Resonance Formation in Two Photon Collisions at LEP with the L3 detector

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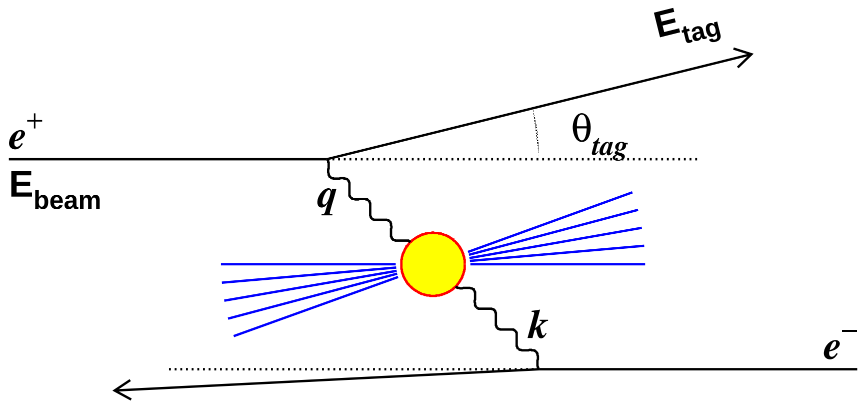
- Introduction
- The η' (958) : two-photon width and form factor
- The η_c (2980) and χ_{c2} (3555)
- The $K_s^0 K_s^0$ channel
- Summary

Most of these results are PRELIMINARY and include 1997 data at $\sqrt{s} = 183$ GeV.

Resonance Formation



The total cross section for the formation of a resonance R is :

$$\sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^- R) = \int d^5\mathcal{L}(\alpha_i) \cdot \sigma(W_{\gamma\gamma}, q^2, k^2)$$

$$\sigma(W_{\gamma\gamma}, q^2, k^2) \sim (2\,J_R{+}1) F^2(q^2, k^2) \frac{\Gamma_{\gamma\gamma}\,\Gamma_R}{(W_{\gamma\gamma}^2 - m_R^2)^2 + m_R^2\,\Gamma_R^2}$$

- ❑ The luminosity function $\mathcal{L}_{\gamma\gamma}$ is calculable by QED
- ❑ $\sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^- R) = K \times \Gamma_{\gamma\gamma}$
- ❑ The form factor can be parametrised with a pole form

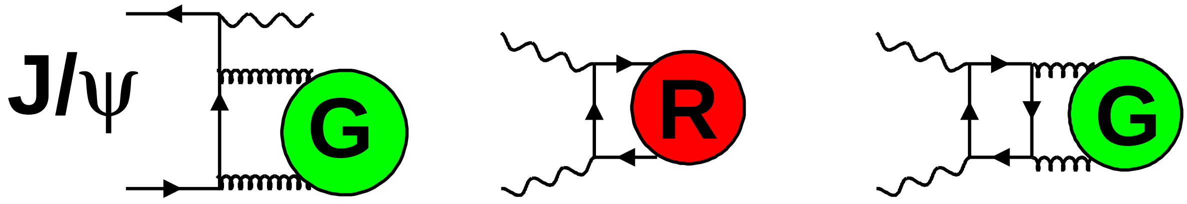
$$F^2(q^2, k^2) = F^2(q^2) F^2(k^2) = \left[\frac{1}{1 - q^2/\Lambda^2}\right]^2 \left[\frac{1}{1 - k^2/\Lambda^2}\right]^2$$

$Q^2 = -q^2$, $\Lambda = m_\rho, m_\omega, m_{J/\psi}$..... in the VDM

QCD potential models and Glueballs

From two-photon coupling and form-factor we obtain informations on

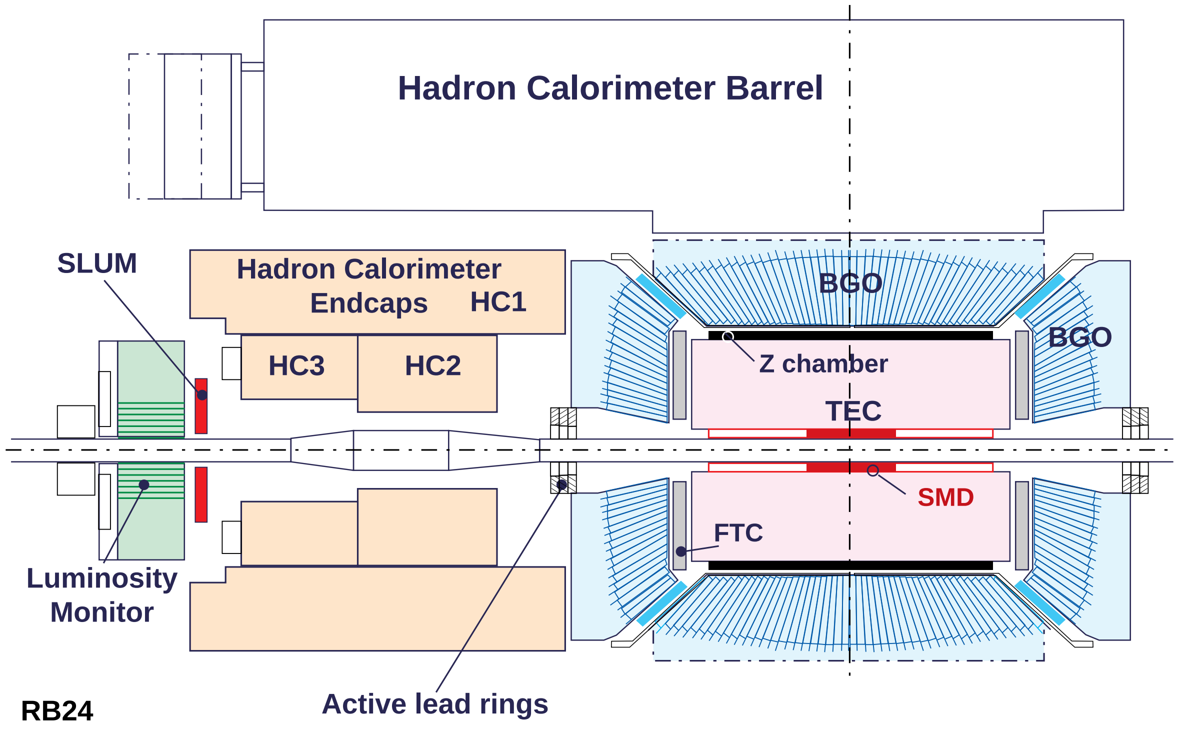
- ❏ The quark charge and singlet-octet mixing of $q\bar{q}$ states.
- ❏ The quark wave function inside the hadron
- ❏ The value of α_s, for heavy quark systems
- ❏ $\gamma\gamma$ coupling to gluon rich states must be small



Properties of glueballs :

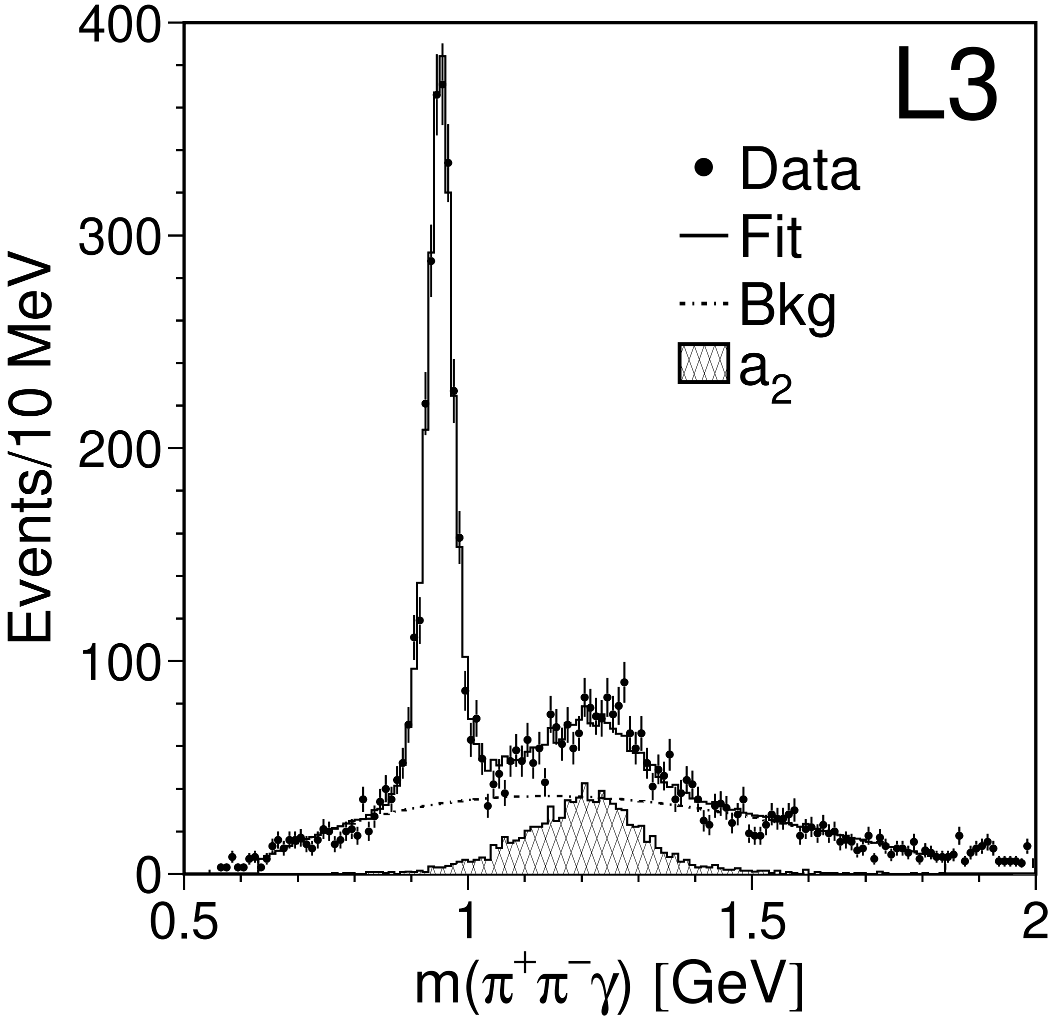
- ❏ produced in gluon rich environments like $p\bar{p}$, pp collisions and radiative J/ψ decays
- ❏ Flavour blind decay branching ratios

L3 Detector



- Central tracking system : Silicon Microvertex Detector + Time Expansion Chamber
- Electromagnetic Calorimeters : BGO - High resolution (5% at 100 MeV, 1.4% above 2 GeV)
- Charged-track Trigger : Low p_T threshold $\sim$150 MeV

$e^+e^- \to e^+e^-\eta'(958)$ *for quasi-real photons*



Events with $Q^2 < 0.01\ \mathrm{GeV}^2$. Fitted function is :

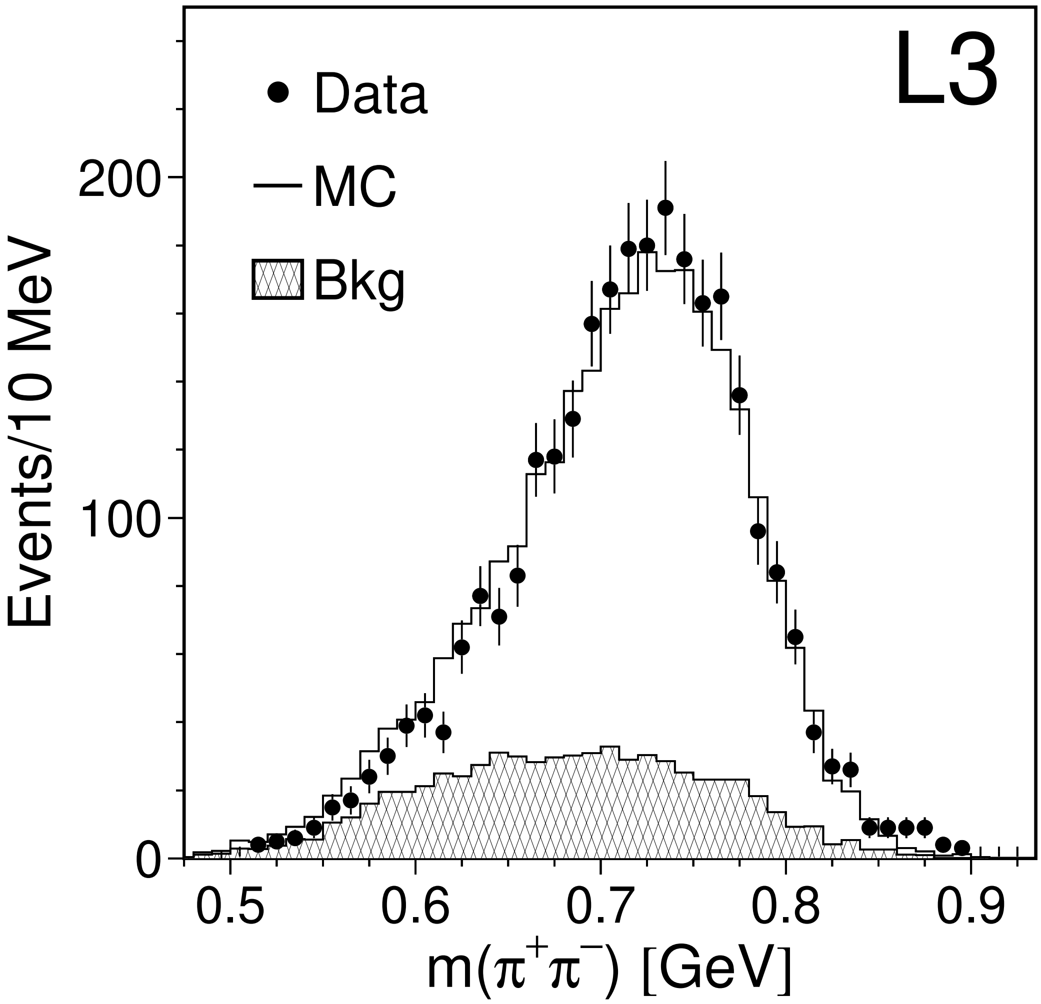
$$E_i = [\Gamma_{\gamma\gamma}(\eta') \cdot BR] \cdot N_i^{(MC)}(\eta') + N_i^{(MC)}(\mathrm{a}_2) + B_i$$

Fit result

$$\boldsymbol{\Gamma_{\gamma\gamma}(\eta') \cdot \mathrm{BR} = 1.26 \pm 0.03 \pm 0.06\ \ \mathrm{keV}}$$

$$\boldsymbol{\Gamma_{\gamma\gamma}(\eta') = 4.17 \pm 0.10 \pm 0.27\ \ \mathrm{keV}}$$

$\eta' \to \rho\gamma$



Test possible deviations from a BW due to box anomaly

$$\mathrm{BW}(\rho) = \frac{1}{(m_{12}^2 - m_\rho^2) - i\, m_{12}\, \Gamma_\rho} + \frac{\xi}{m_{\eta'}^2} \exp(i\,\phi)$$

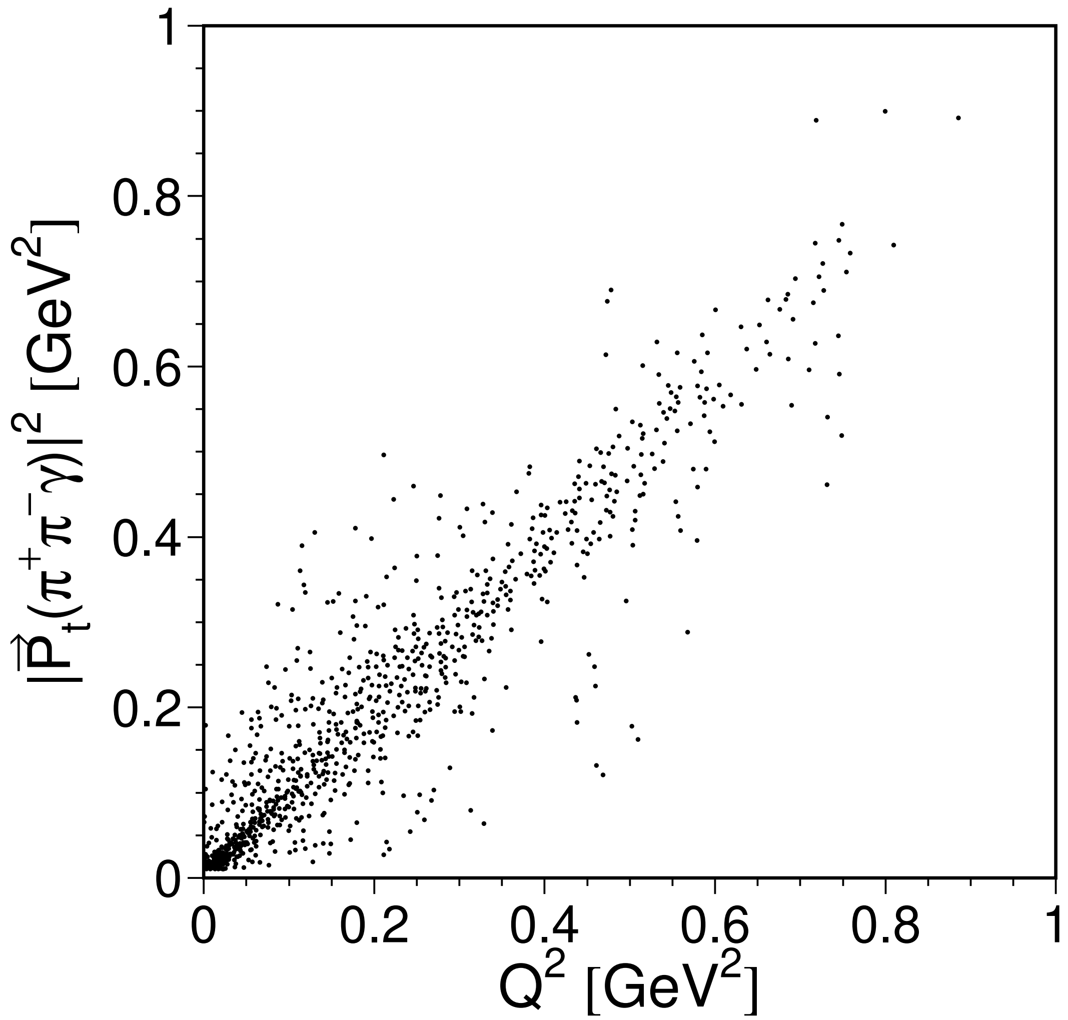
Data give (CL=37%)

$\boldsymbol{\xi = 0, \quad m_\rho = 766 \pm 2 \ \ \mathrm{MeV}, \quad \Gamma_\rho = 150 \pm 5 \ \ \mathrm{MeV}}$

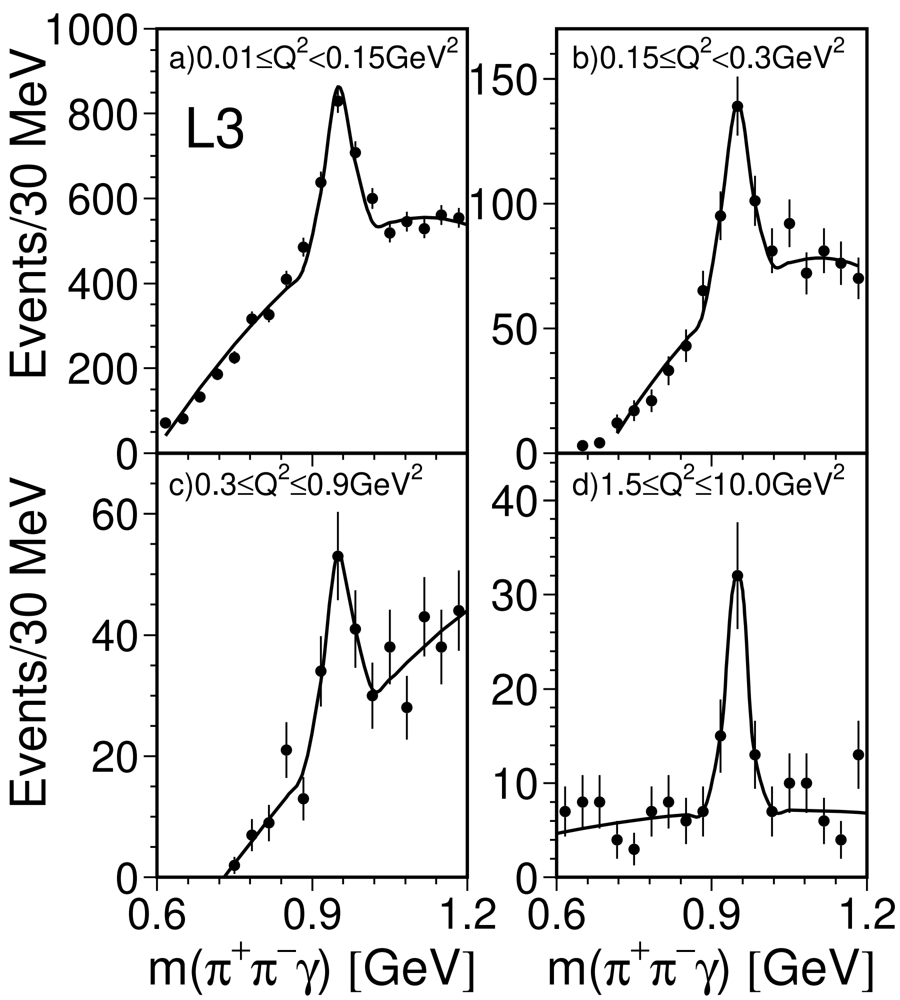
and exclude
S.I. Bityukov *et al.* $\xi = 2.78$ and $\phi = -1.07$ at CL $\sim 10^{-4}$
M. Benayoun *et al.* $\xi = 0.4$ and $\phi = 3.14$ at CL$= 3\%$

Q^2 estimation

It has been used a new technique to determine the Q^2 value of untagged events. The MC simulation demonstrates that $Q^2 = |\vec{p}_t(\pi^+\pi^-\gamma)|^2$ within the experimental resolution.



η' signal at high Q^2



The reconstructed $\pi^+\pi^-\gamma$ mass spectrum for events with high Q^2, separated in four Q^2 intervals:

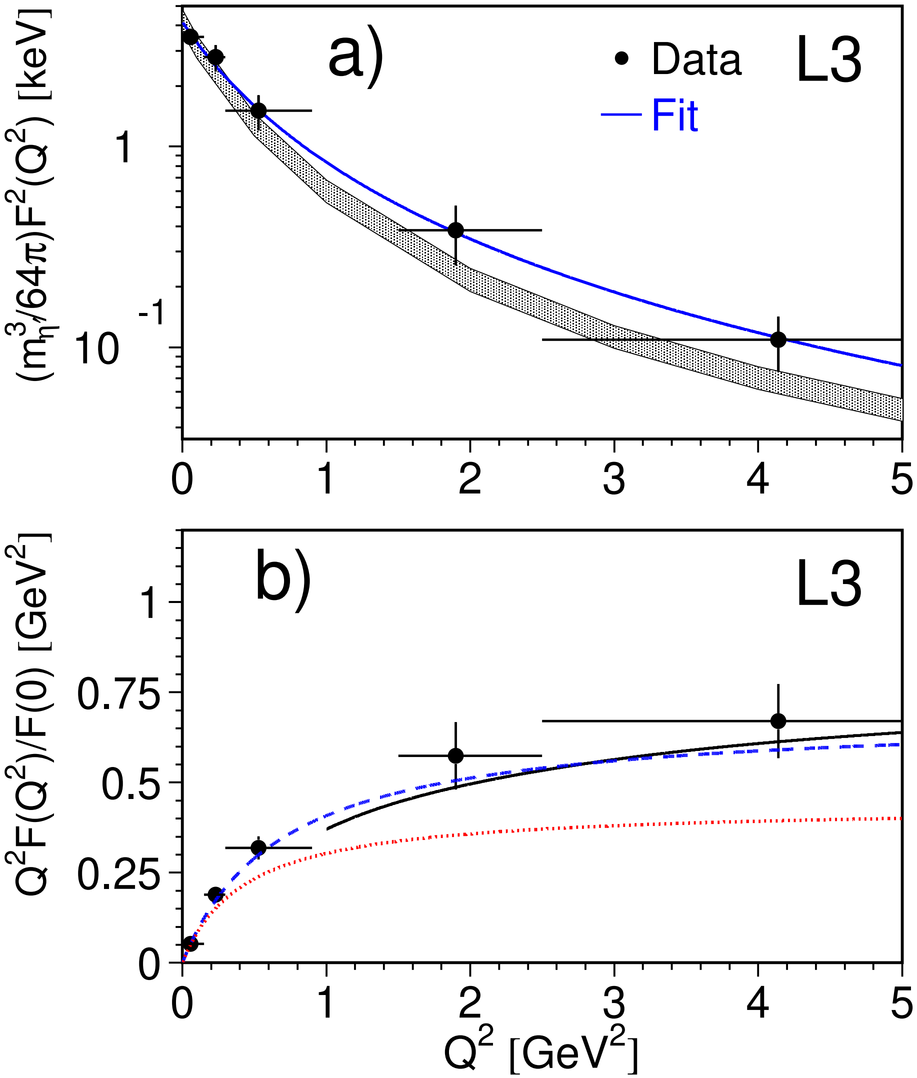
a) $0.01 \leq Q^2 < 0.15\ \mathrm{GeV}^2$,

b) $0.15 \leq Q^2 < 0.30\ \mathrm{GeV}^2$,

c) $0.30 \leq Q^2 \leq 0.90\ \mathrm{GeV}^2$,

d) $1.5 \leq Q^2 \leq 10.0\ \mathrm{GeV}^2$, Tagged events.

η' (958) Form Factor



a) The solid line is the result of the pole fit to the data $(\mathrm{CL} = 95\%)$

$$\mathbf{\Lambda = 900 \pm 46 \pm 22 \quad MeV}$$

$$\langle r^2 \rangle = 6/\Lambda^2 = 0.29 \pm 0.03 \ \mathrm{fm}^2$$

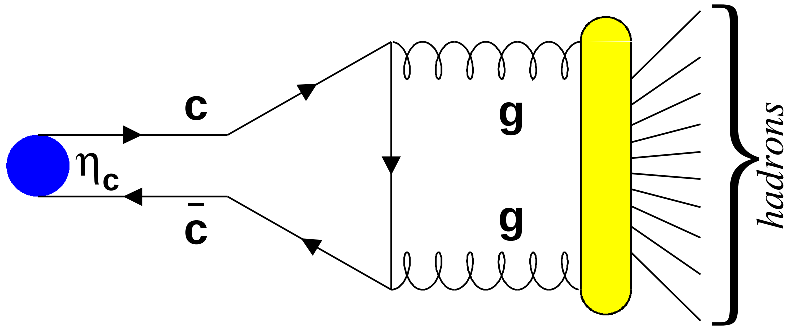
VDM prediction is $\Lambda = 830 \quad \mathrm{MeV}$

The predictions of Anisovich, Bugg, Melikhov, Nikanov,(1997) are indicated as a shaded area, ranging from no **gluonium** content (upper line) to 15% of **gluonium** content (lower line).

b) QCD calculations :
Jacob, Kroll, Raulfs (1996)
Brodsky, Lepage(1981)
VMD predictions :
Ametler, Bijnens, Bramon, Cornet(1992)

η_c(2980) Decay Channels

- ❑ Decay via two intermediate gluons



- ❑ branching ratios in the most common hadronic final states are only a few percent
- ❑ Less than 25% of decay modes have been identified.
- ❑ 10 decay modes are studied here ($\sum_i \mathrm{BR}_i = 10.6\%$)

Channels	BR (%)	Final State
$K^+K^-\pi^+\pi^-$	$2.0^{+0.7}_{-0.6}$	4 charged
$\rho^+\rho^-$ ($\rho^\pm \to \pi^\pm\pi^0$	1.73 ± 0.60	2 charged, 4 photons
$\eta(\gamma\gamma)\pi^+\pi^-$	1.28 ± 0.47	2 charged, 2 photons
$K^0_S(\pi^+\pi^-)K^\pm\pi^\mp$	1.26 ± 0.39	4 charged, 1 sec. vert.
$\pi^+\pi^-\pi^+\pi^-$	1.2 ± 0.4	4 charged
$\pi^0K^+K^-$	0.90 ± 0.28	2 charged, 2 photons
$\eta'(\rho^0\gamma)\pi^+\pi^-$	0.83 ± 0.34	4 charged, 1 photon
$\eta(\pi^0\pi^+\pi^-)\pi^+\pi^-$	0.76 ± 0.28	4 charged, 2 photons
$\eta'(\eta\,\pi^+\pi^-)\pi^+\pi^-$	0.47 ± 0.20	4 charged, 2 photons
$\phi\phi(2\,K^+K^-)$	0.171 ± 0.068	4 charged

Results for each channel. Data at $\sqrt{s} \simeq$ 91 GeV, $L_{ee} \simeq$ 140 pb^{-1}

Channel	events	eff. (%)	$\Gamma_{\gamma\gamma}(\eta_c)^\star$ [keV]
$\pi^+\pi^-\pi^+\pi^-$	$47.5^{+16.1}_{-14.5} \pm 4.9$	$22.3 \pm 0.4 \pm 0.3$	$8.6^{+2.9}_{-2.6} \pm 0.9$
$\eta'(\rho^0\gamma)\pi^+\pi^-$	$25.1^{+9.1}_{-8.2} \pm 2.8$	$3.0 \pm 0.21 \pm 0.07$	$48.8^{+17.8}_{-16.0} \pm 5.5$
$\mathrm{K^0_S}(\pi^+\pi^-)\mathrm{K}^\pm\pi^\mp$	$15.8^{+6.6}_{-6.2} \pm 1.1$	$8.12 \pm 0.23 \pm 0.29$	$7.5^{+3.2}_{-2.9} \pm 0.6$
$\pi^0\mathrm{K}^+\mathrm{K}^-$	$13.8^{+6.5}_{-5.4} \pm 0.9$	$2.1 \pm 0.10 \pm 0.22$	$31.3^{+15.5}_{-13.0} \pm 3.9$
$\eta(\gamma\gamma)\pi^+\pi^-$	$5.4^{+2.6}_{-2.1} \pm 0.08$	$2.18 \pm 0.09 \pm 0.09$	$9.5^{+4.5}_{-3.5} \pm 0.4$
$\mathrm{K}^+\mathrm{K}^-\pi^+\pi^-$	$< 41^\ddagger$	$2.9 \pm 0.2 \pm 0.1$	< 29.1
$\rho^+\rho^-$	$< 14^\ddagger$	$0.6 \pm 0.05 \pm 0.24$	< 60.7
$\phi\phi(2\,\mathrm{K}^+\mathrm{K}^-)$	$< 8.0^\ddagger$	$6.2 \pm 0.2 \pm 0.1$	< 44.4
$\eta'(\eta\,\pi^+\pi^-)\pi^+\pi^-$	$< 4.7^\ddagger$	$1.8 \pm 0.22 \pm 0.09$	< 32.6
$\eta(\pi^0\pi^+\pi^-)\pi^+\pi^-$	$< 4.1^\ddagger$	$1.3 \pm 0.16 \pm 0.05$	< 23.4

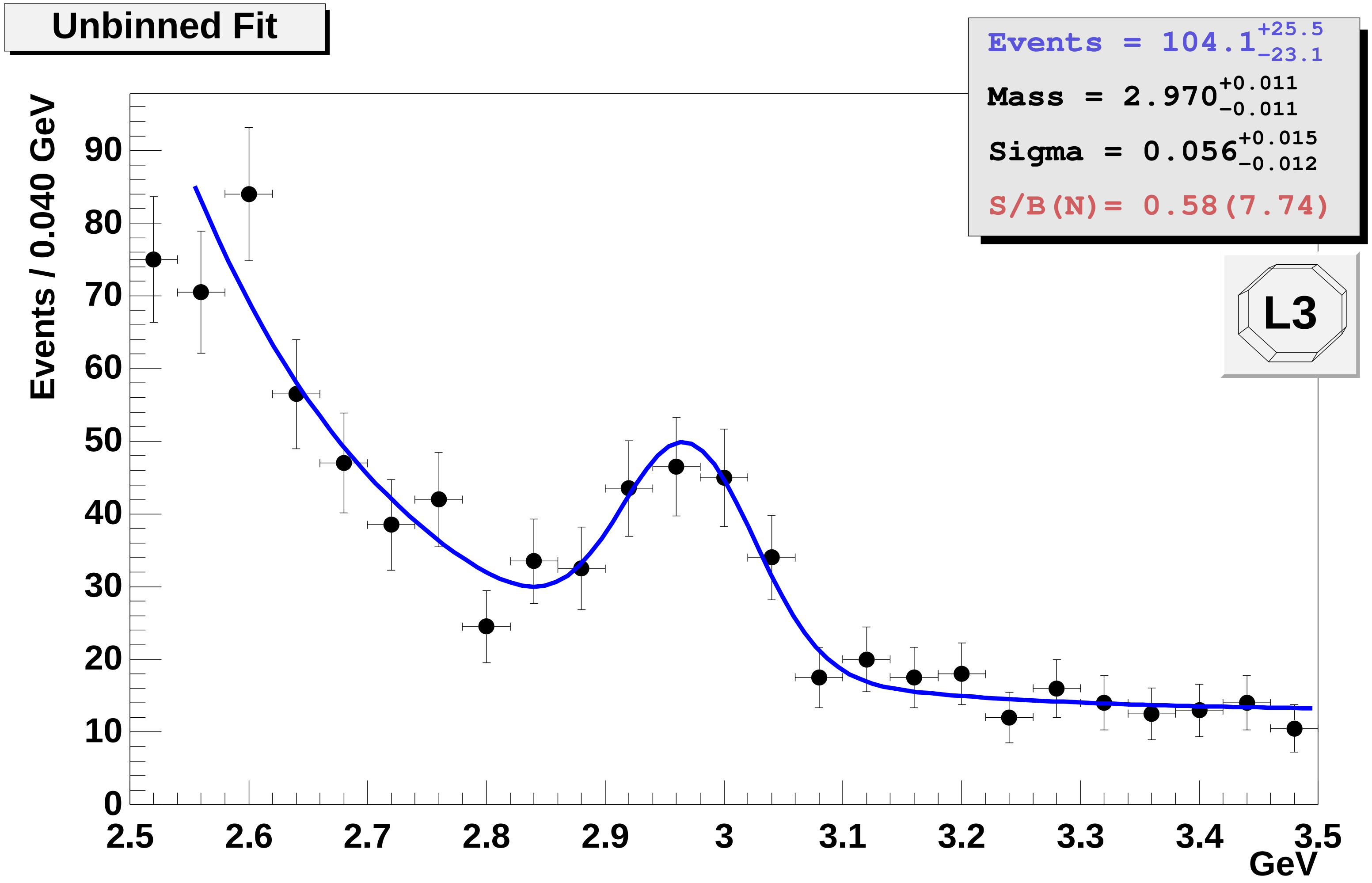
* branching ratio errors are not included

$\ddagger$ upper limits at 95% CL

Combined result with statistical errors only	$\mathbf{9.3^{+1.8}_{-1.7}}$ keV

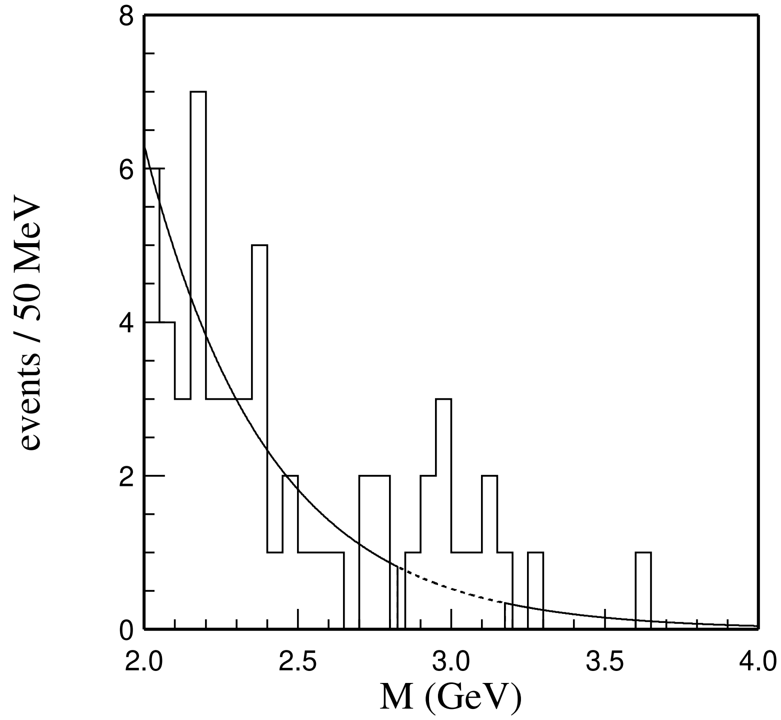
$$\boldsymbol{\Gamma_{\gamma\gamma}(\eta_c) = 9.5^{+2.1}_{-1.9}(\mathrm{stat+sys}) \pm 2.7(\mathrm{BR})}\ \text{keV}$$

η_c : $K^0_S K^\pm \pi^\mp, \eta\,\pi^+\pi^-, \pi^+\pi^-\pi^+\pi^-, \eta'\pi^+\pi^-, \pi^0 K^+ K^-$

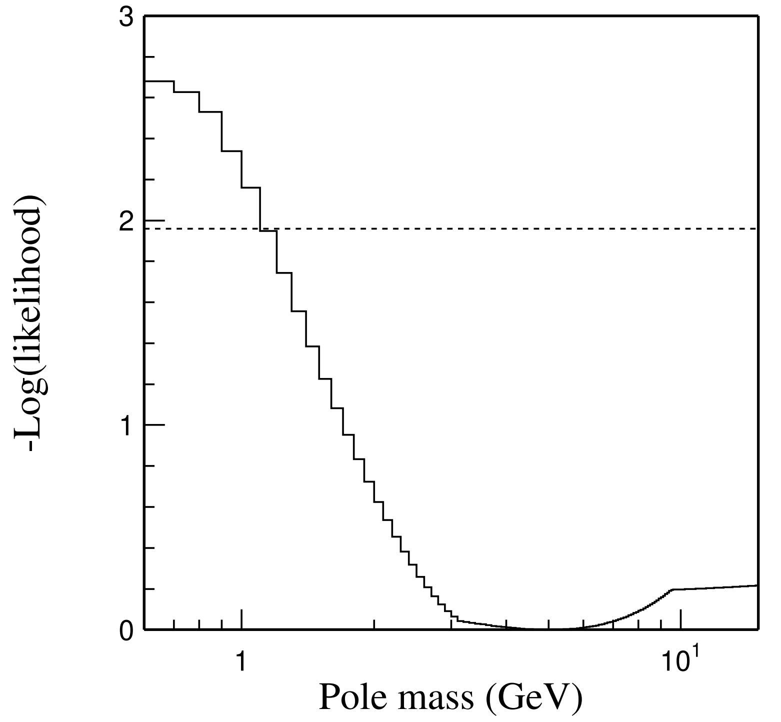


$$\Gamma_{\gamma\gamma}(\eta_c) = 9.5^{+1.8}_{-1.7}(\mathrm{stat})^{+1.1}_{-0.8}(\mathrm{sys}) \pm 2.7(\mathrm{BR})\ \mathrm{keV}$$

$\eta_c(2980)$ Form Factor



Single tag events.
All decay channels combined
8 events in total are observed.
The line is an exponential fit to the η_c sidebands.
Background $\sim$ 2.9 events.



Probability to observe 5.1 η_c events at $< Q^2 > \simeq 2GeV^2$ as function of the pole mass Λ in the VDM form factor.
A pole value below 1 GeV is excluded with 95% CL.

$\chi_{c2}(3555) \to \gamma\, J/\psi$ selection

- The photon must have energy > 300 MeV, no other photon with energy greater than 100 MeV must be present
- The transverse momentum imbalance has to be lower than $0.08\ \mathrm{GeV}^2$ ($0.1\ \mathrm{GeV}^2$ for events with a tagged electron). Exclusive final state.
- The mass of the lepton pair must be near to the nominal J/ψ mass within ± 250 MeV
- The difference $\Delta M = M(\ell^+\ell^-\gamma) - M(\ell^+\ell^-)$ has a good resolution ($\sigma \simeq 20$ MeV)

To fit the background shape we use a threshold function

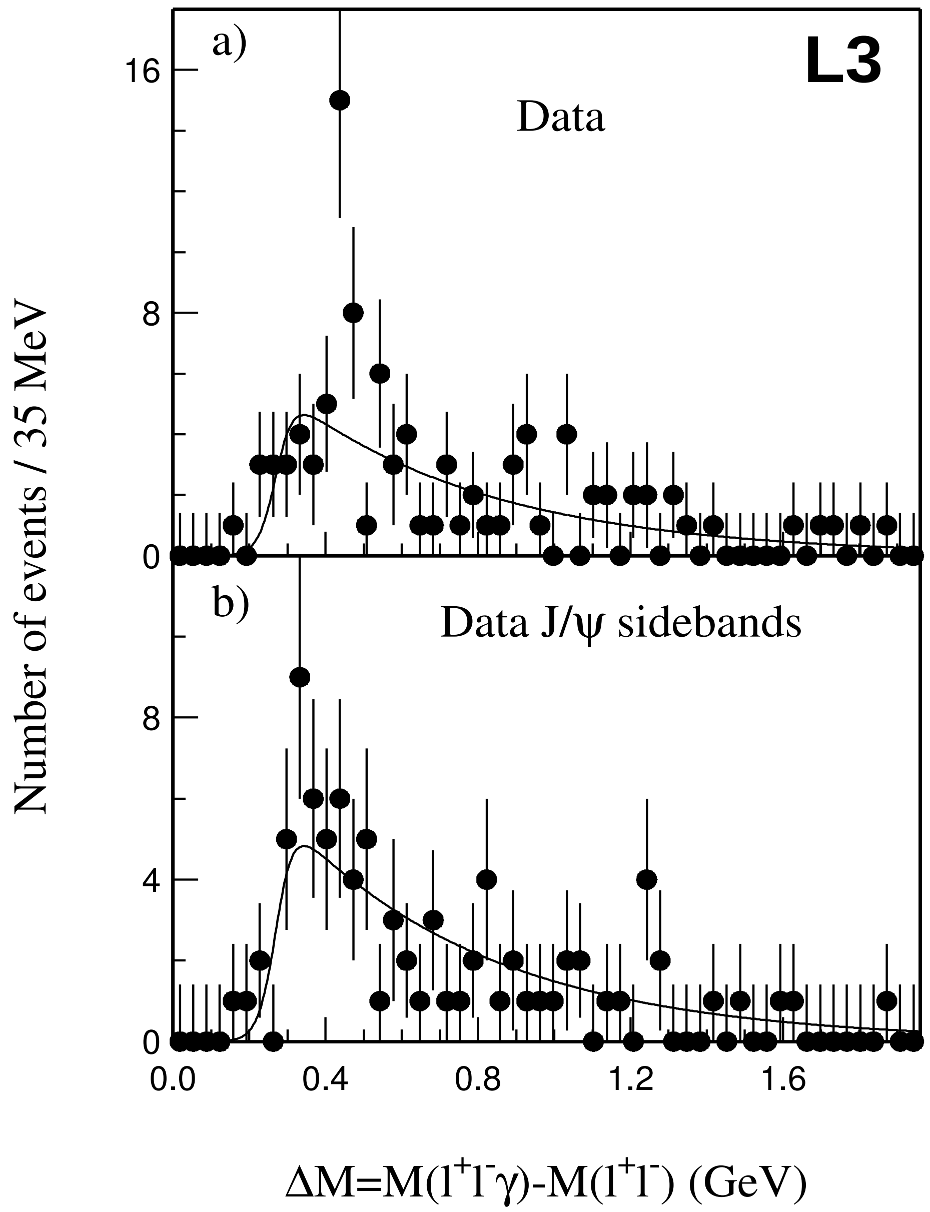
$$c\,\frac{e^{-x/a_1}}{1+e^{(a_2-x)/a_3}}$$

a_1, a_2, a_3 are given by a simultaneous fit on ΔM spectra : the sidebands $2.45 \le M(\ell^+\ell^-) \le 2.75$ and $3.45 \le 3.75$ GeV and the selected sample excluding the signal region.
$\Gamma_{\gamma\gamma}(\chi_{c2})$ is found by maximising the likelihood

$$\mathfrak{L} = \prod_i \frac{\mu_i^{N_i}\, e^{-\mu_i}}{N_i!}$$

where N_i is the number of events observed in the signal region, and $\mu_i = \varepsilon_i\, \mathcal{L}\, \mathrm{BR}_i\, \mathcal{K}_i\, \Gamma_{\gamma\gamma} + \mu_B$ is the number of expected signal events plus the background as obtained from the threshold function fit.

$\chi_{c2}(3555)$

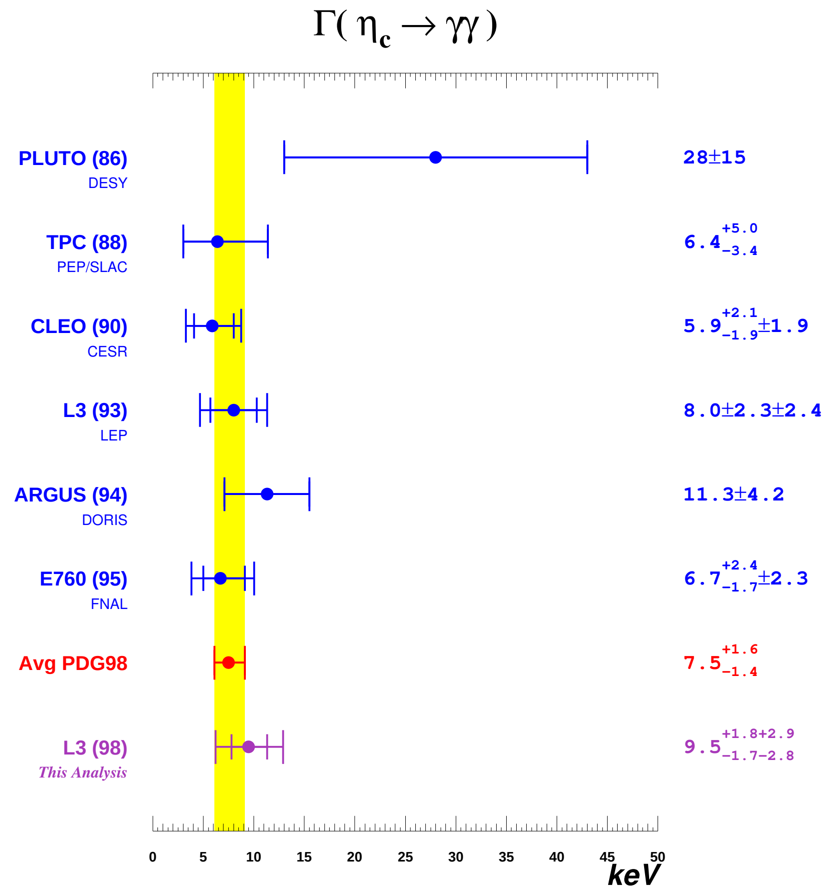


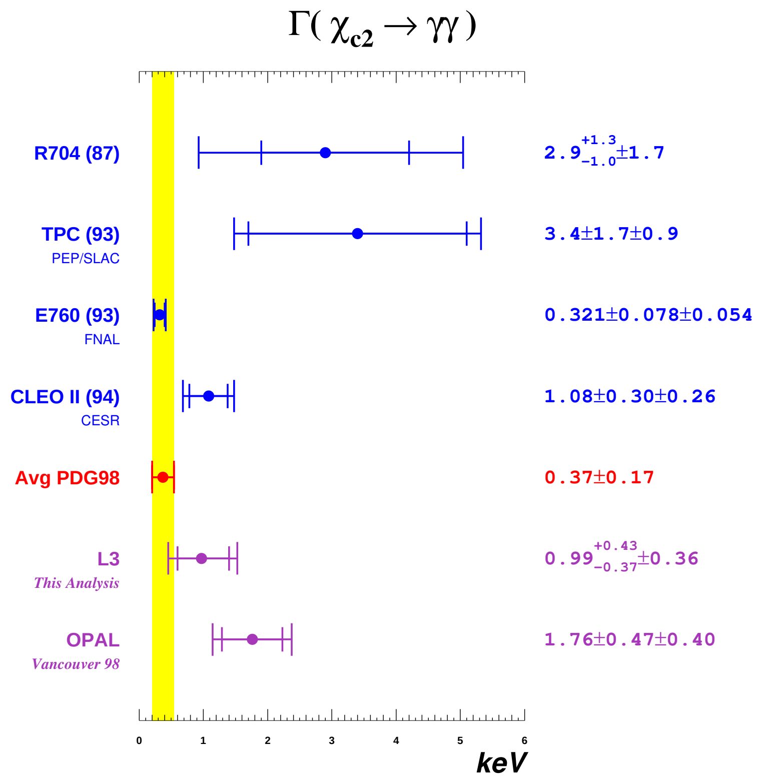
15 signal events above a background of 11

for L_{ee}=140.2 pb^{-1} at $\sqrt{s}$= 91 GeV
and L_{ee}=52.4 pb^{-1} at $\sqrt{s}$= 183 GeV

$$\Gamma_{\gamma\gamma}(\chi_{c2}) = 0.99^{+0.43}_{-0.37}(\text{stat}) \pm 0.36(\text{sys}) \ \ \text{keV}$$

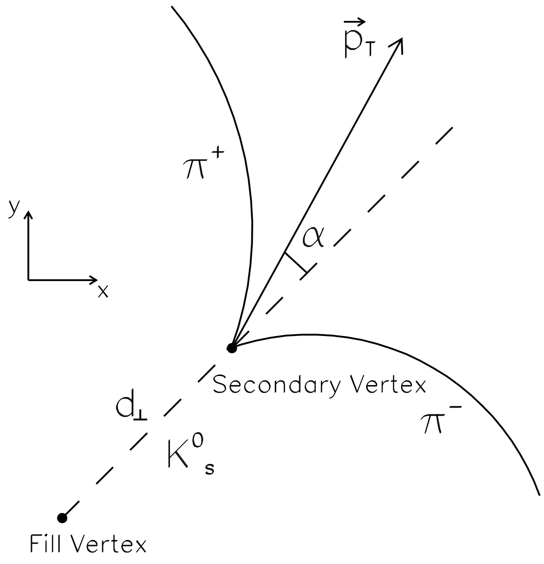
Comparison with Previous measurements

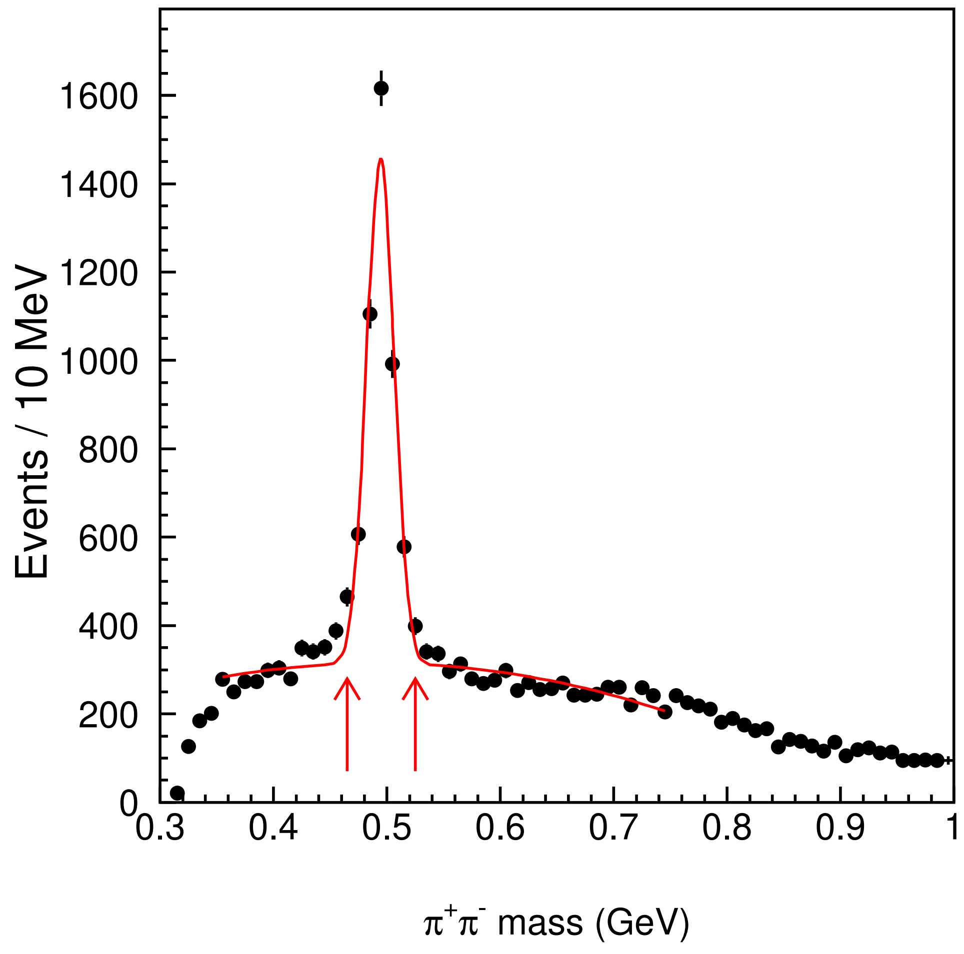




The K^0_s Selection

- ❑ Only $K^0_s \rightarrow \pi^+\pi^-$ decay is considered
- ❑ Search for secondary vertices in four "good" track events with charge balance
- ❑ $|\alpha| < 0.3$ rad
- ❑ $d_\perp > 3$ mm

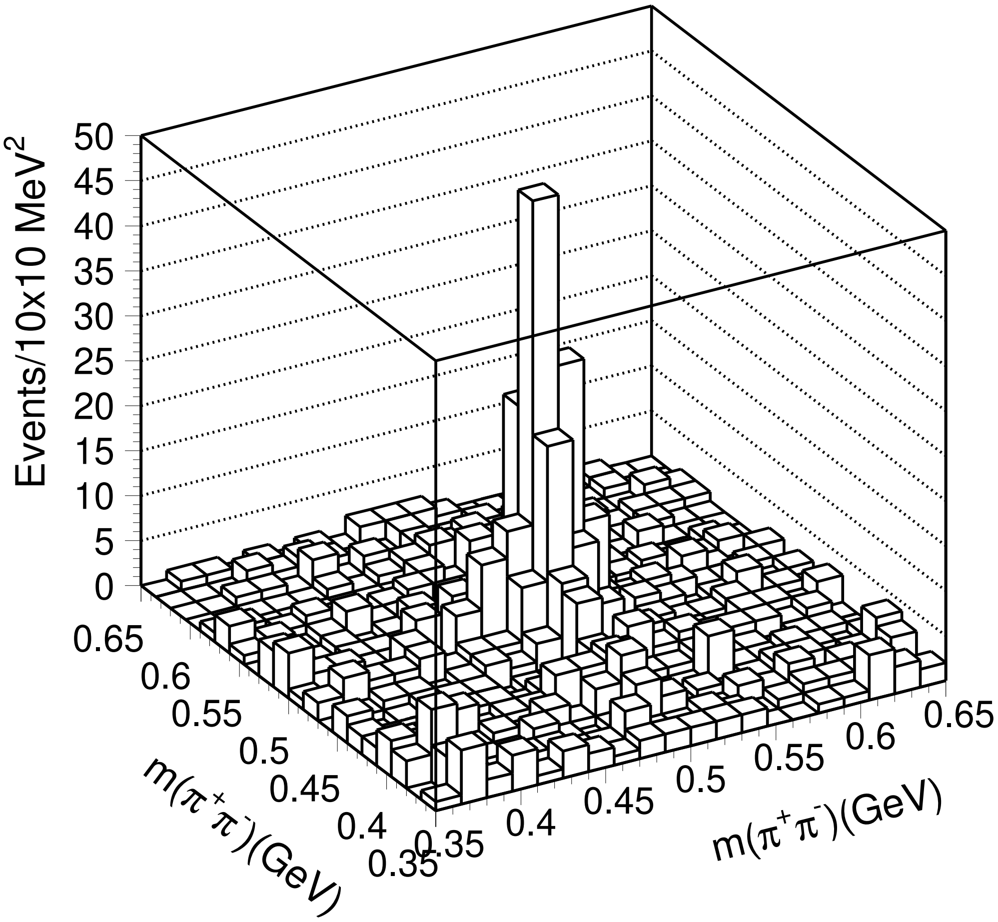




The $K^0_s K^0_s$ Final State

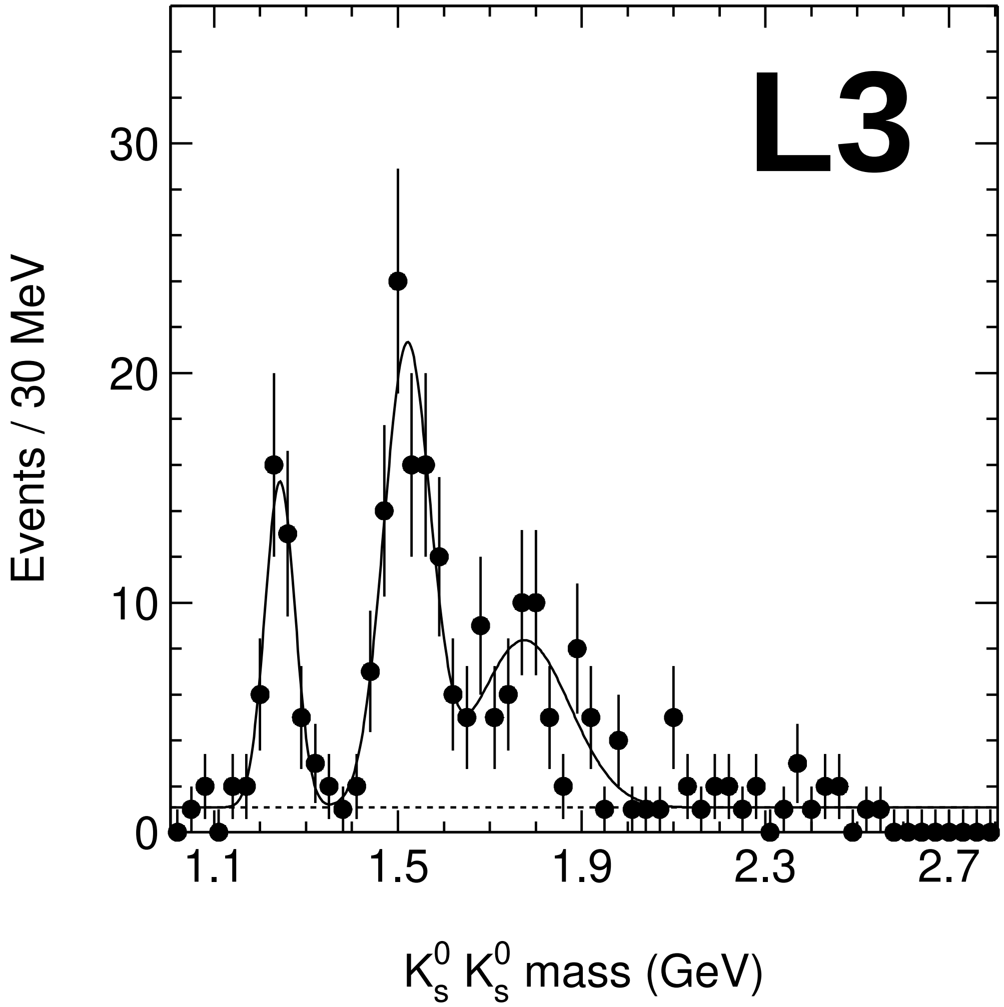
To select $\gamma\gamma \rightarrow K^0_s K^0_s$ exclusive events :

- $|\Sigma \vec{p}_T|^2 < 0.1$ GeV^2
- Events with photons are rejected



- $M_{\pi^+\pi^-}$ inside R = 40 MeV around K^0_s .
- 253 events at $\sqrt{s} \simeq 91$ and 183 GeV.

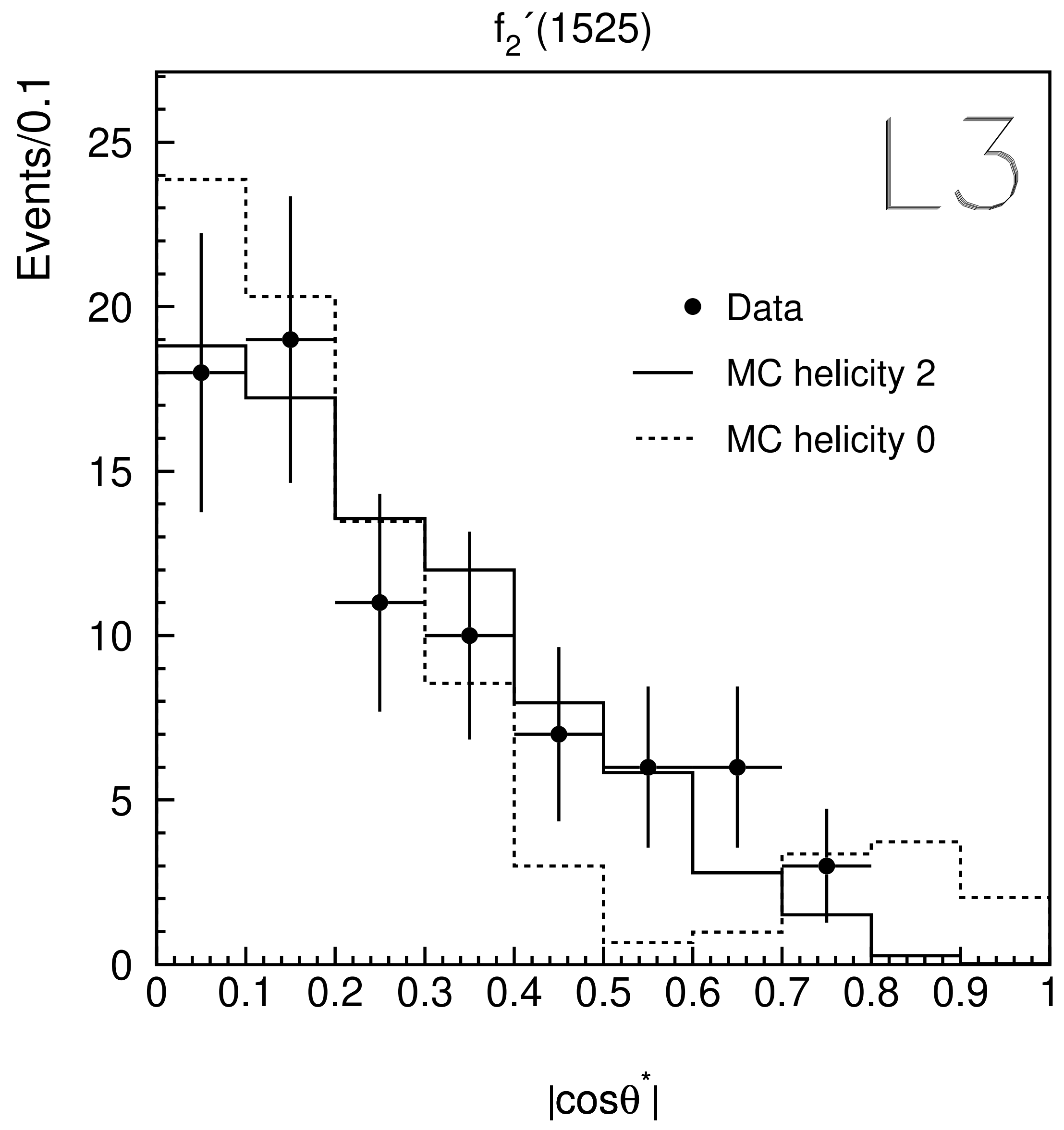
The $K_s^0 K_s^0$ Mass Spectrum



	f_2-a_2	$f_2'(1525)$	X(1750)
Mass (MeV)	—	1520±7	1770±20
Width (MeV)	—	119±15	200±50
Events	38±7	85±11	61±10

- ❏ $f_2 - a_2$ destructive interference
- ❏ Clear $f_2'(1525)$ signal
- ❏ Clear enhancement around 1750 MeV
- ❏ No signal in the $\xi(2230)$ region

The $f_2'(1525)$



	J=2, λ=2	J=2, λ=0
χ^2 for 9 d.o.f.	7	82

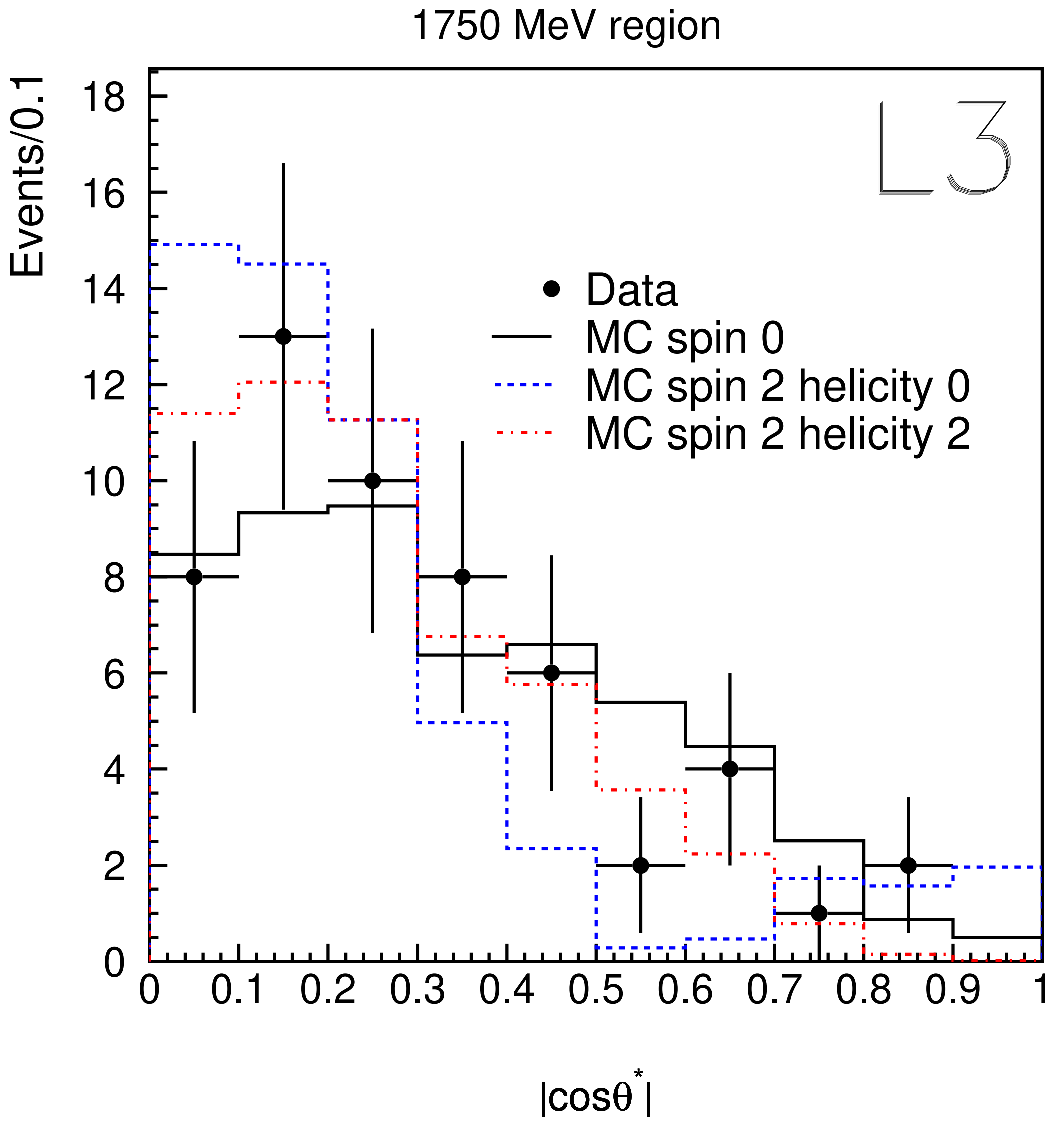
Helicity 2 dominates !

For helicity 2 the detection efficiency is 7.6% and

$$\Gamma_{\gamma\gamma}(f_2') \times Br(f_2' \to K\bar{K}) = (0.085 \pm 0.03)\text{keV}$$

The 1750 MeV Region

- 2⁺⁺ radial recurrence? $f_2''(1740)$, $f_2'''(1820)$
  (C.R.Münz, Nucl.Phys. A609(1996)634)
- 0^{++} $s\bar{s}$ state ?
  (Amsler and Close,Phys.Rev.D53(1996)295)



	J=0	J=2, λ=2	J=2, λ=0
χ^2 for 9 d.o.f.	7	26	50

The $(\xi(2230))$ *Region*

- The experimental resolution for the $\xi(2230)$ is σ=60 MeV
  $\rightarrow$ signal region : $M_{\xi(2230)} \pm 2\sigma$
- The background is estimated by fitting the sidebands
- J=2, λ=2 are assumed

Data Sample	Events in Signal Region	Expected Background	Detection Efficiency	95% Events	C.L. Upper Limits $\Gamma_{\gamma\gamma}(\xi)Br(K_s^0K_s^0)$
LEP I	6	4.9	16.6%	7.3	4.1 eV
LEP II	2	7.9	9.3%	3.6	6.9 eV

Combining the two results by Monte Carlo :

$$\boxed{\Gamma_{\gamma\gamma}(\xi) \times Br(\xi \rightarrow K_s^0 K_s^0) < 3 \text{ eV at 95\% C.L.}}$$

Stickiness of $\xi(2230)$

The ratio between the coupling to gluons respect to photons is expected to be very large for glueballs. This is expressed by the stickiness

$$S_R = N_l \left(\frac{m_R}{k_{J/\psi \to \gamma R}} \right)^{2l+1} \frac{\Gamma(J/\psi \to \gamma R)}{\Gamma(R \to \gamma\gamma)} \sim \frac{|<R|gg>|^2}{|<R|\gamma\gamma>|^2}$$

where:

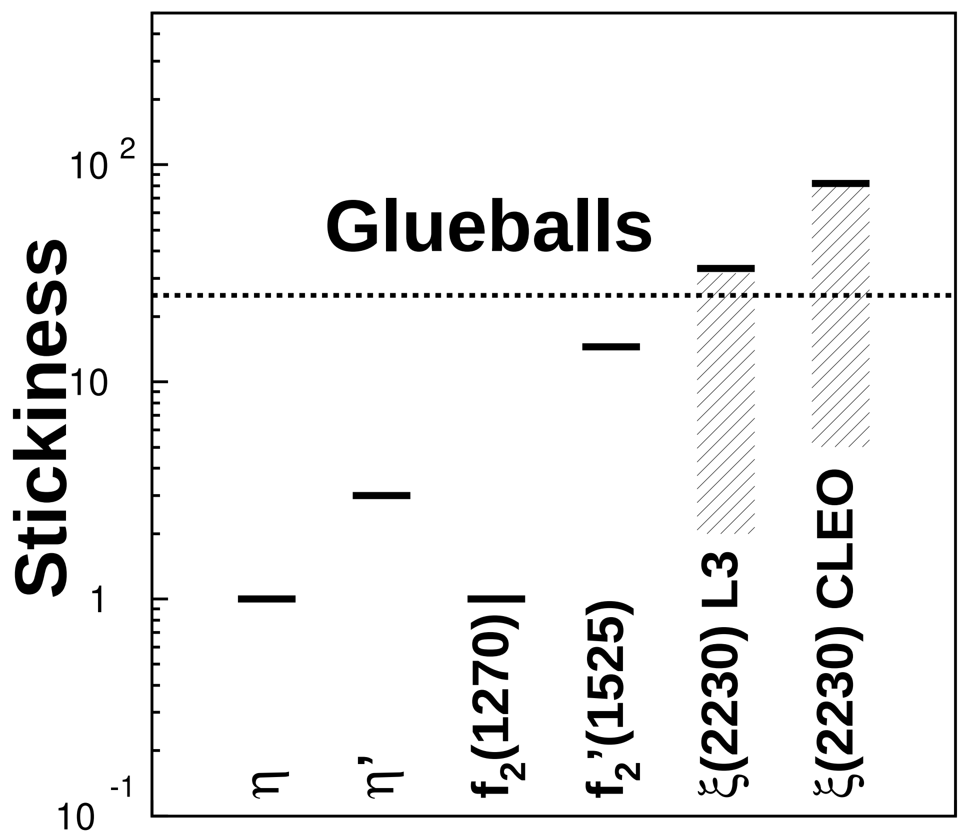
m_R	mass of the state
$k_{J/\psi \to \gamma X}$	photon energy in J/ψ decay
N_l	normalization factor such that $S_{f_2(1270)}$=1

Combining the result by BES (1996) and Mark III (1986)
$\Gamma(J/\psi \to \xi\gamma) Br(\xi \to K_s^0 K_s^0)$=(2.2±0.6)×$10^{-5}$
with our upper limit
$\Gamma(\xi \to \gamma\gamma) Br(\xi \to K_s^0 K_s^0)$ <3 eV at 95% C.L.
we obtain

$$\boldsymbol{S_\xi > 33.3} \text{ at 95\% C.L.}$$

Errors are taken into account by a Monte Carlo calculation.

Stickiness



- The $f_2'(1525)$ is nearly a pure $s\bar{s}$ state. $S_{f_2'(1525)}=14.7$
- Due to its stickiness and its width, the $\xi(2230)$ ia a good glueball candidate, according to lattice QCD theoretical predictions.

Summary

- We have observed new states :
  SU(3)$_f$ 2^{++} recurrences and $0^{++} s\bar{s}$?
- η_c(2980) data agree with J/ψ form factor.
- $\Gamma_{\gamma\gamma}(\chi_{c2})$ is higher than in E760 $p\bar{p}$ experiment.
- Gluonium candidates are not seen.
- Collaboration with theorists is invaluable !!!

Resonances studied by L3 at LEP:

Resonance	final state	J^{PC}	$\Gamma_{\gamma\gamma}(keV)$
(1) η'(958)	$\pi^+\pi^-\gamma$	0^{-+}	4.17±0.10±0.27
(2) a_2(1320)	$\pi^+\pi^-\pi^0$	2^{++}	0.98±0.05±0.09
(2) a_2'(1752)	$\pi^+\pi^-\pi^0$	2^{++}	0.29*±0.04±0.02
(3) f_2'(1525)	$K^0_s K^0_s$	2^{++}	0.085*±0.03
(3) X(1770)	$K^0_s K^0_s$	0^{++}	
(4) η_c(2980)	10 chan	0^{-+}	9.5±2.±2.7
(4) χ_{c2}(3555)	$l^+l^-\gamma$	2^{++}	0.99±0.4±0.36

$\star\ \Gamma_{\gamma\gamma} \times BR$

1) M.Acciari et al.,Phys. Lett. **B** 418 (1998) 399
2) M.Acciari et al.,Phys. Lett. **B** 413 (1997) 147
3) M.Acciari et al.,Phys. Lett. **B** 363 (1995) 118
and S.Braccini, L3 Note 2285 (june 1998)
4) O.Adriani et al.,Phys. Lett. **B** 318 (1993) 575 and B.de la Cruz, E.Pistolesi, T. van Rhee, L3 Note 2297 (july 1998)