CLEO spectroscopy results

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Recent contributions of the CLEO experiment to hadron spectroscopy are presented.

1. INTRODUCTION

Hadron spectroscopy plays a valuable role in particle physics. It was crucial in validating quantum chromodynamics (QCD) and the quark substructure of matter. It provides a stage for understanding nonperturbative techniques, not only in QCD but elsewhere in physics. Hadron spectra are crucial in separating electroweak physics from strong interaction effects, as in charm and beauty decays. Quarks and leptons themselves have an intricate level and weak coupling structure for which we have no fundamental understanding. Sharpening spectroscopic techniques may help solve this problem.

I shall present recent spectroscopy contributions from the CLEO Collaboration based on data at the Cornell Electron Storage Ring (CESR) utilizing CLEO’s excellent particle identification and resolution. Separate sections will treat charmonium, charm, beauty, and upsilons. The CLEO detector is described in another contribution to this Conference [1].

2. CHARMONIUM

The charmonium spectrum is shown in Fig. 1. Specific topics which will be discussed are: (1) a new measurement of $\mathcal{B}(J/\psi \to \ell^+\ell^-)$ using $\psi(2S)$ decays; (2) a study of $\psi(2S)$ decays to baryon-antibaryon, $J/\psi X$, light hadrons, and $\pi^0 h_c$; (3) a remeasurement of $\Gamma(\chi_{c2} \to \gamma \gamma)$; and (4) results on $\psi'' \equiv \psi(3770)$ decays to non-$D\bar{D}$ final states such as $\pi \pi J/\psi$, $\gamma \chi_{c1}$, and light hadrons.

One can compare $\mathcal{B}(\psi(2S) \to \pi^+\pi^- J/\psi \to \pi^+\pi^- \ell^+\ell^-)$ with $\mathcal{B}(\psi(2S) \to \pi^+\pi^- X)$ in order to derive a value of $\mathcal{B}(J/\psi \to \ell^+\ell^-)$ [2]. The results are $\mathcal{B}(J/\psi \to e^+e^-) = (5.945 \pm 0.067 \pm 0.042)\%$, $\mathcal{B}(J/\psi \to \mu^+\mu^-) = (5.960 \pm 0.065 \pm 0.050)\%$, $\mathcal{B}(J/\psi \to \ell^+\ell^-) = (5.953 \pm 0.056 \pm 0.042)\%$, and $\mathcal{B}(e^+e^-)/\mathcal{B}(\mu^+\mu^-) = (99.7 \pm 1.2 \pm 0.6)\%$. These values are consistent with and more precise than current world averages [3].

Decays of $\psi(2S)$ to baryon-antibaryon pairs have been measured more precisely [4]. Results are listed in Table 1.

One expects $Q \equiv \mathcal{B}(\psi(2S) \to f)/\mathcal{B}(J/\psi \to f)$ to be comparable to $\mathcal{B}(\psi(2S) \to \ell^+\ell^-)/\mathcal{B}(J/\psi \to \ell^+\ell^-) = 12.6 \pm 0.7\%$ (the “12% rule”), since light-quark decays are presumably governed by $|\Psi(0)|^2$ as are leptonic decays. In fact, $Q$ is much smaller than 12% for most VP and VT modes, where $P=$pseudoscalar, $V=$vector, $T=$tensor, and severely so in some cases [5-6]. For example, $Q(\rho\pi) = (1.9 \pm 0.6) \times 10^{-3}$, with a similar suppres-
Table 1
Branching ratios in units of $10^{-4}$ for $\psi(2S)$ decays to baryon-antibaryon pairs [4]. The number of $\psi(2S)$ signal events is denoted by $S$.

| Mode       | $S$   | $B(10^{-4})$ | $Q$ (%) |
|------------|-------|--------------|---------|
| $p\bar{p}$ | 557   | 2.87±0.12±0.15 | 13.6±1.1 |
| $\Lambda\bar{\Lambda}$ | 208 | 3.28±0.23±0.25 | 25.2±3.5 |
| $\Sigma^+\Sigma^-$ | 35 | 2.57±0.44±0.25 |         |
| $\Sigma^0\Sigma^0$ | 58 | 2.62±0.35±0.21 | 20.7±4.2 |
| $\Xi^-\Xi^-$ | 63 | 2.38±0.30±0.21 | 13.2±2.2 |
| $\Xi^0\Xi^0$ | 19 | 2.75±0.64±0.61 |         |
| $\Xi^-\Xi^0$ | 2 | 0.72^{+1.48}_{−0.62}±0.10 |         |
| $\Omega^-\Omega^-$ | 4 | 0.70^{+0.55}_{−0.33}±0.10 |         |

Table 2
Branching ratios for $\psi(2S) \rightarrow J/\psi X$ [2].

| Channel | $B$ (%) |
|---------|---------|
| $\pi^+\pi^-J/\psi$ | 33.54±0.14±1.10 |
| $\eta J/\psi$ | 3.25±0.06±0.11 |
| $\pi^0 J/\psi$ | 0.13±0.01±0.01 |
| $\gamma \chi_{c0} \rightarrow \gamma \gamma J/\psi$ | 0.18±0.01±0.02 |
| $\gamma \chi_{c1} \rightarrow \gamma \gamma J/\psi$ | 3.44±0.06±0.13 |
| $\gamma \chi_{c2} \rightarrow \gamma \gamma J/\psi$ | 1.85±0.04±0.07 |
| $J/\psi X$ | 59.50±0.15±1.90 |

a factor of two. The suppression of hadronic $\psi'$ final states thus appears to be confined to certain species such as $\rho \eta, K^* K\bar{K}$.

The elusive $h_c(1^{1}P_1)$ state of charmonium has been observed by CLEO [10] via $\psi(2S) \rightarrow \pi^0 h_c \rightarrow \pi^0 \eta \eta_c$ as shown by the bold arrows in Fig. 1. While S-wave hyperfine charmonium splittings are $M(J/\psi)−M(\eta_c)\simeq115$ MeV for 1S and $M(\psi')−M(\eta_c')\simeq48$ MeV for 2S levels, one expects less than a few MeV P-wave splittings since the potential is expected to be $\sim\delta^3(\vec{r})$ for the Coulomb-like $c\bar{c}$ interaction. Lattice QCD [11] and relativistic potential [12] calculations confirm the expectation of a small P-wave hyperfine splitting. One expects $M(h_c)\equiv M(1^{1}P_1)\simeq\langle M(3P_3)\rangle=3525.36\pm0.06$ MeV.

Earlier $h_c$ sightings (see [10] for references), based on $p\bar{p}$ production in the direct channel, include a few events at 3525.4±0.8 MeV seen in CERN ISR Experiment R704; a state at 3526.2±0.15±0.2 MeV, decaying to $\pi^0 J/\psi$, reported by Fermilab E700 but not confirmed by Fermilab E835; and a state at 3525.8±0.2±0.2 MeV, decaying to $\eta \eta_c$ with $\eta_c \rightarrow \gamma \gamma$, reported by E835 with about a dozen candidate events [13].

CLEO data have been analyzed in two different ways: exclusive, in which the $h_c$ is reconstructed through one of seven decay modes, and inclusive, in which the $\eta_c$ is not identified through its decay products. Both analyses see a signal near $\langle M(3P_3)\rangle$.

The exclusive signal is shown in Fig. 2. A total of 19 candidates were identified, with a signal of 17.5±4.5 events above background. The mass and product branching ratio for the two tran-
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Figure 2. Exclusive $h_c$ signal from CLEO (3 million $\psi(2S)$ decays) [10]. Data events correspond to open histogram; Monte Carlo background estimate is denoted by shaded histogram. The signal shape is a double Gaussian, obtained from signal Monte Carlo. The background shape is an ARGUS function [14].

Figure 3. Inclusive $h_c$ signal from CLEO (3 million $\psi(2S)$ decays) [10]. The curve denotes the background function based on generic Monte Carlo plus signal. The dashed line shows the contribution of background alone.

The result of one of two inclusive analyses is shown in Fig. 9. These yield $M(h_c) = (3524.9 \pm 0.7 \pm 0.4$) MeV, $B_1B_2 = (3.5 \pm 1.0 \pm 0.7) \times 10^{-4}$. Combining exclusive and inclusive results yields $M(h_c) = (3524.4 \pm 0.6 \pm 0.4$) MeV, $B_1B_2 = (4.0 \pm 0.8 \pm 0.7) \times 10^{-4}$, indicating little P-wave hyperfine splitting in charmonium. The $h_c$ mass is $(1.0 \pm 0.6 \pm 0.4$) MeV below $\langle M(3P) \rangle$, barely consistent with the (nonrelativistic) bound $M(h_c) \geq \langle M(3P) \rangle$ [15]. The value of $B_1B_2$ agrees with theoretical estimates of $\approx 4 \times 10^{-4}$ obtained from ($B_1 \approx 10^{-3}$) · ($B_2 \approx 0.4$) [16,17].

In $\psi(2S) \rightarrow \pi^0h_c$ one expects the $\psi(2S)$ polarization to be transmitted to the $h_c$. In $h_c \rightarrow \gamma\eta_c$ one then expects photons to be distributed with respect to the beam axis according to $1 + \cos^2 \theta$. This is confirmed by the observed signal.

CLEO has reported a new measurement of $\Gamma(\chi'_{c2} \rightarrow \gamma\gamma)$ = 559±57±45±36 eV based on 14.4 fb$^{-1}$ of $e^+e^-$ data at $\sqrt{s} = 9.46$–11.30 GeV [18]. The result is compatible with other measurements when they are re-evaluated using CLEO’s new $\mathcal{B}(\chi'_{c2} \rightarrow \gamma\psi)$ and $\mathcal{B}(J/\psi \rightarrow \ell^+\ell^-)$. The errors are statistical, systematic, and $\Delta\mathcal{B}(\chi'_{c2} \rightarrow \gamma\psi)$.

When the CLEO value is combined with one from Belle [19], the average is 565 ± 57 eV. Using the Fermilab E835 value of $\Gamma(\chi_{c2}) = 1.94 \pm 0.13$ MeV [20] and $\mathcal{B}(\chi_{c2} \rightarrow \gamma\psi) = (19.9 \pm 0.5 \pm 1.2)$%, one finds $\Gamma(\chi_{c2} \rightarrow \text{hadrons}) = 1.55 \pm 0.11$ MeV = $(2.74 \pm 0.34 \times 10^5) \Gamma(\chi_{c2} \rightarrow \gamma\gamma)$, implying $\alpha_S(m_c) = 0.293 \pm 0.013$ if $\Gamma(\chi_{c2} \rightarrow \text{hadrons})$ is dominated by the two-gluon width. Here the QCD corrections in [21] have been used.

CLEO [22] and BES [23] have measured the $D\bar{D}$ production cross sections at the peak of the $\psi''$ resonance, resulting in values [24] that are somewhat less than the average [25] $\sigma(\psi'') = (7.9 \pm 0.6)$ nb of various direct measurements. A new value based on BES data, $\sigma(\psi'' \rightarrow \text{non-}\bar{D}D) = (0.72 \pm 0.46 \pm 0.62)$ nb [26], does not say whether there are significant decay modes of $\psi''$ other than $\bar{D}D$.

Some branching ratios for $\psi'' \rightarrow XJ/\psi$ are summarized in Table 2 [27]. The value of $\mathcal{B}(\psi'' \rightarrow \pi^+\pi^-J/\psi)$ found by CLEO is about 2/3 that reported by BES [28]. The entries in Table 3 account for less than 0.5% of the total $\psi''$ decays.
Table 3
Recent CLEO results on $\psi'' \to X J/\psi$ decays.\cite{27}

| $\psi''$ mode | $B$ (%) |
|---------------|---------|
| $\pi^+ \pi^- J/\psi$ | 0.214±0.025±0.022 |
| $\pi^0 \pi^0 J/\psi$ | 0.097±0.03±0.020 |
| $\eta J/\psi$ | 0.083±0.049±0.021 |
| $\pi^0 J/\psi$ | <0.034 (90% c.l.) |

Table 4
CLEO results on radiative decays $\psi'' \to \gamma \chi_{cJ}$.\cite{29} Theoretical predictions of Ref.\cite{30} are (a) without and (b) with coupled-channel effects; (c) shows predictions of Ref.\cite{25}.

| Mode | Predicted (keV) | CLEO (keV) |
|------|----------------|------------|
|      | (a)           | (b)        | preliminary |
| $\gamma \chi_{c2}$ | 3.2 | 3.9 | 24±4 | <40 (90% c.l.) |
| $\gamma \chi_{c1}$ | 183 | 59 | 73±9 | 75±14±13 |
| $\gamma \chi_{c0}$ | 254 | 225 | 523±12 | <1100 (90% c.l.) |

$\gamma \chi_{cJ}$ partial widths, based on the exclusive process $\psi'' \to \gamma \chi_{c1,2} \to \gamma J/\psi \to \gamma \ell^+ \ell^-$.\cite{29} The results are compared in Table 4 with some predictions.\cite{25,30}. The exclusive analysis has no sensitivity to $\chi_{c0}$ since $B(\chi_{c0} \to J/\psi)$ is small. Although the $\psi'' \to \gamma \chi_{c0}$ partial width is expected to be high, it must be studied in the inclusive channel, which has high background, or using exclusive hadronic $\chi_{c0}$ decays. Even with the maximum likely $B(\psi'' \to \gamma \chi_{c0})$, one thus expects $B(\psi'' \to \gamma \chi_{cJ}) < 0(2\%)$.

Several CLEO analyses search for $\psi'' \to (\text{light hadrons})$. The value of $\sigma(\psi'' \to \text{hadrons})$ also is being re-checked. Two analyses\cite{31,32} find no evidence for any light-hadron $\psi''$ mode above expectations from continuum production except $\phi \eta$. Upper limits on the sum of 26 modes imply a bound $B[\psi'' \to (\text{light hadrons})] \leq 1.8\%$. The cross sections at 3.77 GeV for the most part are consistent with continuum at 3.67 GeV. Both CLEO\cite{31} and BES\cite{33}, in searching for enhanced light-hadron modes, find the $\rho \pi$ mode, suppressed in $\psi(2S)$ decays, also suppressed in $\psi''$ decays with respect to continuum expectations, perhaps as a result of interference between a $\psi'' \to \rho \pi$ amplitude and continuum\cite{33}.

One thus can ascribe no more than a few percent of the total $\psi''$ width to the non-$D\bar{D}$ decays studied thus far, including $<0.5\%$ for $J/\psi + \text{(hadrons)}$, $<0.5\%$ for $\gamma \chi_{c1,2}$, probably $<2\%$ for $\gamma \chi_{c0}$, and at most a couple of percent for light hadrons. The question of significant non-$D\bar{D}$ modes of $\psi''$ remains open. One is trying to understand a possible discrepancy of 1–2 nb in $\sigma(e^+e^- \to \psi'')$, or $B(\psi'') = 10–20\%$. Could this call for more careful treatment of radiative corrections? A remeasurement of $\sigma(\psi'')$ by CLEO, preferably through an energy scan, is crucial.

3. CHARM

CLEO has recently remeasured mass differences and widths of the singly-charmed baryon $\Sigma_c^*(2516, J^P = 3/2^-)$.\cite{34} Splittings between the doubly-charged and neutral masses are quite small, in accord with theoretical expectations. The prediction of heavy quark symmetry that $\Gamma(\Sigma_c^*+/+) = \Gamma(\Sigma_c^-) = 7.5 \pm 0.1$ is borne out by the data, in which $\Gamma(\Sigma_c^*+/+) = 6.5 \pm 1.3$, $\Gamma(\Sigma_c^-) = 7.5 \pm 1.7$.

4. BEAUTY

A search was performed for an energy at which $\Lambda_b \bar{\Lambda}_b$ production might be enhanced.\cite{35} No such enhancement was found. Upper bounds include $R(\Lambda_b \bar{\Lambda}_b) \lesssim 0.04$ (95% c.l.), where $R$ refers to the cross section normalized by $\mu^+ \mu^-$. Events with $\geq 1 \bar{p}$ and events with $\geq 1 \Lambda$ did not show any evidence of enhanced $\Lambda_b \bar{\Lambda}_b$ production just above threshold.

5. BOTTOMONIUM

CLEO data continue to yield new results on $b\bar{b}$ spectroscopy. New values of $B[\Upsilon(1S, 2S, 3S) \to \mu^+ \mu^-] = (2.39 \pm 0.02 \pm 0.07, 2.03 \pm 0.03 \pm 0.08, 2.39 \pm 0.07 \pm 0.10)\%$\cite{36} imply lower values of $\Gamma_{\text{tot}}(2S, 3S)$, which will be important in updating comparisons with perturbative QCD. The study of $\Upsilon(2S, 3S) \to \gamma \chi$ decays\cite{37} has provided new measurements of E1 transition rates to $\chi_{bJ}(1P), \chi_{bJ}(2P)$ states. Searches in these data for the forbidden M1 transitions to spin-singlet
states of the form \( \Upsilon(n'S) \to \gamma \eta_b(nS) \) \((n \neq n')\) have excluded many theoretical models. The strongest upper limit, for \( n' = 3, n = 1 \), is \( B \leq 4.3 \times 10^{-4} \) (90% c.l.). Searches for the lowest \( bb \) spin-singlet, the \( \eta_b \), using the sequential processes \( \Upsilon(3S) \to \pi^0 h_b(1^1P_1) \to \pi^0 \eta_b(1S) \) and \( \Upsilon(3S) \to \gamma \chi_{b0} \to \gamma \eta_b(1S) \) are being conducted. The direct photon spectrum in \( \Upsilon(1S, 2S, 3S) \to \gamma X \) decays has been measured using CLEO data and is used to extract the ratio of radiative to purely gluonic decay widths. The ratios \( R_\gamma \equiv B(\gamma \gamma)/B(\gamma g) \) are found to be \( R_\gamma(1S) = (2.50 \pm 0.01 \pm 0.19 \pm 0.13)\% \), \( R_\gamma(2S) = (3.27 \pm 0.02 \pm 0.58 \pm 0.17)\% \), \( R_\gamma(3S) = (2.27 \pm 0.03 \pm 0.43 \pm 0.16)\% \). \( R_\gamma(1S) \) is consistent with an earlier CLEO value of \( (2.54 \pm 0.18 \pm 0.14)\% \), and the other two are first measurements.

The transitions \( \chi_b \to \chi_b \gamma \to \pi^0 \pi^- \) have been observed for the first time \( \text{[10]} \). One looks for \( \Upsilon(3S) \to \gamma \to \gamma \pi^+ \pi^- \to \gamma \pi^+ \pi^- \gamma \Upsilon(1S) \) in CLEO data, consisting of 5.8 million \( \Upsilon(3S) \) events. \( \text{[10]} \) Two methods are employed, whereby either both or only one of the transition pions are identified, trading sample cleanliness against statistical power. The resulting signal event counts are \( 7 \) events above 0.6\pm0.2 background and \( 17 \) events above 2.2\pm0.6 background, respectively. Assuming \( \Gamma(\chi_{b1} \to \pi^+ \pi^- \chi_{b1}) = \Gamma(\chi_{b2} \to \pi^+ \pi^- \chi_{b2}) \), both are found equal to \( (0.80 \pm 0.21 \pm 0.17) \) keV, which is in satisfactory agreement with theoretical expectations \( \text{[11]} \). Analysis of \( \chi_b \to \pi^0 \pi^0 \chi_b \) is in progress.

6. SUMMARY

CLEO has contributed many recent charmonium, charm, beauty, and \( bb \) spectroscopy results. The long-sought \( h_c \) (the spin-singlet P-wave ground state of charmonium) has been identified. Its mass and production rate confirm basic ideas about quark confinement and isospin-violating \( \pi^0 \)-emission transitions. The decays of \( \psi'' \) are shedding light on its nature and we look forward to much more data on this state. A rich CLEO program will include much further spectroscopy, such as the study of resonances above thresholds for non-strange and strange charmed meson pair production; \( D_s \) studies; and the study of \( J/\psi \to \) light-quark and glueball states.

The CLEO Collaboration gratefully acknowledges the effort of the CESR staff in providing us with excellent luminosity and running conditions. This work was supported by the National Science Foundation and the United States Department of Energy. I thank H. Mahlke-Krüger for a careful reading of the manuscript and M. Tigner for hospitality of the Laboratory for Elementary-Particle Physics at Cornell and the John Simon Guggenheim Foundation for partial support.

REFERENCES
1. J. L. Rosner, “CLEO Dalitz plot results,” presented at Beauty 2005, Assisi, June 20–24, 2005, [hep-ex/0508024]
2. Z. Li [CLEO Collaboration], Phys. Rev. D 71, 111103(R) (2005),
3. S. Eidelman et al. [Particle Data Group], Phys. Lett. B 592, 1 (2004).
4. T. K. Pedlar et al. [CLEO Collaboration], [hep-ex/0505057] to be published in Phys. Rev. D.
5. N. E. Adam et al. [CLEO Collaboration], Phys. Rev. Lett. 94, 012005 (2005).
6. J. Z. Bai et al. [BES Collaboration], Phys. Rev. D 69, 072001 (2004).
7. N. E. Adam [CLEO Collaboration], Phys. Rev. Lett. 94, 232002 (2005).
8. S. B. Athar et al. [CLEO Collaboration], Phys. Rev. D 70, 112002 (2004).
9. R. A. Briere et al. [CLEO Collaboration], Phys. Rev. Lett. 95, 062001 (2005).
10. J. L. Rosner et al. [CLEO Collaboration], Phys. Rev. Lett. 95, 102003 (2005); P. Rubin et al. [CLEO Collaboration], hep-ex/0508037 submitted to Phys. Rev. D.
11. T. Manke et al. [CP-PACS Collaboration], Phys. Rev. D 62, 114508 (2000); M. Okamoto et al. [CP-PACS Collaboration], ibid. 65, 095408 (2002).
12. D. Ebert, R. N. Faustov and V. O. Galkin, Phys. Rev. D 67, 014027 (2003); Mod. Phys. Lett. A 20, 875 (2005).
13. M. Andreotti et al. [Fermilab E835 Collaboration], Phys. Rev. D 72, 032001 (2005).
14. H. Albrecht et al. [ARGUS Collaboration], Phys. Lett. B 241, 278 (1990).
15. J. Stubbe and A. Martin, Phys. Lett. B 271, 208 (1991).
16. Y. P. Kuang, Phys. Rev. D 65, 094024 (2002).
17. S. Godfrey and J. L. Rosner, Phys. Rev. D 66, 014012 (2002).
18. R. A. Briere et al. [CLEO Collaboration], CLEO Report CLEO-CONF 05-10, paper no. LP-2005-436, 2005 Lepton-Photon Symposium, Uppsala (unpublished); updated version to be submitted for publication.
19. K. Abe et al. [Belle Collaboration], Phys. Lett. B 540, 33 (2002).
20. M. Andreotti et al., Nucl. Phys. B 717, 34 (2005).
21. W. Kwong, P. B. Mackenzie, R. Rosenfeld and J. L. Rosner, Phys. Rev. D 37, 3210 (1988).
22. Q. He et al. [CLEO Collaboration], Phys. Rev. Lett. 95, 121801 (2005).
23. M. Ablikim et al. [BES Collaboration], Phys. Lett. B 603, 130 (2004).
24. H. Mahlke-Krüger, “Absolute D hadronic branching fractions from CLEO,” presented at Beauty 2005, Assisi, June 20–24, 2005.
25. J. L. Rosner, Ann. Phys. (N.Y.) 319, 1 (2005).
26. G. Rong et al., hep-ex/0506051.
27. N. E. Adam [CLEO Collaboration], hep-ex/0508023 submitted to Phys. Rev. Letters.
28. J. Z. Bai et al. [BES Collaboration], Phys. Lett. B 605, 63 (2005).
29. T. E. Coan et al. [CLEO Collaboration], Cornell University Report No. CLNS 05-1931, to be submitted for publication.
30. E. J. Eichten, K. Lane and C. Quigg, Phys. Rev. D 69, 094019 (2004).
31. G. S. Adams et al. [CLEO Collaboration], Cornell University Report No. CLNS 05-1933, hep-ex/0509011 submitted to Phys. Rev. Letters.
32. G. S. Huang et al. [CLEO Collaboration], CLEO Report CLEO-CONF 05-13, paper no. LP-2005-443, 2005 Lepton-Photon Symposium, Uppsala (unpublished).
33. M. Ablikim et al. [BES Collaboration], paper no. 123, 2005 Lepton-Photon Symposium, Uppsala (unpublished).
34. S. B. Athar et al. [CLEO Collaboration], Phys. Rev. D 71, 051101 (2005).
35. D. Besson et al. [CLEO Collaboration], Phys. Rev. D 71, 012004 (2005).
36. G. S. Adams et al. [CLEO Collaboration], Phys. Rev. Lett. 94, 012001 (2005).
37. M. Artuso et al. [CLEO Collaboration], Phys. Rev. Lett. 94, 032001 (2005).
38. M. B. Voloshin, Mod. Phys. Lett. A 19, 2895 (2004).
39. D. Besson et al. [CLEO Collaboration], CLEO Report CLEO-CONF 05-7, paper no. LP-2005-434, 2005 Lepton-Photon Symposium, Uppsala (unpublished).
40. T. Skwarnicki, hep-ex/0505050 presented at 40th Rencontres de Moriond on QCD and High Energy Hadronic Interactions, 12-19 Mar 2005, La Thuile, Aosta Valley, Italy.
41. Y. P. Kuang and T. M. Yan, Phys. Rev. D 24, 2874 (1981).