Production of $\eta_c$ in two photon interactions at CLEO

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OUTLINE

✔ Motivation for the study of $\eta_c$
✔ Expectations (theory & current experiment - PDG98)
✔ Two-photon production of $\eta_c$ at CLEO
✔ CLEO Results for $\eta_c$ Resonance Parameters
✔ Comparison to Theoretical predictions
✔ Comparison to Other Recent Experimental Results
✔ Conclusions
MOTIVATION

\( \eta_c \) is the ground state of the charmonium system (cc). \( \Delta M(1S) \) reveals the strength of the spin-spin coupling in the charm quark sector. The total width \( (\Gamma(\eta_c) = \Gamma_{gg}(\eta_c)) \), together with the 2\( \gamma \) partial width, gives an indication of the strength of \( \alpha_s(m_c) \).

Note: The thickness of the line representing each charmonium state is roughly proportional to the state's observed total width. States which are labeled in cyan are either unconfirmed or as yet unobserved in any experiment.

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Theoretical & experimental expectations

Expect hyperfine splitting to be $\sim 110-130$ MeV

This calculation depends on:

- value of $\alpha_s(m_c)$ (contributes $\pm 10$ MeV)
- choice of potential (also $\pm 10$ MeV)

Particle Data Group 98 gives:

$$M(\eta_c) = 2979.8 \pm 1.8 \text{ MeV}$$

$$\Delta M(1S) = 117.1 \pm 2.1 \text{ MeV}$$

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Theoretical & Experimental Expectations

Simple ratios possible for comparison to pQCD (at NLO)

\[
R_1 \equiv \frac{\Gamma_{gg}}{\Gamma_{\gamma\gamma}} = \frac{9\alpha_s^2}{8\alpha_s} \frac{(1 + 4.8\alpha_s / \pi)}{(1 - 3.4\alpha_s / \pi)} = 3.4 \times 10^3 \quad \text{for } \alpha_s(m_c) = 0.30
\]

\[
R_2 \equiv \frac{\Gamma_{\gamma\gamma}}{\Gamma_{\psi\to ee}} = \frac{4}{3} (1 + 1.96\alpha_s / \pi) \frac{M(\psi)^2}{2(m_c^2)} \left|\Psi_{\eta_c}(O)\right|^2 = 1.57
\]

for \( \alpha_s(m_c) = 0.30 \) and assuming \( \left|\Psi_{\eta_c}(O)\right|^2 = \left|\Psi_{J/\psi}(O)\right|^2 \)

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Current results compared to theory

Using PDG98 results, and taking $\alpha_s(m_C) = 0.30$

$$R_1 \equiv \frac{\Gamma_{gg}}{\Gamma_{\gamma\gamma}} = \frac{13.2^{+3.8}_{-3.2} \text{ MeV}}{7.5^{+1.6}_{-1.4} \text{ keV}} = (1.8 \pm 0.6) \times 10^3$$

recall $R_1 \text{(theory)} = (3.4) \times 10^3$

$$R_2 \equiv \frac{\Gamma_{\gamma\gamma}}{\Gamma_{(J/\psi \rightarrow ee)}} = \frac{7.5^{+1.6}_{-1.4} \text{ keV}}{5.26 \pm 0.37 \text{ keV}} = 1.43^{+0.31}_{-0.27}$$

recall $R_2 \text{(theory)} = 1.57$

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Predictions for the present measurements

Using $\Gamma(J/\psi \to e^+e^-) = 5.26 \pm 0.37$ keV, and $R_2$,

$\Rightarrow \Gamma_{\gamma\gamma} = 8.2 \pm 0.6$ keV

Using $\Gamma_{\gamma\gamma} = 8.2 \pm 0.6$ keV (pQCD) and $R_1$,

$\Rightarrow \Gamma_{\text{tot}} = 26 \pm 6$ MeV

Using $\Gamma_{\gamma\gamma} = 7.5^{+1.6}_{-1.4}$ keV (PDG98) and $R_1$,

$\Rightarrow \Gamma_{\text{tot}} = 28 \pm 6$ MeV

in addition, sum-rule models (Shifman, et al.)

tend to favor $\Gamma_{\text{tot}}$ of $15 - 25$ MeV

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Two Photon Physics at CLEO

CLEO operates at the $\Upsilon(4S)$ - $E_{cm} = 10.58$ GeV

Two photon interactions arise from "double Bremstrahlung" events:

$e^+e^- \rightarrow e^+e^-\gamma\gamma \rightarrow e^+e^-\eta_C$

$2\gamma$ collisions: C-even states

$cc: \chi_2, \chi_0, \eta_C$ and $\eta'_C$

State is formed with low PT

$\text{yield is } \alpha L_{\gamma\gamma} \times \Gamma_{\eta_C \rightarrow \gamma\gamma}$

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Study of $\eta_c$ at CLEO

- Choose clean final state with large Branching fraction:
  $$\eta_c \rightarrow K_s^0 K^{\pm} \pi^{\mp} : \text{Br} = (1.8 \pm 0.6)\%$$

- Measure $M(\eta_c)$, $\Gamma(\eta_c)$ and $\Gamma_{yy}(\eta_c)$ together

- Selection criteria (briefly)
  - low total PT
  - low total visible E
  - displaced vertex for $K_s$
  - total efficiency @ 10%
CLEO data at a glance

CLEO has obtained each of $M(\eta_c)$, $\Gamma(\eta_c)$ and $\Gamma_{\gamma\gamma}(\eta_c)$ by ML fit. The two data sets have been fit simultaneously, constraining the fit parameters.
### CLEO results summary

<table>
<thead>
<tr>
<th></th>
<th>CLEO</th>
<th>PDG98</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M(\eta_c)$</td>
<td>$2980.4 \pm 2.3 \pm 0.6$ MeV</td>
<td>$2979.8 \pm 2.1$ MeV</td>
</tr>
<tr>
<td>$\Gamma_{\gamma\gamma}(\eta_c)$</td>
<td>$7.6 \pm 0.8 \pm 0.4 \pm 2.3$ keV</td>
<td>$7.5^{+1.6}_{-1.4}$ keV $^*$</td>
</tr>
<tr>
<td>$\Gamma_{\text{tot}}(\eta_c)$</td>
<td>$27.0 \pm 5.8 \pm 1.4$ MeV</td>
<td>$13.2^{+3.8}_{-3.2}$ MeV</td>
</tr>
</tbody>
</table>

Recall the theoretical predictions:

- $\Gamma_{\gamma\gamma} = 8.2 \pm 0.6$ keV
- $\Gamma_{\text{tot}} \approx 27 \pm 6$ MeV (NLO pQCD)
- $\Gamma_{\text{tot}} \approx 15 - 25$ MeV (sum-rule)

As an added attraction, our data, along with $R_1$, may be used to estimate $\alpha_s(m_c) = 0.285 \pm 0.025$

Caveat - NOT renormalization scheme or scale independent

Advert: This has been submitted to PRL, and may be found in preprint form at hep-ex/0006026

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Comparison to other experimental results

While CLEO has measured both $\Gamma$, $\Gamma_{yy}$ and $M(\eta_c)$, other results since PDG98 have been presented by:

BES: (hep-ex/0002006, PRD 60 072001) $\Gamma$ and $M(\eta_c)$
E835: (Photon 99) $\Gamma$, $\Gamma_{yy}$ and $M(\eta_c)$
L3: (Phys. Lett. B461, 1999, 155) only $\Gamma_{yy}$
DELPHI: (ICHEP 2000) only $\Gamma_{yy}$
Comparison to other experimental results

Mass

Errors include common error from $J/\psi \rightarrow \eta \eta$

$\gamma \gamma$ Partial Width

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Comparison to other experimental results

Total Width

Included in PDG 98

- CBAL
- E760

PDG

- BES
- E835

new average

CLEO

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## Comparison to other experimental results

<table>
<thead>
<tr>
<th>Experiment</th>
<th>mass (MeV)</th>
<th>Total width (MeV)</th>
<th>$\gamma\gamma$ width (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARGUS</td>
<td>-</td>
<td>-</td>
<td>11.3 +/- 4.2</td>
</tr>
<tr>
<td>CLEO(90)</td>
<td>-</td>
<td>-</td>
<td>5.9 +/- 1.8 +/- 1.9</td>
</tr>
<tr>
<td>CBAL</td>
<td></td>
<td>11.5 +/- 4.5</td>
<td>-</td>
</tr>
<tr>
<td>Mk III</td>
<td>2980.6 +/- 1.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DM2</td>
<td>2974.4 +/- 1.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>E760</td>
<td>2988.3 +/- 3.3 -3.1</td>
<td>23.9 +/- 12.6 -7.1</td>
<td>6.7 +/- 2.4 -1.7 +/- 2.3</td>
</tr>
<tr>
<td>PDG98</td>
<td>2979.8 +/- 2.1</td>
<td>13.2 +/- 3.5</td>
<td>7.5 +/- 1.5</td>
</tr>
<tr>
<td>BES</td>
<td>2976.3 +/- 3.1</td>
<td>11.0 +/- 8.1 +/- 4.1</td>
<td>-</td>
</tr>
<tr>
<td>E835</td>
<td>2985.1 +/- 2.1</td>
<td>22.4 +/- 7.8 -6.4</td>
<td>4.1 +/- 1.7 -1.4 +/- 1.5</td>
</tr>
<tr>
<td>L3</td>
<td>-</td>
<td>-</td>
<td>6.9 +/- 1.9 +/- 2.0</td>
</tr>
<tr>
<td>DELPHI</td>
<td>-</td>
<td>-</td>
<td>10.9 +/- 2.7 +/- 3.4</td>
</tr>
<tr>
<td>CLEO(00)</td>
<td>2980.4 +/- 2.4</td>
<td>27.0 +/- 6.0</td>
<td>7.6 +/- 0.9 +/- 2.3</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>2981.1 +/- 1.7</td>
<td>18.0 +/- 3.0 -2.7</td>
<td>7.1 +/- 0.8 -0.7 +/- 2.0</td>
</tr>
</tbody>
</table>

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Comparison to other experimental results

One of the more interesting features of these results is our measurement of $\Gamma(\eta_c)$. E835, an experiment using a completely different technique, $PP \rightarrow \eta_c \rightarrow \gamma\gamma$, reports a very similar width, also significantly larger than the PDG value.

In E835, mass & width measured by "scanning" the momentum of the antiproton beam across the resonance width.

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Comparison to other experimental results

The present CLEO result, $\Gamma = 27.0 \pm 6.0 \text{ MeV}$

cmpares very well with E835’s direct width measurement of $\Gamma = 22.4^{+7.8}_{-6.4} \text{ MeV}$

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Conclusions

- CLEO has measured $M(\eta_c)$, $\Gamma(\eta_c)$ and $\Gamma_{\gamma\gamma}(\eta_c)$ in $2\gamma$ collisions
- Results for $M(\eta_c)$ and $\Gamma_{\gamma\gamma}(\eta_c)$ are consistent with those from PDG98, with comparable errors
- Most interestingly, the result for $\Gamma(\eta_c)$, $27.0 \pm 5.8 \pm 1.4$ MeV, is significantly different than the PDG98 average of $13.2^{+3.8}_{-3.2}$ MeV

It does, however, compare very well with the heretofore “anomalously large” width reported by E760/E835 (and is closer to theoretical predictions)

For more details, see: hep-ex/0006026