Exclusive Production of Hadronic States in $\gamma\gamma$ Collisions with L3

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International Workshop
"e^+e^- Collisions from ϕ to J/ψ"
Novosibirsk, Russia,
1 – 5 March 1999

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Introduction

The Large Electron Positron Collider starts to be a powerful source of high-energy $\gamma\gamma$ collisions. The luminosity of such collisions essentially increased during last years not only because of the e^+e^- c.m. energy rise from 91 GeV (LEP-1) to 190 GeV (LEP-2)

$$\mathcal{L}_{\gamma\gamma} \sim \ln^2\left(\frac{m_V^2}{m_e^2}\cdot\frac{1}{z}\right)\cdot\ln\left(\frac{1}{z}\right) \quad ,$$

$$z = \frac{m_X^2}{4E_e^2} \quad ,$$

but also because of a fantastic improvement of the LEP machine performance with a significant increase of e^+e^- luminosity

$$N(e^+e^- \to e^+e^-X) \sim \mathcal{L}_{e^+e^-}\cdot\mathcal{L}_{\gamma\gamma}\cdot\sigma_{\gamma\gamma}(m_X)$$

Introduction

Delivered luminosity now becomes comparable with the one integrated by DORIS-II storage ring, where the bulk of $\gamma\gamma$-collision data came from ARGUS.

Table 1

LEP program phase	e^+e^- c.m. energy	e^+e^- luminosity	Years
LEP-1	91 GeV	140 pb^{-1}	91 – 95
LEP-2	161 – 162 GeV	20 pb^{-1}	96
	182 – 184 GeV	55 pb^{-1}	97
	190 GeV	180 pb^{-1}	98

Remark: shown in the Table 1 are round numbers. Actually, the luminosity is known with an accuracy better than a percent.

Unfortunately, the detection efficiency of low-mass resonances decreases with the beam energy. Thus, the net gain in the number of events is rather moderate.

Introduction

The resonance production cross-section is determined by

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

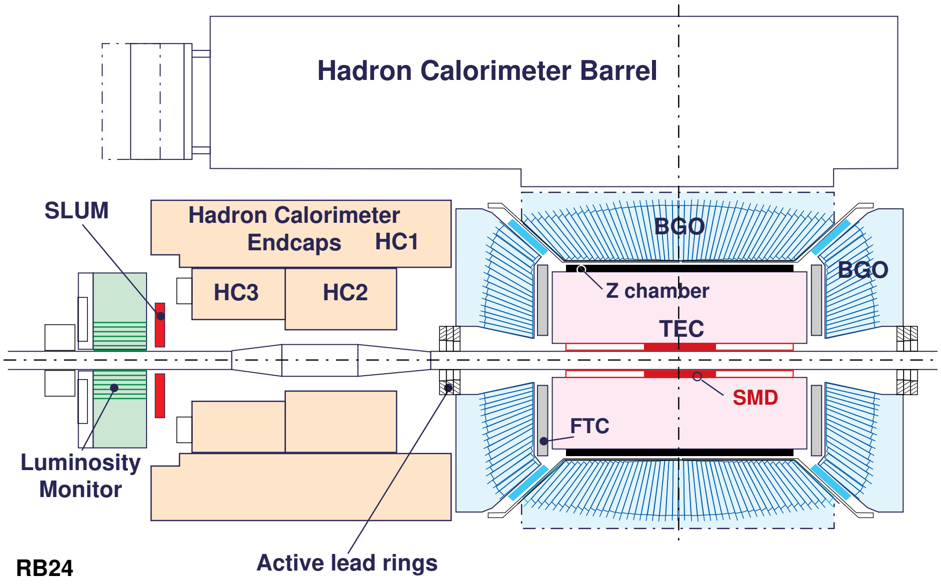
The two-photon width $\Gamma_{\gamma\gamma}$ is proportional to the fourth power of the constituent quark charges, and for this reason is sensitive to the flavour content of a resonance.

Selection of quasi-real photons also determines the resonance spin (0 or 2) and C-parity (positive).

Such features of $\gamma\gamma$ collisions are being used for

1. determination of spin-parity quantum number for the hadronic resonances;
2. understanding of the resonance flavour content;
3. comparison of the measured $\Gamma_{\gamma\gamma}$ with theoretical calculations based on QCD.

L3 Detector



A detailed description of the L3 detector has been published[a]. The most essential for the following presentation detecting elements are:

- Silicon Microvertex Detector (SMD) and Time Expansion Chamber (TEC) to measure the kinematical parameters of charged tracks and dE/dx;
- Electromagnetic calorimeter (EC) made of BGO crystals providing a high accuracy of photons energy measurements (5% at 100 MeV, 1.4% above 2 GeV).

[a] L3 Collaboration, B.Adeva et al., Nucl.Inst.Meth. A289 (1990) 35.

Hadronic Resonances Studied by L3 at LEP-1

Hadronic resonances studied by L3 at LEP-1 are listed in Table 2. Most of these results are published.

Table 2

Resonance	final state	J^{PC}	$\Gamma_{\gamma\gamma}(keV)$
1. $\eta'(958)$	$\pi^+\pi^-\gamma$	0^{-+}	4.17±0.10±0.27
2. $a_2(1320)$	$\pi^+\pi^-\pi^0$	2^{++}	0.98±0.05±0.09
2. $a_2'(1752)$	$\pi^+\pi^-\pi^0$	2^{++}	$0.29^\star$±0.04±0.02
3. $f_2'(1525)$	$K_s^0K_s^0$	2^{++}	$0.085^\star$±0.03
3. X(1770)	$K_s^0K_s^0$	0^{++}	
4. $\eta_c(2980)$	10 chan.	0^{-+}	9.5±2.±2.7
5. $\chi_{c2}(3555)$	$l^+l^-\gamma$	2^{++}	1.02±0.4±0.15±0.09

$^\star\Gamma_{\gamma\gamma} \times BR$

1. Phys.Lett. B418 (1998) 399
2. Phys.Lett. B413 (1997) 147
3. Phys.Lett. B363 (1995) 118 and L3 Note 2285 (June 1998)
4. Phys.Lett. B318 (1993) 575 and L3 Note 2297 (July 1998)
5. CERN-EP/98-184

Some comments can be made on these results:

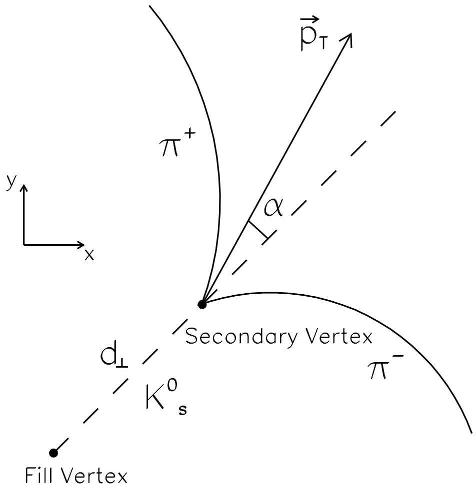
a) as it was expected, resonances with spin 0 or 2 and positive C-parity are copiously produced;
b) with the relatively small accumulated luminosity, charmonium states had a very limited statistics.

The $K_s^0 K_s^0$ Final State (update)

The results presented below are based on the latest analysis of LEP-1 data, with an addition of 52 pb^{-1} of LEP-2 data at $\sqrt{s} = 183$ GeV.

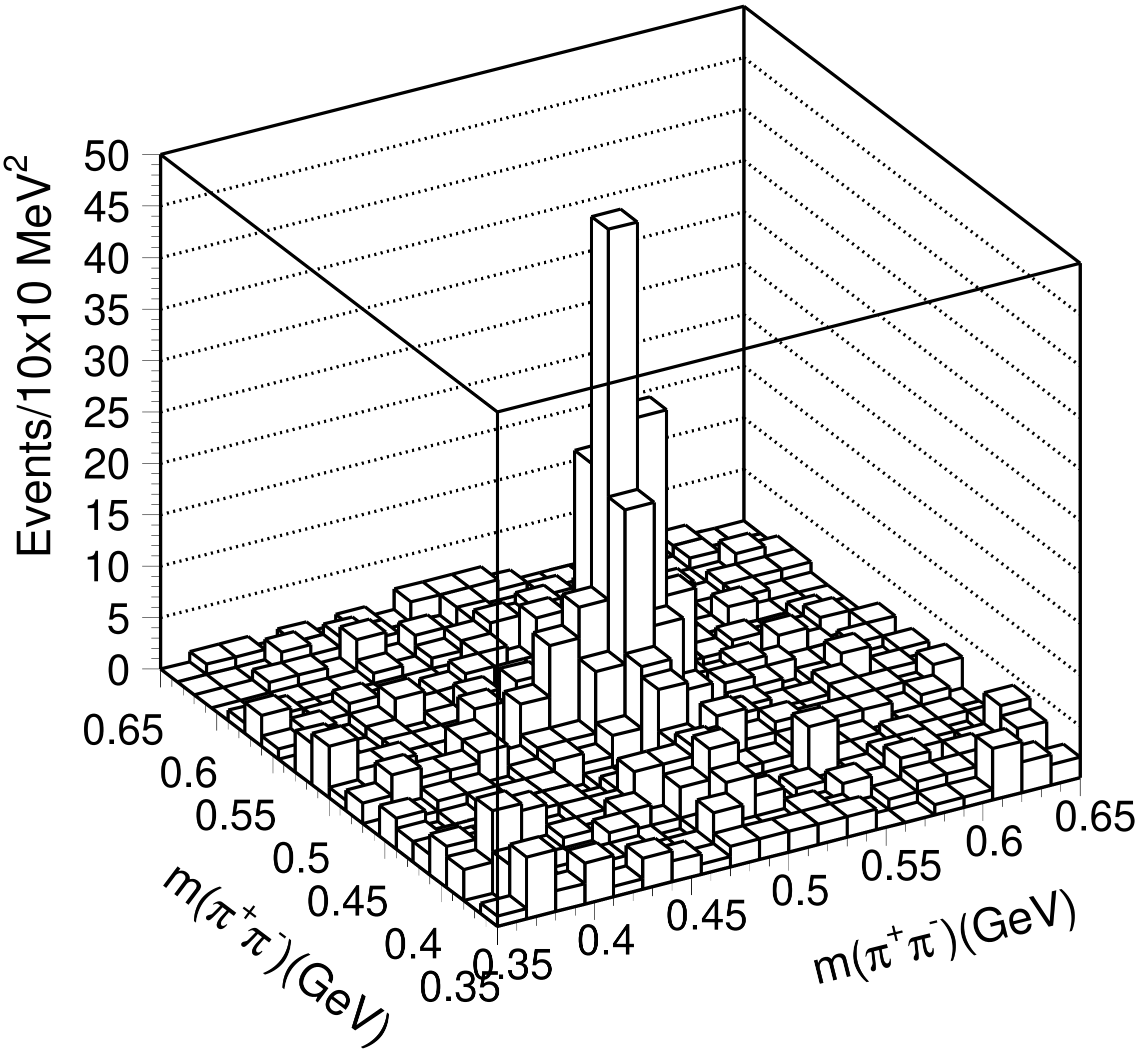
The selection of the $K_s^0 K_s^0$ ($K_s^0 \to \pi^+\pi^-$) final state included several criteria:

1. four charged tracks ($\pi^+\pi^-\pi^+\pi^-$) with the total charge equal to zero and no photons in the final state;
2. there should be 2 secondary vertices with $\pi^+\pi^-$ pairs;
3. secondary vertices should be at least 3 mm away from the fill vertex (in the transverse XY-plane);
4. the angle α between the flight direction of the K_s^0 candidate and the total transverse momentum of the two pions should be less than 0.3 rad.



The $K_s^0 K_s^0$ Final State

After such selection, there is a strong correlation of the two $(\pi^+\pi^-)$ masses corresponding to the K_s^0 mass.

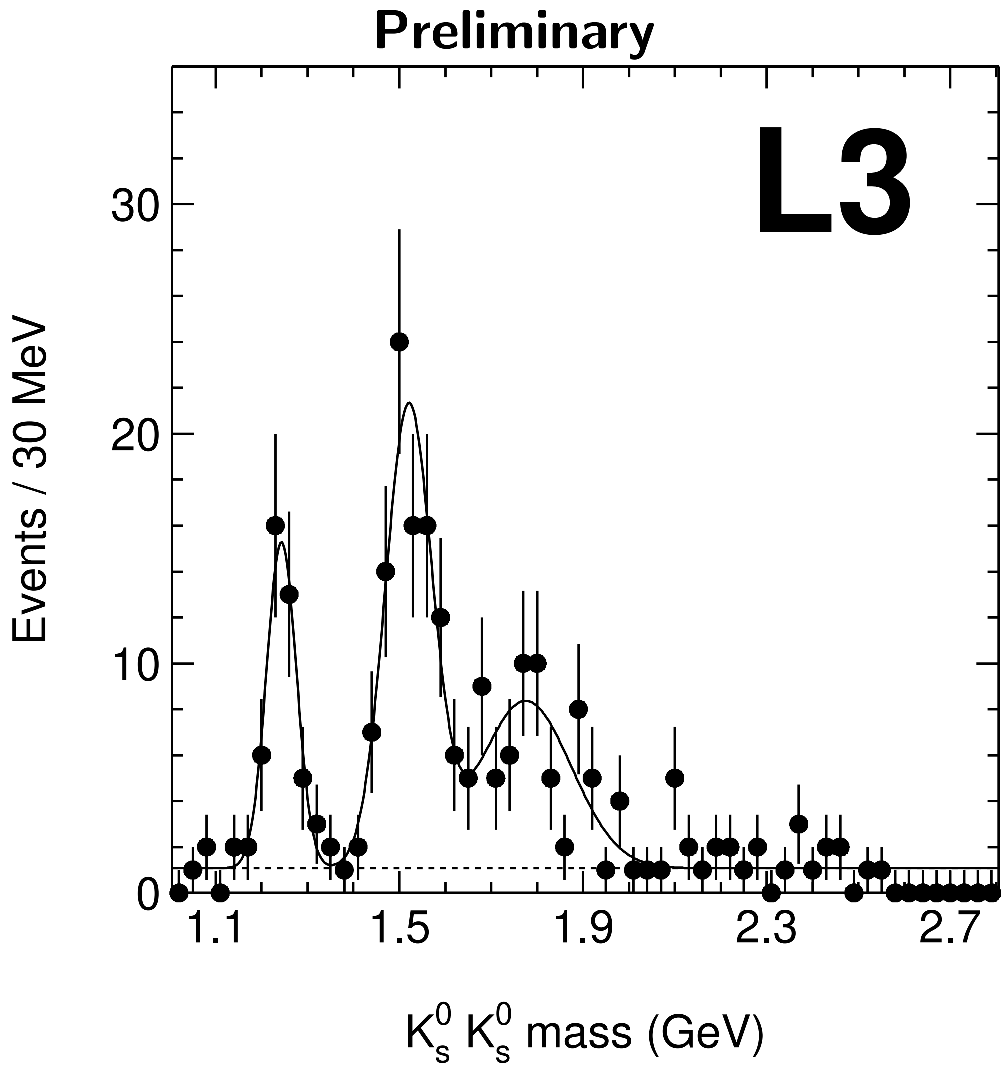


To select the exclusive $K_s^0 K_s^0$ channel, a cut on the total momentum transfer ($|\Sigma\vec{P}_T|^2 < 0.1$ GeV^2) and the requirement that $m_{\pi^+\pi^-}$ be within the circle of 40 MeV on the $m_1(\pi^+\pi^-)$ vs. $m_2(\pi^+\pi^-)$ plane were applied.

$K_s^0 K_s^0$ – Mass Spectrum

Finally, 253 $K_s^0 K_s^0$ events were selected. The spectrum of the $K_s^0 K_s^0$ invariant mass is dominated by the $f_2'(1525)$ resonance. The region $f_2(1270)$ – $a_2(1320)$ shows a destructive interference predicted by SU(3). A clear enhancement is visible in the 1750 MeV region.

In an attempt to determine a resonance spin-parity, the angular distribution of decay products can be analysed in the resonance rest frame.

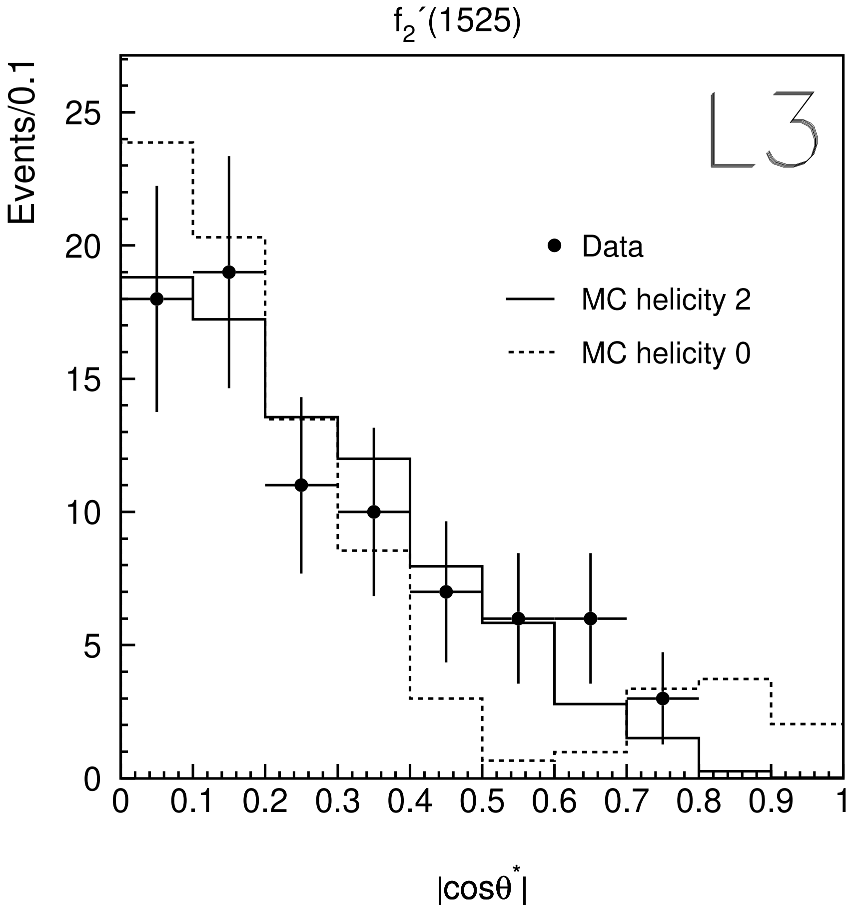


$K_s^0 K_s^0$ – $f_2'(1525)$ Region

The $K_s^0 K_s^0$ polar angle distribution can be simulated by Monte Carlo for two hypothesis of a pure helicity 0 and helicity 2 states, and then compared with the experimental data. The χ^2 values for these hypothesis for the $f_2'(1525)$ state are 81 and 7, respectively, for 9 degrees of freedom. Thus, the pure helicity 0 state is excluded. In this case, an estimate of the $\gamma\gamma$ width of the resonance can be made:

$$\Gamma_{\gamma\gamma} \cdot BR(f_2' \to K\bar{K}) = (0.093 \pm 0.018 \pm 0.022)\ \mathrm{KeV}$$

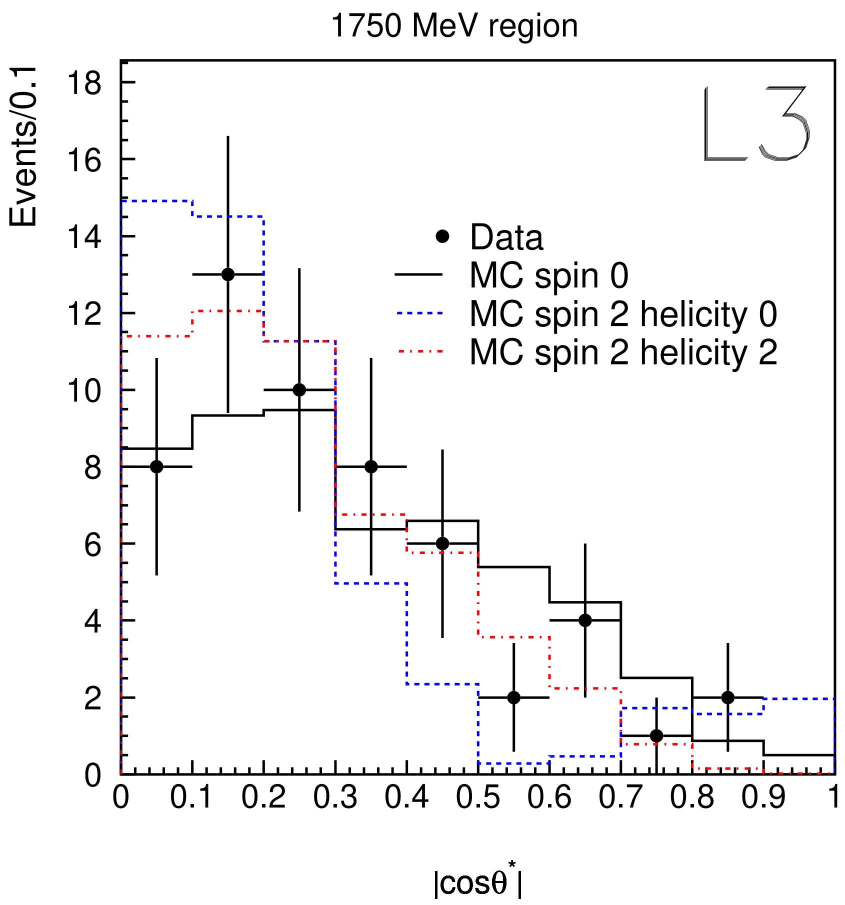
Preliminary



$K_s^0 K_s^0$ – 1750 MeV Region

A similar procedure has been applied to the 1750 MeV region with the hypothesis $(J = 2, \lambda = 0)$, $(J = 2, \lambda = 2)$ and $(J = 0)$. Corresponding values of χ^2 for 9 degrees of freedom are 50, 26 and 7. So, the assignment of the 0^{++} state to this enhancement is the most probable.

Preliminary



$K_s^0 K_s^0$ – 1750 MeV Region

Such a conclusion would support the interpretation of the $f_0(1500)$ observed recently[a] by the Crystal Barrel collaboration as a scalar glueball candidate.

They have reported an observation of three 0^{++} states: $a_0(1450)$, $f_0(1370)$, and $f_0(1500)$. $a_0(1450)$ may be the isovector member of the 0^{++} meson nonet, but $f_0(1370)$ and $f_0(1500)$ cannot be the isoscalar members of this nonet. The $f_0(1500)$ is compatible with the ground state scalar glueball. This hypothesis also predicts a scalar state with the mass in the region of (1500 – 1800) MeV, strongly coupled to $K\bar{K}$.

So, our observation of an enhancement in the 1750 MeV region might very well be an evidence of such state. Statistics being still limited makes this statement probable, but not terminal.

[a] Phys.Lett. B333 (1994) 277, Phys.Lett. B342 (1995) 433, Phys.Lett. B353 (1995) 571

$K^0_sK^0_s$ – $f_J(2230)$ Region

The situation is much clearer with the tensor nonet where all the members correspond to physical resonances. The narrow ($\Gamma \approx 20$ MeV) resonance $f_J(2230)$ observed by MARK III[a] and BES[b] collaborations can be considered as the tensor glueball. Then the production of this state in $\gamma\gamma$-collisions should be strongly suppressed.

We do not see any enhancement in this mass region, and only an upper limit can be obtained:

$$\Gamma_{\gamma\gamma}(f_J(2230)) \times BR(f_J(2230) \to K^0_sK^0_s) < 3 \text{ eV}$$

at 95% C.L.

To quantify the flavour content of a resonance X, a parameter called stickiness has been introduced:

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

$K_{J/\psi\to\gamma X}$ is the energy of photon in a $J/\psi \to \gamma X$ decay, N_l is a normalisation factor chosen to be equal to one for $f_2(1270)$.

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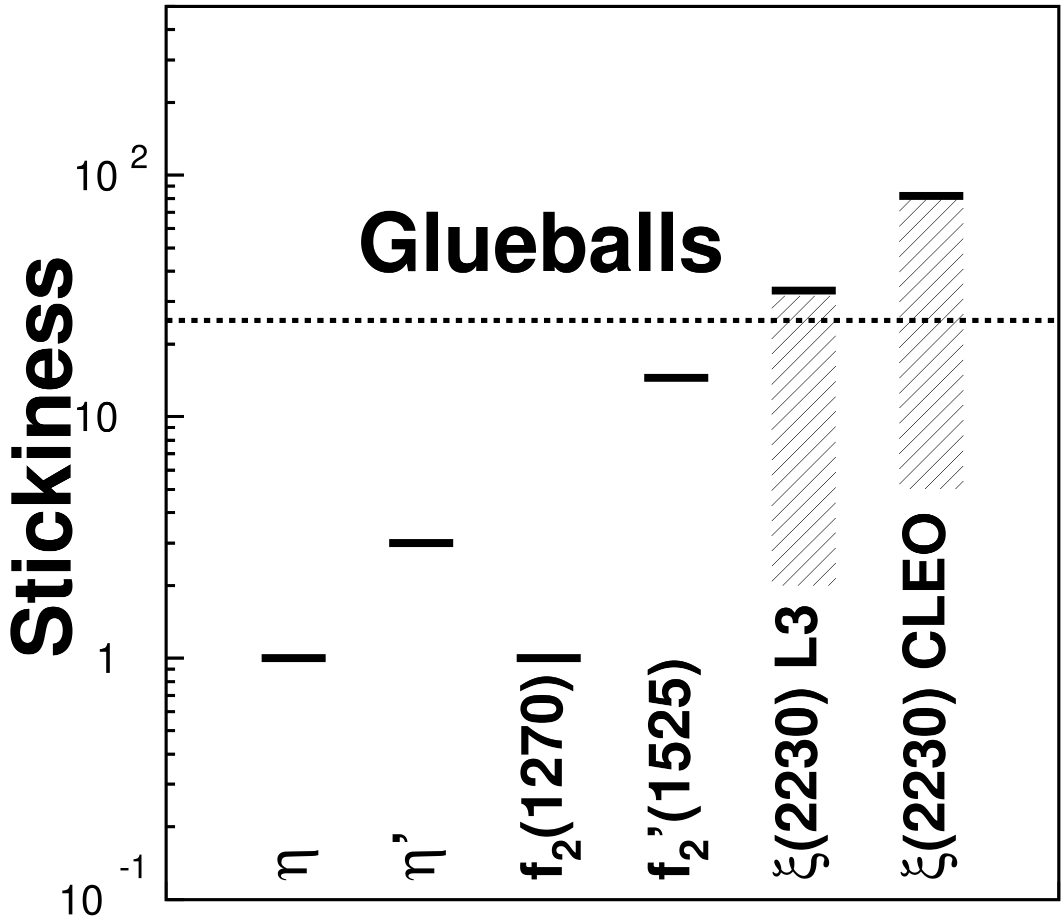
[a] Phys.Rev.Lett. 56 (1986) 107
[b] Phys.Rev.Lett. 77 (1996) 3959

$K_s^0 K_s^0$ – $f_J(2230)$ Region

Combining the results of MARK III and BES with our upper limit, we obtain:

$$S_{f_J(2230)} > 33.5 \text{ (at 95\% C.L.)}$$

This value is much larger than those measured for the established $q\bar{q}$ states.



The $K_s^0 K^\pm \pi^\mp$ Final State

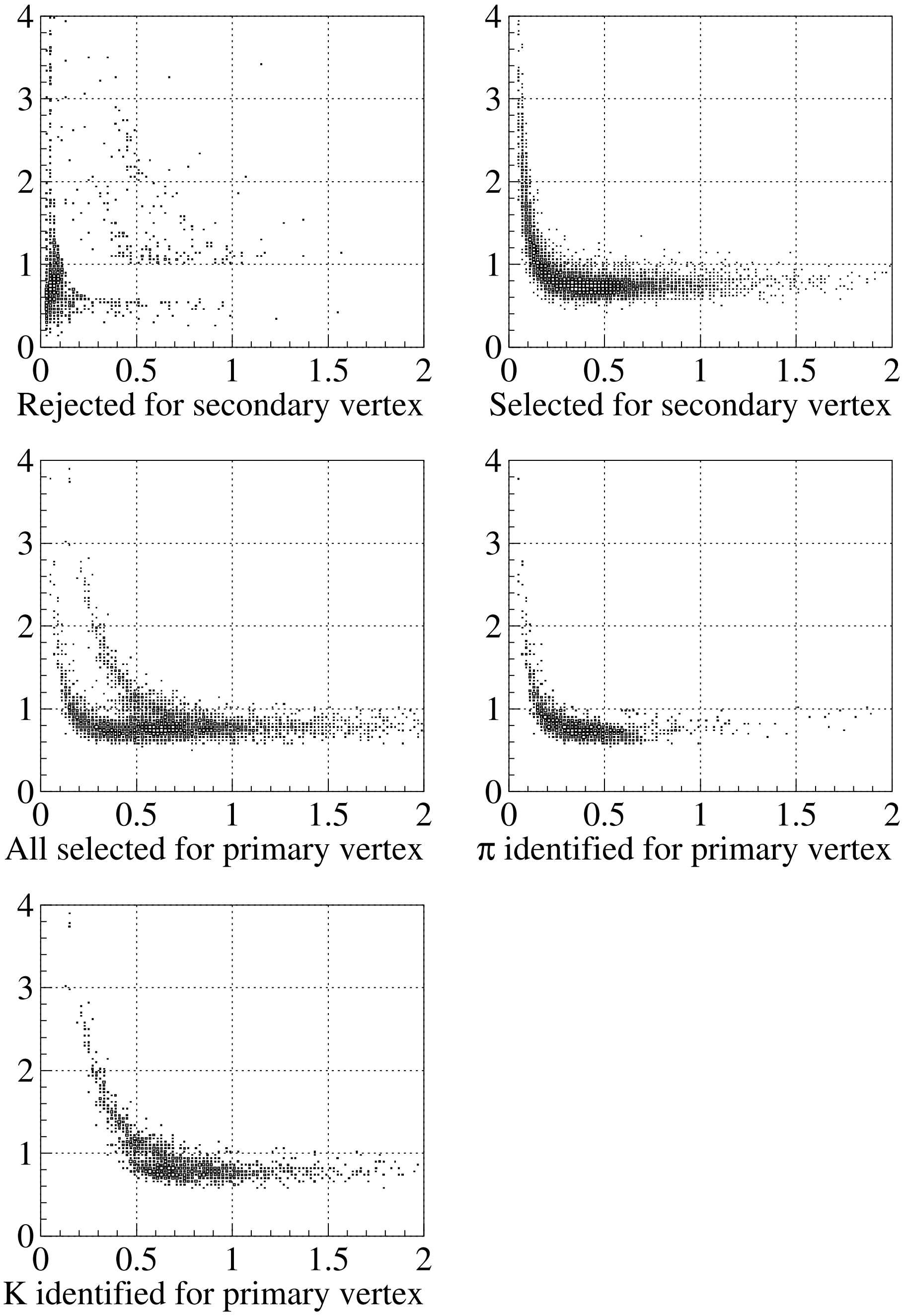
The $K_s^0 K^\pm \pi^\mp (K_s^0 \to \pi^+\pi^-)$ final state consists of four charged particles without photons. The K_s^0 candidates are selected as described above:

- a secondary vertex with $\pi^+\pi^-$ particles 2.5 mm away from the primary vertex (in the transverse plane);
- a window $m_{K_s^0} \pm 40$ MeV in the $(\pi^+\pi^-)$mass,
- ± 0.2 rad. cut in the α angle.

An attempt to identify K and π was made with the use of dE/dx information. If neither of these particles had been identified, both possible choices have been taken with the weight of 0.5 (approx. 30% of the total number of events).

$K_s^0 K\pi$ – dE/dx selection

dE/dX (arbitrary units) vs P (GeV)



$\eta_c \to \mathbf{K}_s^0\mathbf{K}\pi$

In the $K_s^0K\pi$ mass spectrum an $\eta_c(2980)$ signal is seen. The value of $\Gamma_{\gamma\gamma}(\eta_c)$ has been estimated as

$$\Gamma_{\gamma\gamma} = \frac{N_{\eta_c}}{\varepsilon K \cdot BR(\eta_c \to K_s^0(\pi^+\pi^-)K\pi) \cdot \mathcal{L}_{e^+e^-}} \quad ,$$

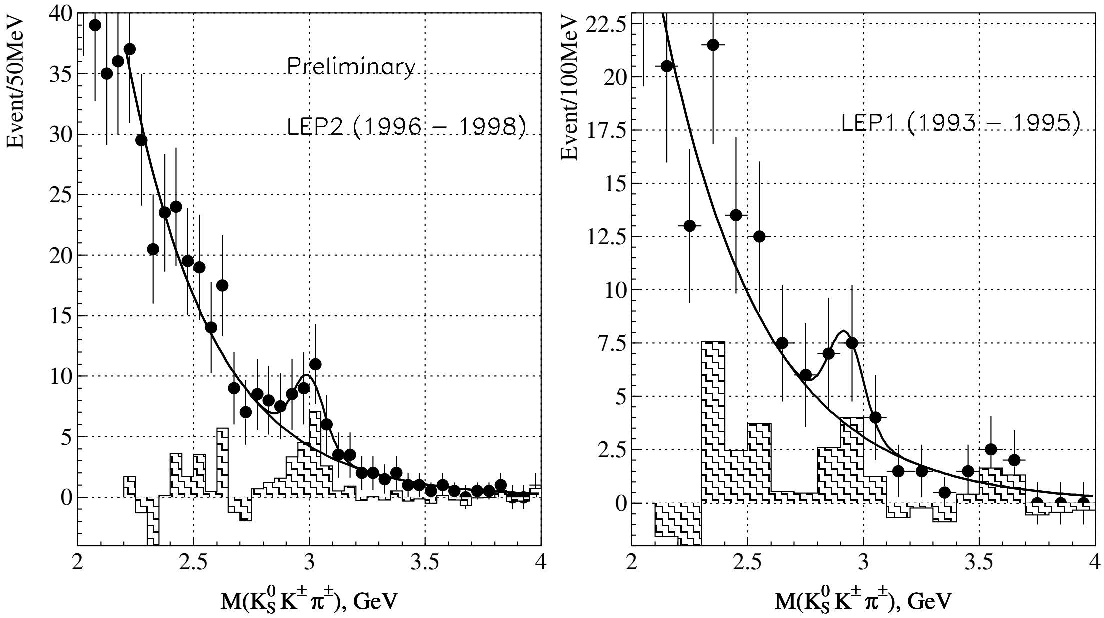
where K is a factor containing the luminosity function numerically integrated, ε – efficiency of $K_s^0K\pi$ detection, including the trigger efficiency. The values of $\Gamma_{\gamma\gamma}$ for LEP-1 and LEP-2 data were evaluated separately with the results

$$\Gamma_{\gamma\gamma} = 9.6 \pm 6.1(\pm 3.0) \qquad \text{(LEP-1)}$$
$$\Gamma_{\gamma\gamma} = 5.8 \pm 2.8(\pm 1.8) \qquad \text{(LEP-2)}$$

with the weighted mean value

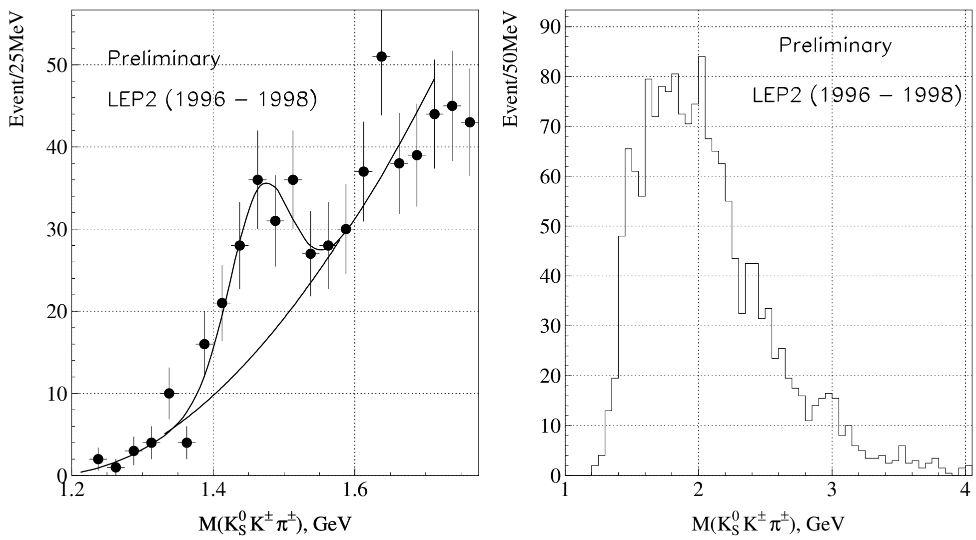
$$\Gamma_{\gamma\gamma} = 6.5 \pm 2.5(\pm 2.0) \qquad \text{(L3)}$$

Shown in the brackets are the systematic errors coming from the uncertainty of the branching ratio.



$K^0_s K\pi$ – 1450 MeV Region

An enhancement is seen in the region of 1450 MeV. This could be the first observation of $\gamma\gamma \to \eta(1440)$ state. This state is produced with high probability in J/ψ decay into $\gamma\eta(1440) \Rightarrow \gamma K\bar{K}\pi$ ($BR = (9.1 \pm 1.8) \cdot 10^{-4}$).



Thus, our finding might lead to a conclusion that this state is not a gluonium one. However, the limited statistics does not yet give us an opportunity to make a firm conclusion. Rather large non-resonant background does not leave much hope to perform a partial wave analysis in order to prove that this is a state with $J^{PC} = 0^{-+}$. Of course, the production of $J^{PC} = 1^{++}$ states in $\gamma\gamma$-collisions is strongly suppressed.

According to our estimate,

$$\Gamma_{\gamma\gamma} \times BR(\eta(1440) \to K^0_s K\pi \to \pi^+\pi^- K^\pm \pi^\mp \doteq 120 \text{ eV} \quad ,$$

which corresponds to the stickiness parameter $S_\eta \approx 6$, i.e. to $\eta(1440)$ having usual (u,d) flavour contents.

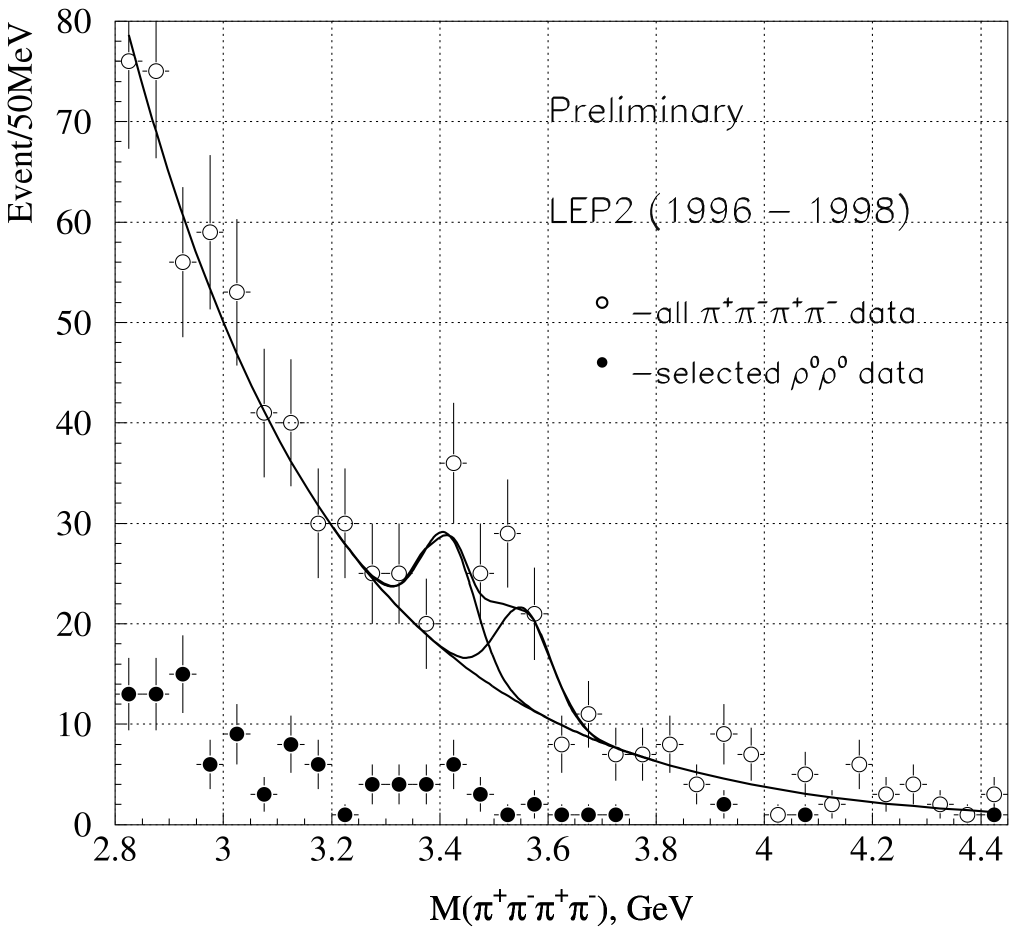
The $\pi^+\pi^-\pi^+\pi^-$ Final State

We have also studied the 4-pion final state. The selection of such events is quite simple: four charged particles with the net charge equal to zero should be connected in the one (collision) vertex, and, where possible, events with kaons should be excluded.

It is well known that this state is strongly connected to a two-ρ^0 state up to total four-pion mass less than 2 GeV. At higher masses, the cross-section drops down, and it is natural to study the high mass resonances production like η_c, χ_c, ... which might decay into four pions.

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

Indeed, we do see a structure in the mass region of 3.5 GeV. This might very well be $\chi_{c0} + \chi_{c2}$ states produced in $\gamma\gamma$-collisions. It is interesting to note that these states are <u>not</u> produced in the $\rho^0\rho^0$ channel.



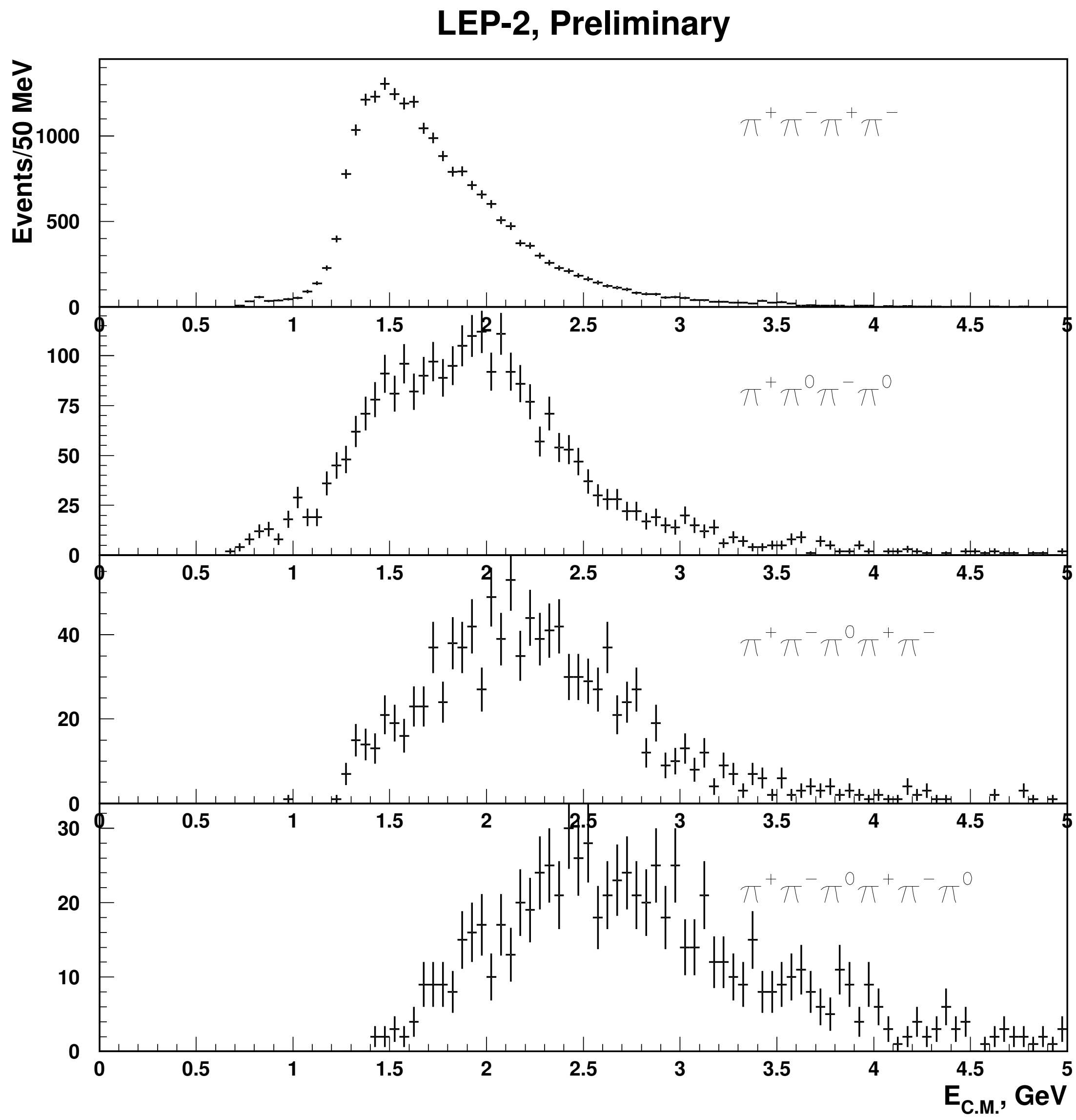
Multi-Pion States Exclusive Production

Measurement of the exclusive production of vector mesons is of a special interest because of the high probability of photons to fluctuate into neutral vector mesons. The Vector Dominance Model (VDM) is an important ingredient of all models of $\gamma\gamma$-interactions, and a thorough check of its predictions would play a fundamental role.

The dominant process, having quite high cross-section, is the $\rho^0\rho^0$ production. The final states with $\rho^0\omega$, $\omega\omega$, or $\rho^+\rho^-$ are produced with much lower cross-sections, and it was only after the LEP-2 data became available that a reasonable analysis of these states became feasible.

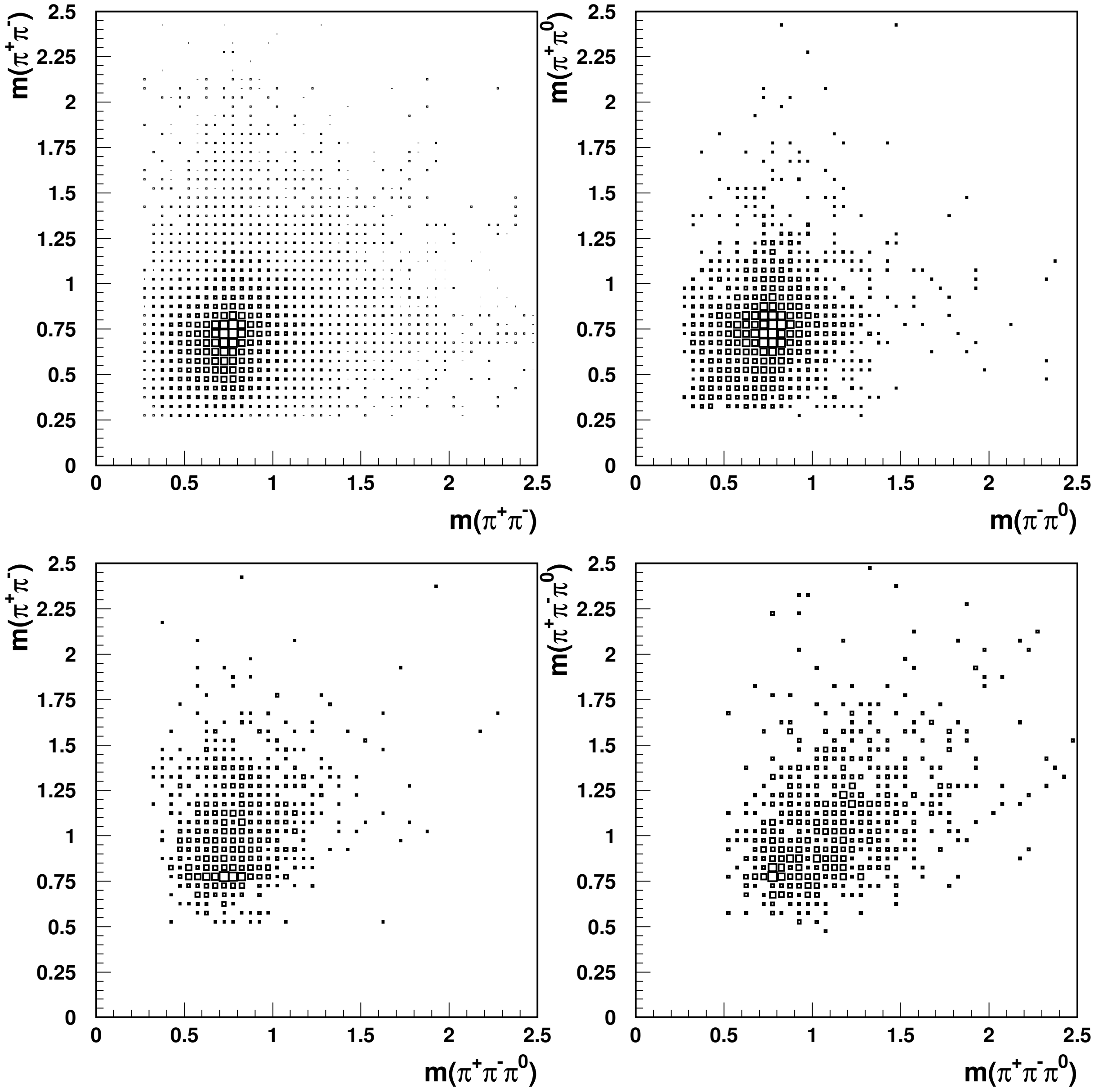
The energy dependence of the production rates are quite similar for all listed channels: a sharp rise at close-to-threshold energy, and then a fast decrease. It is only with LEP-2 energies and more than 500 pb^{-1} of luminosity that we can study these dependences up to high energies (10 GeV, or so).

Topological Production Rate of Multi-Pion States



Mass Correlations

LEP-2, Preliminary



Valery Schegelsky
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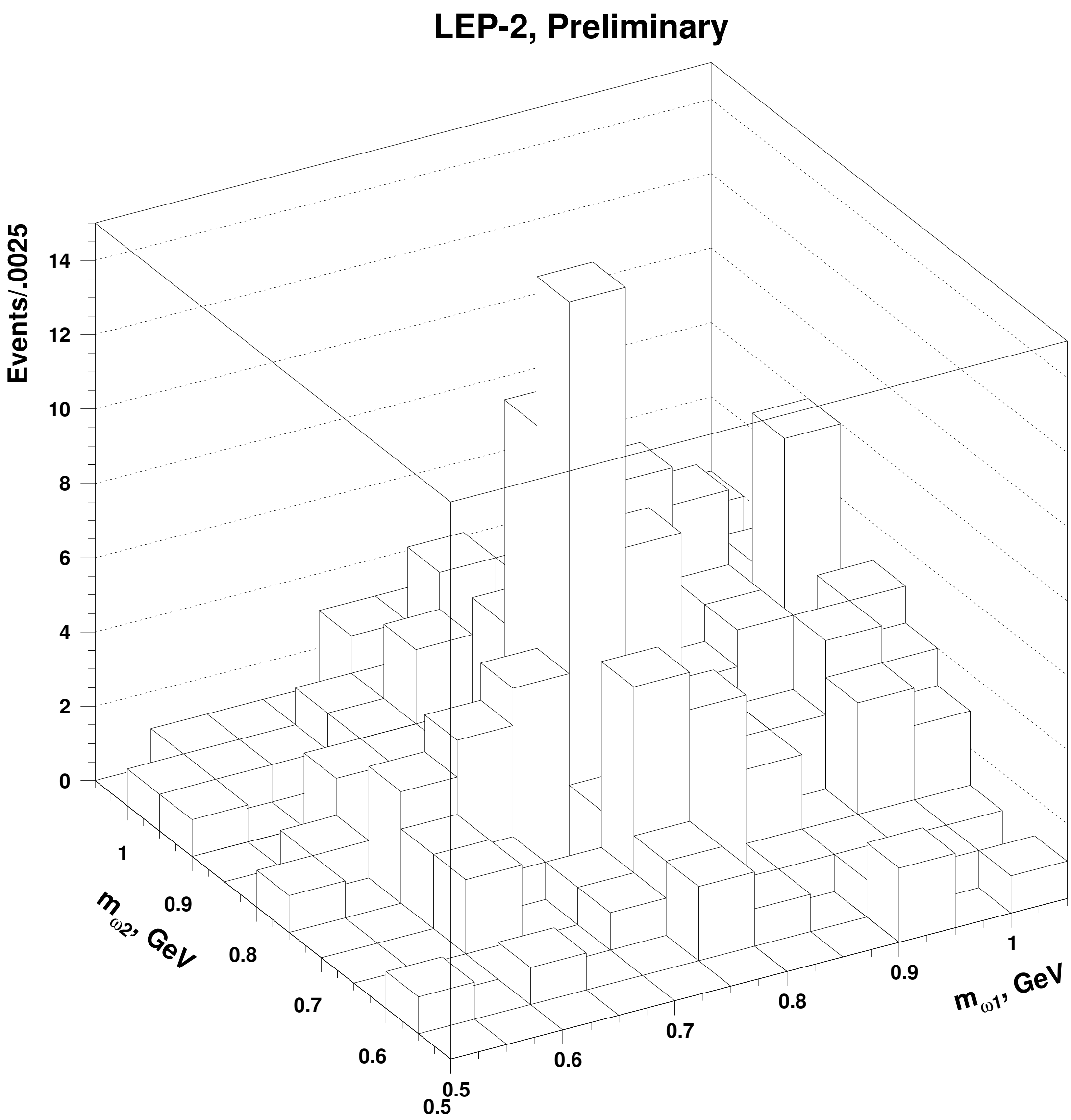
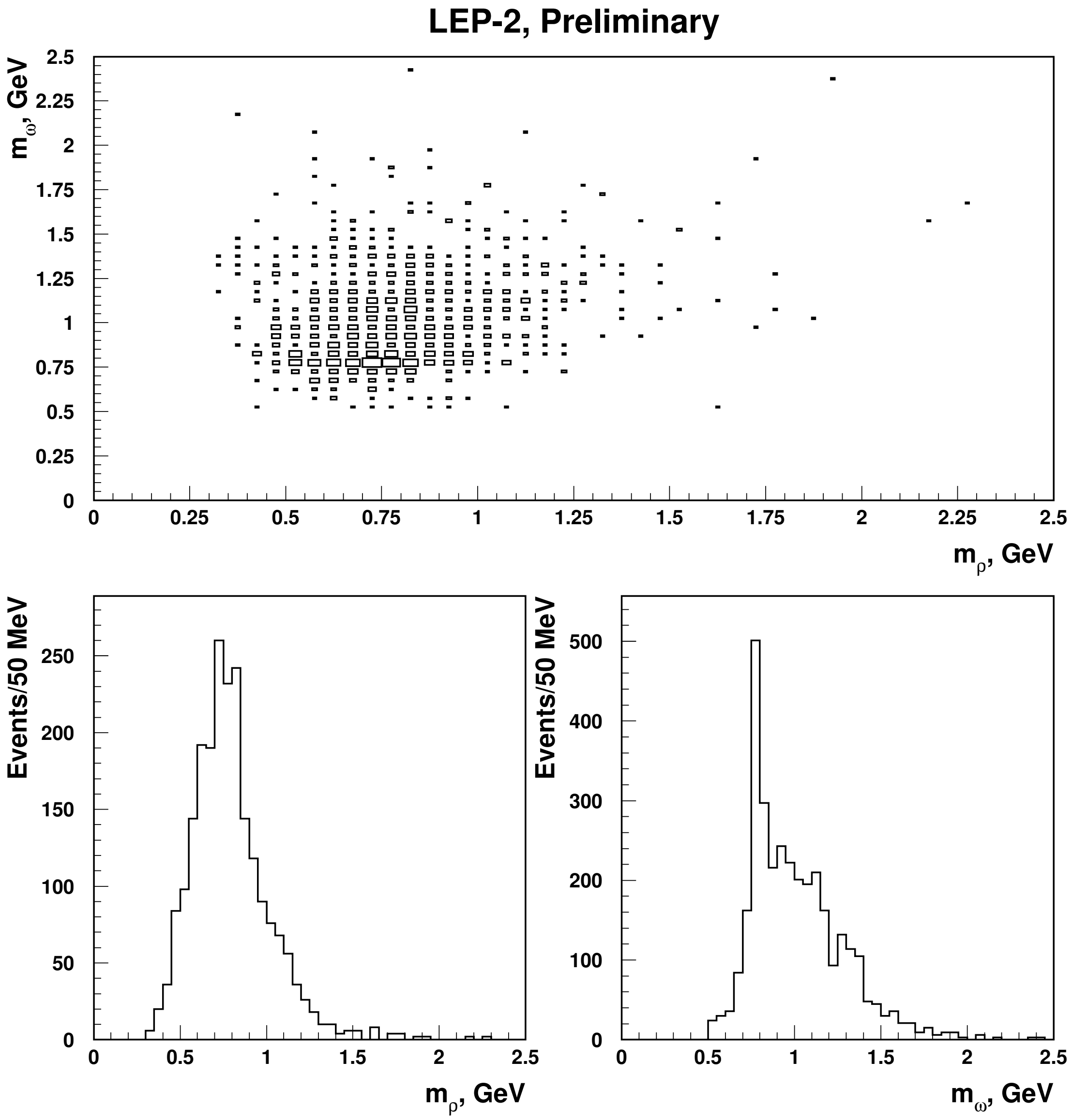
on behalf of L3

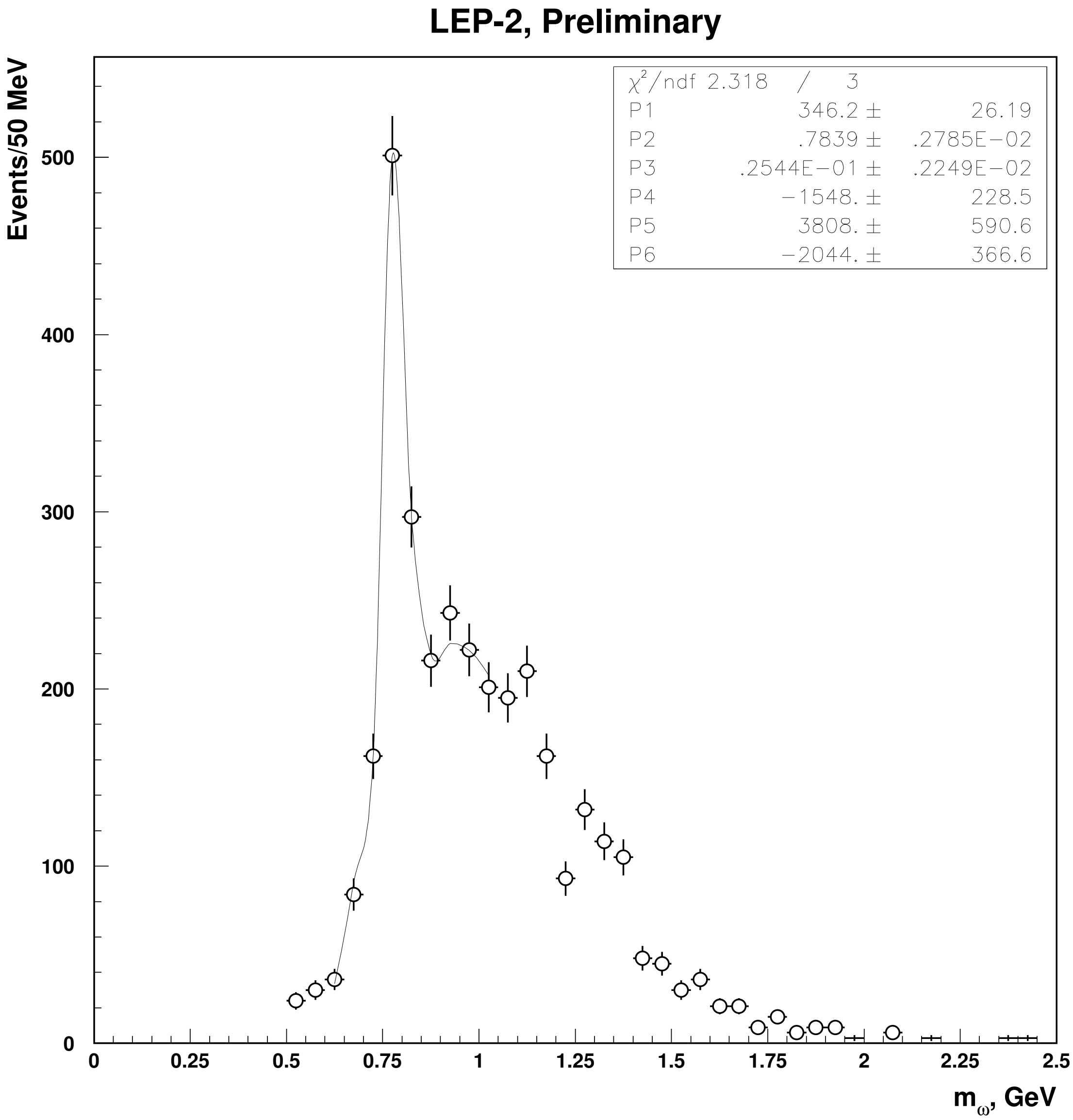
$m(\omega)$, Best Choice



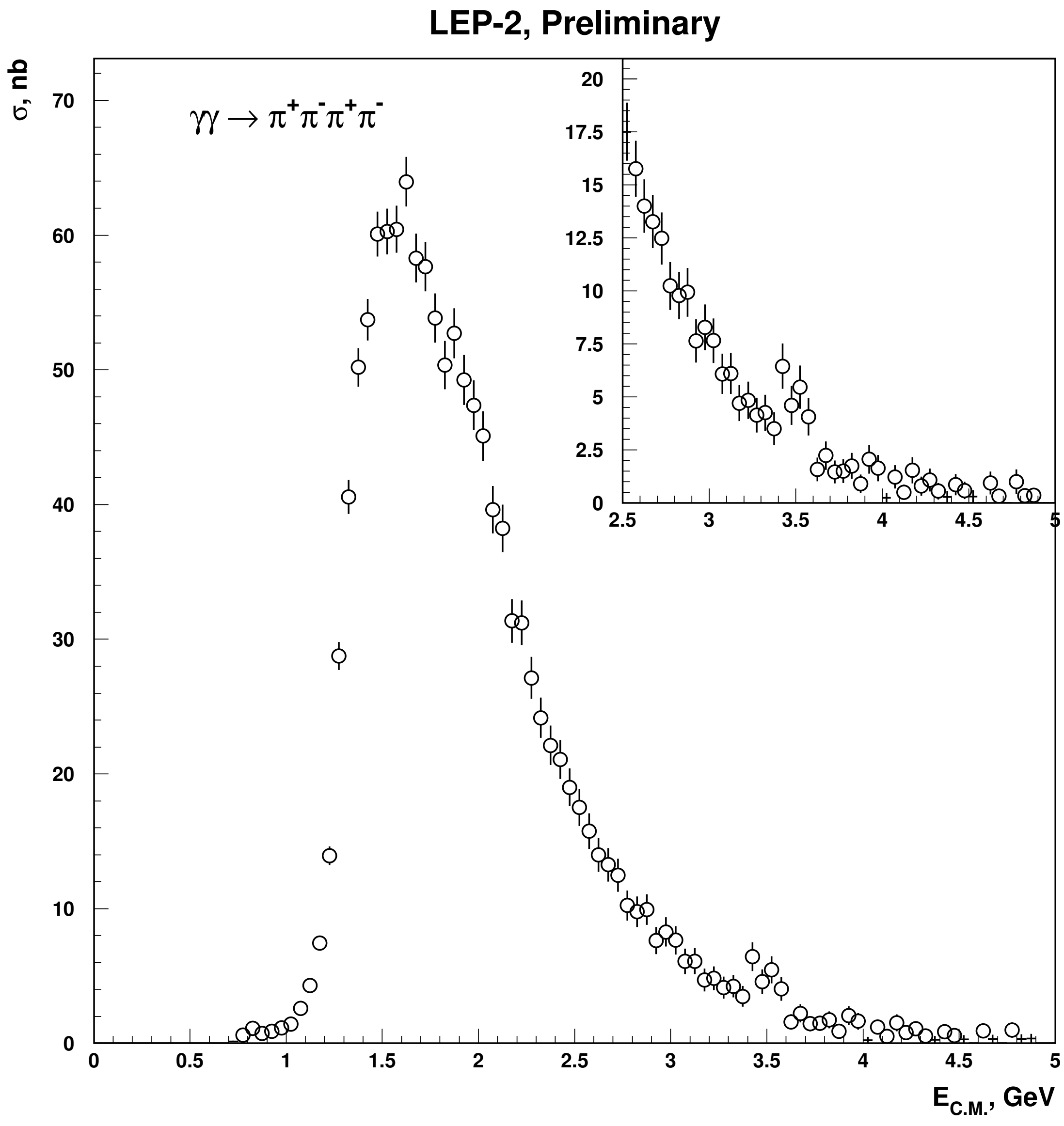
$m(\omega)$ vs. $m(\rho)$



Fit to the $m(\omega)$



Four-Pion Production Cross-Section



Multi-Pion States Exclusive Production

To illustrate the importance of the vector mesons production, it is natural to plot the correlations between the best choices of the two final-state mesons with the minimum χ^2 calculated as

$$\chi^2 = \frac{1}{\sigma_m^2}\left[(m_{12} - m_{V1})^2 + (m_{34} - m_{V2})^2\right] \quad ,$$

where σ_m is the mass "resolution", proportional to the mass distribution width.

Indeed, the vector mesons production is an essential part of the corresponding topological cross-section at energies close to the threshold.

Conclusions

Rather large integrated luminosity of LEP opens the opportunities for a high-statistics study of the $\gamma\gamma$-interaction. First analysis results of LEP-2 data clearly demonstrate this.

- A detailed measurement of vector mesons production is possible now.
- Production of charmonium states starts to become sizeable.
- The uncertainties in the branching ratios become now the main source of errors. New measurements of those in J/ψ decays are very much welcome.