MEASUREMENT OF THE REACTION $\gamma\gamma \to \rho^+\rho^-$ WITH THE CELLO DETECTOR

CELLO Collaboration

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Results on the reaction $\gamma\gamma\to\pi^+\pi^-\pi^0\pi^0$ are presented. There is clear evidence for correlated $\rho^+\rho^-$ production. The cross section is much lower than for $\gamma\gamma\to\rho^0\rho^0$.

The unusually large cross section [1–5] of the reaction

$$\gamma\gamma\to\rho^0\rho^0 \quad (1)$$

near threshold has caused great interest [#1], and several models [7–9] have been proposed which attempt to reproduce the experimental results. The peculiarity of reaction (1) was further enhanced by preliminary upper limits [10] for the reaction

$$\gamma\gamma\to\rho^+\rho^- \quad (2)$$

which were much lower than the cross section values of reaction (1) near threshold and had a different dependence on the two photon invariant mass $W_{\gamma\gamma}$. This ruled out the interpretation of (1) as a single resonance decaying into ρρ in the $W_{\gamma\gamma}$ region where the reaction showed a large enhancement. The enhancement and the small cross section for reaction (2) could be explained, however, if one assumed production of several $I=0$ and $I=2$ resonances which interfere with each other [7,8]. Specific states which have been considered are exotic $I=2$ $q\bar{q}q\bar{q}$ mesons as predicted for example by the MIT bag model [11]. A more conventional explanation of reaction (1) can be obtained by using factorization [9] to connect data from ρ photoproduction, nucleon–nucleon scattering and $\gamma\gamma\to\rho\rho$ reactions. This model predicts the cross section values of reaction (2) to be considerably lower than the measured upper limits. A model using a dual picture between perturbative QCD and resonance production gives predictions [12] which are very close to the upper limits of ref. [10].

It is thus of interest to measure the cross section of reaction (2). In this letter we present positive evidence for charged ρ pair production in γγ interactions. Parallel to our work, the ARGUS Collaboration has also found evidence for the existence of this reaction [13].

The experiment was performed with the CELLO detector at the e^+e^- storage ring PETRA at a center-of-mass energy of 35 GeV. The data correspond to an integrated luminosity of 86 pb^{-1}. Charged tracks are reconstructed in the central detector consisting of nine cylindrical drift chambers and five proportional chambers in a 1.3 T magnetic field provided by a superconducting solenoid, yielding a momentum resolution of $\sigma(p)/p=0.02p$ (p in GeV/c) which can be improved by a vertex constraint. The central detector is surrounded by a fine grained lead–liquid-argon calorimeter which consists of 16 barrel and 4 end cap modules with altogether 10 688 electronic channels. The identification and removal of signals due to noise and to charged pion reactions in the coil is made possible by means of its good spatial resolution in both the longitudinal and the lateral direction. A detailed description of the CELLO detector has been given elsewhere [14].

Low multiplicity no tag γγ events were triggered by a fast track finding processor [15], which basically required two tracks with transverse momentum p_T above 650 MeV/c or two tracks above 250 MeV/c with an opening angle in the plane perpendicular to the beam ϕ larger than 45^0 (135° for part of the experiment). By applying the same algorithm to the hit pattern of Monte Carlo events, the trigger decision could reliably be simulated.

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In order to select the final state $\rho^+\rho^-$ an event is accepted if it fulfills the following criteria:
- one positively and one negatively charged track in the angular region $|\cos\theta|<0.9$, θ being the polar angle with respect to the beam line;
- 3 or 4 neutral showers in the liquid argon calorimeter not linked to charged particle tracks;
- no energy measured in the forward lead glass arrays (no tag) in order to avoid events arising from $\gamma\gamma$ processes where one of the photons is highly virtual.

The charged particles particles are assumed to be pions. To ensure that this final state is produced by the interaction of two photons, the total invariant mass is limited to 3 GeV. The events are further subjected to an interaction vertex cut of ± 2.5 cm along the beam line to reduce the beam–gas interaction background.

In the event sample containing 4 photons clear evidence for the production of two correlated π^0's is found. The π^0 mass resolution is in accordance with the Monte Carlo expectation. To suppress combinatorial background we combine the highest energy photon with that nearest to in space. Monte Carlo studies show that this procedure leads to the correct combination with 95% probability. Fig. 1 shows a scatter plot of the invariant mass of this $\gamma\gamma$ pair against the recoiling photon pair. One sees a clear signal for $\pi^0\pi^0$ production. Further Monte Carlo studies indicate that the event yield can be increased by a factor of more than 4 (the acceptance increases from 0.13% to 0.6%) if one also accepts events where one photon is missing. In this case we combine those two photons which have the smallest azimuthal angle difference. Fig. 2 shows the invariant mass of two photons in the 3 photon sample. The shaded part shows those combinations that are selected as π^0 candidates. The invariant $\gamma\gamma$ mass is required to be between 75 and 200 MeV. The other photon is accepted as a π^0 if it has an energy larger than 150 MeV, points well into the central barrel calorimeter, and has an azimuthal angle ϕ between its momentum and the vector sum of the other three pion momenta larger than 140°. Finally, we restrict the total transverse momentum squared to be less than 0.1 GeV^2 in order to suppress non-exclusive background.

The vector meson content is analysed by fitting the $m_{\pi^+\pi^0}$ versus $m_{\pi^-\pi^0}$ correlation plot (2 entries per event, see fig. 3a) to the sum of a (Bose symmetrised) $\rho^+\rho^-$, a $\rho^\pm\pi^\mp\pi^0$ and a non-resonant 4π Monte Carlo simulation in W-bins of 300 MeV width. We observe clear evidence for correlated charged ρ production. The correlation plot of neutral $\pi\pi$ combinations (fig. 3b) does not show ρ signals. Leaving out the $\rho^+\rho^-$ contribution results in a fit which is worse by 4.7 standard deviations. A fit without a $\rho\pi\pi$ contribution is, however, possible, resulting in a $\rho^+\rho^-$ cross section about twice as high as in the 3 parameter fit with only a marginally worse fit probability. The results are summarized in table 1, where both the 2 and the 3 parameter fit results are presented.

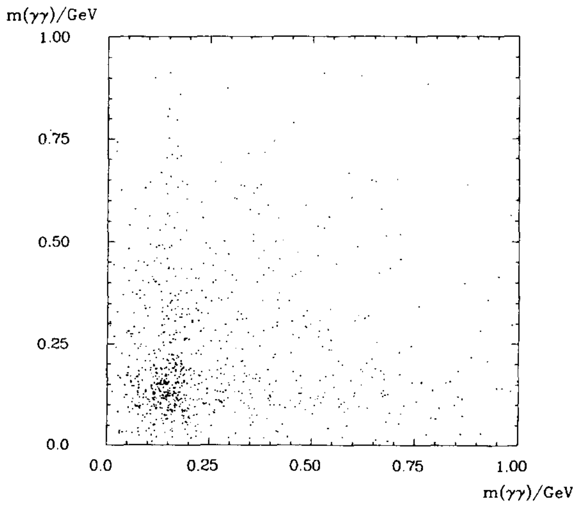

Fig. 1. $m_{\gamma\gamma}$ versus $m_{\gamma\gamma}$ in the 4 photon sample.

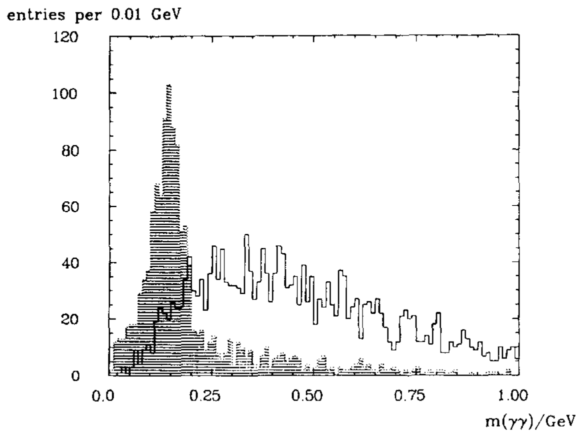

Fig. 2. $m_{\gamma\gamma}$ in the 3 photon sample. Selected (shaded) and rejected (unshaded) combinations.

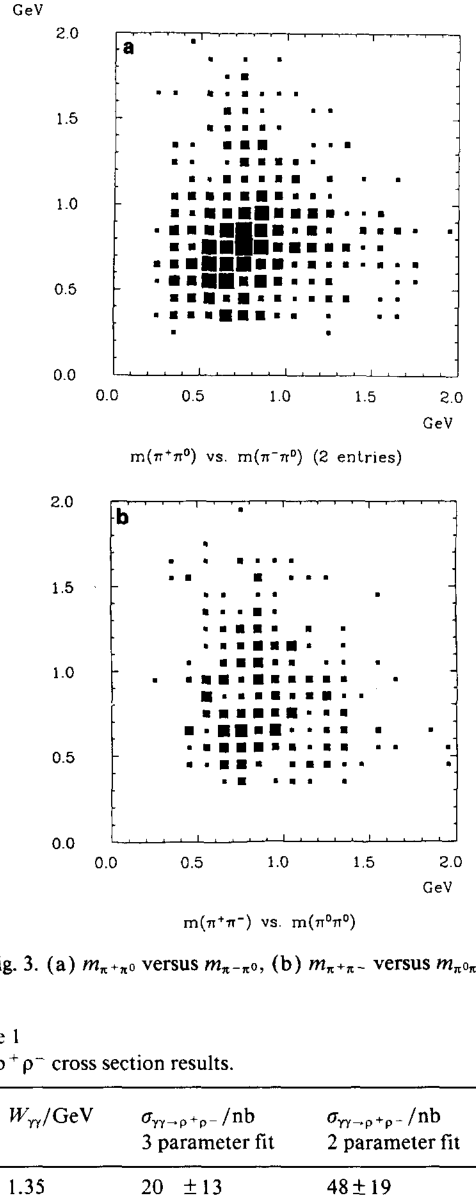

Fig. 3. (a) $m_{\pi^+\pi^0}$ versus $m_{\pi^-\pi^0}$, (b) $m_{\pi^+\pi^-}$ versus $m_{\pi^0\pi^0}$.

Table 1
$\gamma\gamma\to\rho^+\rho^-$ cross section results.

$W_{\gamma\gamma}$/GeV	$\sigma_{\gamma\gamma\to\rho^+\rho^-}$/nb 3 parameter fit	$\sigma_{\gamma\gamma\to\rho^+\rho^-}$/nb 2 parameter fit
1.35	20 ±13	48±19
1.65	20.5±6.5	40±8
1.95	22 ±6	50±10
2.25	13 ±7	38±12
2.55	3 ±5	8±12
2.85	2 ±5.5	1±7

The errors given are statistical only. Within these errors the results of the fit were not sensitive to changing the event selection cuts, nor to the binning in the scatter plot. We estimate a 25% systematic error. Fig. 4 shows the cross section values for reaction (2) obtained from our 3 parameter fit.

It is not possible to disentangle the spin parity content and interference effects with the low statistics and limited resolution available; thus we remain confined to this simple model. As pointed out in ref. [7], a basic amplitude $\rho^0\pi^+\pi^-$ with the pions in an $I=0$ state is forbidden by C parity. In the reaction $\rho^+\pi^-\pi^0$ it is allowed only if the $\gamma\gamma$ system as well as the $\pi^-\pi^0$ system is in an $I=2$ state. Other isospin states necessarily lead to odd angular momentum between these pions and thus should be dominated by the ρ^-. The $\rho\pi\pi$ partial cross section in our model can also contain an interference term between 4π and $\rho\rho$ as well as final states such as $a_1\pi$ or $a_2\pi$, which lead to one ρ and two largely uncorrelated pions. Thus, the existence of a $\rho\pi\pi$ term appears to be quite natural, although the fit does not necessarily require it. Therefore the result of the 3 parameter (i.e. a non-zero $\rho\pi\pi$ contribution) fit is the more plausible one. In the absence of more detailed knowledge, one could interpret the result of the 2 parameter fit as an upper limit. The 3 parameter fit result is in good agreement with the result of ARGUS [13].

We turn now to a comparison with the models (fig. 4). As mentioned in the introduction, four predictions have been made for the cross section values of reaction (2). Two of these are based on the production of exotic $q\bar{q}q\bar{q}$ mesons. Achasov et al. [7] assume one exotic $I=2$, $J=2$ resonance which inter-

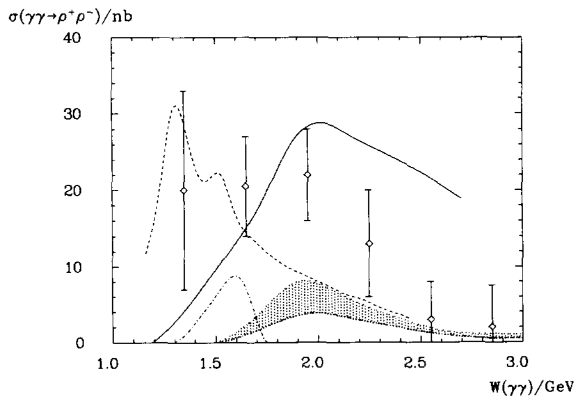

Fig. 4. Cross section for $\gamma\gamma\to\rho^+\rho^-$ as extracted from a 3 parameter fit. Errors are statistical only. Predictions: t-channel factorization [16] (shaded), 4-quark [7] (dashed), 4-quark [8] (dash-dotted) and dual QCD [12] (full line).

feres with two $I=0$, $J=2$ resonances to give the observed enhancement seen in reaction (1) and to obtain the relative supression of reaction (2). Li and Liu [8] need six 4-quark resonances; three $J^P=0^+$ and three $J^P=2^+$ with one of the resonances in each spin state being exotic. Though both models give similar results for reaction (1), they differ substantially in their predictions for reaction (2). Achasov et al. predict a low energy enhancement around 1.3 GeV followed by a secondary maximum near 1.5 GeV and then a gradual decrease of the cross section to a value of about 2 nb at 2.5 GeV (dashed line in fig. 4). The calculations of Li and Liu give a single peak of about 10 nb around 1.6 GeV and a sharp decrease to 0 at 1.75 GeV (dash-dotted line in fig. 4).

The t-channel factorization model of Alexander et al. [9], which describes well the behaviour of the diffractive reaction (1), attempts to apply factorization also to π-exchange reactions. Using measured cross sections of the reactions $\gamma n \to \rho p$ and $np \to pn$, the authors predict the cross section of reaction (2) to rise from a value of about 1 nb at 1.5 GeV to about 8 nb around 1.9 GeV and then to decrease gradually to about 2 nb at 2.9 GeV [16] (shaded region in fig. 4).

The perturbative QCD model of Brodsky et al. [12] uses a dual picture, which is well understood for heavy quarks, and assumes its applicability also for light quarks. Using the standard quark masses, a value of $\Lambda=200$ MeV and restricting $\alpha_s \leqslant 1$, they predict the cross section of reaction (2) to rise gradually from 0 at 1.2 GeV to a value of about 30 nb around 2.1 GeV and then decreasing gradually to about 20 nb at 2.7 GeV (solid line in fig. 4). Above this energy the dual representation of the vector mesons by the colour neutral blobs used in ref. [12] ceases to be valid and no predictions are given.

As is evident from fig. 4 none of the models gives a good description of the data over the whole available $W_{\gamma\gamma}$ range. However, we should stress again that the measured error bars are statistical only and we estimate a systematic error of about 25%. Thus, while the Li and Liu model can be excluded and the agreement with the Alexander et al. prediction is only marginal, we are unable to conclude about the remaining two models.

In summary, we have analysed the final state $\pi^+\pi^-\pi^0\pi^0$ in $\gamma\gamma$ reactions in the no-tag mode in the energy range of $W_{\gamma\gamma}=1.2$–3.0 GeV. We have measured the cross section of the reaction $\gamma\gamma \to \rho^+\rho^-$ and find it to behave differently from that of the diffractive reaction $\gamma\gamma \to \rho^0\rho^0$. None of the existing models for non-diffractive $\gamma\gamma \to$ vector–vector mesons can describe the behaviour of our measured cross section completely satisfactorily. However, the limited precision of the measurement does not allow us to exclude all of the models.

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References

[1] TASSO Collab., R. Brandelik et al., Phys. Lett. B 97 (1980) 448;
TASSO Collab., M. Althoff et al., Z. Phys. C 16 (1982) 13.
[2] MARK II Collab., D.L. Burke et al., Phys. Lett. B 103 (1981) 153.
[3] CELLO Collab., H.J. Behrend et al., Z. Phys. C 21 (1984) 205.
[4] PLUTO Collab., Ch. Berger et al., Z. Phys. C 38 (1988) 521.
[5] TPC/2γ Collab., H. Aihara et al., Phys. Rev. D 37 (1988) 28.
[6] Ch. Berger and W. Wagner, Phys. Rep. 136 (1987) 136;
J. Olsson, talk 1987 Intern. Symp. on Lepton and photon interactions at high energies (Hamburg, 1987), DESY 87-136;
H. Kolanoski and P. Zerwas, DESY 87-175 (1987);
U. Maor, Vector meson production in γγ reactions,

invited talk VIIIth Intern. Workshop on Photon–photon collisions (Shoresh, Israel, April 1988);
A.W. Nilsson, Exclusive final states continuum (experimental), invited talk VIIIth Intern. Workshop on Photon–photon collisions (Shoresh, Israel, April 1988);
A. Levy, Two photon production of exclusive final states, rapporteur talk 24th Intern. Conf. on High energy physics (Munich 1988), DESY 88-115 (1988).
[7] N.N. Achasov, S.A. Devyanin and G.N. Shestakov, Z. Phys. C 27 (1985) 99.
[8] B.A. Li and K.F. Liu, Phys. Rev. D 30 (1984) 613.
[9] G. Alexander, U. Maor and P.G. Williams, Phys. Rev. D 26 (1982) 1198;
G. Alexander, A. Levy and U. Maor, Z. Phys. C 30 (1986) 65.
[10] JADE Collab., presented by H. Kolanoski, Proc. 5th Intern. Workshop on $\gamma\gamma$-Interactions (Aachen, 1983).
[11] R.L. Jaffe, Phys. Rev. D 15 (1977) 267.
[12] S.J. Brodsky, G. Köpp and P.M. Zerwas, Phys. Rev. Lett. 58 (1987) 443.
[13] ARGUS Collab., H. Albrecht et al., DESY 88-150 (1988).
[14] CELLO Collab., H.J. Behrend et al., Phys. Scrip. 23 (1981) 610.
[15] H.J. Behrend, Comput. Phys. Commun. 22 (1981) 365.
[16] A. Levy, 7th Intern. Workshop on $\gamma\gamma$ collisions, (Paris, 1986), TAUP 86-1446, unpublished.