Glueball searches in $\gamma\gamma$ collisions at LEP

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We report about the work, still preliminary, done by the LEP experiments on glueball searches in $\gamma\gamma$ collisions. The ALEPH experiment has studied the production of the glueball candidate $f_0(1500)$ via its decay to $\pi^+\pi^-$. No signal is observed and an upper limit to the $\gamma\gamma$ width of the $f_0(1500)$ has been calculated. The process $\gamma\gamma \to K^0_s K^0_s$ has been studied with the L3 detector. In the spectrum a clear enhancement is observed around 1750 GeV; it can be due to the formation of a radial recurrence of the $f_2'(1525)$ or to the $s\bar{s}$ member of the 0^{++} meson nonet. An upper limits for the two-photon width of the glueball candidate $\xi(2230)$ has been calculated

1 Introduction

Quantum Cromo-Dynamics (QCD) is a non abelian gauge theory whose intermediate gauge bosons are the gluons; it is by now a well established theory to describe the strong interactions and many experimental confirmations had already been obtained in the high energy regime and in hadron spectroscopy. Due to the fact that QCD is a non abelian theory, gluons can interact and therefore they can form new states of matter called glueballs. Unfortunately, no evidence for glueball has yet been established even if evidence of self-interactions of gluons has been observed in multi-jet events produced at high energy colliders. The theoretical calculations in the non pertubative region are still not precise and then the understanding of the $q\bar{q}$ mass spectrum is crucial in glueball searches.

The formations of glueball is expected to be enhanced in gluon rich environment such as pp, $p\bar{p}$ or J/ψ decays, and suppressed in $\gamma\gamma$ collisions; this is due to the fact that, being the gluons neutral, they cannot directly couple to electric charge, but only via a box diagram, as shown in figure 1c. Thus, the major role of the two-photon collisions in glueball searches is to anti-tag known resonances.

1.1 $\gamma\gamma$ collisions

The resonance formation in $\gamma\gamma$ collisions proceed via the diagram shown in figure 1b and its cross section is

$$\sigma(e^+e^- \to e^+e^- R) = \int d^5\mathcal{L}(\alpha_i) \cdot \sigma(\gamma\gamma \to R) \tag{1}$$

The luminosity function $\mathcal{L}(\alpha_i)$ is QED calculable

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

where $W_{\gamma\gamma}$ is the two photon invariant mass, m_R, J, $\Gamma_{\gamma\gamma}$, and Γ_R are the mass, the spin, the two photon width and the total width of the resonance R. Combining the equations 1 and 2, the cross section can be rewritten as:

$$\sigma(e^+e^- \to e^+e^- R) = \mathcal{K} \cdot \Gamma_{\gamma\gamma}(R) \tag{3}$$

where the proportionality factor $\mathcal{K}$ can be calculated by Monte Carlo integration. The resonance R has the quantum number of the $\gamma\gamma$ initial state so must be a neutral, unflavoured meson with positive C-parity and spin 0 or 2 (if the e^+e^- are undetected, as usually it is, the two photons are quasi-real and hence spin 1 is highly suppressed). Assuming gluons as massless spin 1 particle, as well as photons, the structure of $\gamma\gamma$ and gluons-gluons coupling is similar even if γs couple through electric charge while gluons couple through colour charge.

Some models [3 4] predict the possibility of mixing of bare glueball with $q\bar{q}$ states, then for a given resonance the ratio of its $\gamma\gamma$ coupling to gloun-gloun coupling it's different in case it is a glueball or a $q\bar{q}$ meson. This ratio is expressed by a quantity called *stickiness*, defined as

$$S_R = N_l \left(\frac{m_R}{k_{J/\psi\to\gamma R}}\right)^{2l+1} \frac{\Gamma(J/\psi \to \gamma R)}{\Gamma(R \to \gamma\gamma)} \propto \frac{|< R|gg >|^2}{|< R|\gamma\gamma >|^2} \tag{4}$$

where $\Gamma(R \to \gamma\gamma)$ is the two-photon width, $\Gamma(J/\psi \to \gamma R)$ the J/ψ partial width in γR, m_R and l the mass and the spin of the resonance, k the energy of the photon coming from the $J/\psi \to \gamma R$ decays, and N_l is a normalisation factor such that $S_{f_2(1270)}$=1. A high value os S is a sign of a gluons rich state.

2 Search for the $f_0(1500)$

The $f_0(1500)$ resonance has been observed in $p\bar{p}$ collisions by the Crystal Barrel Collaboration [2]. This state has a mass of 1503 ± 11 MeV and a width of 120 ± 19 MeV. This resonance doesn't

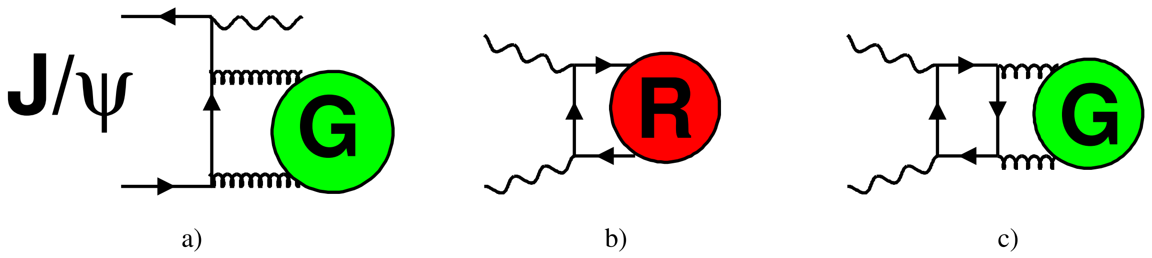


Figure 1: Production of glueballs in J/ψ radiative decay and formation of resonances and glueballs in $\gamma\gamma$ collisions.

fit very well in the $q\bar{q}$ meson octet and it is considered a possible candidate for the lightest scalar glueball which from recent calculations [3] is expected to lie in that mass region. If so its production via the process $\gamma\gamma \rightarrow f_0(1500)$ should be highly suppressed. Thus, a measurement of the two photon width $\Gamma_{\gamma\gamma}$ of the $f_0(1500)$ would allow the determination of its quark to gluons content.

The process $\gamma\gamma \rightarrow f_0(1500) \rightarrow \pi^+\pi^-$ has been studied with the ALEPH detector using a sample of integrated luminosity L =160.9 pb^{-1} collected at LEP from 1990 to 1995 at $\sqrt{s}$ = 91 GeV. The $\pi^+\pi^-$ events are selected by imposing the following conditions: only 2 tracks originating from interaction point and with opposite charge, small total transverse momentum, small visible energy and mass to reject Z decays and no energy in the forward detectors to select only quasi real photons. The figure 2 shows the $\pi^+\pi^-$ invariant mass spectrum obtained; a clear peak, due to the $f_2(1270)$, is visible while no evidence for $f_0(1500)$ formation is present.

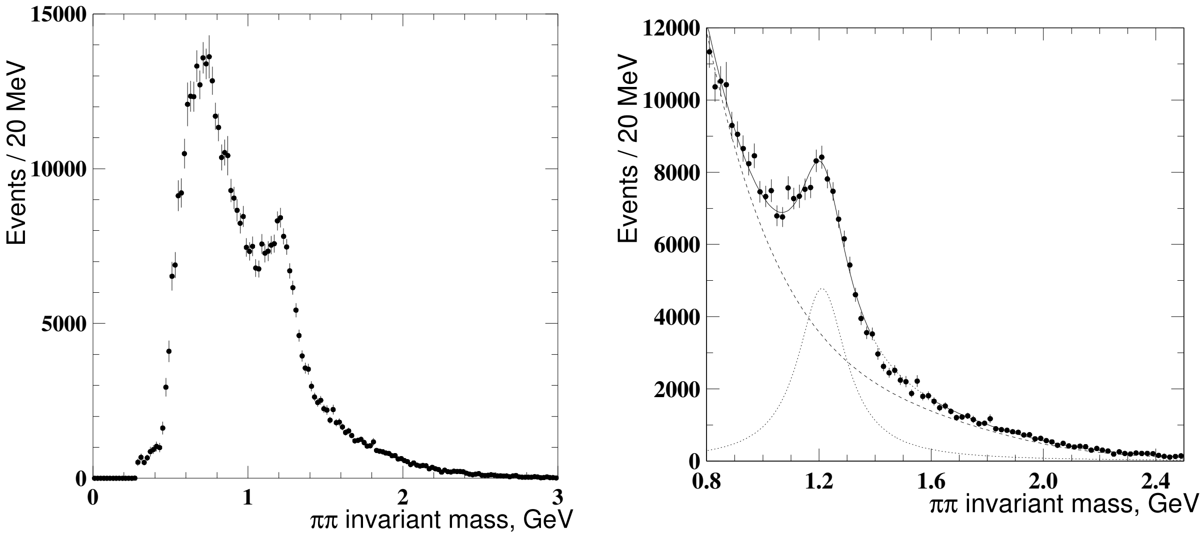


Figure 2: $\pi^+\pi^-$ mass spectrum for the events selected by ALEPH. The figures also shows the fit to the data of a 5^{th} order polynomial for the $\pi^+\pi^-$ continuum and the Breit-Wigner for the f2(1270).

Using a Monte Carlo simulation, the experimental resolution for the $f_2(1270)$ and for $f_0(1500)$ is evaluated and for both it is found to be 10 MeV. The background due to the $\pi\pi$ continuum has been fitted with a 5^{th} order polynomial; the background in the region of $f_0(1500)$, ranging from 1.38 GeV to 1.62 GeV, is estimated extrapolating the fit into this region. The mass and the width of the $f_2(1270)$ are 1211±4 MeV and 211±18 MeV , values that differs from the ones in the PDG [5] (1275±1 MeV and 185±4 MeV), but is due to the large interference with the $\pi\pi$ continuum [1,2].

Using a likelihood fit, a limit at 95 % C.L. is set for $\Gamma_{\gamma\gamma}(f_0(1500))$ <0.17 keV and for the stickiness $S_{f_0(1500)}$ >13. The errors are taken into account by Monte Carlo and a value $\Gamma(J/\psi \rightarrow f_0\gamma)$=0.071 KeV is used [5].

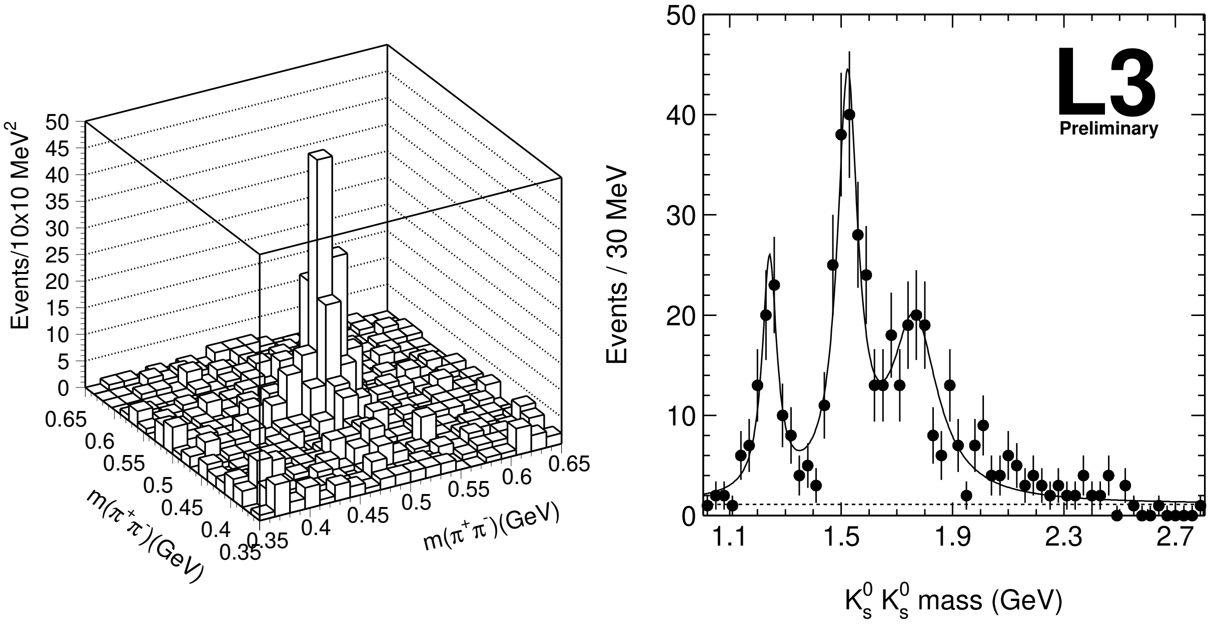
3 Searches in the $K^0_sK^0_s$ Final State.

The L3 collaboration has already published [6] the results of the study of the $K^0_sK^0_s$ final state in $\gamma\gamma$ formation with a sample of L=114 pb^{-1} collected at $\sqrt{s}$=91 GeV. The reaction studied is $e^+e^- \rightarrow e^+e^-K^0_sK^0_s \rightarrow \pi^+\pi^-\pi^+\pi^-$. This results has been update including the samples of L=52 pb^{-1} collected at $\sqrt{s}$ = 183 GeV and L=172 pb^{-1} collected at $\sqrt{s}$ = 189. The event $e^+e^- \rightarrow e^+e^-\pi^+\pi^-\pi^+\pi^-$ are selected requiring four charged tracks with net zero charge and no photons, small total energy and small transverse momentum imbalance. The $K^0_sK^0_s$ event

Table 1: Results from the maximum likelihood fit of the $K_s^0 K_s^0$ invariant mass spectrum.

	$f_2'(1525)$	1750 MeV Region
Mass (MeV)	1523 ± 8	1765 ± 22
Width (MeV)	89 ± 37	200 ± 50
Nb. of events	184 ± 27	171 ± 26

identification is obtained requiring two secondary vertices away from the interaction point. The two K_s^0s are produced back to back in the transverse plane and the directions of flight, defined as the the line lying in the transverse plane connecting the interaction point and the secondary vertex, are required to be collinear.



a)

b)

Figure 3: a) $\pi^+\pi^-$ mass of one K_s^0 system versus the other . b) The $K_s^0 K_s^0$ invariant. The solid line correspond to the result of the maximum likelihood fit and the dashed to the background. The peak are fitted using a unbinned Gaussian function. The results are reported in table 1

The figure 3a shows the $\pi^+\pi^-$ invariant mass for the selected events. By fitting this distributions, a mass resolution of 9.6± 0.8 MeV has been found, consistent with the Monte Carlo simulation.

Only the 499 events lying in a radius of 40 MeV around the $K_s^0 K_s^0$ nominal mass point are used in the $K_s^0 K_s^0$ invariant mass spectrum shown in figure 3b. Two clear peaks are visible in the spectrum; the first one around 1200 MeV is due to the destructive interference [1] between the $f_2(1270)$ and the $a_2(1320)$ in the $K_s^0 K_s^0$ final state; the second one is the well established $f_2'(1525)$ resonance [8].

At 1765 MeV there is a clear enhancement with a statistical significance of about 7σ (table 1), while no excess is visible in the $\xi(2230)$ region [9].

3.1 The $f_2'(1525)$ tensor meson

The $f_2'(1525)$ is a well established tensor meson which theory predicts to be formed predominantly in helicity 2. In order to determine its helicity state a Monte Carlo simulation has been performed for the different allowed spins and helicities. The angular distribution of the two K_s^0 in the two-photon centre of mass depends on the helicity of the resonance formed.

Figure 4a shows the comparison between data and Monte Carlo for different helicity state. The χ^2 values for nine degrees of freedom are 21 for the spin 0 hypothesis, 93 for the spin 2 helicity 0 hypothesis, and 4.6 for spin 2 helicity 2 hypothesis, confirming the prediction that helicity 2 state dominates. Using the helicity 2 hypothesis the value of 0.08±0.02 keV (stat.+syst.) for the $\Gamma_{\gamma\gamma} \times BR(f_2' \to K\bar{K})$ is found.

The detection efficiency has been estimated to be 3.9 % for helicity 0 and 7.6% for helicity 2 at $\sqrt{s}$ = 91 GeV and 3.7% and 7.2% respectively at $\sqrt{s}$ = 183-189 GeV.

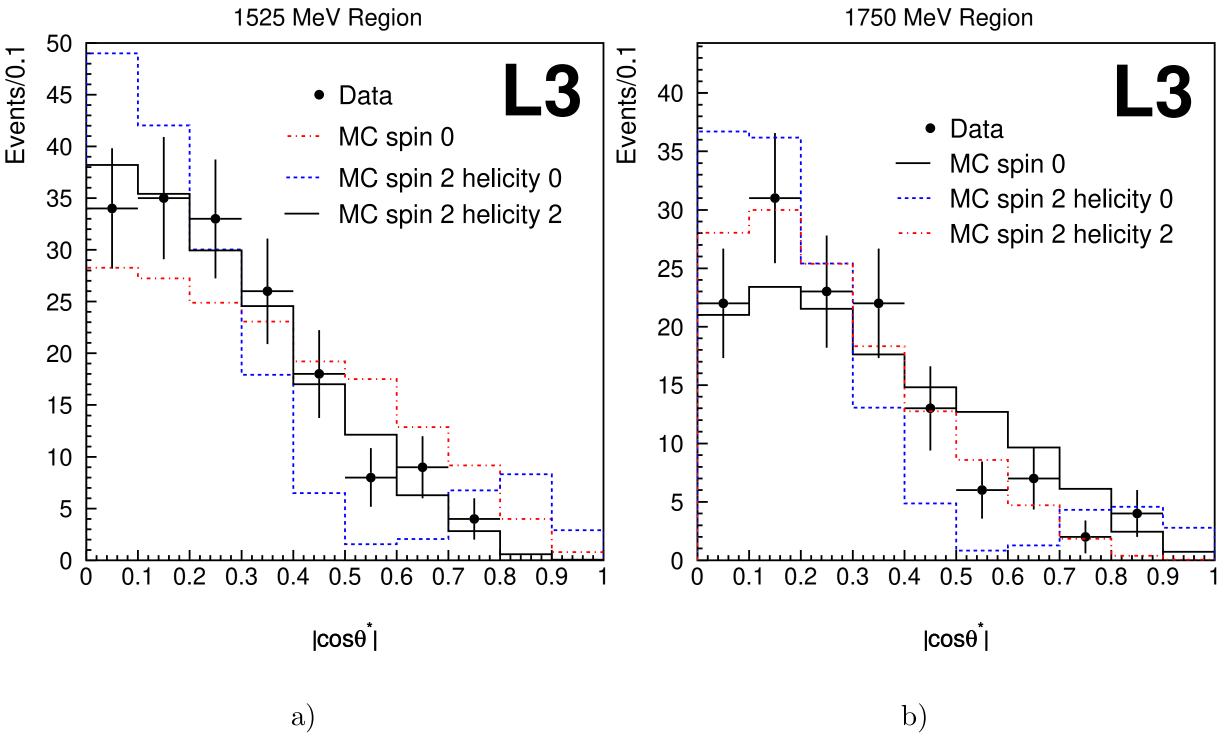


Figure 4: $\pi^+\pi^-$ mass invariant mass of one K_s^0 system versus the other (a). The $K_s^0 K_s^0$ invariant mass is shown in figure b). The solid line correspond to the result of the maximum likelihood fit and the dashed to the background. The peak are fitted using a Gaussian function.

3.2 The 1750 MeV region.

Even if the statistics is not too large an attempt has been made to determine the helicity of this resonance that is of great interest. In fact, following the recent [5] observation of three $J^{PC} = 0^{++}$ states:the $a_0(1450)$, the $f_0(1370)$ and the $f_0(1500)$, it has been suggested [3] that the $a_0(1450)$ is the isovector member of the 0^{++} meson nonet while the $f_0(1370)$ and the $f_0(1500)$ cannot both isoscalar members of this nonet. The $f_0(1370)$ is very likely composed by u and d quarks while the $f_0(1500)$ is compatible with the ground state scalar glueball expected around 1500 MeV (see previous discussion). This scenario also predicts a further scalar $s\bar{s}$ state that should strongly couple to $K\bar{K}$. Its observation is essential to support the $f_0(1500)$ glueball nature.

The figure 4b show the comparison between data and Monte Carlo predictions for different helicity and spin values. The Monte Carlo distributions are normalised to the same number of events present in the data and no background subtractions is done.

The χ^2 values for nine degree of freedom are 12 for spin 0, 89 for spin 2 helicity 0 and 38 for spin 2 helicity 2 and they don't allow to draw a clear statement even if spin 0 is favoured. This is consistent with other experimental indications [11] of a scalar state around 1750 MeV decaying into K^+K^-.

3.3 The 2230 MeV region.

The QCD lattice calculations predict the ground state tensor glueball to have a mass around 2200 MeV. The BES collaboration confirmed a previous observations, done by the Mark III, of a narrow resonance, the $\xi(2230)$, produced in radiative J/ψ decay [9]. Due to the narrow width and due to the fact that it has been observed so far only in gluon rich environment, this state is considered a good candidate for the ground state tensor glueball. In the $K_s^0 K_s^0$ spectrum there is no excess in the $\xi(2230)$ region but some limit can be obtained.

Using the mass and width value for the $\xi(2230)$ from a combination of the results by BES and Mark III, a Monte Carlo simulation has been done; a mass resolution of 60 MeV is found and the detection efficiencies, under the assumption of a pure helicity 2 state, are 16.5% at $\sqrt{s}$ = 91 Gev, 15.2 % at $\sqrt{s}$ = 183 GeV and 14.1 % at $\sqrt{s}$ = 189 GeV. The signal region chosen is 2σ wide around the $\xi(2230)$ mass and the background has been evaluated fitting 2σ wide sidebands. Then the upper limit $\Gamma_{\gamma\gamma}$ $(\xi(2230)) \times BR(\xi(2230) \rightarrow K_s^0 K_s^0) < 1.5$ eV at 95 % C.L. is derived. Using this upper limit and the results by BES and Mark III for the $\Gamma(J/\psi \rightarrow \gamma\xi) \times BR(\xi \rightarrow K_s^0 K_s^0) = (2.2 \pm 0.6) \times 10^{-5}$, a lower limit on the stickiness can be put: $S_{\xi(2230)} > 68$ at 95 % C.L.

4 Conclusions

We have reviewed new result on glueball searches in two-photon collisions at LEP.

The L3 analysis show an enhancement of about 7 standard deviation at M = (1765±22) MeV, Γ = (200±50) MeV. From the polar angle distribution the spin 0 hypothesis is favoured supporting its interpretation as the $s\bar{s}$ member of the 0^{++} scalar meson nonet.

No evidence for the $f_0(1500)$ candidate nor for the $\xi(2230)$ has been found in $\pi^+\pi^-$ and $K_s^0 K_s^0$ decay channels, thus supporting their glueball interpretation. New limits on their stickiness had also been put:

- $S_{f_0} > 13$ at 95 % C.L. by ALEPH
- $S_{\xi(2230)} > 68$ at 95 % C.L. by L3

In the coming years LEP luminosity will increase and will allow to collect larger a data sample; higher statistic and the anlysis of more channel will highly improve our knowledge of meson spectroscopy.

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