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Two Photon Width of χ_{c2}*

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Abstract

The two-photon width of χ_{c2} ($^3P_2$) state of charmonium has been measured using 14.4 fb^{-1} e^+e^- data taken at $\sqrt{s}$ = 9.46 - 11.30 GeV with the CLEO III detector. The two-photon fusion reaction studied is $e^+e^- \to e^+e^-\gamma\gamma$, $\gamma\gamma \to \chi_{c2} \to \gamma J/\psi \to \gamma l^+l^-$. We measure $\Gamma_{\gamma\gamma}(\chi_2) \times B(\chi_2 \to \gamma J/\psi) \times B(J/\psi \to l^+l^-) = 13.3 \pm 1.3(stat) \pm 1.2(syst)\ eV$ and obtain $\Gamma_{\gamma\gamma}(\chi_2) = 559 \pm 59(stat) \pm 50(syst) \pm 36(br)\ eV$. This preliminary result is in excellent agreement with the results of previous good statistics two-photon fusion measurements including the latest Belle measurement [1] and also the $\bar{p}p \to \chi_2 \to \gamma\gamma$ measurement, when they are all corrected for the recent CLEO result for the radiative decay $\chi_{c2} \to \gamma J/\psi$ [2].

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The P-wave states of charmonium (^3P_J, $^1P_1$) have provided valuable information about the $q\bar{q}$ interaction and QCD. The two-photon decays of the positive C-parity states (^3P_J) are particularly interesting because in the lowest order the two-photon decay of charmonium is a pure QED process akin to the two-photon decay of positronium. Its study can shed light on higher order relativistic and QCD radiative corrections.

The measurement of the two-photon width of χ_2, $\Gamma_{\gamma\gamma} \equiv \Gamma(\chi_2 \to \gamma\gamma)$, has a very checquered history, with large differences in results from measurements using different techniques. The pre-1992 measurements of $\Gamma_{\gamma\gamma}$ were very inconclusive. They all indicated $\Gamma_{\gamma\gamma}$ to be $\geq$ 1000 eV. In 1993, the E760 experiment at Fermilab reported the result from their $\bar{p}p \to \chi_2 \to \gamma\gamma$ measurement, $\Gamma_{\gamma\gamma} = 320 \pm 80 \pm 50$ [3] eV, i.e., a factor of >3 smaller than the smallest limit established by $\gamma\gamma$–fusion measurements. Since that time, several other measurements have been reported. Unfortunately, the $\gamma\gamma$–fusion experiments continue to report much larger valuers of $\Gamma_{\gamma\gamma}$ than the $\bar{p}p$ experiments, with the latest Belle measurement [1] reporting $\Gamma_{\gamma\gamma} = 850 \pm 127$ eV*, which is still three times larger than the latest $\bar{p}p$ measurement of Fermilab E835 [4], $\Gamma_{\gamma\gamma} = 270 \pm 59$ eV* (* All errors added in quadrature). It is this continuing discrepancy between the present good statistics measurements which has motivated the investigation reported here.

In this investigation we report on a new measurement of the two-photon width of the $\chi_2(^3P_2)$ state of charmonium by the study of the two-photon fusion reaction

$$e^+e^- \to e^+e^-(\gamma\gamma)\ ,\ \gamma\gamma \to \chi_2 \to \gamma J/\psi \to \gamma l^+l^-. \tag{1}$$

The data sample used for analysis was taken with the CLEO III detector at $\Upsilon(1S-5S)$ resonances and around the $\Lambda\bar{\Lambda}$ threshold in the range $\sqrt{s}$ = 9.46 - 11.30 GeV [5]. Center of mass (c.m.) energies and the integrated luminosities of the data are shown in Table I.

We measure the two-photon partial width $\Gamma_{\gamma\gamma}$ of the χ_2 state of charmonium, produced in untagged two-photon fusion reaction (1). We select the events with γe^+e^- or $\gamma\mu^+\mu^-$ in the final state.

We use CLEO standard selection criteria for shower and track selection. We require:
- number of charged tracks = 2;
- total charge = 0;
- only one shower with 0.3< E_γ <0.6 GeV;
- total energy of remaining photon showers in the event $E_{tot}(neut)$ <0.3 GeV;
- total energy of the l^+, l^- and γ system $E_{tot}(\gamma l^+l^-)$ <5 GeV;
- total transverse momentum of the system $p_{tot}^{\perp}(\gamma l^+l^-)$ <0.15 GeV;
- total transverse momentum of the charged tracks $p_{tot}^{\perp}(l^+l^-)$ >0.1 GeV;
- track identified as muon if 0<E/P<0.3, as electron if 0.85<E/P<1.15.

We use E/P cut to distinguish between $e^\pm$ and $\mu^\pm$.

We have generated the signal Monte Carlo (MC) sample for untagged $\gamma\gamma$ fusion production of χ_2 resonance using the $\gamma\gamma$ fusion formalism from Budnev *et al*. [6]. MC samples were produced for each c.m. energies listed in the Table I. For calculation of event selection efficiencies, MC samples were weighted according to the luminosities of each c.m. energy data set.

For the untagged $\gamma\gamma$ production, when the two photon are transversely polarized, the total cross section is related to the two-photon cross section by

$$d\sigma_{e^+e^-\to e^+e^-\chi_2} = d\mathcal{L}_{\gamma\gamma}^{TT}(W^2)\sigma_{\gamma\gamma\to\chi_2}^{TT},$$

where $\mathcal{L}_{\gamma\gamma}^{TT}$ is the $\gamma\gamma$ luminosity function and W is the two photon invariant mass.

We calculate $\sigma(\chi_2) \equiv \sigma^{TT}_{\gamma\gamma\to\chi_2}$ for each c.m. energy with the usual assumptions that χ_2 production in the fusion of two transverse photons is significant only in helicity 2 state, and the decay $\chi_2 \to \gamma J/\psi$ is pure E1. We assume that the intermediate vector meson in the Budnev formalism is J/ψ, and we implement the proper angular distribution [7] in calculating efficiencies. The luminosity weighted average value of $\sigma(\chi_2)$ is determined to be 4.93 pb per 1 keV of $\Gamma_{\gamma\gamma}(\chi_2)$.

Good agreement is observed between the data and MC distributions for $E_{tot}(\gamma l^+l^-)$, $p^{\perp}_{tot}(\gamma l^+l^-)$, p_γ, p_l, $E_{tot}(neut)$, E/P for leptons, and the photon and lepton angular distributions. The latter two are illustrated in Figs.1 and 2.

Efficiencies of all event selection requirements, determined from the signal MC are listed in Table II.

In order to derive the signal counts we analyze the spectra for the difference in invariant masses $\Delta M = M(\gamma l^+l^-) - M(l^+l^-)$ for e^+e^- and $\mu^+\mu^-$ separately, as well as together. $M(l^+l^-) = M(J/\psi) \pm 30$ MeV was assumed. The results are shown in Fig.3.

Three different methods, all using the background shape determined from J/ψ sideband region [$M(l^+l^-)$=2.7-3.5 GeV, omitting $M(l^+l^-)$=3.0-3.2 GeV], were used. Fits using Crystal Ball line shape [8], signal MC peak shape, and simple counts in the region ΔM=0.42-0.49 GeV led to counts which differ by $< \pm 2\%$. The observed yields of l^+l^- are related to the two-photon width as

$$\Gamma_{\gamma\gamma}(\chi_2)\ in\ keV = (Observed\,Yield)/(Expected\,Yield\ per\ 1\ keV),$$

where,

$$Observed\,Yield = \epsilon L \sigma(\chi_2) B(\gamma l^+l^-)[\Gamma_{\gamma\gamma}(\chi_2)\ keV],$$

$$Expected\,Yield\ per\ 1\ keV\ of\ \Gamma_{\gamma\gamma}(\chi_2) = \epsilon L \sigma(\chi_2) B(\gamma l^+l^-),$$

ϵ is a total efficiency, L is the total luminosity of the data used, σ=4.93 pb as above, and $B(\gamma l^+l^-) = B_1(\chi_2 \to \gamma J/\psi) \times B_2[J/\psi \to e^+e^-(\mu^+\mu^-)]$.

In Table III we present the results for $\Gamma_{\gamma\gamma}B(\gamma l^+l^-)$ which are directly determined, and $\Gamma_{\gamma\gamma}$ which are obtained by using the $B_1(\chi_2 \to \gamma J/\psi) = 19.9 \pm 0.5 \pm 1.2$ (%), $B_2(J/\psi \to e^+e^-) = 5.945 \pm 0.067 \pm 0.042$ (%) and $B_2(J/\psi \to \mu^+\mu^-) = 5.960 \pm 0.065 \pm 0.050$ (%), as measured by CLEO [2], [9]. The averages of the results for the three different signal yield extraction methods are presented separately for e^+e^- and $\mu^+\mu^-$ channels, and for their sums. Our preliminary results are

$$\Gamma_{\gamma\gamma}(\chi_2) \times B_1(\chi_2 \to \gamma J/\psi) \times B_2(J/\psi \to l^+l^-) = 13.3 \pm 1.3\ eV,$$

$$\Gamma_{\gamma\gamma}(\chi_2) = 559 \pm 59\ eV.$$

Various sources of systematic uncertainty were studied. Their individual contributions, which add to $\pm 9.0\%$ are listed in Table IV. Thus our preliminary result is

$$\Gamma_{\gamma\gamma}(\chi_2) = 559 \pm 59(stat) \pm 50(syst) \pm 36(br)\ eV,$$

where the first error is statistical, the second is systematic, and the third is from the branching ratios used.

We find that a large part of the discrepancy between the earlier two-photon fusion results and the $\bar{p}p \to \chi_2 \to \gamma\gamma$ results arises from the use of the old value of $B(\chi_2 \to \gamma J/\psi)$. When these results are recalculated using $B(\chi_2 \to \gamma J/\psi) = (19.9 \pm 1.3)\%$, as recently measured by CLEO [2], we obtain the values listed in Table V. The Belle result becomes identical to ours, and even the $\bar{p}p$ result becomes statistically consistent with ours.

Many theoretical predictions based on potential model calculations exist in the literature. As examples, we quote two, both of which include both relativistic and one-loop radiative corrections. Gupta et al. predict $\Gamma_{\gamma\gamma}(\chi_2)$ =570 eV [13], and Ebert et al. predict $\Gamma_{\gamma\gamma}(\chi_2)$ =500 eV [14]. Both are in excellent agreement with our result.

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TABLE I: Data used in present analysis. Center of mass energies shown are the averaged values of the c.m. energies at and in the vicinity of each Υ resonance.

Data	L fb^{-1}	c.m. energy (GeV)
$\Upsilon(1S)$	1.399	9.458
$\Upsilon(2S)$	1.766	10.018
$\Upsilon(3S)$	1.598	10.356
$\Upsilon(4S)$	8.566	10.566
$\Upsilon(5S)$	0.416	10.868
$\Lambda\bar{\Lambda}$	0.688	11.296

TABLE II: Efficiencies of the cuts used for the data event selection.

Selection cut	e^+e^- Channel (%)	$\mu^+\mu^-$ Channel (%)
N(charge)=2	68.9	70.8
Total Charge=0	98.7	98.7
Only one γ with 0.3< E_γ <0.6 GeV	52.8	53.7
Lepton E/P	92.4	98.3
$E_{tot}(\gamma l^+ l^-)$ <5 GeV	96.1	95.3
$E_{tot}(neut)$ <0.3 GeV	99.0	99.1
$p^{\perp}_{tot}(l^+ l^-)$ >0.1 GeV	99.0	98.9
$p^{\perp}_{tot}(\gamma l^+ l^-)$ <0.15 GeV	62.1	62.4
$M(l^+ l^-) = M(J/\psi) \pm 30$ MeV	81.9	93.0
Trigger	97.5	85.7
Overall efficiencies	15.5	17.1

TABLE III: Average of results for the three signal count extraction methods. $\Gamma_{\gamma\gamma}(\chi_2)$ is derived using $B(\gamma l^+ l^-) \equiv B_1(\chi_2 \to \gamma J/\psi) \times B_2[J/\psi \to e^+e^-(\mu^+\mu^-)]$ from CLEO measurements [2],[9] as described in the text.

Leptons	Counts	$\Gamma_{\gamma\gamma}(\chi_2)B(\gamma l^+ l^-)$ (eV)	$\Gamma_{\gamma\gamma}(\chi_2)$ (eV)
e^+e^-	68±11	6.5±1.0	544±89
$\mu^+\mu^-$	79±11	6.8±0.9	571±78
Total	147±15	13.3±1.3	559±59

TABLE IV: Sources of systematic uncertainties.

Source	Systematic uncertainty (%)
integrated luminosity	±3.0
trigger efficiency	±3.0
signal yield extraction	±1.3
J/ψ line shape modeling	±1.6
photon resolution modeling	±1.3
event selection	±4.5
variation in acceptance	±1.8
tracking	±2.0
photon finding	±2.0
theoretical cross section	±5.0
overall	±9.0

TABLE V: Comparison of our preliminary result for the two-photon width of χ_2 with the results of the two recent two-photon fusion measurements and the Fermilab E835 $\bar{p}p$ experiment. The first column gives the results as published and the second column gives the result after correction for the CLEO measured values for $B_1(\chi_2 \to \gamma J/\psi)$ and $B_2(J/\psi \to l^+l^-)$ [2],[9]. Also, Fermilab E835 measured value of $\Gamma_{tot}(\chi_2)$ [10] is used to recalculate E835 result [4], and PDG2004 value of $B(\chi_2 \to 4\pi)$ [11] is used to recalculate CLEO result [12].

Measurement	$\Gamma_{\gamma\gamma}(\chi_2)$ (eV) (as published)	$\Gamma_{\gamma\gamma}(\chi_2)$ (eV) (after correction)
Present Experiment ($\gamma\gamma \to \chi_2 \to \gamma l^+l^-$)		**559(59)(50)(36)**
Belle [1] ($\gamma\gamma \to \chi_2 \to \gamma l^+l^-$)	850(80)(70)(70)	570(55)(46)(37)
CLEO [12] ($\gamma\gamma \to \chi_2 \to 4\pi$)	530(150)(60)(220)	432(122)(54)(61)
E835 [4] $(\bar{p}p \to \gamma\gamma)/(\bar{p}p \to \gamma J/\psi)$	270(49)(33)	384(69)(47)

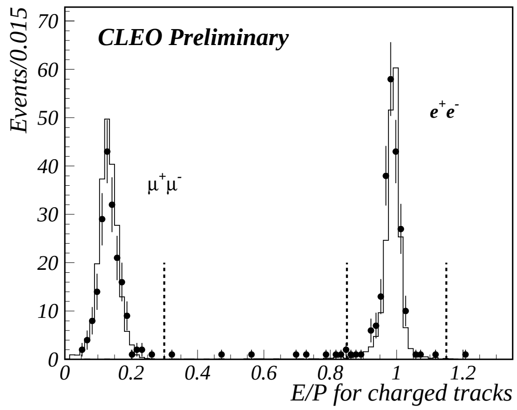

FIG. 1: E/P distribution of the charged tracks in data (points) and in the signal MC for e^+e^- and $\mu^+\mu^-$ channels (histograms). Vertical dashed lines indicate the cut regions for electron and muon identification.

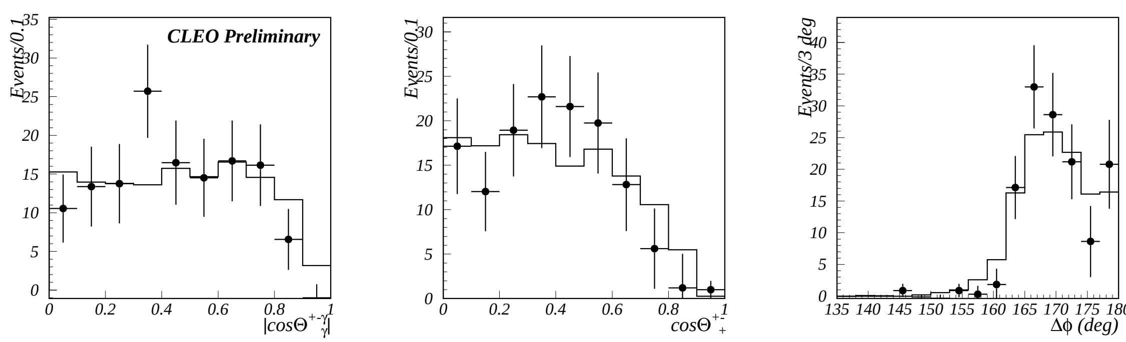

FIG. 2: Comparison of the background subtracted data (points) and the signal MC (histograms) distributions of $cos\Theta_{\gamma}^{+-\gamma}$, $cos\Theta_{+}^{+-}$ and $\Delta\phi$. $\Theta_{\gamma}^{+-\gamma}$ is the polar angle of the photon in the $l^+l^-\gamma$ rest frame, Θ_{+}^{+-} is the polar angle of the positron in the l^+l^- rest frame and the $\Delta\phi$ is the azimuthal angle difference between the two lepton's momenta in the laboratory frame.

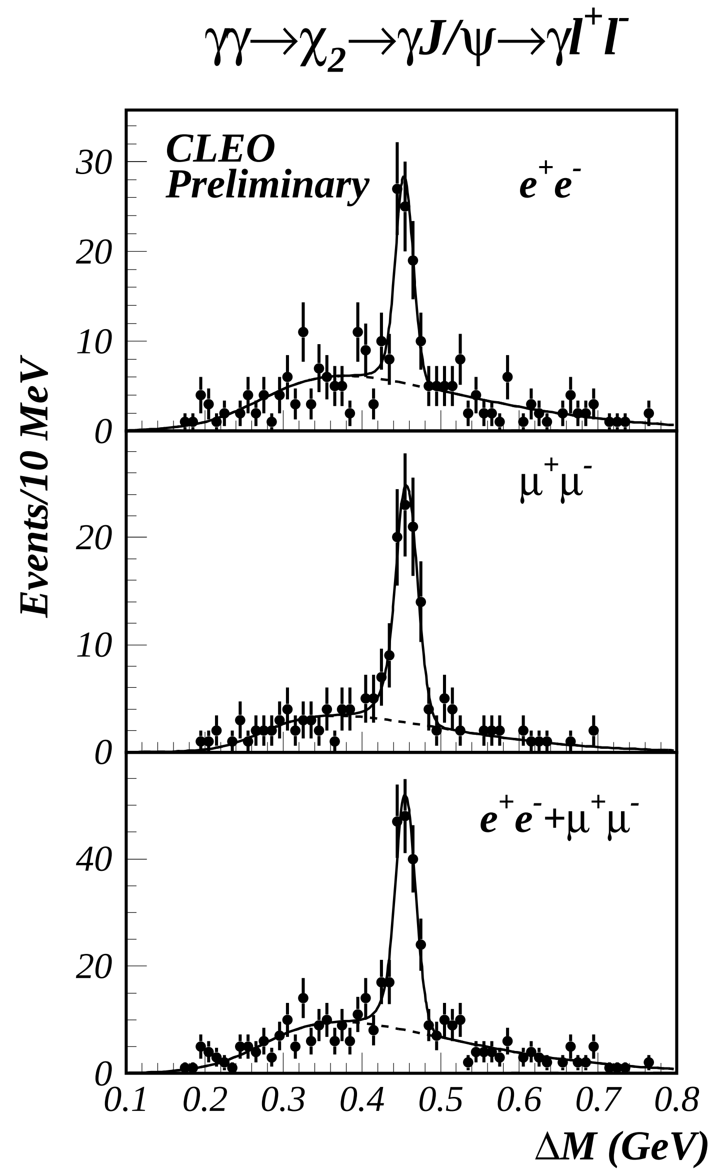

FIG. 3: $\Delta M = M(\gamma l^+l^-) - M(l^+l^-)$ mass difference distributions in the data for e^+e^- channel (top), $\mu^+\mu^-$ channel (middle) and the sum (bottom).