CLEO Results From Υ Decays

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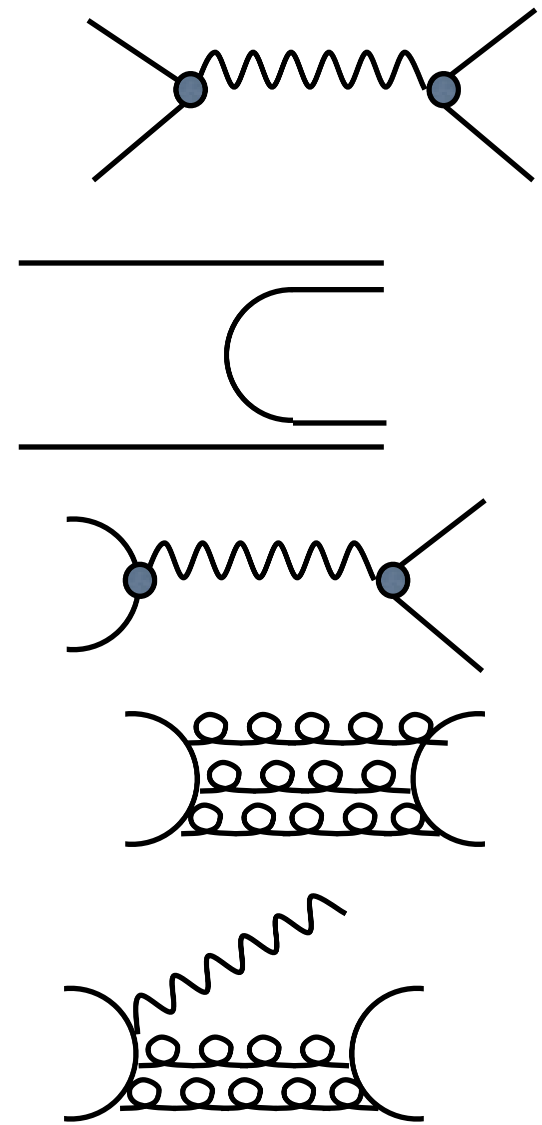
EPS2005

CLEO Υ and χ_b Results: Outline

- The Υ system
- CLEO Detector
- CLEO Data Sample
- B_s Production at the $\Upsilon(5S)$
- $\Upsilon \rightarrow \tau\tau$, ee
- Direct Photons in Υ Decay
- $\Upsilon(1S) \rightarrow h^+h^-\gamma$
- $\chi_b' \rightarrow \chi_b$ Transition

The Υ System

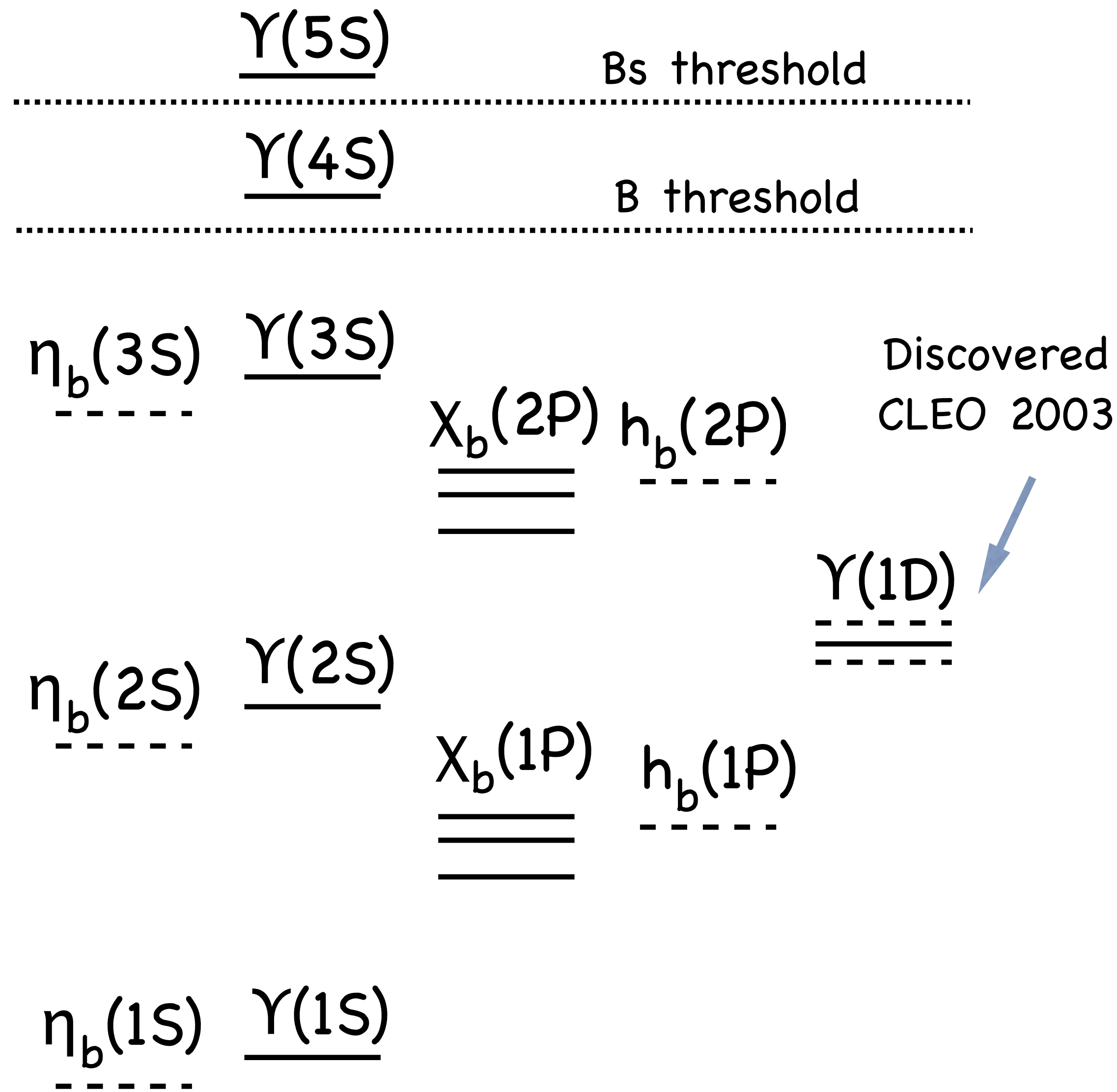
- The Υ is a bound state of $b\bar{b}$
- CESR collides e+e- to produce Υ(nS) states
- For n>= 4, the Υ decay to B mesons and b-baryons
- For n=1,2,3 - below B threshold - $b\bar{b}$ annihilate - can produce hadrons or lepton pairs
- Also cascades to other $n^{(2s+1)}L_J$ states mostly via γ or π π emission



The Υ System Part Two

The Υ are part of the bottom-onium family QCD analog of positronium

b quark is heavy → Non relativistic QM



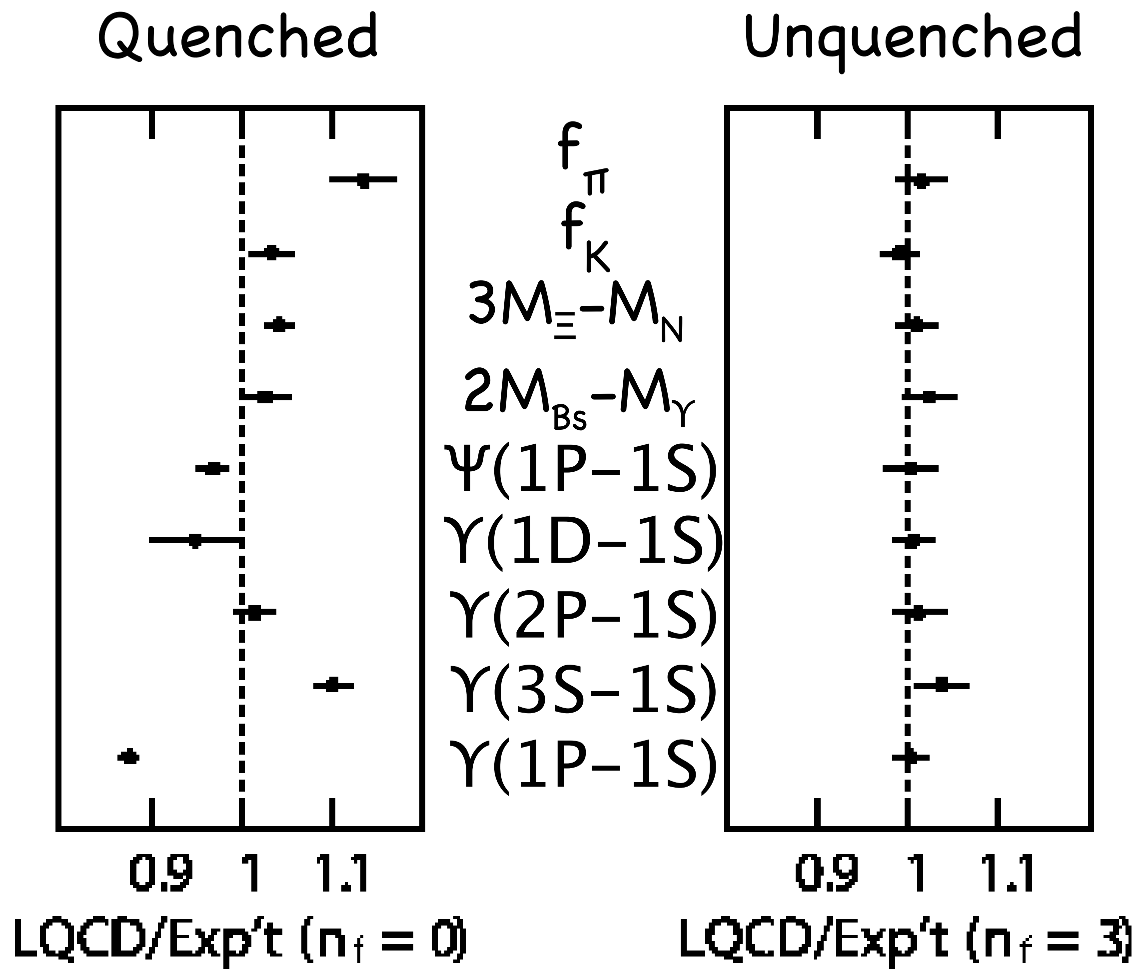
Are Upsilons Interesting?

Most Upsilon decays unaccounted for: $\Sigma BR(\Upsilon(1s))$ < 10% in PDG

Another place to study the b quark

Non perturbative QCD laboratory

if LQCD right here it might be right elsewhere



hep-lat/0304004

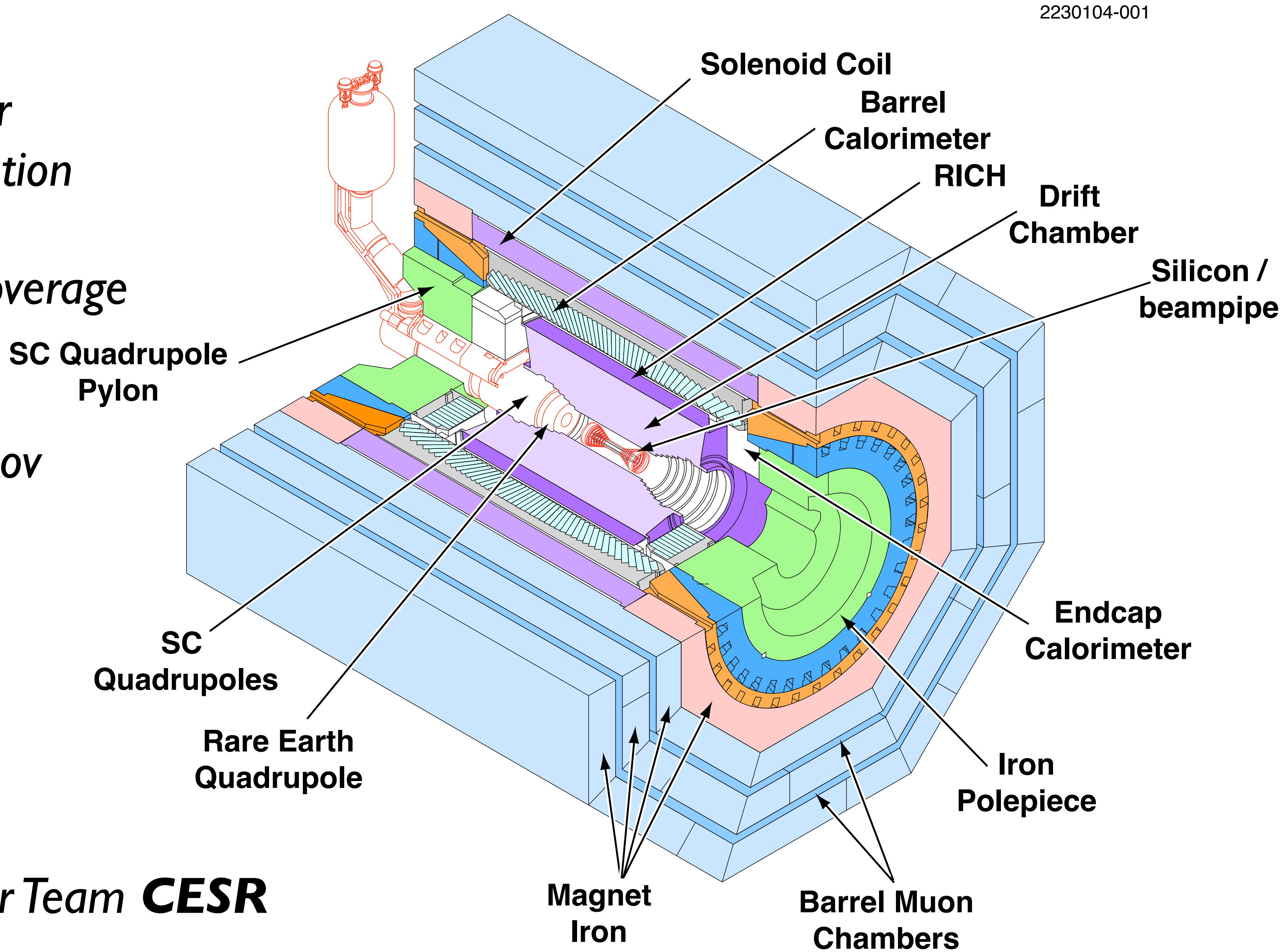
The CLEO III Detector

Excellent Calorimeter Coverage and Resolution

Excellent Tracking Coverage and Resolution

Ring Imaging Cerenkov and dE/dx for PID

Muon Chambers



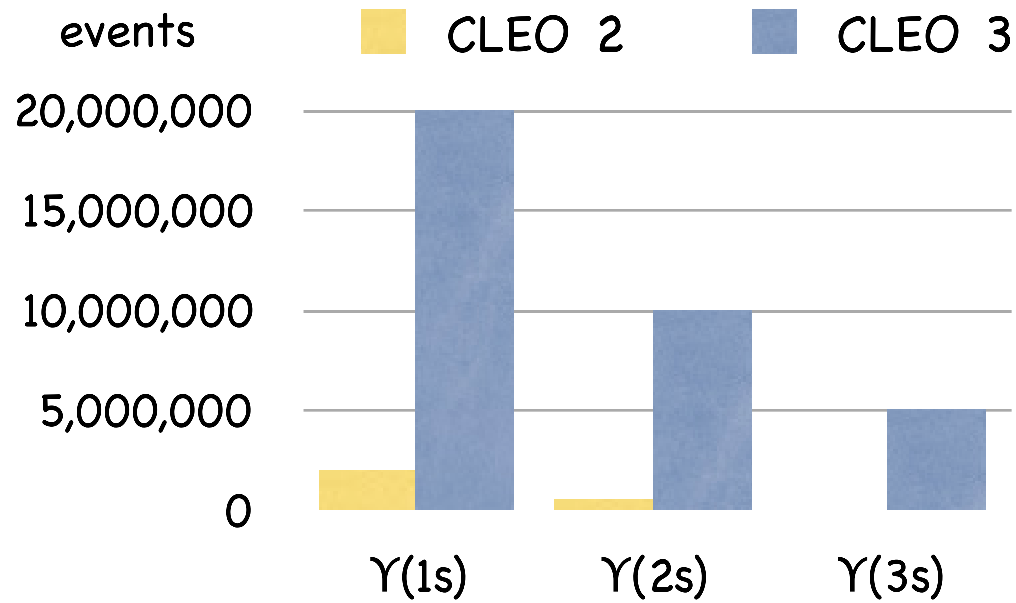
+ *A Great Accelerator Team* ***CESR***

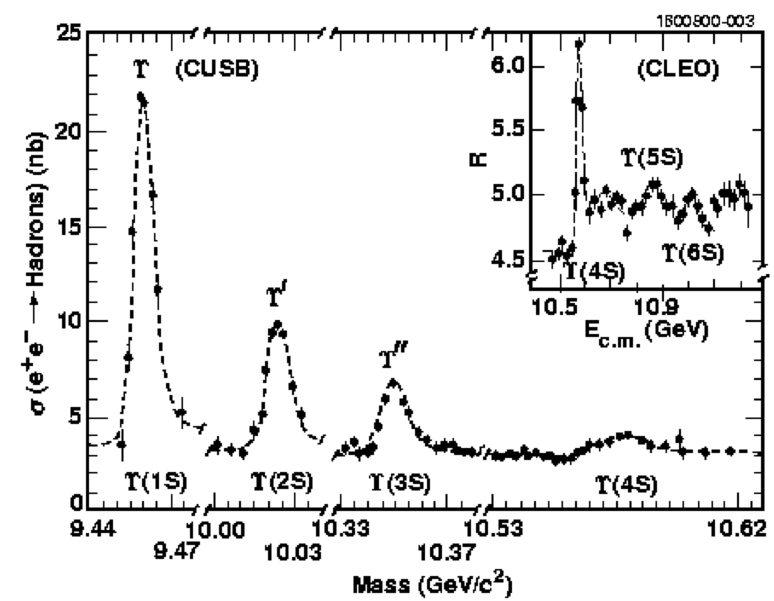
CLEO Upsilon Datasets

CLEOIII has the largest world sample of clean Υ events below b threshold

Also has off resonance and scan data

CLEO has also collected 0.42 fb^{-1} at the $\Upsilon(5S)$

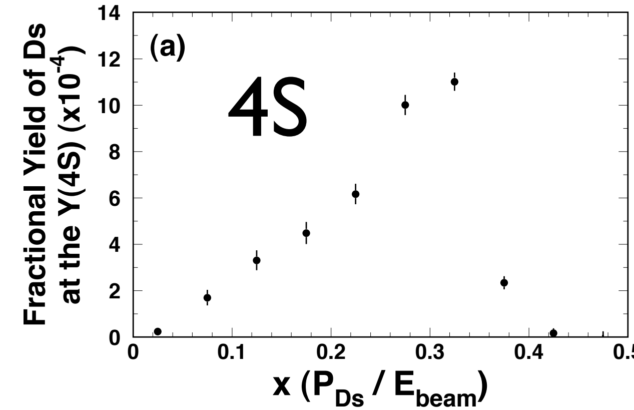


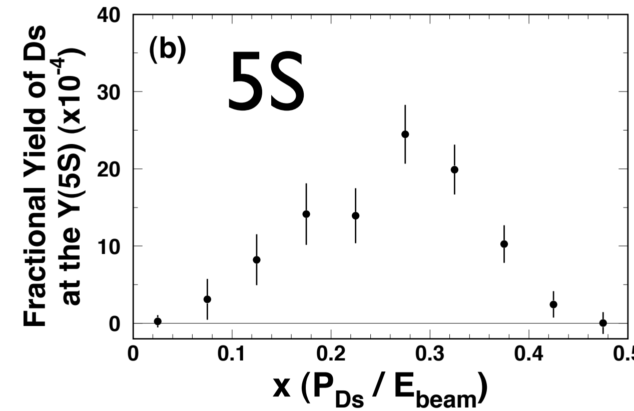


B_s Production at $\Upsilon(5S)$

Bs Production at the $\Upsilon(5S)$

- The 5S should produce $B_s\bar{B}_s$, $B_s\bar{B}_s^*$, $B_s^*\bar{B}_s^*$ - interesting place to run for strange B Factories
- But - no Bs yet observed at the 5S
- Expect $B(B_s \to D_s X) = 92 \pm 11\%$ and $B(B \to D_s X) = 10.5 \pm 2.6\%$
- CLEO measures $D_s \to \varphi\pi$ production vs momentum for Off 4s, On 4s, On 5s
- Excess at 5S is from $B_s^{(*)}\bar{B}_s^{(*)}$





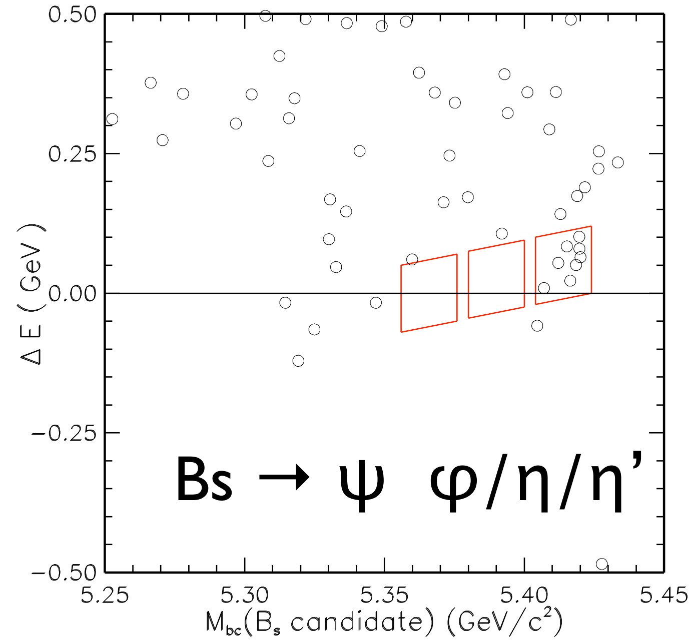
Preliminary

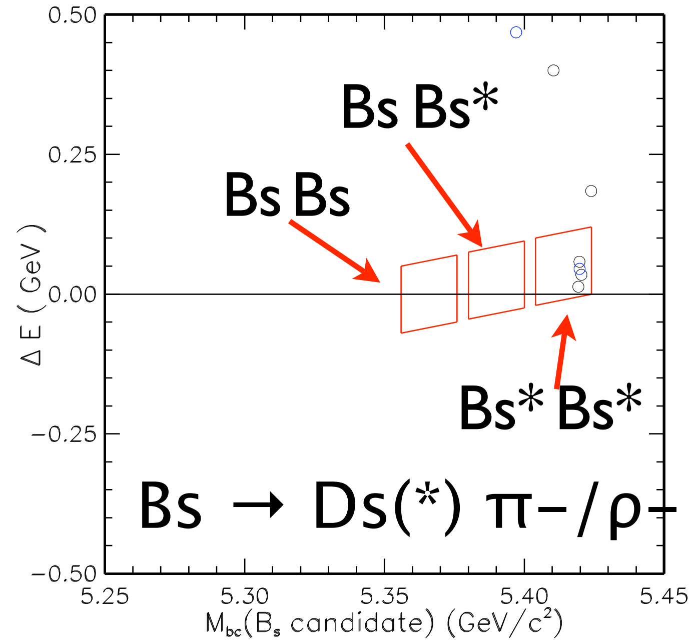
$$B(\Upsilon(5S) \to B_s^{(*)}\bar{B}_s^{(*)}) = 21 \pm 3 \pm 9\ \%$$

Bs Production at the Υ(5S) Exclusive Search

- Search for Bs → ψ φ/η/η' and Bs → $Ds^{(*)}$ π^-/ρ^-
- Clear dominance of $Bs^*\overline{B}s^*$ (expected)

Results forthcoming





Υ Decays to 2 Leptons

Υ Decays to 2 Leptons

- $\Upsilon \rightarrow l^+ l^-$ interesting as a probe of the bbγ vertex
- Universality of (e,e), (,), (τ,τ) final states (N.B.: Phase space effects tiny)
- Probe of possible new physics (eg: Sanchis-Lozano hep-ph0503266)
- Test Bed for Lattice QCD (See talk by C. Davies on 7/26)

Υ Decays to 2 Leptons

This Morning's Status

PDG2005	1S	2S	3S
B(ee)	2.38±0.11%	1.92±0.17%	seen
B( )	2.48±0.05%	1.93±0.17%	2.18±0.21%
B(ττ)	2.67±0.15%	1.7±1.6%	?

B(ee) driven by older experiments - CBAL, ARGUS, CLEO

B( ) driven by CLEO 05 : PRL 94:012001,2005

B(ττ) driven by old CLEO results

New Analysis of $\Upsilon \to \tau\tau$

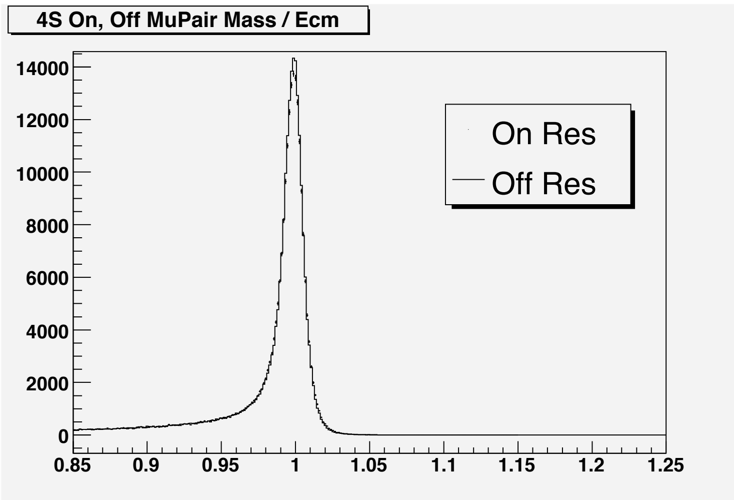
New Analysis of $\Upsilon \rightarrow \tau\tau$

- Follow the $\Upsilon \rightarrow$ technique:
  - Identify ($\tau\tau$) + ( ) On & Off Resonance - (use 1 Prong Tau decays = 75% of all τ decays)
  - Signal = On Resonance - S* Off Resonance

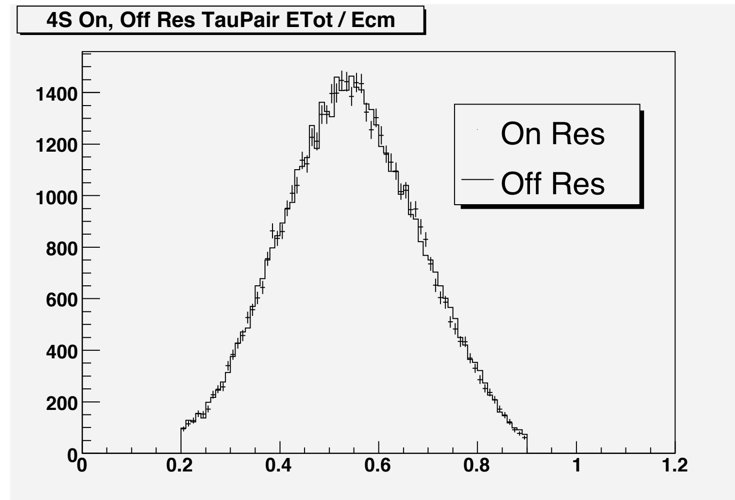
$$S = \frac{L_{On}}{L_{Off}} \left(\frac{E_{Off}}{E_{On}}\right)^2$$

  - Account for Interference Off Resonance
  - Cross Check $B(\Upsilon(4S) \rightarrow l^+ l^-) = 0$
  - Quote $B(\tau\tau)/B(\ \ )$

$\Upsilon \rightarrow \tau\tau$

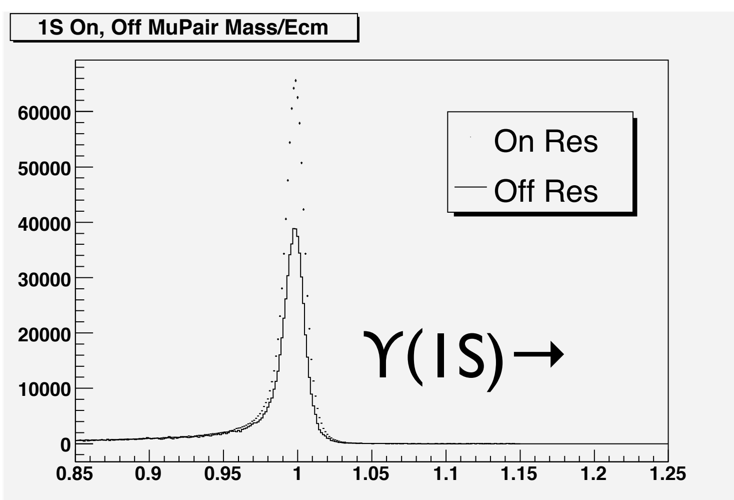


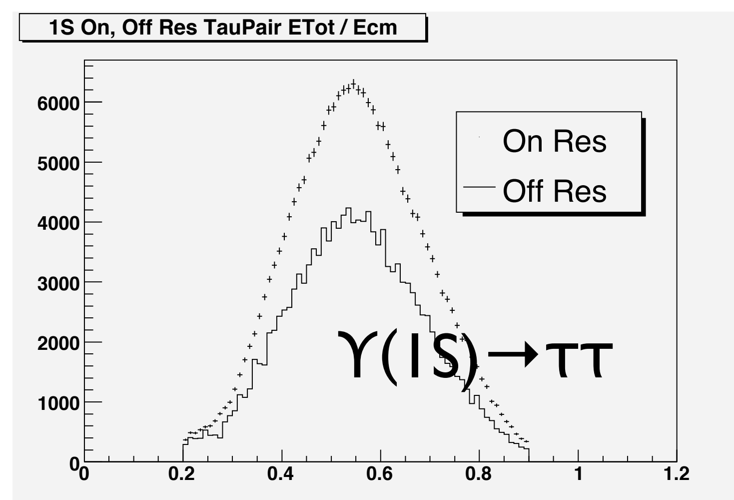
$B(\Upsilon(4S) \rightarrow \quad)=0$



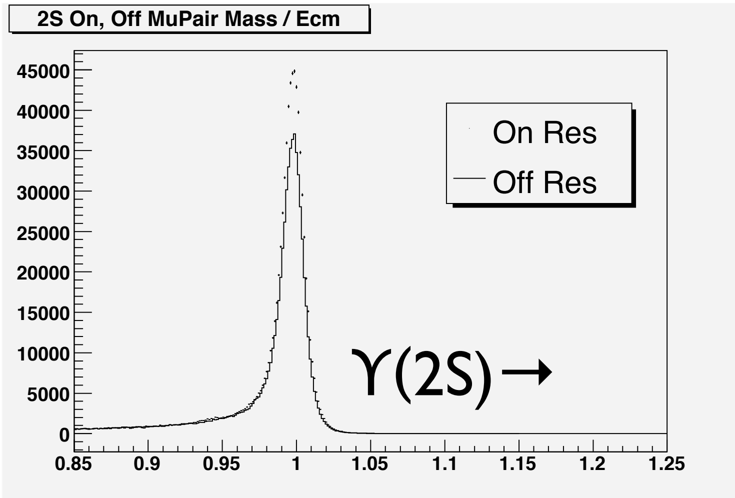
$B(\Upsilon(4S) \rightarrow \tau\tau)=0$

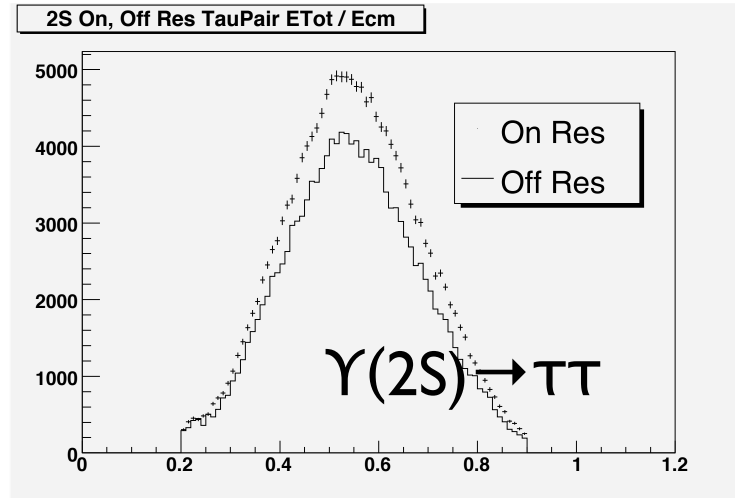
log(s) bgd small!

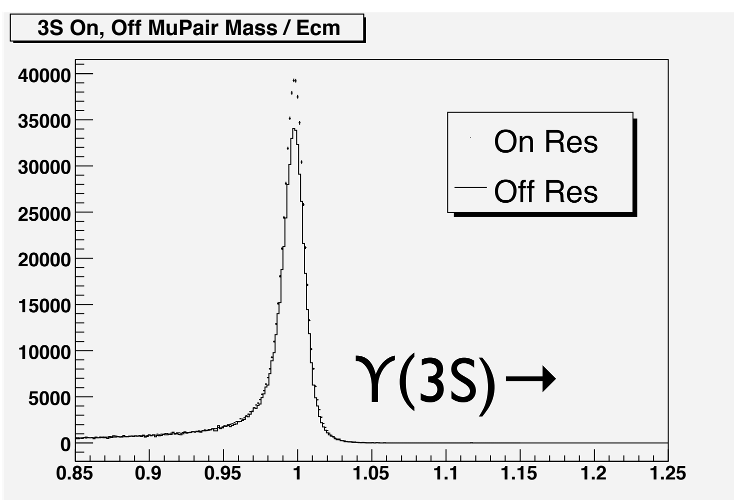




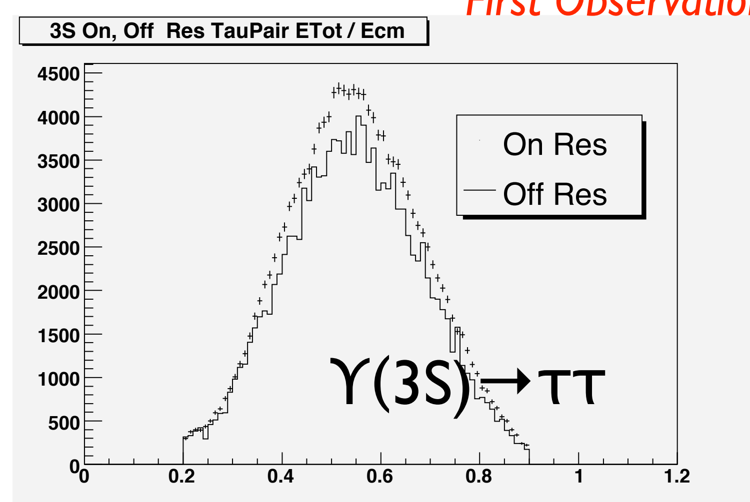
$\Upsilon \rightarrow \tau\tau$







First Observation



$\Upsilon \to \tau\tau$

Raw Yields	1S	2S	3S
	345020±1883	123185±1637	83545±2381
$\tau\tau$	28113±534	11082±473	7544±690

≈10 σ

- *Correct Raw Yields for Efficiency, Interference, Cascade Decays*

Preliminary

$$R = \frac{B(\Upsilon \to \tau\tau)}{B(\Upsilon \to \quad)}$$

$$R(1S) = 1.06 \pm 0.02 \pm 0.00 \pm 0.03$$

$$R(2S) = 1.00 \pm 0.03 \pm 0.12 \pm 0.03$$

$$R(3S) = 1.05 \pm 0.07 \pm 0.05 \pm 0.03$$

Errors are Stat, Cascade Feedthrough, Systematic

Cascade + Systematics will improve substantially in final result

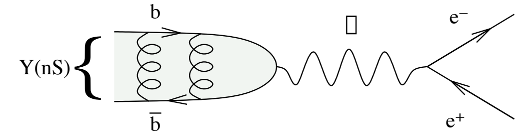
Central values will also move a little

Caveat for Higgs Search (Sanchis-Lozano hep-ph0503266):

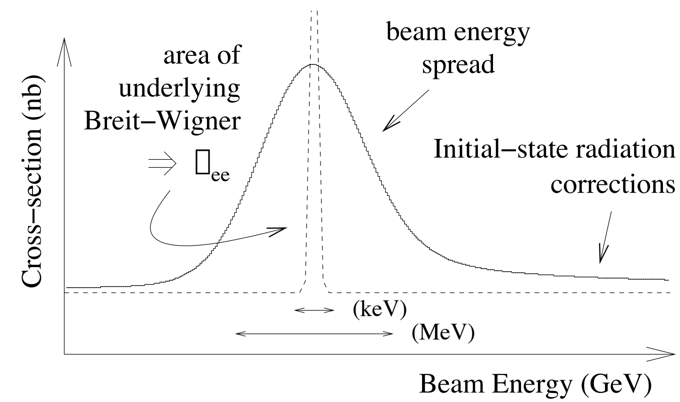
$$\epsilon(\tau\tau\gamma) \neq \epsilon(\tau\tau)$$

Investigation of $\Upsilon \rightarrow ee$

Investigation of Υ→ee

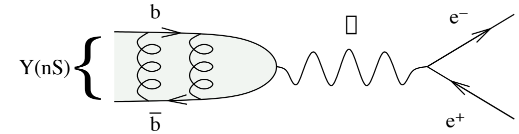


- Γ(Υ→ee) probes Wave Function (LQCD)
- Direct Measurement of B(ee) using On-S*Off is hindered by LARGE Bhabha Cross Section + is one step removed from Γ(Υ→ee)
- At CLEO - we can measure the Line Shape σ(ee→Υ→X) vs E_{cm}

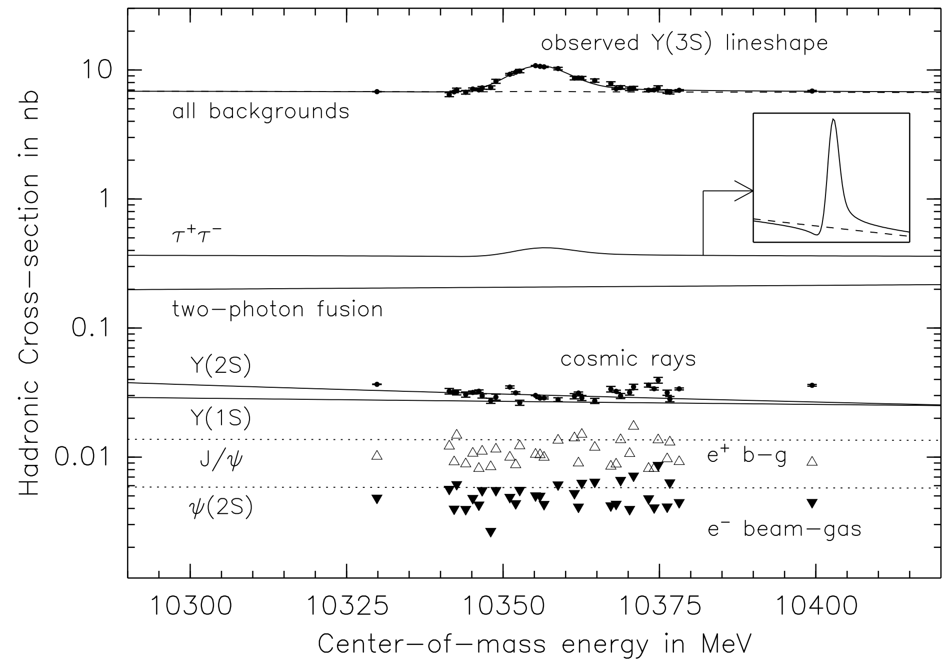


- Line Shape is a convolution of:
  - Υ Physics Γ(ee→Υ)≈keV
  - ISR - Kuriev+Fadin
  - Accelerator Beam Energy Spread ≈ 4 MeV

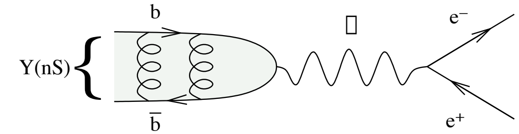
Investigation of ϒ→ee



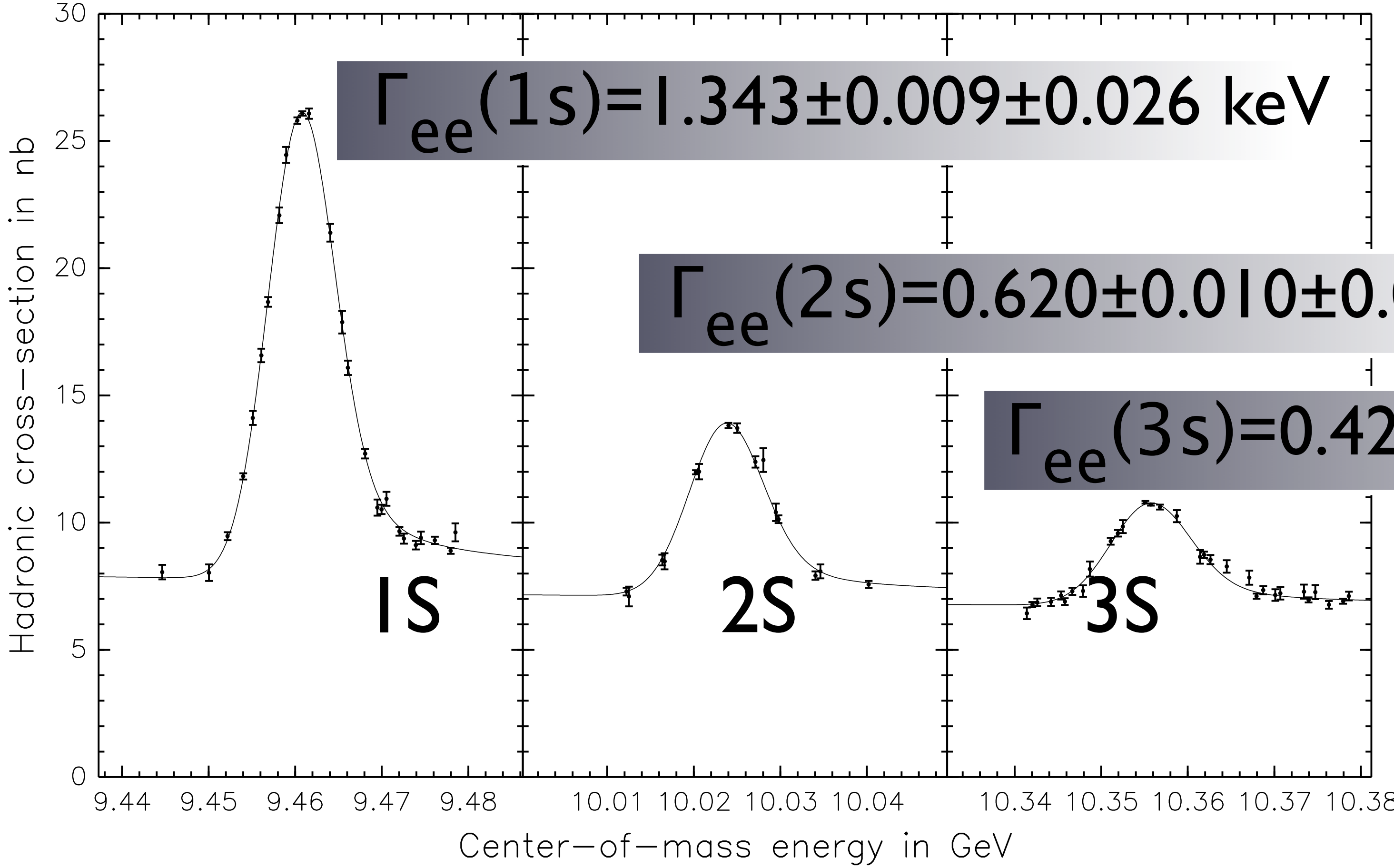
- Method:
  - Weekly Scans over Resonances - Revisit Large Derivative Points for Energy Calibration
  - Select "hadronic" events
  - Energy cut for 2γ backgrounds (log s)
  - Correct for τ, cosmics, beam gas
  - Check Efficiencies with Cascade Decays



Investigation of $\Upsilon \rightarrow ee$



- Fit Result to $\Gamma \otimes \sigma_{CESR} \otimes ISR$



$\Gamma_{ee}(1s)=1.343\pm0.009\pm0.026$ keV

$\Gamma_{ee}(2s)=0.620\pm0.010\pm0.012$ keV

$\Gamma_{ee}(3s)=0.427\pm0.009\pm0.009$ keV

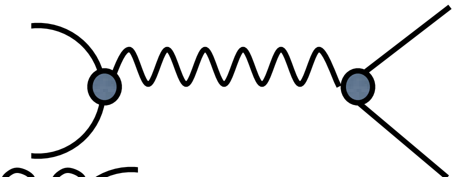
Preliminary

Dominant Syst = Lumi = 1.8%

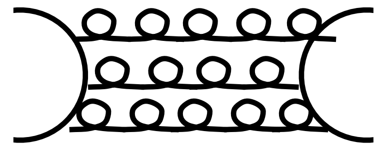
Direct Photons in Υ Decays

Direct Photons in Υ Decays

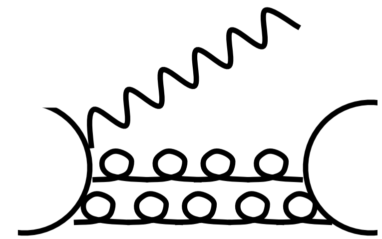
- Below B meson threshold, Υ decays can occur via:
  - virtual photon (γ*)



  - 3 gluons (ggg)



  - 2 gluons + 1 direct photon (ggγ)

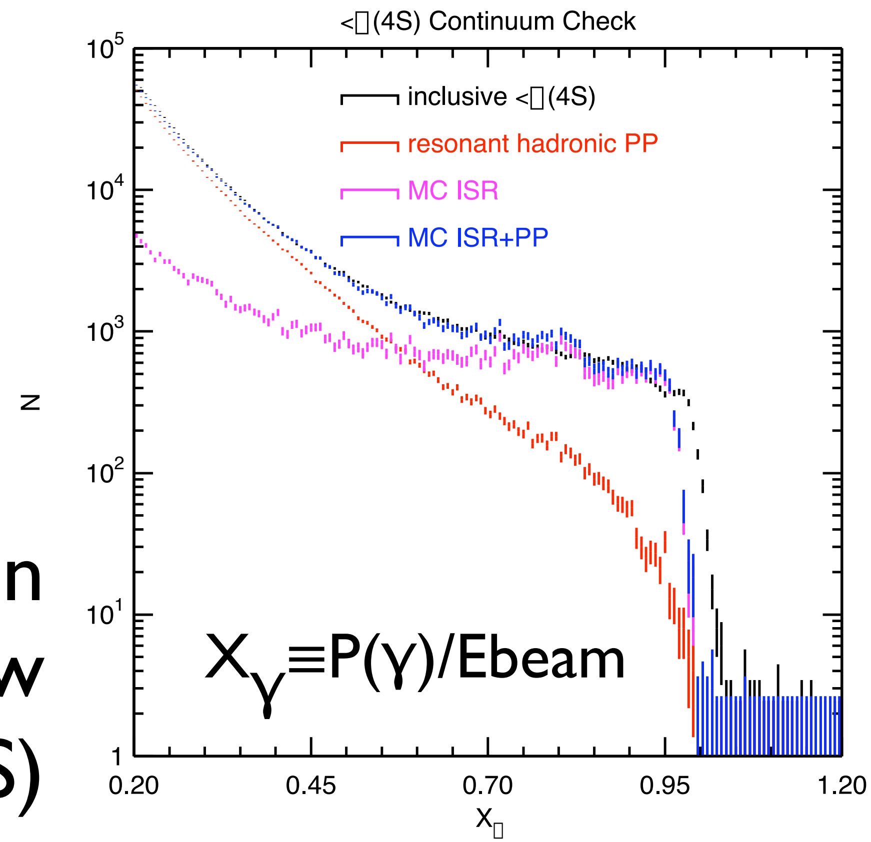


  - Cascades
- Isolating the Direct Photon gives info about $(b\bar{b})$ Wavefunction & α(EM) + α(QCD)

$$R\gamma = \frac{N(gg\gamma)}{N(ggg)} = f(q_b, \alpha_{EM}, \alpha_{QCD})$$

Direct Photons in Υ Decays

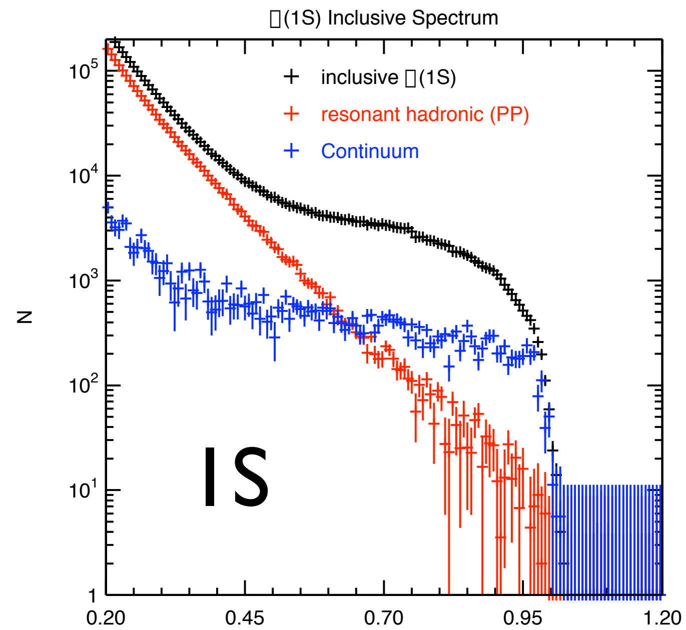
- We look for hadronic events with a nice isolated photon
- Backgrounds :
  - ISR (high X_γ)
  - π^0 decays (low X_γ)

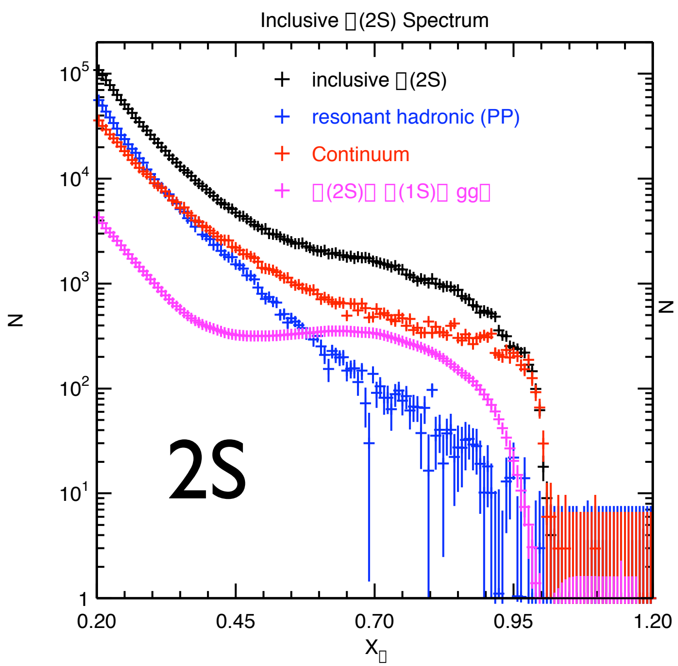


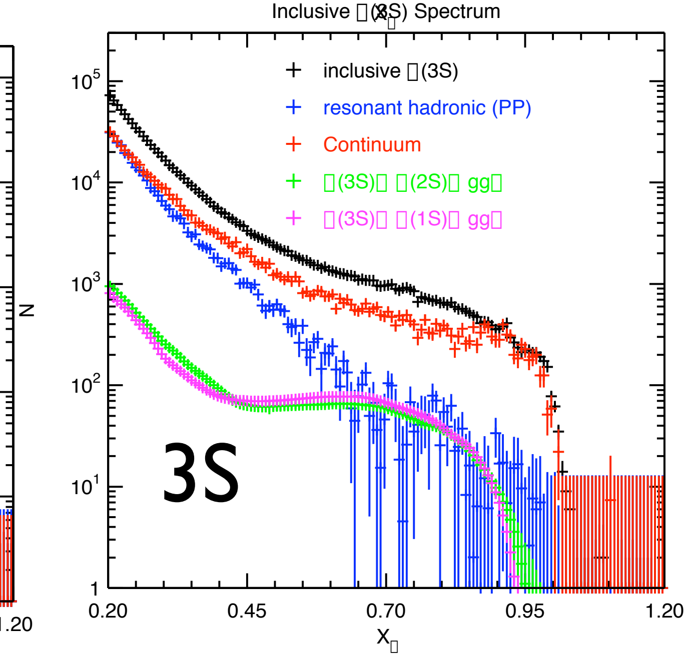
Photon Spectrum Below Υ(4S)

Direct Photons in Υ Decays

Raw Photon Energy Distributions with off Resonance Data and MC of Resonance π^0 feed through



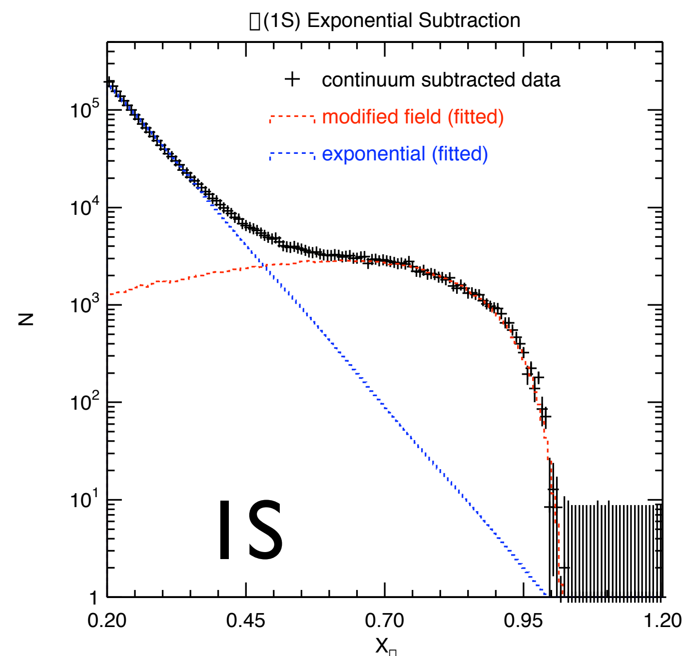


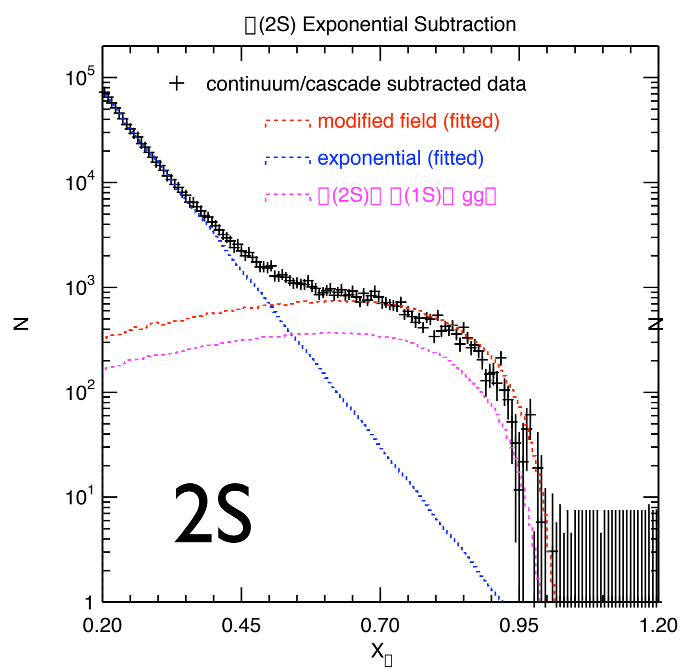


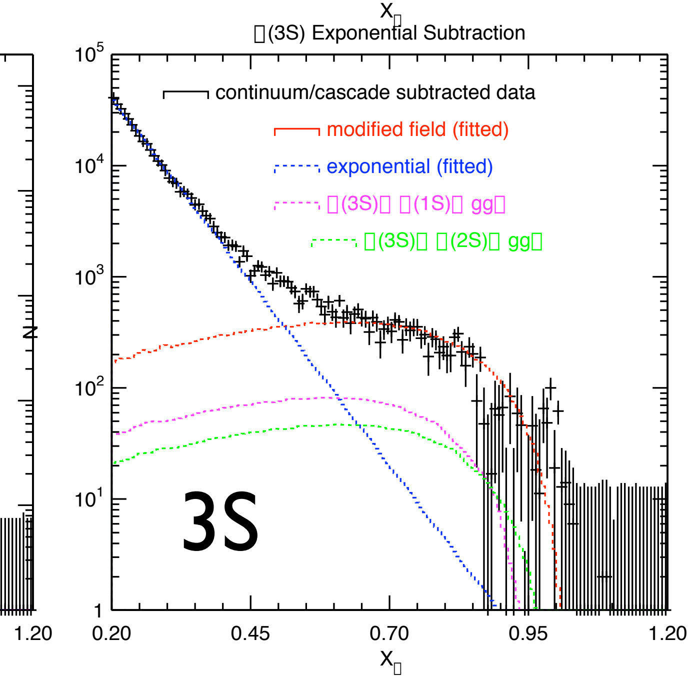
Direct Photons in Υ Decays

- Fit Subtracted Spectrum to an exponential for “left over” photons + direct photon model (Field or Garcia+Soto)

N.B.: Models are strictly speaking for 1S only







Direct Photons in Υ Decays: Results

$$R\gamma = \frac{N(gg\gamma)}{N(ggg)} = f(q_b, \alpha_{EM}, \alpha_{QCD})$$

N(ggg) determined from N(Υ), PDG and MC

Preliminary

$R\gamma(1S) = 2.90 \pm 0.007 \pm 0.22 \pm 0.15\%$

$R\gamma(2S) = 3.49 \pm 0.03 \pm 0.58 \pm 0.18\%$

$R\gamma(3S) = 2.88 \pm 0.03 \pm 0.38 \pm 0.12\%$

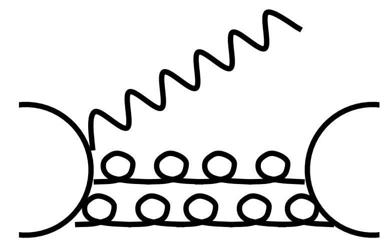
Errors are Stat, Syst, Model

Syst Error dominated by π^0 modeling

- R(1S) consistent with previous values, similar syst, but smaller stat error
- First measurement of R(2S), R(3S)

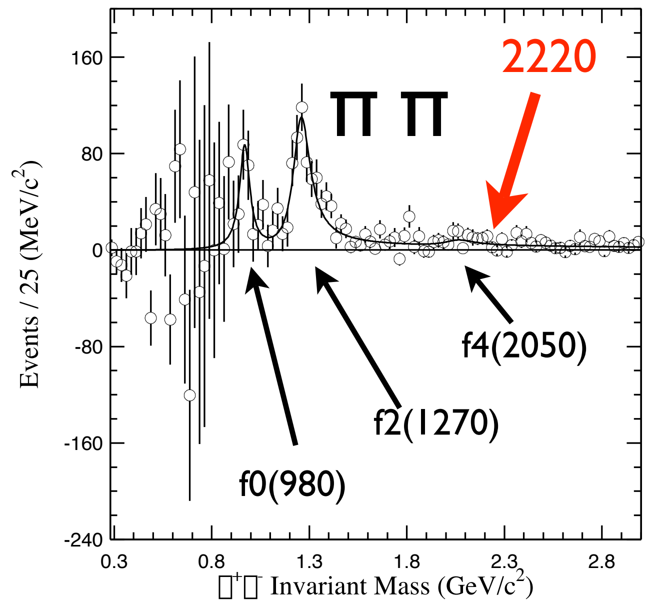
$\Upsilon(1S) \to h^+ h^- \gamma$

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

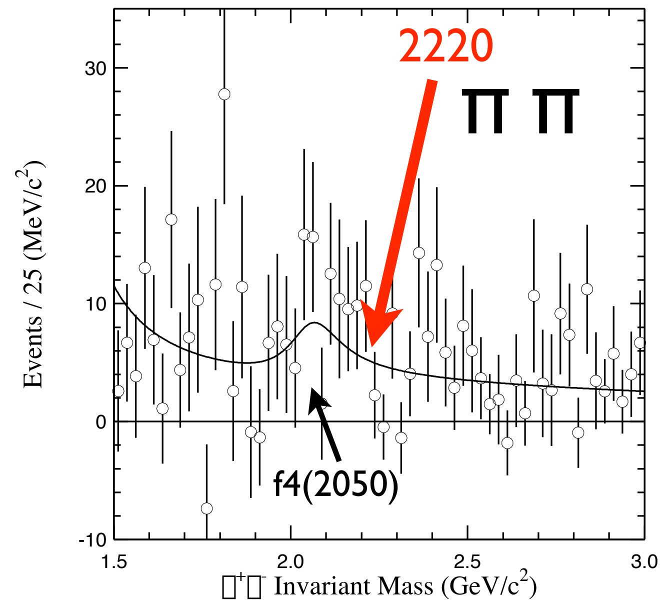


- Radiative decays probe 2 gluon structure
- Many interesting results from J/ψ
  - tensor states $f_2(1270)$, $f_2'(1525)$
  - glueball candidate $f_J(2220)$
  - X(1860) = pp threshold enhancement (BES)
- In $\Upsilon(1S)$, rates suppressed by $(q_b m_c / q_c m_b)^2 \approx 0.025$
- We look for $\Upsilon(1S) \rightarrow h^+h^-\gamma$
  - Require $E\gamma > 4$ GeV
  - $h^\pm$ IDed as π/K/p with dE/dx and RICH
  - Also use CM 4-momentum constraint for PID
  - Use Off Resonance Subtraction

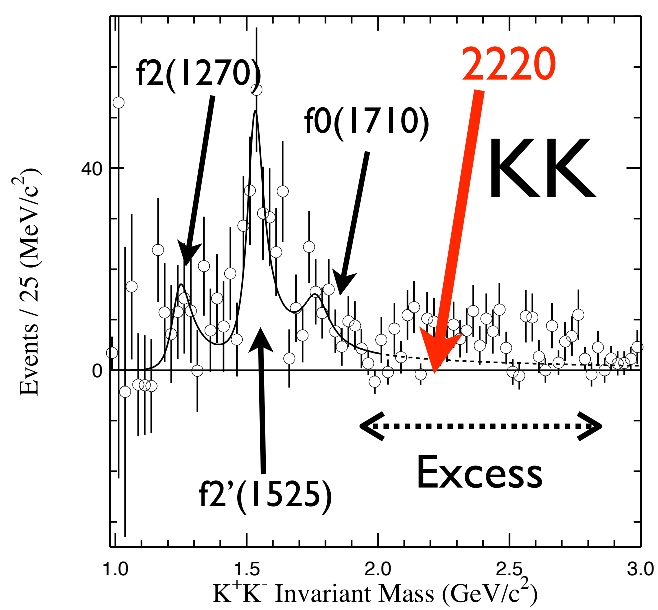
Υ(1S)→h⁺h⁻γ



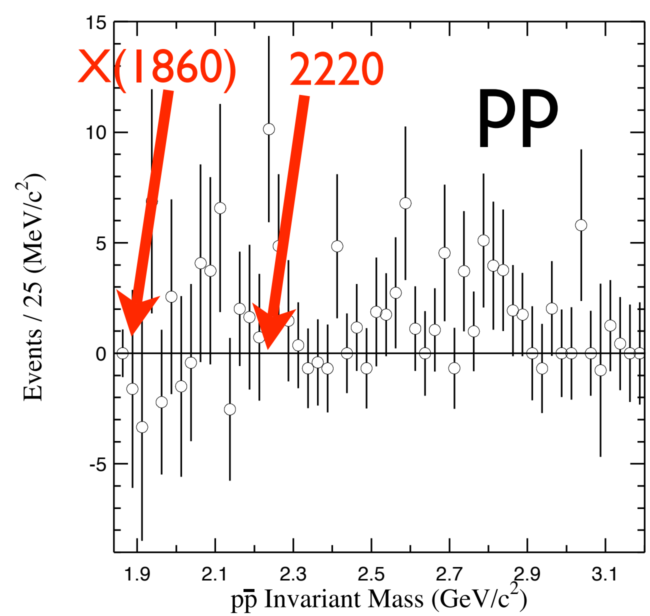
2220
π π
f0(980)
f2(1270)
f4(2050)
Events / 25 (MeV/c2)
Invariant Mass (GeV/c2)



2220
π π
f4(2050)
Events / 25 (MeV/c2)
Invariant Mass (GeV/c2)



f2(1270)
2220
f0(1710)
KK
f2'(1525)
Excess
Events / 25 (MeV/c2)
K+K- Invariant Mass (GeV/c2)



X(1860)
2220
PP
Events / 25 (MeV/c2)
pp̄ Invariant Mass (GeV/c2)

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

- Fit decay angles - get decay helicities for f2(1270) & f2'(1525) - predominantly helicity 0
- Fit Mass to spin dependent relativistic BW

Scales OK from J/ψ

$B(\Upsilon(1S)\rightarrow\gamma f2(1270))=10.2 \pm 0.8 \pm 0.7 \times 10^{-5}$

$B(\Upsilon(1S)\rightarrow\gamma f2'(1525))=3.7\ {}^{+0.9}_{-0.7} \pm 0.8 \times 10^{-5}$

$B(\Upsilon(1S)\rightarrow\gamma KK)=1.14 \pm 0.08 \pm 0.10 \times 10^{-5}$ $\quad$ $2GeV<M(KK)< 3GeV$

$B(\Upsilon(1S)\rightarrow\gamma f2(980)\rightarrow\pi\pi) < 3 \times 10^{-5}$

$B(\Upsilon(1S)\rightarrow\gamma f2(2050)\rightarrow\pi\pi) < 0.6 \times 10^{-5}$

$B(\Upsilon(1S)\rightarrow\gamma f0(1710)\rightarrow KK) < 0.7 \times 10^{-5}$

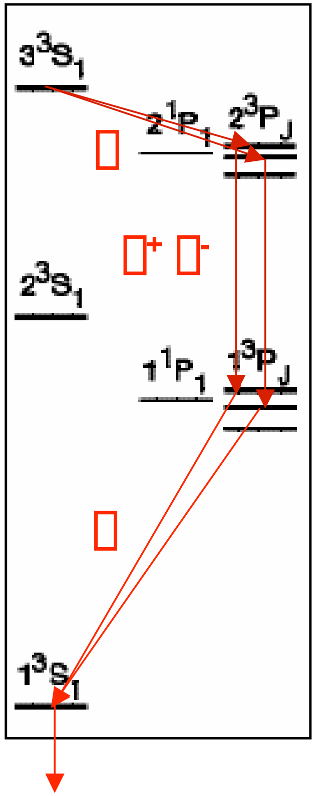
$B(\Upsilon(1S)\rightarrow\gamma pp)<0.6 \times 10^{-5}$ $\quad$ $2GeV<M(pp)< 3GeV$

Limits on $f_J(2200)$ and X(1860) around 10^{-6}

Complimentary analysis under way for $\pi^0\pi^0\gamma$, $\eta\eta\gamma$, $\pi^0\eta\gamma$ *All results preliminary*

Observation of $\chi_b(2P) \rightarrow \chi_b(1P)\pi^+\pi^-$

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



Search for $\gamma\pi\pi\gamma$ (ee) ( )

χ_b' **Dominant backgrounds**

$\Upsilon(3S) \longrightarrow \Upsilon(2S)\ \pi^+\pi^-$ *Same final state*

$\quad \hookrightarrow \chi_b\ \gamma$

$\quad\quad \hookrightarrow \Upsilon(1S)\ \gamma$

χ_b $\Upsilon(3S) \longrightarrow \chi_b'\gamma$

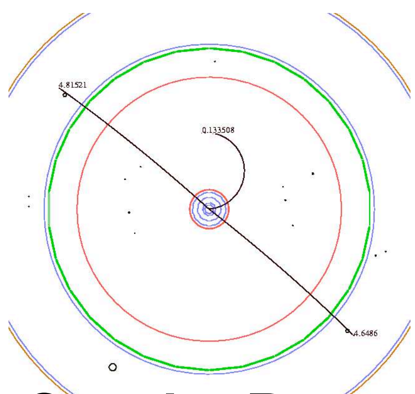
$\quad \hookrightarrow \Upsilon(1S)\ \omega$ *Lose a γ*

$\quad\quad \hookrightarrow \pi^+\pi^-\pi^0$

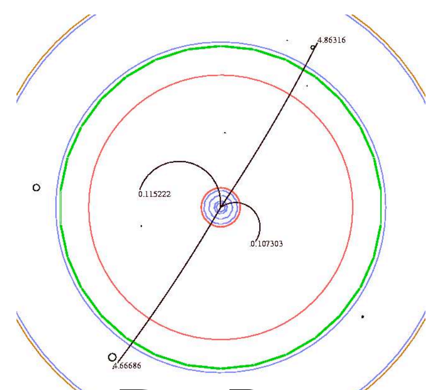
$\Upsilon(3S) \longrightarrow \Upsilon(2S)\ \pi^+\pi^-$

$\quad \hookrightarrow \Upsilon(1S)\ \pi^0\pi^0$ *Lose 2 γ*

π are low momentum - hard to track - 2 analyses

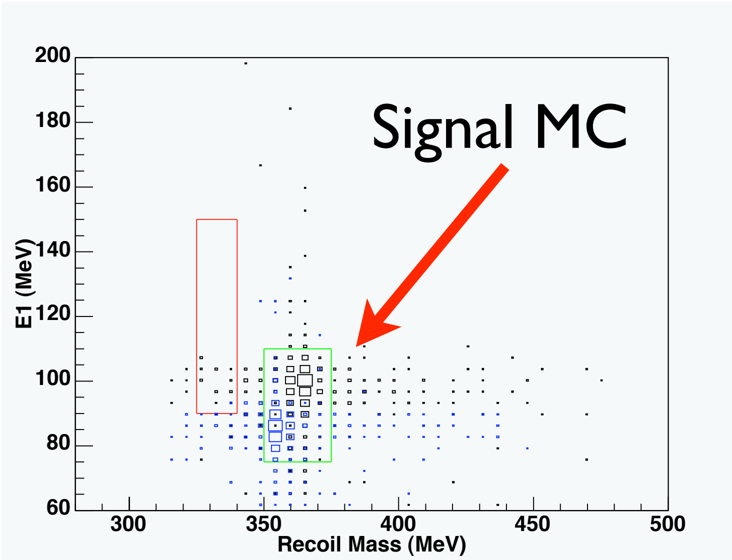


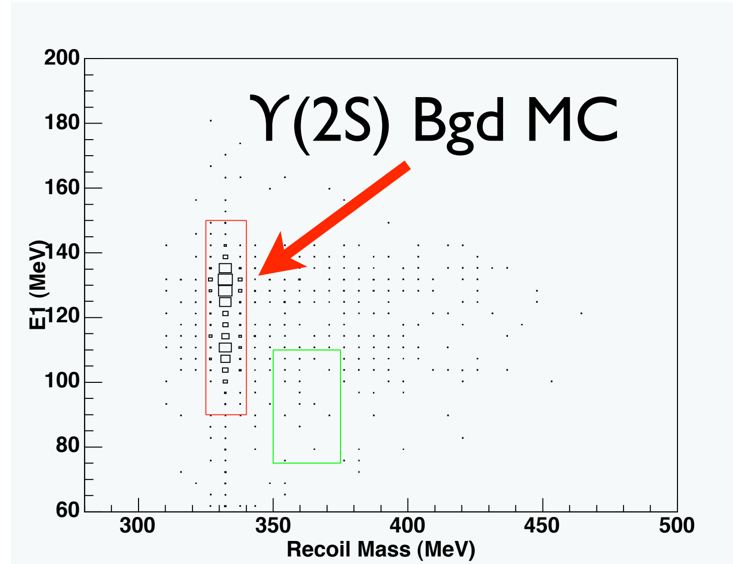
Single Pion

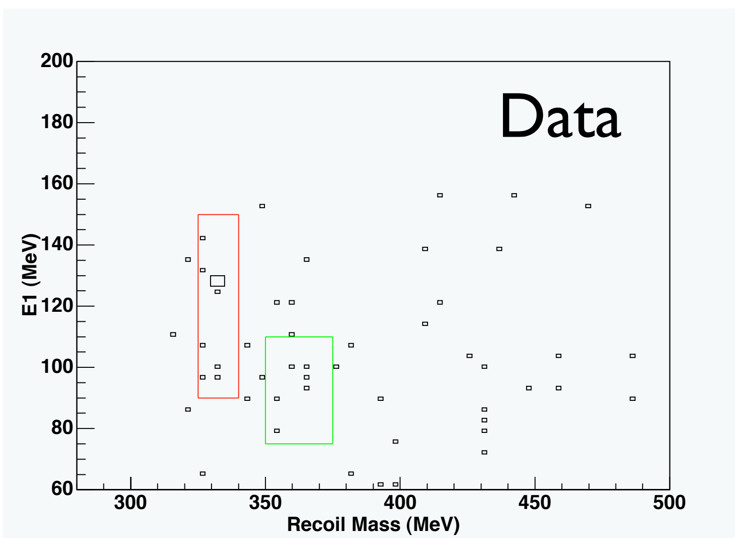


Di-Pion

$\chi_b(2P) \to \chi_b(1P)\pi^+\pi^-$: Di-pion







7 Events Observed

1.2 Expected background

Size of Υ(2S) is as expected

$\epsilon \approx 4.5\%$

$\chi_b(2P)\rightarrow\chi_b(1P)\pi^+\pi^-$ Results

- Single Pion Analysis see 17 events, background expected to be 3.3 events, $\epsilon\approx 8.5\%$
- Single Pion + Di-Pion significance $\approx 6\sigma$

Preliminary

First Observation of a $\pi\,\pi$ transition outside of ${}^3S_1$ system

$$\Gamma(\chi_b(2P)\rightarrow\chi_b(1P)\pi^+\pi^-) \approx 0.9\ \text{keV}$$

CLEO Υ Results Summary

- First Observation of Bs Production in Υ(5S) decays
- First Observation of $\Upsilon(3S) \rightarrow \tau\tau$
- Precision results on $B(\Upsilon \rightarrow \tau\tau)/B(\Upsilon \rightarrow \quad)$
- Direct Measurements of $\Gamma(\Upsilon \rightarrow ee)$
- Measurements of Direct Photons in $\Upsilon \rightarrow X\gamma$
- Measurements of substructure in $\Upsilon(1S) \rightarrow h^+ h^- \gamma$
- First Observation of $\chi_b' \rightarrow \chi_b \pi^+ \pi^-$

Many more CLEO results still in the pipeline - stay tuned