The observation of the second nonet of tensor mesons with the L3 Experiment

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1. **Introduction**
2. **Analysis of the** $\gamma\gamma \to \pi^+\pi^-\pi^0$ **data**
3. **Analysis of the** $\gamma\gamma \to K_s K_s$ **reaction**
4. **Second nonet of tensor mesons**

1 Inroduction

The L3 detector is universal set up to detect particles with momentum up to 100 GeV on Large Electron Collider of CERN. Colliding electron beams each with 100 GeV momentum are very powerful source of 'colliding quasi-real photons '. These photons then can produce hadronic final states with an effective mass of several GeV. Typical energy of hadrons is 1 GeV and less. Very good central tracker and BGO electromagnetic calorimeter of L3 provide excelent measurements even at so low energies. Unique trigger is based on the central tracker information. High energy electrons (the source of photons) are not detected (in beam pipe). Two-photon interaction is very interesting tool for hadronic resonances identifications : resonance R produced should have positive C-parity; G-parity and resonance isospin I are not independent: $G = Ce^{i\pi I}$. $q\bar{q}$-states with positive G-parity may have only I=0. Meson molecules and glueballs production are strongly supressed.

Quark systematics of tensor states

From three quarks u, d and s the following meson eigenstates can be constructed:

$$K^0 = d\bar{s} \qquad K^+ = u\bar{s}$$

$$\pi^- = d\bar{u} \qquad \pi^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d}) \qquad \pi^+ = u\bar{d}$$

$$K^- = s\bar{u} \qquad \bar{K}^0 = s\bar{d}$$

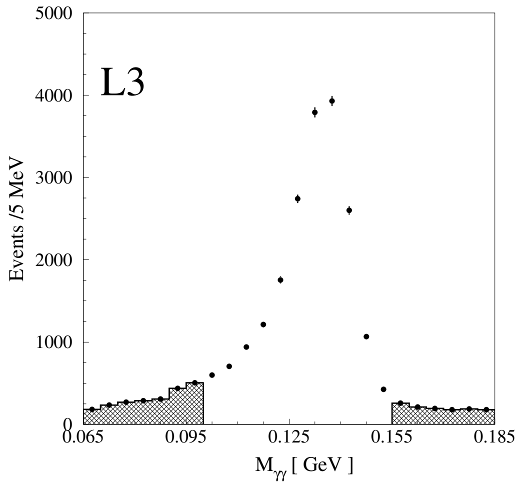
$$\eta_8 = \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s}) \qquad \eta_1 = \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} + s\bar{s})$$

$$\begin{aligned} \eta &= \eta_8 \cos\phi + \eta_1 \sin\phi \\ \eta' &= -\eta_8 \sin\phi + \eta_1 \cos\phi \end{aligned}$$

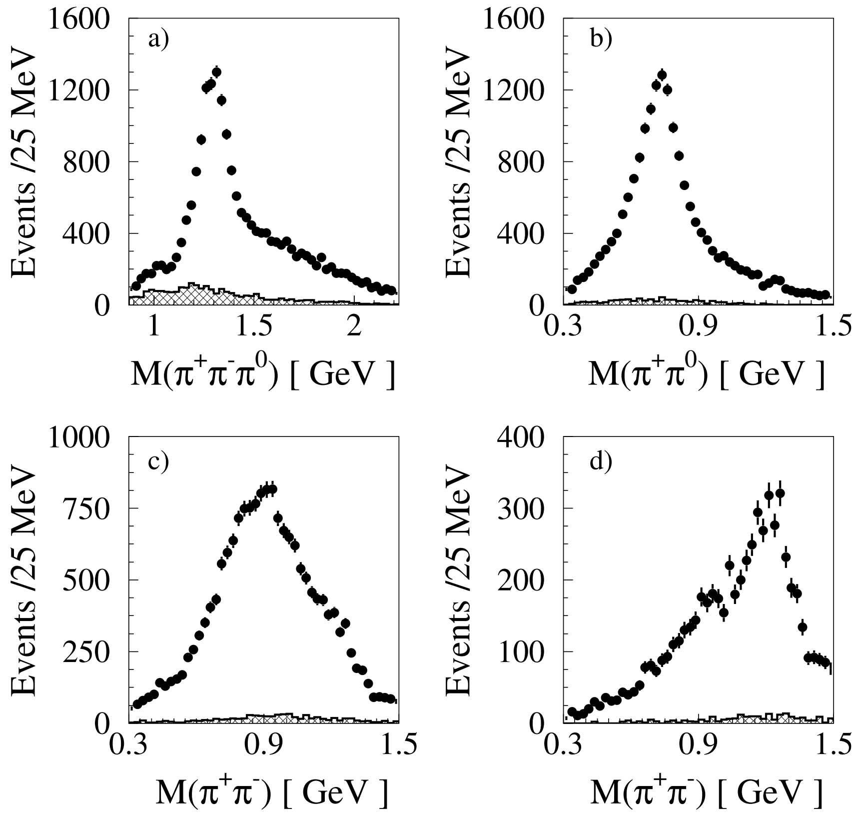
Analysis of the L3 data on reaction $\gamma\gamma \to \pi^+\pi^-\pi^0$

The two-photon reaction $e^+e^- \to e^+e^-\pi^+\pi^-\pi^0$ selection requires in the final state two charged particles and two gammas with an effective mass close to π^0 mass.

Effective mass of two candidate photons.The side bands of the π^0, used to evaluate the background, are indicated as shaded areas, with mass resolution of 8 MeV.



Mass spectra with cuts $P_t < 0.1$ GeV and $P_t^c > 0.05$ GeV , a) $M(\pi^+\pi^-\pi^0)$; b) $M(\pi^\pm\pi^0)$; c) $M(\pi^+\pi^-)$; d) $M(\pi^+\pi^-)$ with 3 pion mass higher than 1.5 GeV; The background estimated from the side bands of the π^0 is shown as a shaded area.



$\gamma\gamma$ channel couples only to states with C=+1 parity. 3π has a negative G-parity. For a $q\bar{q}$ system $G = Ce^{i\pi I}$:

1. **Only $I = 1$ $q\bar{q}$ states are produced in $\gamma\gamma$ channel.**

2. **Only f-states, $J^{PC} = 0^{++}$, 2^{++}, 4^{++}... are produced in the $\pi^+\pi^-$ channel.**

3. **Only ρ-states $1^{--}, 3^{--}$ mesons are produced in $\pi^{\pm}\pi^0$ channel.**

Partial Wave Analysis (PWA)

The amplitude for the two photon interaction:

$$A = \sum_i \epsilon_\mu^{(1)} \epsilon_\nu^{(2)} A^i_{\mu\nu}.$$

Here index i describes three possible spin states ($S = 0, 2$).

$$\begin{aligned} |A|^2 &= \frac{1}{4} \sum_{ij} \sum_{kl} \epsilon_\mu^{(1)}(k) \epsilon_\nu^{(2)}(l) A^i_{\mu\nu} \epsilon_\xi^{(1)}(k) \epsilon_\tau^{(2)}(l) A^{j*}_{\xi\tau} = \\ & \frac{1}{4} \sum_i g^{\perp\perp}_{\mu\xi} g^{\perp\perp}_{\nu\tau} A^i_{\mu\nu} A^{i*}_{\xi\tau}, \end{aligned}$$

where

$$g^{\perp\perp}_{\alpha\beta} = g_{\alpha\beta} - \frac{q_\alpha q_\beta}{q^2} - \frac{P_\alpha P_\beta}{P^2}.$$

and q is the relative momentum of two photons.

Fit of the data

From the four-vectors of each event, j, a likelihood function is constructed as:

$$L = \frac{1}{\sigma_{tot}} \prod_j \frac{d\sigma_j}{d\Phi} = \frac{1}{\sum_n^{MC} d\sigma_n} \prod_j \frac{d\sigma_j}{d\Phi}$$

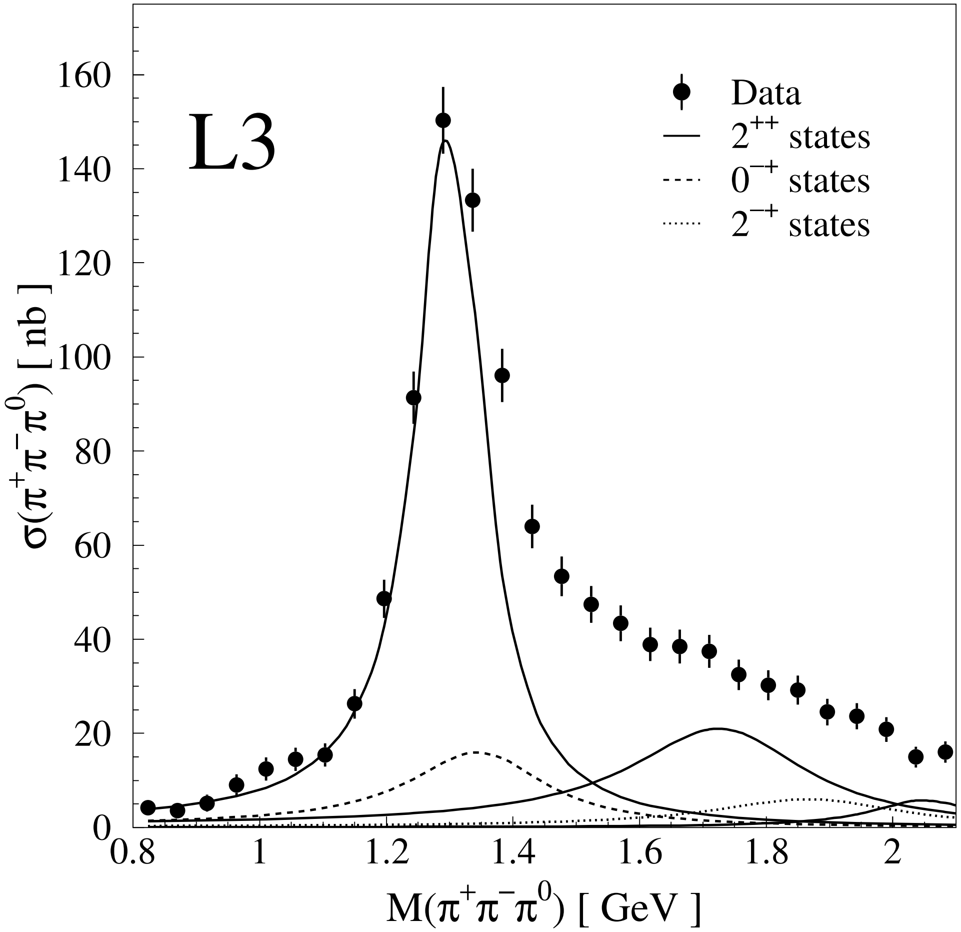
where σ_{tot} is the integrated cross section over the available phase space, calculated as the sum of all the Monte Carlo events that passed the detector acceptance and the selection cuts. The parameters of the different states are: the pole mass, the couplings and the width of the resonances R as well as the parameters of the polynomial background are fitted to minimize the function $-ln\ L$.

Table 1: Masses, widths and production of the $\Gamma_{\gamma\gamma}$ partial width and the branching ratio into 3π for the observed resonances.

Resonance	**M (MeV)**	Γ**(MeV)**	$\Gamma_{\gamma\gamma} Br(3\pi)(KeV)$
$a_2(1320)$	$1300 \pm 2 \pm 4$	$126 \pm 6 \pm 20$	$0.65 \pm 0.02 \pm 0.02$
$a_2(1700)$	$1722 \pm 9 \pm 15$	$340 \pm 20 \pm 20$	$0.37^{+0.12}_{-0.08} \pm 0.10$
$a_2(2030)$	$2050 \pm 10 \pm 10$	$200 \pm 22 \pm 30$	$0.11 \pm 0.04 \pm 0.05$
$\pi(1300)$	1350 ± 40	320 ± 50	≤ 0.8
2^{-+}	$1860 \pm 12 \pm 10$	$360 \pm 30 \pm 40$	$0.15 \pm 0.03 \pm 0.05$
$\pi_2(1670)^*$	1670	260	≤ 0.1

* **- results of the fit with the 2^{-+} signal fixed as $\pi_2(1670)$ with values taken from PDG.**

The contribution of different resonances into cross section: black - 2^{++} states, red - 0^{-+} state and blue 2^{-+} states



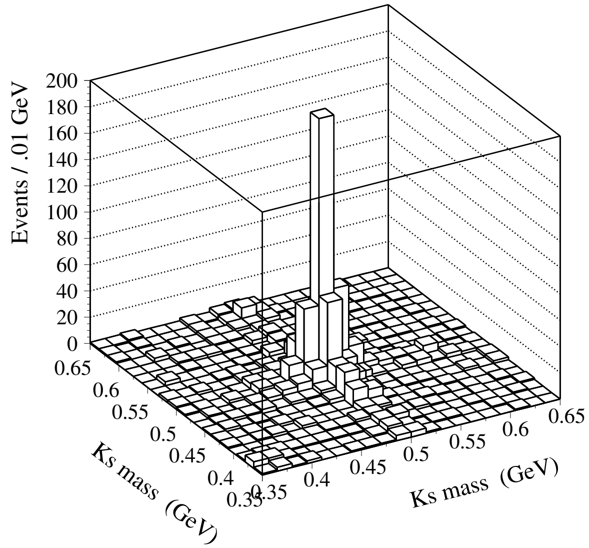
Analysis of the L3 data on the reaction $\gamma\gamma \to K_s K_s$

The selection of $\gamma\gamma \to K_s K_s$ events is based on the K_s decay to $\pi^+\pi^-$.

The following criteria are used :

- **There must be exactly four charged tracks with a zero total charge; not more than 2 tracks from the primary vertex**
- **Events with photons are rejected.**

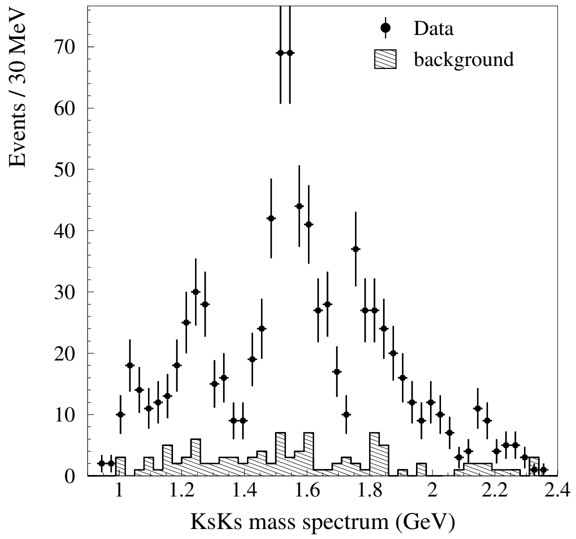
The K_s are identified by the secondary vertex reconstruction. The K_s mass resolution $\sigma = 9.5 \pm .2$ MeV is observed. The distribution of the mass of one K_s candidate versus the mass of the other candidate.



We require that the reconstructed masses of two K_s candidates must be inside a circle of 40 MeV radius centered at the peak of the K_s signal. Events inside a ring of the same surface outside the circle are used as an estimate of the background in the accepted events sample.

With these selection criteria 870 events are found. The background due to misidentified K_s pairs is estimated to be less than 10%.

The K_s mass spectrum of selected events with the mass spectrum of the background estimated as mentioned above.



Only $J^{PC} = (2n)^{++}, \quad n = 0, 1, 2, \ldots$ states decay into $K_s K_s$ system.

For quasi-real photons only one combination of spin and angular momentum operators forms 0^{++} state: ${}^{2s+1}L_J = {}^1S_0$. The 2^{++} partial wave can be produced from 2 $\gamma\gamma$ states: ${}^1D_2$ and ${}^5S_2$. A 4^{++} state is from ${}^1G_4$ and ${}^5D_4$.

For nonpolarised case only the following amplitudes interfere:

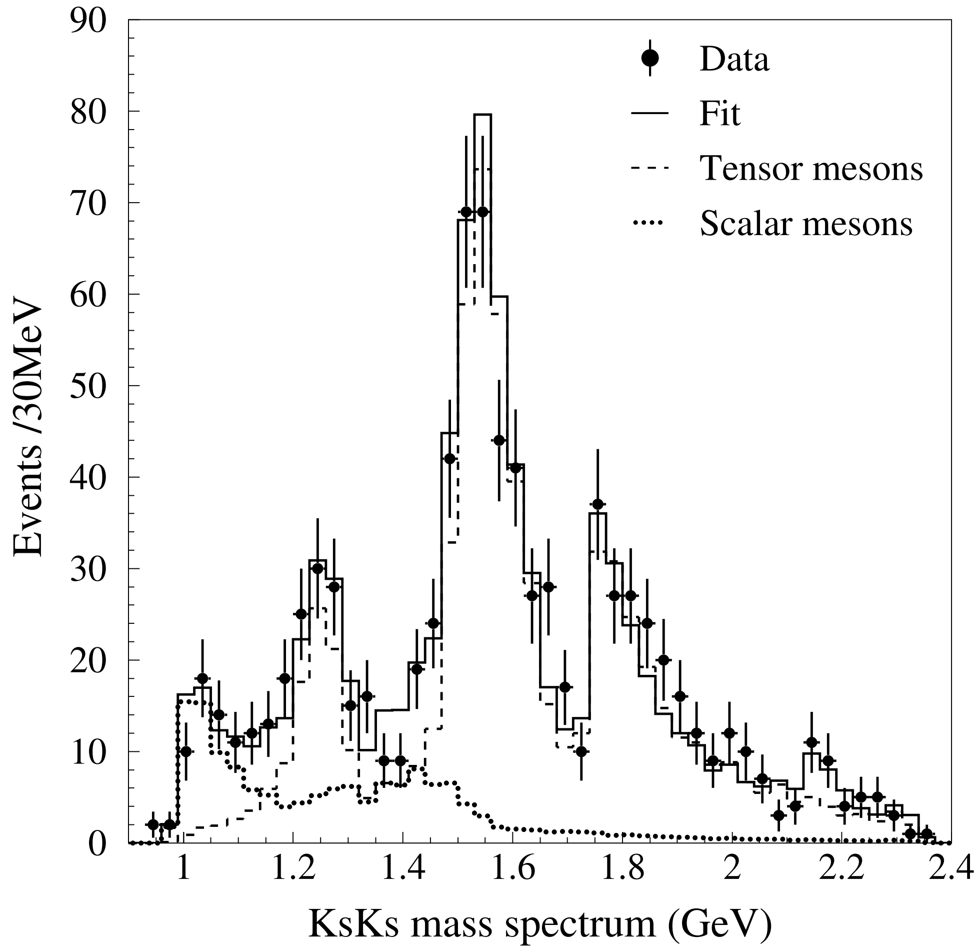
$$
\begin{array}{ccc}
{}^1S_0, & {}^1D_2, & {}^1G_4 \\
 & {}^5S_2, & {}^5D_4
\end{array}
$$

Prediction from quark diagram calculations:

$$\sigma({}^5S_2) \sim 6\sigma({}^1D_2)$$

Thus 0^{++} and 2^{++} interfere only very weakly.

The description of the $\gamma\gamma$ spectrum. Dashed line shows the contribution of tensor states and dotted line the contribution of scalar states.

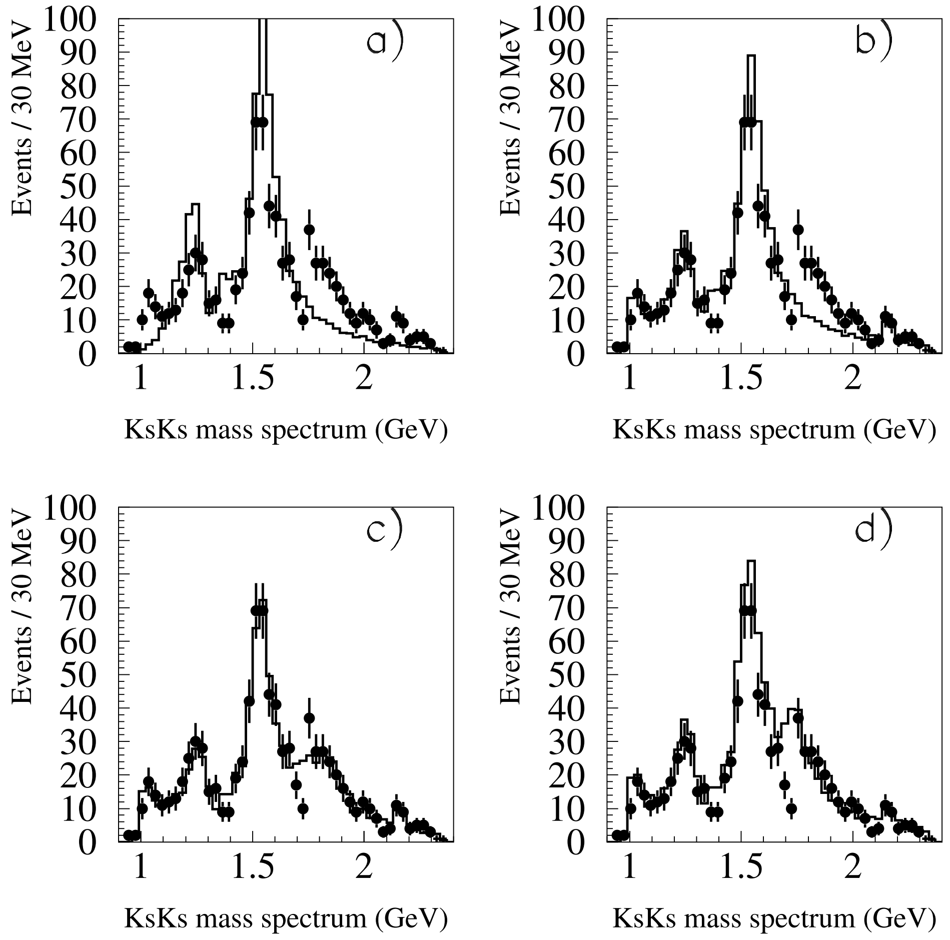


a) the description of the data with the first tensor nonet,

b) the same as (a) + scalar states + 4^{++} state,

c) (b) + a scalar state with free parameterts ,

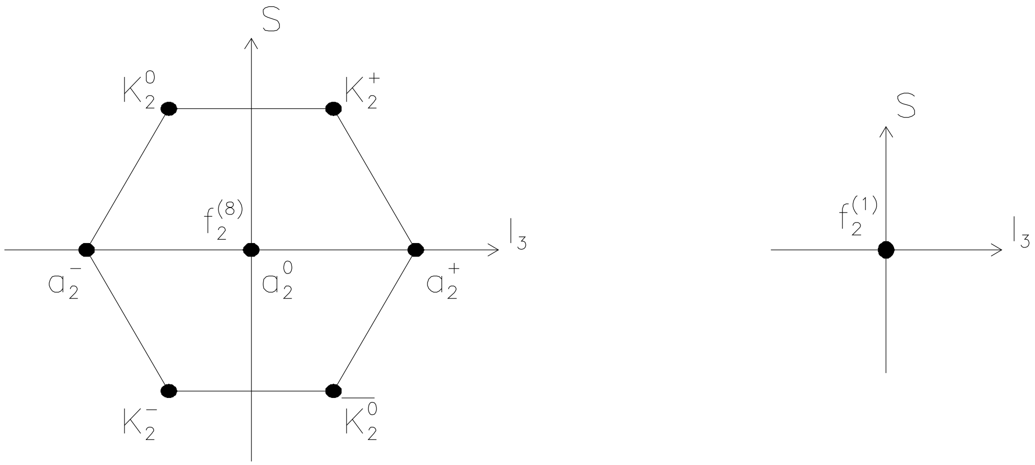
d) (b) + $f_0(1710)$ state with parameters fixed from the latest BES results.



2 Tensor-meson nonets

Tensor particles, ground states

$J^{PC} = 2^{++}$:



$f_2(1275)$ $f_2'(1525)$ $a_2(1320)$ $K_2(1430)$

Nonet of the first radial excitations of tensor states:

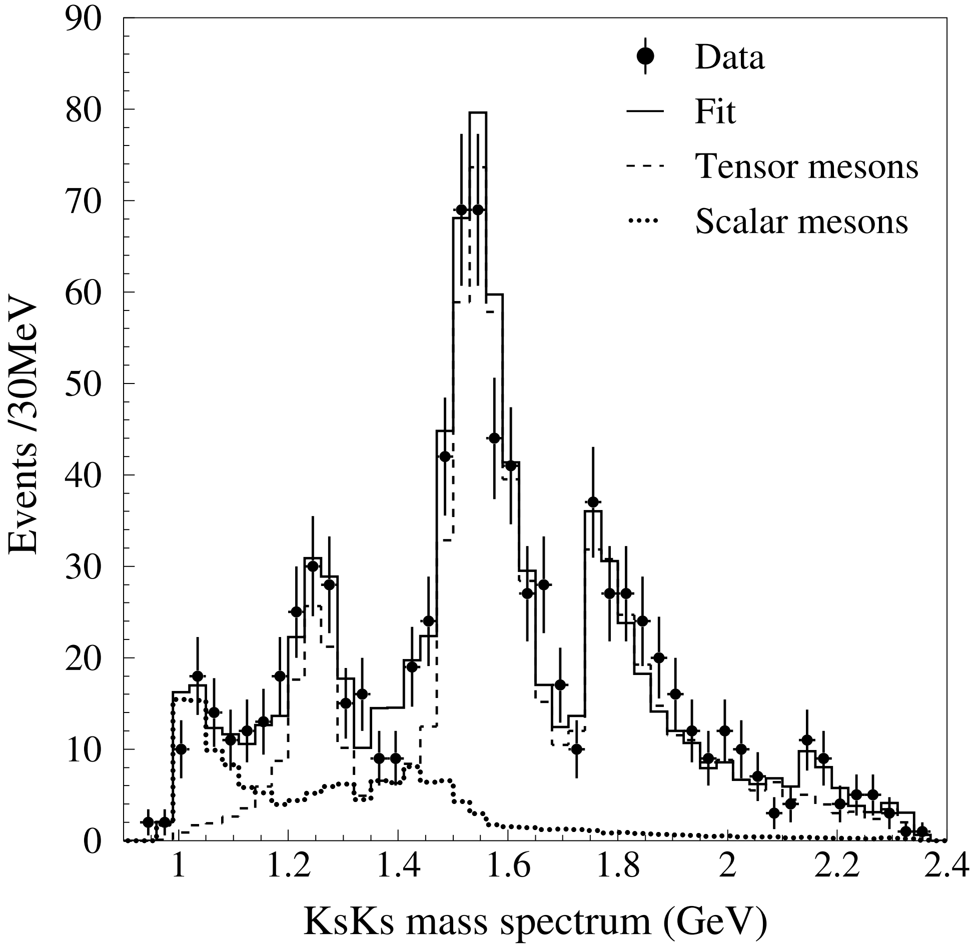
$f_2(1560)$ $a_2(1700)$ $f_2(1750)$ $K_2(1980)$

Coupling constants, mixing angles and decay widths for tensor nonets calculated from $SU(3)$ based fit. Values with star were fixed from another data.

	First nonet			Second nonet		
	$a_2(1320)$	$f_2(1270)$	$f_2'(1525)$	$a_2(1700)$	$f_2(1560)$	$f_2(1750)$
Mass (MeV)	1304 ± 10	1277 ± 6	1523 ± 5	1730^*	1570^*	1755 ± 10
Width (MeV)	120 ± 15	195 ± 15	104 ± 10	340^*	160^*	67 ± 12
$K\bar{K}$ **width (MeV)**	$7.0^{+2.0}_{-1.5}$ (7.0 ± 0.6)	7.5 ± 2 (8.5 ± 0.8)	68^*	5 ± 3	2 ± 1	17 ± 5

g (MeV)	0.95 ± 0.08			0.38 ± 0.05		
Φ (deg)	-1 ± 3			-10^{+5}_{-10}		
$\Gamma(\gamma\gamma)$ (KeV)	0.91^*	2.55 ± 0.15 (2.60 ± 0.2)	0.13 ± 0.03	0.30 ± 0.05	0.70 ± 0.14	0.13 ± 0.04
$\Gamma(\pi\pi)$ (MeV)		152 ± 8 (157 ± 4)	$0.2^{+1.0}_{-0.2}$ (0.8 ± 0.4)		25^*	1.3 ± 1.0
$\Gamma(\pi\eta)$ (MeV)	18.5 ± 3 (16.1 ± 0.3)			9.5 ± 2		
$\Gamma(\eta\eta)$ (MeV)		1.8 ± 0.4 (0.83 ± 0.2)	5.0 ± 0.8 (7.6 ± 2.5)		1.2 ± 0.3	2.0 ± 0.5

The description of the $\gamma\gamma$ spectrum. Dashed line shows the contribution of tensor states and dotted line shows the contribution of scalar states.



Summary

1. The $a_2(1720)$ state is discovered in the L3 data.

2. The gamma-gamma partial width of tensor resonances are defined with a good accuracy.

3. The newly selected data on $\gamma\gamma \rightarrow K_s K_s$ shows undoubtedly NEW narrow state at 1750 MeV with spin 2.

4. SU(3) based calculations show that this state can be naturally considered as a member of the second tensor nonet.