Nuclear Physics B (Proc. Suppl.) 21 (1991) 126–131
North-Holland

# TWO-PHOTON PRODUCTION OF $\eta\pi\pi$ FINAL STATES

Karl-Heinz KARCH

Deutsches Elektronen-Synchrotron, Notkestrasse 85, D-2000 Hamburg 52, Germany
Representing the Crystal Ball Collaboration

Recent results from the Crystal Ball and CELLO experiments are presented. Evidence for the observation of a new $\eta\pi\pi$ resonance with a mass of about 1900 MeV/c$^2$ is reported.

## 1. INTRODUCTION

Electron-positron colliders provide a good laboratory for the study of two-photon (or $\gamma\gamma$) reactions. The high energetic leptons each radiate space-like virtual photons, which may interact with each other and create a variety of final states. The photons are dominatly emitted at small angles and with low energy, thus, in the majority of the events, the scattered leptons can not be detected (no-tag experiments). The "virtuality" of these photons is small, they are "quasi-real" photons, and they are transversely polarized.

The possible quantum numbers of states which can be produced in $\gamma\gamma$–interactions are limited. Only states $X$ with helicity 0 or 2 can be created. The C-Parity of $X$ is fixed to $+1$, and the Landau-Yang theorem [1] forbids the formation of states with spin 1, if the photons are quasi-real. The observation of the $\eta\pi\pi$ decay mode of a resonance limits its isospin assignment $I$ to 0 or 2. The study of the $\gamma\gamma$–formation of resonances allows to probe their flavor content, because in the quark model the partial width to two photons is proportional to the fourth power of the constituent quark charges.

Because of the small scattering angles of the leptons, the momentum component $p_t$ of $X$, perpendicular to the beam direction, is small, too. The two "wide band beams" of photons give rise to a rapidly decreasing continuous spectrum of invariant masses $W_{\gamma\gamma}$, and a continuous distribution of the boost of $X$ along the beam direction. These two features make it hard to trigger on or select $\gamma\gamma$–induced events, but the distinct distribution $|\sum\vec{p_t}|^2$, peaking at 0, can be exploited. Efficiencies between 1 % and 5 % are typical for no-tag $\gamma\gamma$ experiments.

The Crystal Ball detector [2] is a nonmagnetic segmented NaI(Tl) calorimeter with spherical geometry. It has good energy resolution for electromagnetically showering particles and good solid angle coverage. Four layers of cylindrical proportional tubes were placed inside the calorimeter to detect charged particles. This experiment collected an integrated luminosity of 250 pb$^{-1}$ between 1982 and 1986, while operating at the DORIS-II collider. The average beam energy was 5 GeV. The CELLO detector [3] operated at the PETRA collider. It was a general purpose magnetic detector with a superconducting solenoid. The tracking system consisted of proportional and drift chambers, and a Lead-liquid Argon calorimeter was used to measure photon energies. The data presented here, collected in 1986, correspond to 86 pb$^{-1}$, at a beam energy of 17.5 GeV.

## 2. CRYSTAL BALL: $\gamma\gamma \to \eta\pi^\circ\pi^\circ$

The analysis of a smaller data sample (133 pb$^{-1}$), logged with special low mass triggers was published in ref. [4]. 185 $\eta'$ events were reconstructed, resulting in a value for the two-photon partial width times the branching ratio to six photons via $\eta\pi^\circ\pi^\circ$ of
$\Gamma_{\gamma\gamma}(\eta')BR(\eta' \to 6\gamma) = (0.39 \pm 0.03 \pm 0.04)$ keV. The first error is statistical, the second systematic.

in addition, events at higher masses were seen (Figure 1). These were used to determine upper limits on the $\gamma\gamma$-coupling of heavier pseudoscalar resonances. The result is $\Gamma_{\gamma\gamma}(X)BR(\eta\pi\pi) < 0.3$ keV at 90 % confidence level, for resonances with total width smaller than 50 MeV and masses around 1300 — 1500 MeV/c$^2$. There is no evidence for the formation of the $\eta(1280)$ or $\iota, \eta(1440)$ resonances. The overall rise of the upper limit curve reflects the decrease of the two-photon flux and of the detection efficiency.

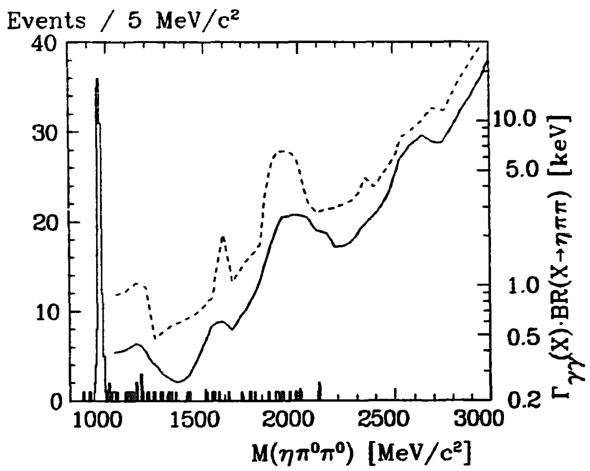


Figure 1: Crystal Ball data on $\gamma\gamma \to \eta\pi^0\pi^0$ [4].
The histogram is the invariant mass distribution of selected events. The curves are the upper limit on $\Gamma_{\gamma\gamma}(X)BR(\eta\pi\pi)$, with the ordinate at the right hand side. The upper limits are at 90 % C.L., the solid curve is for $\Gamma_{tot}$ =50 MeV, the dashed curve for 200 MeV.

However, the "resonance-like" behaviour between 1.8 and 2.1 GeV/c$^2$ gave us reason to repeat this investigation with the full data sample and a selection procedure which is more efficient at higher masses. This new analysis is presented in ref. [5]. The lowest trigger threshold which was activated during the whole data taking period required at least 800 MeV energy deposited in the calorimeter and approximate balance of $p_t$. Events were selected by requiring that they have six energy depositions in the calorimeter, where not more than one of them may be tagged as charged by the proportional tubes. The transverse momentum sum of the six photons was required to be less than 100 MeV/c. These cuts were passed by 1220 events. The six photons can be grouped into 15 different pairs; their invariant mass distribution ($m_{\gamma\gamma}$) shows nice $\pi^0$ and $\eta$ signals on top of a combinatorial background.

The last step of the selection was the $\eta\pi^0\pi^0$ event definition. There are 15 possible configurations to group six photons into three pairs. The $\chi^2$'s for the $\eta\pi^0\pi^0$ and $\pi^0\pi^0\pi^0$ hypotheses were calculated for each configuration, using the three invariant $\gamma\gamma$-masses and the energy dependent resolution functions for the energy and direction measurements. $\eta\pi^0\pi^0$ events were selected by requiring that at least one configuration had $\chi^2(\eta\pi^0\pi^0) < 9$ and that none had $\chi^2(\pi^0\pi^0\pi^0) < 9$. This last cut is very effective in reducing the possible feedthrough from the reaction $\gamma\gamma \to \pi_2(1670) \to \pi^0\pi^0\pi^0$.

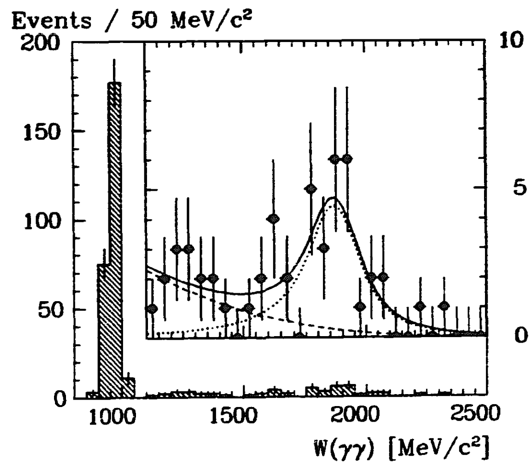


Figure 2: New Crystal Ball data on $\gamma\gamma \to \eta\pi^0\pi^0$ [5].
The histogram is the invariant mass distribution of selected events. The insert shows the distribution of events with 1100 MeV/c$^2$ $< W_{\gamma\gamma} <$ 2500 MeV/c$^2$. The full line is the fit to the data, the dotted line is the Breit-Wigner and the dashed line is the background.

The invariant mass distribution of the 317 selected events is displayed in Figure 2. 266 events are found in the $\eta'$ mass region, giving $\Gamma_{\gamma\gamma}(\eta')BR(\eta' \to 6\gamma) =$

$(0.36 \pm 0.02 \pm 0.03)$ keV, in agreement with the previous measurement. The peak is found at the nominal mass and its width of 25 MeV agrees well with the expected mass resolution.

About 50 events are found above the $\eta'$. Several checks were applied to test whether these events are genuine $\eta\pi^0\pi^0$ events from $\gamma\gamma$ interactions or whether they are remnants of background processes. The distribution of $|\sum \vec{p}_t|^2$ was compared to the Monte Carlo expectation in four different $W_{\gamma\gamma}$ intervals (I: 800 — 1100 MeV/c$^2$, II: 1100 — 1600 MeV/c$^2$, III: 1600 — 2100 MeV/c$^2$ and IV: above 2100 MeV/c$^2$). In the intervals I and III, the events exhibit the expected behaviour, peaking at 0; thus they can be identified as events which originate from $\gamma\gamma$ reactions (see Figure 3). In region II, the distribution is flat. These events are not created in $\gamma\gamma$ reactions or they result from higher multiplicity events which are not completely reconstructed. The events in region IV can not be classified unambiguously.

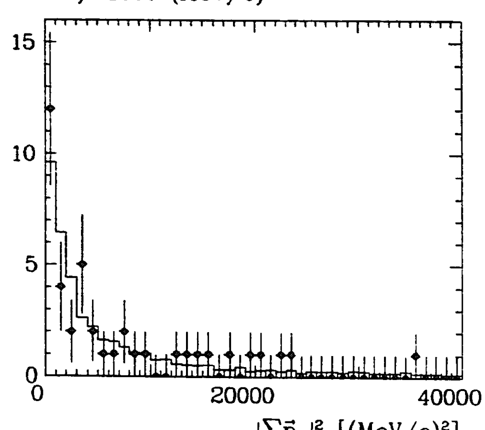


Figure 3: Crystal Ball: Distribution of the square of the transverse momentum sum $|\sum \vec{p}_t|^2$ of data (dots with error bars) and MC events (histogram) for region III ($1600 < W_{\gamma\gamma} < 2200$ MeV/c$^2$).

The distribution of $\chi^2(\eta\pi^0\pi^0)$ in intervals I and III again show the expected enhancement at small values. These are $\eta\pi^0\pi^0$ events. The events in region II have a flat $\chi^2$ distribution, indicating that they are not $\eta\pi^0\pi^0$ events.

A third check was made by requiring that four of the six photons can be grouped to form two $\pi^0$, and the $m_{\gamma\gamma}$ distribution of the remaining pair was plotted. Clear $\eta$ signals are found in regions I and III, but not in II. Part of the events in region II come from the reaction $\gamma\gamma \to a_2(1320) \to \eta\pi^0 \to 4\pi^0$, where two of the eight final state photons escaped detection.

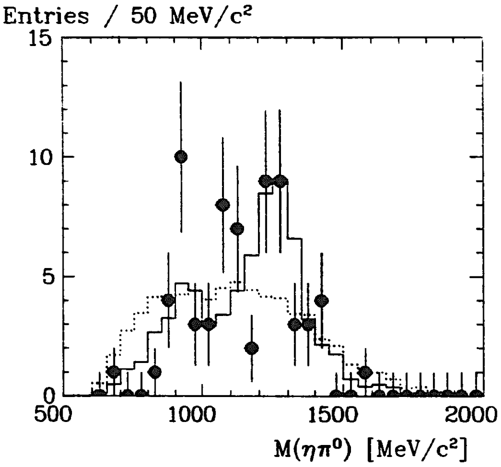


Figure 4: Crystal Ball: Invariant mass distribution of the $\eta\pi^0$ subsystem ($1500 < W_{\gamma\gamma} < 2100$ MeV/c$^2$, 2 entries per event). Dots with error bars are data; the full histogram is the best fit (see text); the dotted histogram is the expected distribution for 3-body phase space decay.

These tests convinced us that, indeed, the formation of $\eta\pi^0\pi^0$ events in $\gamma\gamma$ interactions has been observed in the $\eta'$ mass region as well as in the region $1600 < W_{\gamma\gamma} < 2100$ MeV/c$^2$. The invariant mass distribution of the $\eta\pi^0$ subsystems of events in the latter range is displayed in Figure 4. It can not be well described by the expectation from phase space decay, but exhibits evidence for $a_2(1320)$ and $a_0(980)$ isobars. The spectrum is described best by a mixture of $(70 \pm 20)\%$ $a_2$ and $(30 \pm 20)\%$ $a_0$ in the final state. The corresponding distribution of the $\pi^0\pi^0$ subsystem does not show structure.

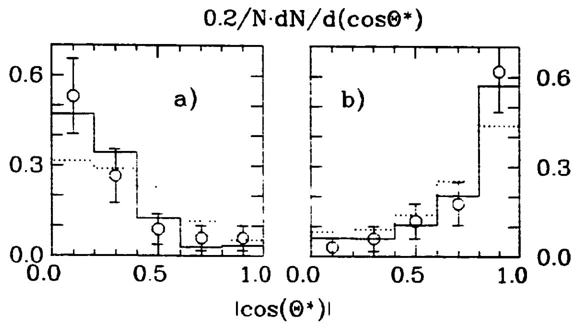


Figure 5: Crystal Ball: Angular distributions in the $\gamma\gamma$ rest frame, for events with $1600 < W_{\gamma\gamma} < 2200$ MeV/c$^2$, normalized to unit area. a) Angle $\Theta^*$ between the $\eta$ momentum and the beam direction. b) Angle $\Theta^*$ between the normal to the decay plane and the beam direction. Circles with error bars are the data, the full line corresponds to $J^P = 2^-$ and decay via $a_2\pi^0$ while the dotted line is the expectation for $J^P = 0^-$ and a 3-body phase space decay.

The polar angle distribution of the $\eta$ meson as well as of the normal to the decay plane, in the $\gamma\gamma$–c.m.s., are both described best by the spin-parity assignment $J^P = 2^-$ and decay via $a_2\pi$, but can not rule out $J^P = 0^-$ and decay via 3-body phase space. The data and the two Monte Carlo predictions are displayed in Figure 5. Other spin-parity assignments and decay modes are still under investigation.

The $W_{\gamma\gamma}$ spectrum above the $\eta'$ is evaluated by a maximum likelihood fit to the unbinned distribution, assuming that it consists of one resonance $X$ and a smoothly decreasing background (see insert to Figure 2). The following parameters of $X$ are derived:

$$\begin{aligned} M(X) &= (1876 \pm 35 \pm 45)\ \text{MeV/c}^2 \\ \Gamma_{tot}(X) &= (229 \pm 90 \pm 33)\ \text{MeV} \\ (2J+1)\cdot\Gamma_{\gamma\gamma}(X)\cdot & \\ BR(\eta\pi\pi) &= (4.5 \pm 1.0 \pm 1.5)\ \text{keV} \end{aligned}$$

The large systematic error on the last quantity is dominated by the model dependency of the detection efficiency, both on $J^P$ and on the decay mode. The fitted background explains most of the events between the $\eta'$ and 1500 MeV/$c^2$, and accounts for 5 of the 34 events between 1500 and 2200 MeV/$c^2$, in agreement with the checks discussed above.

## 3. CELLO: $\gamma\gamma \to \eta\pi^+\pi^-$

In the CELLO analysis [6], the $\eta$ mesons were reconstructed in their $\gamma\gamma$ and $\pi^+\pi^-\pi^0$ decays. The basic trigger requirement was that at least two charged tracks should be found by a fast track-finding processor. Events with two or four charged tracks, identified by the tracking detector, and two photon showers in the calorimeter were selected. Events with extra low momentum tracks, or with additional small energy depostions in the calorimeter or in the forward tagger, were rejected. A kinematical fit, which required balance of the transverse momentum sum, was applied to the selected events.

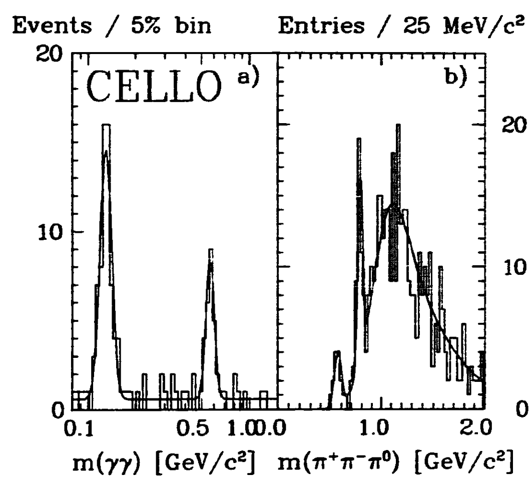


Figure 6: CELLO: a) $\gamma\gamma$–mass spectrum for $\pi^+\pi^-\gamma\gamma$ events and b) $\pi^+\pi^-\pi^0$–mass spectrum for $2\pi^+2\pi^-\pi^0$ events (up to 4 entries/event).

The $m_{\gamma\gamma}$ distribution of the $\pi^+\pi^-\gamma\gamma$ events shows $\pi^0$ and $\eta$ signals, on a very small background, see Figure 6a). The $\pi^+\pi^-\pi^0$–mass distribution of the $2\pi^+2\pi^-\gamma\gamma$ events in Figure 6b) shows clean $\eta$ and $\omega$ signals on a combinatorial background. The final event selection is done by requiring an $\eta$ candidate either in the $\gamma\gamma$ mass or in the $\pi^+\pi^-\pi^0$ mass. About 25 events in the $\pi^+\pi^-\gamma\gamma$ and about 15 events in the $2\pi^+2\pi^-\gamma\gamma$ sample are found, mainly with invariant masses between 1600 and 2200 MeV/c$^2$.

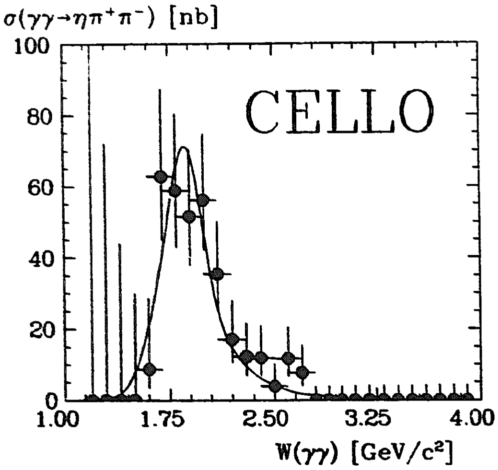


Figure 7: CELLO: Topological cross section for $\gamma\gamma \rightarrow \eta\pi^+\pi^-$. Dots with error bars are the data, the line is a single resonance fit.

The topological cross section, after correction for phase space efficiency, is presented in Figure 7. It displays a resonance-like structure around 1900 MeV/c$^2$. A single resonance fit to this cross sections results in the following preliminary parameters:

$$M(X) = (1850 \pm 50)\ \text{MeV/c}^2$$
$$\Gamma_{tot}(X) = (380 \pm 50)\ \text{MeV}$$
$$(2J+1)\cdot\Gamma_{\gamma\gamma}(X)\cdot BR(\eta\pi\pi) = (15 \pm 5)\ \text{keV}$$

The CELLO group performed a detailed comparison of their data with the Monte Carlo expectation for various spin-parity assignments and decay modes. The limited statistics prohibits a unique assignment. They see evidence for $a_2(1320), f_2(1270), f_0(1400)$ and $a_0(980)$ isobars. The best single resonance assignment is $0^-(f_0\eta)$, followed by $2^-(a_2\pi)$. If the sample is split into two parts, $2^-(a_2\pi)$ is favored for $W_{\gamma\gamma} <$ 1850 MeV/c$^2$ and $0^-(f_0\eta)$ in the higher mass region. A positive parity assignment can be ruled out at the four standard deviation level.

## 4. DISCUSSION

Among the established meson resonances, the $\eta'$ is the one with the largest coupling to two photons. Using the new measurement from the Crystal Ball and the standard value for $BR(\eta' \rightarrow \eta\pi^0\pi^0 \rightarrow 6\gamma)$, the partial width $\Gamma_{\gamma\gamma}(\eta') = (4.6 \pm 0.3 \pm 0.5)$ keV is deduced. This value underlines the observation that the pseudoscalar mesons are far from ideal mixing, and suggests that the $\eta'$ is dominantely made up from non-strange quarks.

The non-observation in $\gamma\gamma$−interaction of the $\eta(1280)$, a candidate for a radial excitation, is a puzzle. A partial width to two photons in the order of several keV is expected for radial excitations of pseudoscalar mesons [7]. At this conference, a new Mark-III analysis [8] of the decay $J/\psi \rightarrow \gamma KK\pi$ showed that the former $\iota/\eta(1440)$, can not be identified as one single state anymore. Instead, at least three states are necessary to explain the spectrum. Thus, the simple glueball interpretation of the $\iota$ is not valid anymore, and even more puzzles are added to the field of meson spectroscopy.

The Crystal Ball and CELLO observations of $\eta\pi\pi$ formation in the mass range between 1.6 and 2.2 GeV/c$^2$ are in qualitative agreement with each other. There are numerical discrepancies at the 2 standard deviation level, but the extraction of resonance parameters is severely hampered by the small number of events. The observed structure is not an artefact, created by the interplay of increasing efficiency and decreasing two-photon flux. While the detection efficiency of the CELLO analysis opens up across the signal, the efficiency of the Crystal Ball analysis varies only slightly between 1.6 and 2.2 GeV/c$^2$.

The data can be interpreted as one (or more) negative parity states. The present data samples do not allow an unambigiuous determination of the spin $J$. The peak lies far above the $\eta\pi\pi$ threshold, thus it is not likely to be a non-resonant enhancement. The interpretation as a two-body threshold enhancement, i.e. $a_2\pi$ or $f_2\eta$, is doubtful. In contrast to hadronic production experiments, there is no obvious process which would result in a large $\gamma\gamma$−cross section at threshold.

A possible explanation of the observed peak could be the pseudotensor $J^{PC} = 2^{--}$ $\eta_2$ meson, the yet unobserved isoscalar partner of the well established $\pi_2(1670)$. This state is predicted [9] to have a mass of about 1700 MeV/$c^2$, a total width of about 400 MeV and a rather large branching fraction to the $a_2\pi$ decay mode. These quantum numbers and the decay mode are consistent with the two mesurements. If the pseudotensor meson were ideally mixed, a $\gamma\gamma$−width of 3 to 5 keV would be expected for the $\eta_2$, in agreement with the Crystal Ball measurement.

A rather large enhancement, of several hundred events, between 1600 — 2000 MeV/$c^2$ in the decay $J/\psi \to \gamma\eta\pi\pi$ has been observed by the Crystal Ball (at SPEAR) [10] and Mark-III [11] experiments, suggesting the existence of at least one possible resonance. Unluckily, this mass range has not yet been investigated in a partial wave analysis [12]. The analysis of $\eta\pi^+\pi^-$ production in $K^-p$ interactions by the LASS experiment, presented at this conference [13], does not show any significant enhancement above the $\eta'$ mass, but this is not contradicting the reported observation in $\gamma\gamma$−reactions.

If the observed peak is indeed the $\eta_2$, decaying via $a_2\pi$, a signal is expected in the reaction $\gamma\gamma \to \pi^+\pi^-2\pi^\circ$, too, where the $a_2$ decays to $\rho^\pm\pi^\mp$. Indications for a signal exist in a CELLO analysis [14], but this channel is dominated by a rather large signal from $\gamma\gamma \to \rho^+\rho^-$ with positive parity, obscuring a small negative parity signal.

In conclusion, an unique explanation of the $\eta\pi\pi$ structure around 1.9 GeV/$c^2$ is not yet possible. Further evidence for its two-photon formation may be found in already existing data from the ARGUS [15] and JADE [16] experiments, and more data might be collected by the CLEO-II experiment.

## ACKNOWLEDGEMENTS

This work profitted a lot from the pleasant and stimulating atmosphere in the Crystal Ball collaboration, thus I would like to thank all my colleagues. I further thank J.H. Peters and M. Feindt from the CELLO group for interesting discussions and explaining their analyses.

## REFERENCES

1. L.D. Landau: Sov. Phys. Doklady 60 (1948) 207; C.N. Yang: Phys. Rev. 77 (1950) 242.50) 242.
2. D.A. Williams et al.: Phys. Rev. D 38 (1988) 1365.
3. H.J. Behrend et al.: Phys. Scrip. 23 (1981) 610.
4. D. Antreasyan et al.: Phys. Rev. D 36 (1988) 2633.
5. K. Karch et al.: Preprint DESY 90-068, SLAC-PUB-5266, Phys. Lett. B in press; K. Karch: Ph.D. thesis, Hamburg University, in preparation.
6. H.J. Behrend et al.: "Observation of a Resonant Structure in the Reaction $\gamma\gamma \to \eta\pi^+\pi^-$", Contributed paper to the International Conference on High Energy Physics, Singapore, 1990.
7. M.S. Chanowitz, "Resonances in Photon-Photon Scattering", in: Proceedings of the VIII International Workshop on Photon-Photon Collisions, Shoresh, Israel, April 1988, ed. U. Karshon (World Scientific, Singapore 1988), p. 205.
8. J. Drinkard: these proceedings.
9. R. Kokoski and N. Isgur: Phys. Rev. D 35 (1987) 907; S. Godfrey and N. Isgur: Phys. Rev. D 32 (1985) 189.
10. C. Edwards et al.: Phys. Rev. Lett. 51 (1983) 859.
11. J.J. Becker: Ph.D. thesis, University of Illinois, Urbana-Champaign (1984).
12. M. Burchell: these proceedings; W. Lockman: these proceedings.
13. T. Bienz: these proceedings.
14. M. Feindt, "Light Hadrons as Seen via Two Photons by CELLO", in: Proceedings of HADRON '89, III International Conference on Hadron Sepectroscopy, Ajaccio, Corsica (France), Sept. 23-27, 1989, eds. F. Binon, J.M. Frere and J.P. Peigneux (Edition Frontieres; Gif-Sur-Yvette 1989), p. 133.
15. H. Albrecht et al.: Phys. Lett. 199B (1987) 577.
16. A. Wegner et al.: Preprint DESY 90-069.