Search for $\eta_b(nS)$ at CLEO

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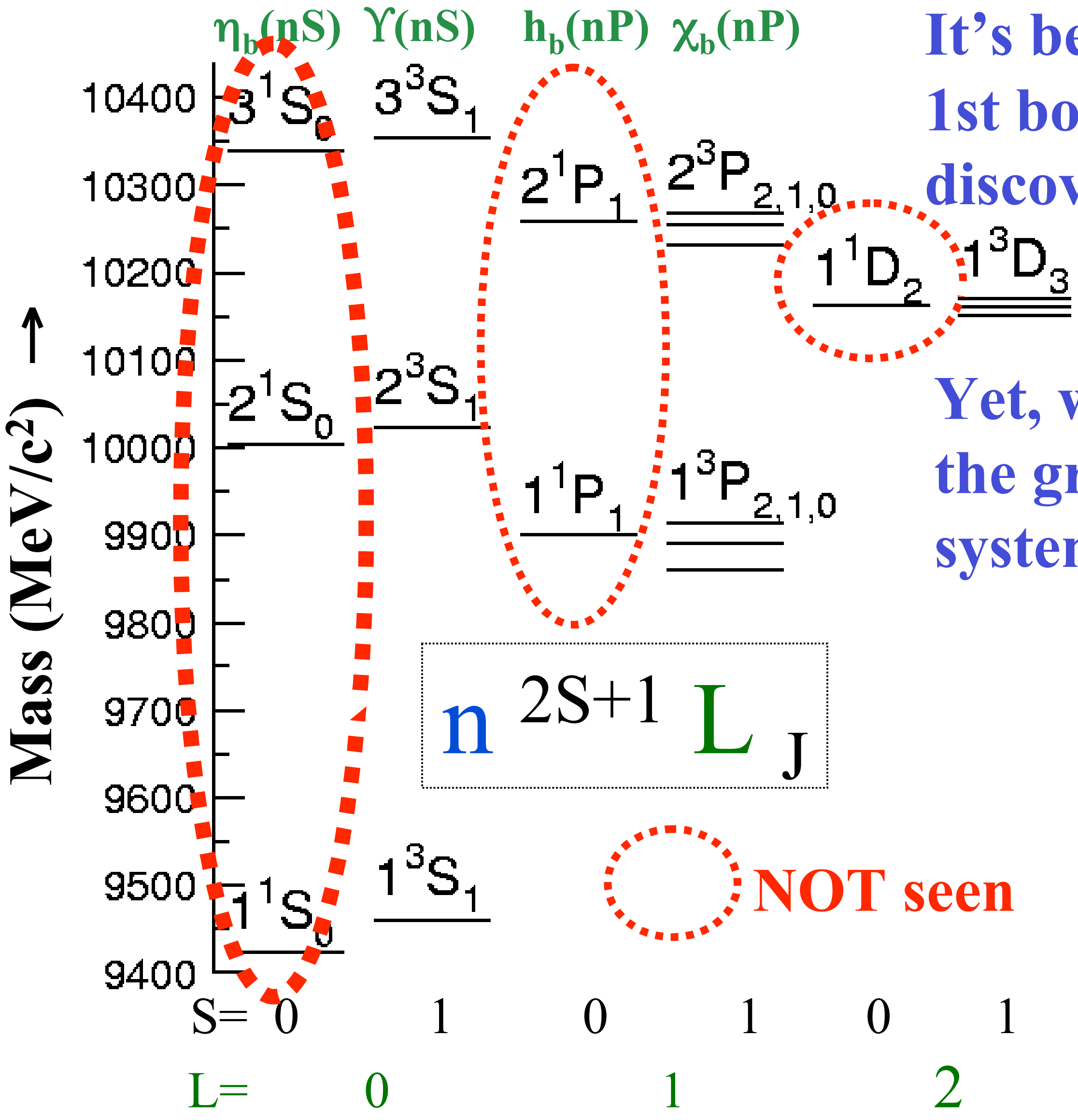
Bottomonium States - below threshold



It's been 30 years since the 1st bottomonium state was discovered.

Yet, we have still not seen the ground state of the system!!

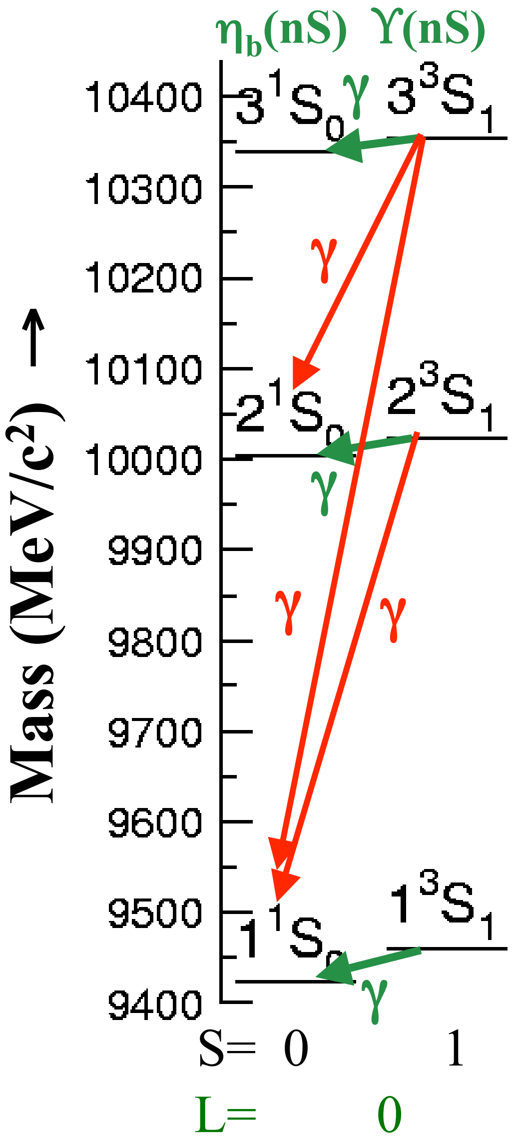
Experimental Status on $\eta_b(1S)$ - I

- **PDG lists (omitted from summary table)**
  $M(\eta_b(1S)) = 9300\pm20\pm20$MeV (ALEPH coll. see below).
  Most of the potential models predict
  $M(\eta_b(1S)) \sim 9.40^{+0.03}_{-0.05}$ GeV
  summarized in S. Godfrey and J. L. Rosner PRD64,074011(2001).
- **ALEPH collaboration (PLB530, 56 (2002))**
  - **Looked for 4 and 6 charged tracks (π and K) in 2-photon fusion processes.**
  - **Saw no events in 4-tk mode**
    Saw one event (over expected bkg of 0.74±0.34) in 6-tk mode.
    It looked like $K_S K^- \pi^+ \pi^- \pi^+$.
  - **Provided ULs @ 95% C.L. on**
    $\Gamma_{\gamma\gamma}(\eta_b)\times B(\eta_b(1S) \rightarrow 4\ \text{tracks}) < 48\text{eV}$
    $\Gamma_{\gamma\gamma}(\eta_b)\times B(\eta_b(1S) \rightarrow 6\ \text{tracks}) < 132\text{eV}$

Experimental Status on $\eta_b(1S)$ - II

- **DELPHI collaboration (PLB634, 340 (2006))**
  - **Similarly, looked for 4, 6, and 8 charged tracks (π and K) in 2-photon fusion processes.**
  - **Saw 0 events (1.2 bkg expected) in 4-tk mode**
    Saw 2 events (1.1 bkg expected) in 6-tk mode
    Saw 1 event (1.5 bkg expected) in 8-tk mode
    in the range of $9.2\text{GeV} < M_{tk} < 9.6\text{GeV}$.
  - **Provided ULs @ 95% C.L. on**
    $\Gamma_{\gamma\gamma}(\eta_b)\times B(\eta_b(1S) \rightarrow 4\ \text{tracks}) < 190\text{eV}$
    $\Gamma_{\gamma\gamma}(\eta_b)\times B(\eta_b(1S) \rightarrow 4\ \text{tracks}) < 470\text{eV}$
    $\Gamma_{\gamma\gamma}(\eta_b)\times B(\eta_b(1S) \rightarrow 4\ \text{tracks}) < 660\text{eV}$

SOME ways to produce $\eta_b(nS)$ at CLEO



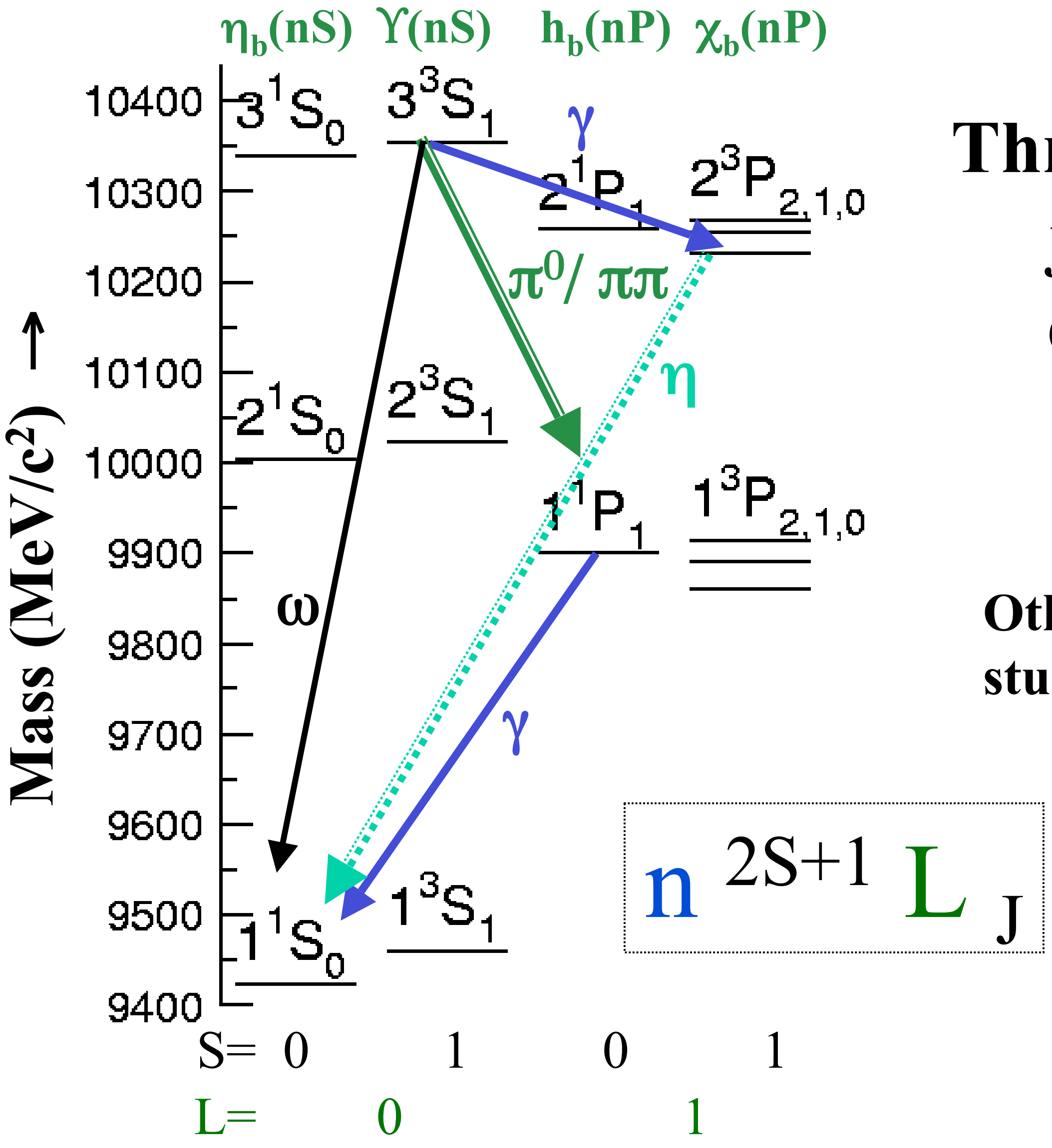
Magnetic Dipole (M1) Transitions

- $\Gamma_{M1} \propto k^3/m^2_Q \cdot |\langle f|j_0(kr/2)|i\rangle|^2$

- Allowed M1 ($n^3S_1 \rightarrow n^1S_0$)
  - $|\langle f|j_0(kr/2)|i\rangle| \sim 1$
  - k is small (~60MeV for 1S → 1S)
- Forbidden M1 ($n^3S_1 \rightarrow m^1S_0$)
  - $|\langle f|j_0(kr/2)|i\rangle| << 1$
  - k is large (~600/900MeV for 2/3S → 1S)

$n\,^{2S+1}L_J$

SOME ways to produce $\eta_b(nS)$ at CLEO

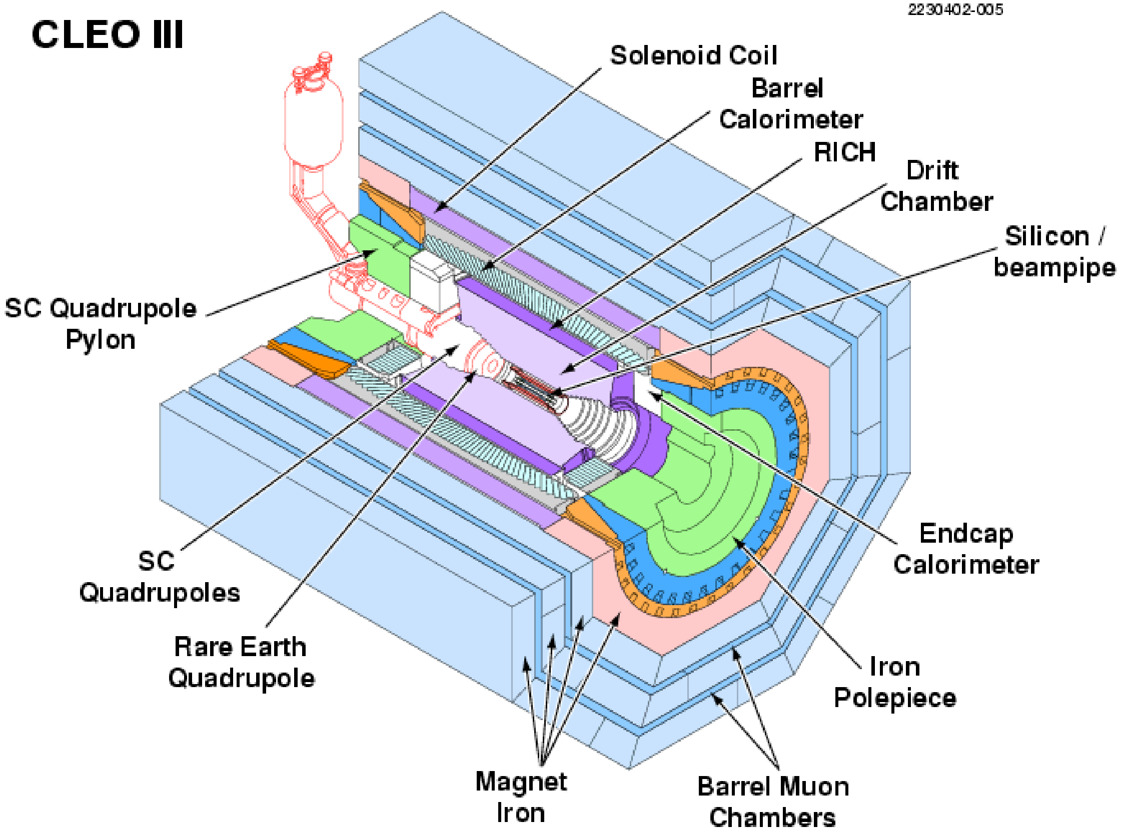


Through the $h_b(1P)$ just like how we discovered $h_c(1P)$

Other paths will be studied as well (see later slides)

CLEO-III detector

- Located at Cornell Electron Storage Ring
- e^+e^- collisions at √s ~ 10GeV (2001~2002)



- **EM calorimeter** - Essential for photon spectroscopy
  - ~8000 CsI(Tl) crystals + photo-diodes
  - First crystal calorimeter in magnetic field (1.5T)
  - 2.2 (5)% at E_γ=1(0.1)GeV
- Excellent charged particle detection
- Excellent particle identification
  - dE/dx
  - Ring Imaging Cherenkov (RICH)

Data sets taken with CLEO-III detector

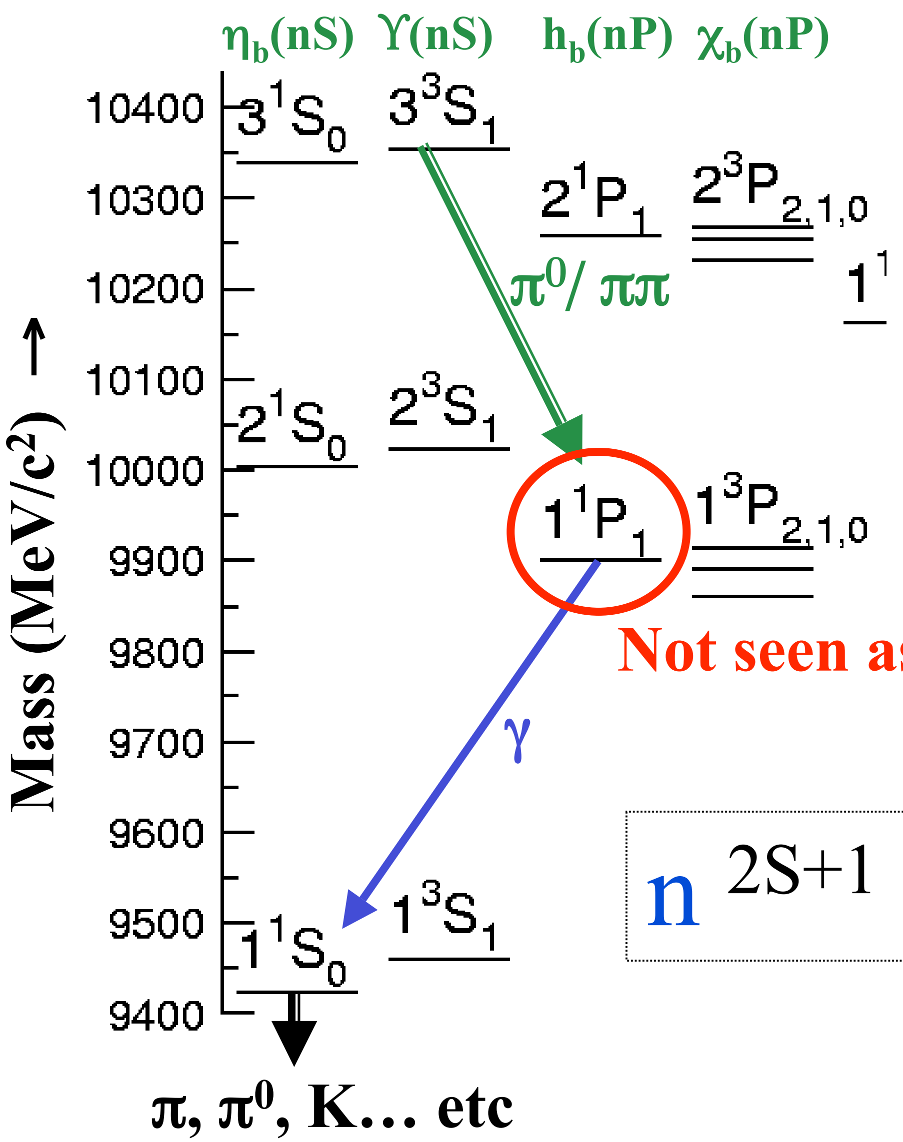
Reso-nance	CLEO-III Integrated Luminosity (fb^{-1})	Number of resonance decays (10^6)				
		CLEO III	CLEO II	Crystal Ball *(CUSB)*	Belle	BaBar
$\Upsilon(3S)$	1.2	6	0.46	*(1.3)*	11	???
$\Upsilon(2S)$	1.2	9	0.49	0.19		
$\Upsilon(1S)$	1.0	21	1.9	0.48		

~30/fb by March

Still the largest samples in the world!!

Belle and BaBar can tag (e.g.) $\pi^+\pi^-$ to reach $\Upsilon(1,2S)$ states → can avoid continuum ($B_{\pi+\pi-} \cdot \varepsilon_{\pi+\pi-} \sim$ a few %).

Search for $h_b(1P) \rightarrow \eta_b(1S)\ \gamma$ *exclusively*



Not seen as well

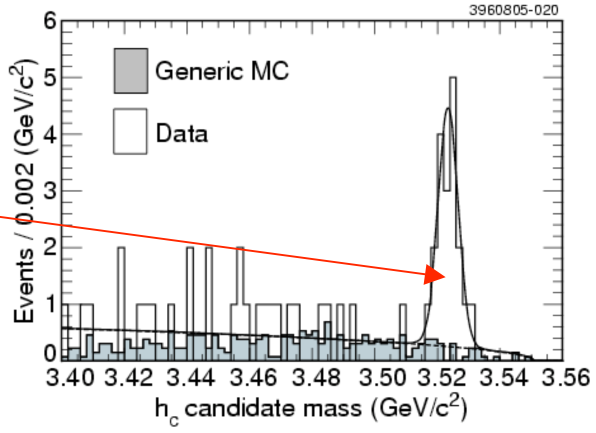
$$n\ ^{2S+1}L_J$$

$\Upsilon(3S) \rightarrow (\pi^0$ or $\pi^+\pi^-)$ $h_b(1P)$, $h_b(1P) \rightarrow \eta_b(1S)\,\gamma$

violates isopin!

- Similar to h_c study at CLEO
  - Predicted: $B(\psi(2S) \rightarrow \pi^0 h_c) \cdot B(h_c \rightarrow \eta_c \gamma) \sim 4\times10^{-4}$ (i.e. see S.Godfrey and J.L.Rosner, PRD66,014012 (2002))
  - Measured: $B(\psi(2S) \rightarrow \pi^0 h_c) \cdot B(h_c \rightarrow \eta_c \gamma) = (4.0\pm0.8\pm0.7)\times10^{-4}$ based on 3M $\psi(2S)$ sample (PRL95,102003(2005),PRD72,092004(2005))

Reconstructed η_c exclusively based on 15% of η_c decays according to PDG2007



- We have ~6M $\Upsilon(3S)$ sample.
- $B(\Upsilon(3S) \rightarrow \pi^0 h_b) \cdot B(h_b \rightarrow \eta_b \gamma) \sim 4\times10^{-4}$ predicted by M.B. Voloshin, Sov.J.Nucl.Phys.43, 1011 (1986) and S.Godfrey and J.L.Rosner, PRD66,014012 (2002))
- Not enough phase space between $M(\Upsilon(2S))$ and $M(h_b)$ assuming $M(h_b)$ = 9.9GeV (predicted to be ~9900±4MeV, see the above summary of Godfrey and Rosner).

Can we detect 7% of η_b decays ?

$\Upsilon(3S) \rightarrow (\pi^0 \text{ or } \pi^+\pi^-)\ h_b(1P)$, $h_b(1P) \rightarrow \eta_b(1S)\ \gamma$

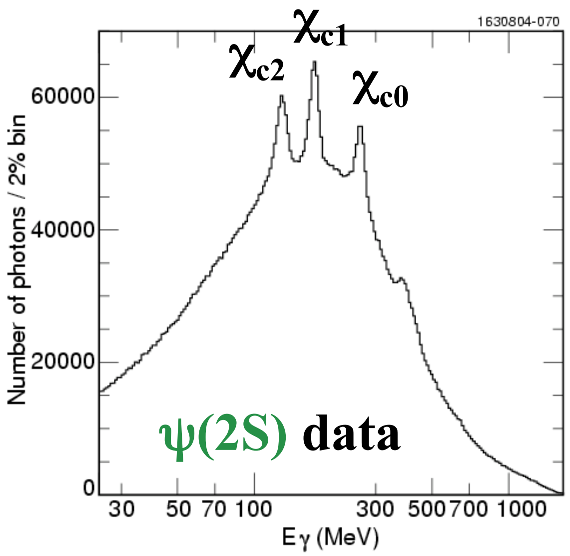
- **Between $M(\Upsilon(3S))$ and $M(h_b)$, there IS enough phase space to produce two π and we don't have to violate isospin conservation!.**
- **Predictions vary: $B(\Upsilon(3S) \rightarrow \pi^+\pi^-\ h_b)\cdot B(h_b \rightarrow \eta_b\ \gamma) \sim {<}4\times10^{-4} \sim 8\times10^{-3}$ (i.e. see S.Godfrey and J.L.Rosner, PRD66,014012 (2002))**

- **Also the transition photon is detectable.**
  $E_\gamma \sim 500$MeV from $h_c \rightarrow \eta_c\ \gamma$ likewise $E_\gamma \sim 490$MeV from $h_b \rightarrow \eta_b\ \gamma$ assuming $M(h_b)$=9.9GeV and $M(\eta_b)$=9.4GeV.

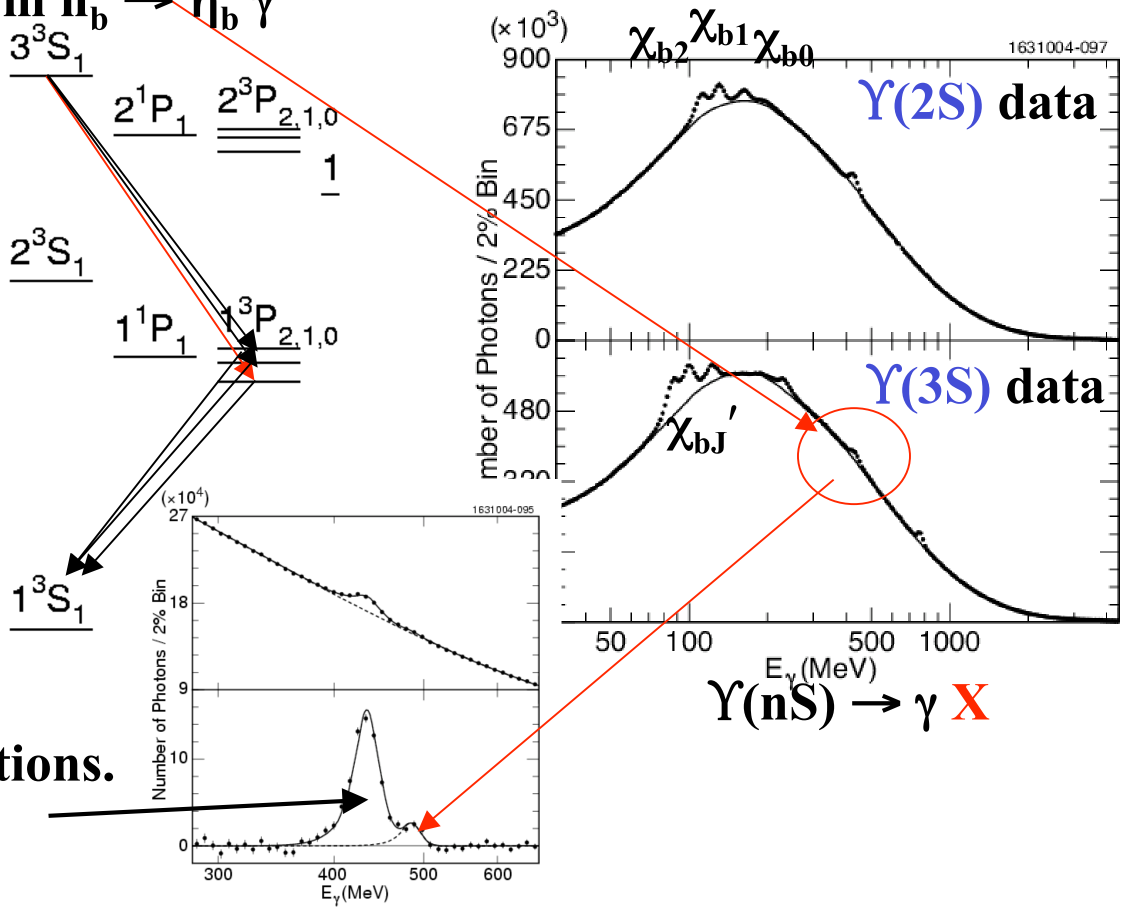
This is all good news. BUT ……

$\Upsilon(3S) \rightarrow (\pi^0 \text{ or } \pi^+\pi^-)\, h_b(1P)$, $h_b(1P) \rightarrow \eta_b(1S)\, \gamma$

- **Higher particle average multiplicities (neutrals) in ϒ data makes much more difficult to isolate a photon (and larger relative production of continuum).**
- **$E_\gamma = 483$MeV from $\Upsilon(3S) \rightarrow \gamma\, \chi_b(1P_0)$ might make things worse since $E_\gamma \sim 490$MeV from $h_b \rightarrow \eta_b\, \gamma$**



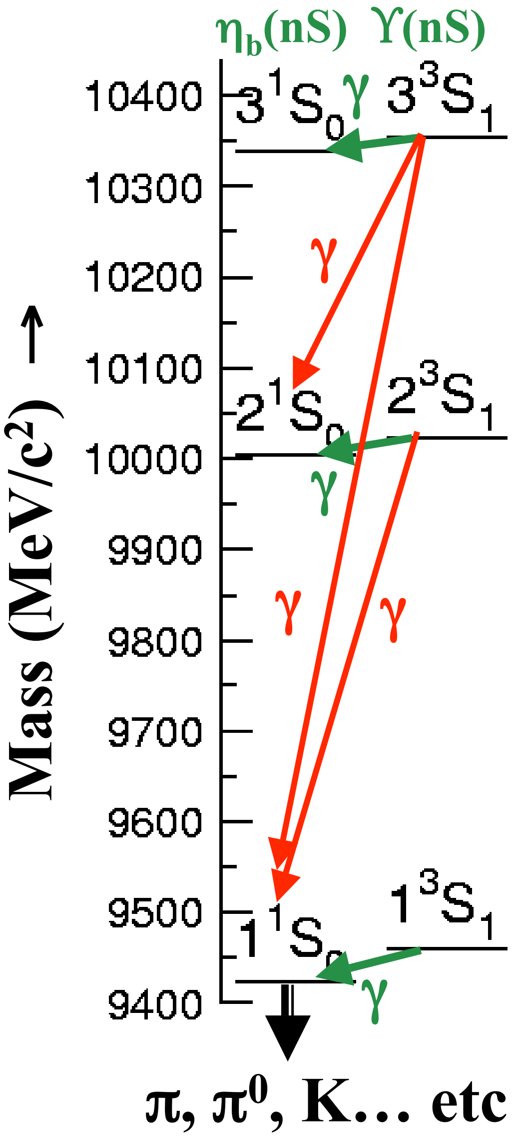
$\psi(2S) \rightarrow \gamma\, X$



$\Upsilon(nS) \rightarrow \gamma\, X$

Other hindered E1 transitions.
5 photon lines overlapped.

Search for $\Upsilon(nS) \rightarrow \eta_b(mS)\,\gamma$ *exclusively*



$$n\ {}^{2S+1}L_J$$

$\Upsilon(nS) \rightarrow \eta_b(mS)\,\gamma$

- RECALL: $\Gamma_{M1} \propto k^3/m^2_Q \cdot |\langle f|j_0(kr/2)|i\rangle|^2$
  - Allowed M1 ($n^3S_1 \rightarrow n^1S_0$)
    - $|\langle f|j_0(kr/2)|i\rangle| \sim 1$
    - k is small (~60MeV for 1S → 1S)
  - Fobidden M1 ($n^3S_1 \rightarrow m^1S_0$)
    - $|\langle f|j_0(kr/2)|i\rangle| \sim 0$
    - k is large (~600/900MeV for 2/3S → 1S)
  - Could the larger k^3 factor compensate the smaller $|\langle f|j_0(kr/2)|i\rangle|^2$ in cases of 3S→1S and 2S→1S?
- CLEO has looked for $\Upsilon(nS) \rightarrow \eta_b(mS)\,\gamma$ inclusively. No signals were seen, set Uls @ 90% C.L. (PRL94,032001(2005))

  → $B(\Upsilon(2S) \rightarrow \eta_b(1S)\,\gamma) < 5.1\times10^{-4}$

  $B(\Upsilon(3S) \rightarrow \eta_b(1S)\,\gamma) < 4.3\times10^{-4}$

  $B(\Upsilon(3S) \rightarrow \eta_b(2S)\,\gamma) < 6.2\times10^{-4}$
- Predictions vary: $B(\Upsilon(2,3S) \rightarrow \eta_b(1S)\,\gamma) \sim 10^{-6} \sim 10^{-3}$

  See S. Godfrey and J. L. Rosner PRD64,074011(2001).

$\Upsilon(nS) \rightarrow \eta_b(mS)\,\gamma$

- **Sensitivity to inclusive $\Upsilon(1S) \rightarrow \eta_b(1S)\,\gamma$ limited due to the large background in E_γ<100MeV region.**
- **At CLEO, we are currently investigating BOTH allowed and forbidden M1 transistions exclusively.**

Which η_b decay modes should we exclusively look for?

$\Upsilon(nS) \rightarrow \eta_b(mS)\,\gamma$

- The η_c-like modes found in PDG?
  There are SOME more η_c-like modes NOT found in PDG (see the next slide).
- $M(\eta_b) > \sim 3 \times M(\eta_c)$
  ==> η_b should have higher average multiplicities.
- We also see significant χ_{cJ} peaks produced via
  $\psi(2S) \rightarrow \chi_c(1P_J)\,\gamma$ for these exclusive modes.

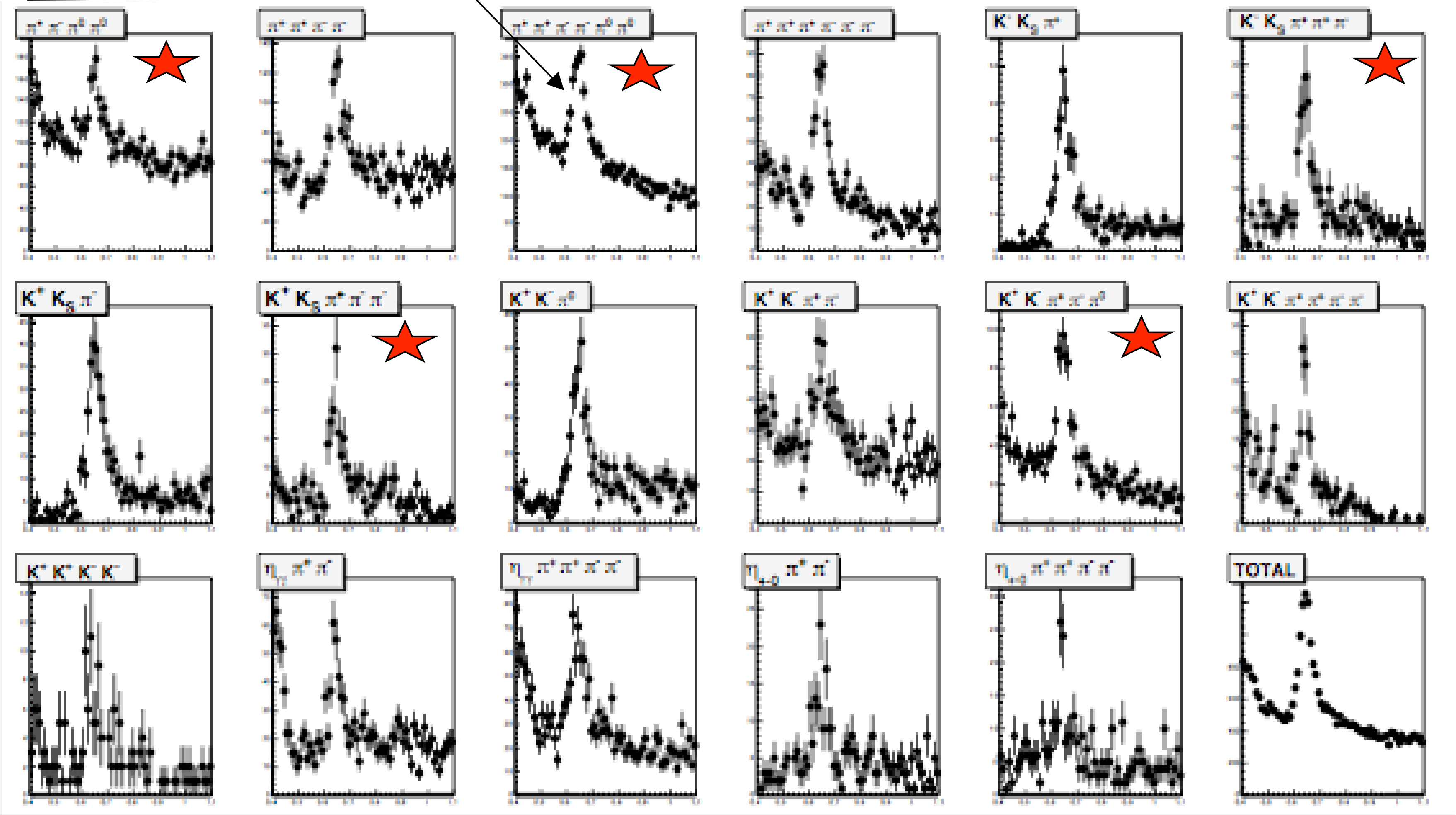
How about $\chi_b(1,2P_J)$-like modes?

$\psi(2S) \rightarrow \eta_c(1S)\,\gamma$

Preliminary

The largest yields!!??

See Ryan Mitchell's QWG07 talk for more detail



E_γ in GeV from $\psi(2S) \rightarrow \eta_c(1S)\,\gamma$

★ ≡ NOT listed in PDG

$\Upsilon(nS) \to \eta_b(mS)\,\gamma$

Currently trying to conduct the following 3 tests

- **Test 1:**
  - **We know $B(\Upsilon(2S) \to \gamma\,\eta_b(1S)) < 0.00051$ (0.00043 for $\Upsilon(3S)$ decays).**
  - **Assuming $B(\Upsilon(2S) \to \gamma\,\chi_{bJ}) = 6\%$ for each J**
    (3.8, 6.9, 7.15% for J=0,1,2)
    and assuming efficiencies and branching ratios of events from

    $$\Upsilon(2S) \to \gamma\,\chi_{bJ},\ \chi_{bJ} \to X$$

    are the same as the ones from

    $$\Upsilon(2S) \to \gamma\,\eta_b,\ \eta_b \to X$$

    for the same exclusive modes, X,
    then we should see one η_b event while seeing ~100 χ_{bJ} events
    (for each J).

Can we see *significant* $\chi_b(nP_J)$ signals exclusively?
(which, itself, is interesting…)
Then, choose modes based on $\chi_b(1,2P_J)$ signals.

$\Upsilon(nS) \rightarrow \eta_b(mS)\ \gamma$

- **Test 2:**
  - **We have measured a hindered E1 transition; $B(\Upsilon(3S) \rightarrow \chi_b(1P_0)\ \gamma) = (3.0\pm0.4\pm1.0)\times10^{-3}$ (PRL94,032001(2005)).**
  - **What we are looking for is $\sim10^{-4}$ at most.**
  - **Better be able to see the transition $\Upsilon(3S) \rightarrow \chi_b(1P_J)\ \gamma$, $\chi_b(1P_J) \rightarrow$ exclusives. (which, itself, is interesting … Recall the overlapped photon peaks shown earlier).**

$\Upsilon(nS) \rightarrow \eta_b(mS)\,\gamma$

- **Test 3: Consistency check ("IF" we pass Test 1 and 2)**
  - **Do we see an enhancement around invariant mass of 9400±50MeV?**
  - **Do we see similar enhancements in all of the $\Upsilon(1,2,3S)$ data with the same mass (in $\Upsilon(1S)$, there could be an additional experimental challenge to detect ~60MeV-photon)?**
  - **Do we see a similar enhancement with the same mass with the following chains:**
    - **$\Upsilon(3S) \rightarrow \pi^0 h_b$, $h_b \rightarrow \eta_b\gamma$, $\eta_b \rightarrow$ exclusives**
    - **$\Upsilon(3S) \rightarrow \pi^+\pi^- h_b$, $h_b \rightarrow \eta_b\gamma$, $\eta_b \rightarrow$ exclusives**
    - **$\Upsilon(3S) \rightarrow \chi_b(2P_0)\,\gamma$, $\chi_b(2P_0) \rightarrow \eta_b\,\eta$, $\eta_b \rightarrow$ exclusives M.B.Voloshin M.P.L.A19,2895 (2004) predicts $B(\chi_b(2P_0) \rightarrow \eta_b\,\eta) \sim 10^{-3}$.**

Summary/Comments

- **Currently, we are working on:**
  - **$\Upsilon(nS) \rightarrow X\,\gamma, X \rightarrow$ exclusives, (n=1,2, and 3)**
    where $X=\eta_b(mS)$, $\chi_b(mP)$
  - **$\Upsilon(3S) \rightarrow \pi^0/\pi\pi\ h_b$, $h_b \rightarrow \eta_b\gamma$**
- **Potential excitements in the near future**
  - **BaBar plans to have ~30/fb data taken at $\Upsilon(3S)$ by March. Is the boosted frame an issue?**
  - **Belle already has 11M $\Upsilon(3S)$ decays.**
  - **If Super B factory could devote a few days (~1/ab???) to run on lower resonances, such data should allow us to do precision study on η_b properties.**