Rare decays and transitions at CLEO

[singlets (1^1P_1 and 1^1S_0) in $b\bar{b}$ and $c\bar{c}$]

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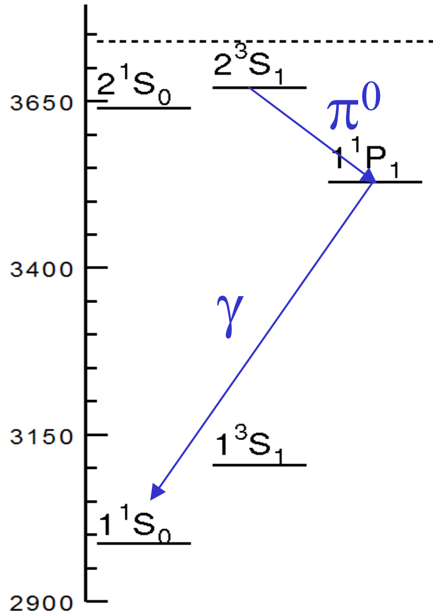
Searches/measurements of rare transitions

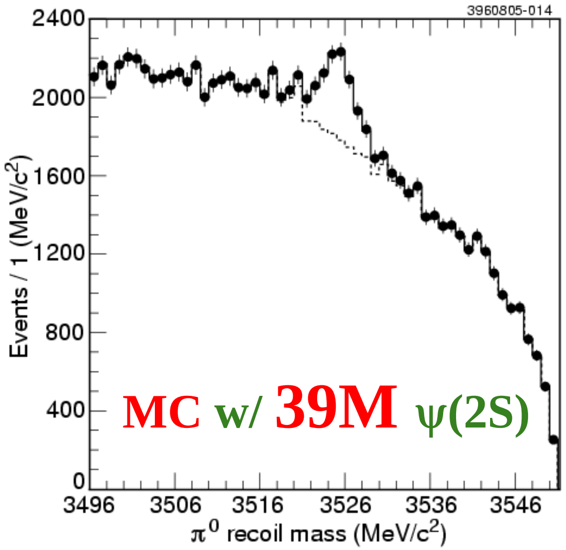
- **The discovery of $h_c(1^1P_1)$**
  Will have 10× more $\psi(2S)$ data (~30M decays).
  Measure M(h_c) at ~0.2MeV level w/ the new data.
- **We see $\psi(2S) \rightarrow \pi^0 h_c \rightarrow \pi^0 \eta_c \gamma$ with 3M $\psi(2S)$'s.**
  Why not $\Upsilon(3S) \rightarrow \pi^0 h_b \rightarrow \pi^0 \eta_b \gamma$ 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 ~15M J/ψ decays!

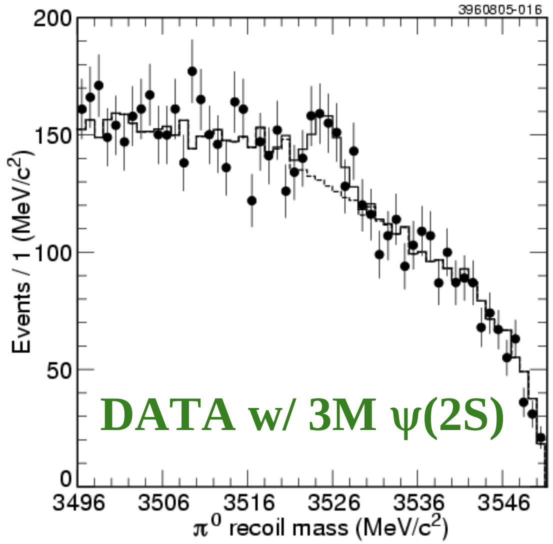
Discovery of h_c

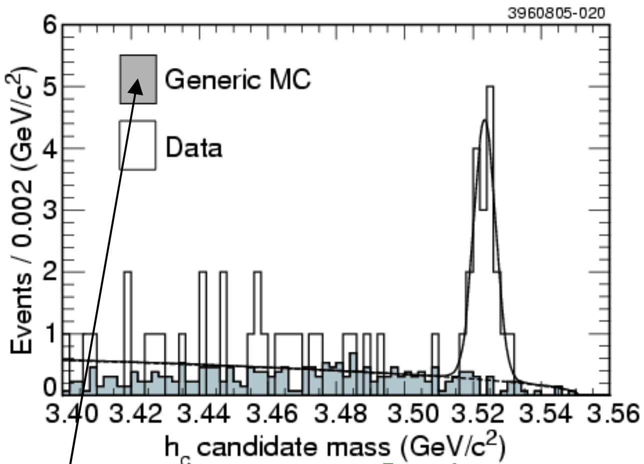
- **Predicted: $B(\psi(2S) \to \pi^0 h_c)\times B(h_c \to \eta_c \gamma)$~$4\times10^{-4}$**
  M.B. Voloshin (Sov.J.Nucl.Phys.43, 1011 (1986)) and S. Godfrey and J. Rosner (PRD66, 014012 (2002)).
- **Procedures:**
  - **Inclusive:**
    - **Demand recoil mass vs ($\pi^0\gamma$) be consistent with $M(\eta_c)$ Or demand the E_γ be consistent with the expected energy.**
    - **Then look at recoil vs π^0.**
  - **Exclusive: does full reconstructions of η_c (7 modes).**
- **Obtained: PRD72,092004 and PRL95,102003**
  - **Incl:**
    $\langle M(1^3P_J)\rangle - M(h_c) = (+0.5\pm0.7\pm0.4)$ MeV/c^2
    $B\times B = (3.5\pm1.0\pm0.7)\times10^{-4}$
  - **Inclusive+Excl:**
    $\langle M(1^3P_J)\rangle - M(h_c) = (+1.0\pm0.6\pm0.4)$ MeV/c^2
    $B\times B = (4.0\pm0.8\pm0.7)\times10^{-4}$
    w/ >5σ significance
  - **where $\langle M(1^3P_J)\rangle = 3525.4\pm0.1$ MeV/c^2.**
  - **E835: PRD72, 032001**
    $\langle M(1^3P_J)\rangle - M(h_c) = (-0.4\pm0.2\pm0.2)$ MeV/c^2
    w/ ~3σ significance.



Discovery of h_c : part II







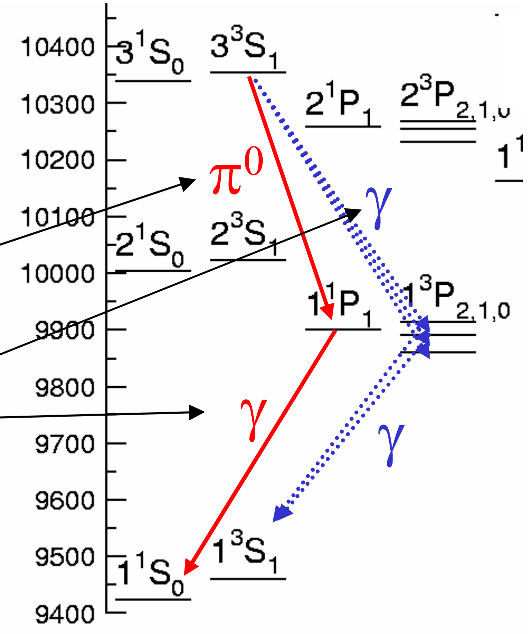
DATA exclusive

Generic ψ(2S) decays withOUT h_c signals.

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

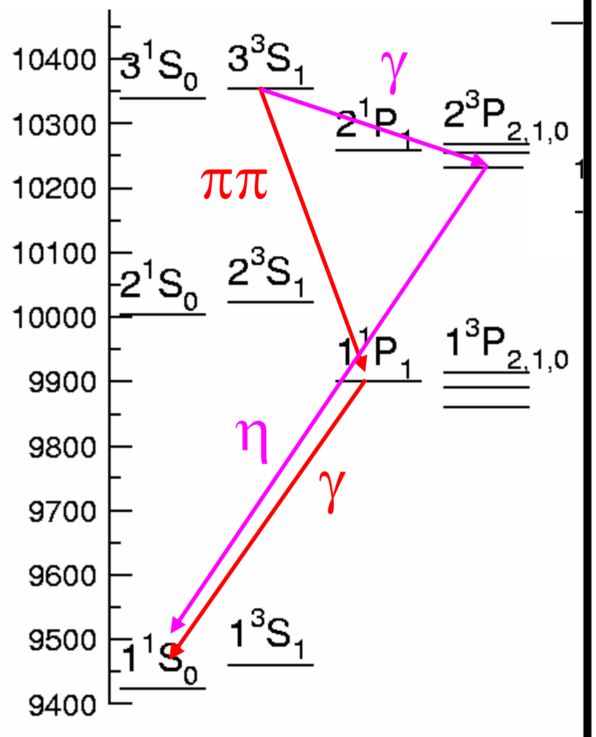
How about h_b ?

- **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_{CM}=3686MeV vs E_{CM}=10355MeV: Much higher charged/neutral multiplicities.**
    - **$\sigma(e^+e^-\rightarrow\psi(2S))/\sigma(e^+e^-\rightarrow qq)$ ~ 500nb/15nb ~ 30 vs $\sigma(e^+e^-\rightarrow\Upsilon(3S))/\sigma(e^+e^-\rightarrow qq)$ ~ 4nb/3nb ~ 1**
    - **$E_{\pi0}$~160MeV vs $E_{\pi0}$~450MeV (see below)**
    - **E_γ~500MeV vs E_γ~490MeV (see above/below)**
    - **E_γ~483MeV from $\Upsilon(3S)\rightarrow\gamma\chi_{b0}(1P)$ Note: σ_E @ ~480MeV = 10~12MeV.**



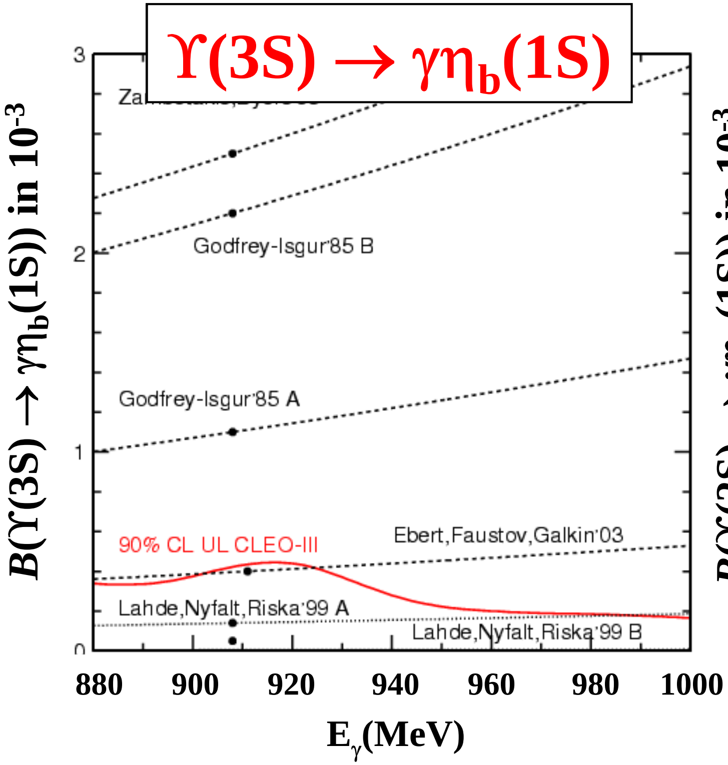
How about h_b ? : part II

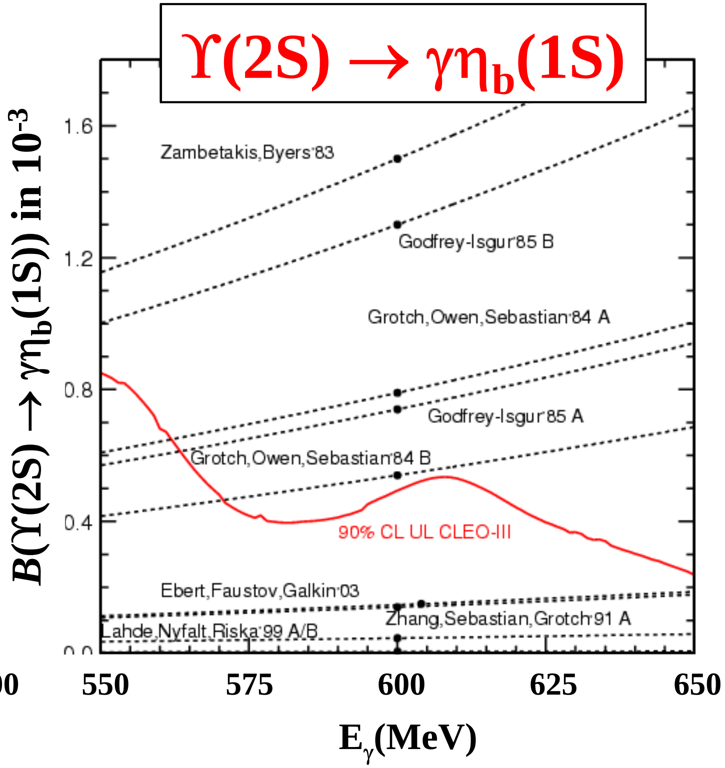
- **Early result indicated no sign of signal.**
- **Knowing $M(\eta_b)$ would be a great help (demanding the recoil vs $\pi^0\gamma$ be consistent with it).**
- **We are also working on:**
  - **Voloshin (hep-ex/0410368) predicts $B(\chi_{b0}(2P) \rightarrow \eta\eta_b) \sim 0.001$.**
  - **$\Upsilon(3S) \rightarrow \pi\pi h_b$**
    - **$B(\Upsilon(3S) \rightarrow \pi\pi h_b) < 10^{-4}$ (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 (~0.5M $\Upsilon(3S)$'s) (27×10^{-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)**

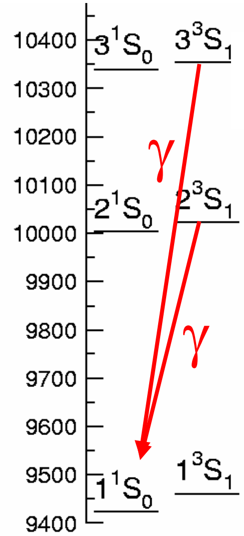


Search for $\Upsilon(2,3S) \rightarrow \gamma\eta_b(1S)$

- **Hindered M1 transition:** $\Gamma_{M1} \propto \frac{e_Q^2}{m_Q^2} \left| \langle nL | n'L \rangle \right|^2 E_\gamma^3$
- **But E_γ ~911 (604) MeV from $\Upsilon(3S)$ ($\Upsilon(2S)$) $\rightarrow \gamma\eta_b(1S)$ with $M(\eta_b)$~9400 MeV/c^2.**
- **CLEO has already set ULs (90%CL) on these *BR*'s (PRL94,032001)**





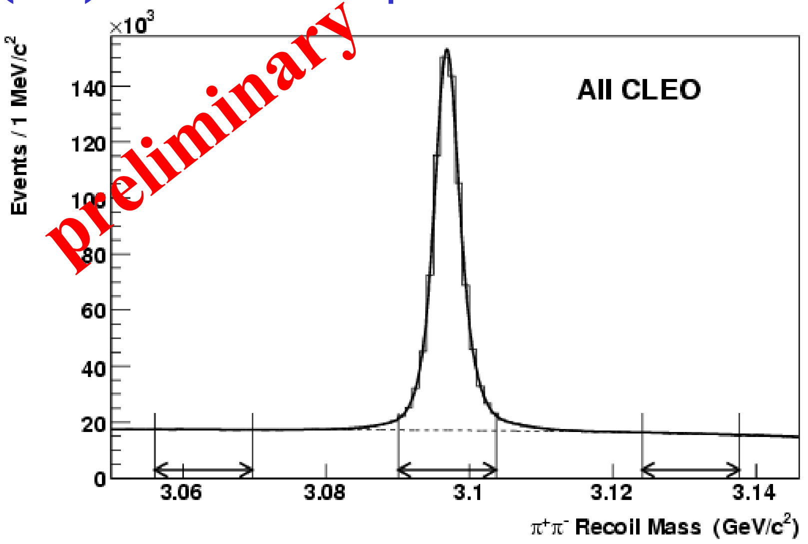


Search for $\Upsilon(2,3S) \rightarrow \gamma\eta_b(1S)$

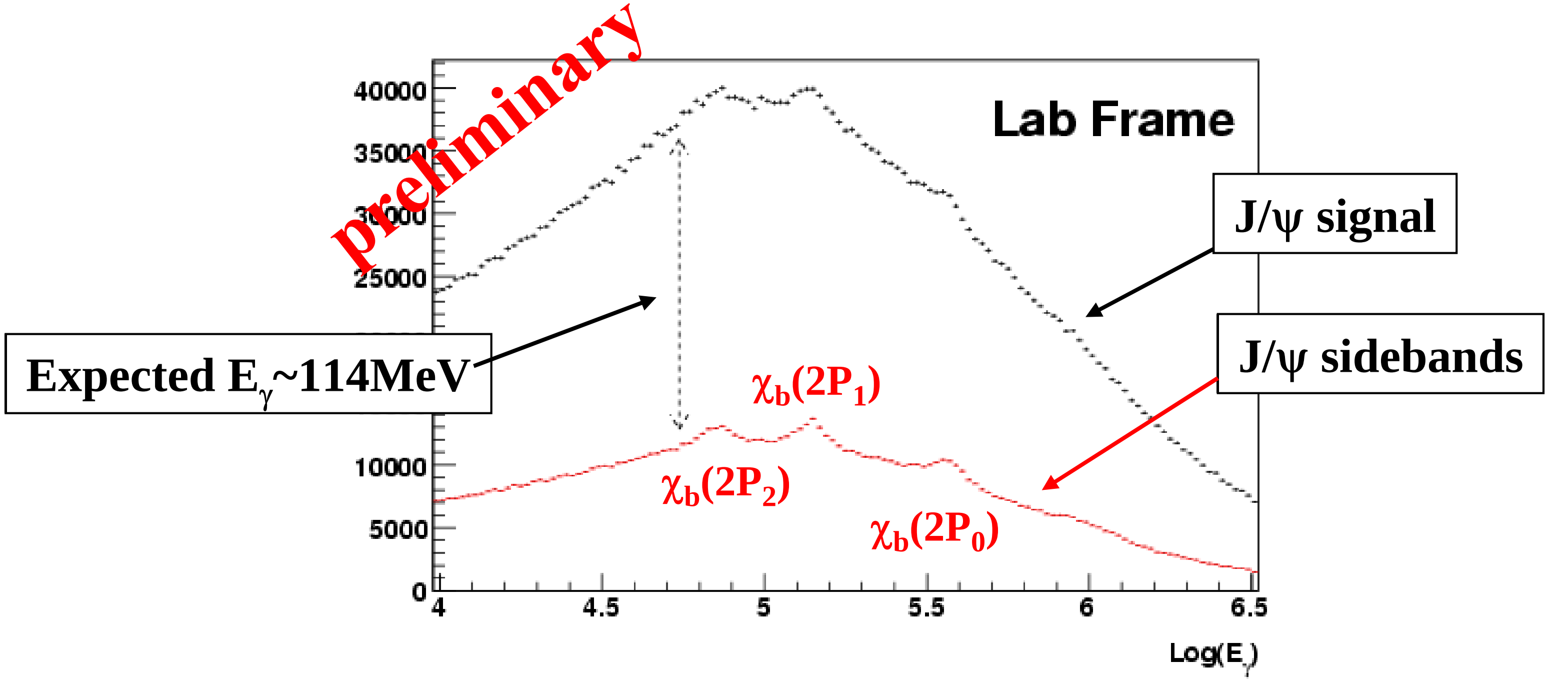
- Wondering if we could approach semi-exclusively such as selecting particular track multiplicity events.
- Or try to reconstruct η_b based on known modes of η_c via direct and hindered M1 transition, $\Upsilon(1,2,3S) \rightarrow \gamma\eta_b(1S)$.

Some new analyses : part I

- Looking for $J/\psi \to \gamma\eta_c(1S)$ in our $\psi(2S)$ data.
- $B(J/\psi \to \gamma\eta_c(1S))=0.0127\pm0.0036$:C. Ball (PRD34,711(1986)).
- This is the only observed direct M1 transition in quarkonia.
- Has been used to extract *BR*'s of many η_c decay modes in the PDG.
- Could tag J/ψ by means of $\psi(2S) \to \pi^+\pi^- J/\psi$ $\to$ ~ 700k tagged J/ψ events.
- Select the signal (J/ψ) and sidebands and do a subtraction in E_γ 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

- $J/\psi \to \gamma X$, $X=2\gamma$ final state: π^0, η, η', and η_c. And $J/\psi \to \gamma\gamma\gamma$ directly.
  - Crystal Ball has done this analysis (PRL44, 712 (1980)). Set UL at 90%CL on $B(J/\psi \to \gamma\gamma\gamma) < 5.5\times10^{-5}$ with ~0.9M J/ψ.
  - Our goal is at least to improve the above limit with 30M $\psi(2S)$ data.
  - Expect $B(J/\psi \to \gamma\gamma\gamma) / B(J/\psi \to ggg) \propto (\alpha/\alpha_s)^3$?
- Multipoles in $\psi(2S) \to \gamma\chi_{cJ}$, $\chi_{cJ} \to \gamma J/\psi$
  - E1 transitions dominate.
  - The expected M2 amplitudes for $\chi_{cJ} \to \gamma J/\psi$ are:
    $a_2(\chi_{c1}) = -E_\gamma/(4m_c)\times(1+\kappa_c)$
    $a_2(\chi_{c2}) = -3E_\gamma/(4\sqrt{5}m_c)\times(1+\kappa_c)$, where κ_c is the charm quark's anomalous magnetic moment.
  - $a_2(\chi_{c1})/a_2(\chi_{c2}) = \sqrt{5}/3\times E_\gamma(\chi_{c1})/E_\gamma(\chi_{c2}) = 0.676$ expected!
  - Present experimental data (E835,E760,C.Ball) do not agree, but not really significant either.

Conclusions

- CLEO has discovered h_c via $\psi(2S)\to\pi^0 h_c\to\gamma\pi^0\eta_c$.
- 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:
  - $\Upsilon(3S)\to\pi^0 h_b\to\gamma\pi^0\eta_b$
  - $\Upsilon(3S)\to\pi\pi\, h_b\to\gamma\,\pi\pi\,\eta_b$
  - $\Upsilon(2,3S)\to\gamma\,\eta_b$
  - $\Upsilon(2,3S)\to\gamma\,\chi_{b0}(2P)$, $\chi_{b0}(2P)\to\eta\,\eta_b$

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

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