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MESON FORMATION IN PHOTON-PHOTON COLLISIONS AT LEP WITH THE L3 DETECTOR*

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We report on the study of several meson resonances and on $\rho^0\rho^0$ production in photon–photon collisions with the L3 detector at LEP. The $\eta'(958)$ and its form factor are studied in the $\pi^+\pi^-\gamma$ final state. The $\pi^+\pi^-\pi^0$ final state shows evidence for the formation of the $a_2(1320)$ and its radial recurrence around 1750 MeV. The formation of the $f_2'(1525)$ is studied in the $K_s^0K_s^0$ final state. The χ_{c2} is observed in its decay to $\gamma J/\psi$. The observation of diffractive $\rho^0\rho^0$ events is compared with MC predictions for $W_{\gamma\gamma} \geq 3$ GeV.

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1. Introduction

The LEP e^+e^- collider can be used to study photon-photon interactions when both the electron and the positron radiate a photon. The photons produce a final state with even total spin and positive charge conjugation: $e^+e^- \to e^+e^-\gamma\gamma \to e^+e^-X$. The photon energy is in general small compared to the beam energy, so that the scattered electrons stay in the beam pipe and go undetected. Events where one scattered electron is seen in a small angle detector are called single tagged events.

The center of mass energy of the LEP machine has been increased since 1995 from $\sqrt{s} = 91$ GeV up to $\sqrt{s} = 183$ GeV. Most of the analyses here presented use data taken from 1991 to 1997. The L3 detector is described in detail in [1].

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2. The η' and its form factor

In order to select $\eta' \to \rho^0\gamma$ events, we select events with two opposite charged tracks and one isolated electromagnetic cluster with an energy larger than 140 MeV [2]. Non resonant background is reduced by requiring $|\cos\theta_\pi| < 0.94$ in the ρ rest frame We first study the sample with $|\vec{p}_t(\pi^+\pi^-\gamma)|^2 < 0.01$ GeV^2. The $\pi^+\pi^-\gamma$ mass spectrum is shown in Fig. 1(a), where the enhancement around 1250 MeV is due to $a_2 \to \pi^+\pi^-\pi^0$ when one photon goes undetected. The spectrum is fitted with a Gaussian for the η', a background for the a_2 contribution, and a third order polynomial. The two-photon width $\Gamma_{\gamma\gamma}$ is directly related to the total production cross section, and determined to be $\Gamma_{\gamma\gamma}(\eta') = 4.17 \pm 0.10 \pm 0.27$ keV. We also check the ρ^0 line shape for a possible deviation from the Breit–Wigner shape due to the box anomaly [3]. No deviation is found.

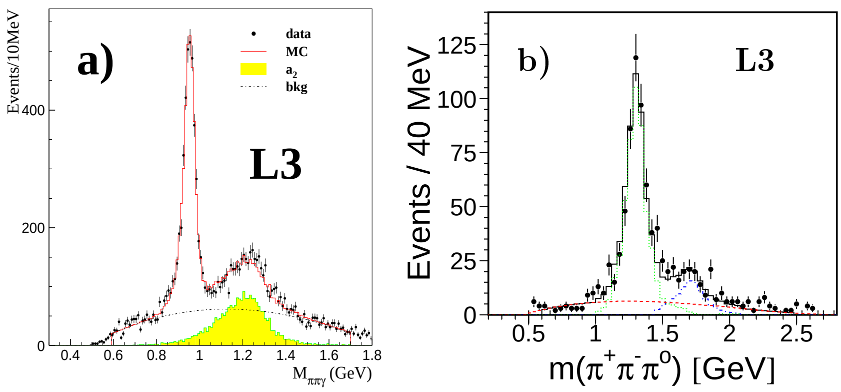


Fig. 1. (a) The $\pi^+\pi^-\gamma$ mass spectrum, (b) the $\pi^+\pi^-\pi^0$ mass spectrum.

The dependence of the η' cross section on the photon virtuality Q^2 and the η' the transition form factor are studied using both single tagged and untagged events. Single tagged events can be detected in the range $1.5 < Q^2 < 10.0$ GeV^2. For the untagged events, we use the observation that $Q^2 \simeq |\vec{p}_t(\pi^+\pi^-\gamma)|^2$. This allows us to explore the region $0.01 < Q^2 < 0.9$ GeV^2. The form factor is calculated by comparing the differential cross section to a Monte Carlo with a form factor equal to one for all Q^2. A fit to the data points assuming the Vector Dominance Model pole form factor yields for the pole mass $\Lambda = 0.900 \pm 0.046 \pm 0.022$ GeV. Our measurement favours a low gluonium component for the η' [4].

3. The $\pi^+\pi^-\pi^0$ final state

We search for $\gamma\gamma \to \pi^+\pi^-\pi^0$ formation [5] by selecting events with two opposite charged tracks and two isolated electromagnetic clusters with an energy larger than 80 MeV and $m_{\gamma\gamma}$ between 105 and 165 MeV. To select exclusive events, we require a small transverse momentum imbalance $\left|\vec{p}_t\,(\pi^+\pi^-\pi^0)\right|^2 < 0.0015$ GeV^2.

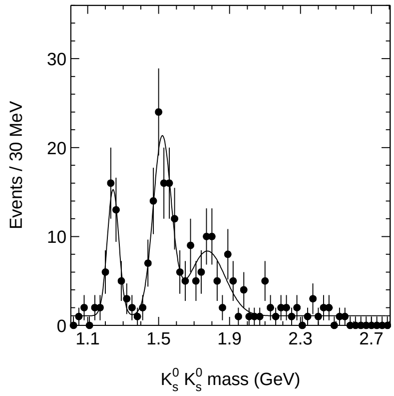
The invariant mass spectrum is shown in Fig. 1(b) and is dominated by the formation of the $a_2(1320)$ tensor meson, which decays to $\rho^\pm\pi^\mp \to \pi^\pm\pi^0\pi^\mp$. A clear enhancement is visible around 1750 MeV, where the study of the total transverse momentum shows evidence for an exclusive process. Therefore, the data sample is divided into two mass ranges: from 1.0 to 1.55 GeV, with a cut on the ρ mass in order to study the a_2, and from 1.55 to 2.1 GeV to study the high mass region.

The angular distributions show that the a_2 formation is dominated by a $J^P = 2^+$ helicity 2 wave. The helicity 2 fraction is measured to be $0.92 \pm 0.05 \pm 0.05$. We measure $\Gamma_{\gamma\gamma}(a_2) = 0.98 \pm 0.05 \pm 0.09$ keV, in agreement with recent theoretical predictions [7].

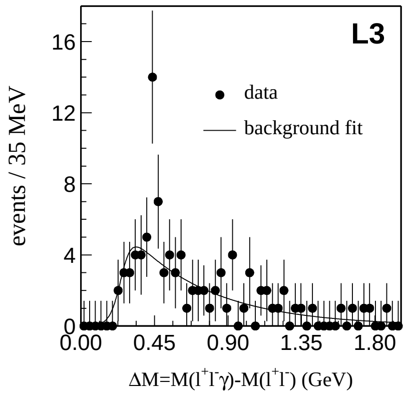
The spin-parity of the high mass sample is studied using the Dalitz parameter [6] and the angular distributions of the decay products. In both cases, a $J^P(\lambda) = 2^-(0)$ wave is disfavored by the fits, leading to an upper limit of $\Gamma_{\gamma\gamma}(\pi_2)\mathrm{Br}(\pi^+\pi^-\pi^0) < 0.072$ keV at 90% confidence level. Equal branching ratios to the $\rho\pi$ and $f_2\pi$ intermediate states are observed. As for the a_2, the high mass region is found to be dominated by a $J^P = 2^+$ helicity 2 wave, with a helicity 2 fraction of 0.77 ± 0.12. We interpret these events as a resonance with mass $1752 \pm 21 \pm 4$ MeV and width $150 \pm 110 \pm 34$ MeV, and a two-photon width $\Gamma_{\gamma\gamma}\mathrm{Br}(\rho\pi + f_2\pi) = 0.29 \pm 0.04 \pm 0.02$ keV. The mass and two-photon width are in agreement with the OGE-SRM relativistic quark model calculation in reference [7] for the radial recurrence of the a_2.

4. The $K_s^0K_s^0$ final state

In order to study the $K_s^0K_s^0$ final state [8], we select events with four charged tracks, charge balance and no photons. Exclusive events are selected by requiring $|\vec{p}_t(\pi^+\pi^-\pi^+\pi^-)|^2 < 0.1$ GeV^2. There must be two $\pi^+\pi^-$ pairs forming two secondary vertices at a distance larger than 3 mm from the beam axis, and with masses within 30 MeV of the nominal K_s^0 mass. Fig. 2(a) shows the $K_s^0K_s^0$ invariant mass spectrum, where there is clear evidence for $f_2'(1525)$ production. $f_2 - a_2$ destructive interference [9] is observed around 1300 MeV. The enhancement of 3 standard deviations around 1750 MeV could be due to the formation of a radially excited state [7] of the f_2'.



(a)



(b)

Fig. 2. (a) The $K_s^0 K_s^0$ mass spectrum, (b) The mass difference $m(l^+l^-\gamma) - m(l^+l^-)$ for $\gamma \mathrm{J}/\psi$ events.

For the f_2', we measure $\Gamma_{\gamma\gamma}(f_2') = 0.093 \pm 0.018 \pm 0.022$ keV under the hypothesis of a pure helicity 2 wave and $\Gamma_{\gamma\gamma}(f_2') = 0.198 \pm 0.040 \pm 0.050$ keV for a pure helicity 0 wave. A study of the angular distributions favours helicity 2 over helicity 0, in agreement with theoretical predictions [10].

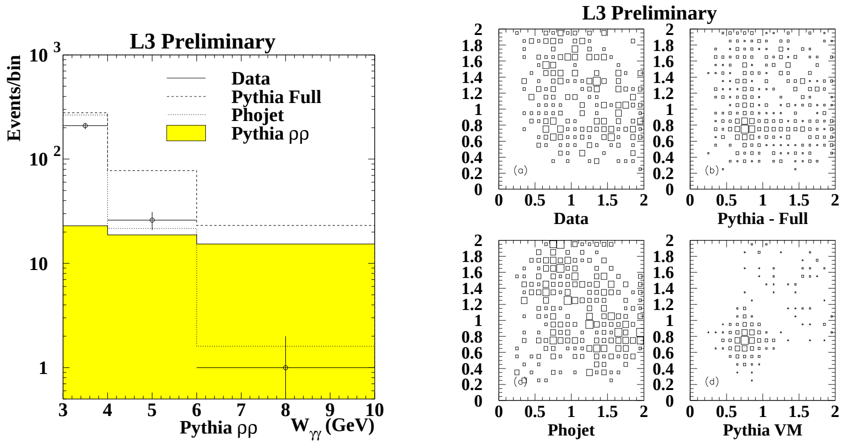
5. Observation of χ_{c2} formation

Events with two opposite charged tracks and one isolated photon with an energy larger than 300 MeV are selected to study $\gamma\gamma \to \chi_{c2}(3556) \to \gamma \mathrm{J}/\psi$ formation [11], with $\mathrm{J}/\psi \to e^+e^-$ or $\mu^+\mu^-$. The invariant mass of the two tracks is required to be in the J/ψ mass range $2.85 < m(l^+l^-) < 3.35$ GeV, and the transverse momentum imbalance $|\vec{p}_t(l^+l^-\gamma)|^2 < 0.08$ GeV^2 must be small. In Fig. 2(b) we plot the mass difference $\Delta m = m(l^+l^-\gamma) - m(l^+l^-)$, where the χ_{c2} signal is expected at $m(\chi_{c2}) - m(\mathrm{J}/\psi) = 0.459$ GeV.

Twelve events are observed above the background of 11, corresponding to a two-photon width of $\Gamma_{\gamma\gamma}(\chi_{c2}) = 0.99^{+0.43}_{-0.37} \pm 0.36$ keV. This measurement agrees better with the CLEO two-photon formation measurement $\Gamma_{\gamma\gamma}(\chi_{c2}) = 1.08 \pm 0.30 \pm 0.26$ keV than with the E760 $p\bar{p}$ annihilation measurement $\Gamma_{\gamma\gamma}(\chi_{c2}) = 0.32 \pm 0.08 \pm 0.05$ keV [12].

6. $\rho^0\rho^0$ production

According to the Vector Dominance Model, a photon can fluctuate into a vector meson with the same quantum numbers. When both photons fluctuate into a ρ^0 meson, diffractive $\rho^0\rho^0$ scattering can be observed. Our goal is to measure $\rho^0\rho^0$ quasi-elastic scattering above an two-photon center of mass energy $W_{\gamma\gamma} \geq 3$ GeV, and to compare it to two $\gamma\gamma \to$ hadrons event generators, Phojet [13] and Pythia [14]. This measurement allows a first test of the validity of the Vector Dominance Model in this region.



(a) (b)

Fig. 3. (a) Number of events observed in bins of $W_{\gamma\gamma}$ for data, Pythia, Phojet, and a Pythia diffractive $\rho^0\rho^0$ sample, (b) Scatter plot of the two ρ^0 masses.

We select events with four charged pions and charge balance. To ensure exclusive events, we cut at $|\vec{p}_t(\pi^+\pi^-\pi^+\pi^-)|^2 < 0.05$ GeV^2. A cut $|\cos\theta_\rho| < 0.8$ has to be made in the two-photon center of mass system to exclude the forward region, where the detector acceptance is very low.

In Fig. 3(a) the number of events versus the two-photon center of mass $W_{\gamma\gamma} = m(\pi^+\pi^-\pi^+\pi^-)$ is shown for data, for the Pythia and Phojet event generators, and for a Pythia sample of $\rho^0\rho^0$ only. Both Pythia and Phojet predicts more $\pi^+\pi^-\pi^+\pi^-$ than observed. The shape of the $W_{\gamma\gamma}$ distribution is much steeper than predicted by Pythia, while there is reasonable agreement with Phojet.

The invariant mass of one $\pi^+\pi^-$ pair against the other $\pi^+\pi^-$ pair is shown in Fig. 3(b). Phytia predicts a clear excess of the $\rho^0\rho^0$ signal over the background, which is not observed in the data.

7. Conclusions

We have studied the formation of several resonances in photon–photon collisions at LEP. The results for the two-photon widths are summarised in Table. For the η', the form factor in the Q^2 range between 0.01 and

Resonance	Decay	L (pb^{-1})	$\Gamma_{\gamma\gamma}(R)$ (keV)
$\eta'(958)$	$\pi^+\pi^-\gamma$	129	4.17±0.10±0.27
$a_2(1320)$	$\pi^+\pi^-\pi^0$	140	0.98±0.05±0.09
$a_2'(1750)$	$\pi^+\pi^-\pi^0$	140	(0.29±0.04±0.02)/BR
$f_2'(1525)$	$K_s^0K_s^0$	190	(0.093±0.018±0.022)/BR
$\chi_{c2}(3556)$	$\gamma J/\psi$	190	$0.99^{+0.43}_{-0.37}\pm$ 0.36

10.0 GeV^2 can be fitted with a pole parameter of $\Lambda = 0.900 \pm 0.046 \pm 0.022$ GeV. In the $\pi^+\pi^-\pi^0$ final state, dominated by a $J^{PC} = 2^{++}$ helicity 2 wave, the $a_2(1320)$ and an enhancement around 1750 MeV are observed, while there is no evidence for a $J^P = 2^-$ state. The f_2' is observed in the $K_s^0K_s^0$ final state, where also an enhancement around 1750 MeV is visible as well. The $a_2(1750)$ and $f_2'(1750)$ can be interpreted as radial excitations of the lower lying $J^{PC} = 2^{++}$ states. The formation of diffractive $\rho^0\rho^0$ events is studied using $\pi^+\pi^-\pi^+\pi^-$ events for $W_{\gamma\gamma} > 3$ GeV. We observe a smaller number of $\rho^0\rho^0$ and $\pi^+\pi^-\pi^+\pi^-$ events than predicted by the Pythia and Phojet event generator.

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