Antisearch for the glueball candidate $f_J(2220)$ in two-photon interactions

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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, $\Gamma_{\gamma\gamma}\mathcal{B}(f_J(2220)\rightarrow K_S^0K_S^0)$, of less than 1.1 eV at the 95% confidence level; systematic uncertainties are included. This data set is four times larger than that used in the previous CLEO publication.

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In the theory of quantum chromodynamics hadrons comprise quarks, antiquarks and gluons in color singlet combinations. Hadrons composed of gluons but no valence quarks, and bound together by the gluons' mutual attraction, are known as pure "glueballs." Many different QCD-based models and calculations make predictions for such states, including bag models [1–3], constituent-glue models [4–6], QCD sum rules [7], and lattice gauge calculations based on the quenched approximation [8,9]. Low mass scalar ($J=0$) glueballs are expected to lie within the dense spectrum of conventional mesons. These states are expected to mix and to have large widths, making them hard to identify. Tensor ($J^P=2^+$) glueballs, however, are expected to have higher masses. They would then be comparatively isolated from other states, have narrower widths, and be easier to identify. To find glueballs, it is logical to look in a "glue rich" environment such as radiative J/ψ or $\Upsilon(1S)$ decays. Conversely, in the analysis presented here, we search for a tensor glueball in two-photon collisions. As gluons do not couple directly to photons (they do so only via a box diagram) the glueball two photon widths $\Gamma_{\gamma\gamma}$ are expected to be small relative to those of mesons. Thus we refer to our search as an "antisearch," as we do not expect to find a glueball in this reaction. Upper limits derived from $\gamma\gamma$ data play a major role in the quest to find and identify glueballs, as they shed light on the parton content of states that are seen in other reactions.

Our analysis is inspired by observations of the $f_J(2220)$, also known as $\xi(2230)$, which is a candidate for the lightest tensor glueball. The Mark III Collaboration [10] 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 $K^0_SK^0_S$ 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 [11], using a sample 8.6×10^6 J/ψ radiative decays, searched for the $f_J(2220)$ in the $\pi^+\pi^-$, K^+K^-, and $K^0_SK^0_S$ final states. They 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 $\pi^+\pi^-, K^+K^-$, $K^0_SK^0_S$ [12], and $\pi^0\pi^0$ [13], again in radiative J/ψ decays. In hadron production the GAMS Collaboration [14] reported a state, decaying to $\eta\eta'$ in $\pi^-p\to\eta\eta' n$ interactions, at 2220.0 MeV/c^2. The angular distribution of the decay strongly indicated $J\geq2$. The LASS Collaboration [15] 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. By averaging the above results, the Particle Data Group [17] find a mass of 2231.1 ± 3.5 MeV/c^2 and a width of 23^{+7}_{-8} MeV/c^2 for the $f_J(2220)$.

In 1997, the CLEO Collaboration reported tight limits on the two-photon coupling of the $f_J(2220)$ in $\gamma\gamma\to K^0_SK^0_S$ [16] and $\gamma\gamma\to\pi^+\pi^-$ [18]. Recent CERN e^+e^- collider LEP results from the L3 [19] Collaboration showed no evidence for $f_J(2220)$ production in two-photon interactions searching for the $K^0_SK^0_S$ final state, and they derived an upper limit of $\Gamma_{\gamma\gamma}\mathcal{B}(f_J(2220)\to K^0_SK^0_S)<1.4$ 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 by $p\bar{p}$ annihilation into final states of $\pi^+\pi^-$ [20], K^+K^- [21,22], $K^0_SK^0_S$ [23], $\phi\phi$ [24], $p\bar{p}\pi^+\pi^-$ [25], $\eta\eta$, $\eta\eta'$, and $\pi^0\pi^0$ [26]. None of the experiments have shown any evidence for a narrow $f_J(2220)$ resonance.

The different experiments have shown contradictory results, and it is clear that further experimental work is necessary to determine the existence and nature of the $f_J(2220)$. Here we report on an expanded search for the decay $f_J(2220)\to K^0_SK^0_S$ in untagged two-photon interactions at CLEO. We find no significant signal, and so find a new upper limit on the two-photon partial width times the branching fraction for this process.

The data presented here were taken by the CLEO II [27] and CLEO II.V [28] 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 [16,18] on this subject. The CLEO detector includes several concentric tracking devices to detect and measure charged particles over 95% of 4π steradian and a CsI electromagnetic calorimeter, both operating inside 1.5 T superconducting solenoid. The tracking system in CLEO II [27] consisted of a 6-layer straw tube chamber, a 10-layer precision tracker and a 51-layer main drift chamber. For CLEO II.V [28] 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 [29].

The Monte Carlo generation of two photon production is modeled on the Budnev-Ginzburg-Meledin-Serbo (BGMS) formalism [30], using $J=2$ 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 [31]. We estimate a $K^0_SK^0_S$ mass resolution of $\sigma=7.86$ MeV/c^2 near the Particle Data Group (PDG) [17] average for the $f_J(2220)$ mass.

Spin 2 resonances from two-photon events can have two helicity projections, 0 and 2. The efficiencies of the 0 and ±2 helicities are very different due to their different final state angular distributions ($|Y^2_2|^2$ and $|Y^0_2|^2$ respectively). They are found to be 9.3% and 19.1% respectively; these numbers include the 69% branching fraction for each $K^0_S\to\pi^+\pi^-$ decay. The Monte Carlo events were generated with weights to reproduce the helicity ratio based solely on Clebsch-Gordan coefficients (ratio for helicity-2 to helicity-0 of 6:1) [32,33].

In untagged two-photon events the two photons are almost on mass shell, and so the photons have a large fraction of their momenta along the beam line. The scattered electron and positron do not in general have sufficient transverse momentum to be detected. As the two photons rarely have the same energy, the two-photon center of mass is boosted along the beam axis. We thus select events containing exactly four reconstructed charged tracks with zero net charge, and no

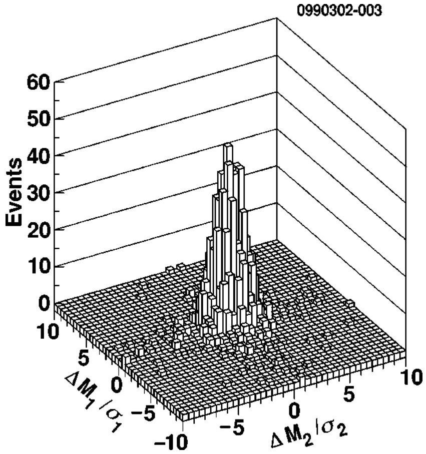

FIG. 1. $\Delta M_1/\sigma_1$ vs $\Delta M_2/\sigma_2$ for data, with ΔM being the difference between the invariant mass of a dipion combination and the known K_S^0 mass. We select good $K_S^0K_S^0$ candidates within a circle of radius 3.5 units.

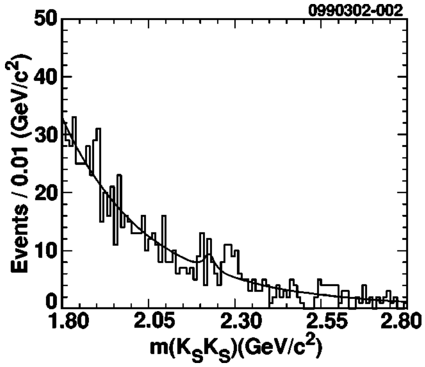

FIG. 2. $K_S^0K_S^0$ mass distribution observed in data around $f_J(2220)$ mass region. The solid line is the sum of a fit to the background and the signal line shape which was obtained from Monte Carlo. The number of observed events at 95% C.L. upper limit is 29.9.

accompanying photon showers (that is, neutral energy less than 0.6 GeV). To suppress non-two-photon events from $udsc$ continuum and $\tau^+\tau^-$ production, we require that 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. We make K_S^0 candidates by constraining two oppositely charge tracks to a common vertex. To suppress two-photon events that do not have K_S^0 mesons in the final state, we required that the flight distance significance (flight distance divided by its uncertainty) be at least 3 for CLEO II and at least 5 for CLEO II.V data, and required that each charged pion daughter of the K_S^0 candidates not point back to the interaction point. Finally, we selected good events with two good K_S^0 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_S^0 mass of 497.7 MeV/c^2, and σ_1 and σ_2 are the mass resolutions for the two K_S^0 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_S^0 mass. We conclude from Fig. 1 that we have no substantial background that does not contain K_S^0 mesons. The K_S^0 candidates that pass all requirements are then kinematically constrained to the K_S^0 mass.

Using the data sample described above, we combine the two K_S^0 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 [$AW^n_{\gamma\gamma}$, where A and n are free parameters and $W_{\gamma\gamma} = M(KK)$], and a signal shape comprising Breit-Wigner terms 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 [17] values.

A statistically insignificant excess of 15 ± 11 events is found in this signal region. The fitted mass of this enhancement is 2228 MeV/c^2, and the width 31 MeV/c^2. This corresponds 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. This mass of 2290.0 MeV/c^2 for this excess is completely inconsistent with the previous measurements of the $f_J(2220)$. Other than the invariant mass of the $K_S^0K_S^0$ system, we find no significant differences between the properties of the events in this region of excess and the properties of other events in Fig. 2. There are no known narrow resonances in this region, and we consider this enhancement to be a statistical fluctuation. In this analysis we do not have enough events in the high mass region to interpret quantitatively any interference effect between resonant ($\gamma\gamma \to f_J(2220) \to K_S^0K_S^0$) and nonresonant ($\gamma\gamma \to K_S^0K_S^0$) events. Therefore in the above fit we did not include an interference term between them.

To extract the value of $\Gamma_{\gamma\gamma}\mathcal{B}(f_J \to K_S^0K_S^0)$ 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,

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

Note that this procedure is independent of the actual values used for $\Gamma_{\gamma\gamma}$ and $\mathcal{B}(f_J \to K_S^0K_S^0)$ 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, and 3% from online software filtering. We assign systematic uncertainties of 8% from our background parametrization and 1% due to the luminosity measurement. We add these in quadrature to obtain a total systematic uncertainty of 13%.

Using the efficiency found from this Monte Carlo sample, and taking the ratio of helicity 2 to helicity 0 decays as 6:1 as described above, we calculate

$$\Gamma_{\gamma\gamma}\mathcal{B}(f_J\to K_S^0K_S^0)\le 1.1\ \text{eV}\quad (95\%\ \text{C.L.}). \tag{2}$$

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,

$$(0.53\Gamma_{\gamma\gamma}^{2,0}+1.08\Gamma_{\gamma\gamma}^{2,2})\mathcal{B}(f_J\to K_S^0K_S^0)\le 1.1\ \text{eV}\quad (95\%\ \text{C.L.}). \tag{3}$$

The ratio of the coefficients is the ratio of the efficiencies for the two helicities, normalized to the 6:1 ratio in Eq. (2). For a pure helicity-2 state the limit becomes 1.0 eV. This can be compared with the L3 [19] limit of 1.4 eV using the same assumption.

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 [34] and L3 [19] values.

Under the assumption that the f_J resonance has a large branching fraction to kaons, the low limit on the $\Gamma_{\gamma\gamma}\mathcal{B}(f_J\to K_S^0K_S^0)$ 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. A naive glueball figure of merit known as "stickiness" is frequently used to make comparisons of the gluon content of different states. 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 $k_X=(m_\psi^2-m_X^2)/2m_\psi$ is the energy of the photon from the radiative J/ψ decay in the J/ψ rest frame. In our case we have $l=2$, and the normalization factor N_2 is so chosen that the value of S_X is unity for the $f_2(1270)$ meson, which is used as a representative ud tensor meson.

In order to determine an upper limit for stickiness, we first average the results of the Mark III [10] and BES [12] experiments, obtaining a product branching fraction $\mathcal{B}(J/\psi\to\gamma f_J(2220))\cdot\mathcal{B}(f_J(2220)\to K_S^0K_S^0)=(2.2\pm0.6)\times10^{-5}$. Within each experiment we form a branching fraction to $K\bar{K}$ by adding twice the branching fraction to $K_S^0K_S^0$ to that for K^+K^-. We combine our upper limit for $\Gamma_{\gamma\gamma}\mathcal{B}(f_J\to K_S^0K_S^0)$ with this product branching fraction and the J/ψ width of $\Gamma=87$ keV [17] 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 $K_S^0K_S^0$ invariant mass distribution consistent with those reported by previous experiments [17]. Therefore, we set an upper limit on $\Gamma_{\gamma\gamma}\mathcal{B}(f_J\to K_S^0K_S^0)$ for the $f_J(2220)$ of 1.1 eV at the 95% confidence level. We allowed the width and mass to float within $\pm1\ \sigma$ of the PDG values. Our limit is lower than the previous CLEO measurement [16] based on a quarter of the present luminosity.

The low value of $\Gamma_{\gamma\gamma}\mathcal{B}(f_J(2220)\to K_S^0K_S^0)$ we obtain 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 are also consistent with the nonexistence of any narrow resonance in the mass region.

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