The observation of new mesons with the L3 Experiment

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1 Introduction

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 excellent 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. Such features are valid only for the 'orthodox' $q\bar{q}$-states. Meson molecules and glueballs production are strongly suppressed.

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.

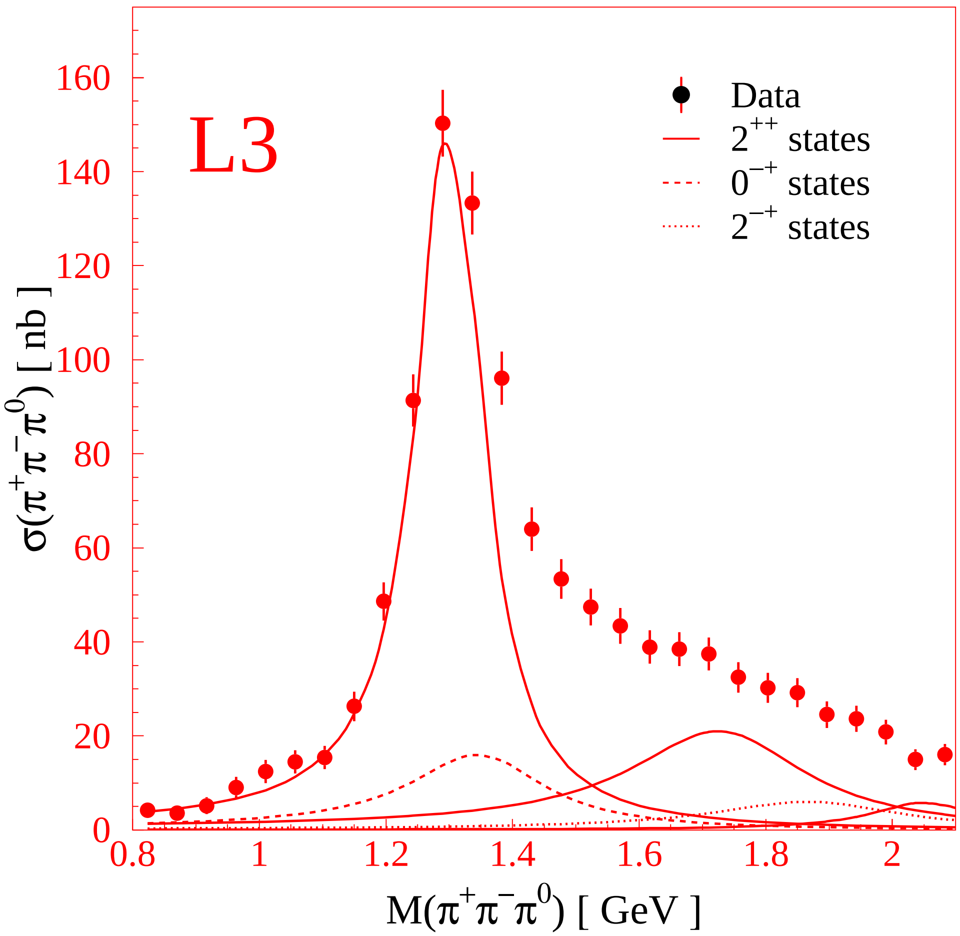
Fit of the data

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

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

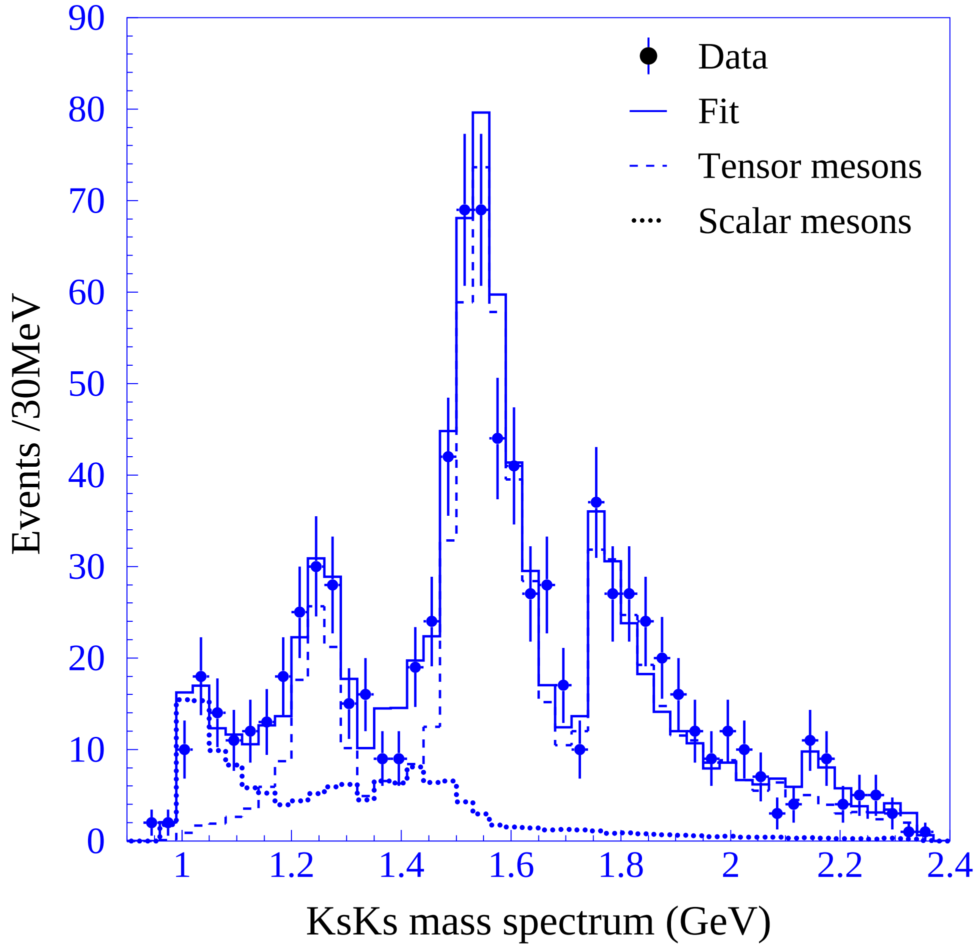
where σ_{tot} is the integrated cross section over the available phase space, calculated as the sum of all the Monte Carlo events that passed the detector acceptance and the selection cuts. The parameters of the different states are: the pole mass, the couplings and the width of the resonances R as well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

Analysis results of the $\gamma\gamma \to \pi^+\pi^-\pi^0$



Analysis results of the $\gamma\gamma \longrightarrow K_s K_s$

Dashed line shows the contribution of tensor states and dotted line the contribution of



scalar states.

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

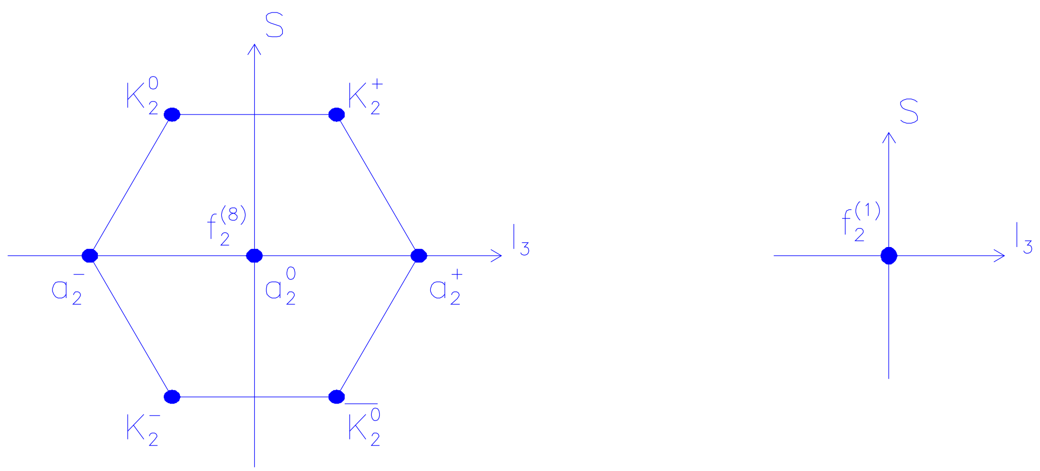
Resonance	**M (MeV)**	Γ**(MeV)**	$\Gamma_{\gamma\gamma}Br(3\pi)(KeV)$
$a_2(1320)$	$1300 \pm 2 \pm 4$	$126 \pm 6 \pm 20$	$0.65 \pm 0.02 \pm 0.02$
$a_2(1700)$	$1722 \pm 9 \pm 15$	$340 \pm 20 \pm 20$	$0.37^{+0.12}_{-0.08} \pm 0.10$
$a_2(2030)$	$2050 \pm 10 \pm 10$	$200 \pm 22 \pm 30$	$0.11 \pm 0.04 \pm 0.05$
$\pi(1300)$	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.**

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:

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

Second Tensor Nonet is now filled up

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

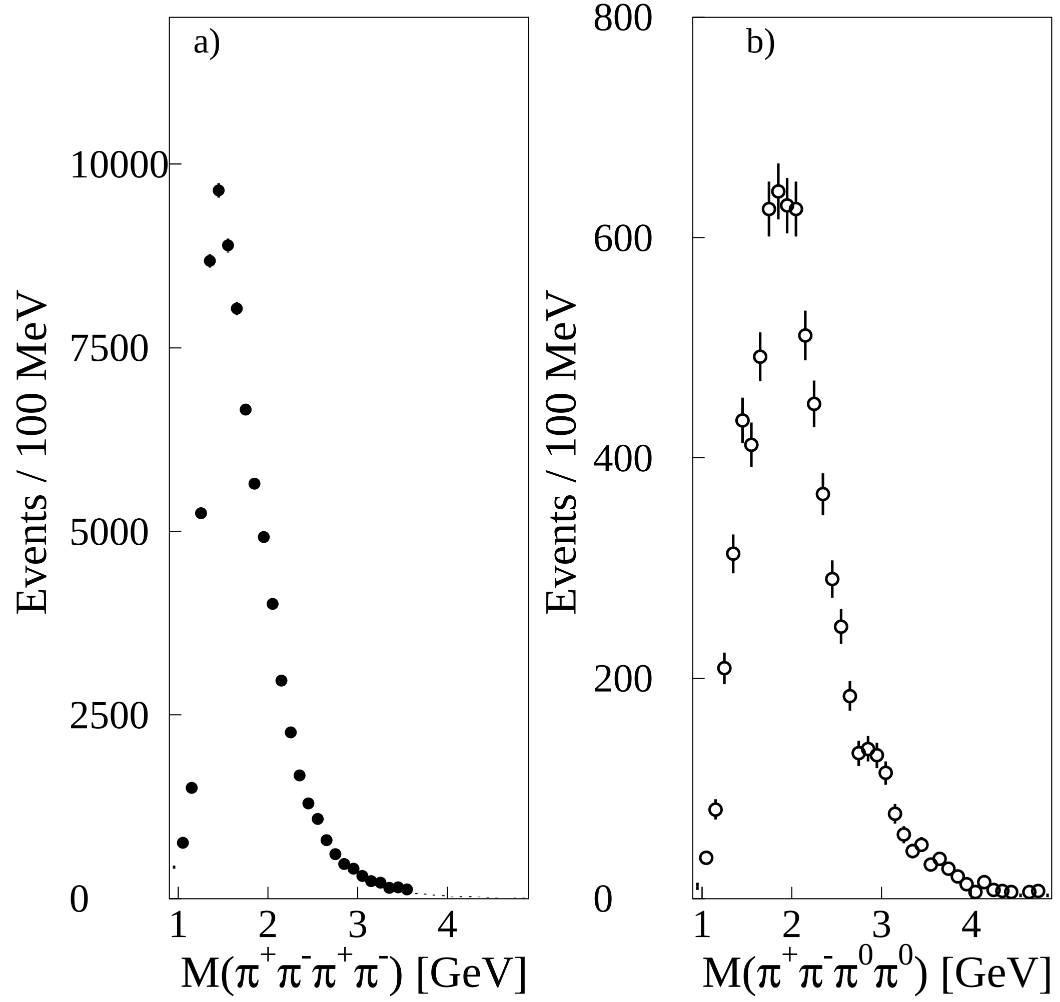
2. NEW narrow state at 1750 MeV with spin 2 is found in the reaction $\gamma\gamma \rightarrow K_s K_s$

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

L3 data on $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$ and $\gamma\gamma \to \pi^+\pi^-\pi^0\pi^0$ reactions

Large event sample of the reactions $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$ (70000 events) and $\gamma\gamma \to \pi^+\pi^-\pi^0\pi^0$ (6400 events) was collected by the L3 experiment. Statistics is 5-10 times higher than in the best previous experiment (ARGUS).

The distribution of the 4 pion mass exhibits resonance behavior. The mass resolution depends weakly on the mass and is 50 MeV and 65 MeV for the reactions $\gamma\gamma \rightarrow \pi^+\pi^-\pi^+\pi^-$ and $\gamma\gamma \rightarrow \pi^+\pi^-\pi^0\pi^0$.



Partial Wave Analysis

Only Partial Wave Analysis (PWA) provides detailed information on the final state subprocesses.

1) The transition $\gamma\gamma$ into:

a) $X(2\pi)X(2\pi)$

b) $Y(3\pi)\pi \to X(2\pi)\pi\pi$

2) All interferences in $\gamma\gamma \to mesons$ cross section are taken into account.

3) We performed a free fit and fits with isotopic relations directly imposed in the combined analysis of two reactions.

In present analysis we included:

In 2π channel: $\rho(770)$, f_0 ($\pi\pi S - wave$), $f_2(1275)$.

In 3π channel: $a_1(1260)$, $\pi(1350)$, $a_2(1320)$

We also investigated: $\rho(1450)$, $a_2(1700)$, $\pi_1(1400)$

Energy independent PWA has been performed first. Difficult to provide the stability of solutions (but possible).

Energy dependent partial wave analysis

There are no clear narrow structures in the $\gamma\gamma$ spectrum for the both reactions. At low energies the contribution of known tensor and scalar resonances $f_2(1270)$, $f_2(1560)$, $f_0(1370)$ and the broad $f_0(1400)$ is require. The high energy region demands a contribution from the states with higher mass. Adding to the fit 2^{-+}, 3^{++} and 4^{++} states although improved the solution did not solve the problem: other tensor or/and scalar states are needed.

The best description were obtained from the introduction of the tensor state with mass around 1800 MeV ,the scalar state around 2050 MeV and the tensor state with mass 2300 GeV and quite a large width about 550 MeV. We obtain significant improvement in the description if at high mass region additional 2^{-+} and 3^{++} states are included.

This is a confirmation of the results obtained in the energy independent partial wave analysis where some additional structures were observed in all partial waves in the region 2.3-2.6 GeV. With this set of the resonances we find very good description of the data when reactions are fitted separately.

There is no doubts that some isospin $I = 2$ contribution is needed to describe the data. Moreover the ratio of the experimental cross section and that predicted from production of the isospin 0 states only has a clear resonance structure at the region 1300-1500 MeV. The isospin 2 contribution can be defined by t(or u)-channel exchanges which naturally contains the isotensor component. In this case an interference with a isoscalar resonance (resonances) can create a resonance like structure. Another explanation is the observation of the isotensor resonance produced in $\gamma\gamma$ collision and decaying into 4π.

The isotensor tensor state indeed solved the problem with combined description of the data. It was found to be with mass 1300 ± 25 MeV and width 325 ± 35 MeV. The isotensor scalar state also had been introduced in the analysis but gave only marginal improvement.

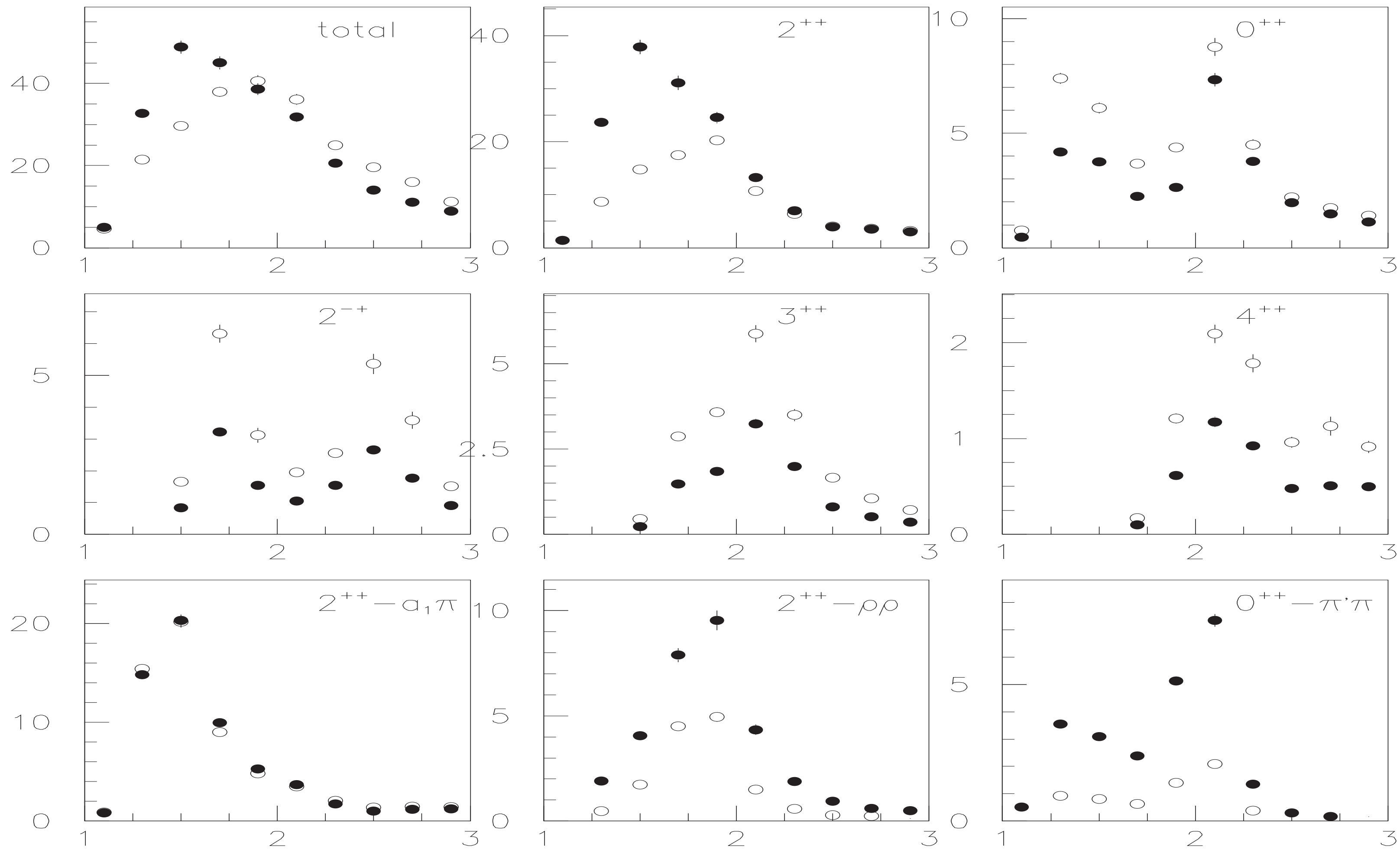


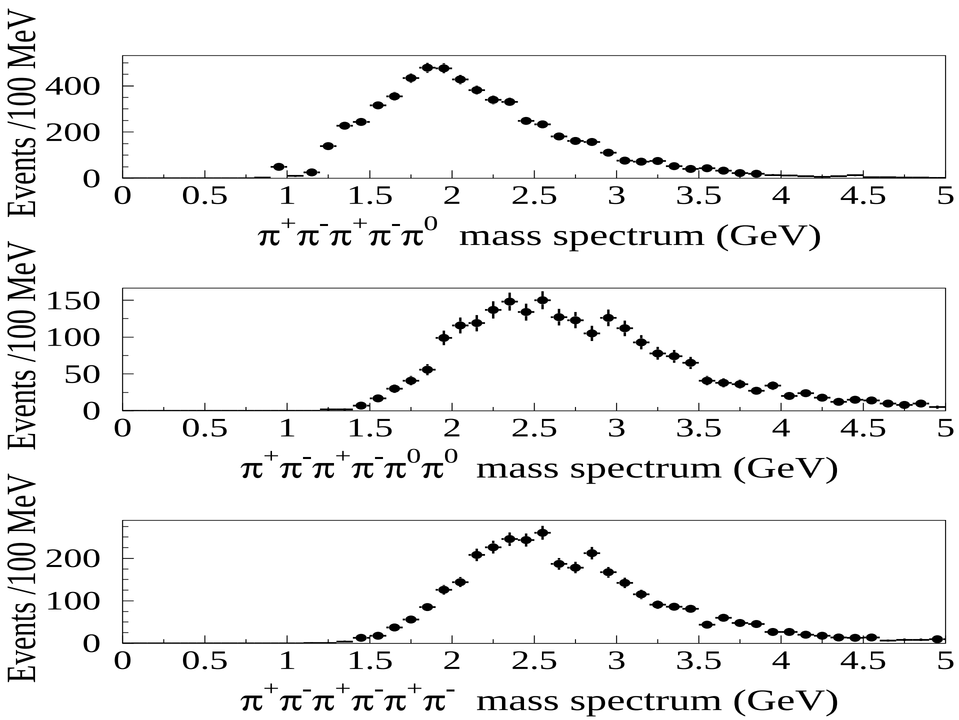
Figure 1: The contribution of the different decay channels to the total cross sections for the reactions $\gamma\gamma \rightarrow \pi^+\pi^-\pi^+\pi^-$ (full circles) and $\gamma\gamma \rightarrow \pi^+\pi^-\pi^+\pi^-0$ (open circles)

$I^G J^{PC}$	Mass (MeV)	Width (MeV)	$\rho\rho$ (%)	$a_1\pi$ (%)	$\pi'\pi$ (%)	$f_0 f_0$ (%)	$a_2\pi$ (%)
0^+0^{++}	1.290	260		12 (20)	6 (5)		
	1.420	700		1 (3)	2 (2)	4 (1)	
	2.045	245	2 (6)	0.5 (1)	6 (8)	2 (1)	
0^+2^{++}	1.275	185		15 (30)		1 (0.5)	1.5 (5)
	1.550	175		3 (7)	1 (2)	1 (0.5)	2.5 (8)
	1.800	330	4 (11)	0.5 (1)		2.5 (1)	
	2.300	550		0.5 (1)	2.5 (5)		0.5 (1.5)
0^+2^{-+}	1.633	195	1 (3)				1.5 (4)
	2.540	290		1 (3)			1 (3)
0^+3^{++}	1.600	180		1 (3)			1.5 (5)
	2.105	400		1.5 (5)			1.5 (5)
0^+4^{++}	1.940	450		1.5 (4)			
2^+2^{++}	1.295	325	4(2)	2 (7)			

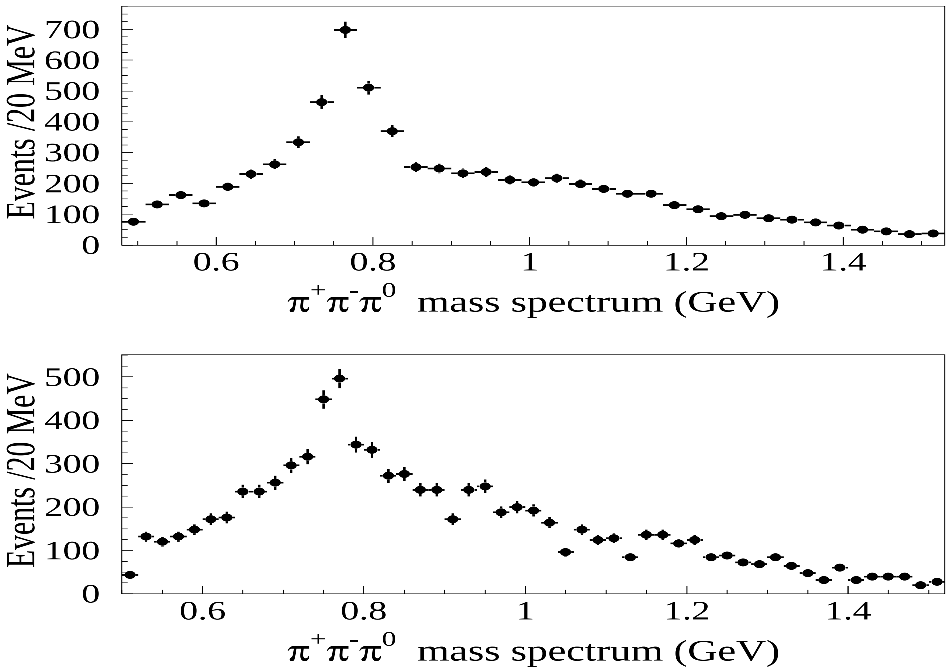
Table 2: Resonances and contributions of the different decay modes to the cross section of $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$. The contribution of the resonance decay modes into $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-0$ reaction is given in parenthesis

3 Multipion final state

Study of exclusive multipion final state is motivated by many reasons, in particular as search high mass resonances, an influence of 4 quarks states ... We have quite a few such kind of events already phenomenologically investigated. One can see some structure at high invariant masses of 6 pions.



It is intersting to see a copious production of $\omega(770)$ in the multipion reactions with π^0



in the final state.

Specific difficulty in the interpretation of a multiparticle state is combinatoric, i.e. it is not easy to demonstrate 'peaks' in the mass spectra. As an example, in the exclusive $\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$ there are 8 possibility to form the ω meson. To determine the cross section of ω production quite sofisticated PWA is needed.

Conclusions

1. The interpretation of I=2 contribution into the cross section of 4 pions production has to be clarified. To-day resonance interpretation looks quite probable. However it is still early to announce 4 quark resonance state.

2. PWA of multipion exclusive states is being planning. The importance of these tasks is not only in the discovery of new resonances . Some models predict ratios of different decay channels for ’exotic’ 4 quarks states.

3. We do have possibilities to determine the formfactors of produced resonances. It looks as an easy job but in my list this task has lowest priority.