Universality & LFV in Upsilon Decays at CLEO

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For the CLEO Collaboration

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Topics

- CLEOIII Detector and Data
- A Search for the Lepton Flavor Violating decay $\Upsilon \to \mu\tau$
- Test of Lepton Universality in $\Upsilon \to \tau\tau$ and $\Upsilon \to \mu\mu$

The CLEOIII Detector

CLEOIII

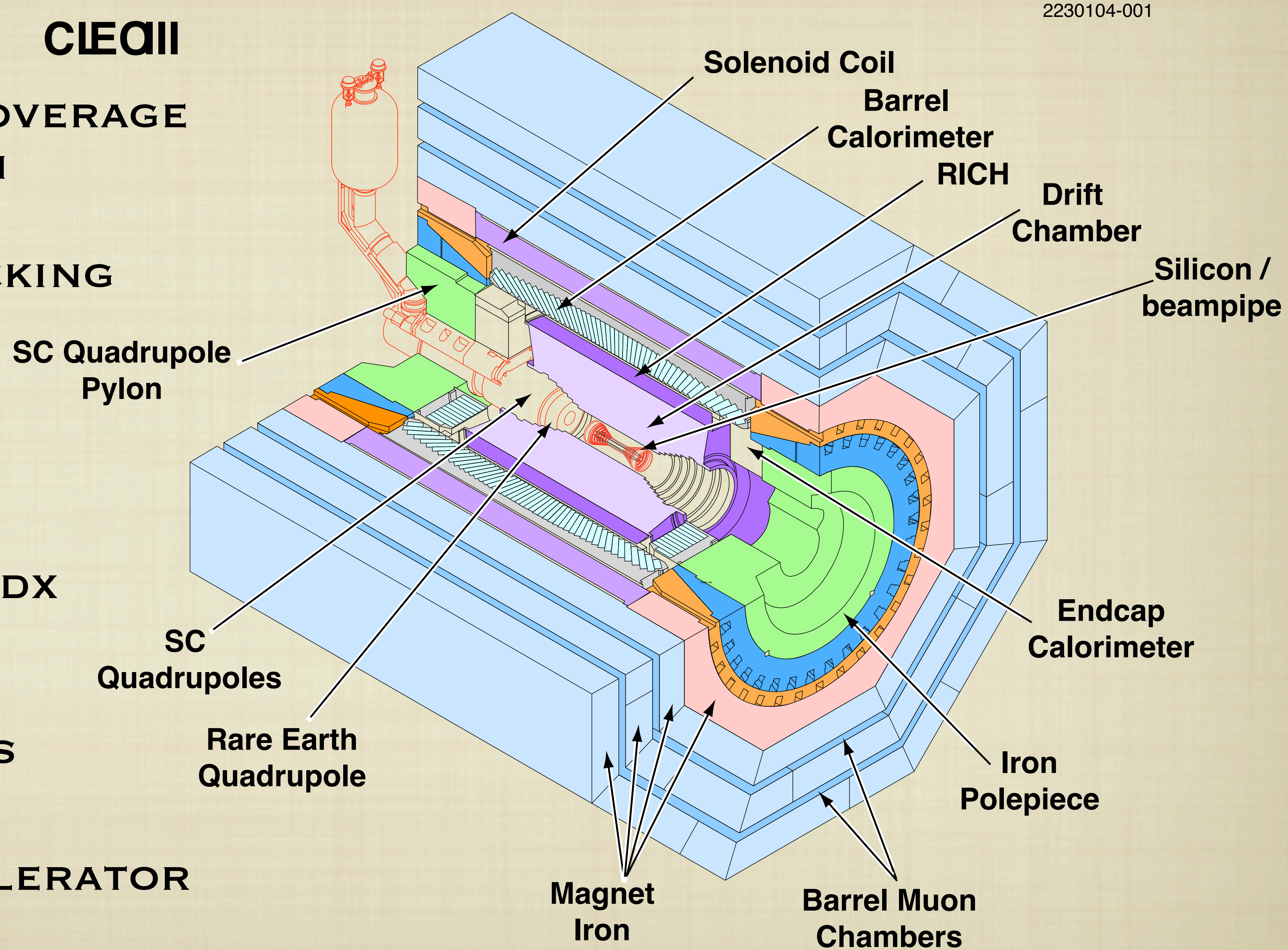
Excellent Calorimeter Coverage and Resolution

Excellent Tracking Coverage and Resolution

Ring Imaging Cerenkov & dE/dx for PID

Muon Chambers

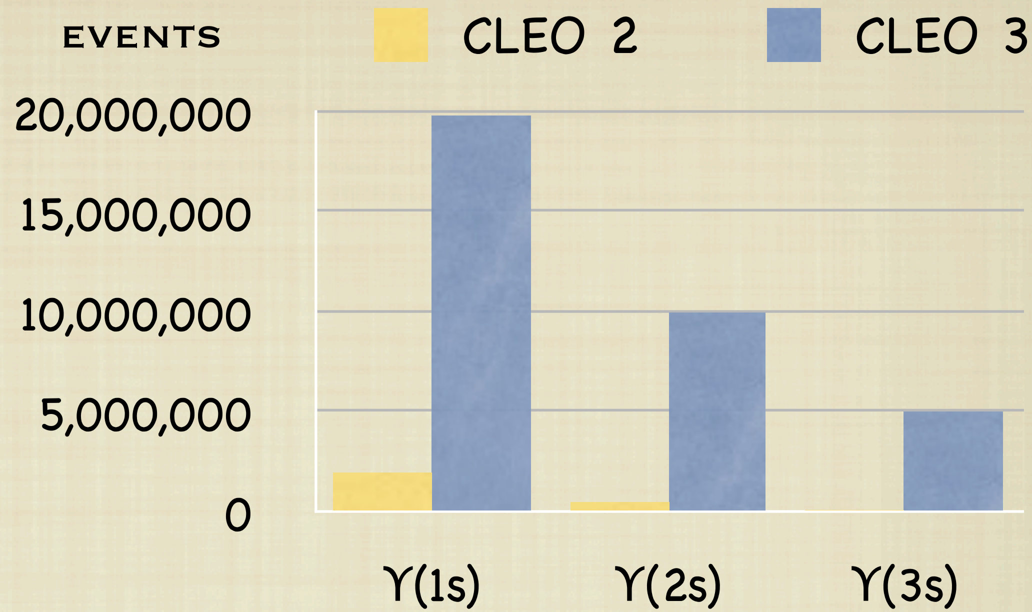
+ A Great Accelerator Team CESR

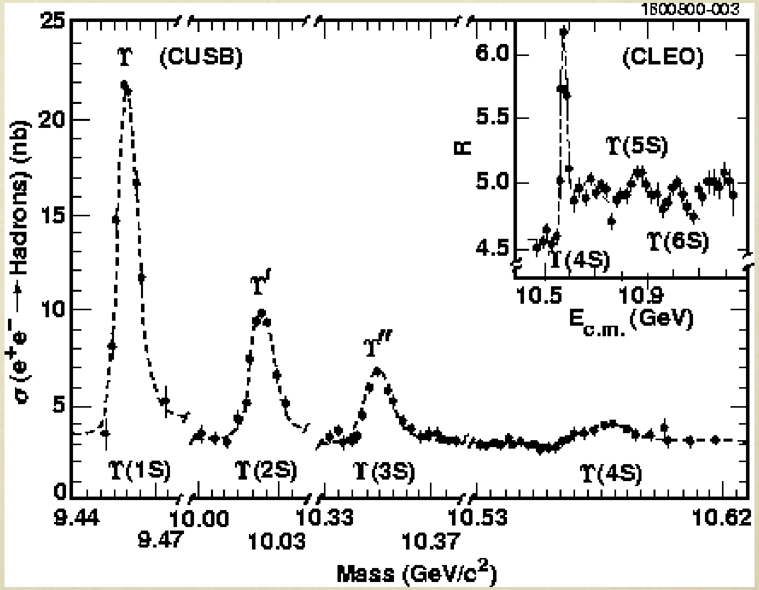


CLEO Upsilon Data

CLEOIII **HAD** the largest world sample of clean Υ events below B threshold (cf Belle 3s)

Also has off-resonance data + scan data + data at Υ (5S)





Search for LFV Violation in $\Upsilon \to \mu\tau$

Lepton Flavor Violation

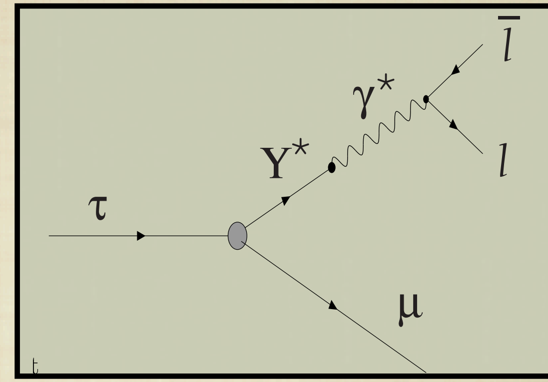
- We don't annihilate when we shake hands.
- Baryon Asymmetry generated via Sakharov conditions: B & C & CP violation, + Universe out of thermal Equilibrium for a while
- B, L are accidental symmetries of SM
- B-L is however conserved
- Maybe B is violated because L is violated and maybe this is related to LFV ?

LFV for τ and Υ Decays

- τ Decay LFV talks about Υ LFV

  S.Nussinov, R.D.Peccei, X.M. Zhang PRD63(2000), 016003

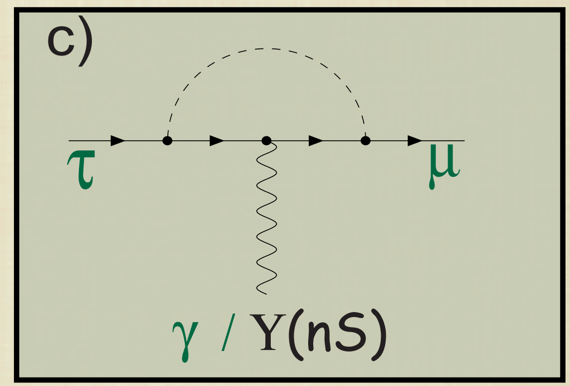
  $B(\tau \rightarrow 3\mu) < 10^{-6} \Rightarrow B(\Upsilon \rightarrow \mu\tau) < 10^{-2}$

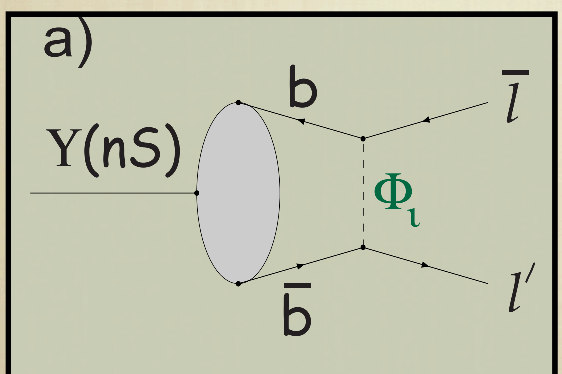


SUSY Loops

W.J. Huo, C.X. Yue, T.F. Heng, PRD67(2003), 114001

$B(\Upsilon \rightarrow \mu\tau) < 2.2\mathrm{x}10^{-9}$

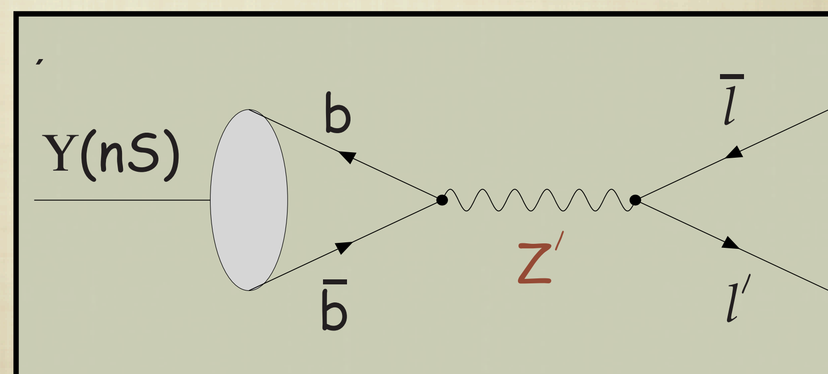




LeptoQuark

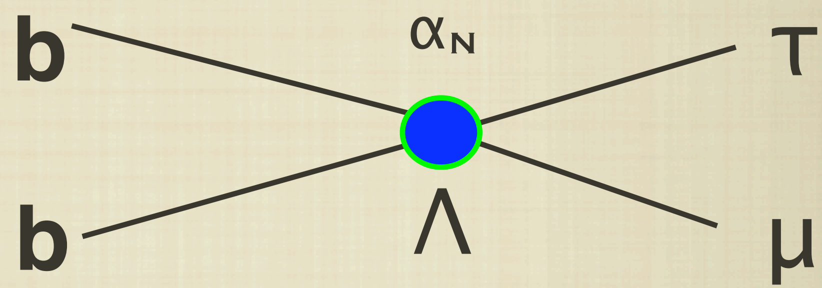
Z'

$B(\Upsilon \rightarrow \mu\tau) < 1.3\mathrm{x}10^{-8}$



LFV for τ, Υ Decays

Z. Silagadze, Phys. Scripta 64(2001), 128



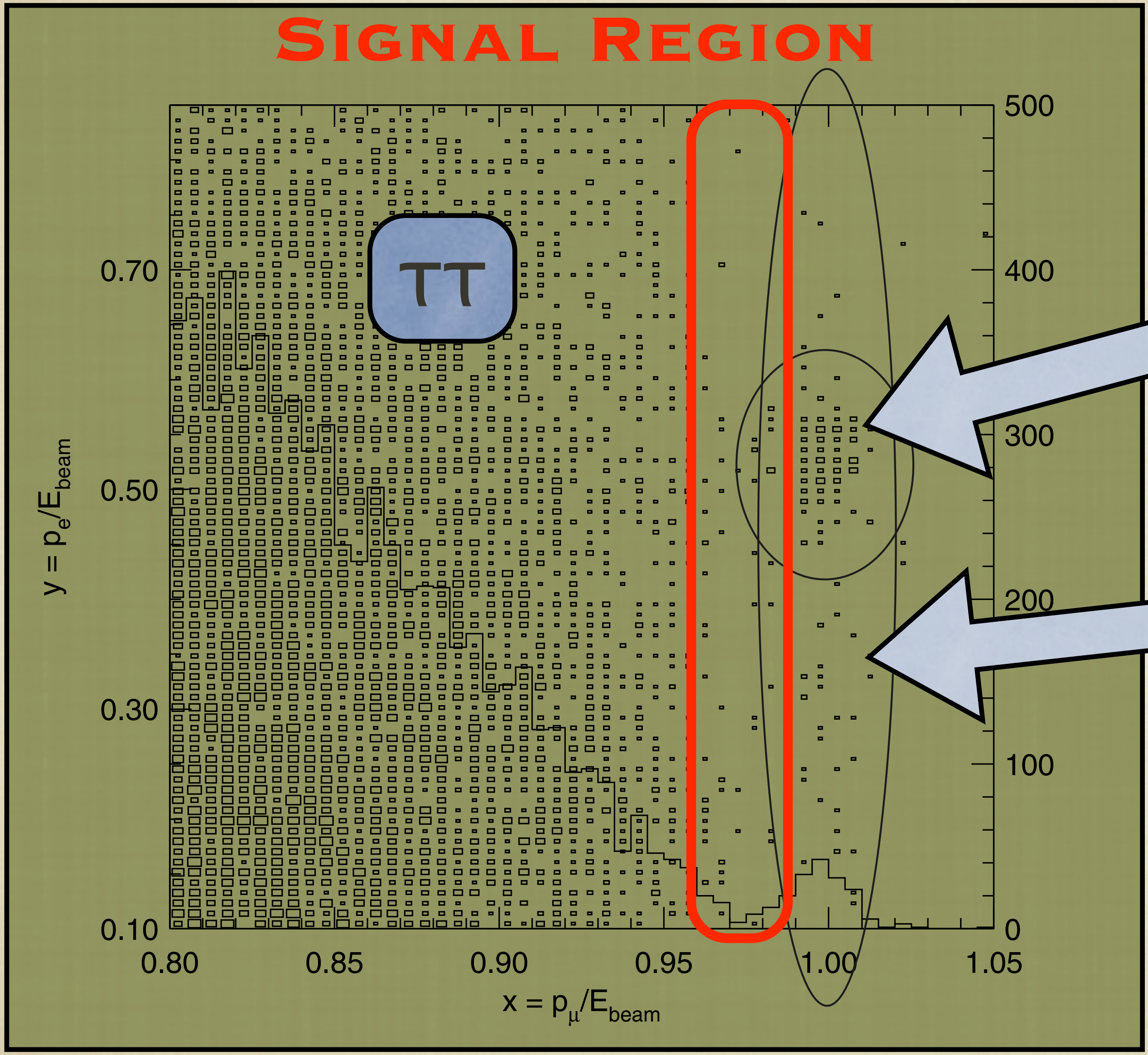
Generic 4 fermion coupling α_N at scale Λ added to SM to get LFV

$$\frac{B(\Upsilon \to \mu\tau)}{B(\Upsilon \to \mu\mu)} \propto (\alpha_N/\alpha)^2 (M_\Upsilon/\Lambda)^4$$

LFV: The analysis

- Search for $\Upsilon \to \mu\tau$, $\tau \to e\nu\nu$
- 2 tracks: μ (muon ID), e (E/p, dE/dx) μ near Ebeam
- Extended Max Likelihood $\mathcal{L} = e^{-N_{evnt}} \Pi_{evnt} \left(\Sigma N_i \mathcal{P}_i(X|S)\right)$
- Use Product PDF: $\mathcal{P}(p_\mu) \times \mathcal{P}(p_e) \times \mathcal{P}(dE/dx(e)) \times \mathcal{P}(E/p(e))$
- Sum over: Signal LFV decay $\oplus$ $\tau\tau$ $\oplus$ $\mu\mu$ (γ) w/ hard γ $\oplus$ $\mu\mu$ with μ decay to electron
- Υ(4S), off res used as calibration & control samples

Background & Signal Regions



Ups(4S) data

μμ + hard γ

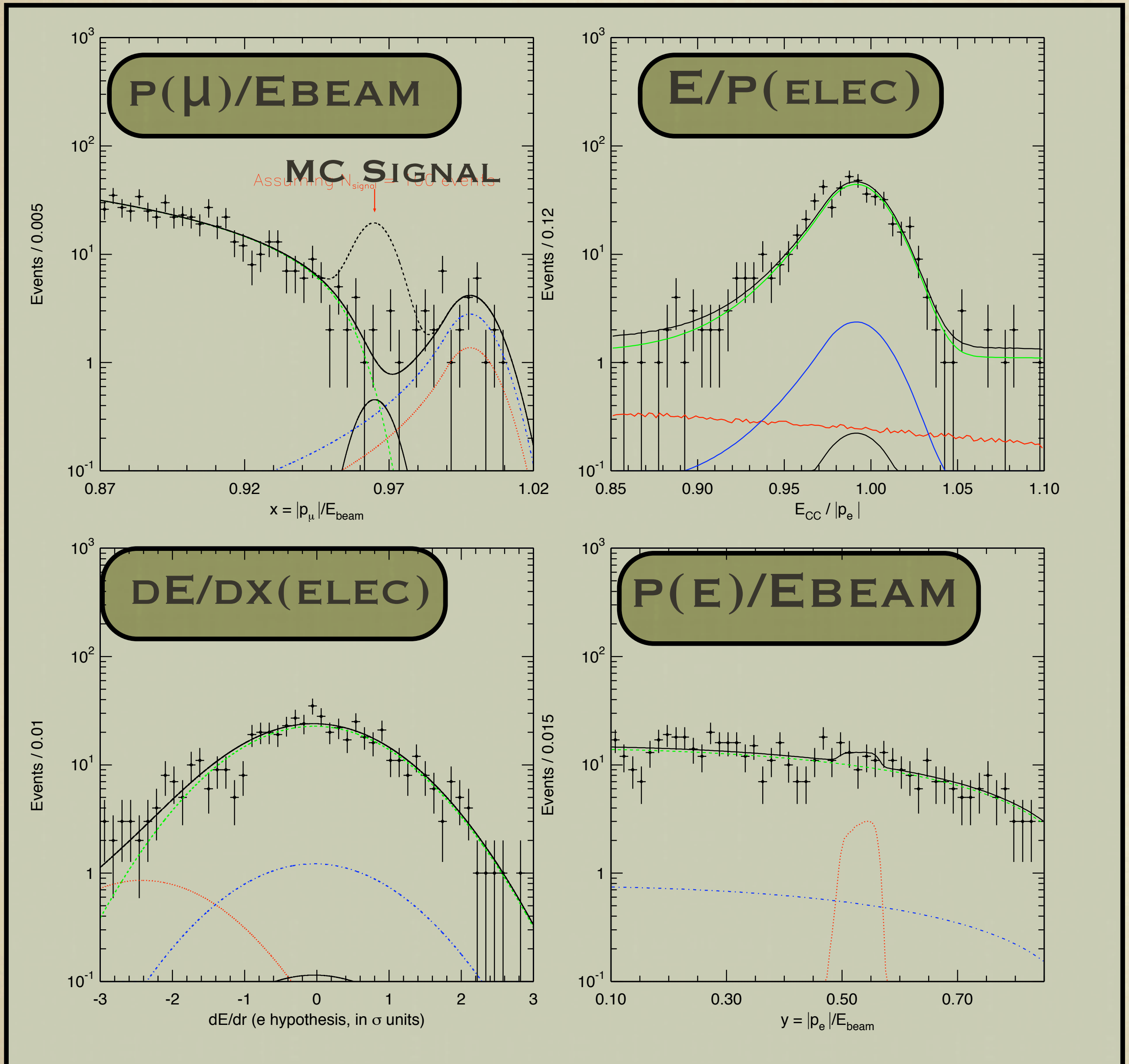
γ hits CC and fakes E/p

μμ & μ decay in flight

about 100 in ϒ(4S) data

Extract most PDFs from ϒ(4S) data

Fits to Υ(1S) Data



ττ

μμ hard γ

μμ, decay in flight

Preliminary LFV Results

Resonance	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
Efficiency	8.9%	8.9%	8.9%
Nevents	< 10.0	< 10.7	< 8.5
$B(\Upsilon \to \mu\tau)(10^{-6})$	< 6.2	< 25	< 22
$B(\Upsilon \to \mu\tau)/B(\Upsilon \to \mu\mu)$	< 0.023%	< 0.17%	< 0.13%

All limits are 90% CL UL

- Largest Syst: PDF shapes & correlations
- First Limits on $\Upsilon \to \tau\mu$
- These BRs set a lower limit of $\approx$ 1 TeV on generic LFV scale (assuming strong coupling)

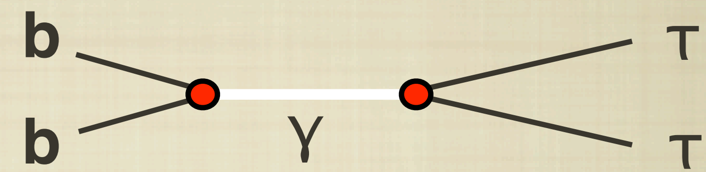
Universality in Υ Decays with Υ→μμ,ττ

$\Upsilon \to \tau\tau$ Motivation

- CLEO has measured $B(\Upsilon(nS) \to \mu\mu)$, $\Gamma(ee \to \Upsilon(nS))$ n=1,2,3 - see talk by Istvan Danko
- $\Upsilon \to \tau\tau$ rounds out this series
- $B(\Upsilon(1S) \to \tau\tau)$ known to $\approx$ 10 % in PDG
- $\Upsilon(2S) \to \tau\tau$ "observed"
- $\Upsilon(3S)$ not yet seen

$\Upsilon \to \tau\tau$ Motivation

- Naive Universality:



  - $B(\Upsilon \to ee) = B(\Upsilon \to \mu\mu) = B(\Upsilon \to \tau\tau)$

- If this ain't the case, there's some explaining to do

- Sanchis-Lozano: Higgs searches have a blind spot near the Υ — cf next talk, hep-ph/0307313

- The decay chain $\Upsilon \to \gamma\eta_b$, $(\eta_b \to A^0)$, $A^0 \to \tau\tau$ could alter $N(\Upsilon \to \tau\tau)/N(\Upsilon \to \mu\mu)$, if γ soft&undetected

Goal: $B(\Upsilon \to \tau\tau)/B(\Upsilon \to \mu\mu)$

- Isolate $\mu\mu$ and $\tau\tau$ signals at & below $\Upsilon(nS)$, $n=1..4$

Technique Check

- Apply On -S*Off to $\Upsilon(4S)$ data for $\mu\mu$ and $\tau\tau$ - expect $B(4S \to \ell\ell) \approx 0$

  $s = \mathcal{L}_{on}/\mathcal{L}_{off}\,(E_{off}/E_{on})^2$

Technique Check

- Find Off Resonance $\sigma(e^+e^- \to \tau\tau)$; compare with $\sigma(e^+e^- \to \mu\mu)$

- Apply On-S*Off to 1S, 2S, 3S data for $\mu\mu$ and $\tau\tau$

- Extract $R = N(\Upsilon \to \tau\tau)/N(\Upsilon \to \mu\mu)$

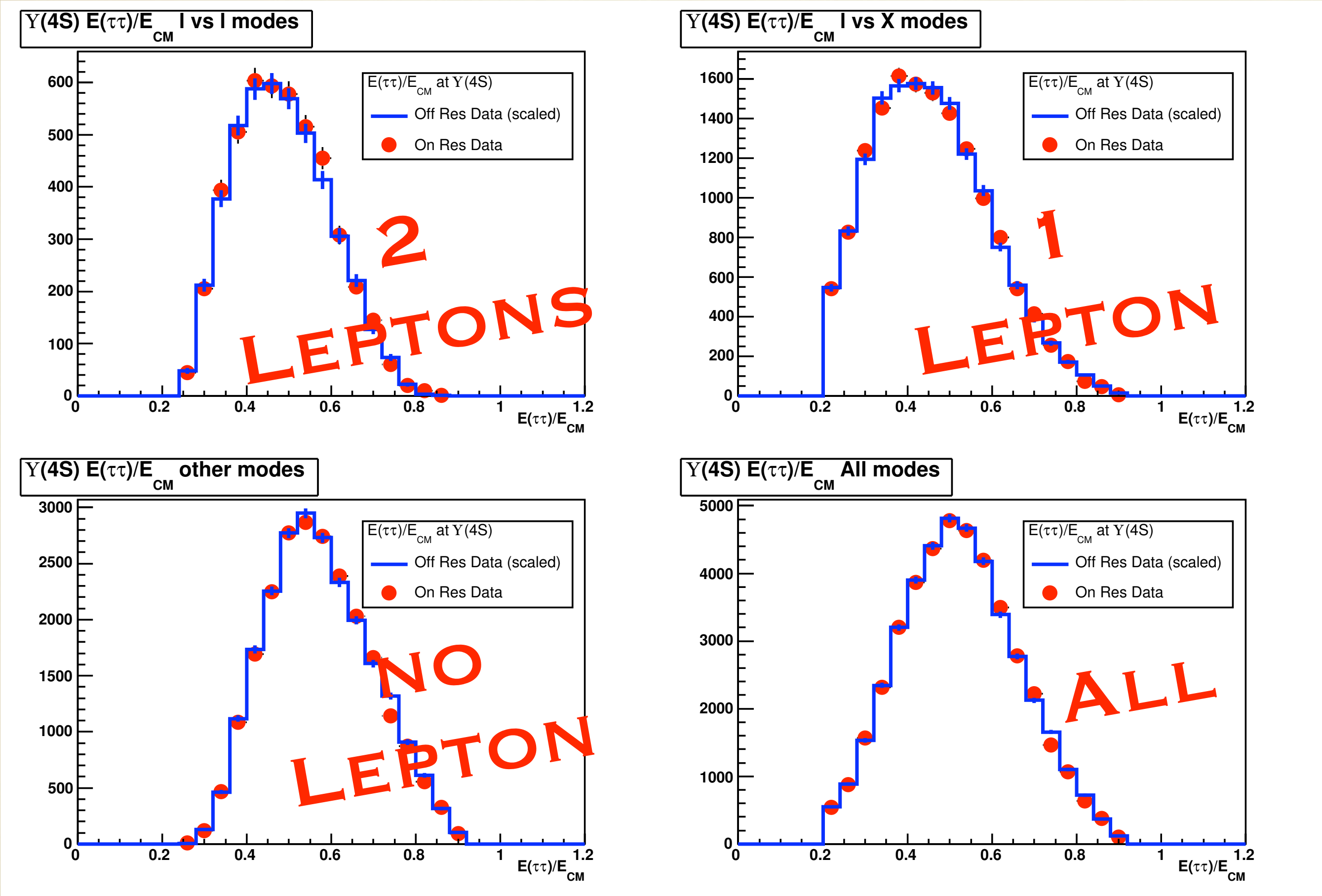
- Get Branching Ratio $B(\Upsilon \to \tau\tau)$ using $B(\Upsilon \to \mu\mu)$

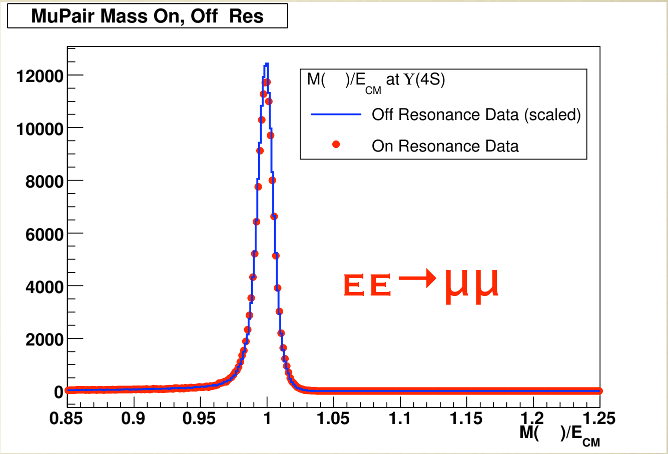
How to find $\Upsilon \to \tau\tau, \mu\mu$

- Use $\mu\mu$ cuts similar to previous $\Upsilon \to \mu\mu$ study
- Use 1 Prong decays : $B(\tau \to 1\text{prong}) \approx 75\%$
- 2 Track events, passing generic $\tau\tau$ missing momentum, energy cuts (neutrinos!)
- Classify tracks as e, μ, X
- Include neutral energy, shower cuts

Cosmics are rejected

On & S*Off at the Υ(4S)





On-S*Off works at Υ(4S)

No evidence for non-$1/E^2$ background

Off Res σ(ττ)/σ(μμ)/Exp

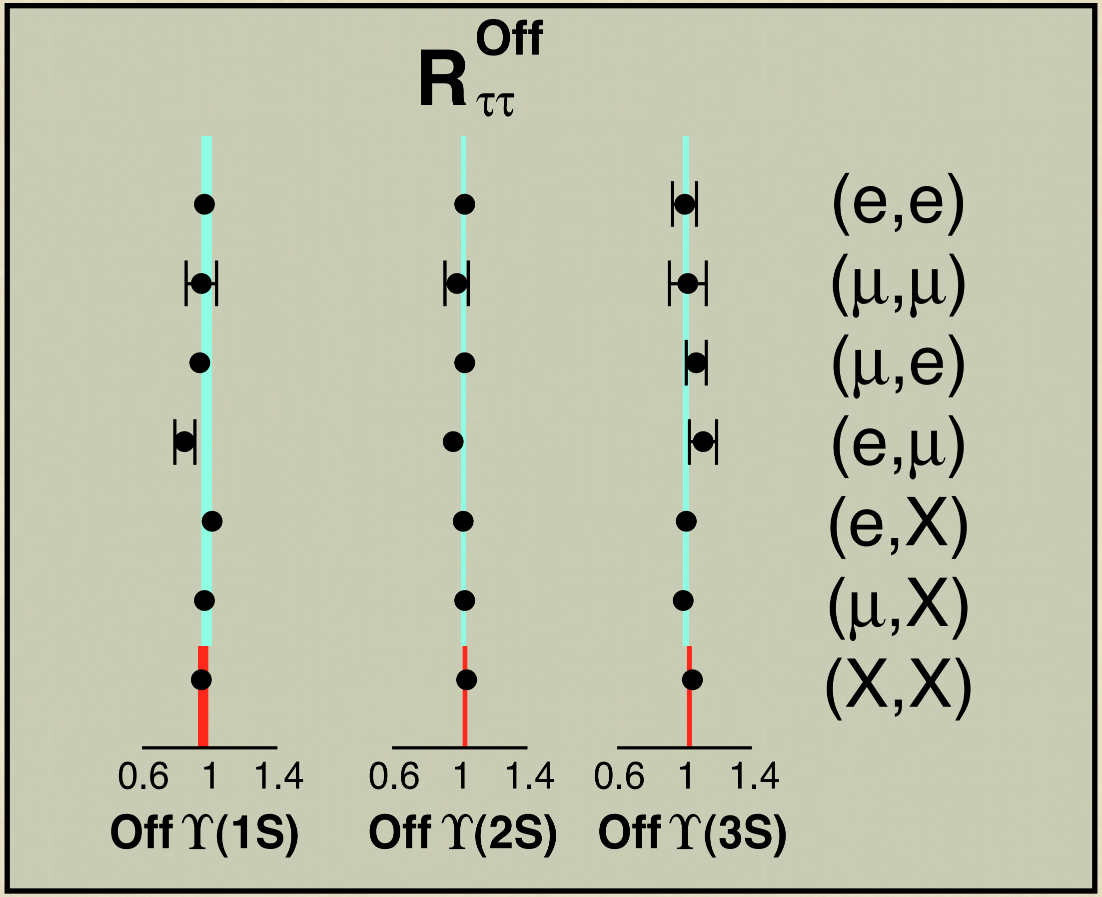
Breakdown by τ decay channels

$$\frac{\sigma^{theory}(e^+e^- \to \tau\tau)}{\sigma^{theory}(e^+e^- \to \mu\mu)} = 0.82$$

(X,Y) = P(X)> P(Y)

Average over lepton modes

overall average

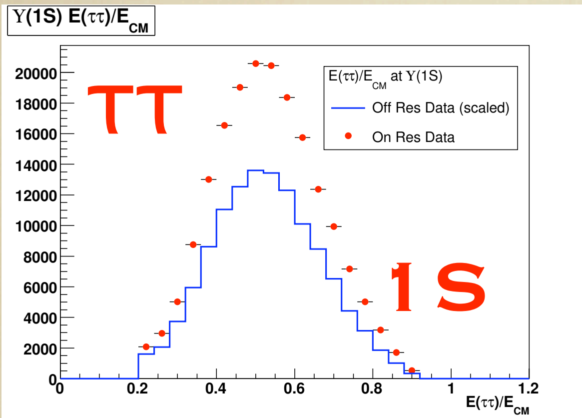


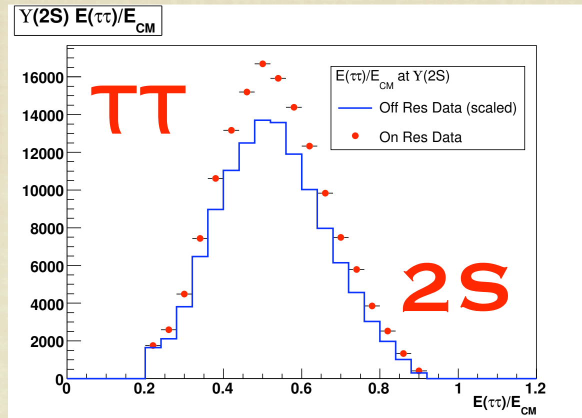
All decay channels agree

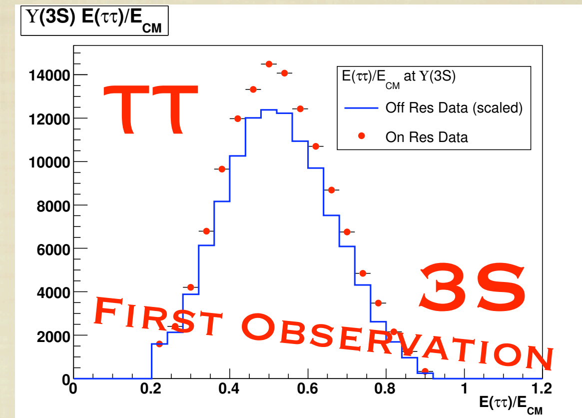
We can reconstruct ee→ττ, μμ

On And S*Off Res For ττ, μμ

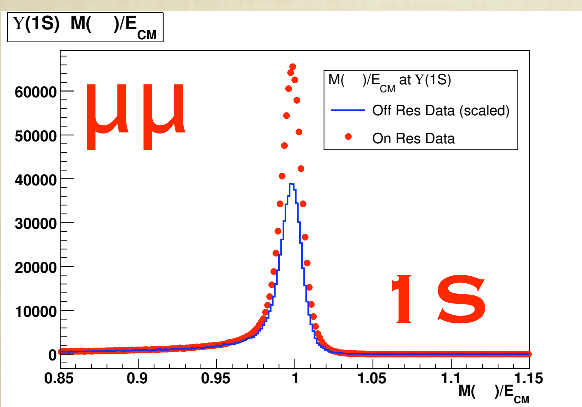
Total ττ Reconstructed Energy /Ecm :

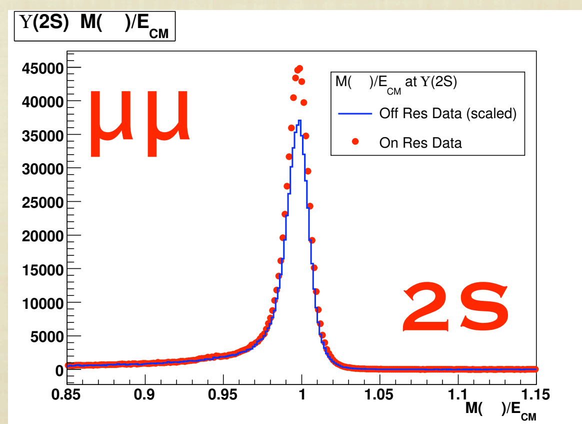


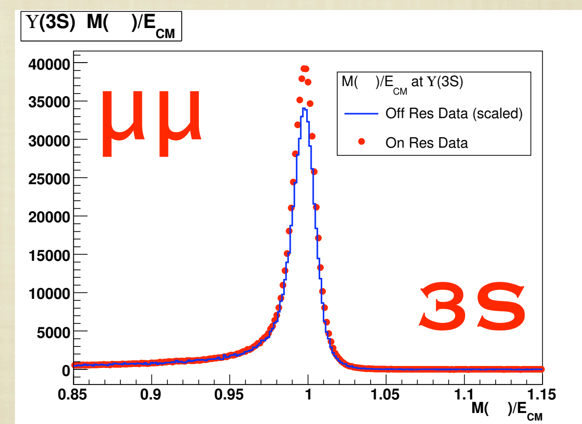




Mass of μμ /Ecm :





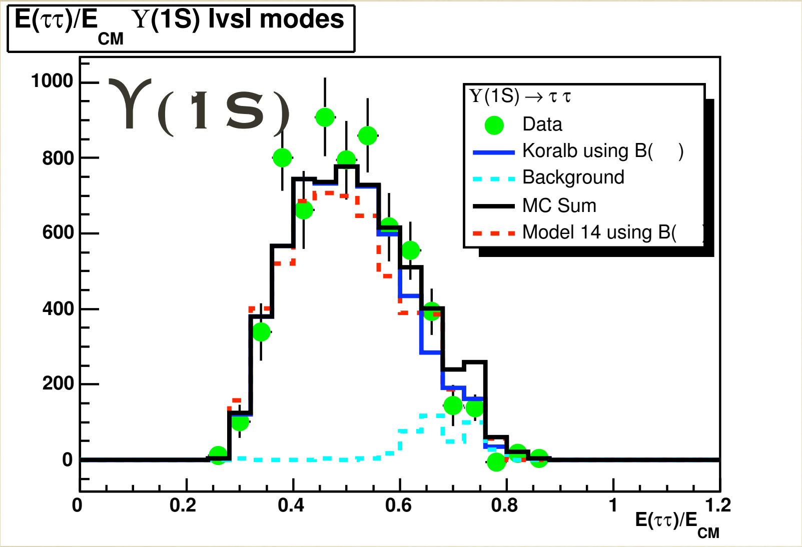


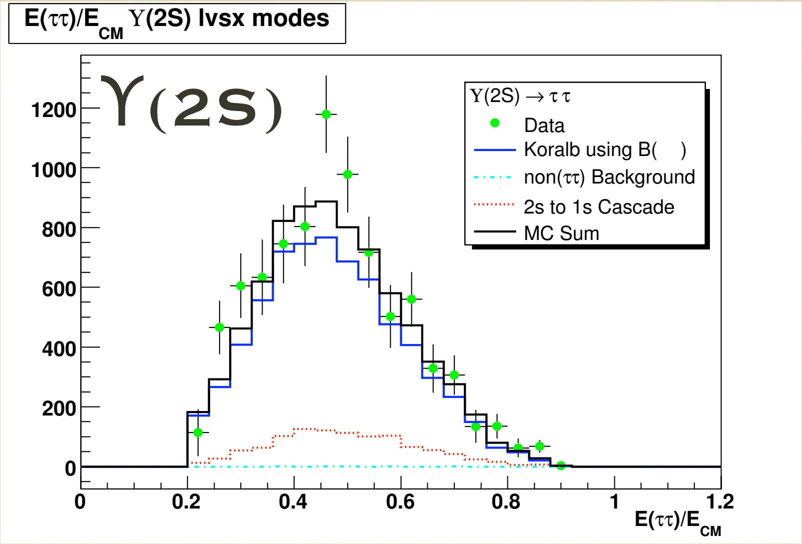
Data remaining after On-S*Off subtraction should be all due to ϒ decays

Getting N($\Upsilon \to \ell\ell$)

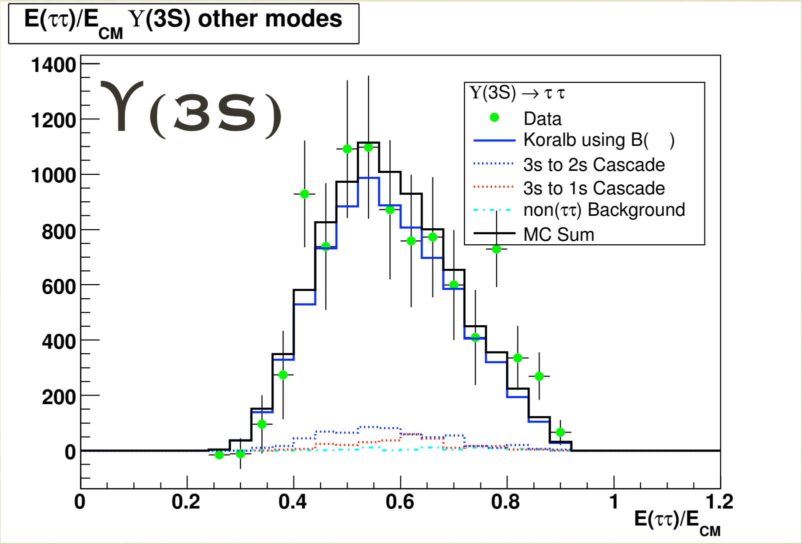
- Data after On-S*Off is a sum of Signal $\Upsilon \to \ell\ell$, Cascade to lower $\Upsilon \to \ell\ell$, Other Υ decays.
- Measure Br($\Upsilon(1S) \to \ell\ell$) to scale MC cascade bgd for $\Upsilon(2S)$ decays, iterate for $\Upsilon(3s)$.
- Use Koralb for $\Upsilon \to \tau\tau$ with ISR turned off
  - Υ has the quantum numbers of the photon
  - Koralb has helicity correlations

A Sprinkling of plots

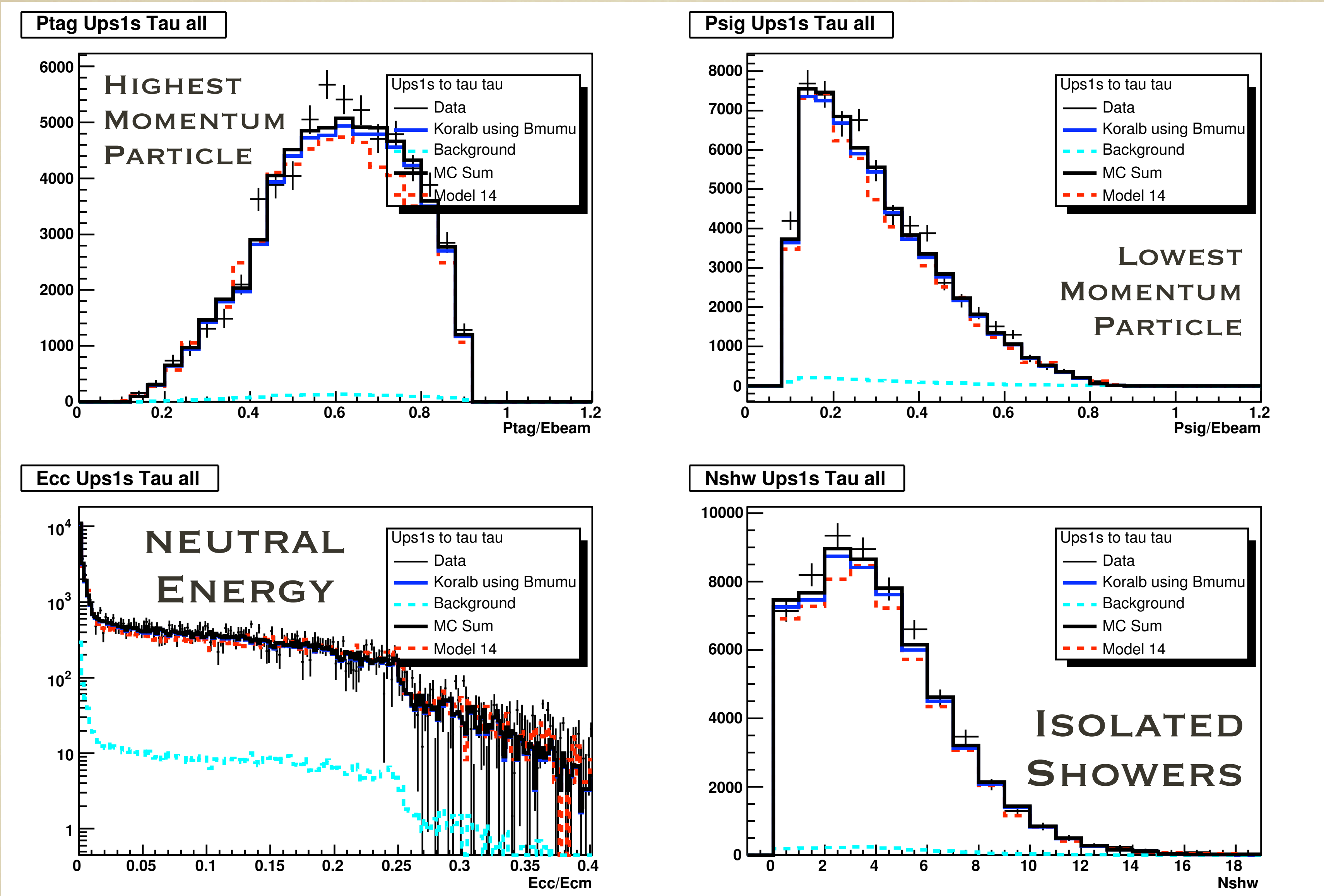




Total Energy Distribution for 3 different modes at 3 resonances for ττ, assuming universality



Need More Convincing ?



Good agreement w/ MC across Resonances, Final states, and kinematic quantities

How Many Events ?

Sum of all Υ decay modes

	1S	2S	3S
On-S*Off	61697±1536	25085±1399	16290±1522
background	1556±83	3334±593	1536±474
$\epsilon(\tau\tau)$	11.2±0.1%	11.3±0.1%	11.1±0.1%
$N(\tau\tau)/\epsilon$ (10^3)	537±14	193±12	132±13
$N(\mu\mu)/\epsilon$ (10^3)	527±15	185±11	126±11

Stat, MC Stat errors inc

$\mathcal{R} = B(\Upsilon \to \tau\tau)/B(\Upsilon \to \mu\mu)$

FINAL RESULT

$\mathcal{R}(1S) = 1.02 \pm 0.02 \pm 0.05$

$\mathcal{R}(2S) = 1.04 \pm 0.04 \pm 0.05$

$\mathcal{R}(3S) = 1.07 \pm 0.08 \pm 0.05$

Largest Syst from τ selection criteria (2.9%) and Trigger (1.6%)

Almost all Stat Error from On/Off Subtraction

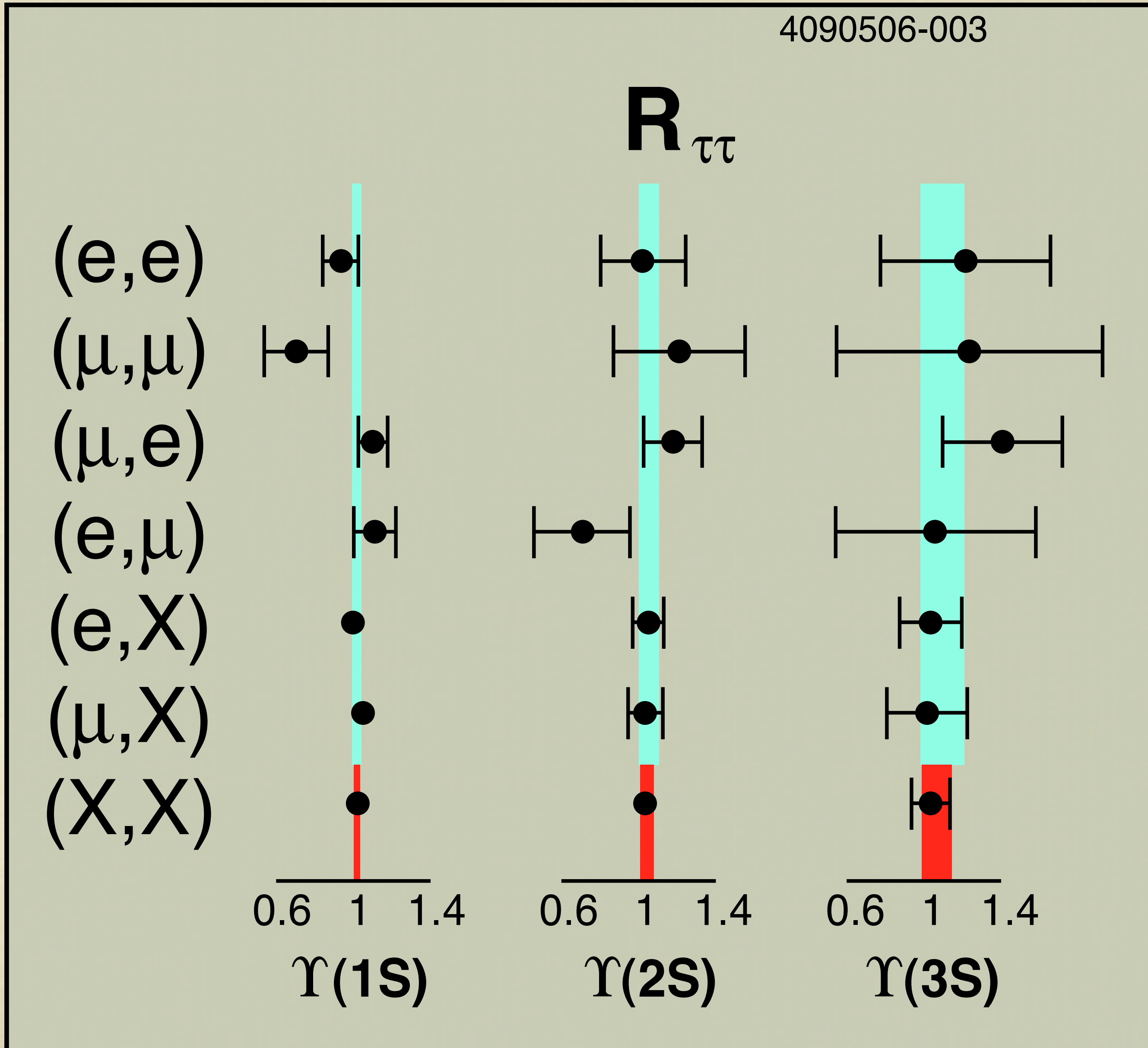
To be submitted to PRL any minute

$\mathcal{R}$ by Decay Mode

(X,Y) = P(X)> P(Y)

Average over lepton modes

overall average



Extracting B(ϒ→ττ)

- Use CLEO's published B(ϒ→μμ) - cf I. Danko Talk

  PRL94,012001(2005)
- Avoid syst error double counting

τ stat

syst+μ stat

$$B(\Upsilon(1S)\to\tau\tau) = 2.54 \pm 0.04 \pm 0.12\ \%$$

$$B(\Upsilon(2S)\to\tau\tau) = 2.11 \pm 0.07 \pm 0.13\ \%$$

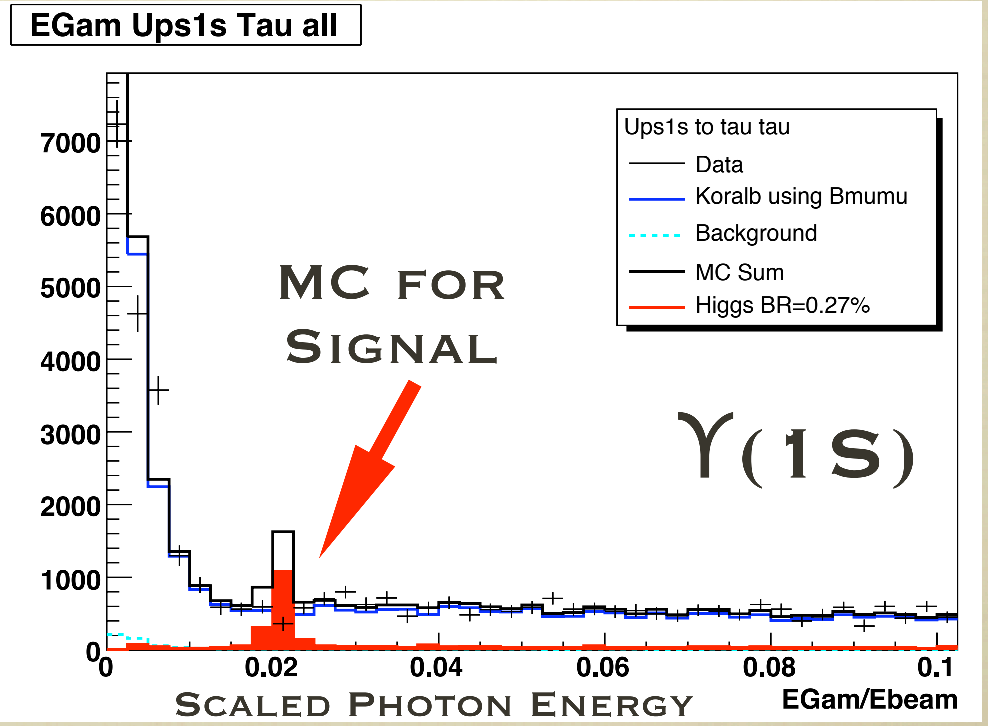
$$B(\Upsilon(3S)\to\tau\tau) = 2.55 \pm 0.19 \pm 0.15\ \%$$

What about η_b/Higgs?

- $\mathcal{R}$ is consistent with 1 - no big signal
- Attribute deviation $\mathcal{R}(1S)-1$ to "Higgs"

  $B(\Upsilon\to\gamma\eta_b,\ \eta_b\to A^0,\ A^0\to\tau\tau) < 0.27\%$ 90% CL UL

- Look at γ spectrum
  - No obvious spike in the 1S Spectrum
  - Expected region is falling fast - hard syst
  - No obvious spike in 2S, 3S spectra



Conclusions

CLEO has:

- Searched for LFV gives BR($\Upsilon \to \mu\tau$) $\approx< 10^{-5}$ 90%CL UL
- Measured B($\Upsilon \to \tau\tau$)/B($\Upsilon \to \mu\mu$) consistent with 1
- measured B($\Upsilon \to \tau\tau$)
  - Consistent with PDG at 1S (but lower)
  - Best Value for 2S
  - First value for 3S
- Set limit on CP odd Higgs in Υ(1S) region