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$K^0_s K^0_s$ Final State in Two-Photon Collisions and Glueball Searches

The L3 Collaboration

Abstract

The $K^0_S K^0_S$ final state in two-photon collisions is studied with the L3 detector at LEP using data collected at centre-of-mass energies from 91 GeV to 202 GeV. The mass spectrum is dominated by the formation of the $f'_2(1525)$ tensor meson in the helicity two state. Clear evidence for destructive $f_2(1270)$-$a_2(1320)$ interference is observed. In addition a clear signal for $f_J(1750)$ is observed. The study of the decay angular distribution in the 1750 MeV mass region shows that the spin two helicity two wave is dominant. No signal is observed in the region around 2.2 GeV. An upper limit for the two-photon partial width of the $\xi(2230)$ tensor glueball candidate is derived.

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1 Introduction

Electron-positron storage rings are a good laboratory 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 characterized 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 cross section for the formation of a resonance R is given by:

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

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:

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

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

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

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 from the measurement of the cross section. 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, $J\neq1$ and helicity-zero (λ=0) or two (λ=2) can be formed. In order to decay into $K^0_SK^0_S$, a resonance must have $J^{PC} = (\text{even})^{++}$.

For the 2^{++}, 1^3P_2 tensor meson nonet, the $f_2(1270)$, the $a_2^0(1320)$ and the $f_2'(1525)$ can be 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].

Since gluons do not couple directly to photons, the two photon width of a glueball is 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. According to lattice QCD predictions [2], the ground state glueball has $J^{PC}= 0^{++}$ and a mass between 1400 and 1800 MeV. The 2^{++} tensor glueball is expected in the mass region around 2200 MeV. Since several 0^{++} states have been observed in the 1400-1800 MeV mass region, the scalar ground state glueball can mix with nearby quarkonia, making the search for the scalar glueball and the interpretation of the scalar meson nonet a complex problem [3] [4] [5].

In this paper an analysis of the reaction $e^+e^- \to e^+e^-K^0_SK^0_S$ is presented, where only the $K^0_S \to \pi^+\pi^-$ 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, 52 pb^{-1}at $\sqrt{s} = 183$ GeV and 393 pb^{-1}at $\sqrt{s} = 189-202$ GeV. A study of the $K^0_SK^0_S$ final state in two-photon collisions was already published by the L3 Collaboration [8] with a luminosity of 114 pb^{-1}at $\sqrt{s} = 91$ GeV.

The analysis described in this paper is mainly based on the central tracking system and the high resolution electromagnetic calorimeter. The L3 detector is described in detail elsewhere [6]. The events used in this analysis are collected predominantly by the charged particle track triggers [7].

2 Event selection

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 12 hits out of a maximum of 62 and a transverse momentum greater than 100 MeV.
- The total momentum imbalance in the transverse plane must satisfy: $|\sum \overrightarrow{p_T}|^2 < 0.1$ 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 signal must be present in more than two crystals, in order to reduce the noise contribution. The ratio between the energies deposited in the hadronic and electromagnetic calorimeters must be less than 0.2. There must be no charged track in a cone of 200 mrad around the photon direction.

The K^0_S's are identified by requiring a secondary vertex with a distance greater than 1 mm from the primary interaction point in the transverse plane. In order to select $K^0_SK^0_S$ 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^0_S candidate (taken as the line between the interaction point and the secondary vertex in the transverse plane) and 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. 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 centred on the $K^0_SK^0_S$ signal region (Fig. 2).

With these selection criteria, 801 events are found in the data sample. The background due to misidentified K^0_S pairs is estimated to be less than 5% by a study of the K^0_S sidebands. The backgrounds due to the $K^0_SK^\pm\pi^\mp$ final state and to beam-gas and beam-wall interactions are found negligible.

3 Results

The resulting $K^0_SK^0_S$ invariant mass spectrum is shown in Fig. 3. The spectrum is dominated by the formation of the $f'_2(1525)$ tensor meson. The mass region between 1100 and 1400 MeV shows destructive $f_2(1270)$–$a^0_2(1320)$ interference in the $K^0_SK^0_S$ final state [1]. A clear signal is visible in the 1750 MeV mass region. No excess is observed around 2230 MeV.

A maximum likelihood fit using three Breit-Wigner functions plus a second order polynomial for the background is performed on the full $K^0_S K^0_S$ mass spectrum. A χ^2 of 51.1 for 47 degrees of freedom is obtained. The confidence level is 31.7%. The fit is shown in Fig. 3 and the results are summarized in Table 1. The parameters of the $f'_2(1525)$ are in good agreement with the PDG [10] values for the mass (1525±5 MeV) and for the width (76±10 MeV), when the experimental resolution σ= 29 ± 4 MeV is taken into account.

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

In order to correct the data for the detector acceptance and efficiency, a Monte Carlo procedure is used [9]. The nominal $f'_2(1525)$ parameters [10] 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 (J=0) 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 spin-two helicity-zero (J=2, λ=0) contribution and $w = \sin^4\theta^*$ for the spin-two helicity-two (J=2, λ=2) contribution. All the events are passed through the full detector simulation program and are reconstructed following the same procedure used for the data.

In order to determine the spin and the helicity state in the mass region of the $f'_2(1525)$, 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 (J=0), (J=2, λ=0) and (J=2, λ=2) cases. A χ^2 is calculated on the distribution normalizing the Monte Carlo distributions to the same number of events as in the data. Bins are grouped in order to have at least 10 entries both in the data and in the Monte Carlo. The confidence level values for the (J=0) and (J=2, λ=0) hypotheses are less then 10^{-6}. For the (J=2, λ=2) hypothesis a confidence level of 99.9% is obtained. Thus data are in agreement with a pure spin two, helicity two wave contribution in agreement with the theoretical predictions [11].

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

$$\sigma_{measured} = \frac{N_{obs} - N_{back}}{\mathcal{L} \cdot \varepsilon} \tag{4}$$

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 (Table 1 and 2). From our data only $\sigma \times \mathrm{Br}(f'_2 \to K^0_S K^0_S \to \pi^+\pi^-\pi^+\pi^-)$ is measured. Using the PDG [10] 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 symmetry, $\sigma \times \mathrm{Br}(f'_2 \to K\bar{K})$ is 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

$$\Gamma_{\gamma\gamma}(f'_2) \times \mathrm{Br}(f'_2 \to K\bar{K}) = \frac{\sigma_{measured}}{\mathcal{K}} \cdot \frac{4}{\mathrm{Br}(K^0_S \to \pi^+\pi^-)} \tag{5}$$

where the proportionality factor $\mathcal{K}$ is evaluated by Monte Carlo integration.

The total detection efficiency ε is determined by Monte Carlo under the hypothesis of a pure (J=2, λ=2) state. It includes detector acceptance, trigger and selection criteria. Three separate measurements are performed for data collected at $\sqrt{s} = 91$ GeV, $\sqrt{s} = 183$ GeV and $\sqrt{s} = 189 - 202$ GeV. The luminosity, the $\mathcal{K}$ factor, the total efficiency and the measured $\Gamma_{\gamma\gamma}(f'_2) \times \mathrm{Br}(f'_2 \to K\bar{K})$ for the three data samples are reported in Table 2. The main source of

systematic error comes from the fitting procedure. A contribution of 10% is evaluated by varying the shape of the background. Other sources of systematic errors are trigger efficiency (5%) and cut variations (7%). Combining the three measurements, the value $\Gamma_{\gamma\gamma}(f_2') \times \mathrm{Br}(f_2' \to K\bar{K}) = 0.076 \pm 0.006 \pm 0.011$ keV is obtained. This result is in good agreement with the value $\Gamma_{\gamma\gamma}(f_2'(1525)) \times \mathrm{Br}(f_2'(1525) \to K\bar{K}) = (0.093 \pm 0.018 \pm 0.022)$ keV previously published by L3 [8].

3.2 The 1750 MeV region

To investigate the spin composition of the 1750 MeV mass region the angular distribution of the two K^0_S's in the two-photon center of mass is studied by comparing data and Monte Carlo distributions. A resonance with a mass of 1750 MeV and a total with of 200 MeV is generated with the same Monte Carlo procedure adopted for the $f_2'(1525)$. The total detection efficiencies for the various spin and helicity hypotheses are reported in Table 3.

The polar angle distribution is compared in Fig. 5 with the Monte Carlo predictions for (J=2, λ=0), (J=2, λ=2) and (J=0) cases. A χ^2 is calculated on the distribution normalizing the Monte Carlo to the same number of events as in the data. Bins are grouped in order to have at least 10 entries both in the data and in the Monte Carlo. The confidence level for the (J=2, λ=0) hypothesis is less then 10^{-6} while for the (J=2, λ=2) and (J=0) hypotheses confidence levels of 33% and 8% are found respectively. The (J=2, λ=2) wave is therefore dominant. A fit is performed by considering both the (J=2, λ=2) and the (J=0) waves. A confidence level of 84% is found for a (J=0) contribution of 24±16%. The BES Collaboration [12] reported the presence of both 2^{++} and 0^{++} waves in the 1750 MeV region in K^+K^- in the reaction $e^+e^- \to J/\psi \to K^+K^-\gamma$. The (J=0) fraction is estimated to be 30±10%, in good agreement with our measurement.

The signal around 1750 MeV may be due to the formation of a radially excited f_2' state. The f_2'' is in fact predicted to have a mass of 1810 MeV and a two-photon width of 1.0 keV [13]. The 1750 MeV region is also very interesting for glueball searches and for the understanding of the 0^{++} scalar meson nonet. In the scenario presented in [3] the $f_0(1500)$ is indicated as the scalar 0^{++} ground state glueball. 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.

3.3 The 2230 MeV region

The BES Collaboration confirmed the 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 directly 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] is introduced for a state X:

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

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 orbital angular momentum between the two gluons.

For spin two states $l = 0$. N_l is a normalization factor that can be calculated assuming by definition the stickiness of the $f_2(1270)$ tensor meson to be 1.

A Monte Carlo simulation is used to determine the detection efficiency for the $\xi(2230)$. For the simulation we use a mass of 2230 MeV and a total width of 20 MeV. A mass resolution of σ= 60 MeV is found. The total detection efficiency is reported in Table 4 for the three different data samples, 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. The number of events in the signal region (N_{ev}) and the expected background (N_{bkg}) evaluated with a linear fit in the sideband region are reported in Table 4. Using the standard method [10] for extracting an upper limit for a Poisson distribution with background, we determine the upper limits at 95% C.L. on the number of events (N_{ul}). The results are reported in Table 4. Using the same method adopted for measuring the two-photon width of the $f_2'(1525)$, an upper limit of $\Gamma_{\gamma\gamma}(\xi(2230))\times \mathrm{Br}(\xi(2230) \to K^0_S K^0_S)$ is derived for each data sample. The three probability distributions for $\Gamma_{\gamma\gamma}(\xi(2230))\times \mathrm{Br}(\xi(2230) \to K^0_S K^0_S)$ are then combined by using a Monte Carlo technique. The errors on the detection efficiency are taken into account by convoluteing the corresponding gaussian function with the probability distribution. We obtain $\Gamma_{\gamma\gamma}(\xi(2230))\times \mathrm{Br}(\xi(2230) \to K^0_S K^0_S) < 1.4$ 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 $\Gamma(J/\psi \to \gamma\xi)\times \mathrm{Br}(\xi \to K^0_S K^0_S)$=1.9$\pm$0.5 eV and our upper limit on $\Gamma(\xi \to \gamma\gamma)\times \mathrm{Br}(\xi \to K^0_S K^0_S)$, we obtain a lower limit on the stickiness $S_{\xi(2230)}$ >73 at 95% C.L. The large error on $\Gamma(J/\psi \to \gamma\xi)\times \mathrm{Br}(\xi \to K^0_S K^0_S)$ is taken into account by convoluteing the corresponding gaussian function with the probability distribution of $\Gamma_{\gamma\gamma}(\xi(2230))\times \mathrm{Br}(\xi(2230) \to K^0_S K^0_S)$ using a Monte Carlo technique. This value is much larger than the values measured for all the well established $q\bar{q}$ states and supports the interpretation of the $\xi(2230)$ as the tensor glueball. A further confirmation of its existence in other gluon rich environments becomes now very important.

4 Conclusions

The reaction $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^- K^0_S K^0_S$ is studied with the L3 detector at LEP. The spectrum is dominated by the $f_2'(1525)$ tensor meson. The angular distribution is consistent with its formation in a pure spin-two helicity-two state. The two-photon width is measured to be $\Gamma_{\gamma\gamma}(f_2') \times \mathrm{Br}(f_2' \to K\bar{K})$= 0.076 $\pm$ 0.006 $\pm$ 0.011 keV. Clear evidence for destructive $f_2(1270)$-$a_2(1320)$ interference is observed. Around 1750 MeV a clear signal is observed. The spin-two helicity-two wave is found dominant in this mass region. The presence of both spin two and spin zero waves is possible. No signal is present in the mass region of the $\xi(2230)$ glueball candidate. We obtain the upper limit $\Gamma_{\gamma\gamma}(\xi(2230))\times \mathrm{Br}(\xi(2230) \to K^0_S K^0_S) < 1.4$ eV at 95% C.L. under the hypothesis of a pure spin-two helicity-two state.

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	f_2-a_2 Region	$f_2'(1525)$	1750 MeV Region
Mass (MeV)	1239 ± 6	1523 ± 6	1767 ± 14
Width (MeV)	78 ± 19	100 ± 15	187 ± 60
Nb. of events	123 ± 22	331 ± 37	220 ± 55
Mass interval (MeV)	1100 – 1400	1400 – 1640	1640 – 2000
$N_{obs} - N_{back}$	–	247 ± 28	149 ± 37

Table 1: Results from the maximum likelihood fit on the full $K^0_S K^0_S$ mass spectrum.

$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$\mathcal{K}$ (pb/keV)	ε (%)	$N_{obs} - N_{back}$	$\Gamma_{\gamma\gamma}(f_2') \times \mathrm{Br}(f_2' \to KK)$ (keV)
91	142.6	605	5.0	42.0 ± 7.8	$0.083 \pm 0.015 \pm 0.012$
183	51.9	841	6.4	24.4 ± 6.2	$0.074 \pm 0.018 \pm 0.011$
189-202	392.8	846	6.4	188.5 ± 20.5	$0.075 \pm 0.008 \pm 0.011$

Table 2: The measurement of the two-photon width of the $f_2'(1525)$ for the three data samples.

$\sqrt{s}$ (GeV)	J=0	J=2, $\lambda = 2$	J=2, $\lambda = 0$
91	6.0%	8.2%	4.1%
183	6.1%	8.4%	4.2%
189-202	6.3%	8.8%	4.5%

Table 3: The total detection efficiency in the 1750 MeV mass region for the various spin and helicity hypotheses.

$\sqrt{s}$(GeV)	$\mathcal{L}$(pb^{-1})	$\mathcal{K}$(pb/keV)	ε(%)	N_{ev}	N_{bkg}	N_{ul}	$\Gamma_{\gamma\gamma}(\xi) \times \mathrm{Br}(K^0_S K^0_S)$(eV)
91	142.6	161	16.6	6	4.9	7.3	4.1
183	51.9	227	15.2	2	7.9	3.6	4.2
189-202	392.8	230	14.1	34	37.5	11.9	2.1

Table 4: The upper limits at 95% C.L. on the two-photon width of the $\xi(2230)$ for the three data samples.

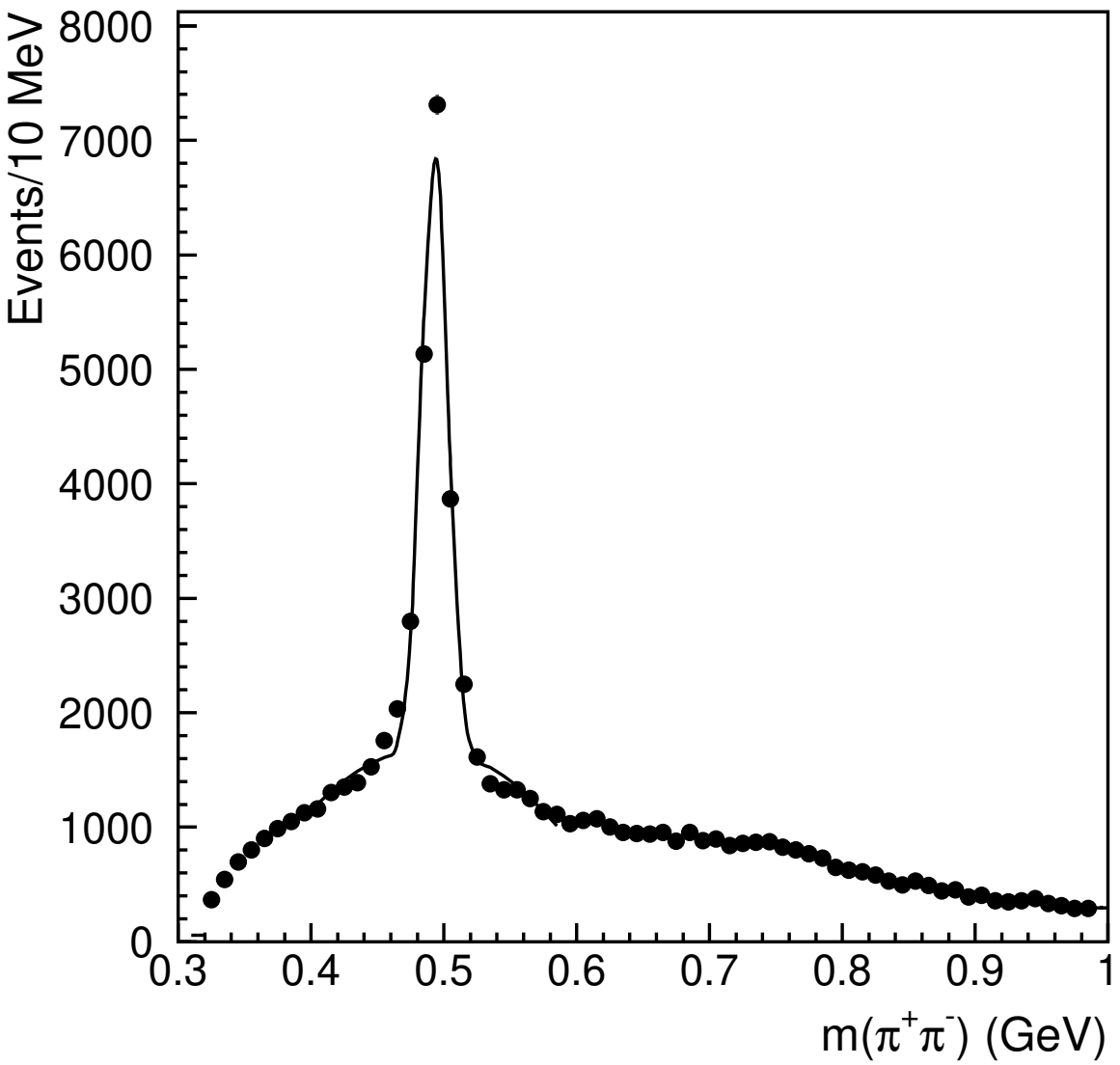

Figure 1: The $\pi^+\pi^-$ mass spectrum for reconstructed secondary vertices which are more than 3 mm from the interaction point.

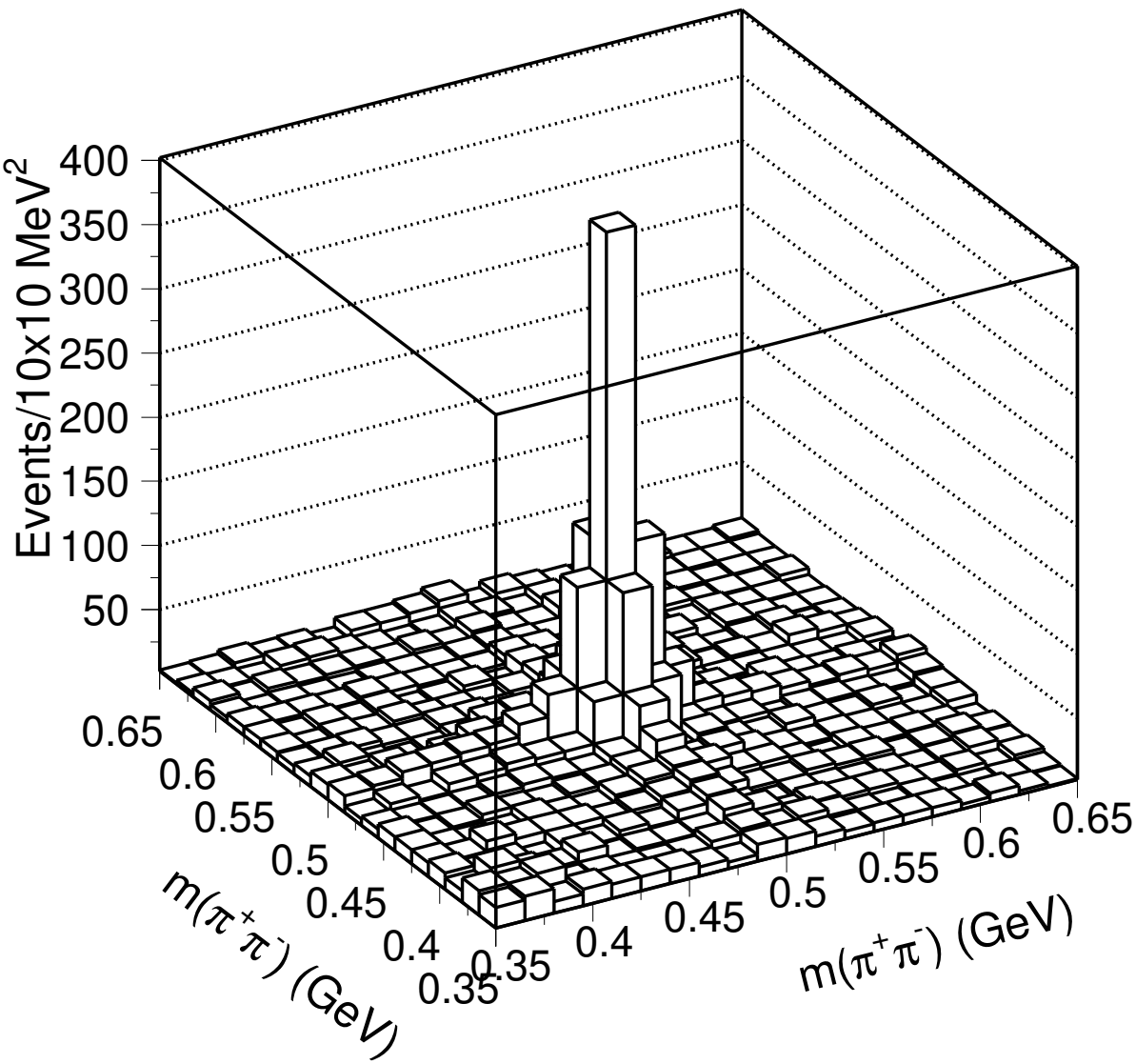

Figure 2: The mass of a K^0_S candidate versus the mass of the other candidate (two entries per event). There is a strong enhancement corresponding to the $K^0_S K^0_S$ signal over a small background.

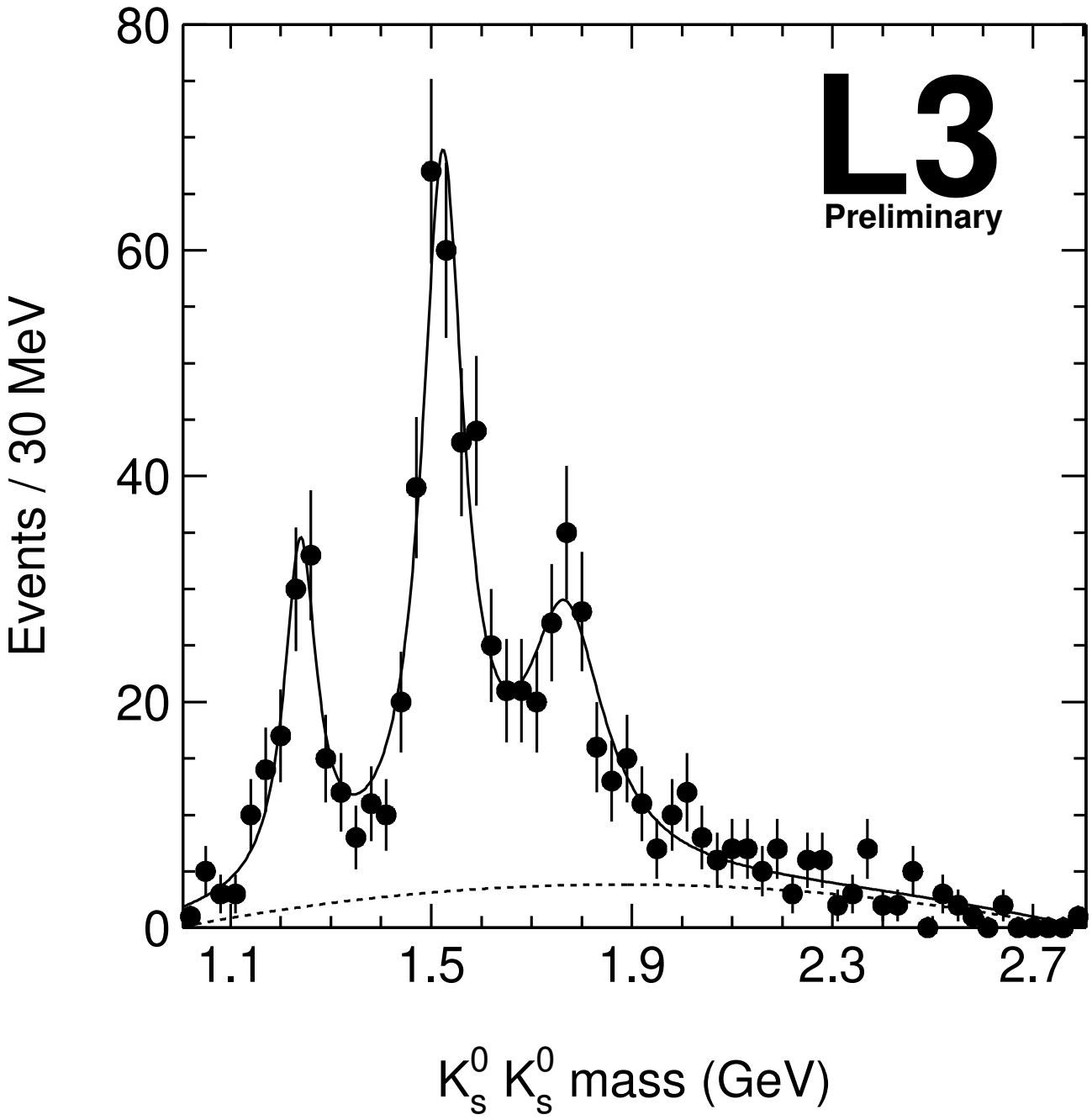

Figure 3: The $K^0_S K^0_S$ invariant mass spectrum: the solid line corresponds to the maximum likelihood fit. The background is fitted by a second order polynomial (dashed line) and the three peaks by Breit-Wigner functions.

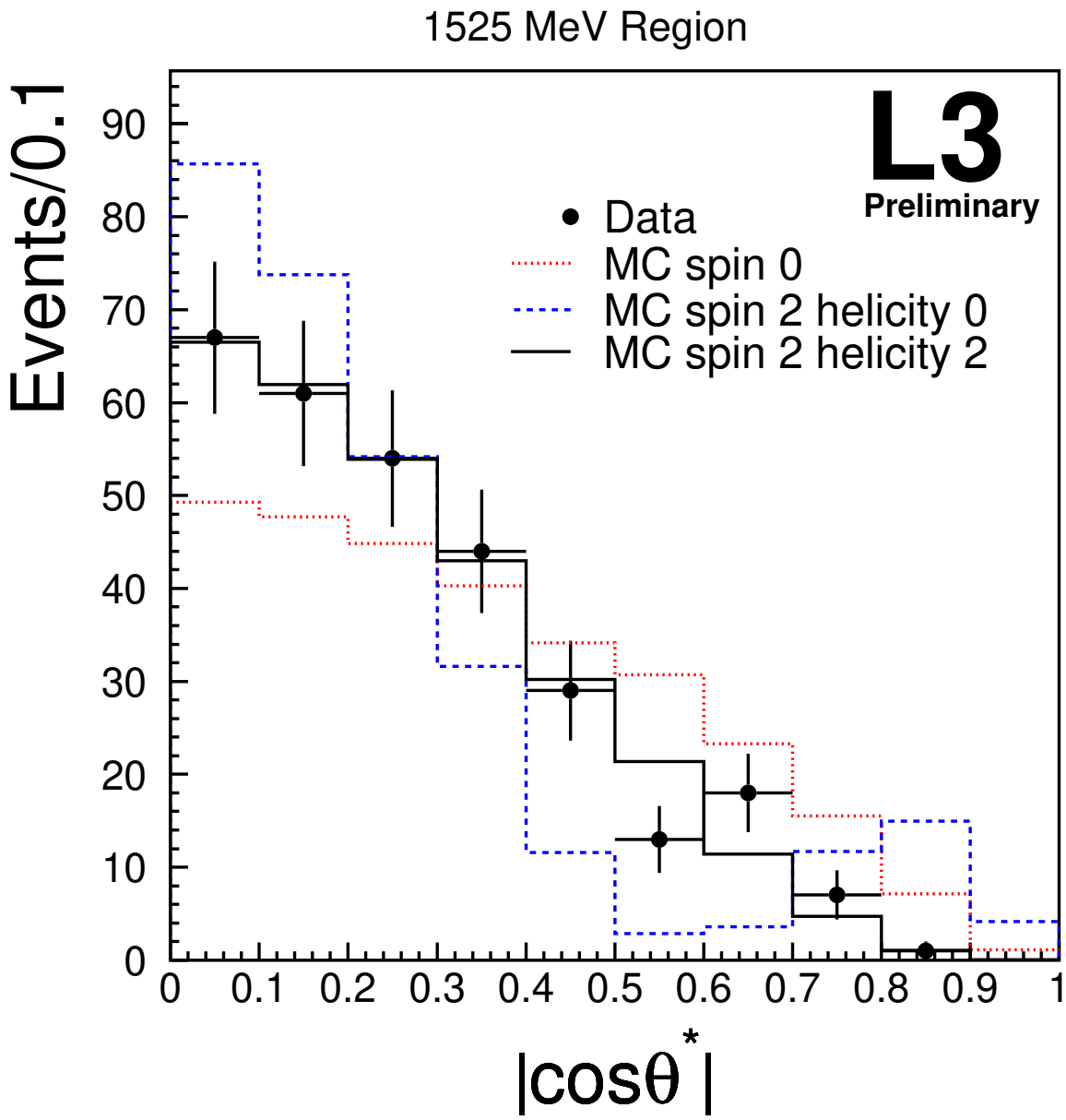

Figure 4: The $K^0_S K^0_S$ polar angular distribution compared with the Monte Carlo distributions for the hypothesis of a pure spin zero, spin two helicity-zero and spin two helicity-two contribution for the $f'_2(1525)$. The Monte Carlo curves are normalized to the same number of events as the data.

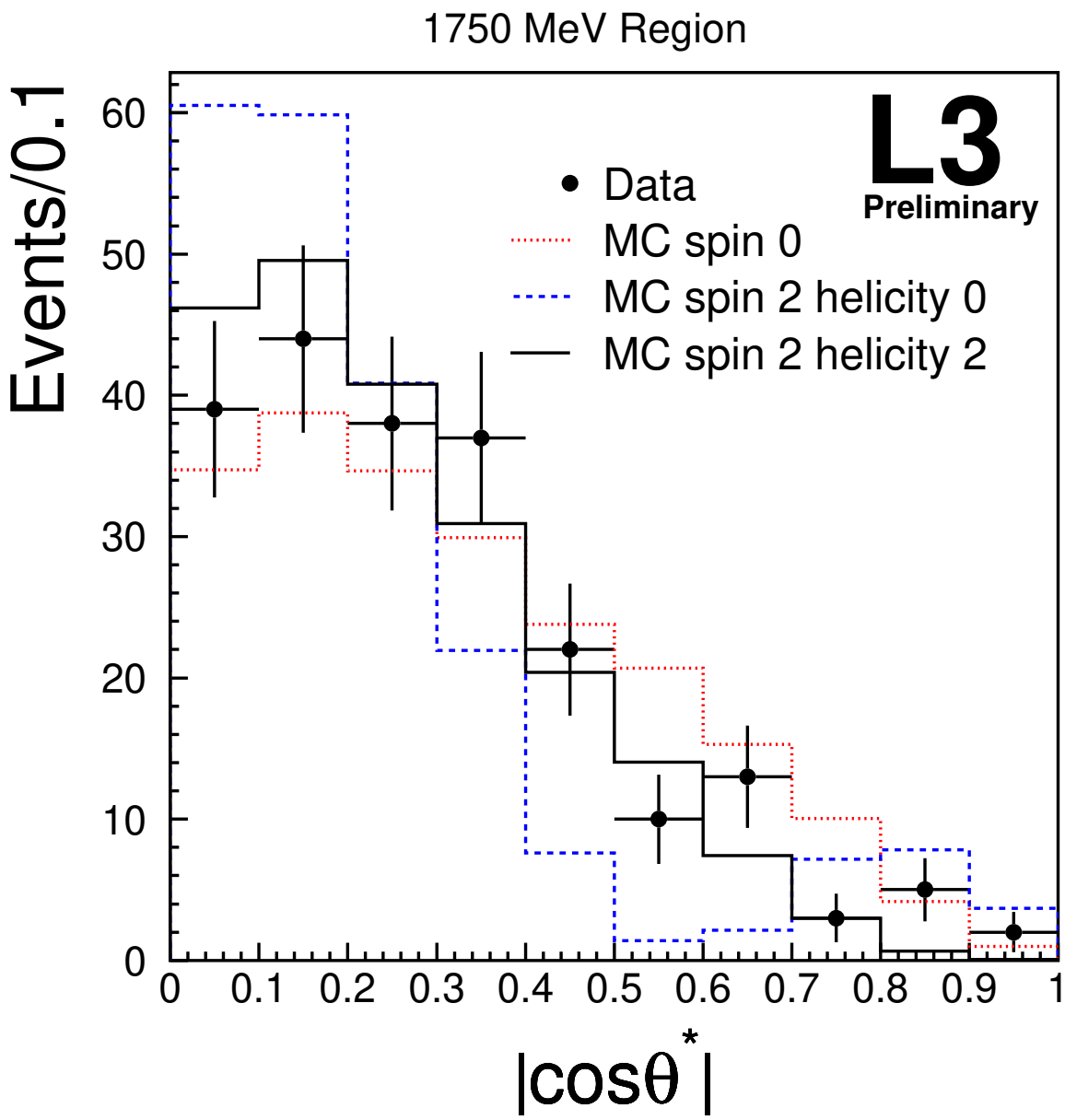

Figure 5: The $K^0_S K^0_S$ polar angular distribution compared with the Monte Carlo distributions for the hypothesis of a pure spin two helicity-zero, spin two helicity-two and spin zero contribution in the 1750 MeV region. The Monte Carlo curves are normalized to the same number of events as the data.