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The $K^0_s K^0_s$ Final State in Two-Photon Collisions and Some Implications for Glueball Searches

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The $K^0_s K^0_s$ final state in two-photon collisions is studied with the L3 detector at LEP using data at centre of mass energies from 91 GeV to 183 GeV. The $K^0_s K^0_s$ mass spectrum is dominated by the formation of the $f_2'(1525)$ tensor meson whose two-photon partial width is measured. Clear evidence for destructive f_2-a_2 interference is observed. No signal is present in the region around 2.2 GeV. An upper limit for the two-photon partial width times the $K^0_s K^0_s$ branching ratio of the $\xi(2230)$ glueball candidate is then derived. An enhancement is observed around 1750 MeV. It may 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.

1. Introduction

Electron-positron storage rings are widely used to investigate the behaviour of two-photon interactions via the process $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$, where γ^* is a virtual photon. The outgoing electron and positron carry nearly the full beam energy and their transverse momenta are usually so small that they are not detected. This kind of event is characterised by an initial state $e^+e^-\gamma^*\gamma^*$, calculable by QED, and a low multiplicity final state. This process is particularly useful in the study of the properties of hadron resonances.

The total cross section σ_T for the formation of a resonance R is given by:

$$\sigma_T(e^+e^- \to e^+e^-R) = \int d^5\mathcal{L}_{\gamma\gamma}\sigma(\gamma^*\gamma^* \to R) \quad (1)$$

where $d^5\mathcal{L}_{\gamma\gamma}$ is the differential luminosity function giving the flux of virtual photons. For quasi-real photons $\sigma(\gamma^*\gamma^* \to R)$ is given by the Breit-Wigner formula:

$$\sigma = 8\pi(2J_R+1)\frac{\Gamma_{\gamma\gamma}(R)\Gamma(R)}{(W^2_{\gamma\gamma}-m^2_R)^2+m^2_R\Gamma^2(R)} \quad (2)$$

where $W_{\gamma\gamma}$ is the invariant mass of the two-photon system, m_R, J_R, $\Gamma_{\gamma\gamma}(R)$ and $\Gamma(R)$ are the mass, spin, two-photon partial width and total width of the resonance, respectively. Combining equations (1) and (2) leads to the proportionality relation

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

where the proportionality factor $\mathcal{K}$ can be evaluated by a Monte Carlo integration. Equation (3) is used to determine the two-photon partial width of the resonance.

The quantum numbers of the resonance must be compatible with the initial state of the two quasi-real photons. A neutral, unflavoured meson with even charge conjugation and helicity-zero or two can be formed. In order to decay into $K^0_S K^0_S$, the resonance must have $J^{PC} = (\text{even})^{++}$.

For the 2^{++}, 1^3P_2 tensor meson nonet, the $f_2(1270)$, the $a^0_2(1320)$ and the $f_2'(1525)$ can be

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formed. However, since these three states are close in mass, interferences must be taken into account. According to SU(3), the $f_2(1270)$ interferes constructively with the $a_2^0(1320)$ in the K^+K^- final state but destructively in the $K^0\bar{K}^0$ final state [1]. Therefore, among the states of the tensor meson nonet, only the $f_2'(1525)$ was observed by previous experiments in the $K_S^0K_S^0$ final state [2].

Since gluons do not couple to photons, a pure glueball couples to two photons only via a box diagram and its two photon width is therefore expected to be very small. A state that can be formed in a gluon rich environment but not in two photon fusion has the typical signature of a glueball.

An analysis of the reaction $e^+e^- \to e^+e^-K_S^0K_S^0$ is presented here, where only the $K_S^0 \to \pi^+\pi^-$ decay is considered. The data correspond to an integrated luminosity of 143 pb^{-1}collected by the L3 detector at LEP at $\sqrt{s} = 91$ GeV and 52 pb^{-1}at $\sqrt{s} = 183$ GeV.

A study of the $K_S^0K_S^0$ final state in two-photon collisions was already published by the L3 Collaboration [3] with a luminosity of 114 pb^{-1}at $\sqrt{s} = 91$ GeV.

The L3 experiment is described in detail elsewhere [4]. In this analysis, the charged particle tracker is mainly used. It is composed by a silicon microstrip vertex detector and a multiwire drift chamber. The events are triggered by a low p_t threshold charged-track trigger [5].

2. Event Analysis

In order to select $e^+e^- \to e^+e^-\pi^+\pi^-\pi^+\pi^-$ events, we require:

- The total energy seen in the calorimeters must be smaller than 30 GeV to exclude annihilation events.

- There must be exactly four good charged tracks in the tracking chamber with a net charge of zero. A good track requires more than 20 hits out of a maximum of 62.

- The total momentum imbalance in the transverse plane must satisfy:

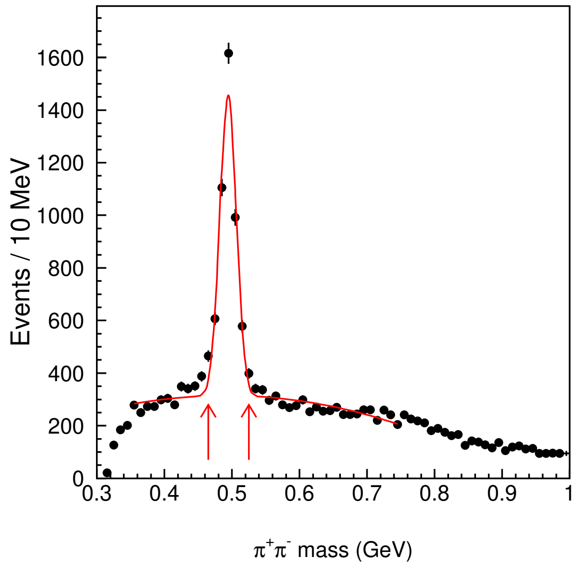

Figure 1. The $\pi^+\pi^-$ mass spectrum for reconstructed secondary vertices which are more than 3 mm from the interaction point. The curve is the result of a fit using a third-order polynomial for the background and a Gaussian for the peak. The arrows indicate the signal region.

$$|\sum \vec{p_T}|^2 < 0.1 \ \ \mathrm{GeV}^2.$$

- Events with photons are rejected. A photon is defined as an isolated shower in the electromagnetic calorimeter with an energy larger than 100 MeV.

The K_S^0's are identified by requiring a secondary vertex distinct from the primary interaction point with a distance greater than 1 mm in the transverse plane. In order to select $K_S^0K_S^0$ exclusive events, we require:

- At least one of the two secondary vertices must be at a distance greater than 3 mm from the interaction point in the transverse plane.

- The angle between the flight direction of each K_S^0 candidate (taken as the line between the interaction point and the secondary vertex in the transverse plane) and

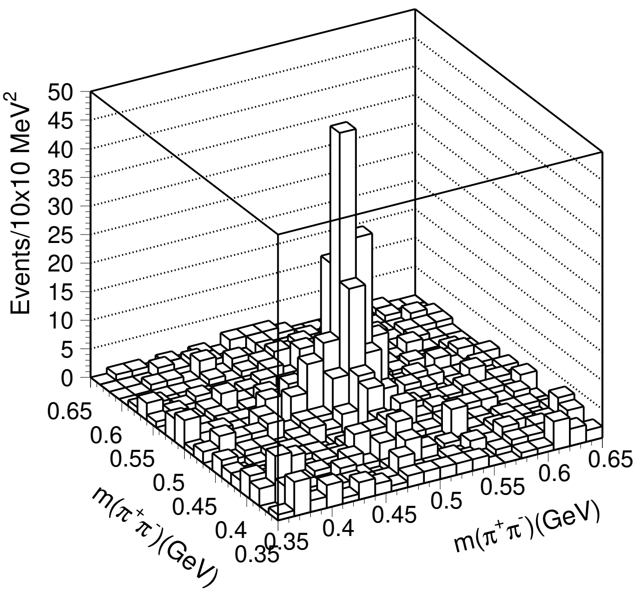

Figure 2. m($\pi^+\pi^-$) at one secondary vertex versus m($\pi^+\pi^-$) at the other secondary vertex. There is a strong enhancement near the $K^0_S K^0_S$ point over a very small background.

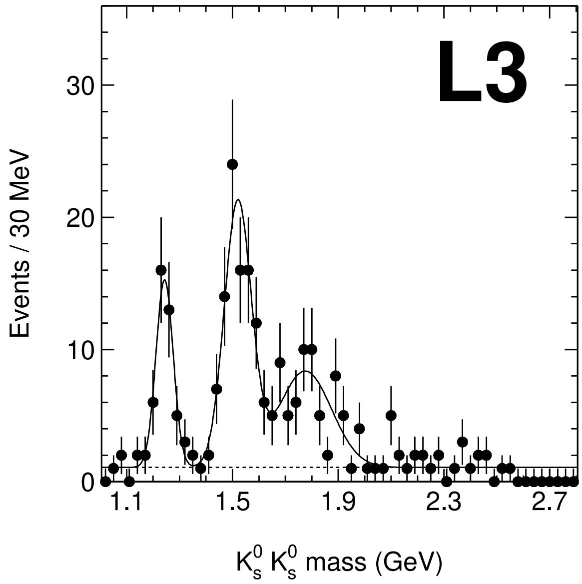

Figure 3. The $K^0_S K^0_S$ invariant mass spectrum: the solid line corresponds to the maximum likelihood fit. The background is fitted by a constant (dashed line) and the three peaks by Gaussian curves.

the total transverse momentum vector of the two outgoing tracks must be less than 0.3 rad.

- Since the two K^0_S's are produced back-to-back in the transverse plane, the angle between the flight directions of the two K^0_S candidates in this plane is required to be $\pi \pm 0.3$ rad.

Fig. 1 shows the $\pi^+\pi^-$ mass distribution with a 3 mm vertex cut for the K^0_S. Fitting this distribution, a mass resolution of $\sigma = 9.6 \pm 0.8$ MeV is found, consistent with the Monte Carlo simulation. The invariant masses of the two K^0_S candidates must be inside a circle of 40 MeV radius around the $K^0_S K^0_S$ point (Fig. 2).

With these selection criteria, 253 events are found in the data sample. The background due to misidentified K^0_S pairs is estimated to be negligible by a study of the K^0_S sidebands. The background due to the $K^0_S K^{\pm}\pi^{\mp}$ final state is determined to be negligible by a Monte Carlo simulation. The beam-gas and beam-wall contributions are found negligible.

The resulting $K^0_S K^0_S$ invariant mass spectrum is shown in Fig. 3. The spectrum is dominated by the $f'_2(1525)$ resonance. The $f_2(1270)-a^0_2(1320)$ region shows the destructive $f_2-a^0_2$ interference in the $K^0_S K^0_S$ final state [1]. A clear enhancement is visible in the 1750 MeV region. No excess is present around 2230 MeV.

A maximum likelihood fit using three Gaussians plus a constant is then performed on the $K^0_S K^0_S$ mass spectrum. The masses and widths of the Gaussians are left free in the fit. The fit is shown in Fig. 3 and the results are summarised in Table 1.

The $f'_2(1525)$ statistical significance is about 8 standard deviations, the statistical significance of the enhancement around 1750 MeV is about 6 standard deviations. From the fit 38±7 events are found in the f_2-a_2 region.

In order to correct the data for the detector acceptance and efficiency, a Monte Carlo procedure

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

	$f'_2(1525)$	1750 MeV Region
Mass (MeV)	1520 ± 7	1770 ± 20
Width (MeV)	119 ± 15	200 ± 50
Nb. of events	85 ± 11	61 ± 10

is used [6]. The nominal $f'_2(1525)$ parameters [7] are used for the generation. The angular distribution of the two K^0_S's in the two-photon center-of-mass system is generated according to phase space i.e. uniform in $\cos\theta^*$ and in ϕ^*, where θ^* and ϕ^* are the polar and azimuthal angles taking the z direction parallel to the electron beam. In order to take into account the helicity of a spin-two resonance, a weight is assigned to each generated event according to the weight functions: $w = (\cos^2\theta^* - \frac{1}{3})^2$ for the helicity-zero contribution and $w = \sin^4\theta^*$ for the helicity-two contribution.

All the events are passed through the full detector simulation program and are reconstructed following the same procedure used for the data. Although the detector acceptance is rather high (15% for helicity-zero and 30% for helicity-two), the trigger efficiency (83%) and the analysis cuts ($\sim$ 30%) give a total efficiency of 3.9% for helicity-zero and 7.6% for helicity-two for the $f'_2(1525)$ at $\sqrt{s}$ = 91 GeV. At $\sqrt{s}$ = 183 GeV the total efficiencies are 3.1% and 7.2% respectively.

3. Results

3.1. The $f'_2(1525)$ tensor meson

In order to determine the helicity state, a study of the angular distribution of the two K^0_S's from f'_2 decay in the two-photon center of mass is performed. The experimental polar angle distribution is compared with the Monte Carlo in Fig. 4 for both the helicity-zero and helicity-two cases. The Monte Carlo distributions are normalised to the same number of events as in the data and no background subtraction is done. The χ^2 values for the helicity-zero and helicity-two hypotheses are 81 and 7 for nine degrees of freedom respectively. Thus pure helicity-zero is excluded

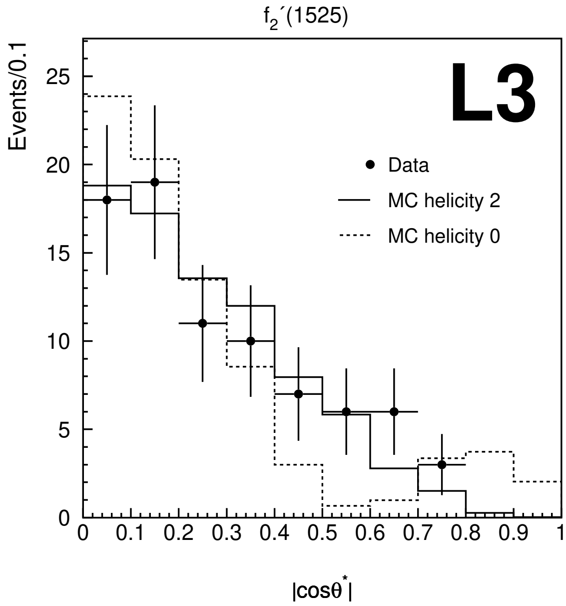

Figure 4. The $K^0_S K^0_S$ polar angular distribution compared with the Monte Carlo distributions for the hypothesis of a pure helicity-zero and helicity-two contribution for the $f'_2(1525)$. The Monte Carlo curves are normalised to the same number of events as the data.

and helicity-two is largely dominant, in agreement with the theoretical predictions [8].

The total cross section σ_T times the branching ratio Br into $K\bar{K}$ for the $f'_2(1525)$ is measured using the formula

$$\sigma_T \times \mathrm{Br} = \frac{N_{obs} - N_{back}}{\mathcal{L}\varepsilon} \quad (4)$$

where $\mathcal{L}$ is the integrated luminosity and ε is the total efficiency. The number of signal events $N_{obs} - N_{back}$ is determined from the maximum likelihood fit. From our data only $\sigma_T \times \mathrm{Br}(f'_2 \to K^0_S K^0_S \to \pi^+\pi^-\pi^+\pi^-)$ can be measured. Using the PDG [7] value for $\mathrm{Br}(K^0_S \to \pi^+\pi^-)$ and $\mathrm{Br}(f'_2 \to K\bar{K}) = 4\times\mathrm{Br}(f'_2 \to K^0_S K^0_S)$ from isospin symmerty, $\sigma_T \times \mathrm{Br}(f'_2 \to K\bar{K})$ can be determined.

The product $\Gamma_{\gamma\gamma}(f'_2)\times$ $\mathrm{Br}(f'_2 \to K\bar{K})$ is measured from the cross section using the formula

$$\Gamma_{\gamma\gamma}(f'_2) \times \mathrm{Br}(f'_2 \to K\bar{K}) = \frac{\sigma_T \times \mathrm{Br}(f'_2 \to K\bar{K})}{\mathcal{K}} \quad (5)$$

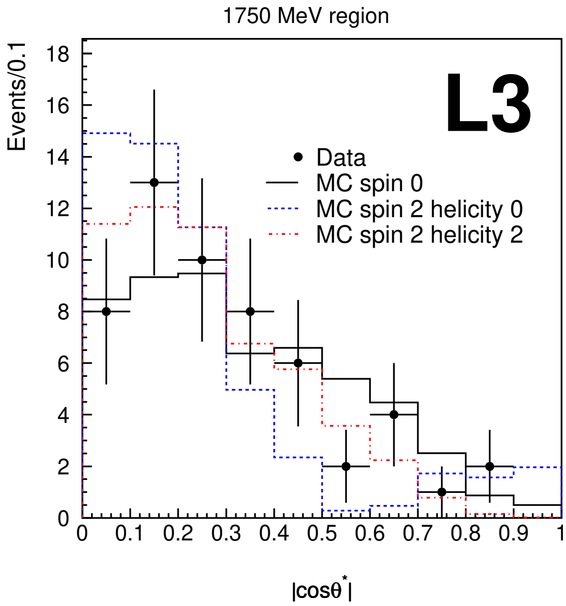

Figure 5. The $K_S^0K_S^0$ polar angular distribution compared with the Monte Carlo distributions for the hypothesis of a pure spin two helicity-zero, spin two helicity-two and spin zero contribution in the 1750 MeV region. The Monte Carlo curves are normalised to the same number of events as the data.

where the proportionality factor $\mathcal{K}$ is evaluated by Monte Carlo integration. Two separate measurements are performed for data collected at $\sqrt{s}$ = 91 GeV and $\sqrt{s}$ = 183 GeV. The results are in very good agreement with the published value [3] $\Gamma_{\gamma\gamma}(f_2')\times Br(f_2' \rightarrow K\bar{K}) = (0.093 \pm 0.018 \pm 0.022)$keV under the hypothesis of a pure helicity-two state.

3.2. The 1750 MeV region

The enhancement around 1750 MeV may be due to the formation of a radially excited f_2' state, according to theoretical predictions [9]. However, the 1750 MeV region is very interesting especially looking at the recent results by the Crystal Barrel Collaboration [10]. They report the observation of three J^{PC}=0^{++} states the $a_0(1450)$, the $f_0(1370)$ and the $f_0(1500)$. In the scenario presented in [11] 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 be isoscalar members of the nonet. The $f_0(1370)$ is very likely mainly composed by u and d quarks while the $f_0(1500)$ is compatible with the ground state scalar glueball expected around 1500 MeV. This hypothesis includes the prediction of a further scalar state, the $f_0'(1500\text{-}1800)$, mainly composed by s quarks. This state will couple strongly to $K\bar{K}$ and its discovery is essential to support the $f_0(1500)$ glueball nature.

In order to investigate the spin of the 1750 MeV region, the angular distribution of the two K_S^0's in the two-photon center of mass is studied. The polar angle distribution is compared in Fig. 5 with the Monte Carlo predictions for the spin two helicity-zero (J=2, λ=0), spin two helicity-two (J=2, λ=2) and spin zero (J=0) cases. The Monte Carlo distributions are normalised to the same number of events as in the data and no background subtraction is done. The χ^2 values are 50, 26 and 7 for nine degrees of freedom for J=2 λ=0, J=2 λ=2 and J=0 hypotheses respectively. J=0 assignment is found 3.2 times more probable than J=2 λ=2.

Experimental indications for a scalar state around 1750 MeV decaying into K^+K^- [12] and $\eta\eta$ [13] have been recently found.

3.3. The 2230 MeV region

The BES Collaboration confirmed the previous observation by the Mark III Collaboration of a resonance, the $\xi(2230)$ [14], produced in radiative decays of the J/ψ particle. Due to its narrow width and its production in gluon rich environment, this state is considered a glueball candidate. Its mass is consistent with the lattice QCD prediction for the ground state tensor glueball.

Since gluons do not couple to photons, the two-photon width is expected to be small for a glueball. To make this statement more quantitative, a parameter called stickiness [15] can be introduced for a state X:

$$S_X = N_l \left(\frac{m_X}{k_{J/\psi\rightarrow\gamma X}}\right)^{2l+1} \frac{\Gamma(J/\psi \rightarrow \gamma X)}{\Gamma(X \rightarrow \gamma\gamma)} \quad (6)$$
$$\sim \frac{|<X|gg>|^2}{|<X|\gamma\gamma>|^2}$$

where m_X is the mass of the state, $k_{J/\psi\to\gamma X}$ is the energy of the photon from a radiative J/ψ decay in the J/ψ rest frame and l is the angular momentum between the two gluons. For spin two states $l = 0$. N_l is a normalisation factor that can be calculated assuming by definition the stickiness of the $\mathrm{f}_2(1270)$ tensor meson to be 1.

Using the same method adopted for the $\mathrm{f}'_2(1525)$, a Monte Carlo simulation is used to determine the detection efficiency for the $\xi(2230)$. For the simulation we use values for the mass and the width determined by combining the results by Mark III and BES. A mass resolution of σ= 60 MeV is found by fitting a Gaussian to the $\mathrm{K}^0_S\mathrm{K}^0_S$ Monte Carlo spectrum. The total detection efficiency is measured to be 16.5% at $\sqrt{s}$ =91 GeV and 9.3% at $\sqrt{s}$ =183 GeV under the hypothesis of a pure helicity-two contribution. The signal region is chosen to be $\pm 2\sigma$ around the $\xi(2230)$ mass. In order to evaluate the background two sidebands of 2σ are considered. At $\sqrt{s}$ =91 GeV and at $\sqrt{s}$ =183 GeV, 6 and 2 events are found in the signal region respectively. Fitting a constant in the sideband region, the expected background are evaluated to be 4.9 and 7.9 events. Using the standard method [7] for extracting an upper limit for a Poisson distribution with background, we determine upper limits of 7.3 and 3.6 events respectively at 95% C.L. Using the same method adopted for measuring the two-photon width of the $\mathrm{f}'_2(1525)$, an upper limit of $\Gamma_{\gamma\gamma}(\xi(2230))\times\mathrm{Br}(\xi(2230) \to \mathrm{K}^0_S\mathrm{K}^0_S)$ is derived combining the results from the two values of $\sqrt{s}$. The combination is performed using a Monte Carlo technique. We obtain $\Gamma_{\gamma\gamma}(\xi(2230))\times\mathrm{Br}(\xi(2230) \to \mathrm{K}^0_S\mathrm{K}^0_S) < 3$ eV at 95% C.L. under the hypothesis of a pure helicity-two state.

Combining the results reported by BES and Mark III for the $\Gamma(J/\psi \to \gamma\xi)\times\mathrm{Br}(\xi \to \mathrm{K}^0_S\mathrm{K}^0_S)$ and our upper limit on $\Gamma(\xi \to \gamma\gamma)\times\mathrm{Br}(\xi \to \mathrm{K}^0_S\mathrm{K}^0_S)$, we obtain a lower limit on the stickiness $S_{\xi(2230)}$ >33 at 95% C.L. Errors are taken into account by a Monte Carlo calculation. This value is much larger than the values measured for all the established $q\bar{q}$ states.

4. Conclusions

The reaction $\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^-\gamma^*\gamma^* \to \mathrm{e}^+\mathrm{e}^-\mathrm{K}^0_S\mathrm{K}^0_S$ is studied with the L3 detector at LEP. The spectrum is dominated by the $\mathrm{f}'_2(1525)$ tensor meson. The angular distribution excludes pure helicity-zero and shows that helicity-two is largely dominant. The $\Gamma_{\gamma\gamma}(\mathrm{f}'_2) \times \mathrm{Br}(\mathrm{f}'_2 \to \mathrm{K}\bar{\mathrm{K}})$ is found to be consistent with the previously published value [3]. Clear evidence for destructive f_2-a_2 interference is observed. An enhancement of about 6 standard deviations is observed around 1750 MeV. It may be due to the formation of a radial recurrence of the $\mathrm{f}'_2(1525)$ tensor meson (J=2, λ =2) but the observed angular distribution favours the J=0 assignment. Therefore the enhancement may be due to the formation of the $s\bar{s}$ member of the 0^{++} meson nonet. The latter case strongly supports the glueball nature of the $\mathrm{f}_0(1500)$ [11]. No signal is present in the region of the $\xi(2230)$ glueball candidate. We obtain the upper limit $\Gamma_{\gamma\gamma}(\xi(2230))\times\mathrm{Br}(\xi(2230) \to \mathrm{K}^0_S\mathrm{K}^0_S) < 3$ eV at 95% C.L. under the hypothesis of a pure helicity-two state.

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REFERENCES

1. H. J. Lipkin, *Nucl. Phys.* **B 7** (1968) 321.
2. TASSO Collab., M. Althoff et al., *Z. Phys.* **C 29** (1985) 189; PLUTO Collab., C. Berger et al., *Z. Phys.* **C 37** (1988) 329; CELLO Collab., H. J. Behrend et al., *Z. Phys.* **C 43** (1989) 91.
3. L3 Collab., M. Acciarri et al., *Phys. Lett.* **363 B** (1995) 118; S. Braccini, “Studio delle interazioni fotone-fotone con il rivelatore L3 al LEP”, Tesi di Laurea, University of Florence, Italy (1995).
4. L3 Collab., B. Adeva et al., *Nucl. Inst. Meth.* **A 289** (1990) 35; L3 Collab., O. Adriani et al., *Phys. Rep.* **236** (1993) 1.

5. P. Béné et al., *Nucl. Inst. Meth.* **A 306** (1991) 150.
6. F. L. Linde, "Charm Production in Two-Photon Collisions", Ph. D. Thesis, Rijksuniversiteit Leiden, (1988).
7. Particle Data Group, *Phys. Rev.* **D 54** (1996) 1.
8. B. Schrempp-Otto et al., *Phys. Lett.* **36 B** (1971) 463; G. Köpp et al., *Nucl. Phys.* **B 70** (1974) 461; P. Grassberger and R. Kögerler, *Nucl. Phys.* **B 106** (1976) 451.
9. C. R. Münz, *Nucl. Phys.* **A 609** (1996) 364.
10. CRYSTAL BARREL Collab., *Phys. Lett.* **333 B** (1994) 277; *Phys. Lett.* **342 B** (1995) 433; *Phys. Lett.* **353 B** (1995) 571.
11. C. Amsler and F. E. Close, *Phys. Rev.* **D 53** (1996) 295 and references therein.
12. BES Collab., *Phys. Rev. Lett.* **77** (1996) 3959.
13. D.V. Bugg, private comunication; A.V. Anisovitch et al., submitted to *Phys. Lett.* B.
14. BES Collab., *Phys. Rev. Lett.* **76** (1996) 3502; Mark III Collab., *Phys. Rev. Lett.* **56** (1986) 107.
15. M. Chanowitz, "Resonances in Photon-Photon Scattering", Proceedings of the VIth International Workshop on Photon-Photon Collisions, World Scientific, 1984.