Formation of Light Resonances in $\gamma\gamma$ collisions in the $K^0_S K^\pm \pi^\mp$ final state at LEP

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The $K^0_S K^\pm \pi^\mp$ final state in two-photon collisions is studied with the L3 detector at LEP at centre of mass energies from 160 GeV to 189 GeV. An enhancement in the mass spectrum around 1450 MeV is seen. The Q^2 distribution indicates the presence of the pseudo scalar $\eta(1440)$, observed in the $\gamma\gamma$ collisions for the first time, and possibly the presence of a vector meson $f_1(1420)$ or $f_1(1510)$. The two-photon width of $\eta(1440)$ for the $K^0_S K^\pm \pi^\mp$ decay mode is determined. The hypothesis of $\eta(1440)$ being a gluonium state is examined.

1. Introduction

Three resonances have been seen in $K\bar{K}\pi$ final state at masses around 1450 MeV [1]. Two of them are $J^{PC} = 1^{++}$ vector mesons, the $f_1(1420)$ and the $f_1(1510)$, while the $\eta(1440)$ is a pseudo scalar meson with $J^{PC} = 0^{-+}$. Most of the measurements were performed in hadron collisions and by studying the radiative decay of the J/ψ. In two-photon collisions only the $f_1(1420)$ was observed by CELLO Collaboration [2] in single-tag events and by TPC-2γ Collaboration [3] in double-tag events. For the $\eta(1440)$ an upper limit for its two-photon width was given by CELLO [2]. This state was therefore considered a glueball candidate.

2. $K^0_S K^\pm \pi^\mp$ final state

The reaction $\gamma\gamma \to K^0_S K^\pm \pi^\mp$ is studied with the L3 detector at LEP using 250 pb^{-1} of data collected at $\sqrt{s}$=160–189 GeV.

Events are selected by requiring four charged tracks with two vertices: a primary vertex associated with $K^\pm \pi^\mp$ and a secondary vertex associated with $K^0_S \to \pi^+\pi^-$ (Figure 1).

Candidates for $K^0_S K^0_S$ events and events with photons are excluded. The dE/dX measurement is used to separate charged π from K.

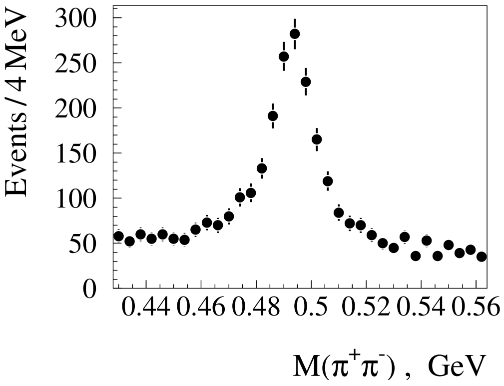

Figure 1. The $\pi^+\pi^-$ mass spectrum for reconstructed secondary vertices

2086 events are selected with $P_t^2(K^0_S K^\pm \pi^\mp) <$ 10 GeV^2. In the mass spectrum (Figure 2) a peak due to $\eta_c(2980)$ formation is observed. The peak in the mass region from 1370 MeV to 1560 MeV is fitted with Gaussian plus a sigmoid-like background function. From the fit the num-

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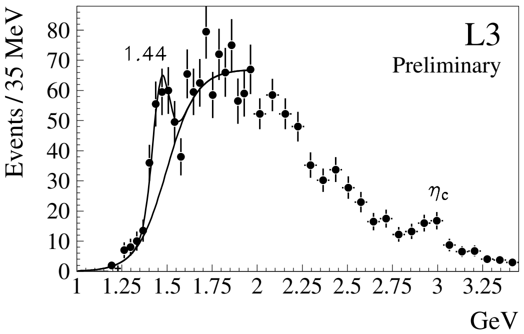

Figure 2. $K^0_S\,K^{\pm}\pi^{\mp}$ mass spectrum

ber of events is evaluated to be 119±22. The fit gives a confidence level of 32%, the confidence level becomes ≈1% if the fit is performed with the background function only. The parameters of the Gaussian function are found to be M=1465±31 MeV and σ=45±5 MeV. The experimental mass resolution, evaluated by Monte Carlo, is σ=24 MeV. The errors for the mass and the width include both the fit and the systematic contribution. The most significant systematic error is due to the P_t^2 cut variation.

2.1. Form factor study

In interaction of quasi-real photons a neutral unflavoured meson with even charge conjugation, J≠1 can be formed. If one of the two photons is highly virtual ($Q^2 \neq 0$), spin one states can also be formed.

The cross section for the resonance formation is described by the formula:

$$\sigma(\gamma\gamma \to R) = \mathrm{F}^2(\mathrm{Q}^2)\,\frac{8\pi(2J+1)\,\Gamma_{\gamma\gamma}\Gamma_R}{(W^2-M^2)^2+M^2\,\Gamma_R^2} \quad (1)$$

where W is the two photon centre of mass energy, M and Γ_R are the mass and the total width of resonance, and $\Gamma_{\gamma\gamma}$ is the two-photon partial width.

The form factor depends on the square of four-momentum of the photon with highest virtuality (Q^2). In the Vector Dominance Model $F^2(Q^2)$ is parametrised by a pole function [4]:

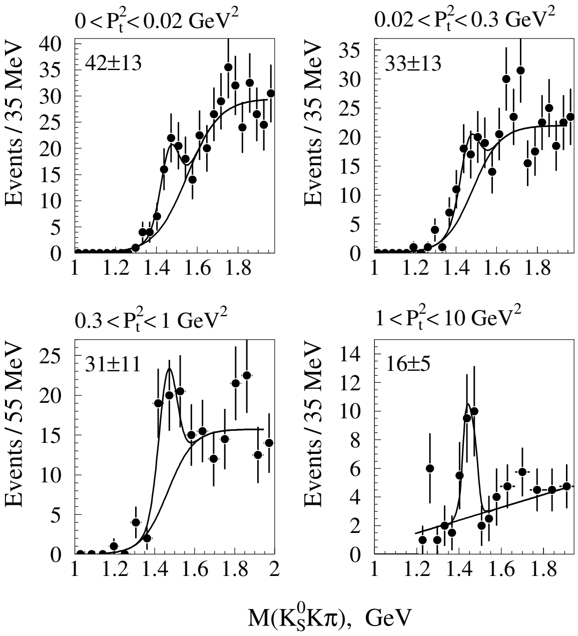

Figure 3. The $K^0_S\,K^{\pm}\pi^{\mp}$ mass spectrum as a function of Q^2. The number of events obtained by fitting a Gaussian and a background function in each Q^2 interval is indicated

$$F^2_{[0^-]}(Q^2) = \frac{1}{(1+Q^2/\Lambda^2)^2} \quad (2)$$

$$F^2_{[1^+]}(Q^2) = \frac{2}{(1+Q^2/\Lambda^2)^4}\frac{Q^2}{\Lambda^2}(1+\frac{Q^2}{2\Lambda^2}) \quad (3)$$

where $\Lambda = m_V$, V= $\rho\,\omega\,\phi\,J/\psi$...

If neither of the outgoing electron or positron is detected, the Q^2 cannot be directly determined. However a Monte Carlo study reveals a very good agreement between Q^2 and $P_t^2(K^0_S\,K^{\pm}\pi^{\mp})$, allowing the study of the formation of resonances as a function of Q^2 using also untagged events. The mass spectrum as a function of Q^2 is shown in figure 3, where the data are subdivided in four bins of P_t^2. The spectra are fitted with a Gaussian function with the mass fixed to 1465 MeV and σ to 45 MeV and a sigmoid-like background

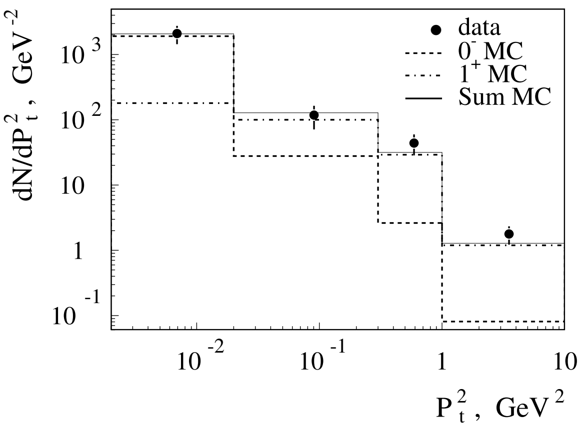

Figure 4. Q^2 – distribution of events in peak R(1450). The Monte Carlo histograms are normalised by fitting their sum to experimental data.

function for the first three bins. For the last bin the parameters of the Gaussian are left free in the fit ($M = 1450 \pm 10$ MeV, $\sigma = 27 \pm 7$ MeV) and a linear parametrization is used for the background.

The Monte Carlo predictions for the Q^2 dependence of a pure $J^P = 0^-$ and a pure $J^P = 1^+$ state (equations (2) and (3) with $\Lambda = m_\rho$) are compared to the data (Figure 4). When fitting the data with the Monte Carlo Q^2 dependence (the normalization is left free in the fit) a confidence level smaller than 1% is obtained for both pure $J^P = 0^-$ and pure $J^P = 1^+$ hypotheses. A fit using a combination of $J^P = 0^-$ and $J^P = 1^+$ waves gives a confidence level of 50%. Thus both waves are required to reproduce the data. The numbers of events for spin-zero and spin-one components estimated by the fit are given in the table 1.

2.2. The $\eta(1440)$ two-photon width and test for gluonium

The two-photon width of the $\eta(1440)$ is determined using events with $P_t^2 < 0.05$ GeV^2. In this P_t^2 region the state with $J^P = 0^-$ clearly dominates (Figure 4). The fraction of $J^P = 0^-$ in this region is found to be about 80%. The number of $\eta(1440)$ is measured to be 36±11 with a detection efficiency of 1.83%. This leads to

Table 1
Distribution of events for spin-parity states resulted from the fit of data Q^2 dependence by Monte Carlo samples. Errors given are from the fit only.

Sample	N_{EVENTS}
$J^P = 0^-$	49±1
$J^P = 1^+$	63±6

$\Gamma_{\gamma\gamma}(\eta(1440)) \cdot BR(\eta(1440) \to K^0_{S(\to\pi^+\pi^-)} K^\pm \pi^\mp)$ $= 38 \pm 12$ eV. From this measurement we can obtain the two-photon width for the $K\bar{K}\pi$ decay channel:

$$\Gamma_{\gamma\gamma} \cdot BR(\eta(1440) \to K\bar{K}\pi) = 166 \pm 52\,\text{eV} \qquad (4)$$

This value is in agreement with the upper limit $\Gamma_{\gamma\gamma}(\eta(1440)) \cdot BR(\eta(1440) \to K\bar{K}\pi) < 1.2$ keV reported by the CELLO Collaboration [2].

Since gluons do not couple to photons, the two-photon width is expected to be small for a glueball. Using the $\Gamma_{\gamma\gamma}$ obtained, a value of the parameter stickiness [5], being the measure of the gluon content of a resonance,
$S_{\eta(1440)} = 9.5 \pm 3.0$ is obtained. This value is similar to the ones obtained for ordinary mesons, thus showing no evidence for a glueball nature of the $\eta(1440)$.

2.3. Decay Modes

The $K\bar{K}\pi$ final state can proceed via intermediate decay states like $K\bar{K}^*(892)$ or $a_0(980)\pi$. For the $f_1(1420)$ the decay mode $K\bar{K}^*(892)$ was reported to be dominant [1]. For the $\eta(1440)$ both intermediate states have been observed. The Particle Data Group [1] reports the experimental indication of two pseudo scalars in the 1440 MeV mass region: one at 1418.7±1.2 MeV dominated by the $a_0(980)\pi$ and one at 1473±4 MeV dominated by the $K\bar{K}^*(892)$ intermediate state.

We do not observe any clear indication for the formation of the $K^*(892)$, neither in the $K\pi$ nor in the $K^0_S\pi$ mass spectra.

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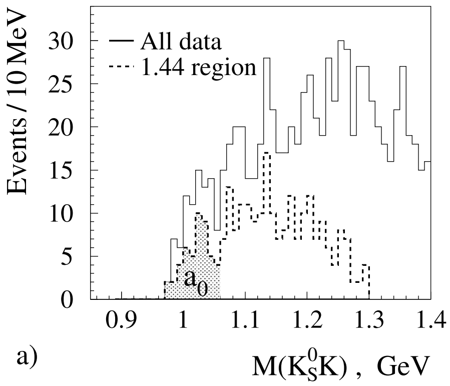

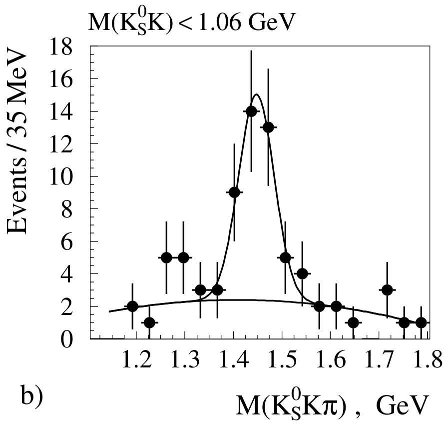

Figure 5. a) K_S^0K mass spectra. b) $K_S^0 K^\pm \pi^\mp$ mass spectrum for events selected with K_S^0K masses consistent with $a_0(980)$

$a_0(980)$ is present in the K_S^0K mass spectrum (Figure 5a) when the events are selected in the 1370 − 1560 MeV $K_S^0 K^\pm \pi^\mp$ mass region. Selecting events with a K_S^0K mass smaller that 1060 MeV, consistent with the $a_0(980)$, a very clean peak is observed in the $K_S^0 K^\pm \pi^\mp$ mass spectrum (Figure 5b). A value of $m = 1450\pm10$ MeV is found by fitting the spectrum with a Gaussian function, a little smaller than the value $m = 1465\pm31$ MeV obtained by fitting the whole sample. The PDG average [1] for the $\eta\,(1440)$ is $m = 1418.7\pm1.2$ MeV in the channel $\eta\,(1440) \rightarrow a_0(980)\pi$.

An attempt is made to study the formation of this resonance in the $a_0(980)\pi$ intermediate decay mode as a function of Q^2 but the present statistics is not sufficient to derive any conclusion.

The branching ratio for this decay mode is found to be 0.28±0.08.

3. Conclusion

An enhancement around 1450 MeV in $K\bar{K}\pi$ final state was observed in untagged $\gamma\gamma$ collisions. Analysis of Q^2 distribution reveals the presence of $\eta\,(1440)$ with $J^{PC} = 0^{-+}$, and a state with $J^{PC} = 1^{++}$ $f_1(1420)$ or $f_1(1510)$ is also possible. At low Q^2 the $J^{PC} = 0^{-+}$ largely dominates. The $\eta\,(1440)$ is observed for the first time in untagged two-photon collisions. Its two-photon width is measured to be $\Gamma_{\gamma\gamma} \cdot BR(\eta\,(1440) \rightarrow K\bar{K}\pi) = 166 \pm 52$ eV. For the stickiness we measure $S_{\eta\,(1440)} = 9.5 \pm 3.0$, showing no evidence for a glueball nature of the $\eta\,(1440)$. The intermediate decay state $a_0(980)\pi$ is clearly observed and its branching ratio is found to be 0.28±0.08.

Acknowledgements

I would like to express my gratitude to the two-photon physics group of the L3 Collaboration in particular to M. N. Focacci-Kienzle, V. A. Schegelsky and J. H. Field.

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