Observation of $\gamma\gamma \to \phi\rho^0$ and $\gamma\gamma \to \phi\omega$

The ARGUS Collaboration

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Abstract

Two-photon production of the hadronic final states $K^+K^-\pi^+\pi^-$ and $K^+K^-\pi^+\pi^0\pi^-$ has been studied using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY. The cross sections of the reactions $\gamma\gamma \to \phi\rho^0$ and $\gamma\gamma \to \phi\omega$ have been measured for the first time. In addition, angular distributions have been determined for the reaction $\gamma\gamma \to \phi\rho^0 \to K^+K^-\pi^+\pi^-$.

Two-photon production of vector mesons pairs, $\gamma\gamma \to V_1V_2$ (V_1, V_2 vector mesons), has been extensively studied by several electron-positron colliders [1]. One of the most interesting experimental observation was the large $\gamma\gamma \to \rho^0\rho^0$ cross section near threshold which exceeds the cross section for $\gamma\gamma \to \rho^+\rho^-$ by more than a factor of 4 [2, 3, 4]. There are several interpretations of this particular observation, either based on conventional interaction mechanisms or requiring $qq\bar{q}\bar{q}$ intermediate states [5, 6]. Each of the respective models leads to predictions for other $\gamma\gamma \to V_1V_2$ processes. For $\phi\rho^0$ and $\phi\omega$ production that are reported in this paper, the $qq\bar{q}\bar{q}$ models [5] predict cross sections of about 60 nb and 7 nb, respectively. The factorization model [6] predicts for $\phi\rho^0$ production a cross section of 0.5 nb. For both reactions, $\gamma\gamma \to \phi\rho^0$ and $\gamma\gamma \to \phi\omega$, only the upper limits had been set by previous experiments [7, 8].

The study was carried out using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY. The data correspond to an integrated luminosity of 472.7 pb^{-1} collected at beam energies between 4.7 and 5.3 GeV The ARGUS detector, its trigger and its particle identification system are described elsewhere [9].

We have analyzed the reactions

$$e^+e^- \to e^+e^-\phi\rho^0 \to e^+e^-K^+K^-\pi^+\pi^- \tag{1}$$

$$e^+e^- \to e^+e^-\phi\omega \to e^+e^-K^+K^-\pi^+\pi^0\pi^- \tag{2}$$

where the hadronic final states are assumed to be produced via two-photon exchange. Candidate events for the reactions (1) and (2) were selected by requiring four charged particles with zero net charge originating from a common event vertex at the interaction point. In interactions of two almost real photons electron and positron scatter mainly in the beam pipe and escape detection (no-tag). Pions and kaons had to be consistent with the corresponding mass hypothesis, by requiring the combined likelihood ratio from specific ionization and time-of-flight measurements to exceed 1%. On the other hand, the likelihood for being electrons or muons [9] had to be less than 10%. Photons are identified by clusters in the calorimeter not associated with the charged tracks. Their minimum energy ranges between 50 MeV and 110 MeV depending on the noise level in the calorimeter modules. These levels were obtained from randomly measured events where no photons are expected. All events that contained secondary vertices corresponding to K^0_s or Λ decays were rejected. Converted photons were allowed only if they could be associated with the decay of a neutral pion. A neutral pion was identified with a photon pair with an invariant

mass less than 75 MeV/c^2 off the nominal mass. This cut was somewhat tighter, 50 MeV/c^2, in case one of the photons was reconstructed from an e^+e^- pair. Beside photons from the π^0, no additional hits were allowed in the calorimeter unless they pointed to the modules that in a certain period almost constantly produced a signal. Also photons near the impact point position of charged particles in the calorimeter ($cos\,\theta_{\gamma p} > 0.8$) are treated as fake.

A cut on the total transverse momentum, $|\sum_i \vec{p}_{T,i}| < 100$ MeV/c, was applied to enhance the photon-photon interactions and suppress τ decays and incompletely reconstructed two–photon events. In the case of reaction (2) the total transverse momentum of the four charged particles was in addition required to exceed 20 MeV/c. This criterion was introduced in order to suppress background from two-photon reactions with only four charged particles in the final state combined with noise hits in the calorimeter.

To determine the acceptance, two-photon interactions were generated according to the exact QED expression for the flux of transverse photons [10] including ρ pole form factors. Isotropic phase space was used to simulate the final states of both reactions (1) and (2). The relativistic Breit-Wigner shaped mass distributions [4] with parameters of ref. [11] were used to describe the decays of vector-mesons $\phi \to K^+K^-$, $\rho^0 \to \pi^+\pi^-$, and $\omega \to \pi^+\pi^0\pi^-$. Each Monte Carlo data set was generated with a beam energy distribution identical with that of the data. The generated events were passed through a full detector [12] and trigger simulation before being subjected to the same selection criteria as the data. Noise in the calorimeter was included in the simulated data by adding calorimeter hits from measured cosmic ray events where no real photons were expected.

For the selected $\gamma\gamma \to K^+K^-\pi^+\pi^-$ events an enhancement is seen in the $\phi\rho$ region of the scatter plot of K^+K^- versus $\pi^+\pi^-$ invariant masses (fig. 1a). Due to a very good kaon-pion separation in the relevant momentum range no double counting was found. To further select events corresponding to the reaction $\gamma\gamma \to \phi\rho^0$ we first identified the ϕ mesons by requiring their invariant mass to differ from the nominal one by less then 12 MeV/c^2. This difference corresponds to three times the standard deviation of the simulated ϕ mass distribution (fig. 1b). The events that satisfy the above selection criteria show for the distribution over the invariant mass of two pions a clear signal in the ρ^0 region (fig. 1c). Since ρ^0 is a broad resonance, its mass distribution depends on the invariant mass $W_{\gamma\gamma}$ of the $\phi\rho$ system. This dependence is particularly strong at the $\phi\rho^0$ threshold where the $\pi^+\pi^-$ invariant mass shifts to values below the ρ^0 nominal mass. Therefore, a cut on the ρ mass has to depend on $W_{\gamma\gamma}$. Using the simulation of the reaction $\gamma\gamma \to \phi\rho^0$ the cut was defined in the following way: for each interval in $W_{\gamma\gamma}$ only 10% of the simulated events are allowed to lie outside the ρ^0 band, i.e. 5% above and 5% below the ρ^0 region. The obtained area is marked in fig. 1d where a two-dimensional distribution of measured $\pi^+\pi^-K^+K^-$ events satisfying the ϕ mass requirement ($m_\phi \pm 12$ MeV/c^2) is plotted. Events within this area are treated as $\phi\rho^0$ events.

The total number of measured events that fulfil the selection criteria for $\gamma\gamma \to \phi\rho^0$

is 33 [13]. To find the contribution of other processes we simulated all measured two-photon interactions with four charge tracks in the final state and the production of tau-pairs and hadrons from e^+e^- annihilation. Scaling the distribution of these events to the $\phi\rho^0$ sidebands in the plane of K^+K^- and $\pi^+\pi^-$ invariant masses (outside $|m_{KK} - m_\phi| < 12$ MeV/c$^2 \wedge m_{\pi\pi} < 1$ GeV/c^2), we found that 5.3$\pm$1.0 of all selected events do not come from the process $\gamma\gamma \to \phi\rho^0$. This background is dominated by two-photon production of $K^+K^-\pi^+\pi^-$ not proceeding via the $\phi\rho^0$ intermediate state (93%). The $W_{\gamma\gamma}$ distribution of events obtained in this way was subtracted from the corresponding $\gamma\gamma \to \phi\rho^0$ distribution. The $\gamma\gamma \to \phi\rho^0$ cross section was then determined by accounting for the acceptance and the $\phi \to K^+K^-$ branching ratio (fig. 2a). The main contribution to the overall systematical error of 12% is due to the unknown spin-parity of the $\phi\rho^0$ system. This error was estimated for each $W_{\gamma\gamma}$ interval by performing a Monte Carlo simulation for different spin-parity assignments. It amounts typically to 9%. Of the remaining systematical errors the uncertainty in the detector simulation contributes 6%, the trigger simulation 5%, the determination of ARGUS integrated luminosity 1.8%, the branching ratio Br($\phi \to 2K$) 1.6%, and the uncertainty in the photon form factor 1.5%.

The small number of measured events does not allow for a thorough partial wave analysis. Nevertheless, an attempt was made to compare the measured angular distributions to Monte Carlo expectations for pure partial waves with spin and parity: $(J^P, J_z) = (0^+, 0)$, $(0^-, 0)$, $(2^+, 2)$, $(2^+, 0)$, $(2^-, 0)$. The simulated angular distributions were obtained assuming $W_{\gamma\gamma}$ distributions identical to the measured ones. Some typical distributions for the peak region ($W_{\gamma\gamma}$ between 1.5 and 2.5 GeV) are shown in fig. 2b, c, d. Fig. 2b seems to exclude the pure $J^P = 0^+$ and $J^P = 0^-$ contributions in this $W_{\gamma\gamma}$ interval. From figs. 2c and 2d it also seems that an assignment restricted to $(J^P, J_z) = (2^+, 2)$ is not most probable. Of the above mentioned pure spin-parity assignments it is only $(2^-, 0)$ that is not in conflict with the data.

An attempt was made to extract the $\gamma\gamma \to \phi\omega$ cross section from the sample of selected $\pi^+\pi^-\pi^0K^+K^-$ events. A clean ϕ peak can be seen in fig. 3a. Restricting the K^+K^- invariant masses to values that differ less than 12 MeV/c^2 from the nominal ϕ mass, we obtain the spectrum of $\pi^+\pi^-\pi^0$ invariant masses shown in fig. 3b. An enhancement can be seen in the ω region. Of the total 9 events, 4 have invariant masses that lie closer to the nominal ω mass than 50 MeV/c^2, a value that corresponds to twice the standard deviation of the detector resolution distribution for the three–pion invariant mass.

The non-$\phi\omega$ contribution to the selected events was estimated in the same way by Monte Carlo simulation and sideband normalization as in the case of $\gamma\gamma \to \phi\rho^0$. An upper limit of 0.6 background events (95% confidence level) was found. After accounting for acceptance and branching ratios for $\phi \to K^+K^-$ and $\omega \to \pi^+\pi^0\pi^-$ [11], the cross section for $\gamma\gamma \to \phi\omega$ was determined. As seen from fig. 3c all the observed events belong to the $W_{\gamma\gamma}$ region just above the reaction threshold. Since above this region no events were observed, only an upper limit could be set to

the cross section.

To conclude, two-photon production of the vector meson pair $\phi\rho^0$ has been studied in the reaction $\gamma\gamma \to K^+K^-\pi^+\pi^-$. The cross section for the reaction $\gamma\gamma \to \phi\rho^0$ has been measured for the first time. The measured cross section is consistent with the previous upper limit set by ARGUS [7]. Within the errors this cross section agrees with the estimate from the t-channel factorization model [6], but it disagrees with the predictions of $qq\bar{q}\bar{q}$ models [5]. Production of $\phi\omega$ has also been found for the first time. A cross section of 1.65 ± 0.86 nb obtained for the $W_{\gamma\gamma}$ energy range between 1.9 and 2.3 GeV is in agreement with predictions of $qq\bar{q}\bar{q}$ models [5]. These results are consistent with our previous upper limit [8]. For the region above 2.3 GeV an upper limit of 0.7 nb is obtained thus improving the upper limit set by ARGUS with a smaller data sample [8].

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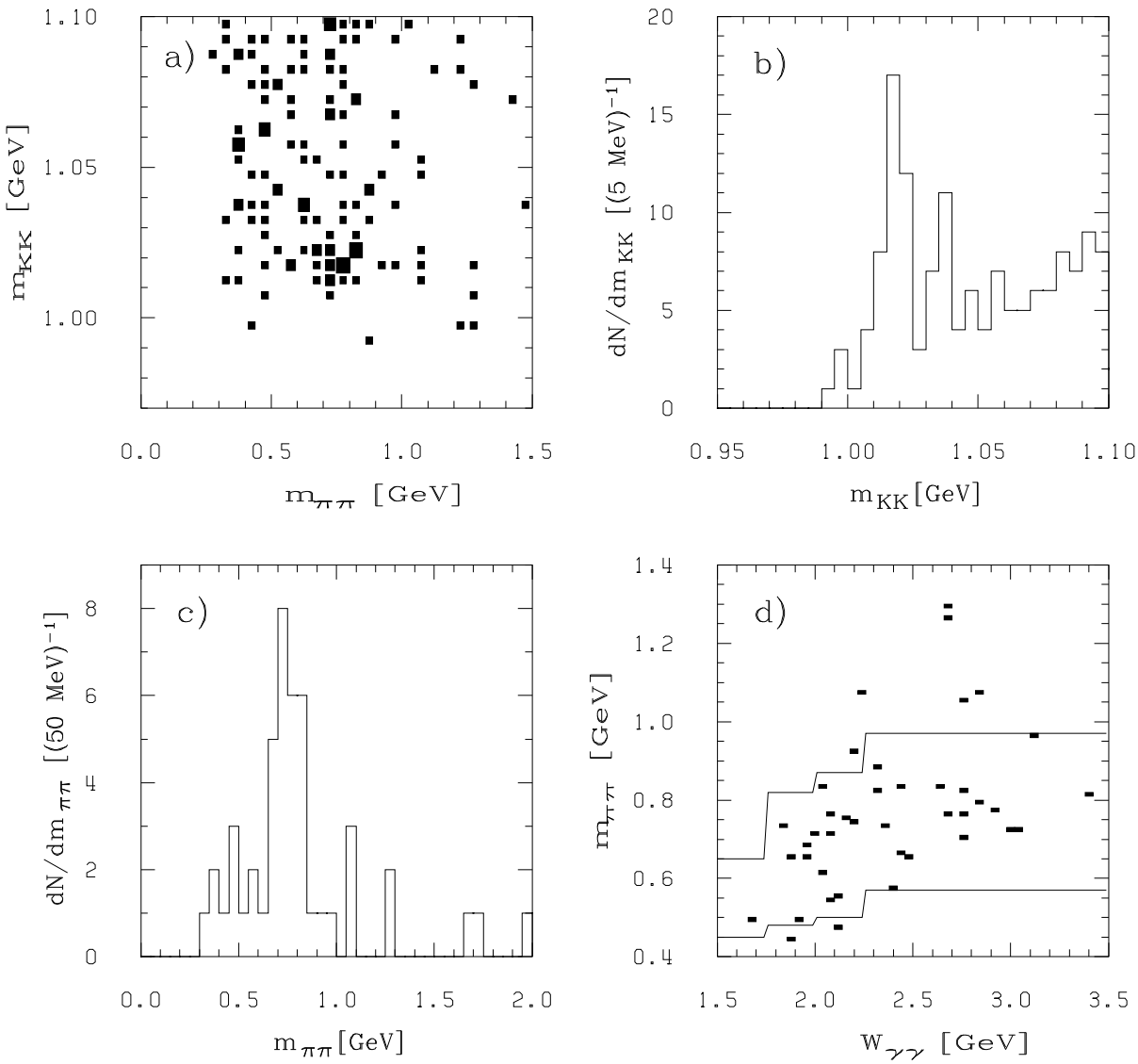

Figure 1: Event distributions for the process $\gamma\gamma \rightarrow K^+K^-\pi^+\pi^-$. **(a)** Scatter plot of the $\pi^+\pi^-$ invariant mass versus the invariant mass of K^+K^- pairs for selected $\pi^+\pi^-K^+K^-$ combinations with invariant masses between 1.5 and 3.5 GeV/c^2. **(b)** Two-kaon invariant mass distribution for selected $\pi^+\pi^-K^+K^-$ events with $W_{\gamma\gamma} < 3.5$ GeV/c^2. **(c)** Two-pion invariant mass $m_{\pi\pi}$ distribution for the selected $\pi^+\pi^-K^+K^-$ events with ϕ candidates ($|m_{KK} - m_\phi| < 12MeV/c^2$). **(d)** Distribution of events from (b) in the $m_{\pi\pi}$, $W_{\gamma\gamma}$ plane. In the scatter plot of (d) the $\pi^+\pi^-$ pairs are recognized as ρ^0 decay products if they lie between both curves. The cut was derived from Monte Carlo simulation.

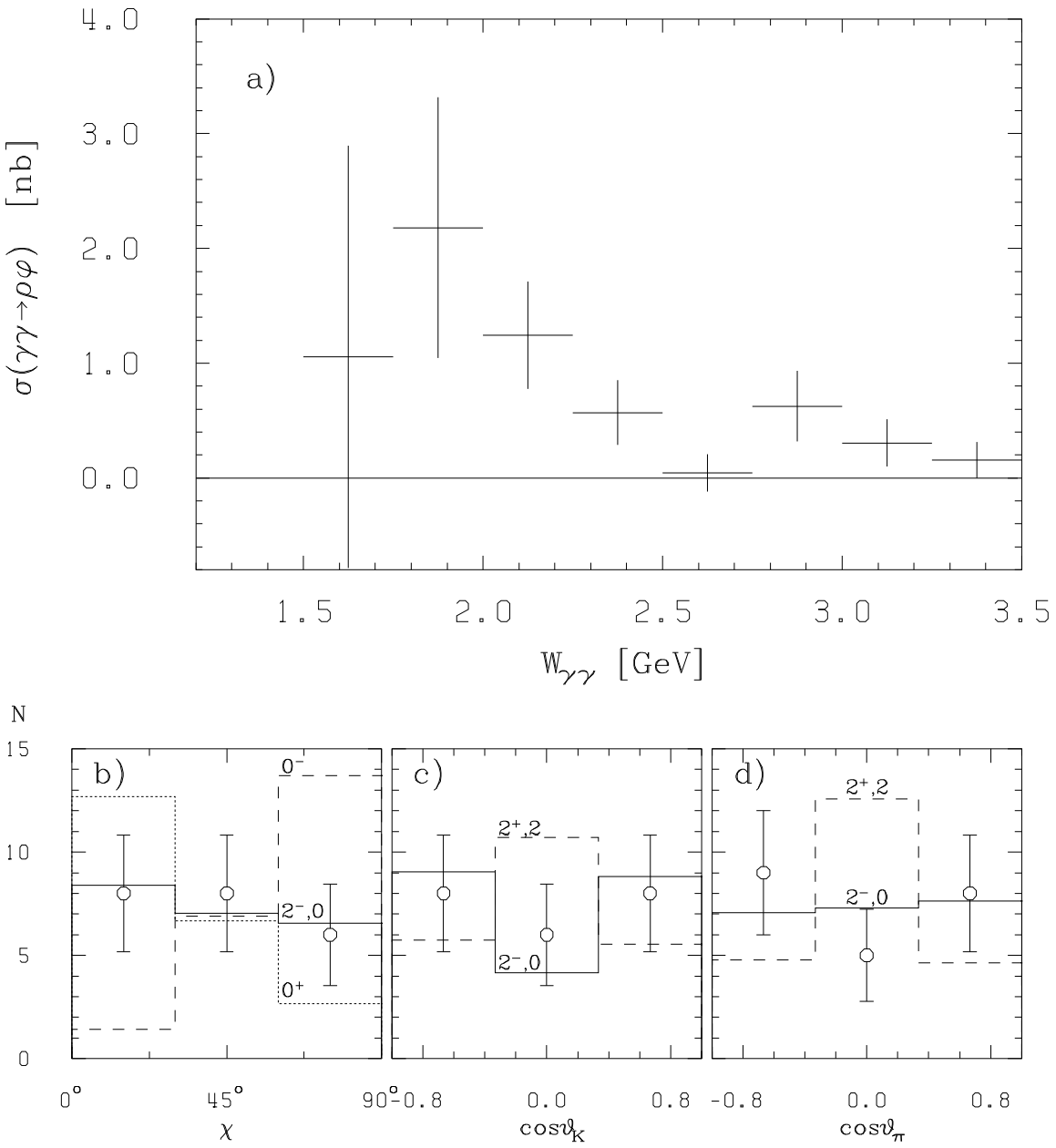

Figure 2: Results from the analysis of the reaction $\gamma\gamma \to \phi\rho^0$. **(a)** Cross section. **(b)** Distribution of the angle χ between the ρ and ϕ decay planes. **(c)** $\cos\vartheta_K$ distribution, where ϑ_K is the polar angle between the direction of K^+ and ϕ in the ϕ center of mass system. **(d)** Same as (c) for π^+ in the ρ system. The measured distributions are represented with circles and error bars. For the Monte Carlo simulated distributions (histograms) of various partial waves the notation J^P, J_z is used where J^P stands for spin and parity, and J_z for the spin component in the beam direction Except for $(2^-, 0)$ only distributions for those spin–parity states are shown for which the disagreement with measured data is most pronounced.

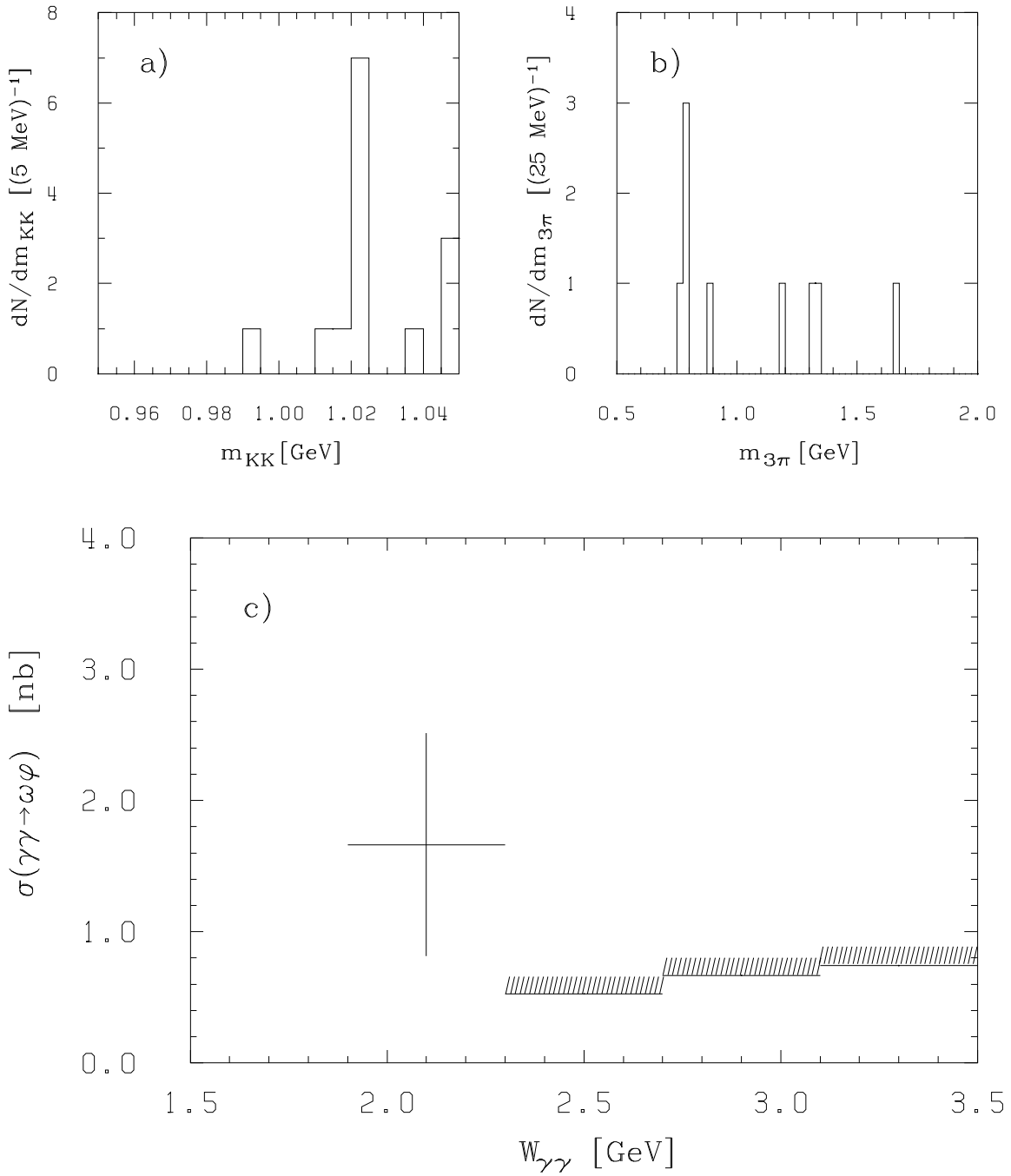

Figure 3: **(a)** Invariant mass of K^+K^- pairs for selected $\pi^+\pi^-\pi^0K^+K^-$ events. **(b)** $\pi^+\pi^-\pi^0$ invariant mass for selected $\pi^+\pi^-\pi^0K^+K^-$ events of which K^+K^- invariant mass differs for less than 12 MeV/c^2 from ϕ mass. **(c)** Cross section and upper limits at 95 % confidence level for the reaction $\gamma\gamma \to \phi\omega$.