Resonance Formation in Two-Photon Collisions

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Meson2000

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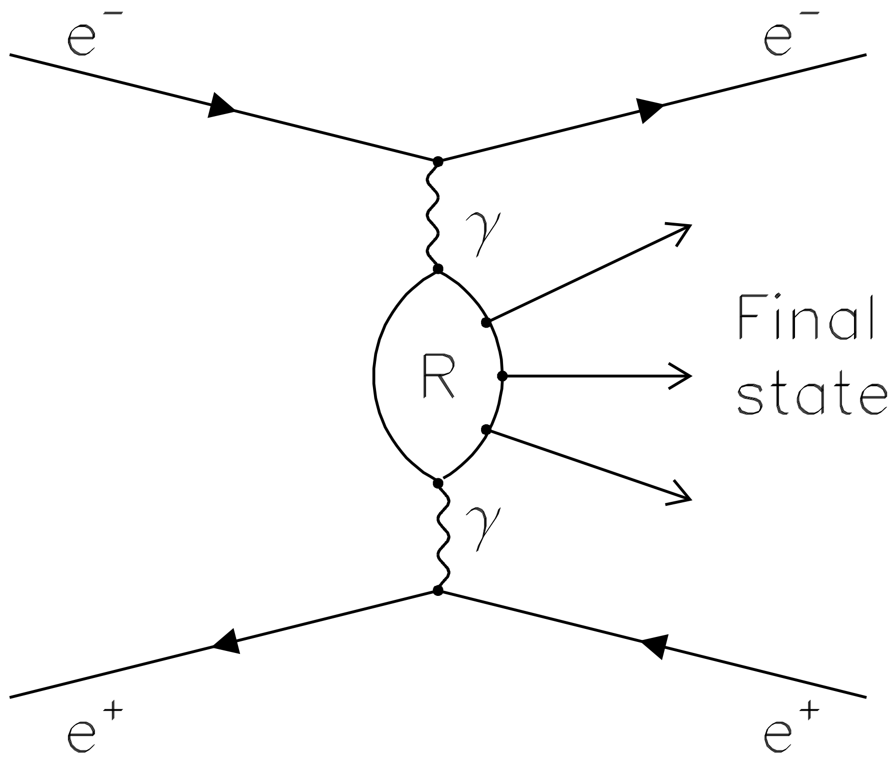
Outline

- Introduction
- Pseudoscalar mesons and their form factors
- The $K_s^0K^{\pm}\pi^{\mp}$ and the $\eta\pi^+\pi^-$ final states
- Glueball searches in the $K_s^0K_s^0$ and $\pi^+\pi^-$ final states
- Charmonium formation
- Conclusions & Outlook

Resonance formation in $\gamma\gamma$ collisions

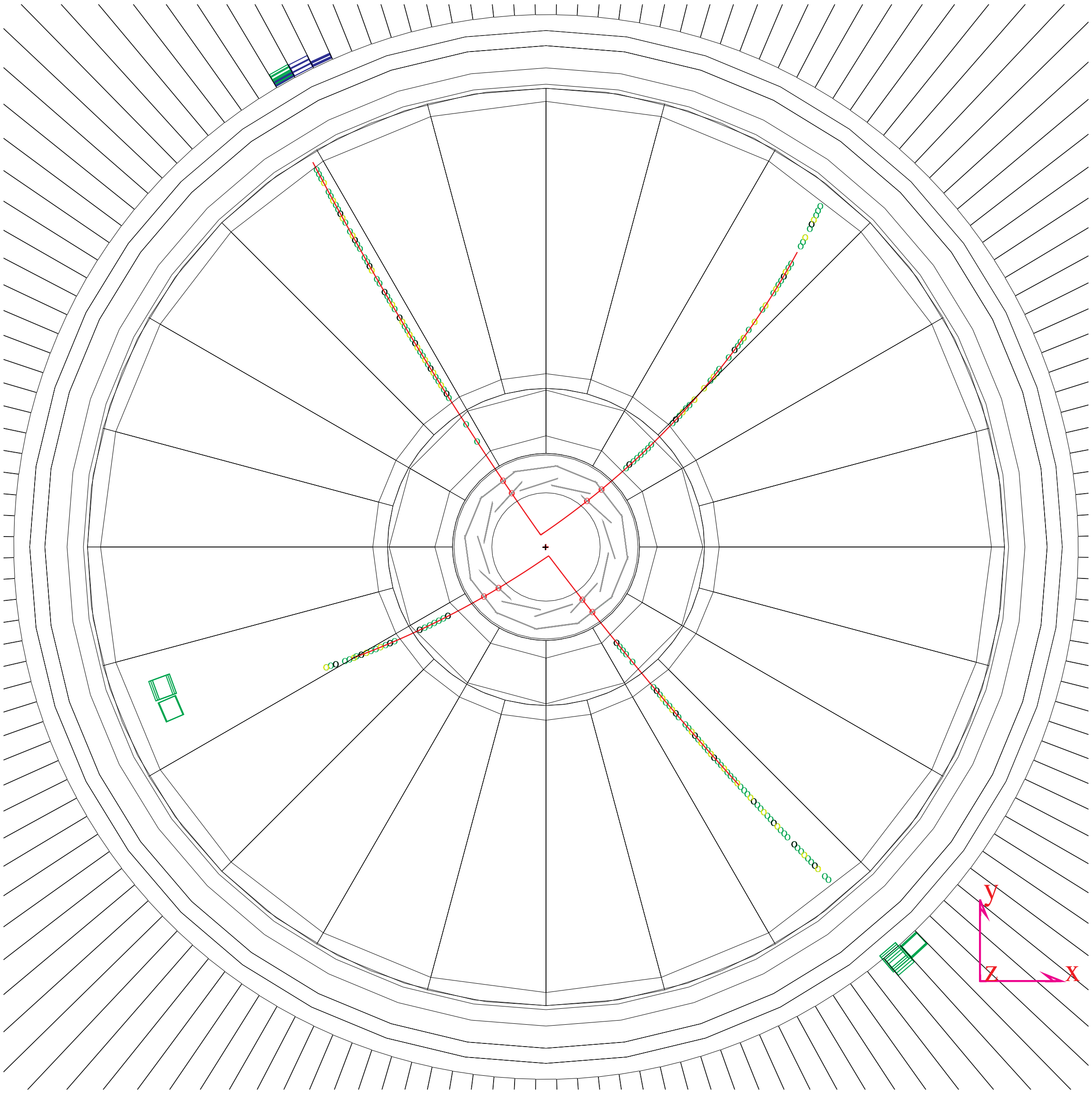


- Outgoing e^+e^- are undetected (“No Tag”)
  - → Quasi-real photons
  - → R neutral unflavoured meson with C=+1
  - → J≠1
- One of the outgoing e^+e^- is detected at low angle (“Single Tag”)
  - → One virtual photon ($Q^2 >> m_e^2$)
  - → R neutral unflavoured meson with C=+1
  - → J can be 1

One typical event

$e^+e^- \rightarrow e^+e^- K^0_s K^0_s$

Run # 689002 Event # 287 Total Energy : .78 GeV



Very clean environment!

The cross section

The cross section can be written as

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

The Luminosity Function $\mathcal{L}(\alpha_i)$ is QED calculable.

⇨ In the "no-tag" mode ($Q^2 \simeq 0$)

$$\sigma(\gamma\gamma\to R) = 8\pi(2J+1)\frac{\Gamma_{\gamma\gamma}\Gamma_R}{(m_R^2 - W_{\gamma\gamma}^2)^2 + m_R^2\Gamma_R^2}$$

J	Spin
m_R	Mass
$\Gamma_{\gamma\gamma}$	Two-photon width
Γ_R	Total width
$W_{\gamma\gamma}$	Mass of the two-photon system

$$\boxed{\boldsymbol{\sigma(\mathrm{e^+e^-} \to \mathrm{e^+e^-}R) = \mathcal{K}\cdot\Gamma_{\gamma\gamma}}}$$

⇨ In the "single-tag" mode ($Q^2 >> m_e^2$)

$$\sigma(\gamma\gamma\to R) = \sigma(\gamma\gamma\to R)|_{Q^2=0}\times F^2(Q^2)$$

where $F(Q^2)$ is the VDM pole transition form factor

$$F(Q^2) = \left(\frac{1}{1+Q^2/\Lambda^2}\right)$$

☞ Perturbative and non-perturbative QCD

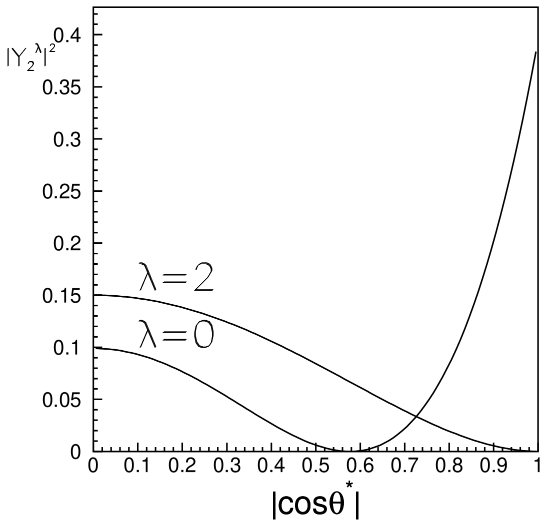
What can be formed?

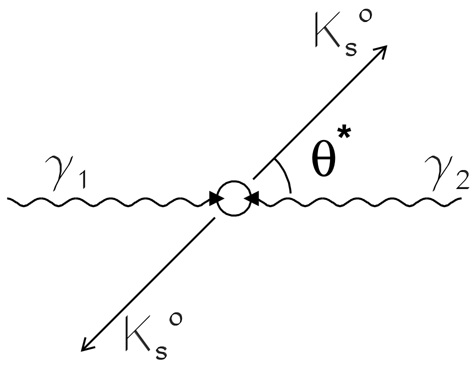
- **Tensor mesons**
  - ➪ Larger cross-section

  $f_2(1270)$, $a_2(1320)$, $f_2'(1525)$

  Helicity 0 or 2

  - ➪ Different angular distributions!



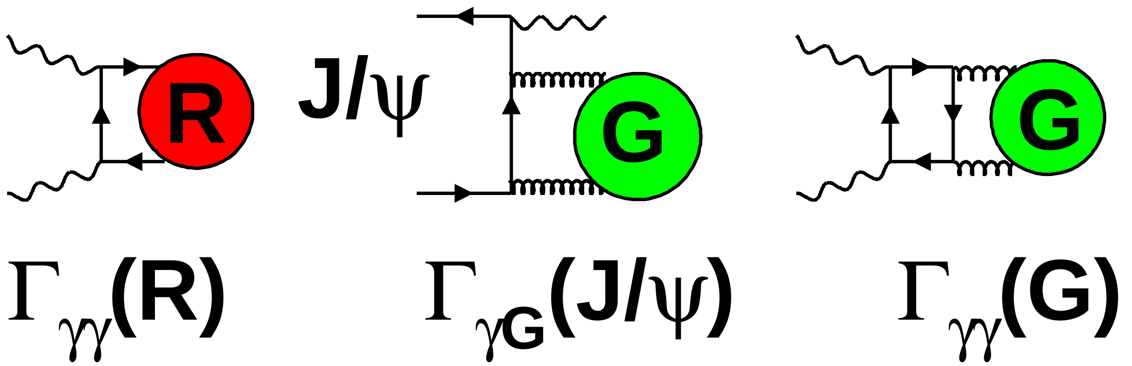


- **Pseudoscalar mesons**

  π^0, $\eta(547)$, $\eta'(958)$

- **Scalar mesons**
- **Vector mesons**
  - ➪ J=1 : Single or double-tag mode only!
- **Radial excitations**

❑ Glueballs?



$\Gamma_{\gamma\gamma}$(G) is very small !

☞ $q\bar{q}$/glueball mixing is possible!

Glueballs

J^{PC}	Lattice QCD Mass (MeV)	Glueball Candidates	
0^{++}	1600±200	"σ" + $f_0(1400)$	(1)
		$f_0(1400)$	(2)
		$f_0(1500)$	(3)
		$f_J(1710)$	(4)
0^{-+}	2100±200	$\eta(1440)$	(4)
2^{++}	2220±200	$\xi(2230)$	(5)

(1) P.Minkowski and W.Ochs (hep-ph/9905250)
(2) U.Gastaldi et al. (LNL-INFN(rep)148/99)
(3) C.Amsler and F.E.Close (Phys.Rev.D53(1996)295)
(4) PDG, Eur. Phys. J. C 3(1998)1
(5) BES Collab., Phys.Rev.Lett. 76(1996)3502

e^+e^- colliders

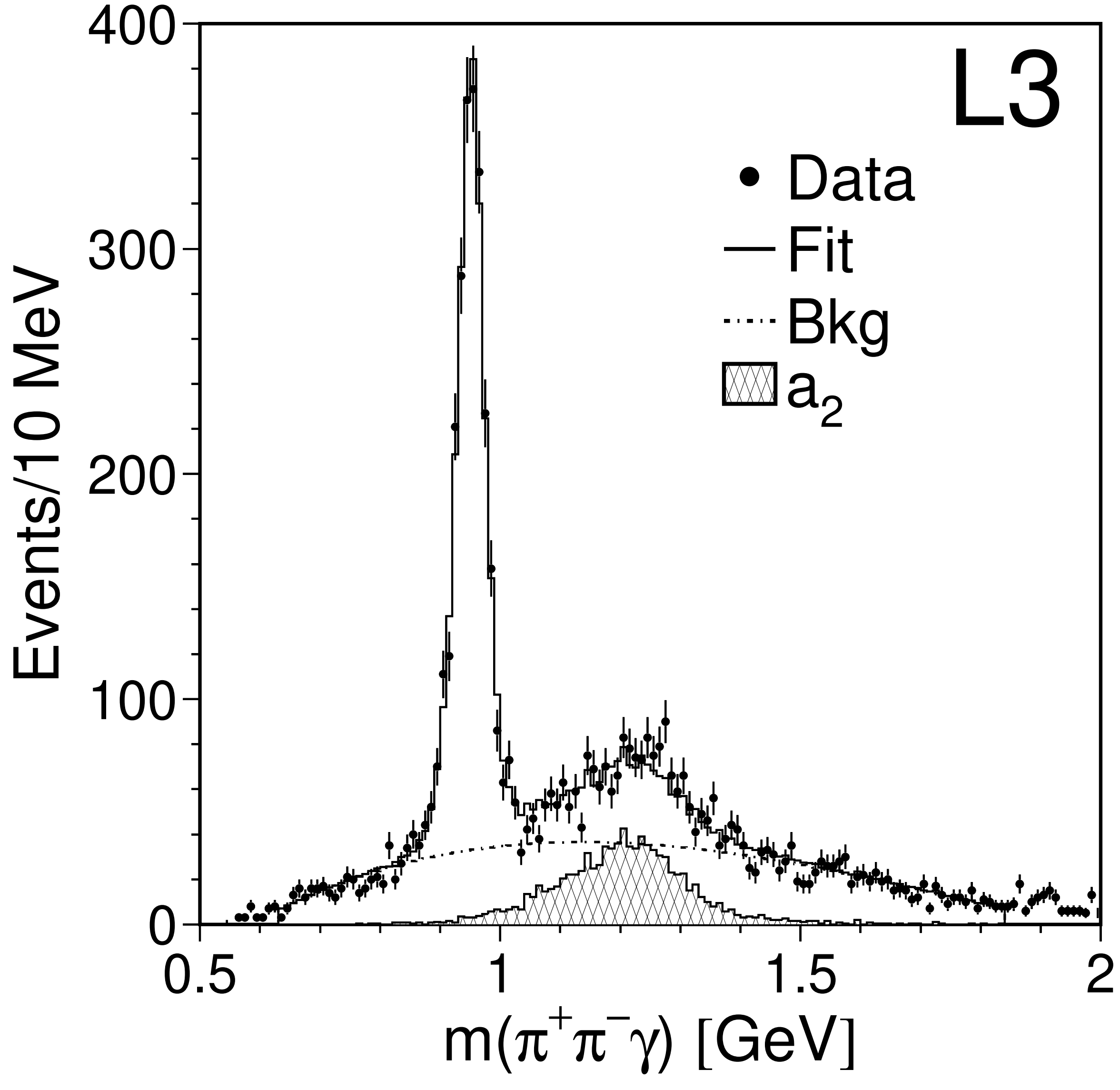
LEP at CERN

- Experiments: ALEPH, DELPHI, L3, OPAL
- $\sqrt{s} \sim$ 91, 183, 189, 191-202 GeV
- $\mathcal{L} \sim$ 150, 52, 175, 240 pb^{-1} per experiment

CESR at Cornell

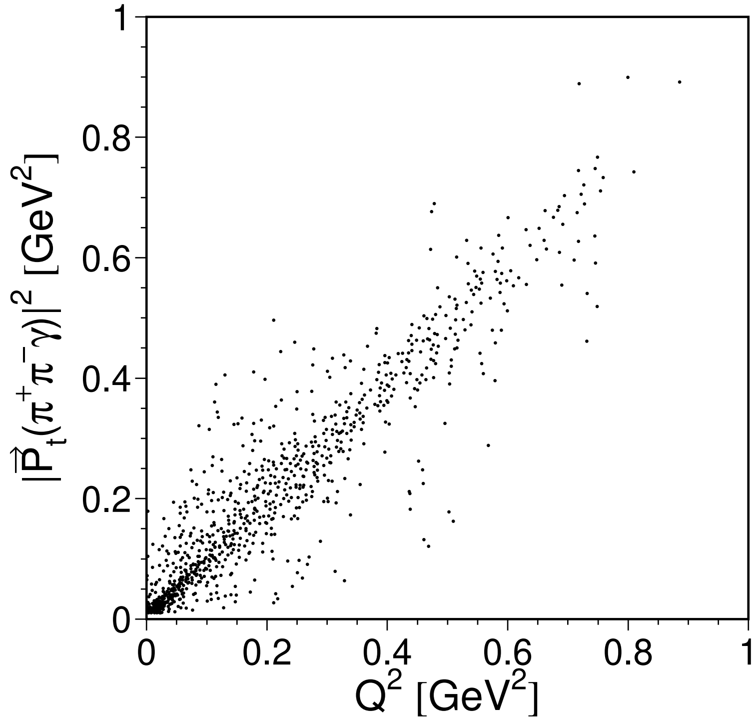
- Experiment: CLEO II
- $\sqrt{s} \sim$ 10.6 GeV
- $\mathcal{L} \sim$ 3000 pb^{-1}

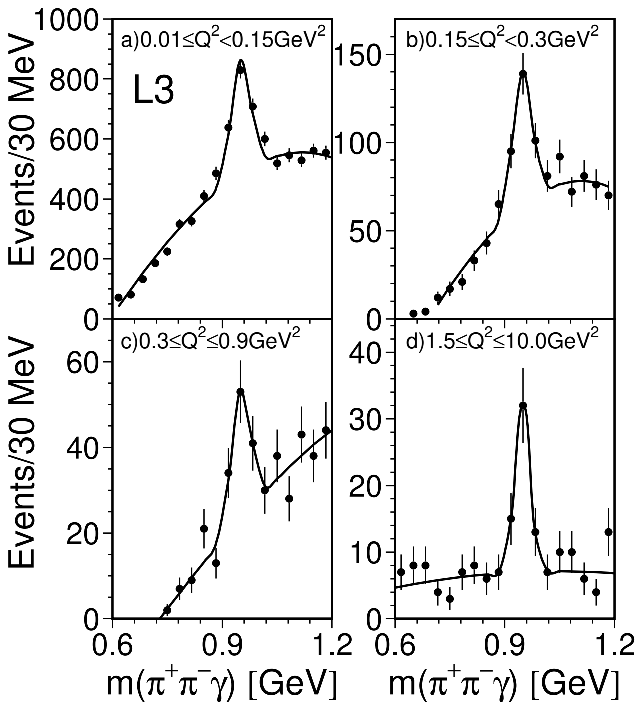
$\gamma\gamma \to \eta' \to \pi^+\pi^-\gamma$



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

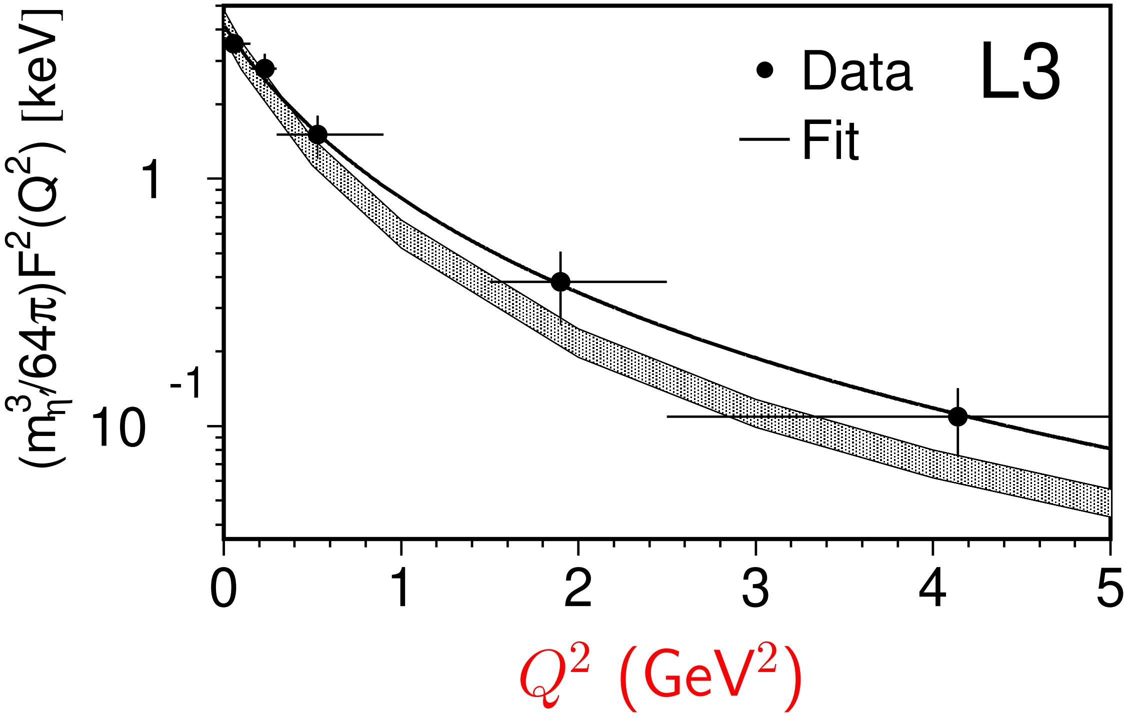
⇨Phys.Lett.B 418(1998)399





- "no-tag" : $Q^2 \simeq |\vec{p}_T(\pi^+\pi^-\gamma)|^2$
- "single-tag" : $Q^2 \simeq 2E_{beam}E_{tag}(1-\cos\theta_{tag})$

The $\eta'(958)$ transition form factor



- Fit : $\Lambda = 0.900 \pm 0.046 \pm 0.022$ GeV
- Predictions by V.V. Anisovich et al. (Phys.Lett.B 404(1997)166)

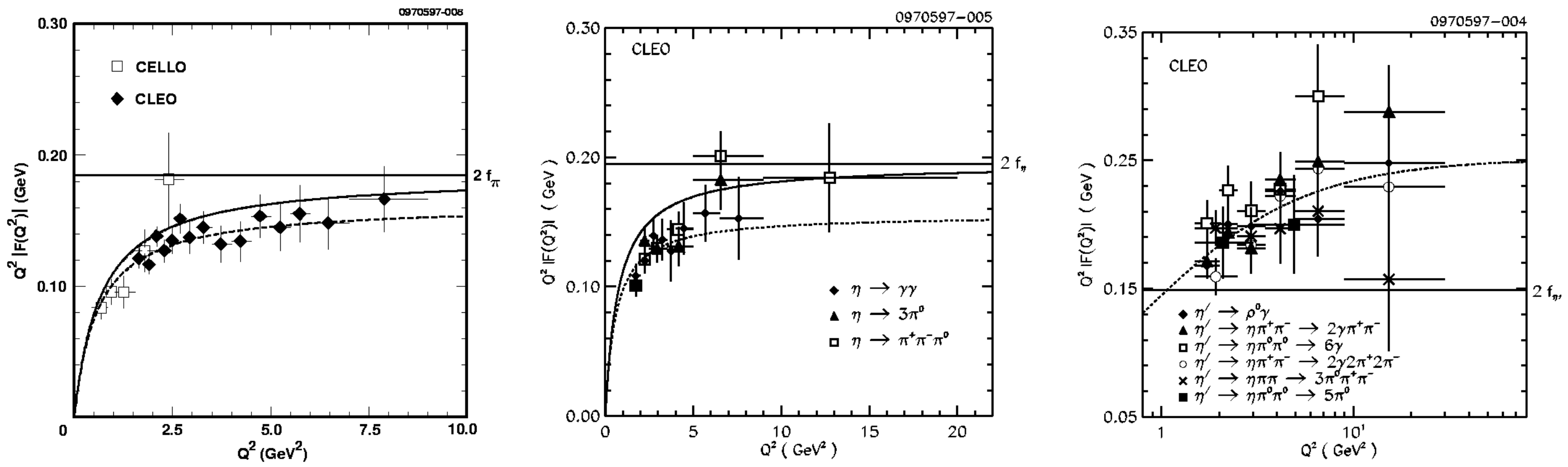
  No gluonium content (upper line)

  15% gluonium content (lower line)

⇨ Low gluonium content in the η' is favoured

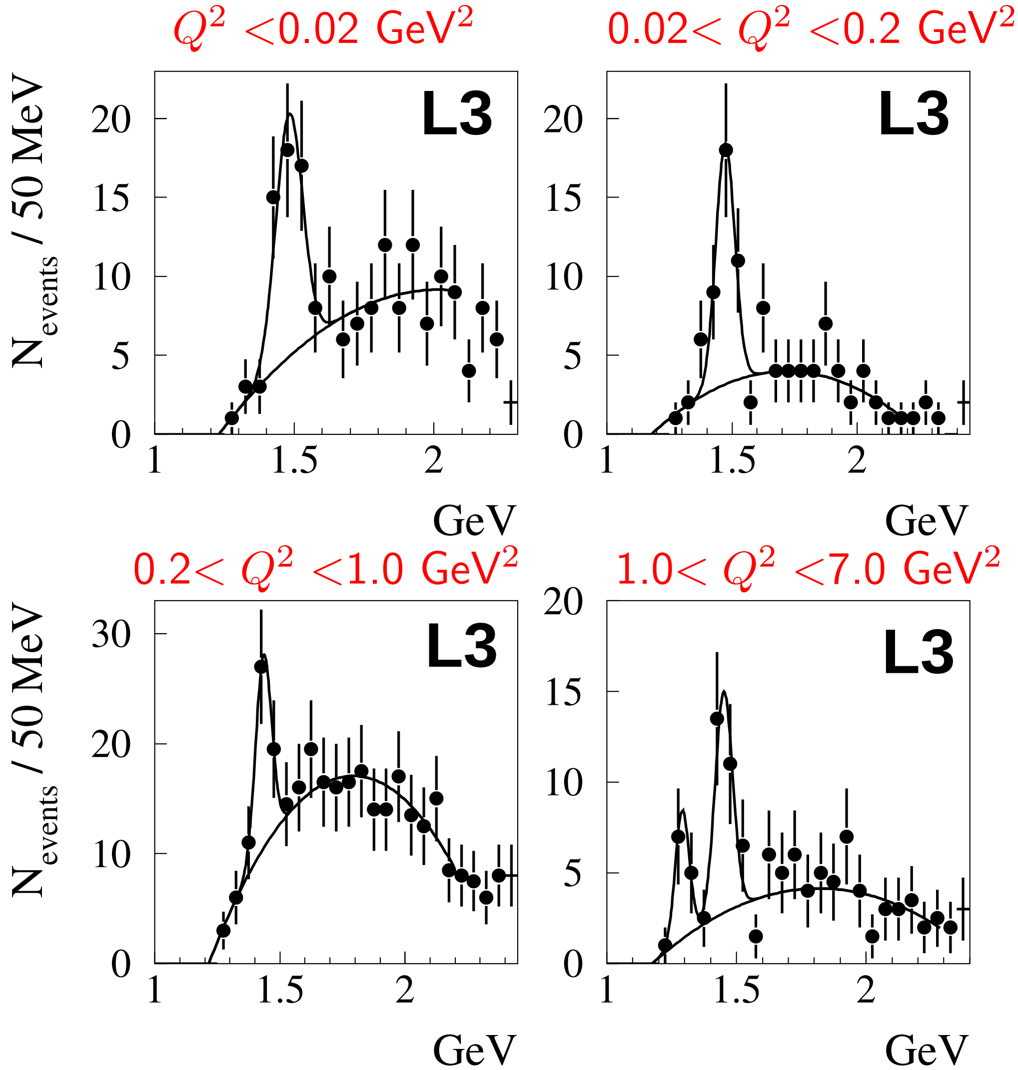
CLEO Collaboration (Phys. Rev.D57(1998)33)

π^0 η η'



- Single-tag events
- Fit (dashed line):
  Λ_{π^0}=0.776±0.010±0.012±0.016 GeV
  Λ_{η}=0.774±0.011±0.016±0.022 GeV
  $\Lambda_{\eta'}$=0.859±0.009±0.018±0.020 GeV
- S.J.Brodsky and G.P.Lepage, Phys.Rev.D24(1981)1808 (Solid lines)

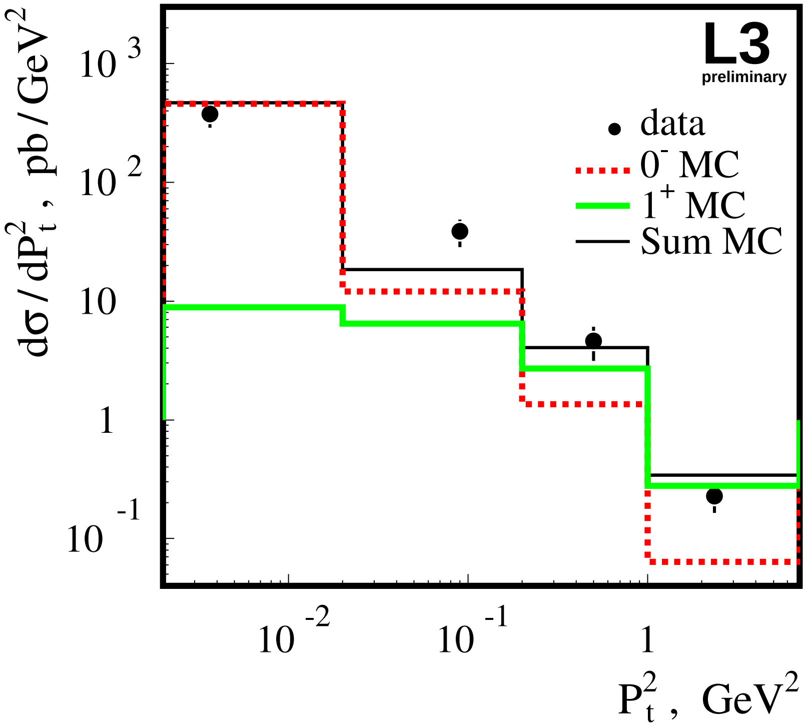
The $K_s^0 K^\pm \pi^\mp$ final state



m($K_s^0 K^\pm \pi^\mp$)

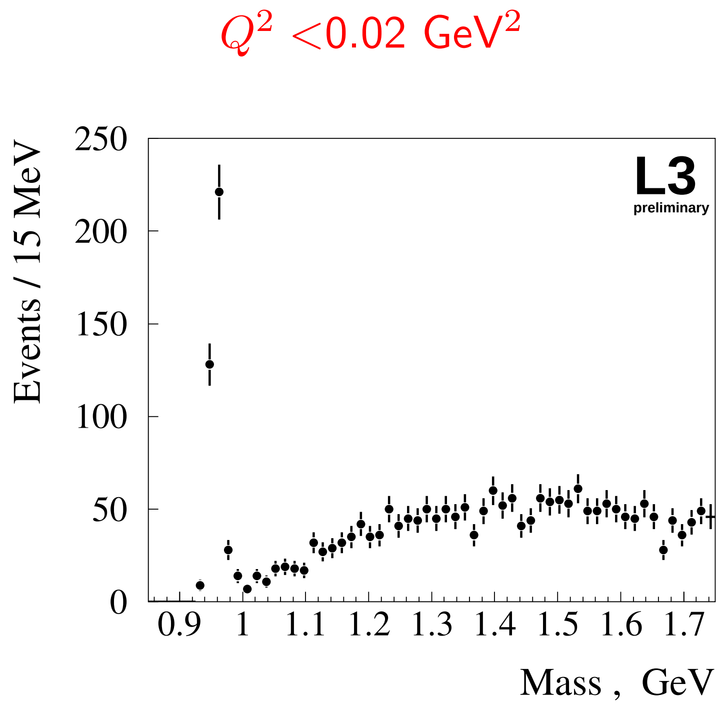
- Prominent peek at 1470 MeV
  - ⇨ Visible at low and high Q^2
- $f_1(1285)$ signal at very high Q^2

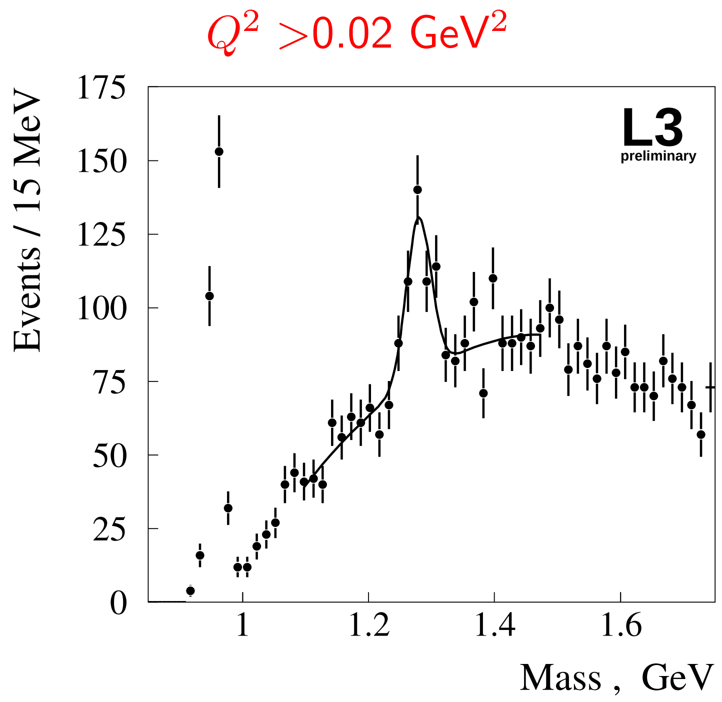
The $K_s^0 K^{\pm}\pi^{\mp}$ final state



- Both 0^{-+} and 1^{++} waves are needed!
- $\eta(1440)$ dominates at low Q^2:
  $\Gamma_{\gamma\gamma}(\eta(1440)) \times BR(\eta(1440) \to K\bar{K}\pi) = 234 \pm 55 \pm 17$ eV
- The glueball interpretation of the $\eta(1440)$ is disfavoured!
- $f_1(1420)$ dominates at high Q^2

The $\eta\pi^+\pi^-$ final state





$m(\eta\pi^+\pi^-)$

- Large $\eta'(958)$ signal
- No signal for the $\eta(1440)$ and $\eta(1295)$ at low Q^2:

  $\Gamma(\eta(1440) \to \gamma\gamma) \times$ BR$(\eta(1440) \to \eta\pi\pi)$ <205 eV at 95% C.L.
  $\Gamma(\eta(1295) \to \gamma\gamma) \times$ BR$(\eta(1295) \to \eta\pi\pi)$ <145 eV at 95% C.L.

- Clear $f_1(1285)$ signal at high Q^2

η and f_1 summary

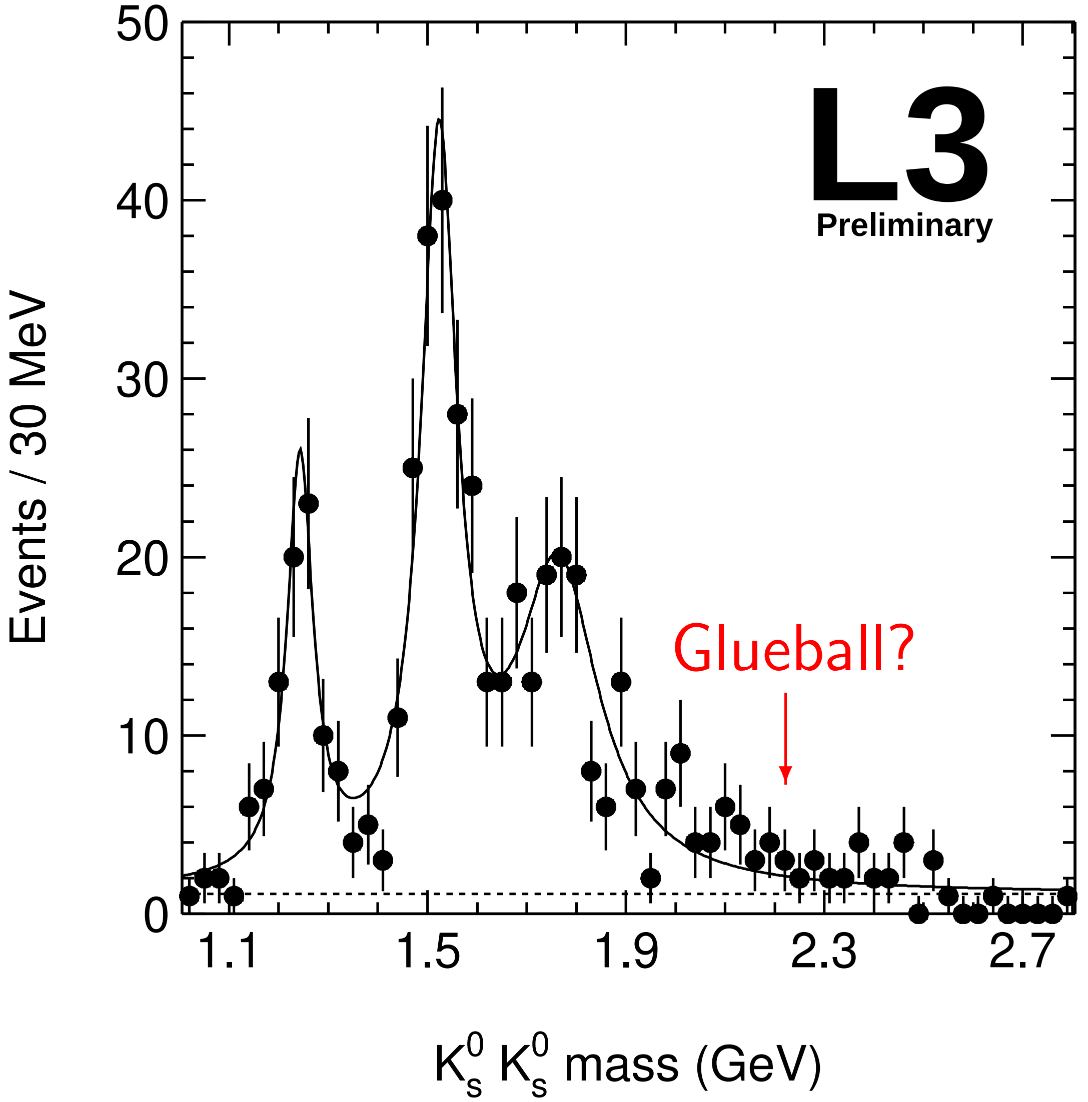
Reaction		$\eta(1295)$	$\eta(1440)$	$f_1(1285)$	$f_1(1420)$
$(\pi p, kp) \to Xn$	(1)	YES	YES	YES	YES
$pp \to pXp$	(1)	NO	NO	YES	YES
$\bar{p}p \to X(\pi, \pi\pi)$	(1)	NO	YES	YES	YES
$J/\psi \to X\gamma$	(1)	NO	YES	YES	YES
$\mathrm{e^+e^-} \to \mathrm{e^+e^-}X$	(2)	NO	NO	YES	YES
$\mathrm{e^+e^-} \to \mathrm{e^+e^-}X$	(3)	NO	YES	YES	YES

- $\eta(1295)$ and $\eta(1440)$:
  Radial excitations of the ground state 0^{-+} nonet?
  (A.V.Anisovich et al., Eur.Phys.J.A 6(1999)247)

(1) A.Rotondi, Frascati Physics Series Vol.XV(1999)677.
(2) TPC-2γ Collab., Phys.Lett.B209(1988)107; Phys.Rev.D 38(1988)1.
CELLO Collab., Z.Phys.C 42(1989)367.
JADE Collab., Z.Phys.C 42(1989)355.
(3) L3 Collab., preliminary results.

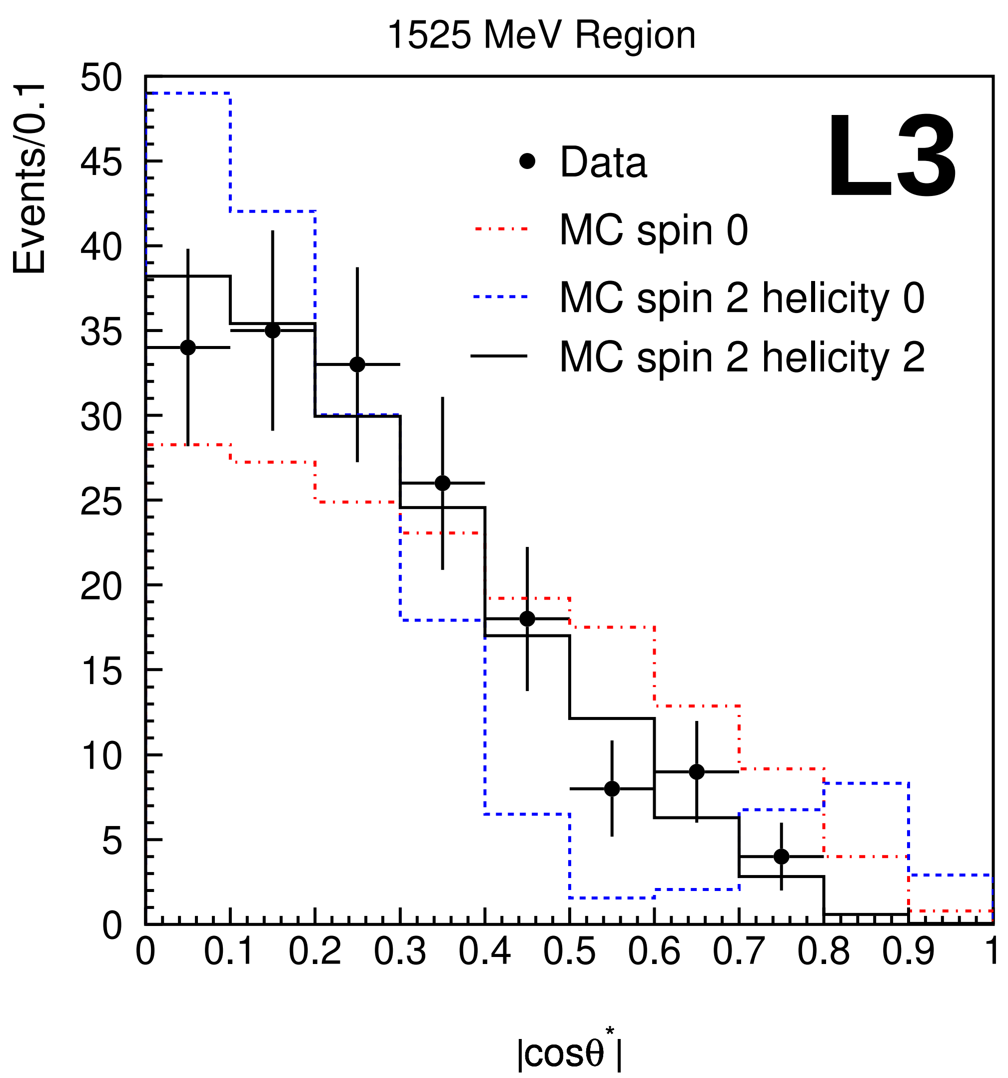
The $K_s^0 K_s^0$ final state

$$\gamma\gamma \to R \to K_s^0 K_s^0$$



- $f_2 - a_2$ destructive interference
- Clear $f_2'(1525)$ signal :
  $\Gamma_{\gamma\gamma}(f_2') \times BR = 0.09 \pm 0.02 \pm 0.02$ keV
- Clear enhancement in the 1750 MeV region
- No signal for the $\xi(2230)$ glueball candidate :
  $\Gamma_{\gamma\gamma}(\xi) \times \mathrm{BR}(\xi \to K_s^0 K_s^0) < 1.5$ eV at 95% C.L.

The $f_2'(1525)$

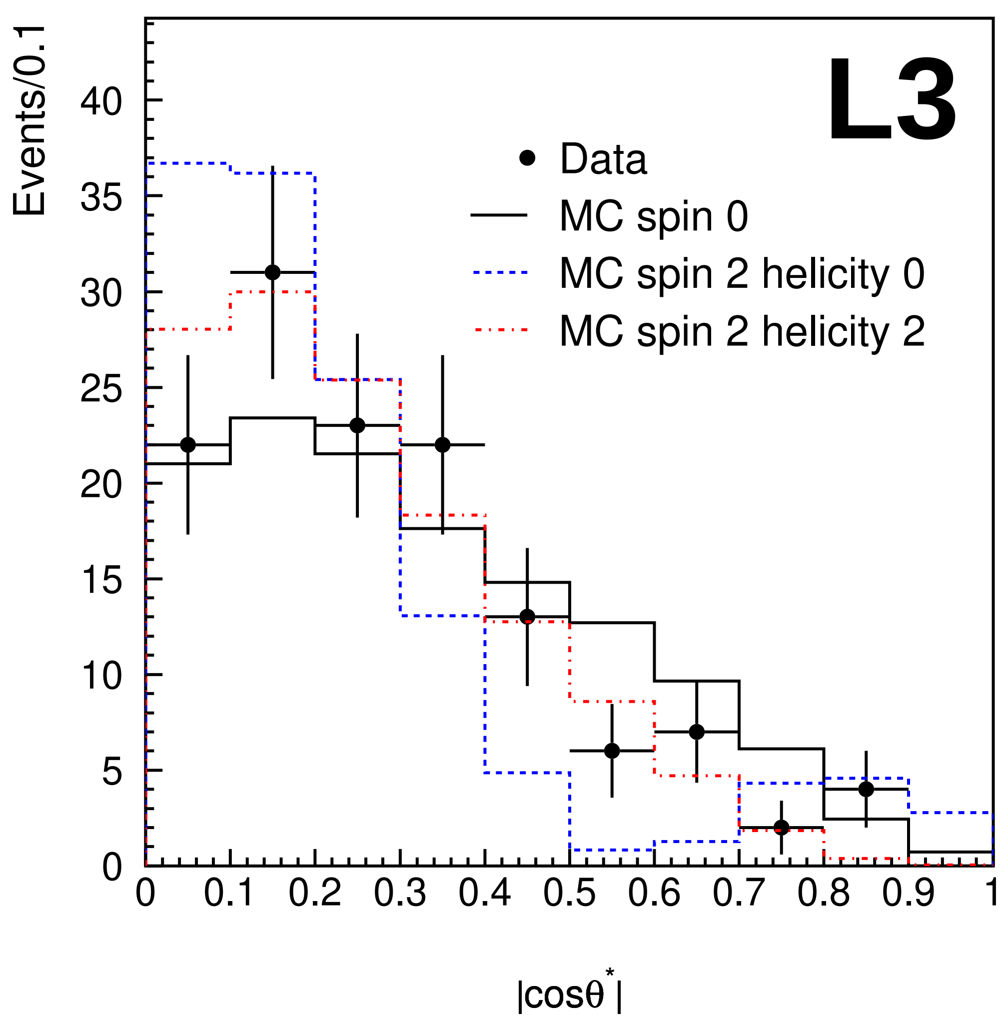


	J=0	J=2, λ=2	J=2, λ=0
C.L.	$\sim$0%	96%	$\sim$0%

Helicity 2 dominates !

The 1750 MeV region

- $f_2'(1525)$ radial recurrence? $f_2''(1740)$, $f_2'''(1820)$ (OGE-SRM model, C.R.Münz,Nucl.Phys.A609(1996)364.)
- 0^{++} $s\bar{s}$ state ? (Supporting the glueball nature of the $f_0(1500)$ - C.Amsler and F.E.Close, Phys.Rev. D53(1996)295)

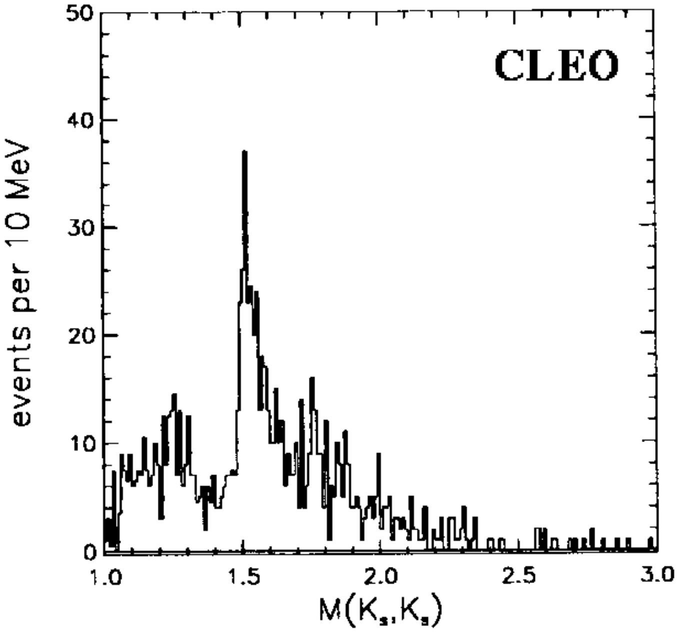


	J=0	J=2, λ=2	J=2, λ=0
C.L.	11%	69%	$\sim$0%

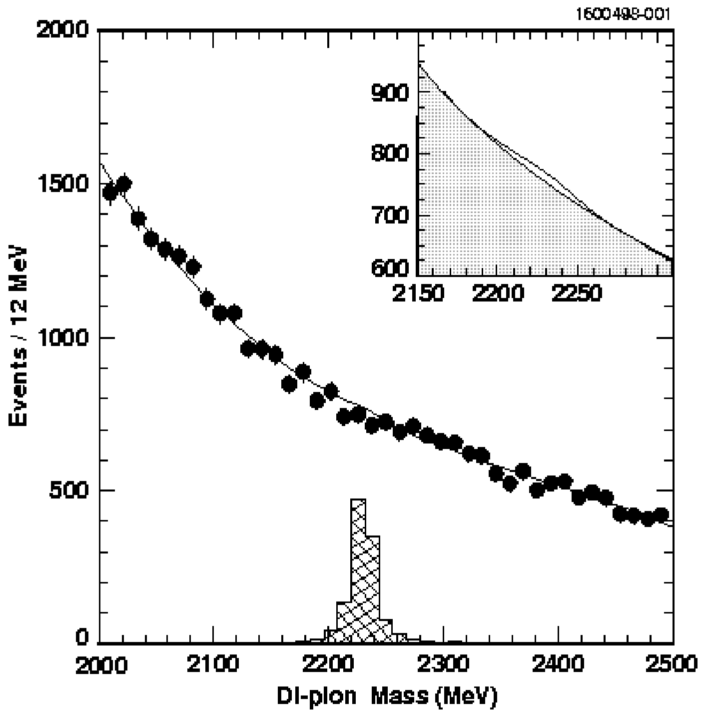
⇨Phys.Lett.B 363(1995)418
S.Braccini, Nucl.Phys.A655(1999)143 and hep-ex/9811017

Search for the $\xi(2230)$ at CLEO

$K_s^0 K_s^0$

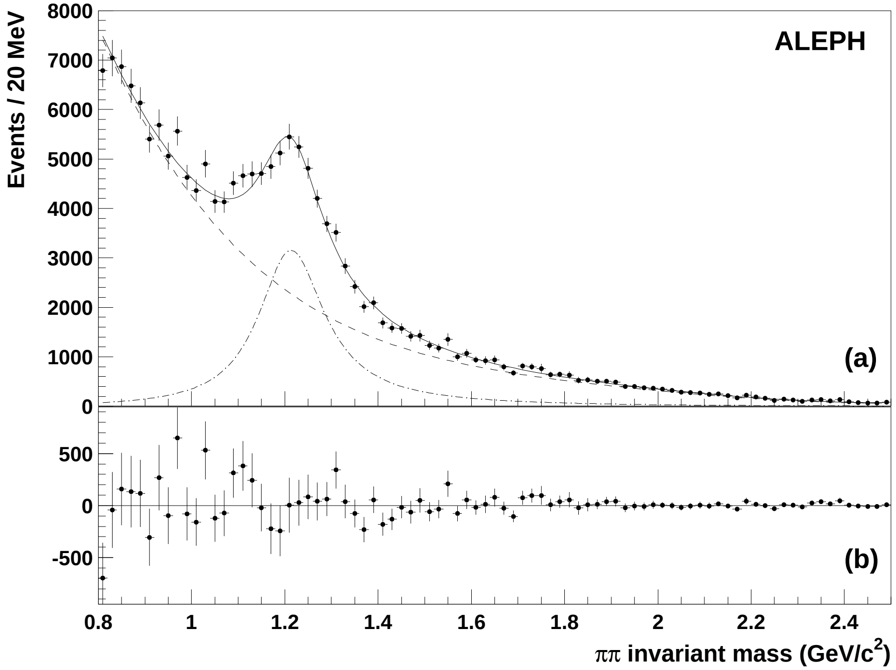


$\pi^+\pi^-$



- ❑ $\Gamma(\xi \to \gamma\gamma) \times \mathrm{BR}(\xi \to K_s^0 K_s^0)$ <1.3 eV at 95% C.L.
  (Phys.Rev.Lett.79(1997)3829)
- ❑ $\Gamma(\xi \to \gamma\gamma) \times \mathrm{BR}(\xi \to \pi^+\pi^-)$ <2.5 eV at 95% C.L.
  (Phys.Rev.Lett.81(1998)3328)

The $\pi^+\pi^-$ final state at ALEPH



$$\gamma\gamma \rightarrow \pi^+\pi^-$$

(Phys.Lett.B 472(2000)189)

- Clear $f_2(1270)$ signal
- $f_0(1500)$ and $f_J(1710)$ are supposed to be scalars
- No interference with the $\pi^+\pi^-$ continuum
- $\Gamma(f_0(1500) \rightarrow \gamma\gamma) \times \mathrm{BR}(f_0(1500) \rightarrow \pi^+\pi^-)$ <310 eV at 95% C.L.
- $\Gamma(f_J(1710) \rightarrow \gamma\gamma) \times \mathrm{BR}(f_J(1710) \rightarrow \pi^+\pi^-)$ <550 eV at 95% C.L.
- According to A.V.Anisovitch and V.V.Anisovitch the $f_0(1500)$ should interfere and appear as a dip (Phys.Lett.B 467(1999)289)

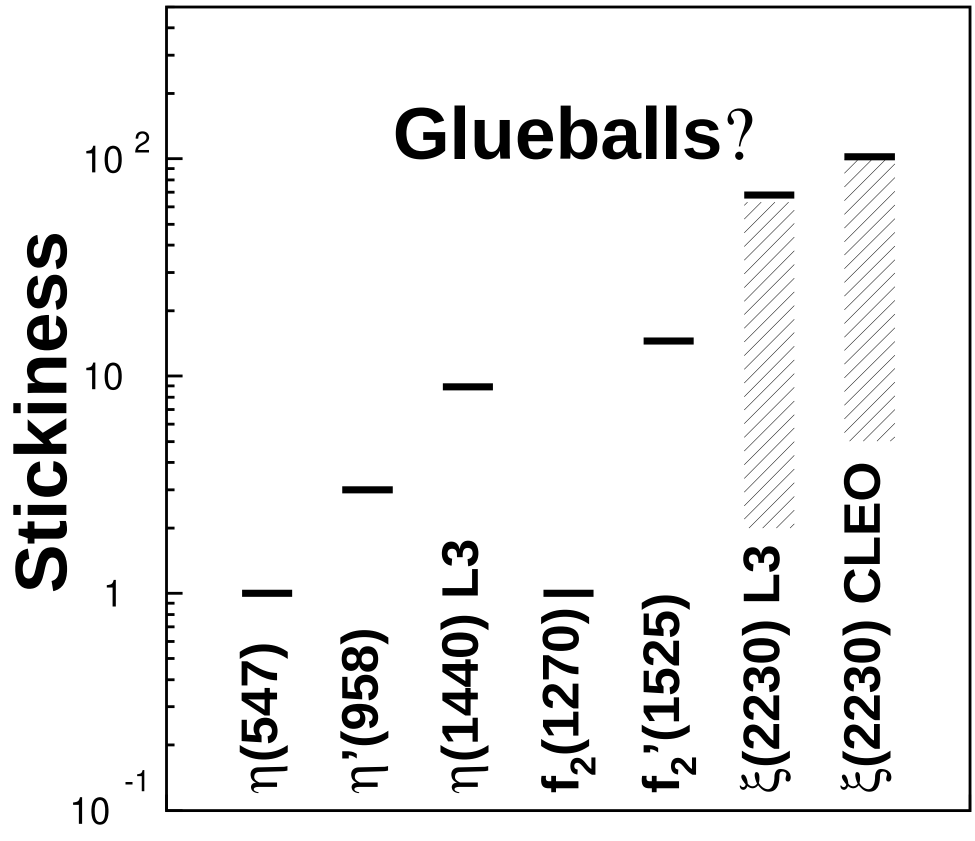
Stickiness

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

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

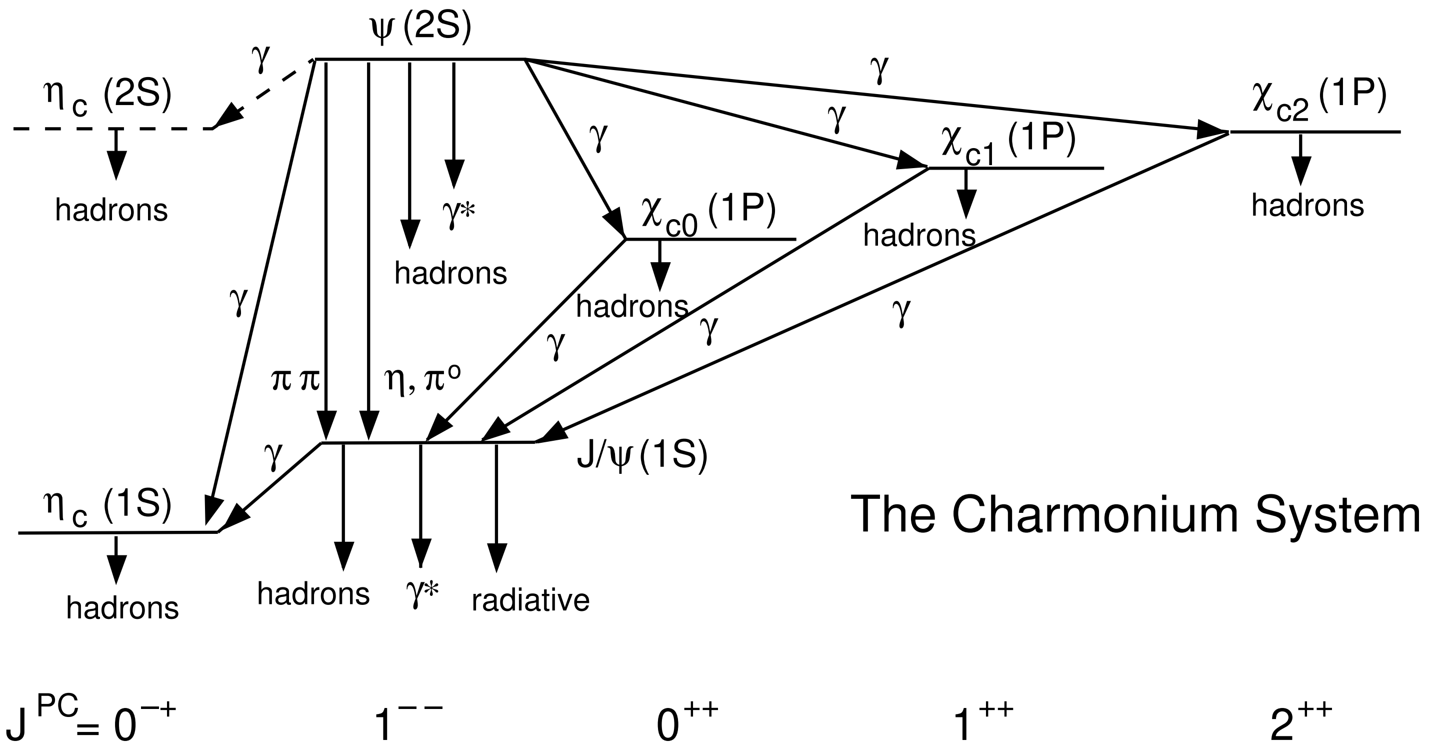
where:

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



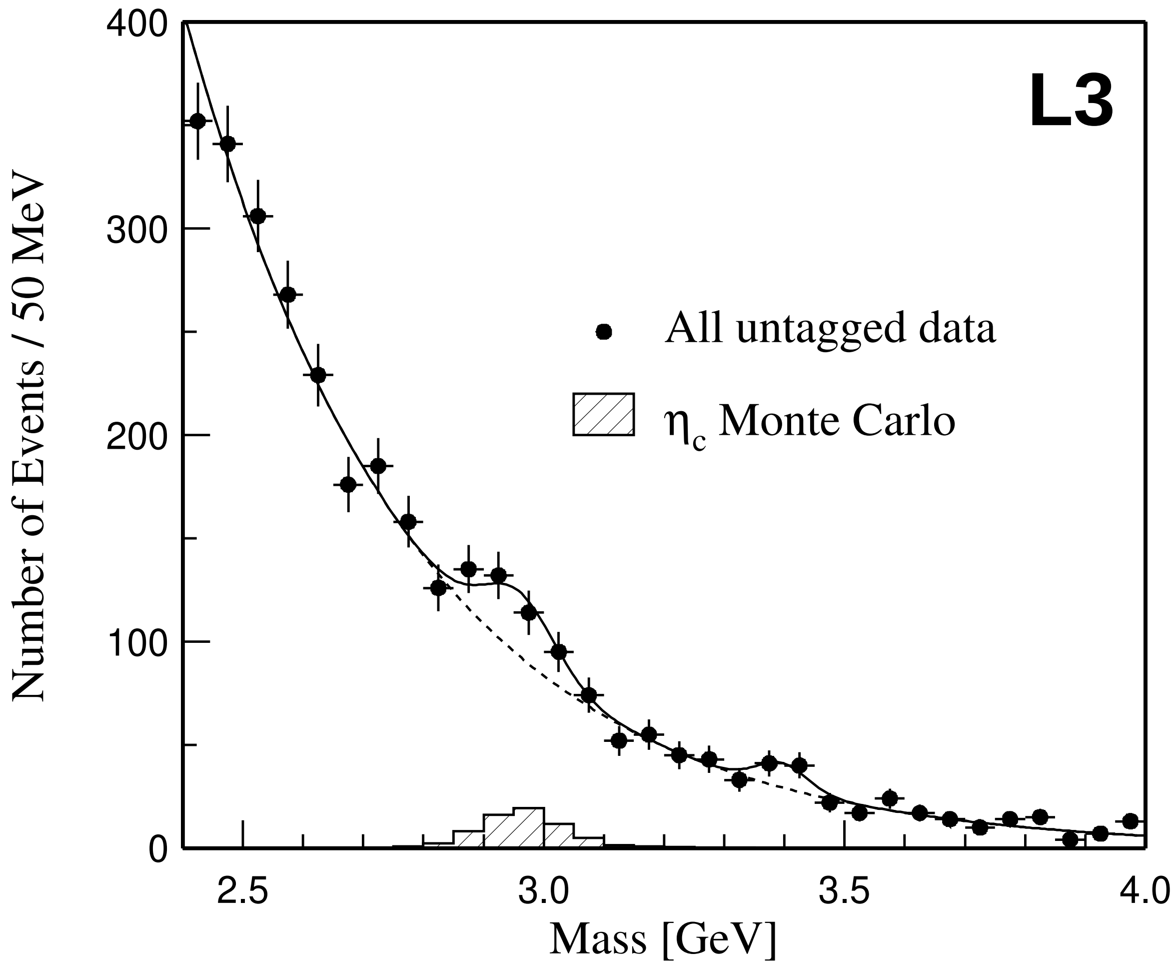
⇨ The $\xi(2230)$ is a good glueball candidate, according to lattice QCD theoretical predictions.

Charmonium formation



The η_c(2980)

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

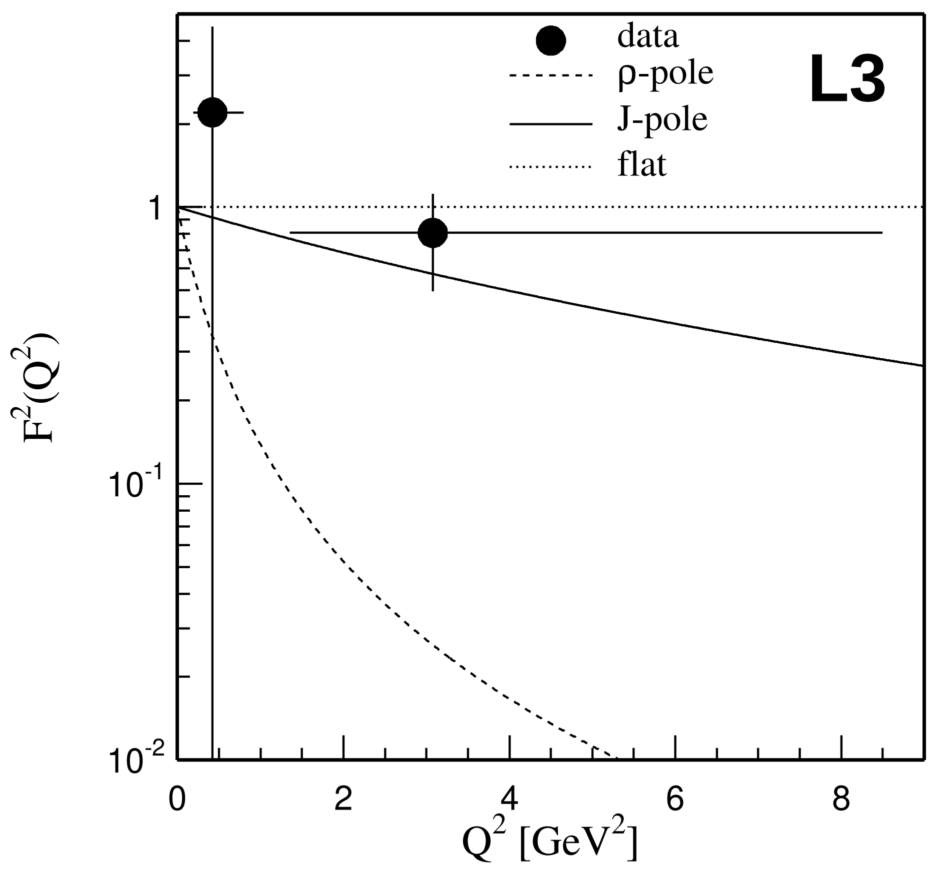


The η_c(2980)

- 9 decay modes $\rightarrow$ Total branching ratio : $\sim$10%
- Combining all the decay channels:

  $\Gamma_{\gamma\gamma}(\eta_c)$ = 6.9 $\pm$ 1.7 (stat.) $\pm$ 0.8 (sys.)$\pm$ 2.0 (BR) keV
- Signal of the $\chi_{c0}(3415)$
- No signal of the η_c'

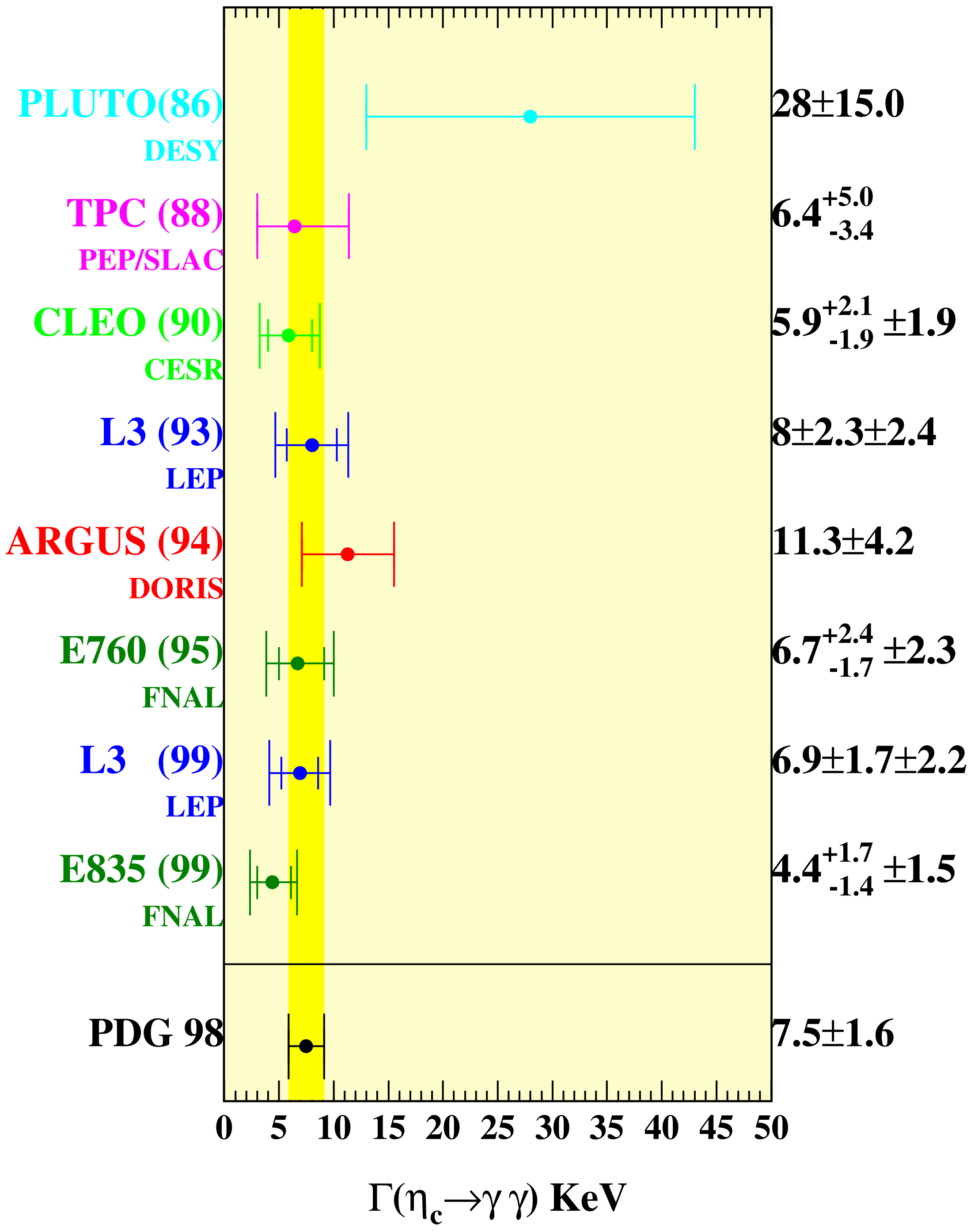
The transition form factor of the η_c



- VDM J/ψ pole form factor is favoured!

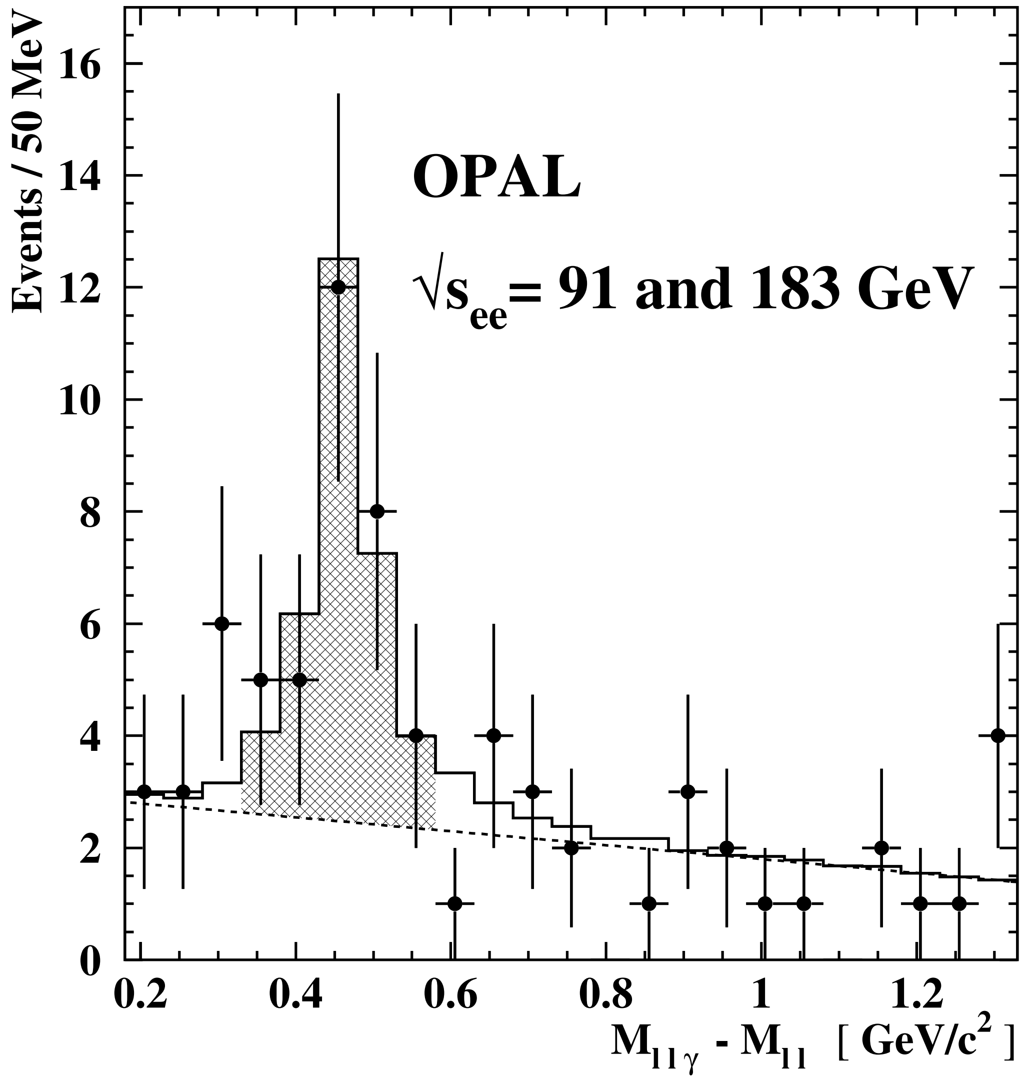
⇨Phys.Lett.B 461(1999)155

The $\Gamma_{\gamma\gamma}$ of the η_c



The $\chi_{c2}(3555)$

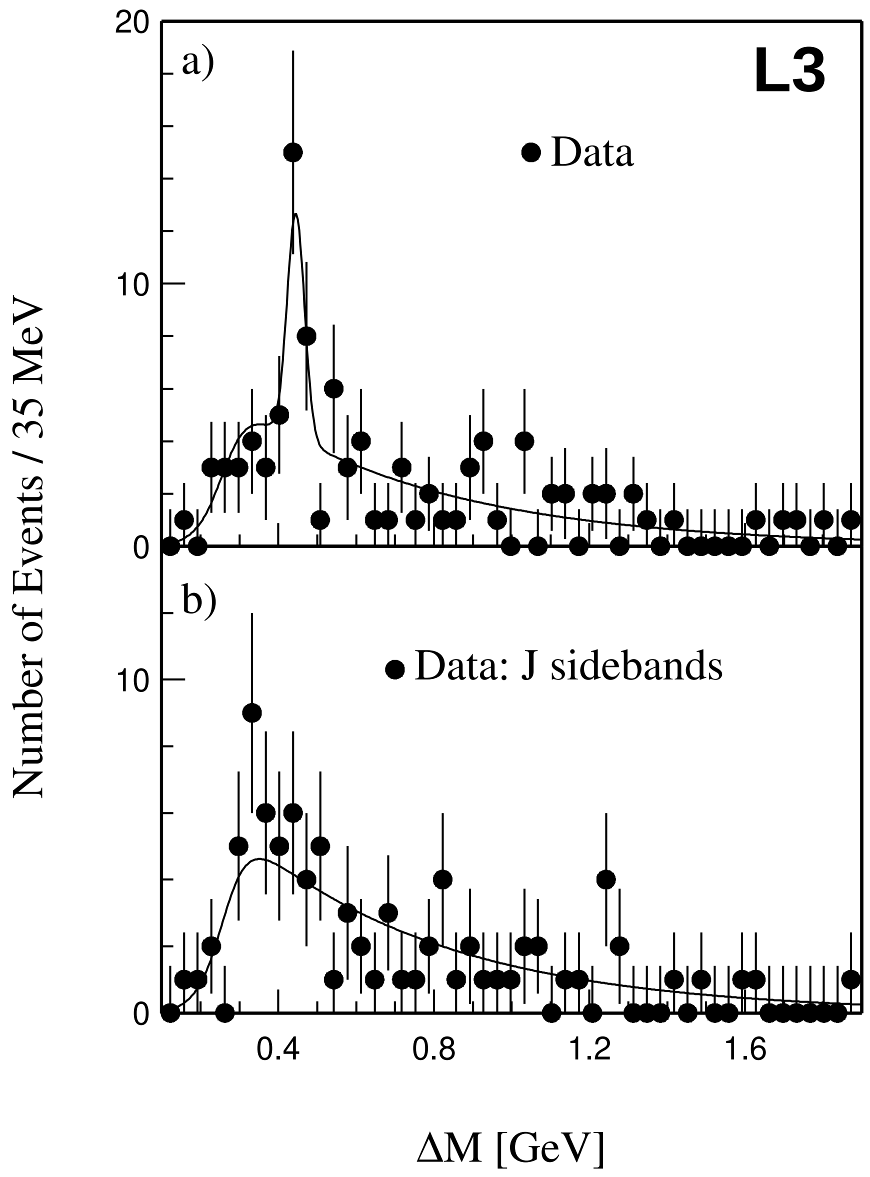
$\gamma\gamma \to \chi_{c2} \to J/\psi\gamma \to e^+e^-\gamma, \mu^+\mu^-\gamma$



- $\Delta M = M(l^+l^-\gamma) - M(l^+l^-)$
- $\Gamma_{\gamma\gamma}(\chi_{c2}) = 1.76 \pm 0.47$ (stat.) $\pm$ 0.37 (sys.)$\pm$ 0.15 (BR) keV

⇨Phys.Lett.B 439(1998)197

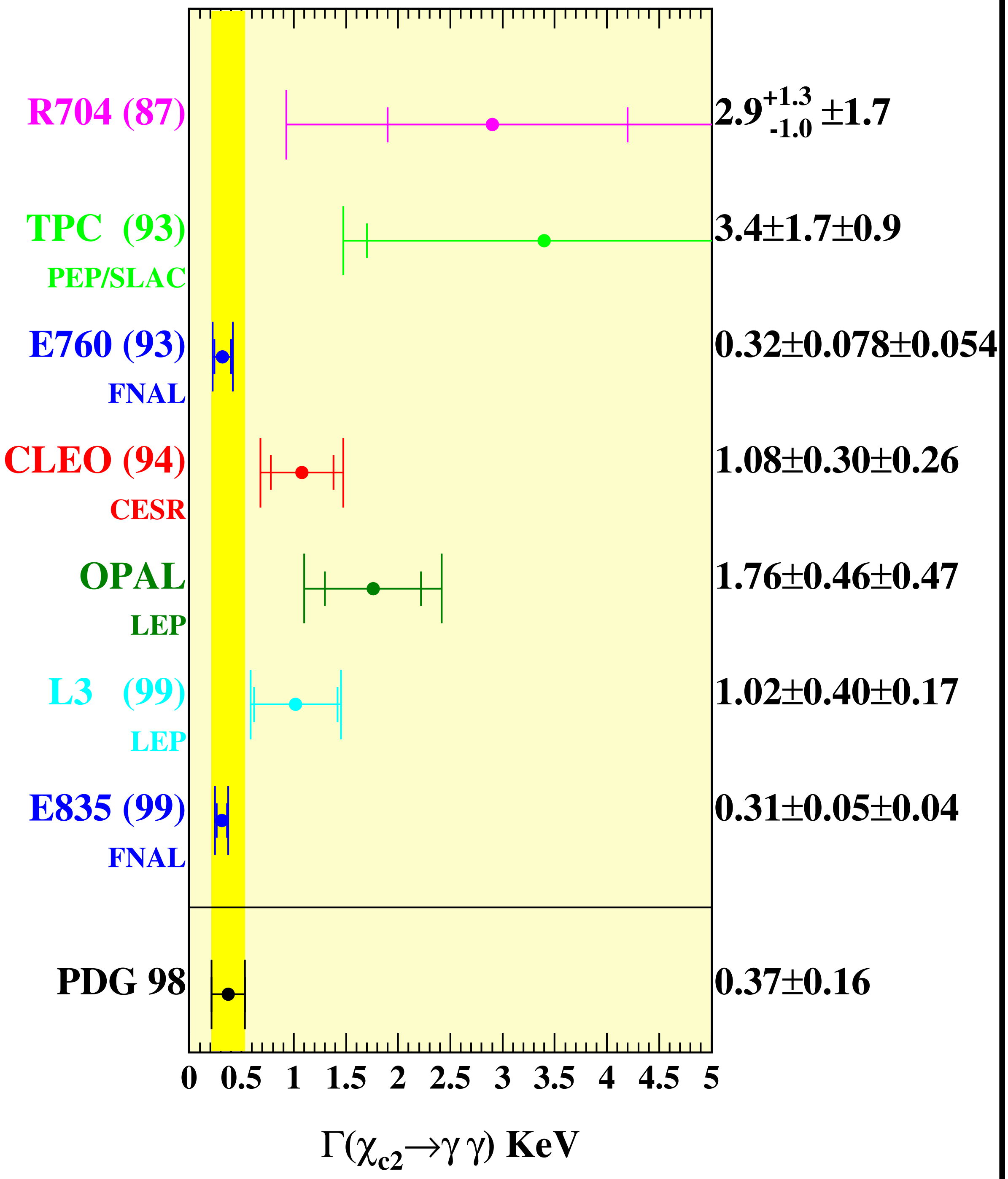
The χ_{c2}*(3555)*



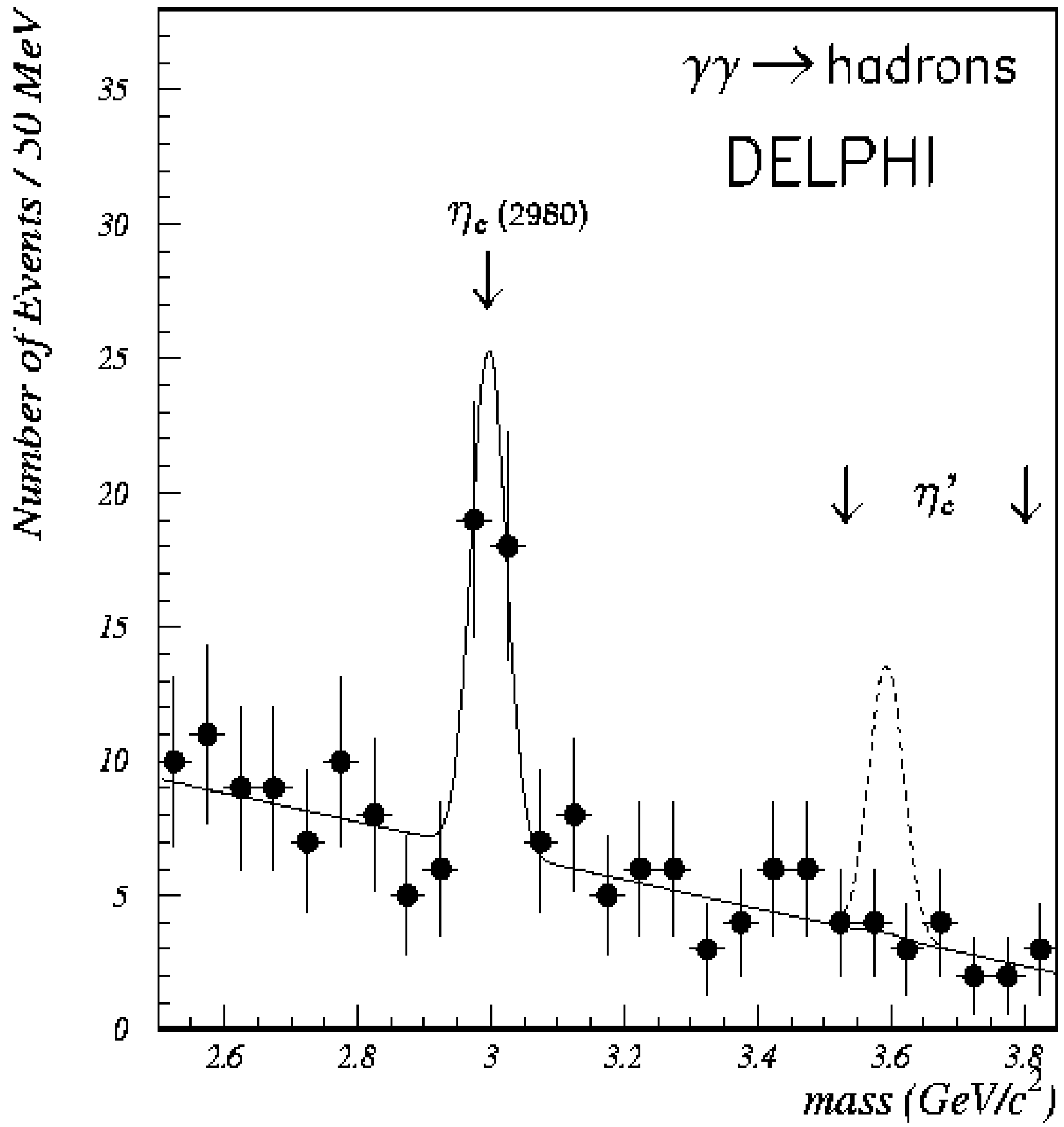
- Same method
- $\Gamma_{\gamma\gamma}(\chi_{c2}) = 1.02 \pm 0.40$ (stat.) $\pm$ 0.15 (sys.)$\pm$ 0.09 (BR) keV

⇨Phys.Lett.B 453(1999)73

The $\Gamma_{\gamma\gamma}$ of the χ_{c2}



Search for the η_c'



No η_c' signal!

- DELPHI: $\frac{\Gamma_{\gamma\gamma}(\eta_c')}{\Gamma_{\gamma\gamma}(\eta_c)} < 0.34$ (90% C.L.)

  (Phys.Lett.B441(1998)479)

- L3 : $\Gamma_{\gamma\gamma}(\eta_c') < 2.0$ keV (95% C.L.)

Conclusions and Outlook

Two-photon widths:

Resonance	Experiment	Final state	J^{PC}	$\Gamma_{\gamma\gamma}$
$\eta'(958)$	L3	$\pi^+\pi^-\gamma$	0^{-+}	4.17±0.10±0.27 keV
$a_2(1320)$	L3	$\pi^+\pi^-\pi^0$	2^{++}	0.98±0.05±0.09 keV
$f_2'(1525)$	L3	$K_s^0K_s^0$	2^{++}	$0.09^\dagger$±0.02±0.02 keV
$\eta_c(2980)$	L3	10 chan	0^{-+}	6.9±1.7.±0.8 keV
η_c'	L3	10 chan	0^{-+}	< 2.0 keV
$\chi_{c2}(3555)$	L3	$l^+l^-\gamma$	2^{++}	1.02±0.4±0.15 keV
$\chi_{c2}(3555)$	OPAL	$l^+l^-\gamma$	2^{++}	1.76±0.47±0.37 keV
$\eta(1440)$	L3	$K_s^0K^\pm\pi^\mp$	0^{-+}	$234^\dagger$±55 eV
$f_J(1710)$	L3	$K_s^0K_s^0$	2^{++} (?)	
$a_2'(1752)$	L3	$\pi^+\pi^-\pi^0$	2^{++}	$0.29^\dagger$±0.04±0.02 keV
$f_0(1500)$	ALEPH	$\pi^+\pi^-$	0^{++}	$< 310^\dagger$ eV
$f_0(1710)$	ALEPH	$\pi^+\pi^-$	0^{++}	$< 550^\dagger$ eV
$\xi(2230)$	CLEO	$\pi^+\pi^-$	2^{++}	$< 2.5^\dagger$ eV
$\xi(2230)$	CLEO	$K_s^0K_s^0$	2^{++}	$< 1.3^\dagger$ eV
$\xi(2230)$	L3	$K_s^0K_s^0$	2^{++}	$< 1.5^\dagger$ eV

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

Transition form factors:

π^0, η (CLEO) η' (CLEO, L3) η_c (L3)

Conclusions and Outlook

- A large number of resonances have been studied at LEP and CESR
- Improved measurements of the two-photon widths
- Study of the transition form factors
- Observation of radial excitations
- Some glueball candidates have a very small two-photon width!

⇨ Significant contribution to meson spectroscopy and glueball searches

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