Search for $X(3872)$ in $\gamma\gamma$ Fusion and ISR at CLEO

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Abstract. We report on a search for the $X(3872)$ state using 15.1 fb^{-1} of e^+e^- annihilation data taken with the CLEO III detector in the $\sqrt{s}$ = 9.46-11.30 GeV region. Separate searches for the production of $X(3872)$ in untagged $\gamma\gamma$ fusion and e^+e^- annihilation following initial state radiation (ISR) are made by taking advantage of the unique correlation of $J/\psi \to l^+l^-$ in $X(3872)$ decay into $\pi^+\pi^-J/\psi$. No signals are observed in either case, and 90% confidence upper limits are established as $(2J+1)\Gamma_{\gamma\gamma}(X(3872))\mathcal{B}(X \to \pi^+\pi^-J/\psi) < 12.9$ eV and $\Gamma_{ee}(X(3872))\mathcal{B}(X \to \pi^+\pi^-J/\psi) < 8.3$ eV.

1. Introduction

The Belle Collaboration reported the observation of a narrow state, $X(3872)$, in the decay $B^\pm \to K^\pm X$, $X \to \pi^+\pi^-J/\psi$, $J/\psi \to l^+l^-$ $(l = e, \mu)$ [1]. The observation was confirmed by the CDF II [2], DØ [3], and BABAR [4] Collaborations with consistent results, i.e., M(X) = 3872.0 $\pm$ 1.4 MeV/c^2 and $\Gamma(X) \leq 3$ MeV/c^2.

Many different theoretical interpretations of the nature of the $X(3872)$ state and its possible quantum numbers have been proposed [5, 6, 7, 8]. These include that (a) $X(3872)$ is a charmonium state [5]; (b) $X(3872)$ is a $D^0\bar{D}^{*0}$ "molecular" state [6]; and (c) $X(3872)$ is an exotic state [7].

No positive signals for $X(3872)$ have been observed in searches for the decays $X(3872) \to \gamma\chi_{c1}$ [1], $\gamma\chi_{c2}$, $\gamma J/\psi$, $\pi^0\pi^0J/\psi$ [9], $\eta J/\psi$ [10], D^+D^-, $D^0\bar{D}^0$, and $D^0\bar{D}^0\pi^0$ [11], or for possible charged partners of $X(3872)$ [12]. Yuan, Mo, and Wang [13] have used 22.3 pb^{-1} of BES data at $\sqrt{s} = 4.03$ GeV to determine the 90% confidence upper limit of $\Gamma_{ee}(X(3872))\mathcal{B}(X \to \pi^+\pi^-J/\psi)$ < 10 eV for ISR production of $X(3872)$. Belle [9] has recently reported a small enhancement in the $\pi^+\pi^-\pi^0J/\psi$ effective mass near the $X(3872)$ mass.

The variety of possibilities for the structure of $X(3872)$ suggests that it is useful to limit the J^{PC} of $X(3872)$ as much as possible. The present investigation is designated to provide experimental constraints for the J^{PC} of $X(3872)$ by studying its production in $\gamma\gamma$ fusion and ISR, and its decay into $\pi^+\pi^-J/\psi$ [14]. Production of $X(3872)$ in $\gamma\gamma$ fusion can shed light on the positive charge parity candidate states, charmonium states $2^3\mathrm{P}_0$, $2^3\mathrm{P}_2$ and $1^1\mathrm{D}_2$ [5], and the 0^{-+} molecular state [6]. ISR production can address the 1^{--} vector state.

2. Event Selection

The data consist of a 15.1 fb^{-1} sample of e^+e^- collisions at or near the energies of the $\Upsilon(nS)$ resonances (n = 1–5) and in the vicinity of the $\Lambda_b\bar{\Lambda}_b$ threshold collected with the CLEO III detector [15]. Table 1 lists the six different initial center-of-mass energies and e^+e^- integrated luminosities at each.

Table 1. Data sample for the present $X(3872)$ search. The average center-of-mass energies and e^+e^- integrated luminosities near $\Upsilon(1S-5S)$ and $\Lambda_b\bar{\Lambda}_b$ threshold are denoted by $\sqrt{s_i}$ and $\mathcal{L}_i(e^+e^-)$, respectively.

	$\sqrt{s_i}$ (GeV)	$\mathcal{L}_i(e^+e^-)$ (fb^{-1})
$\Upsilon(1S)$	9.458	1.47
$\Upsilon(2S)$	10.018	1.84
$\Upsilon(3S)$	10.356	1.67
$\Upsilon(4S)$	10.566	8.97
$\Upsilon(5S)$	10.868	0.43
$\Lambda_b\bar{\Lambda}_b$ threshold	11.296	0.72

Resonance production by untagged $\gamma\gamma$ fusion and by ISR has similar characteristics. The undetected electrons in untagged $\gamma\gamma$ fusion and the undetected radiated photons in ISR have angular distributions sharply peaked along the beam axis. Both processes have total observed energy (E_{tot}) much smaller than the center-of-mass energy, $\sqrt{s}$, of the original e^+e^- system and have small observed transverse momentum. The detailed characteristics for $\gamma\gamma$ fusion and ISR mediated $X(3872)$ production are studied by generating signal Monte Carlo (MC) samples, using the formalism of Budnev *et al.* [16] for $\gamma\gamma$ fusion and the formalism of M. Benayoun *et al.* [17] for ISR.

A fully reconstructed event has four charged particles and zero net charge. All charged particles are required to individually lie within the drift chamber volume, satisfy standard requirements for track quality and distance of closest approach to the interaction point, and satisfy their respective particle identification criteria. Events must also have detected $E_{tot} < 6$ GeV, total neutral energy (E_{neu}) < 0.4 GeV and total transverse momentum (p_{tr}) < 0.3 GeV/c. The lepton pair invariant mass must be consistent with a J/ψ decay; M(e^+e^-) = 2.96-3.125 GeV/c^2 for events with a $J/\psi \to e^+e^-$ decay and M($\mu^+\mu^-$) = 3.05-3.125 GeV/c^2 for events with a $J/\psi \to \mu^+\mu^-$ decay. Figure 1 shows the $\Delta\mathrm{M} \equiv \mathrm{M}(\pi^+\pi^-l^+l^-) - \mathrm{M}(l^+l^-)$ distribution for data events which pass the selection criteria. The $\psi(2S)$ is clearly visible while no enhancement is apparent for $X(3872)$, i.e., at $\Delta\mathrm{M} = 0.775$ GeV/c^2, which is indicted by the arrow in Figure 1.

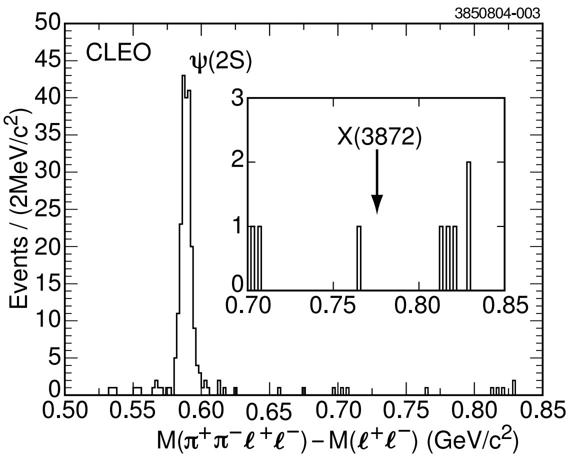

Figure 1. Data events as function of ΔM $\equiv \mathrm{M}(\pi^+\pi^-l^+l^-) - \mathrm{M}(l^+l^-)$. The $\psi(2S)$ is clearly visible and no apparent enhancement is seen in the $X(3872)$ region.

At $\sqrt{s} \sim 10$ GeV, a feature unique to the ISR mediated production of a vector resonance which decays via $\pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ is the correlation between the $\cos(\theta)$ of the two leptons. Figure 2 shows the MC prediction for the two-dimensional $\cos(\theta)$ distributions for leptons from $X(3872)$ decay for the ISR mediated and $\gamma\gamma$ fusion productions. As shown in Figure 2, a parabolic cut applied to the two-dimensional $\cos(\theta)$ distribution efficiently separates the events from the two production processes. With this cut, the $\gamma\gamma$ sample contains $\sim$86% of the $\gamma\gamma$ events and $< 0.5\%$ of the ISR events, and the ISR sample contains $> 99.5\%$ of the ISR events and $\sim$14% of the $\gamma\gamma$ events.

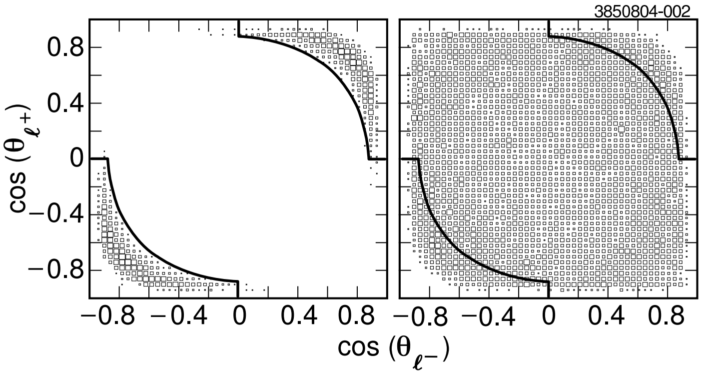

Figure 2. MC predictions for the two-dimensional $\cos(\theta)$ distributions for the lepton pair for ISR mediated (left) and $\gamma\gamma$ fusion (right) $X(3872)$ production. The lines indicate how the ISR and $\gamma\gamma$ fusion samples are separated.

3. Results

The number of observed $X(3872)$ events ($N_{\gamma\gamma,ISR}(X(3872))$) is determined by maximum likelihood fits of the ΔM data distributions using flat backgrounds and the appropriate detector resolution functions for the two production processes. The detector resolution functions are determined by the MC simulations fitted with double Gaussians. The 90% confidence upper limits on the observed number of $X(3872)$ events in $\gamma\gamma$ fusion and ISR mediated production are determined to be $N_{\gamma\gamma,ISR}(X(3872)) < 2.36$ for both processes.

Systematic uncertainty arises from possible biases in the detection efficiency and estimated background level. These are studied by varying the event selection criteria described above. Other systematic uncertainties are from the e^+e^- luminosity measurement and $J/\psi \to l^+l^-$ branching fractions. Adding these in quadrature, the total systematic uncertainties in $\gamma\gamma$ fusion and ISR are 18.5% and 13.2%, respectively. A conservative way to incorporate these systematic uncertainties is to increase the measured upper limits by these amounts. This leads to the 90% confidence upper limits

$$(2J+1)\Gamma_{\gamma\gamma}(X(3872))\mathcal{B}(X \to \pi^+\pi^- J/\psi) < 12.9 \text{ eV}$$

for $X(3872)$ having positive C parity and

$$\Gamma_{ee}(X(3872))\mathcal{B}(X \to \pi^+\pi^- J/\psi) < 8.3 \text{ eV}$$

for $X(3872)$ being a vector meson with $J^{PC} = 1^{--}$.

4. Summary

With 15.1 fb^{-1} of e^+e^- annihilation data taken with the CLEO III detector near $\sqrt{s} = 10$ GeV, we determine 90% confidence upper limits for untagged $\gamma\gamma$ fusion and ISR mediated production of $X(3872)$. If $\mathcal{B}(B^\pm \to K^\pm X(3872)) \approx \mathcal{B}(B^\pm \to K^\pm \psi(2S)) = (6.8\pm0.4)\times10^{-4}$ [18] is assumed, we obtain $\mathcal{B}(X \to \pi^+\pi^- J/\psi) \approx 0.02$ from both the Belle [1] and BaBar [4] results. This leads to 90% confidence upper limits

$$(2J+1)\Gamma_{\gamma\gamma}(X(3872)) < 0.65 \text{ keV}$$

and

$$\Gamma_{ee}(X(3872)) < 0.42 \text{ keV}.$$

The $(2J+1)\Gamma_{\gamma\gamma}(X(3872))$ upper limit is almost 1/4 the corresponding values for χ_{c0} and χ_{c2}, but it is nearly 6 times larger than the prediction for the $1^1\mathrm{D}_2$ state of charmonium [19]. The upper limit for $\Gamma_{ee}(X(3872))$ is comparable to the measured electron width of $\psi(3770)$ and is about 1/2 that of $\psi(4040)$ [20].

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