Two–Photon Production of ω Pairs

Abstract

A maximum likelihood analysis of ARGUS data on two–photon production of $\pi^+\pi^+\pi^0\pi^0\pi^-\pi^-$ is presented. A small fraction of events is due to the production of omega pairs. The $\gamma\gamma \to \omega\omega$ cross section has its maximum value close to threshold.

Measurement of two–photon production of pairs of vector mesons is a direct test of vector dominance models. On the other hand, it is a unique way to study possible $qq\bar{q}\bar{q}$ states. It has been suggested [1, 2] that the analyses of $\gamma\gamma \to \rho\rho$ cross sections [1, 2, 3] indicate a possible interference between isospin 0 and isospin 2 states, both positioned close to the reaction threshold. It would, therefore, be interesting to see whether a similar enhancement takes place in the reaction $\gamma\gamma \to \omega\omega$ where only isospin 0 intermediate states are possible.

An observation of the reaction $\gamma\gamma \to \omega\omega$ was reported earlier [4] by ARGUS. However, due to poor statistics no definite conclusion about the energy distribution of the reaction cross section for $\gamma\gamma \to \omega\omega$ could be obtained. The present analysis is based on a larger data sample and on a careful event selection that permitted the use of a maximum likelihood method.

The data sample presented in this paper corresponds to an integrated luminosity of 455 pb^{-1}. The data were collected using the ARGUS detector at the e^+e^- storage ring DORIS II operating at beam energies between 4.7 and 5.3 GeV. The ARGUS detector, its trigger and its particle identification system are described elsewhere [5].

The two–photon production of $\pi^+\pi^+\pi^0\pi^0\pi^-\pi^-$ was measured with photons generated from the reaction $e^+e^- \to e^+e^-\gamma\gamma$. The final state electrons scatter dominantly close to the beam direction and escape detection. Therefore, six pions were required in the final state.

Several selection criteria had to be applied to the measured events. Two positively and two negatively charged tracks were required to originate from a common event vertex at the interaction point. The charge tracks had to be consistent with the pion mass hypothesis, by requiring the combined likelihood ratio from specific ionisation and time-of-flight measurements to exceed 1%. Knowing the smallness of the $\gamma\gamma \to \omega\omega$ cross section, it is essential that in the process of selection as few as possible six–pion events are lost. Therefore, the following selection procedure for neutral pions was adopted. Neutral pions were reconstructed from their decay photons requiring the invariant mass $m_{\gamma\gamma}$ to be between 80 and 200 MeV/c^2. Photons were identified by their energy deposition in those isolated calorimeter clusters that were not associated with tracks of charged particles. There are two major cases in which calorimeter signals can be misidentified as photons. Firstly, it happens that a shower resulting from an impact of a charged particles appears in the calorimeter as two separated clusters. It is then misinterpreted as being due to hits of a charged particle and a photon. Such signals are characterized by the small angle $\theta_{\gamma p}$ between the photon momentum and the line connecting the common event vertex with the impact point of the charged particle in the calorimeter. Secondly, there are signals that are generated

by the calorimeter noise. They mostly correspond to photon energies $E_\gamma < 80$ MeV. In order not to lose potential six–pion events, photon candidates were divided in two classes. The first class consisted of well isolated shower clusters with $\cos\theta_{\gamma p} < 0.9$ and $E_\gamma > 80$ MeV. All other shower clusters corresponding to $E_\gamma > 30$ MeV represented the second class. Clearly, most fake photons are likely to be found in the second class. The following algorithm was applied for combining photons into neutral pions. At least four photons were required for each event: not more than four had to belong to the first class while the number of second class photons was unlimited. At least one $\pi^0\pi^0$ combination was required. The combination that did not include all first class photons was discarded. In case of more than one combination in the event, the combination with the smallest sum of $\chi^2 = \frac{(m_{\gamma\gamma}-m_{\pi^0})^2}{\Delta m^2_{\gamma\gamma}}$ was accepted, where $\Delta m_{\gamma\gamma}$ is the error on $m_{\gamma\gamma}$ resulting from the measurement of photon energies. Monte Carlo studies show that this procedure ensures that more than 85 % of π^0 mesons are correctly reconstructed. Finally, a constraint fit to m_{π^0}, the table value of the pion mass, was performed on the accepted π^0 candidates.

A cut on the total transverse momentum, $|\sum_i \vec{p}_{T,i}|^2 = 0.020$ MeV^2/c^2, was applied to enhance the interactions induced by a pair of almost real photons. The same cut also suppresses background, such as τ decays and incompletely reconstructed two–photon events. The invariant mass distribution of the accepted events is shown in fig. 1.

The background contribution was obtained from a Monte Carlo simulation of two-photon reactions, tau pair production and reactions $e^+e^- \rightarrow hadrons$ based on their measured cross sections. The main source of background to the selected sample of 3163 events in the invariant mass region between 1.6 and 3.0 GeV/c^2 is the reaction $\gamma\gamma \rightarrow \pi^+\pi^+\pi^0\pi^-\pi^-$ (with fake signals from shower counters contributing the missing π^0). It amounts to 212 events as obtained from Monte Carlo simulation using the known $\gamma\gamma \rightarrow \pi^+\pi^+\pi^0\pi^-\pi^-$ cross section [6]. The background contribution from the reaction $\pi^+\pi^+\pi^0\pi^0\pi^0\pi^-\pi^-$ is found to be almost negligible due to the smallness of the reaction cross section which was estimated from the ARGUS data. The total background contamination amounts to 273 events (fig. 1).

A prominent ω peak is seen in the invariant mass spectrum (fig. 2a) of the three–pion combination which recoils against an ω meson candidate (732 - 832 MeV). A rough estimate of the number of $\omega\omega$ events can be made by comparing the mass spectrum (fig. 2b) of three pions which recoil against three–pion combinations having an invariant mass within the sidebands of the ω meson (682 - 732 MeV and 832 - 882 MeV). It is seen that only a few ω events are left. Keeping in mind that $\omega\omega$ events are counted approximately twice in the ω peak of fig. 2a, one obtains that roughly 100 events correspond to $\omega\omega$ formation.

In contrary to the $\pi^+\pi^0\pi^-$ invariant mass spectrum, two-pion mass spectra do not show prominent structures. From the $\pi^+\pi^-$ invariant mass spectrum we find that in average there are about 0.15 ρ^0 mesons per event. The contribution of $\rho^\pm$ to the $\pi^\pm\pi^0$ spectrum is almost negligible. Due to a small number of observed ρ mesons, we feel justified not to include the waves containing ρ mesons in the analysis. Monte Carlo studies show that the waves $\rho^0\pi^+\pi^-\pi^0\pi^0$ and $\rho^0\rho^0\pi^0\pi^0$ are absorbed by the non–resonant six-pion state leaving $\omega\omega$ contribution unaffected. The total number of events that belongs to the $\omega\omega$ final state as found by this analysis is only about 90 and does not allow a partial wave analysis. This number is in good agreement with

the estimation obtained by comparing distributions 2a and 2b. Therefore, the final states were divided into three groups: $\omega\omega$, $\omega\pi^+\pi^0\pi^-$ and a non–resonant six-pion state. The ω mesons were identified by their invariant mass distribution. Apart from a Breit–Wigner form of mass distribution for ω mesons the final state particles were approximated by a phase space distribution.

The maximum likelihood method was used to determine the production cross sections for the three groups. Each group k is characterized by its decay matrix element D_k:

$$\begin{aligned} D_{\omega\omega} &= C_1 \left(\mathcal{A}^{\omega}_{BW}\mathcal{A}^{\omega}_{BW}\right)_{\pi_1^+\pi_2^+\pi_3^0\pi_4^0\pi_5^-\pi_6^-} + \text{permutations} \\ D_{\omega\pi^+\pi^0\pi^-} &= C_2 \left(\mathcal{A}^{\omega}_{BW}\right)_{\pi_1^+\pi_2^+\pi_3^0\pi_4^0\pi_5^-\pi_6^-} + \text{permutations} \\ D_{\pi^+\pi^+\pi^0\pi^0\pi^-\pi^-} &= C_3, \end{aligned}$$

where C_1, C_2 and C_3 are normalization constants and $\mathcal{A}^{\omega}_{BW}$ is the Breit–Wigner amplitude for ω convoluted with the experimental resolution. The permutations between like sign pions in the above expressions take care of the symmetry of matrix elements. The analysis is done for each final–state invariant mass bin of 200 MeV/c^2 width independently. It consists of finding the maximum of the logarithm of the probability function

$$\ln L(\vec{\lambda}) = \sum_{i=1}^{N}\left(\sum_{k=1}^{3}\lambda_k^2\,\frac{|D_k|^2}{\eta_k}\right) - N\sum_{k=1}^{3}\lambda_k^2$$

by varying the fraction λ_k^2 of measured events belonging to a particular group k of final states. The first summation runs over all selected events N in the chosen invariant mass bin. The second term in the above formula constrains the sum of λ_k^2 to 1. A Monte Carlo simulation was performed to determine the acceptance values η_k. A more detailed description of the method of analysis is available elsewhere [2].

The background events obtained from the simulation were subject to the same maximum likelihood fit as the measured data in order to determine the contribution of background to various cross sections. The resulting cross sections with background subtracted are presented in fig. 3 and table 1.

The cross sections are subject to an overall systematic error of about 26%. The most important contribution to the systematic error comes from the unknown partial wave composition of the $\gamma\gamma \rightarrow \omega\omega$ cross section. It was estimated to 25 % using Monte Carlo simulation. Other sources of systematic error are detector ($\approx$ 6%) and trigger simulation ($\approx$ 5%), luminosity measurement (1.8%) and event generation (1%).

The maximum likelihood method was tested with a sample obtained with Monte Carlo simulation. It had the same composition as the one obtained for the measured data sample. The results of the fit are in good agreement with the composition of the input sample. As an example of a check of reliability, figure 2 shows a comparison of fit results to the measured invariant mass distribution of the $\pi^+\pi^0\pi^-$ system recoiling against an ω meson candidate. Here, ω candidates were taken as those $\pi^+\pi^0\pi^-$ combinations whose invariant masses differed from the ω table mass value for less than 50 MeV/c^2.

We summarize the results of the analysis of two–photon production of $\pi^+\pi^+\pi^0\pi^0\pi^-\pi^-$ as follows. About 3% of the total integrated $\gamma\gamma \rightarrow \pi^+\pi^+\pi^0\pi^0\pi^-\pi^-$ cross section in the mass region between 1.6 and 3 GeV/c^2 is

due to the production of omega pairs. The cross section integrated over $W_{\gamma\gamma}$ for the reaction $\gamma\gamma \rightarrow \omega\omega$ amounts to 2 nbGeV representing about 5% of the corresponding $\gamma\gamma \rightarrow \rho^0\rho^0$ cross section [1, 2]. It is interesting to note that the cross section for reaction $\gamma\gamma \rightarrow \omega\omega$ has its maximum close to the interaction threshold, an effect that was previously observed in the reaction $\gamma\gamma \rightarrow \rho^0\rho^0$.

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$W_{\gamma\gamma}$ [GeV/c^2]	$\omega\omega$	$\omega\pi^+\pi^0\pi^-$	$\pi^+\pi^+\pi^0\pi^0\pi^-\pi^-$
1.6 - 1.8	$4.3 \pm 1.1 \pm 1.0$	$5.7 \pm 1.3 \pm 2.3$	$11.5 \pm 1.7 \pm 3.1$
1.8 - 2.0	$4.0 \pm 1.5 \pm 1.0$	$18.3 \pm 3.2 \pm 5.0$	$20.5 \pm 3.0 \pm 6.3$
2.0 - 2.2	$1.9 \pm 1.0 \pm 0.5$	$19.9 \pm 3.3 \pm 6.2$	$28.5 \pm 3.3 \pm 8.1$
2.2 - 2.4	$-1.8 \pm 0.5 \pm 0.1$	$16.0 \pm 2.9 \pm 4.1$	$41.6 \pm 3.9 \pm 12.1$
2.4 - 2.6	$0.3 \pm 0.6 \pm 0.2$	$14.5 \pm 2.8 \pm 4.3$	$43.1 \pm 3.9 \pm 11.8$
2.6 - 2.8	$0.1 \pm 0.4 \pm 0.0$	$8.3 \pm 2.5 \pm 2.7$	$43.5 \pm 4.1 \pm 12.2$
2.8 - 3.0	$0.5 \pm 0.4 \pm 0.1$	$10.1 \pm 2.4 \pm 3.0$	$40.8 \pm 3.9 \pm 11.3$

Table 1: Cross sections (in nanobarns) for the waves $\omega\omega$, $\omega\pi^+\pi^0\pi^-$ and non–resonant $\pi^+\pi^+\pi^0\pi^0\pi^-\pi^-$ assuming isotropical production.

Figure Captions

Fig. 1 Invariant mass distribution of accepted $\gamma\gamma \to \pi^+\pi^+\pi^0\pi^0\pi^-\pi^-$ events. Dashed histogram represents the estimated background for this data sample.

Fig. 2 Distribution of the $\pi^+\pi^0\pi^-$ invariant mass recoiling against
a) an ω meson candidate (732 - 832 MeV)
b) $\pi^+\pi^0\pi^-$ combination having invariant mass in the ω sideband region (682 - 732 MeV and 832 - 882 MeV).
The fit results (full histogram) are compared with the data (crosses).

Fig. 3 Cross sections for the waves $\omega\omega$, $\omega\pi^+\pi^0\pi^-$ and non–resonant $\pi^+\pi^+\pi^0\pi^0\pi^-\pi^-$ assuming isotropical production. Only statistical errors are plotted. The systematical error is estimated to 26%.

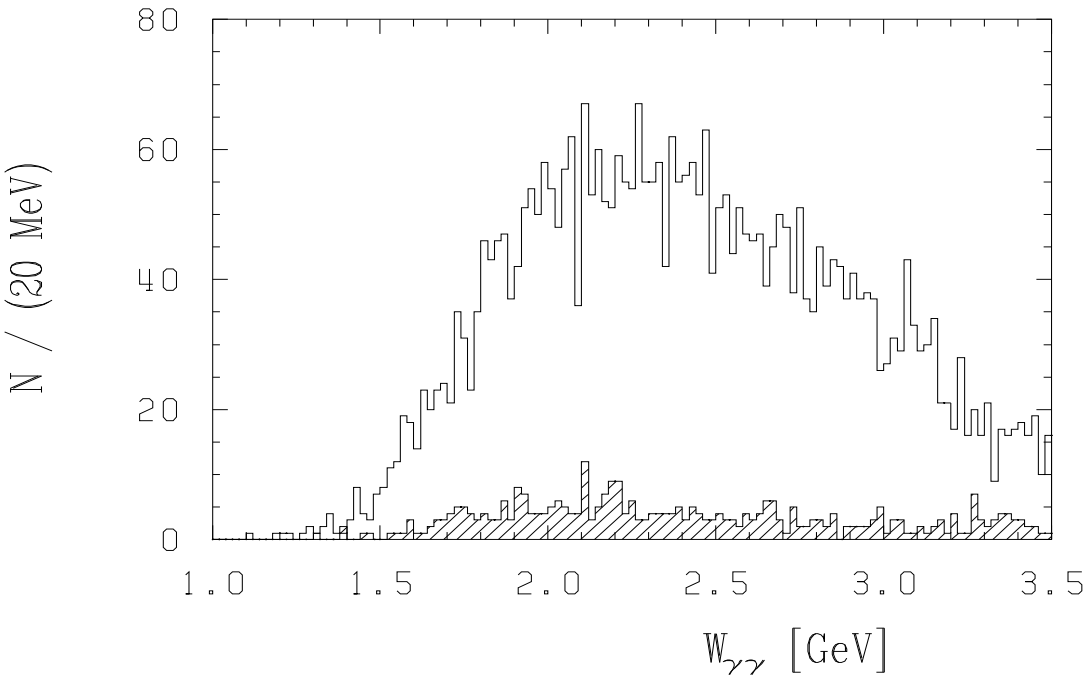

Figure 1:

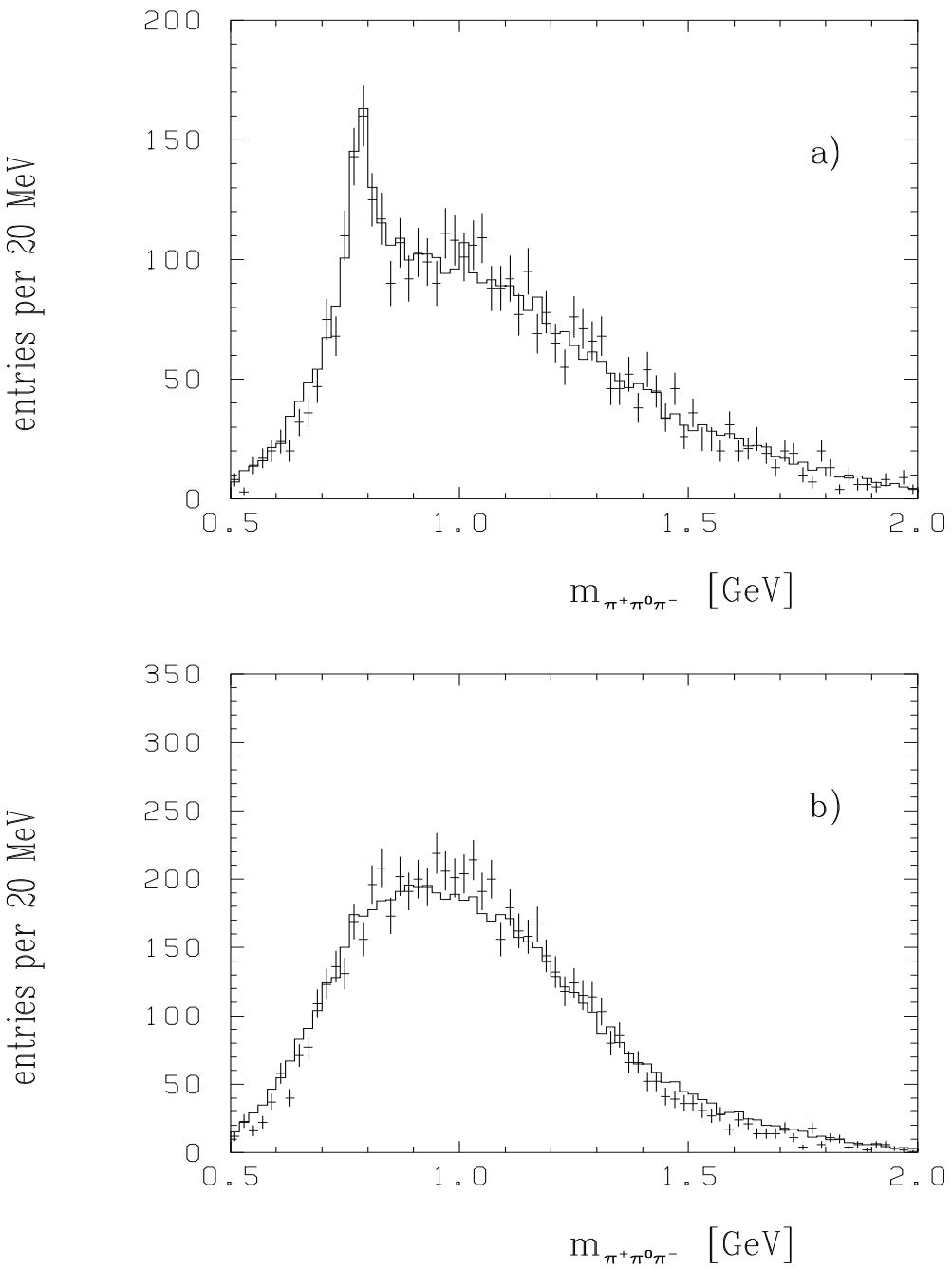
entries per 20 MeV
200
150
100
50
0
0.5
1.0
1.5
2.0
a)
$m_{\pi^+\pi^0\pi^-}$ [GeV]
entries per 20 MeV
350
300
250
200
150
100
50
0
0.5
1.0
1.5
2.0
b)
$m_{\pi^+\pi^0\pi^-}$ [GeV]

Figure 2:

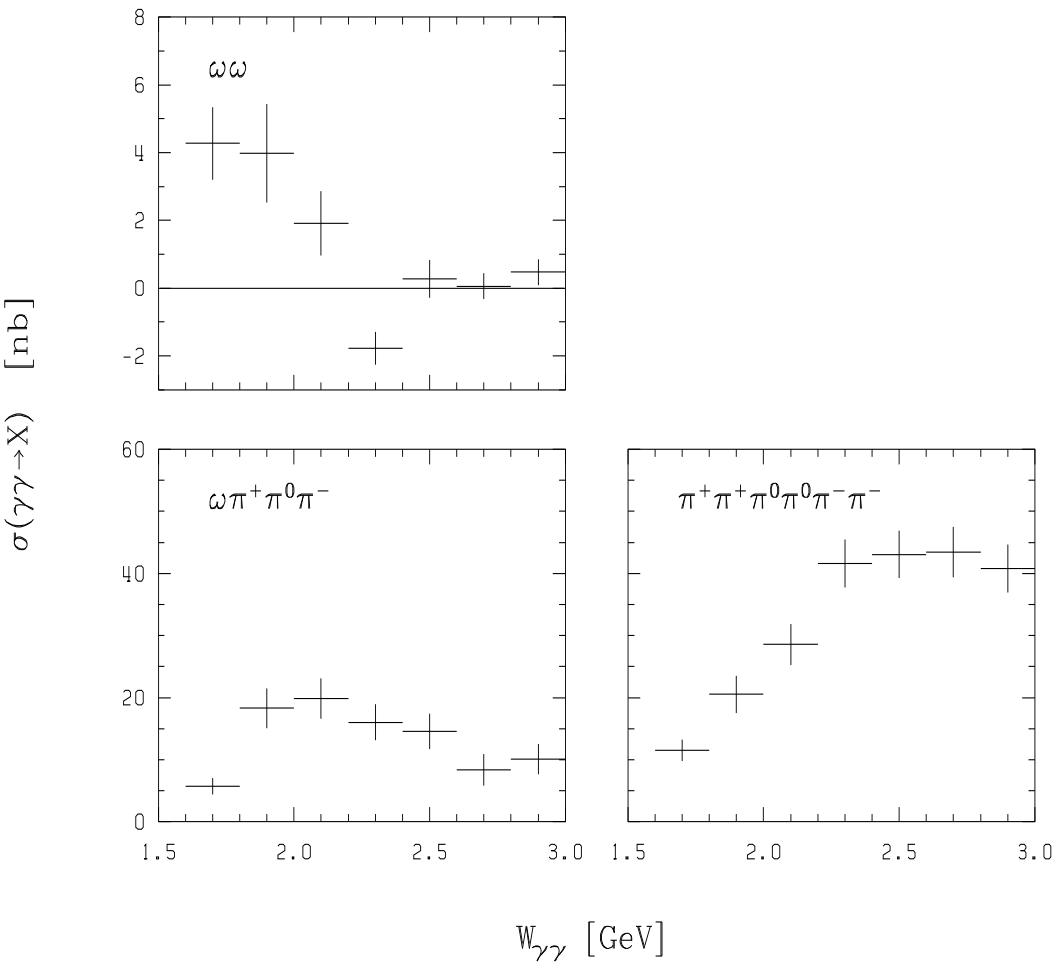

Figure 3: