Resonance Production in Two-Photon Collisions at LEP with the L3 Detector

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Abstract. The $ee \to ee\mathrm{K^0_S}\mathrm{K}^{\pm}\pi^{\mp}$, $ee \to ee\eta\pi^+\pi^-$ and $\mathrm{e^+e^-} \to \mathrm{e^+e^-}\pi^+\pi^-\pi^+\pi^-$ final states are studied with the L3 detector at LEP using data collected at centre–of–mass energies from 160 GeV up to 202 GeV. The mass spectrum of the $\mathrm{K^0_S}\mathrm{K}^{\pm}\pi^{\mp}$ final state shows an enhancement around 1470 MeV, which is identified with the pseudoscalar meson $\eta(1440)$. This state is observed in $\gamma\gamma$ collisions for the first time and its two–photon width is measured. Clear evidence is also obtained for the formation of the axial vector mesons $\mathrm{f}_1(1420)$ and $\mathrm{f}_1(1285)$. In the $\eta\pi^+\pi^-$ channel the $\mathrm{f}_1(1285)$ is observed, and upper limits for the formation of $\eta(1440)$ and $\eta(1295)$ are obtained. The process $\mathrm{e^+e^-} \to \mathrm{e^+e^-}\pi^+\pi^-\pi^+\pi^-$ is dominated by $\rho^0\rho^0$ production. A spin-parity analysis of the $\rho^0\rho^0$ system for $W_{\gamma\gamma} < 3GeV$ shows a dominance of $J^P = 2^+$ and helicity 2. A contribution of $J^P = 0^+$ is also observed whereas contributions of negative parity states and $(J^P, J_z) = (2^+, 0)$ are found to be negligible. For the $\gamma\gamma$ mass region $W_{\gamma\gamma} > 3GeV$ the $f_2(1270)$ meson is observed.

INTRODUCTION

Resonance formation in two–photon interactions offers a clean environment to study the spectrum of mesonic states. The L3 collaboration has been studied the reactions $\gamma\gamma \to \mathrm{K^0_S}\mathrm{K}^{\pm}\pi^{\mp}$ and $\gamma\gamma \to \eta\pi^+\pi^-$ in Ref. [1].

The mass region between 1200 MeV and 1500 MeV is expected to contain several states [2]. For the pseudoscalar sector ($J^{PC} = 0^{-+}$), the $\eta(1440)$ meson, formerly known as E or ι, is expected to be seen. The $\eta(1440)$ was observed in hadron collisions and in radiative J/ψ decay, but not in two–photon collisions, and only upper limits of its two–photon width, $\Gamma_{\gamma\gamma}$, of the order of 1 keV exist [3,4]. There are, possibly, two pseudoscalars [5] in the 1440 MeV mass region: one at lower mass, $\eta_L(1418 \pm 1)$ MeV, which decays into $\mathrm{a}_0\pi$ or directly into $\eta\pi\pi$, and another at higher mass, $\eta_H(1475 \pm 5)$ MeV, decaying to $\mathrm{K^*K}$. Taking into account also the $\eta(1295)$, there are therefore three candidates for the first radial excitations of the pseudoscalar SU(3) nonet. If one of these states is a gluonium, its two–photon width is expected to be small with respect to a $q\bar{q}$ state. However, the gluonium interpretation is disfavoured by lattice gauge theories [6] which predict the lowest lying 0^{-+} gluonium state to be above 2 GeV.

Axial vector mesons ($J^{PC} = 1^{++}$) are also present in these final states in the 1440 MeV mass region. The $f_1(1420)$ was observed in two–photon collisions, in the $K\bar{K}\pi$ decay channel, by the CELLO [4], TPC–2γ [16], JADE [8] and Mark II [9] Collaborations, the $f_1(1285)$ was seen [9,16] in the $\eta\pi^+\pi^-$ decay channel.

The data used here were collected by the L3 detector [10] at LEP from 1997 to 1999 at centre–of–mass energies between 183 GeV and 202 GeV, corresponding to a total integrated luminosity of 449 pb^{-1}. The analysis makes use of the dependence of the signal yield on the total transverse momentum $P_T^2 = (\sum \overrightarrow{p_T})^2$, where the sum runs over all the observed particles. To a good approximation $P_T^2 = Q^2$, where Q^2 is the maximum virtuality of the two photons. According to the Landau–Yang theorem [20], for real photons ($Q^2 \simeq 0$), the production of a spin-0 state is allowed while that of a spin-1 state is suppressed.

A large cross section for the two-photon reaction $\gamma\gamma \to \rho^0\rho^0$ near threshold has been observed in several experiments [11,17]. The cross section exceeds the estimations from the vector dominance model (VDM) by almost one order of magnitude. Similar enhancements have been also found in the decay $J/\psi \to \gamma\rho\rho$ [18] and in inelastic anti-proton scattering on deuterium $\bar{p}d \to \pi^-(2\pi^+2\pi^-)$ [19].

Two Monte Carlo generators are used to describe two–photon resonance formation: EGPC [21] and GaGaRes [22].

RESULTS

The $e^+e^- \to e^+e^- K^0_S K^\pm \pi^\mp$ channel

Events are selected by requiring four charged particles in the central tracker, two tracks ($K^\pm\pi^\mp$), coming from the interaction point, and a K^0_S decaying into $\pi^+\pi^-$ at a secondary vertex. For charged particle identification, consistency of the corresponding dE/dx measurement, with a confidence level CL>1% is evaluated for each particle identity.

The selection results in the $K^0_S K^\pm \pi^\mp$ effective mass spectra shown in Figure 1. A clear peak is seen in the 1440 MeV mass region. The data are subdivided into four P_T^2 intervals of similar statistics in the peak region, in order to study the $\eta(1440)$ and $f_1(1420)$ contributions. For the peak in the lowest P_T^2 interval, Figure 1a, the mass and width, $M = 1481 \pm 12 MeV$ and $\sigma = 48 \pm 9 MeV$, are compatible with those of the η_H . In the highest P_T^2 interval, $1 GeV^2 < P_T^2 < 7 GeV^2$, an $f_1(1285)$ signal is present. The differential cross section $d\sigma/dP_T^2$ is shown in Figure 2. It is fitted, using the predictions for the Q^2 dependence of $\eta(1440)$ and $f_1(1420)$ production given by the GaGaRes Monte Carlo. Pure pseudoscalar $\eta(1440)$ or pure axial vector meson $f_1(1420)$ hypotheses are excluded with a CL$\sim 10^{-3}$ and CL$\sim 10^{-5}$ respectively, while simultaneous presence of the $\eta(1440)$ and $f_1(1420)$ hypothesis

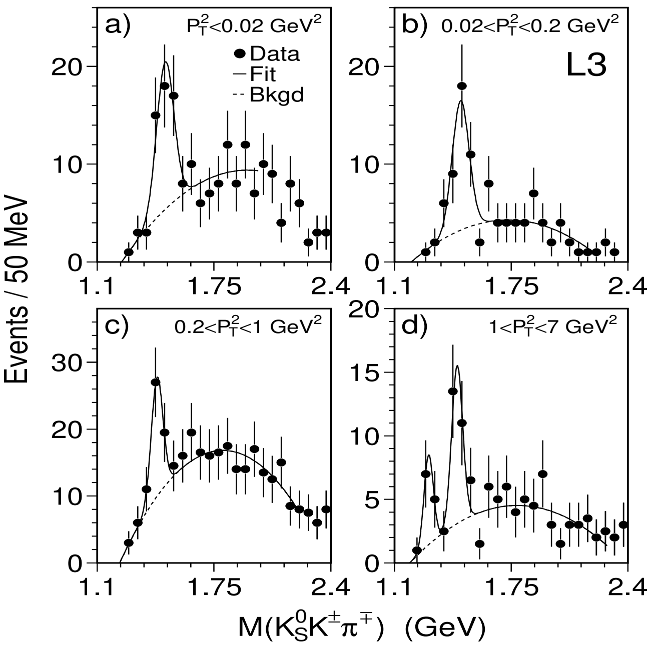

FIGURE 1. $K_S^0K^{\pm}\pi^{\mp}$ spectra for different P_T^2 bins. The fits of a Gaussian plus polynomial background are superimposed on the data. In the highest P_T^2 bin, also the peak of the $f_1(1285)$ is present and the fit includes two Gaussians.

leads to a CL $\simeq$ 9%, with 74 ± 10 events for the spin–0 particle and 42 ± 10 events for the spin–1.

Taking into account the branching ratio values [2], BR($K_S^0 \rightarrow \pi^+\pi^-$) and BR($K^0 \rightarrow K_S^0$), and the isospin factor $K\bar{K}\pi$ / $K^0K^{\pm}\pi^{\mp}$ the two–photon width for the $K\bar{K}\pi$ decay channel is: $\Gamma_{\gamma\gamma}\left((\eta(1440))\right) \times \mathrm{BR}\left((\eta(1440) \rightarrow K\bar{K}\pi\right)) = 212 \pm 50\mathrm{stat} \pm 23\mathrm{sys}\mathrm{eV}$. This value is consistent with the upper limit of 1.2 keV reported by the CELLO Collaboration [4].

To search for signals due to $K^*(892)$ and $a_0(980)$, the $K\pi$ and $K_S^0K^{\pm}$ mass spectra in the $\eta(1440)$ region, $1370MeV < \mathrm{M}(K_S^0K^{\pm}\pi^{\mp}) < 1560MeV$, are investigated. A clear $K^*(892)$ signal is seen in the $K_S^0\pi^{\pm}$ and $K^{\pm}\pi^{\mp}$ spectra. The $K_S^0K^{\pm}$ spectrum shows no clear evidence for the presence of the $a_0(980)$. With the present limited statistics no firm conclusion can be drawn concerning the possible presence of the $\eta_L \rightarrow a_0\pi$ state in the data. The mass and width of $\eta(1440)$ meson as well as the observation of a dominant $K^*(892)K$ decay are compatible with the characteristics of the η_H.

The $e^+e^- \rightarrow e^+e^-\eta\pi^+\pi^-$ channel

The η is detected via its decay $\eta \rightarrow \gamma\gamma$. After all cuts, 6444 events are selected with $\eta\pi^+\pi^-$ masses below 1750 MeV. The $\eta\pi^+\pi^-$ mass spectrum, shown

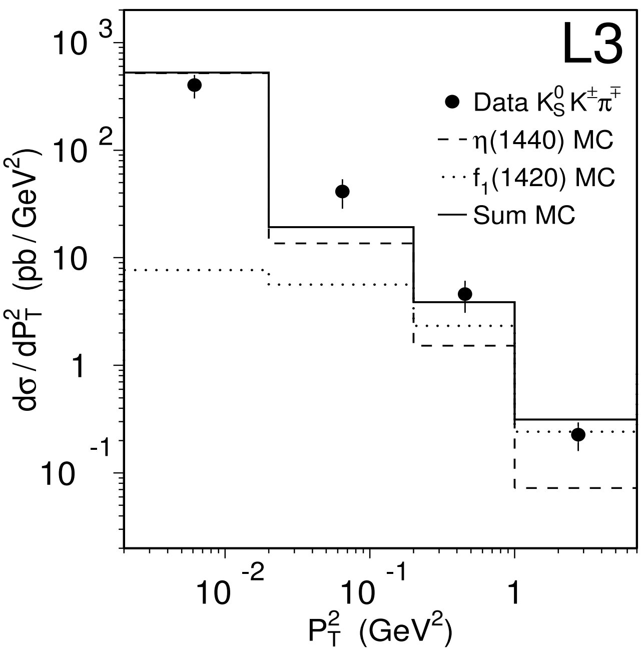

FIGURE 2. Differential cross section for the 1440 MeV mass region, as estimated from the Gaussian fit, as a function of P_T^2 in the $\mathrm{K^0_S K^\pm \pi^\mp}$ channel. The solid line is the sum of the $\eta(1440)$ and $\mathrm{f_1}(1420)$ simulations fitted to the data. The partial contributions of $\eta(1440)$ (dashed line) and $\mathrm{f_1}(1420)$ (dotted line) are also shown.

in Figure 3a, is dominated by the $\eta'(958)$ resonance. The $\eta\pi^+\pi^-$ mass spectrum for $P_T^2 < 0.02GeV^2$ is shown in Figure 3b. No peak is seen in the region 1200−1480 MeV.

The absence of signals of $\eta(1440)$ and $\eta(1295)$ allows to calculate upper limits, at 95% CL on the $\eta\pi\pi$ decay. Taking into account the branching ratio $\mathrm{BR}(\eta \to \gamma\gamma)$ [2] and the isospin factor $\eta\pi\pi \,/\, \eta\pi^+\pi^-$, they are: $\Gamma_{\gamma\gamma}\left((\eta(1440))\right) \times \mathrm{BR}\left((\eta(1440) \to \eta\pi\pi)\right) < 95eV$ and $\Gamma_{\gamma\gamma}\left((\eta(1295))\right) \times \mathrm{BR}\left((\eta(1295) \to \eta\pi\pi)\right) < 66eV$. They improve the limits of the Crystal Ball Collaboration [3].

The peak around 1285 MeV, seen in Figure 3a and absent in Figure 3b at $Q^2 \simeq 0$, is identified with the spin–1 state $\mathrm{f_1}(1285)$. A Gaussian fit plus polynomial background gives $M = 1280 \pm 4$ MeV and $\sigma = 21 \pm 4$ MeV.

Test on glueball

The two–photon width of the $\eta(1440)$, calculated under the assumption that it is a member of the first radial excitation of the pseudoscalar nonet [23], is of the order of 0.1 keV. The $\mathrm{s\bar{s}}$ content gives a negligible contribution. This is in agreement with our measurement, if we assume that $\mathrm{BR}\left((\eta(1440) \to \mathrm{K\bar{K}}\pi)\right) \sim 100\%$.

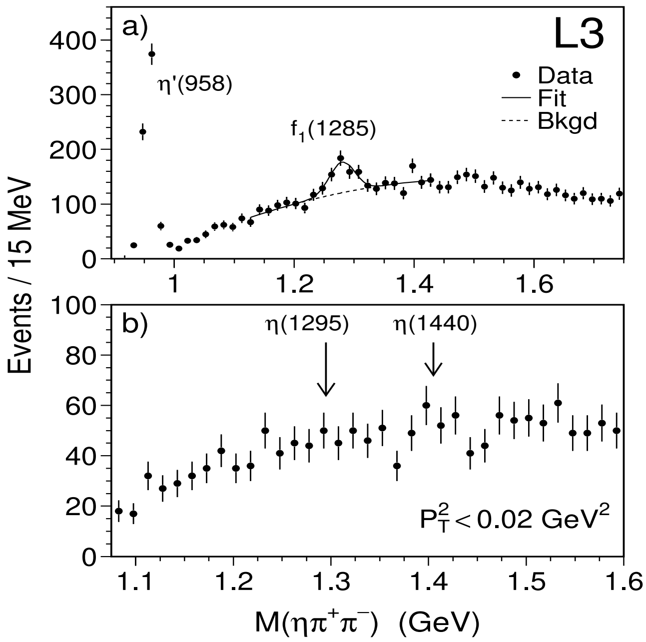

FIGURE 3. The $\eta\pi^+\pi^-$ mass spectra: a) total spectrum, the fit of a Gaussian plus polynomial background for the $f_1(1285)$ region is superimposed on the data; b) for $P_T^2 < 0.02GeV^2$, arrows show the location of $\eta(1295)$ and $\eta(1440)$.

If the $\eta(1440)$ is a gluon rich state, its stickiness parameter [24] is expected to be large. Using the present measurement of $\Gamma_{\gamma\gamma}((\eta(1440))) \times \mathrm{BR}\Big((\eta(1440) \rightarrow \mathrm{K\bar{K}}\pi\Big))$ and $\Gamma(\mathrm{J}/\psi \rightarrow \gamma\eta(1440)) = 79 \pm 16eV$ [2], a value of the stickiness $S_{\eta(1440)} = 79 \pm 26$ is obtained. Another parameter, the gluiness (G), was introduced [25,26] to quantify the ratio of the two–gluon and two–photon coupling of a particle. Whereas stickiness is a relative measure, the gluiness is a normalised quantity and is expected to be near unity for a $\mathrm{q\bar{q}}$ meson. Using the present measurement of $\Gamma_{\gamma\gamma}((\eta(1440))) \times \mathrm{BR}\Big((\eta(1440) \rightarrow \mathrm{K\bar{K}}\pi\Big))$ and the average value of $\alpha_s(1440MeV) = 0.369 \pm 0.022$ [2], a value $G_{\eta(1440)} = 41 \pm 14$ is obtained.

From the upper limit in the $\eta\pi^+\pi^-$ channel and the value $\Gamma(\mathrm{J}/\psi \rightarrow \gamma\eta(1440)) = 29 \pm 6eV$ [2] the limits $S_{\eta(1440)} > 87$ and $G_{\eta(1440)} > 45$ at 95% confidence level are obtained, compatible with the values obtained for the $\mathrm{K^0_S K^\pm \pi^\mp}$ decay channel. Both the stickiness and gluiness of the $\eta(1440)$ point to a large gluonium content in this resonance. For comparison, the η' pseudoscalar meson has $S_{\eta'} = 3.6 \pm 0.3$ and $G_{\eta'} = 5.2 \pm 0.8$ for $\alpha_s(958MeV) = 0.56 \pm 0.07$ [2].

The $e^+e^- \rightarrow e^+e^-\pi^+\pi^-\pi^+\pi^-$ channel

In order to select $\gamma\gamma \rightarrow \pi^+\pi^-\pi^+\pi^-$ events exactly four charged tracks in the tracking chamber with a net charge of zero are required. Events with photons are rejected. Pion identification is based on the dE/dx information. After applying these cuts a sample of 56359 events is obtained, of which 55120 events lie in the mass region between 1.0 and $3.0 GeV$. Data sample is divided in two parts, low mass data ($W_{\gamma\gamma} < 3.0 GeV$) and high mass data ($W_{\gamma\gamma} > 3.0 GeV$). The spin-parity and helicity analysis is performed only on the low mass data. The $\pi^+\pi^-$ mass

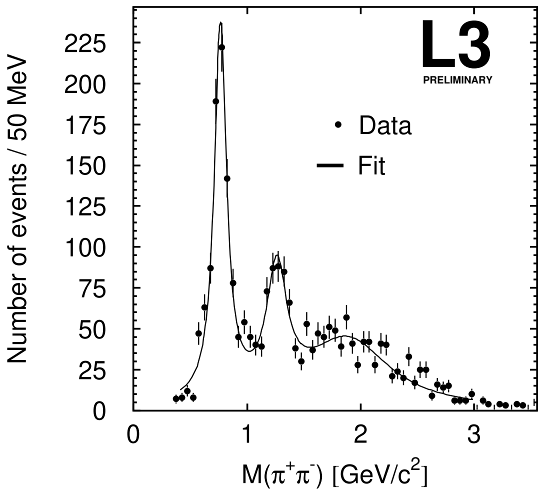

FIGURE 4. The two-pion mass after combinatorial background subtraction for the high mass data $W_{\gamma\gamma} > 3GeV$.

spectrum after subtraction of the $\pi^\pm\pi^\pm$ combinatorial background is presented in Fig. 4 for $W_{\gamma\gamma} > 3.0GeV$. There is still a strong production of the ρ^0 meson but the $f_2(1270)$ meson is also seen. Since the f_2 is a tensor meson $I^G(J^{PC}) = 0^+(2^{++})$ it cannot be produced diffractively because its quantum numbers differ from the ones of the photon. One possibility to produce the f_2 meson is an intermediate resonance decaying into a pair of f_2 mesons : $\gamma\gamma \rightarrow R \rightarrow f_2 f_2$. Additional studies are needed to clarify this hypotheses.

According to the model proposed by TASSO [13] in the analysis of the reaction $\gamma\gamma \rightarrow \pi^+\pi^-\pi^+\pi^-$ we consider the $\rho^0\rho^0$ production in different spin-parity and helicity states (J^P, J_z) and isotropic production of $\rho^0\pi^+\pi^-$ and $\pi^+\pi^-\pi^+\pi^-$. All states are assumed to be produced incoherently and therefore no interference effects between these three final states are taken into account. In each $W_{\gamma\gamma}$ bin a maximum

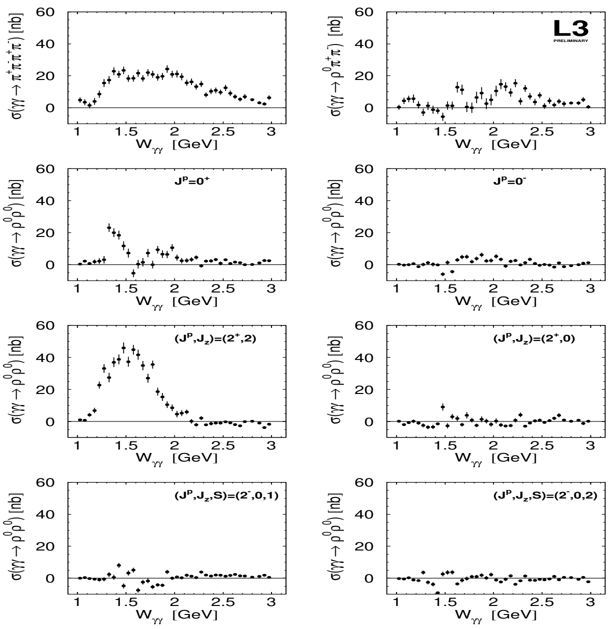

FIGURE 5. Cross sections for different spin-parity and helicity states (J^P, J_z) of $\rho^0\rho^0$ and for the isotropic $\rho^0\pi^+\pi^-$ and $\pi^+\pi^-\pi^+\pi^-$ states as determined by the 8 parameter fit.

likelihood fit is used to determine the contribution λ_j of the eight amplitudes to the data sample. The fit maximizes the logarithm of the likelihood function:

$$\log \Lambda = \sum_{i=1}^{N} \left[\log\Big(\sum_j \lambda_j \frac{|g_j(\xi_i)|^2}{\overline{|g_j|^2}} \Big) - \sum_j \lambda_j \right]$$

with the constraint $\sum_j \lambda_j = 1$, where N is the number of events in the bin and $g_{\rho^0\rho^0} = BW(m_{\rho^0_1})BW(m_{\rho^0_2})\Psi_{J^PJ_z}(1,2)$ + permutations, $g_{\rho^0\pi^+\pi^-} = BW(m_{\rho^0_1})$ + permutations and $g_{4\pi} = 1$, where $BW(m_{\rho^0})$ is the relativistic Breit-Wigner amplitude for the ρ^0 meson [27] and Ψ_{J^P,J_z} is the angular part of amplitude which describe the rotational properties of the $\rho^0\rho^0$ state with definite spin-parity J^P and helicity J_z.

The cross sections derived from the eight parameter fit are shown in Fig. 5. The $\rho^0\rho^0$ state with spin-parity 2^+ and helicity 2 dominates. The $J^P = 0^+$ state is also significant in the $\gamma\gamma$ mass region from $1.3GeV$ to $2.GeV$. The contributions of the negative parity states and of the state with $(2^+, 0)$ are negligible. These results agree well with ARGUS [17] analysis. To check the stability of the fit and the possible migration of the events between different states the fit is repeated with only the four significant states: $\pi^+\pi^-\pi^+\pi^-$, $\rho^0 2\pi$ and $\rho^0\rho^0$ with $(J^p, J_z) = 0^+, (2^+, 2)$. Similar cross-sections are obtained.

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