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A MEASUREMENT OF THE CROSS SECTION FOR FOUR PION PRODUCTION IN $\gamma\gamma$ COLLISIONS AT SPEAR*

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ABSTRACT

We present a measurement of the cross section for the reaction $e^+e^- \to e^+e^-\pi^+\pi^-\pi^+\pi^-$ at SPEAR. This channel is found to be large and dominated by the process $\gamma\gamma \to \rho^o\rho^o \to \pi^+\pi^-\pi^+\pi^-$. The cross section, which is small just above the four pion threshold, exhibits a large enhancement near the $\rho^o\rho^o$ threshold.

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(Submitted to Physics Letters B)

Although photon-photon collisions are expected to produce a large variety of final states, few experimental results can be found in the literature[1]. We have previously reported a measurement of the radiative width of the $\eta'(958)$ in two-photon interactions at SPEAR[2], and in this Letter we give a measurement of the cross section for the production of four charged pions by the two-photon process,

$$e^+e^- \to e^+e^- \pi^+\pi^-\pi^+\pi^- \quad . \tag{1}$$

This channel is found to be dominated by the production of a pair of neutral rho mesons which decay to the final four pions. Our measurements are compared with recent results from PETRA[3].

The measurement presented here is based on all data taken with the SLAC-LBL Mark II detector[2, 4] at SPEAR with beam center of mass energies between 4.8 GeV and 6.5 GeV. This corresponds to an integrated luminosity of 12,200 nb^{-1}. Events were selected according to the topology of process (1); the detected final state was required to consist of four charged tracks with zero total charge and no other particles. The outgoing beam electrons were not detected. Exclusive final states produced by the two-photon process are characterized by invariant masses that are small compared with the beam center of mass energy, and by low net transverse momenta relative to the beam axis. We therefore only retain events with invariant masses below 3.0 GeV/c^2 and, as will be discussed below, we extract the four pion signal (1) from event candidates with net transverse momentum less than 100 MeV/c.

The low-mass sample contains, in addition to process (1), beam-gas events, feed-down from e^+e^- annihilation events, and possibly feed-down from other two-photon initiated final states. The tracks in each accepted event were required to form a vertex with $|z| \leq 7.5$ cm (z is measured along the e^+e^- beam direction). The beam-gas contamination of the data sample was then corrected for by making sideband subtractions. These corrections were typically only a few percent, and have been made to all distributions shown in this Letter.

Backgrounds remain that result from higher multiplicity events with one or more undetected particles. Monte Carlo studies of the e^+e^- annihilation channel and of higher multiplicity two-photon events that might exist indicate that these backgrounds tend to zero at net transverse momenta below 100 MeV/c. Shown separately in Fig. 1 are the observed $|\Sigma\vec{p}_T|$ distributions for events with total charge zero and total charge ±2. The expected shape of the detected p_T distribution of the two-photon process (1) was calculated with a Monte Carlo, and an empirical ansatz was made for the shape of the background. The charge ±2 data indicate that, within the statistics of the experiment, it is reasonable to take the background as a straight line. The data were partitioned into bins according to mass, and fits to the p_T distributions were made with the normalization of the two-photon contribution and the slope and intercept of the background as free parameters. Fig. 1a contains the result of a fit of this type to the total event sample. The full fit is displayed as a solid line; the background piece is separately displayed in the figure as a dashed line.

The numbers of two-photon events with total transverse momentum less than 100 MeV/c as determined by the fits are listed in Table I. The errors are also determined by the fits, and their size is due primarily to the correlation between the normalization of the two-photon distribution and the intercept of the background. Thus they include a reasonable estimate of the systematic uncertainty of the background subtraction.

Before the acceptance of the detector for the process $\gamma\gamma \rightarrow 4\pi$ could be determined, it was necessary to look at the phase space structure that the data exhibit. Each event contains 4 neutral combinations of $\pi^{\pm}\pi^{\mp}$ and 2 charge-two combinations $\pi^{\pm}\pi^{\pm}$. If the pions are pair-wise uncorrelated, then the mass distribution of $\pi^{\pm}\pi^{\mp}$ pairs would have the same shape as that for $\pi^{\pm}\pi^{\pm}$. The relative normalization, furthermore, would just be a factor of 2. The mass distribution of charge-zero pairs is shown in Fig. 2a as points with errors, and the same distribution for charge-two pairs is given as a histogram. Only events, and all events, with total mass between 1.15 GeV/c^2 and 2.25 GeV/c^2 and p_T below 100 MeV/c are included here since little signal is seen outside this region. The shapes are quite different; the neutral pairs are peaked near the rho mass. If the pions are completely correlated as $\rho^o\rho^o$, then the mass distribution of pairs formed by a π^+ from one ρ^o and a π^- from the other ρ^o is equivalent to the charged-two mass distribution[5]. The "rho mass peak" can then be obtained by subtracting the two distributions. The result is shown in Fig. 2b. The histogram in this figure is the result of a Monte Carlo calculation using a mass matrix which is the square of the symmetrized coherent sum of two relativistic p-wave Breit-Wigner amplitudes. Events were generated separately in each mass bin (Table I), renormalized to the number of events observed in each bin, and finally added together. The same subtraction of the charge-two distribution from the neutral pair distribution was then done. Scatter plots of the mass of one pair opposite the remaining pair (two entries per event in the neutral plots and one entry per event in the charge-two plots) have been made for each mass bin, and maximum likelihood fits to them have been done using a combination of the $\rho^o\rho^o$ matrix element and pure phase space. The fits are consistent with the two-photon signal being all $\gamma\gamma \rightarrow \rho^o\rho^o$, but we cannot rule out a $\gamma\gamma \rightarrow 4\pi$ (phase space) component as large as 15 – 20% in a given mass bin.

The production and decay of the ρ^o's can also be studied with the subtraction technique used to produce Fig. 2b. The Monte Carlo was first used to determine the acceptance of the detector as a function of the cosine of the ρ^o production and decay angles in the $\gamma\gamma$ cms. For this purpose, the incident photons were assumed to lie along the e^+e^- beam axis. The efficiency corrected distribution of the ρ^o production angle (in the $\gamma\gamma$ cms) is shown in Fig. 3a. The corresponding distribution of the ρ^o decay angle (in the ρ^o rest frame) is given in Fig. 3b. The efficiency decreases smoothly by about a factor of two as the cosine of the production angle increases from zero to one.

The acceptance of the detector in each $\gamma\gamma$ mass bin was calculated with the Monte Carlo by using the $\rho^o\rho^o$ matrix element for the $\pi^+\pi^-$ mass weighting, and using angular distributions consistent with Fig. 3. The resulting efficiencies vary from 4% at the lowest

masses to 7% at the highest masses. The details of the event selection criteria resulted in an additional loss of four pion events which we estimate to be 17% ± 4% of the desired events.

The cross section $\sigma_{ee \rightarrow eex}$ for the production of the final state eex is written in terms of the corresponding two-photon cross section $\sigma_{\gamma\gamma \rightarrow x}$ as[6]

$$\frac{d\sigma_{ee \rightarrow eex}}{ds_x} = 2\left(\frac{\alpha}{\pi}\right)^2 f\left(E_b, s_x\right) \frac{\sigma_{\gamma\gamma \rightarrow x}}{s_x} \quad , \qquad (2)$$

where E_b is the electron beam energy, s_x is the square of the invariant mass of state x, and the function f results from integration over the rapidity of the final state x. The factors in equation (2) that depend upon the beam energy were calculated separately for each of the energies used in the data sample and luminosity weighted values were then used to calculate the two-photon cross sections. The results are given in Table I and Fig. 4. The errors include the following systematic contributions added in quadrature: (1) event selection (4%), (2) acceptance calculation (10%), and (3) luminosity (6%). After the background subtraction, no signal is left in neither the highest nor in the lowest mass bins, so one standard deviation limits are given for the possible size of these cross sections. Shown also in the figure are the results for $\gamma\gamma \rightarrow \rho^o\rho^o$ that have been previously reported by the TASSO collaboration[3]; the two results are in reasonable agreement.

A current algebra calculation[7a] of the process $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$ gives a value $\sim$ 2nb for the cross section just above the four-pion threshold. A perturbative QCD calculation of the cross section $\gamma\gamma \to \rho^o\rho^o$ has recently been completed[7b] and, although its validity at low masses is uncertain, we give the result in Fig. 4 as a theoretical reference point. Alternatively, vector dominance suggests the estimate

$$\sigma_{\gamma\gamma \to \rho\rho} \sim \left(\frac{1}{250}\right)^2 \sigma_{\rho\rho \to \rho\rho} \sim \left(\frac{1}{250}\right)^2 \left(\frac{\sigma_{\pi p}^{el}}{\sigma_{pp}^{el}}\right)^2 \sigma_{pp}^{el} \sim 30\text{nb} \qquad (3)$$

for the cross section, again at large cms energies. We observe a cross section near the $\rho^o\rho^o$ threshold that is considerably larger than any of these values.

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Figure Captions

Fig. 1. Total vector transverse momenta of events with total mass less than 3.0 GeV/c^2 are shown for the topology (a) total charge zero and (b) total charge ±2.

Fig. 2. Two-pion mass distributions. (a) Masses for like-sign and opposite-sign pairs, and (b) the difference between opposite-sign and like-sign distributions. The histogram in (b) is a Monte Carlo described in the text.

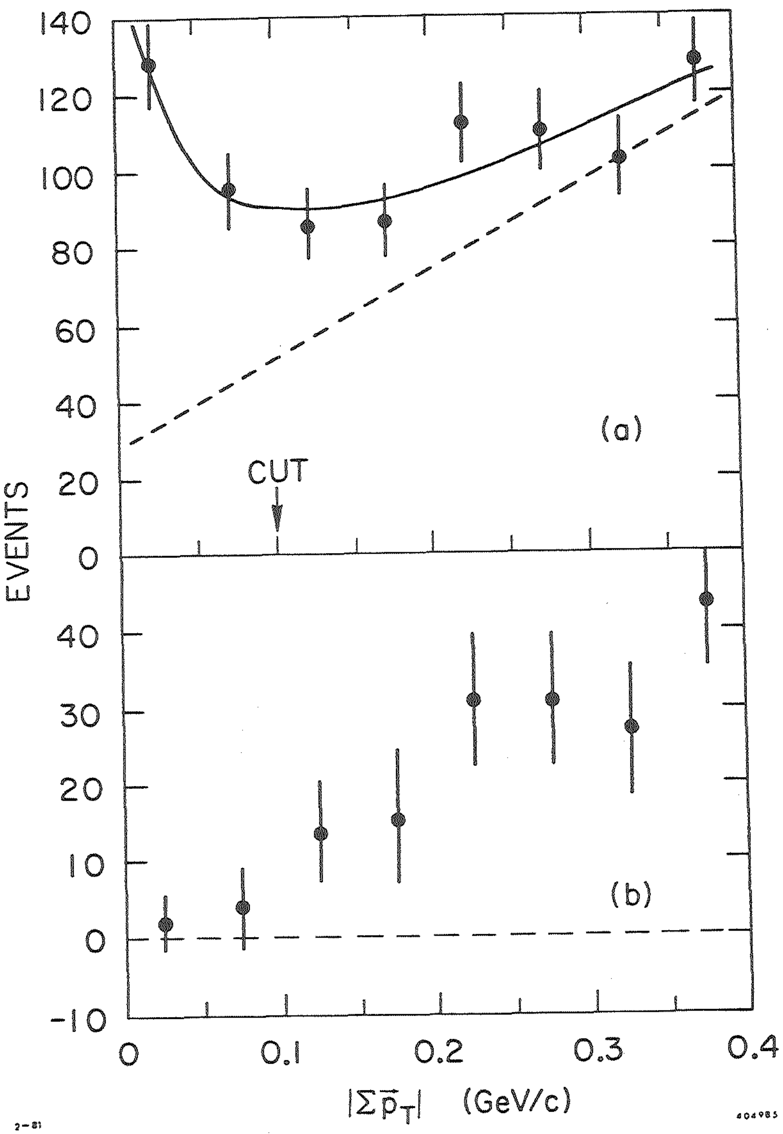
Fig. 3. (a) Production and (b) decay angle distributions for ρ^o. Events with total mass between 1.15 GeV/c^2 and 2.25 GeV/c^2. A curve of the form $a+b \cos\theta_\rho^{*2}$ is shown in (a).

Fig. 4. Measured cross section for $\gamma\gamma \rightarrow \pi^+\pi^-\pi^+\pi^-$. Errors assigned to data from this experiment include all known systematic contributions. The TASSO data are for $\gamma\gamma \rightarrow \rho^o\rho^o$ only. The curve is a theoretical prediction described in the text.

TABLE I

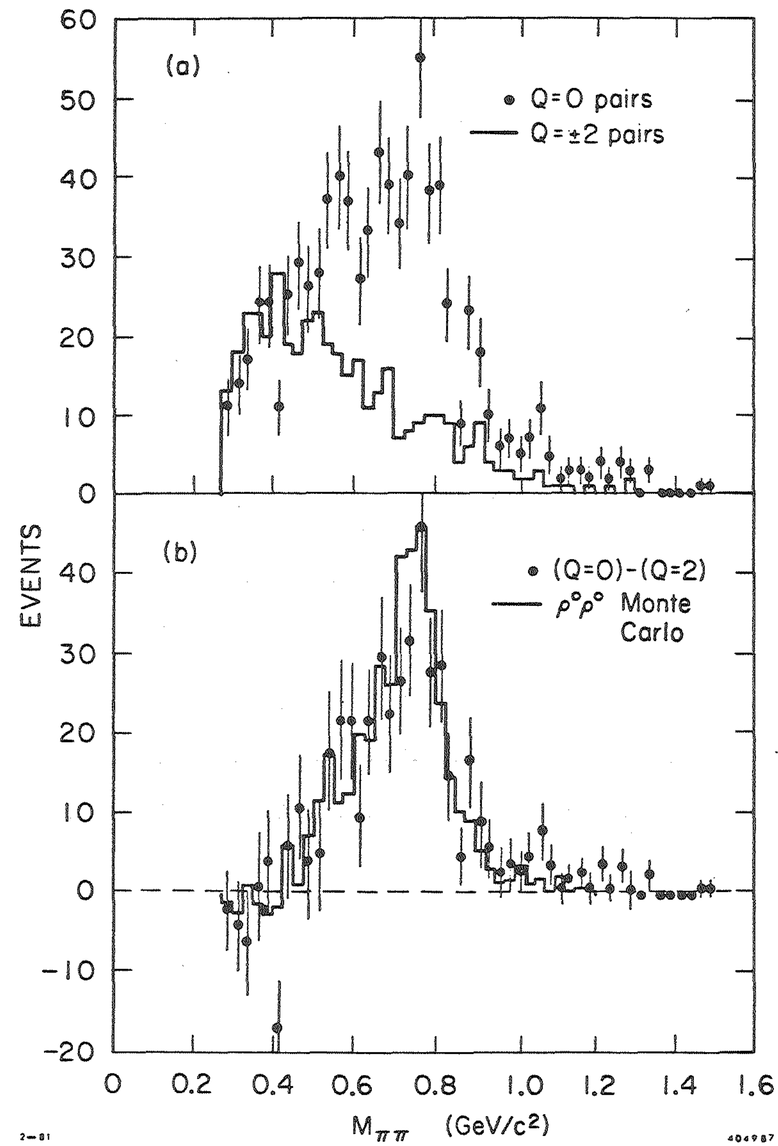
Data Summary

Mass (GeV/c^2)	.75 - 1.15	1.15 - 1.45	1.45 - 1.75	1.75 - 2.25	2.25 - 3.00
Events with $\lvert\Sigma\vec{p}_T\rvert$<.100 GeV/c	12	67	70	57	28
Events after background fit	-6.1 ± 7.7	52.4 ± 15.7	53.3 ± 16.5	45.6 ± 16.1	3.2 ± 11.9
$\sigma_{\gamma\gamma \rightarrow 4\pi}$ (nb)	< 6.0	72.6 ± 21.6	105.0 ± 32.7	89.4 ± 31.7	< 45.1



140
120
100
80
60
40
20
0
40
30
20
10
0
-10
EVENTS
CUT
(a)
(b)
0
0.1
0.2
0.3
0.4
$|\Sigma \vec{p}_T|$ (GeV/c)
2-81
404985

Fig. 1



60
50
40
30
20
10
0
-10
-20
EVENTS
(a)
Q=0 pairs
Q=±2 pairs
(b)
(Q=0)-(Q=2)
$\rho^\circ\rho^\circ$ Monte Carlo
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
$M_{\pi\pi}$ (GeV/c^2)
2-81
404987

Fig 2

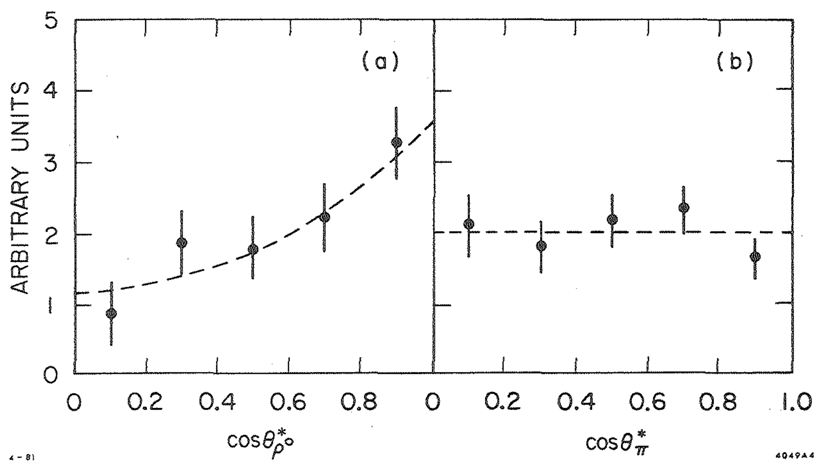

5
4
3
2
1
0
ARBITRARY UNITS
(a)
(b)
0
0.2
0.4
0.6
0.8
1.0
$\cos\theta^*_{\rho^\circ}$
$\cos\theta^*_\pi$
4-81
4049A4

Fig 3

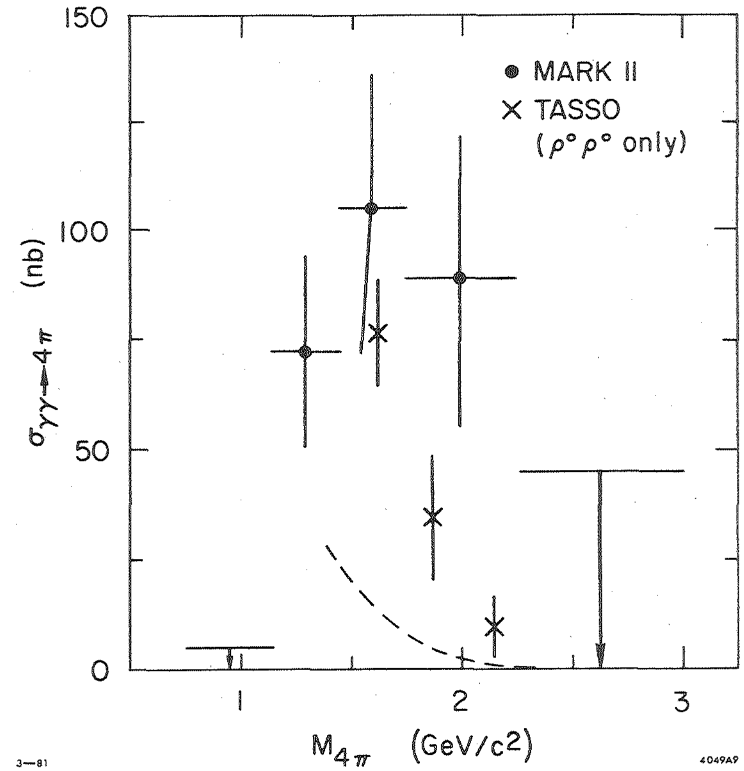

150
100
50
0
$\sigma_{\gamma\gamma\to4\pi}$ (nb)
MARK II
TASSO
($\rho^\circ\rho^\circ$ only)
1
2
3
$M_{4\pi}$ (GeV/c^2)
3-81
4049A9

Fig. 4