DETERMINATION OF THE RADIATIVE WIDTHS OF THE η' AND A_2 FROM TWO-PHOTON EXCHANGE PRODUCTION

CELLO Collaboration

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From the two-photon exchange processes $e^+e^- \to e^+e^-\eta'$ (958) $\to e^+e^-\rho^0\gamma$ and $e^+e^- \to e^+e^-A_2$ (1310) $\to e^+e^-\pi^+\pi^-\pi^0$ observed using the CELLO detector at PETRA the radiative widths of the η' and A_2 have been determined with the results: $\Gamma_{\gamma\gamma}(\eta') = 5.4 \pm 1.0$[stat.] $\pm$ 0.7[syst.] keV; $\Gamma_{\gamma\gamma}(A_2) = 0.59 \pm 0.14$[stat.] $^{+0.31}_{-0.08}$[syst.] keV.

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Introduction. With the advent of high energy e^+e^- storage rings the study of two-photon processes has received considerable attention. One topic of particular recent interest is the exclusive production of even charge conjugation resonances such as f_0, η, η' and A_2. In this letter we present new results on two such reactions. η' and A_2 production have been observed in two-photon interactions in the CELLO detector at PETRA. For this analysis data with two visible charged tracks in the central detector and one photon in the liquid argon calorimeter were used. The scattered electron and positron in the final state were unobserved. The average CMS energy was 34.6 GeV and the total integrated luminosity 11.15 pb^{-1}. A detailed description of the CELLO detector is given in ref. [1]. Charged tracks are measured in a cylindrical wire chamber detector consisting of 7 drift and 5 proportional chamber layers in a magnetic field of 1.3 T. The liquid argon calorimeter samples electromagnetic showers 17 times in depth leading to 6 spatial measurements of the shower, up to a maximum depth of 20 radiation lengths. The fast trigger [2] used required two tracks in a plane perpendicular to the beam axis (Rϕ) and one in the plane containing the beam axis (RZ). The trigger accepts tracks with transverse momentum greater than 200 MeV/c and coming from within ±10 cm of the interaction point along the beam axis. The trigger condition,was verified using more detailed track information read directly from the central wire chambers by an on line filter program.

Event selection. In order to select events for two-photon reactions backgrounds from one-photon annihilation reactions, Bhabha events and cosmic muons must be removed. The first of these backgrounds is eliminated by selecting events of low visible energy and multiplicity. Candidates for low multiplicity events produced in two-photon interactions were first selected using track information recorded by the fast trigger. Events were required to have $\leqslant 4$ charged tracks. Bhabha events satisfying the neutral trigger condition ($E_{neut} > 6$ GeV) were rejected. The selected events were processed through the reconstruction programs for charged tracks in the central detector and for showers in the liquid argon calorimeter. The charged track reconstruction efficiency was 99%. Events with two oppositely charged tracks having the vertex within ±2 cm around the interaction point were kept for further analysis. Cosmic μ background was rejected by a cut on the acollinearity angle α in the RZ-projection: $|\cos\alpha| < 0.995$. After this cut the residual background from cosmic μ's and beam–gas events was ~2%. Background from the QED reaction

$$e^+e^- \to (e^+e^-)\, e^+e^-$$

was removed by rejecting all events where one of the two detected tracks has been identified in the liquid argon calorimeter as an electron. For the electron identification the total energy of the shower linked to the charged track, and the shower development in depth in the liquid argon were used. Electrons accompanied by bremsstrahlung photons were removed by rejecting events with photons within a cone of 100 mrad around a track. Photon candidates in the liquid argon calorimeter were selected using the following cuts:

– Energy > 100 MeV.

– More than 20% of the total charge is deposited between 3 and 8 radiation lengths in depth.

– No charge is found beyond 16 radiation lengths.

– The shower has to be reconstructed in depth by at least two clusters.

In addition all photon candidates possibly originating in the interaction of charged particles in the liquid argon were removed. The background from exclusive $\eta^+\eta^-$, $\pi^+\pi^-$ and residual e^+e^- production in two-photon interactions has been reduced using the following cuts:

– The momentum transverse to the beam direction of the pair has to be larger than 50 MeV/c.

– The acollinearity angle between the two charged tracks in the plane perpendicular to the beam axis has to be at least 200 mrad.

Finally, the background from photons simulated by noise in the liquid argon calorimeter was reduced by the following cuts:

– One and only one photon candidate is found within ±250 mrad of the direction of the missing transverse momentum vector of the pion pair.

– The total transverse momentum of the two pions and the photon has to be < 200 MeV/c.

To improve the energy measurement of the photons we corrected the measured photon energy by multiplying it with the ratio of transverse momentum of the two pions and the transverse momentum of the photon [3]. After this correction a more stringent cut for the transverse momentum of the $\pi^+\pi^-\gamma$ system was applied: $P_\perp(\pi^+\pi^-\gamma) < 100$ MeV/c.

Results for η'. Fig. 1 shows the $\pi^+\pi^-\gamma$ mass distribution for the reaction

$$e^+e^- \to (e^+e^-)\eta' \to (e^+e^-)\ \pi^+\pi^-\gamma\ ,$$

after the cuts detailed above. A clear signal at he η' mass region can be seen. Fitting this distribution in the region of the η'-peak with a gaussian and a linear background gives for $m(\eta') = 957 \pm 3$ MeV, in good agreement with ref. [4]. The mass resolution compares well with that obtained by MC simulation. The shaded histogram in fig. 1 shows the $\pi^+\pi^-\gamma$ mass distribution for events with $600 < m_{\pi^+\pi^-} < 900$ MeV/c^2. Almost all events in the η mass peak are compatible with the η' decay $\eta' \to \rho\gamma$. A linear side band background subtraction gives a signal of 43 (51) events above a background of 32 (34) events for the data with (without) the ρ-cut. To correct the data for all losses due to acceptance, data selection and reconstruction inefficiency, we generated Monte Carlo (MC) events using a detailed detector simulation. In

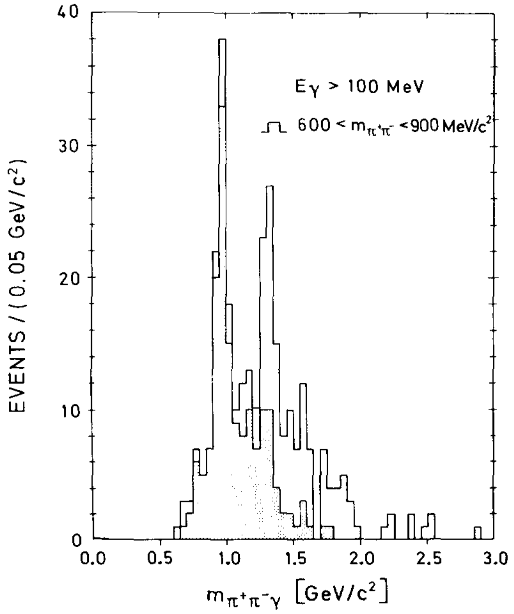

Fig. 1. Distribution of $\pi^+\pi^-\gamma$ effective mass. Shaded histogram: distribution of $\pi^+\pi^-\gamma$ effective mass with the additional cut $600 < m_{\pi^+\pi^-} < 900$ MeV/c^2.

the MC generator we used exact transverse photon luminosity functions [5] and used particle data group values for the η', ρ masses, the ρ width and the $\eta' \to \rho\gamma$ decay branching ratio [4]. The MC events were passed through the same reconstruction programs as the real data. Good agreement between the data and the MC events obtained for the $\pi^+\pi^-$ mass distribution and the transverse momentum distributions of the $\pi^+\pi^-$ and the $\pi^+\pi^-\gamma$ systems. With all cuts mentioned above and the η' mass cut $850 < m_{\pi^+\pi^-\gamma} < 1050$ MeV/c^2, the overall acceptance was found to be 0.78%. This yields a radiative width of the η' of $\Gamma_{\gamma\gamma}(\eta') = 5.4 \pm 1.0$ keV, where the error includes the statistical error and the error due to the background subtraction only. We have checked the dependence of this value on the minimum photon energy required and found it to stay constant within errors. To estimate the systematic errors detailed MC studies were made varying the noise level in the liquid argon detector. To this error (12%) we have added in quadrature the errors due to the uncertainty in the overall normalization (5%), the trigger efficiency (2%) and data selection efficiency (4%), yielding a total systematic error of 0.7 keV.

Results for A_2. Fig. 1 shows in addition to the η' signal a peak at $m_{\pi^+\pi^-\gamma} = 1300$ MeV/c^2. We interpret this as evidence for two-photon production of the A_2 in the reaction

$$e^+e^- \to (e^+e^-)\ A_2 \to (e^+e^-)\ \pi^+\pi^-\pi^0\ ,$$

where one low energy photon from the π^0 decay is not detected. To confirm this interpretation we generated MC events and passed them through the standard reconstruction programs. The virtual photons were generated as for the η'. The A_2 was assumed to be in a pure helicity 2 state [‡1]. Neglecting relativistic corrections, the joint decay distribution of the A_2 is

$$d^2\sigma/d\cos\theta_1\ d\cos\theta_2 \sim 4\sin^4\theta_1\cos^2\theta_1\cos^2\theta_2 + \sin^2\theta_1(\sin^2\theta_1 + 2\cos^4\theta_1)\sin^2\theta_2\ ,$$

where θ_1 is the angle between the virtual photon direction and the ρ direction of flight in the $\gamma\gamma$ CM system, and θ_2 is the angle between the ρ direction of flight

[‡1] This assumption is in agreement with theoretical expectations [6]. Also a direct measurement of the Crystal Ball detector (see ref. [10]) of $f^0 \to \pi^0\pi^0$ production indicates the dominance of the helicity 2 amplitude.

and a ρ decay pion in the ρ CM system. Relativistic Breit–Wigner shapes were used for the A_2 and ρ with standard values for the masses and widths and for the $A_2 \to \rho^{\pm}\pi^{\mp} \to \pi^+\pi^-\pi^0$ decay branching ratio [4]. We calculated the acceptance for this reaction detecting *both* photons from the π^0 decay and demanding *only* a minimum transverse momentum of 50 MeV/c of the two charged pions. With a fully reconstructed π^0 we found the acceptance to be down by a factor of 5.1 in comparison to the detection of only one photon including all the cuts given above for the η' selection. The latter acceptance was found to be 1.96%. Thus within the cuts used in this analysis no significant signal is expected in the fully reconstructed $\pi^+\pi^-\pi^0$ mode. However demaning only one detected photon, we get good agreement for the $\pi^+\pi^-\gamma$ mass distribution between the data and the MC generated A_2 events. Making a linear side band background subtraction we obtain a signal of 35 events above a background of 40 events. This yields a radiative width of

$$\Gamma_{\gamma\gamma}(A_2) = 0.59 \pm 0.14[\text{stat.}]^{+0.31}_{-0.08}[\text{syst.}]\ \text{keV}\ .$$

Again this value was checked to be independent within errors of the minimum photon energy required. The systematic error comes mainly from changes in acceptance resulting from uncertainties in the liquid argon noise level. The detection efficiency for the second low energy photon of the π^0 decay depends strongly on this noise level. Because we demand for the acceptance calculation that one and only one photon be detected within the angular cone of 250 mrad around the missing transverse momentum vector of the charged pion pair, the acceptance decreases when the noise level in the liquid argon calorimeter is increased. Therefore the resulting systematic error shows a strong asymmetry.

Conclusions. Our value of the radiative width of η' of

$$\Gamma_{\gamma\gamma}(\eta') = 5.4 \pm 1.0[\text{stat.}] \pm 0.7\ [\text{syst.}]\ \text{keV}$$

confirms with comparable accuracy the value obtained by the MARK II detector at SPEAR of $\Gamma_{\gamma\gamma}(\eta') = 5.8 \pm 1.1$ [stat.] ± 1.2 [syst.] keV [3] and agrees with the recent result from JADE at PETRA of $\Gamma_{\gamma\gamma}(\eta') = 5.0 \pm 0.5$ [stat.] ± 0.9 [syst.] keV [7]. It also agrees with the prediction (6 keV) of the quark model with fractionally charged quarks using a small octet–singlet mixing angle. Assuming nonet symmetry it rules out the integrally charge quark model which predicts a value of 25.6 keV [8].

For the radiative width of the A_2 we obtained, using the decay mode $A_2 \to \rho^{\pm}\pi^{\mp} \to \pi^+\pi^-\pi^0$

$$\Gamma_{\gamma\gamma}(A_2) = 0.59 \pm 0.14[\text{stat.}]^{+0.31}_{-0.08}\ [\text{syst.}]\ \text{keV}\ ,$$

which may be compared with the preliminary value of JADE [9] of

$$\Gamma_{\gamma\gamma}(A_2) = 1.2 \pm 0.4[\text{stat.}] \pm 0.5[\text{syst.}]\ \text{keV}\ .$$

Our result is in good agreement with that of the Crystal Ball detector, using the decay mode $A_2 \to \eta\pi^0 \to 4\gamma$ [10], of

$$\Gamma_{\gamma\gamma}(A_2) = 0.77 \pm 0.18[\text{stat.}] \pm 0.27[\text{syst.}]\ \text{keV}.$$

Assuming ideal mixing in the 2^{++} nonet, the ratio $\Gamma_{\gamma\gamma}(A_2)$: $\Gamma_{\gamma\gamma}(f^0)$ is predicted to be 9 : 25 [14]. Taking the weighted average of the three measurements of $\Gamma_{\gamma\gamma}(A_2)$ quoted above (statistical and systematic errors have been added in quadrature) one obtains $\Gamma_{\gamma\gamma}(A_2) = 0.75 \pm 0.22$ keV. Taking the corresponding average of the five values quoted in refs. [9]–[13] for $\Gamma_{\gamma\gamma}$ (f^0) leads to the value of $\Gamma_{\gamma\gamma}(f^0) = 3.1 \pm 0.3$ keV. Thus the measured ratio $\Gamma_{\gamma\gamma}(A_2)/\Gamma_{\gamma\gamma}(f^0)$ is 0.24 ± 0.08, to be compared with the above prediction of 0.36. The value found for this ratio by the Crystal Ball detector alone [10], where the same 4γ final state is observed for both the f^0 and A_2 is $0.29 \pm 0.07 \pm 0.07$ in good agreement with the prediction. As not all measurements of $\Gamma_{\gamma\gamma}(f^0)$ used in the average have taken account of the dipion continuum under the f^0peak, clearly seen for example in ref. [12], the value of $\Gamma_{\gamma\gamma}(f^0)$ has perhaps been overestimated. Taking this into account will improve the agreement with the ideal mixing prediction.

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