MEASUREMENT OF THE RADIATIVE WIDTH OF THE $\eta'(958)$ IN TWO-PHOTON INTERACTIONS

TASSO Collaboration

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The reaction $e^+e^- \to e^+e^-\eta'(958)$ has been observed by detecting the final state $\pi^+\pi^-\gamma$. The two-photon width of the η' has been measured to be $\Gamma(\eta' \to \gamma\gamma) = 5.1 \pm 0.4 \pm 0.7$ keV. A search for the $\iota(1440)$ has been made in the $\rho^0\gamma$ final state. An upper limit has been obtained for the product $\Gamma(\iota(1440) \to \gamma\gamma), B(\iota \to \rho^0\gamma) < 1.5$ keV (95% CL).

The determination of the two photon partial width of the $\eta'(958)$ has received considerable attention in recent years [1–3]. It has been motivated by theoretical models [4,5], where this measurement is expected to differentiate between integrally and fractionally charged quarks.

We report on the measurement of the reaction

$$e^+e^- \to e^+e^-\rho^0\gamma \, . \qquad \rho^0 \to \pi^+\pi^- \qquad (1)$$

In this reaction we have measured the two photon partial width of the η' and searched for other resonances in this final state, in particular for the $\iota(1440)$ which possibly [6] has been observed in the $\rho^0\gamma$ final state. The measurement was performed using the TASSO detector at PETRA, at beam energies of 7–18 GeV. The scattered electron and positron in the final state were not detected since they are predominantly emitted at very small angles. The main difficulty in the measurement of this decay mode lies in the detection of a low energy photon ($\langle E_\gamma \rangle \approx 0.2$ GeV). Consequently, a careful evaluation of the response of the electromagnetic detector for low energy photons is required. The measurement was carried out using two different electromagnetic calorimeters of the TASSO experiment. They are the liquid argon barrel calorimeters (LABC) and the hadron arm shower counters (HASH). The LABC are liquid argon–lead sampling calorimeters (0.5 cm argon, 0.2 cm Pb, 14 r.l.) using for energy measurements towers pointing to the interaction region and strips for angular measurements. The LABC covers 40% of 4π. A detailed description has been given in ref. [7]. The HASH are lead-scintillator (0.5 cm Pb, 1.0 cm scintillator, 7.4 r.l.) shower counters where the light produced by electromagnetic showers is collected by wavelength shifter bars and then channeled to photomultipliers. They are located in the hadron arms and cover a total solid angle of 18% of 4π. A detailed description is given in ref. [8]. The present work is based on an integrated luminosity of 66 pb^{-1} for the LABC events and 76 pb^{-1} for the HASH events.

To study reaction (1), events were selected with two oppositely charged tracks and one photon in one of the electromagnetic detectors. The charged tracks were measured with the central tracking detector described in ref. [9]. The trigger required two tracks in the central tracking detector. The trigger efficiency varied as a function of the momentum component of each track transverse to the beam direction (p_t). The trigger efficiency per track was 50% for $p_t \approx 0.17$ GeV/c increasing to 95% for $p_t > 0.29$ GeV/c. The tracks were required to have a polar angle θ with respect to the beam direction satisfying $|\cos\theta| < 0.82$ and to originate within ±5 cm of the interaction point along the beam axis, and to be within ±1 cm in a plane perpendicular to the beam. Shower clusters were considered as photons if the measured energy was larger than 0.1 GeV (0.16 GeV) in the LABC (HASH) and if no charged track pointed to it. Moreover, the clusters had to be isolated from the nearest cluster associated with charged tracks by more than 10°(17°) for the LABC(HASH).

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The charged tracks were assumed to be pions. The following cuts were imposed in order to reject QED reactions of the type $e^+e^- \to \ell^+\ell^-\gamma(\ell = \mu, e)$ and $e^+e^- \to e^+e^-\ell^+\ell^-(\gamma)$:

(1) The total energy observed from charged particles and photon had to be less than 25% of the available CM energy.

(2) The two charged tracks were required to be acollinear in the plane perpendicular to the beam by at least 10°.

(3) The helicity angle (θ_H^ρ) between the π^+ and the photon in the $\pi^+\pi^-$ rest frame was required to satisfy $|\cos\theta_H^\rho| < 0.7$. The last requirement reduced the efficiency for η' detection by less than 12% because the ρ^0-decay angular distribution is proportional to $\sin^2\theta_H^\rho$. In contrast, the background from QED events where a photon is emitted close to the lepton direction is suppressed.

Figs. 1a, 1b show the correlation between the sum of the transverse momenta squared ($|\Sigma p_t|^2$) of the $\pi^+\pi^-\gamma$ system and its mass for the LABC and HASH events, respectively. Strong η' signals are seen in both distributions for events having low $|\Sigma p_t|^2$ values. The signals contain roughly 160 events in the LABC and 80 events in the HASH. Figs. 2a, 2b show the $|\Sigma p_t|^2$ distributions for the η' mass band [$0.90 \leqslant M(\pi^+\pi^-\gamma) \leqslant 1.05$ GeV] for LABC and HASH events, respectively. The distributions peak at $|\Sigma p_t|^2 = 0$ as expected for $\gamma\gamma$ events with no missing particles. For the distributions that follow a cut of $|\Sigma p_t|^2 < 0.0049$ (GeV/c)^2 was imposed.

Figs. 2c, 2d show the $\pi^+\pi^-\gamma$ mass distributions for the LABC and HASH events satisfying the abovementioned cuts. Clear η' signals are observed. The shaded areas correspond to events satisfying the additional requirement of the $\pi^+\pi^-$ mass being in the ρ^0 region ($0.60 \leqslant M_{\pi^+\pi^-} \leqslant 0.85$ GeV). In this case the background is strongly reduced. Figs. 3a, 3b show the $\pi^+\pi^-$ mass distributions for events with protons in the LABC and HASH, respectively. The events were required to have a $\pi^+\pi^-\gamma$ mass in the η' region [$0.90 \leqslant M(\pi^+\pi^-\gamma) \leqslant 1.05$ GeV] and the distributions are shown after background subtraction, where the background was obtained by selecting events in the same mass region but with $0.1 < |\Sigma p_t| < 0.2$ GeV/c. Figs. 3a, 3b show clear ρ^0 peaks but with mass values lower than the nominal ρ^0 mass by about 30 MeV. A mass shift has also been observed by other experiments

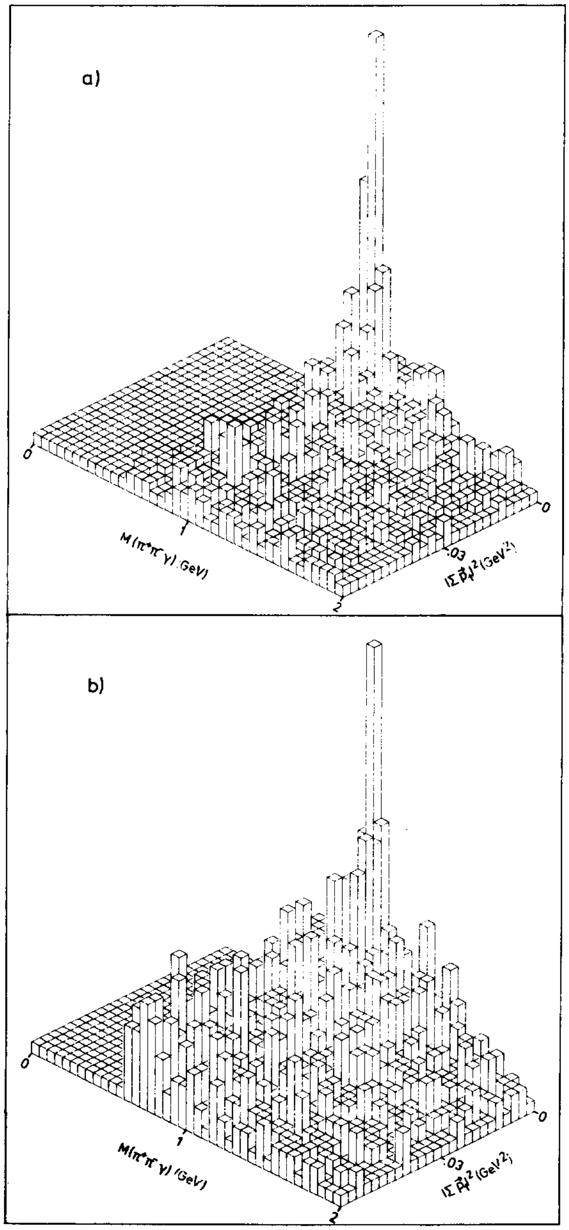

Fig. 1. Correlation between $M(\pi^+\pi^-\gamma)$ (in GeV) and $|\Sigma p_t|^2$ [in (GeV/c)^2] where the photon is detected in (a) the LABC with $E_\gamma > 0.10$ GeV and (b) in the HASH with $E_\gamma > 0.16$ GeV.

[10]. Such an effect is expected for a dipole transition in the decay $\eta' \to \rho^0\gamma$ for which the matrix element is proportional to the photon energy [11] measured in the ρ^0 rest frame.

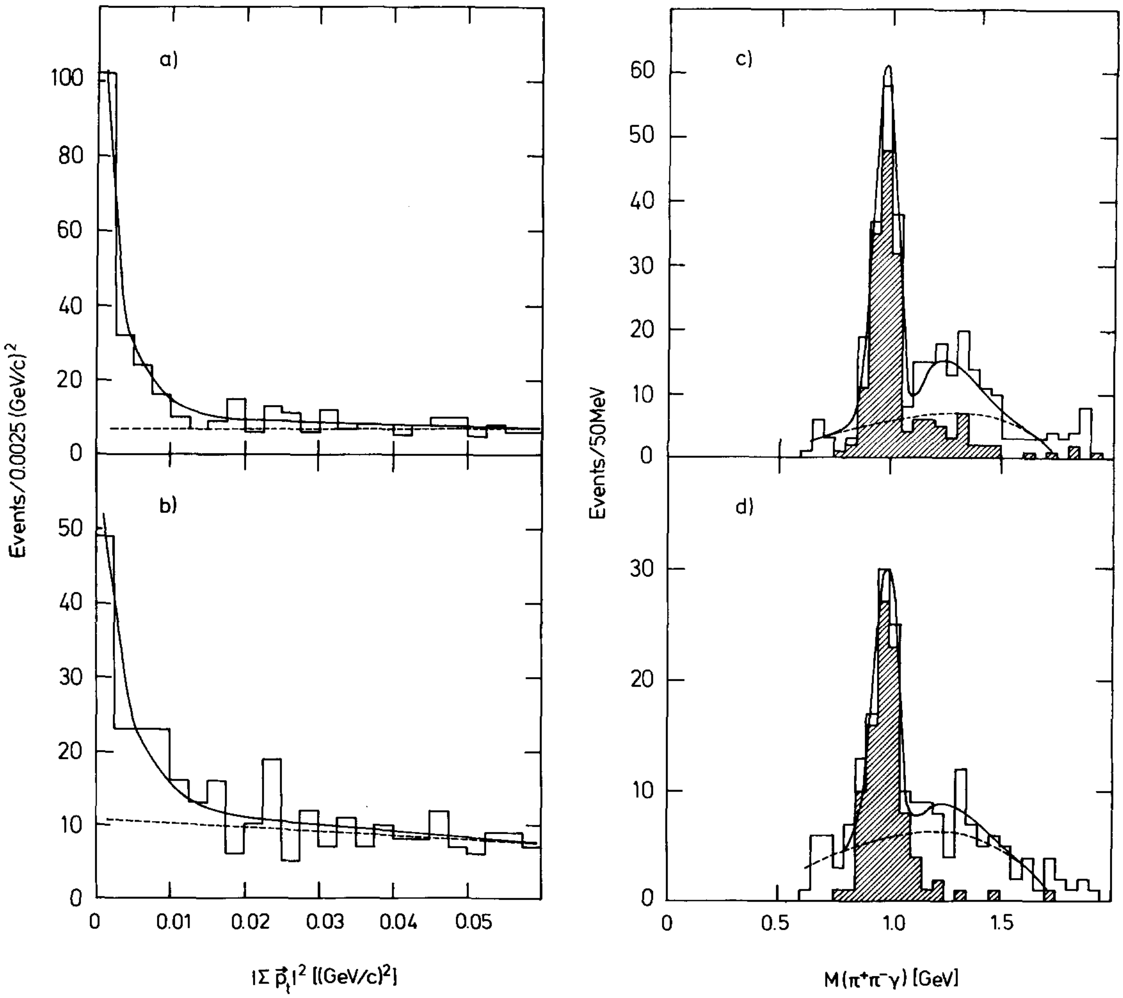

Fig. 2. (a), (b) $|\Sigma p_t|^2$ distribution for $0.90 \leqslant M(\pi^+\pi^-\gamma) \leqslant 1.05$ GeV where the photon is detected in (a) the LABC and (b) in the HASH. The solid lines are the results of fits to the sum of the η' contribution and a polynomial background (dashed lines). (c), (d) $M(\pi^+\pi^-\gamma)$ distribution for $|\Sigma p_t|^2 < 0.0049$ (GeV/c)^2 where the photon is detected in (c) the LABC and (d) in the HASH. The solid lines show the fits results for the sum of the expected η' and A_2 contributions and of a fourth degree polynomial in $M(\pi^+\pi^-\gamma)$ (dashed lines). The shaded areas correspond to a ρ^0 interval of $0.60 \leqslant M_{\pi^+\pi^-} \leqslant 0.85$ GeV.

In order to determine $\Gamma(\eta' \to \gamma\gamma)$, Monte Carlo events were generated using the luminosity functions given in ref. [12]. For the decay $\eta' \to \rho^0\gamma$, the Particle Data Group [13] values for the η' mass ($m_{\eta'} = 958$ MeV) and width ($\Gamma = 0.28$ MeV) as well as for the $\eta' \to \rho^0\gamma$ branching ratio ($B = 0.30$) were used. Events were generated according to three body ($\pi^+\pi^-\gamma$) phase space (R_3) and then weighted with the dipole transition matrix $|M|^2$ according to the relation:

$$\mathrm{d}N/\mathrm{d}M^2_{\pi\pi}\,\mathrm{d}M^2_{\pi\gamma} = (\mathrm{d}R_3/\mathrm{d}M^2_{\pi\pi}\,\mathrm{d}M^2_{\pi\gamma})\,|M|^2\,,$$

$$|M|^2 \propto p^2k^2M^2_{\pi^+\pi^-}\sin^2\theta^{\rho}_{\mathrm{H}} \times [(M^2_{\pi^+\pi^-} - M^2_{\rho})^2 + M^2_{\rho}\Gamma^2]^{-1}\,, \qquad (2)$$

where $p(k)$ is the pion (photon) momentum. All quantities are evaluated in the $\pi^+\pi^-$ rest frame. The width of the ρ is given by $\Gamma = \Gamma_0(p/p_0)^3[2p_0^2/(p^2+p_0^2)]$, where $p_0 = p$ for $M_{\pi^+\pi^-} = M_{\rho}$. The Monte Carlo events were traced through the detector using a de-

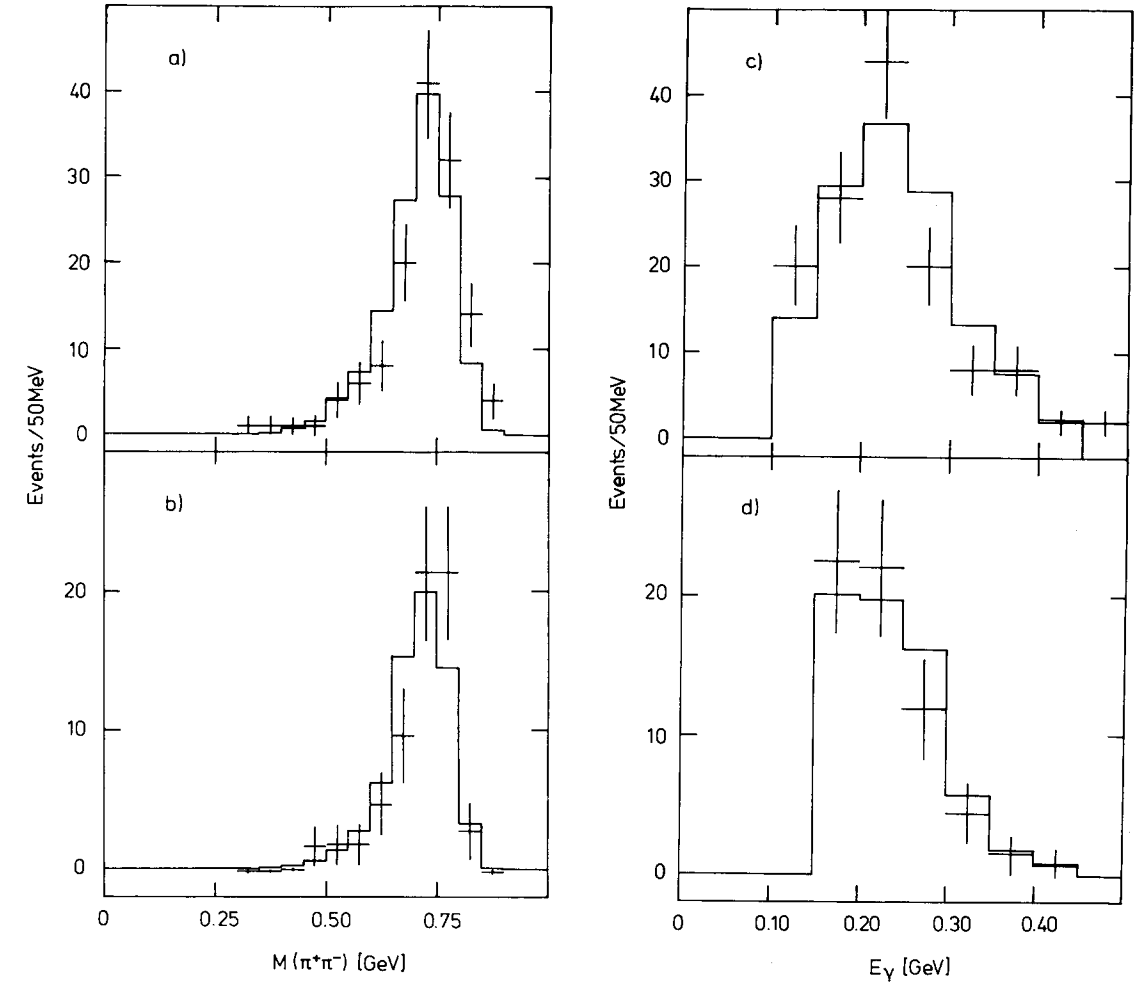

Fig. 3. (a), (b) $M_{\pi^+\pi^-}$ distributions, after background subtraction as described in the text, for $0.90 \leqslant M(\pi^+\pi^-\gamma) \leqslant 1.05$ GeV where the photon is detected in (a) the LABC and (b) the HASH. The histograms show the expected contributions from η' decay. (c), (d) E_γ distributions after background subtraction as described in the text, for $0.90 < M(\pi^+\pi^-\gamma) < 1.05$ GeV, where the photon is detected in (c) the LABC and (d) HASH. The histograms show the expected contributions from η' decay.

tailed detector simulation program. The conversion of photons in the TASSO coil was simulated using the EGS [14] program package. Particles produced in the showering process in the coil were traced into the two shower detectors where their energies were added in each tower or counter, smeared by the respective resolutions, and corrected for absorption in the coil. The systematic errors were estimated by varying the resolutions and the absorption corrections.

Figs. 3c, 3d show the photon energy spectra, after background subtraction, for events in the η' region as obtained in the two electromagnetic detectors. The histograms represent the expectation from the Monte Carlo calculations. The predicted ρ^0 peak is lower by $\approx$25 MeV compared to the data (see solid lines in figs. 3a, 3b).

Two different procedures were used to evaluate $\Gamma(\eta' \to \gamma\gamma)$: In the first procedure the $|\Sigma p_t|^2$ distributions for the LABC and HASH events shown in figs. 2a, 2b were fitted to the sum of a first degree polynomial and the shape expected from the Monte Carlo predictions for the process $\eta' \to \rho^0\gamma$. The resulting fits yielded $\Gamma(\eta' \to \gamma\gamma) = 5.0 \pm 0.5$ keV for the LABC events and 5.3 ± 0.8 keV for the HASH events.

These results were found to be insensitive to the exact ρ mass value used and to the specific parametrization of the background.

In the second procedure the distributions of figs. 2c, 2d were fitted to the sum of the η' shape obtained in the Monte Carlo program, an A_2 contribution and a polynomial background. The A_2 could contribute via $\gamma\gamma \to A_2^0 \to \pi^+\pi^-\pi^0$; $\pi^0 \to \gamma\gamma$ where one of the photons was not detected. This process produces an enhancement in the $\pi^+\pi^-\gamma$ final state near the mass of the A_2 (1.32 GeV). The solid lines in these distributions give the results of the fits which provide a good description of the data. The resulting fit values for $\Gamma(\eta' \to \gamma\gamma)$ are insensitive to the amount of A_2 production with less than 10% variation for $\Gamma(A_2 \to \gamma\gamma)$ ranging from 0 to 2 keV. A value of $\Gamma(A_2^0 \to \gamma\gamma) = 1.0$ keV was used for the final fits. The fits yielded $\Gamma(\eta' \to \gamma\gamma) = 5.1 \pm 0.4$ keV for the LABC events and 5.7 ± 0.8 keV for the HASH events.

The results obtained for both devices and in both methods agree well with each other. For the final result we used the first method, for which the background is best understood. The weighted average for the two devices is:

$$\Gamma(\eta' \to \gamma\gamma) = 5.1 \pm 0.4(\text{stat.}) \pm 0.7(\text{syst.})\ \text{keV}\ .$$

The systematic error is dominated by uncertainties in the shape of the background and in the detection efficiency for low energy photons.

Our value for $\Gamma(\eta' \to \gamma\gamma)$ agrees with previous measurements [1,2] with the possible exception of the PLUTO result [3] of $3.8 \pm 0.26 \pm 0.43$. It also falls in the range of 4–6 keV predicted by most models [4,5] containing fractionally charged quarks while integrally charged models tend to predict values around 25 keV. However, it has been argued [15] that a consistent integrally charged quark model can be built that agrees with the experimental results.

We also made a search for other resonant structures in the reaction $\gamma\gamma \to \rho^0\gamma$. From a study of radiative J/ψ decay [6] preliminary evidence has been reported for a $\rho^0\gamma$ enhancement in the region of the $\iota(1440)$. Our data shows no signal in this mass region (shaded histograms in figs. 2c, 2d). Using for the $\iota(1440)$ a mass of 1460 MeV and a total width of $\Gamma = 105$ MeV a 95% confidence level upper limit for the two photon width of the $\iota(1440)$ times its branching ratio into $\rho^0\gamma$ was found to be:

$$\Gamma(\iota \to \gamma\gamma)B(\iota \to \rho^0\gamma) < 1.5\ \text{keV}\ .$$

In conclusion, the $\eta' \to \gamma\gamma$ partial width was measured to be

$$\Gamma(\eta' \to \gamma\gamma) = 5.1 \pm 0.4(\text{stat.}) \pm 0.7(\text{syst.})\ \text{keV}\ .$$

An upper limit for the $\gamma\gamma$ width of the $\iota(1440)$ times its branching ratio into $\rho^0\gamma$ has been given.

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