A MEASUREMENT OF THE REACTION $e^+e^- \to e^+e^-\eta'$ AND THE RADIATIVE WIDTH $\Gamma_{\eta' \to \gamma\gamma}$ AT PETRA

JADE Collaboration

W. BARTEL, D. CORDS, P. DITTMANN, R. EICHLER [1], R. FELST, D. HAIDT, H. KREHBIEL, K. MEIER, B. NAROSKA, L.H. O'NEILL [2], P. STEFFEN, H. WENNINGER [3]
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

E. ELSEN, A. PETERSEN, P. WARMING, G. WEBER
II. Institut für Experimentalphysik der Universität Hamburg, Germany

S. BETHKE, H. DRUMM [4], J. HEINTZE, G. HEINZELMANN, K.H. HELLENBRAND, R.D. HEUER, J. von KROGH, P. LENNERT, S. KAWABATA, S. KOMAMIYA, H. MATSUMURA, T. NOZAKI, J. OLSSON, H. RIESEBERG, A. WAGNER
Physikalisches Institut der Universität Heidelberg, Germany

A. BELL, F. FOSTER, G. HUGHES, H. WRIEDT
University of Lancaster, England

J. ALLISON, A.H. BALL, G. BAMFORD, R. BARLOW, C. BOWDERY, I.P. DUERDOTH, J.F. HASSARD [5], B.T. KING [6], F.K. LOEBINGER, A.A. MACBETH, H. McCANN, H.E. MILLS, P.G. MURPHY, K. STEPHENS
University of Manchester, England

D. CLARKE, M.C. GODDARD, R. MARSHALL, G.F. PEARCE
Rutherford Appleton Laboratory, Chilton, England

and

J. KANZAKI, T. KOBAYASHI, M. KOSHIBA, M. MINOWA, M. NOZAKI, S. ODAKA, S. ORITO [2], A. SATO, H. TAKEDA, Y. TOTSUKA, Y. WATANABE, S. YAMADA and C. YANAGISAWA [7]
Lab. of Int. Coll. on Elementary Particle Physics and Department of Physics, University of Tokyo, Japan

Received 15 March 1982

The reaction $e^+e^- \to e^+e^-\eta'$ has been observed in the JADE experiment at PETRA, by detecting the final state $\pi^+\pi^-\gamma$, resulting from the decay $\eta' \to \gamma\rho^0$. The cross section was measured at an average beam energy of 17.15 GeV to be $\sigma(e^+e^- \to e^+e^-\eta') = 2.2 \pm 0.2$ (stat.) $\pm$ 0.4 (syst.) nb, yielding the radiative width $\Gamma_{\eta'\gamma\gamma} = 5.0 \pm 0.5$ (stat.) $\pm$ 0.9 (syst.) keV.

[1] Present address: Labor für Hochenergiephysik der ETH-Zürich, Villigen, Switzerland.
[2] Present address: Bell Laboratories, Whippany, NJ, USA.
[3] On leave from CERN, Geneva, Switzerland.
[4] Present address: Staatliches Studienseminar für das Schulamt für Gymnasium, Bad Kreuznach, Germany.
[5] Present address: Harvard University, Cambridge, MA, USA.
[6] Present address: University of Glasgow, Glasgow, Scotland, UK.
[7] Present address: Rutherford Appleton Laboratory, Chilton, England.

0 031-9163/82/0000–0000/$02.75

In recent years a considerable effort has been devoted to the study of the two photon process $e^+e^- \to e^+e^-X$, where X is a meson resonance of C-parity +1. This reaction is of interest, since it provides a measurement of the radiative width of the meson X. So far $\eta'(958)$ [1], f(1270) [2,3], and $A_2(1310)$ [3] have been seen and their radiative widths determined.

In this letter ‡1 we report a measurement of the reaction

$$e^+e^- \to e^+e^-\eta'(958) \\ \to \gamma\rho^0(770) \\ \to \pi^+\pi^- , \qquad (1)$$

which is sketched in fig. 1. The measurement was carried out using the JADE detector at the e^+e^- storage ring PETRA. The data sample comes from an integrated luminosity of 36 pb^{-1}, with beam energies distributed between 13.2 and 18.3 GeV, yielding 17.15 GeV on average.

The outgoing electron and positron in reaction (1) were in general not detected, since they are predominantly emitted at very small angles. Thus the final-state topology consists of two charged particles with low momentum and a single photon of low energy (typically a few hundred MeV). The momenta and the energy loss dE/dx of the charged particles were measured by the jet chambers described in ref. [5]. The photon was detected in the lead glass counters, which consist out of a central cylindrical array and two endcap arrays surrounding the inner drift chambers. The counters cover a solid angle of 90% of 4π. The angular resolution of these arrays varies between 7 and 20 mrad, depending on the angle of incidence and the sharing of energy between counters. The energy resolution has been measured to be 10% for 500 MeV electrons. The read out thresholds for the ADC's were set to 25 MeV.

‡1 Preliminary results have been reported [4], which are superseded by the present final analysis.

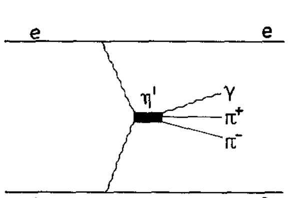

Fig. 1. Feynman diagram for the process $e^+e^- \to e^+e^-\eta'$.

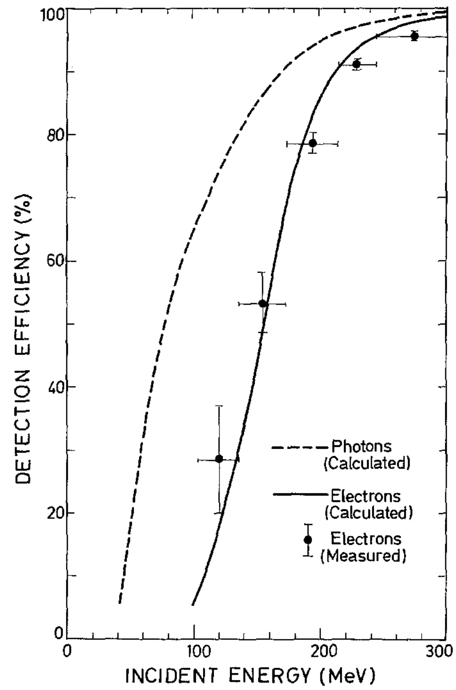

Fig. 2. Detection efficiency for photons and electrons, as function of the incident energy.

The measurement of reaction (1) requires a careful study of the detection efficiency for low-energy photons. It has been determined with help of a computer program which simulates the electromagnetic shower development in the detector and in the material in front of the lead glass [6]. This program also simulates the Čerenkov radiation in lead glass, as well as the wavelength dependence of photocathode sensitivity and light transmission in lead glass and the light guide material. The results of this efficiency calculation are shown in fig. 2. As a check similar calculations of the electron efficiency are compared in fig. 2 with experimental results. Experimentally the electron detection efficiency has been obtained with low-energy electrons from the reaction $e^+e^- \to e^+e^-e^+e^-$, where the momenta of the electrons have been measured with the central drift chamber and where the electrons have been identified by dE/dx. The good agreement between these measurements and the calculation gives confidence in the calculated photon detection efficiency.

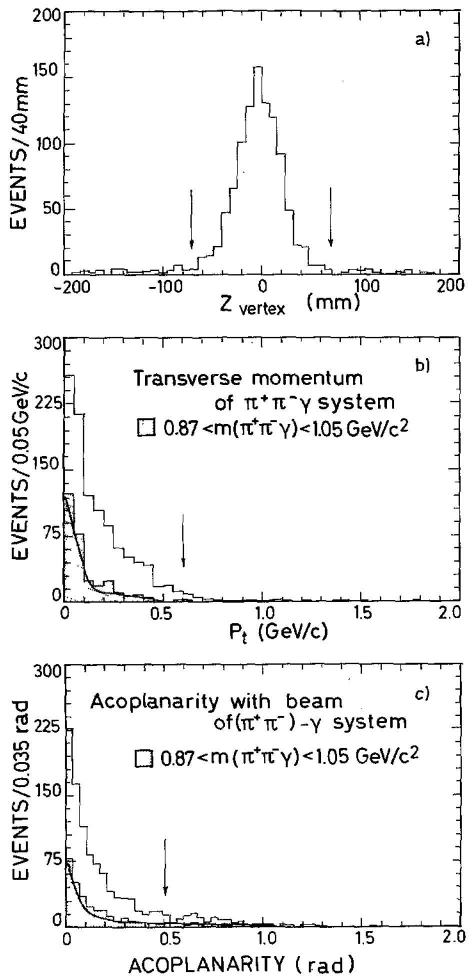

Fig. 3. (a) Event vertex along the beam axis (z). (b) Total transverse momentum of the $\pi^+\pi^-\gamma$ system. (c) Acoplanarity with the beam of the $\gamma - (\pi^+\pi^-)$ system. In the shaded histograms in (b) and (c) the mass of the $\pi^+\pi^-\gamma$ system is restricted to the η' band, $0.87 < m(\pi^+\pi^-\gamma) < 1.05$ GeV/c^2. The curves show the corresponding distributions from the Monte Carlo simulation described in the text.

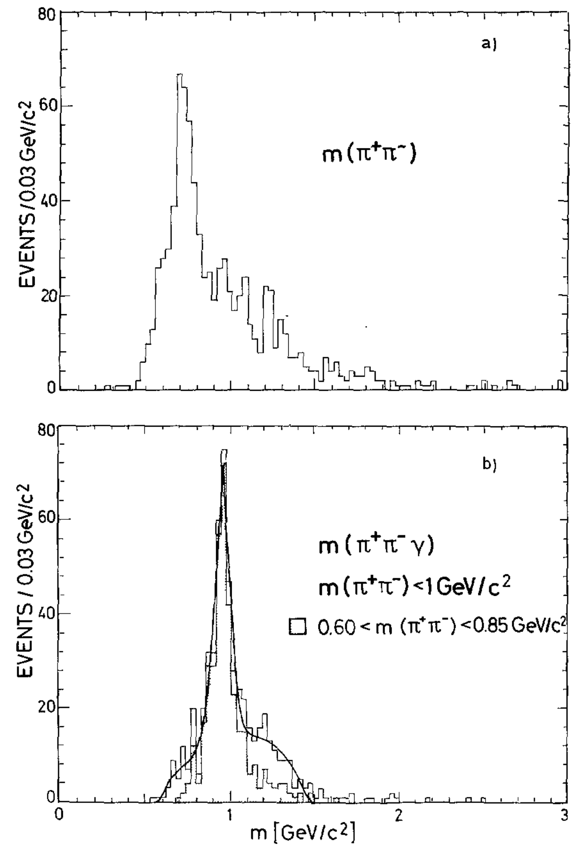

Fig. 4. (a) Mass distribution of the $\pi^+\pi^-$ system. (b) Mass distribution of the $\pi^+\pi^-\gamma$ system, with the restriction that $m(\pi^+\pi^-) < 1.0$ GeV/c^2. In the shaded histogram the mass of the $\pi^+\pi^-$ system is further restricted to the ρ^0 band, $0.60 < m(\pi^+\pi^-) < 0.85$ GeV/c^2.

The trigger requires two tracks to be opposite and coplanar with the beam within $\pm 30°$. It covers the polar angle θ range $|\cos\theta| < 0.85$. The transverse momentum threshold for this trigger is below 150 MeV/c per track. A more detailed description can be found in ref. [5].

From the data, events with two charged particles and one photon were selected. For this, all the information from the lead glass system and the inner detector (conversions in front of the drift chambers) was used, to reject background of events with more than one photon. For the final analysis, only those events with the photon detected in the central lead glass arrays were used, since they have the better energy and angular resolution. In addition, the energy of the photon was required to be bigger than 130 MeV. For the charged tracks the following criteria were applied:

(1) The two charged tracks should have opposite charge and come from a fiducial cylinder around the interaction point, with radius 20 mm and length ±200 mm along the beam axis. The opening angle ω of the tracks was restricted to $\cos(\omega) > -0.97$, to reject background from cosmic rays.

(2) The momentum of each track was required to

be between 0.2 and 3.0 GeV/c.

(3) The energy loss $\mathrm{d}E/\mathrm{d}x$ of the charged particles, which is measured in the inner detector [7], was required to be within 3σ of the expected $\mathrm{d}E/\mathrm{d}x$ for pions. This cut considerably reduced the background from beam gas reactions as well as events from the reaction

$$e^+e^- \to e^+e^-e^+e^-\gamma \,. \qquad (2)$$

(4) At charged-particle momenta above 0.8 GeV/c, electrons from reaction (2) could be rejected by comparing the momentum with the associated lead glass energy. The event was rejected, if the ratio [shower energy (lead glass)/momentum (track)] exceeded 0.7 for both tracks.

(5) To reject remaining events from reaction (2), it was further required that the transverse momentum of the two track system with respect to the beam was >50 MeV/c and that the acoplanarity of the two tracks with the beam was >50 mrad.

After these cuts, 1067 events remained. For this sample, figs. 3a, b and c show the vertex distribution along the beam axis (z), the total transverse momentum with respect to the beam, p_t, and the acoplanarity of the $\gamma - (\pi^+\pi^-)$ system with the beam, respectively. The vertex distribution shows a clean signal of beam–beam events and the transverse momentum and acoplanarity distributions peak at low values, as expected for events of reaction (1). The final cuts in these distributions are indicated by arrows:

$$|z - \text{vertex}| < 70\ \text{mm}\,,$$

$$p_t < 0.60\ \text{GeV}/c\,,$$

$$\text{acoplanarity} < 0.50\ \text{rad}\,.$$

The final sample then consisted of 847 events. Figs. 4a and b show the invariant mass spectra of the $\pi^+\pi^-$ system and of the $\pi^+\pi^-\gamma$ system. In fig. 4b an additional requirement $m(\pi^+\pi^-) < 1.0$ GeV/c^2 was imposed, since $\pi^+\pi^-$ masses above 1 GeV/c^2 do not contribute to reaction (1). Prominent ρ^0 and η' signals are seen. The remaining background comes mainly from feedthrough from final states with more pions and photons, which escaped detection. The association of the ρ^0 with the η' signal is evident in the shaded histogram in fig. 4b, which is obtained by restricting the $\pi^+\pi^-$ mass to the ρ^0-band, $0.60 < m(\pi^+\pi^-) < 0.85$ GeV/c^2. Further evidence that the η' peak is due to reaction (1) is given in the shaded histograms in fig. 3b and c. Here are shown the p_t and acoplanarity distributions for those events with the $\pi^+\pi^-\gamma$ mass in the η' band, $0.87 < m(\pi^+\pi^-\gamma) < 1.05$ GeV/c^2, while the curves show the corresponding distributions from the Monte Carlo simulation described below. The data agree well with the predicted behaviour of reaction (1).

The cross section for reaction (1) can be written [8]

$$\sigma(e^+e^- \to e^+e^-\eta') = \int \sigma_{\gamma\gamma\to\eta'}(s) \times L_{\gamma\gamma}(\sqrt{s}/2E_{\text{beam}})\, \mathrm{d}s/4\sqrt{s}E_{\text{beam}}\,,$$

where s is the squared c.m. energy of the two-photon system, $\sigma_{\gamma\gamma\to\eta'}$ is the cross section for $\gamma\gamma \to \eta'$ and $L_{\gamma\gamma}$ represents the luminosity function for the two photons. The calculation of the luminosity function was performed with a Monte Carlo simulation program using the formulae given in ref. [8]. The simulation of reaction (1) combined the calculation of $L_{\gamma\gamma}$ with the production and subsequent decay of η', yielding the final-particle four-vectors as end products. The particles were passed through a computer program which simulated the response of the various detector components. For the photons, the above mentioned shower program was used. The simulated events were then subjected to the same cuts as those applied to the real data. The resulting overall detection efficiency is 0.0089 ± 0.0004. The error is statistical only and the branching ratio $BR(\eta' \to \gamma\rho^0)$ is not included.

To determine the number of η' events in fig. 4b, the full mass spectrum was fitted with an incoherent sum of a resolution function for the resonance and a polynomial background term. The fit, which is shown in fig. 4b, resulted in 213 ± 15 events due to reaction (1). The cross section is then calculated:

$$\sigma(e^+e^- \to e^+e^-\eta') = 2.2 \pm 0.2\ \text{nb}\,.$$

The error is statistical only. The branching ratio of η' into $\gamma\rho^0$ was taken from ref. [9].

The main systematic error is due to the uncertainty in the photon detection efficiency. The photon spectrum of reaction (1) peaks at about 180 MeV and overlaps considerably with the rising part of the detection efficiency in fig. 2. In order to estimate this uncertainty several different photon-energy cut-off values were applied to the data as well as to the Monte Carlo sample and the cross section calculated in the same manner as above. The result is consistent with the cross section being independent of the photon-energy cut-off value.

One can conclude that the photon-energy spectrum in the Monte Carlo event sample is similar to the real data spectrum. The systematic error in the simulation is estimated to be about 10%. Further systematic errors come from trigger inefficiencies, from the cuts in the selection criteria, from the luminosity measurement and from the parametrization of the fitted background. The total systematic error is estimated to be 18%. The value for the cross section is then

$$\sigma(e^+e^- \to e^+e^-\eta') = 2.2 \pm 0.2\,(\text{stat.}) \pm 0.4\,(\text{syst.})\ \text{nb}\ .$$

The cross section can be related to the radiative width:

$$\sigma(e^+e^- \to e^+e^-\eta') = (8\pi^2 \Gamma_{\eta'\to\gamma\gamma}/m_{\eta'}^2 4E_{\text{beam}}) L_{\gamma\gamma}(m_{\eta'}/2E_{\text{beam}})\ .$$

Here the expression for $\sigma_{\gamma\gamma\to\eta'}$ in ref. [10] was used. With the above result for the cross section, one obtains

$$\Gamma_{\eta'\to\gamma\gamma} = 5.0 \pm 0.5\,(\text{stat.}) \pm 0.9\,(\text{syst.})\ \text{keV}\ .$$

This value agrees well with the previous measurement, $\Gamma_{\eta'\to\gamma\gamma} = 5.8 \pm 1.1$ (stat.) ± 1.2 (syst.) keV from SPEAR [1], and with a recent measurement, $\Gamma_{\eta'\to\gamma\gamma} = 5.4 \pm 1.0$ (stat.) ± 0.7 (syst.) keV by the CELLO-collaboration [11]. It is well below the upper limits obtained earlier at DORIS and ADONE [12].

Values for the width $\Gamma_{\eta'\to\gamma\gamma}$ in the range 6–7 keV are predicted by various models with fractionally charged quarks, while models with integer-charge quarks tend to predict values around 20 keV [13].

η' and η are conventionally regarded as members of the same SU(3) nonet. The relation between their radiative widths $\Gamma_{\eta'\to\gamma\gamma}$ and $\Gamma_{\eta\to\gamma\gamma}$ depends on the isoscalar mixing angle θ [14]. Our measurement corresponds to $\theta = 11 \pm 4$ degrees (using $\Gamma_{\eta\to\gamma\gamma} = 0.323 \pm 0.046$ keV [9]), in agreement with more general considerations of this angle [13,14].

From the branching ratio $BR(\eta' \to \gamma\gamma) = 0.019 \pm 0.002$ [9], we obtain

$$\Gamma_{\eta'} = 263 \pm 61\ \text{keV}\ ;$$

This value agrees well with the direct measurement [15] of the total width, $\Gamma_{\eta'} = 280 \pm 100$ keV, using the reaction $\pi^- p \to \eta' n$ close to threshold.

We acknowledge the outstanding efforts of the PETRA machine group and thank the technical support groups of the participating institutes for their important help. We thank Dr. F. Close, Dr. J. Field, Professor G. Kramer, Dr. H. Krasemann, Dr. F. Schrempp, Dr. B. Schrempp and Dr. J.A.M. Vermaseren for useful discussions. This experiment was supported by the Bundesministerium für Forschung und Technologie, by the Education Ministry of Japan and by the UK Science and Engineering Research Council through the Rutherford Appleton Laboratory. The visiting groups at DESY wish to thank the DESY directorate for their hospitality.

[1] G. Abrams et al., Phys. Rev. Lett. 43 (1979) 477;
P. Jenni, Proc. Intern. Workshop on $\gamma\gamma$ collisions (Amiens, France, 1980).
[2] C. Berger et al., Phys. Lett. 94B (1979) 254;
A. Roussarie et al., Phys. Lett. 105B (1981) 304;
TASSO-Collab., R. Brandelik et al., Z. Phys. C10 (1981) 117.
[3] D. Burke, Proc. 4th Intern. Colloquium on Photon–photon interactions (Paris, 1981).
[4] E. Hilger, Proc. 4th Intern. Colloquium on Photon–photon interactions (Paris, 1981);
C. Berger, Proc. EPS Intern. Conf. on High-energy physics (Lisbon, 1981);
R. Wedemeyer, Proc. Intern. Symp. on Lepton and photon interactions at high energies (Bonn, 1981).
[5] JADE-Collab., W. Bartel et al., Phys. Lett. 88B (1979) 171; 92B (1980) 206; 99B (1981) 277.
[6] A. Sato, Master Thesis, Tokyo University (1978), unpublished;
K. Messel and J.F. Crawford, Electron–photon shower distribution function tables (Pergamon, London, 1970).
[7] JADE-Collab., W. Bartel et al., Z. Phys. C6 (1980) 295.
[8] J. Field, Nucl. Phys. B168 (1980) 477, and Erratum.
[9] Particle Data Group, Rev. Mod. Phys. 52 (1980).
[10] F. Low, Phys. Rev. 120 (1960) 582.
[11] CELLO-Collab., H. Behrend et al., DESY 82/008 (1982).
[12] H. Besch et al., Phys. Lett. 81B (1979) 29;
R. Baldini Celio et al., Phys. Lett. 86B (1979) 239;
S. Orito et al., Phys. Lett. 48B (1974) 380;
L. Paoluzi et al., Lett. Nuovo Cimento 10 (1974) 435.
[13] S. Okubo, in: Symmetries and quark models, ed. R. Chand (Gordon and Breach, New York, 1970);
H. Suura et al., Lett. Nuovo Cimento 4 (1972) 505;
A. Bramon et al., Phys. Lett. 48B (1974) 137;
F. Gault et al., Nuovo Cimento 24A (1974) 259;
M. Chanowitz et al., Phys. Rev. Lett. 35 (1975) 977;
A. Kazi et al., Nuovo Cimento 15 (1976) 120;
E. Etim et al., Nuovo Cimento 42 (1977) 124;
M. Chanowitz, Proc. SLAC Summer Institute (1981), to be published; Phys. Rev. Lett. 44 (1980) 59.
[14] F. Close, An introduction to quarks and partons (Academic Press, London, 1979).
[15] D. Binnie et al., Phys. Lett. 83B (1979) 141.