Measurement of $\mathcal{B}(\Upsilon(nS) \to \mu^+\mu^-)$ at CLEO

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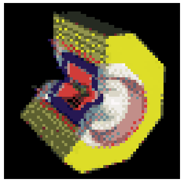
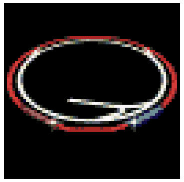
István Dankó
Rensselaer Polytechnic Institute


CLEO

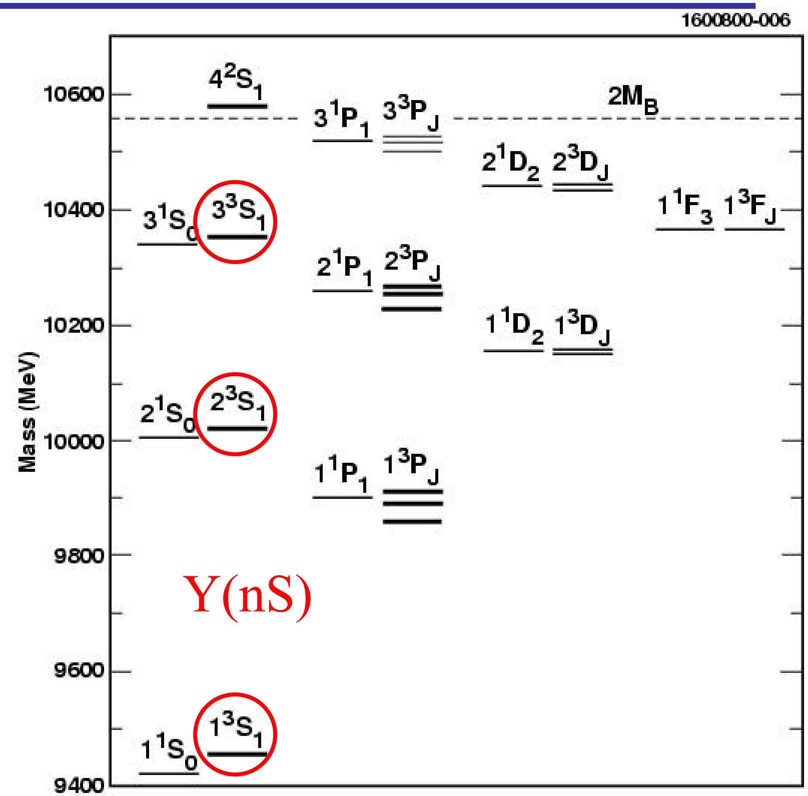
representing the
CLEO Collaboration


CESR

1st Meeting of the APS topical Group on Hadronic Physics
Fermilab, Oct 24-26, 2004

Motivation

- **Heavy bb-resonances**
  - test Lattice QCD and other non-perturbative model predictions
  - establish the accuracy of these calculations.



- Leptonic (Γ_{ee}) and total decay widths (Γ) of Y(nS) are not well established.

✓ Γ_{ee}: from integrated resonant hadron cross section

✓ Γ: too narrow to measure directly

$$\Gamma = \Gamma_{\ell\ell} / B_{\ell\ell} = \Gamma_{ee} / B_{\mu\mu}$$

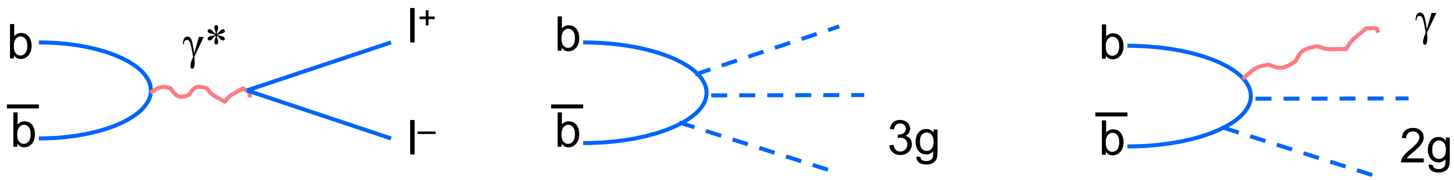
$\Rightarrow$ $B_{\mu\mu}$ is crucial to get Γ!

Res.	Γ_{ee} (keV)	$B_{\mu\mu}$ (%)	Γ (keV)
Y(1S)	1.32±0.05	2.48±0.06	52.5±1.8
Y(2S)	0.520±0.032	1.31±0.21	44±7
Y(3S)	0.48±0.05	1.81±0.17	26.3± 3.5

PDG ‘04

Motivation (continue)

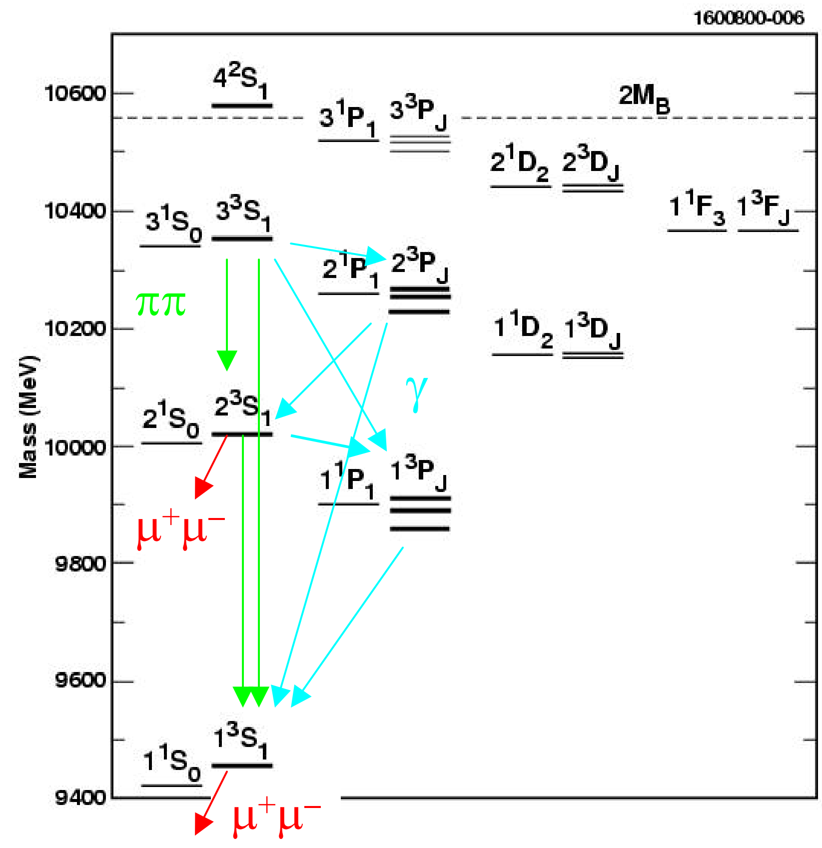
- $B_{\mu\mu}$ measures the relative strength of $\Upsilon \to \gamma^* \to l^+l^-$ to $\Upsilon \to ggg/\gamma gg$.



- Also important to determine transition rates among the bb states since these are often measured in exclusive modes:
  $\Upsilon(nS) \to \pi\pi/\gamma\gamma\Upsilon(mS)$ ($\to e^+e^-/\mu^+\mu^-$).

- Verify lepton universality by comparing the decay rate to $\tau^+\tau^-$
  $\to$ new physics*?!

$$\Upsilon(nS) \to \gamma_s \phi^0 (\to \ell^+\ell^-)$$



*M. A. Sanchez, Mod. Phys. Lett. A 17, 2265 (2003), hep-ph/0401031.

Analysis strategy

- Measure the decay rate to $\mu^+\mu^-$ ($\Gamma_{\mu\mu}$) relative to the decay rate to hadrons ($\Gamma_{had}=\Gamma-\Gamma_{ee}-\Gamma_{\mu\mu}-\Gamma_{\tau\tau}$):

$$\tilde{B}_{\mu\mu}=\frac{\Gamma_{\mu\mu}}{\Gamma_{had}}=\frac{N(\Upsilon\to\mu^+\mu^-)/\varepsilon_{\mu\mu}}{N(\Upsilon\to hadrons)/\varepsilon_{had}}$$

then $B_{\mu\mu}$ (assuming lepton universality, $\Gamma_{ee}=\Gamma_{\mu\mu}=\Gamma_{\tau\tau}$) is:

$$B_{\mu\mu}=\frac{\Gamma_{\mu\mu}}{\Gamma}=\frac{\Gamma_{\mu\mu}}{\Gamma_{had}(1+3\Gamma_{\mu\mu}/\Gamma_{had})}=\frac{\tilde{B}_{\mu\mu}}{1+3\tilde{B}_{\mu\mu}}$$

- uncertainty due to luminosity systematics cancels out
- large background from non-resonant processes (continuum)

$$e^+e^-\to\mu^+\mu^- \quad \text{and} \quad e^+e^-\to q\bar{q}$$

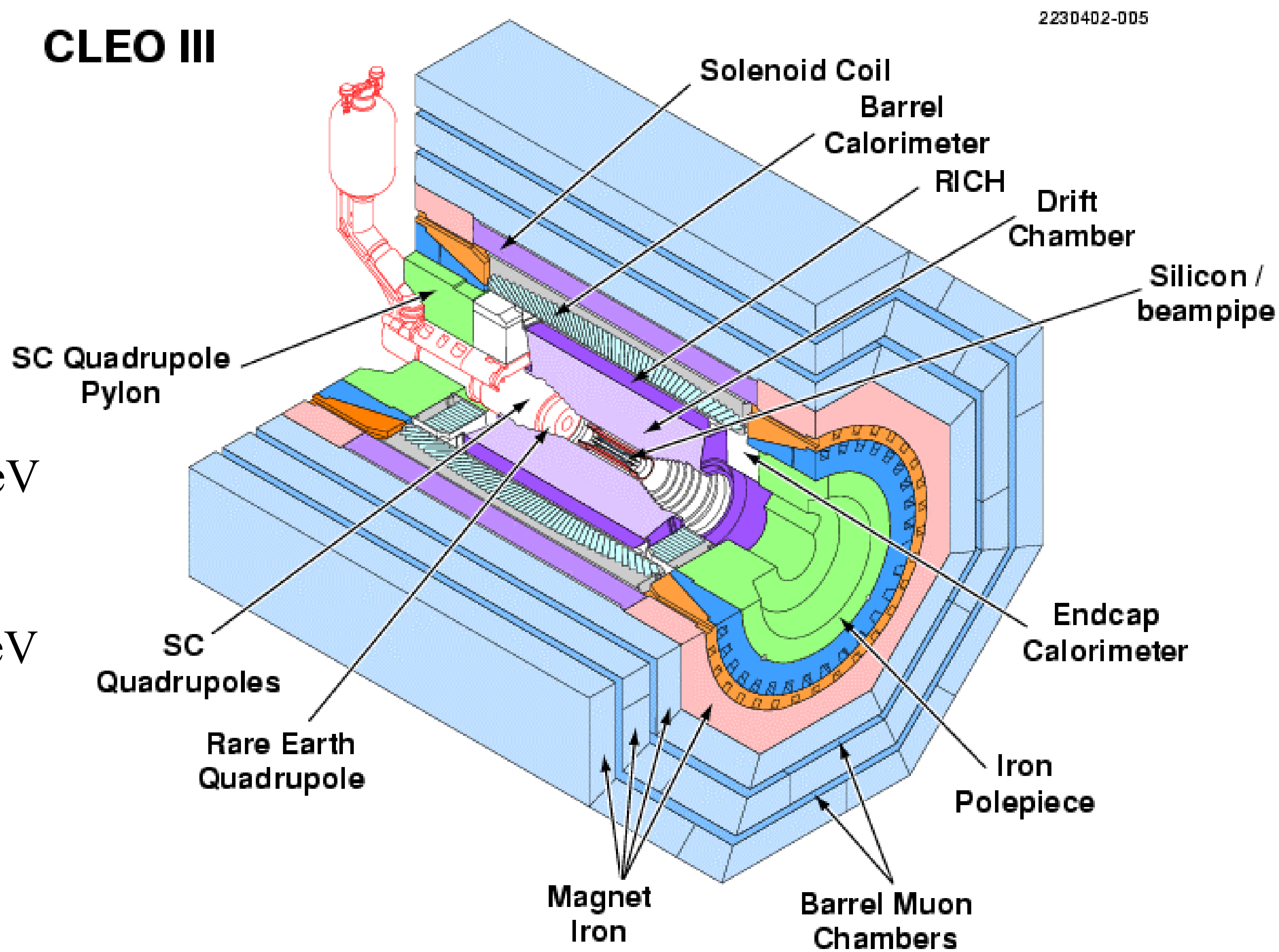
continuum subtraction using off-resonance samples:

$$N(\Upsilon\to\mu^+\mu^-)=N_{\mu\mu}^{on-res.}-S\cdot N_{\mu\mu}^{off-res}$$

CLEO detector

- Data collected with the CLEO III detector at the Cornell Electron-positron Storage Ring (CESR) in 2001-2002.

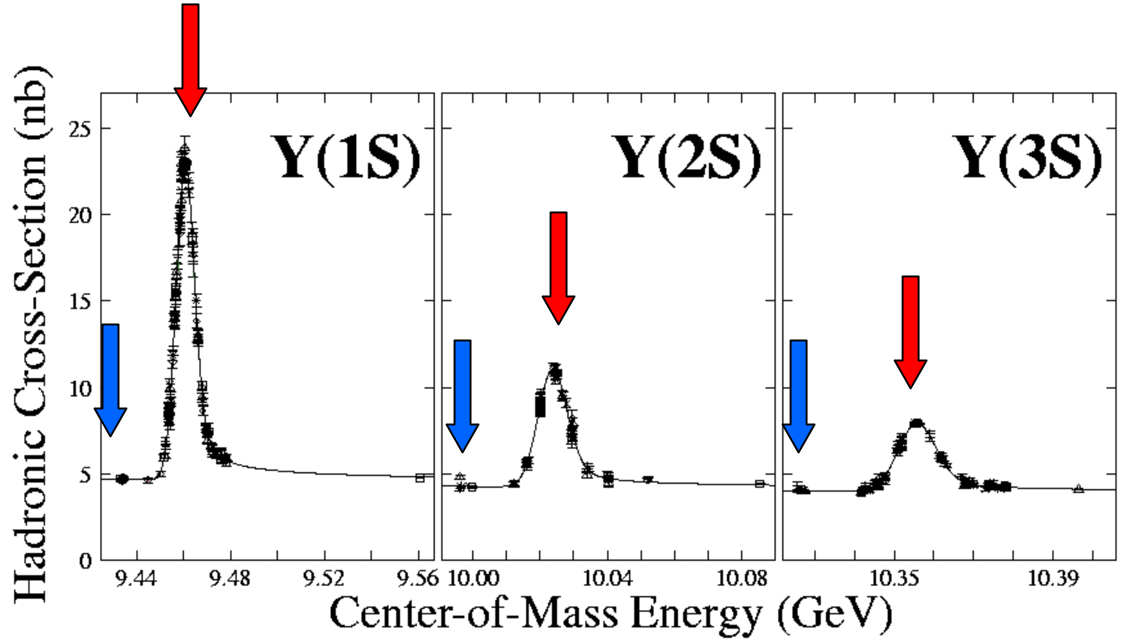
- Si Vertex Detector:
  - 4-layer double sided
- Drift Chamber:
  - 47 layers
  - 93% of 4π
  - $\sigma_p/p = 0.8\%$ @ p=5.3 GeV
- CsI Calorimeter (CC)
  - 93% of 4π
  - $\sigma_E/E = 4\%$ @ E=100 MeV
- Muon Counters (MUON)
  - 85% of 4π @ p > 1 GeV



Data sample

- on-resonance sample:
  on the peak of each resonance within 2-3 MeV.

- off resonance sample:
  20-30 MeV below each peak.



On-res./Off-res. scale factor:

$$S = \frac{\sum L^{on-res} / E_{beam}^2}{\sum L^{off-res} / E_{beam}^2}$$

$$(\sigma \propto 1/s)$$

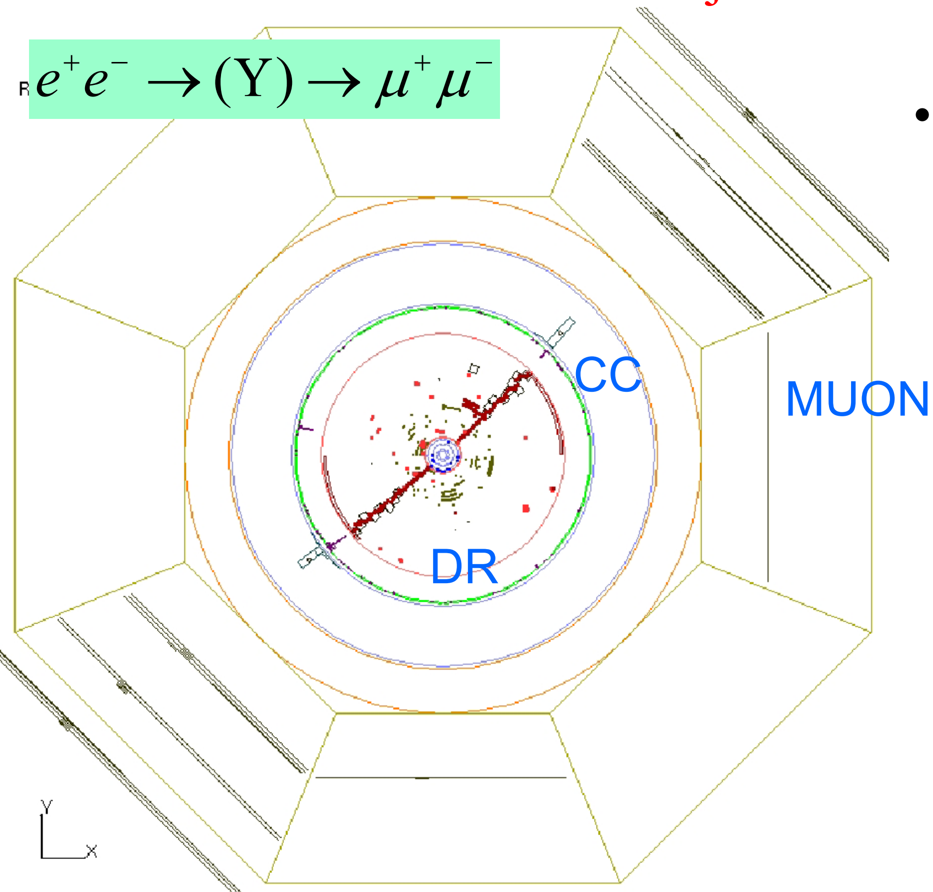
	$\mathcal{L}$ (on), pb^{-1}	$\mathcal{L}$ (off), pb^{-1}	Scale (On/Off)
Y(1S)	1050	190	5.51
Y(2S)	1180	440	2.66
Y(3S)	1190	160	7.51

Selection of $\mu^+\mu^-$ events

- Exactly 2 back-to-back tracks with net charge = 0,

  $|\cos\theta| < 0.80$ and $0.7 < p/E_b < 1.15$
- Cosmic ray rejection: require tracks to come from interaction point,
- Bhabha/hadron rejection: using CsI Calorimeter (CC) and MUON info

$e^+e^- \to (\Upsilon) \to \mu^+\mu^-$



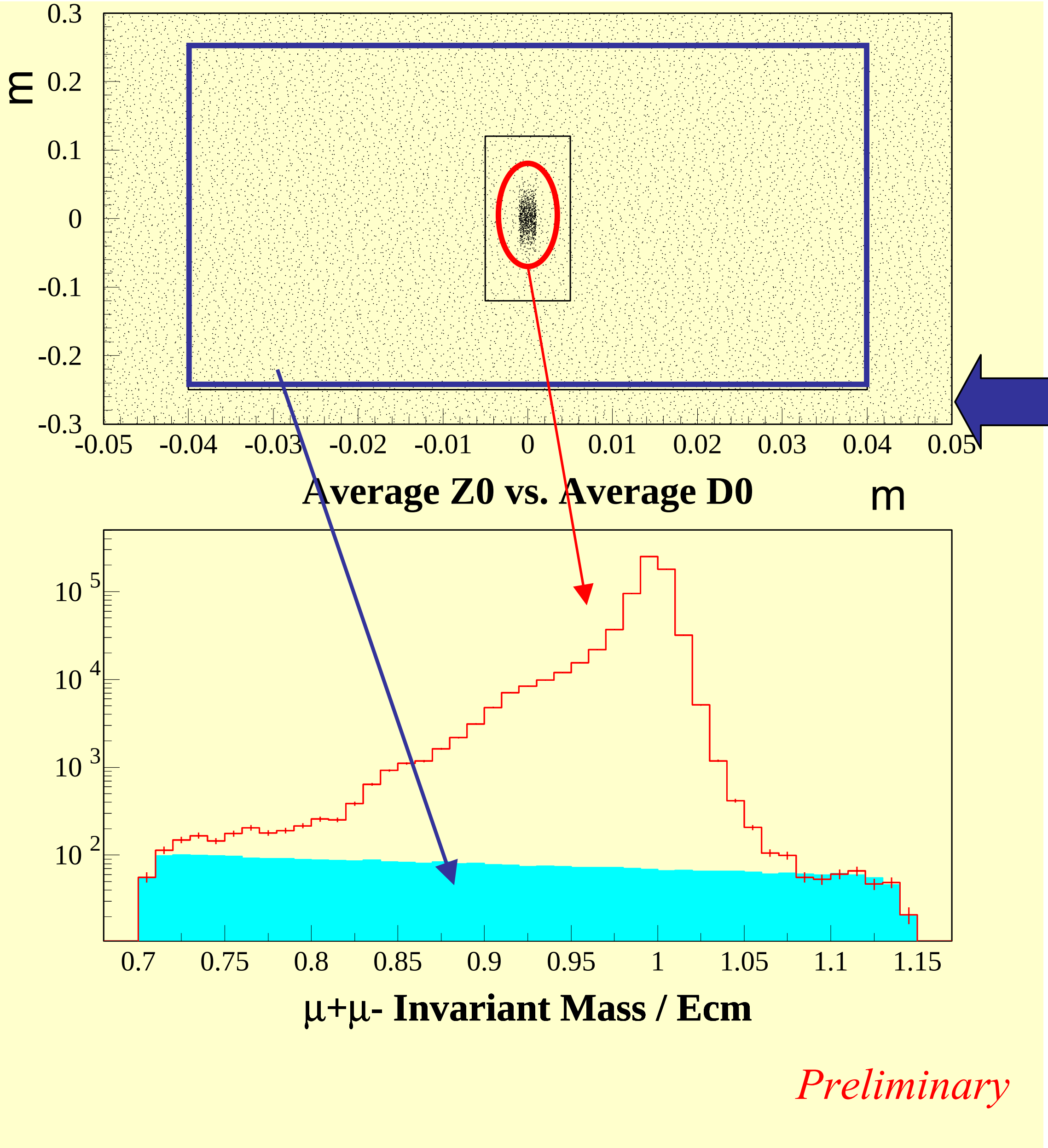
- Number of extra showers in CC < 2

  suppress cascade decays

  $\Upsilon(nS) \to \Upsilon(mS)\ \pi^0\pi^0/\gamma\gamma$, $\Upsilon(mS) \to \mu^+\mu^-$

Efficiency for:
- $\Upsilon \to \mu^+\mu^-$: 65%
- $e^+e^- \to \mu^+\mu^-$: 45%

Cosmic-ray suppression



Separation between the tracks:

< 2mm (x-y)

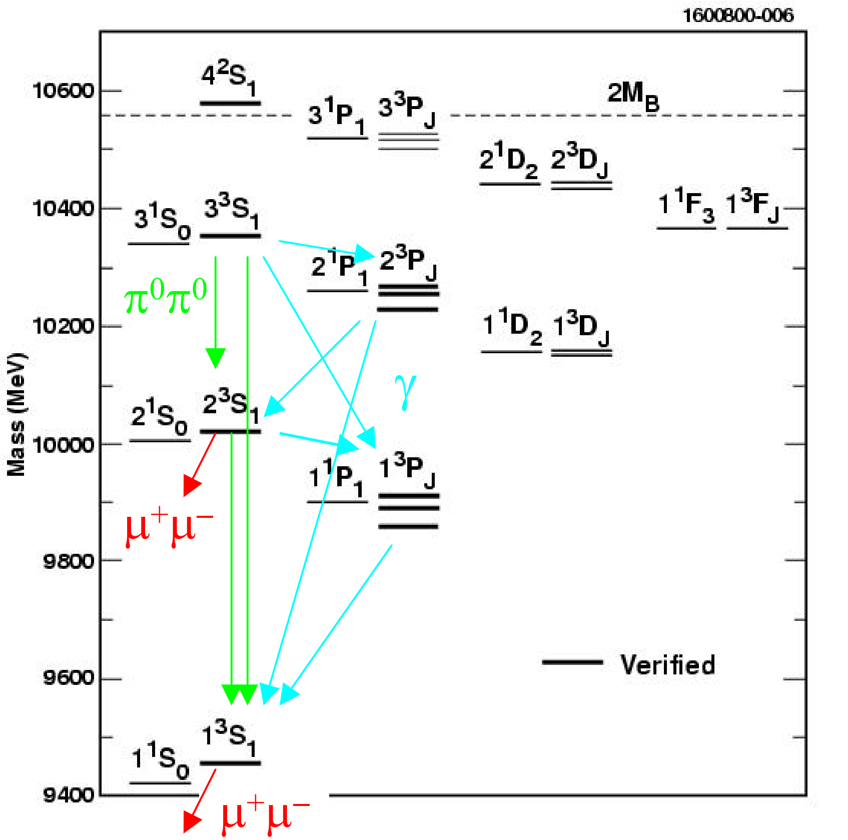
< 5 cm (along z)

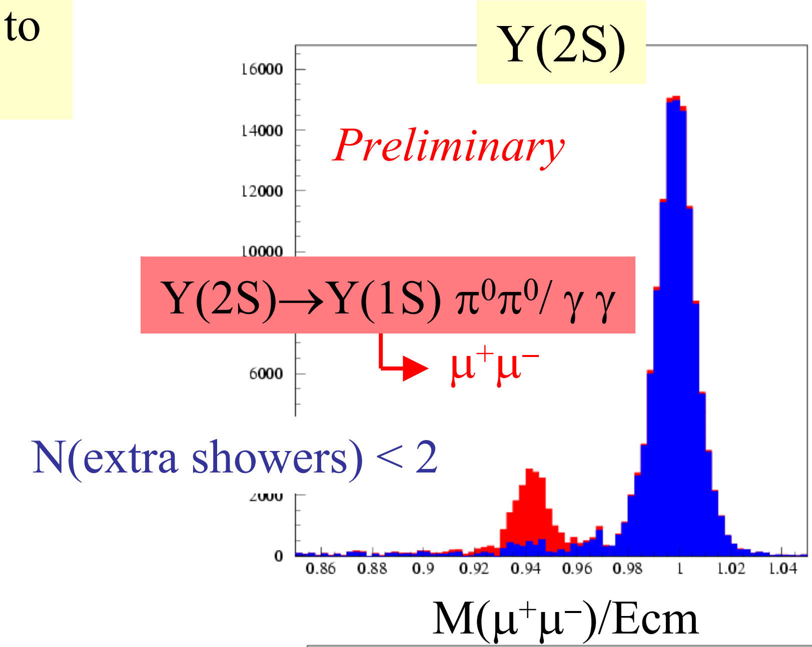
Two-dimensional plot of the average distance from IP can be used to estimate cosmic background.

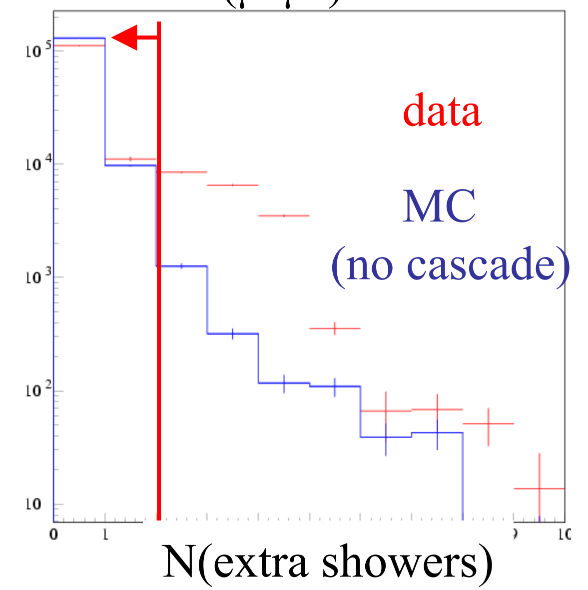
Remaining cosmic background: ~ 0.3-0.6%

Background from cascade decays

On the Υ(2S) and Υ(3S), significant background due to cascade decays.





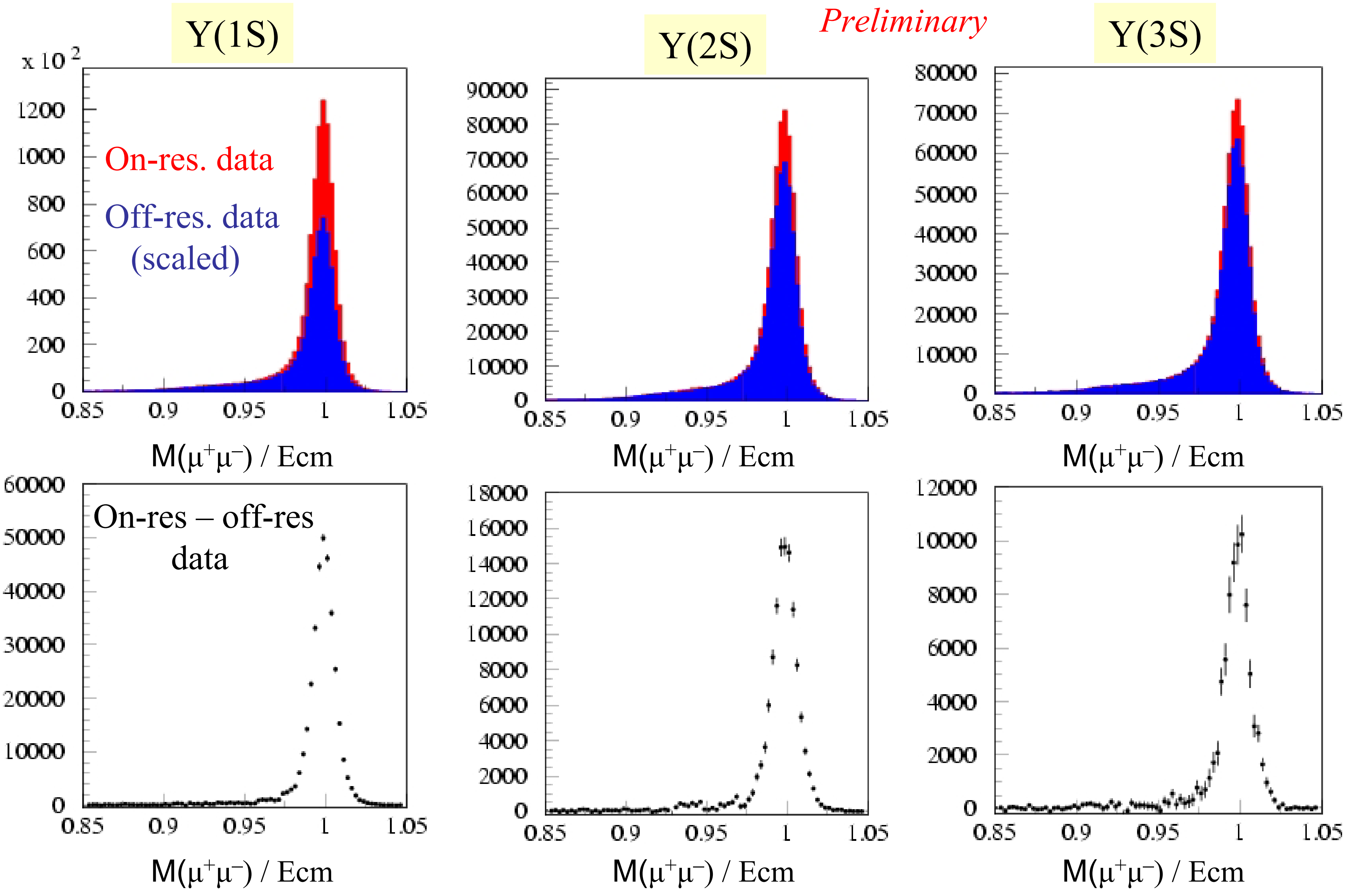


The remaining background is estimated to be

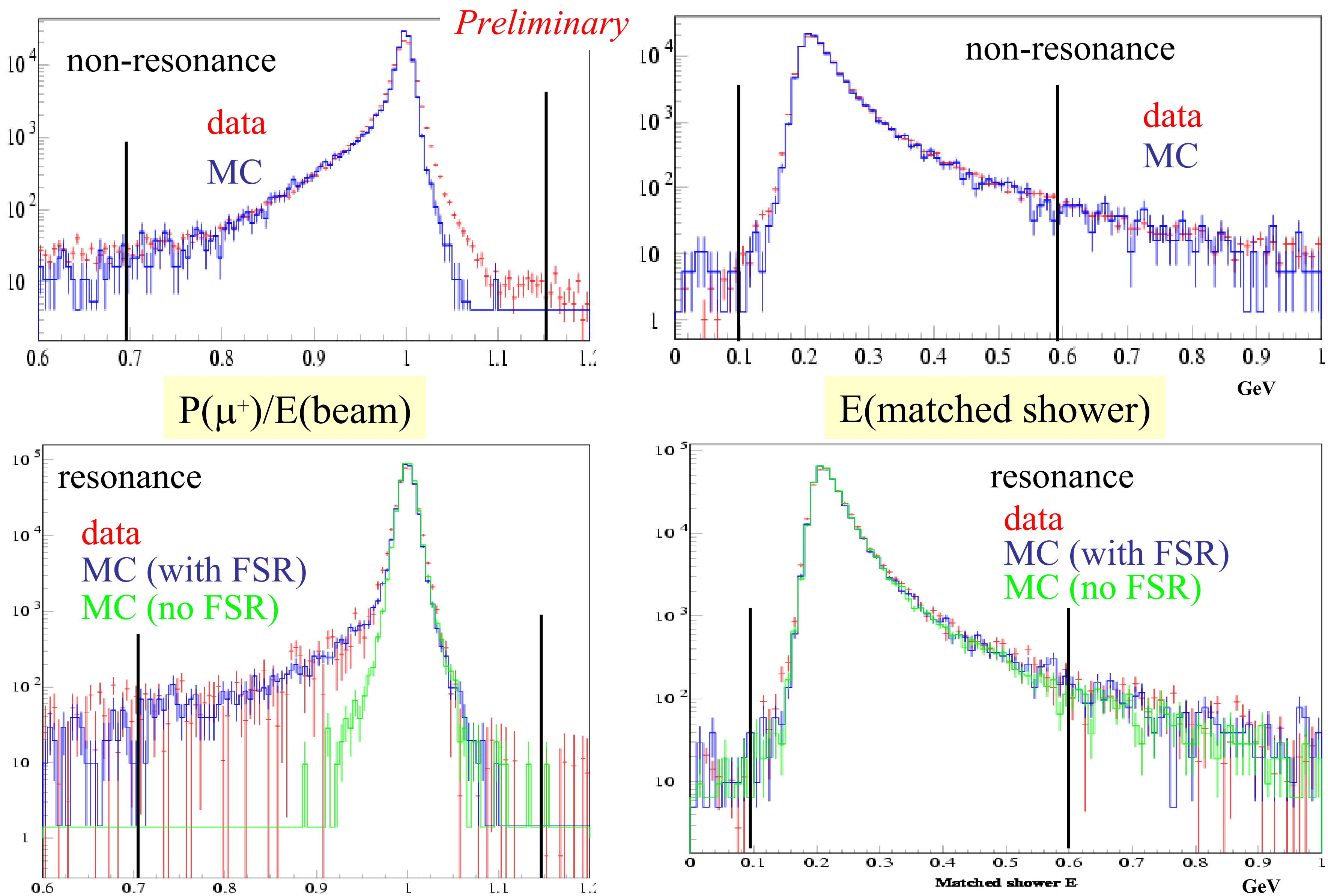
Υ(2S): (2.9 ± 1.5)%

Υ(3S): (2.2 ± 0.7)%

Selected muon pairs

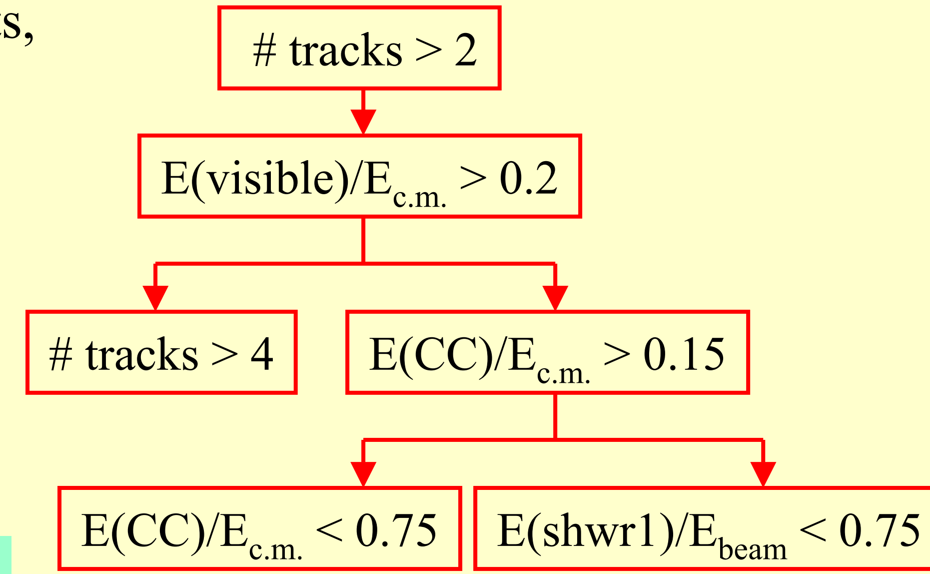


Data - MC comparison



Selecting $\Upsilon \rightarrow$ hadrons

- Rejecting $e^+e^- \rightarrow e^+e^- / \mu^+\mu^- / \gamma\gamma$ events, beam-gas, beam-wall interactions:



- Event vertex position:
  - suppress beam-gas, beam-wall and cosmic background
  - estimate the remaining beam-gas events.

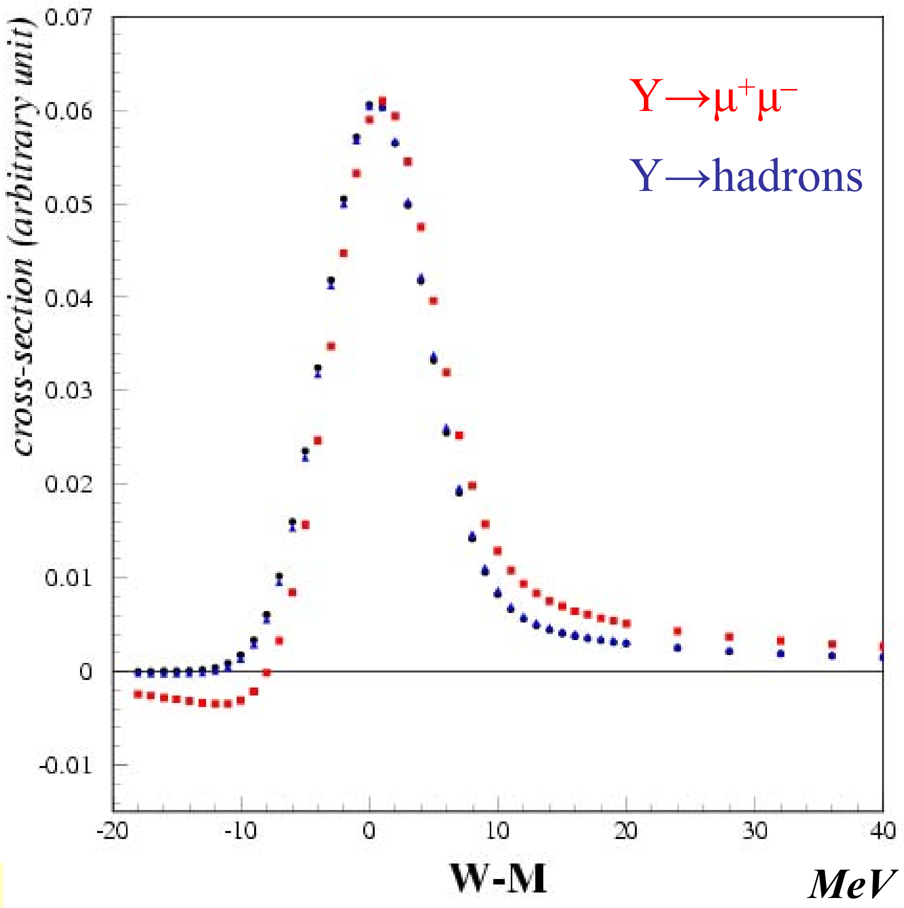
Efficiency for Υ decays to hadrons: 96-98%.

Efficiency for $\Upsilon(nS) \rightarrow \tau^+\tau^-$ is ~26% (effective contribution is ~0.4–0.7%)

Continuum subtraction removes essentially all the remaining non-resonant background from two-photon fusion, $q\bar{q}$, $\tau^+\tau^-$.

Interference

- Interference between resonance decay and continuum production of the same final state distorts the resonance shape.
- Interference effect is different for $\mu^+\mu^-$ and hadrons (only qq interferes) hence the measured relative decay rate depends on E_{cm}.
- Convolute the interference corrected BW shape with a Gaussian energy spread and a radiative tail to estimate the effect of interference.



Fractional correction to $B_{\mu\mu}$: 1S: -1.6%
2S: -3.9%
3S: -1.8%

Statistical and systematic uncertainties

- Statistical uncertainties: subtraction of the <u>scaled</u> off-resonance data increases the stat. uncertainty!

$$\delta N(res) = [\delta N(on)^2 + S^2 \delta N(off)^2 + N(off)^2 \delta S^2]^{1/2}$$

	Y(1S)	Y(2S)	Y(3S)
Fractional statistical uncertainty	<1%	1.5%	3.0%

- Systematic uncertainties:

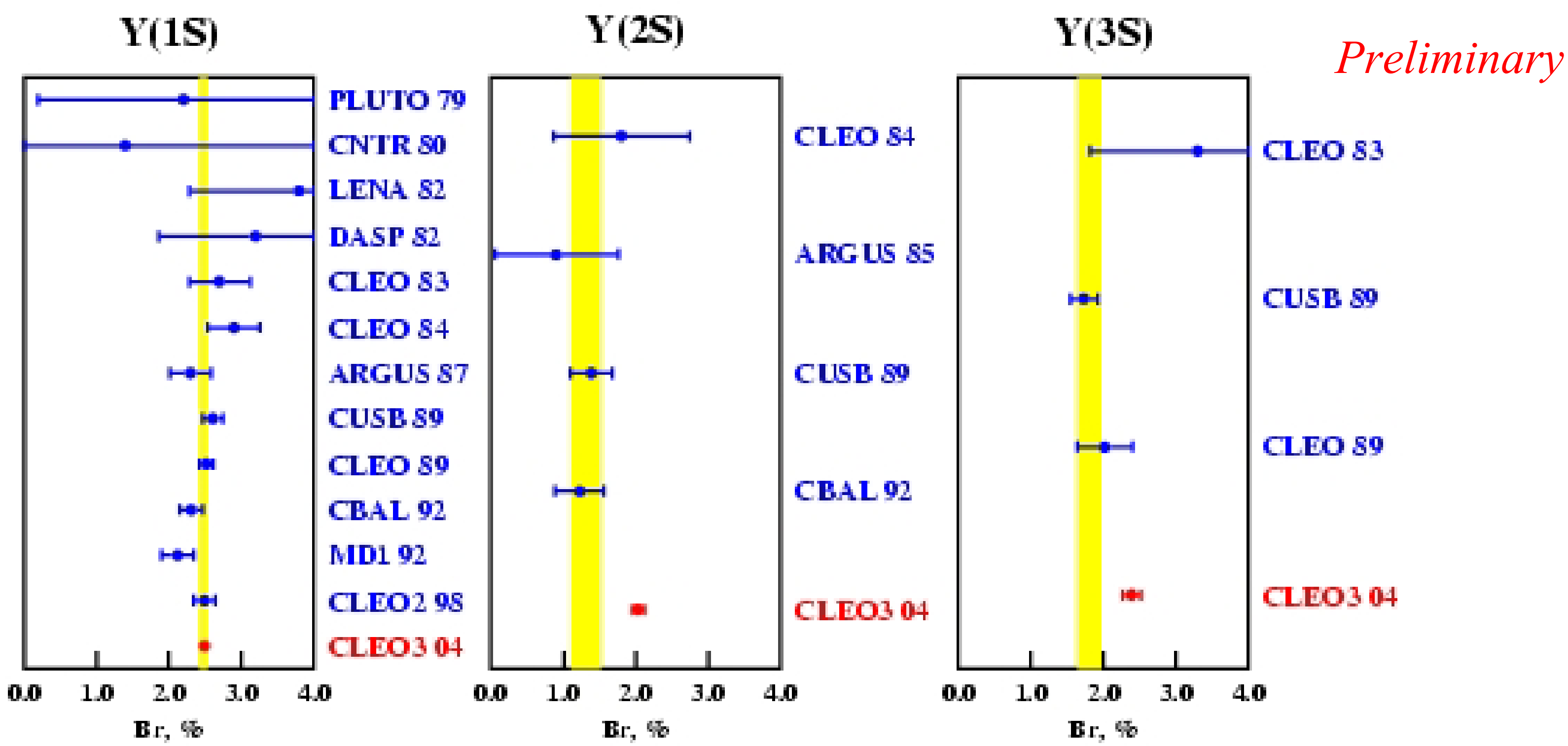
❖ efficiency: detector modeling, trigger, MC statistics
❖ N(events): background subtraction (cosmic, cascade, ττ)
❖ Scale factor: 0.5% variation
❖ Interference: variation in parameters and energy

Preliminary

	Y(1S)	Y(2S)	Y(3S)
ε(had)	1.6%	1.3%	1.4%
N(had)	0.2%	0.3%	0.4%
ε(μμ)	1.8%	1.8%	1.8%
N(μμ)	0.1%	1.6%	0.9%
Scale(on/off)	0.8%	2.3%	3.1%
Interference	1%	1%	1%
Frac. systematic	2.7%	3.7%	4.1%

$\mathcal{B}(\Upsilon(nS) \to \mu^+\mu^-)$

	Υ(1S)	Υ(2S)	Υ(3S)
N(μμ) 10^3	344.9 ± 2.5	119.6 ± 1.8	81.2 ± 2.7
ε(μμ)	0.652 ± 0.002	0.652 ± 0.002	0.652 ± 0.002
N(had) 10^6	18.96 ± 0.01	7.84 ± 0.01	4.64 ± 0.01
ε(had)	0.979 ± 0.001	0.965 ± 0.001	0.975 ± 0.001
$B_{\mu\mu}$ (%)	2.49 ± 0.02 ± 0.07	2.03 ± 0.03 ± 0.08	2.39 ± 0.07 ± 0.10



Summary

- CLEO has measured $B_{\mu\mu}$ for $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$: *Preliminary*

1S:	$(2.49 \pm 0.02 \pm 0.07)\%$	PDG: $(2.48 \pm 0.06)\%$
2S:	$(2.03 \pm 0.03 \pm 0.08)\%$	$(1.31 \pm 0.21)\%$
3S:	$(2.39 \pm 0.07 \pm 0.10)\%$	$(1.81 \pm 0.17)\%$

- Br(1S) is consistent with PDG, but Br(2S) and Br(3S) is much larger.

- Total decay width
  using $\Gamma_{ee}\Gamma_{had}/\Gamma$ from PDG.

$$\Gamma = \frac{\Gamma_{ee}\Gamma_{had}/\Gamma}{B_{\mu\mu}(1-3B_{\mu\mu})}$$

$\Gamma(1S) = (52.8 \pm 1.8)$ keV	PDG: (52.5 ± 1.8) keV
$\Gamma(2S) = (29.0 \pm 1.6)$ keV	(44 ± 7) keV
$\Gamma(3S) = (20.3 \pm 2.1)$ keV	(26.3 ± 3.5) keV

- Results submitted to PRL (hep-ex/0409027)