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Anti-Search for the Glueball Candidate $f_J(2220)$ in Two-Photon Interactions

CLEO Collaboration

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Abstract

Using 13.3 fb^{-1} of e^+e^- data recorded with the CLEO II and CLEO II.V detector configurations at CESR, we have searched for $f_J(2220)$ decays to $K_S^0K_S^0$ in untagged two-photon interactions. We report an upper limit on the product of the two-photon partial width and the branching fraction, $\Gamma_{\gamma\gamma}\mathcal{B}(f_J(2220)\to K_S^0K_S^0)$ of less than 1.1 eV at the 95% confidence level; systematic uncertainties are included. This dataset is four times larger than that used in the previous CLEO publication.

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The $f_J(2220)$, also known as $\xi(2230)$, is a candidate for the lightest tensor (J=2) glueball. The MARK-III Collaboration [1] first observed this state in the radiative decays $J/\psi\to\gamma K^+K^-$ and $J/\psi\to\gamma K^0_S K^0_S$, in a sample of 5.8×10^6 J/ψ decays. The masses (widths) of both modes were consistent with those expected for a narrow tensor glueball; $2230.0\pm6.0\pm14.0$ $(26.0^{+20.0}_{-16.0}\pm17.0)$ MeV/c^2 and $2232.0\pm7.0\pm7.0$ $(18.0^{+23.0}_{-15.0}\pm10.0)$ MeV/c^2 for the K^+K^- and $K^0_S K^0_S$ modes, respectively. They did not observe any enhancement in the two-body final states $\pi^+\pi^-$ and $p\bar{p}$. A year later, the DM2 Collaboration [2], using a sample 8.6×10^6 J/ψ radiative decays, searched for the $f_J(2220)$ in the $\pi^+\,\pi^-$, K^+K^-, and $K^0_S K^0_S$ final states, and did not observe a signal in any of the three modes. They reported a limit on the product branching fraction, $\mathcal{B}(J/\psi\to\gamma f_J(2220))\mathcal{B}(f_J(2220)\to K^+K^-)$, which was in disagreement with the MARK-III result. Ten years later, the BES collaboration observed strong signals for $f_J(2220)$ decays into $\pi^+\,\pi^-$, K^+K^-, $K^0_S K^0_S$ [3], and $\pi^0\pi^0$ [4], again in radiative J/ψ decays. In hadron production the GAMS Collaboration [5] reported a state, decaying to $\eta\eta'$ in π^- p $\to\eta\eta' n$ interactions, at 2220.0 MeV/c^2. The angular distribution of the decay strongly indicated $J\geq2$. The LASS Collaboration [6] reported a narrow resonance, decaying to $K\bar{K}$. Both the mass and the width of GAMS and LASS states were consistent with the previous $f_J(2220)$ measurements in radiative J/ψ decays.

In 1997, the CLEO Collaboration reported tight limits on the two-photon coupling of the $f_J(2220)$ in $\gamma\gamma\to K^0_S K^0_S$ [7] and $\gamma\gamma\to\pi^+\pi^-$ [8]. Recent LEP results from the L3 [9] Collaboration showed no evidence for $f_J(2220)$ production in two-photon interactions searching for the $K^0_S K^0_S$ final state, and they derived an upper limit of $\Gamma_{\gamma\gamma}\mathcal{B}(f_J(2220)\to K^0_S K^0_S) < 1.4\ eV$ at 95% confidence level (C.L.). under the hypothesis of a pure helicity-2 state.

Many experiments have searched for $f_J(2220)$ production in $p\bar{p}$ annihilation-in-flight: $p\bar{p}\to\pi^+\pi^-$ [10], $p\bar{p}\to K^+K^-$ [11,12], $p\bar{p}\to K^0_S K^0_S$ [13], $p\bar{p}\to\phi\phi$ [14], and $p\bar{p}\to p\bar{p}\pi^+\pi^-$ [15]. None of the experiments have shown any evidence for a narrow $f_J(2220)$ resonance. Recent results of a high-sensitivity search in $p\bar{p}\to\eta\eta$, $p\bar{p}\to\eta\eta'$, and $p\bar{p}\to\pi^0\pi^0$ reactions from the Crystal Barrel Collaboration [16] have also shown no evidence for the $f_J(2220)$ state.

The different experiments have shown contradictory results and it is clear that the existence and nature of the $f_J(2220)$ requires further experimental work. Here we report on a search of the $f_J(2220)$ in untagged two-photon interactions at CLEO and a new upper limit on the two-photon partial width times the branching fraction for its decay into $K^0_S K^0_S$.

Color singlet hadronic states, such as mesons($q\bar{q}$) and baryons(qqq) make bound states as a consequence of QCD color confinement. Color singlets can also be constructed with gluons, hence named "glueballs". Glueballs are hadrons with no valence quarks, bound together by the gluons' mutual attraction. Many different QCD-based models and calculations make predictions for such states: bag models [17–19], constituent-glue models [20–22], QCD sum rules [23], and lattice gauge calculations based on the quenched approximation [24,25]. Low mass scalar (J=0) glueballs are hard to detect and identify as their masses lie within the dense spectrum of conventional mesons, but heavy tensor glueballs are expected to be more easily observable. Gluons do not couple directly to photons (only via a box diagram) and glueball two photon widths, $\Gamma_{\gamma\gamma}$, are expected to be small relative to those of mesons. A state that can readily be formed in a gluon rich environment, but not in two-photon collisions, has the quintessential signature of a glueball. Upper limits derived from $\gamma\gamma$ data can thus play a major role in identifying glueballs.

The data presented here were taken by the CLEO II [26] and CLEO II.V [27] detector configurations operating at the Cornell Electron Storage Ring. The sample used in this analysis corresponds to an integrated e^+e^- luminosity of 13.3 fb^{-1} from data taken on the $\Upsilon(4S)$ and at the energies just below the $\Upsilon(4S)$. This is four times the sample size used in the prior CLEO publications [7,8]. The CLEO detector includes several concentric tracking devices to detect and measure charged particles over 95% of 4π steradians and a CsI electromagnetic calorimeter, both operating inside 1.5 T superconducting solenoid. The tracking system in CLEO II [26] consisted of a 6-layer straw tube chamber, a 10-layer precision tracker and a 51-layer main drift chamber. For CLEO II.V [27] the straw tube chamber was replaced by a 3-layer, double-sided silicon vertex detector, and the gas in the main drift chamber was changed from an argon-ethane to a helium-propane mixture. This change in gas improved both the hit efficiency and the specific ionization resolution [28].

The Monte Carlo generation of two photon production is modeled on the BGMS formalism [29], for which we assumed $J=2$ for the glueball candidate. The simulation of the transport and decay of the final state particles through the CLEO detector is performed by the GEANT package [30]. We estimate a $K^0_S K^0_S$ mass resolution of $\sigma = 7.86$ MeV/c^2 near the PDG average mass [31] of 2231 MeV/c^2. The net efficiencies for the 0 and ± 2 helicities are 13.6% and 19.1%, respectively; this includes the 69% branching fraction for each $K^0_S \to \pi^+\pi^-$.

The kinematics of untagged two-photon events are defined by the fact that the photons have a large fraction of their momenta along the beam line; that is the two photons are almost on mass shell. The scattered electron and positron do not in general have sufficient transverse momentum to be detected in the tracking chambers. The two photons rarely have the same magnitude of momentum, and as a result the two-photon center of mass is boosted along the beam axis. We select events containing exactly four reconstructed charged tracks with zero net charge. To ensure these events have no accompanying photon showers, we require the unmatched neutral energy to be less than 0.6 GeV. To suppress non-two photon events ($udsc$ continuum and $\tau^+\tau^-$ events) we require the total charged track energy be less than 4.5 GeV and that the vector sum of transverse momentum of all charged tracks be less than 0.6 GeV/c in magnitude. To suppress two-photon events that do not have K^0_S mesons in the final state, we applied a flight distance significance criterion (flight distance divided by its uncertainty) of 3 for CLEO II and 5 for CLEO II.V data, and required that each charged pion daughter of the K^0_S candidates not point back to the interaction point. Finally, we selected good events with two good K^0_S candidates by requiring $(\Delta M_1/\sigma_1, \Delta M_2/\sigma_2)$ to lie within a circle of radius 3.5. Here $\Delta M = m_{\pi\pi} - m_K$, m_K is the K^0_S mass of 497.7 MeV/c^2, and σ_1 and σ_2 are the mass resolutions for the two K^0_S candidates calculated on an event-by-event basis. In Fig. 1 we show the distribution of these scaled mass differences within $\pm 10\ \sigma$ of the nominal K^0_S mass. We conclude from Fig. 1 that we have no substantial background that does not contain K^0_S mesons.

Using the data sample described above, we combine the two K^0_S candidates in the event and plot the invariant mass distribution (Fig. 2) from 1.8 to 2.8 GeV/c^2. We fit the data to the combination of a power law background function ($AW^n_{\gamma\gamma}$) and a signal shape comprising a Breit-Wigner convolved with a Gaussian resolution function derived from the Monte Carlo studies. The mass and Breit-Wigner width of the signal function are allowed to float within $\pm 1\sigma$ of the PDG [31] values for the $f_J(2220)$: mass of 2231$\pm$3.5 MeV/c^2 and width of 23^{+7}_{-8} MeV/c^2. A statistically insignificant excess of 15 ± 11 events is found in the signal region,

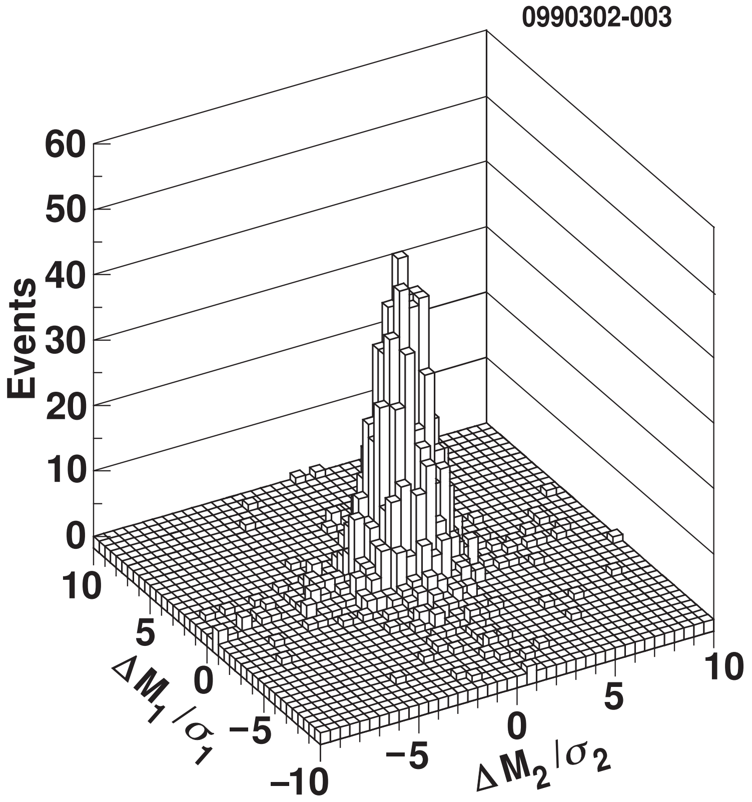

FIG. 1. $\Delta M_1/\sigma_1$ *vs.* $\Delta M_2/\sigma_2$ for data, with ΔM being the difference between the invariant mass of a dipion combination and the known K^0_S mass. We select good $K^0_SK^0_S$ candidates within a circle of radius 3.5 units.

with a mass of 2228 MeV/c^2 and a width of 31 MeV/c^2, corresponding to an upper limit of 29.9 events at the 95% confidence level. The largest excess apparent in the plot is one of 24±8 events at a mass of 2290.0 MeV/c^2. There are no known narrow resonances in this region, and we consider this enhancement to be a statistical fluctuation. The mass of 2290.0 MeV/c^2 for this excess is also completely inconsistent with the previous measurements of the $f_J(2220)$. Allowing this enhancement into the fit (describing it with a single Gaussian with its width allowed to float) slightly lowers the excess found in the 2231 MeV/c^2 region. We therefore conservatively quote our result without this excess at 2290.0 MeV/c^2 in the fit. In this analysis we do not have enough events in the high mass region to interpret quantitatively any interference effect between resonant ($\gamma\gamma \rightarrow f_J(2220) \rightarrow K^0_SK^0_S$) and non-resonant ($\gamma\gamma \rightarrow K^0_SK^0_S$) events. Therefore in the above fit we did not include an interference term between them.

To extract the value of $\Gamma_{\gamma\gamma}\mathcal{B}(f_J \rightarrow K^0_SK^0_S)$ for $f_J(2220)$ from the data, we scaled the branching fraction and the partial width used in the Monte Carlo production by the ratio of the upper limit on the number of data events ($n^{\rm data}$) to the number of Monte Carlo events passing our selection criteria ($n^{\rm MC}$), and the ratio of Monte Carlo to data luminosities,

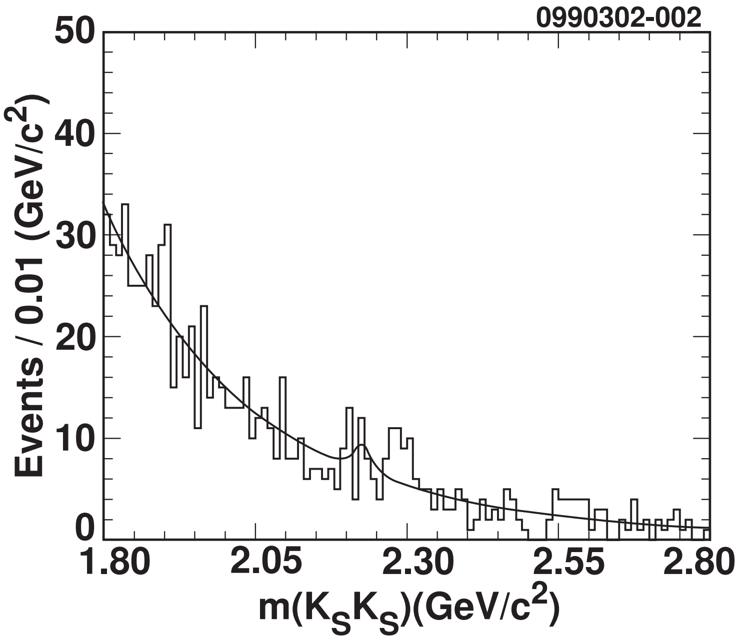

FIG. 2. $K^0_S K^0_S$ mass distribution observed in data around $f_J(2220)$ mass region. The solid line is the sum of a fit to the background and the signal line shape which was obtained from Monte Carlo. The number of observed events at 95% C.L. upper limit is 29.9.

$$\Gamma_{\gamma\gamma}\mathcal{B}(f_J \to K^0_S K^0_S) = \frac{n^{data}}{n^{\rm MC}}\frac{\mathcal{L}^{\rm MC}}{\mathcal{L}^{\rm data}}[\Gamma_{\gamma\gamma}\mathcal{B}(f_J \to K^0_S K^0_S)]^{\rm MC}. \quad (1)$$

Note that this procedure is independent of the actual values used for $\Gamma_{\gamma\gamma}$ and $\mathcal{B}(f_J \to K^0_S K^0_S)$ in the simulation (which were 1 keV and 1.0, respectively).

Our estimate of the systematic uncertainties in the overall detector efficiency is: 7% due to event selection criteria, 5% due to trigger effects, 4% due to tracking, 3% from online software filtering. We assign systematic uncertainties of 8% from our background parameterization and 1% due to the luminosity measurement. We add these in quadrature to obtain a total systematic uncertainty of 13%.

Spin 2 resonances from two-photon events can have two helicity projections, 0 and 2. $\Gamma_{\gamma\gamma}$ is therefore a superposition of two components, $\Gamma^{2,0}_{\gamma\gamma}$ and $\Gamma^{2,2}_{\gamma\gamma}$. The efficiencies for these two helicities, given above, are different due to their different final state angular distributions. States with helicity of 2 should dominate those of helicity zero in a 6:1 ratio, based purely on the Clebsch-Gordon coefficients. The number of Monte Carlo events observed and the Monte Carlo luminosities were therefore reweighted to this 6:1 ratio [32,33], for the $|Y^2_2|^2$ and $|Y^0_2|^2$ angular distributions, yielding

$$\Gamma_{\gamma\gamma}\mathcal{B}(f_J \to K^0_S K^0_S) \le 1.1\,eV, \qquad (95\,\%\ C.L.) \quad (2)$$

This limit includes our systematic uncertainties. Alternatively, we also present our results as a functional limit for a state with $J = 2$, without assuming the ratio of partial widths of the two helicity projections,

$$(0.53\Gamma^{2,0}_{\gamma\gamma} \ + \ 1.08\Gamma^{2,2}_{\gamma\gamma})\mathcal{B}(f_J \to K^0_S K^0_S) \leq 1.1\, eV \quad (95\,\%\ C.L.) \tag{3}$$

The ratio of the coefficients is the ratio of the efficiencies for the two helicities, normalized to the 6:1 ratio in Eq.(2).

To build confidence in our approach for the $f_J(2220)$ search, we have also checked the two-photon partial width and the mass of the well established $f_2'(1525)$ resonance using the same Monte Carlo simulation and analysis technique, and find the values for both the width and the mass consistent with the PDG values [34].

Under the assumption that the f_J resonance has a large branching fraction to kaons, the low limit on the $\Gamma_{\gamma\gamma}\mathcal{B}(f_J \to K^0_S K^0_S)$ implies that the $f_J(2220)$ production is very suppressed in two-photon collisions. This is exactly the behavior that would be expected for a true glueball as gluons, being neutral, do not couple with electric charge. Quantitatively, a naive glueball figure of merit known as "stickiness" is frequently used. Stickiness is a measure of color charge relative to electric charge [35]:

$$S_X \ = \ N_l \left(\frac{m_X}{k_X}\right)^{2l+1} \frac{\Gamma(\psi \to \gamma X)}{\Gamma(X \to \gamma\gamma)}. \tag{4}$$

Where, $k_X \ = \ (m^2_\psi \ - \ m^2_X)/2m_\psi$ is the energy of the photon from the radiative J/ψ decay in the J/ψ rest frame. N_l is the normalization factor and is so chosen that $S_X \ = \ 1$ for the $f_2(1270)$ meson.

In order to determine an upper limit for stickiness, we first extract average the results of the MARK III [1] and BES [3] experiments, obtaining $\mathcal{B}(J/\psi \to \gamma f_J(2220))\mathcal{B}(f_J(2220) \to K^0_S K^0_S) \ = \ (2.2 \pm 0.6) \times 10^{-5}$. Within each experiment we form a branching fraction to $K\bar{K}$ by adding twice the branching fraction to $K^0_S K^0_S$ to that for K^+K^-. We combine our upper limit for $\Gamma_{\gamma\gamma}\mathcal{B}(f_J \to K^0_S K^0_S)$ with this product branching fraction and the J/ψ width of $\Gamma = 87$ keV [31] to set a lower limit on the value of the $f_J(2220)$ "stickiness" of 109 at the 95% C.L.

In conclusion, we do not see a signal for $f_J(2220)$ in the $K^0_S K^0_S$ invariant mass distribution at masses near those reported by previous experiments [31]. Therefore, we set an upper limit on $\Gamma_{\gamma\gamma}\mathcal{B}(f_J \to K^0_S K^0_S)$ for the $f_J(2220)$ of 1.1 eV at the 95% confidence level. We allowed the width and mass to float within $\pm 1\ \sigma$ of the PDG values. Our limit is lower than the previous CLEO measurement based on a quarter of the present luminosity. Recently, L3 [9] published an upper limit for $\Gamma_{\gamma\gamma}\mathcal{B}(f_J(2220) \to K^0_S K^0_S)$ of 1.4 eV at 95% C.L., which is similar to our upper limit of 1.02 eV (from Eq. 3) at 95% C.L. under the hypothesis of a pure helicity-2 state. This low value of $\Gamma_{\gamma\gamma}\mathcal{B}(f_J(2220) \to K^0_S K^0_S)$ indicates that the $f_J(2220)$ coupling to photons is suppressed and argues the case that, if the previous observations of the $f_J(2220)$ by the MARK III and BES collaborations in radiative J/ψ decays are correct, it has the signature of a glueball. On the other hand, our data is also consistent with the non-existance of any narrow resonance in the mass region.

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