Rare decays and transitions at CLEO
[singlets (1^{1}P_{1} and 1^{1}S_{0}) in b\bar{b} and c\bar{c}]

Hajime Muramatsu
University of Rochester
Searches/measurements of rare transitions

• The discovery of $h_c(1^1P_1)$
  Will have $10 \times$ more $\psi(2S)$ data ($\sim 30M$ decays).
  Measure $M(h_c)$ at $\sim 0.2$MeV level w/ the new data.

• We see $\psi(2S) \rightarrow \pi^0 h_c \rightarrow \pi^0 \eta_c \gamma$ with $3M \psi(2S)$’s.
  Why not $\Upsilon(3S) \rightarrow \pi^0 h_b \rightarrow \pi^0 \eta_b \gamma$ with $6M \Upsilon(3S)$’s?

• Any other ways to reach $\eta_b(1S)$ state?

• Some up coming projects with $30M \psi(2S)$ data.
  Means we will also have $\sim 15M J/\psi$ decays!
Discovery of $h_c$

- **Predicted:** $B(\psi(2S) \rightarrow \pi^0 h_c) \times B(h_c \rightarrow \eta_c \gamma) \sim 4 \times 10^{-4}$
  

- **Procedures:**
  - Inclusive:
    - Demand recoil mass vs $(\pi^0 \gamma)$ be consistent with $M(\eta_c)$
    - Or demand the $E_\gamma$ be consistent with the expected energy.
    - Then look at recoil vs $\pi^0$.
  - Exclusive:
    - does full reconstructions of $\eta_c$ (7 modes).

- ** Obtained:** PRD 72, 092004 and PRL 95, 102003
  - Incl:
    - $\langle M(1^3P_J) \rangle - M(h_c) = (+0.5 \pm 0.7 \pm 0.4)$ MeV/c²
    - $B \times B = (3.5 \pm 1.0 \pm 0.7) \times 10^{-4}$
  - Inclusive+Excl:
    - $\langle M(1^3P_J) \rangle - M(h_c) = (+1.0 \pm 0.6 \pm 0.4)$ MeV/c²
    - $B \times B = (4.0 \pm 0.8 \pm 0.7) \times 10^{-4}$
    - w/ >5$\sigma$ significance
  - where $\langle M(1^3P_J) \rangle = 3525.4 \pm 0.1$ MeV/c².
  - E835: PRD 72, 032001
    - $\langle M(1^3P_J) \rangle - M(h_c) = (-0.4 \pm 0.2 \pm 0.2)$ MeV/c²
    - w/ ~3$\sigma$ significance.
Discovery of $h_c$: part II

- **W/ 30M $\psi(2S)$ decays:**
  - Inclusive: $\Delta M(\text{stat}) \sim \Delta M(\text{syst}) \sim 0.2\text{MeV}/c^2$
    $\Delta(B\times B)(\text{stat}) \sim 0.3 \times 10^{-4}$
  - Exclusive: $\Delta M(\text{stat}) \sim \Delta M(\text{syst}) \sim 0.3\text{MeV}/c^2$
    $\Delta(B\times B)(\text{stat}) \sim 0.5 \times 10^{-4}$
  - Can we look for other $h_c$ decays (i.e. $h_c \rightarrow pp$ ... probably too small)?
    And/or can folks with hadron colliders make a precise measurement on $B(h_c \rightarrow \eta_c \gamma)$ so that we can extract $B(\psi(2S) \rightarrow \pi^0 h_c)$?
How about $h_b$?

- Could repeat the same exercise to look for $\Upsilon(3S) \rightarrow \pi^0 h_b \rightarrow \gamma \pi^0 \eta_b$
- Differences between $\psi(2S) \rightarrow \pi^0 h_c \rightarrow \gamma \pi^0 \eta_c$ and $\Upsilon(3S) \rightarrow \pi^0 h_b \rightarrow \gamma \pi^0 \eta_b$
  - **GOOD NEWS**
    - $B(h_c \rightarrow \gamma \eta_c) = 37.7\%$ vs $B(h_b \rightarrow \gamma \eta_b) = 41.4\%$ (Godfrey, Rosner, PRD66, 014012 (2002)).
    - $B(\psi(2S) \rightarrow \pi^0 h_c) = 0.1\%$ vs $B(\Upsilon(3S) \rightarrow \pi^0 h_b) = 0.1\%$ (Voloshin, Sov.J.Nucl.Phys.43, 1011 (1986)).
  - **BAD NEWS**
    - $E_{\pi^0} \sim 160\text{MeV}$ vs $E_{\pi^0} \sim 450\text{MeV}$ (see below)
    - $E_{\gamma} \sim 450\text{MeV}$ vs $E_{\gamma} \sim 490\text{MeV}$ (see above/below)
    - $E_{\gamma} \sim 483\text{MeV}$ from $\Upsilon(3S) \rightarrow \gamma \chi_{b0}(1P)$
      Note: $\sigma_{E} @ \sim 480\text{MeV} = 10 \sim 12\text{MeV}$.
How about $h_b$? : part II

- Early result indicated no sign of signal.
- Knowing $M(\eta_b)$ would be a great help (demanding the recoil vs $\pi^0 \gamma$ be consistent with it).

- We are also working on:
  - Voloshin (hep-ex/0410368) predicts $B(\chi_{b0}(2P) \rightarrow \eta\eta_b) \sim 0.001$.
  - $\Upsilon(3S) \rightarrow \pi\pi h_b$
    - $B(\Upsilon(3S) \rightarrow \pi\pi h_b) < 10^{-4}$ (Voloshin, Sov.J.Nucl.Phys.43, 1011 (1986)).
    - $B(\Upsilon(3S) \rightarrow \pi\pi h_b) \sim 10^{-4}$ (Kuang: hep-ph/0601044)
    - $< 18 \times 10^{-4}$ UL (90% CL) CLEOII ($\sim$0.5M $\Upsilon(3S)$’s) (27 $\times 10^{-4}$ UL for $\Upsilon(3S) \rightarrow \pi^0 h_b$ mode) PRD49,40 (1994).
  - Revisit search for $\Upsilon(2,3S) \rightarrow \gamma\eta_b(1S)$ (see the next slide)
Search for $\Upsilon(2,3S) \rightarrow \gamma \eta_b(1S)$

- **Hindered M1 transition:** 
  \[ \Gamma_{M1} \propto \frac{e^2}{m^2} \left| \langle nL | n'L \rangle \right|^2 E^3 \]

- But $E_\gamma \sim 911 \ (604) \text{ MeV}$ from $\Upsilon(3S) \ (\Upsilon(2S)) \rightarrow \gamma \eta_b(1S)$ with $M(\eta_b) \sim 9400 \text{ MeV}/c^2$.

- CLEO has already set ULs (90%CL) on these $BR$'s (PRL94,032001)
Search for $\Upsilon(2,3S) \rightarrow \gamma \eta_b(1S)$

- Wondering if we could approach semi-exclusively such as selecting particular track multiplicity events.
- Or try to reconstruct $\eta_b$ based on known modes of $\eta_c$ via direct and hindered M1 transition, $\Upsilon(1,2,3S) \rightarrow \gamma \eta_b(1S)$. 
Some new analyses: part I

- Looking for $J/\psi \rightarrow \gamma \eta_c(1S)$ in our $\psi(2S)$ data.
- $B(J/\psi \rightarrow \gamma \eta_c(1S))=0.0127\pm0.0036$: C. Ball (PRD34, 711(1986)).
- This is the only observed direct M1 transition in quarkonia.
- Has been used to extract $BR$’s of many $\eta_c$ decay modes in the PDG.

- Could tag $J/\psi$ by means of $\psi(2S) \rightarrow \pi^+\pi^- J/\psi \rightarrow \sim 700k$ tagged $J/\psi$ events.
- Select the signal ($J/\psi$) and sidebands and do a subtraction in $E_\gamma$ spectrum (see the next slide).
Some new analyses : part II

- Will work in the J/ψ rest frame → the dominant E1 photon peaks from ψ(2S) → γ χ_{cJ} will be broader and the signal peak should be sharpened.
Some new analyses : part III

- **J/ψ → γ X, X=2γ final state: π^0, η, η', and η_c.**
  - And **J/ψ → γ γ γ** directly.
  - Crystal Ball has done this analysis (PRL44, 712 (1980)).
    Set UL at 90%CL on $B(J/ψ → γγγ) < 5.5×10^{-5}$ with ~0.9M J/ψ.
  - Our goal is at least to improve the above limit with 30M $ψ(2S)$ data.
  - Expect $B(J/ψ → γγγ) / B(J/ψ → ggg) ∝ (α/α_s)^3$?

- **Multipoles in ψ(2S) → γ χ_{cJ}, χ_{cJ} → γ J/ψ**
  - E1 transitions dominate.
  - The expected M2 amplitudes for $χ_{cJ} → γ J/ψ$ are:
    - $a_2(χ_{c1}) = -E_γ/(4m_c)(1+κ_c)$
    - $a_2(χ_{c2}) = -3E_γ/(4√5m_c)(1+κ_c)$, where $κ_c$ is the charm quark’s anomalous magnetic moment.
  - $a_2(χ_{c1})/a_2(χ_{c2}) = √5/3×E_γ(χ_{c1})/E_γ(χ_{c2}) = 0.676$ expected!
  - Present experimental data (E835,E760,C.Ball) do not agree, but not really significant either.
Conclusions

• CLEO has discovered $h_c$ via $\psi(2S) \rightarrow \pi^0 h_c \rightarrow \gamma \pi^0 \eta_c$.
• Will improve this measurement (mass and the product of rates) based on the new 30M $\psi(2S)$ data.

• Will set ULs (or see signals!) on the rates of:
  - $\Upsilon(3S) \rightarrow \pi^0 h_b \rightarrow \gamma \pi^0 \eta_b$
  - $\Upsilon(3S) \rightarrow \pi \pi h_b \rightarrow \gamma \pi \pi \eta_b$
  - $\Upsilon(2,3S) \rightarrow \gamma \eta_b$
  - $\Upsilon(2,3S) \rightarrow \gamma \chi_{b0}(2P), \chi_{b0}(2P) \rightarrow \eta \eta_b$

• We are looking at:
  - $J/\psi \rightarrow \gamma \eta_c$.
  - $J/\psi \rightarrow \gamma X, X=2\gamma$ final state: $\pi^0, \eta, \eta'$, and $\eta_c$. And $J/\psi \rightarrow 3\gamma$'s directly.
  - multipole effects in $\psi(2S) \rightarrow \gamma \chi_{cJ}, \chi_{cJ} \rightarrow \gamma J/\psi$, measuring magnetic moment of charm quark!

Stay tuned! Many more exciting results are STILL coming from CLEO in the near future!