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The $K_S^0 K_S^0$ final state in $\gamma\gamma$ interactions

CELLO Collaboration

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Abstract. In the reaction $\gamma\gamma \to K_S^0 K_S^0$ resonance production of the f_2' is observed. For the radiative width $\Gamma_{\gamma\gamma} \cdot B(f_2' \to K\bar{K}) = 0.11 {+0.03 \atop -0.02} \pm 0.02$ keV is found. The small number of events in the f_2, a_2 mass region is consistent with the assumption of destructive $f_2 - a_2$ interference. From the mass distribution we determine the relative phases between the tensor mesons. Upper limits on the radiative widths of the glueball candidates $f_2(1720)$ and $X(2220)$ are derived.

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1 Introduction

In this paper we present results of an analysis of the final state $K_S^0 K_S^0$ produced in two photon collisions. Previous measurements of this channel have been given by TASSO [1], PLUTO [2] and preliminary results by MARK II [3].

The tensor mesons $f_2(1270)$, $a_2(1320)$ and $f_2'(1525)$ all couple to the final state $K\bar{K}$. In the reaction $\gamma\gamma \to K^+K^-$ the f_2 and a_2 are expected to interfere constructively, whereas in the $K_S^0 K_S^0$ decay mode the interference is destructive. As a consequence, the dominant channel in resonant $K_S^0 K_S^0$ production is via the f_2'. In this analysis we measure the f_2' radiative width and investigate the interference between f_2, a_2 and f_2'.

In the reaction $K^- p \to K_S^0 K_S^0 \Lambda$ evidence was recently found for a scalar resonance $f_0'(1525)$ [4], nearly degenerate in mass and width with the f_2'. If confirmed, this state could be interpreted as the $s\bar{s}$ rich state in the 0^{++} nonet, in which case the $f_0(975)$ and probably also the $a_0(980)$ (formerly S^* and δ) would have to be removed from the 0^{++} nonet and might be explained as $K\bar{K}$ molecules as in the model of Weinstein and Isgur [5]. We investigate the possibility that the observed signal in $\gamma\gamma \to K\bar{K}$ is due to the overlap of the f_2' with a scalar resonance $f_0'(1525)$. Using the decay angular distribution an upper limit on the scalar contribution is derived.

The glueball candidate $f_2(1720)$ (formerly $\theta(1690)$) has been observed in radiative J/ψ decays [6, 7] with $K\bar{K}$ being the dominant decay mode. In contrast to its copious production in J/ψ decays there is no clear signal for the $f_2(1720)$ in hadronic reactions; especially in the reaction $K^- p \to K_S^0 K_S^0 \Lambda$ no $f_2(1720)$ production was observed [4]. Several experiments set upper limits on the $\gamma\gamma$ coupling of the $f_2(1720)$ [1, 2, 8], which are necessary to support the glueball interpretation. The $X(2220)$ has been observed in radiative J/ψ decays by the MARK III Collaboration [6], but it is not a well established resonance since it was not confirmed by DM2 [7]. We derive upper limits on the radiative widths of the $f_2(1720)$ and $X(2220)$.

2 Data taking and event selection

The experiment was performed using the CELLO detector at the PETRA storage ring. The data were taken at a beam energy of 17.5 GeV and correspond to an integrated luminosity of 86 pb^{-1}. A detailed description of the CELLO detector has been given elsewhere [9]. Charged particles are measured in the central detector, which consists of a system of cylindrical drift and proportional chambers. The central detector is surrounded by a thin superconducting coil providing a solenoidal magnetic field of 1.3 *T*. The angular acceptance is 91% of 4π and a momentum resolution of $\sigma(p)/p = 0.02 \cdot p$ (p in GeV/c) without beam constraint is achieved. The tracking system is completed by two planes of proportional chambers perpendicular to the beam in the forward and backward region which allows charged particle measurement down to $|\cos\theta| = 0.98$.

A 20 radiation length lead liquid argon calorimeter with fine lateral and longitudinal segmentation is subdivided into two main parts: the barrel covering $|\cos\theta| < 0.86$ and the end caps covering $0.92 < |\cos\theta| < 0.99$. The acceptance gap between barrel and end cap is closed by a lead scintillator sandwich which provides veto capability rather than a precise energy measurement. Hermetic calorimetry down to 50 mrad is completed by forward shower counters consisting of lead glass arrays.

The relevant triggers for low multiplicity charged particle final states use as input the result of a fast track finding algorithm in the central detector [10]. The basic trigger requirements were at least two tracks with p_t above 650 MeV/c or two tracks above 250 MeV/c with an opening angle larger than 45° (135° in part of the experiment). The trigger decision is reliably simulated by applying the same algorithm as used in the experiment to the hit pattern of Monte Carlo events.

In order to isolate events from the reaction $e^+e^- \to e^+e^- K_S^0 K_S^0$, with $K_S^0 \to \pi^+\pi^-$, events with four charged particles and zero net charge were selected. Events containing additional neutrals were removed by requiring that no isolated shower energy above 100 MeV was detected. No tag or anti tag conditions were demanded at this stage. To these events a secondary vertex (V^0) search routine was applied; the V^0 search procedure is described in more detail in [11]. In events with one reconstructed secondary vertex the V^0 search routine was rerun with looser cuts on the tracks recoiling against the V^0. Finally only events with two reconstructed secondary vertices were accepted. To select exclusive $\gamma\gamma$ events the net transverse momentum of the charged particles was restricted to be $|\sum \mathbf{p}_t| < 200$ MeV for untagged events. For tagged events a shower energy above 5 GeV in the end caps or in the forward calorimeter and a momentum balance $|\sum \mathbf{p}_t| < 450$ MeV including the tag was required. Figure 1 shows the scatter plot of the V^0 masses of the selected events. A clear clustering in the K_S^0 mass region is observed above very little

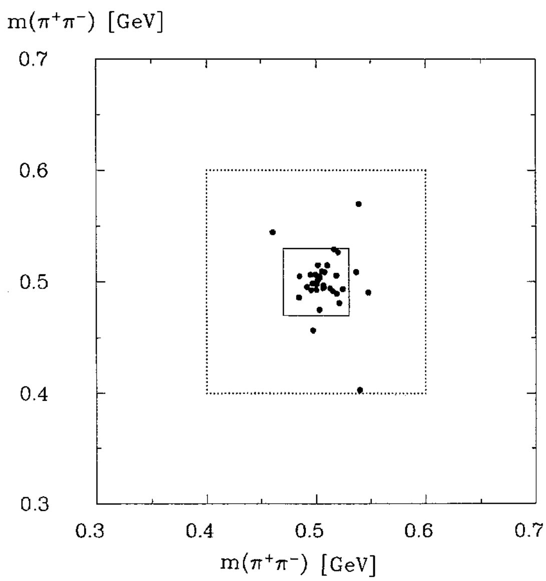

Fig. 1. Invariant $\pi^+\pi^-$ masses in events with two secondary vertices. The solid line defines the signal region; the area within the dotted line is used for the background determination

background. For the further analysis we require that both V^0 masses are between 470 MeV and 530 MeV and assign the K_S^0 mass of 498 MeV. After the mass cut 30 events with two accepted K_S^0 remain, including 3 tagged events. The background due to misidentified K_S^0 was estimated from the sidebands to be 0.3 ± 0.2 events in the $K_S^0 K_S^0$ sample. Investigation of the $|\sum \mathbf{p}_t|$ distribution showed no indications of background due to nonexclusive events, and the contamination is estimated to be <1 event.

3 Results

In Fig. 2 the invariant $K_S^0 K_S^0$ mass distribution is shown, clearly demonstrating evidence for exclusive f_2' production. Only three events are seen in the $f_2 - a_2$ region, a first indication of their destructive interference. For the further analysis we have restricted ourselves to untagged events. The coupling of a tensor state to two quasi-real photons is described by two contributions, namely the coupling of two transversely polarized photons to helicity 0 and 2 states. Following [2] the $\gamma\gamma$ cross section for tensor meson production and decay into $K\bar{K}$ can be written as:

$$\sigma_{\gamma\gamma \to K\bar{K}}(W) = \frac{40\pi}{W^2} \cdot (|A_0|^2 + |A_2|^2), \tag{1}$$

W is the invariant $\gamma\gamma$ mass and the complex helicity amplitudes A are defined by:

$$A_0 = \mathrm{BW}(W) \cdot \left(\frac{W}{m}\right)^2 \cdot (\Gamma_{\gamma\gamma}^{(0)} \cdot B(K\bar{K}))^{\frac{1}{2}}, \tag{2}$$

$$A_2 = \mathrm{BW}(W) \cdot (\Gamma_{\gamma\gamma}^{(2)} \cdot B(K\bar{K}))^{\frac{1}{2}} \tag{3}$$

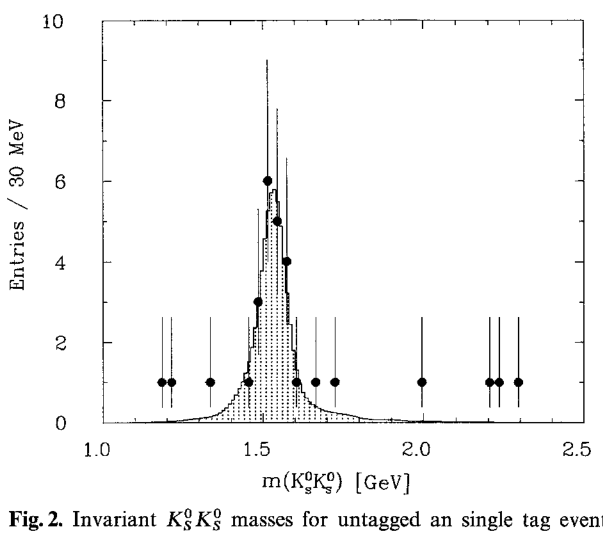

Fig. 2. Invariant $K_S^0 K_S^0$ masses for untagged an single tag events. Data points are denoted by dots, which are suppressed in bins with no entries. the histogram is from a f_2' Monte Carlo, normalized to the observed number of events

where the $\Gamma^{(i)}$ denote the radiative widths corresponding to helicity 0 and 2 and m is the resonance mass; the Breit Wigner amplitude BW(W) is given by:

$$\mathrm{BW}(W) = \frac{m\sqrt{\Gamma(W)}}{W^2 - m^2 + i\, m\, \Gamma(W)} \tag{4}$$

with an energy dependent width:

$$\Gamma(W) = \Gamma(m) \cdot \left(\frac{k^*(W)}{k^*(m)}\right)^5 \cdot \frac{m}{W} \cdot \frac{f^2(k^*(W))}{f^2(k^*(m))}. \tag{5}$$

The energy variation of the decay form factor was assumed to be $f^2 \propto (9 + 3(k^* r) + (k^* r)^4)^{-1}$, where k^* is the K_S^0 momentum in the $\gamma\gamma$ c.m.s. and the effective interaction radius r was fixed to 1 fm [12, 13].

For the determination of resonance parameters we applied the same technique as used by the PLUTO collaboration in the analysis of $K_S^0 K_S^0$ production [2]. $K_S^0 K_S^0$ Monte Carlo events were generated with a flat K_S^0 decay angle ($\cos\theta$) distribution, a fixed $\gamma\gamma$ cross section $\sigma_{\gamma\gamma}^{\mathrm{MC}}$, and invariant masses varying between threshold and 3 GeV. The photon flux was generated using the exact formula of Budnev et al. [14]. All events were passed through the full detector simulation program and through the analysis chain as used for the data. Resonance parameters were extracted by using a cross section of the form (1), and by weighting each event with $\sigma_{\gamma\gamma}^{\mathrm{Res}}(W, \cos\theta, x)/\sigma_{\gamma\gamma}^{\mathrm{MC}}$ (x denotes resonance parameters as radiative widths, relative phases etc.), so that the Monte Carlo model fits the observed distribution optimally.

In the determination of the f_2' radiative width we assumed that only the helicity 2 component contributes, since it is expected to be dominant at low Q^2 [15, 16]. Recently this has been experimentally confirmed [2]. Furthermore it was assumed that the f_2 and a_2 interfere destructively in the $K_S^0 K_S^0$ decay mode, an assumption that is justified by the Zweig rule and approximate $SU(3)_{Fl}$ symmetry [17]. With the radiative widths of f_2 and a_2 fixed at their standard values [18] a maximum likelihood fit to the invariant mass distribution results in:

$$\Gamma_{\gamma\gamma} \cdot B(f_2' \to K\bar{K}) = 0.11^{+0.03}_{-0.02} \pm 0.02\ \mathrm{keV} \tag{6}$$

where the first error is statistical and the second one systematic. This value is in good agreement with previous measurements [1–3, 8, 19]. The systematic error contains the uncertainties in the acceptance calculation and in the luminosity measurement. However, it should be noted that the systematic error does not include uncertainties arising from the helicity assumption or possible deviations from the assumed interfer-

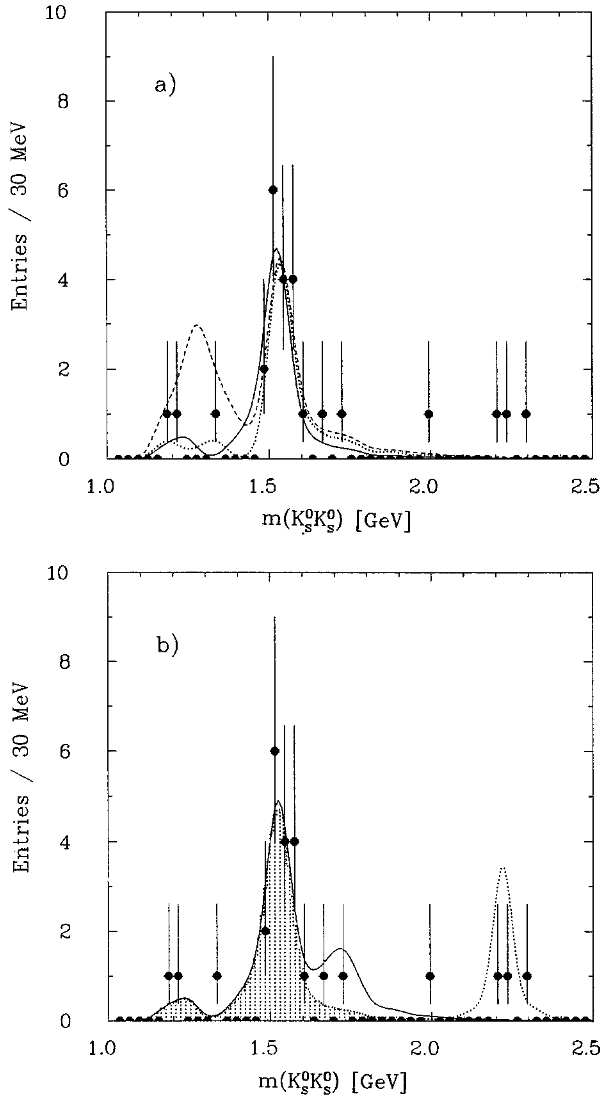

Fig. 3a, b. Invariant $K^0_S K^0_S$ masses for untagged events. In data bins with no entries the error bars are not displayed. In **a** the fitted curves for destructive f_2-a_2 interference (full line), constructive superposition (dashed line) and for the best fit $\varphi_{a_2}=256°$ and $\varphi_{f_2'}=252°$ (dotted line) are included. In **b** the dotted area represents the f_2' fit result (destructive f_2-a_2 interference), the full line corresponds to the 95% c.l. upper limit for an incoherently added $f_2(1720)$; the dotted line is the $X(2220)$ upper limit

ence pattern. In Fig. 3a the fit result is shown; the fit describes well the observed invariant mass distribution in the f_2, a_2, f_2' mass region. Also included is the fit curve for constructive a_2-f_2 production, clearly not favoured by the data, if one takes into account the zero entries in the f_2-a_2 region.

The three single tag events have $K^0_S K^0_S$ masses in the f_2' region and are candidates for f_2' production at high Q^2. Using the coupling $\Gamma_{\gamma\gamma}(f_2')=0.11$ keV we expect 0.5 (0.8) single tag events by extrapolating the cross section for transverse photons σ_{TT} to large Q^2 using a $\rho(\phi)$ form factor. The slight excess might indicate the presence of reactions involving longitudinal photons, which give two further contributing cross sections σ_{LT} and σ_{LL}.

We now consider to what extent the interference pattern affects the result for $\Gamma_{\gamma\gamma}(f_2')$. With the relative phases of the resonance residua φ_{a_2} and $\varphi_{f_2'}$ in the amplitude

$$A(W)=A_{f_2}(W)+A_{a_2}(W)\cdot e^{i\varphi_{a_2}}+A_{f_2'}(W)\cdot e^{i\varphi_{f_2'}} \tag{7}$$

also treated as free parameters, we fitted the invariant mass distribution from threshold to 1.8 GeV. The couplings $\Gamma_{\gamma\gamma}\cdot B(K\bar{K})$ of the f_2 and a_2 were also allowed to vary within their uncertainties [18] and helicity 2 was assumed for all three states. The relative phases corresponding to the best fit are:

$$\begin{aligned}\varphi_{a_2}&=\left(256\,^{+20}_{-36}\pm 20\right)^0\\ \varphi_{f_2'}&=\left(252\,^{+41}_{-34}\pm 20\right)^0\end{aligned} \tag{8}$$

which are nevertheless compatible with the quark model expectations of 180° and 360° within $1.7\,\sigma$. The corresponding mass distribution is also included in Fig. 3a. Similar values were found by the PLUTO collaboration [2]. In Fig. 4 the likelihood contours in the $\varphi_{a_2}-\varphi_{f_2'}$ plane are shown. Also indicated are the results for $\Gamma_{\gamma\gamma}\cdot B(f_2'\to K\bar{K})$ at some points. It should be noted that the values vary considerably even in the region of good fits (from 0.09 to 0.15 keV within the $1\,\sigma$ contour).

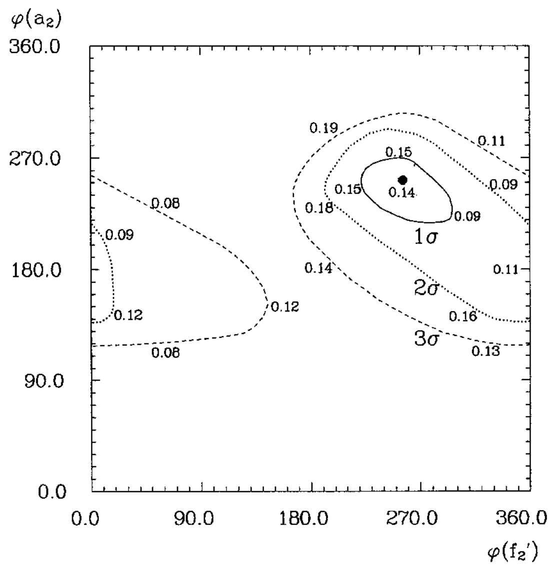

Fig. 4. Likelihood contours in the $\varphi_{a_2}\,\varphi_{f_2'}$ plane. At some points $\Gamma_{\gamma\gamma}\cdot B(f_2'\to K\bar{K})$ is given

Recently the LASS collaboration has reported evidence for a scalar resonance $f_0'(1525)$ in the reaction $K^- p \to K_S^0 K_S^0 \Lambda$ [4]. Since this state is found to be degenerate in mass and width with the $f_2'(1525)$, the signal observed in $\gamma\gamma$ reactions might be due to the overlap of the two resonances. In principle, the two states can be distinguished by the different distributions of the decay angle in the $\gamma\gamma$ c.m.s. for $J=0$ and $J=2$. We observe good agreement with the hypothesis of a pure $J=2$ signal but with the limited statistics available a substantial $J=0$ contribution cannot be excluded. To get a quantitative limit, the decay angle distribution was fitted allowing the $\gamma\gamma$ couplings of both states to vary. In this procedure the contributions due to $J=0$ and due to $J=2$ for helicity 2 were added incoherently, a $J=2$ helicity 0 contribution was not considered. The resulting upper limit is $\Gamma_{\gamma\gamma} \cdot B(f_0'(1525) \to K\bar{K}) < 0.85$ keV (95% c.l.). The consequence for the f_2' radiative width is that the result $\Gamma_{\gamma\gamma}(f_2') = 0.11$ keV remains valid as the most probable value, but the hypothesis of a $f_0'(1525)$ contributing to the $\gamma\gamma$ cross section increases the statistical uncertainty of $\Gamma_{\gamma\gamma}(f_2')$ from $^{+0.03}_{-0.02}$ to $^{+0.03}_{-0.04}$.

We now turn to the discussion of the glueball candidate states $f_2(1720)$ (formerly $\theta(1690)$) and $X(2220)$ (formerly $\xi(2220)$). The $f_2(1720)$ has been observed in radiative J/ψ decays, the most frequent decay mode being $K\bar{K}$ [20]. In the mass region around 1720 MeV no excess of events is observed over the tail of the $f_2'(1525)$. We therefore give an upper limit on the radiative width of the $f_2(1720)$. Assuming that the $f_2(1720)$ and $f_2'(1525)$ add incoherently the resulting limit is:

$$\Gamma_{\gamma\gamma} \cdot B(f_2(1720) \to K\bar{K}) < 0.06 \text{ keV} \quad (95\% \text{ c.l.}). \tag{9}$$

The limit is valid for helicity 2; in case of helicity 0 it is larger by about a factor 2. Again, interference effects must be taken into account since a suppression of the $\gamma\gamma$ cross section in the $f_2(1720)$ region might be due to interference with the $f_2'(1525)$. Taking into account all possible interference patterns, i.e. allowing coherent $f_2'(1525) - f_2(1720)$ superposition with unrestricted phase and $\Gamma_{\gamma\gamma}(f_2')$ as a free parameter, gives the limit:

$$\Gamma_{\gamma\gamma} \cdot B(f_2(1720) \to K\bar{K}) < 0.11 \text{ keV} \quad (95\% \text{ c.l.}) \tag{10}$$

where helicity 2 is assumed. The most conservative limit allowing arbitrary interference and helicity is $\Gamma_{\gamma\gamma} \cdot B(f_2(1720) \to K\bar{K}) < 0.20$ keV.

The $X(2220)$ has likewise been found in radiative J/ψ decays [6]. Although the status of the $X(2220)$ is still controversial [7], we quote here the upper limit for the two photon coupling of a possible 2^{++} state with $m = 2231$ MeV and $\Gamma = 22$ MeV [6]. We observe 3 isolated events in the $X(2220)$ mass region, thus the resulting limit is rather loose:

$$\Gamma_{\gamma\gamma} \cdot B(X(2220) \to K\bar{K}) < 0.12 \text{ keV} \quad (95\% \text{ c.l.}) \tag{11}$$

where helicity 2 is assumed. Since the $X(2220)$ mass is well above all other $J=2$ states interference effects can be neglected here. The distributions corresponding to the upper limits for the $f_2(1720)$ and $X(2220)$ radiative widths are included in Fig. 3b.

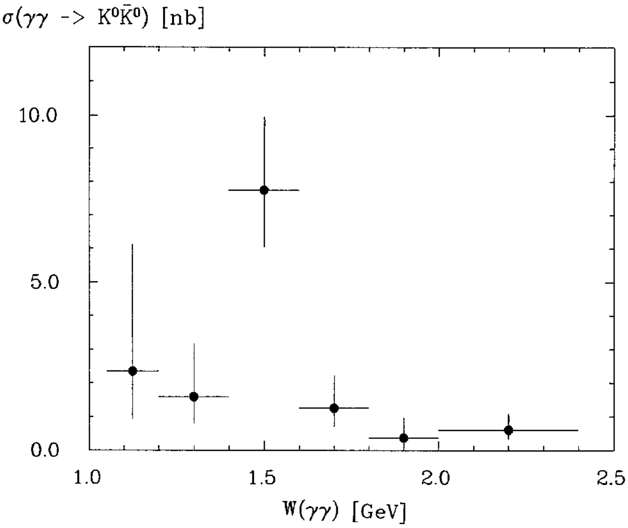

Fig. 5. Cross section for the reaction $\gamma\gamma \to K^0\bar{K}^0$. Indicated are statistical errors only

Figure 5 shows the cross section for the reaction $\gamma\gamma \to K^0\bar{K}^0$ corrected for $K_L^0 K_L^0$ production and unseen K_S^0 decay modes. Indicated are only the statistical errors; the systematic error decreases from 20% in the lowest mass bin to 15% for $W_{\gamma\gamma} > 1.5$ GeV. Since the main contribution to the cross section is due to tensor meson formation, an angular distribution corresponding to $J=2$ and helicity 2 was used in the acceptance calculation. Near threshold the TASSO Collaboration [1] observed an increase in the cross section, explained by a possible contribution of the scalar resonances $a_0(980)$ and $f_0(975)$. We did not take into account a spin 0 component since the efficiency of our selection procedure vanishes near threshold and therefore no information can be extracted in the lowest mass region ($W_{\gamma\gamma} < 1050$ MeV). Comparison of the measured cross section with the TASSO result [1] shows agreement in shape but we find a shift of about 40% to lower absolute values.

4 Summary

We have analyzed the reaction $\gamma\gamma \to K_S^0 K_S^0$ and observe exclusive f_2' production. The f_2, a_2 mass region is found to be well described by destructive interference. Assuming destructive $f_2 - a_2$ interference and helicity 2 formation of the f_2', the radiative width is found to be $\Gamma_{\gamma\gamma} \cdot B(f_2' \to K\bar{K}) = 0.11 {+0.03 \atop -0.02} \pm 0.02$ keV. The hypothesis of a scalar $f_0'(1525)$ under the $f_2'(1525)$ has been considered; the decay angle distribution favours a pure spin 2 signal and the upper limit $\Gamma_{\gamma\gamma} \cdot B(f_0'(1525) \to K\bar{K} < 0.85$ keV is obtained. The phases of the a_2 and f_2' relative to the f_2 are determined to be $\varphi_{a_2} = \left(256 {+20 \atop -36} \pm 20\right)^0$ and $\varphi_{f_2'} = \left(252 {+41 \atop -34} \pm 20\right)^0$ compatible with the quark model expectations of 180° and 360°. No signal is seen for the glueball candidates $f_2(1720)$ and $X(2220)$, resulting in the upper limits for their radiative widths $\Gamma_{\gamma\gamma} \cdot B(f_2(1720) \to K\bar{K}) < 0.06$ keV and $\Gamma_{\gamma\gamma} \cdot B(X(2220) \to K\bar{K}) < 0.12$ keV (both 95% c.l.).

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