# Resonance Formation in $\gamma\gamma$ collisions at LEP with L3

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**Abstract**

Results on the two-photon width of the resonances $\eta'(958)$, $f_2'(1525)$, $\eta_c(2980)$ and $\chi_{c2}(3550)$ are obtained with the L3 detector in the reaction $e^+e^- \to e^+e^- R$. In the $K^0_S K^0_S$ decay channel, a new state is observed with a mass of $1770 \pm 20$ MeV and upper limits for the two-photon width of the gluonium candidate $\xi(2230)$ are given.

## 1 Introduction

The resonance formation in $\gamma\gamma$ interactions is a clean experimental environment to study the spectrum of $q\bar{q}$ bound states. Only C=+1 states can be formed and the spin-parity quantum numbers are limited by angular momentum conservation. The measurement of the two-photon width, $\Gamma_{\gamma\gamma}$, and of the meson form factor, $F(Q^2)$, give an insight on the charge and the wave function of the valence quarks. The presence of a gluon component can be tested and pure glueball states are expected to have a two-photon width much smaller than $q\bar{q}$ states. For heavy quarks, $c\bar{c}$ states, a measurement of $\alpha_s$ is possible by comparing two-photon to two-gluon partial widths. The data have been collected at LEP from 1991 to 1995 at $\sqrt{s} \simeq 91$ GeV and in 1997 at $\sqrt{s} = 183$ GeV. The detailed description of the L3 detector can be found in Ref. [1]. Due to the low value of the resonance masses, the data are collected almost exclusively by a trigger based on the charged tracks which requires at least two back-to-back tracks in the central chamber. For this reason only decay channels with some charged particle can be studied.

## 2 The $\eta'(958)$, $\Gamma_{\gamma\gamma}$ and $F(Q^2)$

The $\eta'(958)$ analysis at $\sqrt{s}$= 91 GeV has been published in [2]. The $\pi^+\pi^-\gamma$ spectrum (Fig.1a) is dominated by the peak of the $\eta'(958)$ resonance, the nearby enhancement is due to the $a_2 \to \pi^+\pi^-\pi^0$, when a photon of the $\pi^0$ decay goes undetected. In Fig.1a the events with small transverse momentum, $|\vec{p_t}(\pi^+\pi^-\gamma)|^2 \leq 0.01$ GeV$^2$, are selected. These events allow an accurate measurement of the two-photon width: $\Gamma_{\gamma\gamma}$= 4.17$\pm$0.10 (stat.)$\pm$0.27 (sys.) keV. We have measured also the $e^+e^- \to e^+e^-\eta'$ cross-section as a function of $Q^2$, by using the relation $|\vec{p_t}(\pi^+\pi^-\gamma)|^2 = Q^2$ and the tagged events. The

$\eta'$ form factor thus obtained is shown in Fig.1b and c. The F($Q^2$) variation is well reproduced by the vector dominance form F($Q^2$) = $[\frac{1}{1+Q^2/\Lambda^2}]$. A fit to the data gives a pole mass value $\Lambda = 900 \pm 46$ (stat.) $\pm$ 22 (sys.) MeV, consistent with the value $\Lambda = 830$ MeV of the VDM prediction quoted in Ref. [3] (dashed line in Fig.1c).

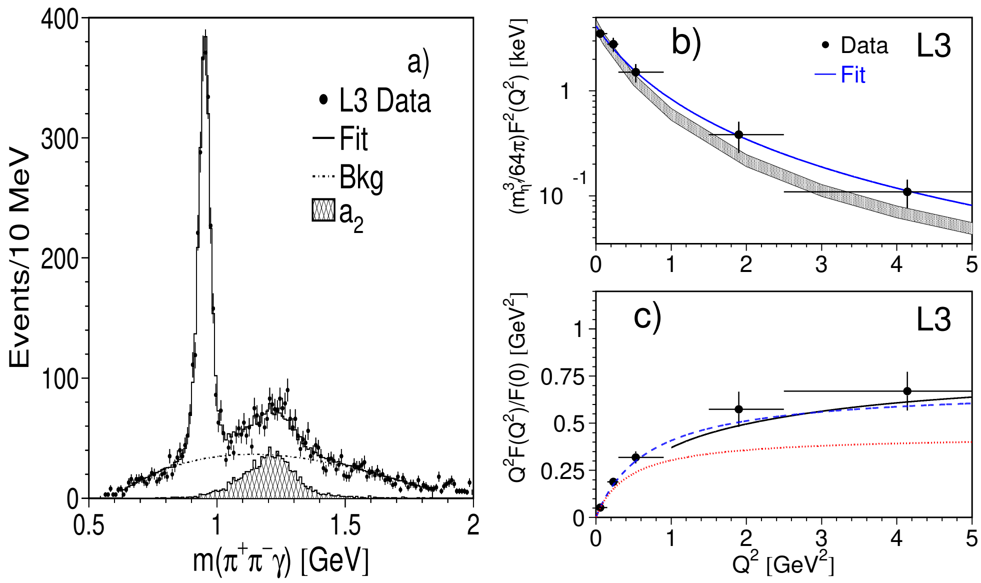


Figure 1: $\eta'(958)$ data at $\sqrt{s}$=91. a) $\pi^+\pi^-\gamma$ mass spectrum. b) and c) Form factor compared to various predictions (see text).

The model of Ref. [4] describes the perturbative and non-perturbative QCD regions with few parameters. These predictions are indicated as a shaded area in Fig.1b, ranging from no gluonium content (upper line) to 15% gluonium content (lower line). No definite conclusion can be derived from the comparison to the data, since the theoretical $Q^2$ dependence is somewhat different from the one we observe. The first perturbative QCD calculations of Ref. [5] give too low values (dotted line in Fig.1c), while the more recent calculations of Ref. [6] agree with our measurements (continous line in Fig.1c).

# 3 The charmonium $\eta_c$ and $\chi_c$

The $\eta_c$(2980) was studied in 1993 [7] with an integrated luminosity of 30 pb$^{-1}$. This study continues in order to accumulate enough statistics to measure the $\eta_c$ form factor. The individual $\eta_c$ decay channels have branching ratios of the order of 1-2 %. As a consequence many decay channels have to be analysed and the two-photon width accuracy is limited by the poor knowledge of the $\eta_c$ branching ratios. The full statistics at $\sqrt{s}$= 91 GeV is now available, for an integrated luminosity of 140 pb$^{-1}$.

We analyse the channels $\pi^+\pi^-\pi^+\pi^-$, $\eta'(\rho^0\gamma)\pi^+\pi^-$, $\mathrm{K^0_S}K^\pm\pi^\mp$, $\pi^0K^+K^-$, $\eta(\gamma\gamma)\pi^+\pi^-$, $K^+K^-\pi^+\pi^-$, $\rho^+\rho^-, \Phi\Phi$ , $\eta(\pi^0\pi^+\pi^-)\pi^+\pi^-$, $\eta'(\eta\pi^+\pi^-)\pi^+\pi^-$. In fig 2a the combined spectrum of the firts five channels, the ones which show a signal, is presented. For the other channels we calculate upper limits at 95 % CL. All the channels are included in a maximum likelihood fit, with $\Gamma_{\gamma\gamma}(\eta_c)$ as a free parameter. The result, $\Gamma_{\gamma\gamma}(\eta_c) = 9.3^{+1.8}_{-1.7}(stat. + sys.) \pm 2.7(BR)\ keV$, is slightly higher than the published value, but statistically compatible. We observe also a signal of $5.1 \pm 2.8$ events in the tagged

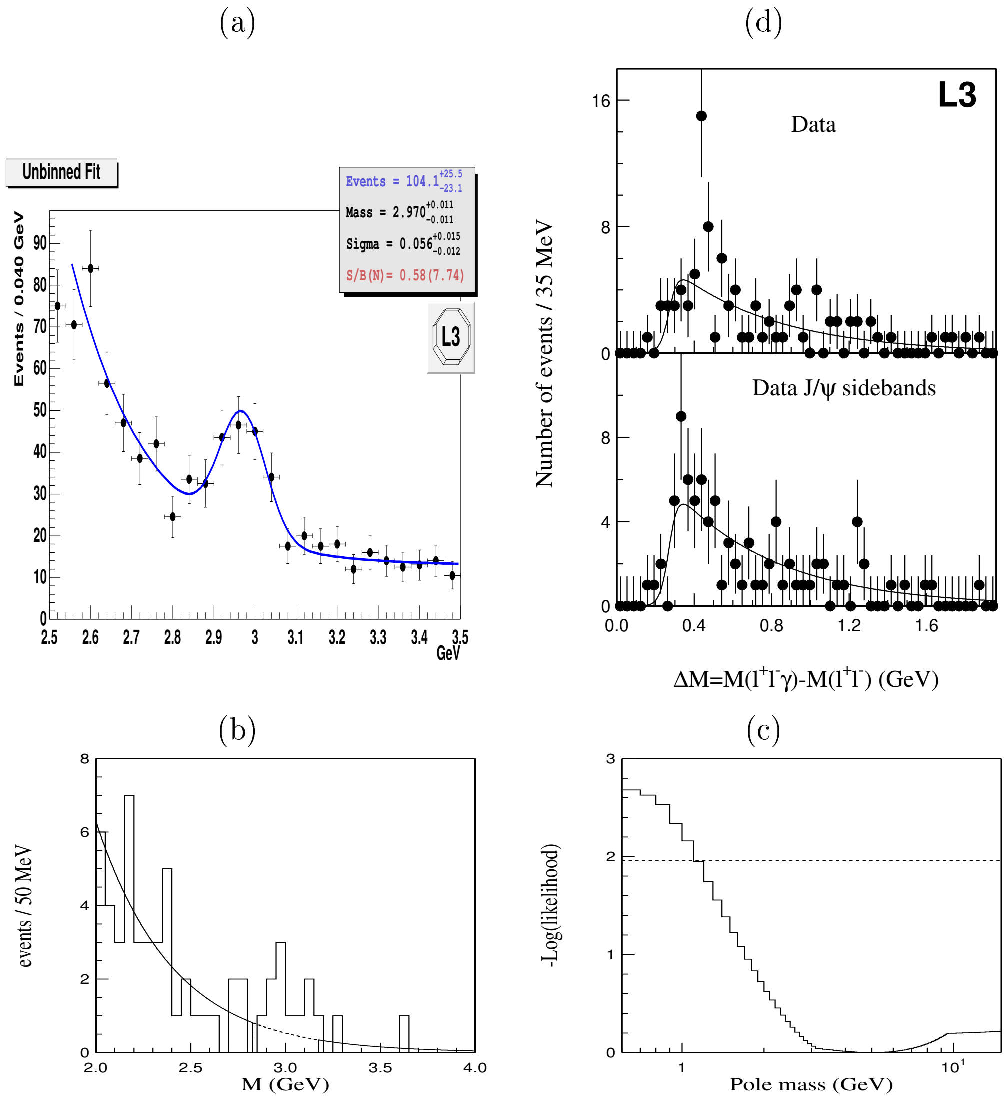


Figure 2: a) $\eta_c$ signal at $\sqrt{s}$= 91 GeV, untagged events. b) $\eta_c$ signal for tagged events. c) Likelihood to observe 5 tagged events as a function of the pole mass in a VDM model. d) $\chi_{c2}$ signal (top) and background (bottom).

sample (Fig.2b), $< Q^2 > \simeq 2$ GeV$^2$. This signal is sufficient to exclude, at 95 % CL, a VDM form factor with $\Lambda < 1$ GeV. The $J/\Psi$ pole, $\Lambda = m_{J/\Psi}$, is well compatible with the data (Fig.2c).

The $\chi_{c2}(3550)$ is detected through its dominant (Br= 13.5 %) radiative decay to $J/\Psi$ and the subsequent leptonic decay: $\chi_{c2} \to \gamma$ J/$\Psi$ $\to \gamma e^+e^-$, $\gamma\mu^+\mu^-$. Combining the data at $\sqrt{s}$= 91 GeV (L$_{ee}$=140 pb$^{-1}$) and at $\sqrt{s}$= 183 GeV (L$_{ee}$=52 pb$^{-1}$), the $\chi_{c2}$ signal appears at the expected value ($\Delta M = 0.445 \pm 0.010$ GeV) in the plot of the mass difference $\Delta M = M(l^+l^-\gamma) - M(l^+l^-)$ (Fig.2d top), when the mass of the lepton pair is within 250 MeV of the nominal J/$\Psi$ mass. The background is obtained by fitting a threshold function simultaneously to the $\Delta M$ spectra from the J/$\Psi$ side bands (Fig.2d bottom) and to the selected data excluding the $\chi_{c2}$ signal region. We observe 14.7 $\pm$ 5.1 events and we obtain the two-photon width $\Gamma_{\gamma\gamma}(\chi_{c2}) = 1.07 \pm 0.39$ (stat.)$\pm$0.22 (sys.)$\pm$0.09(BR) keV, consistent with previous measurements [8]. From this value we calculate $\alpha_s(m_c) = 0.20 \pm 0.05$, a smaller value than expected by the evolution of the QCD coupling constant : $\alpha_s(m_c) \simeq 0.3$.

This was already noticed by Ref. [9] in a study of many $c\bar{c}$ and $b\bar{b}$ states.

## 4 The $K^0_S K^0_S$ channel

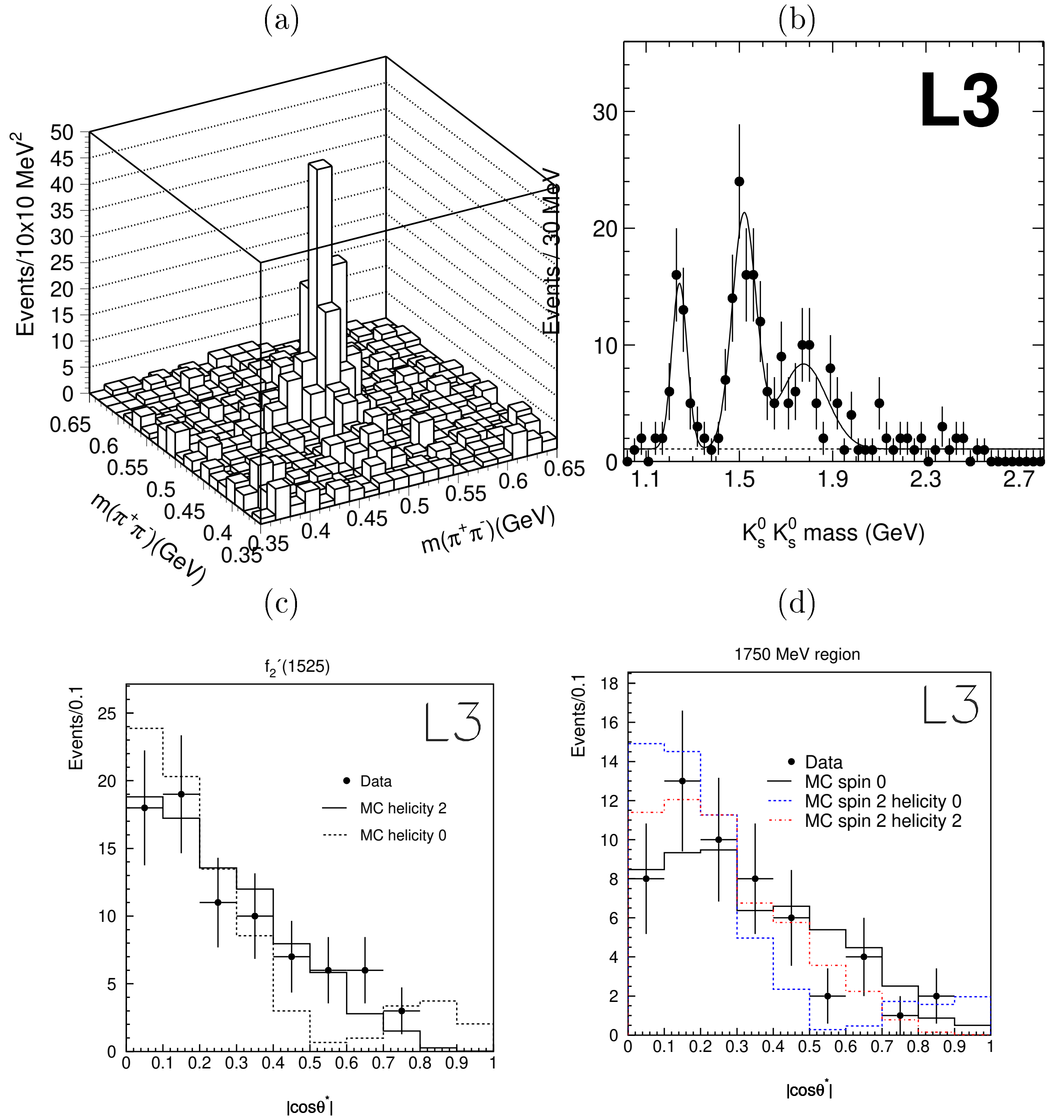


Figure 3: a) Selection of $K^0_S K^0_S$ events. b)$K^0_S K^0_S$ effective mass spectrum. c) and d) Angular distributions of the $K^0$ in the $\gamma\gamma$ centre-of mass, compared with different spin-parity and helicity expectations.

The exclusive $e^+e^- \to e^+e^- K^0_S K^0_S$ channel is well identified (Fig.3a). Results at $\sqrt{s}$=91 GeV have been already published [10]. The $K^0_S K^0_S$ mass spectrum, for all presently available data, $91 < \sqrt{s} < 183$ GeV, is shown in Fig.3b. The backround (dotted line in Fig.3b) is very low. At a mass of $\sim$ 1.2 GeV we observe the interference of the low-lying $2^{++}$ states, the $a_2(1320)$ and $f_2(1250)$. The $s\bar{s}$ state, $f_2'(1525)$, is well identified, with 85$\pm$11 events in the peak. The analysis of the $K^0$ angular distribution in the two-photon centre-of-mass system (Fig.3c), favours a pure helicity $\lambda = 2$ state ($\chi^2/dof$ =7/9, in contrast to $\chi^2/dof$ =81/9 for pure helicity $\lambda = 0$). At higher masses we observe a peak with mass M=1770 $\pm$ 20 MeV and width $\Gamma = 200 \pm 50$ MeV. It can be a radially excited state of the

$f_2^{'}(1525)$ [11], or the $s\bar{s}$ partner of the $0^{++}$ octet [12]. A spin-parity analysis of this region (Fig.3d) favours the second hypothesis with $\chi^2$ values of 50, 26 and 7, for 9 degrees of freedom, for J=2 $\lambda$=0, J=2 $\lambda$=2 and J=0 respectively.

No signal is observed in the $\xi(2230)$ region, where a candidate gluonium is observed in the radiative decay of the $J/\Psi$ [13, 14]. We calculate an upper limit $\Gamma_{\gamma\gamma}(\xi(2230))\times \mathrm{Br}(\xi(2230) \rightarrow \mathrm{K_S^0K_S^0}) < 3$ eV at 95% CL, under the hypothesis of a pure $\lambda = 2$, $2^{++}$ state.

# 5 Conclusions

At LEP we can study the formation of many resonances by two-photon interactions. The clean background conditions allow to investigate the spectrum of radial recurrencies of $q\bar{q}$ states and to test the two-photon coupling of gluonium candidates observed in gluon rich reactions. The following is the table of all results obtained at L3, including also the $\pi^+\pi^-\pi^0$ channel published in [15].

| Resonance | final state | $J^{PC}$ | $\Gamma_{\gamma\gamma}(keV)$ |
|---|---|---|---|
| $\eta^{'}(958)$ | $\pi^+\pi^-\gamma$ | $0^{-+}$ | 4.17±0.10±0.27 |
| $a_2(1320)$ | $\pi^+\pi^-\pi^0$ | $2^{++}$ | 0.98±0.05±0.09 |
| $a_2^{'}(1752)$ | $\pi^+\pi^-\pi^0$ | $2^{++}$ | 0.29*±0.04±0.02 |
| $f_2^{'}(1525)$ | $\mathrm{K}_s^0\mathrm{K}_s^0$ | $2^{++}$ | 0.093*±0.018 ±0.022 |
| X(1770) | $\mathrm{K}_s^0\mathrm{K}_s^0$ | $0^{++}$ | |
| $\xi(2230)$ | $\mathrm{K}_s^0\mathrm{K}_s^0$ | $2^{++}$ | $\Gamma_{\gamma\gamma} \times BR < 3$ eV |
| $\eta_c(2980)$ | 10 chan | $0^{-+}$ | 9.3±1.8±2.7 (BR) |
| $\chi_{c2}(3555)$ | $l^+l^-\gamma$ | $2^{++}$ | 1.07±0.39±0.24 |
| | | | $\star\ \Gamma_{\gamma\gamma} \times BR$ |

# 6 Acknowledgements

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