The $K^0_s K^0_s$ Final State in Two-Photon Collisions and Glueball Searches

Sepehr Saremi
Louisiana State University

representing the
L3 Collaboration

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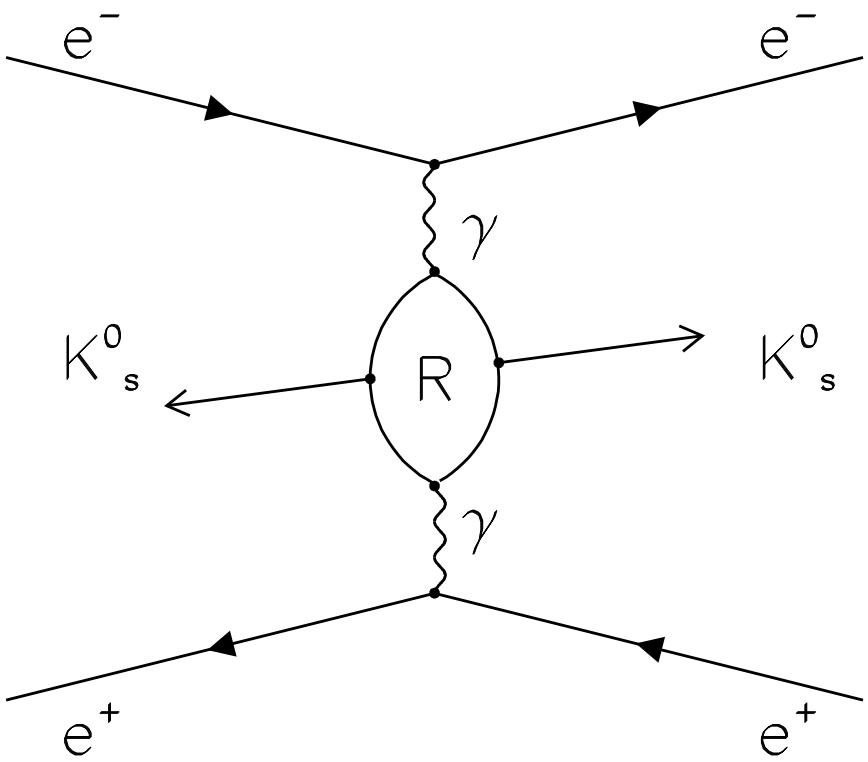
Outline

- Introduction
- The L3 Detector at LEP
- Event Selection
- The $K^0_s K^0_s$ final state :
  $f_2(1270)$-$a_2(1320)$ interference
  $f'_2(1525)$
  The 1750 MeV mass region
  The $\xi(2230)$ glueball candidate
- Conclusions & Outlook

Resonance Formation



$\gamma\gamma \rightarrow \mathrm{R} \rightarrow \mathrm{K}^0_s\mathrm{K}^0_s$

- Outgoing e^+e^- are undetected ("No Tag")
  $\rightarrow$ Quasi-real photons
- R neutral unflavoured meson with C=+1, J$\neq$1
- $\mathrm{K}^0_s\mathrm{K}^0_s$ final state :
  $J^{PC}=(\mathrm{even})^{++} \rightarrow 0^{++}$ and 2^{++} states

The Cross Section

The cross section for the process

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

can be written as

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

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

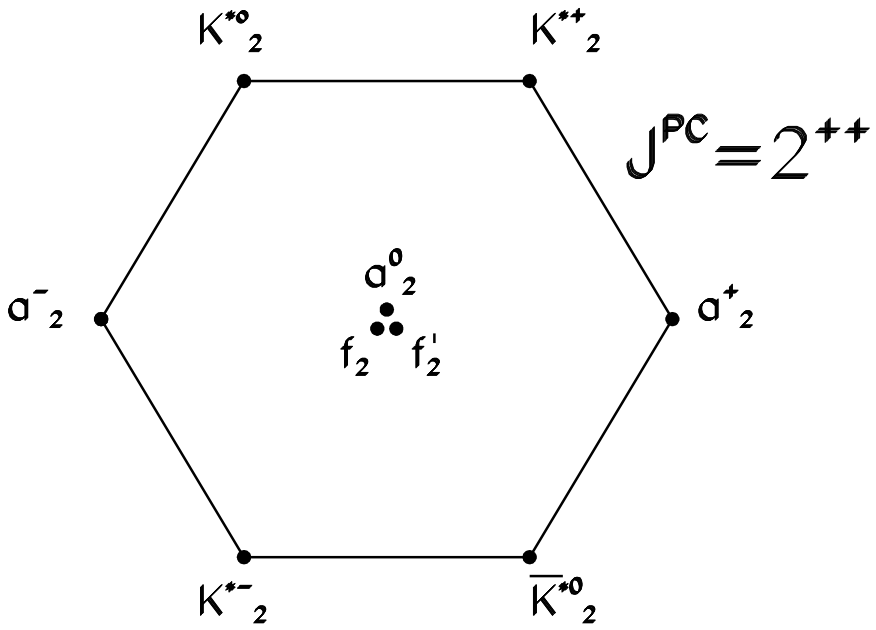
$$\sigma(\gamma\gamma \to R) = 8\pi(2J+1)\frac{\Gamma_{\gamma\gamma}\Gamma_R}{(m_R^2 - W_{\gamma\gamma}^2)^2 + m_R^2\Gamma_R^2}$$

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

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

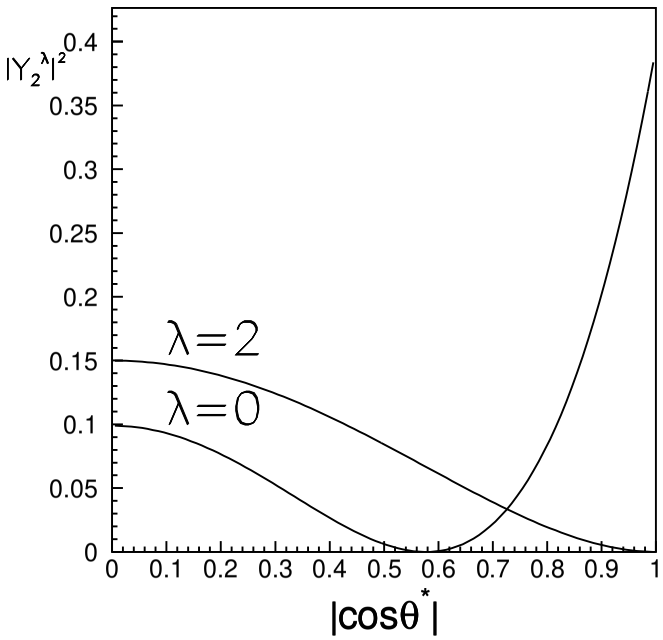
The Tensor Meson Nonet

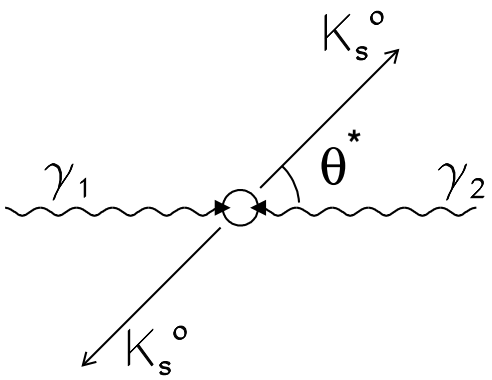


- Neutral members :

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

- $f_2 - a_2$ interference : destructive in $K^0\bar{K}^0$, constructive in K^+K^- (H.J.Lipkin,Nucl.Phys.B7(1968)321)
- Helicity 0 or 2 → Different angular distributions!





0^{++} States

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

$$a_0(1450)\ f_0(1370)\ f_0(1500)$$

The $f_0(1370)$ and the $f_0(1500)$ are incompatible with a $s\bar{s}$ state and cannot be both $u\bar{u} + d\bar{d}$.

There are too many states to fit in a nonet!

According to C.Amsler and F.E.Close :
(Phys.Rev. D53(1996)295)

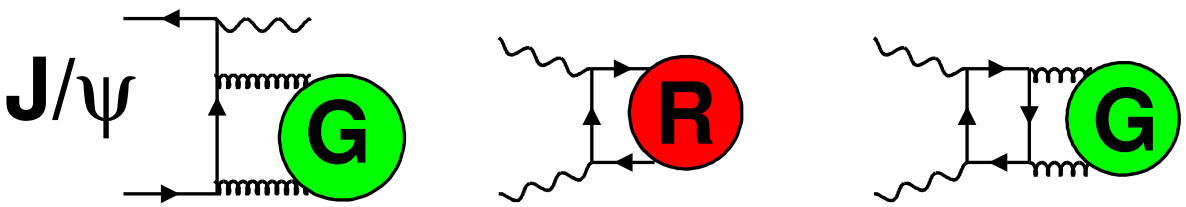
State	Isospin		
$a_0(1450)$	1	✔	
$f_0(1370)$	0	✔	
$f_0'(1500\text{-}1800)$	0		$s\bar{s}$?
$f_0(1500)$	0	✔	Glueball ?

The $f_0'(1500\text{-}1800)$ is expected to be $s\bar{s}$ and to couple strongly to $K\bar{K}$

☞Radial excitations of ground states can also be formed !

QCD is a non-abelian gauge theory :

- gluon-gluon interactions
- Bound states of two or more gluons
  $\Rightarrow$ Glueballs
- $q\bar{q}$/glueball mixing is possible



Properties of glueballs :

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

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

Glueballs and $\gamma\gamma$ Collisions

QCD is very well established but a direct experimental evidence for glueballs is still not clear.

There are many experimental and theoretical hints.

Lattice QCD predictions :

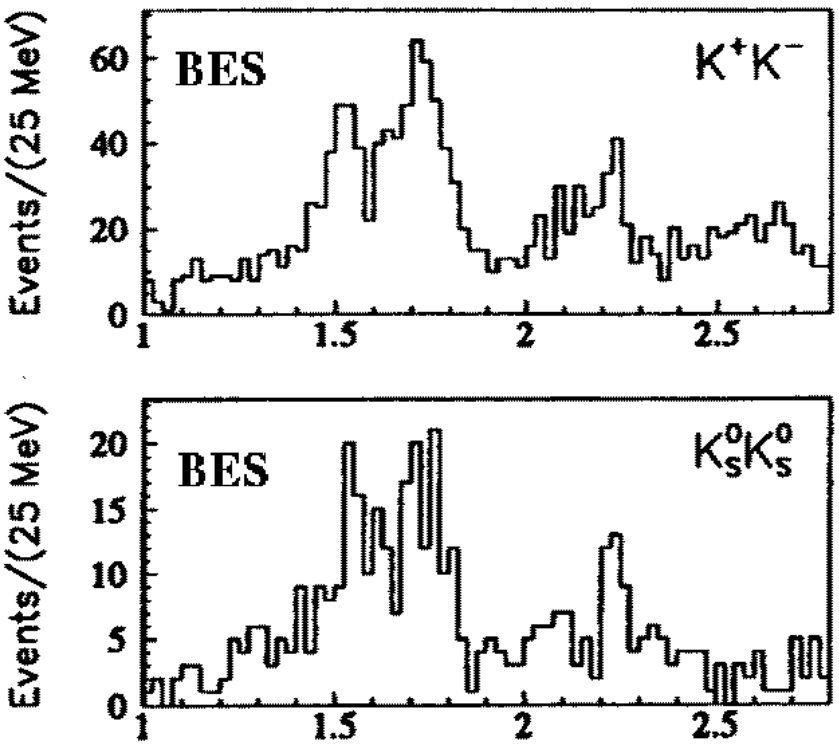
- 0^{++} glueball ground state
  M=1600±200 MeV, $\Gamma \simeq 100$ MeV
- 2^{++} tensor glueball
  $M_{2^{++}}/M_{0^{++}} \simeq 1.5 \rightarrow M \simeq 2200$ MeV

The understanding of the $q\bar{q}$ mass spectrum is crucial in the search for glueballs.

Two-photon interactions are a fundamental tool to distinguish mesons from glueballs

2^{++} Glueballs ?

The BES Collaboration confirmed the observation of the $\xi(2230)$ in J/ψ radiative decays.

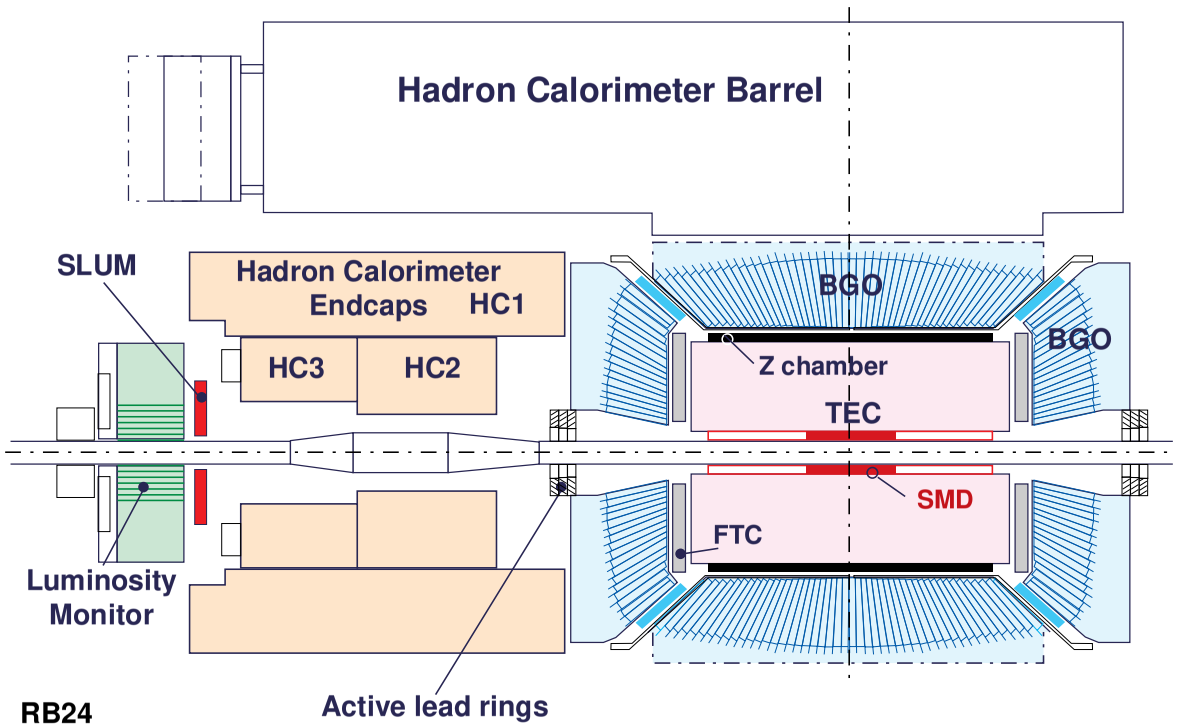


(Phys.Rev.Lett. 76(1996)3502)

- Previously observed by Mark III
- Observed in K^+K^-, $K^0_sK^0_s$, $\pi^+\pi^-$ and $p\bar{p}$ final states
- Very narrow : Γ=20 MeV
- Seems to have flavour blind coupling

Is it visible in two-photon collisions ?

The L3 Detector

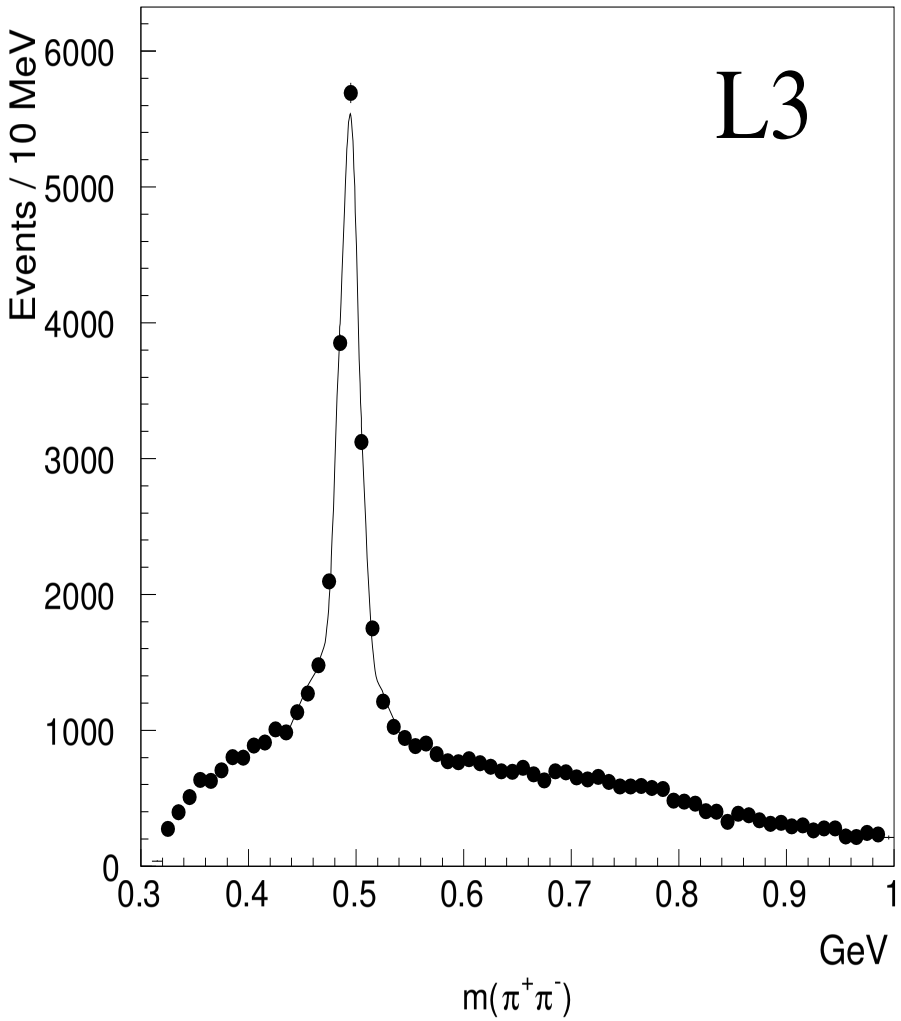


Devices mainly used for $\gamma\gamma \rightarrow$Resonance studies:

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

Event Selection

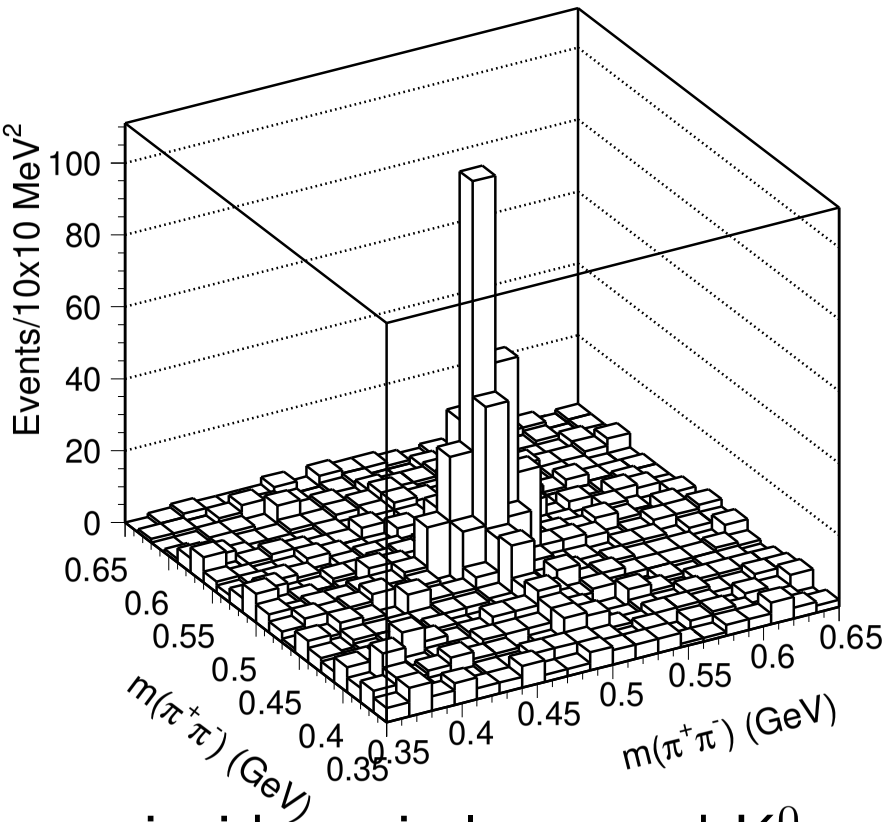
- Events with small energy in the calorimeters :
  $\longrightarrow$ two-photon events
- Small transverse momentum imbalance
  and charge balance :
  $\longrightarrow$ exclusive events
- Good track selection



m_{k_s}=493±9.6 MeV

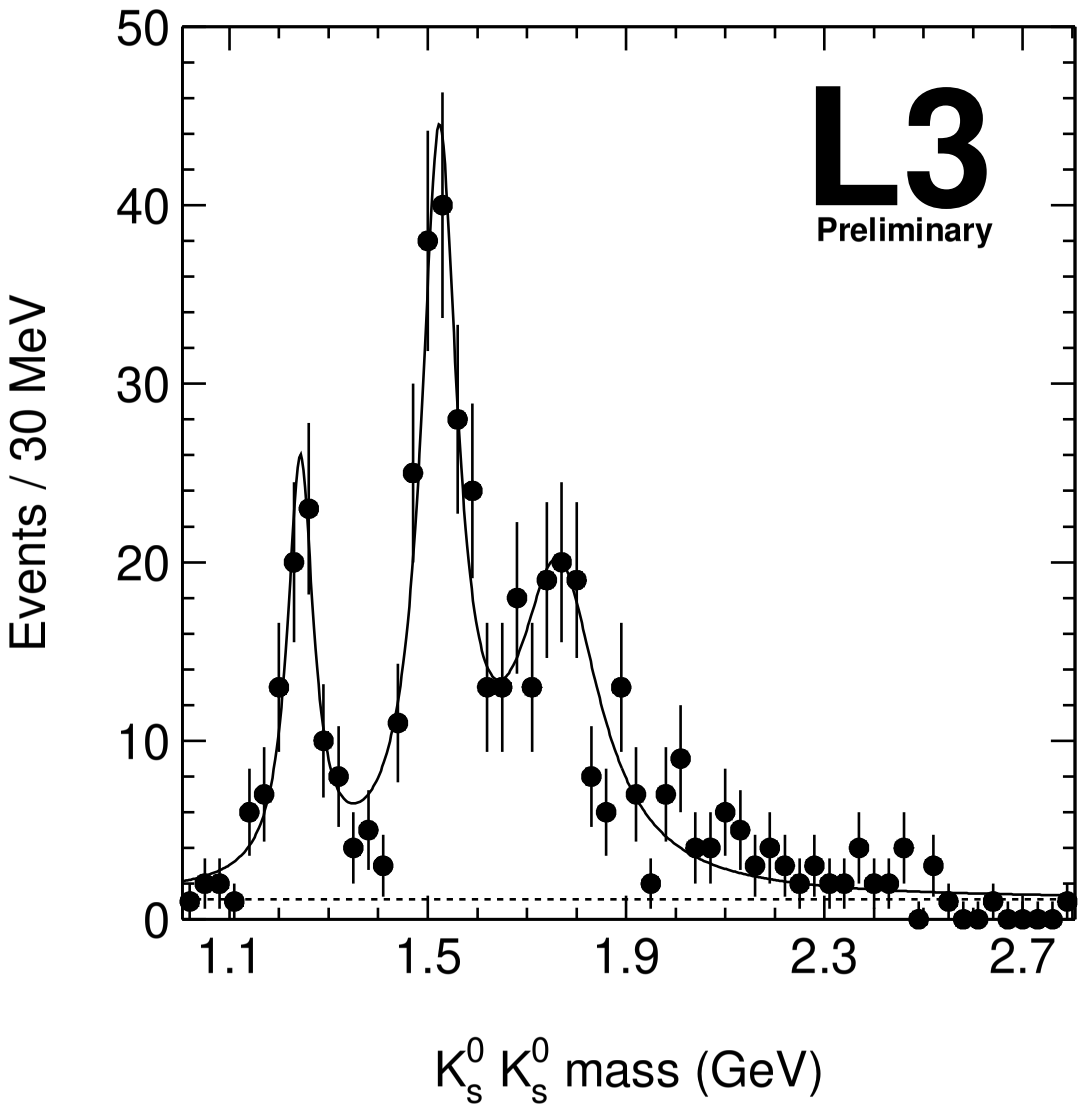
The $K^0_s K^0_s$ Final State

- LEP I ($143 pb^{-1}$) and LEP II ($224 pb^{-1}$) data
- Four charged tracks
- $|\vec{p}_T(\pi^+\pi^-\pi^+\pi^-)|^2 <$ 0.1 GeV^2
- Two secondary vertices
- Events with photons are rejected



- $M_{\pi^+\pi^-}$ inside a circle around K^0_s mass (R= 40 MeV)
- 499 events are selected

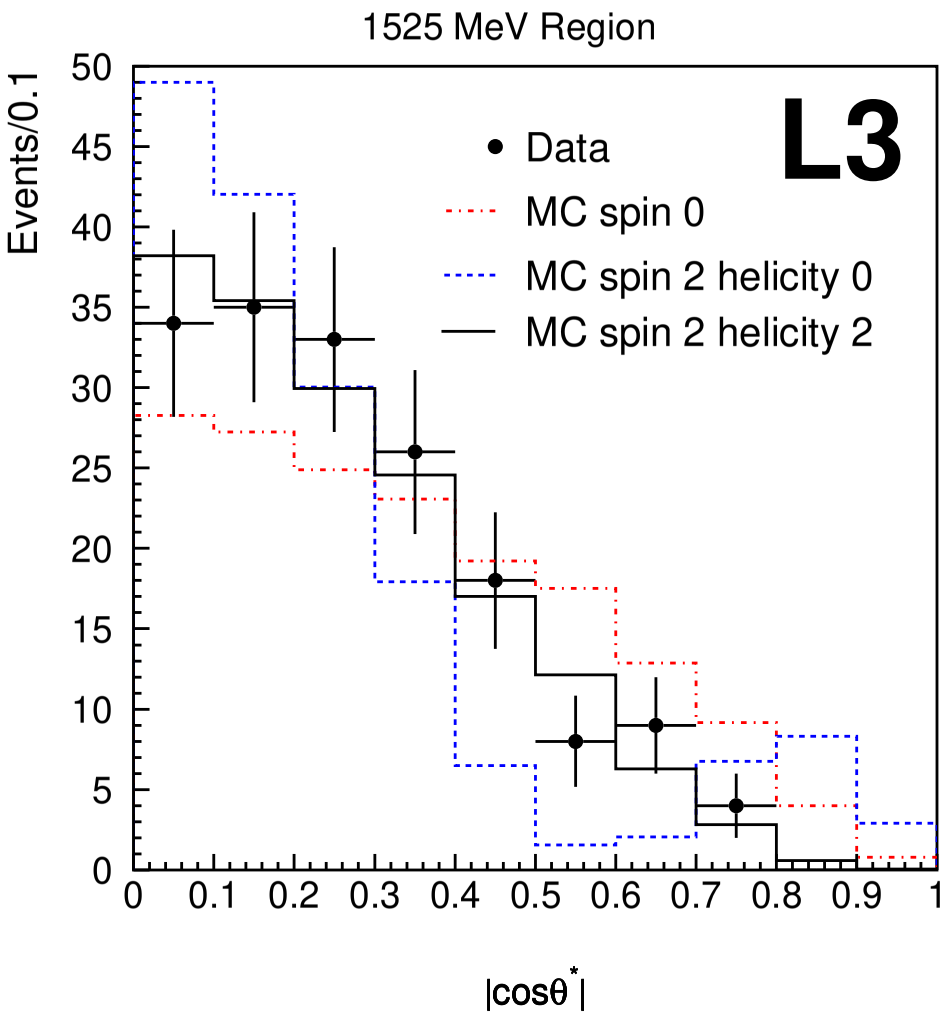
The $K^0_s K^0_s$ Mass Spectrum



	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

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

The $f_2'(1525)$



	J=0	J=2, λ=2	J=2, λ=0
χ^2 for 9 d.o.f.	24.7	4.2	30.6

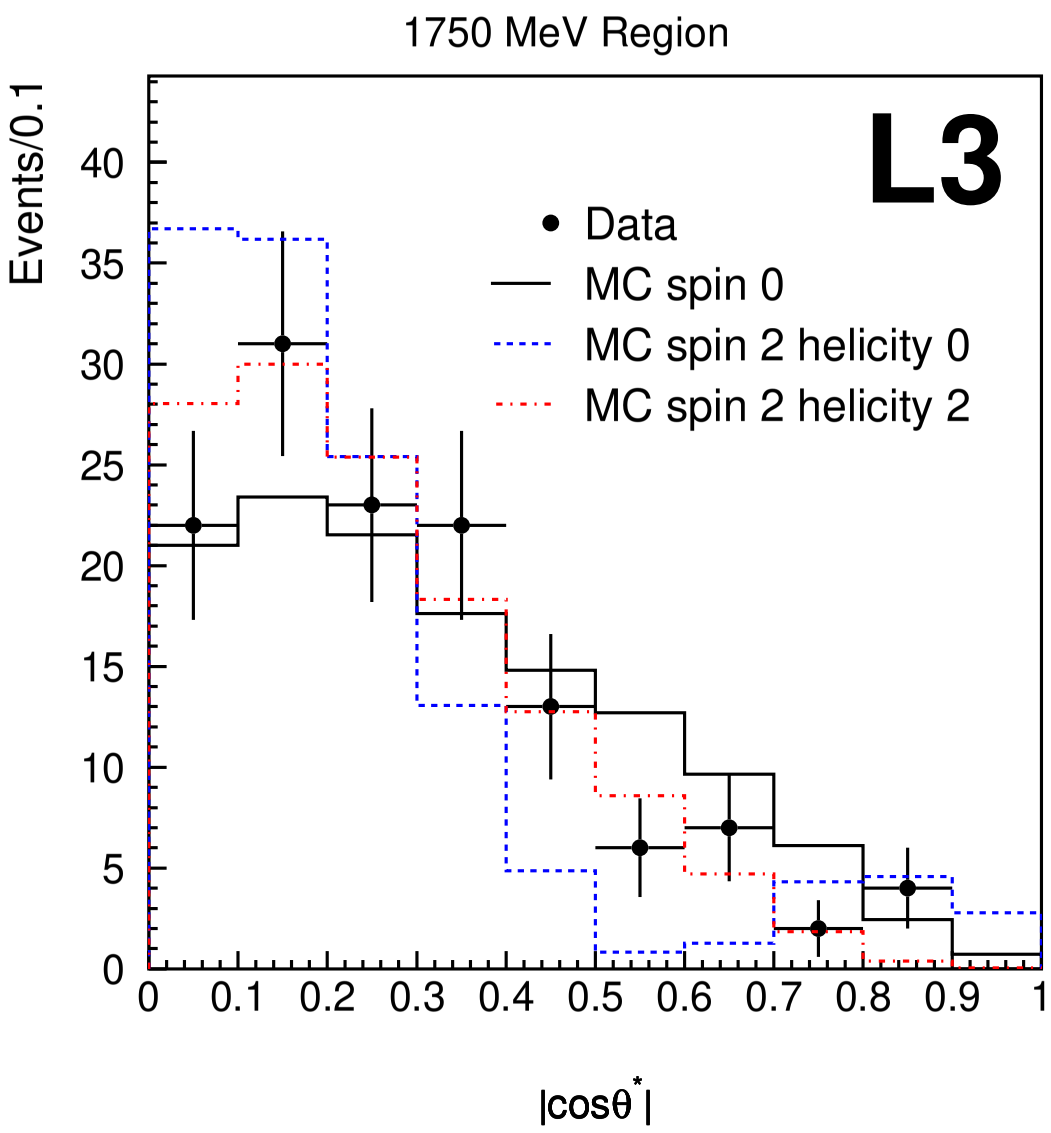
Helicity 2 dominates !

For helicity 2 the detection efficiency is 7.6% at LEP I and 6.4% at LEP II.

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

The 1750 MeV Region

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



	J=0	J=2, λ=2	J=2, λ=0
χ^2 for 9 d.o.f.	20.6	7.6	31.6

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 Signal Region	Expected Background	Detection Efficiency	95% C.L. Upper Limits: Events	95% C.L. Upper Limits: $\Gamma_{\gamma\gamma}(\xi)\mathrm{BR}(K^0_s K^0_s)$
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 :

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

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

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

where:

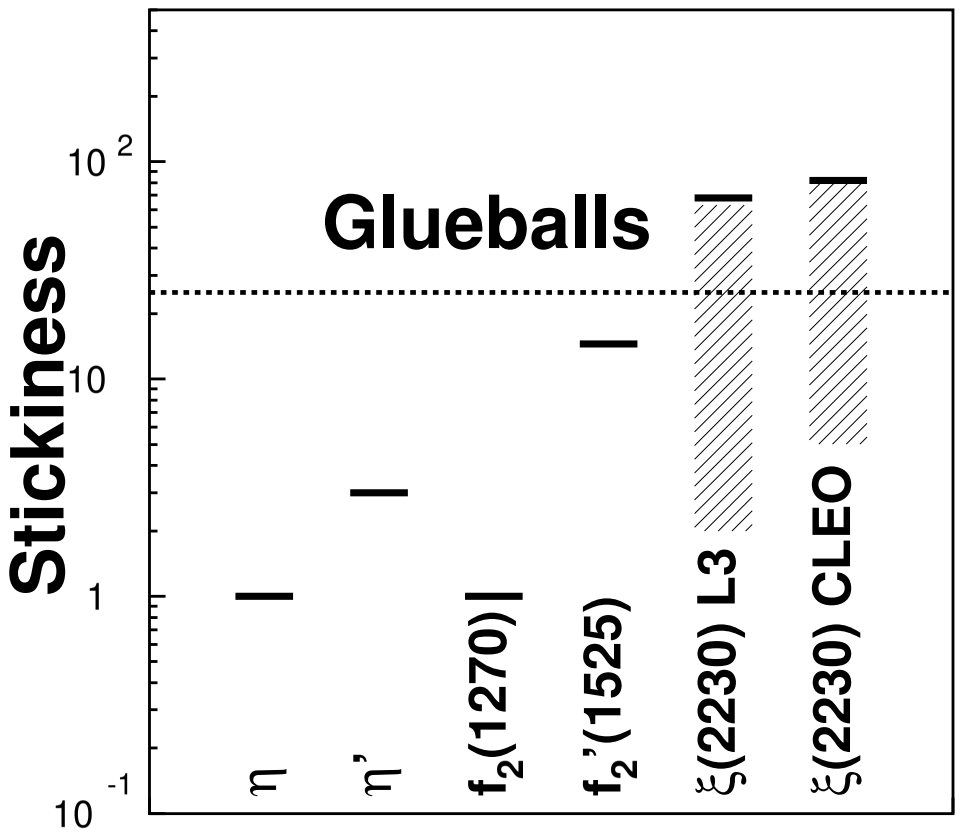
m_R	mass of the state
$k_{J/\psi \to \gamma X}$	photon energy in J/ψ decay
N_l	normalization factor such that $S_{f_2(1270)}$=1

Combining the result by BES and Mark III
$\Gamma(J/\psi \to \xi\gamma) \times \mathrm{BR}(\xi \to K^0_s K^0_s)$=(2.2±0.6)×$10^{-5}$
with our upper limit
$\Gamma(\xi \to \gamma\gamma) \times \mathrm{BR}(\xi \to K^0_s K^0_s)$ <1.5 eV at 95% C.L.
we obtain

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

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

Conclusions & Outlook

- 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:

  ☞ 0^{++} $s\bar{s}$ or 2^{++} state ?

  No signal for the $\xi(2230)$:

  $\Gamma(\xi \to \gamma\gamma) \times \mathrm{BR}(\xi \to K^0_s K^0_s)$ <1.5 eV

  $S_\xi > 68$ at 95% C.L.

- More data from LEP II are expected, taking data up to the year 2000. They will bring a significant contribution to this analysis and glueball searches.