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Measurement of $\Gamma_{\gamma\gamma}(\eta_c)$ in the L3 Detector at LEP and Prospects for $\gamma\gamma \to$ Charmonium at LEP 200 †

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Abstract

The special advantages of the L3 detector for $\gamma\gamma$ collision physics are pointed out. The recent measurement by L3 of $\Gamma_{\gamma\gamma}(\eta_c)$ is briefly described. Agreement of the value of $\alpha_s(M_c)$ determined from the branching ratios: $\Gamma_{\gamma\gamma}(\eta_c)/\Gamma_{\eta_c}$, $\Gamma_{ee}(J/\psi)/\Gamma_{\eta_c}$ with deep inelastic scattering results is much improved by including effective gluon mass corrections. A comparison is made, for charmonium physics in $\gamma\gamma$ collisions, between LEP and B-Factories. Estimates of the rates to be expected at LEP200 for hidden charm and beauty production are given. The important complementarity of LEP and a Tau/Charm factory for charmonium studies is stressed.

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1 Two Photon Physics using the L3 Detector

The central detectors of L3, the TEC (Time Expansion Chamber) [1] and the BGO Electromagnetic Calorimeter [2], (see Fig 1) are well adapted to the study of exclusive final states in photon-photon collisions. The important characteristics of the TEC in this respect are:

- 62 sense wires covering the angular range : $13° < \theta < 167°$
- $\sigma_{p_T} = 0.02 p_T (GeV)^2$
- Good dE/dX measurement (resolution $\simeq$ 10%) for low momentum tracks in the $1/\beta^2$ region.
- A fast trigger [4] with a low p_T threshold of 100-200 MeV.

The modest p_T resolution of the TEC is quite adequate for the low momentum charged particles produced in the final states of $\gamma\gamma$ collisions. The BGO calorimeter has $\simeq$ 11,000

crystals arranged in barrel modules ($42° < \theta < 138°$) and end-cap modules ($11.6° < \theta < 38°, 142° < \theta < 168.4°$). The energy resolution of the detector for low energy photons is

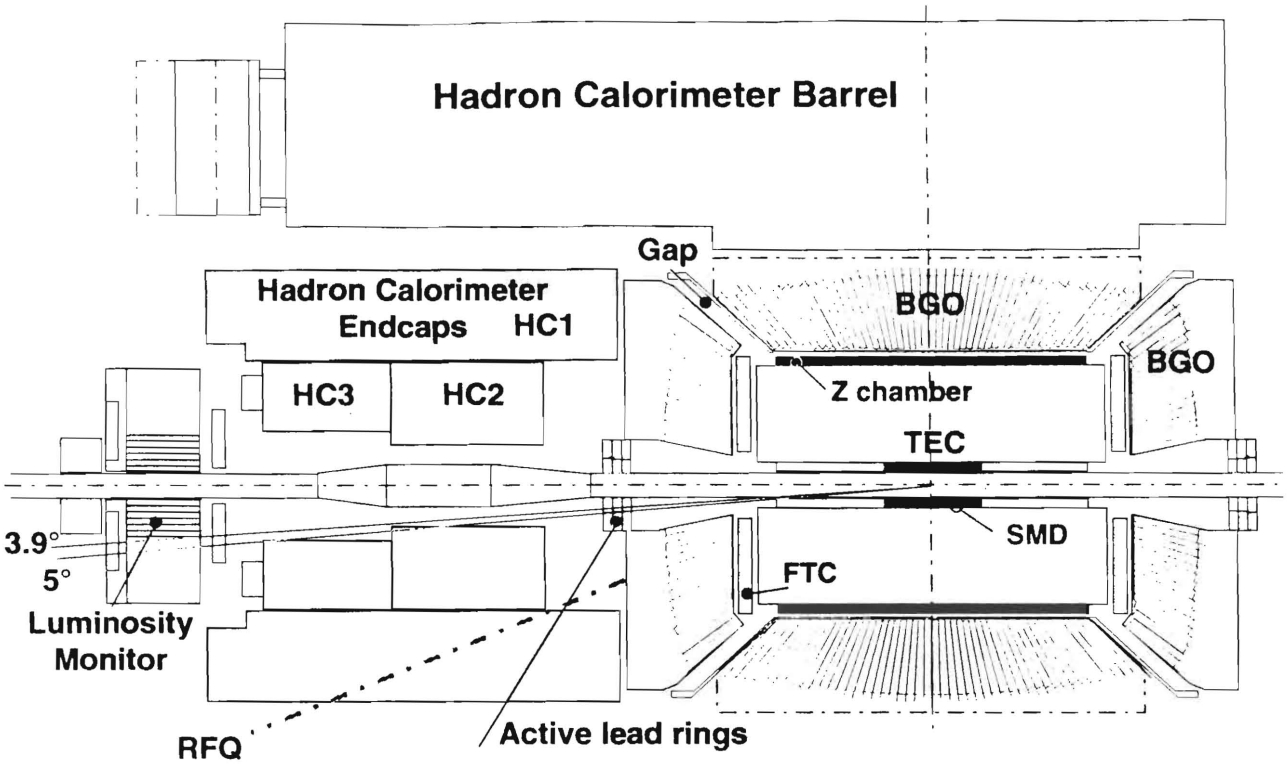

Fig 1. The Central Region of L3

Detector	Type	Angular range	Q^2 range $(\mathrm{GeV})^2$
End cap $\mathcal{EM}$ Cal.	BGO	$11.6° < \theta < 38°$	332-3400
Active Lead Ring	Lead/Scintillator	$3.9° < \theta < 8°$	36-160
Luminosity Monitor	BGO	30 mrad$< \theta <$62 mrad	7-30
Very Small Angle Tagger	Tungsten/Silicon	4 mrad$< \theta <$ 10 mrad	0.2-0.8

Table 1: L3 Tagging detectors. Q^2 estimates are for LEP200 with $E_{beam} = 90GeV$. The Very Small Angle Tagger is still under study.

excellent with $\sigma_E/E \simeq 0.05$ at 100 MeV and $\simeq 0.023$ for $E > 1$ GeV. In addition L3 is well equipped with detectors able to tag the final state $e^{\pm}$ in photon photon collisions. The characteristics of these detectors are summarised in Table 1. All, except the VSAT, behind the first quadrupole, which is currently under study, are shown in Fig 1. Analyses of single tagged data (for example the measurement of the photon structure function) are underway, but are not described here.

The dE/dX measurement in the TEC (see Fig 2) is used to separate $\pi/K/p, \bar{p}$ for momentum below 1 GeV, and also to reject beam gas events which typically contain one or more low energy protons.

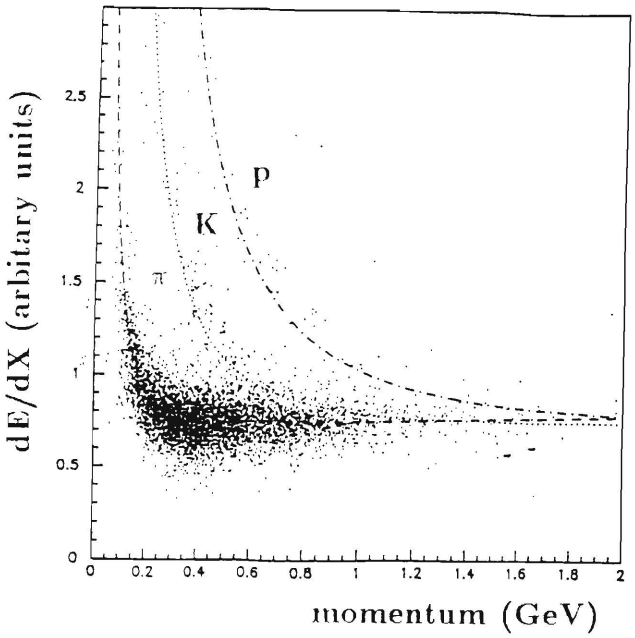

Fig 2. dE/dX versus momentum for the TEC. The π, K, p lines shown are fits to the Bethe-Bloch formula.

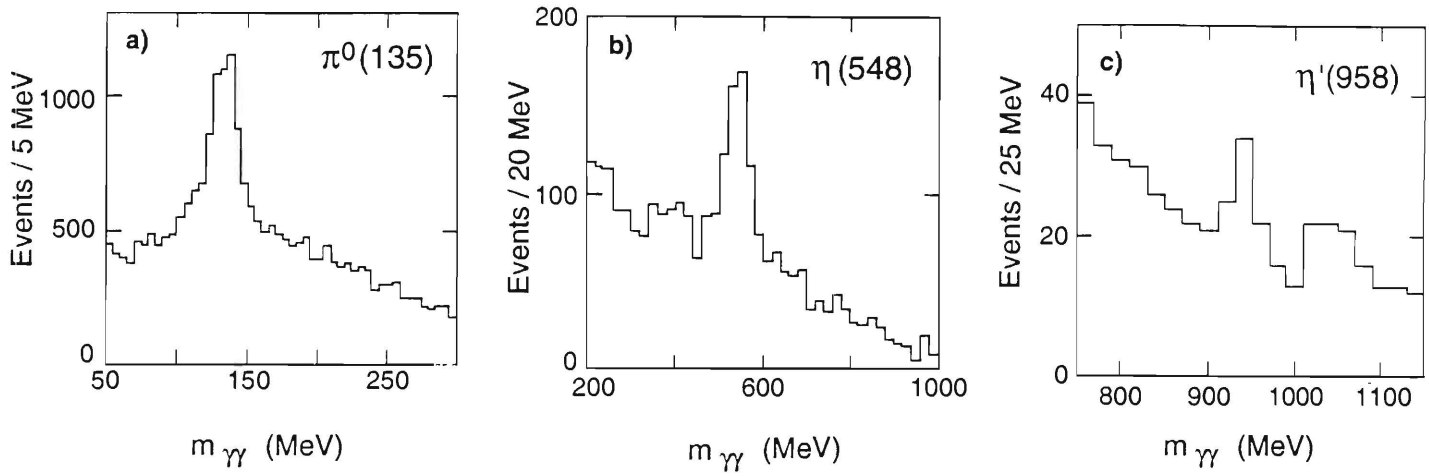

Fig 3. Two photon effective mass distributions showing signals for:
a) π^0, b) η, c) η'

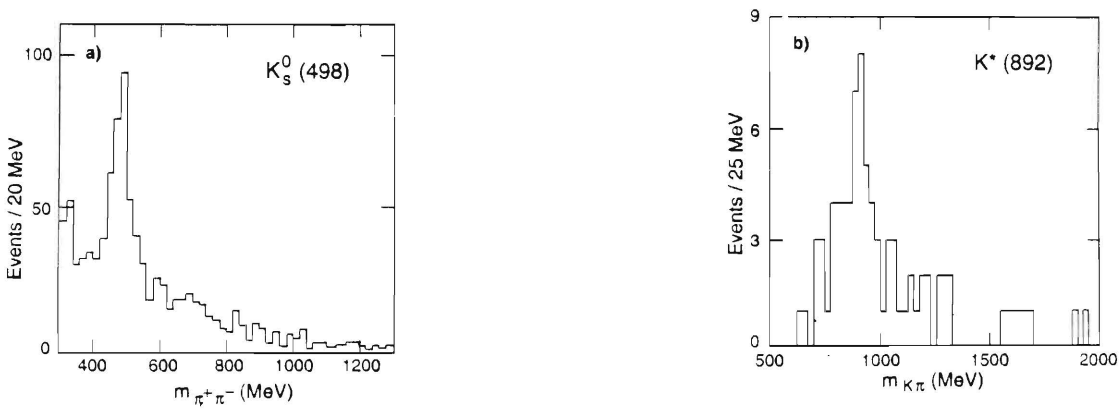

Fig 4. a) $\pi^+\pi^-$ effective mass distribution
b) Kπ effective mass distribution.

The first step in the η_c analysis, described below, is to use the good BGO energy resolution and the dE/dX information to identify the following unstable particles in final states of low charged multiplicity (2 or 4 charged tracks) :

$$\pi^0, \qquad \eta, \qquad \eta', \qquad K^0, \qquad K^*(892)$$

Effective mass distributions showing signals for these particles are shown in Figs 3,4. Such identified unstable particles are used in the search for the different known [5] decay channels of the η_c.

2 Measurement of $\Gamma_{\gamma\gamma}(\eta_c)$

This measurement [6], [7] used data corresponding to an integrated luminosity of 30 pb^{-1} collected in 1991-1992. The basic cuts used to select exclusive final states originating from the η_c decay were:

- 2 or 4 charged tracks
- Charge balance
- Beam gas background (events with protons) removed using dE/dX.
- Small p_T imbalance : $|\sum \vec{p_T}|^2 < 0.015(GeV)^2$.

The 12 different decay modes where an η_c signal was looked for are listed in Table 2. The entries in this Table are: the measured [5] branching ratio (BR), the acceptance (given by a Monte Carlo calculation including full detector simulation), the number of observed events N_{obs}, and the estimated number of background events N_{back}. The Monte Carlo generator [8] used the exact transverse luminosity function [9] and a pure phase space distribution for the final state particles. The background levels were estimated by fitting exponential functions to 'side bands' in the $|\sum \vec{p_T}|^2$ or effective mass distributions. The 'signal' region of effective mass was 2900-3100 MeV. The effective mass distribution for the sum of the 12 analysed channels is shown in Fig 5. 28 candidate events are observed in the signal region with an estimated background of 11 events. A Gaussian fit to the mass peak in Fig 5 gives:

$$M_{\eta_c} = 3003 \pm 15 MeV, \qquad \sigma = 45 \pm 12 MeV$$

The fitted mass value is consistent with the measured [5] η_c mass of $2979 \pm 2 MeV$, and the Gaussian width σ is consistent with the mass resolution, estimated by Monte Carlo to be 60 MeV. The natural width of the η_c [5] of $\Gamma_{\eta_c} = 10 \pm 4 MeV$ is much smaller. The value obtained for the radiative width (see [5], [6]) for more details) is:

$$\Gamma_{\gamma\gamma}(\eta_c) = 8.0 \pm 2.3 \pm 2.4 keV \qquad \text{(L3)}$$

The first error is statistical, the second systematic.

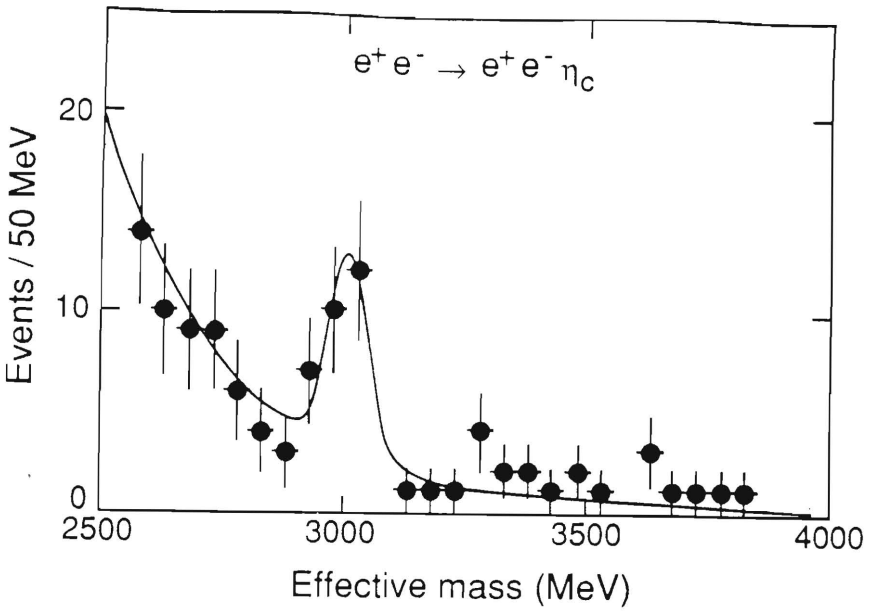

Fig 5. Effective mass distribution summed over the 12 analysed channels.

Channel	$\mathcal{B}R$ [5] %	Acceptance %	N_{obs}	N_{back}
$\eta\pi^+\pi^-$ ($\eta \Rightarrow \gamma\gamma$)	1.27 ± 0.47	2.4 ± 0.1	1	0.
$\eta\pi^+\pi^-$ ($\eta \Rightarrow \pi^+\pi^-\pi^0$)	0.77 ± 0.28	0.53 ± 0.07	2	0.8 ± 0.6
$\eta'\pi^+\pi^-$ ($\eta' \Rightarrow \rho^0\gamma$)	0.82 ± 0.34	5.2 ± 0.2	2	0.5 ± 0.3
$\eta'\pi^+\pi^-$ ($\eta' \Rightarrow \pi^+\pi^-\eta$)	0.47 ± 0.19	1.3 ± 0.2	0	0.5 ± 0.6
$\eta'\pi^+\pi^-$ ($\eta' \Rightarrow \gamma\gamma$)	0.06 ± 0.02	3.0 ± 0.2	1	0.
$\pi^+\pi^-\pi^+\pi^-$	1.2 ± 0.4	3.7 ± 0.1	8	1.7 ± 0.3
$K^+K^-\pi^+\pi^-$	2.0 ± 0.7	3.6 ± 0.2	4	3.2 ± 0.4
$K^{*0}K^\pm\pi^\mp$ ($K^{*0} \Rightarrow K^\mp\pi^\pm$)	1.33 ± 0.46	6.6 ± 0.2	5	2.9 ± 0.3
$K^{*0}K^{*0}$ ($K^{*0} \Rightarrow K^\pm\pi^\mp$)	0.19 ± 0.06	5.8 ± 0.3	1	0.5 ± 0.2
$\phi\phi$ ($\phi \Rightarrow K^-K^+$)	0.17 ± 0.07	5.6 ± 0.2	0	0.
$K^\pm\pi^\mp$ ($\Rightarrow \pi^-\pi^+$)	1.51 ± 0.41	6.9 ± 0.3	3	0.5 ± 0.2
$K^+K^-\pi^0$	1.10 ± 0.30	3.8 ± 0.2	1	0.2 ± 0.1

Table 2: The decay modes explored in this analysis with their measured branching ratio, the detector acceptance, the number of observed events in the mass interval 2900-3100 and their estimated background.

Experiment	Reference	$\Gamma_{\gamma\gamma}(\eta_c)$ (keV)	Decay channel	# Events	$\sum \mathcal{L}(pb^{-1})$
PLUTO†	[10]	23 ± 12	$K^0_s K^\pm\pi^\mp$	10	45
TASSO†	[11]	$16.1 \pm 6.3 \pm 6.0$	$K^0_s K^\pm\pi^\mp$	41	83
TPC/2γ	[12]	$6.4^{+5.3}_{-3.1}$	$\phi\phi$	1	69
CLEO†	[13]	$7.8^{+3.1}_{-2.5} \pm 2.3$ $8.5^{+4.6}_{-4.2} \pm 3.9$	$K^0_s K^\pm\pi^\mp$ $K^+K^-\pi^+\pi^-$	10	429
CLEO II	[14]	$5.7 \pm 1.3 \pm 1.2 \pm 1.6$	$K^0_s K^\pm\pi^\mp$	43	1630
R704	[15]	$4.3^{+3.4}_{-3.7} \pm 2.4$	$\gamma\gamma$	$\simeq 10$	0.511 ($p\bar{p}$)
L3	[7]	$8.0 \pm 2.3 \pm 2.4$	see Table 2	17	30

Table 3: Compilation of measurements of $\Gamma_{\gamma\gamma}(\eta_c)$. Errors are either total (single error) or: statistical,systematic,branching ratio. † indicates that an improved $K\bar{K}\pi$ branching ratio is used.

This result, the first two photon radiative width to be measured at LEP, is compared with previous measurements in Table 3. The L3 determination is remarkable for the large number of channels analysed and the (correlated) large ratio: # signal events / $\sum \mathcal{L}$ obtained. The updated World Average value is found to be:

$$\Gamma_{\gamma\gamma}(\eta_c) = 7.1 \pm 1.1 \pm 2.0 keV \qquad \text{(WA)}$$

Since all measurements have a common large systematic error due to the uncertainty of the branching ratios [1], this common error is removed from the systematic error of each experiment before performing the weighted average. To calculate the weighted average the remaining systematic error and the statistical errors are assumed to be uncorrelated between the different experiments and are added in quadrature. The first error quoted above is that on the weighted average [2], while the second error (28 %) is the systematic error due to the branching ratio.

3 Theoretical Estimate of $\Gamma_{\gamma\gamma}(\eta_c)$

Within the non-relativistic quarkonium model the $\eta_c \to \gamma\gamma$ transition (Fig 6b) is simply related to the decay $J/\psi \to e^+e^-$ (Fig 6a). In fact [16]:

$$\Gamma_{\gamma\gamma}(\eta_c) = \frac{64\pi\alpha^2}{27M_c^2}|\Psi_{\eta_c}(0)|^2[1 - \frac{3.4}{\pi}\alpha_s(M_c)] \tag{1}$$

$$\Gamma_{ee}(J/\psi) = \frac{64\pi\alpha^2}{9M_{J/\psi}^2}|\Psi_{J/\psi}(0)|^2[1 - \frac{16}{3\pi}\alpha_s(M_c)] \tag{2}$$

Assuming:

$$2M_c = M_{J/\psi}, \qquad \Psi_{\eta_c}(0) = \Psi_{J/\psi}(0)$$

and neglecting the $O(\alpha_s)$ QCD corrections leads to the simple prediction:

$$\Gamma_{\gamma\gamma}(\eta_c)/\Gamma_{ee}(J/\psi) = 4/3 \tag{3}$$

The measured value of $\Gamma_{ee}(J/\psi)$ of 5.4 ± 0.3 keV [5] leads to the estimate:

$$\Gamma_{\gamma\gamma}(\eta_c) = 7.2 keV$$

in excellent agreement with the WA value given above [3]

4 Determination of $\alpha_s(M_c)$

In the non-relativistic quark model the total width of the η_c is given, in lowest order of perturbative QCD, by the process shown in Fig 6c. It is the same as for $\eta_c \to \gamma\gamma$

[1] This is due to the poorly known branching ratio $\Gamma(J/\psi \to \eta_c\gamma)/\Gamma(J/\psi \to anything)$. See also Section 5 below.

[2] $\sigma = [\sum \frac{1}{\sigma_i^2}]^{-1/2}$

[3] Including the $O(\alpha_s)$ QCD correction with $\alpha_s(M_c) = 0.33$ gives 8.5 keV

except that the final state photons are replaced by gluons. On taking the ratio of the total width of the η_c: $\Gamma_{\eta_c} = \Gamma_{gg}(\eta_c)$ to $\Gamma_{\gamma\gamma}(\eta_c)$, there is not only an exact cancellation of the wave function at the origin, but also, in view of the close similarity of the diagrams in Fig 6b,6c, relativistic corrections are also expected to largely cancel. Thus α_s at the

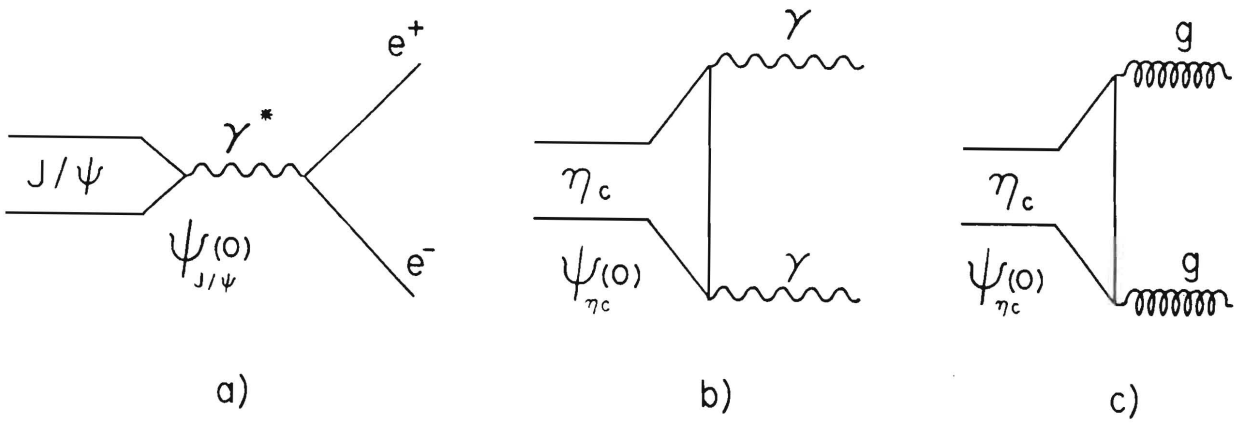

Fig 6. Lowest order diagrams in the non-relativistic quarkonium model:
a) $J/\psi \to e^+e^-$, b) $\eta_c \to \gamma\gamma$ c) $\eta_c \to$ gluon gluon.
$\Psi(0)$ is the wavefunction at the origin of the bound state.

scale of the charm quark mass $\alpha_s(M_c)$ may be determined from the branching ratio [16]:

$$\frac{\Gamma_{\eta_c}}{\Gamma_{\gamma\gamma}(\eta_c)} = \frac{9\alpha_s(M_c)^2}{8\alpha^2}[1 + \frac{8.2}{\pi}\alpha_s(M_c)] \tag{4}$$

With the additional assumptions similar to those made above in deriving Eqn 3, but retaining the $O(\alpha_s)$ correction, $\alpha_s(M_c)$ may also be determined from the branching ratio:

$$\frac{\Gamma_{\eta_c}}{\Gamma_{ee}(J/\psi)} = \frac{3}{2}\left[\frac{\alpha_s(M_c)M_{J/\psi}}{\alpha M_{\eta_c}}\right]^2 [1 + \frac{10.2}{\pi}\alpha_s(M_c)] \tag{5}$$

The experimental widths [5]:

$$\begin{aligned} \Gamma_{\gamma\gamma}(\eta_c) &= 7.1 \pm 2.3 keV \\ \Gamma_{ee}(J/\psi) &= 5.36 \pm 0.29 keV \\ \Gamma_{\eta_c} &= 10.3 \pm 3.6 MeV \end{aligned}$$

then give: (I refers to Eqn(4) , II to Eqn(5))

$$\begin{aligned} \alpha_s^I(M_c) &= 0.21 \pm 0.04 \\ \alpha_s^{II}(M_c) &= 0.20 \pm 0.03 \end{aligned}$$

These two values of $\alpha_s(M_c)$ are quite consistent with each other, but only marginally consistent with the value of $\alpha_s(M_c)$ derived by evolution of the precise Deep Inelastic Scattering (DIL) result [17] which is [18]:

$$\alpha_s^{DIL}(M_c) = 0.326 \pm 0.017$$

The discrepancies observed between α_s^{DIL} and α_s^I, α_s^{II} are, respectively, 2.7σ, 3.7σ. A possible explanation [18] of this inconsistecy based on ideas proposed many years ago by Parisi and Petronzio [19] is a predominantly phase space effect due to a non zero 'effective mass' m_g of the gluons in the final state in the process shown in Fig 6c. Such effects also seem to be necessary [19, 20] to explain the inclusive photon spectra observed in the decays: $J/\psi \to \gamma X$, $\Upsilon \to \gamma X$. For J/ψ decays the value of m_g required to fit the measured photon spectrum was found to be: $m_g = 0.66 \pm 0.08 GeV$ [20]. Including the corresponding correction factor calculated in Ref[18] of 0.70 in Eqns[4,5] leads to the modified results for α_s^I, α_s^{II} presented in Table 4. Two cases are considered 'LO' where the $O(\alpha_s)$ correction terms are neglected [4] and 'NLO' where the $O(\alpha_s)$ corrections calculated assuming massless gluons are used. In both cases the discrepancy with the DIL results is reduced. In the LO case the agreement is now very good while in the NLO case discrepancies for α_s^I, α_s^{II} are reduced respectively to 2.0σ, 2.5σ respectively. As described in Ref[17], inconsistencies with a much greater statistical significance than in the case discussed here, in many other charm and beauty bound state decay branching ratios, are all resolved, without the introduction of any adjustable parameters, by taking into account effective gluon mass effects. A more theoretically orientated discussion of the rôle of the gluon mass in perturbative QCD may be found in Refs[20,21].

BR	α_s (LO)	α_s (NLO)
I	$0.31^{+0.07}_{-0.08}$ [0.23]	$0.24^{+0.04}_{-0.06}$ [2.0]
II	$0.31^{+0.05}_{-0.06}$ [0.22]	0.24 ± 0.03[2.5]

Table 4: Values of $\alpha_s(M_c)$ evaluated including the gluon mass corrections from Refs[19,20]. Also shown in square brackets is the quantity: $|\alpha_s^i - \alpha_s^{DIL}|/\sqrt{(\sigma^i)^2 + (\sigma^{DIL})^2}$ $(i = \text{I,II})$. I,II refer to the branching ratios in Eqns[4,5]. 'LO','NLO' are defined in the text.

5 Charmonium Production in $\gamma\gamma$ Collisions. LEP versus B-Factories

LEP has two considerable advantages over low energy e^+e^- colliders for the study of charmonium production in $\gamma\gamma$ collisions. These are:

- larger cross-sections
- much reduced background from one boson annihilation

In Table 5 the cross-sections for η_c production at colliders with beam energies of 5, 45, and

[4] The neglect of these terms may be justified by noting that the phase phase suppression due to gluon mass effects is expected to be even stronger in the diagrams contributing to the NLO corrections than in the Born term of Fig 6c. In particular gluon splitting: $g \to gg$ should be strongly suppressed [18]. In the NLO case massive gluons are assumed for the Born term and massless gluons for the $O(\alpha_s)$ corrections, so that the latter are surely overestimated. The NLO and LO cases therefore give conservative lower and upper limits respectively, on the size of the gluon mass corrections

$90GeV$ are compared. Even after introducing realistic experimental cuts[5] the cross-section is four times higher for $E = 90GeV$, than for $E = 5GeV$. The improved background situation at high energies is illustrated in Fig 7, which compares the effective mass spectra of candidates for the process $\eta_c \to \pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^+\pi^-$ as as observed by two experiments:

(i) CLEO [13] at the CESR collider at Cornell with $\sqrt{s} = 9.5GeV$ ($\Upsilon(1S)$) and $\sum \mathcal{L} = 429pb^{-1}$

(ii) L3 [6, 7] at LEP with $\sqrt{s} = 91.2GeV$ (Z) and $\sum \mathcal{L} = 30pb^{-1}$

For CLEO no signal is observed above the very large background of events from $\Upsilon(1S)$ decays that fake an exclusive final state. For L3 a small signal is clearly seen above the much reduced background. The difference in energy between the one boson annihilation channel is only 6.5 GeV in the case of CLEO, as compared to 88 GeV for the case of L3!

6 Estimates of Charmonium Production in $\gamma\gamma$ Collisions at LEP200

In Table 6 estimates for the production of the states η_c, η_c', χ_{c0}, χ_{c2} are presented, assuming an integrated luminosity of 500 pb^{-1}. For the η_c and the η_c' an extrapolation of the L3 data presented in Table 2 is given. With $\sqrt{s} = 180GeV$ at LEP200 the following extrapolation factors are used: acceptance (0.94), cross-section (1.43), luminosity (16.6). For the χ_c states the acceptance estimates take into account the calculated geometrical acceptance, and expected improved detector performance[6]. This implies that for the η_c and η_c' where no such improvements are taken into account, the numbers given in Table 6 should be taken as conservative lower limits.

It is important to note that the full physics potential at LEP200 for charmonium production can only be realised if much improved branching ratio measurements of the states are obtained. This requires a high luminosity Tau/Charm factory, and a detector equipped with high resolution calorimetery[7] for low energy photons [23]. The error on the present WA value of $\Gamma_{\gamma\gamma}(\eta_c)$ is already dominated by the 28 % branching ratio (BR) error. In fact the experimental measurement of $BR(J/\psi \to \eta_c\gamma)$ [24] that determines this error is based on only $\simeq$ 30 events. According to Table 6 one may expect the present statistical error of $2.3keV$ on $\Gamma_{\gamma\gamma}(\eta_c)$ as measured by L3 to be reduced to $\simeq 0.6keV$ at LEP200, of the same order as the present (non BR) systematic error and a factor of 4 times smaller than the current BR systematic error. Improved tests of QCD, similar to that described in Section 3 above, can be made only if much more precise measurements of the η_c branching ratios and total width become available.

[5] The acceptance decreases with increasing beam energy due to increased collimation of the final state particles along the beam direction due to larger Lorentz boosts

[6] For example improved determination of the momenta and angles of charged tracks using the recently installed Silicon Microvertex Detector

[7] This is, unfortunately, not the case for the detector at the high luminosity BES collider at Beijing

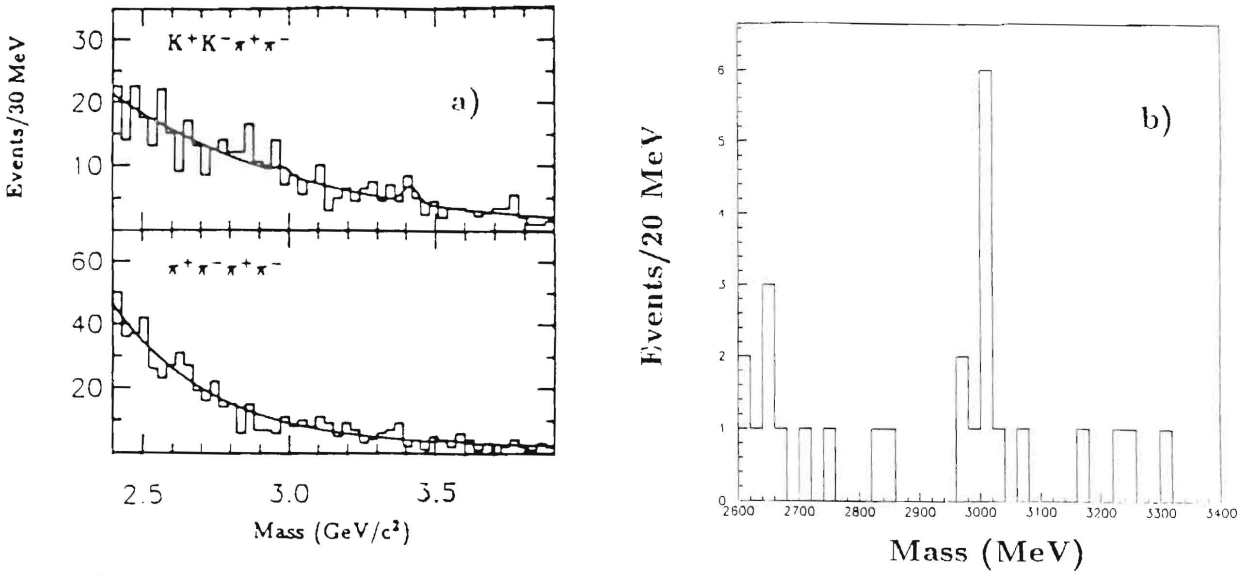

Fig 7. $\pi^+\pi^+\pi^-\pi^-$ and $K^+K^-\pi^+\pi^-$ effective mass distributions from a) CLEO [13], and b) L3 [6]. See text for discussion.

Machine	E_{beam} (GeV)	$\sigma(e^+e^- \to \eta_c e^+e^-)$ (pb)	A	σA (pb)
Cornell	5	13	0.69	9.0
LEP100	45	95	0.33	31.4
LEP200	90	136	0.27	36.7

Table 5: Cross-sections for η_c production. The acceptance A is calculated for the $\pi^+\pi^+\pi^-\pi^-$ state with the cuts: $16° < \theta_\pi < 164°$, $p_T^\pi > 80 MeV$.

State	$\Gamma_{\gamma\gamma}(\eta_c)$ (keV)	Decay channels	$\sum BR$ %	A$\times\epsilon$ %	# Events
η_c	7.1	as L3	11	as L3	290
η_c'	3.6	as L3	11?	as L3	80?
χ_{c0}	1.3	$2(\pi^+\pi^-)$ $K^+K^-\pi^+\pi^-$ $\rho^0\pi^+\pi^-$ $3(\pi^+\pi^-)$ $KK^*\pi$	11	10	70
χ_{c2}	1.3	$2(\pi^+\pi^-)$ $K^+K^-\pi^+\pi^-$ $3(\pi^+\pi^-)$	5.3	10	170
		$\gamma(J/\psi \to e^+e^-, \mu^+\mu^-)$	1.6	20	104

Table 6: Estimates of Charmonium production at LEP200 with $\sqrt{s} = 180 GeV$, $\sum \mathcal{L} = 500 pb^{-1}$. A = acceptance, ϵ = efficiency.

Without measurements of the product branching ratio:

$$BR(\psi' \to \eta_c'\gamma)BR(\eta_c' \to D_i')$$

for different decay channels D_i' of the η_c' it will not be possible to determine $\Gamma_{\gamma\gamma}(\eta_c')$. In this case the only measurements of physical interest are the mass of the η_c' and the relative branching ratios of different decay channels.

7 Estimates of Hidden Beauty Production in $\gamma\gamma$ Collisions at LEP200

Estimates of the two photon radiative widths of hidden beauty states can be made, in the non-relativistic quarkonium model, in a similar way as for the η_c in Section 3 above. For the η_b and $\chi_{b2}(1P)$ states one finds:

$$\frac{\Gamma_{\gamma\gamma}(\eta_b)}{\Gamma_{ee}(\Upsilon)} = \frac{1}{3}[1 + \frac{1.3}{\pi}\alpha_s(M_b)] \tag{6}$$

$$\frac{\Gamma_{\gamma\gamma}(\chi_{b2}(1P))}{\Gamma_{gg}(\chi_{b2}(1P))} = \frac{8\alpha^2}{9\alpha_s^2(M_b)}[1 - \frac{3.2}{\pi}\alpha_s(M_b)] \tag{7}$$

Using the experimental widths [5]:

$$\Gamma_{ee}(\Upsilon) = 1.34keV$$

$$\Gamma_{gg}(\chi_{b2}(1P)) \simeq \Gamma(\chi_{b2}(1P) \to hadrons) \simeq \Gamma(\chi_{b2}(2P) \to hadrons) = 100keV$$

and assuming [18] $\alpha_s(M_b) = 0.21$ the following estimates of the radiative widths are obtained:

$$\Gamma_{\gamma\gamma}(\eta_b) = 0.5keV$$
$$\Gamma_{\gamma\gamma}(\chi_{b2}(1P)) = 0.09keV$$

The approximate formula [25] for the total cross-section for the production, in photon photon collisions, of a narrow resonance R:

$$\sigma(e^+e^- \to Re^+e^-) = \frac{16\alpha^2(2J_R+1)}{M_R^3}\left(\ln\frac{2E}{m_e}\right)^2[4\ln\frac{2E}{M_R} - 3]\Gamma_{\gamma\gamma}(R) \tag{8}$$

leads to the estimates:

$$\sigma(e^+e^- \to \eta_b e^+e^-) = 0.28pb$$
$$\sigma(e^+e^- \to \chi_{b2}(1P)e^+e^-) = 0.20pb$$

For $\sum \mathcal{L} = 500pb^{-1}$ and a combined branching ratio $\times$ acceptance $\times$ efficiency of 10 % only $\simeq$ 10-15 events are expected. By combining many channels it may be possible to observe the η_b and measure its mass. The feasibility of this depends strongly on the background level. More detailed studies, such as the QCD tests which are possible with charmonium are clearly excluded.

Acknowledgements

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