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# Study of the Reaction $\gamma\gamma \to 2\pi^+ 2\pi^- \pi^0$ and Upper Limits on the Production of $\gamma\gamma \to \omega\omega$ and $\gamma\gamma \to \rho^0\omega$

PLUTO Collaboration

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**Abstract.** A search for the reactions $\gamma\gamma \to \omega\omega$ and $\gamma\gamma \to \rho^0 \omega$ has been carried out at an average $e^+e^-$ CM energy of 34.6 GeV with an integrated luminosity of 45 $\mathrm{pb}^{-1}$. Upper limits are set for these two channels over the $\gamma\gamma$ CM Energy range of 1.6 to 2.5 GeV. The cross section is determined for the exclusive channel $\gamma\gamma \to 2\pi^+ 2\pi^- \pi^0$.

## 1. Introduction

The study of vector meson production in photon-photon collisions has attracted great interest, in part because of the large cross section detected for the channel $\gamma\gamma \to \rho^0 \rho^0$ [1–3]. The cross section measured near threshold for the $\rho^0 \rho^0$ final state is much larger than that predicted by QCD [4] and cannot be accounted for by a simple VDM calculation [1]. Various models have been proposed to explain the behaviour of the $\rho^0 \rho^0$ cross section which also make definite predictions for the production rate of other vector meson final states [5] $\omega\omega$, $\rho^0\omega$, $\rho^+\rho^-$, $\rho^0\varphi$, $\omega\varphi$, and $\varphi\varphi$. It has also been pointed out [6, 7] that the above listed vector meson final states should be studied for the possible existence of the scalar and tensor four-quark states predicted by the MIT-bag model [8].

We have carried out a search for the reactions $\gamma\gamma \to \omega\omega$ and $\gamma\gamma \to \rho^0\omega$ using data taken with the PLUTO detector at PETRA at an average $e^+e^-$ CM energy of 34.6 GeV. The integrated $e^+e^-$ luminosity used in this study is 45 $\mathrm{pb}^{-1}$. The PLUTO detector has been described elsewhere [9], and here we will only briefly list the main components which are relevant to the present study. The central tracking detector consists of 13 layers of proportional chambers inside a 1.65 Tesla magnetic field covering a polar angle range of $|\cos\Theta| < 0.87$. The momentum resolution is $\sigma_p/p = 0.03\,p$ $(\mathrm{GeV})^{-1}$ within $|\cos\Theta| < 0.60$. Neutral particle detection is achieved by an array of lead-scintillator sandwich counters which covers the angular range $|\cos\Theta| < 0.96$. The neutral energy resolution is $\sigma_E/E = 0.35\,\mathrm{GeV}^{1/2}/\sqrt{E}$ for $|\cos\Theta| < 0.64$ and $\sigma_E/E = 0.28\,\mathrm{GeV}^{1/2}/\sqrt{E}$ for $0.64 < |\cos\Theta| < 0.96$. Charged particle tracking in the forward direction, $0.966 < |\cos\Theta| < 0.996$, is accomplished by a magnetic spectrometer with momentum resolution $\sigma_p/p = 0.03\,p$ $(\mathrm{GeV})^{-1}$. An array of electromagnetic shower counters referred to as the Small Angle Tagger (SAT) and Large Angle Tagger (LAT) cover, respectively, the polar angular regions of 23–70 mrad ($\sigma_E/\mathrm{E} = 0.17\,\mathrm{GeV}^{-1/2}/\sqrt{E}$ and 70–260 mrad ($\sigma_E/E = 0.25\,\mathrm{GeV}^{-1/2}/\sqrt{E}$.

Since the final states $\omega\omega$ and $\rho^0\omega$ have rather different topological structures, the data reduction and physics analysis for the two final states were carried out along different lines. The search for the $\omega\omega$ final state is presented in Sect. 2. In Sect. 3 we present results on the 5-pion final state $2\pi^+ 2\pi^- \pi^0$, and set limits on the reaction $\gamma\gamma \to \rho^0\omega$. Selection criteria which are common to all channels are discussed in this section.

We selected events having 4 well reconstructed non-showering (shower energy $< 800$ MeV) charged tracks with total charge equal to zero, and having from one to four neutral clusters. The events were required to have a reconstructed vertex along the $z$-axis close to the nominal bunch-crossing, $z_0$, so that $|z_0 - z| < 30$ mm. A statistical correction for the background arising from beam gas interactions and from other non-beam origin was accomplished by subtracting the number of events found in selected side bands of the $z$-distribution from the sample.

To select a sample of two photon initiated events with both photons nearly on their mass shell (low $Q^2$ between the initial and final state electrons) we required an anti-tag signal – no electrons detected in the forward tagging system, SAT and LAT.

It was demanded that the events have overall balance of transverse momentum, i.e. the vector sum of the transverse momenta of all outgoing particles, charged and neutral, $|\Sigma\,\mathbf{p}_T|$ was restricted to $< 0.5$ GeV/c. A cut on the visible energy (charged and neutral), $W_{\mathrm{vis}} < 7.5$ GeV, was also imposed. These cuts efficiently isolate the 2-photon sample from the one-photon sample.

## 2. The Channel $\gamma\gamma \to \omega\omega$

Since the dominant decay mode of the $\omega$ meson, $\omega \to \pi^+\pi^-\pi^0$, accounts for 89.9% [10] of all the $\omega$ meson decays, we have directed our attention to this decay mode in our search for the $\omega\omega$ final state. The low acceptance of the detector for the complete final state $2\pi^+ 2\pi^- 2\pi^0$ (4 photons) makes it impractical to carry out an exclusive search. We have therefore made a semi-inclusive search for the channel $\gamma\gamma \to \omega + \mathrm{anything}$.

The sample of events having 2 positive tracks, 2 negative tracks and from 1 to 4 neutral clusters with $E_\gamma > 40$ MeV was selected. The topology of this sample of events is compatible with the $\omega\omega$ final state. In order to cut down the dominant background which arises from the $\gamma\gamma \to \rho^0\rho^0$ channel with the addition of accidental hits in the shower counters, the accepted events were required to satisfy the condition $|\Sigma\,\mathbf{p}_T|_{\mathrm{total}} < |\Sigma\,\mathbf{p}_T|_{\mathrm{charged}}$. That is, the transverse momentum imbalance for the total event including the neutral clusters is to be smaller than the imbalance when summing only over the charged tracks. Whereas the selected sample of events shows a clear $\rho^0$ signal before implementing this condition, no $\rho^0$ signal is seen in the sample of 1288 events surviving this condition.

To maximize the $\omega$-meson signal we have taken the approach previously used by the CELLO Collaboration in their study of the $A_2$ meson [11], in which the $\omega$-meson is reconstructed using only 1 photon. We have studied the system $\pi^+ \pi^- \gamma$ where we approximate the $\pi^0$ by one energetic photon ($E_\gamma > 135$ MeV) which carries most of the energy and retains well the direction of its parent $\pi^0$.

In order to investigate the sensitivity of observing an $\omega$-signal, the reconstruction procedure was applied to a Monte Carlo sample, which was passed through the detector simulator and pattern recognition routines. A clear $\omega$-mass peak, the central value of which is shifted down by $\simeq 30$ MeV, is seen as shown in Fig. 1b. For this Monte Carlo study the $\omega$-mesons were produced isotropically in the $\gamma\gamma$ CM system, and each $\omega$-meson was allowed to decay isotropically into 3 pions. If the generated $\omega$-mesons are weighted by a factor $\exp(-5p_T^2)$ the detector acceptance deteriorates by about 10%. The position and shape of the $\omega$ signal are insensitive to this and other details of the production. A background subtraction has been accomplished by taking the sample of like-charged mass combinations $\pi^\pm \pi^\pm \gamma$, and after an appropriate normalization subtracting it from the $\pi^+ \pi^- \gamma$ sample.

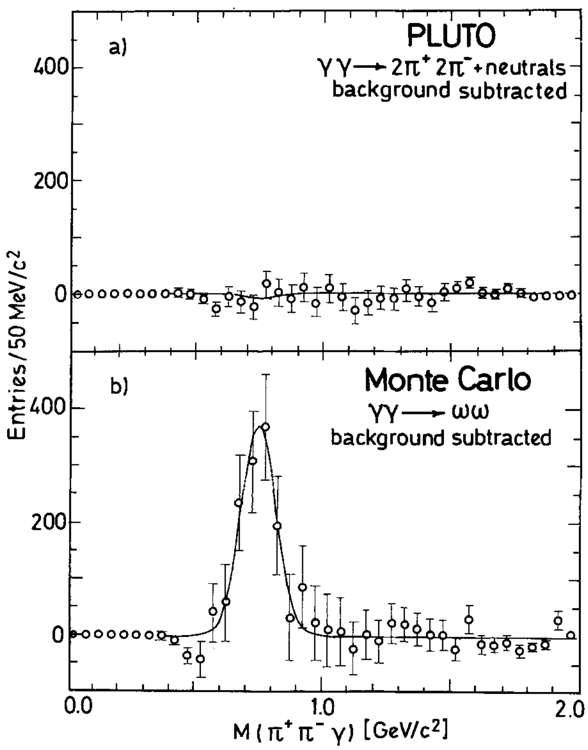


**Fig. 1a and b.** The $M(\pi^+\pi^-\gamma)$ distribution from the channel $\gamma\gamma \to 2\pi^+ 2\pi^- +$Neutrals. The like-charged $M(\pi^\pm \pi^\pm \gamma)$ distribution normalized to the region outside the $\omega$ signal was subtracted from **a** the data, and **b** the Monte Carlo sample normalized to the data luminosity

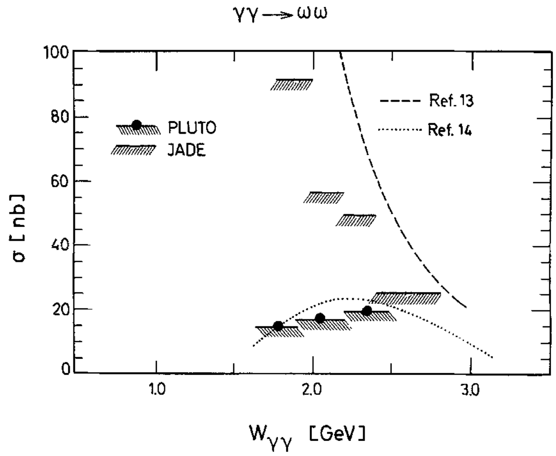


**Fig. 2.** Upper limits at 95% confidence level for the channel $\gamma\gamma \to \omega\omega$. Predictions of a factorization model, [13, 14], are shown

The data, which have been treated identically to the Monte Carlo events, are shown in Fig. 1a. The data do not show any evidence for the channel $\gamma\gamma \to \omega\omega$. Upper limits at the 95% confidence level have been calculated and these are shown in Fig. 2 along with upper limits from the JADE Collaboration [12]. A systematic error of 10% was added in quadrature to the upper limits in order to account for the sensitivity of the acceptance to the different Monte Carlo generators used. In the same figure are shown the predictions of Alexander et al. [13, 14] which are based on a factorization procedure using photoproduction data. This factorization procedure is sensitive to the input data used and the more recent predictions use more reliable data. Our results are inconsistent with the predictions of [13] but are consistent with those of [14].

## 3. The Channel $\gamma\gamma \to 2\pi^+ 2\pi^- \pi^0$

A sample of 896 events was observed having the topology $\gamma\gamma \to 4$ charged prongs and 2 neutral clusters. The energy of each neutral cluster, which is assumed to originate from a single photon, is required to be at least 100 MeV. The four charged prongs are assigned the pion mass and are required to have total charge equal to zero.

To reduce this sample of events to a sample of exclusive events of the type $\gamma\gamma \to 2\pi^+ 2\pi^- \pi^0$ we have made use of the constraints arising from momentum balance in the plane transverse to the beam axis, the $R-\Phi$ plane. A measure which can be used to check this momentum balance is the collinearity in this plane of the momentum of the charged pion system and the momentum of the system of the 2 neutral clusters. At the same time, this collinearity check constitutes an efficient technique for the removal of a major source of background coming from the channel $\gamma\gamma \to \rho^0 \rho^0 \to 2\pi^+ 2\pi^-$ which together with 2 accidental hits in the shower counters simulates a $\gamma\gamma \to 2\pi^+ 2\pi^- \gamma\gamma$ event.

The distribution of the collinearity check does show a pronounced accumulation of events which are nearly collinear. We have selected for further consideration those events which deviate from collinearity by at most 300 mrad, yielding 296 events.

We have taken advantage of the better momentum resolution of our detector for charged tracks as compared to photons in order to improve the energy determination of the latter. The 2 constraints arising from momentum conservation in the $R-\Phi$ plane were utilized in order to scale the neutral clusters' energies. After this scaling we obtain the $M(\gamma\gamma)$ distribution shown in Fig. 3 which exhibits a prominent $\pi^0$-signal.

A further improvement of the signal to noise ratio was achieved by exploiting the kinematics of the decay of a spin zero particle to 2 photons. Such a decay gives rise to a laboratory opening angle distribution which depends only on the velocity ($\beta$) of the decaying particle and is sharply peaked about its minimum value. It turns out that, in general, the imposition of an opening angle cut can effectively reduce accidental and combinatorial background [15]. This cut, which is $\beta$-dependent, is applied event by event. Since the opening angle distribution at fixed $\beta$ is independent of the mass of the decaying particle, this procedure introduces no bias in the $M(\gamma\gamma)$ distribution. An opening angle cut corresponding to the acceptance of 60% of all the decays was applied to the data and the resultant $M(\gamma\gamma)$ distribution is given by the shaded histogram in Fig. 3.

The $M(\gamma\gamma)$ distribution was fitted to a Gaussian function with central mass fixed at the $\pi^0$ mass and a polynomial background. A good fit of $\chi^2/n_D = 0.92$ was obtained which yielded $52 \pm 8$ $\pi^0$ events and a full width of 57 MeV for the $\pi^0$ signal. The acceptance of the PLUTO detector for the $5\pi$ final state was found to vary from 0.4% for the $W_{\gamma\gamma}$ range 1.5–2.0 GeV to 1.3% for the $W_{\gamma\gamma}$ range 3.5–4.0 GeV.

We have studied possible background contamination of the $5\pi$ final state coming from a higher multiplicity channel, e.g. $\gamma\gamma \to 2\pi^+ 2\pi^- 2\pi^0$ where 2 out of the 4 photons escaped detection. A sample of $\gamma\gamma \to 2\pi^+ 2\pi^- 2\pi^0$ Monte Carlo events was generated and after passing through the PLUTO detector simulation program was analyzed in the same way as the data. This study showed that the $5\pi$ final state sample contains at most a 2% contamination stemming from the $6\pi$ final state, if it is assumed that the cross sections $\sigma(\gamma\gamma \to 6\pi)$ and $\sigma(\gamma\gamma \to 5\pi)$ are equal. Background contamination from higher multiplicity channels should obviously be much less. The cross section for the reaction $\gamma\gamma \to 2\pi^+ 2\pi^- 2\pi^0$ corrected for acceptance is shown in Fig. 4.

A study of the $5\pi$ exclusive final state reveals no $\rho^0$ or $\omega$ meson signal. In particular, the presence of the $\gamma\gamma \to \rho^0 \omega$ channel was thoroughly searched for but with negative results. The $\pi^+ \pi^- \pi^0$ mass system recoiling against the dipion system $\pi^+ \pi^-$ where the

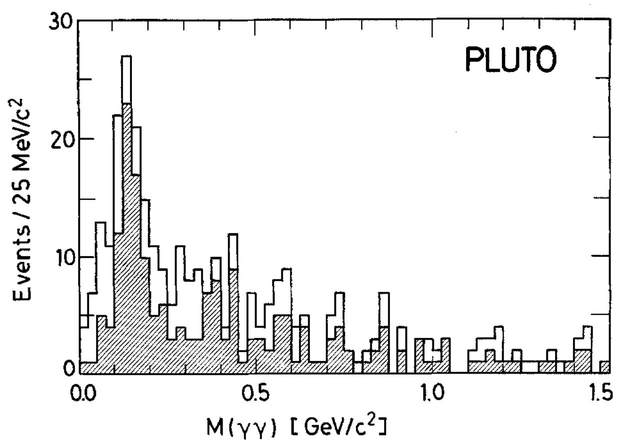


**Fig. 3.** The final state $M(\gamma\gamma)$ distribution from the channel $\gamma\gamma \to 2\pi^+ 2\pi^- \gamma\gamma$. The shaded area is the resulting sample after imposition of an opening angle cut

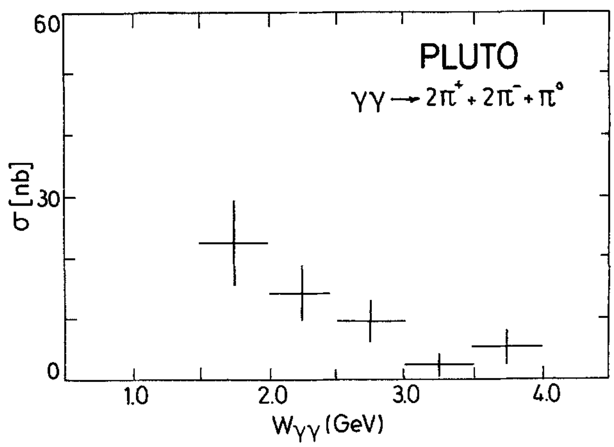


**Fig. 4.** The total cross section for $\gamma\gamma \to 2\pi^+ 2\pi^- \pi^0$ as a function of $W_{\gamma\gamma}$

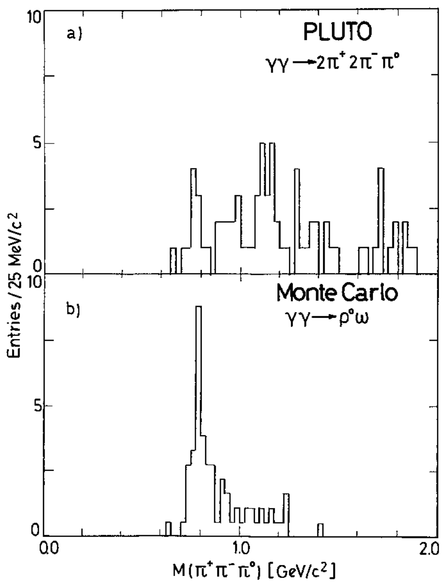


**Fig. 5a and b.** The $M(\pi^+\pi^-\pi^0)$ distribution for channel $\gamma\gamma \to 2\pi^+ 2\pi^- \pi^0$, where the recoiling dipion system satisfies $576 < M(\pi^+\pi^-) < 976$ MeV/c$^2$, for **a** the data and **b** the Monte Carlo sample normalized to the data luminosity

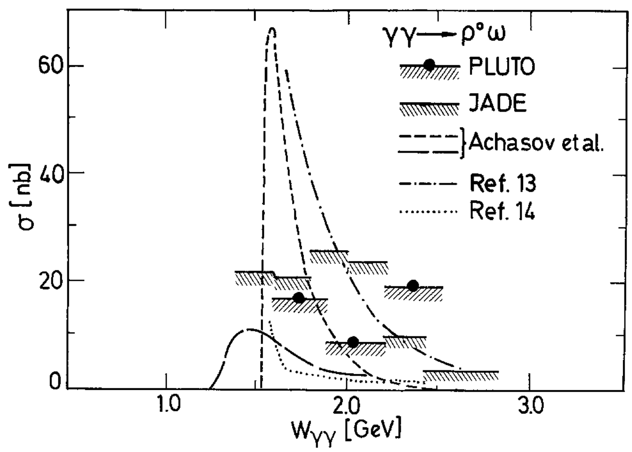


**Fig. 6.** Upper limits at 95% confidence level for the channel $\gamma\gamma \to \rho^0\omega$. The predictions of [13] (—·—·—) and [14] (......) and two extreme predictions of Achasov et al., $m=1.65$, $a_0=0.0$ (------) and $m=1.4$, $a_0=0.5$ (— —) are shown

dipion system is restricted to the $\rho^0$ meson mass range 576–976 MeV is shown in Fig. 5a.

Monte Carlo studies were carried out to determine the acceptance of the PLUTO detector to the $\rho^0\omega$ final state. The generation of the sample of Monte Carlo events was done first assuming an isotropic production of the final state mesons in the $\gamma\gamma$ CM system and their subsequent isotropic decay into pions. A second Monte Carlo study was done in which the final state vector mesons were generated and weighted by the peripheral factor of $\exp(-5p_T^2)$ As in the case of the Monte Carlo study of the $\omega\omega$ final state, the acceptance was found to be higher by $\sim 10\%$ for the isotropically generated sample of events. We have added in quadrature a systematic error of 10% to the upper limits calculated for this channel in order to account for the uncertainty of the Monte Carlo generation. The shape of the expected distribution of the $\pi^+\pi^-\pi^0$ mass system recoiling against the dipion mass system in the $\rho^0$ mass band is shown in Fig. 5b.

Upper limits at 95% confidence level were determined for the $\gamma\gamma \to \rho^0\omega$ channel, and are displayed along with those of the JADE Collaboration [12] in Fig. 6.

The model of Achasov et al. [6] based on the production of $q^2\bar{q}^2$ resonances makes predictions for the production of the $\rho^0\omega$ final state. These predictions are, however, strongly dependent on the assumed mass of the exotic resonance and a parameter $a_0$. We have displayed 2 extreme predictions given by Achasov et al. [16] in Fig. 6. As is evident from the figure, the freedom given by these 2 parameters leaves their model consistent with the established upper limits. The predictions of [14] are consistent with our data.

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