The 1500-1700 MeV Mass Region and Glueball Searches in Two-Photon Collisions

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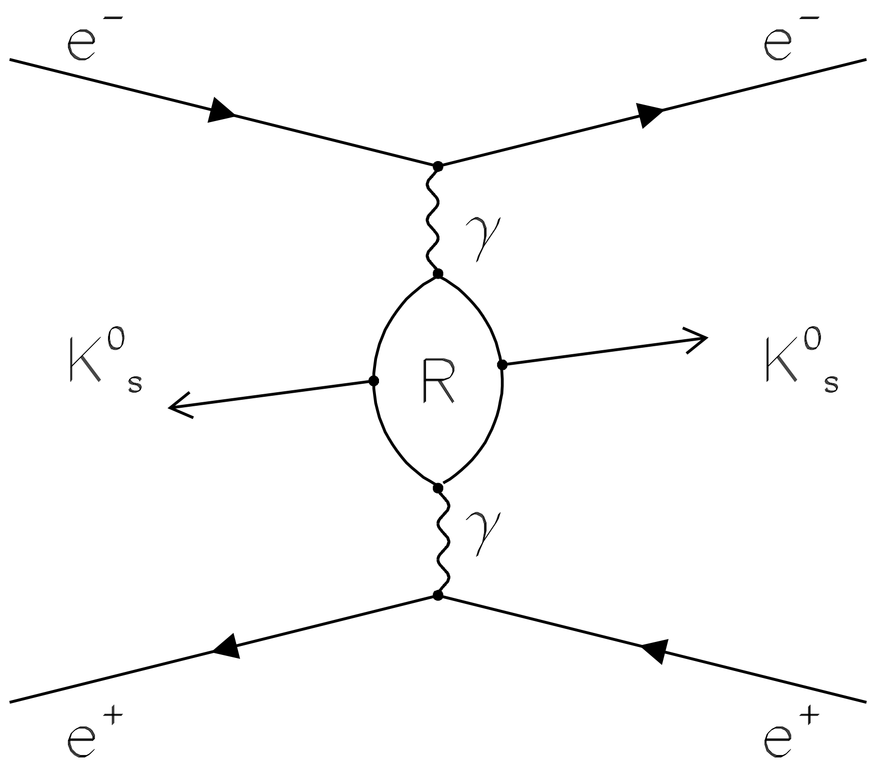
Outline

- Introduction
- The L3 Detector at LEP
- Event Selection
- The $\pi^+\pi^-\pi^0$ final state :
  - $a_2(1320)$
  - The 1750 MeV mass region
- 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



$$\gamma\gamma \rightarrow \mathrm{R} \rightarrow \pi^+\pi^-\pi^0,\ \mathrm{K}^0_s\mathrm{K}^0_s$$

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

The Cross Section

The cross section for the process

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

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

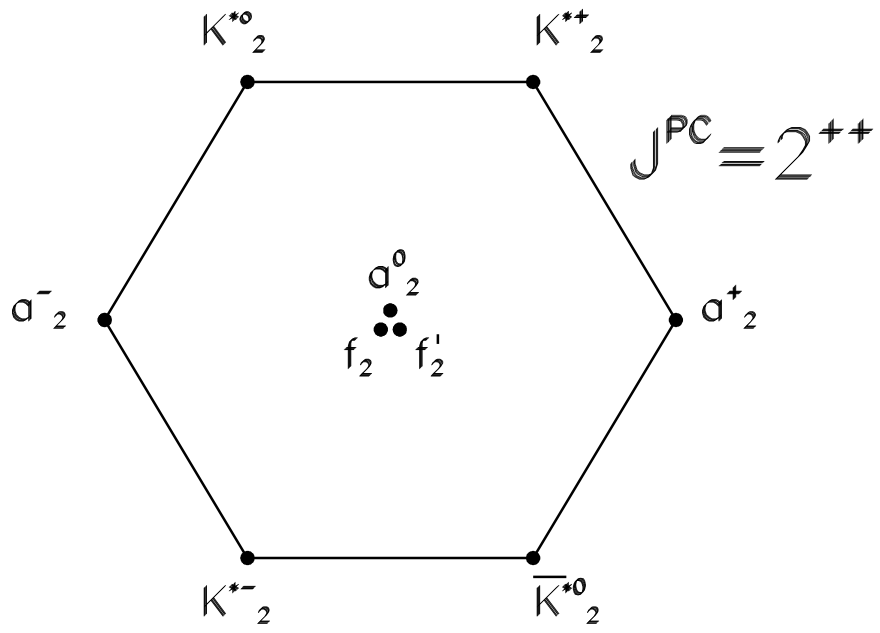
$$\sigma(\gamma\gamma \rightarrow R) = 8\pi(2J+1)\frac{\Gamma_{\gamma\gamma}\Gamma_R}{(m_R^2 - W_{\gamma\gamma}^2)^2 + m_R^2\Gamma_R^2}$$

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

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

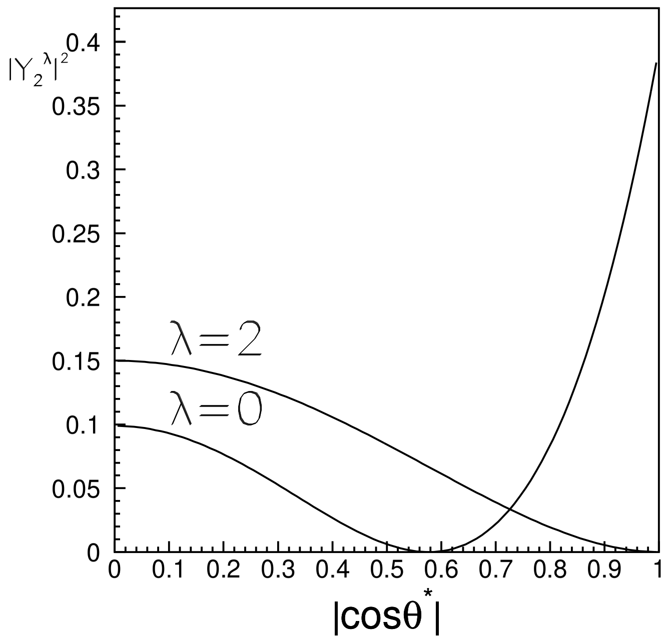
The Tensor Meson Nonet

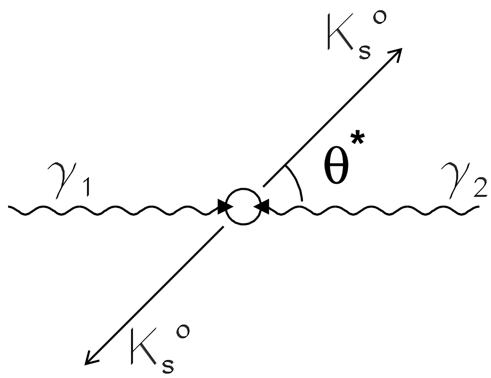


- Neutral members :

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

- $f_2 - a_2$ 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)

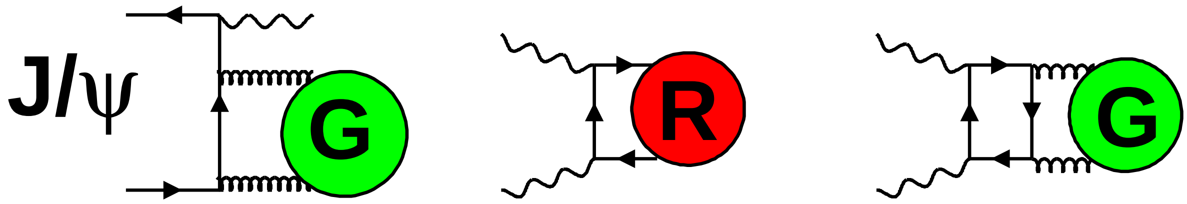
State	Isospin		
$a_0(1450)$	1	✔	
$f_0(1370)$	0	✔	
$f_0'(1500\text{-}1800)$	0		$s\bar{s}$?
$f_0(1500)$	0	✔	Glueball ?

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 !

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 :

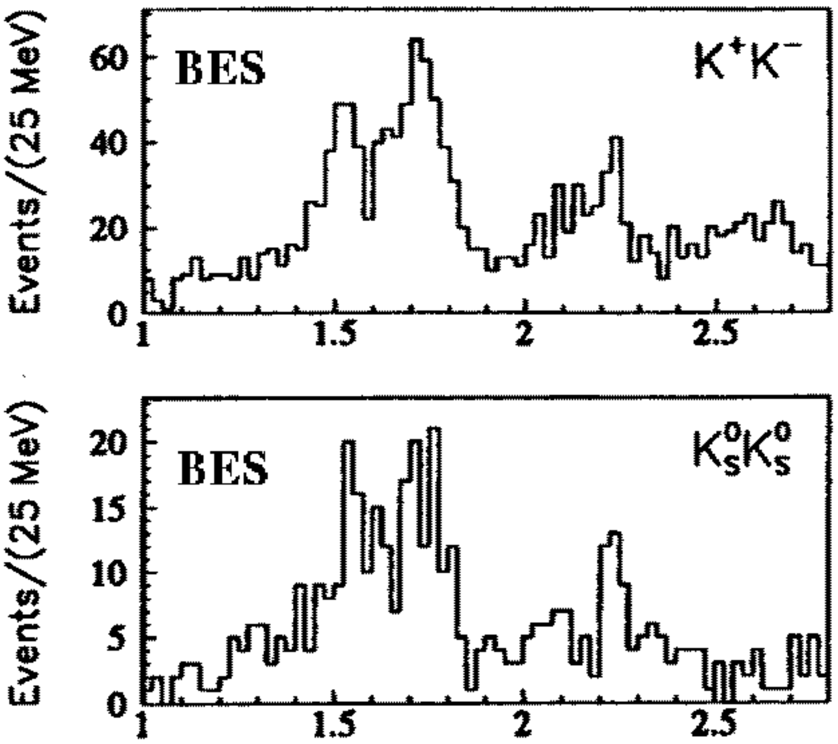
- ❏ 0^{++} glueball ground state
  M=1600±200 MeV, $\Gamma \simeq 100$ MeV
- ❏ 2^{++} tensor glueball
  $M_{2^{++}}/M_{0^{++}} \simeq 1.5 \rightarrow M \simeq 2200$ MeV

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.

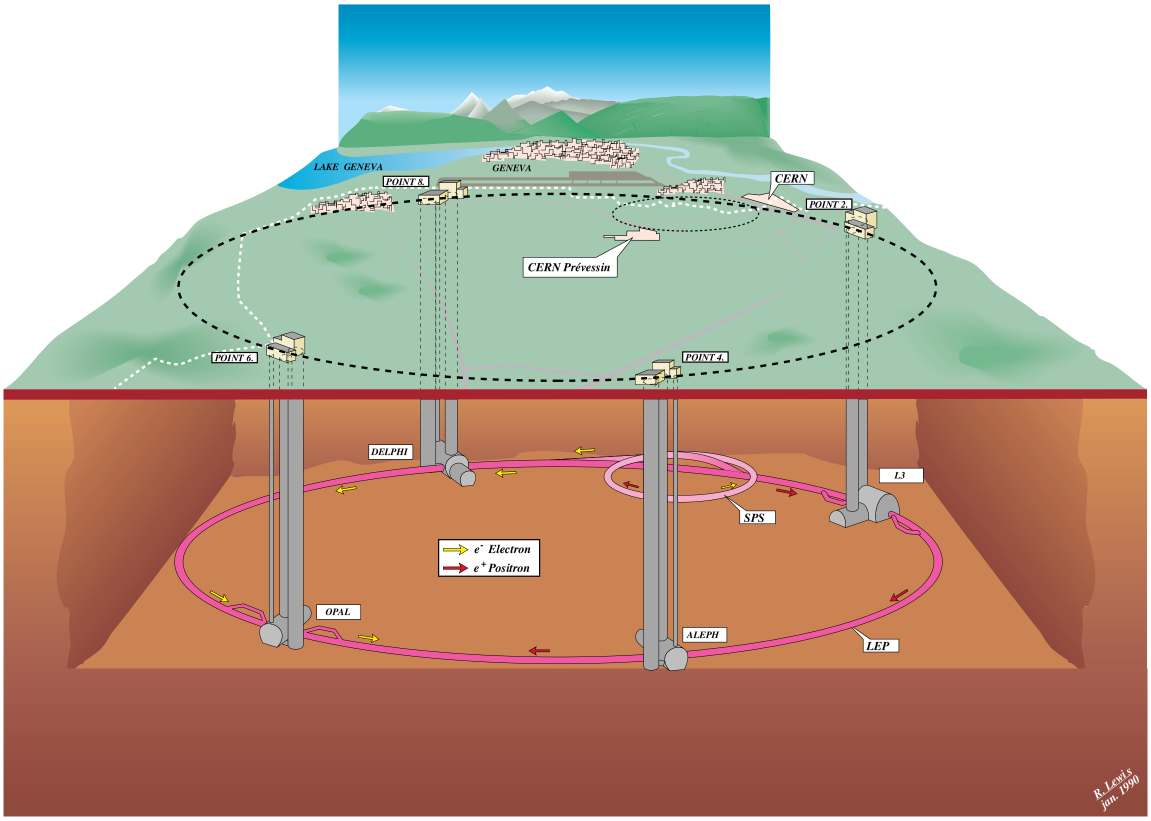


(Phys.Rev.Lett. 76(1996)3502)

- ❏ 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

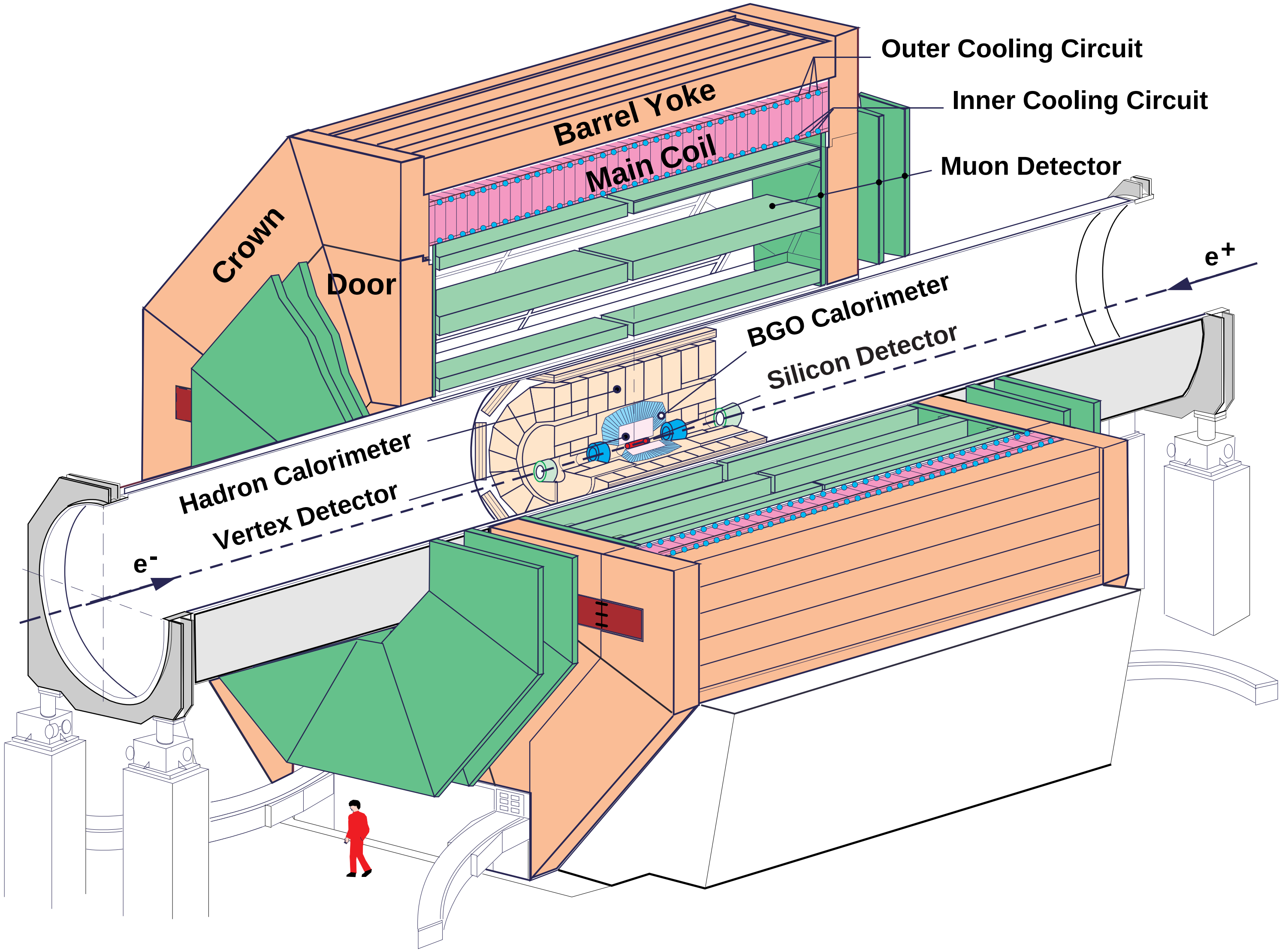
Is it visible in two-photon collisions ?

LEP

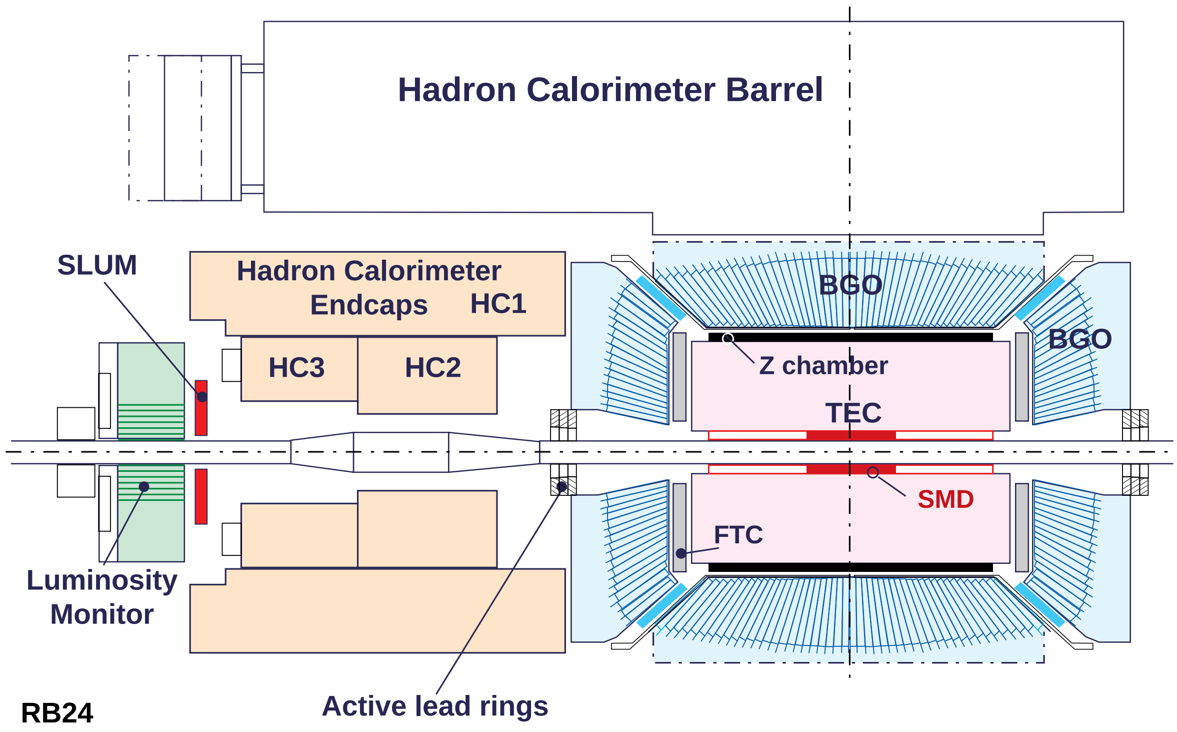


	Year	$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})
LEP I	1991 - 1995	$\simeq$m(Z)	143
LEP II	1997	183	52
LEP II	1998	189	172

The L3 Detector



The L3 Detector

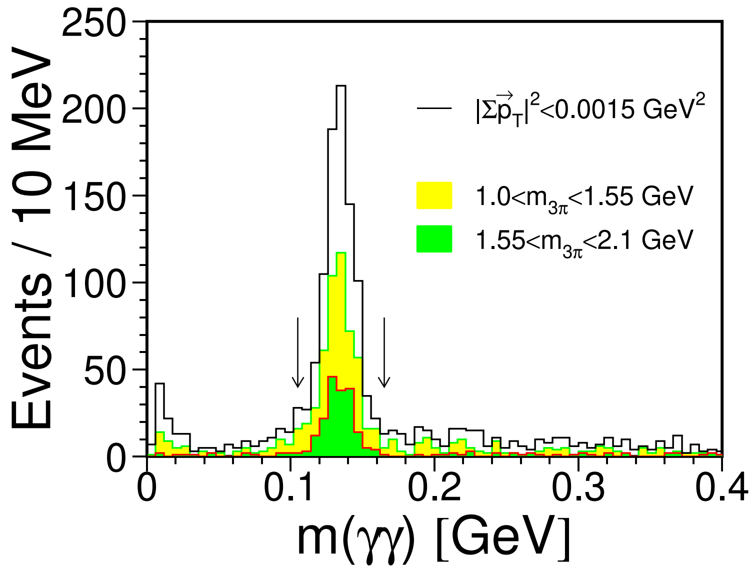


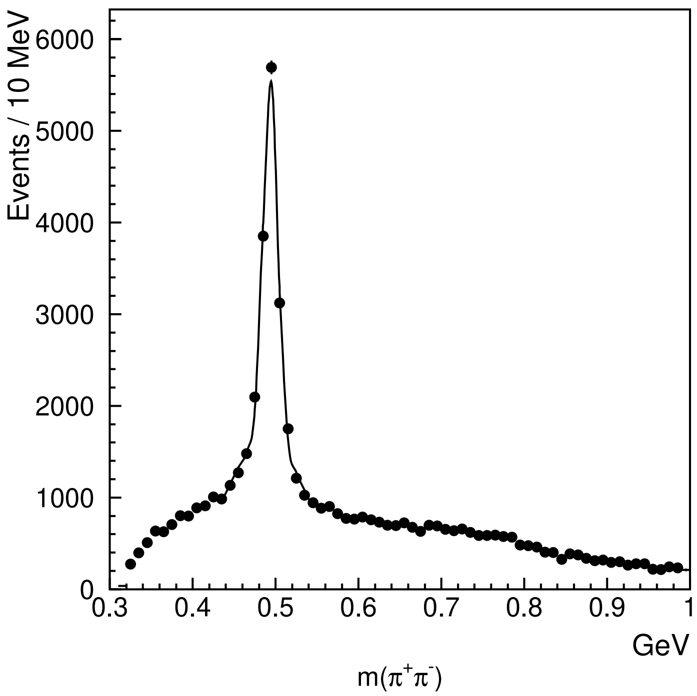
Devices mainly used for $\gamma\gamma \rightarrow$Resonance studies:

- ❑ 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 ∼150 MeV

Event Selection

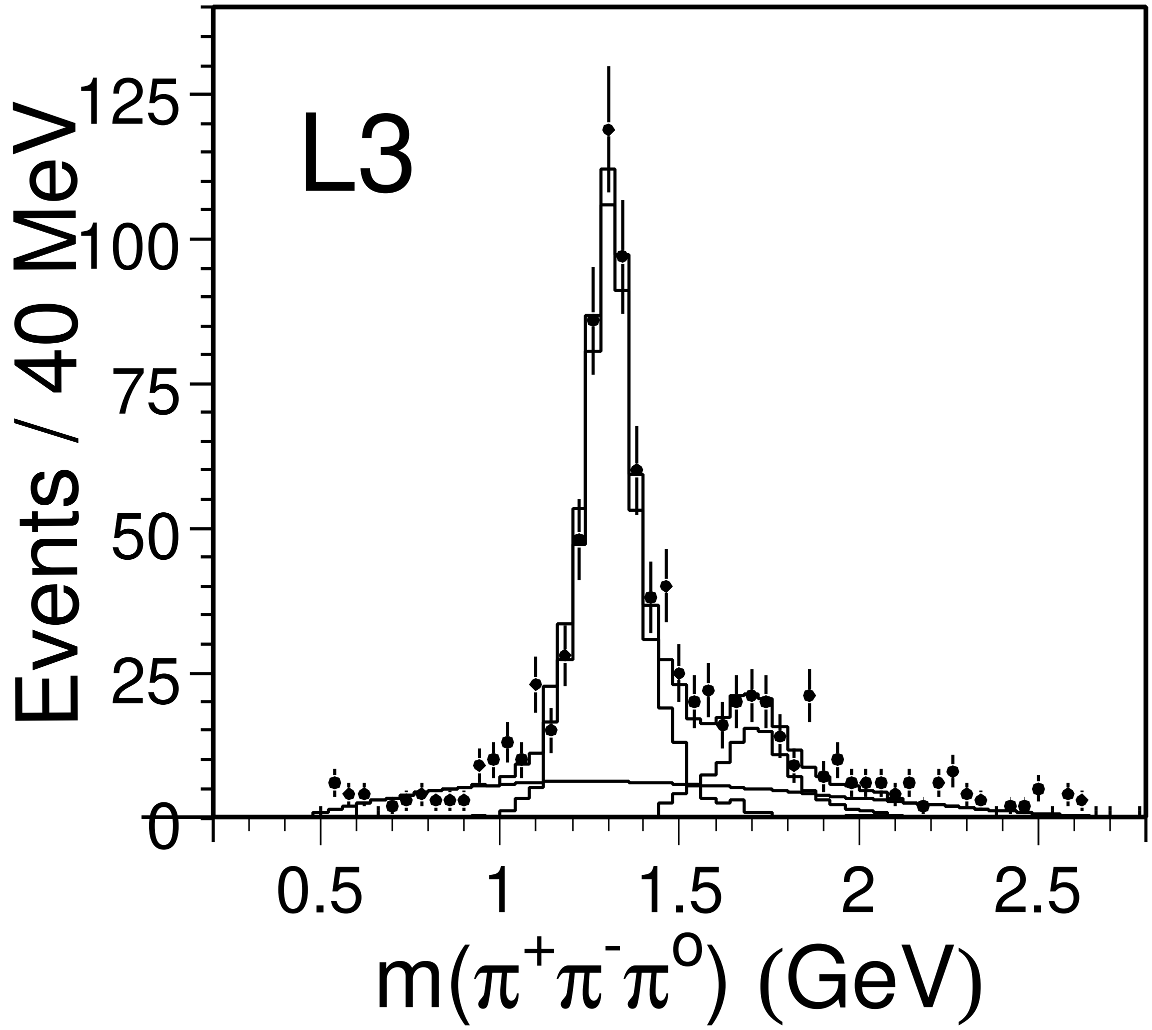
- Events with small energy in the calorimeters :
  $\longrightarrow$ two-photon events
- Small transverse momentum imbalance
  and charge balance :
  $\longrightarrow$ exclusive events
- Good track and photon ($\longrightarrow \pi^0$) selection





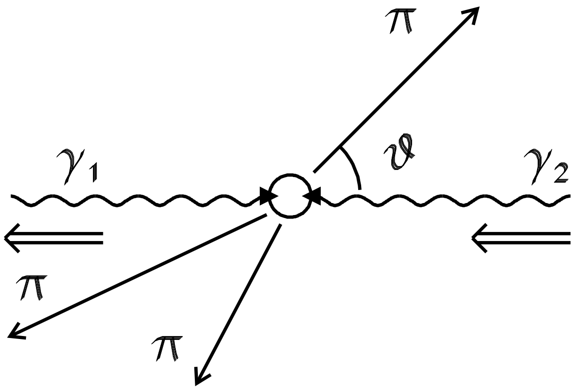
The $\pi^+\pi^-\pi^0$ Final State

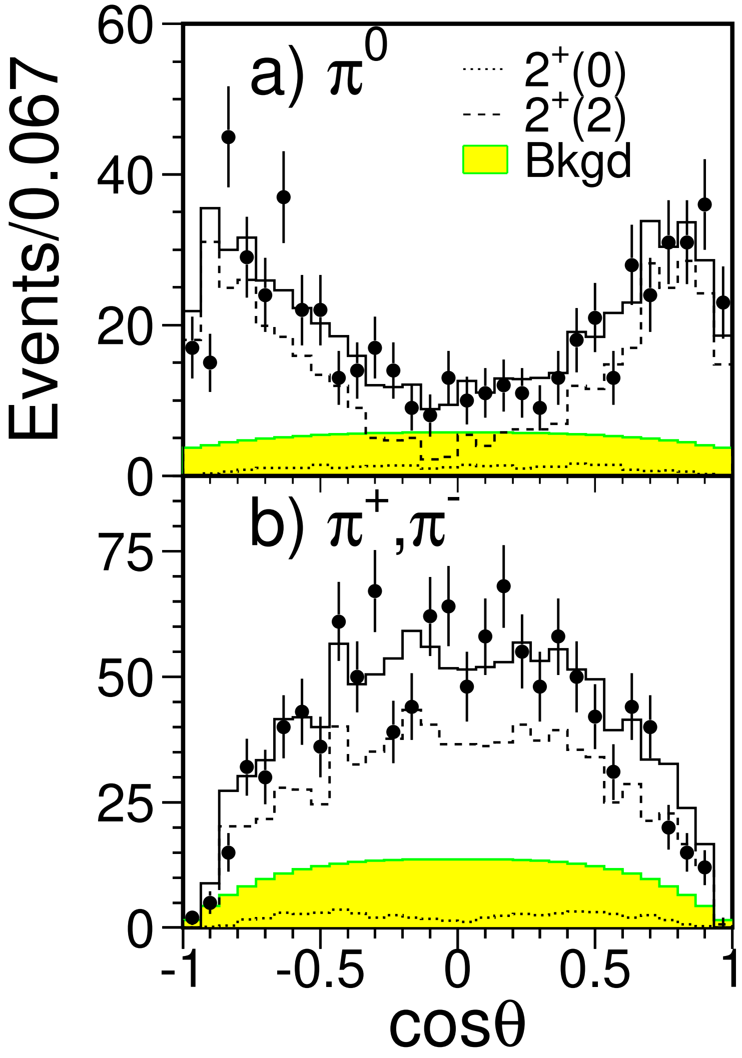
- LEP I data (Phys.Lett.B 407(1997)419)
- Two tracks + Two photons from a π^0
- $|\vec{p}_T(\pi^+\pi^-\pi^0)|^2$ <0.0015 GeV^2



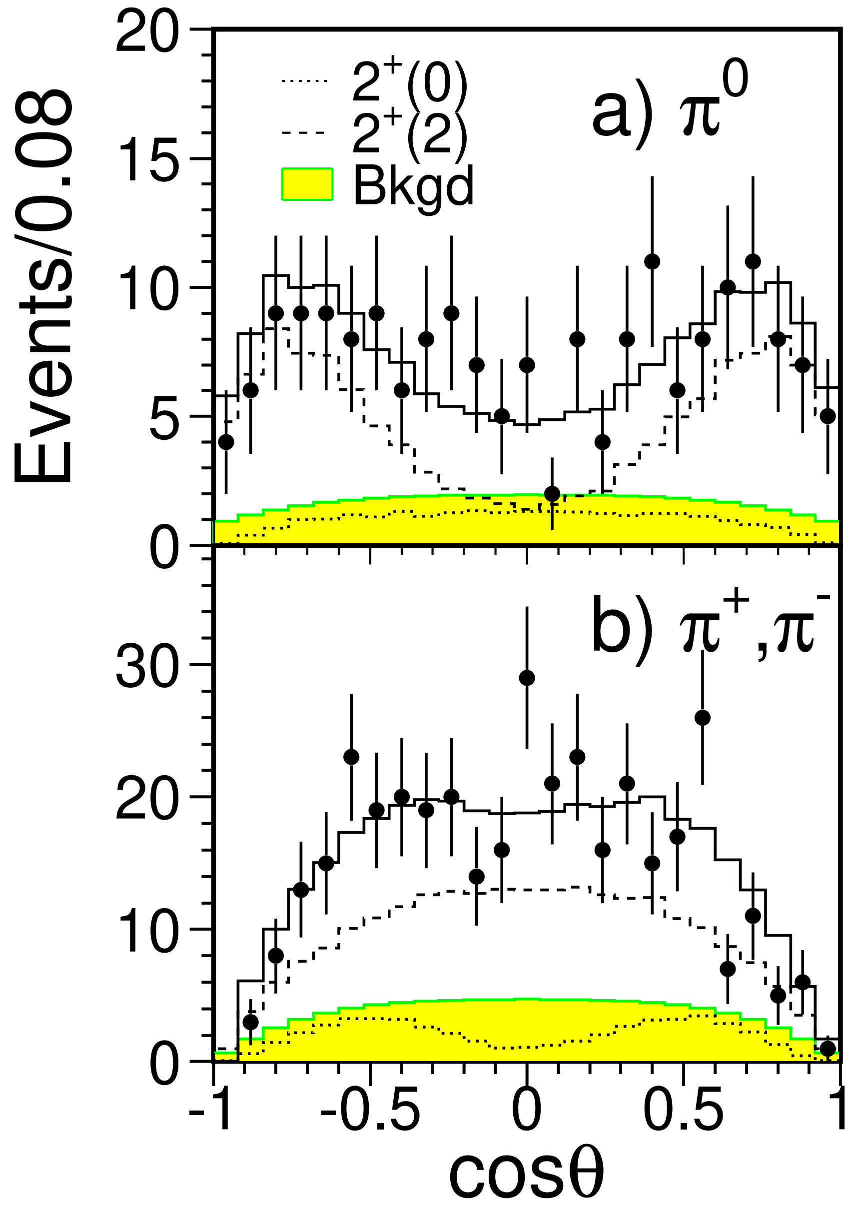
The $a_2(1320)$

- ❑ $J^P = 2^+$
- ❑ Helicity 0 or 2





- ❑ Helicity 2 fraction : 0.92 ± 0.05



- $J^P(\lambda)=2^-(0)$ fraction : 0.12 ± 0.11
- $\Gamma_{\gamma\gamma}(\pi_2) \times BR(\pi^+\pi^-\pi^0) < 72$ eV at 90% C.L.
- $J^P(\lambda)=2^+(2)$ fraction : 0.74 ± 0.13

The $\pi^+\pi^-\pi^0$ Final State

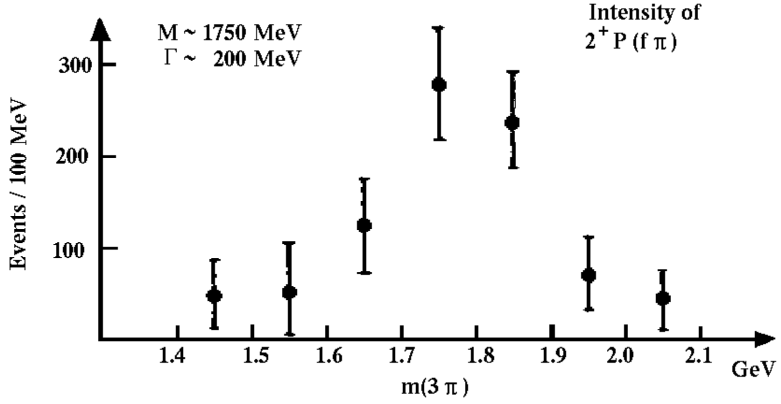
	$a_2(1320)$	1750 MeV Mass Region
Mass (MeV)	$1323 \pm 4 \pm 3$	$1752 \pm 21 \pm 4$
Width (MeV)	$105 \pm 10 \pm 11$	$150 \pm 110 \pm 34$
$J^{PC}(\lambda)$	$2^{++}(2)$	$2^{++}(2)$
$\Gamma_{\gamma\gamma}$ (keV)	$0.98 \pm 0.05 \pm 0.09$	—
$\Gamma_{\gamma\gamma} \times$ BR (keV)	—	$0.29 \pm 0.04 \pm 0.02$

According to OGE-SRM :
(C.R.Münz,Nucl.Phys.A609(1996)364.)

	Mass	$\Gamma_{\gamma\gamma}$
$a_2(1320)$	1280	0.900
a_2'	1740	0.376
a_2''	1820	0.353

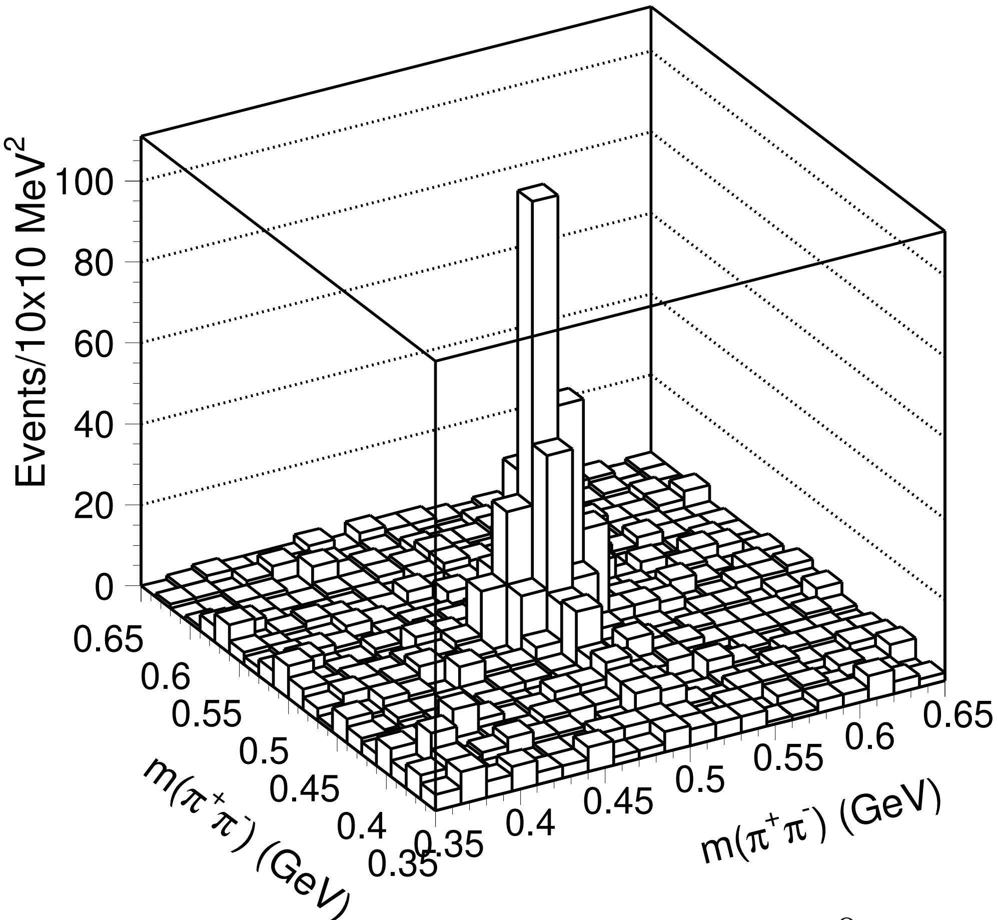
PWA of $\pi^- p \to \pi^+\pi^-\pi^- p$

CERN–IHEP Collab., Nucl. Phys. B63(1973)153.



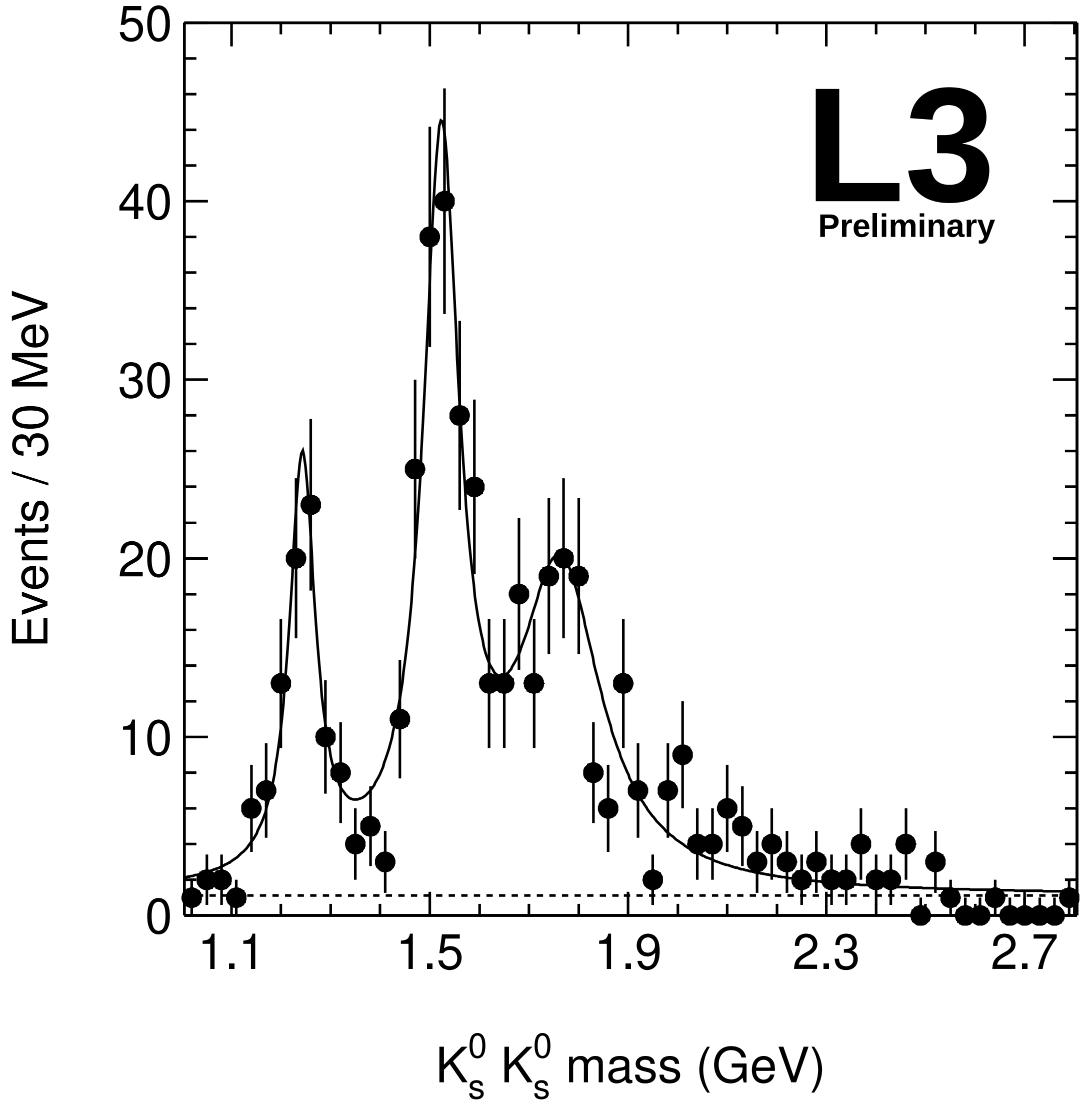
The $K^0_s K^0_s$ Final State

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



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

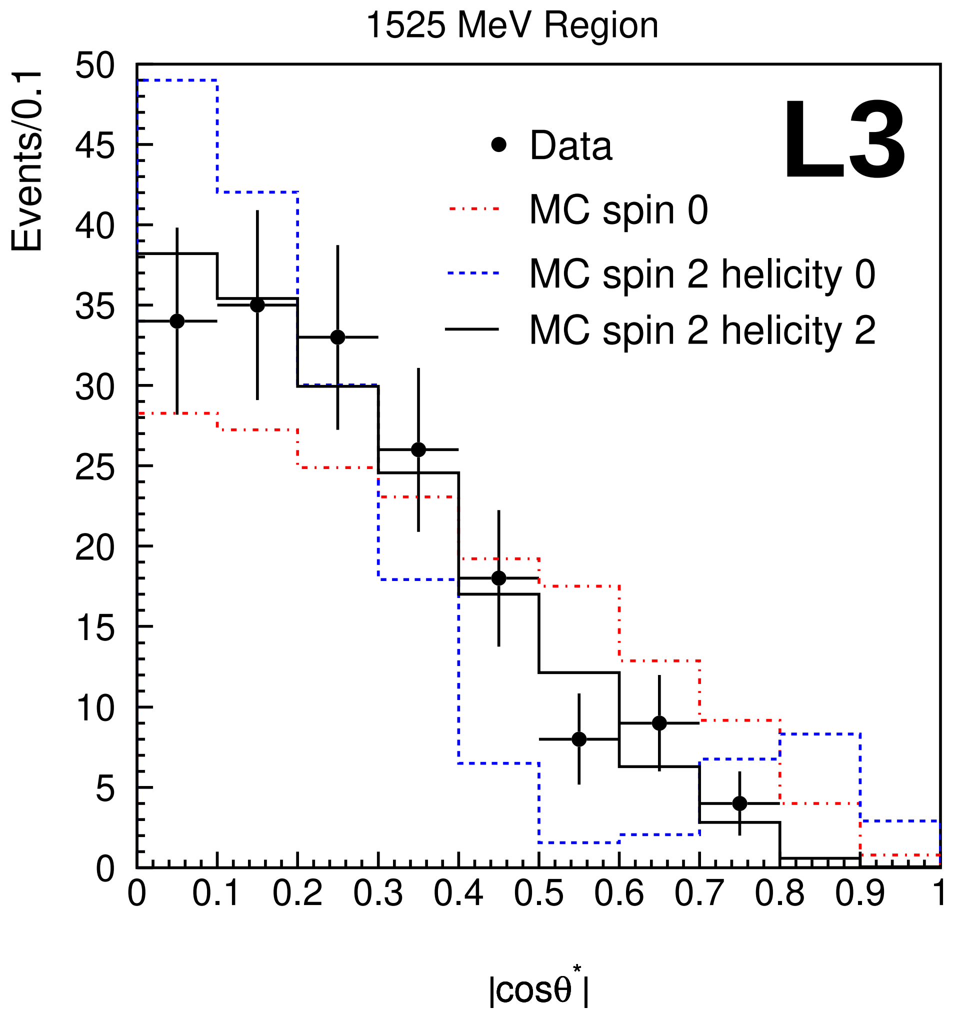
The $K_s^0 K_s^0$ Mass Spectrum



	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.	21	4.6	93

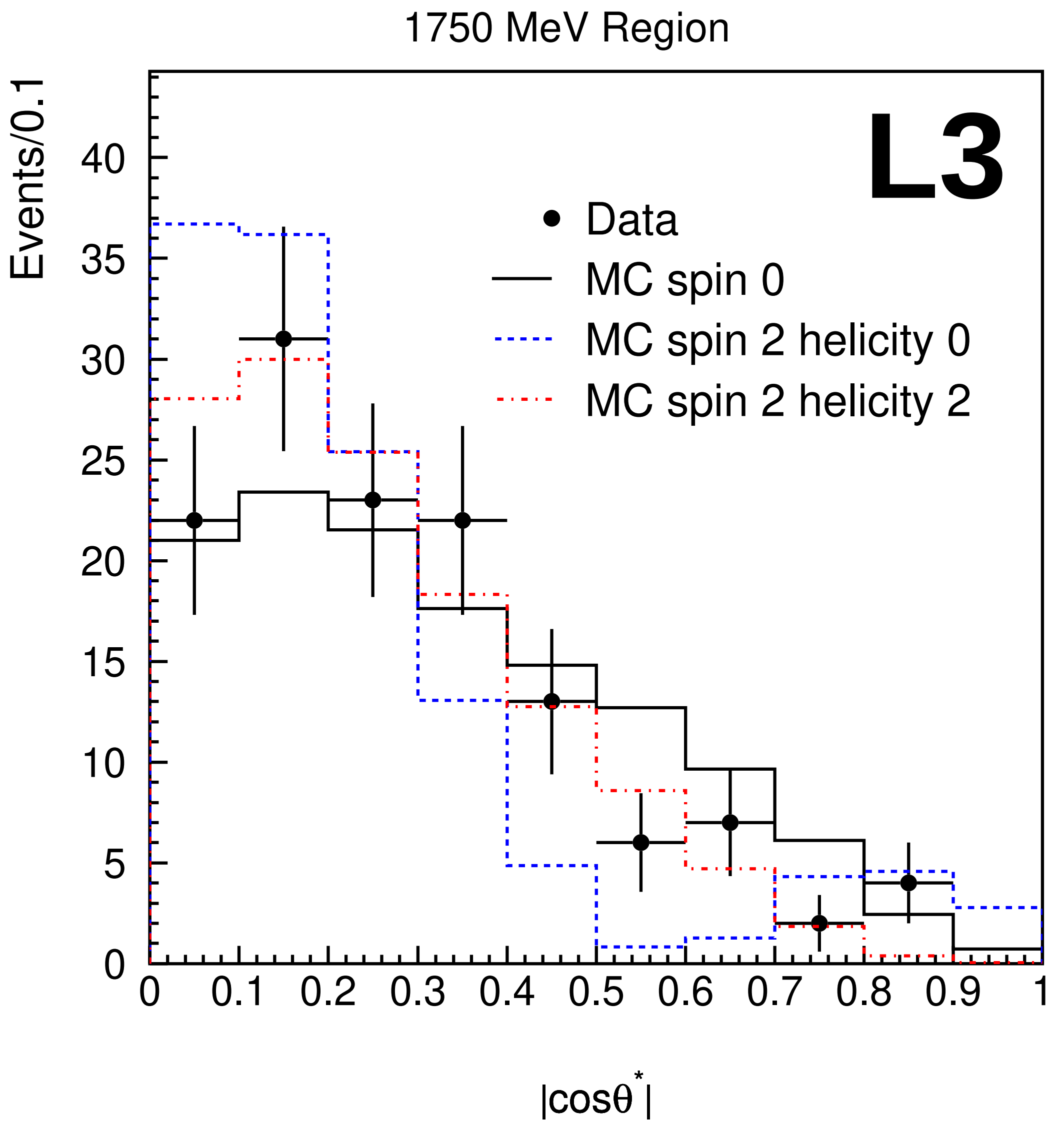
Helicity 2 dominates !

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? $f_2''(1740)$, $f_2'''(1820)$ (OGE-SRM prediction)
- 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.	12	38	89

J=0 assignment is favoured

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 $\Gamma_{\gamma\gamma}(\xi)\mathrm{BR}(K_s^0 K_s^0)$
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 :

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

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:

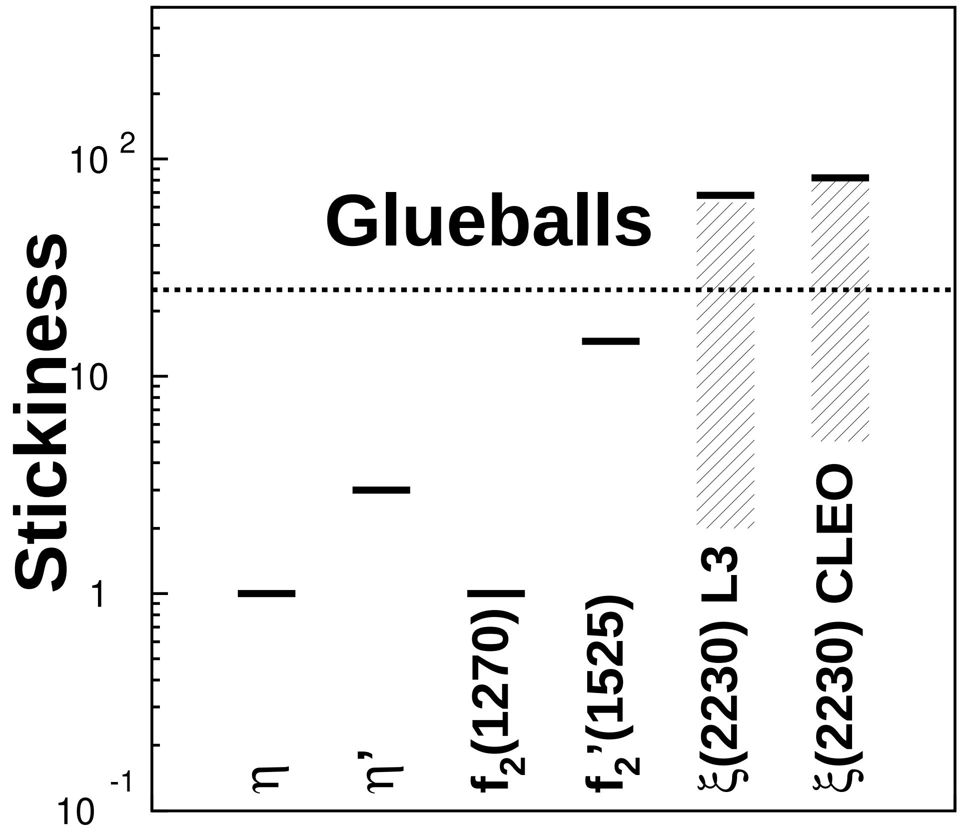
m_R	mass of the state
$k_{J/\psi \to \gamma X}$	photon energy in J/ψ decay
N_l	normalization factor such that $S_{f_2(1270)}=1$

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

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

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

Conclusions & Outlook

- The $\pi^+\pi^-\pi^0$ final state :

  $a_2(1320)$, $J^{PC}(\lambda)=2^{++}(2)$ (dominant)
  $a_2(1750)$, $J^{PC}(\lambda)=2^{++}(2)$

- 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 $\xi(2230)$:
  $\Gamma(\xi \rightarrow \gamma\gamma) \times \mathrm{BR}(\xi \rightarrow K^0_s K^0_s) < 1.5$ 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 hadron spectroscopy and glueball searches.