Searches for glueball candidates in $\gamma\gamma$ collisions at LEP and CLEO

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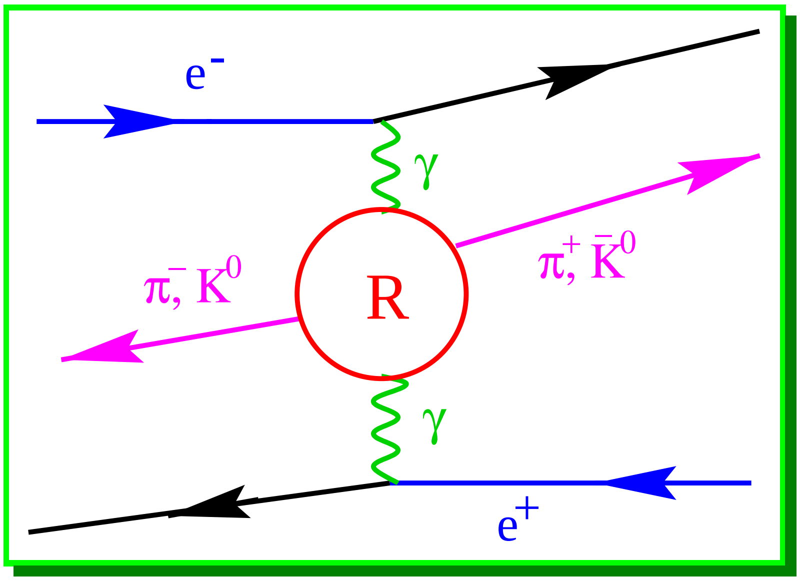
- Introduction
- $\pi^+\pi^-$ final state and searches for $f_0(1500)$ and $f_J(2220)$
- $\mathrm{K^0_S K^0_S}$ final state and searches for $f_J(2220)$
- Summary and conclusions

$\gamma\gamma\rightarrow$ Resonance



♣ Outgoing e^+e^- are undetected $\Rightarrow$ quasi real photons

♣ R neutral unflavoured meson with $C = +1$

Resonance formation :

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

- Resonance Parameters:
  J Spin
  m_R Mass
  $\Gamma_{\gamma\gamma}$ Two-photon width
  Γ_R Total width

- $W_{\gamma\gamma}$ Two-photon system invariant mass

Glueballs

QCD non abelian gauge theory $\Rightarrow$ self-interaction of gluons

$\Downarrow$

Glueballs

- ♣ Bound states of two or more gluons
- ♣ Produced in gluon rich environment $\Rightarrow$ $p\bar{p}$ and pp collisions, J/ψ decays
- ♣ $\Gamma_{\gamma\gamma} \propto \sum_q e_q^4$ very small $\Rightarrow$ only due to sea quarks
- ♣ Flavour blind decay branching ratios

QCD is today firmly established but direct experimental evidence of glueballs is still missing

Theoretical predictions for the ground state glueballs from lattice QCD

- ♣ 0^{++} M $= 1.6 \pm 0.15$ GeV
- ♣ 0^{-+} and 2^{++} M $\simeq 2.2 \pm 0.2$ GeV

Glueballs

Understanding of $q\bar{q}$ mass spectrum is crucial to identify glueballs

$$\Downarrow$$

$\gamma\gamma$ collisions probe only $q\bar{q}$ states $\Rightarrow$
indirect identification of glueballs
(but glueballs/$q\bar{q}$ states mixing is also possible !!)

$$\Downarrow$$

$\Gamma_{\gamma\gamma}$ can be combined with $\Gamma(J/\psi \to \gamma R)$ in the stickiness:
a glueball figure of merit $\Rightarrow$
a measure of colour charge relative to electric charge.

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

m_R = resonance mass, k = photon energy in J/ψ decay,
N_l = normalization factor such that $S_{f_2(1270)} = 1$.

High stickiness $\Rightarrow$ high probability to be a glueball

0^{++} Meson Nonet

- Identification of scalar nonet constituents is difficult $\Rightarrow$ a lot of broad and interfering resonances in the $1.0 \div 1.5$ GeV region
- Recently Crystal Barrel at LEAR discovered 3 new 0^{++} states: $a_0(1450)$, $f_0(1370)$ and $f_0(1500)$ $\Rightarrow$ too many states for a nonet

Two main interpretations:

- $f_0'(1500-1800)$ still missing $\rightarrow$ $s\bar{s}$ state
  $f_0(1500)$ $\rightarrow$ glueball
- $f_0(980)$ and $f_0(1370)$ $\rightarrow$ $s\bar{s}$ state
  $f_0(1500)$ $\rightarrow$ glueball

$f_0(1500)$ too light and narrow to be an $u\bar{u}+d\bar{d}$ excited state
$f_0(1500)$ small $K\bar{K}$ branching ratio $\Rightarrow$ not an $s\bar{s}$ state

$\Downarrow$

Best 0^{++} glueball candidate

2^{++} Meson Nonet

♣ Neutral constituents are: $a_2(1320)$, $f_2(1270)$ and $f_2'(1525)$

Observation of $f_J(2220)$ (also known as $\xi(2230)$) by Mark III and BES becomes statistically more and more significant.

mass spectra from BES (no ps file from them)

$f_J(2220)$ has a spin 2 assignment
$f_J(2220)$ has a narrow width $\Gamma \simeq 20$ MeV
$f_J(2220)$ seems to have flavour blind couplings

$\Downarrow$

can hardly be assigned to a $q\bar{q}$ state

$\Downarrow$

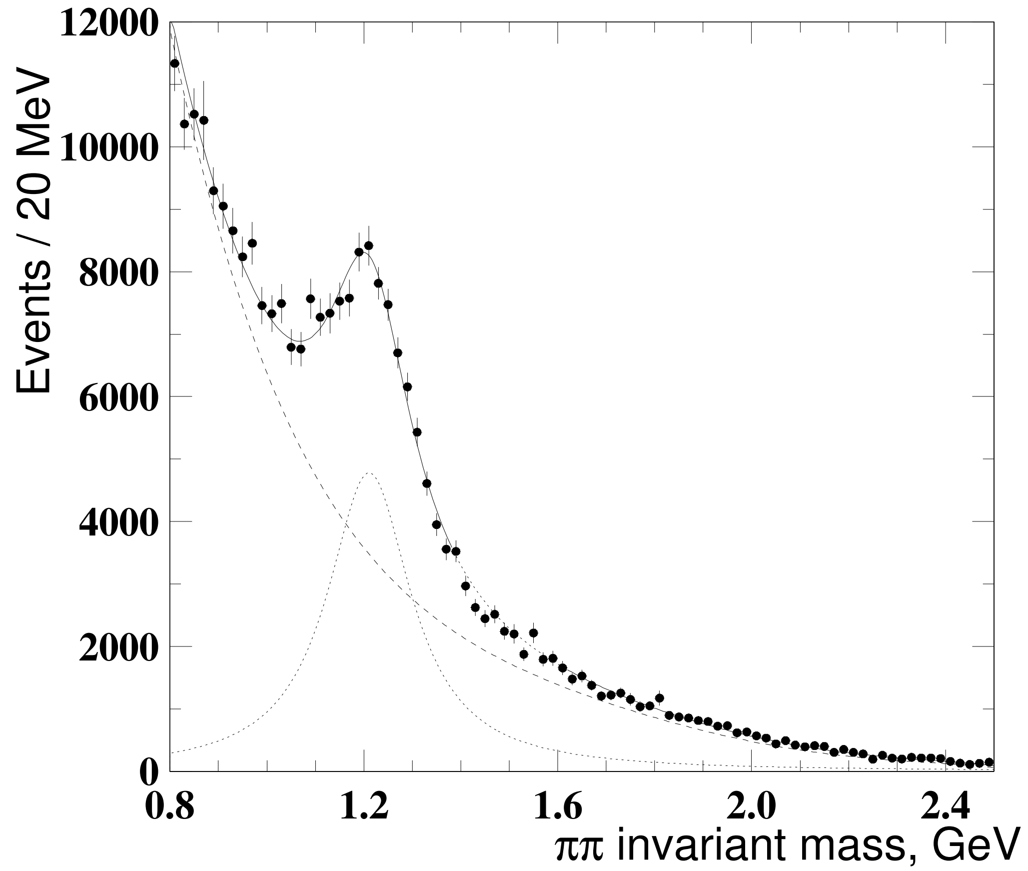
Best 2^{++} glueball candidate

$\pi^+\pi^-$ final state – ALEPH

Search for the process $\gamma\gamma \to f_0(1500) \to \pi^+\pi^-$ in 160.9 pb^{-1} at $\sqrt{s} \simeq 91$ GeV

Selection:

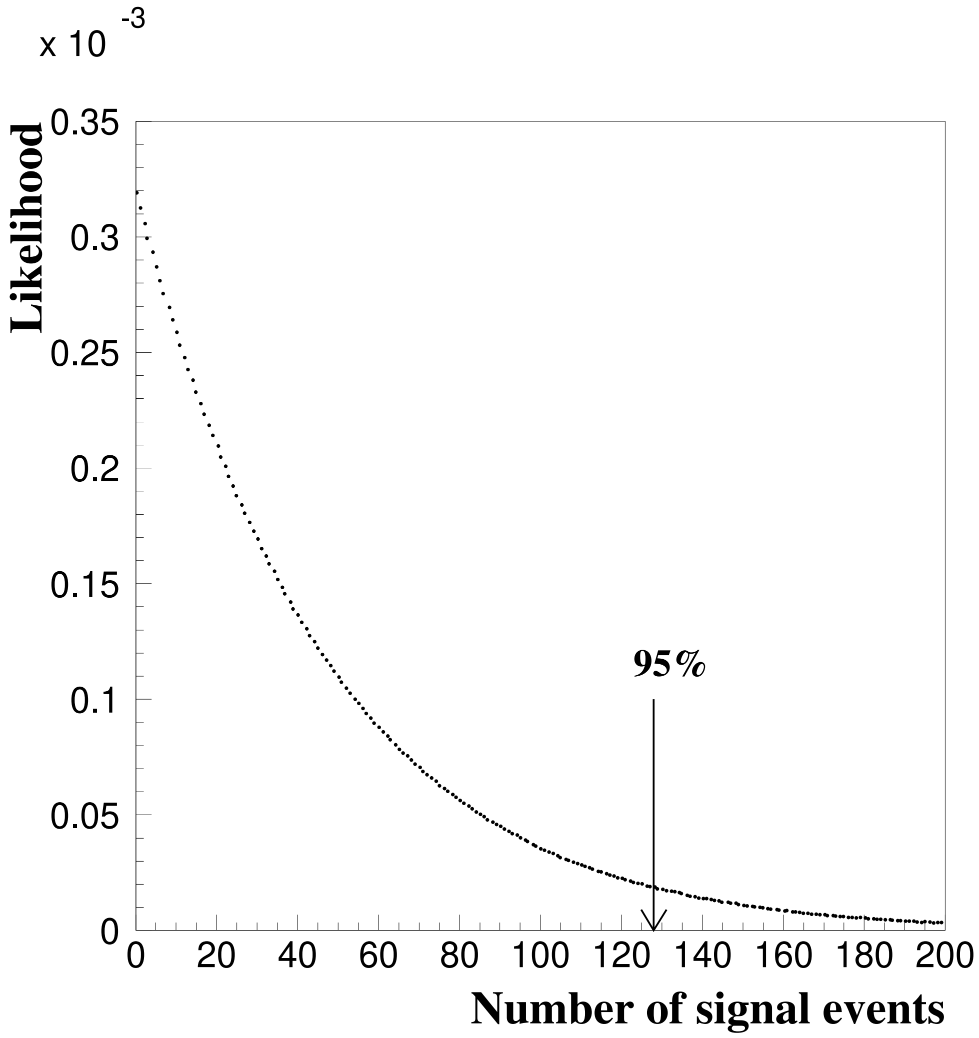
- only 2 tracks with opposite charge
- $E_{vis} < 30$ GeV and $M_{vis} < 10$ GeV
- anti-tag outgoing electron/positron and total $P_\perp < 1.5$ GeV
- veto muons (muon chambers), electrons and kaons (dE/dx)



$\pi^+\pi^-$ final state – ALEPH

$f_2(1270)$	ALEPH	PDG
Mass (MeV)	1211 ± 4	1275 ± 1
Width (MeV)	211 ± 18	185 ± 4

Interference effects NOT taken into account



$\varepsilon_{TOT} = 14\%$ for $\gamma\gamma \rightarrow f_0(1500) \rightarrow \pi^+\pi^-$

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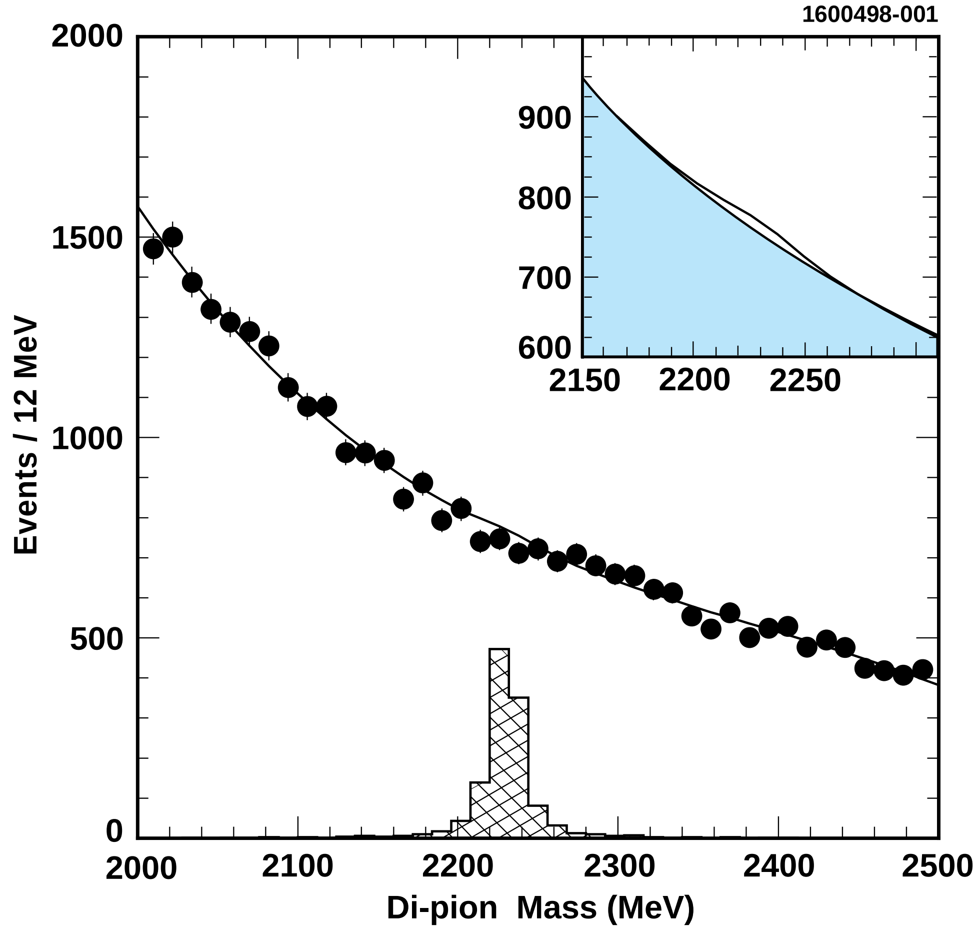
$\Gamma_{\gamma\gamma} \times BR(f_0(1500) \rightarrow \pi^+\pi^-) < 33.6$ eV at 95% C.L.

($\Gamma_{\gamma\gamma} < 0.17$ keV including systematics)

$\pi^+\pi^-$ final state – CLEO

Search for the process $\gamma\gamma \to f_J(2220) \to \pi^+\pi^-$
in 4770 pb^{-1} at $\sqrt{s} \simeq 10.6$ GeV



Assuming NO interference effects

$\varepsilon_{TOT} = 25\%$ for $\gamma\gamma \to f_2(2220) \to \pi^+\pi^-$

assuming J=2 and $\frac{\text{Helicity } 0}{\text{Helicity } 2} = \frac{1}{6}$

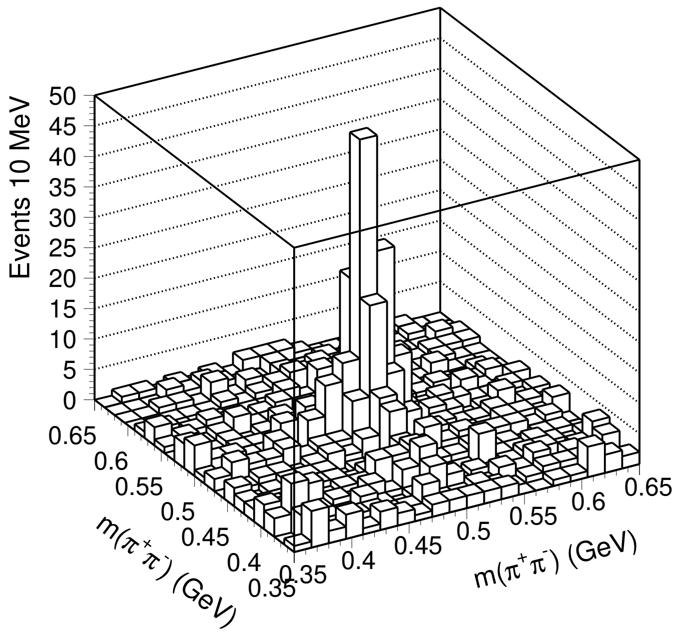
$\Downarrow$

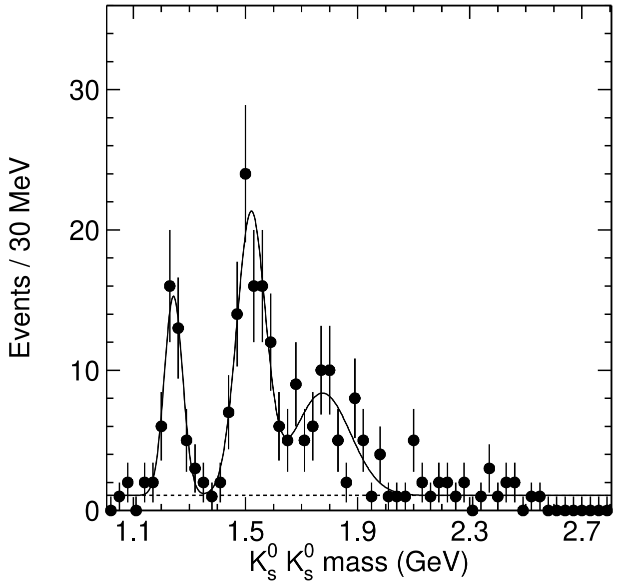
$\Gamma_{\gamma\gamma} \times BR(f_2(2220) \to \pi^+\pi^-) < 2.5$ eV at 95% C.L.

$K^0_S K^0_S$ final state – L3

Search for the process $\gamma\gamma \rightarrow f_J(2220) \rightarrow K^0_S K^0_S$ in 143 pb^{-1} at $\sqrt{s} \simeq 91$ GeV and 52 pb^{-1} at $\sqrt{s} \simeq 183$ GeV

$\sum_i (M_{(\pi^+\pi^-)_i} - M_{K^0_S})^2 < (40\ \mathrm{MeV})^2$ $\quad \sigma_{M_{(\pi^+\pi^-)}} = 9.6$ MeV $\Rightarrow$ 253 events selected



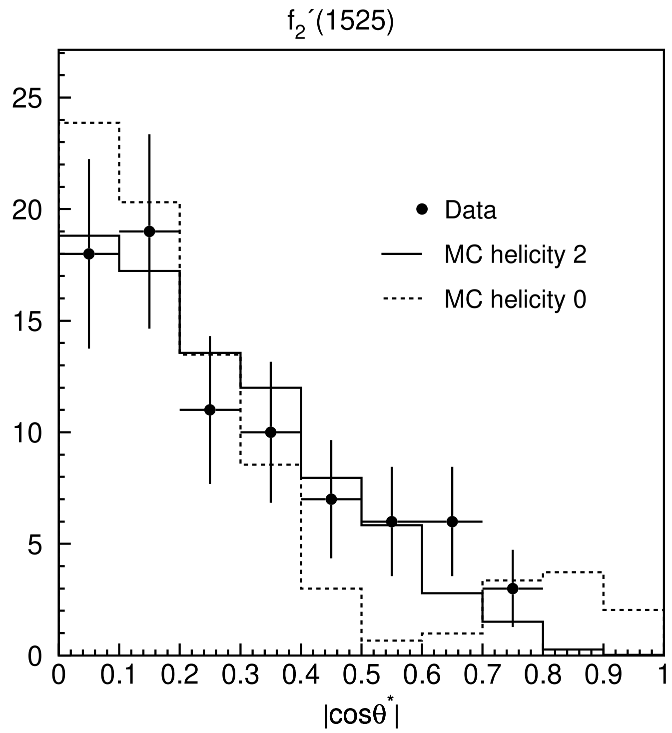


- Destructive interference in the $f_2(1270) - a_2(1320)$ region in agreement with prediction for $K^0_S K^0_S$ final state
- Enhancement in the 1750 MeV region

$K_S^0 K_S^0$ final state – L3

	$f_2(1270)/a_2(1320)$	$f_2'(1525)$	$f_J(1710)$
Mass (MeV)	–	1520 ± 7	1770 ± 20
Width (MeV)	–	119 ± 15	200 ± 50
Events	38 ± 7	85 ± 11	61 ± 10

K_S^0 angular distribution shows helicity 2 is dominant
($\chi^2 = 7$ for 9 d.o.f., $\chi^2 = 81$ for helicity 0)



$\varepsilon_{TOT} = 7.6\%$ for $\gamma\gamma \to f_2'(1525) \to K_S^0 K_S^0 \to \pi^+\pi^-\pi^+\pi^-$

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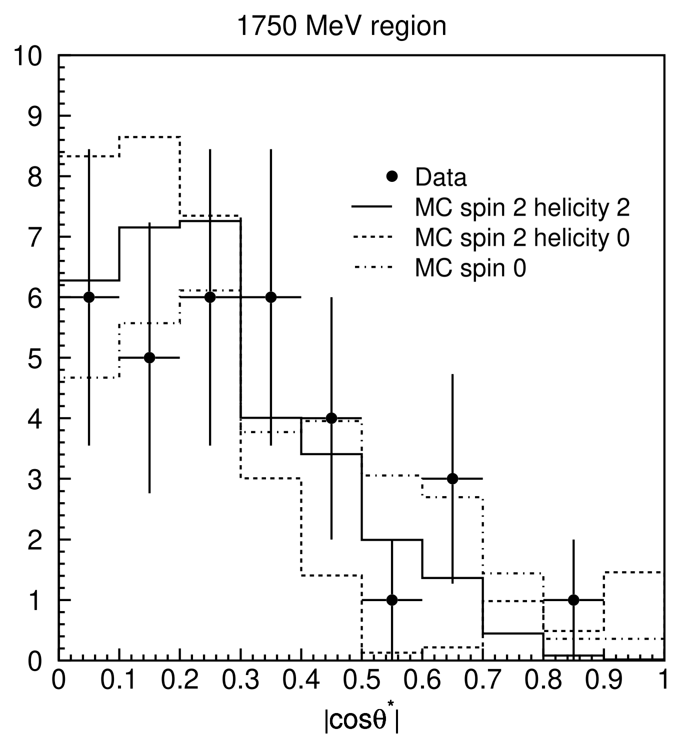
$$\Gamma_{\gamma\gamma} \times BR(f_2'(1525) \to K\bar{K}) = 0.085 \pm 0.012 \text{ keV}$$

$K^0_S K^0_S$ final state – L3

$f_J(1710)$: excited state of f_2' ? or $s\bar{s}$ state of the 0^{++} nonet ?

	J=2, $\lambda=0$	J=2, $\lambda=2$	J=0
χ^2 for 9 d.o.f.	55	15	6



$f_J(2220)$: No excess $\Rightarrow$ 6 data / 4.9 expected
(in the region 2234 ± 120 MeV)

$\varepsilon_{TOT} = 16.5\%$ for $\gamma\gamma \to f_2(2220) \to K^0_S K^0_S \to \pi^+\pi^-\pi^+\pi^-$

assuming J=2 and Helicity 2

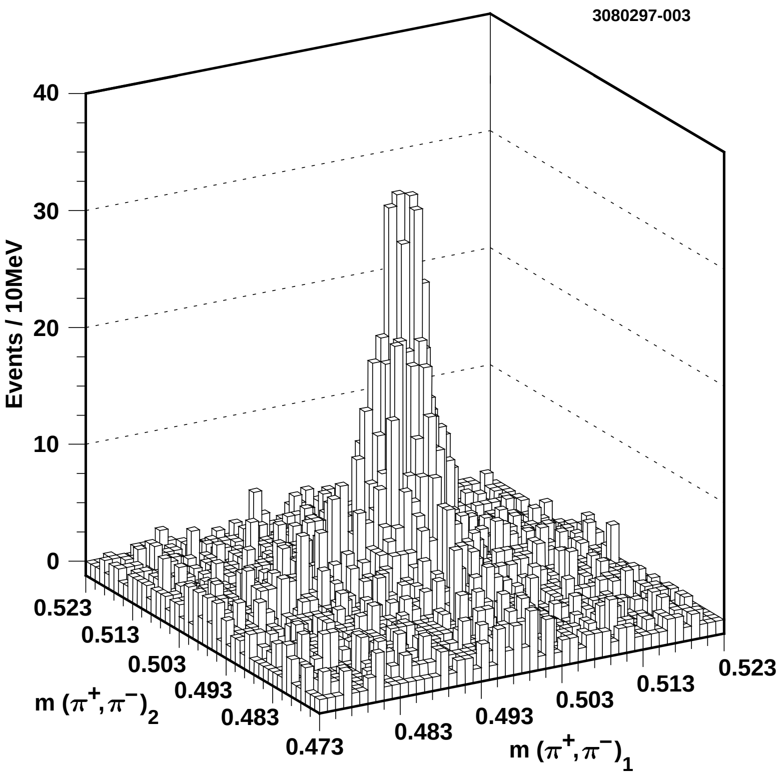
$\Downarrow$

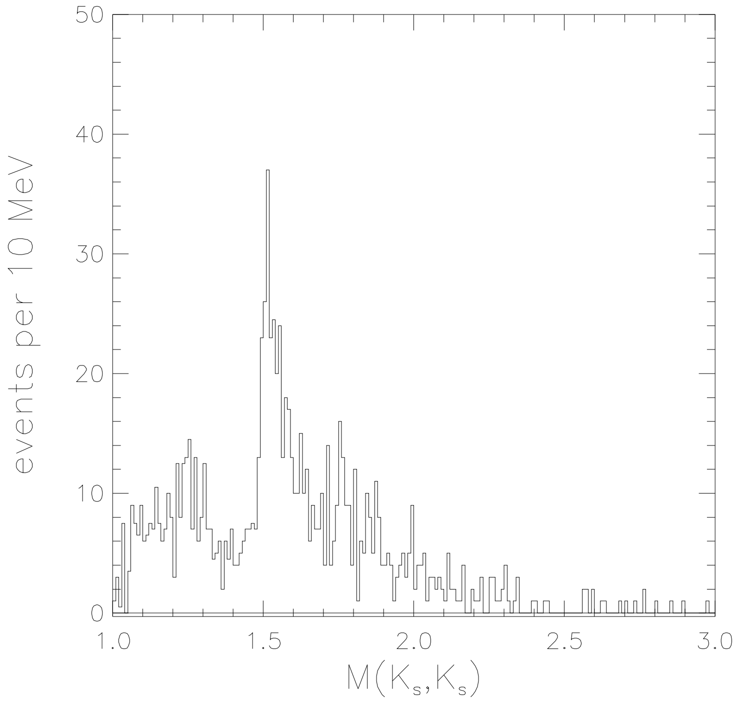
$\Gamma_{\gamma\gamma} \times BR(f_2(2220) \to K^0_S K^0_S) < 4.1$ eV at 95% C.L.

$K^0_S K^0_S$ final state – CLEO

Search for the process $\gamma\gamma \to f_J(2220) \to K^0_S K^0_S$ in 3000 pb^{-1} at $\sqrt{s} \simeq 10.6$ GeV

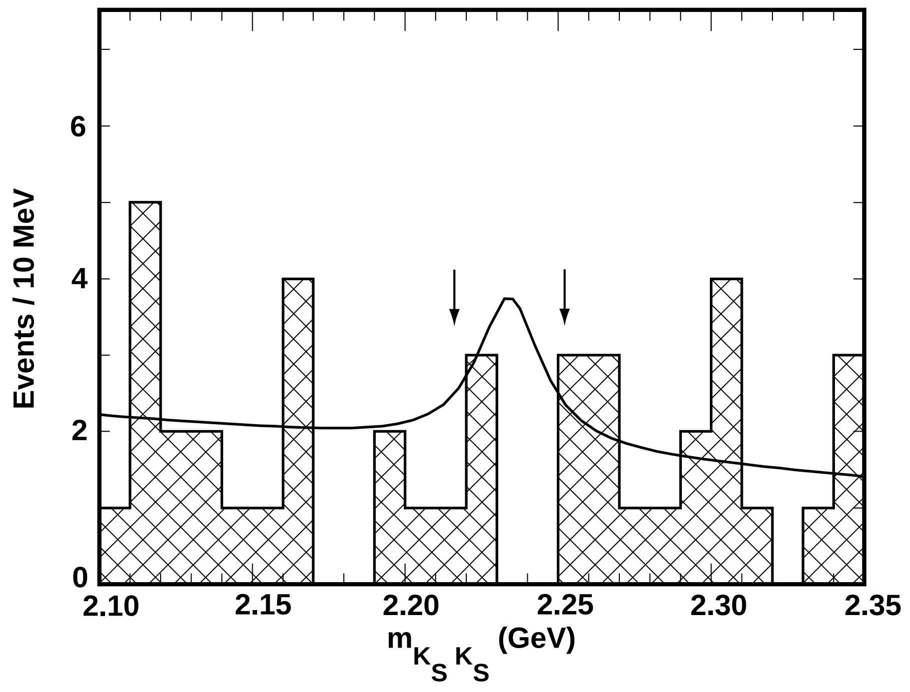
$\sum_i (M_{(\pi^+\pi^-)_i} - M_{K^0_S})^2 < (10 \text{ MeV})^2 \qquad \sigma_{M_{(\pi^+\pi^-)}} = 3.3$ MeV





$\mathrm{K^0_S K^0_S}$ final state – CLEO

$f_J(2220)$: No excess $\Rightarrow$ 4 data / 6.5 expected
(in the region 2234 ± 18 MeV)



Assuming NO interference effects

$$\gamma\gamma \rightarrow f_2(2220) \rightarrow \mathrm{K^0_S K^0_S} \rightarrow \pi^+\pi^-\pi^+\pi^-$$

$\varepsilon_{TOT} = 7\%$ for $\lambda = 0$ and $\varepsilon_{TOT} = 15\%$ for $\lambda = 2$

assuming J=2 and $\frac{\mathrm{Helicity}\ \ 0}{\mathrm{Helicity}\ \ 2} = \frac{1}{6}$

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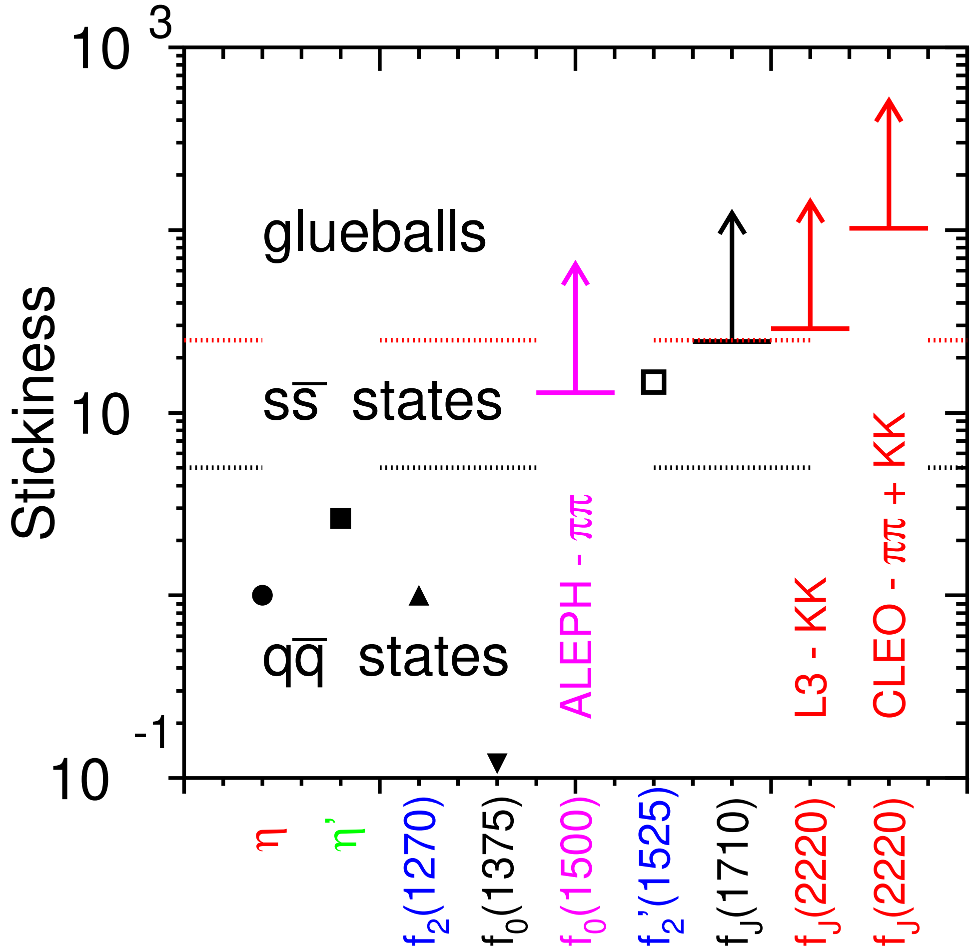
$\Gamma_{\gamma\gamma} \times BR(f_2(2220) \rightarrow \mathrm{K^0_S K^0_S}) < 1.3$ eV at 95% C.L.

Analysis cross check with $f_2^{'}(1525) \Rightarrow$
in agreement with current PDG value

Summary

Upper limits on $\Gamma_{\gamma\gamma}$ can be interpreted in terms of stickiness:
glueball figure of merit $\Rightarrow$
a measure of colour charge relative to electric charge.

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



$f_2'(1525)$ is thought to be an $s\bar{s}$ state
$f_J(1710)$ maybe $s\bar{s}$ state for the 0^{++} nonet
$f_0(1500)$ 0^{++} glueball candidate
$f_2(2220)$ 2^{++} glueball candidate

Conclusions

- ♣ ALEPH: new limit on $S_{f_0(1500)} > 13$ at 95% C.L. Further investigation is needed to understand interference effects.
- ♣ L3: new limit on $S_{f_J(2220)} > 28.6$ at 95% C.L. and new measurements for $f_2^{'}(1525)$ and $f_J(1710)$.
- ♣ CLEO: new limit on $S_{f_J(2220)} > 102$ at 95% C.L. from $\pi^+\pi^-$ and $\mathrm{K_S^0 K_S^0}$ channels combined.

New data from $\gamma\gamma$ collisions confirm the hypothesis of glueball nature for the $f_0(1500)$ and the $f_J(2220)$. Especially for the $f_J(2220)$ lower limits on stickiness are now very stringent.

New data at LEP2 (foreseen 500 pb^{-1} per experiment) and CLEO will bring in the next few years tighter constraints on $S_{f_0(1500)}$ and $S_{f_J(2220)}$.