EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Study of the $K^0_S K^0_S$ Final State in Two-Photon Collisions

The L3 Collaboration

Abstract

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 and the formation of the $f_2'(1525)$ resonance is observed. For an integrated luminosity of 114 pb^{-1}, 31 ± 6 f_2' events are found. Their angular distribution is consistent with a pure helicity two. The radiative width times the branching ratio is measured to be $\Gamma_{\gamma\gamma}(f_2') \times Br(f_2' \to K\bar{K}) = (0.093 \pm 0.018 \pm 0.022)$ keV. Only three events are found in the $f_2(1270) - a_2(1320)$ mass region, consistent with the assumption of destructive $f_2 - a_2$ interference in the $K^0_S K^0_S$ final state. The mixing angle of the tensor meson nonet is determined to be $\theta = (29.4^{+1.4}_{-1.6})^\circ$.

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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 (untagged event). This kind of event is characterized by a simple initial state, 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 of a resonance R is given by:

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

where $d^5\mathcal{L}_{\gamma\gamma}$ is the differential luminosity function giving the flux of virtual photons and $\alpha_i (i = 1, ..., 5)$ are the variables describing the scattered electron and positron. For quasi-real photons $\sigma(\gamma^*\gamma^* \to \mathrm{R})$ is given by the Breit-Wigner formula:

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

where $W_{\gamma\gamma}$ is the invariant mass of the two-photon system, m_R, J_R, $\Gamma_{\gamma\gamma}(\mathrm{R})$ and $\Gamma(\mathrm{R})$ 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

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

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.

A two-photon resonance must be compatible with the initial state of the two quasi-real photons. It must be a neutral, unflavoured meson with even charge conjugation and helicity zero or two. In order to be compatible with a $\mathrm{K^0_SK^0_S}$ final state, the resonance must have $(J)^{PC} = (\mathrm{even})^{++}$.

For the tensor meson nonet only the $\mathrm{f_2}(1270)$, the $\mathrm{a_2^0}(1320)$ and the $\mathrm{f_2'}(1525)$ can be produced. However, since these three states are close in mass, interferences must be taken into account. According to SU(3), the $\mathrm{f_2}(1270)$ interferes constructively with the $\mathrm{a_2^0}(1320)$ in the $\mathrm{K^+K^-}$ final state but destructively in the $\mathrm{K^0\bar{K}^0}$ final state [1]. Therefore, among the states of the 2^{++}, $1^3\mathrm{P}_2$ tensor meson nonet, only the $\mathrm{f_2'}(1525)$ is expected to be observable in the $\mathrm{K^0_SK^0_S}$ final state.

In this paper, we present an analysis of the reaction $\mathrm{e^+e^- \to e^+e^-K^0_SK^0_S}$, where only the $\mathrm{K^0_S} \to \pi^+\pi^-$decay is considered. The data correspond to an integrated luminosity of 114 pb^{-1} collected over the years 1991-94 by the L3 detector at LEP at centre of mass energies around the Z resonance.

2 The L3 detector

The L3 experiment consists of a general purpose detector for $\mathrm{e^+e^-}$ physics at LEP [2]. In this analysis the charged particle tracker TEC (Time Expansion Chamber) is mainly used. The electromagnetic and hadronic calorimeters are only used to veto photons.

The TEC is a cylindrical high resolution drift chamber with a sensitive region between 10 and 45 cm in the radial direction and a polar angle acceptance between 13° and 167°, in a magnetic field of 0.5 T. There are 62 layers of wires with a spatial resolution of $\simeq$50 μm, giving a p_t resolution parametrized as $\sigma_{p_t}/p_t = 0.018 p_t(\mathrm{GeV}) \oplus 0.02$. The polar angle is measured by two layers of cylindrical Z-chambers surrounding the TEC, complemented by the measurement of charge division on the TEC wires. The azimuthal and polar angular resolutions are σ_φ =1.3 mrad and σ_θ =20 mrad, respectively. The latter is dominated by the interaction point spread. The interaction point is determined fill-by-fill using hadronic Z decays and has a r.m.s. width of σ_x =150 μm and σ_y =10 μm, due to the beam size.

The electromagnetic calorimeter consists of an array of 11000 BGO crystals. The crystals are arranged in two half barrels with a polar angle coverage $42^\circ \leq \theta \leq 138^\circ$ and in two endcaps covering $11.6^\circ \leq \theta \leq 38^\circ$ and $142^\circ \leq \theta \leq 168.4^\circ$. A shower is defined with an energy threshold of 40 MeV.

The data of this analysis are collected using a charged-track trigger [3] with a low p_t threshold of 150 MeV. This trigger requires at least one pair of charged tracks to be back-to-back in the plane transverse to the beam within $\pm 41^\circ$.

3 Event analysis

In order to select $e^+e^- \to e^+e^-\pi^+\pi^-\pi^+\pi^-$events, we require [4]:

- 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: $|\sum \overrightarrow{p_T}|^2 < 0.1~\mathrm{GeV}^2$.
- Events with photons are rejected. A photon is defined as a neutral electromagnetic shower in the BGO with an energy larger than 100 MeV. The signal must be in more than two crystals, in order to reduce the noise contribution. The ratio between the energy 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.

24026 events are selected by these criteria with an estimated background of 0.5% evaluated by fittng the $|\sum \overrightarrow{p_T}|^2$ distribution. The beam-gas and beam-wall contributions are negligible.

The $\mathrm{K^0_S}$'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 $\mathrm{K^0_S K^0_S}$ 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 $\mathrm{K^0_S}$ 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 0.6 rad.
- Since the two $\mathrm{K^0_S}$'s are produced back-to-back in the transverse plane, the angle between the flight directions of the two $\mathrm{K^0_S}$ candidates in the transverse is required to be within ± 0.3 rad of π.

- In order to suppress low energy e^+e^- conversion pairs, the invariant mass of the two oppositely charged particles forming each secondary vertex must be greater than 150 MeV, under the hypothesis of electron masses.

- The invariant masses of the two K^0_S candidates must be within ± 25 MeV of the nominal K^0_S mass value. Figure 1 shows the $\pi^+\pi^-$ mass distribution with a 3 mm vertex cut for the K^0_S. Fitting this distribution, we find a mass resolution of $\sigma = 9.6 \pm 0.8$ MeV, consistent with the Monte Carlo simulation.

With these selection criteria, 62 events are found in the data sample. In order to improve the precision on the $K^0_S K^0_S$ invariant mass, a kinematical fit is performed. The resulting $K^0_S K^0_S$ invariant mass spectrum is shown in Figure 2. The spectrum is dominated by the $f_2'(1525)$ resonance: 35 events are in the mass region $1420 \leq M_{K^0_S K^0_S} \leq 1660$ MeV. Only three events are found in the $f_2(1270)-a_2^0(1320)$ mass region: this is consistent with the theoretical prediction [1] of destructive $f_2-a_2^0$ interference in the $K^0_S K^0_S$ final state. 19 events are found in the mass region around 1800 MeV ($1720 \leq M_{K^0_S K^0_S} \leq 1930$ MeV).

The background for the $K^0_S K^0_S$ events is due to misidentified K^0_S pairs and is estimated by a study of the K^0_S sidebands. The background spectrum is found when one $\pi^+\pi^-$ pair is within ± 25 MeV of the K^0_S mass and the other is inside one of the sidebands of 25 MeV, outside the signal region. From the sidebands, a total of 17 events are found concentrated towards the low $K^0_S K^0_S$ masses, 3 events are found in the $f_2'(1525)$ mass region and 2 in the 1800 MeV mass region. The background due to the $K^0_S K^\pm \pi^\mp$ final state is determined to be negligible by a Monte Carlo simulation.

A likelihood fit using two Gaussians and a flat background is then performed on the $K^0_S K^0_S$ spectrum. The masses and widths of the Gaussians are left free in the fit. The fit is shown in Figure 2 and the results are summarized in Table 1. While the $f_2'(1525)$ statistical significance is high, the statistical significance of the second peak is 2.9 standard deviations, thus requiring more luminosity to investigate the nature of this peak.

The measured width for the $f_2'(1525)$ is consistent with the Monte Carlo simulation. If we use the Monte Carlo resolution for a zero width resonance and unfold the Breit-Wigner distribution, a value of $\Gamma(f_2'(1525)) = (76 \pm 40)$ MeV is obtained, consistent with the PDG value [6].

In order to correct the data for the detector acceptance and efficiency, a Monte Carlo procedure is used [5]. The nominal $f_2'(1525)$ parameters [6] are used for the generation. The angular distribution of the two K^0_S's in the two-photon centre 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 [7]: $w = (\cos^2\theta^* - \frac{1}{3})^2$ 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 and are reconstructed following the same procedure used for the data. Although the detector acceptance is rather high (15-30%, depending on the resonance helicity), the trigger efficiency (83%), the data selection (72%) and the analysis cuts ($\sim 30\%$) give a total efficiency of 1.9% for helicity zero and 4.1% for helicity two.

4 Results

The total cross section σ_T times the branching ratio Br into $\mathrm{K\bar{K}}$ is measured using the formula

$$\sigma_T \times \mathrm{Br} = \frac{N_{obs} - N_{back}}{\mathcal{L}\varepsilon}, \tag{4}$$

where $\mathcal{L}$ and ε are the integrated luminosity and the total efficiency, respectively. The number of signal events $N_{obs} - N_{back}$ is determined from the maximum likelihood fit. From our data only $\sigma_T \times \mathrm{Br}(\mathrm{f}_2' \to \mathrm{K^0_SK^0_S} \to \pi^+\pi^-\pi^+\pi^-)$ can be measured. Using the PDG [6] value for $\mathrm{Br}(\mathrm{K^0_S} \to \pi^+\pi^-)$ and $\mathrm{Br}(\mathrm{f}_2' \to \mathrm{K\bar{K}}) = 4 \times \mathrm{Br}(\mathrm{f}_2' \to \mathrm{K^0_SK^0_S})$ from isospin conservation, we determine $\sigma_T \times \mathrm{Br}(\mathrm{f}_2' \to \mathrm{K\bar{K}})$. The results are reported in Table 2 for the helicity-zero and helicity-two hypotheses. The difference between the two helicity results shows clearly the importance of taking the angular distribution into account.

The contributions to the systematic error on $\sigma_T \times \mathrm{Br}$ due to the selection efficiency (16%) and the kinematic cuts (13%) are evaluated using the Monte Carlo simulation and performing cut variations. The trigger efficiency contribution is estimated to be 11%. The contribution due to the maximum likelihood fit procedure is estimated to be 6% and is evaluated by changing the background parametrization and the fitted mass region. The total systematic error on $\sigma_T \times \mathrm{Br}$ for the f_2' is found to be 24%.

A study of the angular distribution of the two $\mathrm{K^0_S}$'s produced in the f_2' decay is also performed. The detector acceptance as a function of the polar angle is shown in Figure 3. The experimental polar angle distribution is compared with the Monte Carlo in Figure 4 for both the helicity zero and helicity two cases. The Monte Carlo distributions are normalized to the same number of events as in the data and no background subtraction is done. A likelihood function is calculated using a product of Poisson functions for the two cases: the helicity-two hypothesis is 20.7 times more probable than the helicity-zero. This is in agreement with the theoretical predictions [8].

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

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

where the proportionality factor $\mathcal{K}$ is evaluated by Monte Carlo integration. The results for the measured $\Gamma_{\gamma\gamma}(\mathrm{f}_2') \times \mathrm{Br}(\mathrm{f}_2' \to \mathrm{K\bar{K}})$ are reported in Table 3 for the hypotheses of a pure helicity-zero and helicity-two contribution to the cross section.

From the measurement of the radiative width of the $\mathrm{f}_2'(1525)$, it is possible to determine the mixing angle θ of the tensor mesons. The ratio of the radiative widths [7]

$$\frac{\Gamma_{\gamma\gamma}(\mathrm{f}_2')}{\Gamma_{\gamma\gamma}(\mathrm{f}_2)} = \frac{m^3_{\mathrm{f}_2'(1525)}}{m^3_{\mathrm{f}_2(1270)}} \cdot \frac{(\cos\theta - 2\sqrt{2}\sin\theta)^2}{(\sin\theta + 2\sqrt{2}\cos\theta)^2} \tag{6}$$

can be evaluated using the result of the present analysis and the PDG value for $\mathrm{Br}(\mathrm{f}_2' \to \mathrm{K\bar{K}}) = (71.2^{+2.0}_{-2.5})\%$ and $\Gamma_{\gamma\gamma}(\mathrm{f}_2) = (2.4 \pm 0.3)$ keV. A value of

$$\theta = (29.4^{+1.4}_{-1.6})^\circ$$

is obtained under the hypothesis of helicity two for the $\mathrm{f}_2'(1525)$. The result indicates a deviation from ideal mixing ($\theta = 35.6^\circ$) and is in agreement with the value of $\theta = (28 \pm 3)^\circ$ found from the Gell-Mann–Okubo mass formula [7].

The peak near 1800 MeV could be due to the production of a resonance belonging to an (even)$^{++}$ meson nonet, since no other effect has been identified to justify the observed enhancement of the cross section. Under the hypothesis of spin 2, it could be a radial recurrence of one of the states of the tensor meson nonet. In this case, its $\Gamma_{\gamma\gamma}\times\mathrm{Br}(\mathrm{K\bar{K}})$ is measured to be $0.05\pm0.02\pm0.02$ keV under the hypothesis of helicity two, where the first error is statistical and the second is systematic.

5 Conclusions

The reaction $\mathrm{e^+e^-\rightarrow e^+e^-}\gamma^*\gamma^*\rightarrow\mathrm{e^+e^-K^0_SK^0_S}$ is studied with the L3 detector at LEP. The $\mathrm{K^0_SK^0_S}$ invariant mass spectrum shows evidence for resonance production of the $\mathrm{f}_2'(1525)$. From an integrated luminosity of 114 pb^{-1}, 31 ± 6 f_2' events are found. The angular distribution is consistent with a pure helicity-two contribution to the cross section. This is in agreement with theoretical predictions [8]. For the radiative width times the branching ratio a value of $\Gamma_{\gamma\gamma}(\mathrm{f}_2')\times$ $\mathrm{Br}(\mathrm{f}_2'\rightarrow\mathrm{K\bar{K}})=(0.093\pm\ 0.018\pm\ 0.022)$ keV is measured under the hypothesis of pure helicity two. This value is consistent with previous measurements [9,10].

The mixing angle between the singlet and octet members of the SU(3) tensor meson nonet is evaluated to be $\theta=(29.4^{+1.4}_{-1.6})^\circ$.

Only three events are found in the $\mathrm{f}_2(1270)-\mathrm{a}_2(1320)$ mass region, consistent with the theoretical prediction [1] of destructive f_2-a_2 interference in the $\mathrm{K^0_SK^0_S}$ final state.

The $\mathrm{K^0_SK^0_S}$ mass spectrum shows another peak near 1800 MeV with a statistical significance of 2.9 standard deviations. Although more luminosity is necessary to establish it as a resonance, this peak could be due to the production of a radial recurrence of the 0^{++} or 2^{++} meson nonets.

6 Acknowledgments

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Tables

	First peak $f_2'(1525)$	Second peak
Mass (MeV)	1529 ± 10	1793 ± 18
Sigma (MeV)	48 ± 8	51 ± 19
Number of events	31.1 ± 6.3	15.0 ± 5.1

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

$\sigma_T \times Br(f_2' \to K\bar{K})$ (pb)	
Helicity 0	Helicity 2
$120.0 \pm 24.0 \pm 28.8$	$56.3 \pm 11.3 \pm 13.5$

Table 2: The measurement of the cross section times the branching ratio for the $f_2'(1525)$ for the two possible helicity states. The first error is statistical and the second is systematic.

$\Gamma_{\gamma\gamma}(f_2') \times Br(f_2' \to K\bar{K})$ (keV)	
Helicity 0	Helicity 2
$0.198 \pm 0.040 \pm 0.050$	$0.093 \pm 0.018 \pm 0.022$

Table 3: The measurement of $\Gamma_{\gamma\gamma}(f_2') \times Br(f_2' \to K\bar{K})$ for the two possible helicity states. The first error is statistical and the second is systematic.

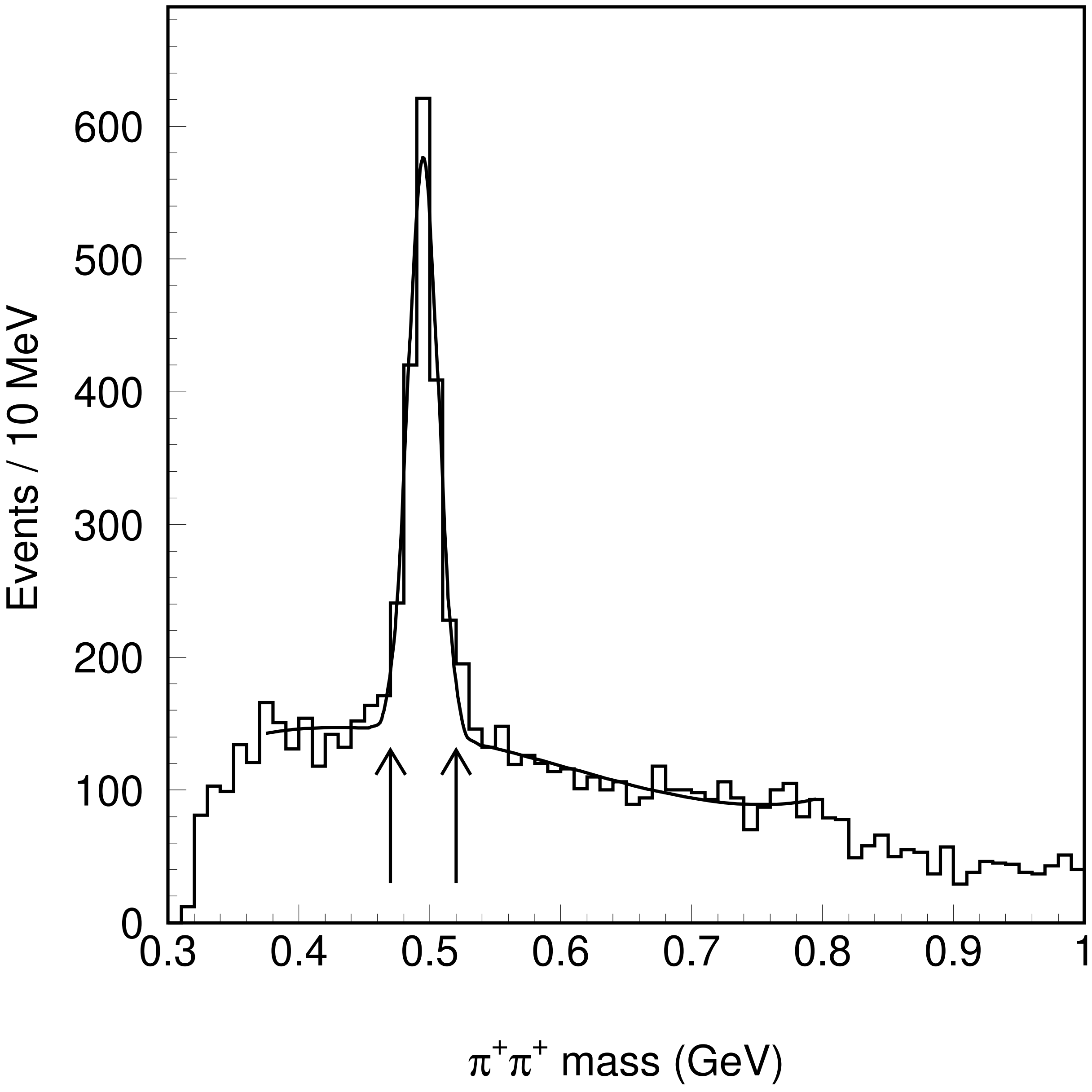
Figure Captions

Figure 1 : The $\pi^+\pi^-$ mass spectrum for reconstructed secondary vertices 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 show the signal region.

Figure 2 : 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 flat polynomial (dahed line) and the two peaks by Gaussian curves.

Figure 3 : The detector acceptance for $K^0_S K^0_S$ events as a function of $|\cos\theta^*|$.

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 (dash-dotted curve) and helicity-two (solid curve) contribution to the cross section for the $f_2'(1525)$. The Monte Carlo curves are normalized to the same number of events as the data.



Events / 10 MeV
0
100
200
300
400
500
600
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
$\pi^+\pi^+$ mass (GeV)

Figure 1

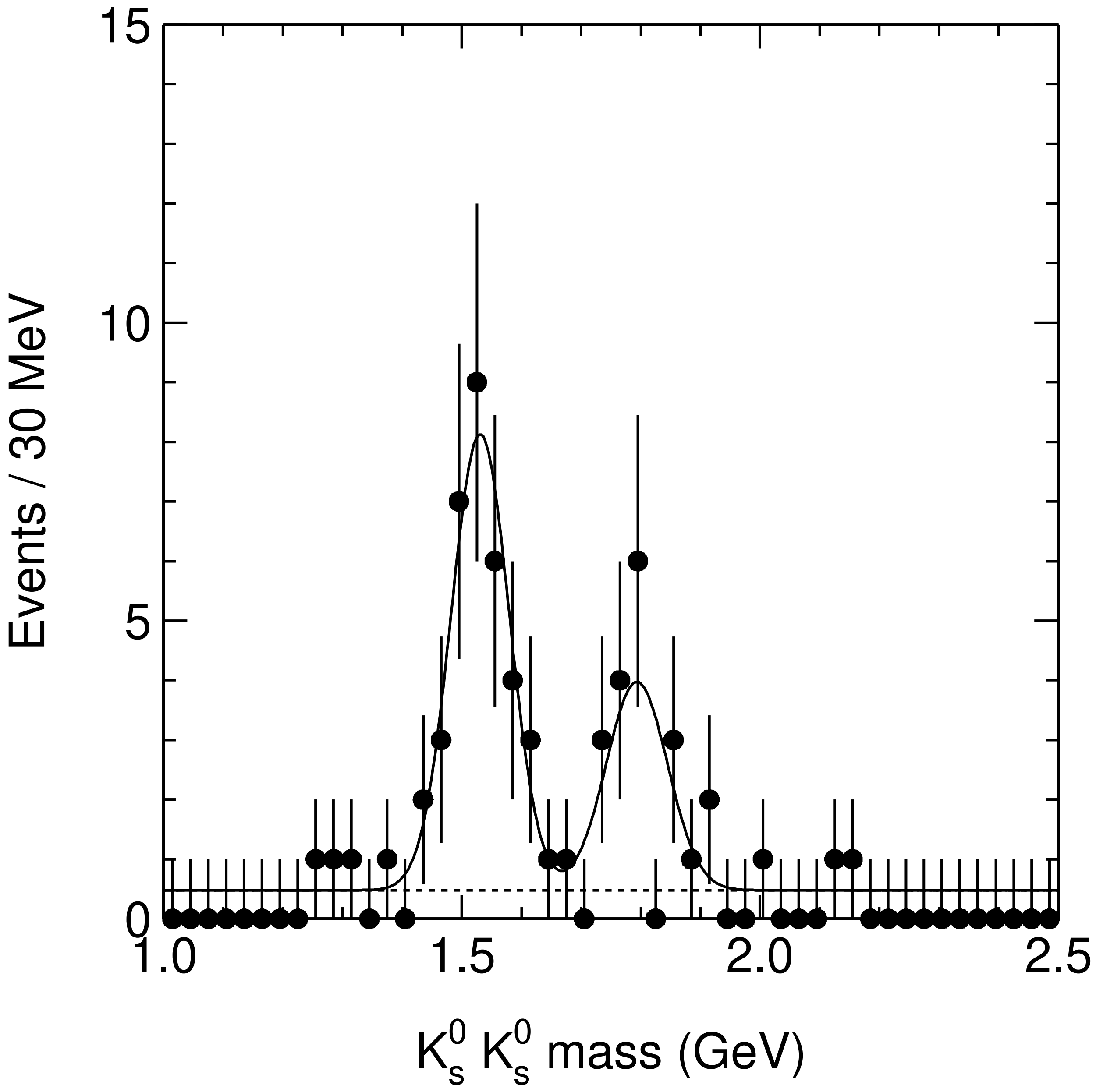


Figure 2

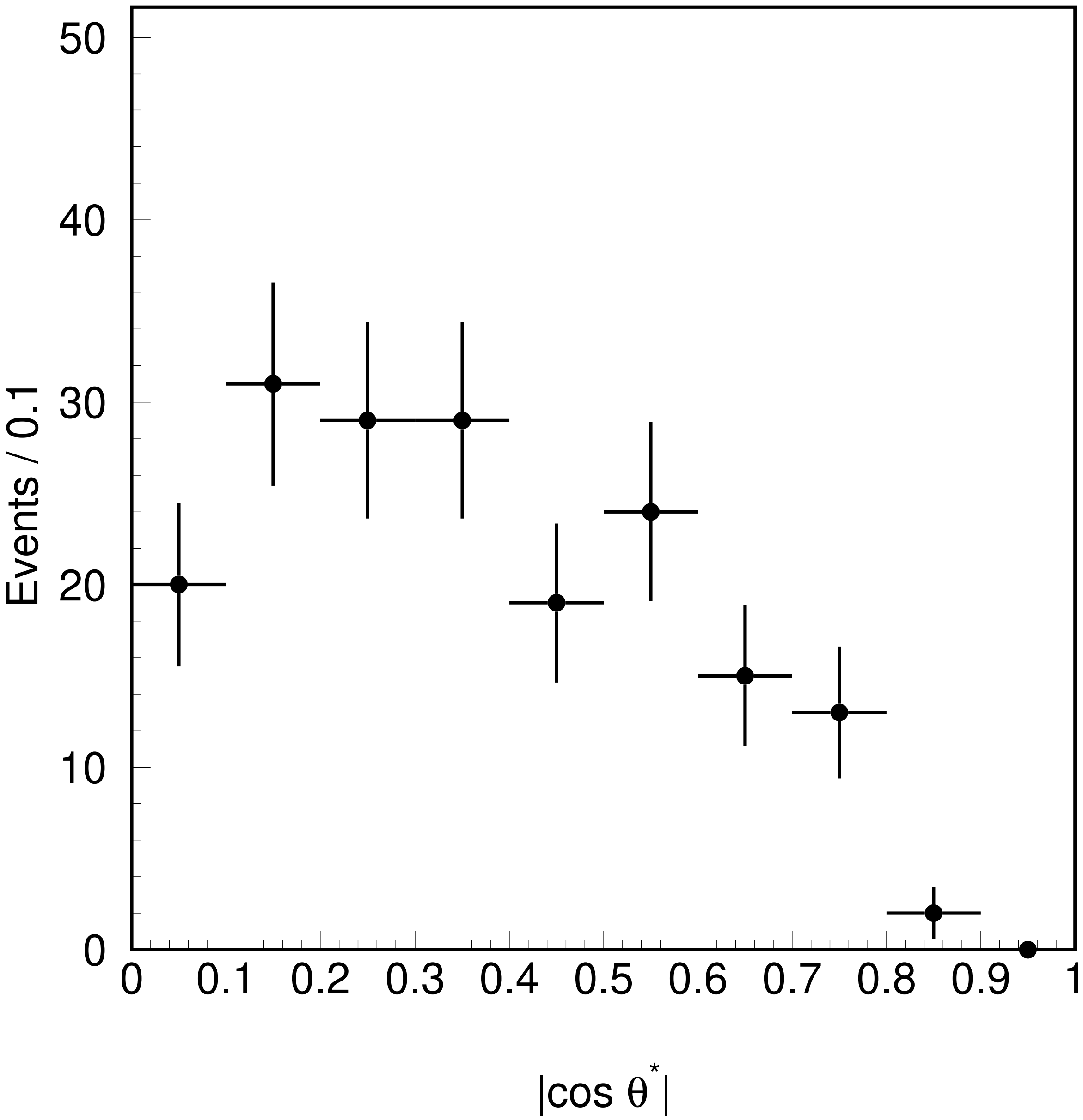


Figure 3

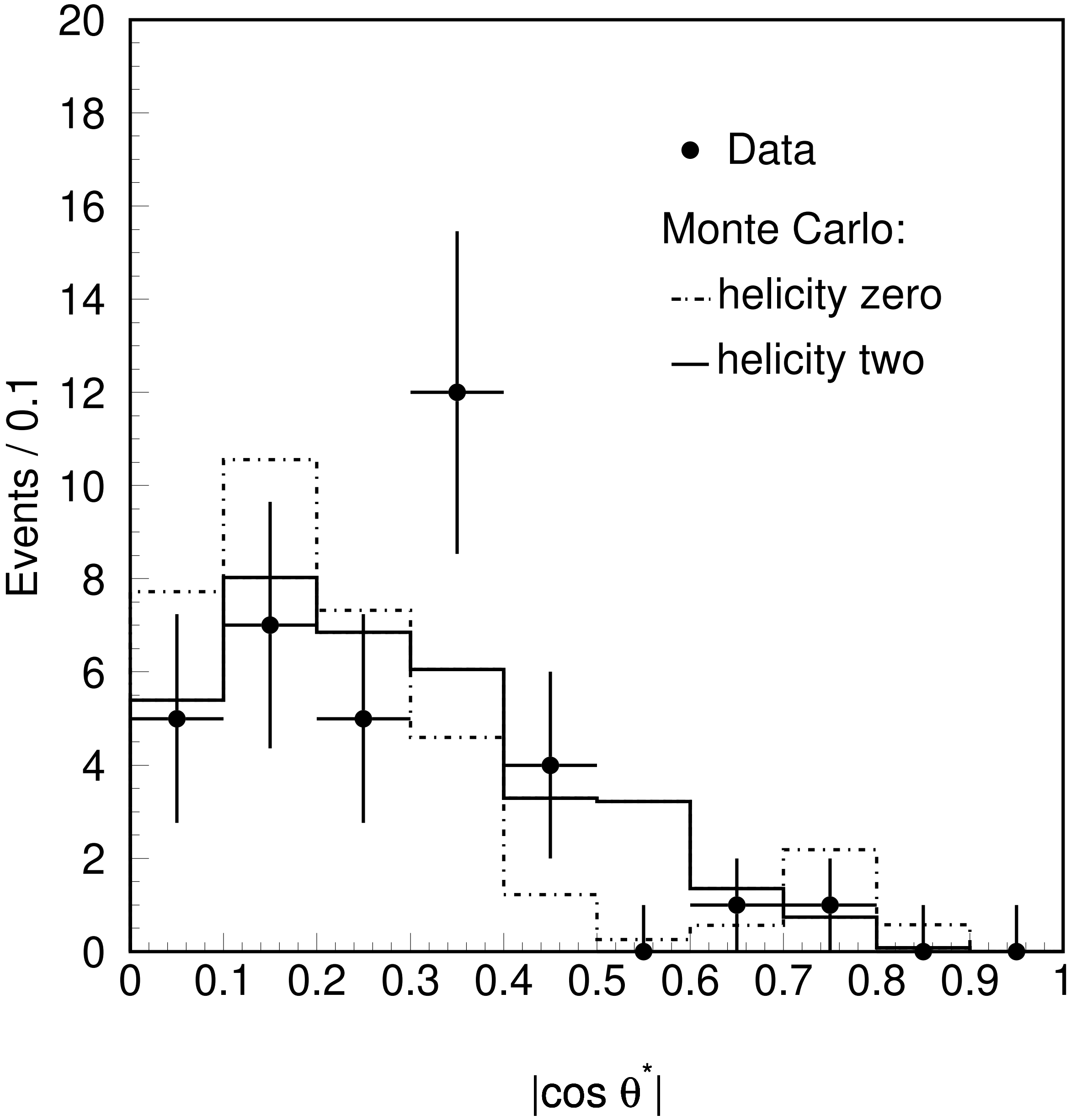

20
18
16
14
12
10
8
6
4
2
0
Events / 0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
|cos θ*|
Data
Monte Carlo:
helicity zero
helicity two

Figure 4