RHO–RHO PRODUCTION BY TWO PHOTON SCATTERING

TASSO Collaboration

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We present the first observation of the reaction $\gamma\gamma \to \rho^0\rho^0$. The data were obtained in a study of e^+e^- scattering at beam energies between 15 and 18.3 GeV. The measured cross-section values near threshold exceed the pomeron contribution calculated in the vector meson dominance model by a large factor.

Besides providing data for the study of the annihilation channels, high energy e^+e^- storage rings offer the opportunity to explore photon–photon interactions via e^+e^- scattering, $e^+e^- \to e^+e^-X$. Investigation of hadron final states produced by photon–photon scattering has started only recently. First results on the total cross section [1] and on the resonance channels $\gamma\gamma \to \eta'$ [2] and $\gamma\gamma \to f^0$ [3] have been reported. In this letter we present the first observation of the reaction

$$\gamma\gamma \to \rho^0\rho^0 . \qquad (1)$$

The experiment was carried out with the TASSO detector at the DESY storage ring PETRA. A description of the detector can be found elsewhere [4]. The present analysis uses the information on charged particles from the central detector. Charged tracks are accepted in 87% of 4π. The rms momentum resolution, including multiple scattering, is $\sigma_p/p = 0.02(1+p^2)^{1/2}$ (p in GeV/c) and the track reconstruction efficiency is 97%. The data were taken at beam energies between 15.0 and 18.3 GeV with a total integrated luminosity of 3710 nb^{-1}.

Candidates for reaction (1) were required to have two positive and two negative tracks (originating from the interaction point) with transverse momenta greater than 0.2 GeV/c with respect to the electron beam direction. In order to suppress background from beam–gas scattering, we rejected events with particles of momenta less than 0.9 GeV/c, identified as protons by time-of-flight. After this selection the distribution of event vertices along the beam direction showed that the contamination from beam–gas scattering was negligible. Fig. 1a gives the distribution of the sum of the particle momenta, $\Sigma|p_i|$, versus the net transverse momentum of the four particle system, $P_T = (\Sigma p_i)_T$. There is an isolated cluster of about 800 events at low $\Sigma|p_i|$ (1–3 GeV/c). This region corresponds to the kinematical configuration expected for events of the type $e^+e^- \to e^+e^-$ + 4 charged particles + undetected particles, where the incident e^+ and e^- are scattered at such small angles that they are not detected. We estimated the background from radiative one-photon annihilation to be about 10 events.

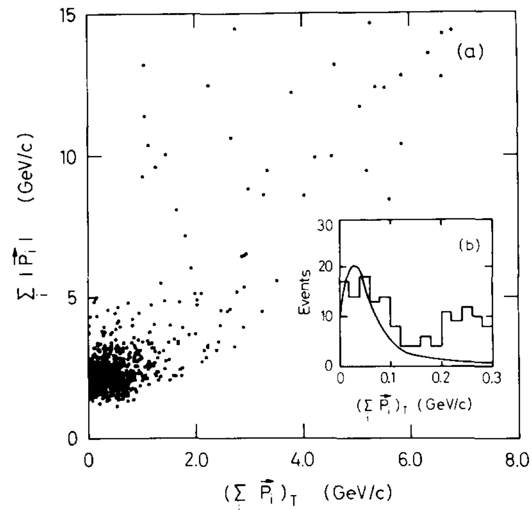

Fig. 1. (a) Distribution of $\Sigma|p_i|$ versus $(\Sigma p_i)_T$ for 4 prong events with net charge zero. (b) Distribution of $(\Sigma p_i)_T$ for 4 prong events with net charge zero and $1.5 < W_{\gamma\gamma} < 2.3$ GeV. The curve shows the distribution expected for the pions in the reaction $e^+e^- \to e^+e^-\pi^+\pi^+\pi^-\pi^-$.

Events of the type $\gamma\gamma \to \rho^0\rho^0$, where the two virtual photons are predominantly almost real and have small angles relative to the beam direction, are expected to cluster at small P_T. Fig. 1b shows the distribution of P_T for events with $1.5 < W_{\gamma\gamma} < 2.3$ GeV, where $W_{\gamma\gamma}$ is the centre of mass energy of the 4 particles assumed to be pions. (As shown below, outside this $W_{\gamma\gamma}$ region the $\rho^0\rho^0$ signal is small.) The curve in fig. 1b shows the expected P_T distribution for $\gamma\gamma \to 4\pi$ events where the effects of resolution and $\gamma\gamma$ kinematics have been taken into account. It has been normalised to the events in the region $P_T < 0.08$ GeV/c. A cut at $P_T = 0.15$ GeV/c selects nearly all the $\gamma\gamma \to 4\pi$ events. The requirements $P_T < 0.15$ GeV/c and $1.5 < W_{\gamma\gamma} < 2.3$ GeV are satisfied by 89 events. We estimated the background from states with additional, unobserved particles to be about 15 events, and from radiative one-photon annihilation to be less than 1 event. The 89 events were therefore assumed to be

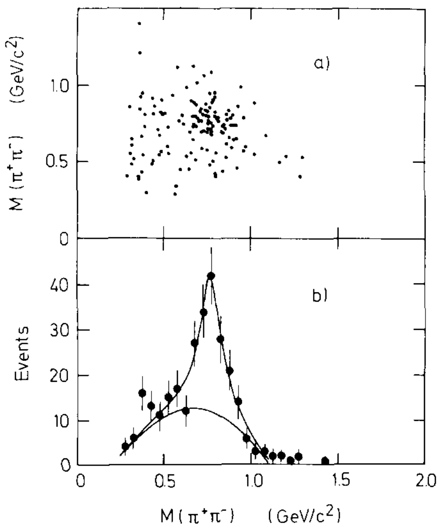

Fig. 2. Mass distributions of $\pi^+\pi^-$ pairs for events with $1.5 < W_{\gamma\gamma} < 2.0$ GeV. (a) Two-dimensional mass distribution of a $\pi^+\pi^-$ combination versus the opposite one (2 entries per event). (b) Distribution of the $\pi^+\pi^-$ masses (4 entries per event). The curves are the result of a fit described in the text.

$$\gamma\gamma \to \pi^+\pi^+\pi^-\pi^- \qquad (2)$$

in the rest of the analysis.

Fig. 2a shows the two-dimensional mass distribution of a $\pi^+\pi^-$ combination versus the opposite one for $1.5 < W_{\gamma\gamma} < 2.0$ GeV. There are 2 entries per event. The pronounced enhancement when both mass values are near the ρ mass is evidence for the final state $\rho^0\rho^0$. Fig. 2b gives the projection onto the $\pi^+\pi^-$ mass axis (4 entries per event).

A Monte Carlo program that simulated the reaction $e^+e^- \to e^+e^-\rho^0\rho^0$ in our detector was used to calculate the cross section for $\gamma\gamma \to \rho^0\rho^0$. The virtual photon fluxes were computed according to ref. [5] which considers only transverse photons but avoids the kinematical approximations of the Weizsäcker–Williams approach. The cross section for $\gamma\gamma \to \rho^0\rho^0$ was expressed as follows [‡1]:

$$\frac{d^5\sigma}{dM_{12}^2\, dM_{34}^2\, d\cos\theta_{12}^H\, d\cos\theta_{34}^H\, d\cos\theta^*} \sim \frac{p^*}{W_{\gamma\gamma}^3}\, \mathrm{BW}(M_{12})\, \mathrm{BW}(M_{34})\, f(\cos\theta^*) \times W(\cos\theta_{12}^H)\, W(\cos\theta_{34}^H)\,,$$

where p^* is the centre of mass momentum of the ρ^0; M_{12}, M_{34} are the $\pi_1^+\pi_2^-$ and $\pi_3^+\pi_4^-$ effective masses; $\theta_{12}^H, \theta_{34}^H$ are the corresponding helicity decay angles (θ^H is the angle between the ρ momentum vector in the $\rho\rho$ rest system and the π^+ momentum vector taken in its ρ rest system); and θ^* is the angle between the ρ and the incoming photon measured in the $\rho\rho$ rest system. The factor $p^*/W_{\gamma\gamma}^3$ accounts for the phase space and the flux factor in the cross section. BW(M) is a Breit–Wigner factor describing the ρ^0,

$$\mathrm{BW}(M) = M_\rho \Gamma / [(M_\rho^2 - M^2)^2 + M_\rho^2\Gamma^2]\,, \qquad (3)$$

where M is the $\pi\pi$ effective mass, and M_ρ the ρ mass, $M_\rho = 776$ MeV/c^2. Γ is the energy dependent ρ width [6],

$$\Gamma = \Gamma_\rho (q/q_\rho)^3 [2q_\rho^2/(q^2 + q_\rho^2)]\,, \qquad (4)$$

where $\Gamma_\rho = 155$ MeV, q is the pion momentum in the $\pi\pi$ rest system, and $q_\rho = q$ for $M = M_\rho$. For the production angular distribution $f(\cos\theta^*)$ we tried reasonable assumptions such as a constant and $1 + \cos^2\theta^*$. For the distribution of the polar helicity decay angle, $W(\cos\theta^H)$, we tried a constant and $\sin^2\theta^H$. The results were insensitive to these assumptions.

The number of $\rho^0\rho^0$ events was determined with a maximum likelihood fit. A sum of noninterfering contributions from $\rho^0\rho^0$ production ($N_{\rho\rho}$) (as described above), ρ^0 + nonresonant $\pi^+\pi^-$ production ($N_{\rho\pi\pi}$), and phase space (N_{PS}) was fitted to the two density distributions $M_{\pi_1^+\pi_2^-}$ versus $M_{\pi_3^+\pi_4^-}$ (fig. 2a) and $M_{\pi^+\pi^+}$ versus $M_{\pi^-\pi^-}$ simultaneously. The fit yielded the number of events shown in table 1 [here we used $f(\cos\theta^*)$ = const. and $W(\cos\theta^H) = \frac{3}{4}\sin^2\theta^H$ in the Monte Carlo program] [‡2].

These results indicate that the four charged pion state results predominantly from the production of $\rho^0\rho^0$ at low $W_{\gamma\gamma}$.

‡1 The average mass squared of the virtual photons was found to be $\langle Q^2 \rangle = 0.05$ GeV^2. In order to determine the cross section for real photons ($Q^2 = 0$) a rho pole form factor, $F = (1 + Q^2/M_\rho^2)^{-1}$, was used in the integration over the photon fluxes. The inclusion of the form factors increased the cross section by ≈10%.

‡2 For footnote see next page.

Table 1

$W_{\gamma\gamma}$ (GeV)	$N_{\rho\rho}$	$N_{\rho\pi\pi}$	N_{PS}	$\sigma(\gamma\gamma \to \rho^0\rho^0)$ (nb)
1.50–1.75	40 ± 6	−6 ± 11	8 ± 8	77 ± 12
1.75–2.0	14 ± 6	−4 ± 12	18 ± 9	35 ± 14
2.0 −2.3	4 ± 3		15 ± 3	10 ± 7

The curves in fig. 2b represent the sum of all fitted contributions and the background of all fitted non-resonant $\pi^+\pi^-$ combinations.

To calculate the cross section from the number of $\rho^0\rho^0$ events we determined the acceptance with the Monte Carlo program mentioned above. Averaged over $1.5 < W_{\gamma\gamma} < 2.3$ GeV the acceptance was found to lie between 5 and 7%. The errors given in table 1 are statistical only. A systematic error of ±25%, mainly due to the uncertainty in the determination of the acceptance, has to be added. The cross-section values are shown in fig. 3a.

The decay and production angular distributions were determined from events with $1.5 < W_{\gamma\gamma} < 2.0$ GeV where one $\pi^+\pi^-$ mass combination and its opposite combination both lie in the ρ^0 mass band (676–876 MeV/c^2). Fig. 3b shows the polar helicity decay-angle distribution $W(\cos\theta^H)$. The curve $\sin^2\theta^H$ given in the figure is expected if the ρ^0 takes the helicity from the incoming (transverse) photon. The production angular distribution of the ρ^0 is shown in fig. 3c.

In the vector meson dominance (VDM) model the channel $\gamma\gamma \to \rho^0\rho^0$ proceeds predominantly via elastic $\rho^0\rho^0$ scattering. The expression for the cross section is given by [7]

$$\frac{d\sigma}{dt}(\gamma\gamma \to \rho^0\rho^0) = \left(\frac{\alpha\pi}{\gamma_\rho^2}\right)^2 \left(\frac{p^*}{k^*}\right)^2 \frac{d\sigma}{dt}(\rho^0\rho^0 \to \rho^0\rho^0) . \quad (5)$$

[‡2] A fit to the *two*-dimensional distribution $M_{\pi_1^+\pi_2^-}$ versus $M_{\pi_3^+\pi_4^-}$ was done to separate $\rho^0\rho^0$ events from a possible contamination by ρ^0 + nonresonant $\pi^+\pi^-$, which cannot be achieved in a fit to the *one*-dimensional distribution $M_{\pi^+\pi^-}$. In the two low $W_{\gamma\gamma}$ intervals which contain most of the 89 events, $N_{\rho\pi\pi}$ is compatible with zero. We repeated the fits with the restriction $N_{\rho\pi\pi} = 0$ and found that $N_{\rho\rho}$ was essentially unchanged (we obtained 38 and 12 events instead of 40 and 14, respectively). Therefore, we set $N_{\rho\pi\pi} = 0$ in the high $W_{\gamma\gamma}$ region, where we have fewer events.

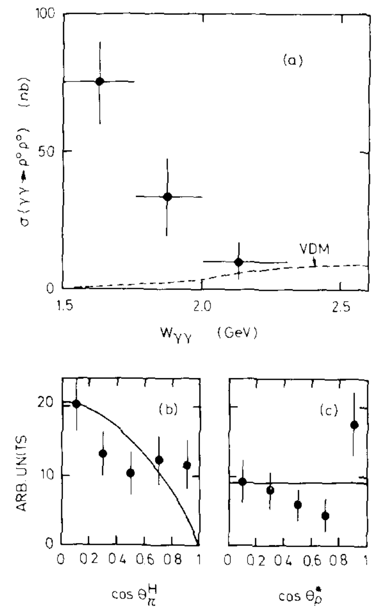

Fig. 3. (a) Cross section for the reaction $\gamma\gamma \to \rho^0\rho^0$. The curve is a prediction of the VDM model described in the text. (b) Acceptance corrected distribution of the polar helicity decay angle compared with $\sin^2\theta^H$. (c) Acceptance corrected distribution of the ρ^0 production angle compared with a constant.

Here k^* is the photon c.m. momentum; t is the square of the four-momentum transfer between the incoming particle and the appropriate outgoing rho; and $\gamma_\rho^2/4\pi$ describes the photon–rho coupling strength, $\gamma_\rho^2/4\pi \approx 0.5$. At high energy the quark model suggests $\sigma(\rho\rho \to \rho\rho) \approx (4/9)^2\,\sigma(pp \to pp)$. Assuming furthermore $d\sigma/dt \sim \exp(At)$ with $A = 5.6\ \mathrm{GeV}^{-2}$ one finds

$$\frac{d\sigma}{dt}(\gamma\gamma \to \rho^0\rho^0) \approx \left(\frac{p^*}{k^*}\right)^2 \cdot 100\exp(5.6t) \quad (\mathrm{nb\ GeV}^{-2}) . \quad (6)$$

We show the integral of this prediction in fig. 3a, even though we expect that it represents the asymptotic (i.e. pomeron) contribution only. It is seen to be far below the observed cross section for $W_{\gamma\gamma} < 2$ GeV. If this simple VDM model is correct at large $W_{\gamma\gamma}$, the substantial discrepancy indicates the presence of a threshold enhancement in the process $\gamma\gamma \to \rho^0\rho^0$.

In summary, the reaction $\gamma\gamma \to \rho^0\rho^0$ has been observed in e^+e^- scattering and its cross section near threshold determined. In this region $\sigma(\gamma\gamma \to \rho^0\rho^0)$ has been found to be an order of magnitude larger than the pomeron contribution predicted by the vector meson dominance model.

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