Test of lepton universality and search for lepton flavor violation in Y(1,2,3S) decays at CLEO

Istvan Danko
Rensselaer Polytechnic Institute

representing
the CLEO Collaboration

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Outline

- Introduction
  - Bottomonia and Υ resonances
  - CLEO III detector and Υ resonance data
- Test of lepton universality:

$$\Upsilon \rightarrow \tau^+\tau^- \text{ vs. } \Upsilon \rightarrow \mu^+\mu^-$$

- Search for lepton flavor violating (LFV) decays:

$$\Upsilon \rightarrow \mu^+\tau^-$$

Bottomonia

- Bound states of the bb quarks:

  Simplest (nearly non-relativistic) strongly interacting system - analogous to positronium in QED

  Several states with $n^{(2S+1)}L_J$ configuration

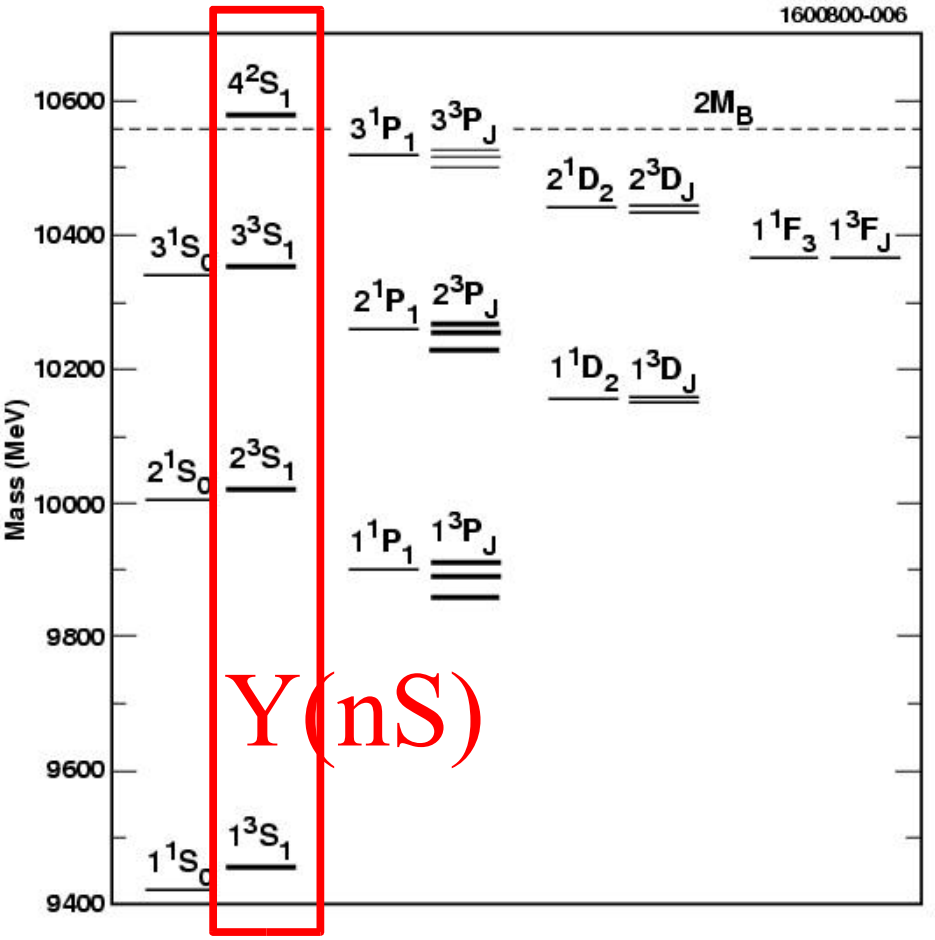
- Y(nS) states are $J^{PC}=1^{--}$ members of the bottomonium family

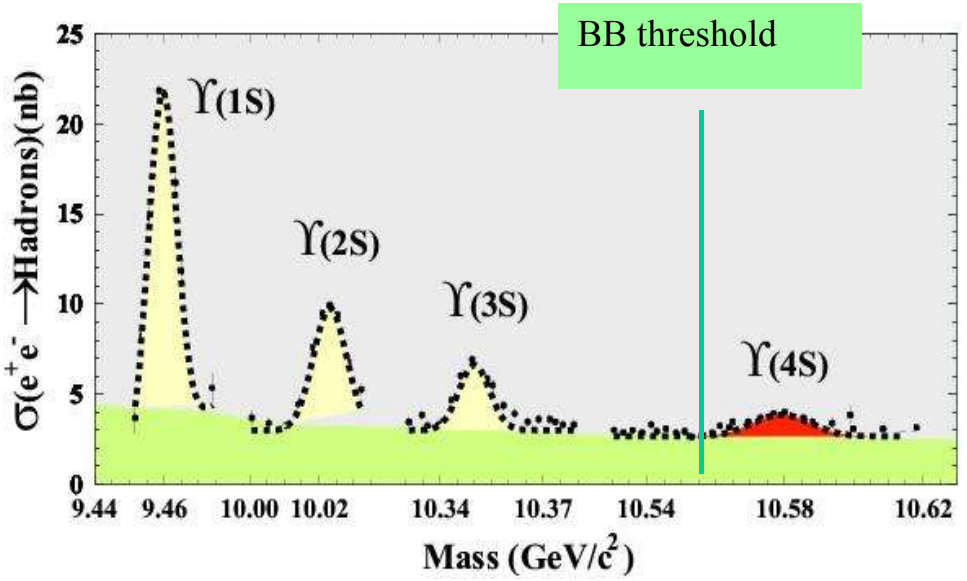
  They can be produced directly in e^+e^- annihilation: $e^+e^- \rightarrow \gamma^* \rightarrow b\bar{b}$

  Y(1,2,3S) below BB threshold decays by annihilation of the quark pair into hadrons or lepton pairs - long lived, narrow resonances ($\Gamma \approx 20$-50keV)

  Decay rate proportional to wavefunction at origin – tests short distance interaction

  Transitions to other states via γ and soft gluon emission becomes competitive





CLEO detector

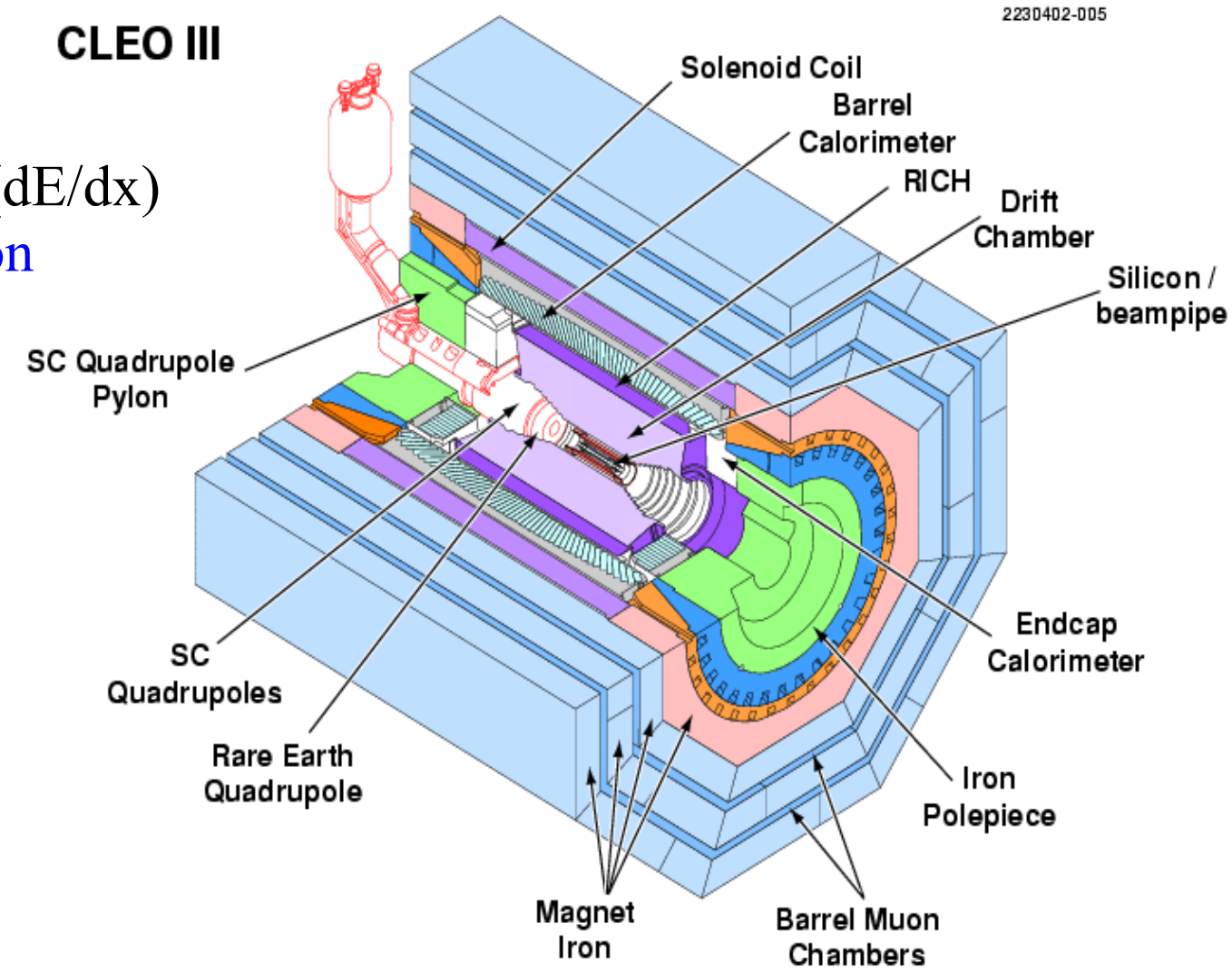
- Y(1,2,3S) data was collected with the CLEO III detector at the Cornell Electron-positron Storage Ring (CESR) in 2001-2002.

Excellent tracking system
- 4-layer Si VX detector
- 47 layer Drift Chamber (dE/dx)

RICH particle identification

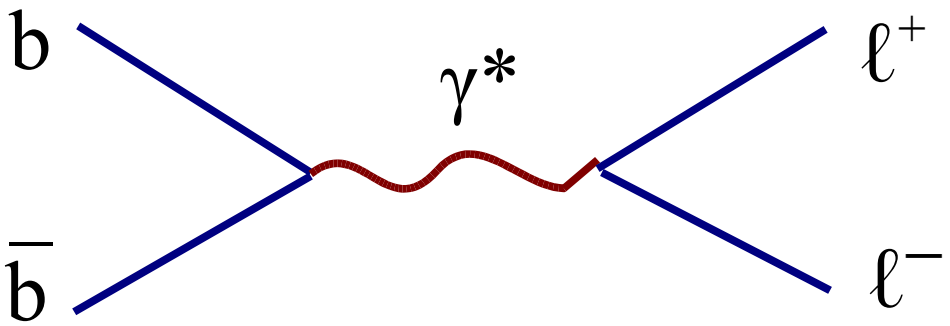
CsI EM calorimeter (CC)

Muon counters



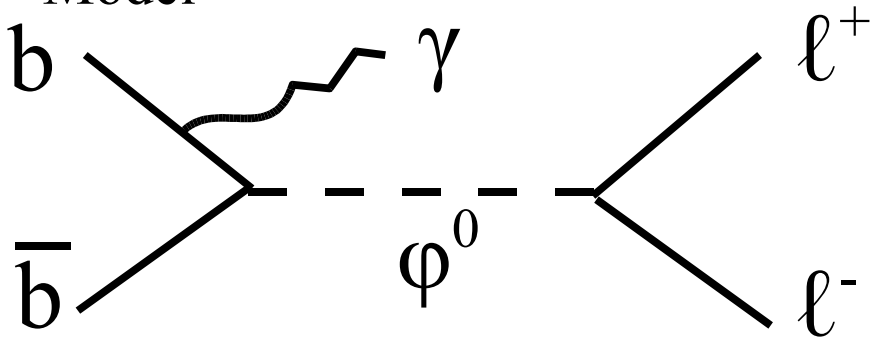
Y-resonance data:
- Y(1S): ~20 M decays
- Y(2S): ~10 M decays
- Y(3S): ~ 5 M decays

Test of lepton universality in Y decays to lepton pairs



$\Upsilon \to \tau^+\tau^-$ / $\mu^+\mu^-$: motivation

- By measuring $B_{\tau\tau}=B(\Upsilon \to \tau^+\tau^-)$ and comparing it to $B_{\mu\mu}=B(\Upsilon \to \mu^+\mu^-)$ we can test lepton universality
- CLEO has recently published high precision measurements of $B_{\mu\mu}$
  PRL 94:012001, 2005
- Previous $B_{\tau\tau}$ measurements are outdated and not competitive
- Any inconsistency could indicate new physics beyond the Standard Model



PDG05	B_{ee}(%)	$B_{\mu\mu}$ (%)	$B_{\tau\tau}$ (%)
Y(1S)	2.38±0.11	2.48±0.05	2.67±0.15
Y(2S)	1.92±0.17	1.93±0.17	1.7±1.6
Y(3S)	seen	2.18±0.21	

e.g. a light pseudo-scalar Higgs boson with mass close to the Y resonances could increase the observed $B_{\tau\tau}$ via the decay

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

since the coupling is proportional to the mass^2 of ℓ

Sanchis-Lozano: hep-ph/0503266

$\Upsilon \rightarrow \tau^+\tau^-$: analysis strategy

- Measure $\tau^+\tau$ yield using one prong tau decays ($\tau \rightarrow \ell\nu\nu$ and $h(n\pi^0)\nu$) which represent about 75% of total decays:
  - Exactly two charged tracks in the event with $0.1 < p/E_{beam} < 0.9$
  - Total transverse momentum of the tracks $> 0.1 * E_{beam}$
  - Total neutral and charged energy $0.2\text{-}0.9 * E_{cm}$
  - e, μ identified using calorimeter and MUON detector info
  - neutral energy cuts
- Subtract continuum background ($e^+e^- \rightarrow \tau^+\tau^-$) using off-resonance data (scaled by luminosity and 1/s)
- Use Y(4S) data and Y(1,2,3S) off-resonance data for consistency check
- Use $\Upsilon \rightarrow \mu\mu$ events for internal normalization of $\Upsilon \rightarrow \tau\tau$
- Calculate $B_{\tau\tau}/B_{\mu\mu}$ (some of the systematic errors cancel in the ratio)

$\Upsilon \rightarrow \tau^+\tau^-$: consistency check on $\Upsilon(4S)$

- Since

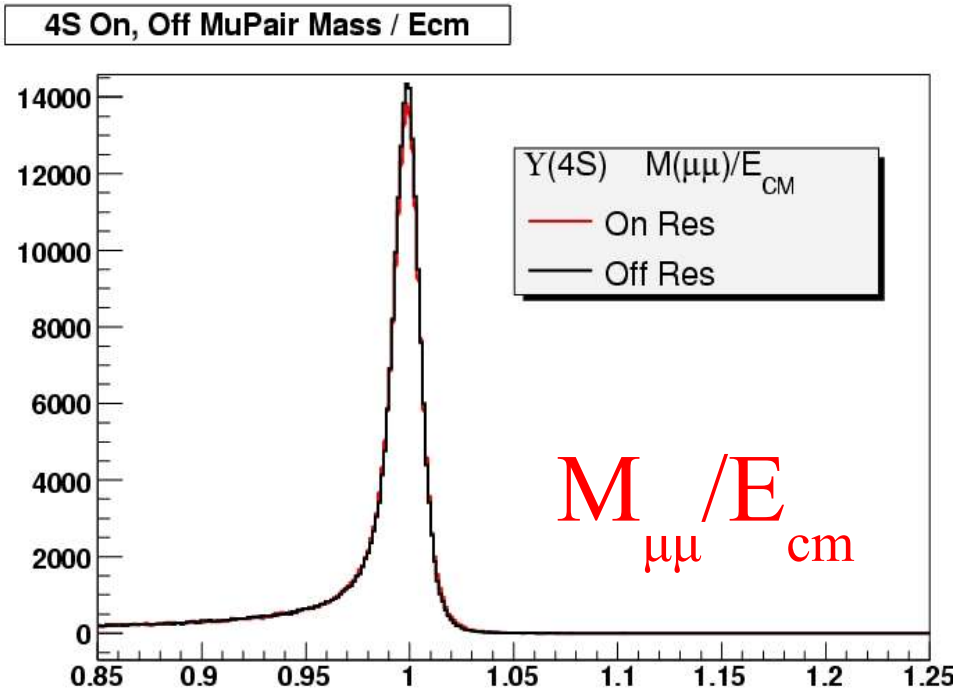
  $B(\Upsilon(4S) \rightarrow e^+e^-) \approx 2.8 \times 10^{-5}$

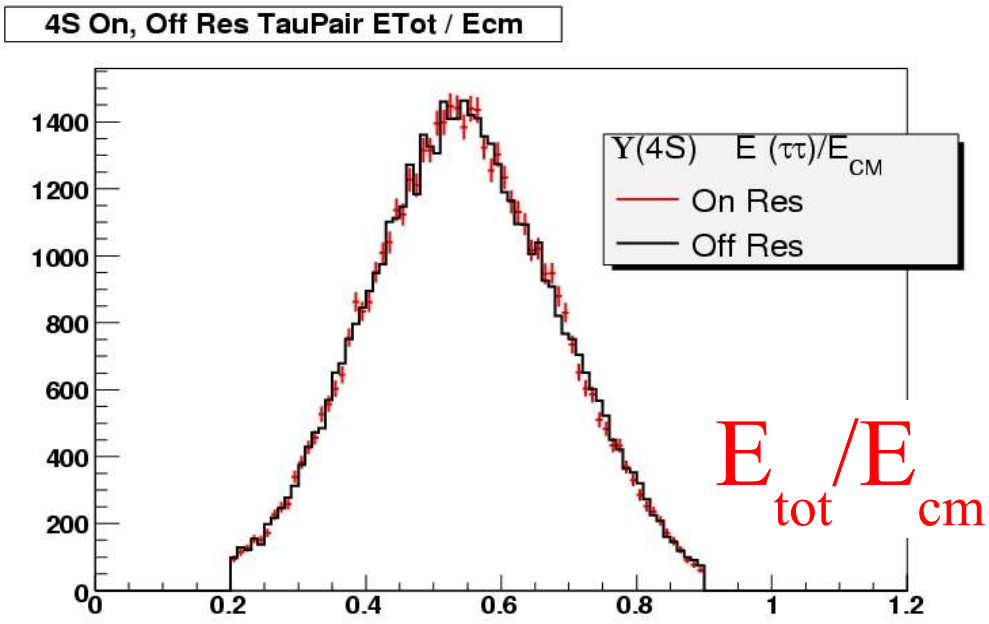
  we do not expect measurable yield at the $\Upsilon(4S)$

- $\Upsilon(4S)$ data can be used for consistency check

- Both $\mu\mu$ and $\tau\tau$ yields at the $\Upsilon(4S)$ resonance is consistent with the normalized off-resonance yield

Preliminary





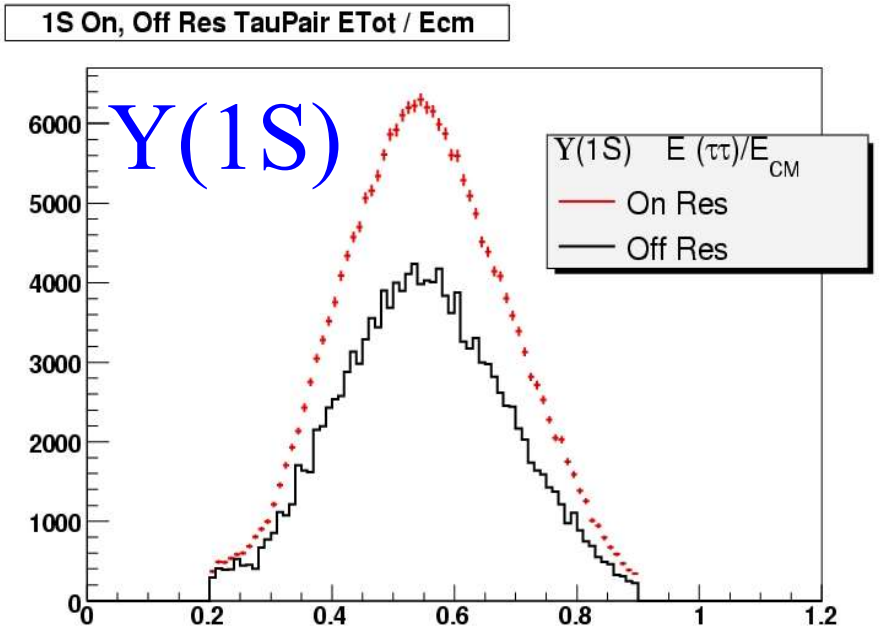
$\Upsilon \to \tau^+\tau^-$: signal on Υ(1,2,3S)

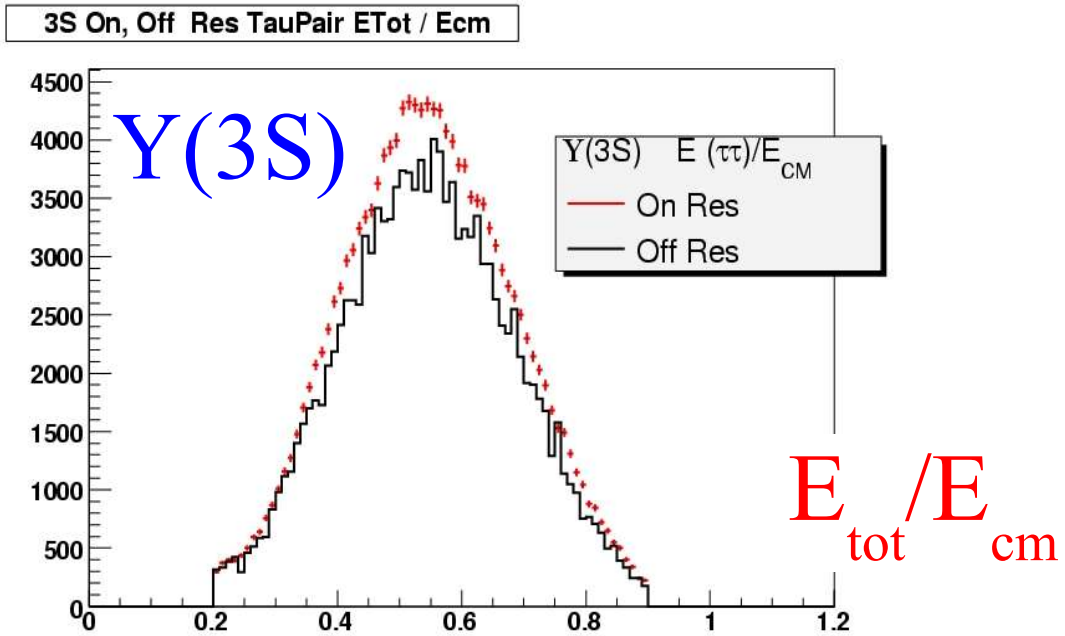
Preliminary

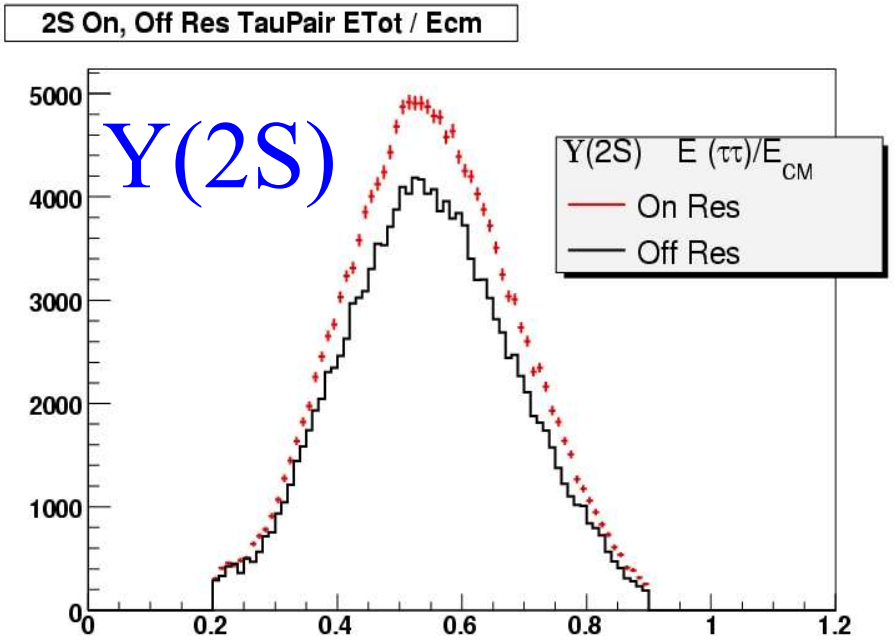
- First clean signal for

  $\Upsilon(3S) \to \tau\tau$ and $\Upsilon(2S) \to \tau\tau$

	$\tau\tau$ yield
Υ(1S)	28113±534
Υ(2S)	11082±473
Υ(3S)	7544±690







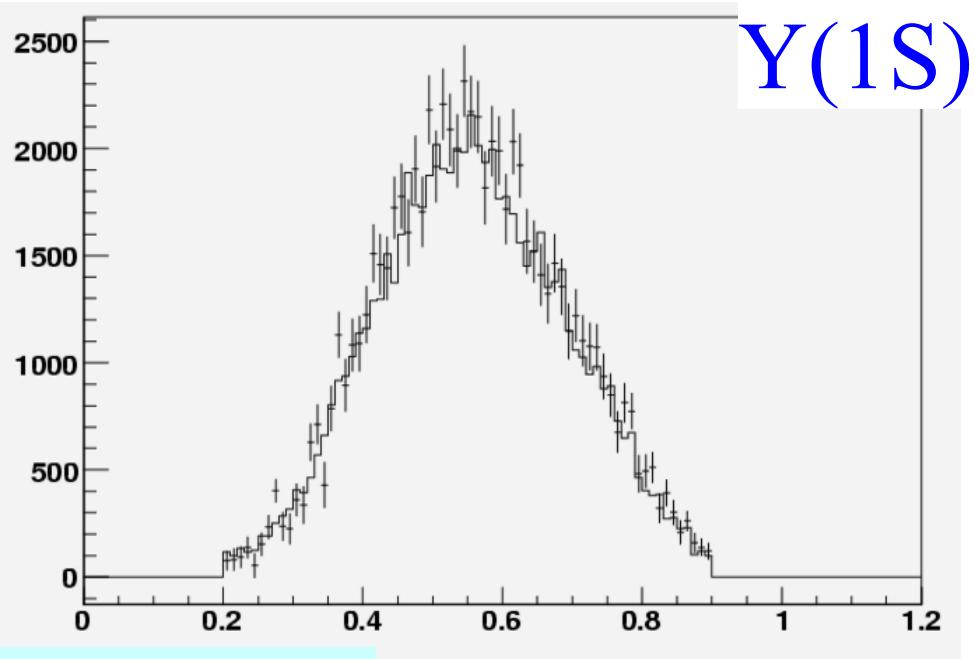
$\Upsilon \to \tau^+\tau^-$: $R = B_{\tau\tau}/B_{\mu\mu}$

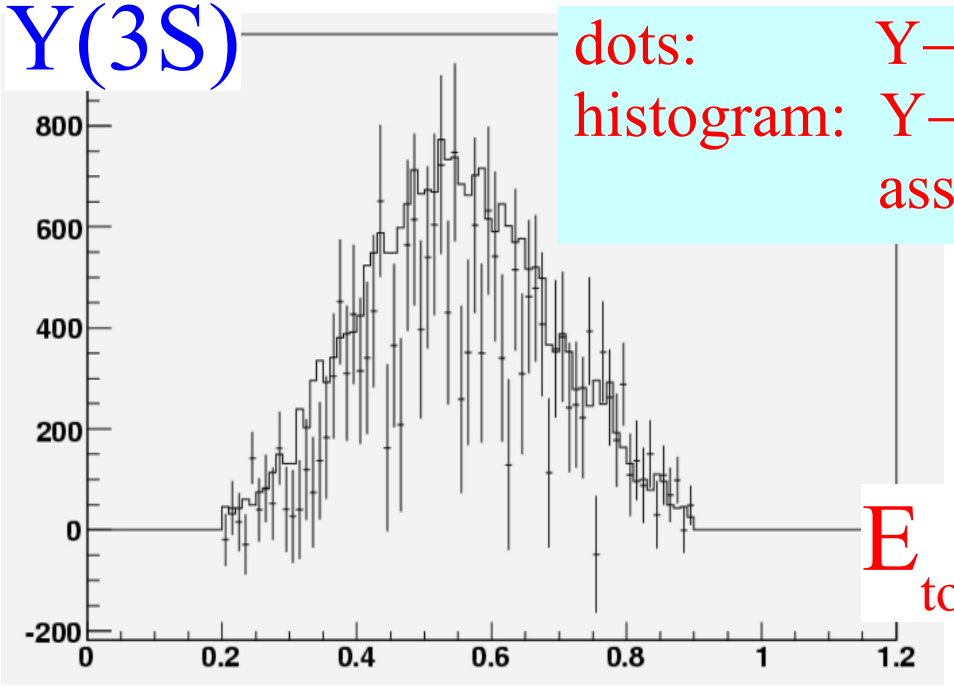
Preliminary

- After correcting raw yields for efficiency, and cascade decays from higher resonances (2S and 3S only):

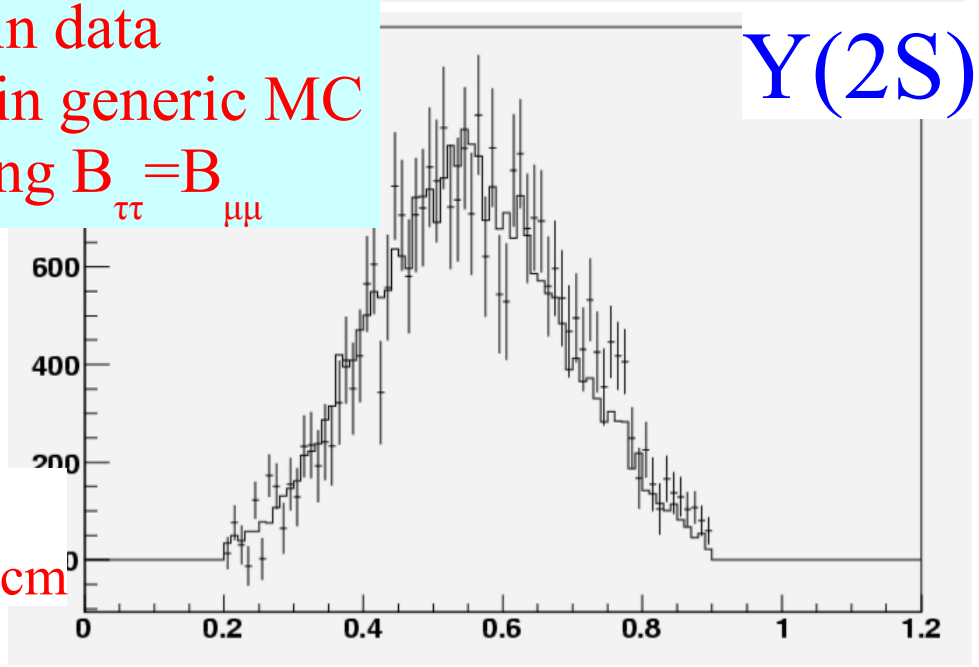
$R(1S) = 1.06 \pm 0.02 \pm 0.00 \pm 0.03$
$R(2S) = 1.00 \pm 0.03 \pm 0.12 \pm 0.03$
$R(3S) = 1.05 \pm 0.07 \pm 0.05 \pm 0.03$

Errors: statistics, cascade feedthrough, systematic





dots: $\Upsilon \to \tau\tau$ in data
histogram: $\Upsilon \to \tau\tau$ in generic MC assuming $B_{\tau\tau} = B_{\mu\mu}$



E_{tot}/E_{cm}

Search for Lepton Flavor Violation in $\Upsilon(1,2,3) \to \mu^+\tau^-$ decays

$\Upsilon \to \mu^+\tau^-$: motivation

- LFV decays are forbidden in the SM but can be easily generated in many theories where lepton flavor is not conserved (consequence of non-zero ν mass and mixing)
  - GUT inspired models with leptoquarks, SUSY with sleptons, technicolor model with special role for t quark (TC2):

    Huo, Feng, and Yue, hep-ph/0212211

    model dependent: $B(\Upsilon \to \mu\tau) < 10^{-7}\text{-}10^{-8}$ and $B(\Upsilon \to \mu e) < 10^{-14}\text{-}10^{-15}$

    model independent: $B(\Upsilon \to \tau\ell) < 10^{-4}\text{-}10^{-5}$ and $B(\Upsilon \to \mu e) < 10^{-8}\text{-}10^{-9}$
  - LFV decays can be induced by low scale quantum gravity effects (or other new physics at the TeV scale) or by extra spacial dimensions:

    Silagadze, hep-ph/9907328

    $B(\Upsilon \to \mu\tau) \approx 2\times10^{-5}$ and $B(J/\psi \to \mu\tau) \approx 10^{-7}$

    Even more optimistic estimates: *Datta et al., PRD 60, 014011, 1999*

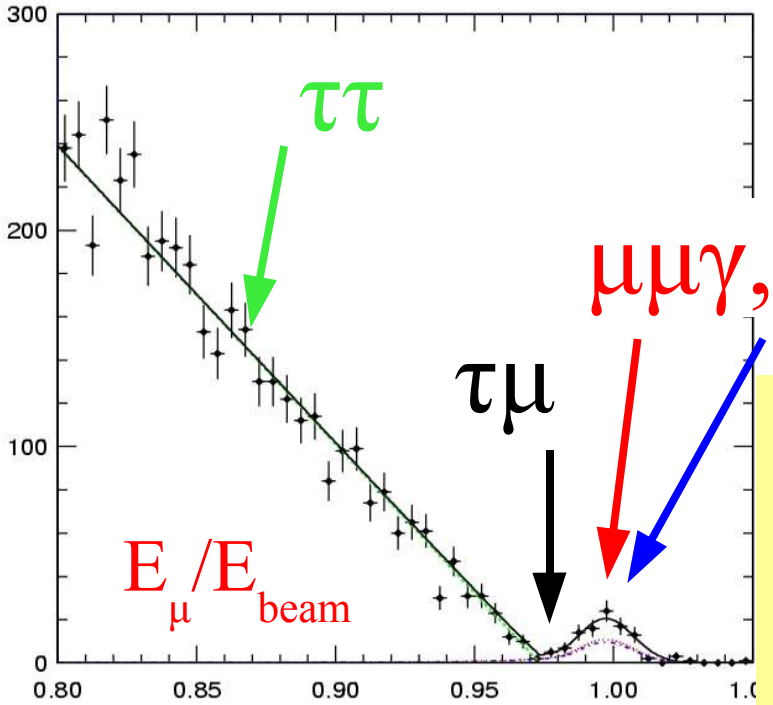
    $B(\Upsilon \to \tau\ell) \leq 10^{-2}$ and $B(J/\psi \to \tau\ell) \leq 6\times10^{-7}$

$\Upsilon \to \mu^+ \tau^-$: exclusive analysis

- Focus on $\Upsilon \to \mu\tau \to \mu e \nu\nu$ mode (requiring exactly two tracks, zero net charge, one e and one μ candidate)
  - ~9% overall efficiency (including $B(\tau \to e\nu\nu) \approx 17\%$)
- Main backgrounds: $\tau\tau$, $\mu\mu\gamma$, $\mu\mu \to \mu e \nu$
- Unbinned extended maximum likelihood fit with four components (signal + 3 backgrounds); observables used in fit:
  - $x = E_\mu / E_{beam}$
  - $y = E_e / E_{beam}$, dE/dx and E(CC)/p for e-
    (help to stabilize the fit and discriminate against background)
- chances of discovery of LFV decays at Y(4S) is smallest (LFV leptonic width is < 0.01 Γee) - use the Y(4S) data for calibration:

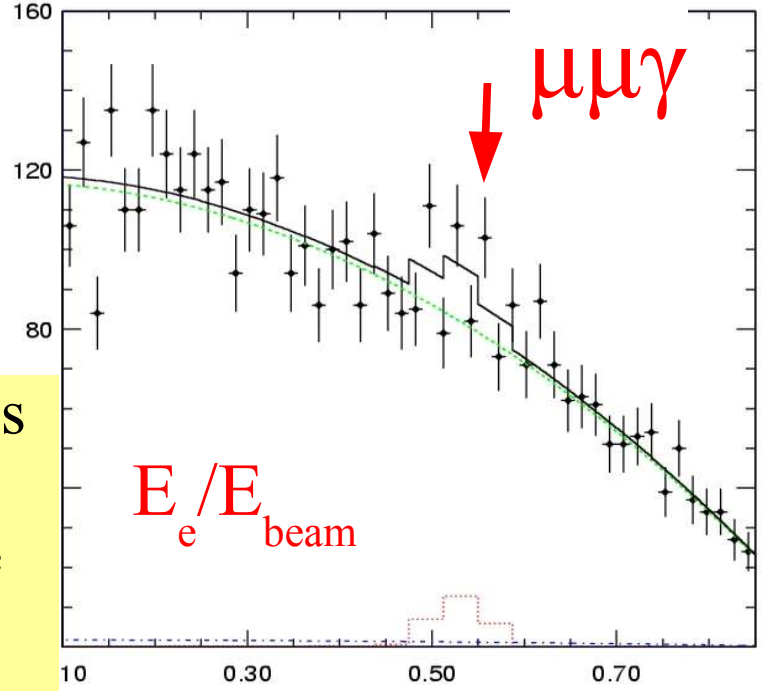
  Derive most of the PDF's from data (on-Y(4S)) → fit on-Y(4S) data, if no signal → fit off-Y(4S) data, if no signal and no bias → open signal box on Y(1,2,3S) - not yet done!

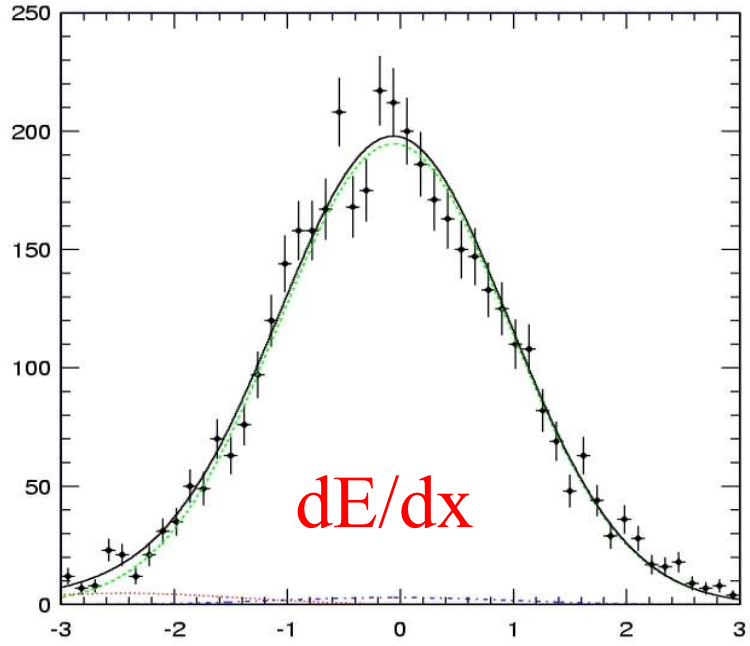
$\Upsilon \to \mu^+\tau^-$: PDF shapes and fit to $\Upsilon(4S)$ data

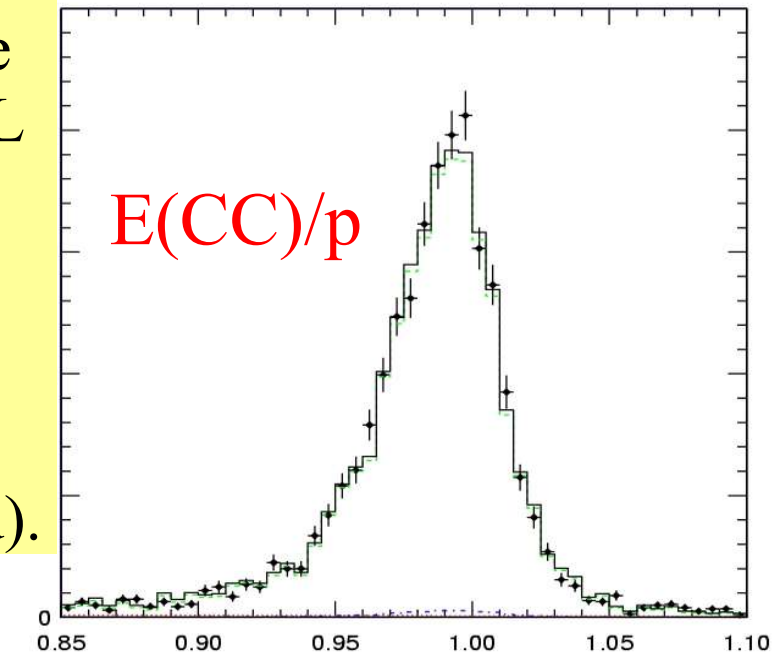


Preliminary

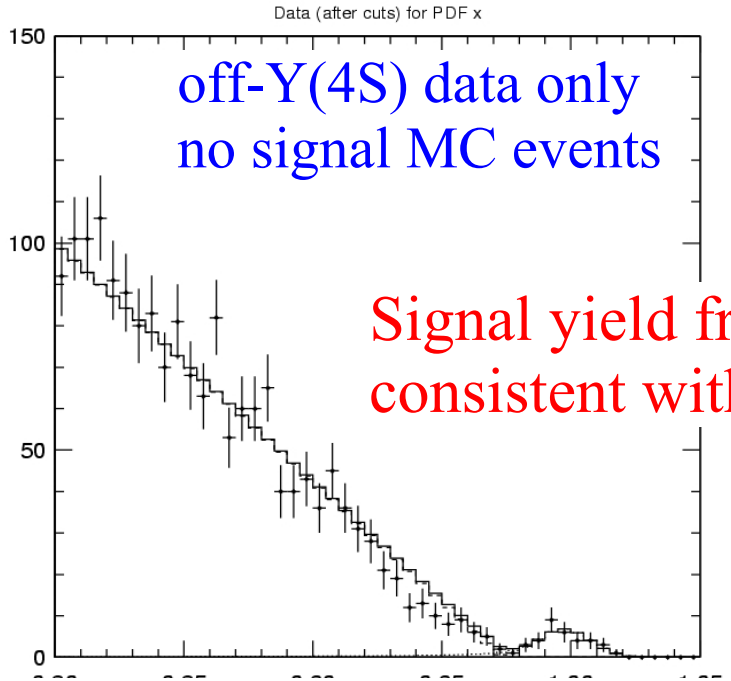
- Most of the PDF's are analytical functions + some histograms
- Projections of the 4-D unbinned ML fit (with four components)
- Signal yield consistent with zero (as expected).







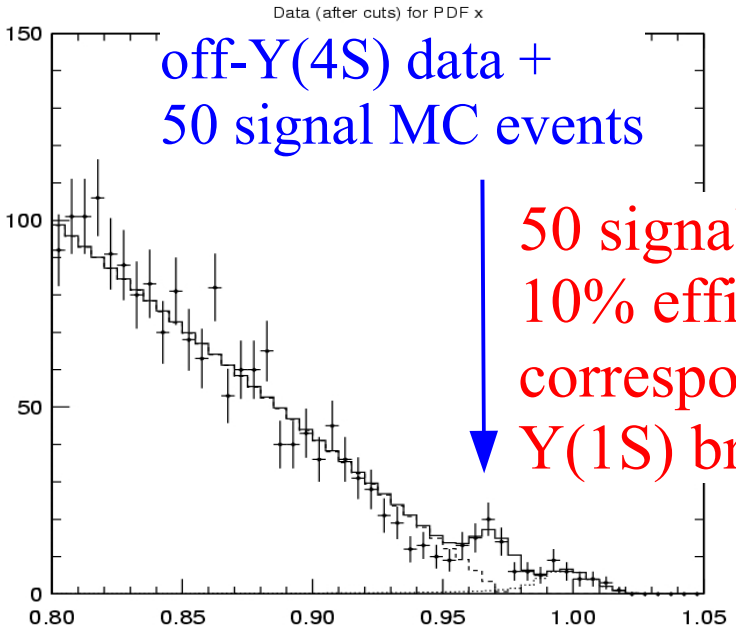
$\Upsilon \to \mu^+ \tau^-$: toy MC study of bias and sensitivity



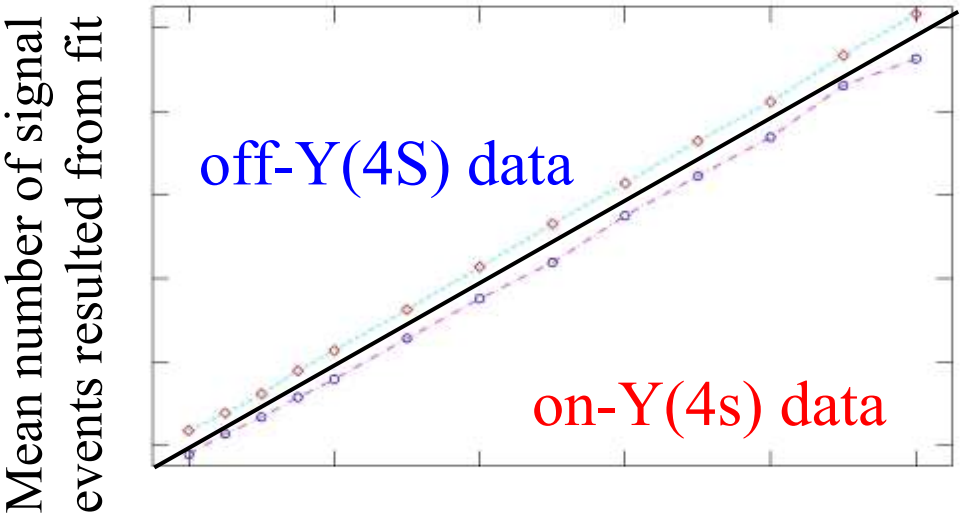
Signal yield from fit is consistent with zero

Preliminary

- Results of 4-D ML fits to off-Y(4S) data merged with toy signal MC events.
- off-Y(4S) data statistics is about the same as background expected in our Y(1,2,3S) data



50 signal events with 10% efficiency corresponds to 2×10^{-5} Y(1S) branching ratio



Summary

- Presented preliminary results on
  - test of lepton universality in $\Upsilon(1,2,3S) \to \tau\tau$ vs. $\mu\mu$ decays

    statistical and systematic errors are still large – some improvement is expected in final version – $\Upsilon(1S)$ result might provide meaningful test

    first observation of $\Upsilon(3S) \to \tau\tau$ decay
  - Search for lepton flavor violating $\Upsilon(1,2,3S) \to \mu\tau$ decays

    unbinned maximum likelihood fit on $\Upsilon(4S)$ data is tested and looks promising

    expect sensitivity $\sim 10^{-5}$

    working on improvements: analytical PDF's only, take into account a slight correlations between variables (y vs. E/p in case of $\mu\mu\gamma$ component) in final version of ML fit

Stay tuned