Search for Lepton Flavor Violating Upsilon Decays at BaBar

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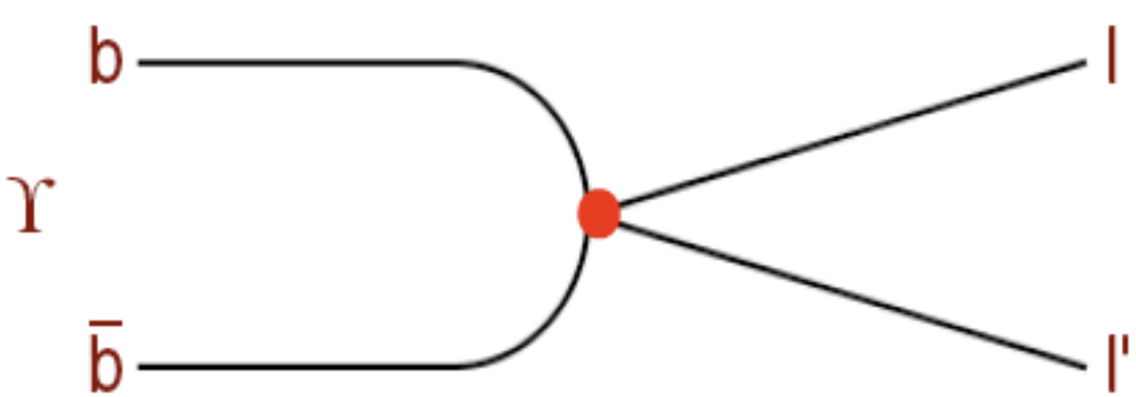
Introduction

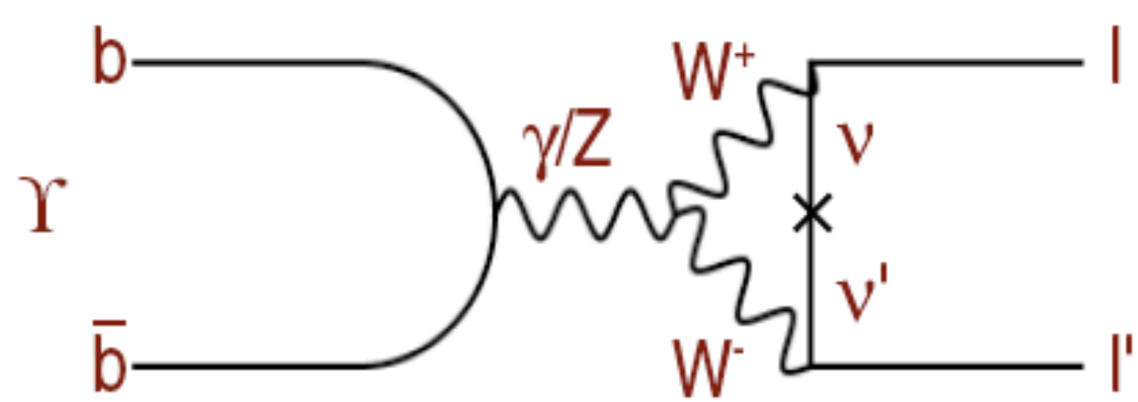
- Lepton flavor violation (LFV)
  - not forbidden by SM gauge symmetry
  - most new models naturally include LFV vertex
- In SM, LF is conserved for zero degenerate ν masses
- Now we have clear indication that ν's have finite mass
  $\Rightarrow$ Lepton Flavor is violated in Nature: but by how much?
- SM extended to include finite ν mass and mixing predicts LFV

Minimal Standard Model ($m_\nu = 0$)



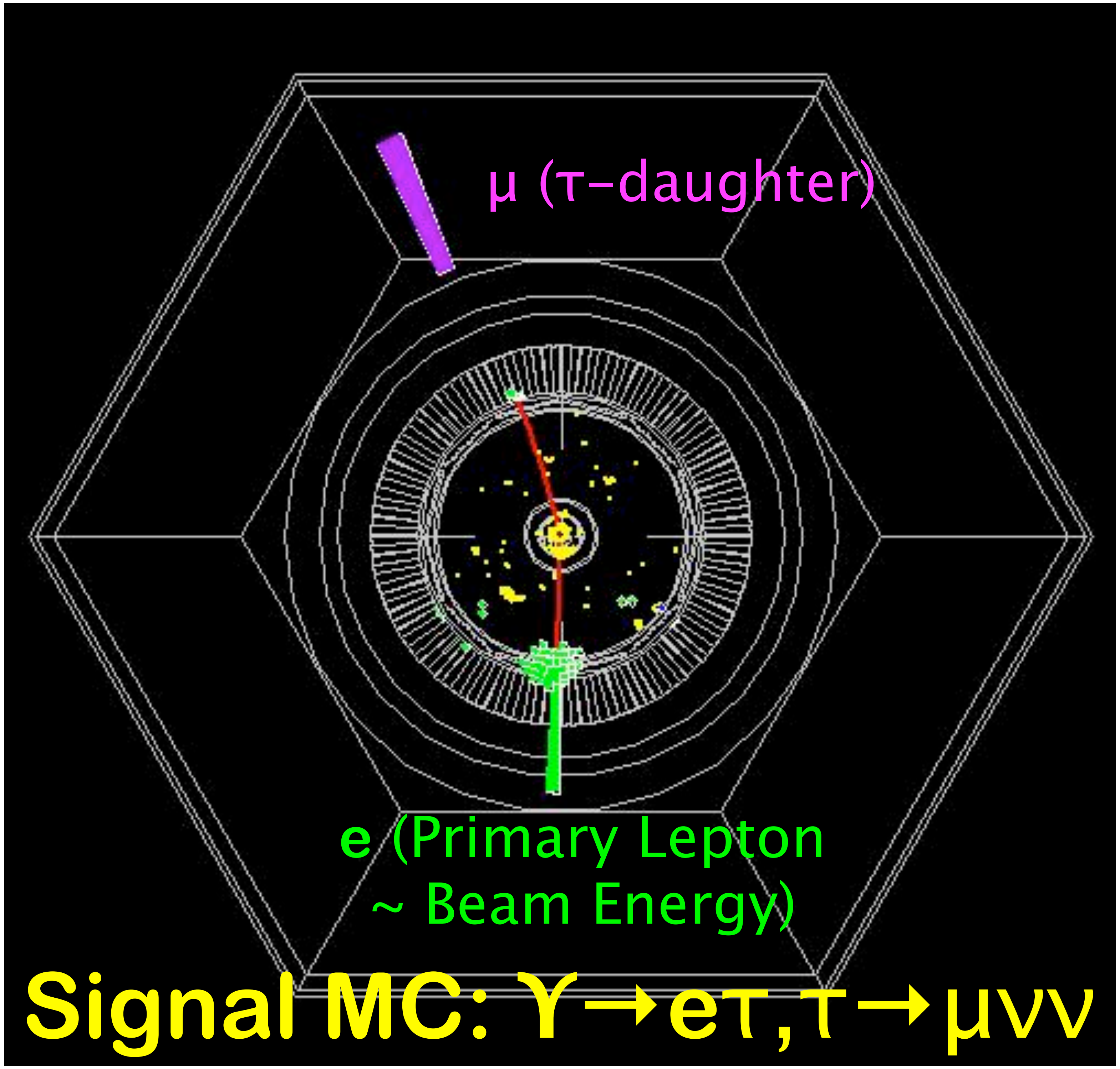
forbidden

Standard Model ($m_\nu \neq 0$)



$BF \sim ((\Delta m_\nu^2)/M_W^2)^2 < 10^{-48} \rightarrow$ unobservable

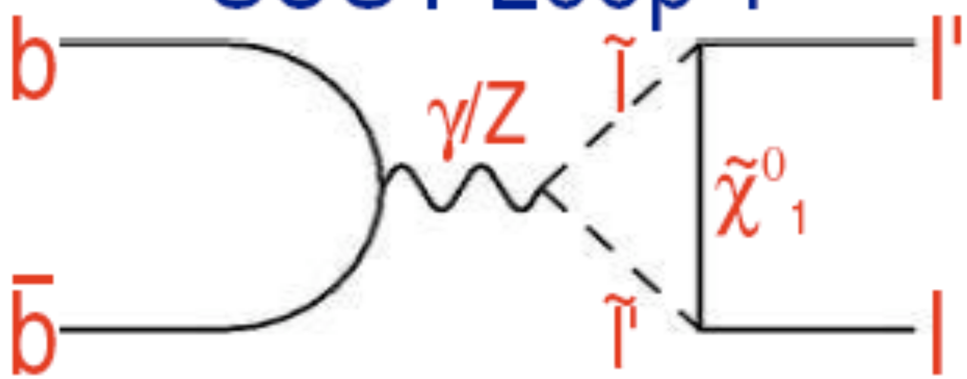
If we saw (enough events)...



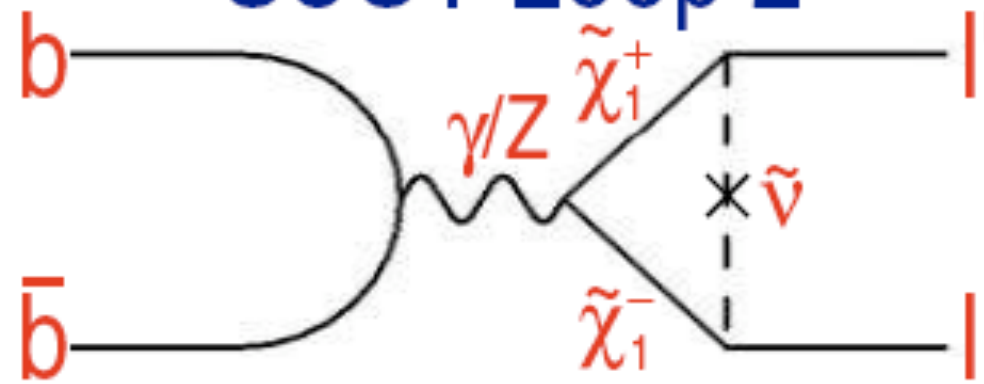
...unambiguous signature of new physics!

Some New Physics Scenarios

SUSY Loop 1

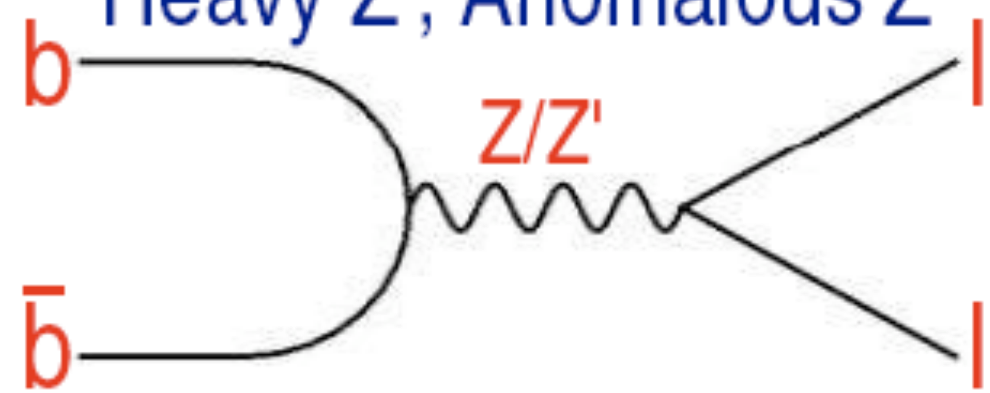


SUSY Loop 2

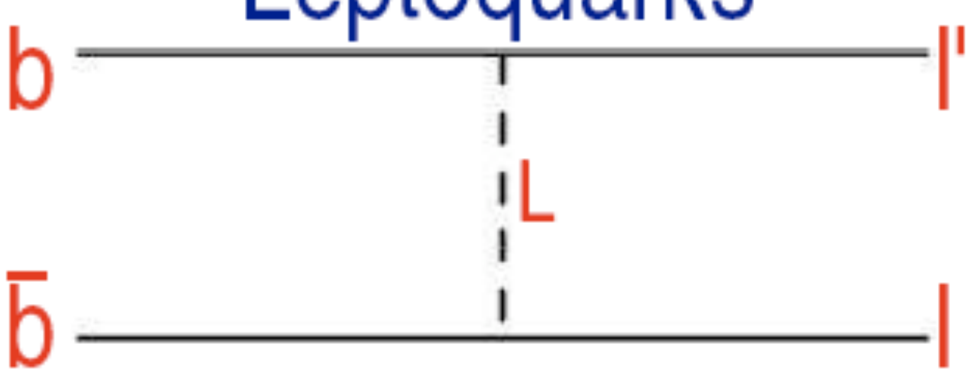


2nd Higgs Doublet

Heavy Z', Anomalous Z



Leptoquarks

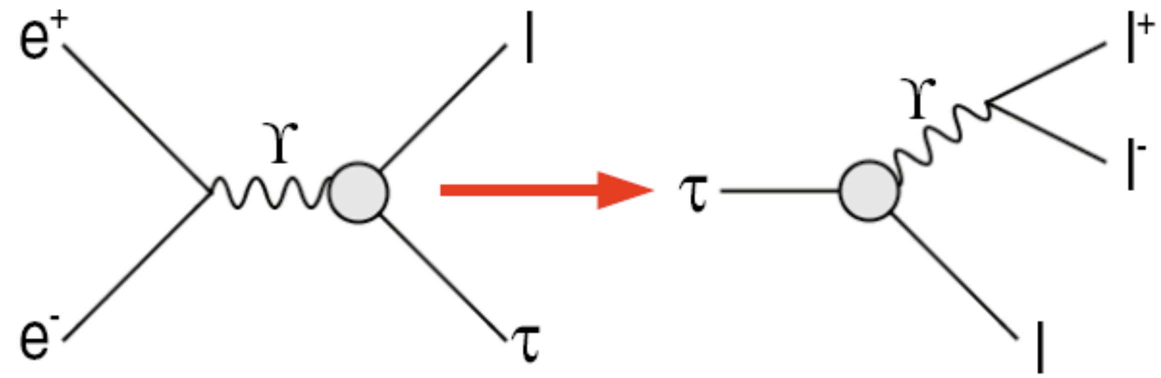


Generic Contact Interaction

How small can the rate be?

- $\Upsilon \to l\tau$ related to $\tau \to lll$ via re-ordering of input/output lines

S.Nussinov, R.D.Pecci, X.M.Zhang
PRD 63, 016003 (2001)



$$BR(\Upsilon \to l\tau) \leq BR(\tau \to lll) \frac{\Gamma(W \to l\nu)^2}{\Gamma(\Upsilon)\Gamma(\Upsilon \to l^+ l^-)} (M_\Upsilon / M_W)^6$$

- SUSY + Higgs (A.Brignole, A.Rossi, PLB566(2003)217)
  - $\mathcal{B}(\tau \to 3\mu) \simeq 10^{-7} \times (\frac{\tan\beta}{50})^6 \times (\frac{100GeV}{m_A})^4 \times (\frac{|50\Delta_L|^2 + |50\Delta_R|^2}{10^{-3}})$
  - If Higgs light, s-particles $\sim \mathcal{O}(\,\mathrm{TeV})$, $\tan\beta \sim 50$
    - No direct observation, but $\tau \to \mu\mu\mu$ observable (?)
    - Sensitivity $\sim 10^{-8} - 10^{-10}$ at B-Factories
  - $BR(\tau \to lll) <$ 2-4 $\times 10^{-8}$ $\to$ **$BF(\Upsilon(3S) \to l\tau) <$ 3-6$\times 10^{-3}$**

BaBar Collab., PRL 99, 251803 (2007)

Belle Collab., PLB 660, 154 (2008)

How small is the rate known to be?

- **Direct Constraints: CLEO search for $\Upsilon \to \mu\tau$, $\tau \to e\nu\nu$**

CLEO Collab., PRL 101, 201601 (2008)

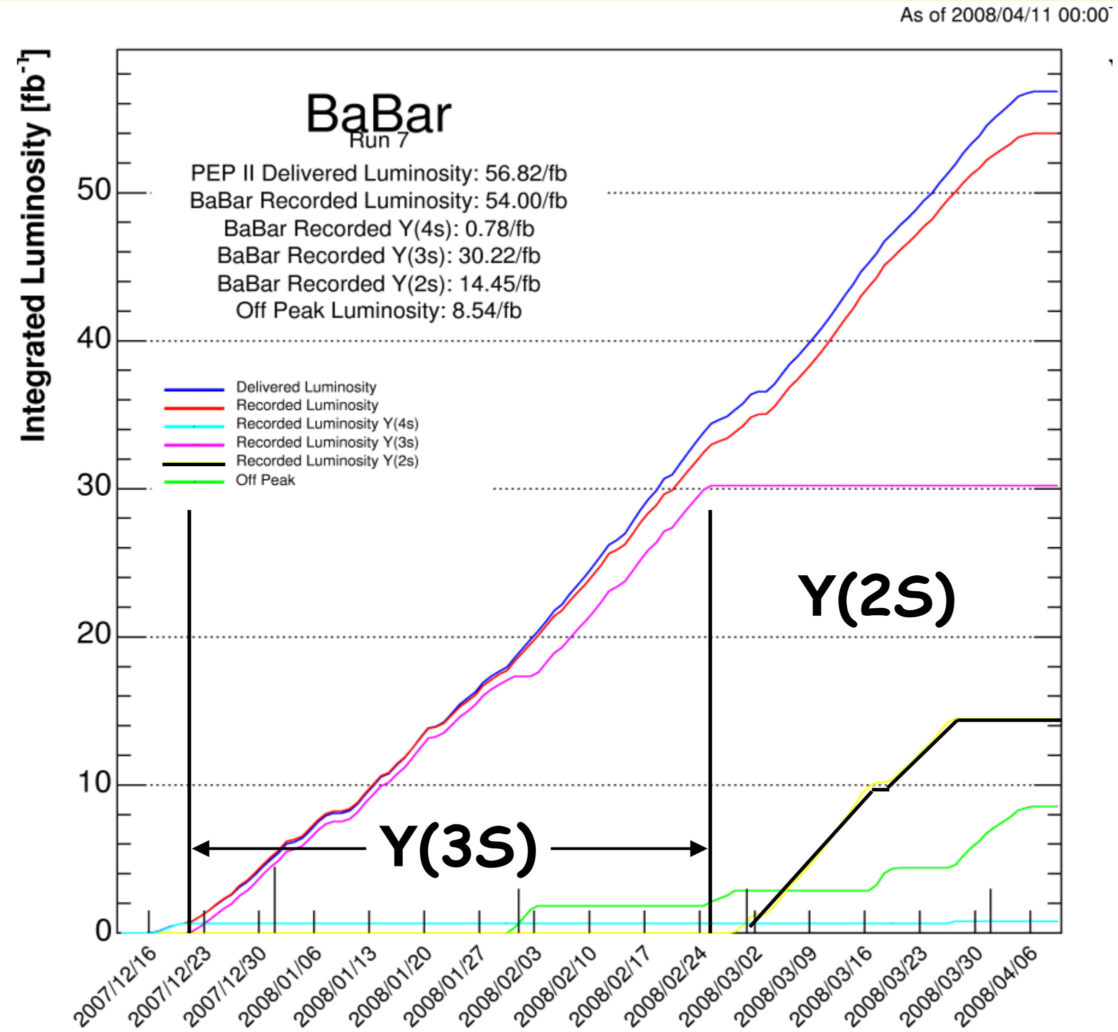
	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
Mass (GeV/c^2)	9.46	10.02	10.36
N decays (millions)	20.8	9.3	5.9
$\Gamma(\Upsilon \to \mu\mu)$ (keV)	1.252	0.581	0.413
$\Gamma(\Upsilon)$ (keV)	53.0	43.0	26.3
$\mathcal{B}(\mu\mu)$ ($\times 10^{-3}$)	23.6	13.5	15.7
$\mathcal{B}(\mu\tau)$ (95% CL UL, $\times 10^{-6}$)	6.0	14.4	20.3
$\mathcal{B}(\mu\tau)/\mathcal{B}(\mu\mu)$ (95% CL UL, $\times 10^{-3}$)	0.25	1.1	1.3
Λ (95% CL LL, TeV, $\alpha_N = 1.0$)	1.30	0.98	0.98

- **Other constraints: BaBar searches for LFV in $B \to ll$ decays**
  - $B^0 \to e^+\mu^-$ $< 9.2 \times 10^{-8}$ @ 90% C.L. — BaBar Collab., PRD 77, 032007 (2008)
  - $B^0 \to e^+\tau^-$ $< 2.8 \times 10^{-5}$ @ 90% C.L.
  - $B^0 \to \mu^+\tau^-$ $< 2.2 \times 10^{-5}$ @ 90% C.L.

  } BaBar Collab., PRD 77, 091104 (2008)

How small a rate can BABAR measure?

Between Dec 2007 - Apr 2008,
PEP II collected data below $\Upsilon(4S)$:
~ 30 fb^{-1} @ $\Upsilon(3S)$ (122 M decays)
~ 15 fb^{-1} @ $\Upsilon(2S)$ (100 M decays)



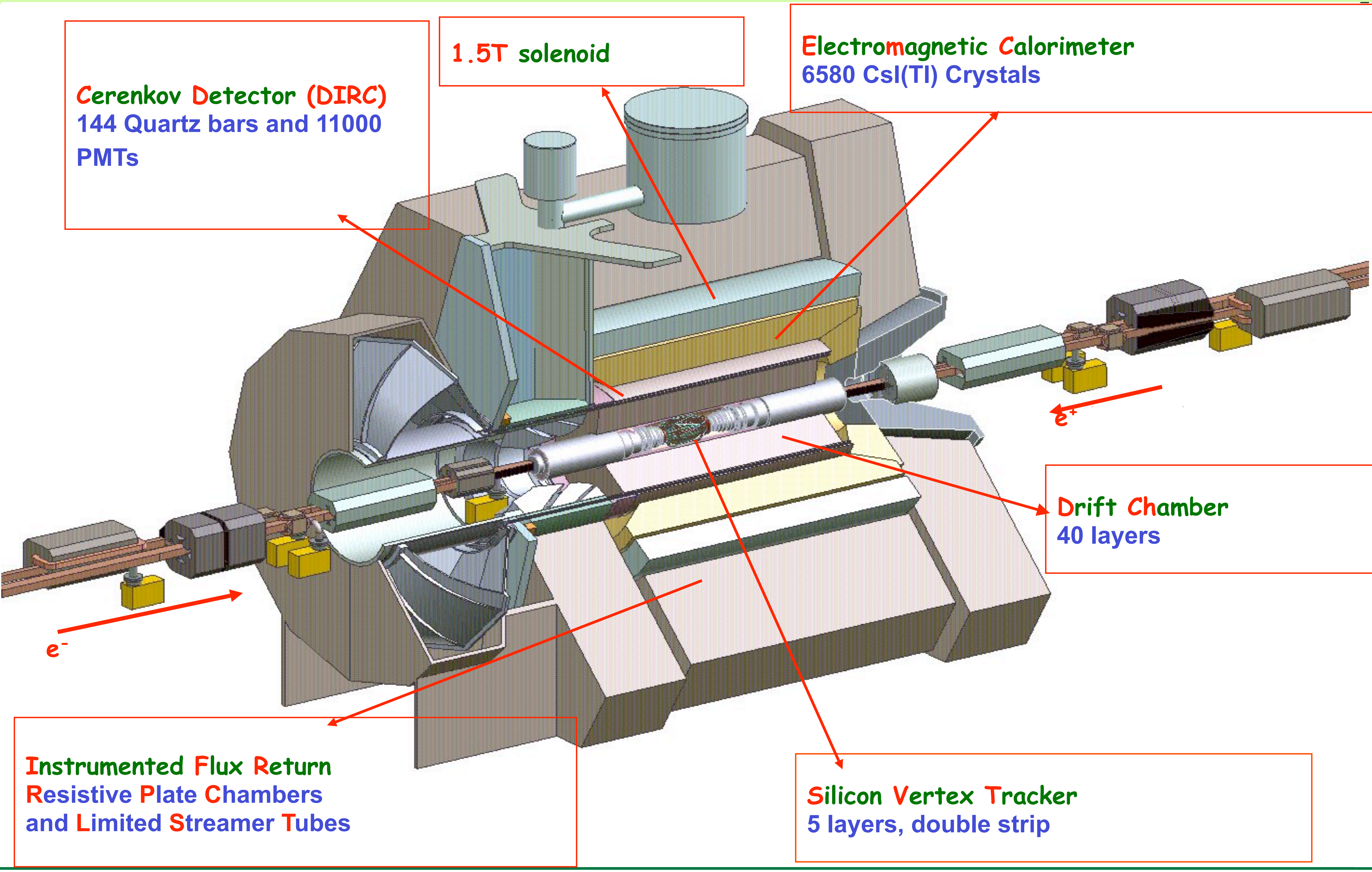
Dramatic increase in
sensitivity to rare decays:
$\Gamma_{\Upsilon(4S)} / \Gamma_{\Upsilon(nS)} \sim 10^3$

Sensitivity for LFV discovery in Υ Decays:

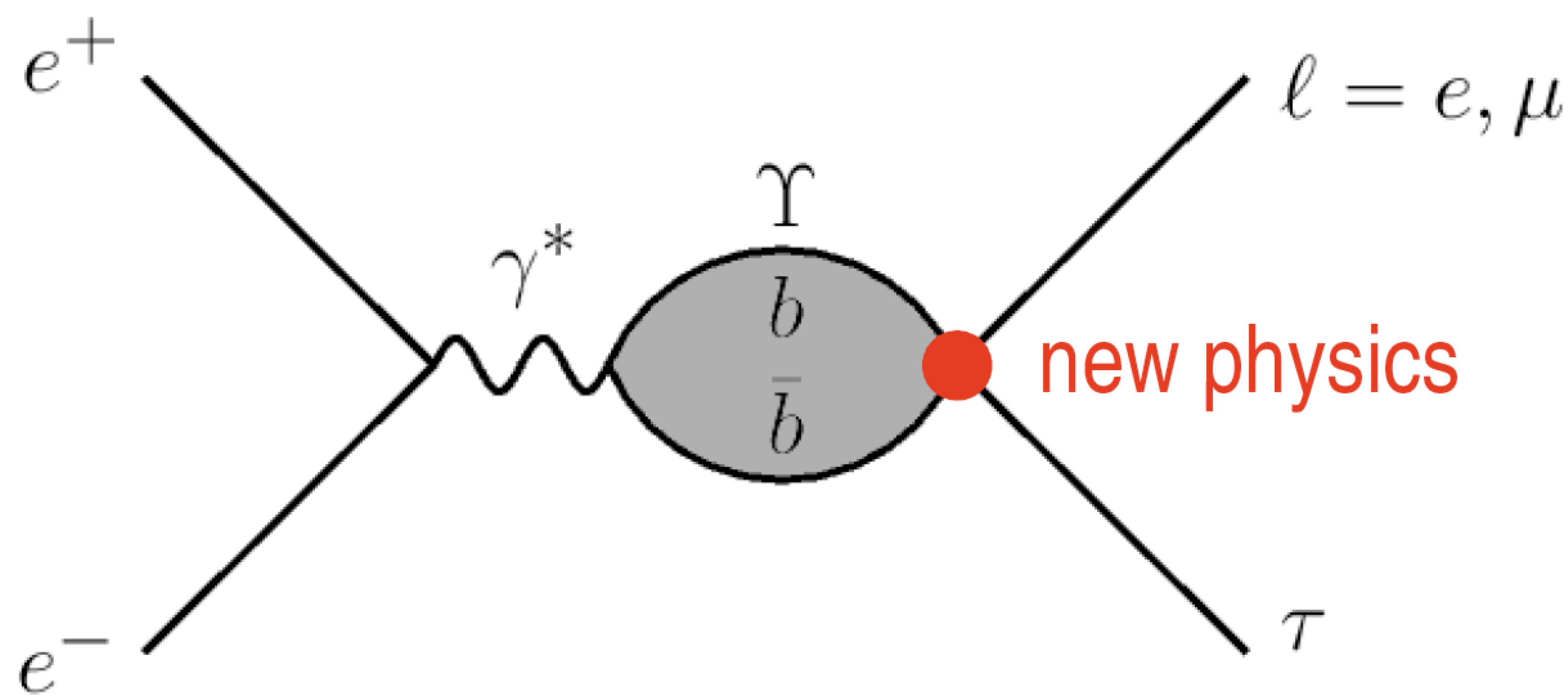
$$\sigma(\mathcal{B}) = \frac{\sqrt{N_{\rm bkg}}}{\varepsilon N_{\Upsilon(3S)}}$$

~20 times more $\Upsilon(3S)$ decays ➪ improve CLEO limits by factor of ~4

The BABAR Detector



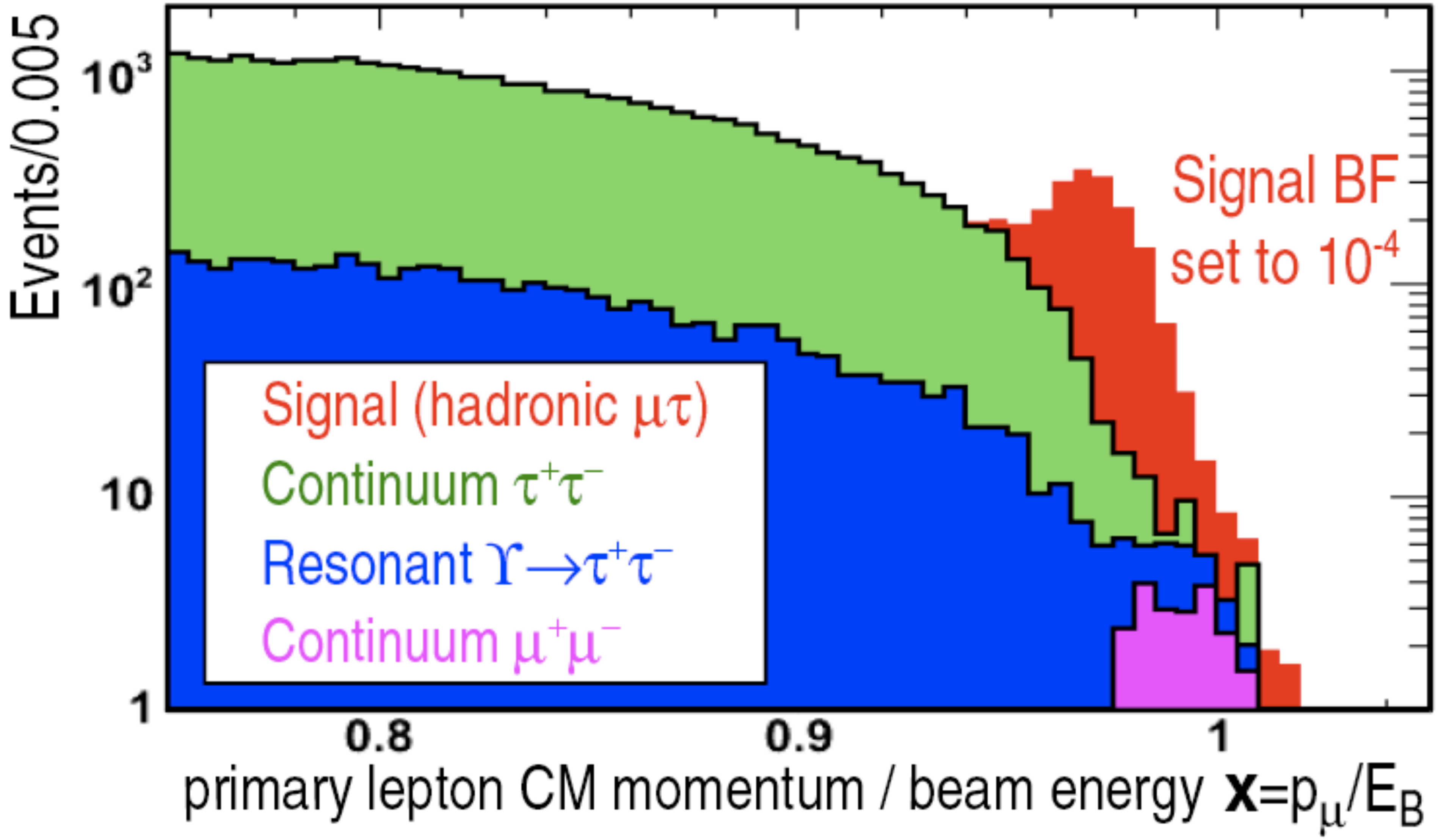
Event Selection



Process	τ Decay	Channel
$\Upsilon(3S) \to e\tau$	$\tau \to \mu\nu\nu$	leptonic $e\tau$
$\Upsilon(3S) \to e\tau$	$\tau \to \pi^{\pm}\pi^{0}\nu / \pi^{\pm}\pi^{0}\pi^{0}\nu$	hadronic $e\tau$
$\Upsilon(3S) \to \mu\tau$	$\tau \to e\nu\nu$	leptonic $\mu\tau$
$\Upsilon(3S) \to \mu\tau$	$\tau \to \pi^{\pm}\pi^{0}\nu / \pi^{\pm}\pi^{0}\pi^{0}\nu$	hadronic $\mu\tau$

- Reconstruct final state from
  - two oppositely charged tracks
  - one or two additional neutral pions
- Primary lepton (e/μ) near beam energy
- τ decay with missing energy in other hemisphere decaying into a lepton with opposite flavor or ρ/a_1
- τ decay with same flavor lepton or a single π vetoed to reduce QED bkgd.

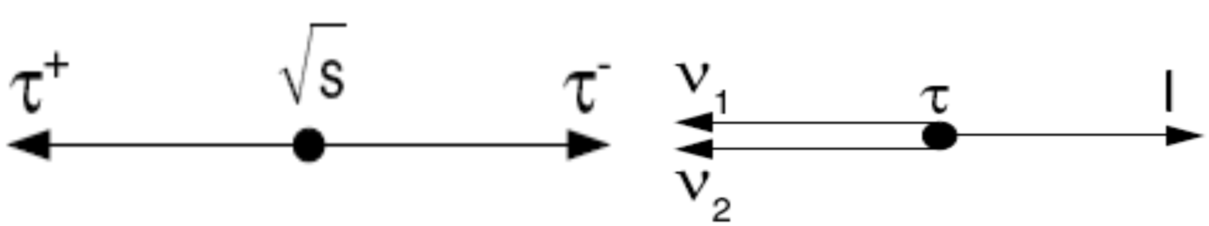
The discriminating variable



$E_l = (m_\Upsilon^2 - m_\tau^2 + m_l^2)/(2\,m_\Upsilon)$ $\quad p_l/E_B = \sqrt{4\,(E_l^2 - m_l^2)/m_\Upsilon^2}$

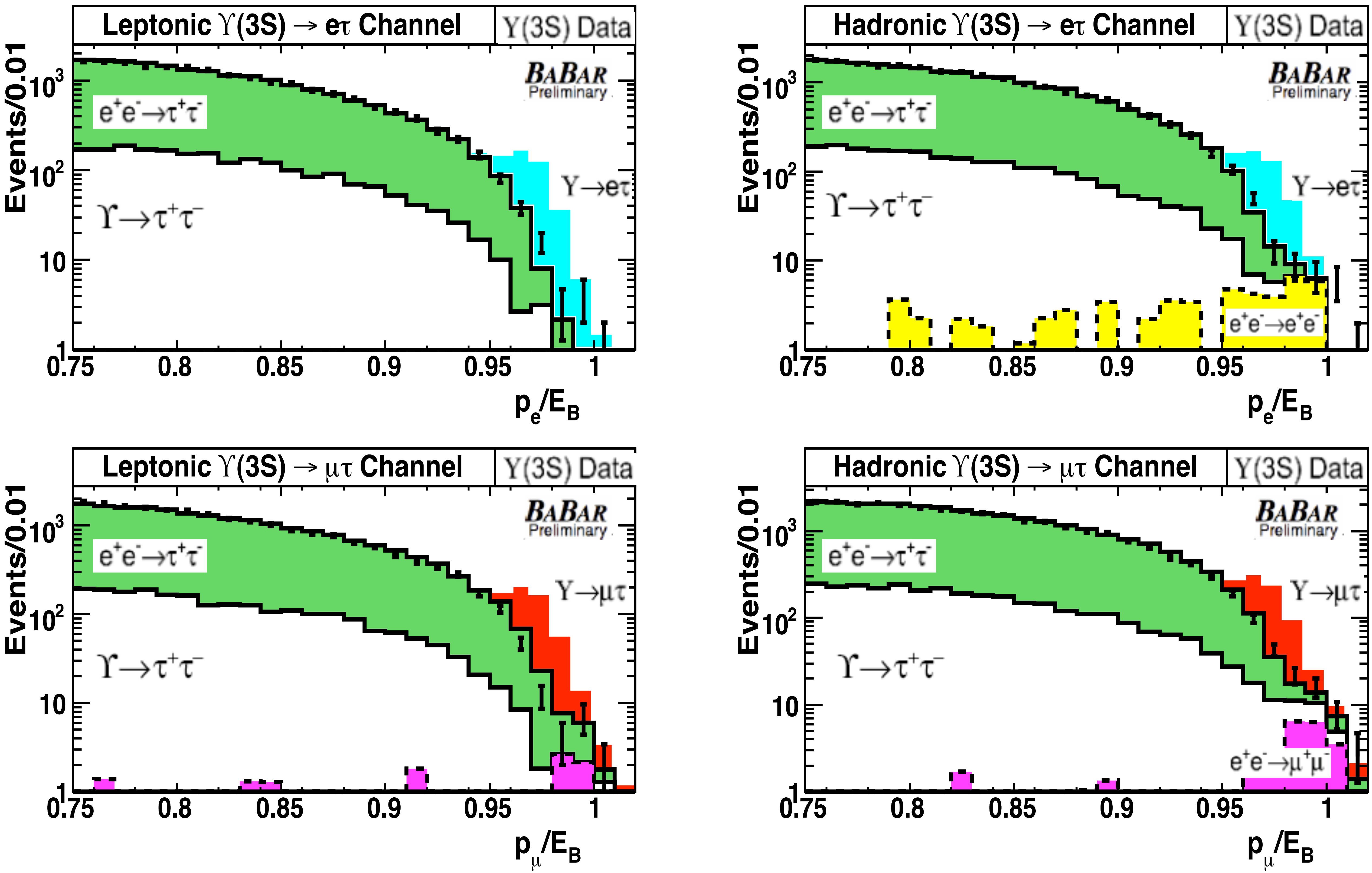
Signal: peak ~ 0.97

Bhabha/Mu-pair Background: peak ~ 1.0

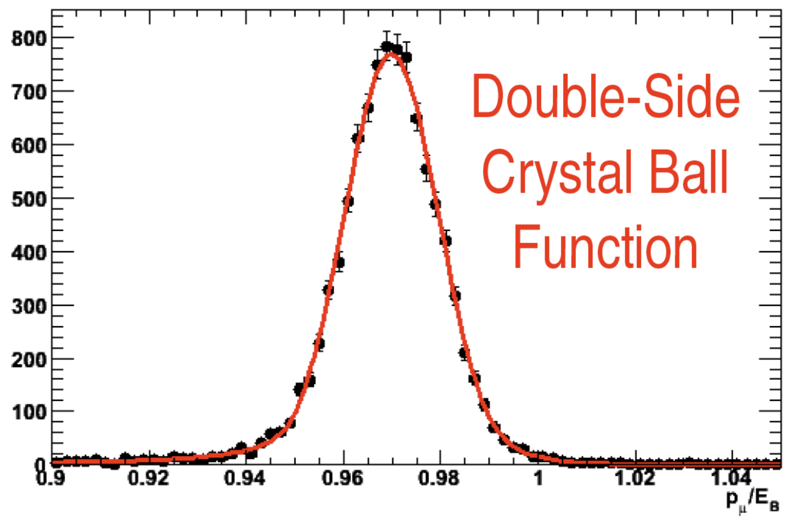


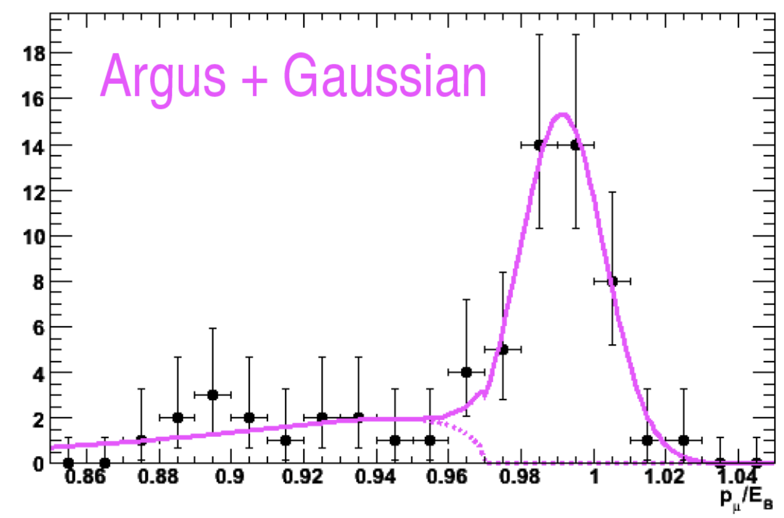
Tau-pair Background: Kinematic cut-off ~ 0.97

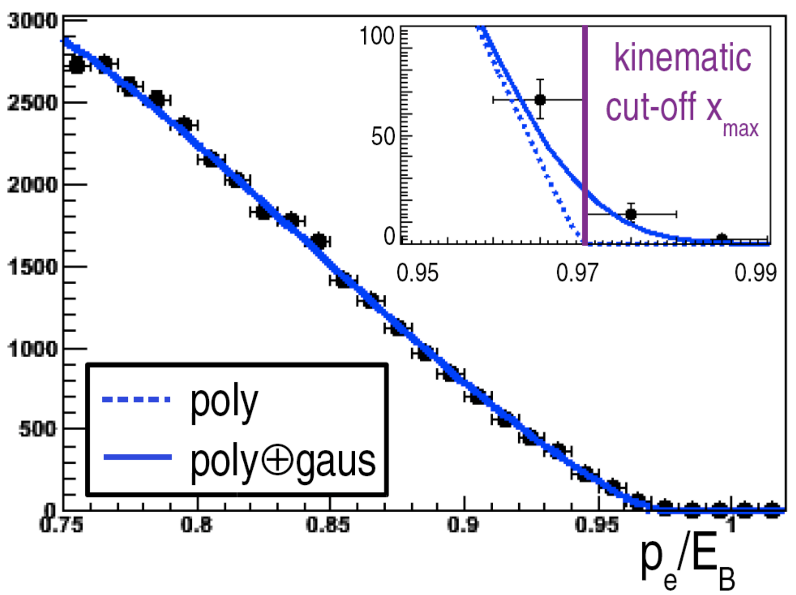
The primary lepton momentum spectrum



Signal and background shapes



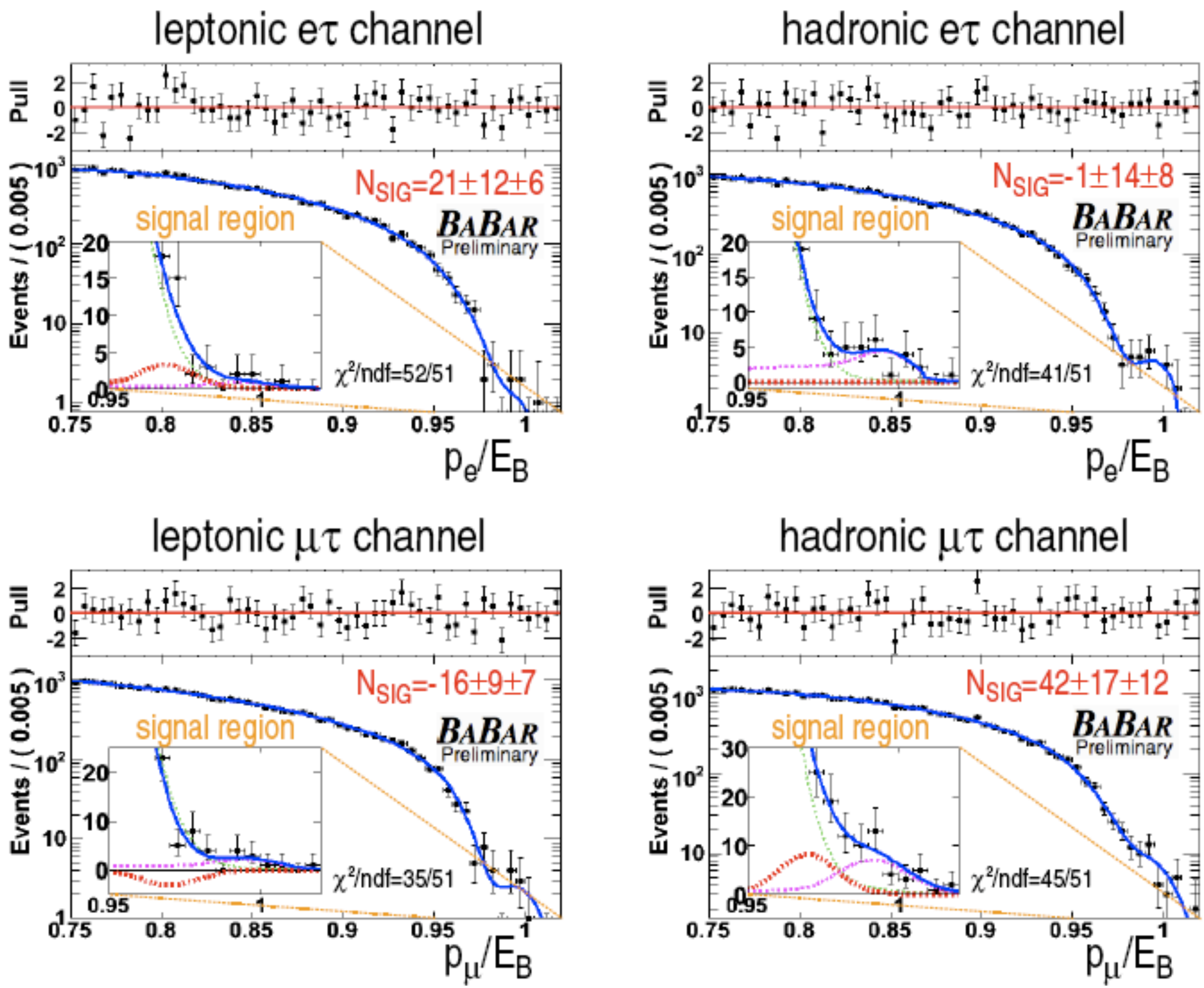




- Signal PDF: double-sided CB function peaked at $x=p_1/E_B = 0.97$
  - Extract shape from fits to signal MC
- Bhabha/m-pair Background PDF: Argus threshold function + Gaussian peaked at $x\approx1$
  - Extract shape from fits to signal MC
- τ-Pair Background PDF: 3rd-order poly ⊕ detector resolution function
  - $poly(x)=(1-x/x_{MAX})+c_2(1-x/x_{MAX})^2+c_3(1-x/x_{MAX})^3$
    - x_{MAX} = kinematic cutoff parameter: extracted from fit to ϒ(4S) data control sample
    - c_2, c_3 = polynomial shape parameters: floated in fit to ϒ(3S) data
  - detector resolution function extracted from MC
- Global PDF = signal + bhabha (μ-pair) + τ-Pair components for eτ (μτ) channels
  - Float component yields and polynomial shape parameters in fit to ϒ(3S) data

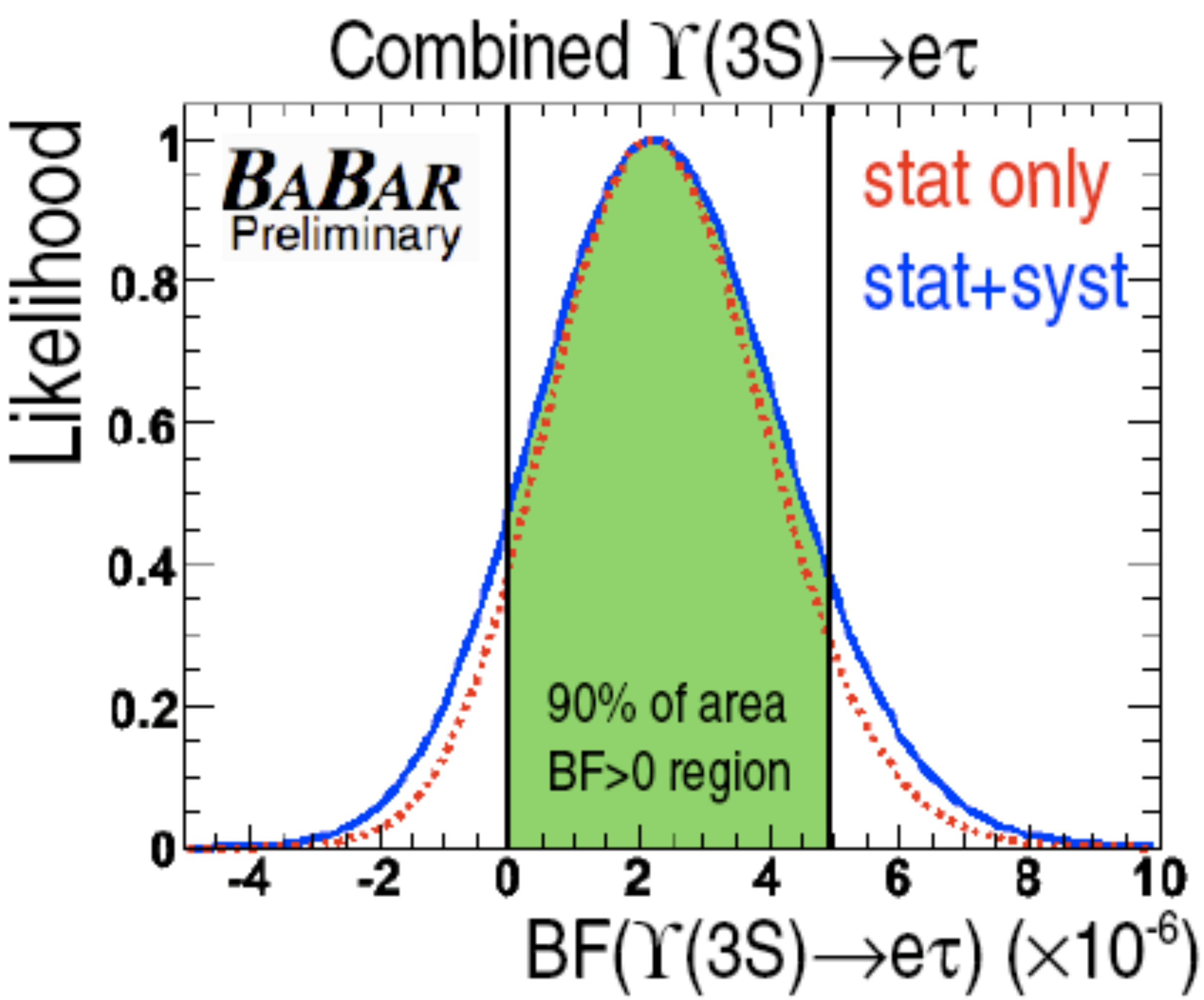
Fit Results

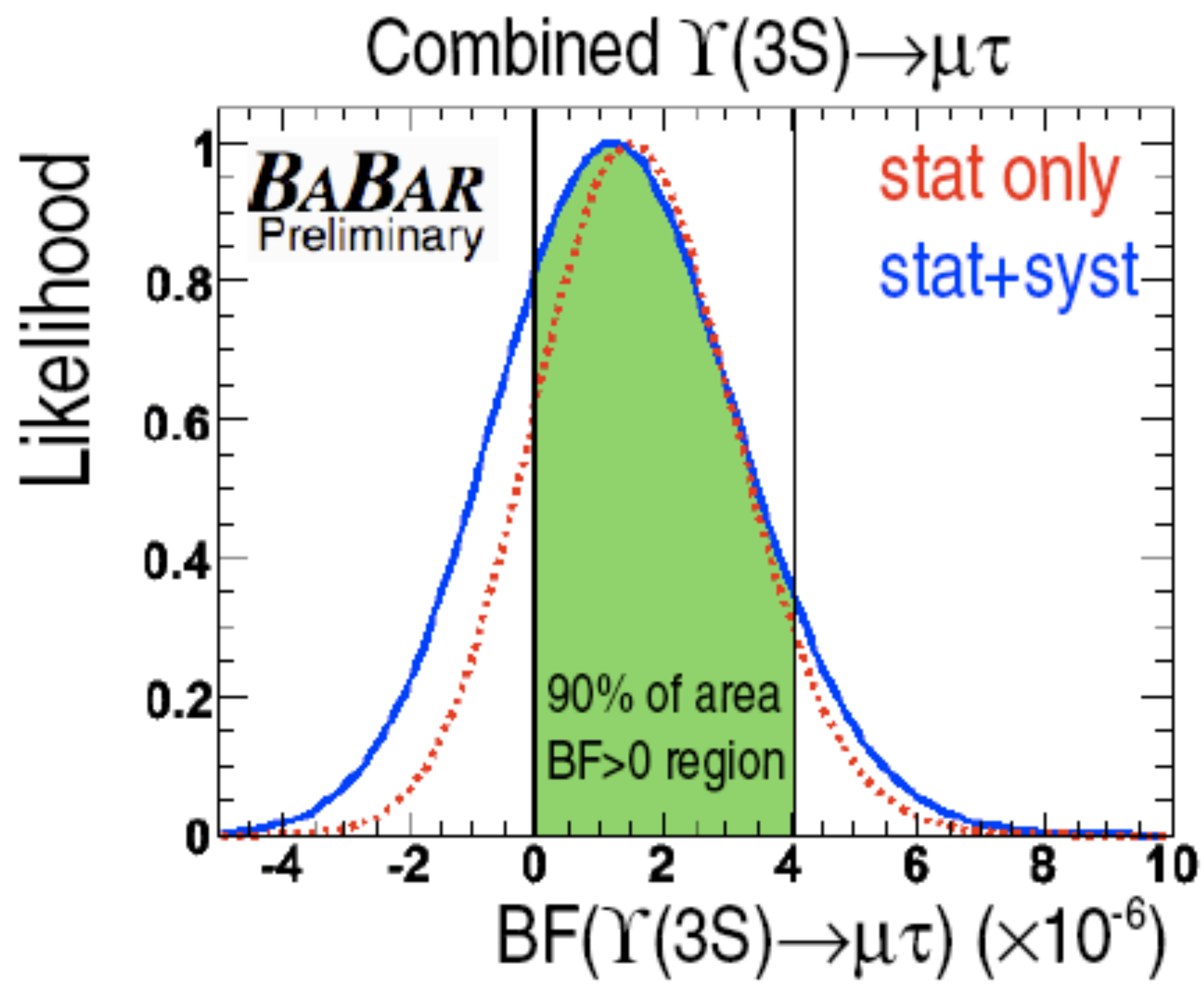
Global PDF
Signal
τ-pair Bkg
Bhabha/ μ-pair Bkg



All channels give signal yield within ±2.1σ of zero

BF(ϒ(3S)→eτ, μτ) Upper Limits @ 90% CL





BF(ϒ(3S)→eτ) < 5.0×10^{-6}

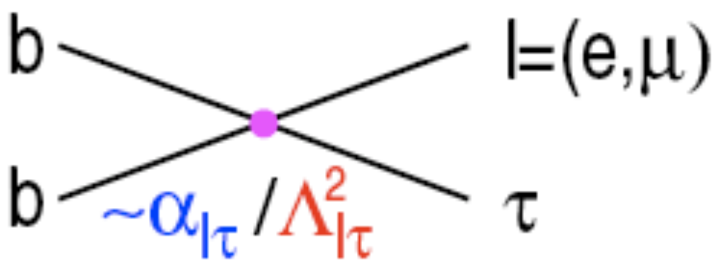
(first upper limit)

BF(ϒ(3S)→μτ) < 4.1×10^{-6}

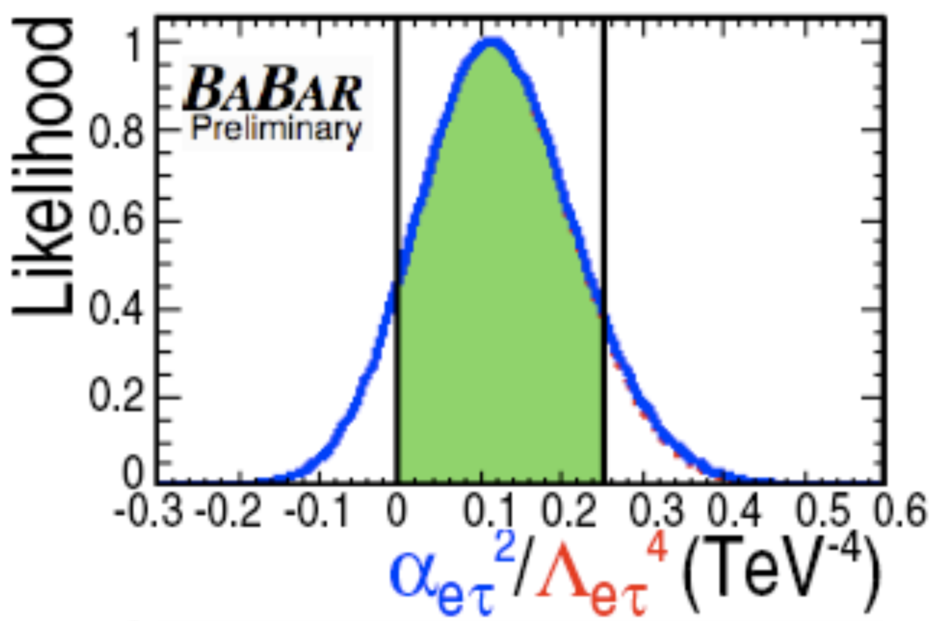
(>4x better than previous UL)

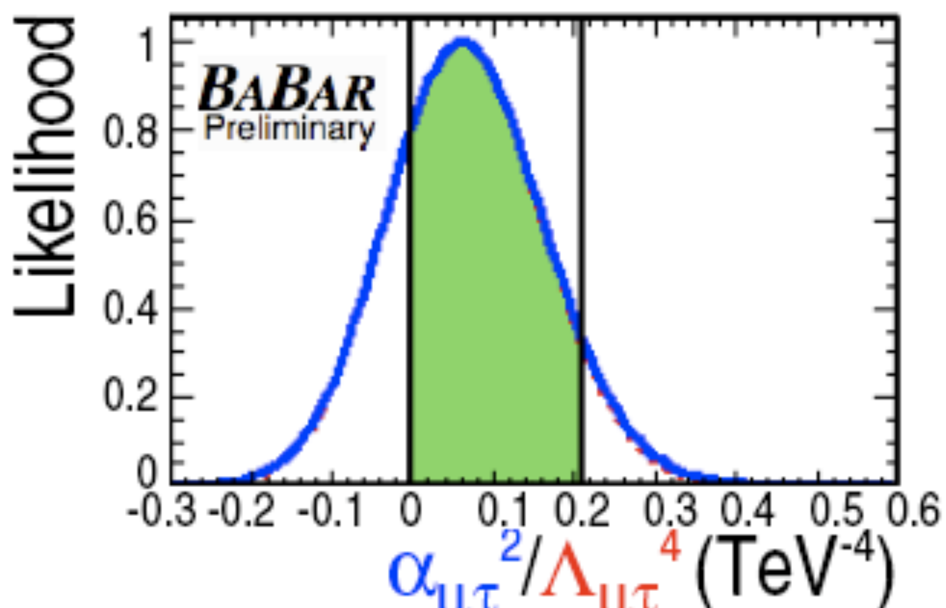
BaBar Collab., arXiv: 0812.1021 [hep-ex]

Limits on Generic Contact Interaction



$$\frac{\Gamma(\Upsilon(3S)\to \ell^\pm\tau^\mp)}{\Gamma(\Upsilon(3S)\to \ell^+\ell^-)} = \frac{1}{2q_b^2}\left(\frac{\alpha_N^{(\ell\tau)}}{\alpha}\right)^2 \left(\frac{M_{\Upsilon(3S)}}{\Lambda^{(\ell\tau)}}\right)^4 \quad (\ell = e,\mu)$$





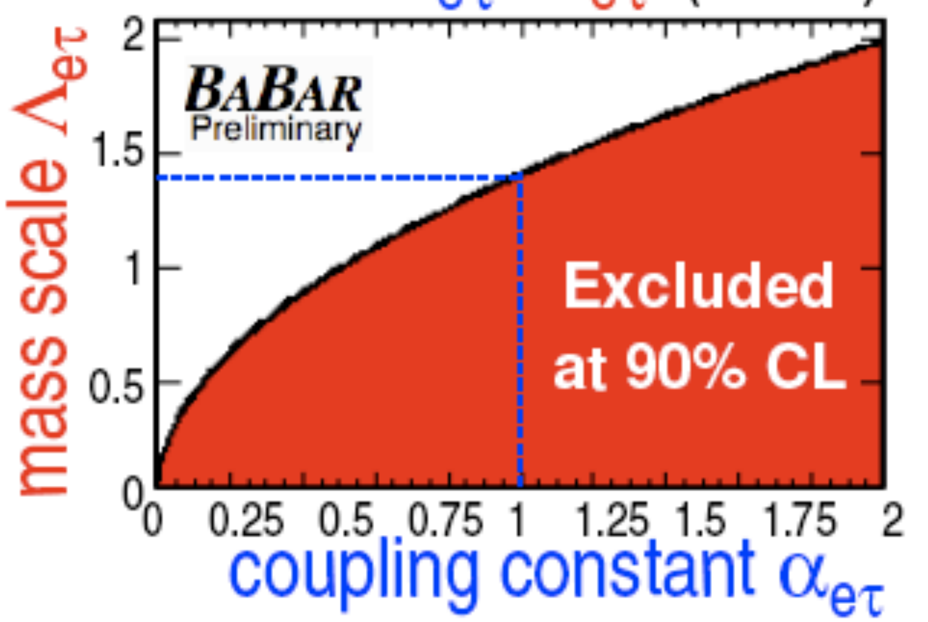
q_b = b quark charge

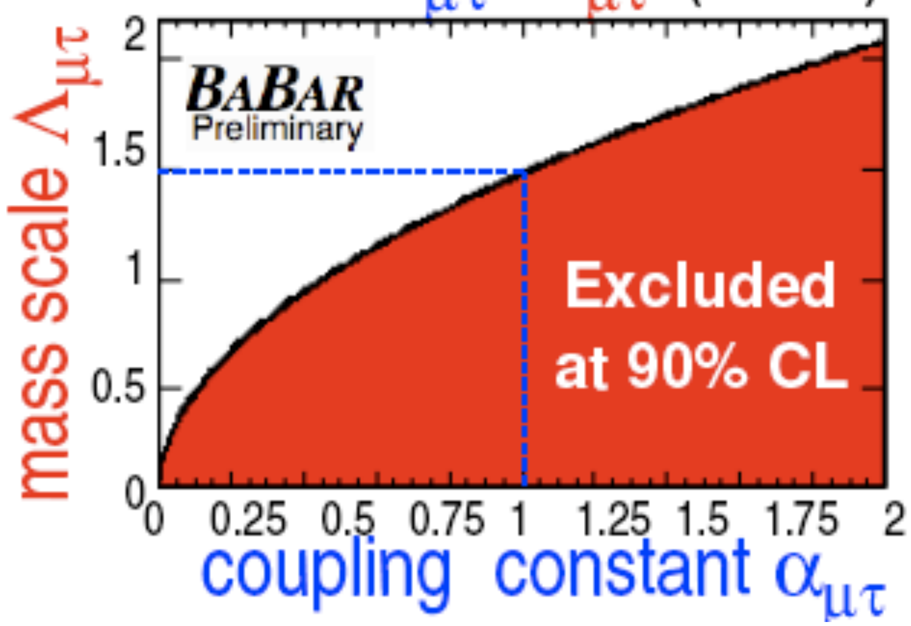
α = fine structure constant

assumes vector coupling

Silagadze Phys. Scripta 64.128

Black et al. PRD 66.053002





Assume strong coupling

$\alpha_{e\tau} = \alpha_{\mu\tau} = 1$:

$\Lambda_{e\tau} > 1.4$ TeV

$\Lambda_{\mu\tau} > 1.5$ TeV

Conclusions

- No evidence for LFV decays of $\Upsilon(3S)$
  - $BF(\Upsilon(3S) \to e\tau) < 5.0 \times 10^{-6}$ (1^{st} upper limit)
  - $BF(\Upsilon(3S) \to \mu\tau) < 4.1 \times 10^{-6}$ (>4x improvement w.r.t. prior UL)
  - Result probes new physics at the TeV-scale
- Limits are more constraining than predicted from τ decays
- More results soon to be available from $\Upsilon(2S)$ data