Test of lepton universality and searches for lepton flavor violation

Elisa Guido

University & INFN Genova

(on behalf of **BABAR Collaboration**)

Rencontres de Moriond 2010 - EW session

La Thuile 6th-13th March 2010

Outline

- ✓ New results from **BABAR** on:

NEW! (LaThuile)

- ✓ Lepton Universality test in Υ(1S) decays — arXiv:1002.4358 (sub.PRL)
- ✓ Searches for Lepton Flavor Violation:
  - ✓ in $\tau \to e\gamma$, $\mu\gamma$ decays — PRL104, 021802 (2010) [arXiv:0908.2381]

NEW!!!

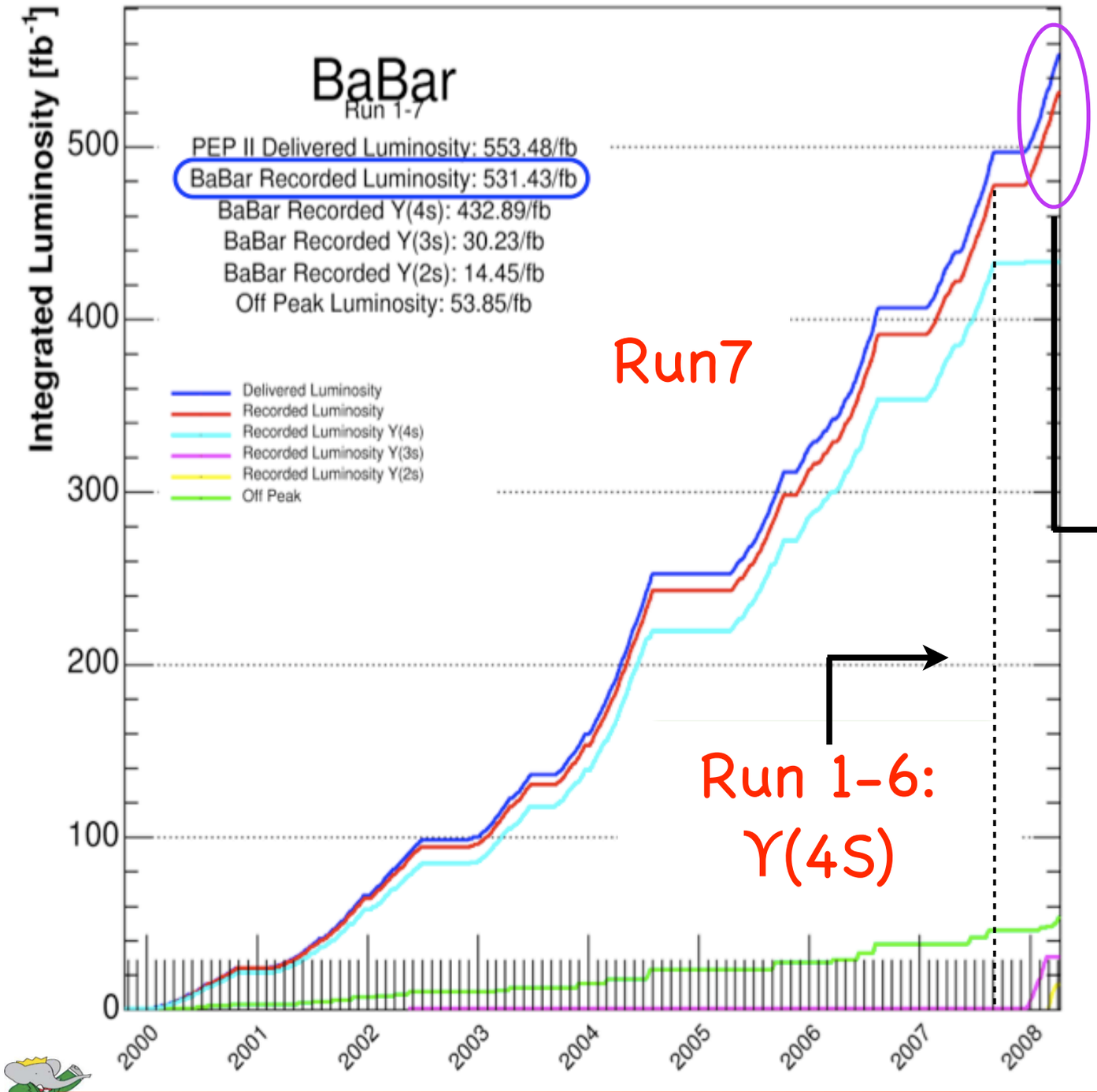
  - ✓ in $\tau \to 3$ charged leptons decays — arXiv:1002.4550(sub.PRD-RC)

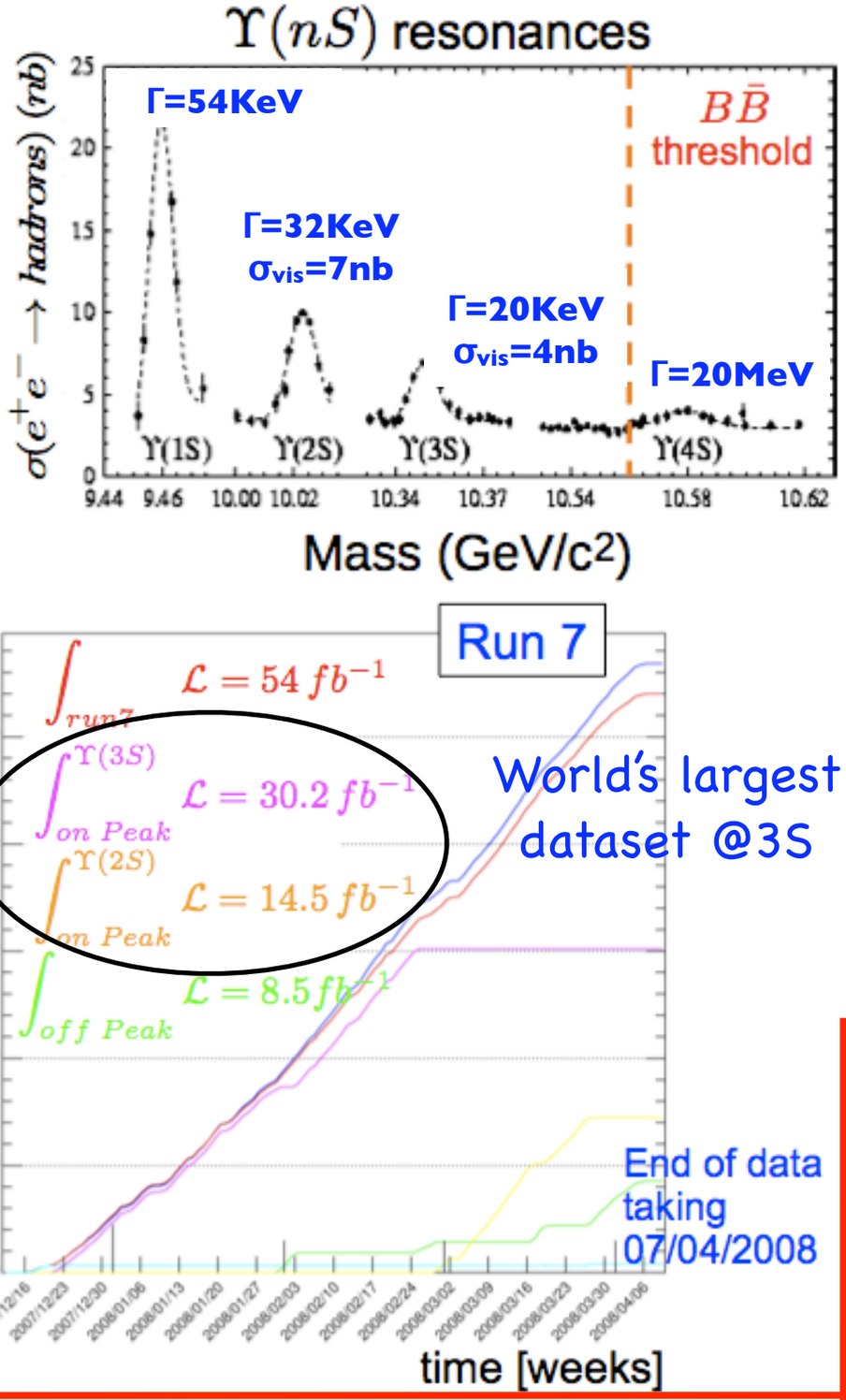
NEW! (LaThuile)

  - ✓ in $\Upsilon(3,2S) \to e^{\pm}\tau^{\mp}$, $\mu^{\pm}\tau^{\mp}$ decays — arXiv:1001.1883 (sub.PRL)

BABAR data samples

- ✓ PEP-II asymmetric energy e^+e^--collider operating at the Υ resonances
- ✓ BABAR recorded luminosity





Lepton Universality Test

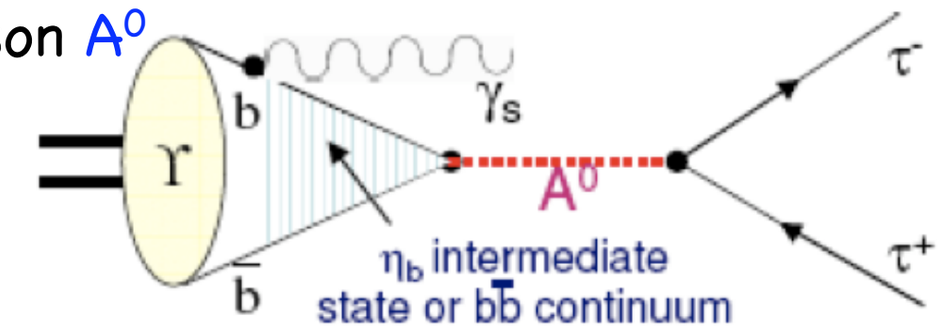
1. Theory

arXiv:1002.4358 (sub. PRL)

- ✓ In the SM couplings between gauge bosons and leptons are independent of lepton flavor
- ✓ SM expectation for $R_{ll'} = BR(\Upsilon(1S)\to l^+l^-)/BR(\Upsilon(1S)\to l'^+l'^-)$ is ~ 1 (except for small lepton-mass effects, $R_{\tau\mu} \sim 0.992$)
- ✓ NMSSM: deviations of $R_{ll'}$ from SM expectation are possible in the hypothesis of existence of a light pseudo-scalar Higgs boson A^0
- ✓ A^0 may mediate the decay chain of the $\Upsilon(1S)$:

$$\Upsilon(1S)\to A^0\gamma,\ A^0\to l^+l^- \quad (1)$$

$$\Upsilon(1S)\to \eta_b(1S)\gamma,\ \eta_b(1S)\to A^0\to l^+l^- \quad (2)$$

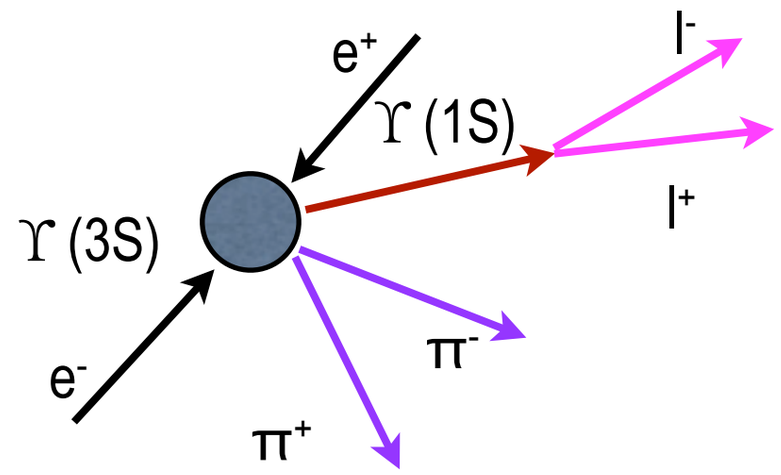


Int.J.Mod.Phys.A19, 2183 (2004);
PL B653, 67 (2007);
JHEP 0901, 061 (2009)

- ✓ If the photon is undetected, the lepton pair would be ascribed to the $\Upsilon(1S)$
- ✓ It can result in a deviation of $R_{ll'}$ from SM expectation (lepton universality breaking) →NP effect
- ✓ Effect more evident when one of the leptons is a τ (up to 4%) → $R_{\tau\mu}$

2. Strategy

- ✓ 28 fb^{-1} of data collected at Υ(3S) CM energy → ~ $122 \cdot 10^6$ Υ(3S)
- ✓ Tag Υ(1S) exploiting $\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(1S) \to \tau^+\tau^-$ and $\mu^+\mu^-$ events:
  - ✓ BF($\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$) ~ 5%
  - ✓ select τ 1-prong decays
  - ✓ 4-charged tracks final state topology
- ✓ Any number of extra photons allowed
- ✓ Separate selections for $\Upsilon(1S) \to \tau^+\tau^-$ and $\mu^+\mu^-$ events
- ✓ Bkg: $q\bar{q}$ events, τ-pairs, QED events, Υ(1S) generic decays
- ✓ A multivariate analysis approach in $\tau^+\tau^-$ channel
- ✓ Signal extraction efficiencies (estimated on MC simulations):



$\epsilon_{\mu\mu} \sim 45\%$

$\epsilon_{\tau\tau} \sim 17\%$

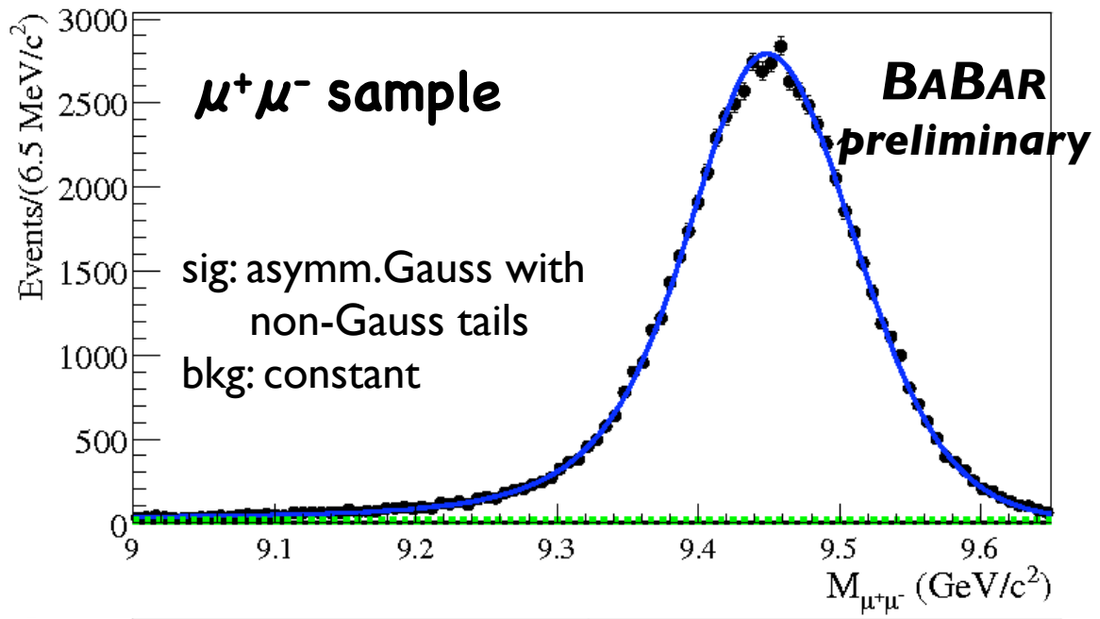
3. Signal extraction

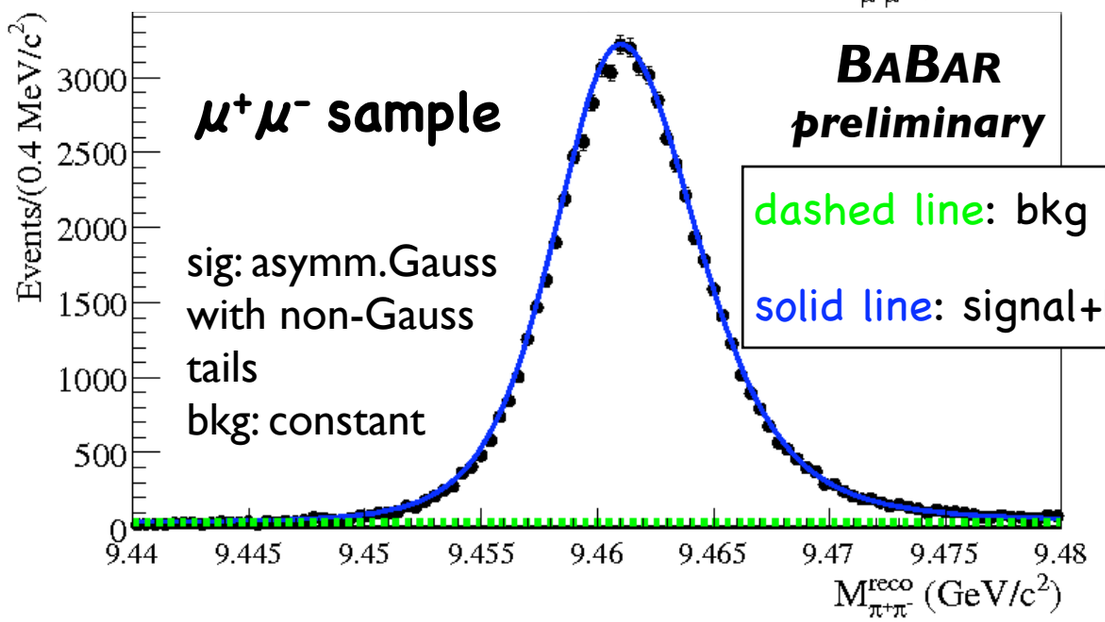
- ✓ Extended and unbinned maximum-likelihood fit:
  - ✓ in $\mu^+\mu^-$ channel a 2-dim likelihood based on $M_{\pi^+\pi^-}^{reco}$ and $M_{\mu^+\mu^-}$
  - ✓ in $\tau^+\tau^-$ channel a 1-dim likelihood based on $M_{\pi^+\pi^-}^{reco}$

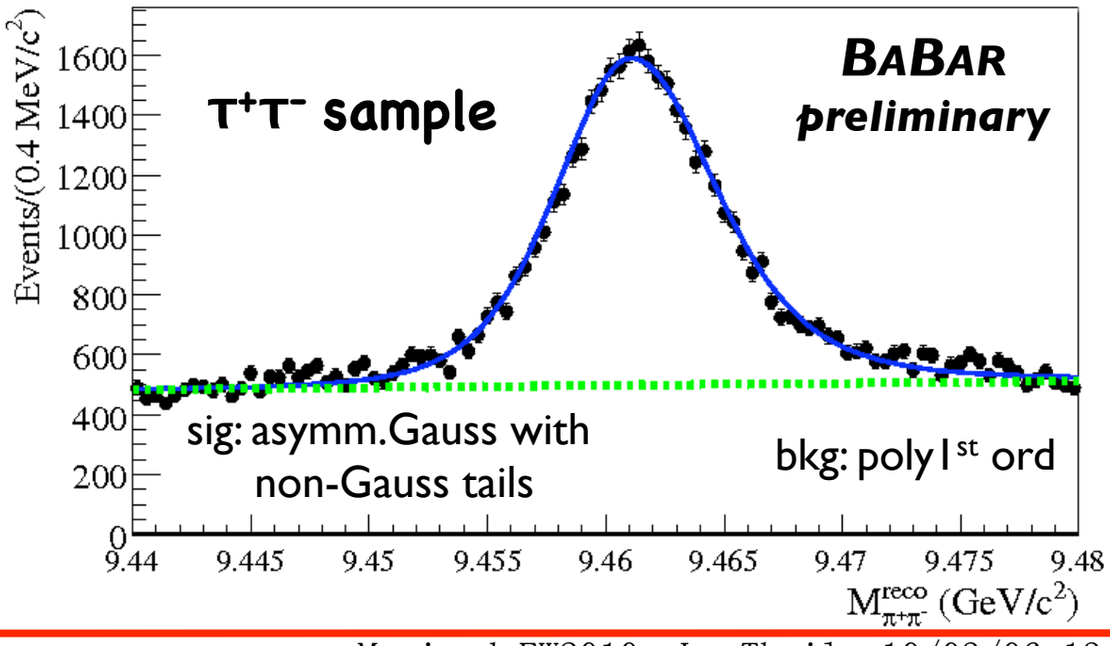
$M_{\mu^+\mu^-}$ invariant $\mu^+\mu^-$ mass

$$M_{\pi^+\pi^-}^{reco} = \sqrt{s + M^2_{\pi^+\pi^-} - 2\cdot\sqrt{s}\cdot\sqrt{M^2_{\pi^+\pi^-} + p^{*2}_{\pi^+\pi^-}}}$$

- ✓ PDFs chosen from a data sub-sample (~1/10 of the total), then discarded
- ✓ Fit performed simultaneously to the 2 datasets
- ✓ $R_{\tau\mu}$ returned







3. Results

- ✓ Correction for known differences between data and simulation efficiencies
- ✓ Systematic uncertainty contributions (up to 2.2%):
  - ✓ event selection efficiency
  - ✓ μ identification
  - ✓ trigger efficiency
  - ✓ imperfect knowledge of signal and bkg shapes
  - ✓ peaking background yield

BABAR ***preliminary***

$$R_{\tau\mu}(\Upsilon(1S)) : \quad 1.005 \pm 0.013 \text{ (stat.)} \pm 0.022 \text{ (syst.)}$$

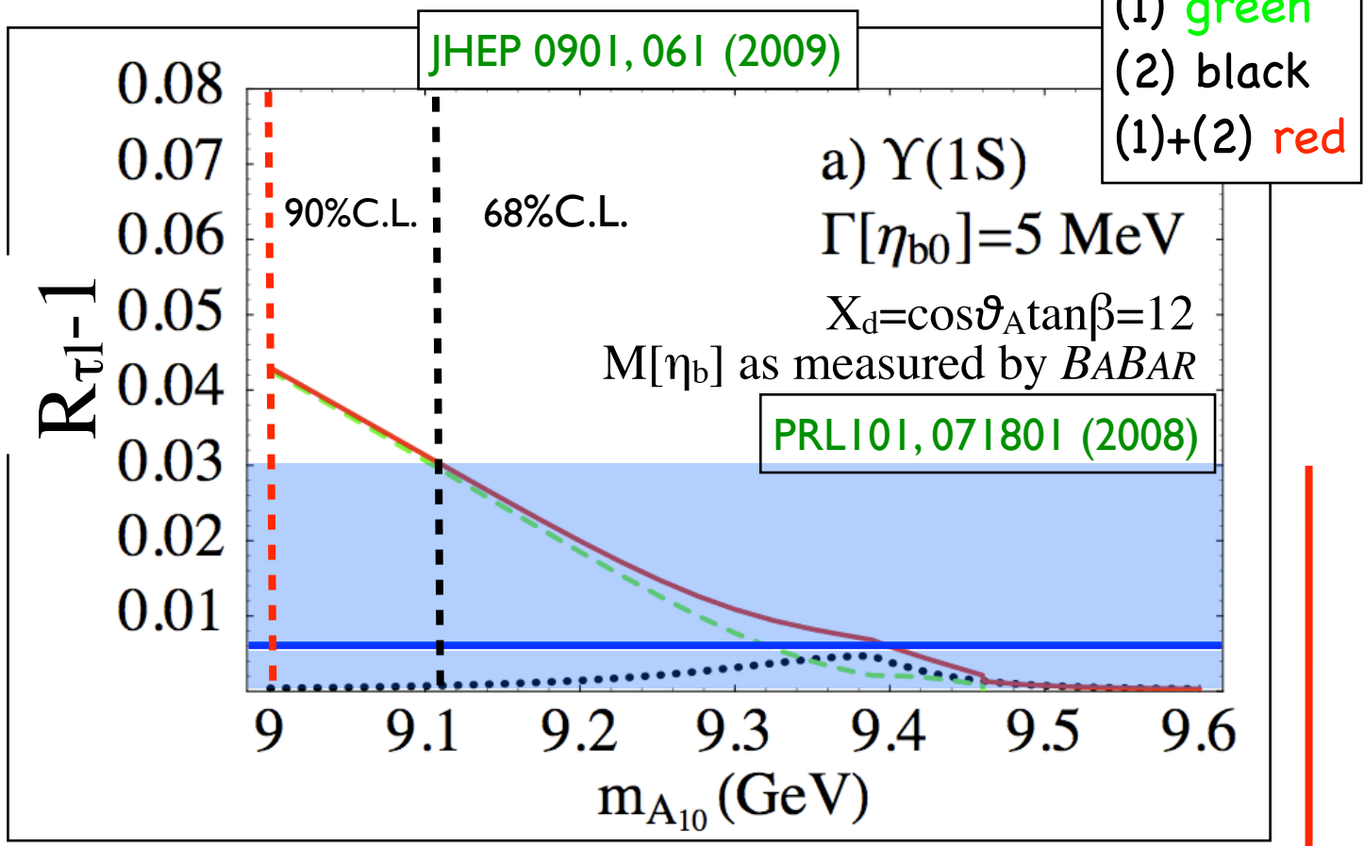
1. Significant improvement in precision

[Previous best result by CLEO:
$R_{\tau\mu}(\Upsilon(1S))$: 1.02 ± 0.02 (stat.) ± 0.05 (syst.)]

PRL98, 052002 (2007)

2. No significant deviations w.r.t. SM expectations ($R_{\tau\mu}(\Upsilon(1S)) \sim 0.992$)

3. Excluded $m(A^0)<9$ GeV/c^2 @90%C.L.



Searches for charged LFV

Theory

- ✓ In the SM with ν-masses oscillation LFV can occur
- ✓ Never observed in processes involving **charged** LFV (tree-level contribution suppressed by $(\Delta m^2_\nu / M^2_W)^2 \lesssim 10^{-48}$ to undetectable levels)
- ✓ Enhancements close to experimental sensitivity (BR~$\mathcal{O}(10^{-8})$) in many extensions of the SM
- ✓ Search for charged LFV in:

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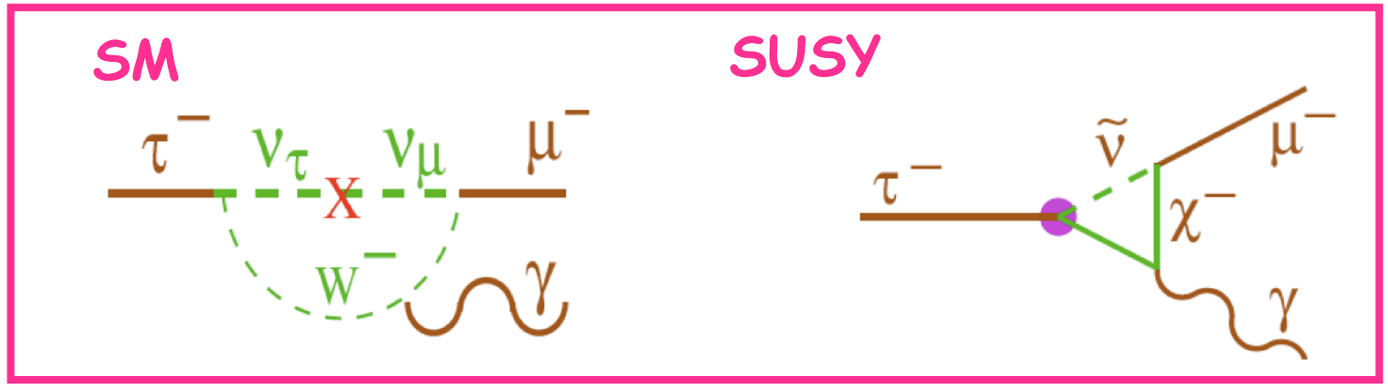

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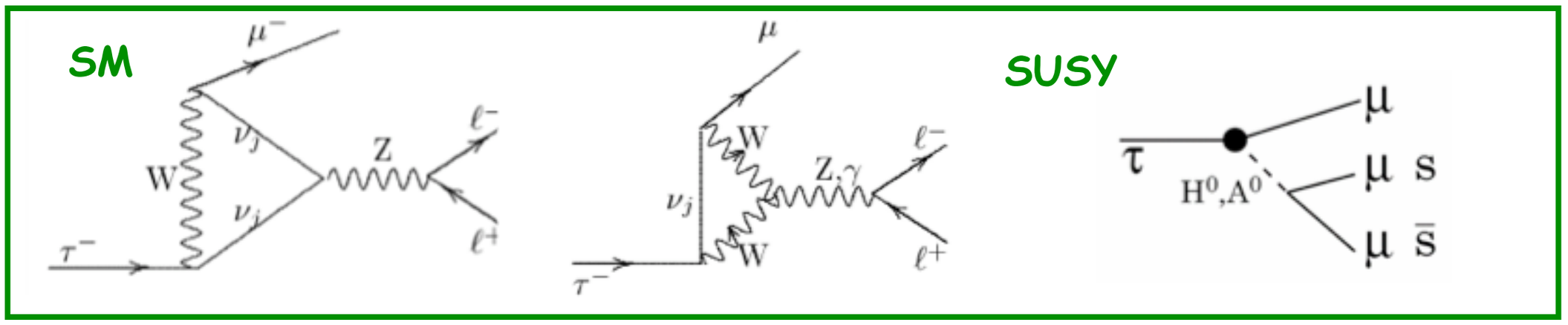
  - ✓ **τ->3l** decays:



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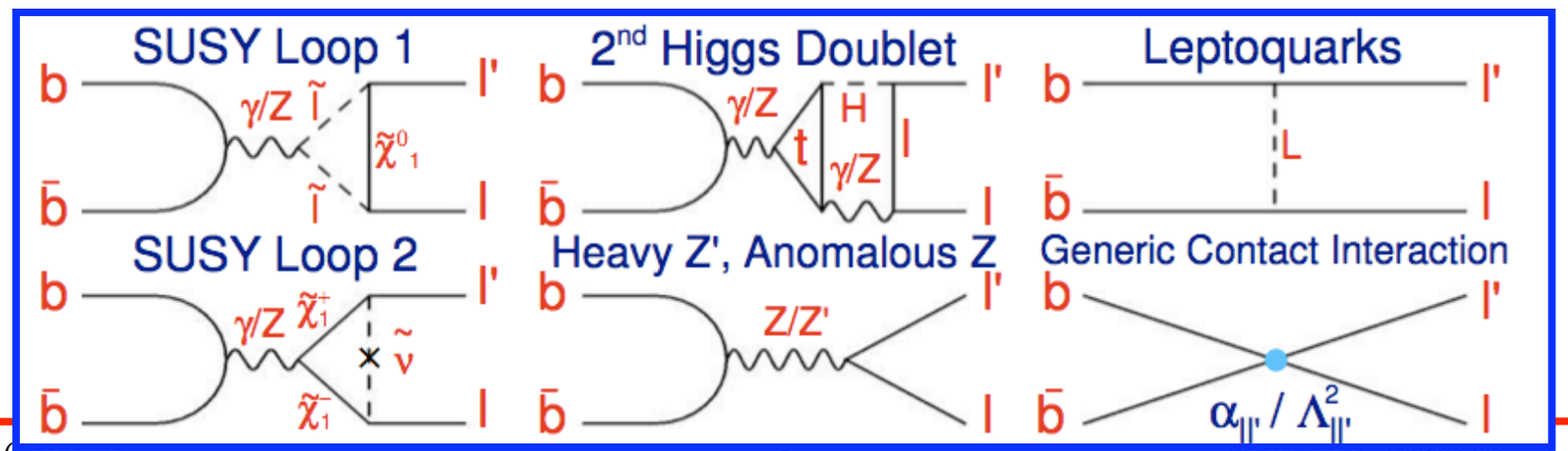
  - ✓ ϒ->ll′ decays:



PRL104, 021802 (2010)
[arXiv:0908.2381]

LFV in $\tau^{\pm}$->$e^{\pm}/\mu^{\pm}\gamma$

$\sigma(e^+e^- \to b\bar{b})$ @Y(4S)~1.05 nb

$\sigma(e^+e^- \to \tau^+\tau^-)$ @Y(4S)~0.92 nb

BR(Y(3,2S)$\to\tau^+\tau^-$)~2%

1. Strategy

- ✓ BABAR is a τ-factory as well: a total of about **960·10⁶ τ decays**
- ✓ Reconstructed events **e^+e^-->$\tau^+\tau^-$**, divided in 2 hemispheres:
- ✓ **SIGNAL side**: - $l^{\pm}\gamma$ pair: $M(l^{\pm}\gamma)\sim M_\tau$

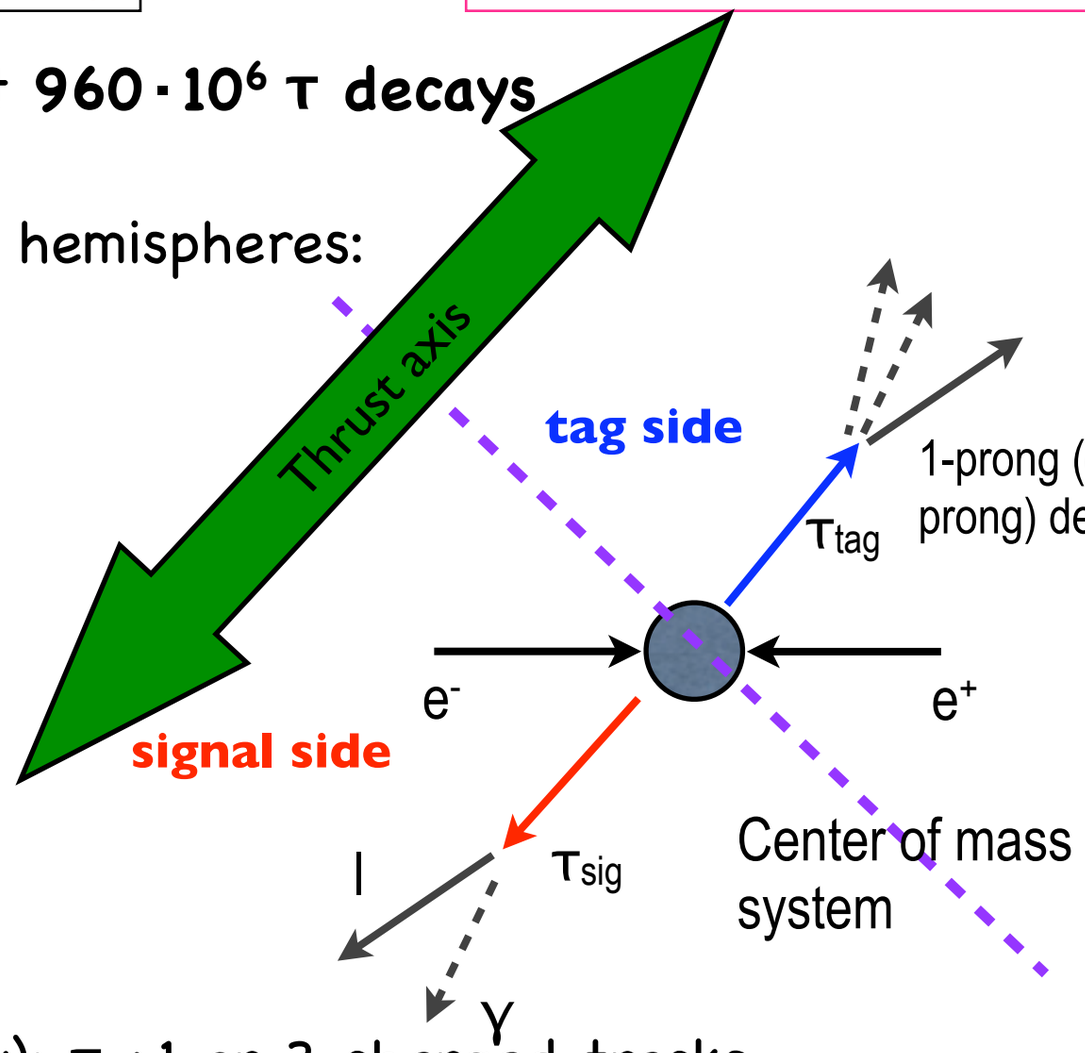
  $E(l^{\pm}\gamma)_{CM}\sim\sqrt{s}/2$

  - only 1 γ with $E(\gamma)_{CM}$>1GeV

  - 1 track with $p_{CM}<0.77\sqrt{s}/2$

  identified as an e or a μ

  - γ and l back-to-back in τ-rest frame
  -> boosted: $\cos\vartheta_{\gamma l}<0.786$



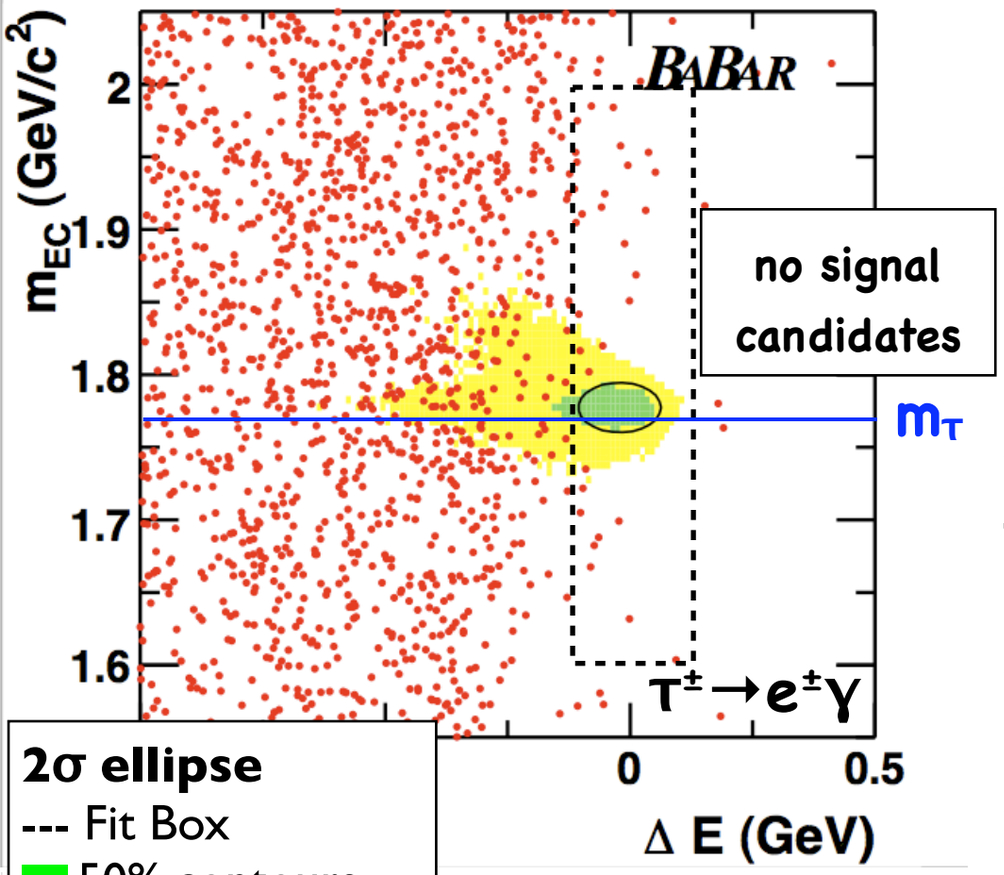
- ✓ **TAG side** (expected to contain a SM τ-decay): τ->1 or 3 charged tracks

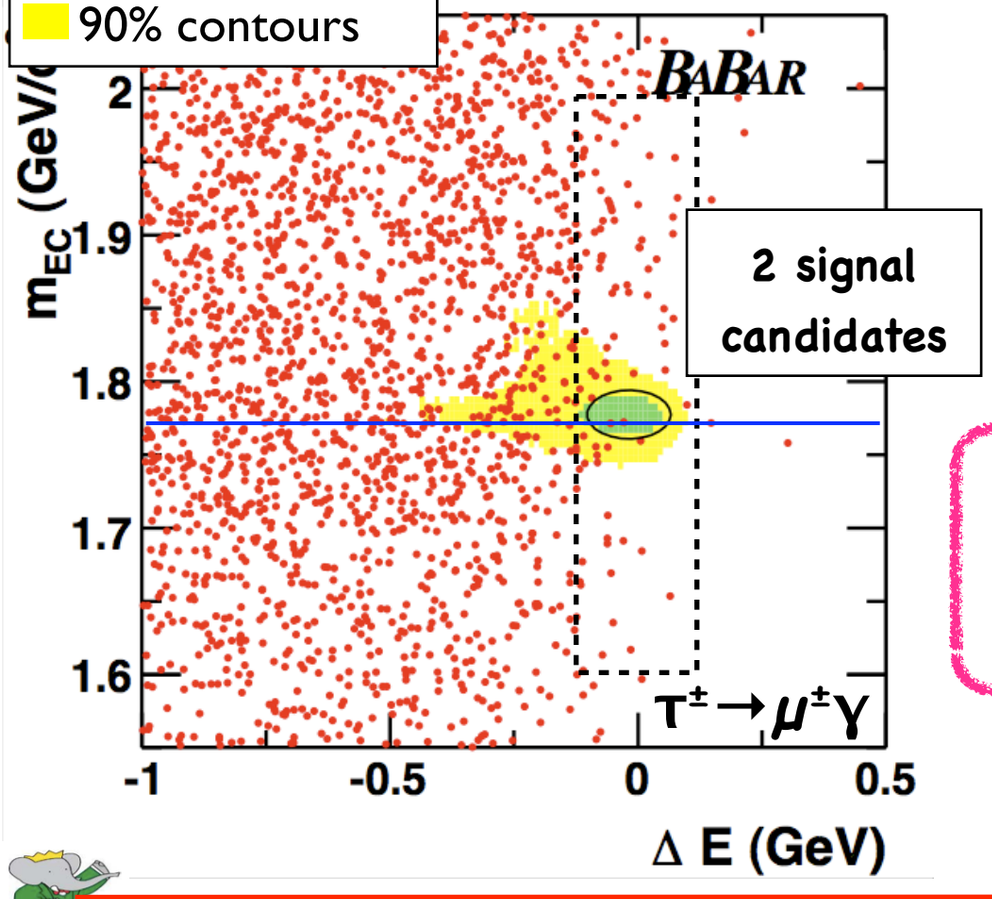
  - e-tag, μ-tag, π-tag, 3h-tag

  - different selections (neural networks approach) for each tag

- ✓ Backgrounds: τ-pairs (irreducible), $e^+e^-\gamma/\mu^+\mu^-\gamma$, hadronic τ decays with π mis-id

2. Results





✓ Signal extraction: $\Delta E = E(l\gamma)_{CM} - \sqrt{s}/2$ and m_{EC} (beam energy-constrained τ mass)

✓ Signal reconstruction efficiency: 4% (6%) for τ->eγ (τ->μγ) final states

✓ Fraction of expected bkg from fits to the Fit Box

✓ Number of events in the 2σ signal ellipses compatible with bkg expectations

✓ Systematic errors: tracking, PID and trigger and bkg filters efficiencies; track momentum and photon energy and resolution in the signal side

✓ **Upper limits @ 90%C.L.:**

$$\mathcal{B}\,(\tau^\pm \to e^\pm\gamma) < 3.3 \times 10^{-8}$$

$$\mathcal{B}\,(\tau^\pm \to \mu^\pm\gamma) < 4.4 \times 10^{-8}$$

Previous:

1.1×10^{-7} **(BABAR)** PRL96, 041801 (2006)

4.5×10^{-8} **(Belle)** PL B666, 16 (2008)

The most stringent limits on LFV in these decays

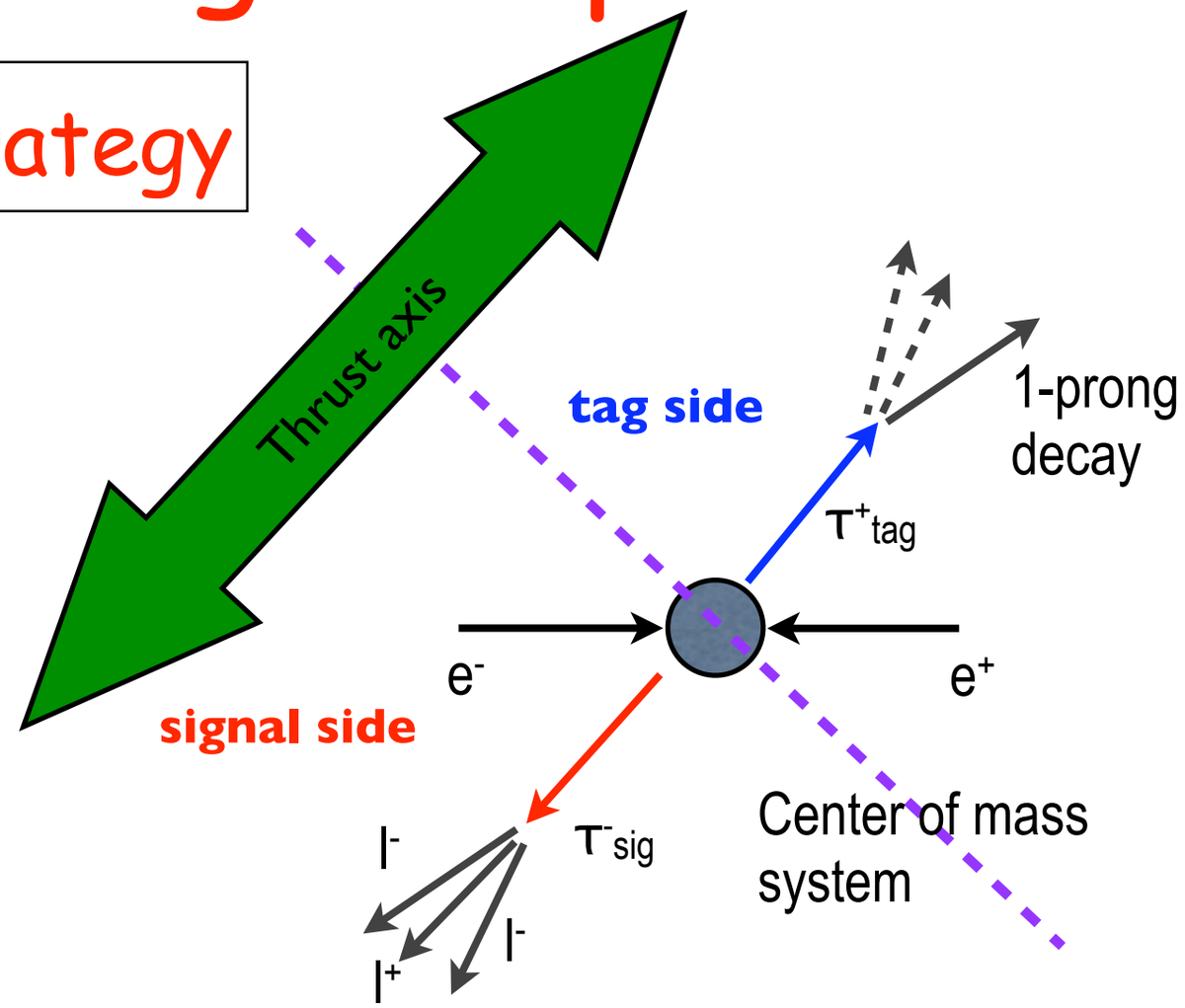
LFV in $\tau^- \to 3$ charged leptons

arXiv:1002.4550 (sub. PRD-RC)

1. Strategy

- ✓ Run 1-6 data ($\Upsilon(4S)$) -> **$430 \cdot 10^6$ τ-pairs**
- ✓ 6 channels studied:

$\tau^- \to e^- e^+ e^-$
$\tau^- \to \mu^- e^+ e^-$
$\tau^- \to e^- \mu^+ e^-$
$\tau^- \to \mu^- \mu^+ e^-$
$\tau^- \to \mu^- e^+ \mu^-$
$\tau^- \to \mu^- \mu^+ \mu^-$



- ✓ 4 charged tracks and zero net charge
- ✓ **SIGNAL**: 3 charged particles, identified as e or μ, with $M(3l) \sim M_\tau$ and $E(3l)_{CM} \sim \sqrt{s}/2$
- ✓ **TAG**: τ-> 1 prong decays
- ✓ PID used in suppressing backgrounds:
  - **$q\bar{q}$ events**
  - **QED events (Bhabha and $\mu^+\mu^-$ pairs)**
  - **SM $\tau^+\tau^-$ decays**
- ✓ Further selection criteria, partially common to all the channels, partially channel-dependent

2. Results

- ✓ Expected selection efficiencies: 6-13% depending on the channel considered

- ✓ Signal extraction: $\Delta E = E(3l)_{CM} - \sqrt{s}/2$ and $\Delta M_{EC} = M_{EC} - m_\tau$

- ✓ Systematic uncertainties due to PID (dominant), tracking efficiency, errors in bkg estimation

- ✓ **Upper limits @ 90%C.L.:**

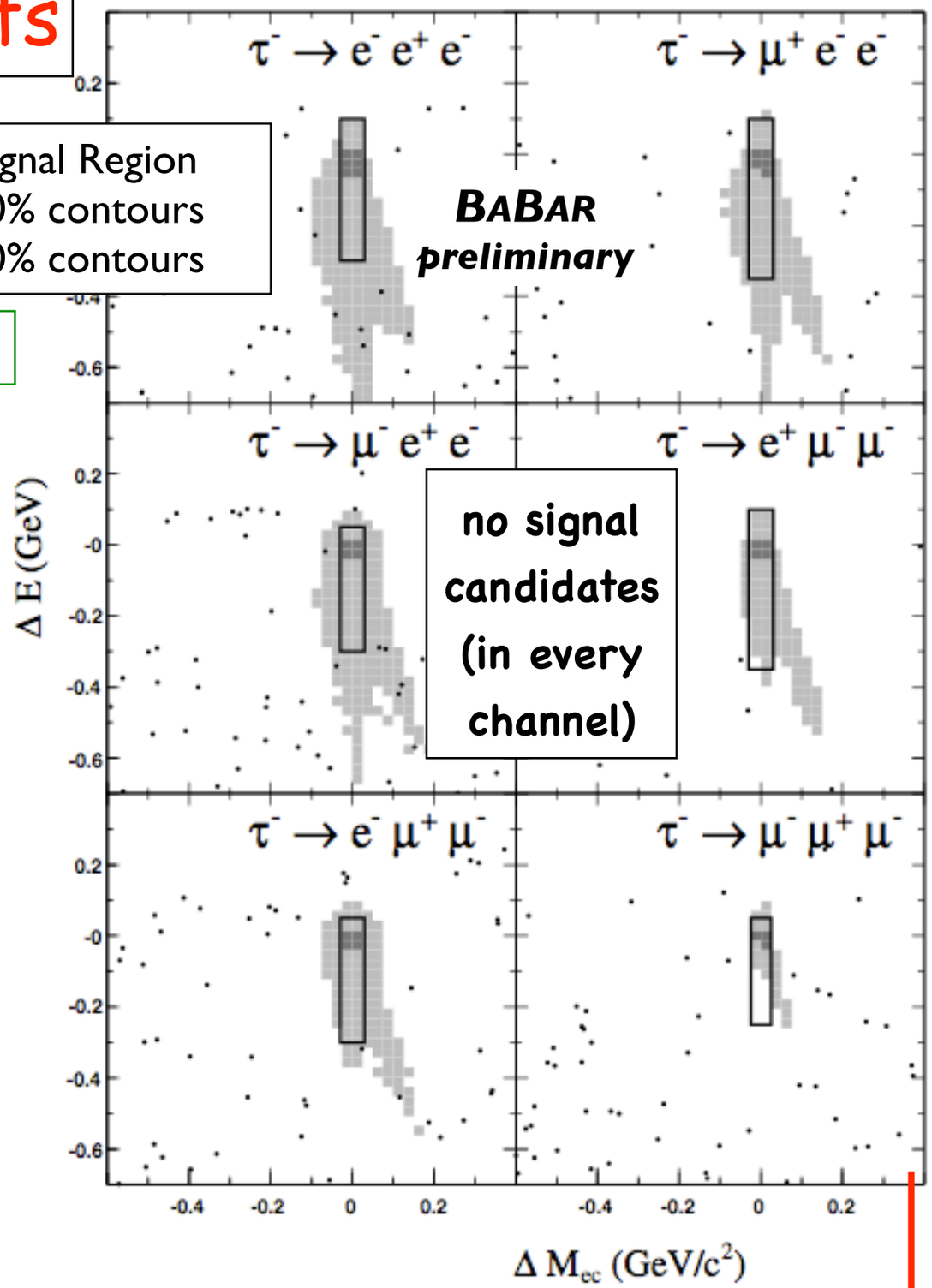
Channel	UL@90%C.L. ($\cdot 10^{-8}$)	
	BABAR	**Belle**
$e^-e^+e^-$	2,9	2,7
$\mu^-e^+e^-$	2,2	1,8
$e^-\mu^+e^-$	1,8	1,5
$\mu^-\mu^+e^-$	3,2	2,7
$\mu^-e^+\mu^-$	2,6	1,7
$\mu^-\mu^+\mu^-$	3,3	2,1
τ-pairs ($\cdot 10^6$)	**430**	**719**

- ✓ Significant improvement wrt previous BABAR result

PRL95, 251803 (2007)

- ✓ Competitive with Belle result, even with a smaller statistics

arXiv:1001.3221 (sub.PLB)



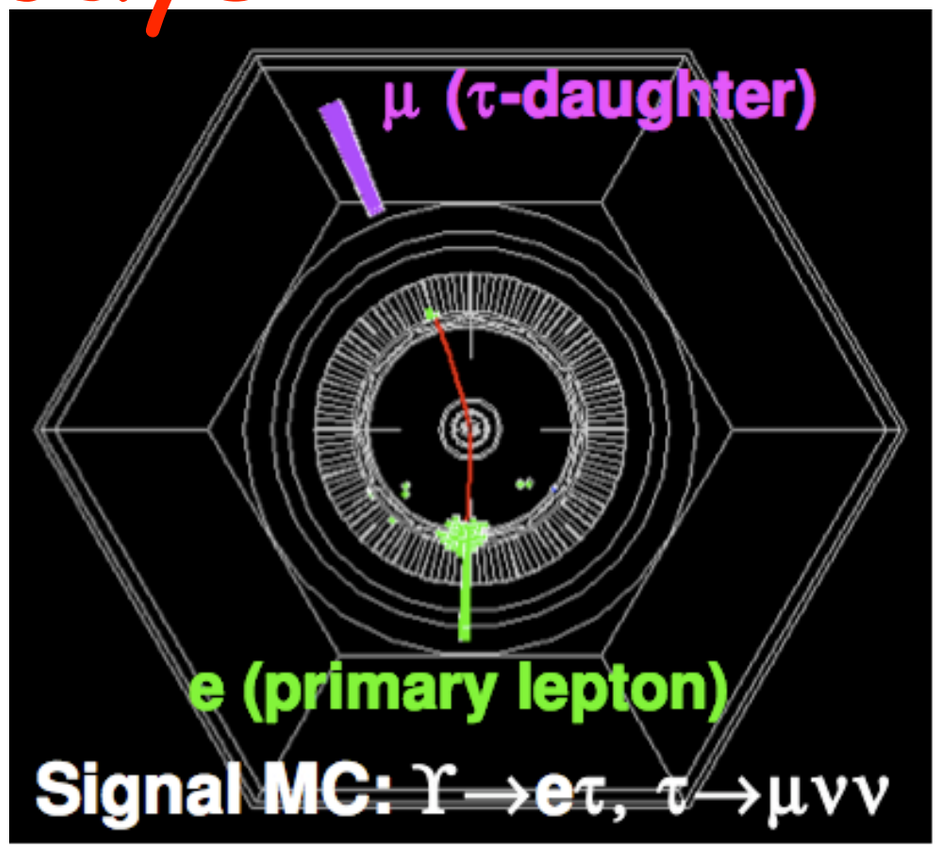
[Resolution different among channels (worst in e channels); radiative losses, tracking resolution.]

LFV in Υ decays

arXiv:1001.1883 (sub.PRL)

1. Strategy

- ✓ Search for $\Upsilon(nS) \to l^{\pm}\tau^{\mp}$ with n=2,3 and l=e,μ
- ✓ 27 fb^{-1} of data collected at Υ(3S) CM energy
  → ~ $117 \cdot 10^6$ Υ(3S)
- ✓ 14 fb^{-1} of data collected at Υ(2S) CM energy
  → ~ $99 \cdot 10^6$ Υ(2S)



- ✓ Signature:
  - 1 primary lepton (e or μ)
  - 1 τ detected through a leptonic (μ or e) or hadronic ($\pi^{\pm}+\pi^0$) decay

Process	τ decay	Channel
Υ(3,2S)->eτ	τ->μνν	leptonic eτ
Υ(3,2S)->eτ	$\tau \to \pi^{\pm}\pi^0\nu / \pi^{\pm}\pi^0\pi^0\nu$	hadronic eτ
Υ(3,2S)->μτ	τ->eνν	leptonic μτ
Υ(3,2S)->μτ	$\tau \to \pi^{\pm}\pi^0\nu / \pi^{\pm}\pi^0\pi^0\nu$	hadronic μτ

- ✓ Background events:
  - Bhabha and μ-pair (and mis-ID)
  - τ-pair
  - multiple π and additional γ
- ✓ Selection partially common to the 4 channels, partially channel-specific (PID, τ-daughter kinematics)

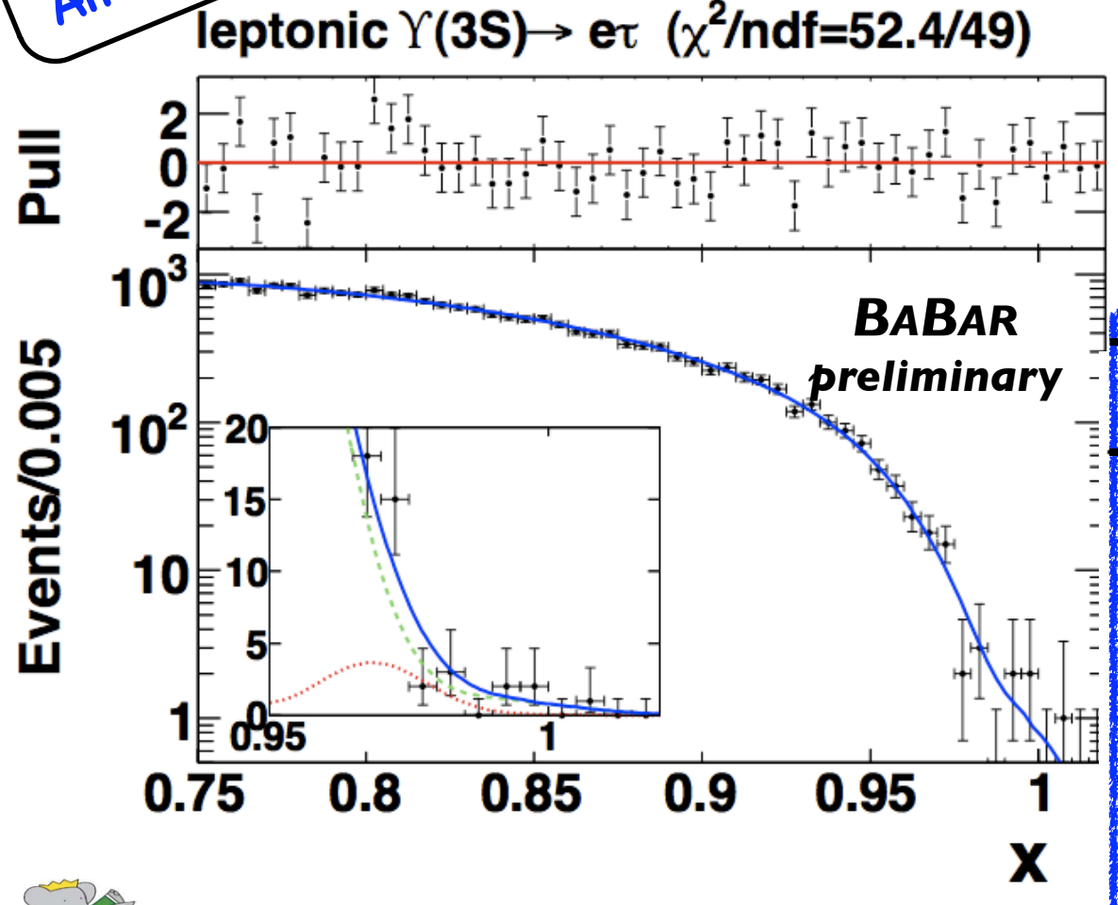
2. Signal extraction and results

- ✓ Discriminating variable: **x** = primary lepton momentum/beam energy
- ✓ Unbinned extended maximum-likelihood fit
- ✓ PDFs chosen for: - signal (peaks at $x=x_{MAX}\sim0.97$) ⟶ from extracted signal yields, BR calculated
  - τ-pair bkg (smooth, endpoint at x_{MAX})
  - Bhabha/μ-pair bkg (peaks at $x\sim1$)
  - hadron bkg (smooth, endpoint at x_{MAX})

$$\mathcal{B} = N_{SIG}/(\epsilon_{SIG} \times N_{\Upsilon(nS)})$$

Systematics uncertainties (mainly from PDF shapes) and corrections applied

An example of fit:



PRL101, 201601 (2008)

	$\mathcal{B}$ (10^{-6})	UL (10^{-6})	Improvement factor
$\mathcal{B}(\Upsilon(2S) \to e^{\pm}\tau^{\mp})$	$0.6^{+1.5+0.5}_{-1.4-0.6}$	< 3.2	first!
$\mathcal{B}(\Upsilon(2S) \to \mu^{\pm}\tau^{\mp})$	$0.2^{+1.5+1.0}_{-1.3-1.2}$	< 3.3	5.5
$\mathcal{B}(\Upsilon(3S) \to e^{\pm}\tau^{\mp})$	$1.8^{+1.7+0.8}_{-1.4-0.7}$	< 4.2	first!
$\mathcal{B}(\Upsilon(3S) \to \mu^{\pm}\tau^{\mp})$	$-0.8^{+1.5+1.4}_{-1.5-1.3}$	< 3.1	3.7

Conclusions

- ✓ BABAR data are a rich harvest for several important and different precision tests on the SM and beyond
- ✓ Now finalizing most of the analyses using the full dataset at Υ(4S) energy
- ✓ Υ(3S) and Υ(2S) datasets give important results too
- ✓ Recent results on:
  - ✓ Lepton Universality in Υ(1S) decays
  - ✓ LFV searches in τ and Υ decays
- ✓ BABAR results are now able to dialogue with theoretical limits and able (or near) to exclude some foreseen parameters' space regions for several models

BACKUP SLIDES

The BABAR detector

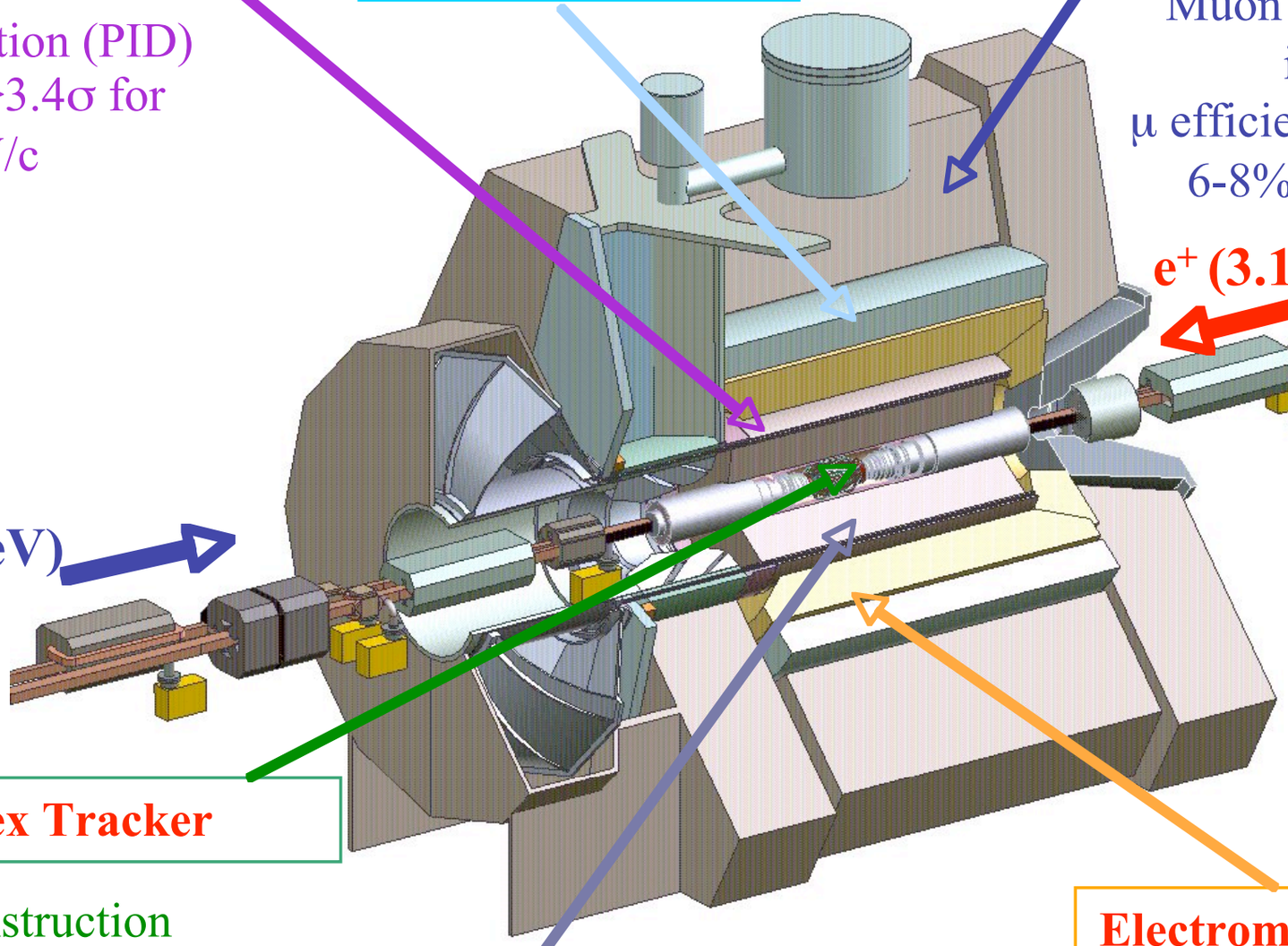
Cherenkov Detector

Particle identification (PID)
K-π separation >3.4σ for
p<3.5GeV/c

Solenoid 1.5T

Instrumented Flux Return

Muon and neutral hadron identification
μ efficiency >~85%, π mis-id 6-8%, for p>1.5 GeV/c



Silicon Vertex Tracker

Vertex reconstruction and tracking + dE/dx.
Efficiency ~ 97%

Drift Chamber

Momentum measurement for charged particles + dE/dx.
$\sigma(p_T)/p_T = 0.13\% p_T \oplus 0.45\%$

Electromagnetic Calorimeter

Electron and photon energy measurement. σ
$(E)/E = 1.33\% E^{-1/4} \oplus 2.1\%$

Lepton Universality Test

- ✓ Likelihood written as:

$$\mathcal{L}_{ext} = \mathcal{L}^{\mu}_{ext} \cdot \mathcal{L}^{\tau}_{ext}, \qquad \mathcal{L}^{i}_{ext} = \frac{e^{-N'_i}(N'_i)^{N_i}}{N_i!} \prod_{k=1}^{N_i} \mathcal{P}^{i}_{k}$$

$$\mathcal{P}^{\mu}_{k} \equiv \frac{N_{sig\mu}}{N'_{\mu}} \mathcal{P}^{\mu}_{k}(M^{reco}_{\pi^+\pi^-}) \cdot \mathcal{P}^{\mu}_{k}(M_{\mu^+\mu^-}) + \frac{N_{bkg\mu}}{N'_{\mu}} \mathcal{P}^{bkg\mu}_{k}(M^{reco}_{\pi^+\pi^-}) \cdot \mathcal{P}^{bkg\mu}_{k}(M_{\mu^+\mu^-})$$

$$\mathcal{P}^{\tau}_{k} \equiv \frac{\epsilon_{\tau\tau}}{\epsilon_{\mu\mu}} \frac{N_{sig\mu}}{N'_{\tau}} R_{\tau\mu} \mathcal{P}^{\tau}_{k}(M^{reco}_{\pi^+\pi^-}) + \frac{N_{bkg\tau}}{N'_{\tau}} \mathcal{P}^{bkg\tau}_{k}(M^{reco}_{\pi^+\pi^-})$$

- ✓ Asymmetric Gaussian with non-Gaussian tails functional form:

$$\mathcal{F}(x) = exp\Big\{ - \frac{(x-\mu)^2}{2\sigma^2(L,R) + \alpha(L,R)(x-\mu)^2} \Big\}$$

- ✓ Summary of systematic uncertainties:

	$\mu^+\mu^-$	$\tau^+\tau^-$
event selection	1.2%	
PID	1.2%	—
Trigger	0.18%	0.10%
BGF	negl.	negl.
PDFs parameters	1.1%	
Bkg PDF	0.22%	
Agreement $\mu^+\mu^-$ *vs.* $\tau^+\tau^-$ in *MassPiPiReco*	0.6%	
Peaking bkg	—	0.4%
MC statistics	0.08%	0.09%
TOTAL	2.2%	
Corrections to efficiency:		
PID	1.023	—
Trigger	—	1.020
Corrections to signal yield:		
Peaking bkg	—	0.996

LFV in τ decays

- ✓ NP models for τ-> e/μγ and τ->lll decays:

		τ->μγ	τ->lll
SM + ν mixing	Lee Shrock, PRD 16 (1977) 1444 Cheng Li, PRD 45 (1980) 1908	UNDETECTABLE	UNDETECTABLE
SUSY Higgs	Dedes Ellis Raidal, PLB 549 (2002) 159 Brignole Rossi, PLB 566 (2003) 517	10^{-10}	10^{-7}
SM + heavy Maj. ν_R	Cvetic Dib Kim Kim, PRD 66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	Yue Zhang Liu, PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	Masiero Vempati Vives, NPB 649 (2003) 189 Fukuyama Kikuchi Okada, PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA + SeeSaw	Ellis Gomez Leontaris Lola Nanopoulos, EPJ C14 (2002) 319 Ellis Hisano Raidal Shimizu, PRD 66 (2003) 115013	10^{-7}	10^{-9}

- ✓ Systematics for τ-> e/μγ decays:

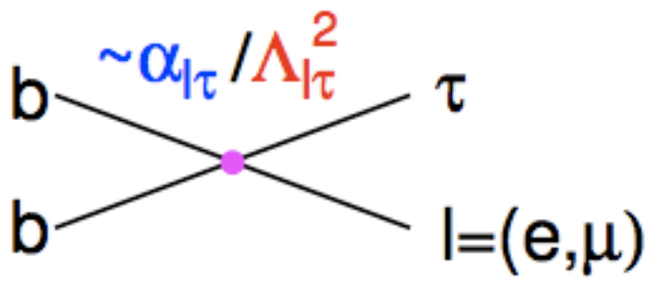
Systematic Influence on the Signal Efficiency	$\tau^{\pm} \to e^{\pm}\gamma$	$\tau^{\pm} \to \mu^{\pm}\gamma$
(i) Trigger and BGFilter efficiency	1.3	1.0
(ii) Tracking reconstruction efficiency	0.4	0.4
(iii) Neutral cluster reconstruction efficiency	1.8	1.8
(iv) PID error associated with electron/muon selectors	2.3	2.7
(v) Modeling of the variables entering the NN	2.7	1.8
(vi) Signal Track and photon energy scale & resolution: vary (ΔE, $m_{\rm EC}$) mean, rms independently	6.4	6.2
(viii) Beam energy scale and spread: anti-correlated (ΔE, $m_{\rm EC}$) shift ($\pm$ 2, $\mp$ .8) MeV	0.7	0.7
(viii) Normalization uncertainty	0.7	0.7
(ix) Model dependence	0.1	0.2
Total	7.7	7.4
Total (without signal box variation)	4.3	4.0

Table 15: Relative Systematic errors (%) associated with the signal efficiency.

LFV in Υ decays

- ✓ NP constraint using effective field theory:

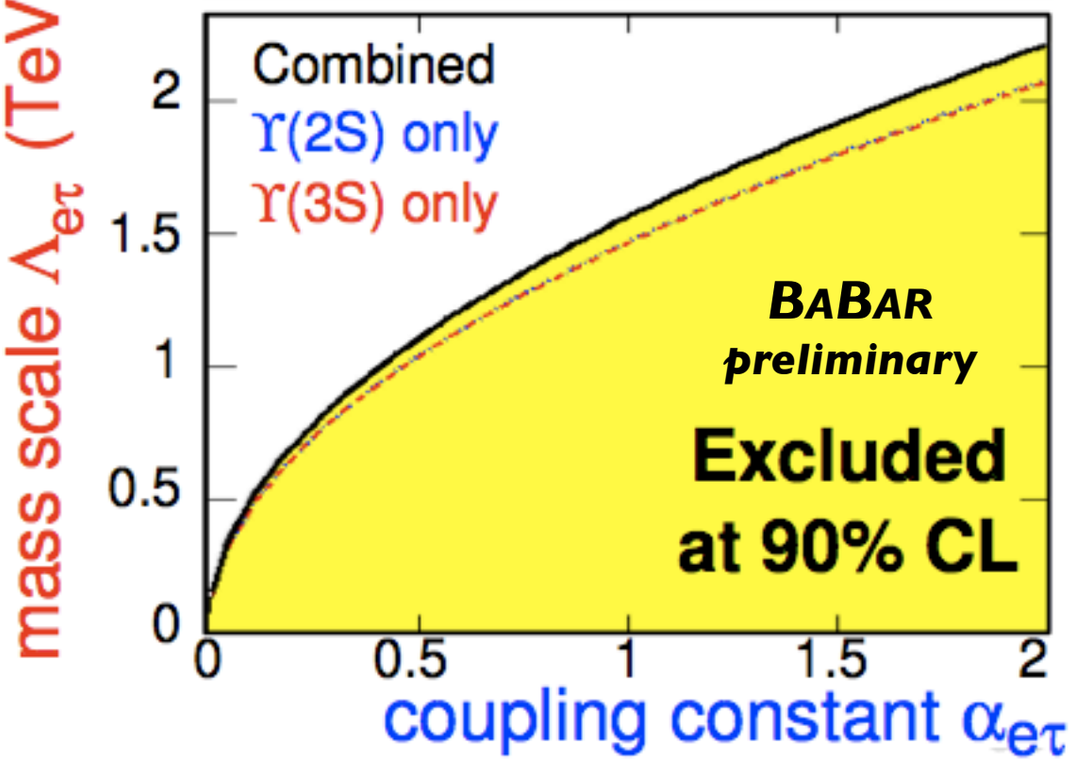
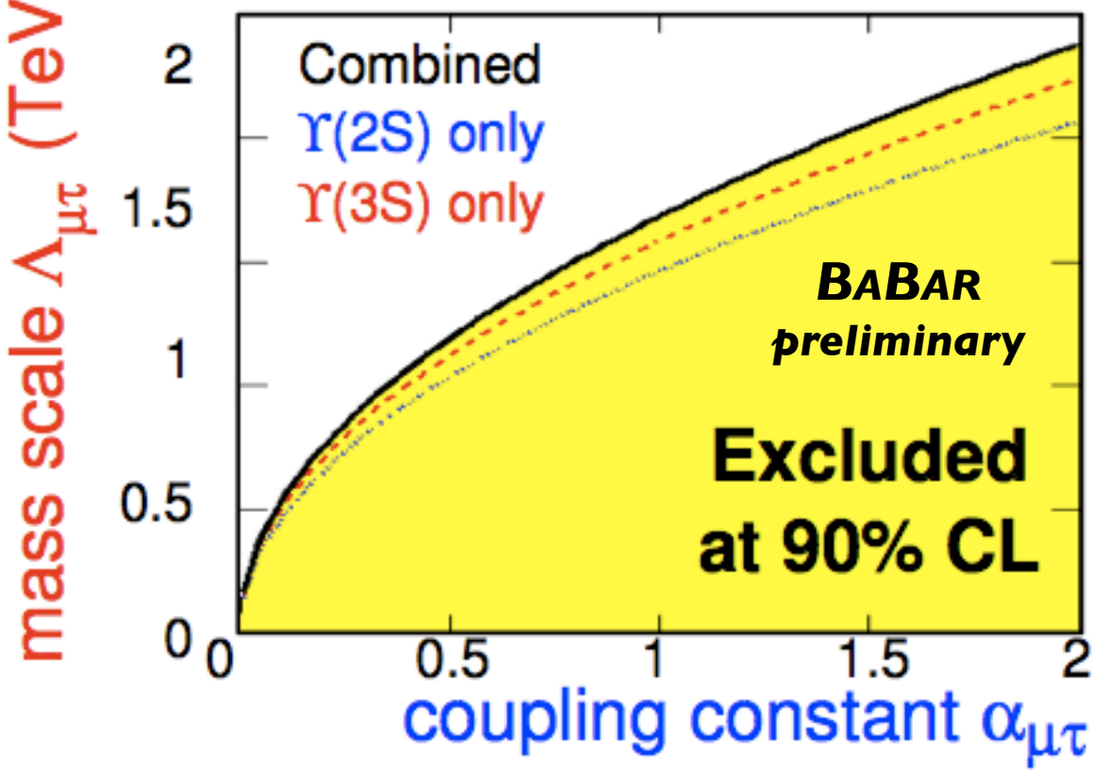
CLFV Υ decays: bblτ contact interaction with NP coupling constant and mass scale



$$\frac{\alpha_{l\tau}^2}{\Lambda_{l\tau}^4} = \frac{BF(\Upsilon(3S)\to l\tau)}{BF(\Upsilon(3S)\to ll)} \frac{2q_b\alpha^2}{(M_{\Upsilon(nS)})^4} \quad l = (e,\mu)$$

Silagadze Phys. Scripta 64.128 & Black et al. PRD 66.053002

$\alpha_{e\tau} = 1 \to \Lambda_{e\tau} > 1.6$ TeV (previously 1.4 TeV)



$\alpha_{\mu\tau} = 1 \to \Lambda_{\mu\tau} > 1.7$ TeV (previously 1.5 TeV)