CLEO Results From Υ Decays

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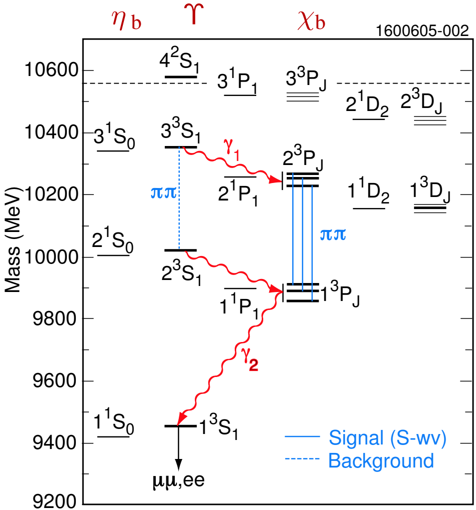
Hadron 05

Outline

Outline

The Bottomonium Spectrum



- Υ ($b\bar{b}$) states are part of the Bottomonium family
  $\Rightarrow$ QCD analogy of Positronium: $e^+e^- \Leftrightarrow b\bar{b}$
- For $n \geq 4$, the Υ's decay predominantly to B mesons
- For $n = 1, 2, 3$: the $b\bar{b}$ system annihilates and can produce hadrons or lepton pairs

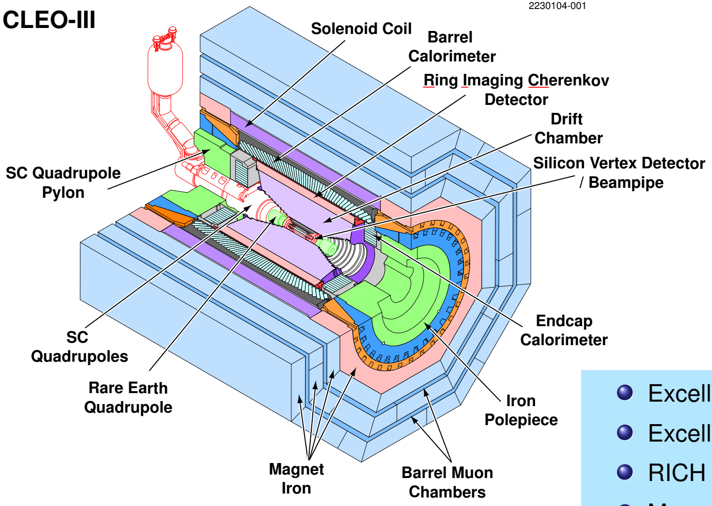
  Or cascades to other $n\,^{2S+1}L_J$ states mostly via γ or $\pi\pi$, but also $\chi_{bJ\,(J=1,2)} \to \Upsilon(1S)\,\omega$

The Υ System ($b\bar{b}$ with $J^{PC} = 1^{--}$)

CESR collides $e^+ e^-$ in order to produce $\Upsilon\,(nS)$ states

- b quark is heavy
  $\Rightarrow$ Non–relativistic QM
- Most Υ decays unaccounted for
  $\Rightarrow \Sigma\,\mathcal{BR}(\Upsilon(1S)) < 10\,\%$ in PDG

Outline



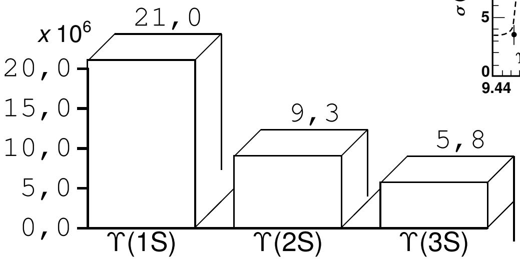
- Excellent Calorimeter
- Excellent Tracking
- RICH and dE/dx for PID
- Muon Chambers

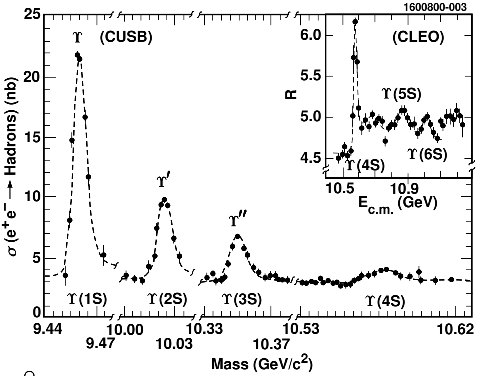
+ A Great Accelerator Team

Outline

CLEO Υ Datasets

- CLEO III has largest world sample of clean Υ events below the $B\bar{B}$ threshold
- Off–resonance and scan data
- CLEO has also collected 0.42 fb^{-1} at the Υ(5S)

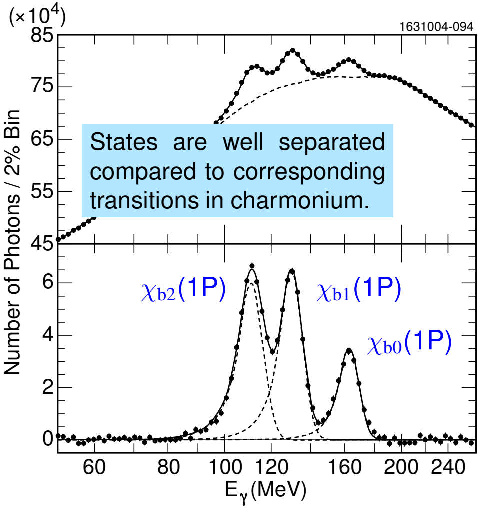




Outline

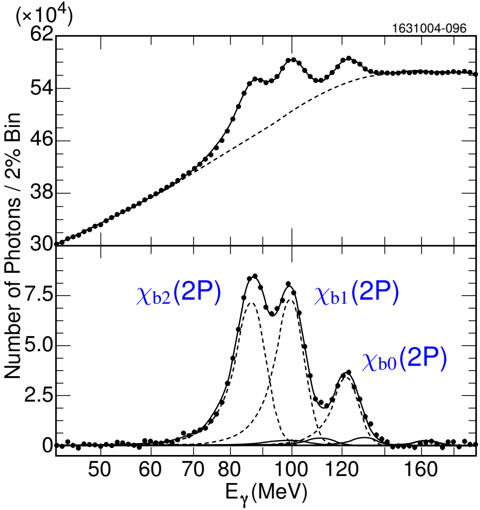
1. Introduction
   - The Υ System
   - CLEO III Detector
   - CLEO III Υ Data Samples
2. Radiative Υ Decays
   - Photon Transitions in $\Upsilon(2S)$ and $\Upsilon(3S)$ Decays
   - $\Upsilon(1S) \to h^+h^- + \gamma$
   - Direct Photons in Υ Decays and $R_\gamma = \frac{N_{gg\gamma}}{N_{ggg}}$
3. Observation of $\chi_{bJ}(2P) \to \chi_{bJ}(1P)\,\pi^+\pi^-$
4. Summary and Outlook

$\Upsilon(2S) \to \gamma\, \chi_{bJ}\,(1P)\ (J = 2, 1, 0)$



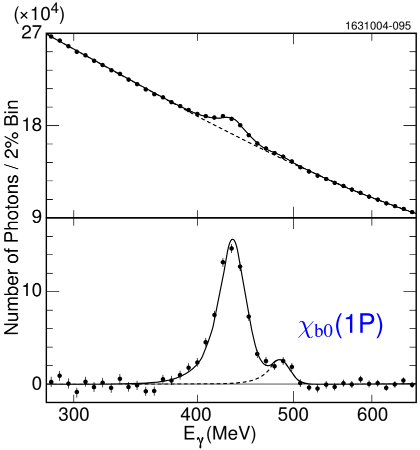
- Statistical errors
  $\Rightarrow$ smaller than point size
- Solid line: total fit
  - Photon lines represented by Gaussian + low–energy tail
- Dashed line: background
  - Photon spectrum observed in off–resonance data ...
  - ... and in $\Upsilon(1S)$ data
  - Slowly varying background component
    $\Rightarrow$ accounts for deviations in decays of χ_b

$\Upsilon(3S) \to \gamma\, \chi_{bJ}(2P)\ (J = 2, 1, 0)$



- Bottom plot:
  background subtracted data
- Three photon lines
- Additional Peaks:
  - $\Upsilon(2S) \to \gamma\, \chi_{bJ}(1P)$
  - $\chi_{bJ}(2P) \to \gamma\, \Upsilon(1D)$

$\Upsilon(3S) \to \gamma\,\chi_{bJ}(1P)$ and $\chi_{bJ}(1P) \to \gamma\,\Upsilon(1S)$ $(J = 2, 1, 0)$



- Six photon lines
  $\Rightarrow$ large overlap
- One line is different and its amplitude can be measured
  $\Rightarrow$ $\Upsilon(3S) \to \gamma\chi_{b0}(1P)$

Rate determined for the first time

$\mathcal{B}(\Upsilon(3S) \to \gamma\,\chi_{b0}(1P))$ =
$(0.30 \pm 0.04 \pm 0.10)\,\%$

Further Results (PRL **94**, 032001 (2005))

$\Upsilon(2S) \to$ final state	$\chi_{b0}(1P)$	$\chi_{b1}(1P)$	$\chi_{b2}(1P)$
# of γ's (10^3)	198 ± 6	407 ± 7	410 ± 6
$\mathcal{B}$ (%)	$3.75 \pm 0.12 \pm 0.47$	$6.93 \pm 0.12 \pm 0.41$	$7.24 \pm 0.11 \pm 0.40$
E_γ (MeV)	$162.56 \pm 0.19 \pm 0.42$	$129.58 \pm 0.09 \pm 0.29$	$110.58 \pm 0.08 \pm 0.30$

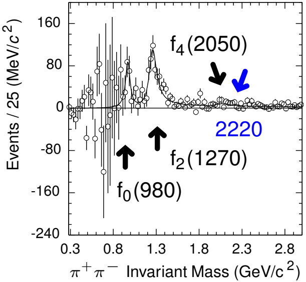
$\Upsilon(3S) \to$ final state	$\chi_{b0}(2P)$	$\chi_{b1}(2P)$	$\chi_{b2}(2P)$
# of γ's (10^3)	225 ± 7	537 ± 7	568 ± 6
$\mathcal{B}$ (%)	$6.77 \pm 0.20 \pm 0.65$	$14.54 \pm 0.18 \pm 0.73$	$15.79 \pm 0.17 \pm 0.73$
E_γ (MeV)	$121.55 \pm 0.16 \pm 0.46$	$99.15 \pm 0.07 \pm 0.25$	$86.04 \pm 0.06 \pm 0.27$

- E_γ's in transitions to $\chi_{bJ}(1P)$ and $\chi_{bJ}(2P)$ in good agreement with previous measurements $\Rightarrow$ Most precise determinations
- Branching ratios for $\Upsilon(2S) \to \gamma\,\chi_{bJ}(1P)$ also in good agreement with previous measurements $\Rightarrow$ Improved experimental errors
- $\mathcal{B}$'s for $\Upsilon(3S) \to \gamma\,\chi_{bJ}(2P)$ significantly larger than CUSB II

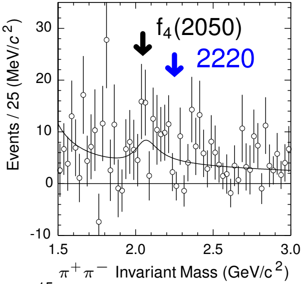
Outline

$\Upsilon(1S) \rightarrow h^+h^- + \gamma$

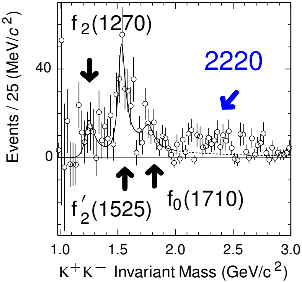
- Radiative decays of heavy quarkonia useful in studying color–singlet two–gluon systems
  $\Rightarrow$ For example, two gluons can hadronize into a meson or directly form a glueball
- Many interesting results from radiative J/ψ decays
  - Tensor states $f_2(1270)$ and $f_2'(1525)$ observed
  - In 1996, glueball candidate $f_J(2220)$ observed by BES
  - Enhancement observed at $p\bar{p}$ threshold $\rightarrow$ X(1860) (BES)
    $\Rightarrow$ Threshold effect or $p\bar{p}$ bound state ? (under investigation)
- Experimental observation of radiative $\Upsilon(1S)$ decays challenging
  $\Rightarrow$ Rates suppressed by a factor $(\frac{q_b}{q_c})^2(\frac{m_c}{m_b})^2 \approx 0.025$



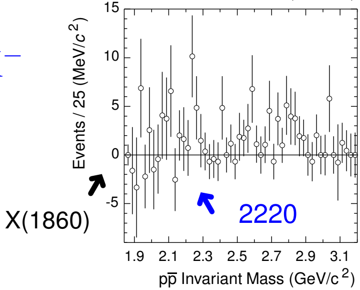
$\pi^+\pi^-$



$\pi^+\pi^-$



K^+K^-



$p\bar{p}$

$\Upsilon(1S) \to h^+h^- + \gamma$: Results

- Fit decay angles
  $\Rightarrow$ Decay helicities for $f_2(1270)$ and $f'_2(1525)$ predominantly 0
- Fit mass to spin dependent relativistic Breit Wigner (LP2005–446)
  - $\mathcal{B}(\Upsilon(1S) \to \gamma\, f_2(1270)) = (10.2 \pm 0.8 \pm 0.7) \cdot 10^{-5}$
  - $\mathcal{B}(\Upsilon(1S) \to \gamma\, f'_2(1525)) = (3.7^{+0.9}_{-0.7} \pm 0.8) \cdot 10^{-5}$
  - $\mathcal{B}(\Upsilon(1S) \to \gamma\, K^+K^-) = (1.14 \pm 0.08 \pm 0.10) \cdot 10^{-5}$
    (2 GeV < M_{KK} < 3 GeV)
  - $\mathcal{B}(\Upsilon(1S) \to \gamma\, f_0(980) \to \gamma\, \pi^+\pi^-) < 3 \cdot 10^{-5}$
  - $\mathcal{B}(\Upsilon(1S) \to \gamma\, f_4(2050) \to \gamma\, \pi^+\pi^-) < 0.6 \cdot 10^{-5}$
  - $\mathcal{B}(\Upsilon(1S) \to \gamma\, f_0(1710) \to \gamma\, K^+K^-) < 0.7 \cdot 10^{-5}$
  - $\mathcal{B}(\Upsilon(1S) \to \gamma\, p\bar{p}) < 0.6 \cdot 10^{-5}$ (2 GeV < $M_{p\bar{p}}$ < 3 GeV)
- Limits on $f_J(2220)$ and $X(1860) < 10^{-6}$

Preliminary

Outline

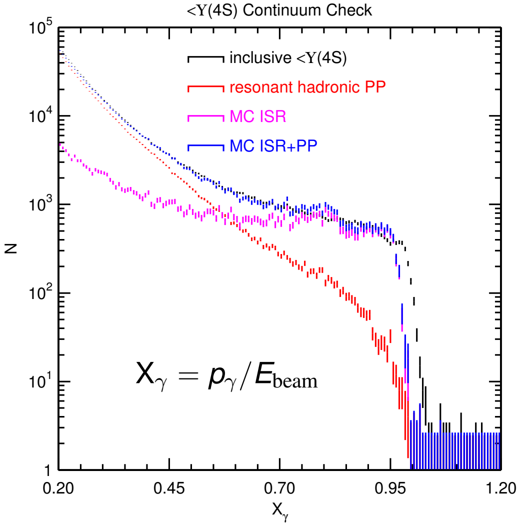
Direct Photons in Υ Decays: Motivation

- Preferred decay mode for an Υ meson is through the production of a $B\overline{B}$ meson pair (Zweig rule)
  $\Rightarrow$ Energetically impossible for resonances below $\Upsilon(4S)$
- Therefore, below B meson threshold, Υ decays can occur via:
  - Three–gluon decay (ggg)
  - Single photon QED decay $\Upsilon \to \gamma^* \to q\bar{q}$
  - Two–gluon + single photon (ggγ) mode
  - Cascades (e.g. two–pion transitions to other Υ states)
- Since $\Gamma_{ggg} \propto \alpha^3_{QCD}$ and $\Gamma_{gg\gamma} \propto \alpha^2_{QCD}\,\alpha_{em}$

$$\boxed{R_\gamma} = \frac{\Gamma_{gg\gamma}}{\Gamma_{ggg}} = \frac{N_{gg\gamma}}{N_{ggg}} = f\,(q_b, \alpha_{em}, \alpha_{QCD})$$

Experimentally determined $\Rightarrow$ Results

Background and Procedure



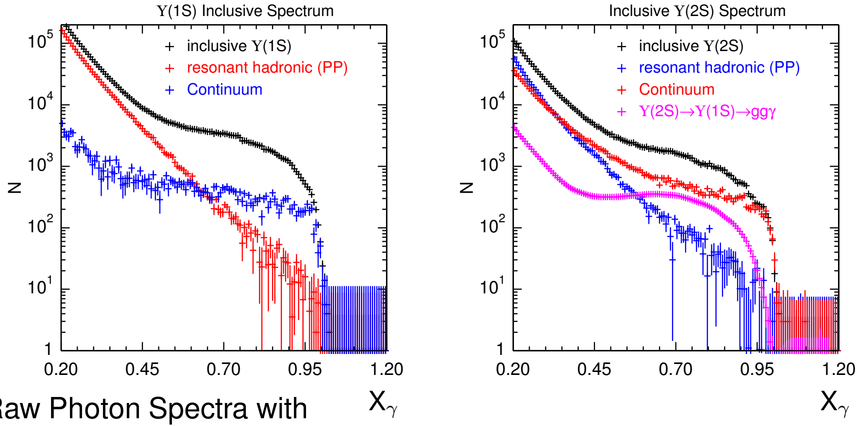
Idea: search for hadronic events with a nice isolated photon

Sources of Background

- ISR (high X_γ)
- π^0 Decays (low X_γ)

$\Leftarrow$ Photon spectrum using below–Υ(4S) data

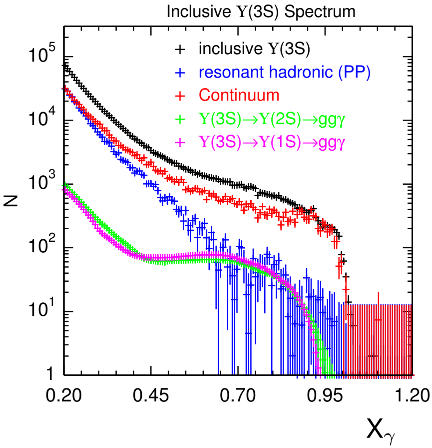
Direct Photons in Υ Decays: Raw Photon Spectra



Raw Photon Spectra with

- Off-resonance data (continuum contribution)
- MC resonant non–direct pseudo–photons

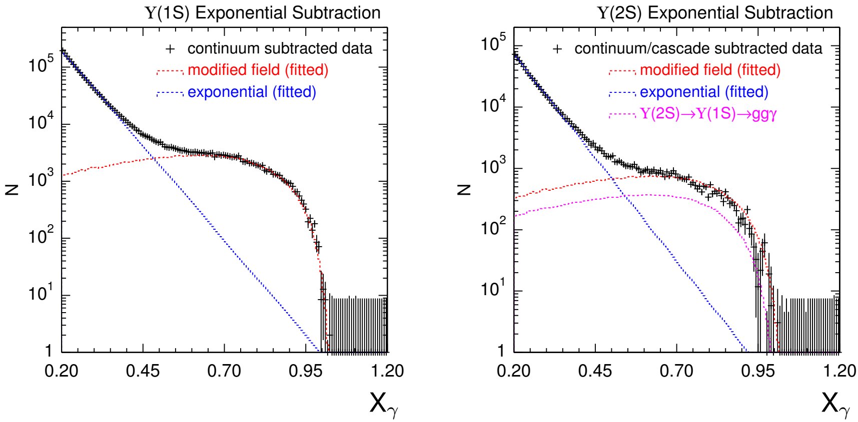
Direct Photons in Υ Decays: Raw Photon Spectra



Raw Photon Spectra with

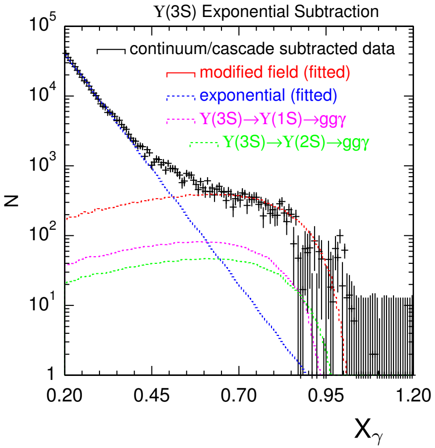
- Off-resonance data (continuum contribution)
- Resonant non–direct pseudo–photons from hadron decays
- Cascade contribution from Υ(2S) decays
- Cascade contribution from Υ(2S) decays

Direct Photons in Υ Decays: Yield Determination



- Subtraction of backgrounds using an exponential
- Direct spectrum fit using model (Field)

Direct Photons in Υ Decays: Raw Photon Spectra



- Subtraction of backgrounds using an exponential
  - $\Rightarrow$ floating normalization to estimate non–direct photon spectrum
- Direct spectrum fit using model (Field)

Direct Photons in Υ Decays: Results

Determination of $R_\gamma = \frac{\Gamma_{gg\gamma}}{\Gamma_{ggg}} = \frac{N_{gg\gamma}}{N_{ggg}} = f(q_b, \alpha_{em}, \alpha_{QCD})$

(N_{ggg} not mentioned $\Rightarrow$ determined from N_Υ, PDG, and MC)

$$R_\gamma(1S) = (2.90 \pm 0.007 \pm 0.22 \pm 0.15)\,\%$$
$$R_\gamma(2S) = (3.49 \pm 0.030 \pm 0.58 \pm 0.18)\,\%$$
$$R_\gamma(3S) = (2.88 \pm 0.030 \pm 0.38 \pm 0.12)\,\%$$

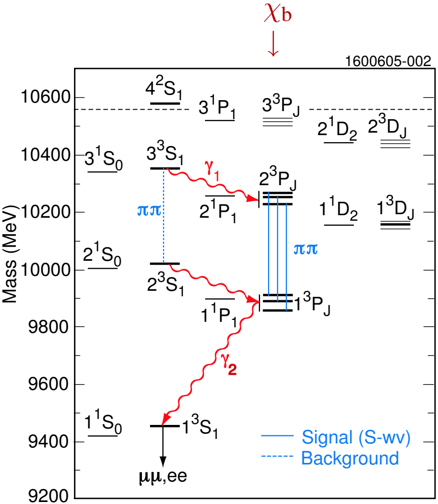
Preliminary

Errors are statistical, systematic, and model (Field vs. Garcia/Soto)

R.D. Field,
Phys. Lett. **B133**, 248 (1983)
X. Garcia, J. Soto,
Phys. Rev. **D69**, 114006 (2004)

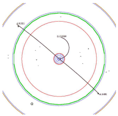
- R_γ(1S) consistent with previous value
  $\Rightarrow$ similar systematic, but smaller statistical error
- First measurements of R_γ(2S) and R_γ(3S)

$\chi_b(2P) \to \chi_b(1P)\,\pi^+\pi^-$

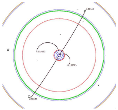


Dominant Background Reactions

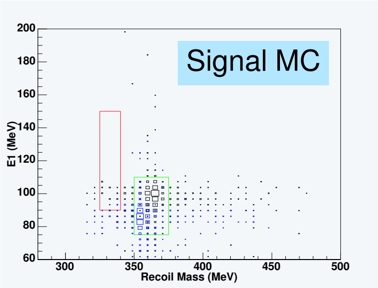
- $\Upsilon(3S) \to \Upsilon(2S)\,\pi^+\pi^-$
  $\Upsilon(2S) \to \chi_b\,\gamma$
  $\chi_b \to \Upsilon(1S)\,\gamma$
- $\Upsilon(3S) \to \chi_b(2P)\,\gamma$
  $\chi_b(2P) \to \Upsilon(1S)\,\omega$
  $\omega \to \pi^+\pi^-\pi^0$
- $\Upsilon(3S) \to \Upsilon(2S)\,\pi^+\pi^-$
  $\Upsilon(2S) \to \Upsilon(1S)\,\pi^0\pi^0$

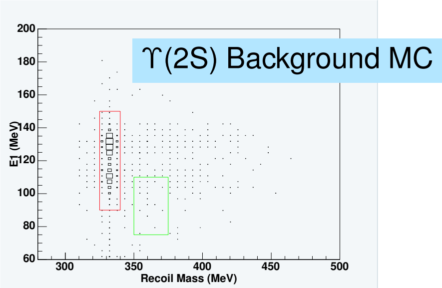


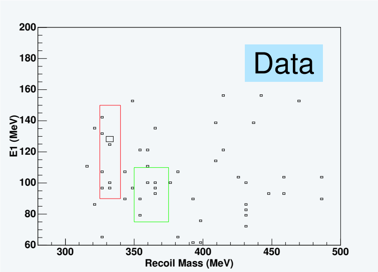
Single-Pion



Di-Pion







Numerous Monte Carlo simulations

- to evaluate selection criteria
- to predict eventual background

$\Leftarrow$ Example: 2π Analysis

$\chi_b(2P) \to \chi_b(1P)\,\pi^+\pi^-$: Results

Results from two analyses using events with both and only one soft pion, respectively:

- 2π Analysis: 7 events seen, expected background 0.6 ± 0.2
- 1π Analysis: 17 events seen, expected background 2.2 ± 0.6

$$\Gamma(\chi_b(2P) \to \chi_b(1P)\,\pi^+\pi^-) = (0.80 \pm 0.21^{+0.23}_{-0.17})\ \text{keV}$$

Preliminary

First observation of a $\pi\pi$ transition outside of $^3S_1$ system

Work on $\chi_b(2P) \to \chi_b(1P)\,\pi^0\pi^0$ in progress

Summary

Many interesting results from Υ physics

- $\Upsilon(1S) \to h^+h^- + \gamma$
- Photon Transitions in $\Upsilon(2S)$ and $\Upsilon(3S)$ Decays
- Direct Photons in Υ Decays and $R_\gamma = \frac{N_{gg\gamma}}{N_{ggg}}$
- Observation of $\chi_{bJ}(2P) \to \chi_{bJ}(1P)\,\pi^+\pi^-$

Many more CLEO results still in the pipeline ...