CLNS 03/1853
CLEO 03-14

Observation of η_c' Production in $\gamma\gamma$ Fusion at CLEO

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(Dated: December 23, 2003)

Abstract

We report on the observation of the $\eta_c'(2^1S_0)$, the radial excitation of $\eta_c(1^1S_0)$ ground state of charmonium, in the two-photon fusion reaction $\gamma\gamma \to \eta_c' \to K_S^0 K^\pm \pi^\mp$ in 13.6 fb^{-1} of CLEO II/II.V data and 13.1 fb^{-1} of CLEO III data. We obtain $M(\eta_c')$=3642.9±3.1(stat)±1.5(syst) MeV, and $M(\eta_c)$=2981.8±1.3(stat)±1.5(syst) MeV. The corresponding values of hyperfine splittings between $^1S_0$ and $^3S_1$ states are $\Delta M_{hf}(1S)$=115.1±2.0 MeV, $\Delta M_{hf}(2S)$=43.1±3.4 MeV. Assuming that the η_c and η_c' have equal branching fractions to $K_S K\pi$, we obtain $\Gamma_{\gamma\gamma}(\eta_c')$=1.3±0.6 keV.

Quantum Chromodynamics (QCD) is the accepted theory of the strong interaction. Charmonium ($c\bar{c}$) states provide an excellent laboratory for the study of the QCD interactions. Experimental data are generally compared with perturbative predictions with the QCD interaction modeled by a potential. The central part of the popular Cornell potential consists of a one–gluon exchange "Coulombic" part $\propto 1/r$, and a "confinement" part $\propto r$. The spin–dependence of this potential, with spin–orbit, spin–spin and tensor components, is generally assumed to arise only from the vector Coulombic part. The confinement potential is assumed to be scalar with only a minimal spin–orbit contribution due to Thomas precession. There is little experimental evidence to support the assumption of the pure Lorentz scalar nature of the confinement potential. One of the best ways to study the validity of this assumption is to measure the hyperfine splitting of states which sample the confinement region of the $q\bar{q}$ potential. The 2S states of charmonium, the $\psi'(2^3S_1)$ and $\eta_c'(2^1S_0)$, are ideal for this purpose. The mass of the ψ' is known very precisely, $M(\psi')$=3685.96$\pm$0.09 MeV [1], but the η_c' has not been firmly identified until recently. In this Letter we report on the observation of the η_c' in independent CLEO II and CLEO III measurements of the two-photon fusion reaction

$$e^+e^- \to e^+e^-(\gamma\gamma), \quad \gamma\gamma \to \eta_c' \to K_S^0 K^\pm \pi^\mp . \tag{1}$$

In 1982 the Crystal Ball collaboration reported the observation of a small enhancement at $E_\gamma \approx 91$ MeV in the inclusive photon spectrum from the reaction $e^+e^- \to \psi' \to \gamma X$, and interpreted it as due to η_c' with $M(\eta_c')$=3594$\pm$5 MeV, $\Gamma(\eta_c')$<8 MeV [1,2]. This observation, which corresponds to a 2S hyperfine splitting ΔM_{hf}(2S)=$M(\psi') - M(\eta_c')$=92$\pm$5 MeV, was in qualitative accord with the well established 1S hyperfine splitting, ΔM_{hf}(1S)=$M(J/\psi) - M(\eta_c)$=117$\pm$2 MeV [1]. However, it was not confirmed, and the listing of the η_c' was dropped by the PDG [1] from the meson summary list. The Fermilab experiments E760 [3] and E835 [4] failed to identify η_c' by its direct formation in $\bar{p}p$ annihilation, and its decay into two photons, $\bar{p}p \to \eta_c' \to \gamma\gamma$, and only established the upper limit, $B(\eta_c' \to \bar{p}p) \times \Gamma_{\gamma\gamma}(\eta_c') \leq 0.7$ eV (90% CL) for η_c' mass in the range $M(\eta_c')$=3575–3660 MeV, and width $\leq$15 MeV. In e^+e^- collisions at $\sqrt{s} \approx 91$ GeV DELPHI [5], and later L3 [6], searched for η_c' in two-photon fusion reaction $\gamma\gamma \to$ *hadrons*. They found no evidence for η_c' in the mass range, 3500–3800 MeV, and concluded that its population in this reaction was less than a third of that of the η_c. A recent preliminary CLEO measurement [7] of the inclusive photon spectrum from $\psi' \to \gamma X$ has not found any evidence for the excitation of η_c' in the mass region reported by the Crystal Ball collaboration.

The theoretical situation was equally uncertain. The perturbative prediction for the hyperfine splitting of the S states of charmonia is, in the lowest order

$$\Delta M_{hf}(S) = [32\pi\alpha_s/(9m_c^2)]|\Psi(0)|^2 . \tag{2}$$

Thus, assuming that the strong coupling constant $\alpha_s(2S) = \alpha_s(1S)$,

$$\frac{\Delta M_{hf}(2S)}{\Delta M_{hf}(1S)} = \frac{|\Psi(0)/m_c|^2_{2S}}{|\Psi(0)/m_c|^2_{1S}} = \frac{\Gamma(\psi' \to e^+e^-)}{\Gamma(J/\psi \to e^+e^-)} \frac{M^2(\psi')}{M^2(J/\psi)}$$

since $\Gamma(^3S_1 \to e^+e^-)$ is proportional to $|\Psi(0)|^2/M^2(^3S_1)$. Substituting experimental values [1] yields, $\Delta M_{hf}(2S)$=68$\pm$7 MeV. Buchmüller and Tye [8] have pointed out that in order to take approximate account of binding energy, m_c in Eq. (2) can be replaced by $M(^3S_1)/2$, which leads to $\Delta M_{hf}(2S)$=48$\pm$5 MeV.

Numerous potential model predictions for $\Delta M_{hf}(1S, 2S)$ exist. Most of them make the assumption that the confinement potential is scalar. The predictions range from

$\Delta M_{hf}(2S)$=60–100 MeV. A recent calculation with a screened Coulombic potential [9] predicts $\Delta M_{hf}(2S)$=38 MeV, but it gives splittings for the ^3P_J states which are factor of two smaller than experimentally measured. Two recent quenched lattice calculations predict $\Delta M_{hf}(2S)$=94–106 MeV [10], and $\Delta M_{hf}(2S)$=25–43 MeV [11], respectively. Most predictions make the caveat that coupled-channel effects, which were not included, may be important for $\Delta M_{hf}(2S)$ because of the proximity of the 2S states to the $D\bar{D}$ threshold at 3.73 GeV.

The first reports of a successful identification of η_c' came recently from two measurements by the Belle collaboration. In the decay of 45 million B mesons, $B \to K(K_S K\pi)$, they observed peaks in the $K_S K\pi$ invariant mass spectrum corresponding to the η_c and η_c', and reported $M(\eta_c')$=3654±6±8 MeV [12] [13]. They also reported [14] η_c' observation in double charmonium production, $e^+e^- \to J/\psi + \eta_c'$, in 46.2 fb^{-1} of e^+e^- data at $\sqrt{s} \approx 10$ GeV. They reported $M(\eta_c')$=3622±12(stat) MeV, subsequently updated to $M(\eta_c')$=3630±8(stat) MeV with the analysis of 101 fb^{-1} of data [15]. The fact that both masses were significantly larger than that reported by the Crystal Ball collaboration provided for great interest in confirming the η_c' observation in independent measurements at CLEO. Barnes, Browder and Tuan [16] made the specific suggestion for CLEO to make the kind of measurement we report in this Letter.

At CLEO we had earlier reported [17] the identification and study of $\eta_c(^1S_0)$ in the two-photon fusion reaction of Eq. (1) in 13.6 fb^{-1} of CLEO II data (4.6 fb^{-1} with the CLEO II and 9.0 fb^{-1} with the CLEO II.V detector) at the Υ(4S) and vicinity. We have reanalyzed CLEO II data with the resonance search extended for $M(K_S K\pi)$ up to 4.1 GeV. A positive signal was observed for an η_c' mass of ∼3643 MeV. The preliminary results were reported earlier [18]. In order to confirm this observation, 13.1 fb^{-1} of data taken at, and in the vicinity of, the Υ(1S→4S) resonances with the improved CLEO III detector were analyzed. Results which were consistent with those from the CLEO II data were obtained.

Charged particle tracking and dE/dx measurements in the CLEO II [19] and CLEO II.V [20] detectors were done by various concentric devices (straw tube chamber, drift chamber, and silicon vertex detector) operating in a 1.5 T superconducting solenoid. They have been described in detail in Ref. [17]. K_S^0 were uniquely reconstructed from the displaced vertex of their $\pi^+\pi^-$ decay [17]. K/π separation was done by using the dE/dx and TOF information (when available), and by applying probability criteria.

For CLEO III [21], the charged particle tracking system was replaced with four layers of double-sided silicon detectors, surrounded by a new, 47-layer drift chamber [22]. The CLEO II time-of-flight system was replaced by a ring-imaging Cherenkov detector (RICH) [23] which distinguishes $K^\pm$ from $\pi^\pm$ over 80% of 4π. The two charged tracks not from the K_S^0 decay were tested as being either kaons or pions. All events were used in which the charged particle candidate is identified as a K or π by the RICH detector. For $p > 2$ GeV/c (as for most of our $K^\pm$ candidates) the RICH identifies kaons with efficiency greater than 81% while having less than 2% probability of a pion faking a kaon. When the K/π candidate was not identifiable by the RICH, dE/dx measurements from the drift chamber were used. For $1 < p < 2$ GeV/c, however, K/π separation was difficult using dE/dx, and such events were rejected.

Other criteria included using specific trigger requirements, requiring minimal transverse momentum P_T of the $K_S K\pi$ system, and minimal neutral energy E$_{neut}$ not associated with the charged particles.

The Monte Carlo simulation of the CLEO detector response was based upon GEANT [24].

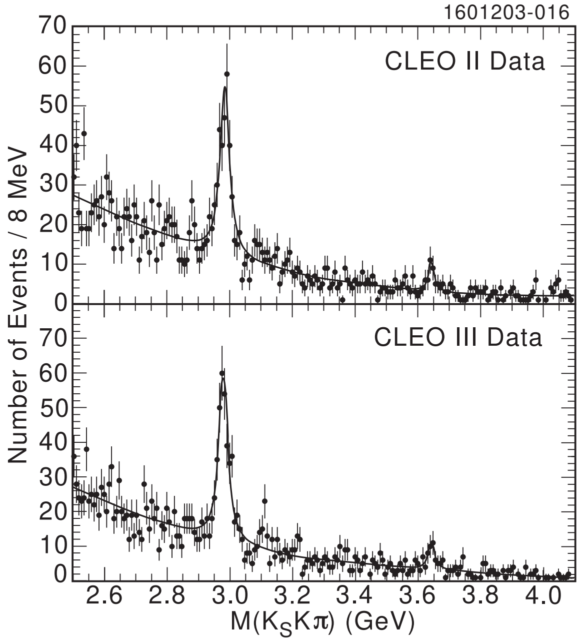

FIG. 1: Invariant mass distributions for $K_S^0K^{\pm}\pi^{\mp}$ events from (top) the CLEO II data and (bottom) the CLEO III data. The curves in the figures are results of fits described in the text.

The events for reaction (1) have been simulated using the formalism of Budnev *et al.* [25]. Simulated events were processed in the same manner as the data to determine the $K_S^0K^{\pm}\pi^{\mp}$ detection efficiency. Efficiencies for trigger, K_S^0 identification, four–charged track reconstruction, π/K identification, and cuts on P_T and E_{neut} were determined. The overall detection efficiencies(ϵ) for $K_S^0K^{\pm}\pi^{\mp}$ obtained from large statistics Monte Carlo samples are listed in Table I.

The $K_S^0K^{\pm}\pi^{\mp}$ invariant mass plots using the event selections for CLEO II and CLEO III are shown in Fig. 1. Clear enhancements at masses ∼2982 and ∼3643 MeV are visible in both, which we label as η_c and η_c', respectively.

In order to extract numerical results from these data we have made maximum likelihood fits to these spectra using a polynomial background and two resonances with Breit–Wigner parametrization, convoluted with double Gaussians representing the experimental resolution functions as obtained from Monte Carlo simulations. For CLEO II data the widths (relative magnitudes) of the Gaussians were σ_1=10.0 MeV (78%), σ_2=37.2 MeV (22%). For CLEO III data the corresponding numbers were σ_1=8.7 MeV (74%), σ_2=26.6 MeV (26%).

As described in our previous publication [17], most of the observed background under our signal events is expected to arise from non $\gamma\gamma \to K_S^0K^{\pm}\pi^{\mp}$ sources such as events with at least one missing π^0 or γ, as well as events of the type $e^+e^- \to$ hadrons, $e^+e^- \to \tau^+\tau^-$, and $\gamma\gamma \to \tau^+\tau^-$. We have therefore not taken into account possible interference between resonance and continuum in fitting our data. The results presented in Table I are based on our final event selections, P_T<0.6 GeV, E_{neut}<0.2 GeV (CLEO II), or E_{neut}<0.4 GeV (CLEO III), second-order polynomial backgrounds, and separate fits in the mass regions 2.5–3.5 GeV(η_c), and 3.3–4.1 GeV(η_c'). The "significance levels" of the enhancements listed in Table I were obtained as $\sigma \equiv \sqrt{-2ln(L_0/L_{max})}$, where L_{max} is the maximum likelihood value from the fits described above, and L_0 is the likelihood value from the fits with either no η_c or no η_c' resonance.

TABLE I: Summary of the results for η_c and η_c' for both CLEO II and CLEO III data sets. The errors shown are statistical only.

	CLEO II		CLEO III	
	η_c	η_c'	η_c	η_c'
ϵ (%)	10.0	13.8	8.9	11.9
N, events	282±30	28^{+13}_{-10}	310 ±29	33^{+14}_{-11}
M(MeV)	2984.2±2.0	3642.4±4.4	2980.0±1.7	3643.4±4.3
Γ(MeV)	24.7±5.1	3.9±18.0	24.8±4.5	8.4 ±17.1
signif.(σ)	15.1	4.4	17.0	4.8
$R(\eta_c'/\eta_c)$	0.17±0.07		0.19±0.08	

Photon-photon fusion is expected to populate positive charge conjugation resonances mainly when the photons are almost real, *i.e.,* when the transverse momenta of both of them, and therefore of the sum of final state particles is small. In order to test whether the observed η_c' peaks are due primarily to two-photon events, we have examined the production of η_c' in several subregions of transverse momentum. We find that both the CLEO II and CLEO III P_T distributions are statistically consistent with the expectations from our two-photon Monte Carlo simulations [24, 25], and we conclude that in both data sets the η_c' peak is mainly due to two-photon fusion.

It is of interest to compare the two-photon partial width of η_c' to that of η_c. The quantity that can be directly obtained from the data is

$$R(\eta_c'/\eta_c) \equiv \frac{\Gamma_{\gamma\gamma}(\eta_c') \times B(\eta_c' \to K_S K\pi)}{\Gamma_{\gamma\gamma}(\eta_c) \times B(\eta_c \to K_S K\pi)}.$$

In terms of the measured quantities

$$R(\eta_c'/\eta_c) = \frac{N(\eta_c')}{N(\eta_c)} \times \frac{\Phi(m_{\eta_c})}{\Phi(m_{\eta_c'})} \times \frac{\epsilon(\eta_c)}{\epsilon(\eta_c')} \quad .$$

$\Phi(m_{\eta_c})/\Phi(m_{\eta_c'})$=2.40±0.05 is the ratio of the two-photon fluxes at the η_c and η_c' masses [25]. This leads to results for $R(\eta_c'/\eta_c)$ given in Table I.

We have attempted to determine the uncertainty in our mass measurements due to the calibration of our mass scale by comparing the masses we measure from our data for $K_S^0(\to \pi^+\pi^-)$, $D^0(\to K_S^0\pi^\pm\pi^\mp)$, and $D^\pm(\to K^\pm\pi^\pm\pi^\mp)$ with their known values [1]. We estimate this uncertainty to be less than 1 MeV in the η_c and η_c' mass regions for both CLEO II and CLEO III data. Systematic uncertainties may also arise due to the fitting procedures for the invariant mass spectra. We find that the different choices of the background parametrization (polynomials, power–law, or exponential) and peak shape parametrization lead to variations in mass of less than 0.5 MeV. It is also found that Monte Carlo events have a reconstructed invariant $K_S^0K^\pm\pi^\mp$ mass that differs from the input mass at levels less than 1 MeV.

We consider the above contributions as being independent of each other, and obtain our best estimate of possible systematic bias in the η_c and η_c' masses to be 1.5 MeV for both CLEO II and CLEO III.

Using high statistics samples of D mesons and the larger η_c samples, we have checked that variations in PID and event selection criteria do not give rise to changes in our results in a statistically significant way.

The dominant source of systematic uncertainty in the determination of total widths, two-photon widths and the ratio R is found to be the choice of the background shape.

The present analysis of the CLEO II data (Table I), including the systematic errors, yields $M(\eta_c)$=2984.2±2.0±1.5 MeV. In our earlier publication for the same data we reported [17] $M(\eta_c)$=2980.4±2.3±0.6 MeV. A careful examination of the event selection used there has revealed that an algorithm used for charged track identification led to the inclusion of some (∼13%) false and poorly measured events. Rejection of these events is the main reason for the larger mass obtained here. The present determination supersedes the earlier reported mass value. The present analysis of CLEO II data also yields $\Gamma(\eta_c)$=24.7±5.1±3.5 MeV, and $\Gamma_{\gamma\gamma}(\eta_c)$=7.2±0.8±0.7±2.2(br) keV (the last error is due to the uncertainty in the branching ratio $B(\eta_c \to K^0_S K^\pm \pi^\mp)$), which are in agreement with our previously reported values. The two-photon width from CLEO III data is $\Gamma_{\gamma\gamma}(\eta_c)$=7.5±0.5±0.5±2.3(br) keV. The average of the two results is $\Gamma_{\gamma\gamma}(\eta_c)$=7.4±0.4±0.5±2.3(br) keV.

To summarize our results, we have analyzed 13.6 fb^{-1} of e^+e^- data of CLEO II at Υ(4S) and its vicinity, and 13.1 fb^{-1} data of CLEO III at Υ(1S→4S) and vicinity for resonances in the reaction $e^+e^- \to e^+e^-(\gamma\gamma) \to e^+e^-(\eta_c') \to e^+e^-(K^0_S K^\pm \pi^\mp)$. We see clear evidence for the excitation of the $\eta_c(1^1S_0)$, and another resonance which we assign to $\eta_c'(2^1S_0)$. Our results for separate analyses of CLEO II and CLEO III data are presented in Table I. We combine the results of these independent data sets to obtain the following as our final results

$$\begin{aligned}
&M(\eta_c)=\ 2981.8\pm1.3\pm1.5 \quad \text{MeV}, \\
&\Gamma(\eta_c)=24.8\pm3.4\pm3.5 \ \ \text{MeV}, \\
&M(\eta_c')=\ 3642.9\pm3.1\pm1.5 \quad \text{MeV}, \\
&\Gamma(\eta_c')=6.3\pm12.4\pm4.0 \ \ \text{MeV}, \quad \text{or} \\
&\qquad \le 31 \ \text{MeV (90\% CL)}, \\
&R(\eta_c'/\eta_c)=0.18\pm0.05\pm0.02.
\end{aligned}$$

Using the known masses of the J/ψ and ψ' [1], and combining statistical and systematic errors in quadrature, these correspond to $\Delta M_{hf}(1S) = 115.1 \pm 2.0$ MeV, and $\Delta M_{hf}(2S) = 43.1 \pm 3.4$ MeV.

Assuming that the branching fractions for η_c and η_c' decays to $K_S K \pi$ are equal [16], and using the average value of $\Gamma_{\gamma\gamma}(\eta_c)$ as obtained above, our result for R leads to the first estimation of $\Gamma_{\gamma\gamma}(\eta_c')$=1.3±0.6 keV.

In a concurrent analysis of the $\gamma\gamma \to K^0_S K^\pm \pi^\mp$ reaction BaBar collaboration has recently reported $M(\eta_c')$= 3630.8±3.4±1.0 MeV [26].

As mentioned earlier, all four new measurements contradict the earlier Crystal Ball identification of η_c' with a mass of 3594±5 MeV, and therefore $\Delta M_{hf}(2S) = 92 \pm 5$ MeV. The present results reduce this hyperfine splitting by nearly a factor two. We hope that this will lead to a reexamination of the $c\bar{c}$ hyperfine interaction in the confinement region, as well as coupled-channel effects for $^3S_1$ and $^1S_0$ states.

We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. This work was supported by the National Science Foundation, the U.S. Department of Energy, the Research Corporation, and the Texas Advanced

Research Program.

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[1] Review of Particle Properties, Phys. Rev. D**66**, 1 (2002).

[2] C. Edwards *et al.*, Crystal Ball Collaboration, Phys. Rev. Lett. **48**, 70 (1982).

[3] T. A. Armstrong *et al.*, E760 Collaboration, Phys. Rev. D**52**, 4839 (1995).

[4] M. Ambrogniani *et al.*, E835 Collaboration, Phys. Rev. D**64**, 052003 (2001).

[5] P. Abreu *et al.*, DELPHI Collaboration, Phys. Lett. **B441**, 479 (1998).

[6] M. Acciarri *et al.*, L3 Collaboration, Phys. Lett. **B461**, 155 (1999).

[7] T. Skwarnicki, talk presented at Int. Symp. On Lepton And Photon Interactions, Aug 2003, Batavia; hep-ph/0311243.

[8] W. Buchmüller and S. H. H. Tye, Phys. Rev. D**24**, 132 (1981).

[9] T. A. Lähde and D. O. Riska, Nucl. Phys, A**707**, 425 (2002).

[10] G. S. Bali, K. Schilling and A. Wachter, Phys. Rev. D**56**, 2566 (1997).

[11] M. Okamoto *et al.*, CP–PACS Collaboration, Phys. Rev. D**65**, 094508 (2002).

[12] S. K. Choi *et al.*, BELLE Collaboration, Phys. Rev. Lett. **89**, 102001 (2002).

[13] Whenever two or more uncertainties are listed, the first is statistical and the second is systematic.

[14] K. Abe *et al.*, BELLE Collaboration, Phys. Rev. Lett. **89**, 142001 (2002).

[15] T. Uglov, BELLE Collaboration, talk presented at the Europhysics Conference, July 2003, Aachen, Germany.

[16] T. Barnes, T. E. Browder and S. F. Tuan, Phys. Lett. **B385**, 391 (1996).

[17] G. Brandenberg *et al.*, CLEO Collaboration, Phys. Rev. Lett. **85**, 3095 (2000).

[18] Z. Metreveli, CLEO Collaboration, talk presented at APS/PDF–2003 meeting, Philadelphia, April 2003. J. Ernst et *et al.*, CLEO Collaboration, Submitted to Europhysics Conference, July 2003, Aachen, Germany; hep-ex/0306060.

[19] Y. Kubota *et al.*, Nucl. Instrum. Meth. A**320**, 66 (1992).

[20] T. S. Hill, Nucl. Instrum. Meth. A**418**, 32 (1998).

[21] G. Viehhauser, Nucl. Instrum. Meth. A**462**, 146 (2001).

[22] D. Peterson *et al.*, Nucl. Instrum. Meth. A**478**, 142 (2002).

[23] M. Artuso *et al.*, Nucl. Instrum. Meth. A**502**, 91 (2003); hep-ex/0209009.

[24] R. Brun *et al.*, GEANT 3.15, CERN Report No. DD/EE/84–1, 1987.

[25] V. M. Budnev *et al.*, Phys. Rep. **C15**, 181 (1975).

[26] T. Aubert *et al.*, BaBar Collaboration, hep–ex/0311038.