaction (2).

To determine the acceptance, $\gamma\gamma$ interactions were generated according to the exact QED expression for collisions of transverse photons [17]. The events were generated with a constant cross section. Isotropic phase space was used to simulate the final states $K^+K^-\pi^+\pi^-\pi^0$, $\omega\phi\to K^+K^-\pi^+\pi^-\pi^0$ and $\phi\phi\to 2K^+2K^-$. Each Monte Carlo data set was generated with a beam energy distribution identical to that of the data. The Monte Carlo events were passed through a full detector simulation [18] and were reconstructed and selected by using the same programs as for real data. The trigger simulation uses thresholds for detector components as determined from data and accounts for the variation in actual trigger conditions. The simulation of random noise in the calorimeter was determined from the data as well by two different methods. The first used $\Upsilon(1S)\to\ell^+\ell^-$ with $\ell=e$ or $\mu$ events, tagged by the pions from the transition $\Upsilon(2S)\to\pi^+\pi^-\Upsilon(1S)$, and the second used cosmic rays.

The sensitivities derived for reactions (1) and (2) were about 2 and 3, respectively, expressed in units of events per nb of the $\gamma\gamma$ cross section and per 200 MeV/$c^2$ of $W_{\gamma\gamma}$. $W_{\gamma\gamma}$ is the invariant mass of the two-

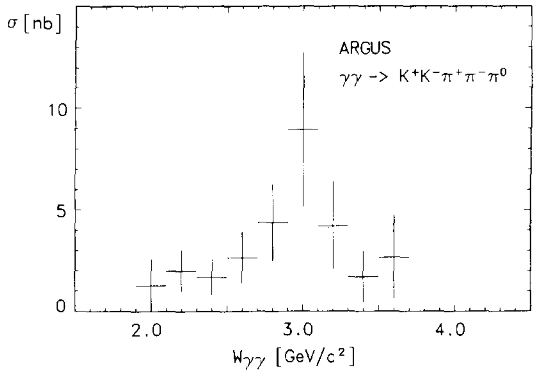


Fig. 4. Topological cross section for $\gamma\gamma\to K^+K^-\pi^+\pi^-\pi^0$ versus $W_{\gamma\gamma}$. Systematic errors of ±13% are not shown.

photon system or, equivalently, the invariant mass of the detected final state. The systematic uncertainties are the same, ±13%, for all channels considered, including contributions from Monte Carlo acceptance (±10%), experimental luminosity (±5%) and trigger simulation (±5%).

The topological cross section for $\gamma\gamma\to K^+K^-\pi^+\pi^-\pi^0$ is shown in fig. 4. This is the first measurement of this reaction. The cross section shows an enhancement reaching up to about 10 nb for $W_{\gamma\gamma}$ close to 3.0 GeV/$c^2$. No resonance with this mass and decay mode is known. The structure is too broad to originate from the $\eta_c$, which would decay with a width comparable to the detector resolution of 30 MeV/$c^2$. Due to the limited statistics, no definite resonance interpretation can be made.

No candidates for $\gamma\gamma\to\omega\phi$ or $\gamma\gamma\to\phi\phi$ were found in the final state $K^+K^-\pi^+\pi^-\pi^0$. An ω was defined as a 3π combination with a mass between 0.72 and 0.84 GeV/$c^2$, and a φ as a mass combination between 1.0 and 1.04 GeV/$c^2$ in the $K^+K^-$ mode, and between 0.97 and 1.07 GeV/$c^2$ in the 3π mode, respectively. These mass intervals correspond to at least 3 standard deviations of the expected experimental widths. This leads to the upper limits at the 95% confidence level shown in tables 1 and 2 for ωφ production in γγ reactions. The limit (table 1) does not contradict estimates from the $q\bar{q}q\bar{q}$ models [1,2], which are the only available predictions. Due to the low branching ratio for $\phi\to\pi^+\pi^-\pi^0$ the final state $K^+K^-\pi^+\pi^-\pi^0$ was not used to derive an upper limit for φφ production.

Only three events $\gamma\gamma\to 2K^+2K^-$ were found, all with invariant masses between 2.5 and 3 GeV/$c^2$. None of these could be interpreted as arising from $\gamma\gamma\to\phi\phi$, with a φ being a $K^+K^-$ combination with a mass in the interval from 1.0 to 1.04 GeV/$c^2$. This leads to the upper limits, at the 95% confidence level, shown in tables 1 and 2 for $\gamma\gamma\to\phi\phi$. The $q\bar{q}q\bar{q}$ models [1,2] predict cross sections well below the obtained limit (see table 1). The *t*-channel factorization model [3] predicts a cross section for φφ production of less than 0.05 nb, which is also well below the obtained limits.

In conclusion, the reaction $\gamma\gamma\to K^+K^-\pi^+\pi^-\pi^0$ has been measured for the first time. The cross section shows an enhancement for $W_{\gamma\gamma}$ close to 3 GeV/$c^2$,

Table 2
Upper limits (95% CL) for the cross sections for $\gamma\gamma\to\omega\phi$ and $\gamma\gamma\to\phi\phi$ for different ranges of $W_{\gamma\gamma}$ not covered in table 1.

| $W_{\gamma\gamma}$ range (GeV/$c^2$) | $\sigma(\gamma\gamma\to\omega\phi)$ (nb) | $\sigma(\gamma\gamma\to\phi\phi)$ (nb) |
|---|---|---|
| 2.5–2.8 | <2.0 | <1.9 |
| 2.8–3.1 | <2.0 | <2.4 |
| 3.1–3.4 | <2.6 | <2.9 |
| 2.5–3.4 | <0.7 | <0.8 |

Table 1
Upper limits for the cross sections for $\gamma\gamma\to\omega\phi$ and $\gamma\gamma\to\phi\phi$, together with $q\bar{q}q\bar{q}$ model predictions. The upper limits are restricted to the part of the $W_{\gamma\gamma}$ range of the $q\bar{q}q\bar{q}$ states sensitive to this experiment. The version used for each model is indicated by the year and the quoted values are the predicted mean [1] and maximum [2] cross sections in nb, respectively.

| Channel | $W_{\gamma\gamma}$ range (GeV/$c^2$) | σ (nb) | | |
|---|---|---|---|---|
| | | present work | (1985) [a] | (1983) [b] |
| ωφ | 1.9–2.5 | <1.7 (95% CL) | ≈1.1 | <1.3 |
| φφ | 2.2–2.5 | <7.1 (95% CL) | ≈3.5 | <0.9 |

[a] Ref. [1]. [b] Ref. [2].

reaching about 10 nb. Upper limits were derived for ωϕ and ϕϕ production which are compatible with $q\bar{q}q\bar{q}$ model predictions.

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