τ-decays in B-factories

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BABAR Collaboration

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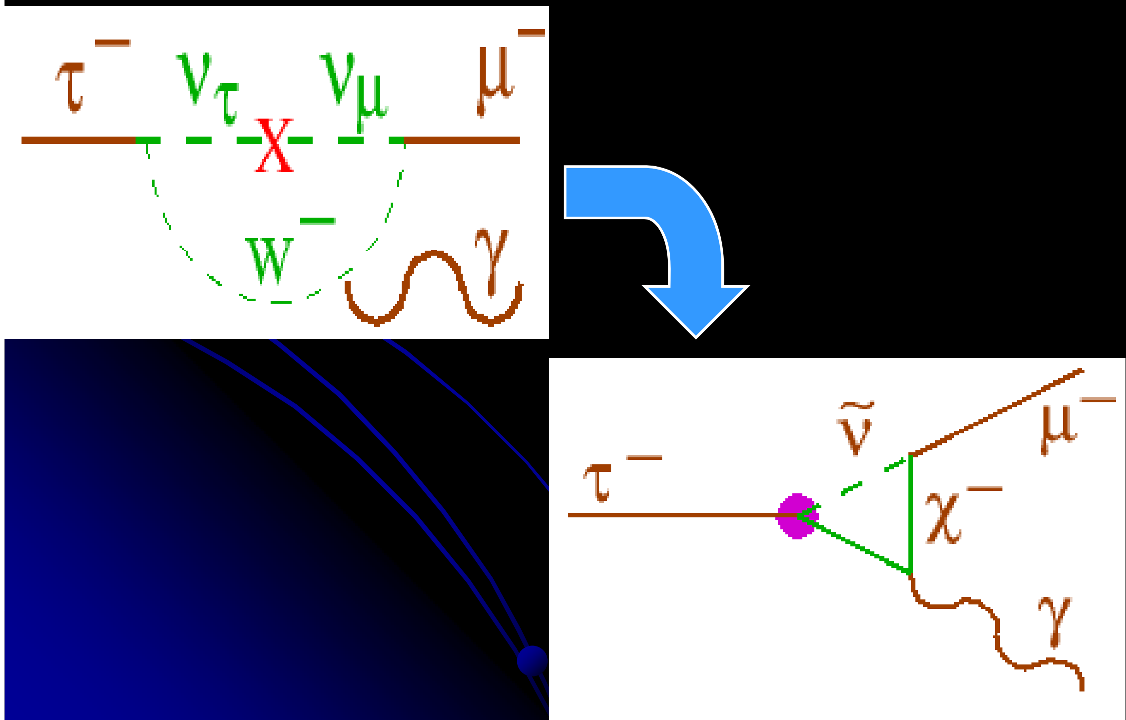
SUSY07 @ Karlsruhe



Outline

- Introduction
- $\tau \to \ell\gamma$ (ℓ = e, μ)
- $\tau \to \ell K_s$
- $\tau \to \ell P^0$ ($P^0 = \pi^0, \eta, \eta'$)
- $\tau \to \ell\ell\ell$ / ℓhh (h = K, π)
- $\tau \to \Lambda$ h
- Conclusion

Lepton Flavor Violation (LFV) in τ-decays

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

$$\begin{bmatrix} \begin{pmatrix} \nu_e \\ e^- \end{pmatrix} & \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} & \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix} \end{bmatrix}$$

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

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

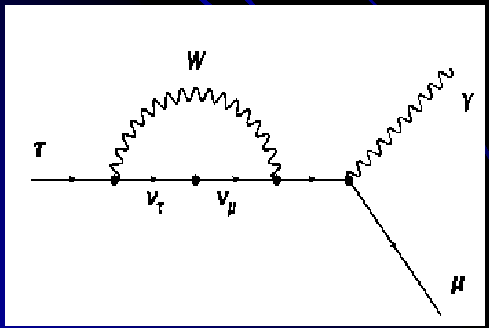
$\mathcal{L}_\tau = 1 \quad \mathcal{L}_\tau = 0 \quad \Rightarrow \Delta\mathcal{L}_\tau = 1$

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

- But neutrino oscillation implies:

$\nu_\mu \longrightarrow \nu_e$ => Lepton Flavor is violated

- The LFV in neutral sector induces LFV in charged lepton sector



But $\mathcal{B}(\tau \to \mu\gamma) \ \alpha \left(\frac{\Delta M_\nu^2}{M_W^2} \right)^2$ $\qquad \Delta M_\nu^2 \sim 10^{-3}\ \text{eV}^2$

$M_W \sim 10^{11}$ eV

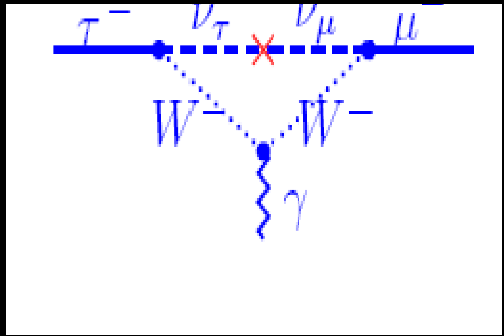
$\sim 10^{-54}$

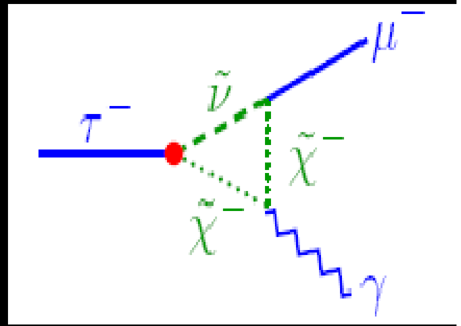
Lee-Shrock, Phys. Rev. D 16, 1444 (1977)

New physics phenomena in τ-decays

1.

Things would be completely if we replace





The slepton have same lepton numbers and do have mixing

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

2.

$$\mathcal{B}(\tau\to\mu\gamma)\simeq 7\times10^{-7}\left(\frac{\tan\beta}{60}\right)^2\left(\frac{1\ \mathrm{TeV}/c^2}{m_{SUSY}}\right)^4$$

⇒The branching fraction can be enhanced significantly

	$\mathcal{B}(\tau\to\ell\gamma)$	$\mathcal{B}(\tau\to\ell\ell\ell)$
SM+ν-mixing (PRL95(2005)41802,EPJC8(1999)513)	10^{-54}	10^{-14}
SUSY Higgs (PLB549(2002)159, PLB566(2003)217)	10^{-10}	10^{-7}
SM+Heavy Majorana ν_R (PRD66(2002)034008)	10^{-9}	10^{-10}
Non-Universal Z' (PLB547(2002)252)	10^{-9}	10^{-8}
SUSY SO(10) (NPB649(2003)189, PRD68(2003)033012)	10^{-8}	10^{-10}
mSUGRA+seesaw (EPJC14(2000)319, PRD66(2002)115013)	10^{-7}	10^{-9}

Two asymmetric energy B-factories

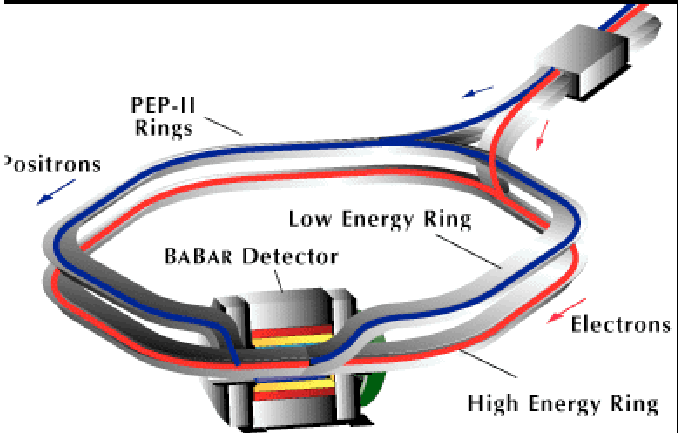
PEP-II at SLAC

9GeV (e^-) $\times$ 3.1GeV (e^+)
peak luminosity:
1.12×10^{34}cm^{-2}s^{-1}

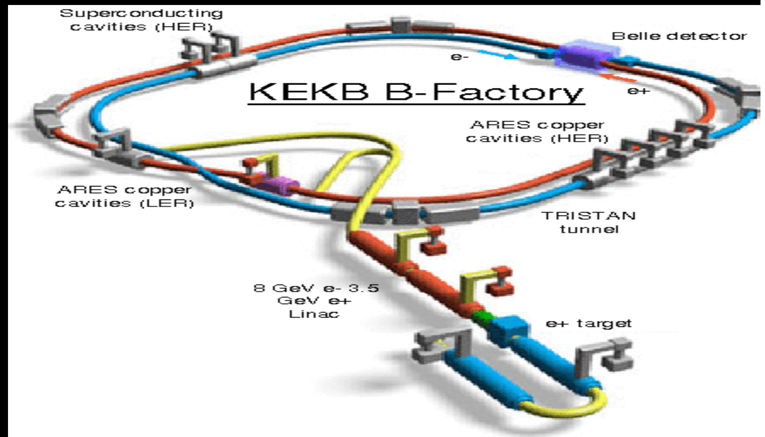
B-factories

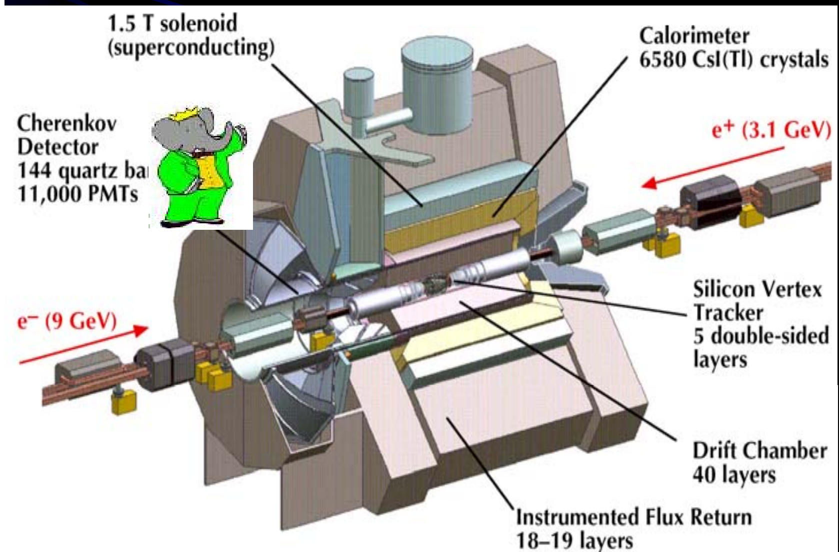
KEKB at KEK

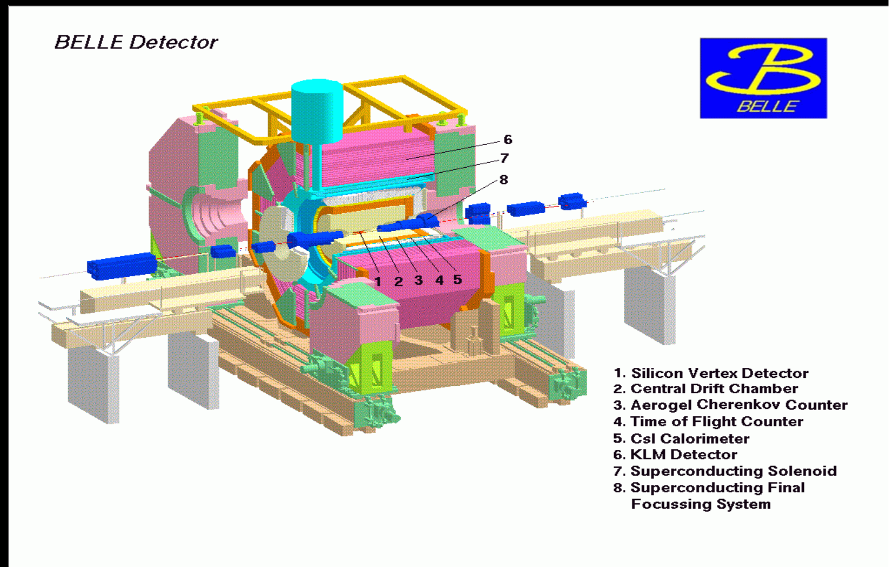
8GeV (e^-)$\times$3.5GeV (e^+)
peak luminosity:
1.71×10^{34}cm^{-2}s^{-1}



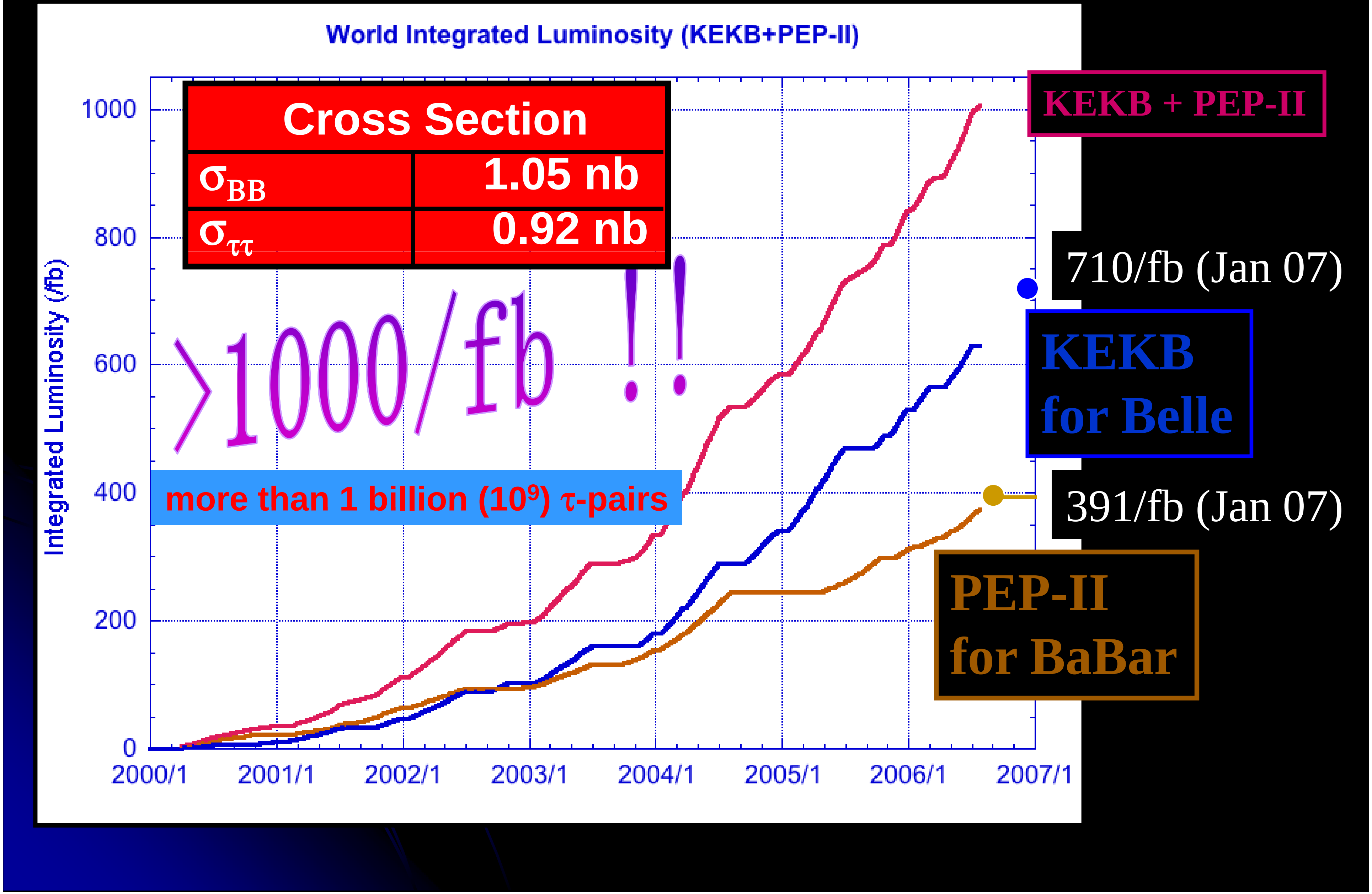
BaBar Belle





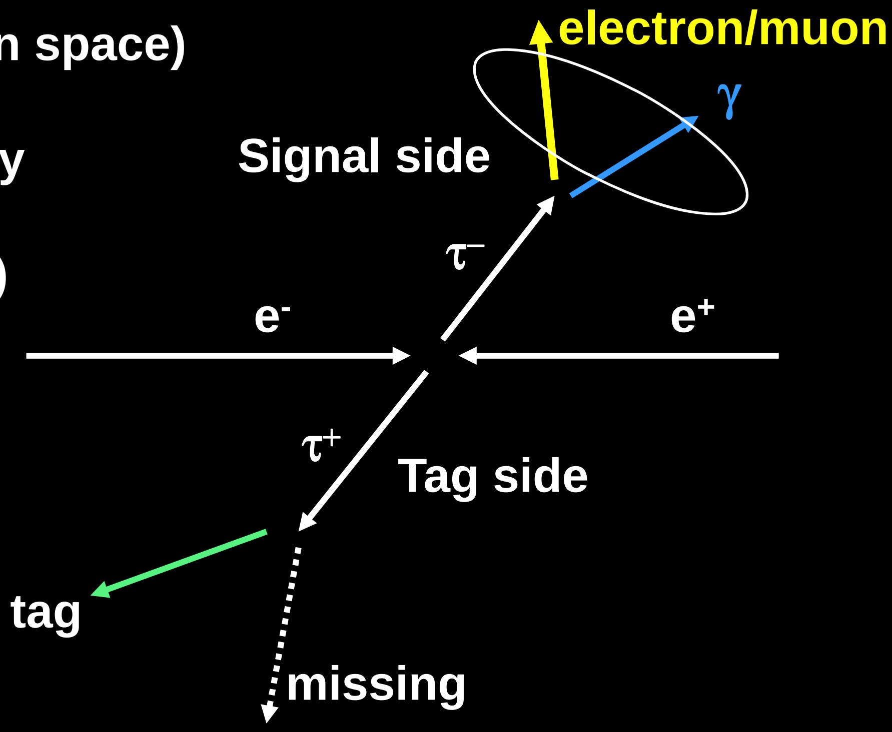


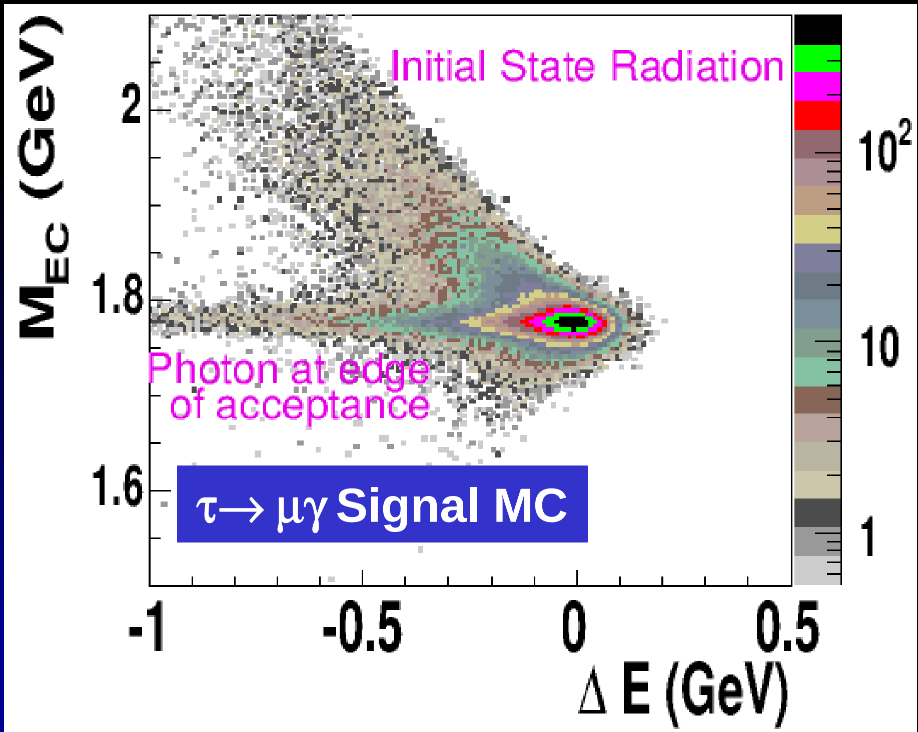
Integrated Luminosity



τ-decay topology

- Two hemispheres ⊥ thrust (separated in space)
- Signal side: neutrino-less 1-prong decay
  –> electron / muon
  (all the particles are fully reconstructed)
- Tag side: 1-prong or 3-prong
  $e\nu\nu$, $\mu\nu\nu$, $\pi\nu$, $\rho\tau$



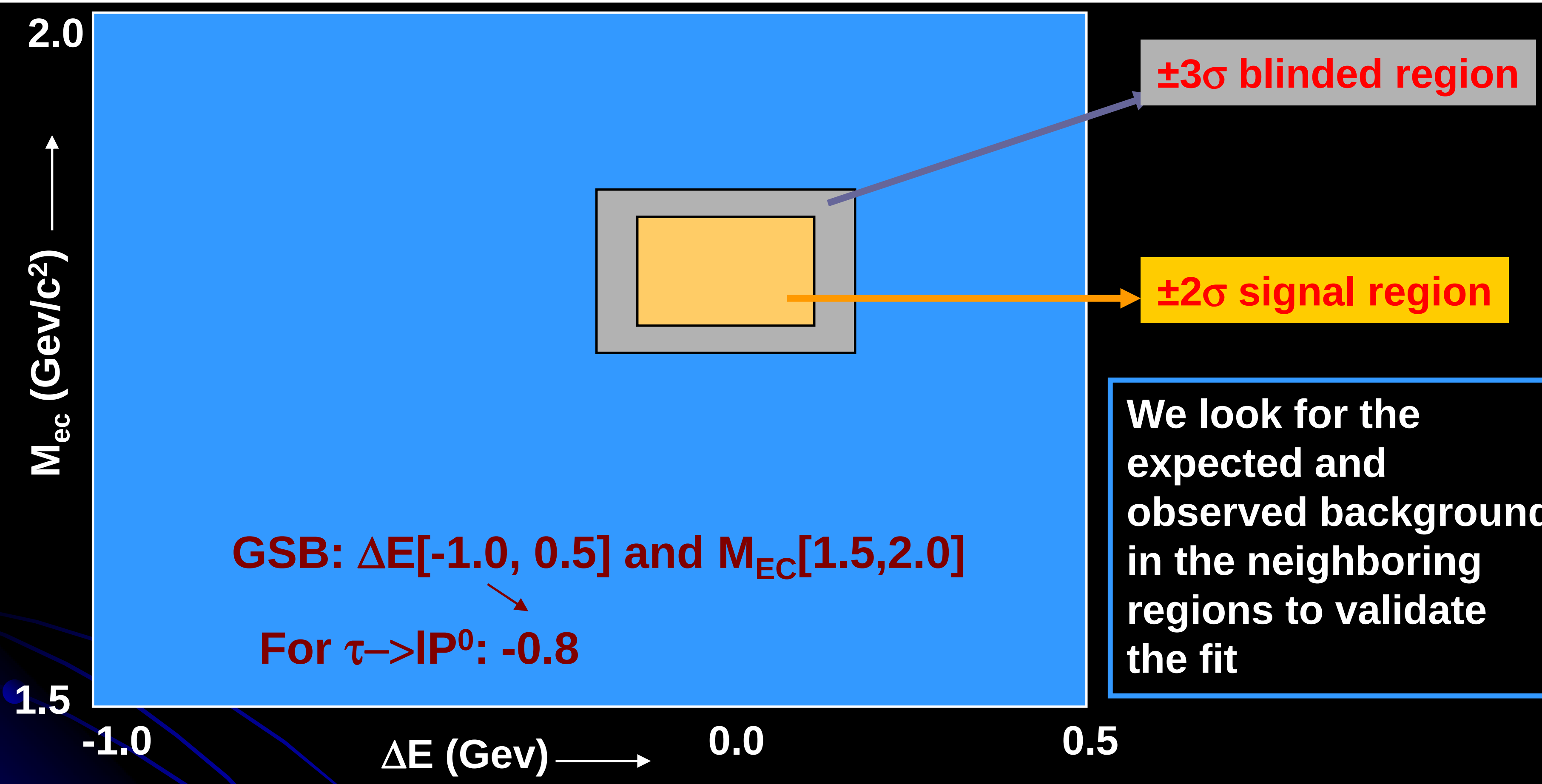


M_{EC} : beam energy
constrained τ mass

ΔE: energy difference
E_τ - E_{beam}

Sometimes, variables used are ΔE and $\Delta M = M_{rec} - M_\tau$

Analysis methodology

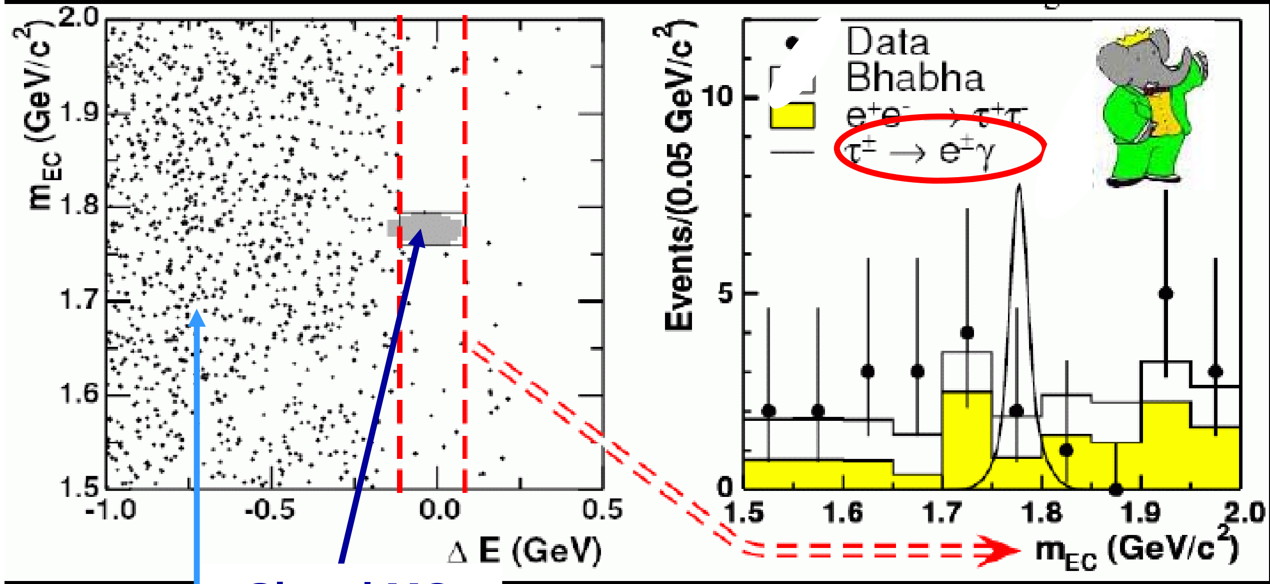


We look for the expected and observed background in the neighboring regions to validate the fit

For τ–>lγ, the expected background in the signal box is obtained by fitting the sidebands of M_{EC} distribution from the ±2σ band in ΔE where as

for τ–>lP^0, the background is obtained by 2D un-binned maximum likelihood fit to un-blinded region in M_{EC} and ΔE.

Results from $\tau \to \ell\gamma$



Efficiency=(4.7±0.3)%

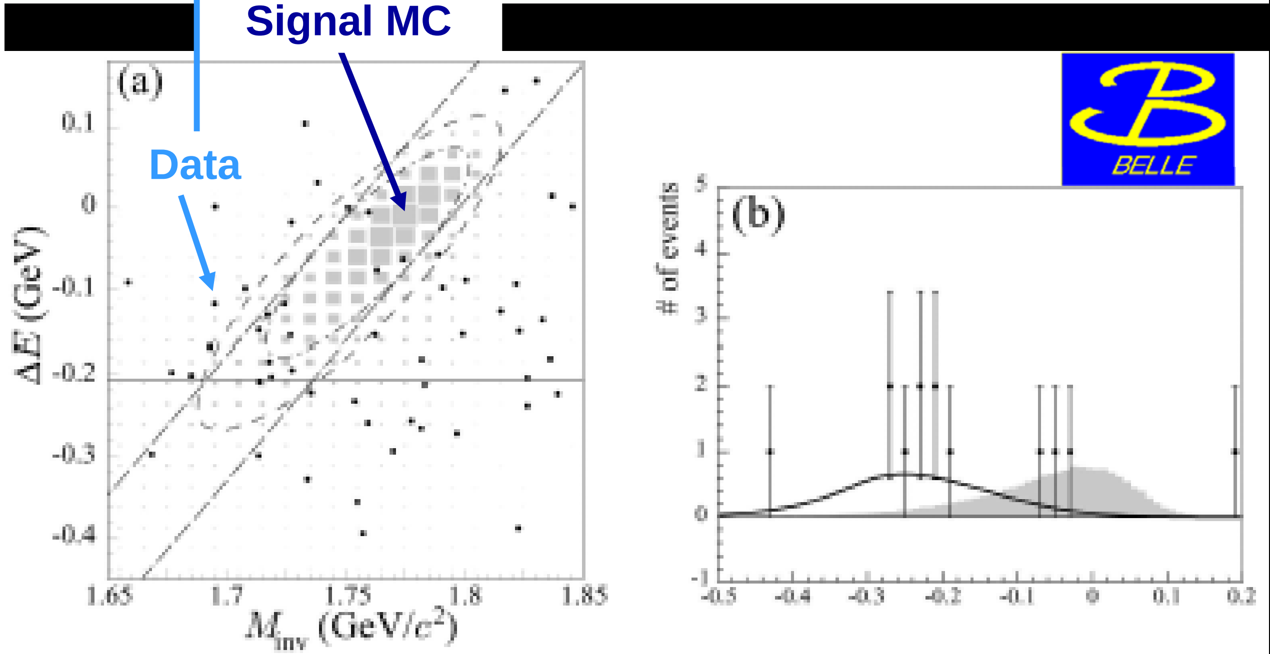
BF ($\tau^- \to e^- \gamma$) < 11 x10^{-8}

PRL 96, 041801 (2006)

Efficiency=(7.42±0.65)%

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

PRL 95, 041802 (2006)



Efficiency=2.99%

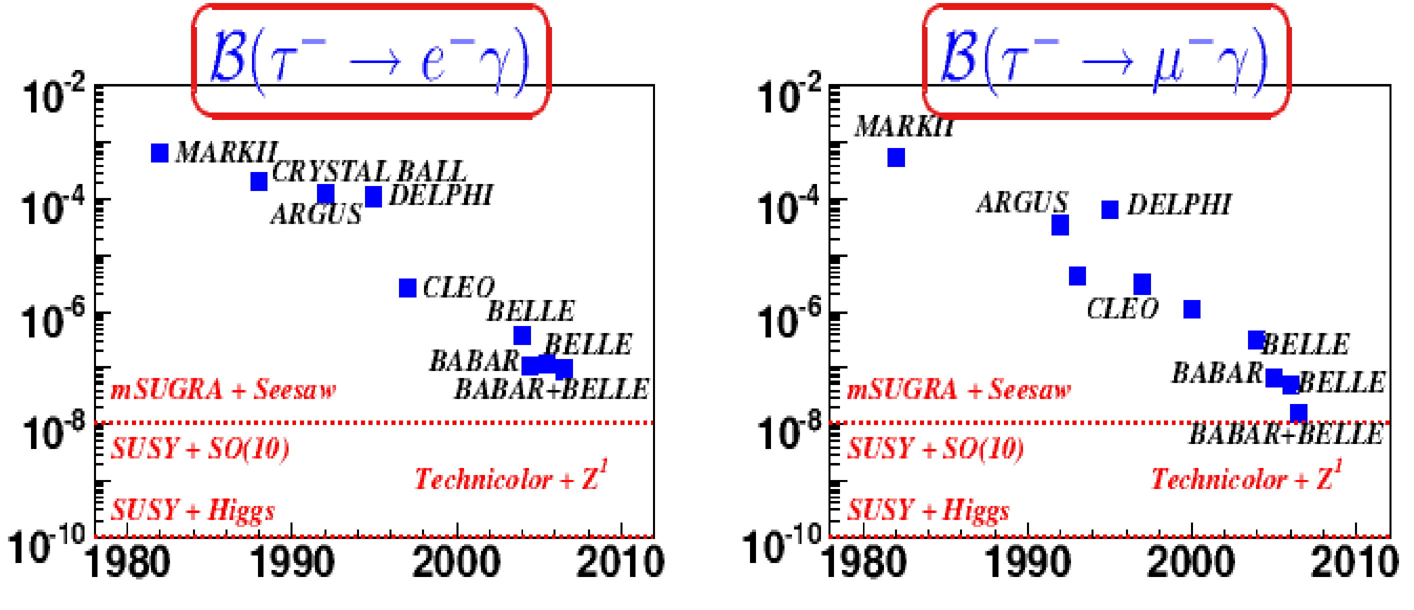
BF ($\tau^- \to e^- \gamma$) < 12 x10^{-8}

Efficiency=5.07%

BF ($\tau^- \to \mu^- \gamma$) < 4.5 x 10^{-8}

ar-Xiv:0705.0650 [hep-ex]

Results from τ→ℓγ and impact on new physics



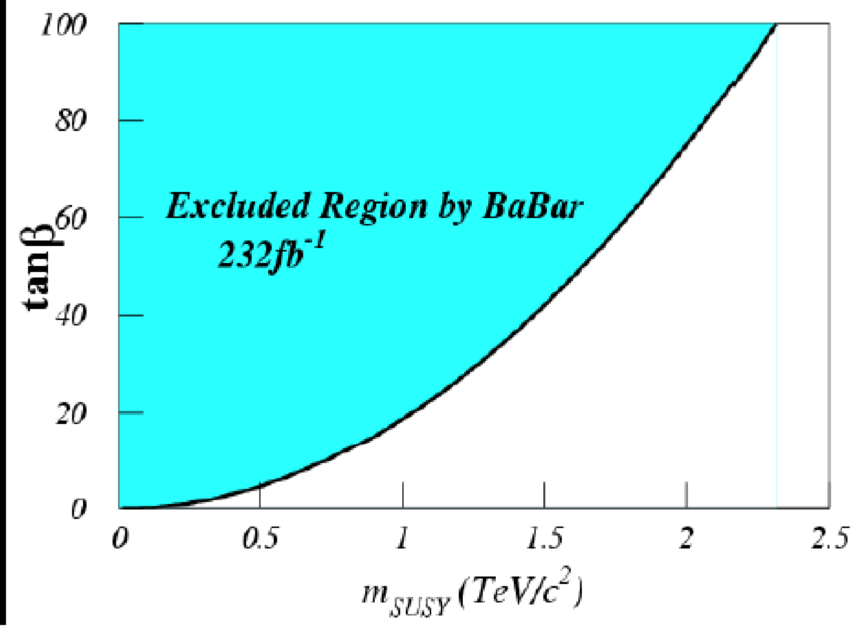
S. Banerjee (Tau06) Nucl. Phys. Proc. Suppl. 169, 199 (2007)

MSSM with seesaw:

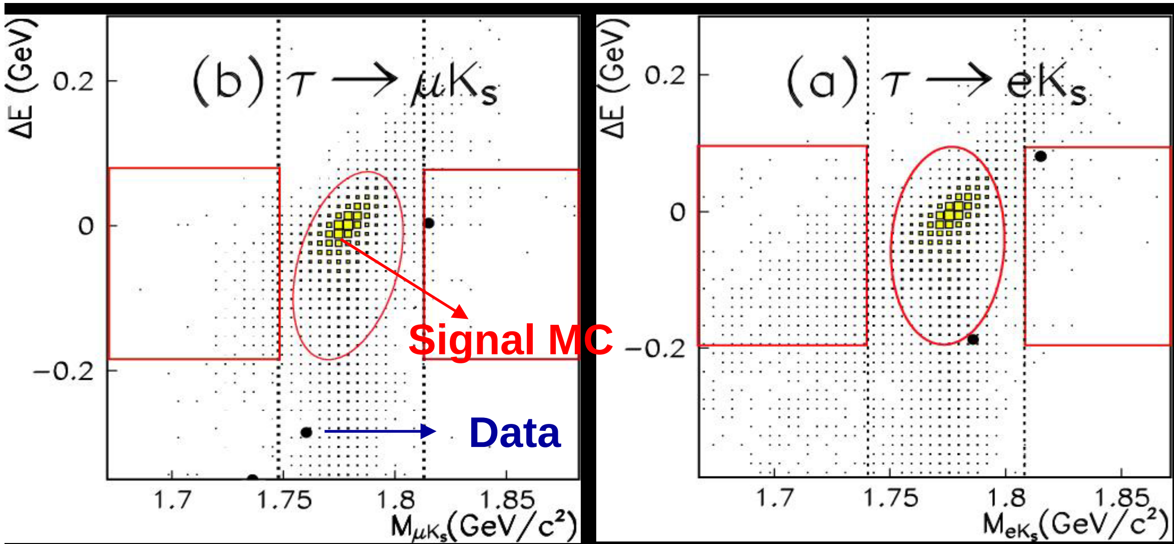
$$\mathcal{B}(\tau \to \mu\gamma) \simeq 7 \times 10^{-7} \left(\frac{\tan\beta}{60}\right)^2 \left(\frac{1\ \mathrm{TeV}/c^2}{m_{SUSY}}\right)^4$$

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

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



$\tau \to \ell K_s$ (ℓ = e or μ)



BELLE used 281 fb^{-1} data

$\mathcal{B}(\tau^- \to \mu^- K_s) < 4.9 \times 10^{-8}$

$\mathcal{B}(\tau^- \to e^- K_s) < 5.6 \times 10^{-8}$

@90% CL

PLB 639, 159 (2006)

1. In R-parity violating SUSY scenario-> λ, λ', λ'' (with 45 couplings)

   → τ decays lK_s via tree level scalar neutrino exchange by λλ' coupling

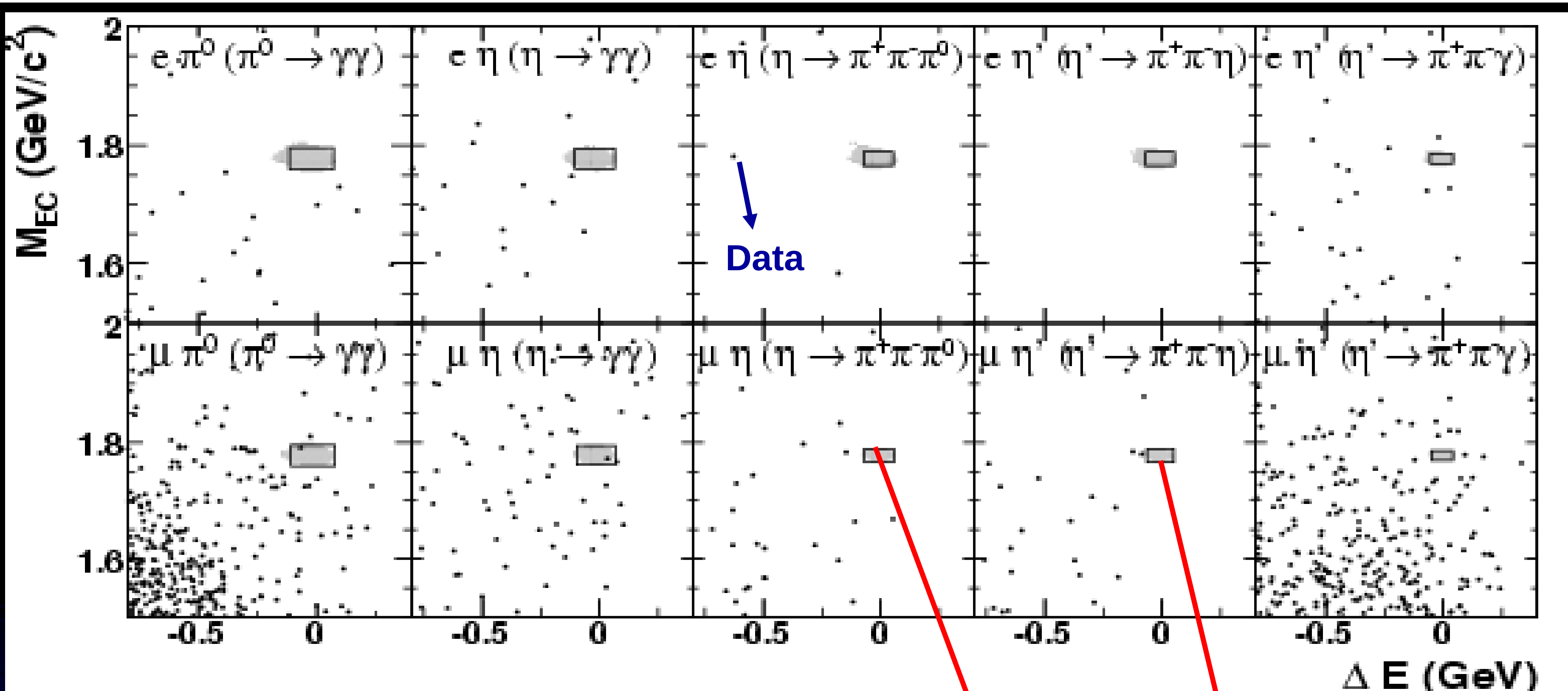
scalar neutrino mass ($M_{\tilde\nu}$)

$$|\lambda_{i31}\lambda'_{i12}|(i=1,2), |\lambda_{i31}\lambda'_{i21}|(i=2,3) < 4.5 \times 10^{-4}(M_{\tilde\nu}/100\mathrm{GeV}/c^2)^2 \text{ for } \tau^- \to e^- K_S^0$$
$$|\lambda_{i32}\lambda'_{i12}|(i=1,2), |\lambda_{i23}\lambda'_{i21}|(i=1,3), < 4.1 \times 10^{-4}(M_{\tilde\nu}/100\mathrm{GeV}/c^2)^2 \text{ for } \tau^- \to \mu^- K_S^0$$

2. This result can be used to constrain new physics scale in dimension-six fermionic effective operator involving τ–μ flavor violation motivated by neutrino oscillations

→lower bounds on axial-vector and pseudo-scalar operators: 36.2TeV and 37.2 TeV

$\tau \rightarrow \ell P^0$ ($P^0 = \pi^0, \eta, \eta'$)



Using 339 fb^{-1} data, the upper limit is (1 - 6) x 10^{-7}

Total expected events = 3.1

Total observed events = 2

Signal box
($\pm 2\sigma$ in ΔE and M_{EC})

Shaded region covers 68% of signal MC

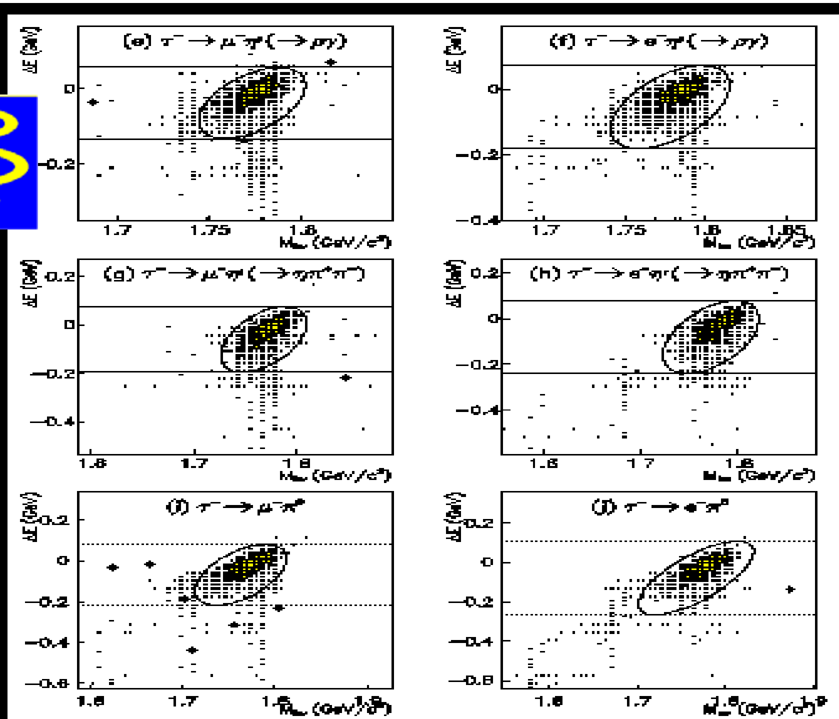
PRL 98, 061803 (2007)

$\tau \rightarrow \ell P^0$ ($P^0 = \pi^0, \eta, \eta'$)

Mode	M^0 subdecay mode	Upper limit on $\mathcal{B}$ at 90% C.L.
$\tau^- \rightarrow \mu^- \eta$	$\eta \rightarrow \gamma\gamma$	1.2×10^{-7}
	$\eta \rightarrow \pi^+\pi^-\pi^0$	2.0×10^{-7}
	Combined	6.5×10^{-8}
$\tau^- \rightarrow e^- \eta$	$\eta \rightarrow \gamma\gamma$	1.7×10^{-7}
	$\eta \rightarrow \pi^+\pi^-\pi^0$	2.6×10^{-7}
	Combined	9.2×10^{-8}
$\tau^- \rightarrow \mu^- \eta'$	$\eta' \rightarrow \rho\gamma$	1.9×10^{-7}
	$\eta' \rightarrow \eta\pi^+\pi^-$	4.1×10^{-7}
	Combined	1.3×10^{-7}
$\tau^- \rightarrow e^- \eta'$	$\eta' \rightarrow \rho\gamma$	2.5×10^{-7}
	$\eta' \rightarrow \eta\pi^+\pi^-$	4.7×10^{-7}
	Combined	1.6×10^{-7}
$\tau^- \rightarrow \mu^- \pi^0$	$\pi^0 \rightarrow \gamma\gamma$	1.2×10^{-7}
$\tau^- \rightarrow e^- \pi^0$	$\pi^0 \rightarrow \gamma\gamma$	8.0×10^{-8}

401 fb^{-1} data

BELLE



PLB 648, 341 (2007)

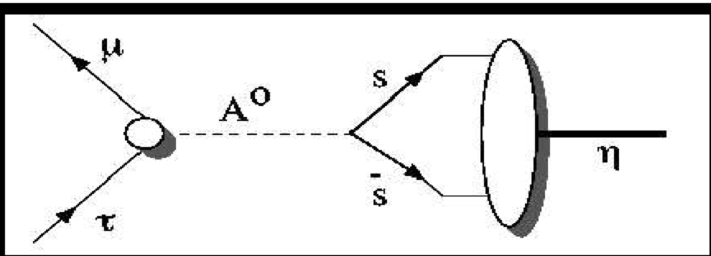
These improved upper limit can be used to constrain the parameters of Heavy Dirac neutrino model.

Branching fractions of different modes are evaluated in terms of Model Parameters:

$$y_{\tau e} \text{ and } y_{\tau\mu} \rightarrow [0, 1]$$

Using $\tau \rightarrow l\pi^0$, $y_{\tau e} < 0.17$ and $y_{\tau\mu} < 0.47$ @ 90% C.L

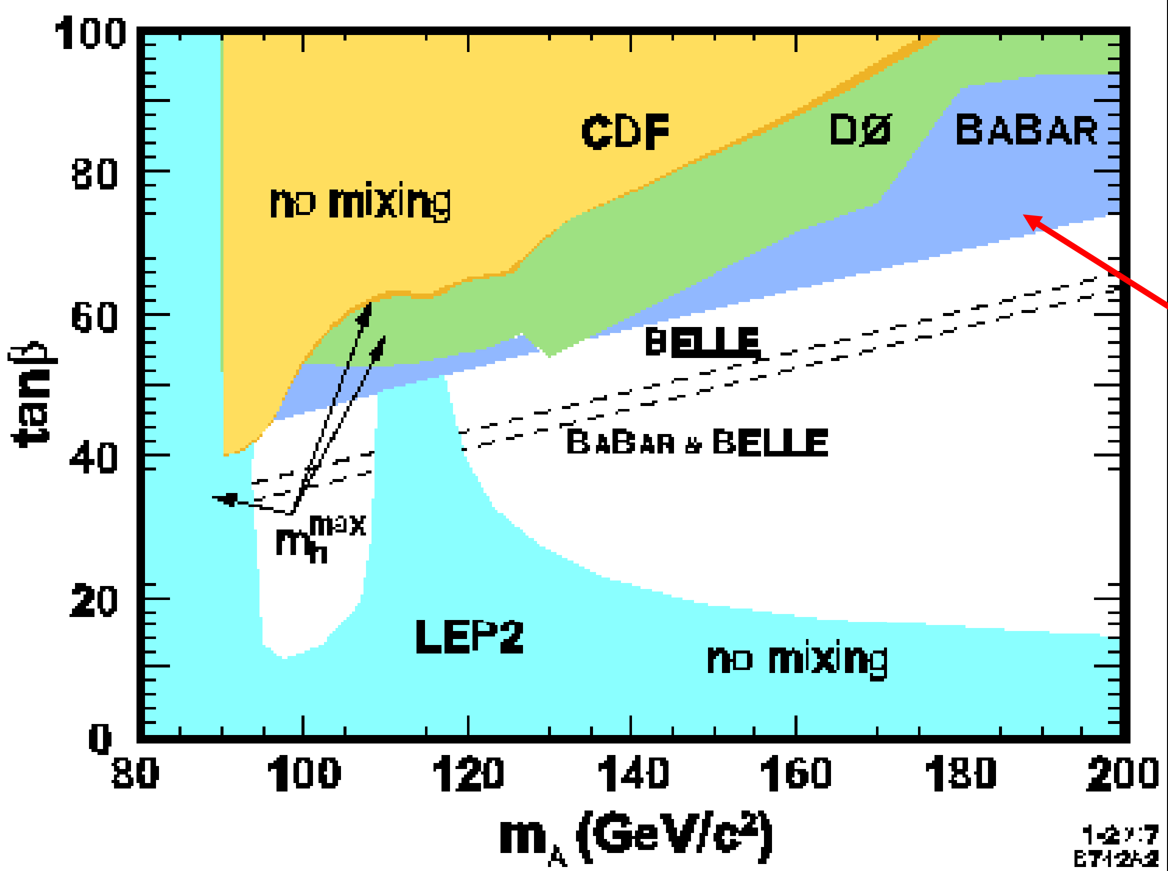
Constraining new physics using $\tau \to \mu\eta$ result



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

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 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

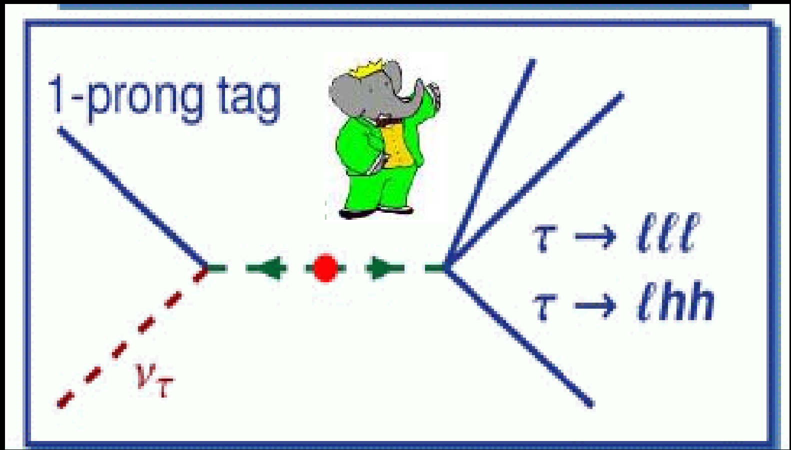
CDF: $p\bar{p} \to H \to \tau^+\tau^-$ (310 fb^{-1})

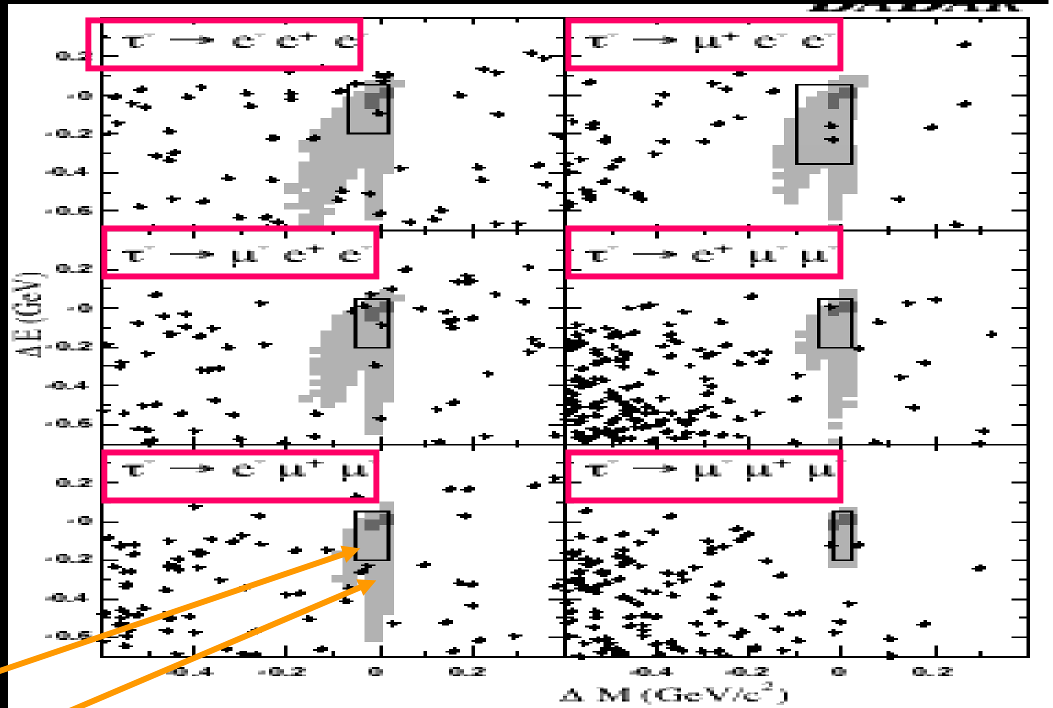
D0: $p\bar{p} \to H \to b\bar{b}$ (260 fb^{-1})

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

S.Banerjee (Tau 06) Nucl. Phys. Proc. Suppl. 169, 199 (2007)]

$\tau \to \ell\ell\ell$ ($\ell = e$ or μ)





376 fb^{-1} BABAR data used

Total expected events = 4.2
Total observed events = 6

Signal box

90% of the selected MC events

Upper limits ~ (4 – 8) x 10^{-8}

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

$\tau \to \ell h h'$ and $\tau \to \ell V^0$

h (h') –> K or π V^0 –> $K^*(892)$, ρ^0, ϕ

Vector

Belle used 158 fb^{-1} data

PLB 640, 138 (2006)

Decay modes used:

[e, μ]

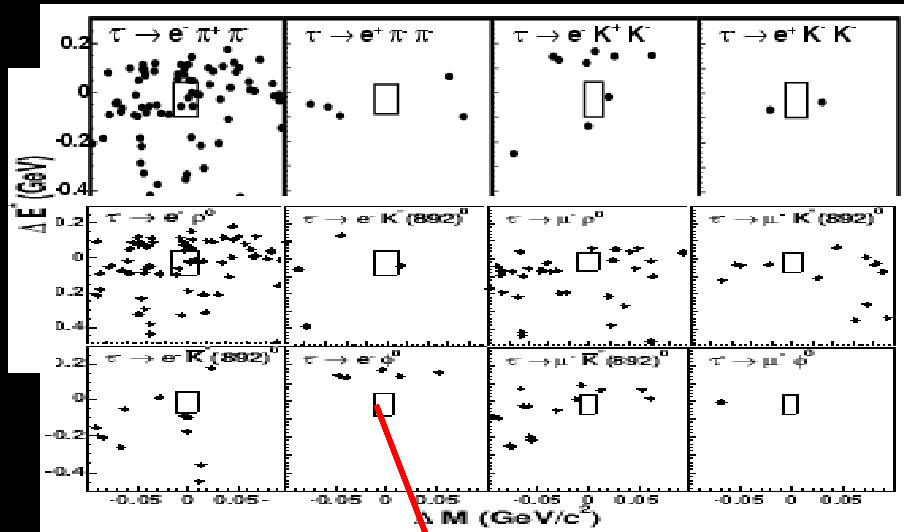
x

[$\pi^+\pi^-$, $\pi^-\pi^-$, π^+K^-, $K^+\pi^-$, $K^-\pi^-$, K^-K^+, K^-K^-,

ρ^0, k^{*0}, $\bar{K}^{*0}$, ϕ]   →22 decay modes

(including modes violating total lepton number)

The upper limit varies (1.6 - 8.0) X 10^{-7}



Signal Box

1. These improved upper limit can be used to constrain the parameters of Heavy Dirac neutrino model.

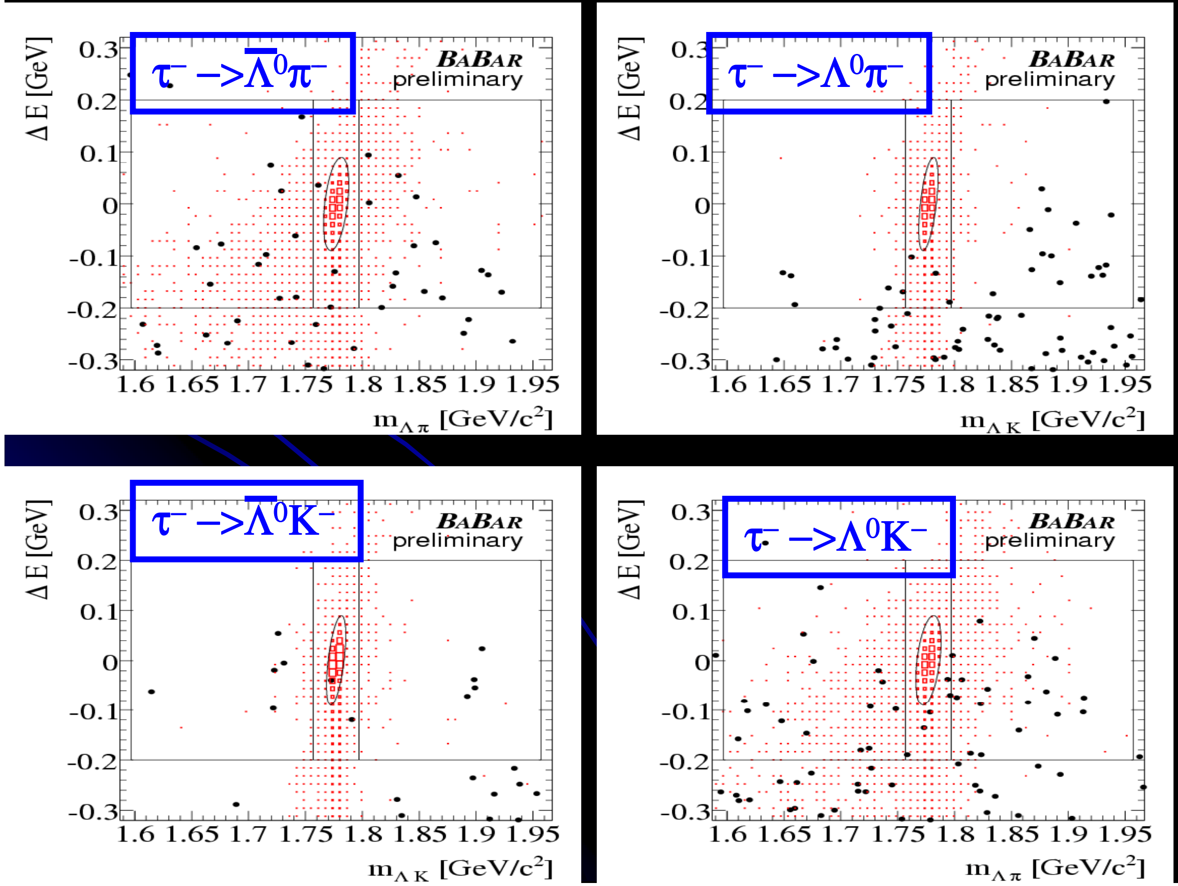
   Using τ –> $l\rho^0$, $y_{\tau e}^2 < 0.24$ and $y_{\tau\mu}^2 < 0.38$ @ 90% C.L

2 Constraint the energy scale of dimension-six fermionic effective operator

   $\Lambda_{uu,dd} >$ 29.4TeV, $\Lambda_{ss} >$ 24.8 TeV and $\Lambda_{ds} >$ 26.8 TeV

Lepton and baryon number violating τ-decay

- **The baryon asymmetry of the universe –> Baryon number violation (Sakharov condition)**
- **For lepton -> baryon + meson decays, the angular momentum conservation requires, Δ(B-L) = 0 or 2**



The following decays modes used in this analysis: (237 fb^{-1})

(hep-ex: 0607040)

mode	upper limit on $\mathcal{B}$ @ 90% C.L.
$\tau^- \to \bar{\Lambda}^0\pi^-$	5.9×10^{-8}
$\tau^- \to \Lambda^0\pi^-$	5.8×10^{-8}
$\tau^- \to \bar{\Lambda}^0K^-$	7.2×10^{-8}
$\tau^- \to \Lambda^0K^-$	15×10^{-8}

Summary

- None of the lepton flavor violating processes has been observed yet.
- For $\tau \rightarrow \ell\gamma$, the best upper limit is ~ 4.5 X 10^{-8}
- For $\tau \rightarrow \ell P0$, the best upper limits are ~ (1-9) X 10^{-8}
- For $\tau \rightarrow \ell K_S$, the upper limits are ~ 5 X 10^{-8}
- For $\tau \rightarrow \ell\ell\ell$ (hh'), the upper limits are ~ (1 - 8) X 10^{-8}

- Further probe into the LFV using more data can put constraint on different theoretical models.
- If LFV is discovered in near future, it is possible that LFV-inducing particles will be produced directly at high energy. The LFV effects from real particles production may then also be seen at colliders

STAY TUNED !