MEASUREMENT OF EXCLUSIVE η' PRODUCTION IN $\gamma\gamma$ REACTIONS

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We observe $\gamma\gamma \to \eta'$ production in the reaction $e^+e^- \to e^+e^-\pi^+\pi^-\gamma$. We measure the product $\Gamma_{\gamma\gamma}(\eta')B(\eta' \to \rho^0\gamma)$ to be $1.14 \pm 0.08 \pm 0.11$ keV. A first measurement of the $\gamma\gamma \to \eta'$ transition form factor is made for Q^2 up to 1 GeV^2.

In this letter, we describe an investigation of the two-photon reaction

$$e^+e^- \to e^+e^-\gamma\gamma\,, \quad \gamma\gamma \to \eta'\,,$$

where the η' is identified through its decay into $\rho^0\gamma$. If both photons are close to mass shell (no tag), this process can be used to measure the two-photon width $\Gamma_{\gamma\gamma}$ of the η'. This measurement has been made by other experiments [1–4]. In this experiment, the process with one photon in the Q^2 range from 0.2 to 1.0 GeV^2 is detected in addition (single tag), allowing the first measurement of the $\gamma\gamma \to \eta'$ form factor.

The differential cross section of the above process factorises into a photon luminosity function and the total two-photon cross section $\sigma_{\gamma\gamma}(q_1^2, q_2^2)$ where q_1^2, q_2^2 are the invariant masses squared of the virtual photons. For the luminosity function we have used the standard formula given by Budnev et al. [5]. Since the η' has spin–parity 0^-, the two-photon cross section is linked to the radiative width $\Gamma_{\gamma\gamma}$ of the η' through a single transition form factor $F(q_1^2, q_2^2)$. The partial width $\Gamma_{\gamma\gamma}$ is of interest because it tests the flavour symmetry of the quark wave functions of the meson. It has been argued that a value of $\Gamma_{\gamma\gamma}$ which is below the expectations of SU(3) could indicate a glueball admixture in the η' [‡1].

In this paper, we adopt the form factor definition given by Köpp et al. [6]. Calling Γ and m the total width and mass of the η', the $\gamma\gamma$ cross section is then

$$\sigma_{\gamma\gamma} = (4\sqrt{X})^{-1}(\nu^2 - m^2\tilde{Q}^2)F^2(q_1^2, q_2^2)$$
$$\times \sqrt{s}\Gamma/[(s - m^2)^2 + \Gamma^2 m^2]\,,$$

where $\sqrt{X}$ is Moeller's flux factor $X \equiv (q_1 \cdot q_2)^2 - q_1^2 q_2^2$, $\tilde{Q}$ is defined as $(q_1 - q_2)/2$, P is the η' four-momentum, $\nu \equiv \tilde{Q} \cdot P$, and $\sqrt{s}$ is the invariant mass of the $\gamma\gamma$-system.

For real photons, the cross section becomes

$$\sigma_{\gamma\gamma} = (8\pi/m)\sqrt{s}\Gamma_{\gamma\gamma}\Gamma/[(s - m^2)^2 + \Gamma^2 m^2]\,,$$

with the normalisation $F^2(0, 0) = 64\pi\Gamma_{\gamma\gamma}/m^3$. In order to extract $\Gamma_{\gamma\gamma}$ from the data, a small extrapolation from $\langle q^2 \rangle = -0.001$ GeV^2 to $q^2 = 0$ had to be made. For this purpose, we have assumed that the form factor varies like a ρ^0 pole i.e. $F(q^2) = F(0)/(1 - q^2/m_\rho^2)$ for the quasireal photons.

The data were taken by the PLUTO detector at PETRA at a beam energy of 17.34 GeV. Details of the PLUTO detector have been given elsewhere [8]. The integrated luminosity was $\int L\,dt = 46$ pb^{-1} for the width measurement and 25 pb^{-1} for the form factor measurement.

For this analysis, we have used the inner track detector, the barrel and endcap shower counters and the small angle tagger (SAT). The trigger conditions relevant for this analysis required either two coplanar tracks (±30° in a plane perpendicular to the beam axis) in the inner detector, or, for the form factor measurement, one track in the inner detector together with a shower of more than 6 GeV in the small angle tagger.

The event topology selected is two oppositely charged tracks and one photon. In order to reduce QED background, events in which one of the tracks points to an electromagnetic shower of more than 600 MeV are excluded. Because the pions coming from η' decays have low momenta, this cut is estimated to reduce the number of η' events by only 4 ± 1%. In order to obtain a sample with good momentum resolution, the analysis is restricted to events in which all charged tracks make an angle with the beam direction of less than 45° and have a transverse momentum of at least 150 MeV.

We accept photons detected in the barrel and endcap shower counters which together cover a solid angle of $(96\%) \cdot 4\pi$. Photons which deposit less than 100 MeV are treated as noise and ignored. This implies that the acceptance as a function of the true photon energy is essentially determined by the energy resolution of the shower counters. We improve the mass resolution of the detector by an energy tuning method which has

‡1 An extensive list of predictions can be found as ref. [38] in ref. [11].

also been used by the CELLO collaboration [3], i.e. we replace the measured shower energy by the value $E_\gamma(\text{seen}) \cdot p_\perp(\pi^+\pi^-, \text{seen})/p_\perp(\gamma, \text{seen})$. In order to eliminate fake photons it is demanded that the transverse momentum $p_\perp(\pi^+\pi^-)$ of the charged system alone exceeds 100 MeV. Furthermore, the angle between $p_\perp(\pi^+\pi^-)$ and $p_\perp(\gamma)$ must differ from π by less than 500 mrad.

Cosmic events in the no tag sample are excluded by the requirements that $\cos(\boldsymbol{p}_{\pi^+}, \boldsymbol{p}_{\pi^-}) > -0.97$ and that $\varphi(\boldsymbol{p}_{\pi^+}, \boldsymbol{p}_{\pi^-})$ which is the angle between the pions in a plane perpendicular to the beam direction, may not be closer to π than ± 100 mrad. The remaining background consists mainly of residual QED events and incompletely reconstructed multi-hadron events, in particular from the reaction $\gamma\gamma \to A_2$. The QED contributions are due to $\gamma\gamma \to e^+e^-$ events where one of the electrons radiates a photon and elastic $\gamma\gamma$ scattering with subsequent pair creation by one of the photons. Radiating electrons are removed by demanding $\cos(\boldsymbol{p}_\pi, \boldsymbol{p}_\gamma) < 0.95$ and converted photons are eliminated by the requirement $\cos(\boldsymbol{p}_{\pi^+}, \boldsymbol{p}_{\pi^-}) < 0.95$. Most of the incompletely reconstructed multi-prongs are eliminated by the requirement that the event (after photon energy correction) should have an overall $p_\perp$ of less than 100 MeV.

The $\pi^+\pi^-\gamma$ invariant mass spectra obtained in this manner are shown in fig. 1. There is a clear enhancement of events in the η' region for both the tagged and the untagged sample. In both cases the corresponding $\pi^+\pi^-$ spectra are consistent with 100% ρ^0 decays. For the determination of the two-photon width and the η' form factor, the data must be corrected for acceptance effects. This was done by Monte Carlo techniques. Since the acceptance turns out to depend on the details of the η' decay, we give the decay formulae explicitly.

The decay of the resonance was simulated in a two-stage process: the radiative decay of the η' into a ρ, followed by the decay of the ρ meson into two pions. The η' decay was modelled such that the $\eta' \to \rho\gamma$ transition matrix element M is proportional to the photon energy E_γ in the η' rest frame. The ρ mass spectrum was generated according to a prescription given by Jackson [8]:

$$\frac{\mathrm{d}\Gamma(\eta' \to \rho^0\gamma)}{\mathrm{d}m^2_{\pi\pi}} = E_\gamma |M|^2 \frac{m_\rho \Gamma(m_{\pi\pi})}{(m^2_\rho - m^2_{\pi\pi})^2 + m^2_\rho \Gamma^2(m_{\pi\pi})} .$$

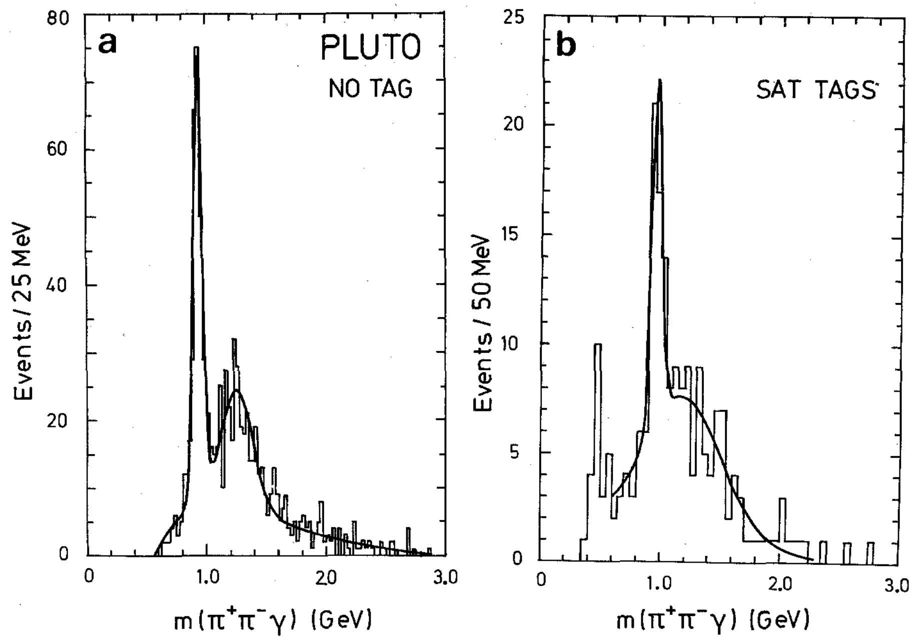

Fig. 1. $\pi^+\pi^-\gamma$ invariant mass spectra (a) from the collision of quasireal photons ("no tag"), and (b) from single tag events with $\langle Q^2 \rangle = 0.4$ GeV^2. The curves are fits to the data (see text). The apparent "signal" at 500 MeV in the tagged data is due to residual converted photons which are not triggered in the no tag mode.

The additional E_γ factor comes from the $\rho\gamma$ phase space, m_ρ is the nominal ρ^0 mass (770 MeV), and the variation of the ρ^0 width can be parameterised as $\Gamma(m_{\pi\pi}) = \Gamma(m_\rho)\cdot 2p^3_{\pi\pi}/p_\rho(p^2_\rho + p^2_{\pi\pi})$ where p_ρ ($p_{\pi\pi}$) is the pion momentum in the rest frame of the ρ^0 at nominal (actual) ρ mass. Calling ϑ the angle between the $\gamma\gamma$ axis and the ρ^0 in the η' rest frame, the distribution in $\cos(\vartheta)$ should be isotropic, whereas the ρ^0 is expected to have helicity ±1, giving rise to the characteristic $\sin^2(\lambda)$ term in the ρ^0 decays, λ being the angle between the π^+ and the ρ^0 helicity in the ρ^0 rest frame. The data confirm these assumptions as can be seen in fig. 2 where the corrected angular distributions for (a) the decay $\eta' \to \rho^0\gamma$ and (b) the decay $\rho^0 \to \pi^+\pi^-$ are shown. The generated events were processed through a full detector simulator. The resulting Monte Carlo spectra reproduce the data well. In fig. 3 we show the photon energy spectrum in the lab frame since the understanding of its shape is crucial for the determination of the acceptance.

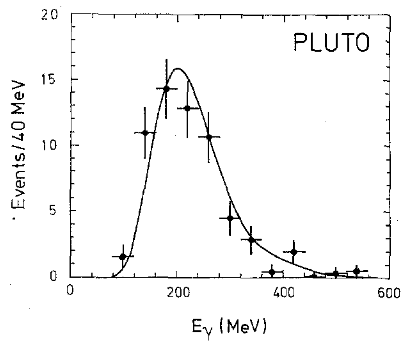

Fig. 3. The visible photon energy spectrum of the no tag η' sample, folded with the detector resolution (after background subtraction). The solid line is the Monte Carlo expectation normalised to the number of η' events.

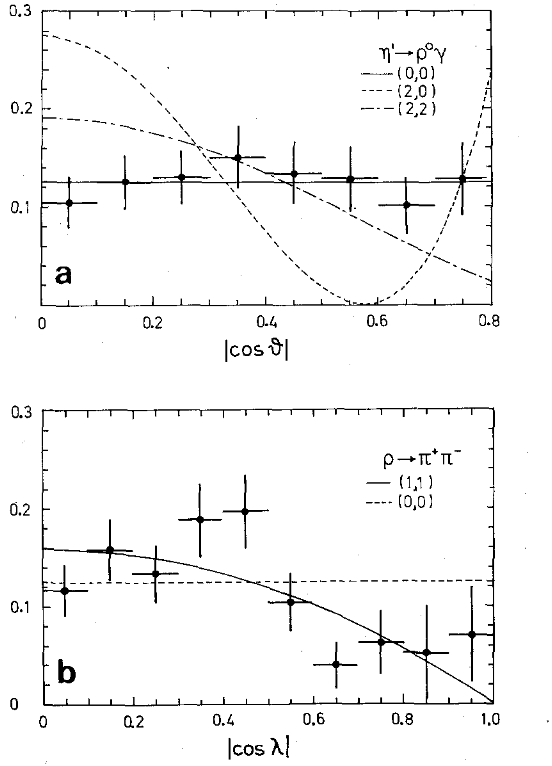

Fig. 2. Corrected angular distributions (a) for the decay $\eta' \to \rho^0\gamma$ and (b) for the subsequent ρ^0 decay into $\pi^+\pi^-$. The angles are defined in the text. The solid lines are the expectations for a decay of the type $0^- \to 1^-1^-$. The curves are labelled with (spin, helicity) and normalised to the data shown.

In order to determine the number of η' events in fig. 1a, the mass spectrum was fitted with the sum of two gaussians, for the η' signal and an A_2 contribution respectively, as well as a smooth background. The values for the central mass and width of the A_2 were determined by a Monte Carlo program simulating the two-photon production and the subsequent decay of the A_2 into two charged pions and two photons (from a π^0 decay), using only those events where one of the photons was not detected. The result of the four-parameter fit is an η' signal of 243 ± 16.5 events. This number corresponds to the product

$$\Gamma_{\gamma\gamma}B(\eta' \to \rho^0\gamma) = 1.14 \text{ keV} \pm 0.08 \text{ keV (stat.)}.$$

A similar fit involving three free parameters and the signal width and position fixed gives 35 ± 9 events in the tagged sample. For the purpose of extracting the form factor, the tagged data were split into three Q^2 bins and the number of events in each bin was compared with the corresponding Monte Carlo expectation. The result is shown in fig. 4, together with a ρ^0 pole form factor.

Using the ρ^0 pole for both photons and taking our no tag measurement for normalisation, we expect 0.8 ± 0.2 events in the sample with both electrons in the tagging range. In the data, we find four double tagged η' events with an estimated background of less than 0.3 events.

The η' events populate an energy region which is close to the detector threshold. Thus, the trigger effi-

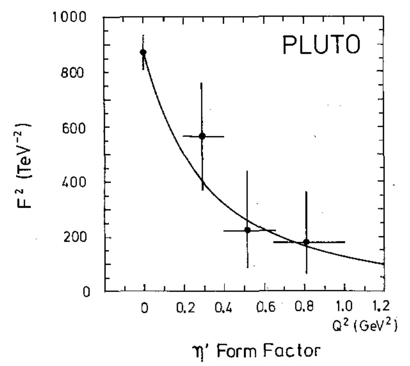

Fig. 4. The $\eta'-\gamma\gamma$ transition form factor. The line is a simple ρ^0 pole, normalised to the no tag result.

ciency and the calorimeter response to low energy photons are the main sources of systematic uncertainties. The trigger efficiency was evaluated with sets of data in which the triggers used for this analysis were redundant. This algorithm enables us to determine the trigger efficiency to within 6%. The photon detection efficiency was determined with a Monte Carlo program which had been calibrated with a sample of 300 converted photons. The accuracy of this calibration leaves a 6% uncertainty on the event loss due to the photon energy cut and 4% for residual electronic losses. The luminosity is known to within 3%. Remaining effects like hadronic interactions in the detector, wrong topology assignments due to electronic noise etc., lead to an additional uncertainty of 2%. Adding the errors in quadrature gives a total systematic error of 10%.

Taking the accepted value for the branching ratio [9] $B(\eta' \to \rho^0\gamma) = 30.0\% \pm 1.6\%$, our measurement corresponds to a partial width

$$\Gamma_{\gamma\gamma} = 3.80 \pm 0.26(\text{stat.}) \pm 0.43(\text{syst.})\ \text{keV}\ .$$

This value, together with the branching ratio $B(\eta' \to \gamma\gamma) = 1.9 \pm 0.2\%$ [9] gives the most precise value of the total width of the η' currently available, namely $\Gamma = 200 \pm 34$ keV.

The value we obtain for the two-photon width of the η' is considerably lower than previously reported numbers. This may be due to the fact that in previous analyses, the dynamics of the η' decay was not fully taken into account [10]. If we had assumed a simple ρ^0 Breit–Wigner function with cutoffs at the kinematic limits, the resulting $\Gamma_{\gamma\gamma}$ width would have been around 5 keV.

In the framework of flavour SU(3), one expects the following mixing angle independent relation for the 0^{-+} nonet:

$$\Gamma_{\gamma\gamma}(\eta')/m^3(\eta') = 3\Gamma_{\gamma\gamma}(\pi)/m^3(\pi) - \Gamma_{\gamma\gamma}(\eta)/m^3(\eta)\ .$$

This relation leads to an expected two-photon width for the η' of 5.4 ± 1.0 keV according to the Crystal Ball measurement of $\Gamma_{\gamma\gamma}(\eta)$ [11] and 6.7 ± 0.6 keV according to the Cornell measurement [12] for $\Gamma_{\gamma\gamma}(\eta)$. So, taking the Crystal Ball measurement, our result is consistent with flavour SU(3), while, taking the Cornell (Primakoff effect) result, there is a significant deviation from this symmetry. In either case, the measured $\gamma\gamma$ width of the η' is lower than expected in the framework of SU(3).

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