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T/E

MEASUREMENT OF THE RADIATIVE WIDTH OF THE η' IN TWO-PHOTON INTERACTIONS AT SPEAR*

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ABSTRACT

Events of the type $e^+e^- \rightarrow e^+e^-\eta'$ (958) have been observed with the Mark II detector at SPEAR by detecting the decay mode $\eta' \rightarrow \rho^0\gamma$. From the observed cross section and known branching fractions of the η', the radiative width of the η' is $\Gamma_{\gamma\gamma} = 5.9\pm1.6\pm^{1.2}_{\mp}$ KeV and the total width is $\Gamma = 300\pm90\pm60$ KeV (statistical and systematic errors).

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We report evidence for the production of η' mesons by the two-photon process:

$$e^+e^- \rightarrow e^+e^-\eta'(958) . \tag{1}$$

Previous experiments have identified lepton pairs(1,2) and multihadronic events(3) as coming from this process. The events reported here were found with the Mark II detector at the Stanford Linear Accelerator Center e^+e^- storage ring facility SPEAR through the decay mode $\eta' \rightarrow \rho^o\gamma$. The outgoing e^+ and e^- were not detected. The transverse momenta of these η' mesons are limited to very low values, their angular distribution is strongly peaked along the beam direction and their total energy is much smaller than the beam energies. These kinematical features are those expected for η' production by reaction (1).

A schematic view of the Mark II detector is shown in Fig. 1. A particle that moves outward from the e^+e^- interaction region first traverses the 0.15-mm thick stainless steel vacuum pipe and two concentric 0.64-cm thick cylindrical scintillation counters. It then enters the drift chamber(4) (DC) which contains 16 sense-wire layers of radii 0.41 m to 1.45 m. The magnetic field is 4.1 kG and the momenta of charged particles are measured with an accuracy of $\delta p/p = \pm\left[(0.010p)^2+(0.0145)^2\right]^{\frac{1}{2}}$ where p is the momentum in GeV/c.(5) The DC is surrounded by 48 scintillation counters, 2.54-cm thick, viewed on both ends by XP2230 photomultipliers. With the beam crossing reference signal they provide a rms time-of-flight (TOF) resolution of 300 ps. Next, the particle traverses 1.36 radiation-lengths of solenoidal coil and support material and enters one of eight liquid argon calorimeter modules (LA).(6) These contain about 14 radiation lengths of lead and argon with readout strips parallel, perpendicular and at 45^{o} to the beam axis giving an rms angular resolution of about 8 mrad both in azimuth and dip angle. The rms energy resolution for electrons and photons at high energies ($\gtrsim 0.5$ GeV) has been measured to be $\delta E/E = 0.11/\sqrt{E}$ (E in GeV). At lower energies the resolution is worse ($0.13/\sqrt{E}$) because of the increasing importance of the energy loss in the coil material. The measured photon detection efficiency is 15% at 100 MeV, 50% at 200 MeV and $\gtrsim 90\%$ above 400 MeV. These values agree well with detailed electromagnetic shower Monte Carlo calculations(7) which are also used to correct the measurements for the energy loss in the coil material. Finally, two steel walls each followed by one plane of proportional tubes are used for the detection of muons above $p \sim 700$ MeV/c.

The fraction of the full solid angle covered by the drift chamber and TOF counters is about 75%, by the LA modules is 70%, and by the muon detection system is 55%. At small angles relative to the beams there are additional shower counters (at one end a liquid argon calorimeter and at the other end two planes of proportional chambers each preceded by 1.1 cm of lead) which extend the solid angle coverage to 90% of 4π sr.

The detector is triggered with a two stage hardware trigger[8] that selects with efficiency $\geq 99\%$ all interactions that emit at least one charged particle through the entire drift chamber and another particle through at least its first 5 layers. The luminosity is measured with independent shower counters detecting Bhabha scattering at 22 mrad and checked against wide angle Bhabha events observed in the detector. The systematic uncertainty in the luminosity is less than $\pm 6\%$.

Data taken at beam energies E_b between 2.21 and 3.70 GeV are used for the present analysis. The total integrated luminosity is 5640 nb^{-1}. Events having only two oppositely charged tracks coming from the interaction region and one photon detected in the LA barrel modules were selected. Photons are required to have energies greater than 170 MeV in order to reduce background that is generated by electronic noise fluctuations. Photons within 60 cm of the charged tracks were ignored in order to reduce backgrounds from interacting charged tracks and from pattern recognition ambiguities.

A succession of further cuts was imposed upon the events in this data sample. Pions were selected by requiring that the TOF be within 3 standard deviations of the expected time, that the deposited energy in the LA be less than that expected for electrons, and that there be no track-associated hits in the muon chambers. Possible background from one photon e^+e^- annihilation was reduced by requiring that the transverse momentum of the $\pi^+\pi^-\gamma$ state ($p_\perp$) be < 250 MeV/c, that the acoplanarity angle between the $\pi^+\pi^-$ and the γ momentum vectors defined with respect to the beam axis ($\Delta\phi$) be ≤ 0.5 rad and that the acoplanarity angle between the two pions ($\Delta\phi_{\pi\pi}$) be < 1.8 rad ($\Delta\phi = 0$ for back-to-back decays). The background from radiatively degraded Bhabha scattered electrons was rejected by requiring that the pion momentum and the photon energy be < 1 GeV. Finally, the contribution from lepton or pion pairs produced in two-photon interactions combined with noise-generated false photons was suppressed by requiring that the transverse momentum of the $\pi^+\pi^-$ state be > 50 MeV/c and $\Delta\phi_{\pi\pi}$ be > 0.05 rad.

Sixty nine events fulfill all these criteria. They have been visually scanned and 7 of them rejected because of additional unreconstructed small angle charged tracks.

The $\pi^+\pi^-\gamma$ mass distribution for the remaining events, given in Fig. 2, shows a clear $\eta' \to \pi^+\pi^-\gamma$ signal. The mass resolution is dominated by the photon energy measurement and is expected to be about 50 MeV/c^2 (rms) for the η' mass region. No cut has been made on the $\pi^+\pi^-$ mass. We have verified that for the subsample of events lying in the η' mass region defined as $800 < m_{\pi\pi\gamma} < 1100$ MeV/c^2 the $\pi^+\pi^-$ mass distribution is compatible with all pairs coming from ρ^0 decays.

The transverse momentum $p_\perp$, total energy E and angular distribution $\cos\theta$ (with respect to the beam axis) are shown in Figs. 3a-c for all events (full histograms) and for the events lying in the η' mass region (shaded). The η' events occur mainly at low transverse momenta in contrast with the background events. Their total energy peaks at low values thus excluding an interpretation of two-body production like $\eta'\gamma$ where the γ is undetected. The angular distribution is highly peaked in the forward and backward directions. We also observe a flat rapidity (y) distribution within the detector acceptance of about $-0.6 < y < 0.6$.

The background from e^+e^- annihilation events has been studied in multihadron events. The $\pi^+\pi^-\gamma$ mass combinations have been calculated independently of the existence of additional charged tracks or photons, with all other criteria unchanged. No peaking in the mass and energy distributions is seen, and the $p_\perp$ distribution peaks above 200 MeV/c. The correction for annihilation events is included in the background subtraction using the adjacent mass regions which leaves a total of 23 ± 6 η' events (see Table 1).

The detection probability for reaction (1) was determined by a Monte Carlo simulation that used calculations of Ref. (9). The result is listed in Table 1. All the kinematical distributions for the η' events shown in Figs. 3a-c are well reproduced by the generated two-photon events. The expected distributions, normalized to the same number of η'

events, are shown as solid curves. The cross section for reaction (1) has been calculated using the branching ratio $B(\eta' \rightarrow \rho^{o}\gamma) = 0.298 \pm 0.017$[10] and is given in Table 1.

The two-photon cross section is directly proportional to the radiative width $\Gamma_{\gamma\gamma}(\eta')$.[11] We determine $\Gamma_{\gamma\gamma}(\eta') = 5.9 \pm 1.6$ KeV[12] using the two-photon cross section calculation of Ref. (9). The error is statistical only and does not include an estimated systematic uncertainty of $\pm 20\%$.[13] With the $B(\eta' \rightarrow \gamma\gamma) = 0.0197 \pm 0.0026$,[10] the total width can then be determined to be $\Gamma_{tot}(\eta') = 300 \pm 90$ KeV (or $\tau = (2.2 \pm 0.7) \times 10^{-21}$ sec). The total width has recently been measured in a $\pi^{-}p \rightarrow n$ + missing mass experiment.[14] Our result is in excellent agreement with their measured value of $\Gamma_{tot}(\eta') = 280 \pm 100$ KeV.

There is considerable interest in a measurement of $\Gamma_{\gamma\gamma}(\eta')$.[15-17] Quark models with fractionally charged quarks and a small pseudoscalar octet-singlet mixing angle[10] lead under the assumption of equal singlet and octet decay constants[16] to the prediction $\Gamma_{\gamma\gamma}(\eta') \simeq 6$ KeV.[15] This is in good agreement with our measurement. The data are also in agreement with a recent relativistic quark model[17] calculation which predicts $\Gamma_{\gamma\gamma}(\eta') = 7.3$ KeV.

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Footnotes and References

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Figure Captions

1. Schematic view of the Mark II detector; (A) vacuum chamber, (B) pipe counter, (C) drift chamber, (D) time-of-flight counters, (E) solenoid coil, (F) liquid argon shower counters, (G) iron absorber, (H) muon proportional tubes.
2. Effective $\pi^+\pi^-\gamma$ mass distribution.
3. Kinematical distributions for (a) transverse momentum, (b) total energy, and (c) cosine of the production angle with respect to the beam axis. The full histograms contain all events, the events in the η' mass peak are shaded. The curve represents the Monte Carlo calculation assuming $e^+e^- \to e^+e^-\eta'$ normalized to the observed η' signal.

TABLE 1

SUMMARY OF THE CROSS SECTION CALCULATION

E_b (GeV)	$\int \mathcal{L} dt$ (nb^{-1})	ϵ	$n_{\eta'}$	σ (nb)
2.21	798	0.017	5.1 ± 2.6	0.98 ± 0.50
2.25-2.50	2131	0.0224	4.3 ± 2.6	0.30 ± 0.18
2.50-3.00	1730	0.0217	10.3 ± 3.6	0.91 ± 0.32
3.70	984	0.0125	3.1 ± 2.2	0.84 ± 0.60

E_b is the beam energy, $\int \mathcal{L} dt$ the integrated luminosity, ϵ the detection efficiency $\left(\text{not including } B(\eta' \to \rho\gamma)\right)$, $n_{\eta'}$ is the number of η' events (background subtracted) and σ is the observed cross section. Errors shown are statistical only.

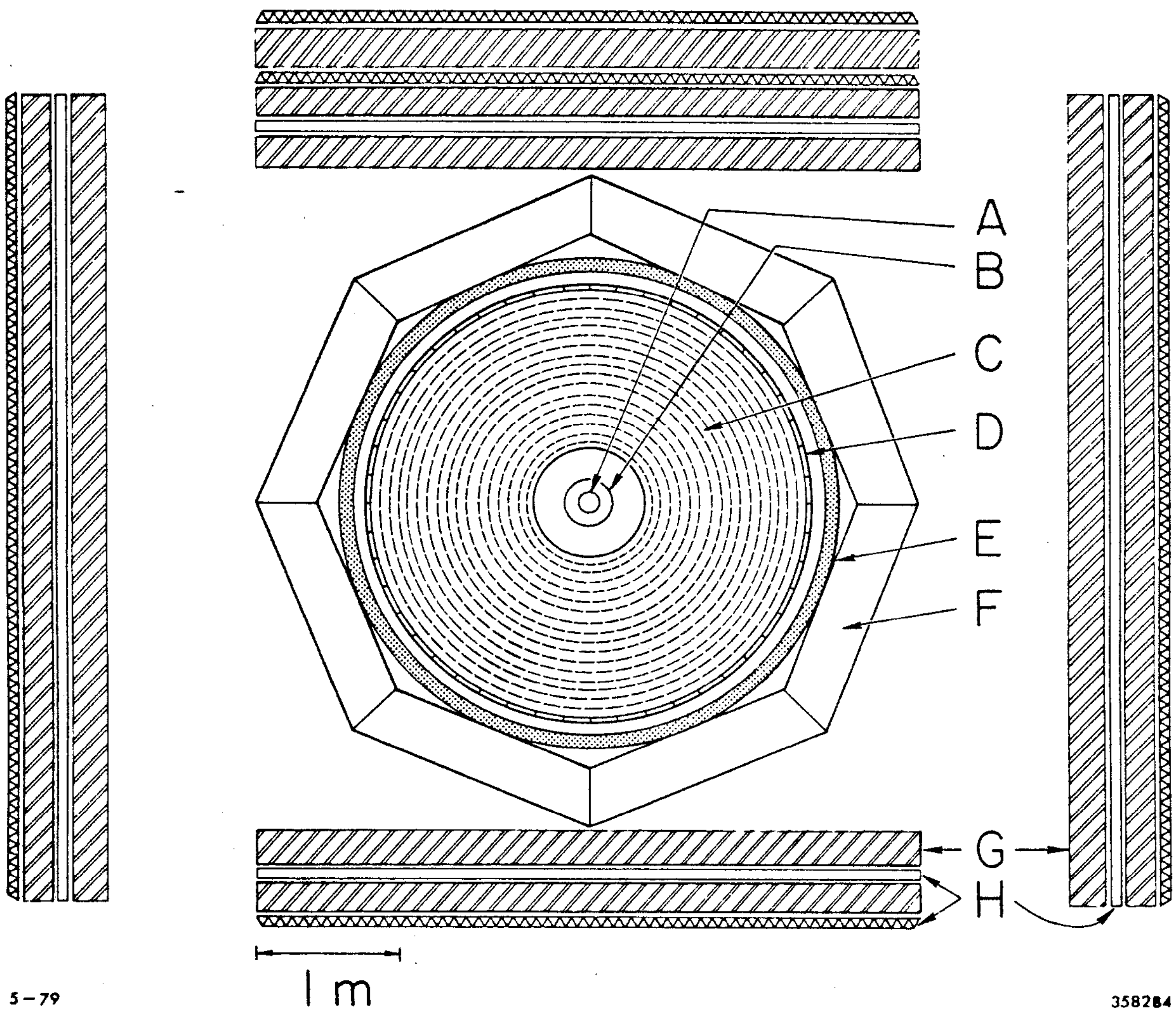
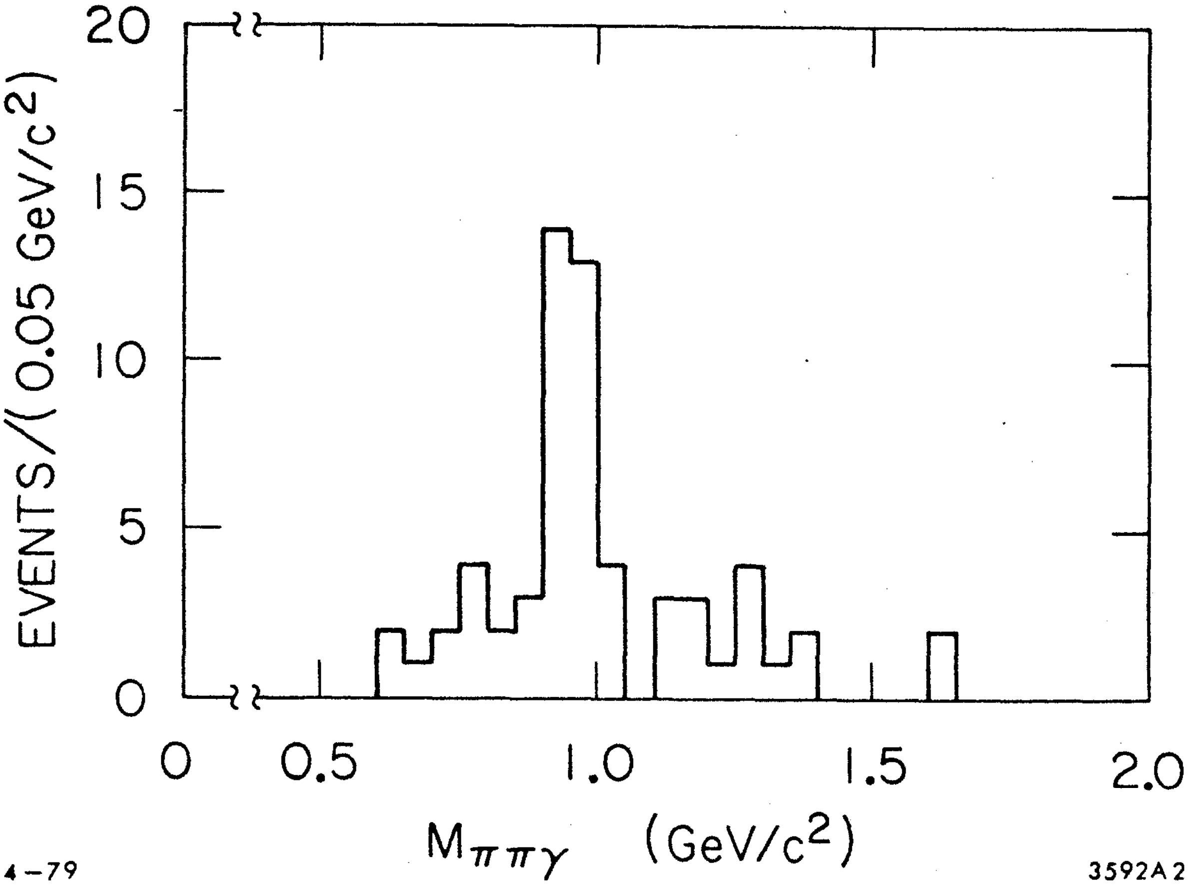


Fig. 1



EVENTS/(0.05 GeV/c²)
20
15
10
5
0
0
0.5
1.0
1.5
2.0
$M_{\pi\pi\gamma}$ (GeV/c²)
4–79
3592A2

Fig. 2

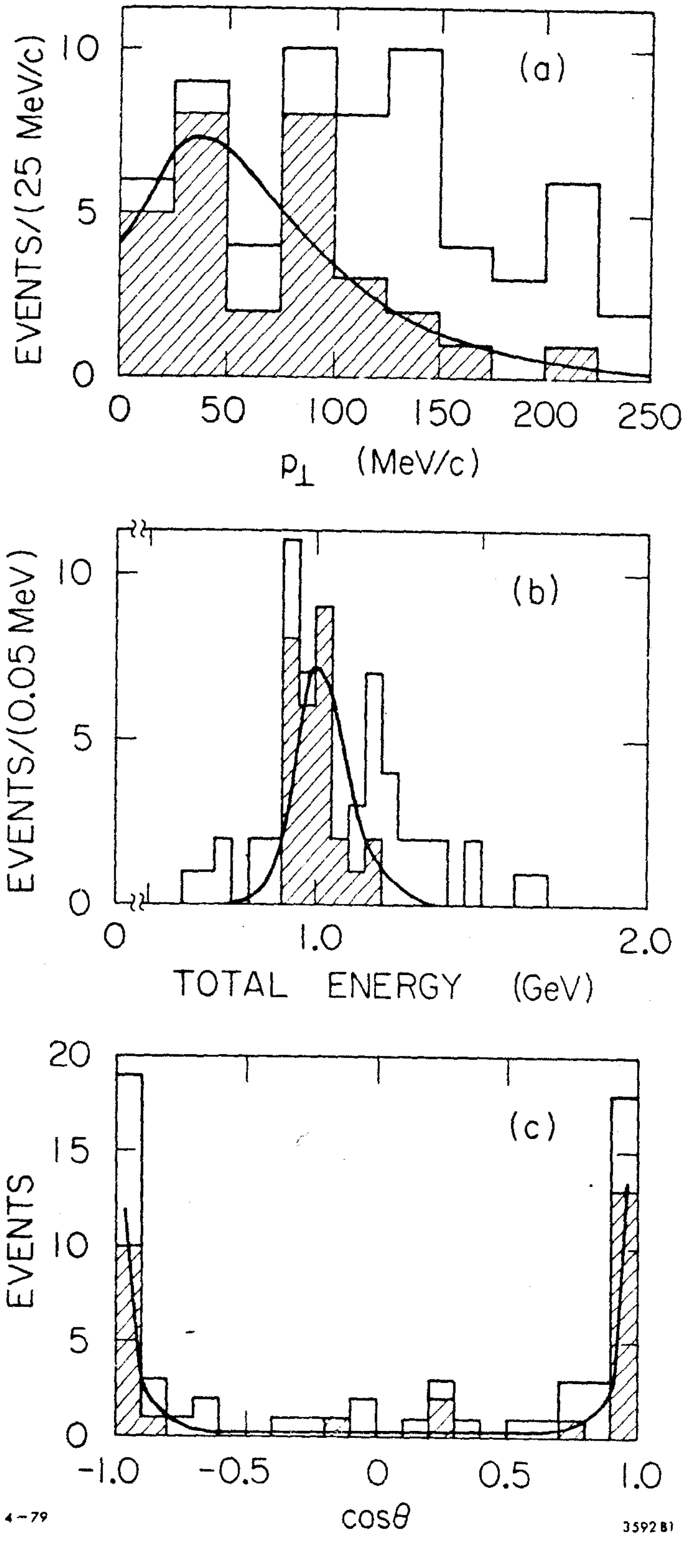

EVENTS/(25 MeV/c)
(a)
0
5
10
0
50
100
150
200
250
p⊥ (MeV/c)
EVENTS/(0.05 MeV)
(b)
0
5
10
0
1.0
2.0
TOTAL ENERGY (GeV)
EVENTS
(c)
0
5
10
15
20
-1.0
-0.5
0
0.5
1.0
cosθ
4-79
3592B1

Fig. 3