EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

L3 Note 1781.1
July 4, 1995

Observation of the Formation of the χ_{c2} in Photon-Photon Collisions at LEP

The L3 Collaboration

Submitted to the EPS95 conference

Abstract

We report on a measurement of the exclusive reactions $\gamma\gamma \rightarrow \mu^+\mu^-\gamma$ and $\gamma\gamma \rightarrow e^+e^-\gamma$. The data were taken with the L3 detector at the e^+e^- colliding beam accelerator LEP. From these channels we have extracted a preliminary value for the two-photon width of the χ_{c2}: $\Gamma_{\gamma\gamma}(\chi_{c2}) = 1.6 \pm 0.8 \pm 0.6$ keV.

1 Introduction

The LEP e^+e^- colliding beam accelerator at CERN near Geneva is very well suited for the study of two-photon processes because the background from annihilation events can be easily separated from the signal events with a cut in visible energy, and be removed from the data sample. The high beam energy also makes high $\gamma\gamma$-masses more accessible.

Here we report on preliminary results on resonance formation in two-photon collisions, from one of the four LEP detectors, L3. We have observed the reactions $\gamma\gamma \rightarrow \mu^+\mu^-\gamma$ and $\gamma\gamma \rightarrow e^+e^-\gamma$. From these, we have obtained a preliminary value of the two-photon width of the χ_{c2}.

2 The two-photon width of the χ_{c2}

The two-photon decay widths of heavy-quark mesons are particularly interesting, because the high mass of the quarks allows one to treat the decays non-relativistically and perturbatively. Up to now, results on formation of the charmonium states η_c, χ_{c0} and χ_{c2} have been reported. These results still suffer from statistical uncertainties.

In a simple model, comparison of the QED and QCD transition amplitudes gives for the χ_{c2}-state:

$$\frac{\Gamma(\chi_{c2} \rightarrow \mathrm{gg})}{\Gamma(\chi_{c2} \rightarrow \gamma\gamma)} = \frac{9}{8}\,(\frac{\alpha_s}{\alpha})^2. \tag{1}$$

If the two-gluon width is identified with the total hadronic width, which is equal to the total width minus the radiative width, the two-photon width of the χ_{c2} can be obtained. For a frequently used value of $\alpha_s(m_c)$=0.25, and for $\Gamma(\chi_{c2} \rightarrow \mathrm{gg})$= 1.73±0.16 MeV[1], eq. (1) gives $\Gamma_{\gamma\gamma}(\chi_{c2}) \simeq 1.4$ keV.

A more extended model[2] also takes into account that a P-wave meson like the χ_{c2} can decay into hadrons not only by radiating two gluons, but also by radiating a third one, see figure 1. In the process $\chi_{c2} \rightarrow$ ggg, the original $q\bar{q}$-pair is transformed from a colour-singlet P-wave to a colour-octet S-wave, whose contribution is independent of the total angular momentum J. Because J=1 particles like the χ_{c1} are forbidden to decay into two massless gluons according to the Yang-Landau theorem, the three-gluon term can be identified with the process $\chi_{c1} \rightarrow$ hadrons. Equation (1) is now replaced by

$$\frac{\Gamma(\chi_{c2} \rightarrow \mathrm{hadrons}) - \Gamma(\chi_{c1} \rightarrow \mathrm{hadrons})}{\Gamma(\chi_{c2} \rightarrow \gamma\gamma)} = \frac{9}{8}\,(\frac{\alpha_s}{\alpha})^2. \tag{2}$$

For α_s= 0.25±0.02 this gives $\Gamma_{\gamma\gamma}(\chi_{c2})$ = 0.82 ± 0.23 ± 0.30 keV, where the first error reflects uncertainties in experimental input, and the second estimates the theoretical uncertainty.

Mangano and Petrelli[3] extend this model even further and give the next-to-leading

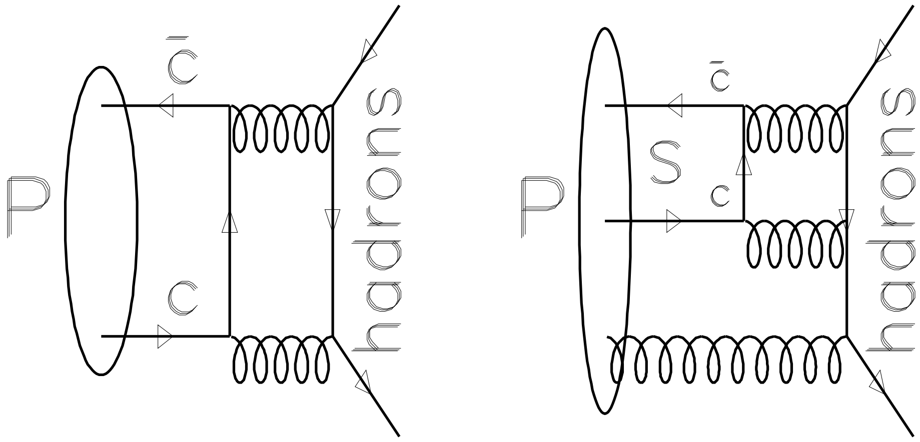

Figure 1: Decay of a P-wave cc̄-pair into hadrons, on the left by the decay into two gluons and on the right by the decay into three gluons. In the process cc̄ → ggg, the original qq̄-pair is transformed from a colour-singlet P-wave to a colour octet S-wave.

order expressions for χ_c decay widths:

$$\Gamma(\chi_J \to \gamma\gamma) = A_J^{\gamma\gamma} e_c^4 \alpha^2 \frac{|\, R'(0)\,|^2}{m_c^4}(1 + B_J \frac{\alpha_s}{\pi}) \quad (J = 0, 2), \tag{3}$$

$$\Gamma(\chi_J \to \mathrm{hadrons}) = A_J^{gg} \alpha_s^2 \frac{|\, R'(0)\,|^2}{m_c^4}(1 + C_J \frac{\alpha_s}{\pi}) + \pi\alpha_s^2 H_8 \quad (J = 0, 2), \tag{4}$$

$$\Gamma(\chi_{c1} \to \mathrm{hadrons}) = -\frac{56 n_f}{27}\alpha_s^2 \frac{\alpha_s}{\pi}\frac{|\, R'(0)\,|^2}{m_c^4} + \pi\alpha_s^2 H_8, \tag{5}$$

where $|\, R'(0)\,|$ corresponds to the derivative of the non-relativistic P-wave function at the origin, H_8 is a function of α_s, $|\, R'(0)\,|^2 / m_c^4$, and the infrared cutoff energy E_{bind}, and

$$A_0^{\gamma\gamma} = 27, \quad A_2^{\gamma\gamma} = \frac{36}{5}, \quad B_0 = \frac{\pi^2}{3} - \frac{28}{9}, \quad B_2 = -\frac{16}{3},$$
$$A_0^{gg} = 6, \quad A_2^{gg} = \frac{5}{8}, \quad C_0 = 8.772, \quad C_2 = -4.827, \quad n_f = 3.$$

Equation (2) is also replaced by its next-to-leading order equation:

$$\frac{\Gamma(\chi_{c2} \to \mathrm{hadrons}) - \Gamma(\chi_{c1} \to \mathrm{hadrons})}{\Gamma(\chi_{c2} \to \gamma\gamma)} = \frac{9}{8}\,(\frac{\alpha_s}{\alpha})^2 \frac{1 + \frac{\alpha_s}{\pi} B_2}{1 + (C_2 + \frac{35}{9})\frac{\alpha_s}{\pi}}. \tag{6}$$

Inserting α_s=0.25 in this equation yields $\Gamma_{\gamma\gamma}(\chi_{c2}) = 0.55 \pm 0.10$ keV. However, Mangano and Petrelli do it the other way around: When experimental values are inserted for the decay widths (3), (4), and (5), the parameters α_s, $|\, R'(0)\,|^2 / m_c^4$, and H_8, which are assumed to have about the same value for these decays, can be determined with a global fit. For $\Gamma_{\gamma\gamma}(\chi_{c2})$ the measurements of CLEO[4], TPC/2γ[5], and E760[6] have been used. When the value for α_s (0.286$\pm$0.031) obtained with the global fit is inserted into eq. (6), a ratio of 3.3$\pm$1.0 is obtained [3]. This is equivalent to $\Gamma_{\gamma\gamma}(\chi_{c2}) = 0.36\pm0.12$ keV. However, the quality of the fit is poor, mainly due to the discrepancy between the different measured values of $\Gamma_{\gamma\gamma}(\chi_{c2})$.

Other models, depending on various other mechanisms, predict values for $\Gamma_{\gamma\gamma}(\chi_{c2})$ in the range 0.5 - 2.0 keV. For example, a calculation with relativistic wave functions by Barnes [7] gives 0.56 keV.

3 The Experiment

The L3 experiment is a general purpose detector with the usual components for detecting charged particles and measuring their momenta, for measuring the energy and the position of electromagnetically and hadronicallly interacting particles and for identifying high-energy muons. It has a calorimetric system at small angles for detecting tagging electrons. This system is also used for measuring the luminosity of the e^+e^- beams.

An exceptional feature of the L3 detector, especially useful for studies of two-photon events containing photons, is the electromagnetic calorimeter, an array of about 11 000 BGO crystals, covering $\simeq$ 97% of the solid angle. This calorimeter has an excellent energy resolution, due to its intrinsic resolution of 1.4% at high energies and to the fact that it is located inside the magnet, so that the amount of material between the interaction point and the calorimeter is small. This detector was used for the following purposes in the analyses presented here: *i)* for identifying photons and measuring their energy, *ii)* for the identification of electrons, and *iii)* for the identification of low-energy muons.

Charged particles are measured over $\simeq$ 90% of the solid angle with the Time Expansion Chamber (TEC), a set of two cylindrical drift chambers with wires parallel to the beam axis, arranged in 12 inner sectors and 24 outer sectors. The polar angle measurement of TEC by means of charge division is complemented by means of a z-detector which surrounds the TEC.

The luminosity of the accelerator, as well as the presence and energies of tagging electrons are established by a set of forward detectors on either side of the interaction point. The forward detectors are made of 304 BGO crystals each, and cover the polar angles between 31 and 62 mrad.

The other detector components were not used in these analyses and are therefore not described here. The LEP accelerator was operated at, or near the cm energy corresponding to the mass of the Z boson, around 91 GeV. The requirement of a low visible mass, combined with a balance in total transverse momentum, removes any annihilation background completely. The data shown in this conference were taken from 1991 to 1994 and correspond to an integrated e^+e^- luminosity of about 110 pb^{-1}.

4 The Event Selection

We have studied the χ_{c2} through its decay to γJ/ψ, with the subsequent decay of the J/ψ to e^+e^- or $\mu^+\mu^-$. Thus the final state consists of two oppositely charged tracks and a photon. We require that the transverse momentum balance squared (possibly including a tagging electron) be smaller than 0.05 GeV^2. In this sample we find still a large signal due to the $\eta'(958)$. Its two-photon width agrees to satisfaction with the PDG value, which increases our confidence in our analysis procedure.

For the selection of χ_{c2} events, we require that the energy of the photon be above 300 MeV and separated by at least 300 mrad from any charged track. We identify electrons by requiring that for both tracks the ratio of energy observed in BGO to momentum measured in the TEC be within 15% of unity. Muons are identified by requiring that their energy deposit be less than 500 MeV. We then select lepton pairs which are compatible with coming from the J/ψ by requiring that the invariant mass be within 280 MeV of the nominal J/ψ mass. The resolution at these masses is not very good, therefore we are not able to see the J/ψ signal above the background. However, the excellent energy resolution of the BGO calorimeter allows us to perform a difference measurement which is to a large extent insensitive to the mass resolution.

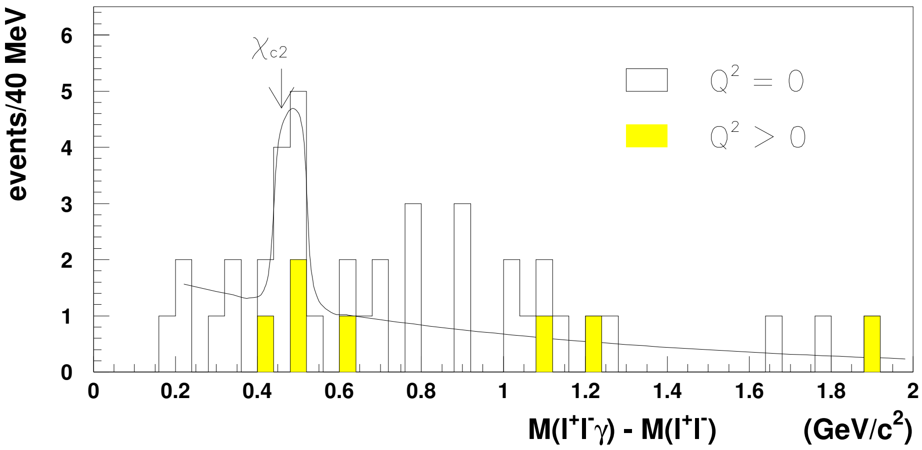

Figure 2: The event distribution as a function of the mass difference $m(l^+l^-\gamma) - m(l^+l^-)$. The arrow indicates the expected value for the χ_{c2}. The shaded events are events in which a tagging electron was observed.

In fig. 2 we have plotted the $e^+e^-\gamma$ and $\mu^+\mu^-\gamma$ events as a function of the mass difference $m(l^+l^-\gamma) - m(l^+l^-)$, with $l =$ e or μ. We see an enhancement of 6.8 ± 3.5 events over background at the expected value for the χ_{c2}.

5 Results

We have calculated the two-photon width of the χ_{c2} using a Monte Carlo technique, taking into account the helicity amplitudes[4] of the χ_{c2}, and assuming a J/ψ-pole form factor for the Q^2 dependence. The overall efficiency (not including the branching ratio for χ_{c2} to γe^+e^- and $\gamma\mu^+\mu^-$) is 5.9%. Using 6.8 events as the signal, we find the preliminary value

$$\Gamma_{\gamma\gamma}(\chi_{c2}) = 1.6 \pm 0.8 \pm 0.6 \text{ keV}.$$

The first error is again statistical, and the second systematic. This agrees with earlier measurements, but is statistically not yet sufficiently significant to make a statement about the models mentioned earlier.

References

[1] L. Montanet et al., The Particle Data Group Phys. Rev. **D50** (1994) 1173.

[2] G. T. Bodwin, E. Braten, and G. P. Lepage, Phys. Rev. **D46** (1992) 1914.

[3] M. L. Mangano and A. Petrelli, CERN-TH/95-67 (1995).

[4] CLEO Collaboration, J. Dominick et al., Phys. Rev. **D50** (1994) 4265.

[5] TPC/2γ Collaboration, D. A. Bauer et al., Phys. Lett. **B302** (1993) 345.

[6] E760 Collaboration, T. A. Amstrong et al., Phys. Rev. Lett. **70** (1993) 2988.

[7] T. Barnes, Proceedings of the IXth International Workshop on Photon-Photon Collisions, La Jolla, CA (1992).