# Search for Baryon and Lepton Number Violation in BABAR

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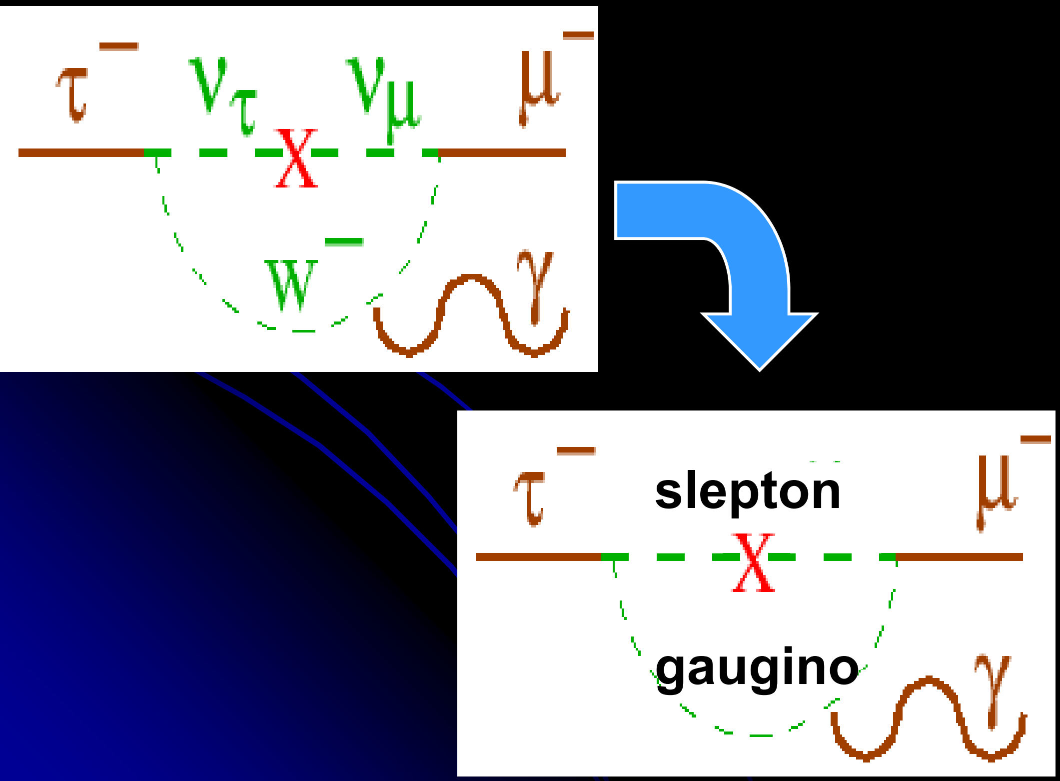
on behalf of *BABAR* Collaboration

22nd Sept 2007

*Search for baryon and lepton number violations workshop, LBNL*




## Outline

- Lepton flavor violation (LFV)
- Search for LFV at *BABAR*
- Constraints on new physics
- Baryon number violation
- Future sensitivity
- Summary

# *LFV in τ-decays*

- In the Standard Model, lepton flavor is conserved for each generation

$$\left[ \begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix} \right]$$

$\mathcal{L}_e = 1 \quad \mathcal{L}_\mu = 1 \quad \mathcal{L}_\tau = 1 \qquad \mathcal{L} = \mathcal{L}_e + \mathcal{L}_\mu + \mathcal{L}_\tau$

e.g $\tau \to \mu\gamma$ is not allowed

$\mathcal{L}_\tau = 1 \quad \mathcal{L}_\tau = 0 \quad \Rightarrow \Delta\mathcal{L}_\tau \neq 0$

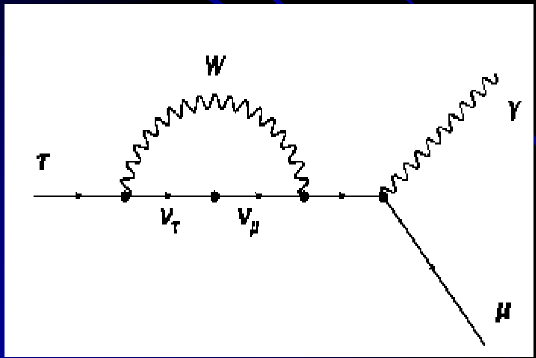
$\mathcal{L}_\mu = 0 \quad \mathcal{L}_\mu = 1 \quad \Rightarrow \Delta\mathcal{L}_\mu \neq 0$ but $\mathcal{L} = 0$

- But neutrino oscillation implies:

$$\nu_\mu \longrightarrow \nu_e$$

$\Rightarrow$ Lepton Flavor is violated but in neutral sector

- This flavor oscillation in neutral sector induces LFV in charged leptons




$$BR(\tau \to \mu\gamma) = \frac{2\alpha}{128\pi}\left(\frac{\Delta m_{23}^2}{m_w^2}\right)^2 \sin 2\theta_{mix} BR(\tau \to \mu\nu\nu) \approx 10^{-54}$$

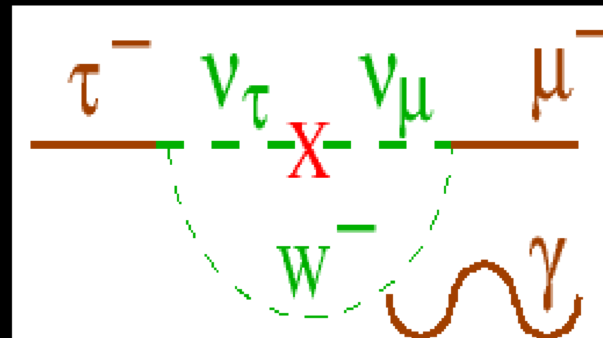
$m_w \cong 10^{11}$ eV $\quad \Delta m_{23}^2 \cong 10^{-3}$ eV$^2$

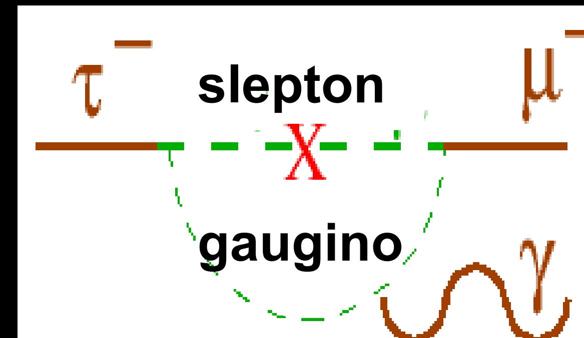
Lee, Shrock, Phys. Rev. D 16, 1444 (1977)

# *New physics phenomena in τ-decays*

1. Improving the rate for LFV process

Now $\mathcal{B}(\tau \to \mu\gamma) \;\alpha\; \left(\frac{\Delta M_{\tilde{\nu}}^2}{M_{\tilde{\chi}}^2}\right)^2$




$\Delta M_{\tilde{\nu}}$ and $M_{\tilde{\chi}}$ have different (higher) mass scale

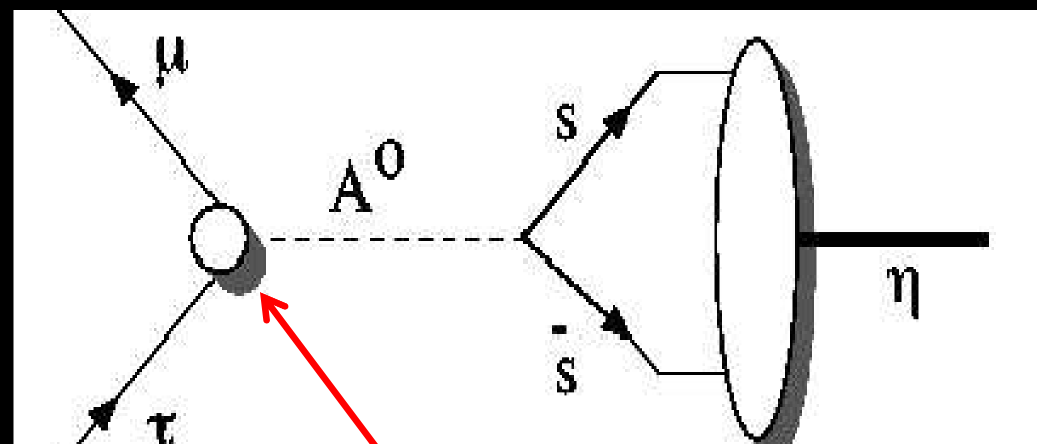
New particles carrying lepton flavor numbers, which have very large mass and simultaneously mix among themselves (sleptons).

2. Mediation through $H^0$ or $A^0$ (heavy scalar or pseudoscalar)

$$BR(\tau \to \mu\eta) = (0.84 \times 10^{-6}) \times \left(\frac{\tan\beta}{60}\right)^6 \times \left(\frac{100\ \mathrm{GeV}}{m_A}\right)^4$$

$$\tan\beta = \frac{\langle v_u \rangle}{\langle v_d \rangle}$$

M. Sher, PRD 66, 057301 (2002)




LFV coupling

$v_{u,d}$ are VEVs of neutral higgs coupled to up-type or down-type fermion fields

⇒The branching fraction can be enhanced significantly in large $\tan\beta$ region

Replacing $A^0$ with $H^0$ –> $\mu^+\mu^-$

$$BR(\tau \to 3\mu) = (1 \times 10^{-7}) \times \left(\frac{\tan\beta}{60}\right)^6 \times \left(\frac{100\ \mathrm{GeV}}{m_H}\right)^4$$

# New physics phenomena in $\tau$-decays (cont.)

| | | $\tau \to \ell\gamma$ | $\tau \to \ell\ell\ell$ |
|---|---|---|---|
| SM + $\nu$ mixing | Lee, Shrock, PRD 16 (1977) 1444<br>Cheng, Li, PRD 45 (1980) 1908<br>Pham EPJ C8 (1999) 513 | $10^{-54}$ | $10^{-14}$ |
| SUSY Higgs | Dedes, Ellis, Raidal, PLB 549 (2002) 159<br>Brignole, Rossi, PLB 566 (2003) 517 | $10^{-10}$ | $10^{-7}$ |
| SM + heavy Maj $\nu_R$ | Cvetic, Dib, Kim, Kim , PRD66 (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<br>Fukuyama, Kikuchi, Okada, PRD 68 (2003) 033012 | $10^{-8}$ | $10^{-10}$ |
| mSUGRA + Seesaw | Ellis, Gomez, Leontaris, Lola, Nanopoulos, EPJ C14 (2002) 319<br>Ellis, Hisano, Raidal, Shimizu, PRD 66 (2002) 115013 | $10^{-7}$ | $10^{-9}$ |

- **If observed $\Rightarrow$ signature of new physics**
- **if not observed $\Rightarrow$ strong constraint on the nature of new physics, which is expected to be present above EW scale.**

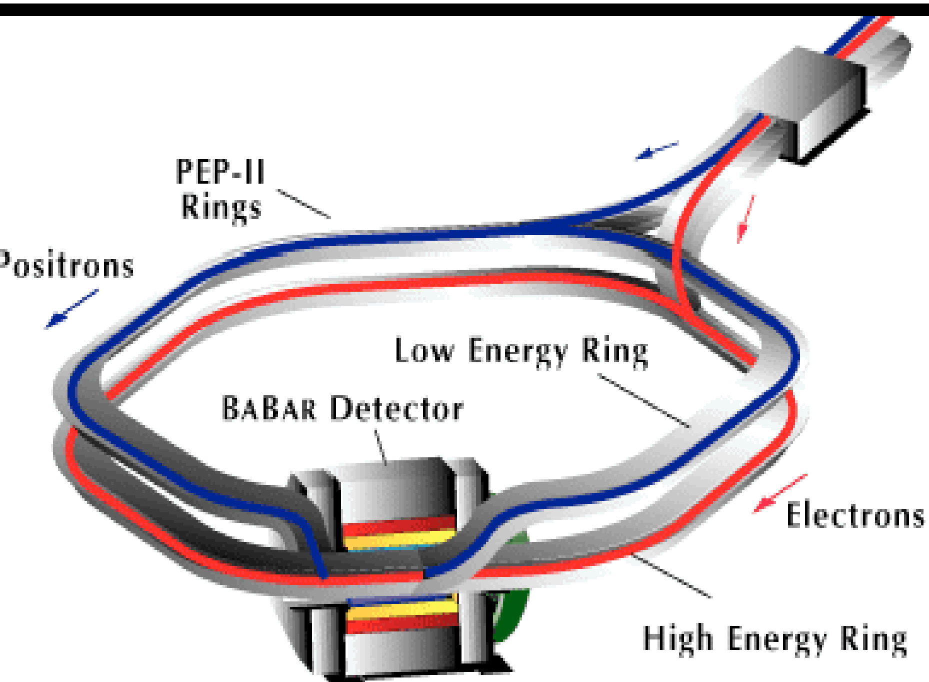
**Question: can we search for these LFV modes in B-factories; if yes, how ?**

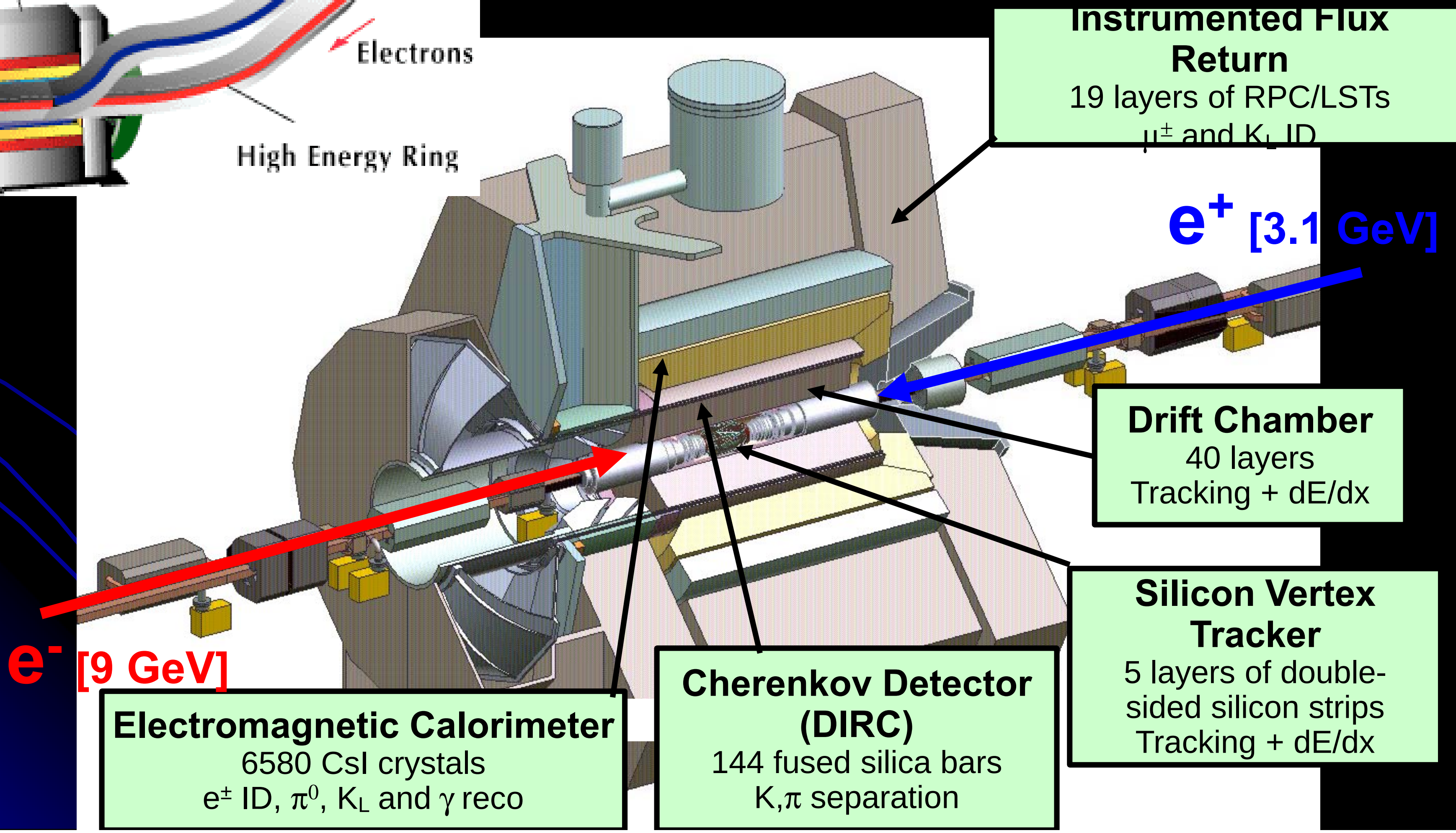
# *Asymmetric energy B-factory*

9GeV ($e^-$) × 3.1GeV ($e^+$)

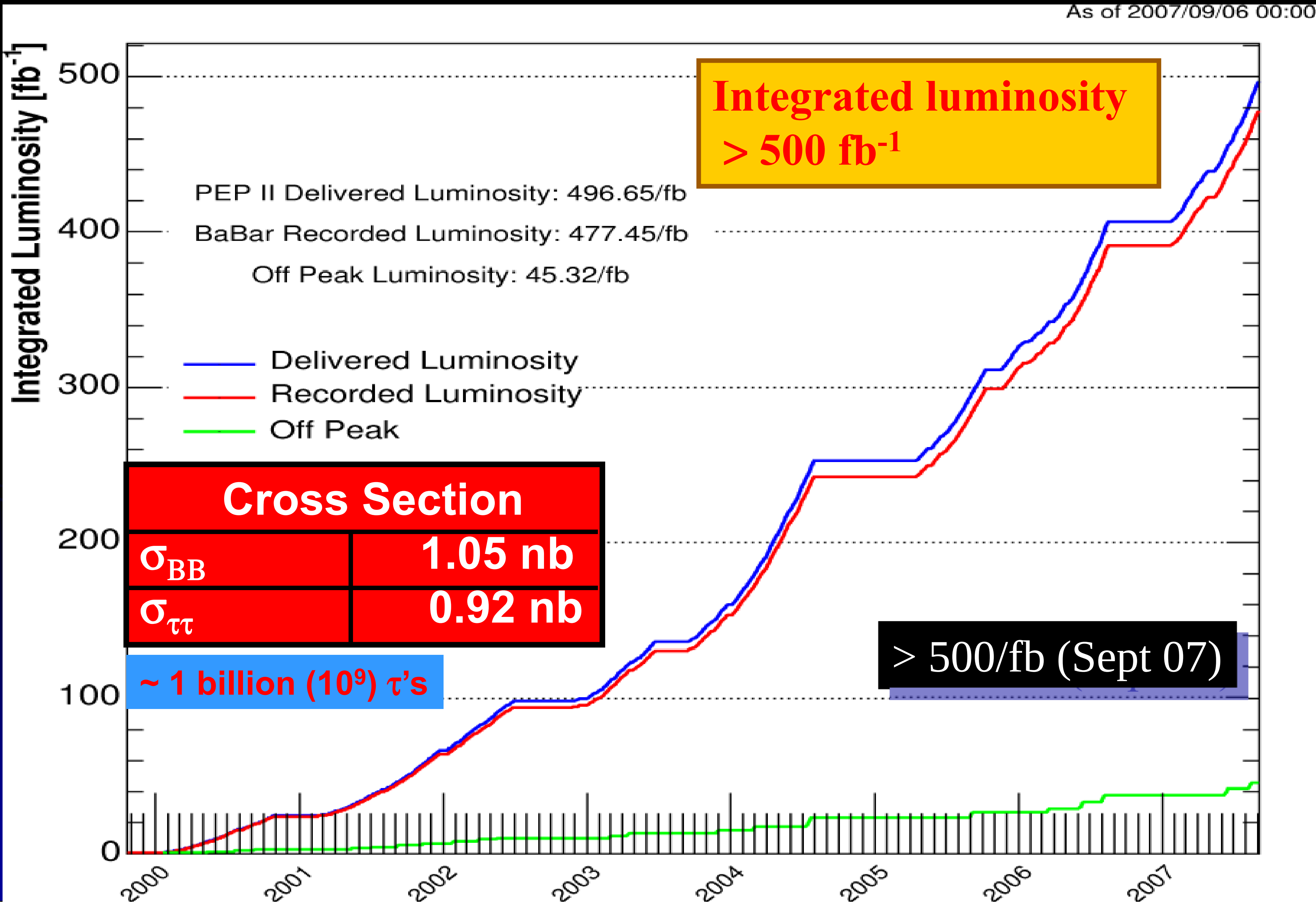
Peak luminosity:

**$1.12 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$**



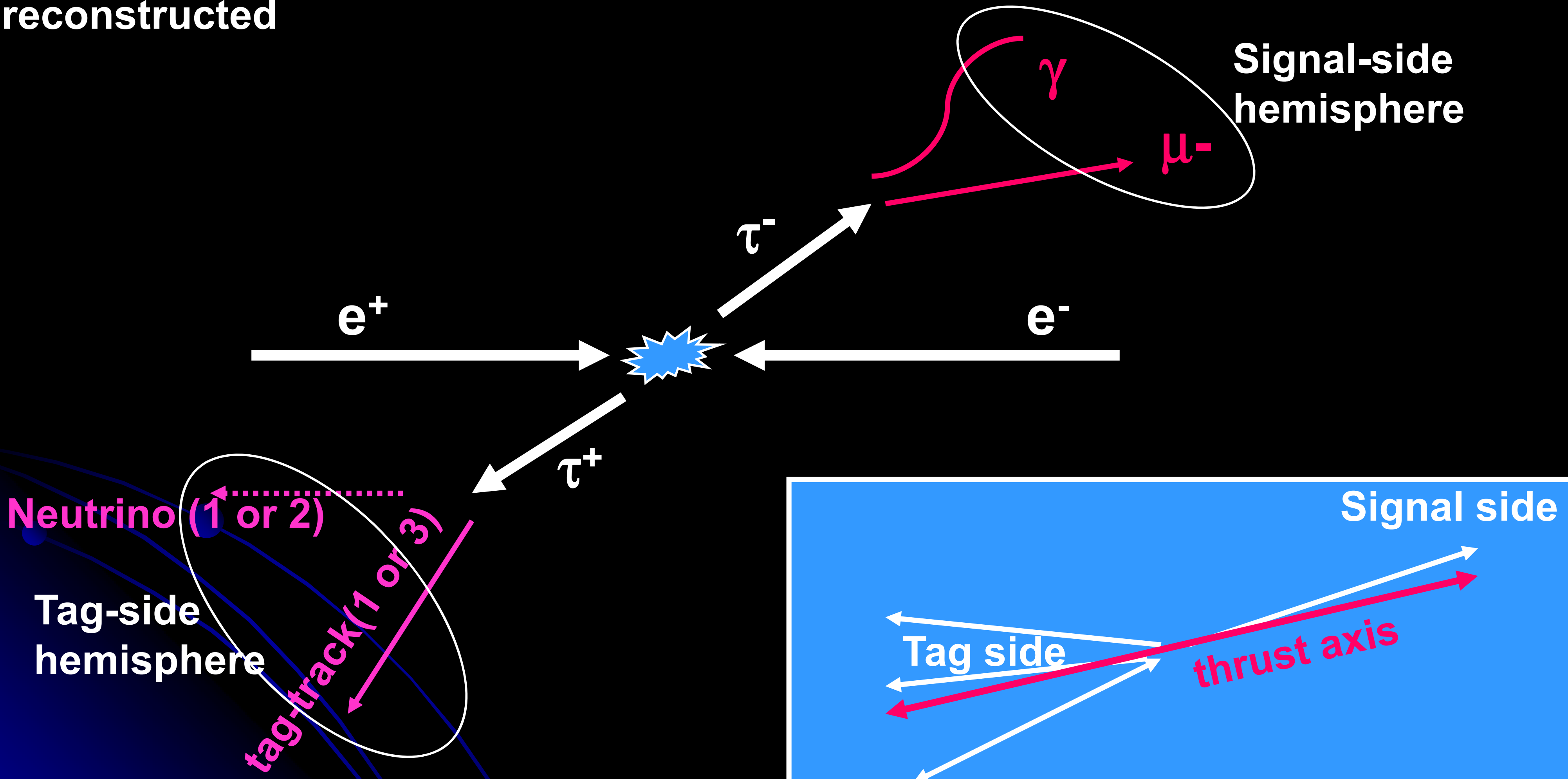



# PEP-II and BABAR performance



# *How do we search for LFV in τ-decay ?*

- Divide the event space by the plane perpendicular to the thrust axis into two hemispheres: **tag-side**, in which SM τ decay ( 1 or 3 prong) is observed and **signal-side**, in which a neutrinoless τ decay is reconstructed

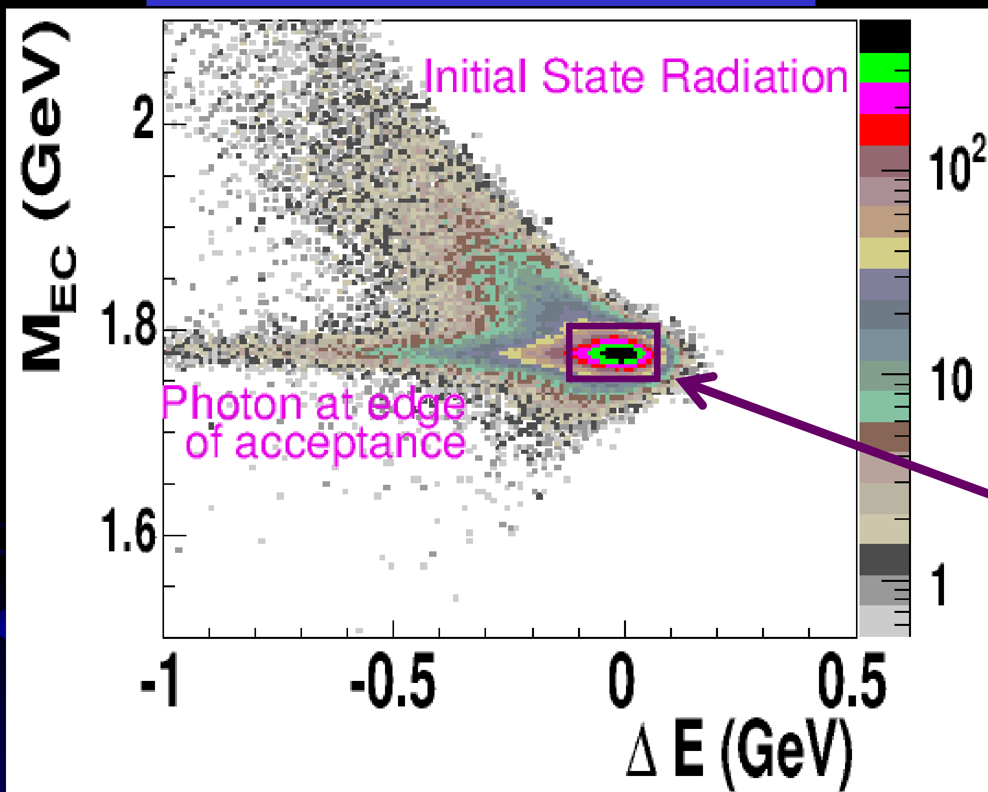



- τ phase space MC simulation
  KK2f for τ production
  TAUOLA for τ decay

# *The variables used to identify the signal*

- **BLIND ANALYSIS:**
- **Blind the signal region → optimize all the selection criteria using MC**

**$\tau \rightarrow \mu\gamma$ Signal MC**




**The beam-energy constrained $\tau$ mass: $M_{EC}$**

**The energy difference $\Delta E = E_{\tau\text{-recon}} - E_{beam}$**

**For signal events: $M_{EC} \approx M_\tau$**

**$\Delta E \approx 0$**

**Signal region:**

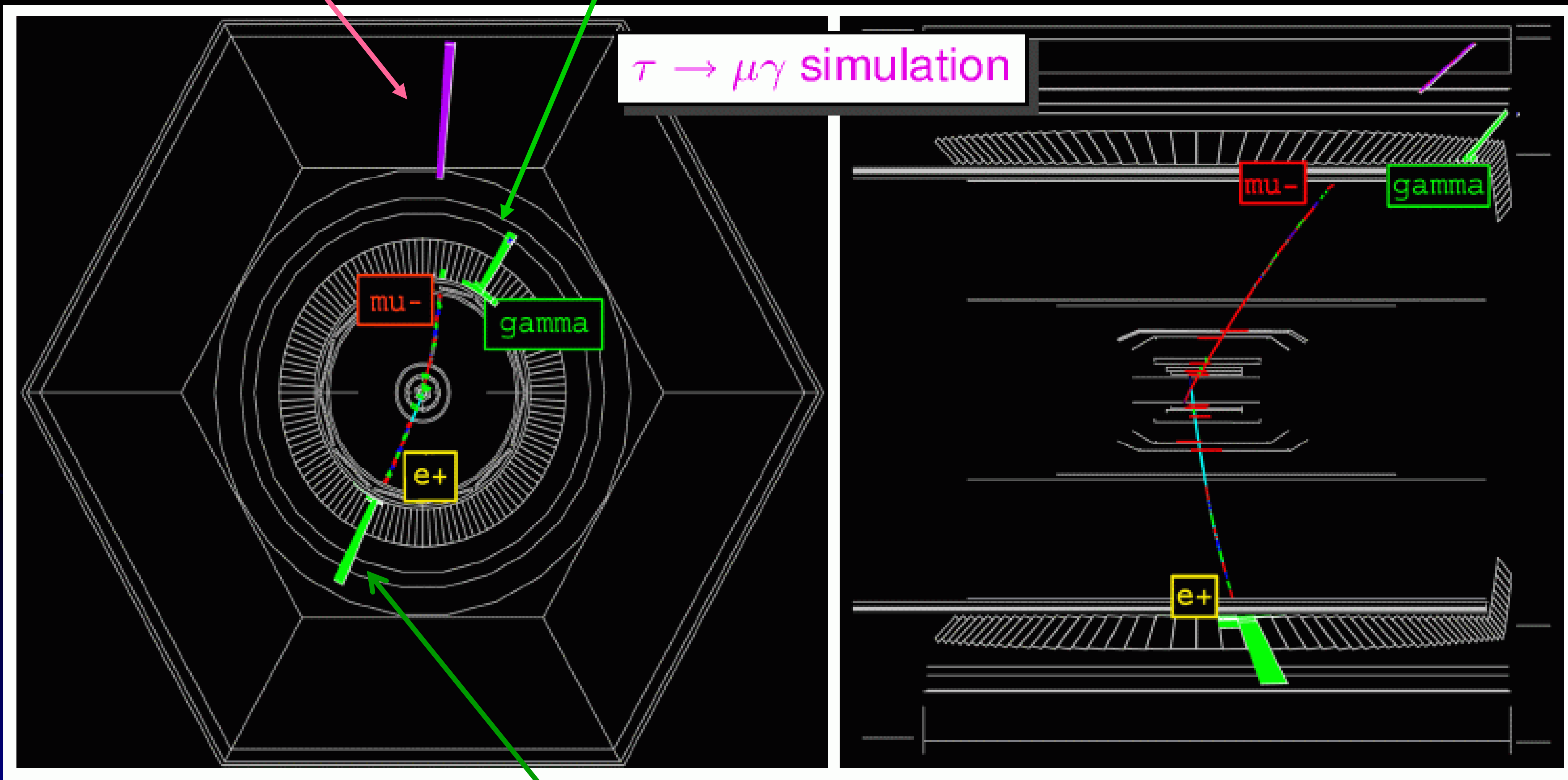
**signal events mostly populated in signal region**

- **As these decays are very rare => mostly background is detected on the signal-side. Various kinematical, topological and particle identification cuts are applied to suppress the background. Compare different distributions in data with MC to make sure the background is well understood.**

# $\tau \to \mu\gamma$ simulated event in BABAR detector

IFR hits of the muon track

Photon energy deposition in calorimeter



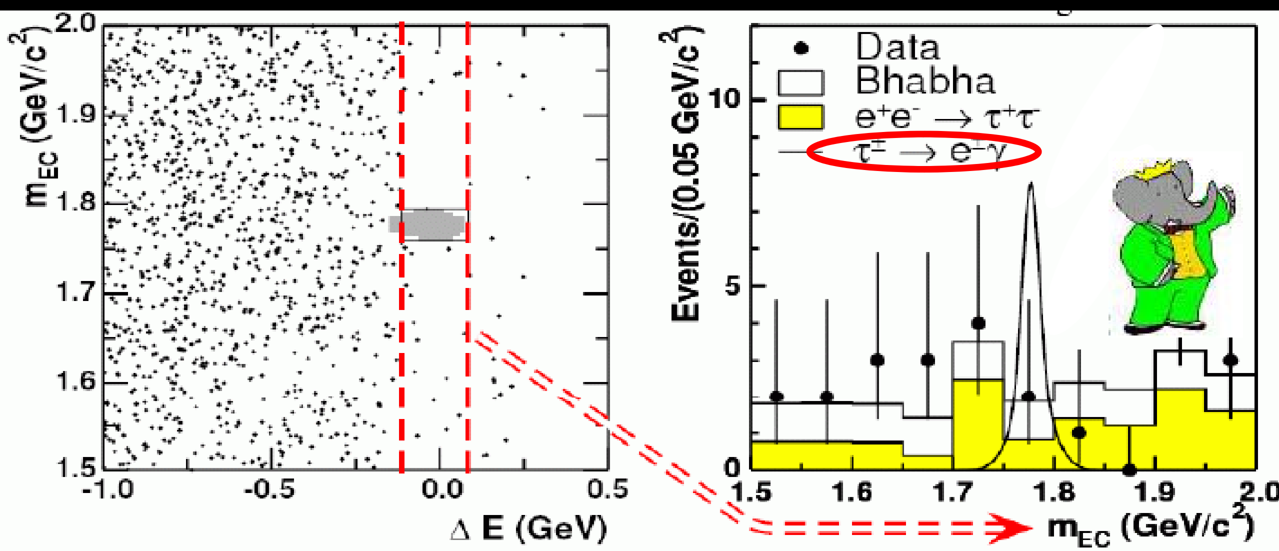

r-ϕ view

x-z view

Electron from tag-side $\tau$ decay

# *BABAR results for $\tau \to \ell\gamma$*

- $\tau \to \mu\gamma$ is considered to be the golden mode for the search for LFV
- B*A*B*A*R used 232 fb-1 data to look for both $\tau \to (\mu, e)\,\gamma$




Efficiency=(4.7±0.3)%

BF ($\tau^- \to e^- \gamma$) < 11 x $10^{-8}$

**Dominant backgrounds:**
Bhabha,
$\tau^+\tau^-$ [$\tau \to e\nu\nu$ with ISR, FSR
$\tau \to e\nu\nu\gamma$]

Background expected =1.9±0.4

No. of observed events = 1

PRL 96, 041801 (2006)

Efficiency=(7.4±0.7)%

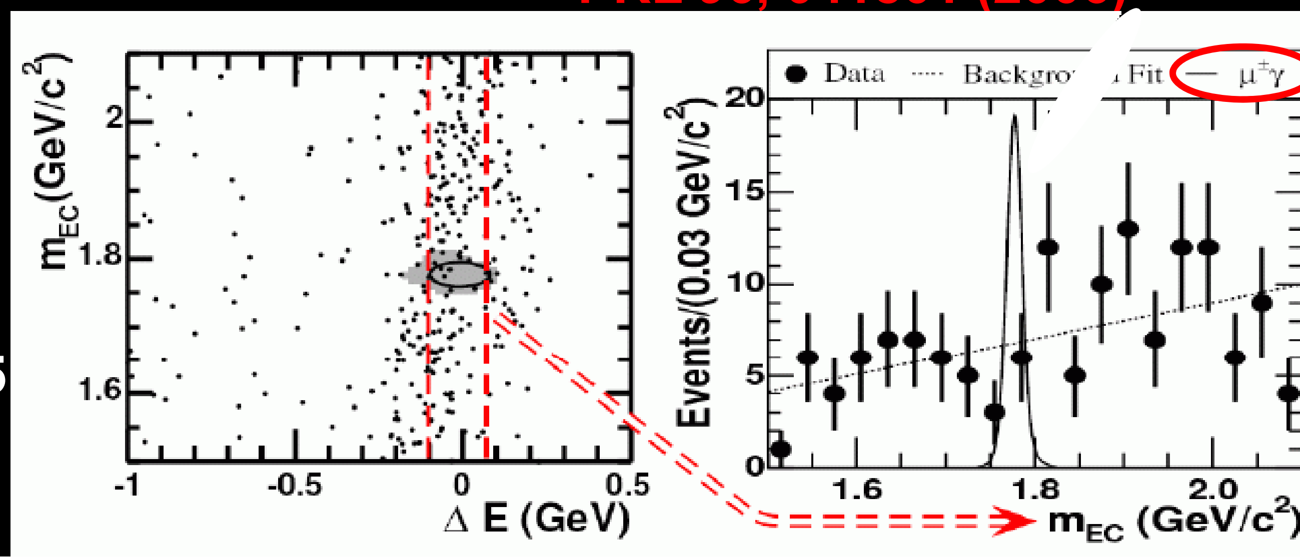
BF ($\tau^- \to \mu^- \gamma$) < 6.8 x $10^{-8}$

**Dominant backgrounds:**
dimuon ($\mu^+\mu^-$),
$\tau^+\tau^-$ [$\tau \to \mu\nu\nu$ with ISR, FSR]

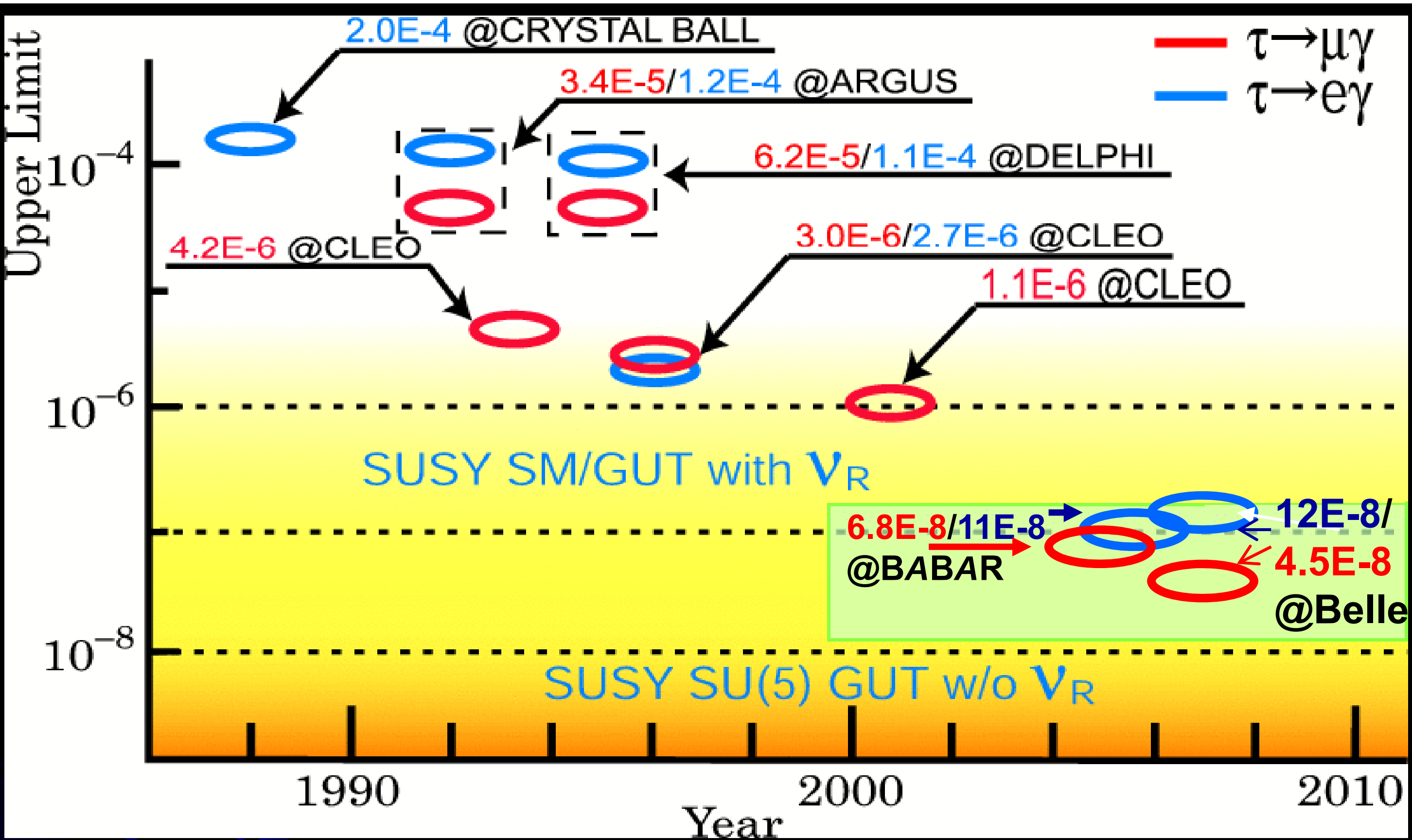
Background expected =6.2±0.5

No. of observed events = 4

PRL 95, 041802 (2005)



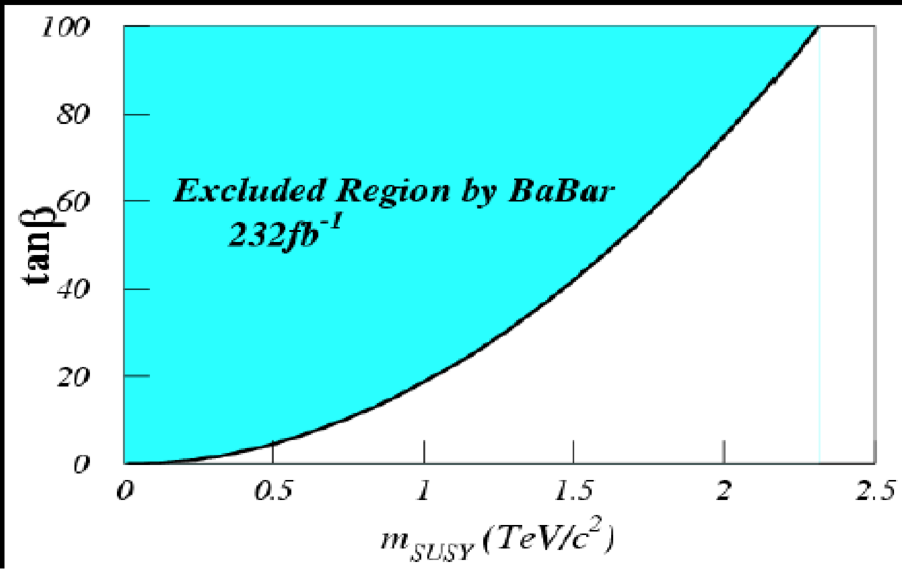
# Results from $\tau \to \ell\gamma$ and impact on new physics




The current measurements start probing predicted new physics effect

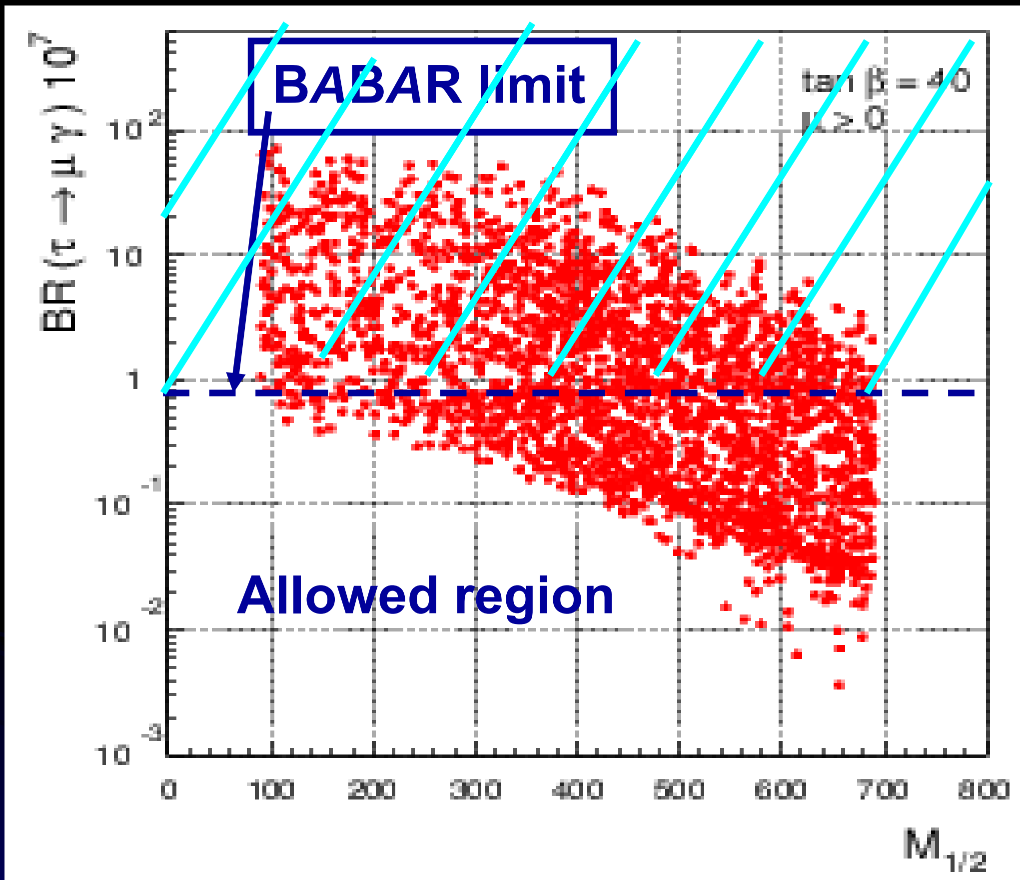
MSSM with seesaw:

$$\mathcal{B}(\tau \to \mu\gamma) \simeq 7 \times 10^{-7} \left(\frac{\tan\beta}{60}\right)^2 \left(\frac{1\ \mathrm{TeV}/c^2}{m_{SUSY}}\right)^4$$



# New physics constraints

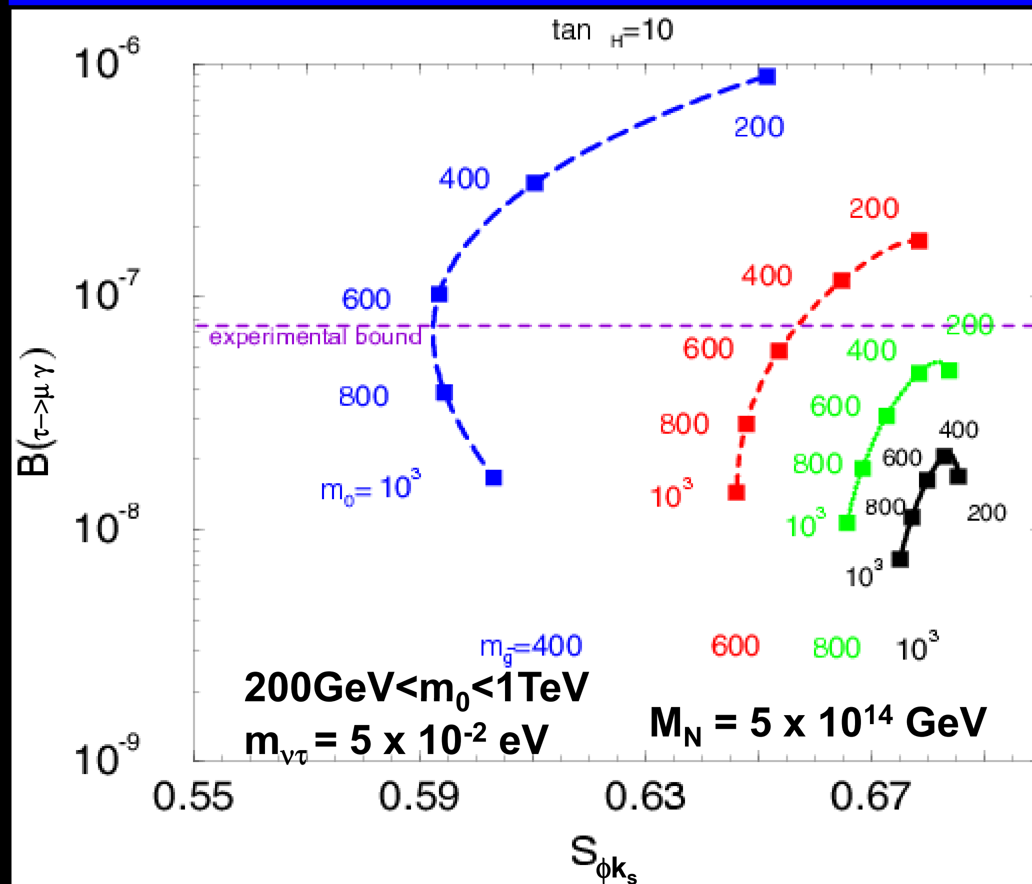
**SUSY SO(10) + seesaw**
**Masiero eta l. NJP 6 (2004) 202**




Reaching a sensitivity of $10^{-9}$ for $\mathcal{B}(\tau\to\mu\gamma)$ would probe the SUSY spectrum up to $M_{1/2}$ = 700GeV

($M_{1/2}$ is the gaugino mass)

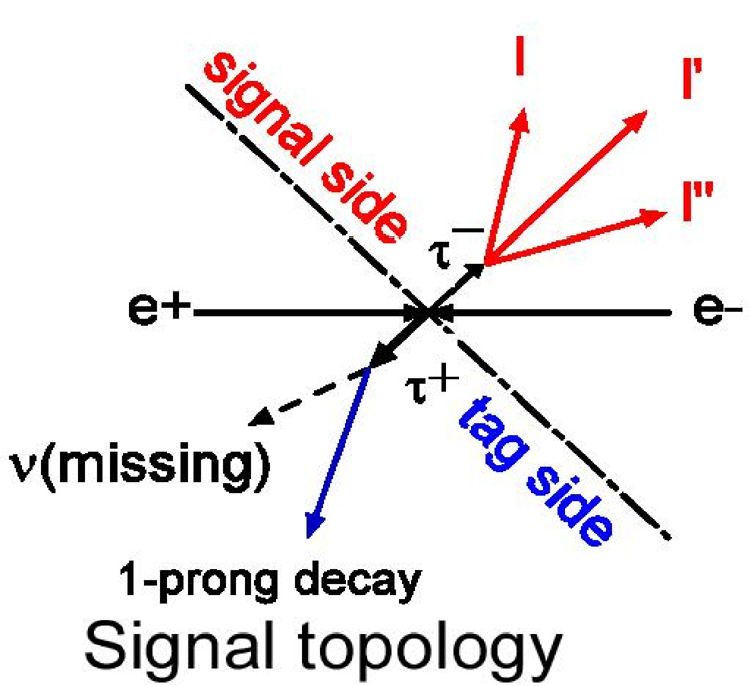
**SUSY SU(5) GUT**
**Hisano eta l. Phys. Lett. B565 (2003) 183**

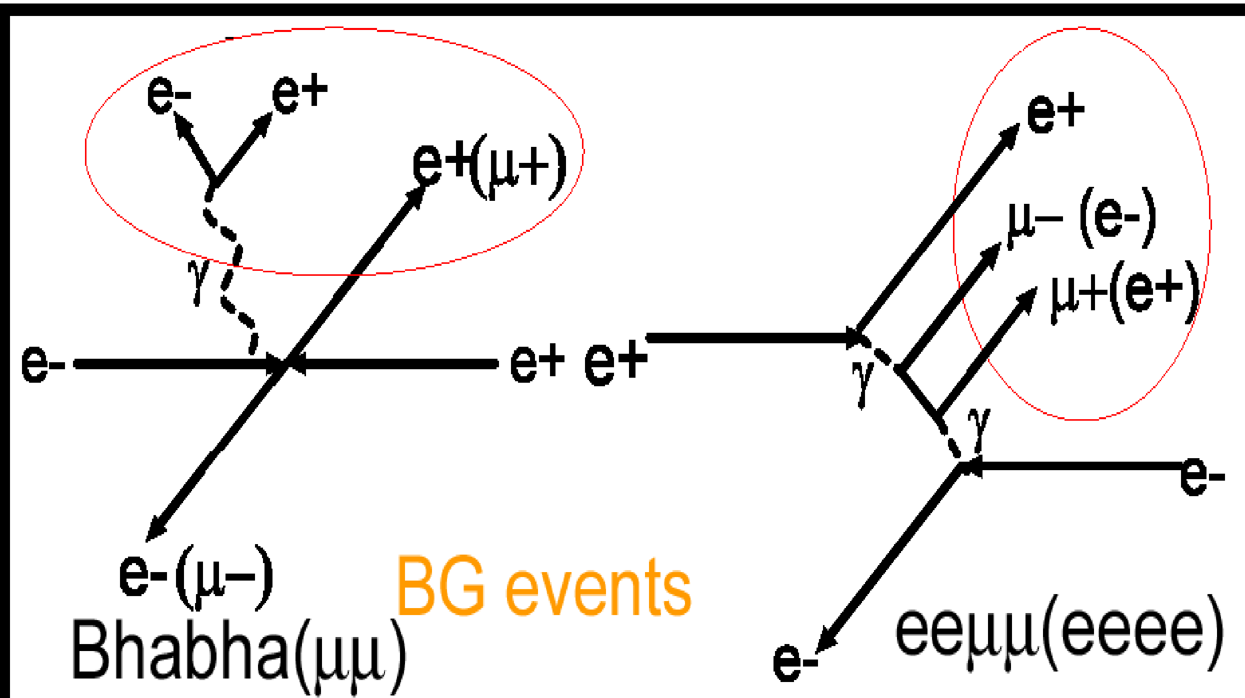



SUSY SU(5) GUT with right handed neutrino

$\Rightarrow$The current bound on $\mathcal{B}(\tau\to\mu\gamma)$ constraints the allowed region for $S_{\phi ks}$

# $\tau \to \ell\ell'\ell''$ ($\ell$, $\ell'$, or $\ell''$ = $e$, $\mu$)




**Searched modes:**

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

| $\tau \to \ell\ell'\ell''$ **Signal Mode** | $\mu^-\mu^+\mu^-$ | $e^-e^+e^-$ | $\mu^-e^+e^-$ $e^-\mu^+\mu^-$ | $\mu^+e^-e^-$ $e^+\mu^-\mu^-$ |
|---|---|---|---|---|
| **Dominant Background** | $\tau\tau$ uds $\mu\mu\mu\mu$ | Bhabha eeee $\tau\tau$ | ee$\mu\mu$ $\tau\tau$ $\mu\mu$ | $\tau\tau$ uds |

**optimize event selection for each signal mode separately accounting for different background composition**

# $\tau \to \ell\ell'\ell''$ ($\ell$, $\ell'$, or $\ell''$ = $e, \mu$) NEW

376 $fb^{-1}$ BABAR data used

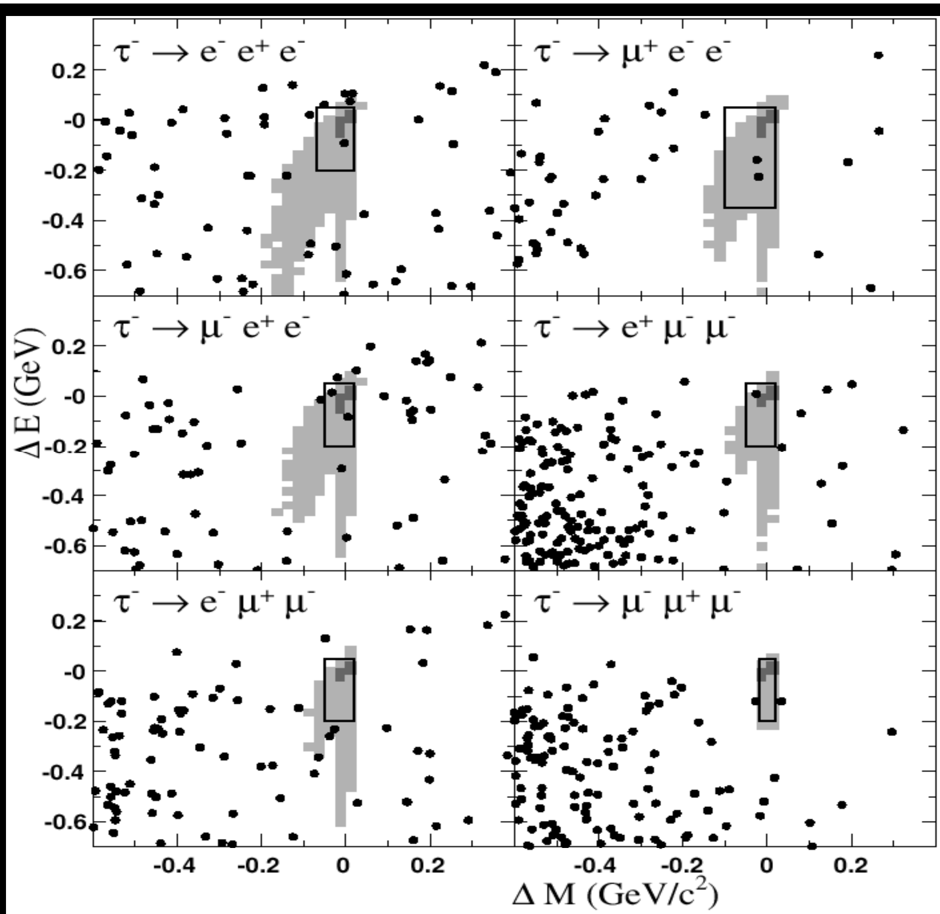
Efficiency: 5.5-12.4%
Expected background events:0.3-1.3 depending on mode

Total estimated background = 4.2±0.8 events
Total number of observed events =6

90%CL limits:
$BR(\tau \to \ell\ell'\ell'') < (3.7\text{-}8.0) \times 10^{-8}$

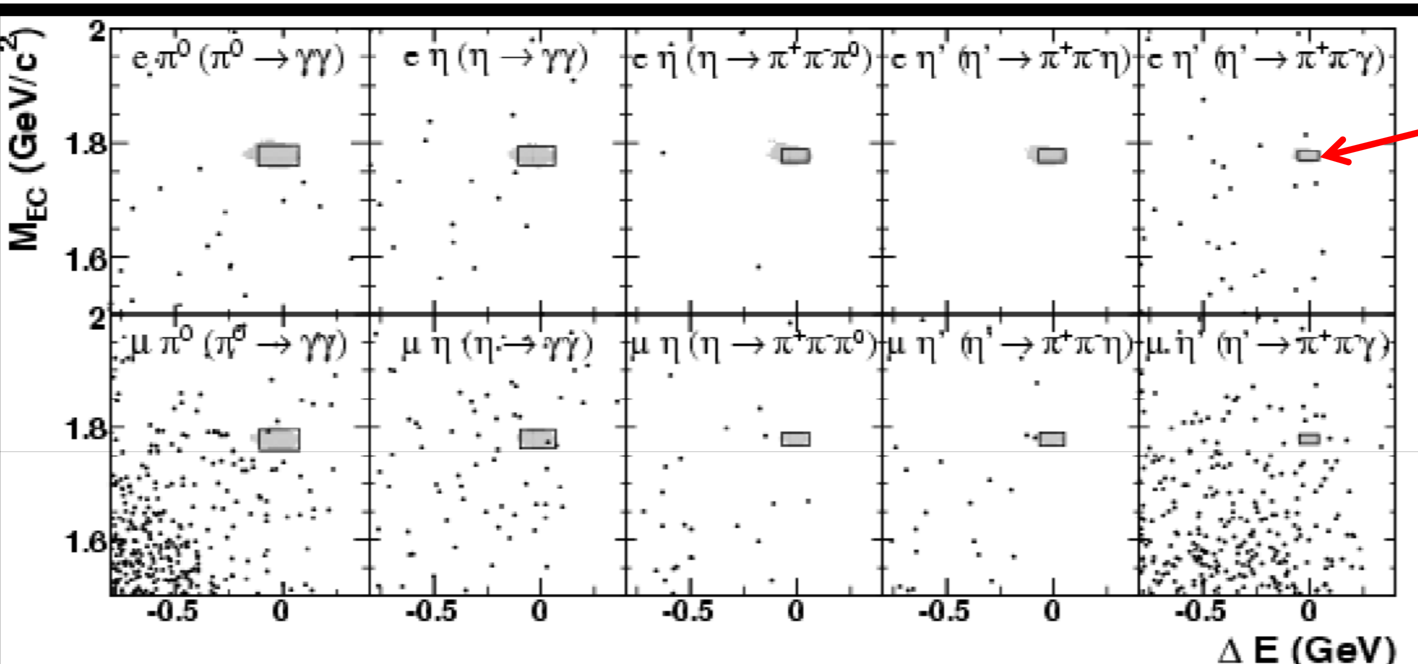
2-5 fold lower limits over previous BABAR results

arXiv:0708.3650v1 (submitted to PRL)
(*Preliminary results*)

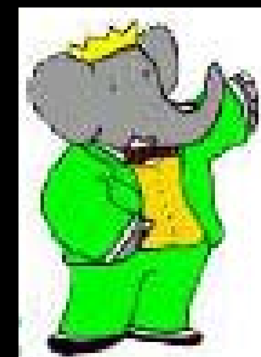



| Mode | Eff. [%] | $N_{bgd}$ | $UL_{90}^{exp}$ | $N_{obs}$ | $UL_{90}^{obs}$ |
|---|---|---|---|---|---|
| $e^-e^+e^-$ | $8.9 \pm 0.2$ | $1.33 \pm 0.25$ | $4.9 \cdot 10^{-8}$ | 1 | $4.3 \cdot 10^{-8}$ |
| $\mu^-e^+e^-$ | $8.3 \pm 0.6$ | $0.89 \pm 0.27$ | $5.0 \cdot 10^{-8}$ | 2 | $8.0 \cdot 10^{-8}$ |
| $\mu^+e^-e^-$ | $12.4 \pm 0.8$ | $0.30 \pm 0.55$ | $2.7 \cdot 10^{-8}$ | 2 | $5.8 \cdot 10^{-8}$ |
| $e^+\mu^-\mu^-$ | $8.8 \pm 0.8$ | $0.54 \pm 0.21$ | $4.6 \cdot 10^{-8}$ | 1 | $5.6 \cdot 10^{-8}$ |
| $e^-\mu^+\mu^-$ | $6.2 \pm 0.5$ | $0.81 \pm 0.31$ | $6.6 \cdot 10^{-8}$ | 0 | $3.7 \cdot 10^{-8}$ |
| $\mu^-\mu^+\mu^-$ | $5.5 \pm 0.7$ | $0.33 \pm 0.19$ | $6.7 \cdot 10^{-8}$ | 0 | $5.3 \cdot 10^{-8}$ |

# $\tau \to \ell P^0$ ($\ell = e, \mu$ and $P^0 = \pi^0, \eta, \eta'$)




Signal box
(±2σ in ΔE and $M_{EC}$)



PRL 98, 061803 (2007)

Using 339 $fb^{-1}$ data

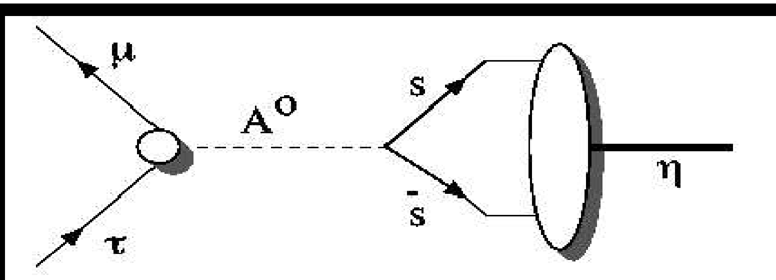
Estimated background :
0.1-1.3 depending on mode

Total estimated background
= 3.1

Total observed events = 2

| τ decay mode | UL ($10^{-7}$) | τ decay mode | UL ($10^{-7}$) |
|---|---|---|---|
| $e\pi^0$ | 1.3 | $\mu\pi^0$ | 1.1 |
| eη (η–>γγ) | 2.5 | μη (η–> γγ) | 1.9 |
| eη (η–>$\pi\pi\pi^0$) | 5.4 | μη (η–>$\pi\pi\pi^0$) | 4.5 |
| eη (combine) | 1.6 | μη (combine) | 1.5 |
| eη' (η'–>ππη) | 5.8 | μη' (η'–>ππη) | 3.6 |
| eη' (η'–>ργ) | 4.2 | μη' (η'–>ργ) | 2.7 |
| eη‘ (combine) | 2.4 | μη' (combine) | 1.4 |

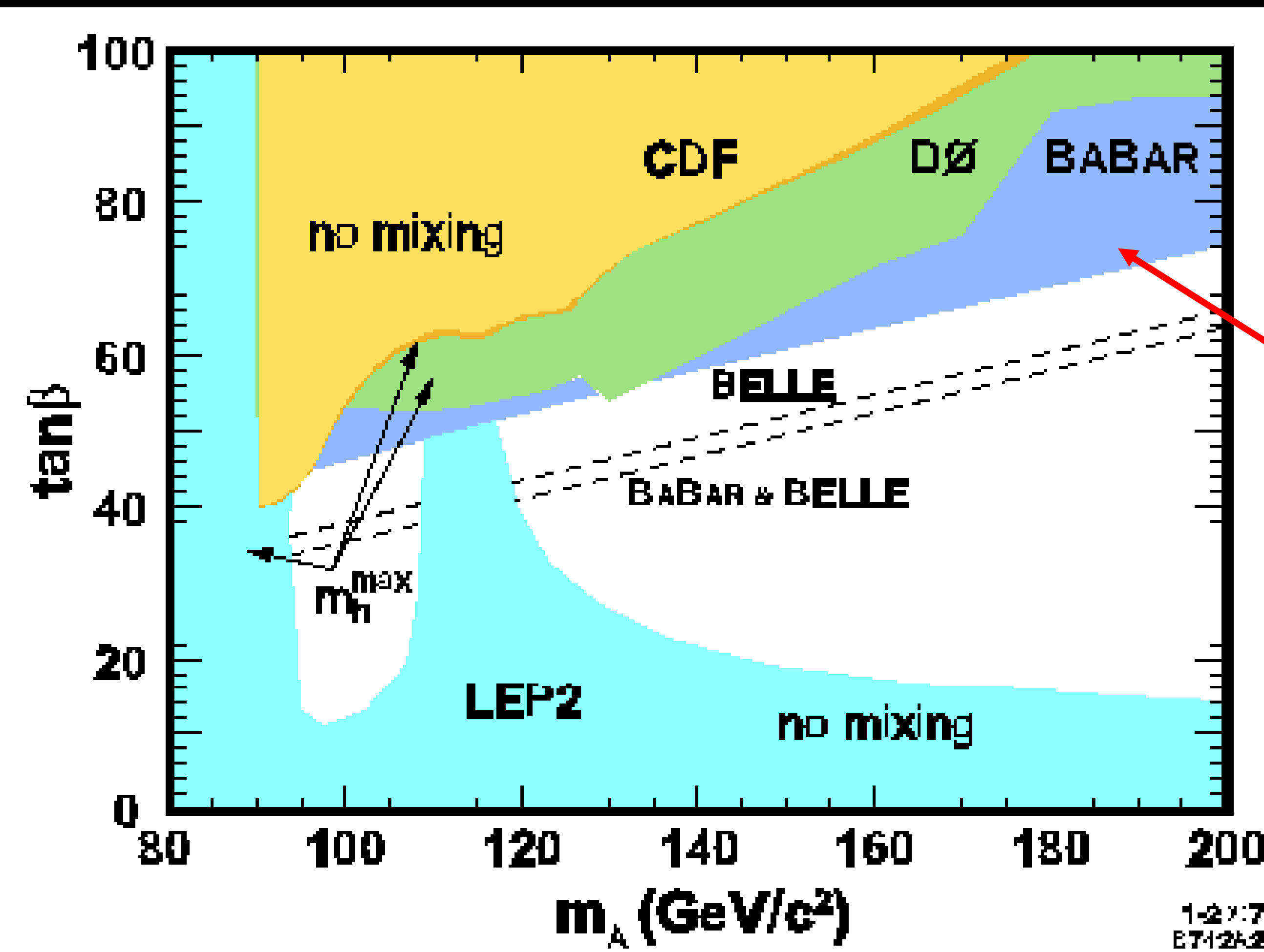
# Constraining new physics using $\tau\to\mu\eta$ result




$$\mathcal{B}(\tau^\pm \to \mu^\pm \eta) = 0.84 \times 10^{-6} \times \left(\frac{\tan\beta}{60}\right)^6 \left(\frac{100\ \mathrm{GeV}}{m_A}\right)^4$$

where $m_A$ is the pseudoscalar Higgs mass and $\tan\beta = \langle \mathrm{H_u} \rangle / \langle \mathrm{H_d} \rangle$

M. Sher, PRD 66, 057301 (2002)




The left plot shows the exclusion regions obtained in the $m_A$ and $\tan\beta$ plane by different experiments

(@ 95% C.L.)

New result from *BABAR*

Competitive with the direct Higgs searches at CDF and D0

CDF: $p\bar{p} \to H \to \tau^+\tau^-$ (310 pb$^{-1}$)

D0: $p\bar{p} \to H \to b\bar{b}$ (260 pb$^{-1}$)

$\to \tau^+\tau^-$ (325 pb$^{-1}$)

S. Banerjee, Nucl. Phys. Proc. Suppl. 169, 199 (2007)

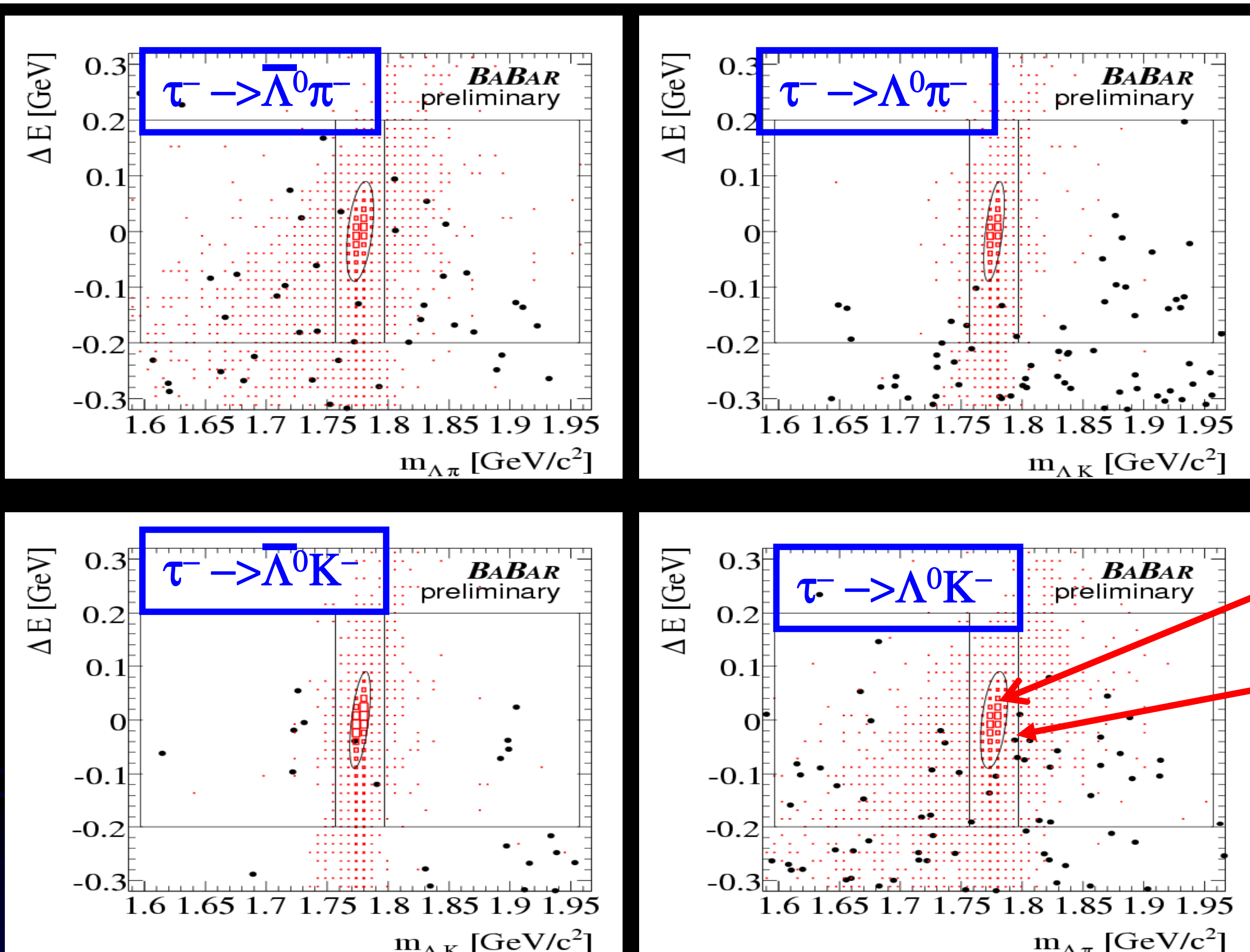
# *Baryon number violating τ-decay*

- The baryon asymmetry of the universe (BAU) is one of the pressing questions today. Why do we see a large imbalance of matter and anti-matter in today's universe ?
- SM assumes both lepton number L and baryon number B, and (B-L) conservation.
- However, many supersymmetry and superstring models allow B and L violation.
- We searched for two kinds of baryon instabilities: $\Delta$(B-L) =0 or 2. So, the conservation or violation of (B-L) determines the mechanism of baryon instability.

**Two modes considered here: (one can replace $\pi^-$ with $K^-$)**

| | $\tau^- \to \Lambda^0\pi^-$, $\Lambda^0 \to p^+\pi^-$ | $\tau^- \to \overline{\Lambda}^0\pi^-$, $\overline{\Lambda}^0 \to p^-\pi^+$ |
|---|---|---|
| B: | 0 –> 1 + 0 | 0 –> -1 + 0 |
| L: | +1 –> 0 + 0 | +1 –> 0 + 0 |
| (B-L): | -1 –> 1 | -1 –> -1 |
| | **(B-L) violating** | **(B-L) conserving** |

# Baryon number violating decay τ–>Λπ (K)




**237 fb$^{-1}$ *BABAR* data used for this analysis.**

**(hep-ex: 0607040)**

***(Preliminary results)***

**Signal MC with arbitrary normalization**

**Elliptical signal region**

**90% c.l. upper limit for signal yield**

| mode | $(B-L)$ | expected background | efficiency % | observed events | $\ell$ | upper limit on $\mathcal{B}$ @ 90% C.L. |
|---|---|---|---|---|---|---|
| $\tau^- \to \bar{\Lambda}^0\pi^-$ | conserving | $0.42 \pm 0.42$ | 12.28 | 0 | 1.97 | $5.9 \times 10^{-8}$ |
| $\tau^- \to \Lambda^0\pi^-$ | violating | $0.56 \pm 0.56$ | 12.21 | 0 | 1.90 | $5.8 \times 10^{-8}$ |
| $\tau^- \to \bar{\Lambda}^0 K^-$ | conserving | $0.26 \pm 0.26$ | 10.63 | 0 | 2.08 | $7.2 \times 10^{-8}$ |
| $\tau^- \to \Lambda^0 K^-$ | violating | $0.12 \pm 0.12$ | 9.47 | 1 | 3.78 | $15 \times 10^{-8}$ |

# Future sensitivity

- The upper limit on branching fraction depends on background

$$BF_{UL}^{90} \;\alpha\; N_{sig}^{90}$$
$$\alpha\; \frac{1}{\mathcal{L}}$$

- In the absence of background, the $BF_{UL}^{90}$ varies as $\frac{1}{\mathcal{L}}$
- In presence of background, the $BF_{UL}^{90}$ varies as $\frac{1}{\sqrt{\mathcal{L}}}$

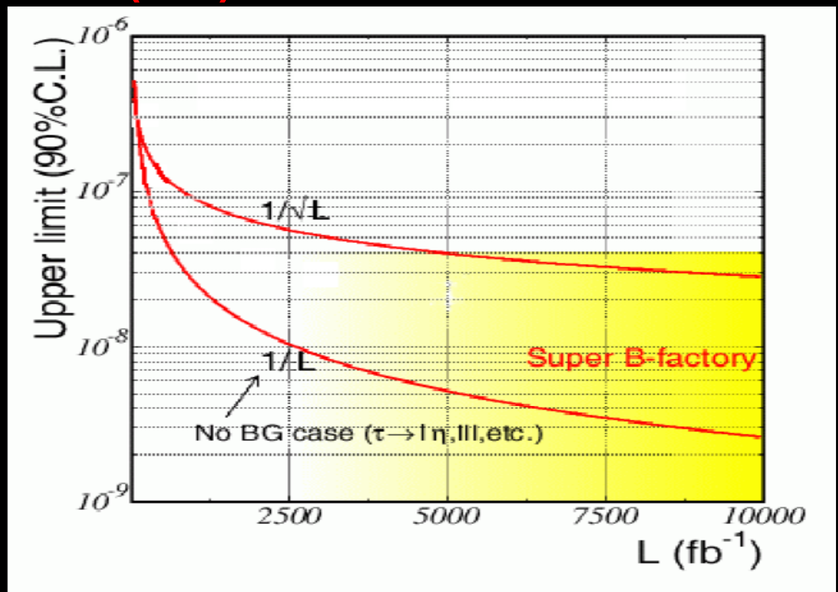
An example: for $\tau \to \mu\gamma$, the irreducible background is $\tau \to \mu\nu\nu$ + ISR

(which is 1/5th of the total background)

So, the $B_{UL}^{90}$ with irreducible background would be **(1-2) x $10^{-8}$** with 1/ab data

For $\tau \to \ell\ell\ell$ or $\ell hh$, no significant irreducible background. So, the $BF_{UL}^{90}$ is expected to be $\sim 10^{-8}$

- Depending on background and decay mode, the Super B-factory with 100 $ab^{-1}$ data would bring the limits to $10^{-9}$ - $10^{-10}$



# Summary

- BABAR has looked in many channels for evidence of LFV in $\tau$-decay
  No signal for LFV decay has been observed yet

- The limits are probing branching ratios around $10^{-8}$ well inside the parameter space of several new physics models, therefore imposing significant constraints

- The upper limit on branching fraction will improve as the B-factories accumulate more and more data

- However, it would be slow improvement due to the background for some modes, e.g. $\mu\gamma$, $e\gamma$

- There is still lots of data to come : at BABAR we expect about 750 fb-1 by end of next year

- Look forward to interesting limits (or something very interesting) from combined B*A*B*A*R/Belle full data set

**Stay tune**