MEASUREMENT OF $\eta' \to \pi^+\pi^-\gamma$ IN $\gamma\gamma$ COLLISIONS

ARGUS Collaboration

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The production of the pseudoscalar meson $\eta'(958)$ is observed in the reaction $e^+e^- \to e^+e^-\eta' \to e^+e^-\pi^+\pi^-\gamma$ with the ARGUS detector at DESY. We measure the product $\Gamma_{\gamma\gamma}(\eta')\mathrm{Br}(\eta' \to \rho\gamma)$ to be $1.13 \pm 0.04 \pm 0.13$ keV. Using the known branching ratios, we calculate $\Gamma_{\gamma\gamma}(\eta')$ to be $3.76 \pm 0.13 \pm 0.47$ keV and $\Gamma_{\eta'}$ to be 203 ± 32 keV.

The $\gamma\gamma$ couplings of mesons reveal aspects of their structure, for example the degree of mixing between singlet and octet states and the behaviour of the wave functions at the origin. A departure from the expectations of flavour SU(3) symmetry for the pseudoscalars could indicate a non $|q\bar{q}\rangle$ contribution [1].

We report here a measurement of the $\gamma\gamma$ width of the η' using the ARGUS detector at DORIS II operating at centre of mass energies around 10 GeV. ARGUS is a universal magnetic detector and is described in ref. [2]. Good spatial and momentum resolution for charged particles and photons of momenta as low as 50 MeV/c over a large solid angle enables us to make a detailed study of the reaction $e^+e^- \to e^+e^-\eta' \to e^+e^-\pi^+\pi^-\gamma$. The outgoing leptons are predominantly produced at very small angles and are not detected. The data used for this analysis corresponds to an integrated luminosity of 106.8 pb^{-1}. The production of η' mesons in $\gamma\gamma$ collisions has been investigated previously at the SPEAR and the PEP-/PETRA storage rings operating at centre of mass energies between 4 and 7 GeV and between 30 and 40 GeV, respectively [4–9].

The triggers sensitive to $\gamma\gamma$ processes require charged tracks to hit trigger elements composed of Time of Flight (ToF) counters and appropriate groups of shower counters. Two distinct trigger requirements were used in parallel. The first requires at least one charged particle in each hemisphere defined by the transverse plane through the interaction point. The second accepts an event if any pair of charged particles hits ToF counters separated by at least 90° in the transverse plane. A second level trigger processor, known as the Little Track Finder (LTF), searches for tracks with transverse momenta greater than 125 MeV/c originating from the center of the drift chamber. At least two LTF tracks were required in each event.

The raw data sample contains about 2×10^6 reconstructed events, with at least two charged tracks traced within 8 cm of the interaction point along the beam line and 1.5 cm in the transverse plane. 7×10^5 of these are selected as candidates for two-prong events from $\gamma\gamma$ collisions by requiring that the scalar sum of momenta be less than 4.0 GeV/c. Beam–gas events are rejected by the vertex constraint and by ignoring any event containing protons or heavier particles. 88 087 of these events contain a well-defined single photon. A further sample of 13 140 events contains, in addition to the well-defined photon, an isolated hit consistent with known calorimeter noise. Both of these samples are used in the analysis.

The $\gamma\gamma$ QED processes are major background reactions ($e^+e^- \to e^+e^-\ell^+\ell^-\gamma$) where the $\ell^+\ell^-$ are leptons and γ may be a real photon or noise in the calorimeter). Requiring that the cosine of the opening angle between the photon and any charged track be less than 0.8 removes most of these QED events. The resulting $\pi^+\pi^-\gamma$ mass spectrum is shown in fig. 1. To insure that the $\pi^+\pi^-\gamma$ events arise from completely reconstructed $\gamma\gamma$ collisions, it is required that $\cos(\phi_{\pi^+\pi^-} - \phi_\gamma) < -0.8$, where ϕ is the angle in the transverse plane. This is a geometric expression of transverse momentum balance. The component of the total transverse momentum in the plane containing the beam-axis and the photon direction is required to be less than 100 MeV/c while the normal component, which is not affected by photon resolution, is required to be less than 50 MeV/c. The

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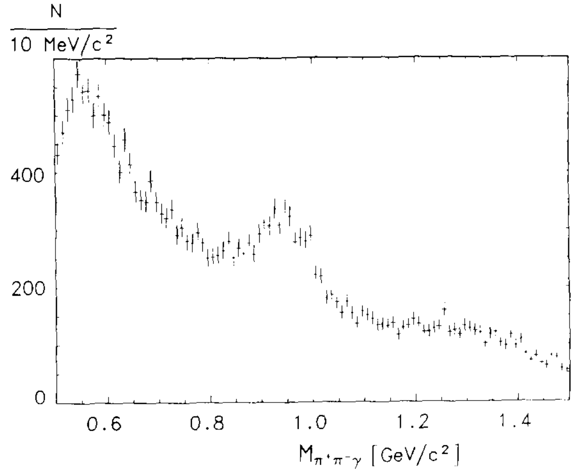

Fig. 1. $\pi^+\pi^-\gamma$ invariant mass spectrum from events with a single well-defined photon with only the anti-bremsstrahlung cut (maximum $\cos\theta_{\pi\gamma} < 0.8$).

transverse momentum of the $\pi^+\pi^-$ system is required to be greater than 100 MeV/c to reject the exclusive two-charged-particle topologies from $\gamma\gamma$ processes with additional fake photons. A total of 2212 events survive these cuts (fig. 2a).

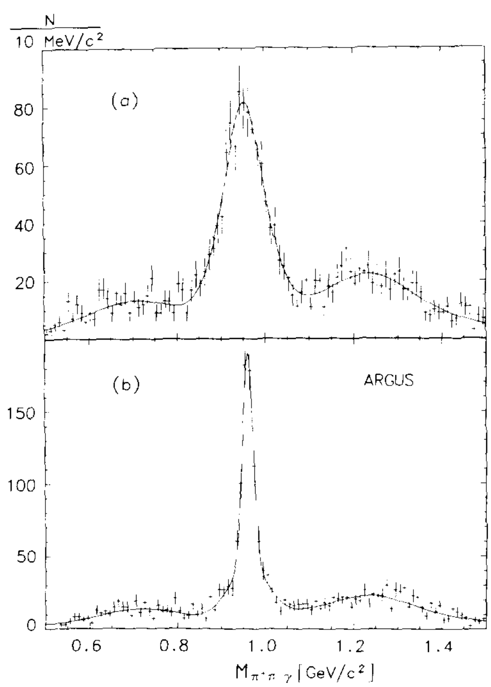

Fig. 2. Fit to the $\pi^+\pi^-\gamma$ invariant mass spectrum after all analysis cuts are applied. (a) Before and (b) after γ energy tuning.

As the mass resolution is dominated by the photon energy resolution, one can (following the earlier work at MARK II [4], PLUTO [8], and TPC/2γ [9]) improve this by tuning the photon energy so that the transverse momenta of the photon and the $\pi^+\pi^-$ system are equal in magnitude. This is justified because the final state is produced by collisions of virtual photons radiated at small transverse momenta by the e^+e^- beams. The resulting mass spectrum is shown in fig. 2b.

To translate this signal into an expression for the radiative width of the η′ one must use a Monte Carlo program to determine the acceptance and the integral of the product of the γγ luminosity and the cross section. The Monte Carlo generator uses the expressions for the γγ luminosity derived by Budnev et al. [10]. The formation of a pseudoscalar meson in collisions of transverse photons is described by one form factor only [11]. The complete expression for the γγ cross section is

$$\sigma(\gamma\gamma\to\eta') = \frac{1}{4\sqrt{X}}(\nu^2 - m^2\tilde{Q}^2)F^2(q_1^2, q_2^2)$$

$$\times \frac{\sqrt{s}\Gamma}{(s-m^2)^2 + \Gamma^2 m^2},$$

$$F^2(0,0) = 64\pi\Gamma_{\gamma\gamma}(\eta')/m^3,$$

where q_1 and q_2 are the four-momenta of the virtual photons, $X = (q_1\cdot q_2)^2 - q_1^2 q_2^2$, $\tilde{Q} = (q_1 - q_2)/2$, $P = q_1 + q_2$, $\nu = P\cdot\tilde{Q}$, m and Γ are the mass and width of the η′ and $\sqrt{s}$ is the mass of the final state. The shape of the form factor $F(q_1^2, q_2^2)$ has been parametrized according to the GVDM model [1]. The final state is generated as three-particle phase space with a matrix element incorporating the dipole character of of the $\eta'\to\rho\gamma$ transition and the the ρ pole:

$$|M(m_{\pi^+\pi^-}, E_\gamma, \theta)|^2$$

$$\propto \frac{P_\pi^2 E_\gamma^2 \sin^2(\theta) m_{\pi^+\pi^-}^2}{(m_\rho^2 - m_{\pi^+\pi^-}^2)^2 + m_\rho^2\Gamma^2(m_{\pi^+\pi^-})}.$$

The decay algorithm is similar to that used in the TASSO [7], PLUTO [8], and TPC/2γ [9] analyses. E_γ and P_π are, respectively, the energy and momentum of the photon and pions in the ρ rest frame. θ

is the angle between the pion and photon in the same system. The E_γ^2 dependence follows from the magnetic dipole nature of the transition. The ρ meson is polarized as its helicity is limited to be ±1 by angular-momentum conservation. m_ρ and $m_{\pi^+\pi^-}$ refer to the mass of the ρ and the invariant mass of the two-pion system, respectively. The ρ width is parametrized [12] as

$$\Gamma(m)=\Gamma_0\cdot 2P_\pi^3/[P_0\cdot(P_\pi^2-P_0^2)]\ ,$$

where P_0 is the pion momentum for $m_{\pi^+\pi^-}=m_\rho$. The acceptance is insensitive to reasonable variations of the matrix elements in this analysis. The standard particle data book values [13] for m_ρ and Γ_0 are used in the simulation.

The data are divided into trigger periods distinguished by changes in logic, threshold values, or efficiencies. The Monte Carlo events are processed through a full detector simulation [3] for each trigger period, and passed through the same selection and analysis programs as the data. The LTF is simulated using an algorithm identical to that of the hardware with its efficiency determined from data (88%–94% per track depending on trigger period). Similarly, shower counter threshold shape parametrizations determined from the data of each trigger period are used (the efficiency for minimum ionizing particles varies between 91% and 95%). Each event is then assigned a trigger probability, defined as the luminosity weighted fraction of the trigger periods in which it is detected. There is good agreement (fig. 3) between the results of the Monte Carlo and the data for the $M(\pi^+\pi^-)$ and E_γ spectra. No cut was made on the mass of the $\pi^+\pi^-$ system.

Above the η′ peak an $A_2\rightarrow\rho^\pm\pi^\mp\rightarrow\pi^+\pi^-\pi^0$ signal is visible (from events where the second photon from the π^0 decay is lost). The background below the η′ mass is produced by γγ QED processes. The peak of this distribution as seen below the η′ peak in figs. 1 and 2 is determined by acceptance effects. The η′ peak is fitted by a sum of two gaussians with the mass fixed (fig. 2). The number of η′ events was found to be 867±30 and is relatively insensitive to the background parametrization and the use of the photon energy tuning. The error is purely statistical – uncertainties from the fitting procedure are included in the systematic error. We calculate the systematic uncertainties in the measurement of $\Gamma_{\gamma\gamma}(\eta')$ to be: 9%

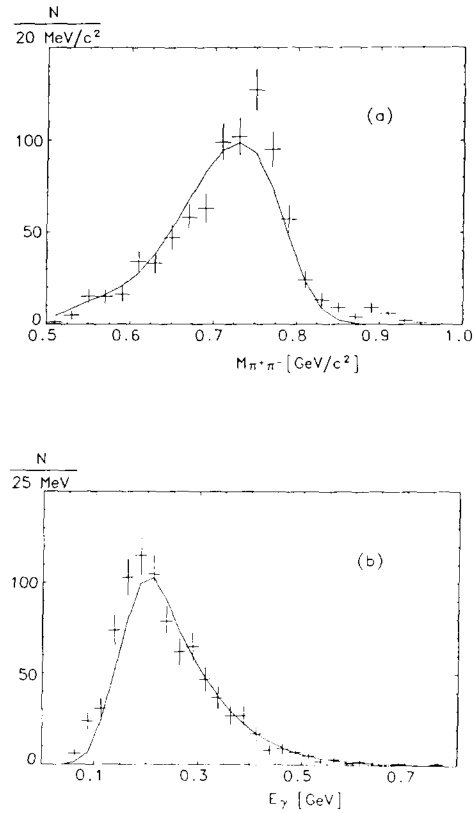

Fig. 3. (a) $M(\pi^+\pi^-)$ spectrum, (b) E_γ spectrum. The solid line is the result of the Monte Carlo simulation. Points with error bars represent data. Only events with the $\pi^+\pi^-\gamma$ mass between 0.87 GeV and 1.03 GeV are used.

from the acceptance calculation, 5% in the luminosity measurement, and 4% from fitting the $m(\pi^+\pi^-\gamma)$ spectrum. This leads to the value for the product of the γγ width and the η′→ργ branching ratio

$$\Gamma_{\gamma\gamma}(\eta')\mathrm{Br}(\eta'\rightarrow\rho\gamma)=1.13\pm0.04\pm0.13\ \mathrm{keV}\ .$$

With the independent experimental value [14,13] for Br(η′→ργ) of 0.300±0.016 this yields a value for the γγ width of the η′:

$$\Gamma_{\gamma\gamma}(\eta')=3.76\pm0.13\pm0.47\ \mathrm{keV}\ .$$

This measurement is consistent with the latest published values for the γγ width of the η′ of 5.8±1.1±1.2 keV [4], 5.0±0.5±0.9 keV [5], 6.2±1.1±0.8 keV [6], 5.1±0.4±0.7 keV [7], 3.8±0.3±0.4 keV [8] and 4.2±0.3±0.6 keV [9]. Since the systematic errors enter in markedly different ways in all these measurements, no attempt is made here to give a world average. Using $Br(\eta' \to \gamma\gamma) = 0.0185 \pm 0.0016$ for the branching ratio [13] for $\eta' \to \gamma\gamma$ we find the total width of the η' to be

$$\Gamma_{\eta'} = 203 \pm 32 \text{ keV},$$

one of the most accurate measurements available (see ref. [13], p. 182).

Our value of $\Gamma_{\gamma\gamma}(\eta')$ can be combined with the world averages of $\Gamma_{\gamma\gamma}(\pi^0) = 7.48 \pm 0.32$ eV and $\Gamma_{\gamma\gamma}(\eta) = 0.56 \pm 0.04$ keV (the latter from $\gamma\gamma$ collision experiments only (see ref. [13], p. 119)) to obtain the pseudoscalar nonet flavour SU(3) mixing parameters as defined in ref. [1]:

$$\Gamma^{\eta}_{\gamma\gamma}/\Gamma^{\pi^0}_{\gamma\gamma} = \tfrac{1}{3}(\cos\theta - r2\sqrt{2}\sin\theta)^2(m_\eta/m_{\pi^0})^3 ,$$

$$\Gamma^{\eta'}_{\gamma\gamma}/\Gamma^{\pi^0}_{\gamma\gamma} = \tfrac{1}{3}(\sin\theta + r2\sqrt{2}\cos\theta)^2(m_{\eta'}/m_{\pi^0})^3 .$$

We find the singlet/octet mixing angle $\theta = -20.2° \pm 2.0°$ and the nonet symmetry breaking parameter $r = 0.91 \pm 0.04$. One can introduce a gluonium component in addition to the SU(3) singlet and octet $q\bar{q}$ components in the η and η' wave functions [15]. To constrain the models, one needs additional information from other experiments, for example J/ψ decays into a pseudoscalar meson and a vector meson, and pseudoscalar to vector meson transitions. However, these experiments [16] are not yet sufficiently precise to permit any definitive conclusions.

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