Glueball Searches in $\gamma\gamma$ Collisions at LEP

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Outline

- Introduction
- Present situation
- The $\gamma\gamma \to \pi^+\pi^-$ at ALEPH
- The $\gamma\gamma \to K^0_s K^0_s$ at L3
- Conclusions and Remarks

What is a Glueball

The QCD is a Yang-Mills Non Abelian Gauge Theory whose intermediate bosons are the gluons.

- Non Abelian $\Longrightarrow$ gluon can interact
- Interacting Gluon $\Longrightarrow$ Bound States (Glueball)

Something more about glueballs

- *Flavor blind* decay branching ratios
- produced in `gluon rich` environment
  (pp, $p\bar{p}$, radiative J/ψ decay)
  Gluon are neutral $\Longrightarrow$ no direct coupling to γ
- $\Downarrow$
  $\Gamma_{\gamma\gamma}(G)$ very small!

Even if QCD is well estabilished, no direct experimental evidence for glueball is firmily established.

Theoretical QCD calculation on glueball exist:
(`P.Minkowsky,W. Ochs` hep-ph/9811518 and reference therein)

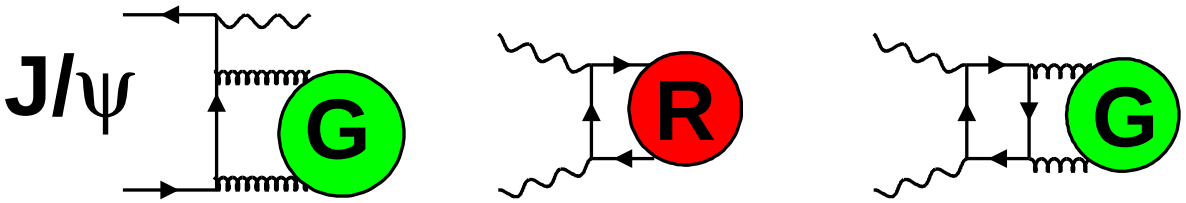
- 0^{++} (ground state) $M = 1600 \pm 200 \;\; MeV$, $\Gamma \simeq 100$
- 2^{++} (tensor state) $M_{2^{++}} \simeq 1.5 * M_{0^{++}} \simeq 2200 \;\; MeV$

$\gamma\gamma$ collisions play a crucial role in distinguishing between glueball and $q\bar{q}$ states

$e^+e^- \to \gamma\gamma$

- e^+e^- are undetected $\Longrightarrow$ Quasi-real γ $\Longrightarrow$ $C = +1$ and $J \neq 1$
- R is neutral unflavoured meson
- $\pi^+\pi^-, K^0_s K^0_s$ final state:

  $J^{PC} = (even)^{++} \Longrightarrow 0^{++}, 2^{++}$



The Cross Section

The cross section for the process

$$e^+e^- \rightarrow e^+e^-\gamma\gamma \rightarrow e^+e^-R$$

can be written as

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

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

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

where :

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

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

Stickiness

The ratio between the coupling of a state R to gluons with 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

0^{++} *States*

There are 3 known 0^{++} states:

$$a_0(1450), f_0(1370), f_0(1500).$$

The f_0's seems incompatible with a $s\bar{s}$ state and moreover they can't be both $u\bar{u} + d\bar{d}$;

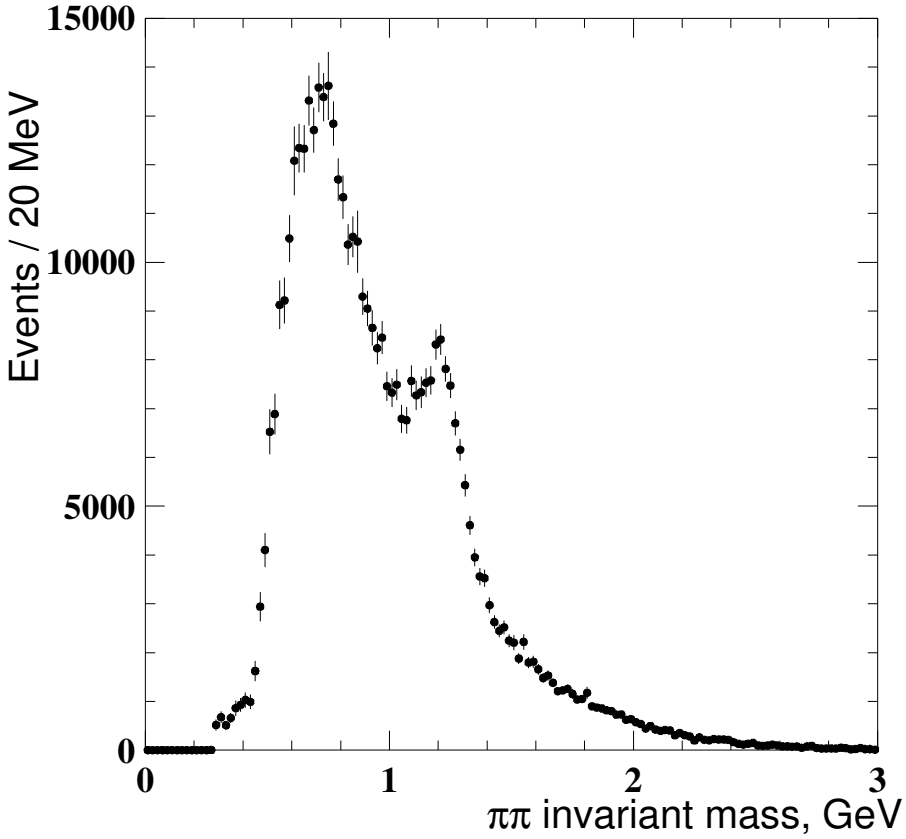
Too many states to fit in a nonet!!

C.Amsler and F.E. Close gave a classification:
Phys. Rev., **53** (1996) 295

State	Isospin		
$a_0(1450)$	1	✔	
$f_0(1370)$	0	✔	
$f_0'(1500\text{-}1800)$	0		$s\bar{s}$?
$f_0(1500)$	0	✔	Glueball ?

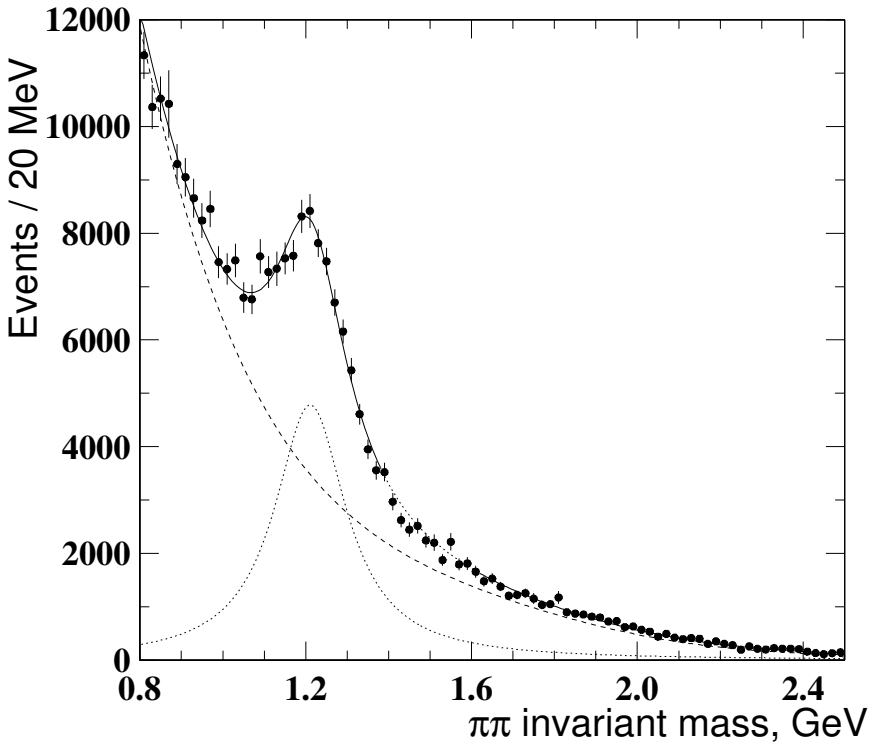
Thus, the $f_0(1500-1800)$ is expected to be an $s\bar{s}$ and hence it should strongly couple to $K\bar{K}$ sistems.

The $\gamma\gamma \to \pi^+\pi^-$ Decay at ALEPH



- 2 charged tracks & primary vertex
- No photons
- small Visible Energy
- small Transverse Momentum

The $f_2(1270)$ State



- Clear evidence of $f_2(1270)$
- no evidence of signal $f_0(1500)$
- no evidence of signal $\xi(2230)$

$f_2(1270)$

Mass (MeV)	1211 ± 4
Width (MeV)	211 ± 18
χ^2/d.o.f	1.1

The $\Gamma_{\gamma\gamma}(f_0(1500))$

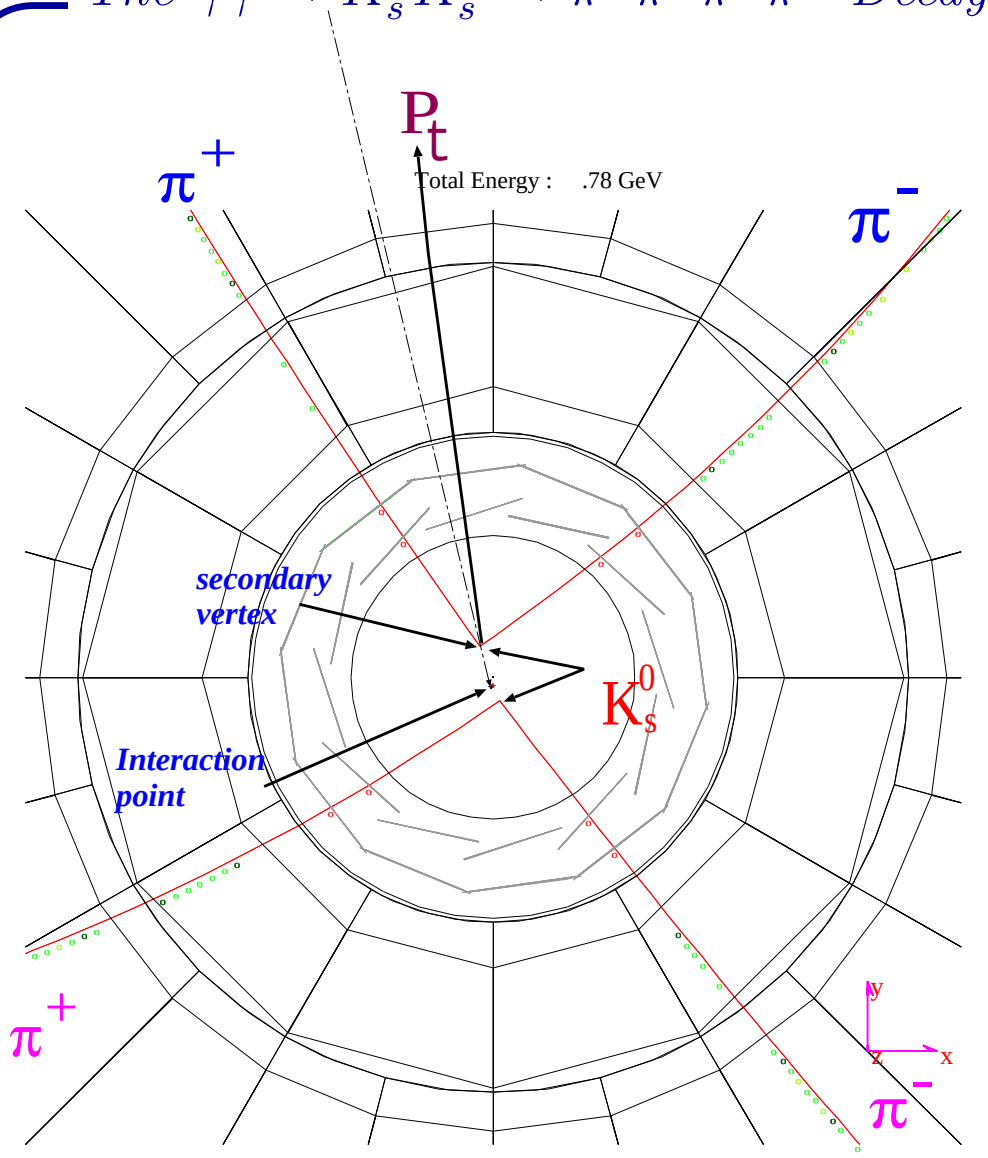
- The experimental resolution for the $f_0(1500)$ is σ=10 MeV
  - → signal region : $M_{f_0(1500)}$ $\pm 120\ MeV$
  - → PDG : 1500 $\pm 112\ MeV$
- The background due to the $\pi\pi$ continuum process and from $\gamma\gamma \to \mu\mu$ is estimated by fitting a 5^{th} order polnomial

$$\boldsymbol{\Gamma_{\gamma\gamma}(f_0(1500))) < 0.17}\ \text{keV}\ \text{ at 95\% C.L.}$$

$$\boldsymbol{S_{f_0} > 13}\ \text{at 95\% C.L.}$$

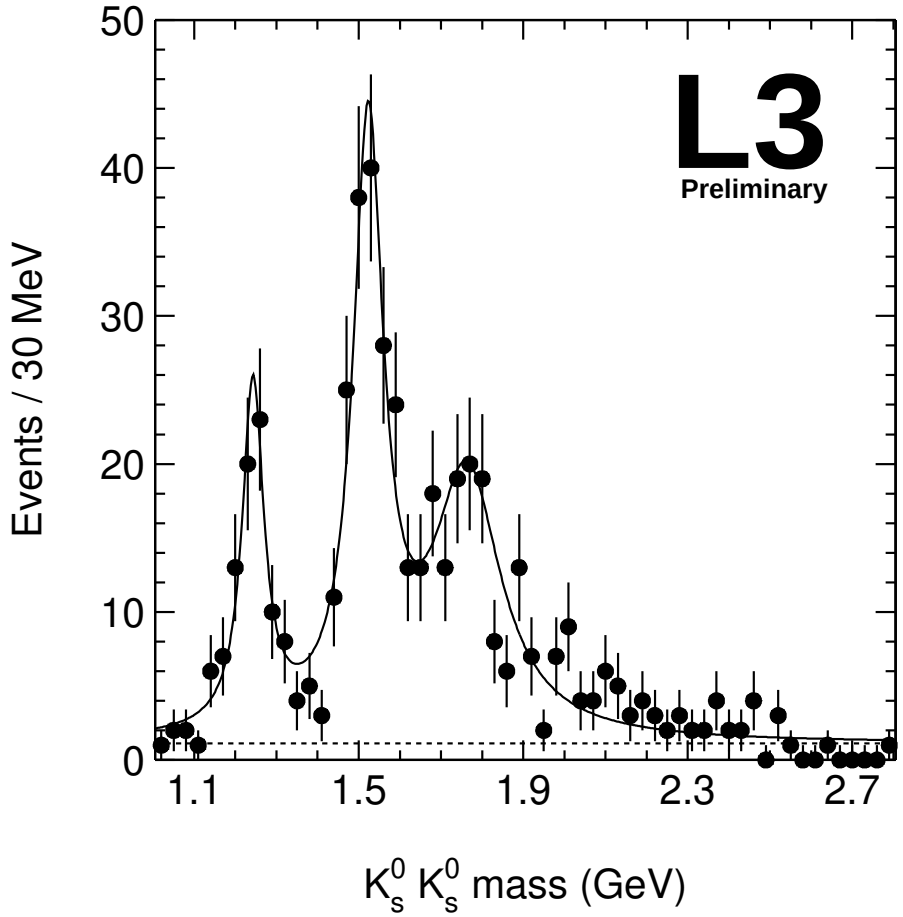
Errors are taken into account by a Monte Carlo calculation.
$\Gamma(J/\psi \to f_0\gamma)$=0.071 keV value used is the PDG one.

The $\gamma\gamma \to K^0_s K^0_s \to \pi^+\pi^-\pi^+\pi^-$ Decay at L3



- 4 charged tracks & secondary vertices
- No photons
- K^0_s direction & $\vec{P}_t(\pi^+\pi^-)$ matching
- small Transverse Momentum Imbalance
- $M_{\pi^+\pi^-} \simeq M_{K^0_s} \pm 40\ MeV$

The $K^0_s K^0_s$ Invariant Mass Spectrum

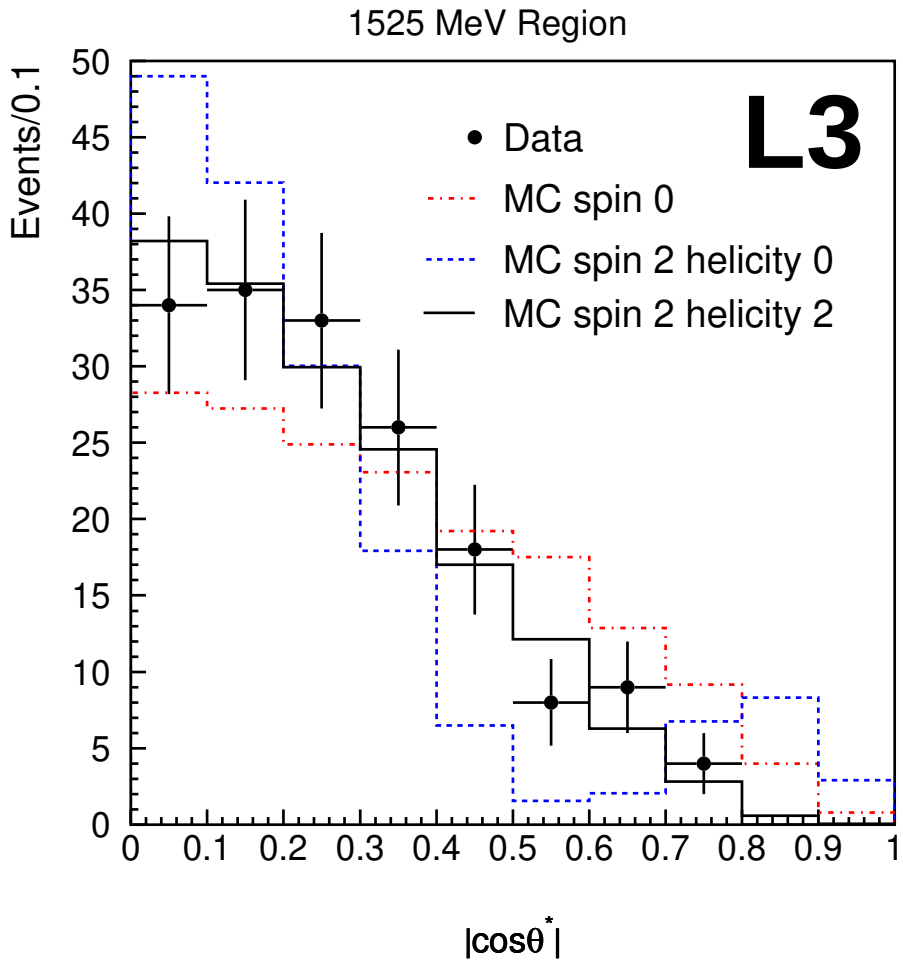


- $f_2 - a_2$ destructive interference
- Clear evidence of f_2'
- Clear enhancement around 1750 MeV
- No evidence of $\xi(2230)$

Year	$\sqrt{s}$(GeV)	L(pb^{-1})
91-95	91	143
97	183	52
98	189	172

	f_2-a_2	$f_2'(1525)$	1750 MeV
Mass (MeV)	—	1523±8	1765±22
Width (MeV)	—	89±37	200±50
Events	75±15	184±27	171±26

The $f_2'(1525)$ State

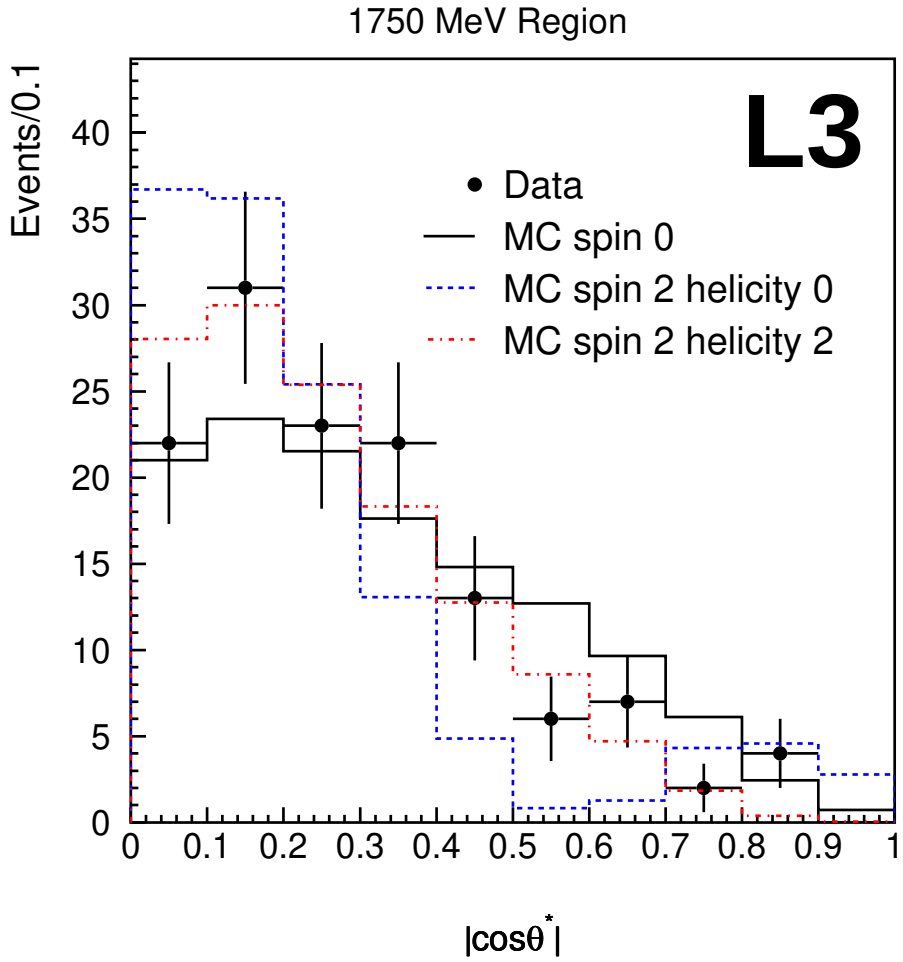


χ^2(9 d.o.f.)		
J=0		21
J=2,	λ=0	93
J=2,	λ=2	**4.6**

Helicity λ=2 dominates

$$\Gamma_{\gamma\gamma}(f_2') \times \mathrm{BR}(K\bar{K}) = (0.08 \pm 0.02)\mathrm{k\ eV}$$

The 1750 Region



	χ^2(9 d.o.f.)
J=0	**12**
J=2, λ=0	89
J=2, λ=2	38

$J = 0$ is favoured

- $f_2'(1525)$ radial recurrence?? $f_2''(1740)$, $f_2''(1820)$ (OGE-SRM prediction) (C.R.Münz,Nucl.Phys.A609(1996)364.)
- 0^{++} $s\bar{s}$ state (C. Amsler & F. Close)

The $\Gamma_{\gamma\gamma}(\xi(2230))$

- 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

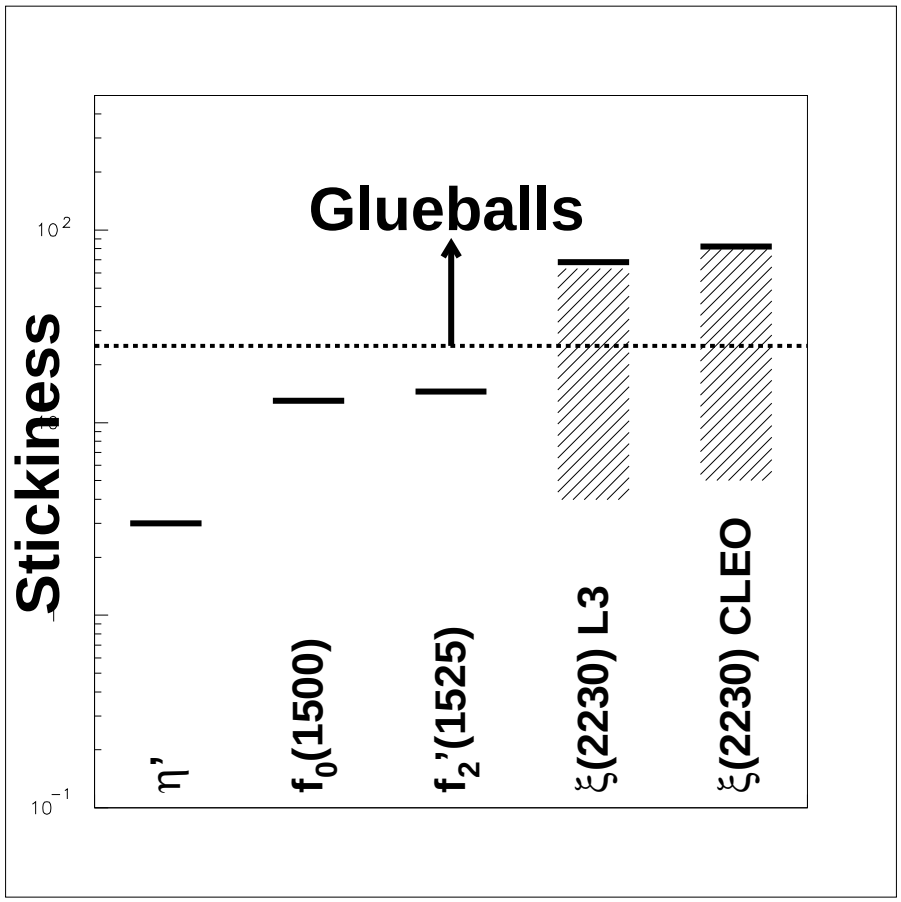
Data Sample	Events in Region	Expected Background	Detection Efficiency	95% C.L. Upper Limits Events	$\Gamma_{\gamma\gamma}(\xi)\mathrm{BR}(K_s^0K_s^0)$
LEP I	6	4.9	16.6%	7.3	4.1 eV
LEP II '97	2	7.9	15.2%	3.6	4.2 eV
LEP II '98	13	18.9	14.1%	6.5	2.5 eV

Combining the three results by a Monte Carlo calculation :

$$\boldsymbol{\Gamma_{\gamma\gamma}(\xi) \times \mathrm{BR}(\xi \rightarrow K_s^0K_s^0) < 1.5}\ \mathrm{eV} \quad \text{at 95\% C.L.}$$

$$\boldsymbol{S_\xi > 68}\ \text{at 95\% C.L.}$$

Errors are taken into account by a Monte Carlo calculation.
$\Gamma(J/\psi \rightarrow \xi\gamma) \times \mathrm{BR}(\xi \rightarrow K_s^0K_s^0)=(2.2\pm0.6)\times10^{-5}$ obtained combining the result by BES and Mark III



- 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.

Conclusion

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

  Clear evidence of the $f_2(1270)$

  No signal for the $f_0(1500)$: $\Gamma_{\gamma\gamma}$ <0.17 keV
  Stickiness (f_0)> 13 at 95% C.L.

- The $K^0_s K^0_s$ final state :

  $f_2'(1525)$, $J^{PC}(\lambda)=2^{++}(2)$

  $f_2 - a_2$ destructive interference

  Enhancement of 7σ in the 1750 MeV region:
  ➥ radial recurrence of the f_2' (1525)?
  ➥ 0^{++} $s\bar{s}$ state?

  No signal for the $\xi(2230)$: $\Gamma_{\gamma\gamma} \times \mathrm{BR}(\xi \to K^0_s K^0_s)$ <1.5 eV
  Stickiness (ξ) > 68 at 95% C.L.