Resonance Production in $\gamma\gamma$ Collisions at L3

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- ◀ $\pi^+\pi^-\pi^0$ final state
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- ▶ $\mathrm{K}^0_S\mathrm{K}^0_S$ final state
- ◀ Glueballs
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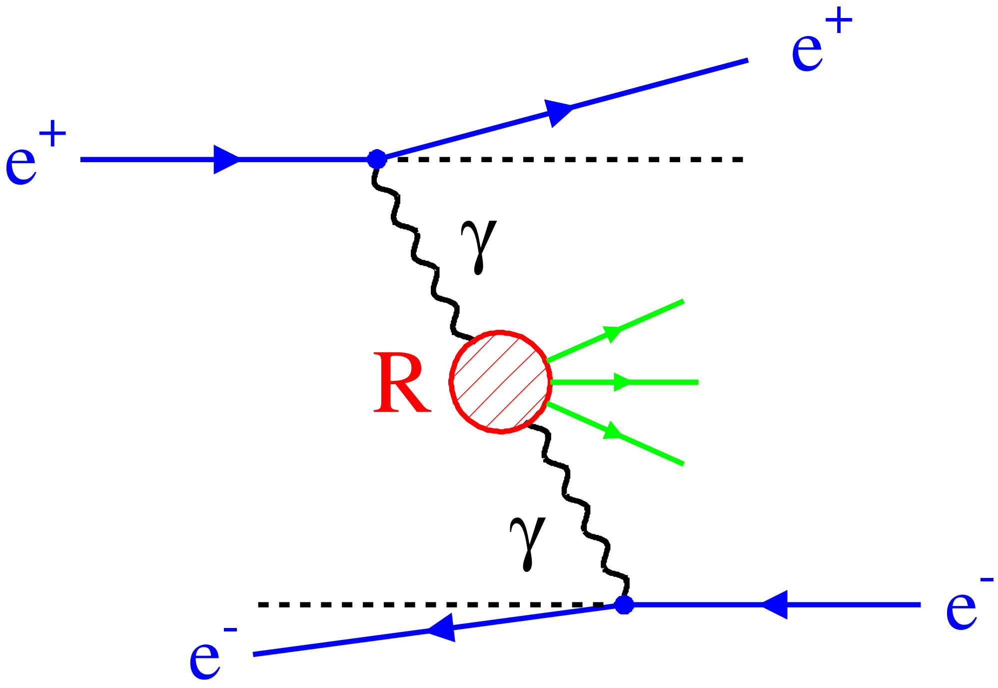
Introduction

Resonance Production: $e^+e^- \longrightarrow e^+e^-\gamma^*\gamma^* \longrightarrow e^+e^-R$



- Electrons undetected $\Longrightarrow$ quasi real photons
- Maximum virtuality of the photon:

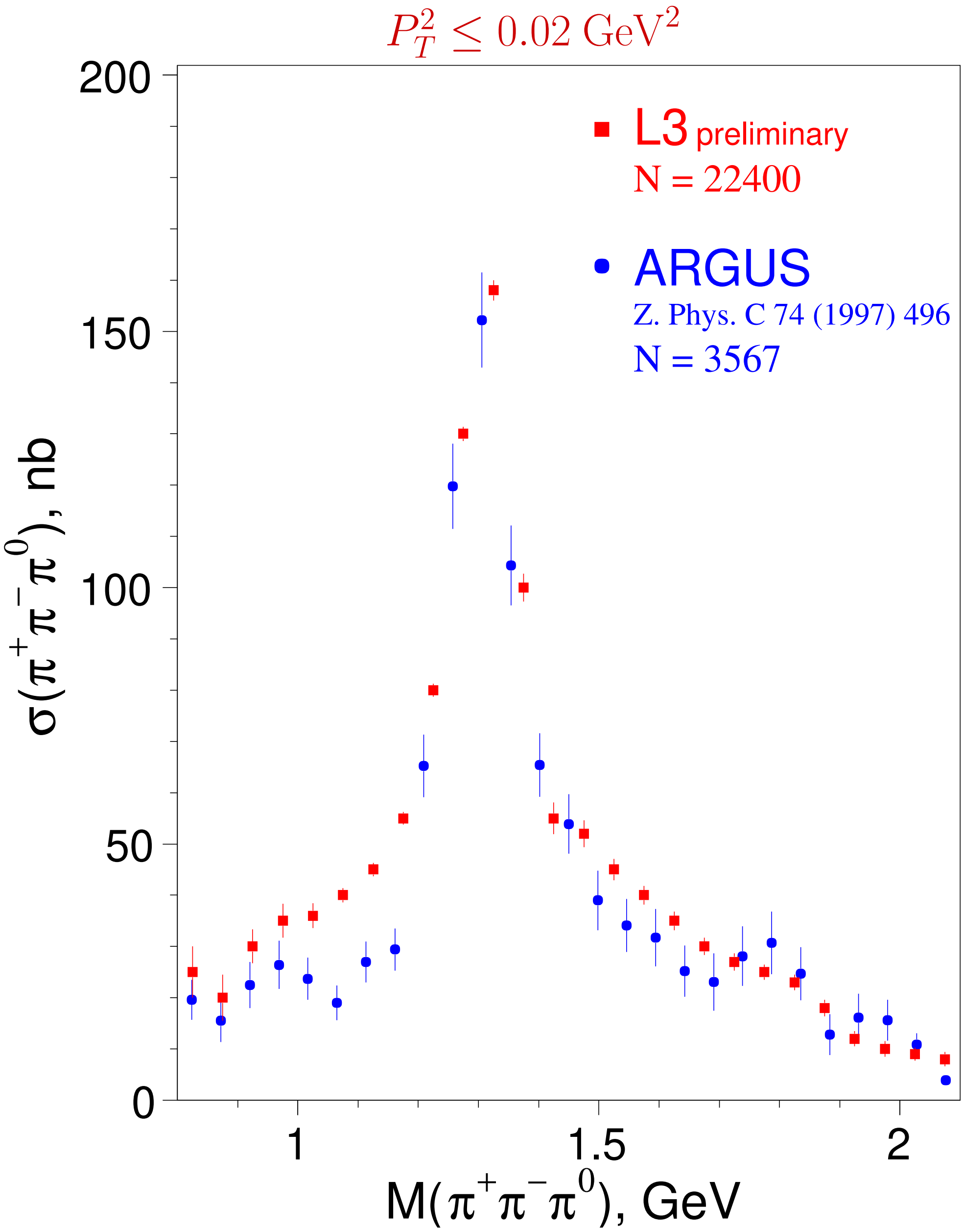
$$Q^2 \simeq P_T^2 \equiv (\sum \vec{p_T})^2$$

- C-even mesons produced
  - mainly with spin 0 or 2 at $Q^2 \simeq 0$
  - spin 1 possible when $Q^2 > 0$

(L.D. Landau, Sov. Phys. Dok. 60 (1948) 207;
C.N. Yang, Phys. Rev. 177 (1969) 2426)

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

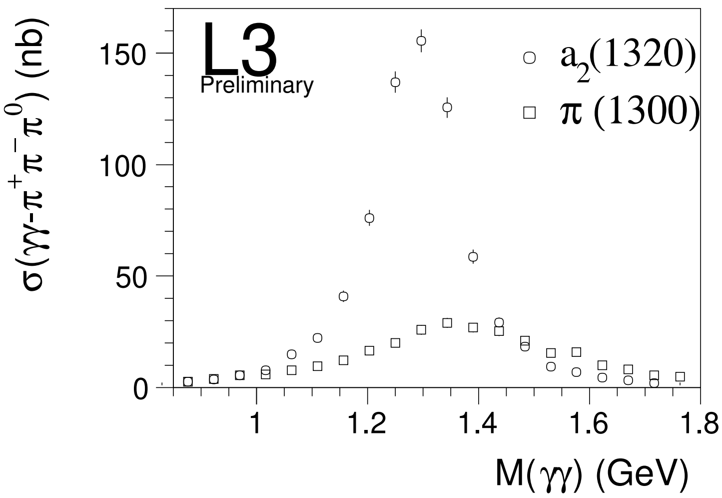
- preliminary results for $\sqrt{s} = 183 - 209$ GeV, $\mathcal{L} = 682.6\ \mathrm{pb}^{-1}$
- selection:
  - Require 2 tracks and 2 photons
  - $0.105 < M_{\gamma\gamma} < 0.165$ GeV
  - Kinematical fit with π^0 mass constraint



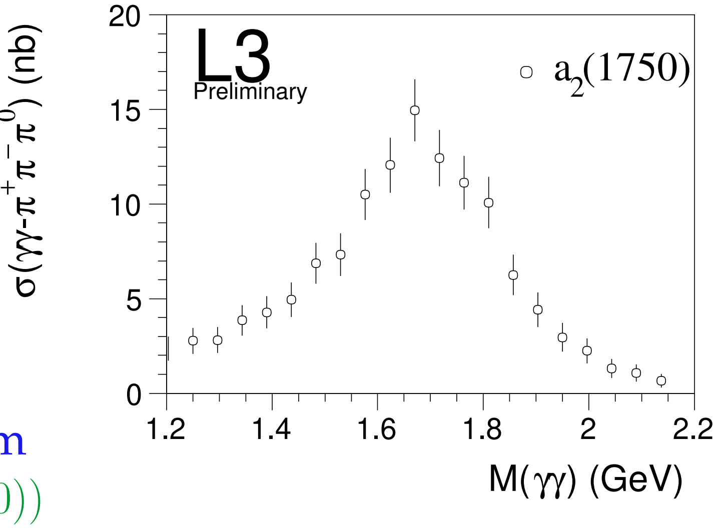
Partial Wave Analysis

- formation of $\gamma\gamma \to R \to R'\pi$ and $R' \to \pi\pi$
  R: $J^P = 0^-, 2^+, 2^-$
  R': $\sigma(f_0(400-1200)), \rho(770), f_2(1270)$
- production amplitude $\Rightarrow$ sum of Breit-Wigner resonances
- unbinned maximum likelihood fit to determine contributions from different resonances
- 1998 data ($\sqrt{s} = 189$ GeV, $\mathcal{L} = 176.7$ pb^{-1})

1300 MeV mass region:
2^{++}: $a_2(1320)$
0^{-+}: $\pi(1300)$

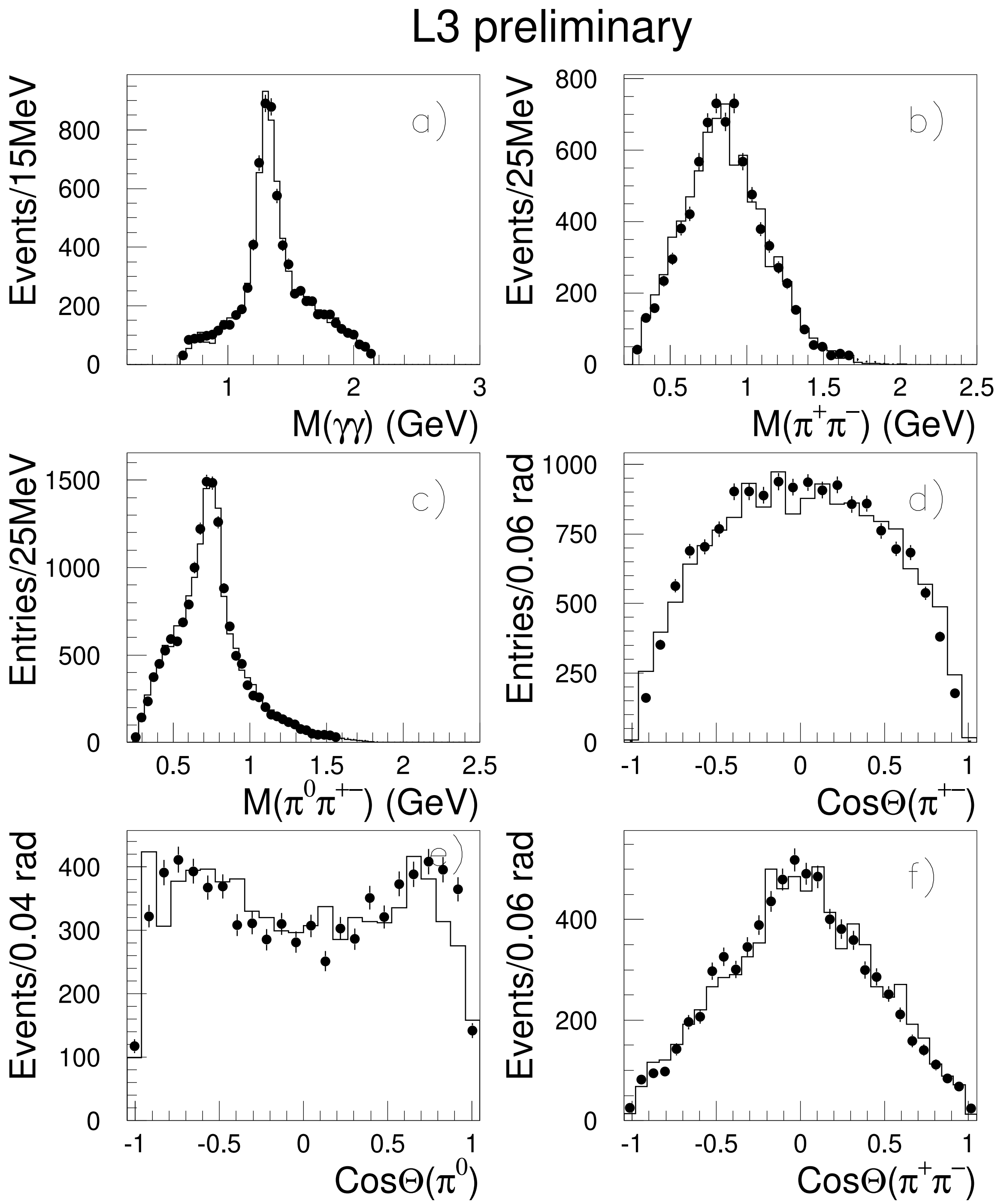


1750 MeV mass region:
2^{++}: $a_2(1750)$)



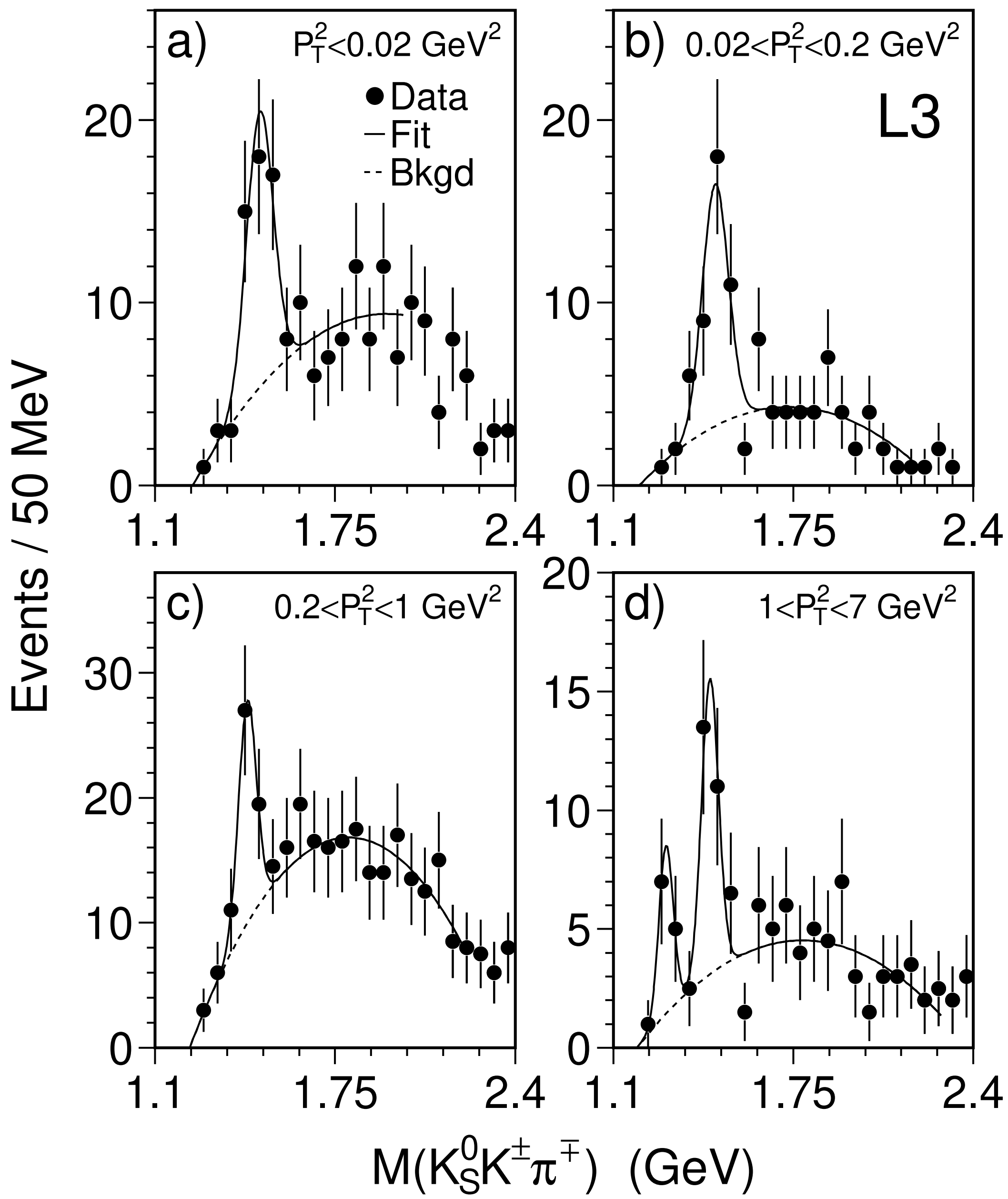
- small contributions from $2^{-+}(\pi_2(1670))$ and $0^{-+}(\pi(1800))$

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



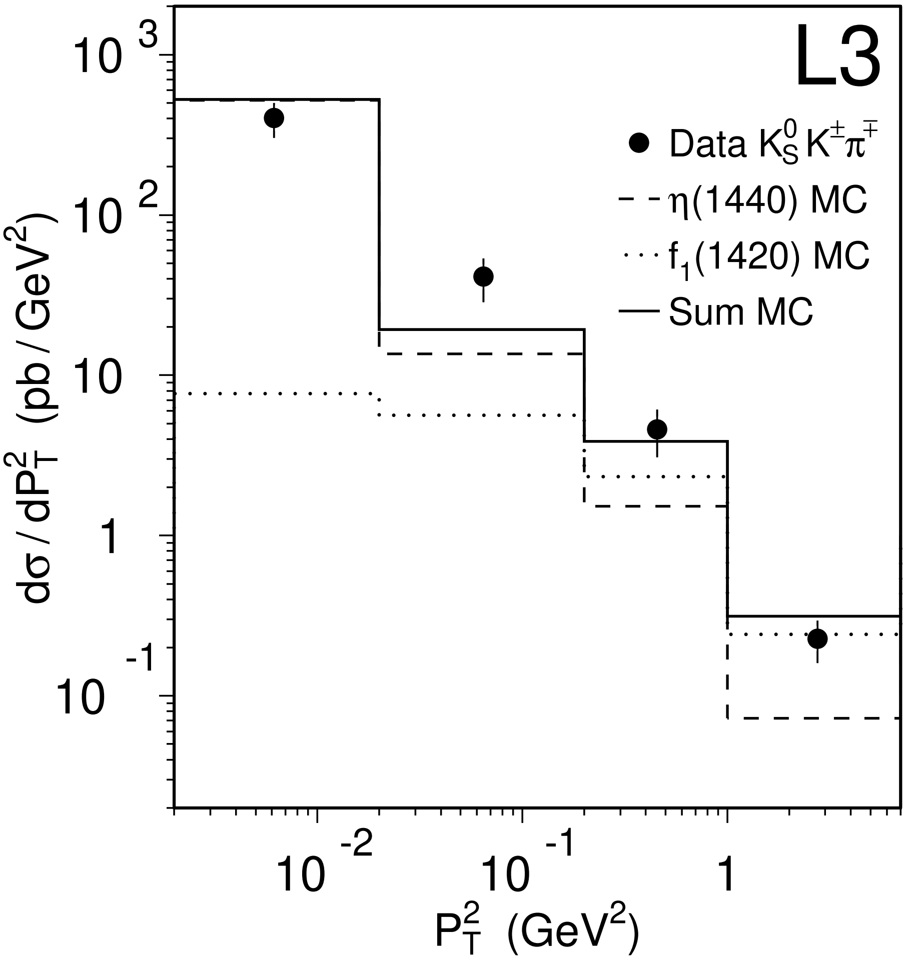
	$\chi^2/d.o.f.$
mass spectra	0.69
angular distributions	1.66

- Physics Letters B 501 (2001) 1-11
  $\sqrt{s} = 183 - 202$ GeV, $\mathcal{L} = 449$ pb^{-1}
- untagged electrons: $Q^2 \simeq P_T^2$



signal in region ▷ 1285 MeV: $f_1(1285)$
▷ 1440 MeV: $f_1(1420)$ and/or $\eta(1440)$

Fit $d\sigma/dP_T^2$ for peak around 1440 MeV



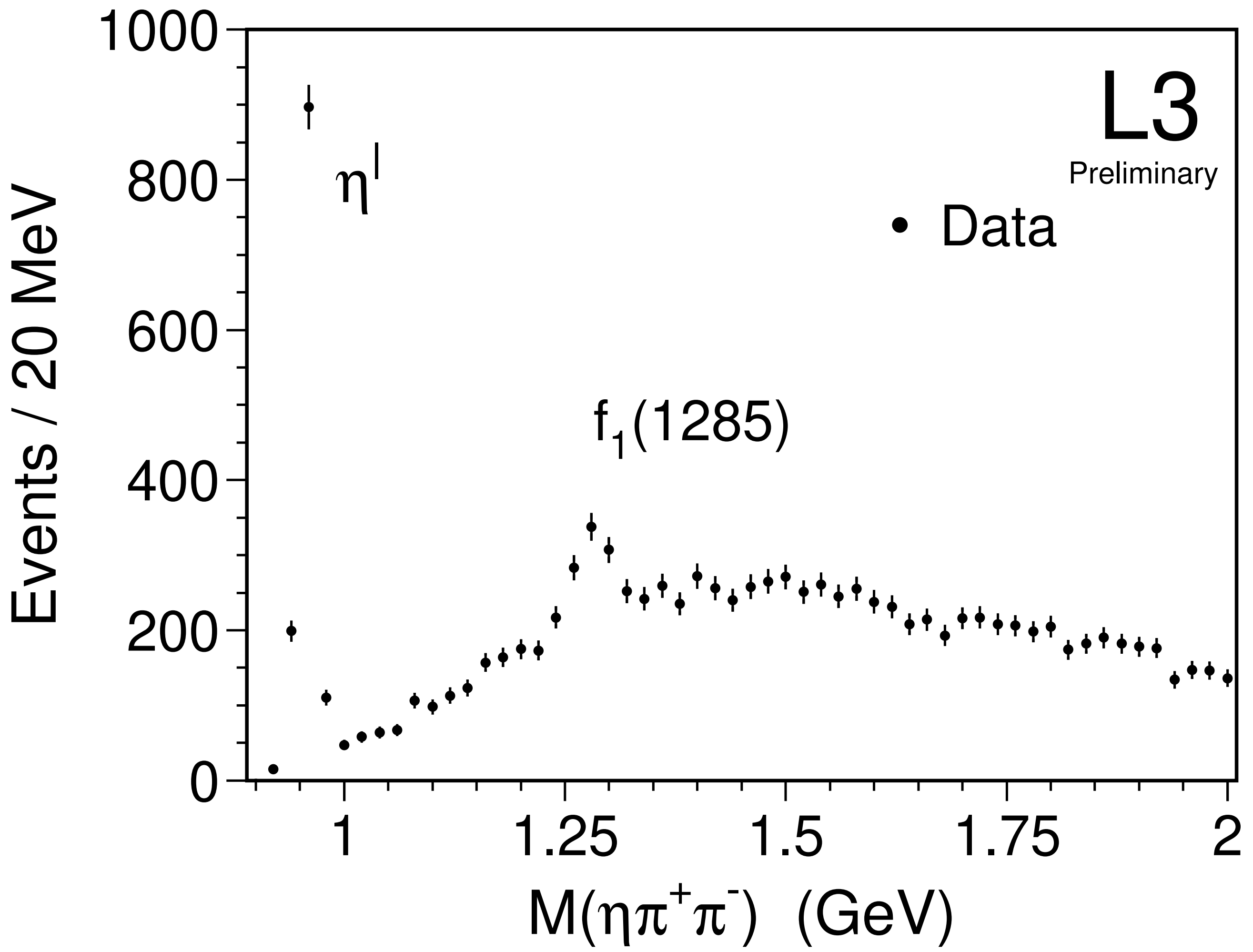
Resonance	C.L.
pure pseudo scalar $\eta(1440)$	$\sim 10^{-3}$
pure axial vector $f_1(1420)$	$\sim 10^{-3}$
simultaneous $\eta(1440)$ and $f_1(1420)$	9%

$P_T^2 < 0.02\ \mathrm{GeV}^2$:

- dominated by the spin-0 state
- $M = 1481 \pm 12$ MeV and $\sigma = 48 \pm 9$ MeV
- $\Gamma_{\gamma\gamma}(\eta(1440)) \times \mathrm{BR}(\eta(1440) \to K\bar{K}\pi) = 212 \pm 50(\mathrm{stat}) \pm 23(\mathrm{sys})$ eV

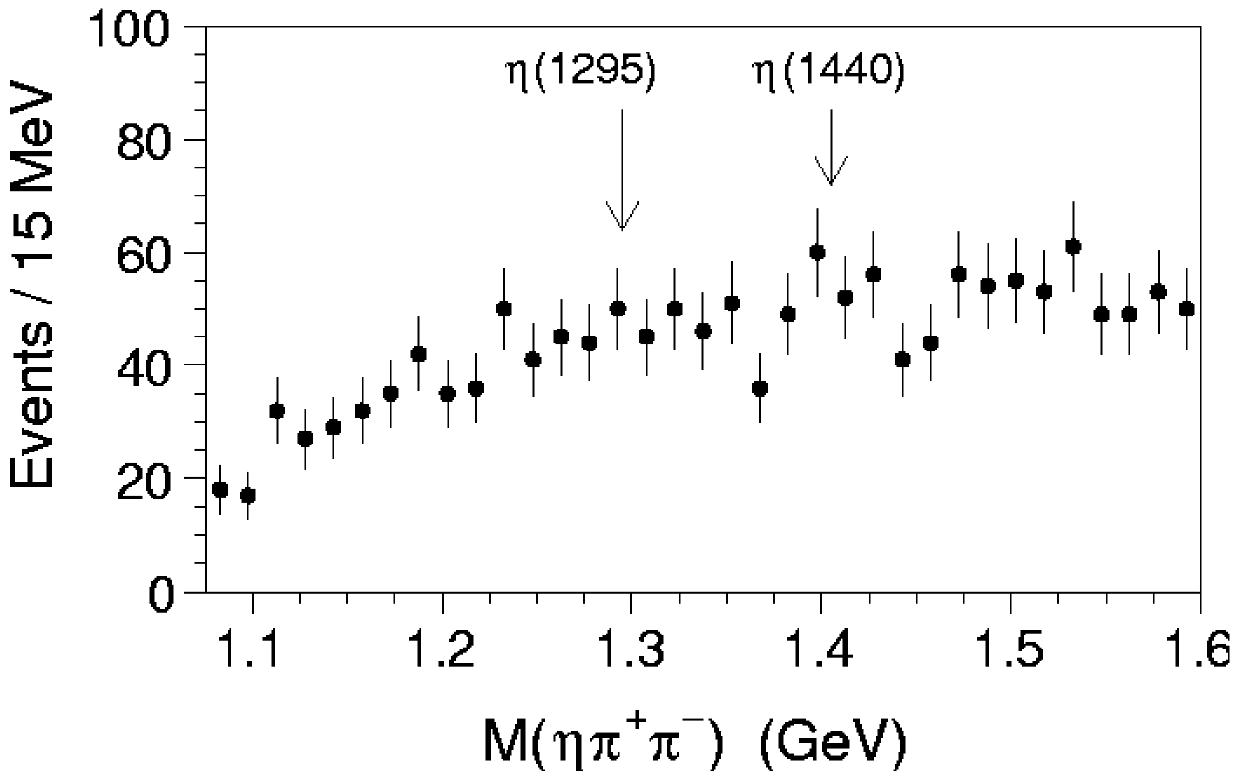
$\eta\pi^+\pi^-$ final state

- Physics Letters B 501 (2001) 1-11
  $\sqrt{s} = 183 - 202$ GeV, $\mathcal{L} = 449$ pb^{-1}
- Prelim. results for $\sqrt{s} = 183 - 209$ GeV, $\mathcal{L} = 682.6$ pb^{-1}
- selection:
  - Require 2 tracks and 2 photons
  - $0.47 < M_{\gamma\gamma} < 0.62$ GeV
  - Kinematical fit with η mass constraint



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

$P_T^2 < 0.02$ GeV^2 (*):



- No $f_1(1285)$ signal at $Q^2 \simeq 0 \Longrightarrow$ spin-1 state
- absence of $\eta(1440)$ or $\eta(1295)$ signal:

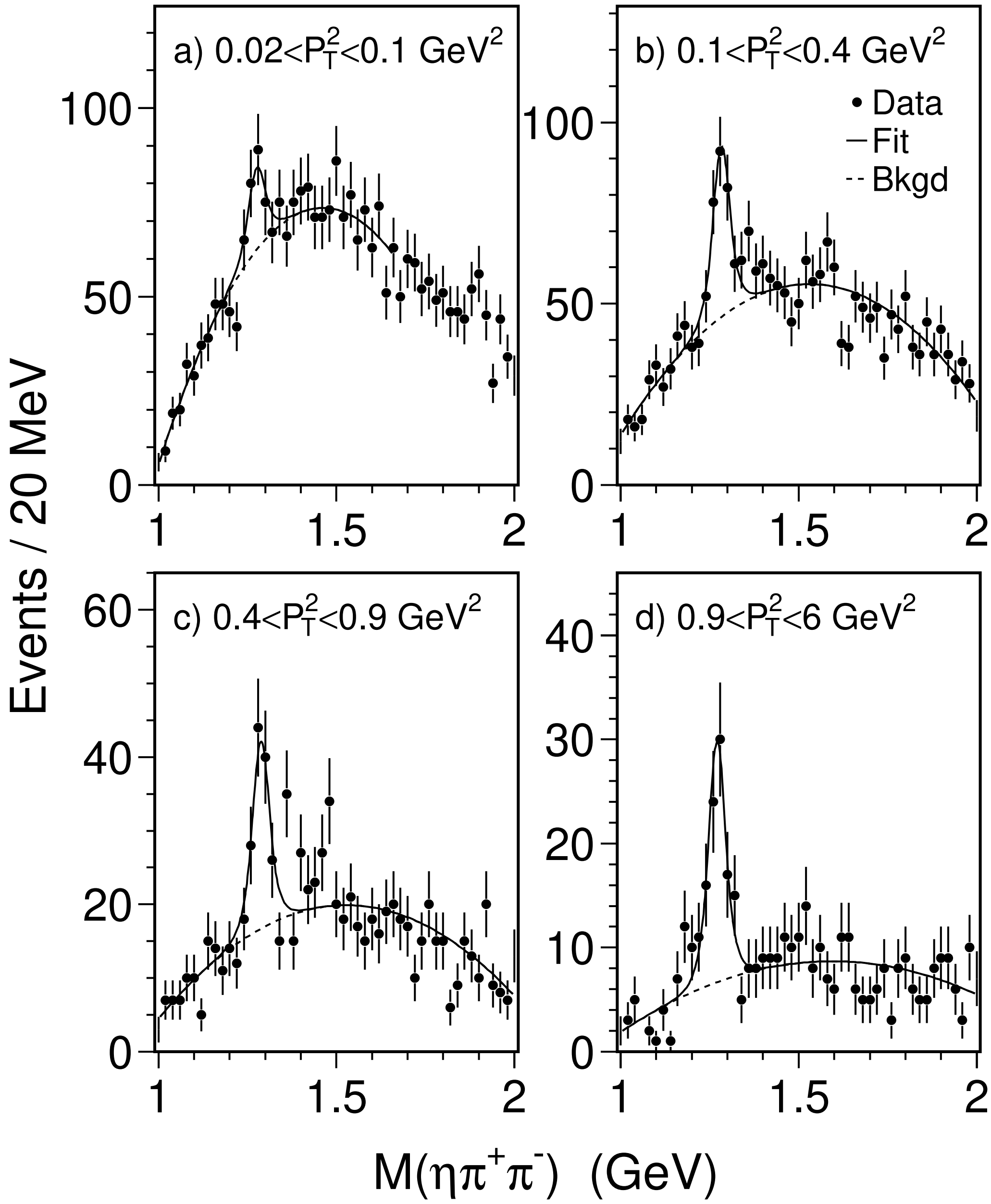
$$\Gamma_{\gamma\gamma}(\eta(1440)) \times BR(\eta(1440) \to \eta\pi\pi) \;<\; 95 \text{ eV } (95\% \text{ CL})$$
$$\Gamma_{\gamma\gamma}(\eta(1295)) \times BR(\eta(1295) \to \eta\pi\pi) \;<\; 66 \text{ eV } (95\% \text{ CL})$$

(*): Physics Letters B 501 (2001) 1-11

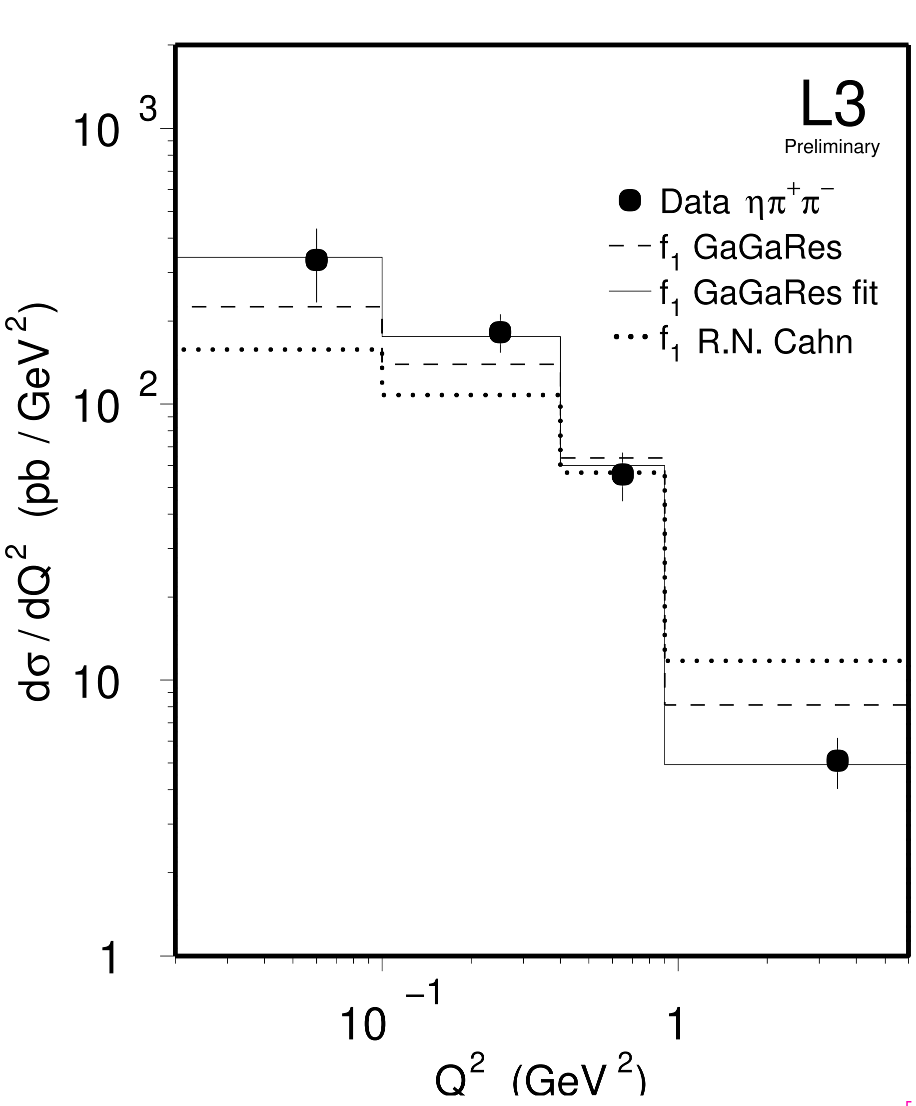
$\eta\pi^+\pi^-$ final state

$P_T^2 > 0.02$ GeV^2:

P_T^2 [GeV^2]	N_{events}	M [MeV]
$0.02 - 0.1$	72 ± 21	1276 ± 8
$0.1 - 0.4$	155 ± 21	1283 ± 4
$0.4 - 0.9$	84 ± 14	1288 ± 5
$0.9 - 6.0$	77 ± 11	1271 ± 5



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



- Formation of axial vector meson:

$$\sigma_{\gamma\gamma\to R} \propto \frac{\tilde{\Gamma}_{\gamma\gamma}}{M}\left(1+\frac{Q^2}{M^2}\right)\tilde{F}^2(Q^2) \quad [1]$$

$$\tilde{\Gamma}_{\gamma\gamma} = \lim_{Q^2\to 0}\frac{M^2}{Q^2}\Gamma^{TS}_{\gamma\gamma} \quad [2]$$

$$\tilde{F}(Q^2) = \frac{Q^2}{M^2}\left(1+\frac{Q^2}{2M^2}\right)\frac{2}{(1+Q^2/\Lambda^2)^4} \quad [3]$$

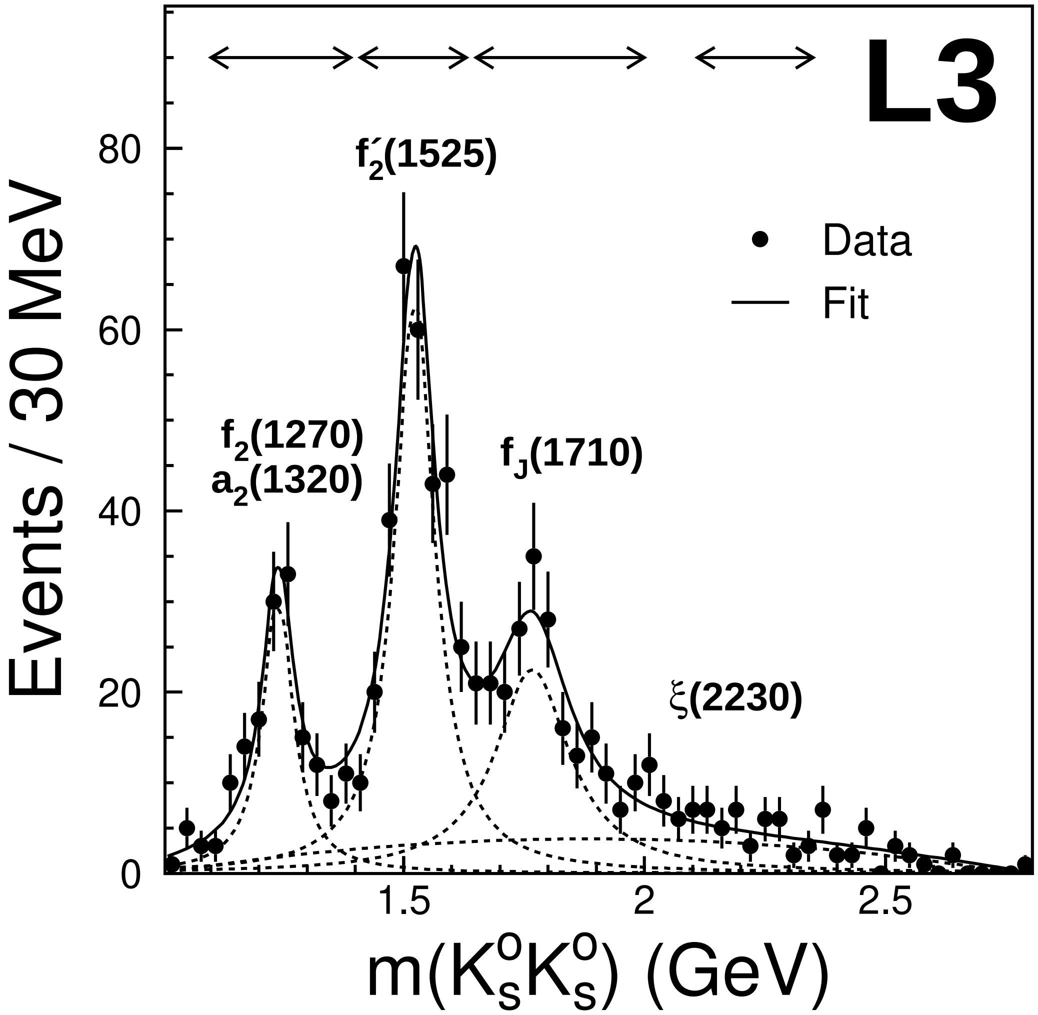
- fit GaGaRes [4] prediction to data:

$$\Lambda = 1105 \pm 74 \text{ MeV}$$
$$\tilde{\Gamma}_{\gamma\gamma} = 3.2 \pm 0.2 \pm 1.0 \text{ keV}$$
$$\text{C.L.} = 89\%$$

- form factor Cahn [5] $\Longrightarrow$ C.L. $< 10^{-9}$

[1] G.A. Schuler *et al.*, Nucl. Phys. B 523 (1998) 423
[2] H. Aihara *et al.*, Phys. Let. B 209(1988) 107; Phys. Rev. D 38 (1988) 1
[3] Brodsky and Lepage, Phys.Rev.D22 (1980) 2157; Phys. Rev.D 24 (1981) 1808
[4] R. van Gulik, Nucl. Phys. B 82 (2000) 311
[5] R.N. Cahn, Phys. Rev. D35 (1987) 3342; Phys. Rev. D37 (1988) 883

- Physics Letters B 501 (2001) 173-182
  $\sqrt{s} = 91 - 202$ GeV, $\mathcal{L} = 588$ pb^{-1}
- $K_S^0 \to \pi^+\pi^-$ at secondary vertex



- destructive $f_2 - a_2$ interference
- clear $f_2'(1525)$ signal
- enhancement in 1750 MeV region
- no signal in $\xi(2230)$ tensor glueball candidate region

1525 MeV region:

	J = 0	J = 2, $\lambda = 2$	J = 2, $\lambda = 0$
C.L.	$< 10^{-6}$	99.9%	$< 10^{-6}$

$\Longrightarrow$ Dominated by helicity 2

$$\Gamma_{\gamma\gamma}(f_2'(1525)) \times BR(f_2' \to \mathrm{K\bar{K}}) = 76 \pm 6(stat) \pm 11(syst)\ \mathrm{eV}$$

1750 MeV region:

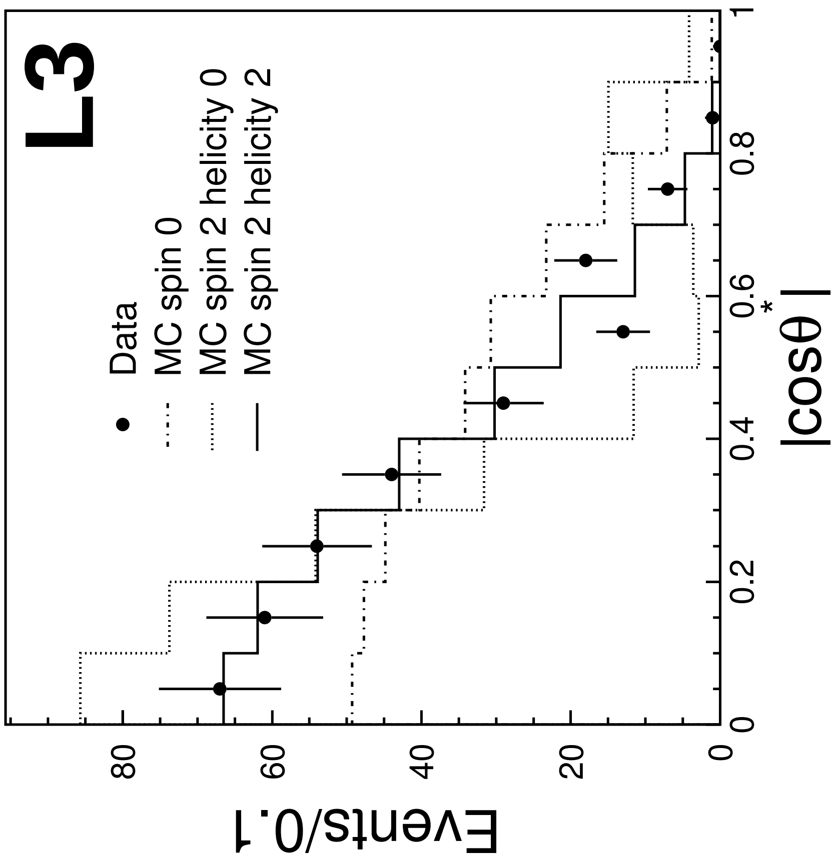
- contamination $f_2'(1525)$ in 1750 MeV region is 14%
- assumption of pure $(J = 2, \lambda = 2) \Longrightarrow$ C.L. = 24%
- including a $(J = 0)$ fraction of $24 \pm 16\% \Longrightarrow$ C.L. = 68%

$$\Gamma_{\gamma\gamma}(f_2(1750)) \times BR(f_2 \to \mathrm{K\bar{K}}) = 49 \pm 11(stat) \pm 13(syst)\ \mathrm{eV}$$

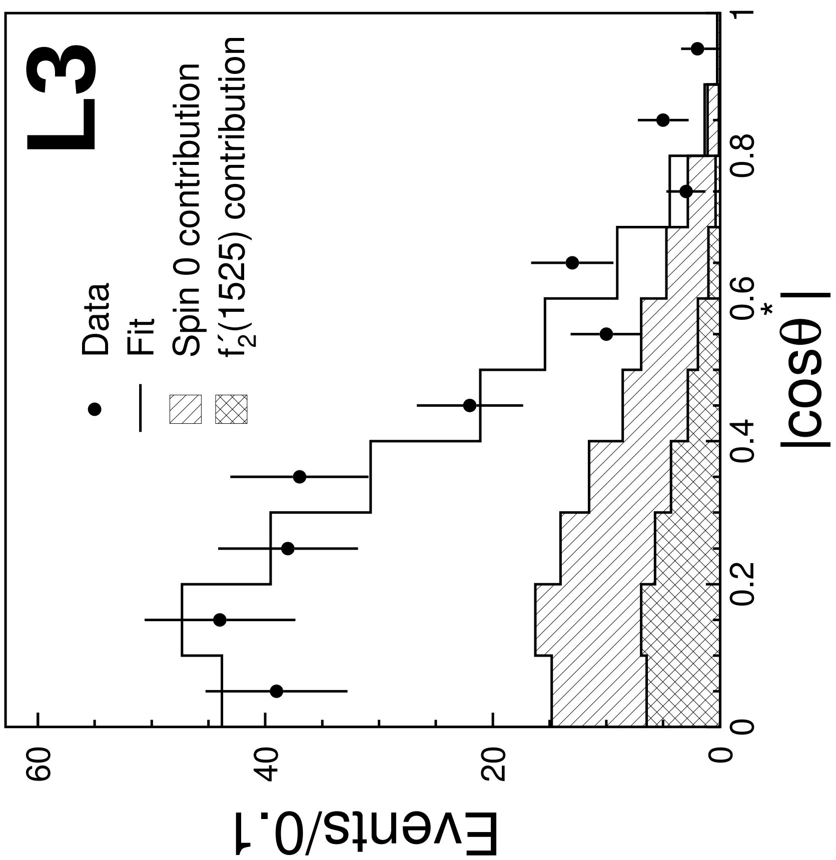
- both waves seen by BES Collaboration
  $(J = 0)$ fraction of $30 \pm 10\%$
  (Bai *et al.*, Phys. Rev. Lett. 77 (1996) 3959)
- 2^{++}: radial excitation? $f_2''(1740)$
  (OGE-SRM model; Münz, Nucl. Phys. A609 (1996) 364)
- 0^{++}: $s\bar{s}$ state?
  (glueball nature $f_0(1500)$; Amsler and Close, Phys. Rev. D53 (1996) 295)

$K_S^0 K_S^0$ **final state**

1525 MeV region:



1750 MeV region:



Glueballs

- Gluonium: bound state of gluons
- No direct coupling to photons $\Longrightarrow$ $\Gamma_{\gamma\gamma}(G)$ small
- Stickiness $\Longrightarrow$ expected to be large for gluon rich state

$$\frac{|\langle R|gg\rangle|^2}{|\langle R|\gamma\gamma\rangle|^2} \sim S_R \;=\; N_l \left(\frac{m_R}{K_{\mathrm{J}/\psi\to\gamma\mathrm{R}}}\right)^{2l+1} \frac{\Gamma(\mathrm{J}/\psi \to \gamma\mathrm{R})}{\Gamma(R \to \gamma\gamma)}$$

N_l: normalised such that $S_\eta = 1$

- Gluiness $\Longrightarrow$ expected to be near unity for $q\bar{q}$

$$G \;=\; \frac{9e_q^4}{2}\left(\frac{\alpha}{\alpha_s}\right)^2 \frac{\Gamma(R \to gg)}{\Gamma(R \to \gamma\gamma)}$$

$\xi(2230)$

$\mathrm{K}^0_S\mathrm{K}^0_S$: $\Gamma_{\gamma\gamma}(\xi(2230)) \times BR(\xi \to \mathrm{K}^0_S\mathrm{K}^0_S) < 1.4$ eV (95% C.L.)

$S_{\xi(2230)} > 74$ (95% C.L.)

$\Longrightarrow$ supports interpretation as tensor glueball

Lattice QCD prediction for 2^{++}: 2220 ± 200 MeV

$\eta(1440)$

$\mathrm{K}^0\mathrm{K}^\pm\pi^\mp$: $S_{\eta(1440)} = 79 \pm 26$

$G_{\eta(1440)} = 41 \pm 14$

$\eta\pi^+\pi^-$: $S_{\eta(1440)} > 87$ (95% C.L.)

$G_{\eta(1440)} > 45$ (95% C.L.)

$\Longrightarrow$ Strong gluon admixture

Lattice QCD predicts pseudo scalar gluonium only at ~ 2 GeV

Conclusions and Outlook

- Extensive study of meson resonances at L3
- Improved measurements of $\gamma\gamma$ widths
- Improved description of Q^2 dependence
- Test for glueball candidates

$\Longrightarrow$ $\gamma\gamma$ collisions can help to clarify the complex region of low mass resonances

- The full LEP data sample will be included to improve the measurements