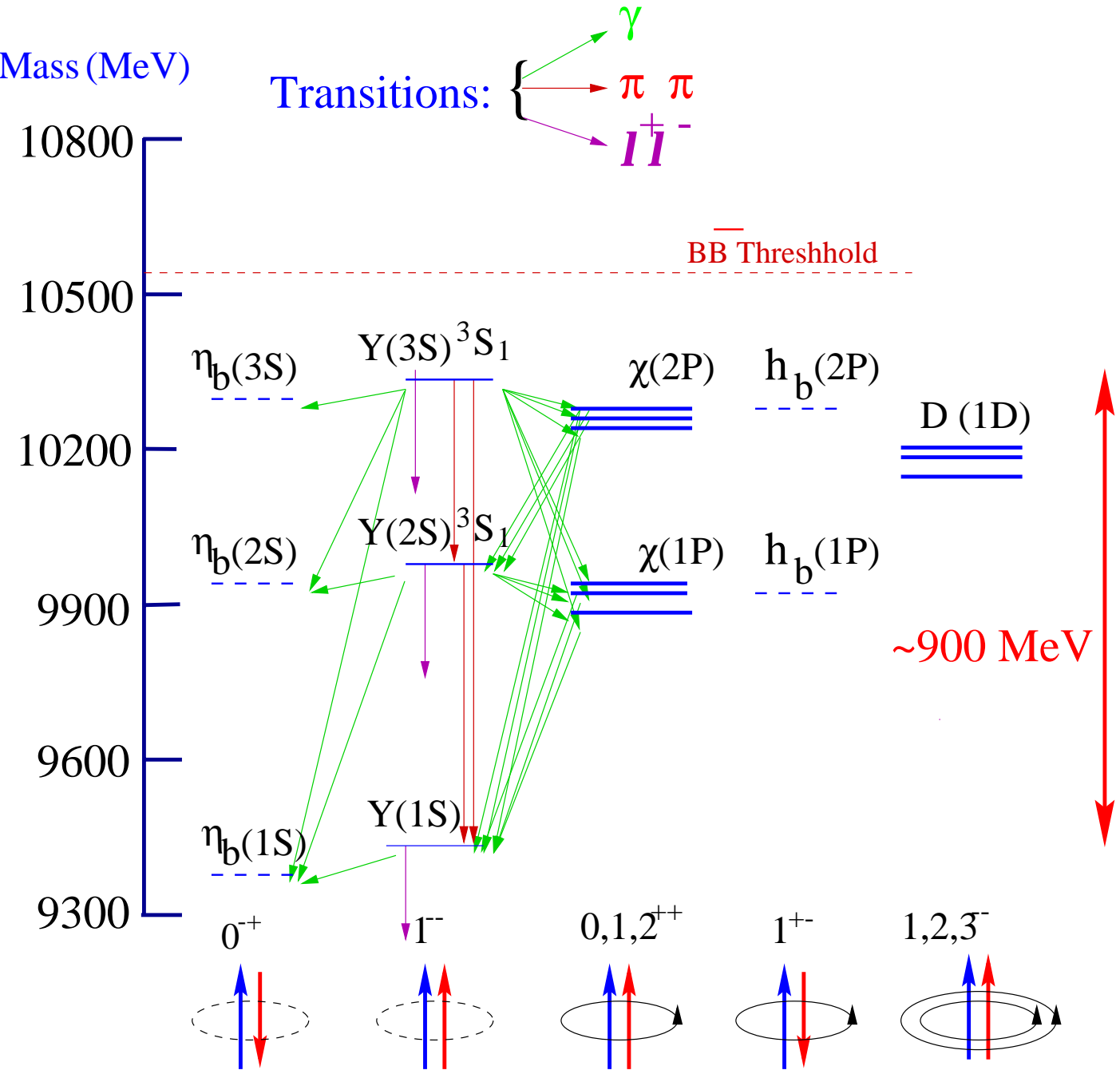# Hadronic Transitions among Bottomonium States

David L. Kreinick

Cornell University

for the CLEO Collaboration

- $\Upsilon(3S) \rightarrow \pi\,\pi\,\Upsilon(1S)$
- $\Upsilon(3S) \rightarrow \gamma\,\chi_{b1}'$
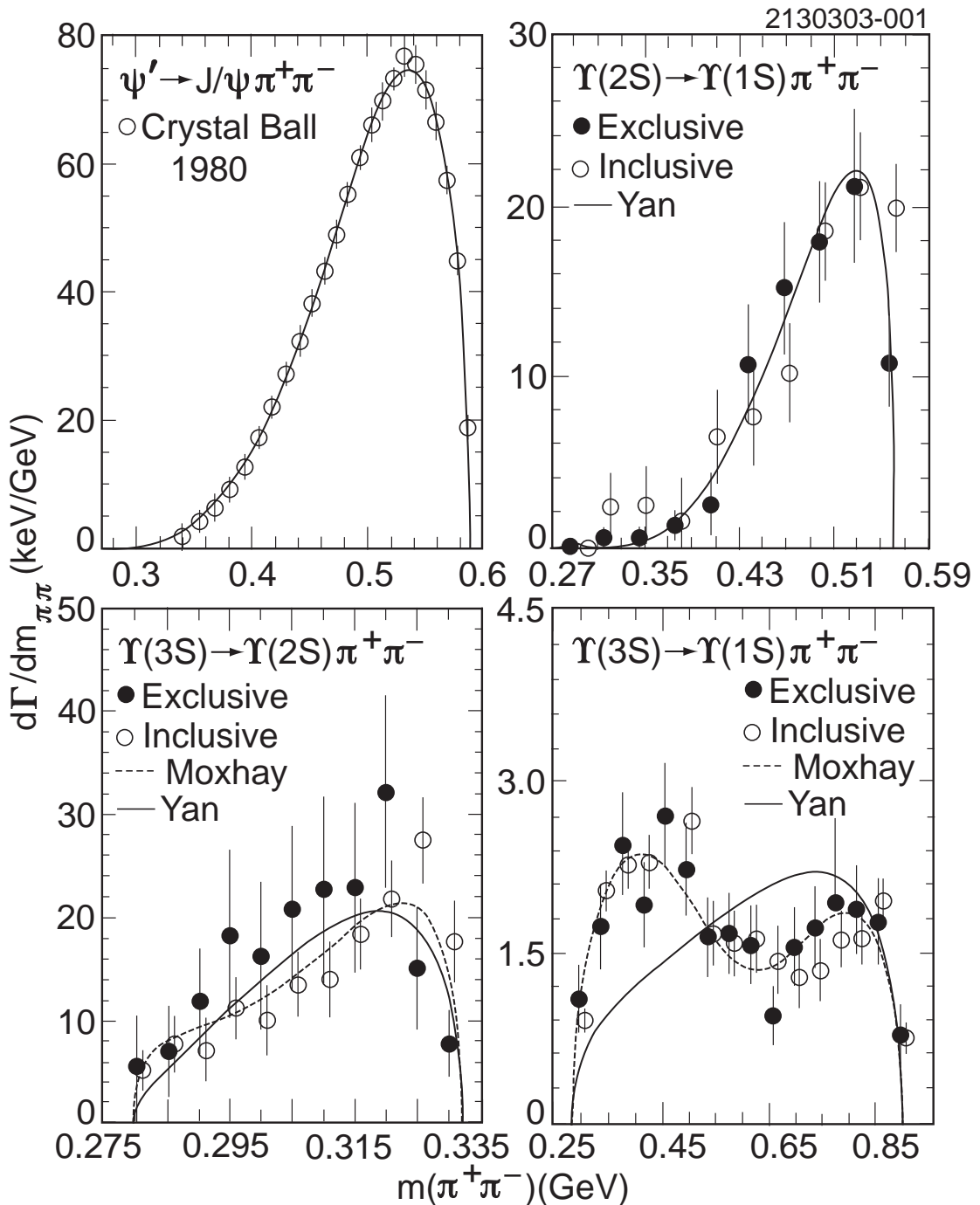  $\hookrightarrow \omega\,\Upsilon(1S)$

# Bottomonium Spectrum



- Quantum number conservation (strong, EM)

- Limited Q: $\gamma$, $\pi\pi$, 3-6$\pi$, $\eta$, $\rho$, $\omega$, but not KK

# CLEO-III Detector



CLEO III — Solenoid Coil, RICH, Calorimeter, Drift Chamber, Muon Chambers, Magnet Iron, Silicon Vertex Detector, SC and Rare Earth Quads

2230801-005

**Luminosity!!**

**1994: 0.130 fb$^{-1}$,   0.47 Million $\Upsilon$(3S)**

**here: 1.130 fb$^{-1}$,   4.7  Million $\Upsilon$(3S)**

# Dipion Mass Spectra

## Status: 1994



2130303-001

Figure panels:
- $\psi' \to J/\psi\,\pi^+\pi^-$ — ○ Crystal Ball 1980
- $\Upsilon(2S) \to \Upsilon(1S)\,\pi^+\pi^-$ — ● Exclusive, ○ Inclusive, — Yan
- $\Upsilon(3S) \to \Upsilon(2S)\,\pi^+\pi^-$ — ● Exclusive, ○ Inclusive, --- Moxhay, — Yan
- $\Upsilon(3S) \to \Upsilon(1S)\,\pi^+\pi^-$ — ● Exclusive, ○ Inclusive, --- Moxhay, — Yan

Axis labels: $d\Gamma/dm_{\pi\pi}$ (keV/GeV) vs $m(\pi^+\pi^-)$ (GeV)

———T-M Yan, PRD <u>22</u>, 1652 (1980) multipole exp.

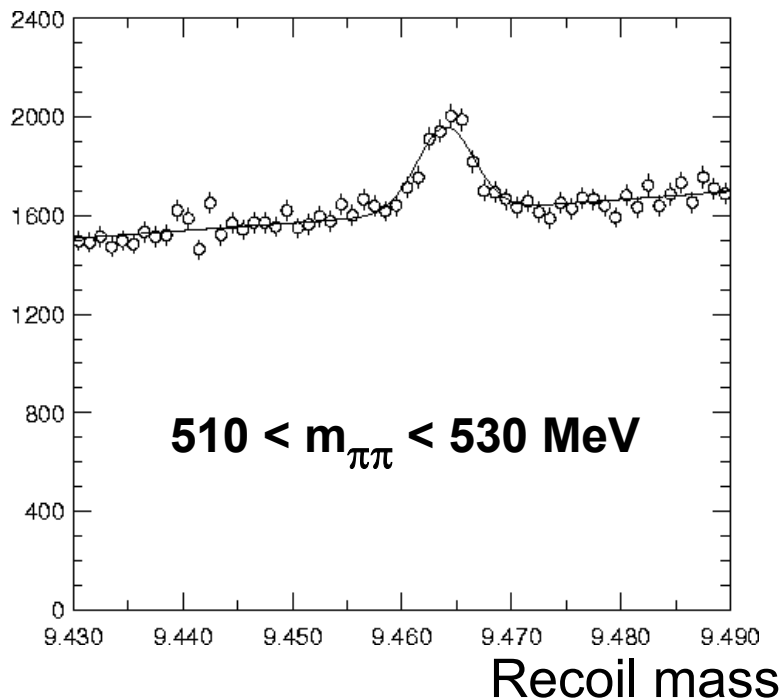----- P. Moxhay, PRD <u>39</u>, 3497 (1989) virtual BB*

# Event Criteria - Inclusive

Cuts as few and simple as possible

$\pi^+\pi^-$ Tracks

- P$\pi$ < 800 MeV/c
- Both tracks originate in beam spot
   - ±3mm in r$\phi$, ±30 mm in Z
- $|z_0^+ - z_0^-|$ < 2mm - tight!

$M_{\pi\pi}^2 = ( p^+ + p^- )^2$

$M_{recoil}^2 = \{(M_{\Upsilon(3S)},0,0,0) - ( p^+ + p^- )\}^2$



510 < $m_{\pi\pi}$ < 530 MeV

Recoil mass

For $\pi^0\pi^0$
- Combinatorics even worse (4$\gamma$'s)
- poorer resolution

# Event criteria - Exclusive

$\Upsilon(3S) \rightarrow \pi\pi\Upsilon(1S)$

$\longrightarrow e^+e^-$ or $\mu^+\mu^-$

Leptons
- $p_\ell > 4.5$ GeV/c
- $9.3 < m_{\ell\ell} < 9.55$ GeV

$\pi^+\pi^-$
- Same vertexing as inclusive
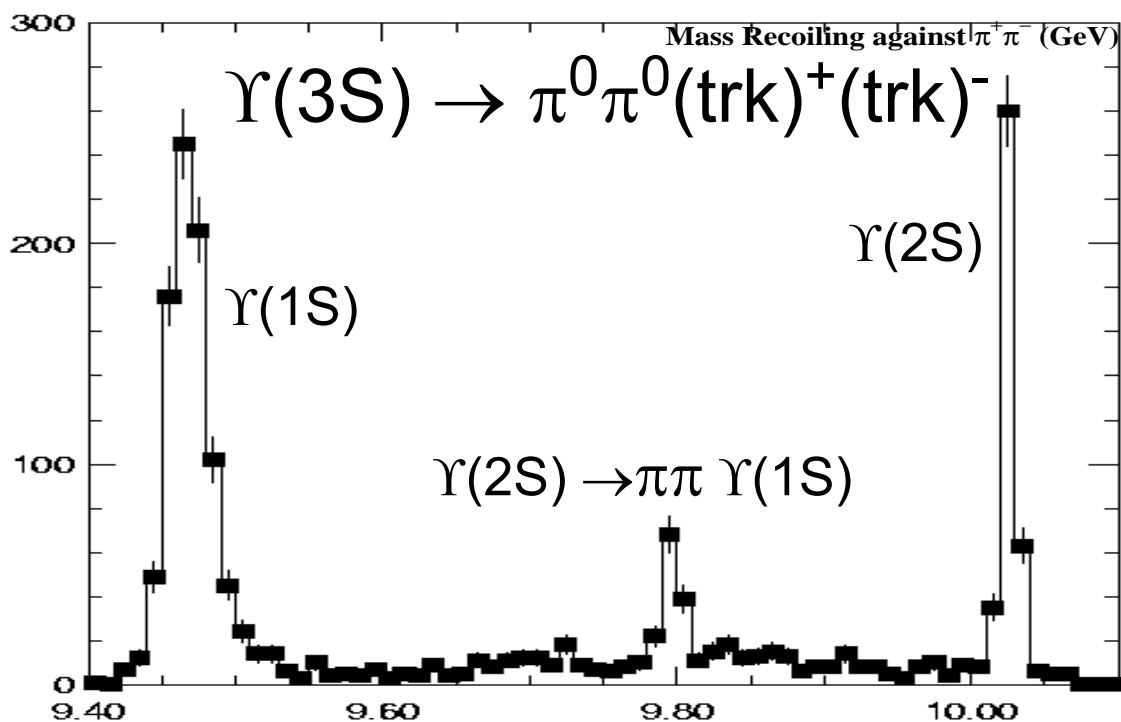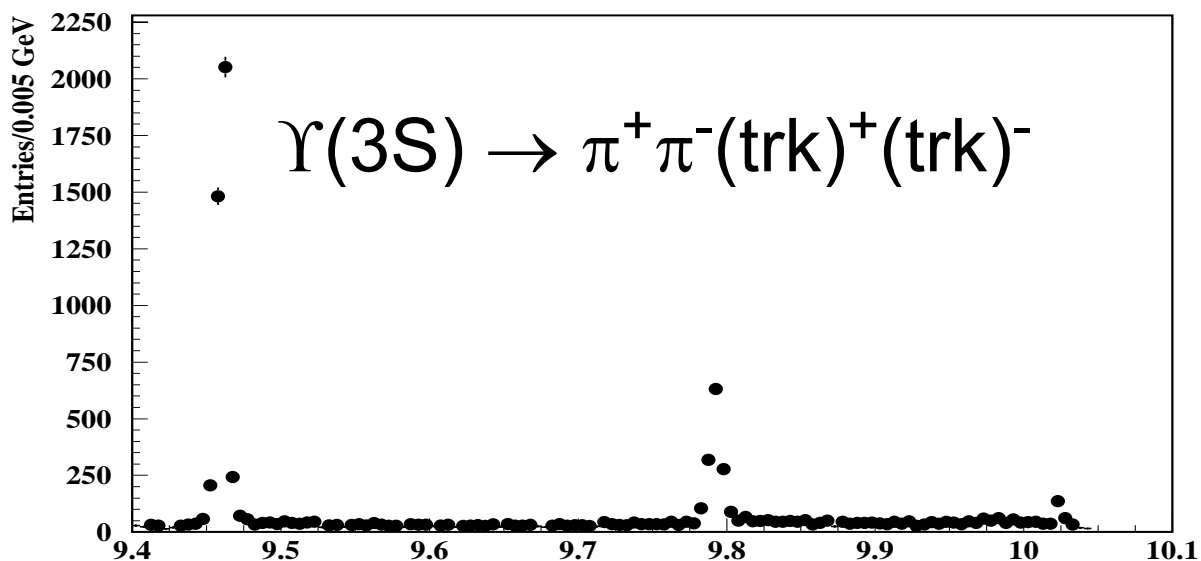- $p_{\pi\pi}$ not aligned with either lepton (to reject $\gamma$ conversions)

$\pi^0\pi^0$
- $E_\gamma > 30$ MeV for each $\gamma$ in $\pi^0$
- No $\gamma$ in barrel-endcap transition region
- $|m_{\gamma\gamma} - 135$ MeV$| < 20$ MeV
- $p_{\pi^0} < 750$ MeV/c
- $M_{\pi\pi} < 900$ MeV
- $|p_{\ell\ell} \cdot p_{\pi\pi}| > 0.9$

Mass recoiling against $\pi\pi$ > 9 GeV
No particle ID!

# Mass Recoiling against $\pi\pi$



$\Upsilon(3S) \rightarrow \pi^+\pi^-(trk)^+(trk)^-$

Entries/0.005 GeV

Mass Recoiling against $\pi^+\pi^-$ (GeV)

$\Upsilon(3S) \rightarrow \pi^0\pi^0(trk)^+(trk)^-$

$\Upsilon(2S)$

$\Upsilon(1S)$

$\Upsilon(2S) \rightarrow \pi\pi \ \Upsilon(1S)$

Mass recoiling against $\pi\pi$

# $\pi\pi$ Mass Distribution



● $\pi^+\pi^-$, exclusive
○ $\pi^+\pi^-$, inclusive

■ $\pi^0\pi^0$, exclusive

Dipion mass, GeV
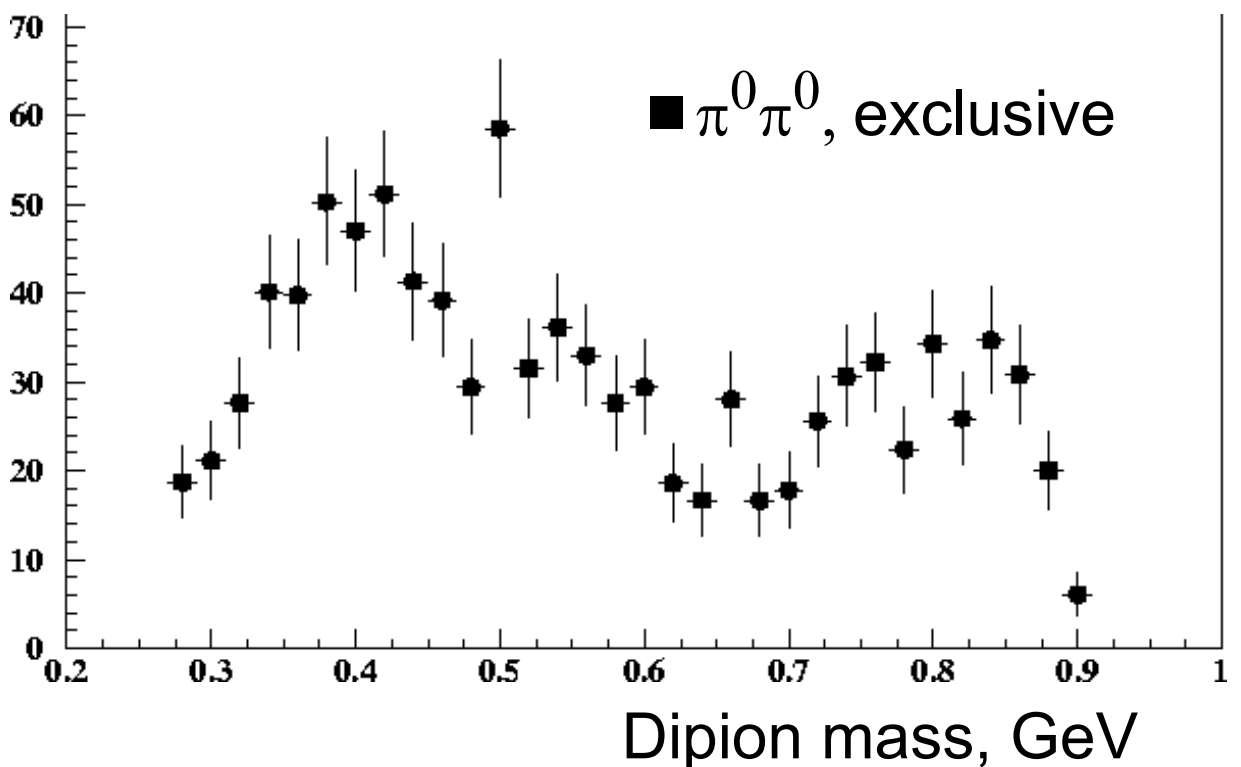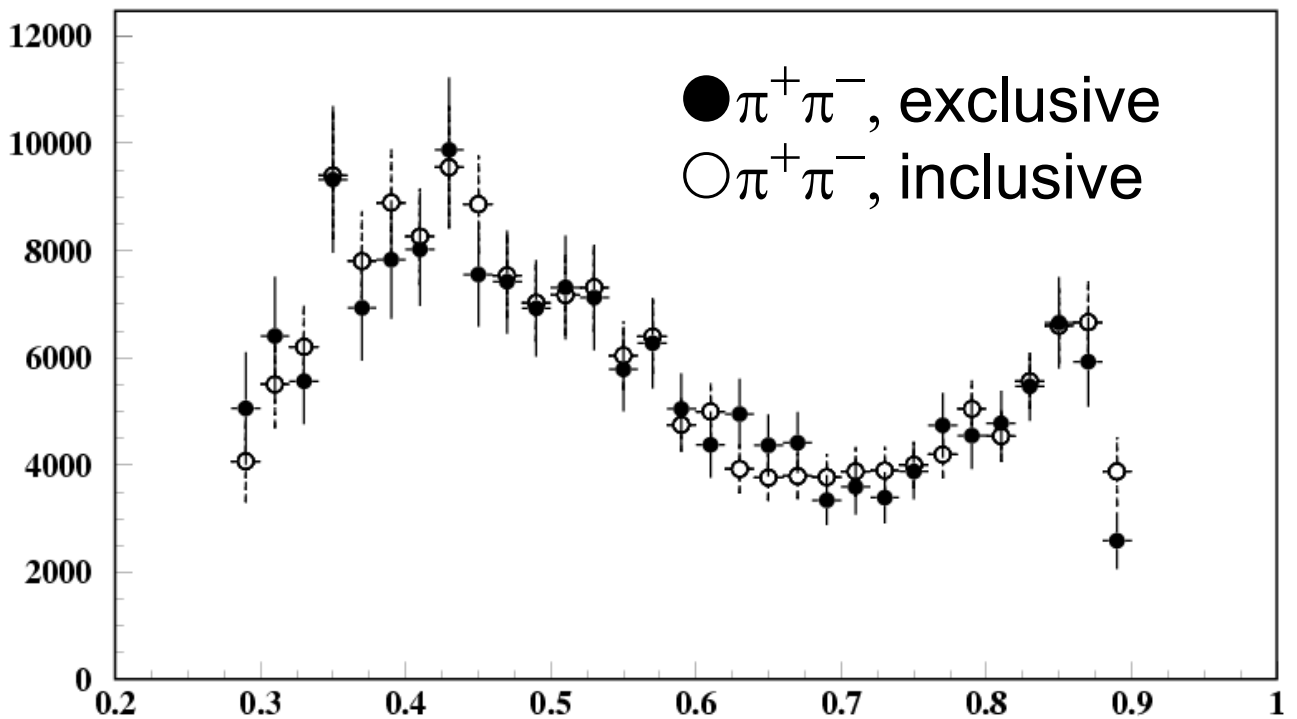
# Fishing Expedition

Running at $\Upsilon$ (3S), tag with $\Upsilon$ (1S) to dileptons and seek resonances in $\pi^+\pi^-\pi^0$

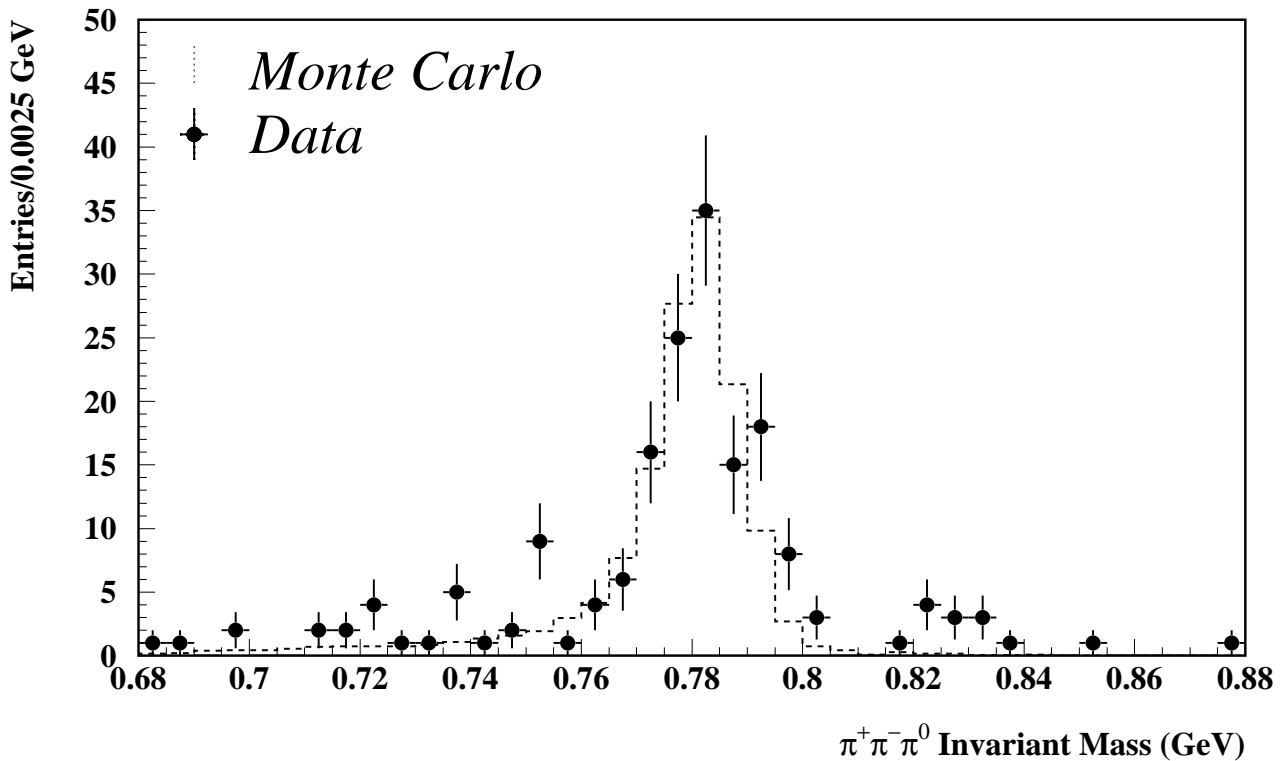Criteria: 4 or 5 total charged tracks

- 2 lepton candidate tracks, +- charge
  - $p_\ell > 4$ GeV/c
  - $9.3 < M_{\ell\ell} < 9.6$ GeV
- 2 pion candidate tracks, +- charge
  - p<0.75 GeV/c
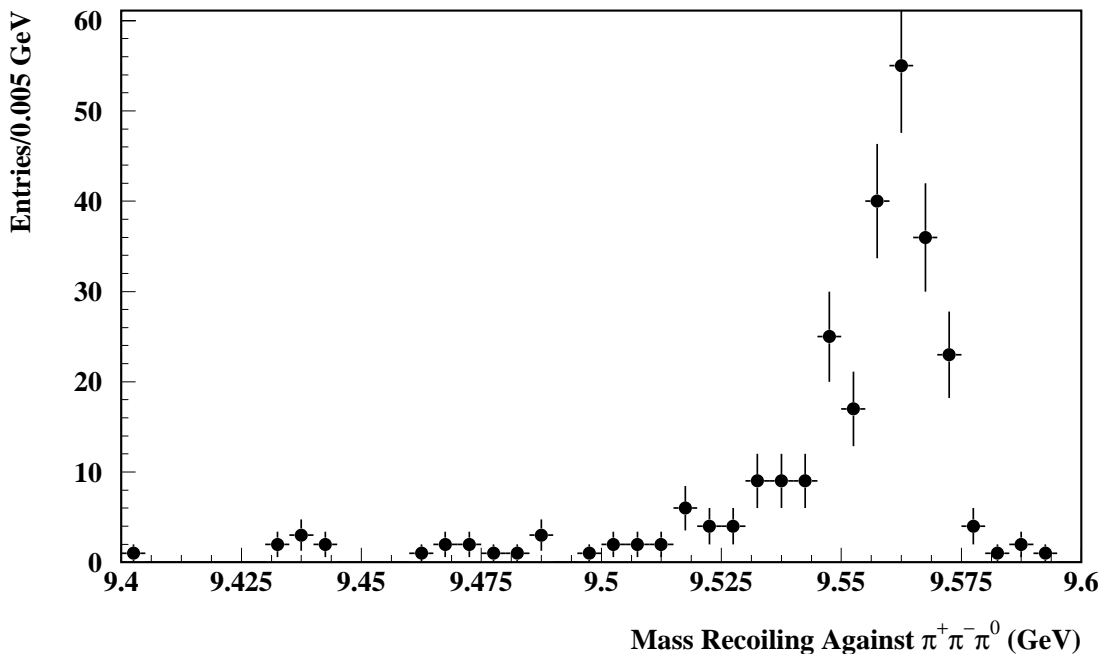  - vertexing cuts

No particle ID

- 2 add'l showers make $\pi^0$ with $\chi^2 < 10$ for a constrained fit to $m_\pi$ (1 DOF)
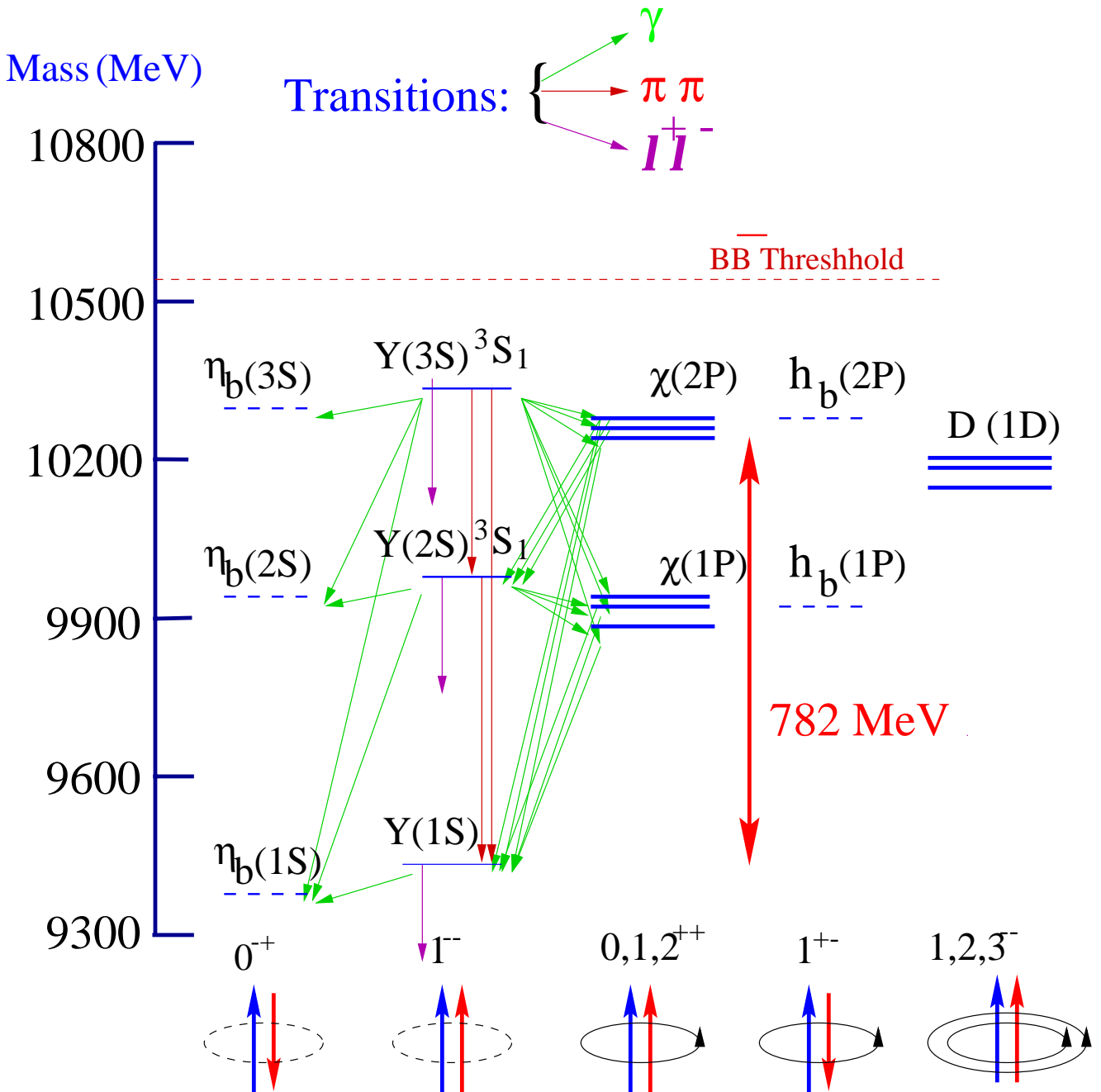
# $\Upsilon(3S) \rightarrow \Upsilon(1S) \, \omega \, X$



*Monte Carlo*

*Data*

$\pi^+\pi^-\pi^0$ **Invariant Mass (GeV)**

ASSUME $\pi^+\pi^-\pi^0$ form an $\omega$

$$M_{recoil}^2 = \{(M_{\Upsilon(3S)},0,0,0) - (p_{\pi^+}+p_{\pi^-}+p_{\pi^0})\}^2$$



**Mass Recoiling Against $\pi^+\pi^-\pi^0$ (GeV)**

# Bottomonium Spectrum

Mass (MeV)

Transitions: $\{$

$\gamma$

$\pi\,\pi$

$l^+l^-$

10800

$B\bar{B}$ Threshhold

10500

$\eta_b(3S)$   Y(3S) $^3S_1$   $\chi(2P)$   $h_b(2P)$

10200   D (1D)

$\eta_b(2S)$   Y(2S) $^3S_1$   $\chi(1P)$   $h_b(1P)$

9900

782 MeV

9600

$\eta_b(1S)$   Y(1S)

9300

$0^{-+}$   $1^{--}$   $0,1,2^{++}$   $1^{+-}$   $1,2,3^{--}$

# Backgrounds

Four possible sources of bkgnd $\gamma\pi^0\pi^+\pi^-\ell^+\ell^-$

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

2) $\Upsilon(3S) \to \pi^+\pi^-\,\Upsilon(2S) \to \pi^+\pi^-\gamma\chi_b \to \pi^+\pi^-\gamma\gamma\,\Upsilon(1S)$
   with an additional fake $\gamma$

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

4) $\Upsilon(3S) \to \pi^+\pi^-\,\Upsilon(2S) \to \pi^+\pi^-\pi^0\pi^0\,\Upsilon(1S)$
   with one of the $\pi^0$ photons lost

$\pi^+\pi^-$ come from dipion cascades from $\Upsilon(2S)$ or $\Upsilon(3S)$, so reject events whose $\pi^+\pi^-$ recoil mass is consistent with $\Upsilon(3S) \to \pi^+\pi^-\,\Upsilon(2S)$ or $\Upsilon(2S) \to \pi^+\pi^-\,\Upsilon(1S)$

Monte Carlo estimates < 1.1 bkg event remains at 90% C.L. after this cut

$\gamma$ spectrum: additional cuts for cleanliness
- Constrained fit for $m_\omega$ has $\chi^2 < 10$ (1 DOF)
- 9.44 < Mass recoiling against $\omega$ < 9.48 GeV
- Energy conserved within 100 MeV
- At most one extra $\gamma$ in event

# Photon Spectrum
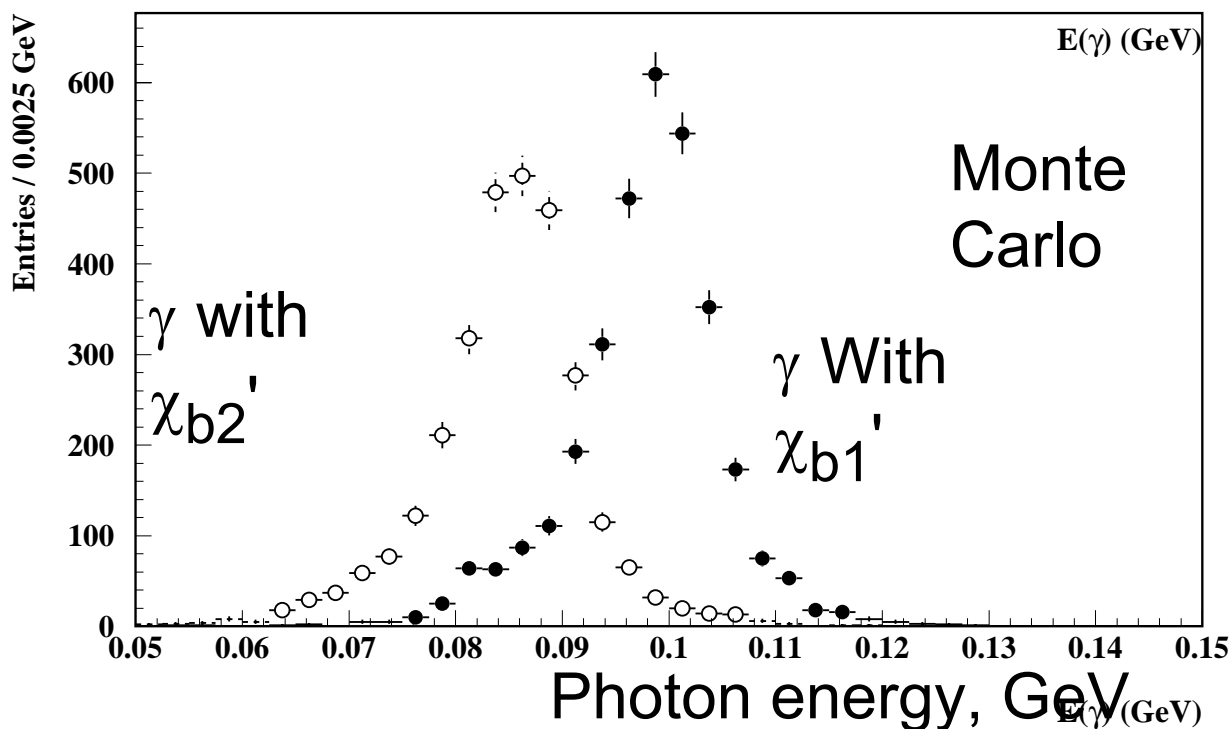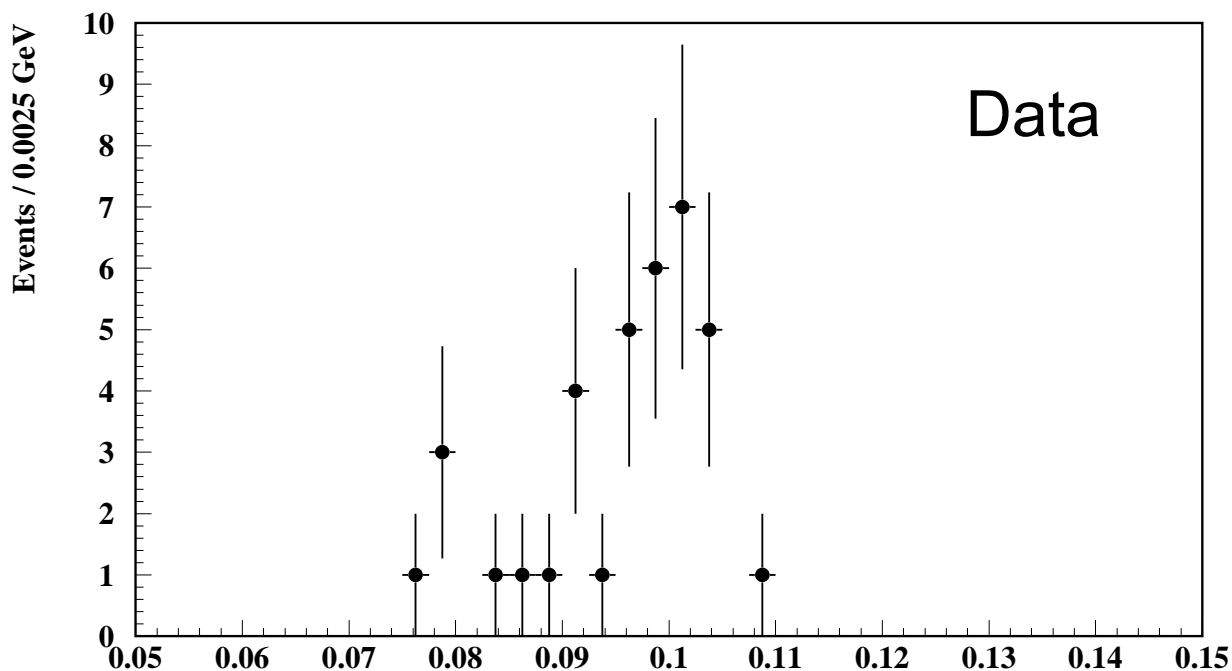
# Branching Ratio

- ASSUME all the signal is $\chi_{b1}'$
- MC estimate efficiency 6.42%
- signal is 36±6 events
- subtract 1.1 event for background

$$B(\Upsilon(3S) \to \gamma\chi_{bJ}' \to \gamma\omega\Upsilon(1S) \to$$
$$\gamma\pi^+\pi^-\pi^0\,\ell^+\,\ell^-) = (1.15 \pm 0.20)\times10^{-4}$$

Divide this by the branching ratios for
$\Upsilon(3S) \to \gamma\chi_{b1}'$, $\omega \to \pi^+\pi^-\pi^0$, and
$\Upsilon(1S) \to e^+e^-$ plus $\Upsilon(1S) \to \mu^+\mu^-$

$B(\chi_{b1}' \to \omega\ \Upsilon(1S)) = (2.3 \pm 0.4)\%$
with a systematic error smaller than the
statistical error, except for the assumptions

# Summary

- CLEO-III has measured the distribution of dipion masses in $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$ and $\Upsilon(3S) \to \pi^0\pi^0\,\Upsilon(1S)$

The order of magnitude greater statistics should help differentiate among models

- CLEO-III has observed a new decay mode of $\chi_{b1}'$ or $\chi_{b2}'$ most naturally explained as

$$\chi_{bJ}' \to \omega\,\Upsilon(1S)$$

with a branching ratio of about 2%