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Search for the lepton flavor violation τ decay at the Belle experiment (2)

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and Belle Collaboration

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  (Motivation, Analysis method, Belle detector)
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Introduction

Lepton Flavor Violation (LFV) decays have a very small probability in the Standard Model (and proceed only due to neutrino oscillation).

$\Downarrow$

Many extensions of the SM predict LFV decays, enhanced up to the current experimental sensitivity. (SUSY, Extra dimension and etc.)

$\Rightarrow$ Observation of LFV from τ decay would be a clear signature of New Physics.

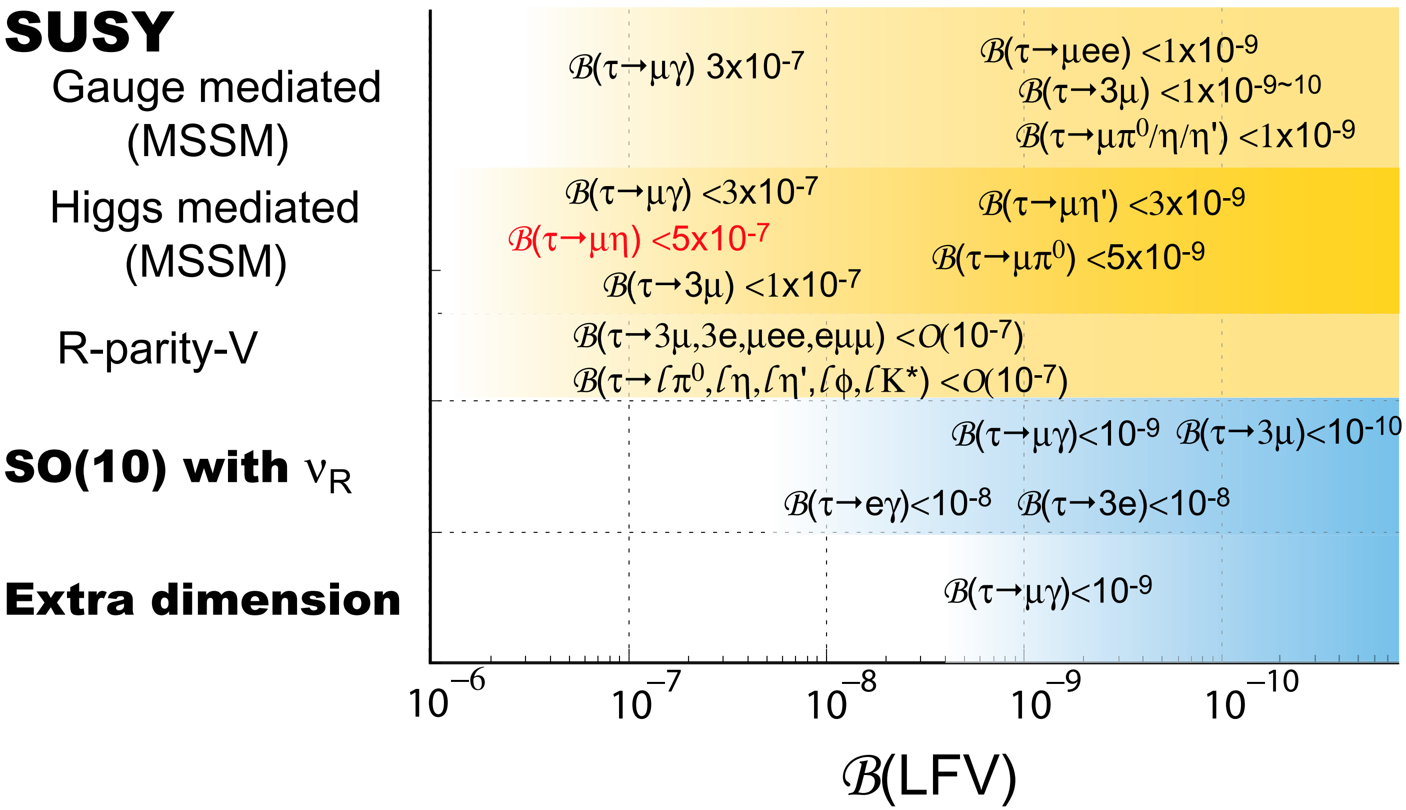
Previous results

CLEO sensitivities on $\mathcal{B}$ $\sim$O(10^{-6}) for LFV τ decay with $\sim 10^7$ $\tau\tau$ pairs

$\Rightarrow$ The Belle has sensitivities of $\mathcal{B} \sim$ O(10^{-7} $\sim$$10^{-8}$)

Expected branching fraction for LFV τ decay

Reach the level of some New Physics predictions



In previous talks, showed

- $\tau^- \longrightarrow e^-\gamma$ and $\mu^-\gamma$

$\Downarrow$

will show various LFV decay modes:

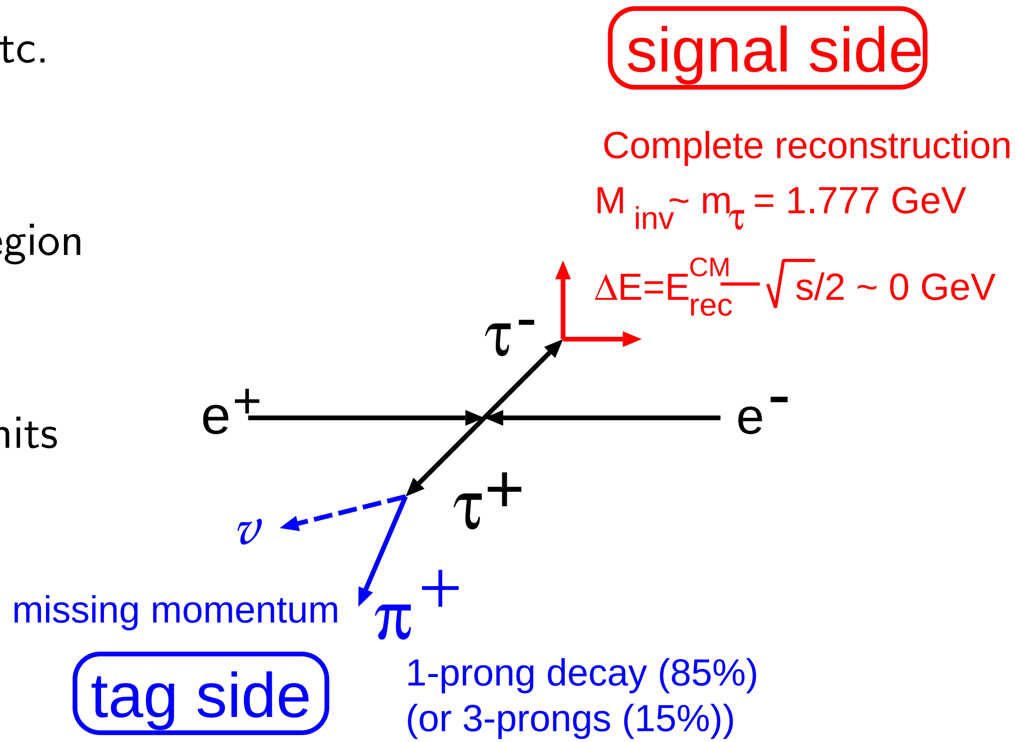
- $\tau^- \longrightarrow \ell^- K_S^0$
- $\tau^- \longrightarrow \ell^- \eta/\eta'/\pi^0$
- $\tau^- \longrightarrow \ell^- V^0$
- $\tau^- \longrightarrow \ell h h'$ and $\ell\ell'\ell''$
- $\tau^- \longrightarrow \bar{\Lambda}\pi^-$ and $\Lambda\pi^-$

Analysis method for LFV τ decay

Procedure for LFV τ decay

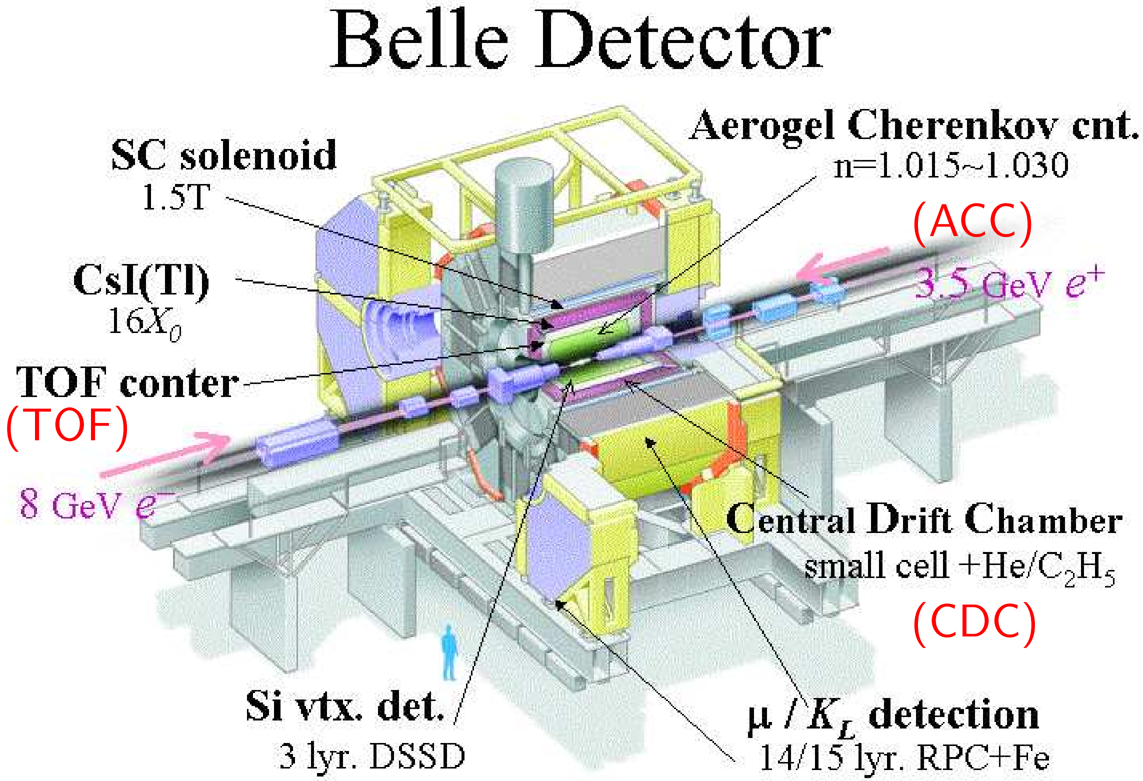
1. Select low multiplicity track with a zero net charge
2. Separate into two hemispheres using thrust axis
   $\longrightarrow$ signal and tag
3. Reduce background using PID and kinematic informations
   $\longrightarrow$ missing momentum, # of γ's etc.
4. Calculate M_{inv} and ΔE
   $\longrightarrow$Blind the signal region
5. Estimate the background in signal region
   using sideband data
6. Open the blinded region
   LFV observation or set an upper limits

$e^+e^- \longrightarrow \tau^+\tau^-$ production
LFV τ decay
generic τ decay



$$B(\text{LFV } \tau \text{ decay}) < \frac{s_{90\%C.L.}}{2\varepsilon N_{\tau\tau}}$$

Belle Detector



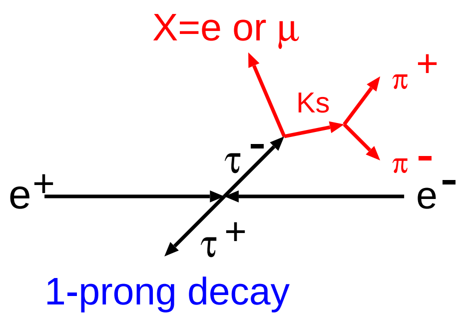
KEKB:e^+(3.5GeV)e^-(8 GeV)
$\sqrt{s}$ = 10.58 GeV
$\sigma(\tau\tau) \sim$ 0.9 nb
($\sigma(B\bar{B}) \sim$ 1.0 nb)
B-factory is also τ factory!!!

Integrated luminosity:
$>$500/fb collected by Belle detector
($>$ 300/fb for Babar)

For lepton ID
e efficiency 93%
μ efficiency 88%

Hadron ID in Belle is obtained by likelihood function from CDC, TOF and ACC. The separation between each hadron is used by the likelihood ratio as $L(i/j) = L_i/(L_i + L_j)$ where $i(j)$ is a kind of hadron (π, K and p)

$\tau \to \ell K_S^0$ (1)



$\tau \to \ell K_S^0$ (where $K_S^0 \to \pi^+\pi^-$)

Dataset for this analysis @ 281 fb^{-1}

Event selection

- $p_{\rm miss} > 0.4$ GeV/c
  within the fiducial volume
- $10 > E_{total}^{CM} > 5.29$GeV
- $\cos\theta_{tag-mis}^{CM} > 0.0$
- # of γ in signal side ≤ 1
- # of γ in tag side ≤ 2
- $\cos\theta_{\ell K_S^0}$ vs. $p_{\ell K_S^0}$ cut

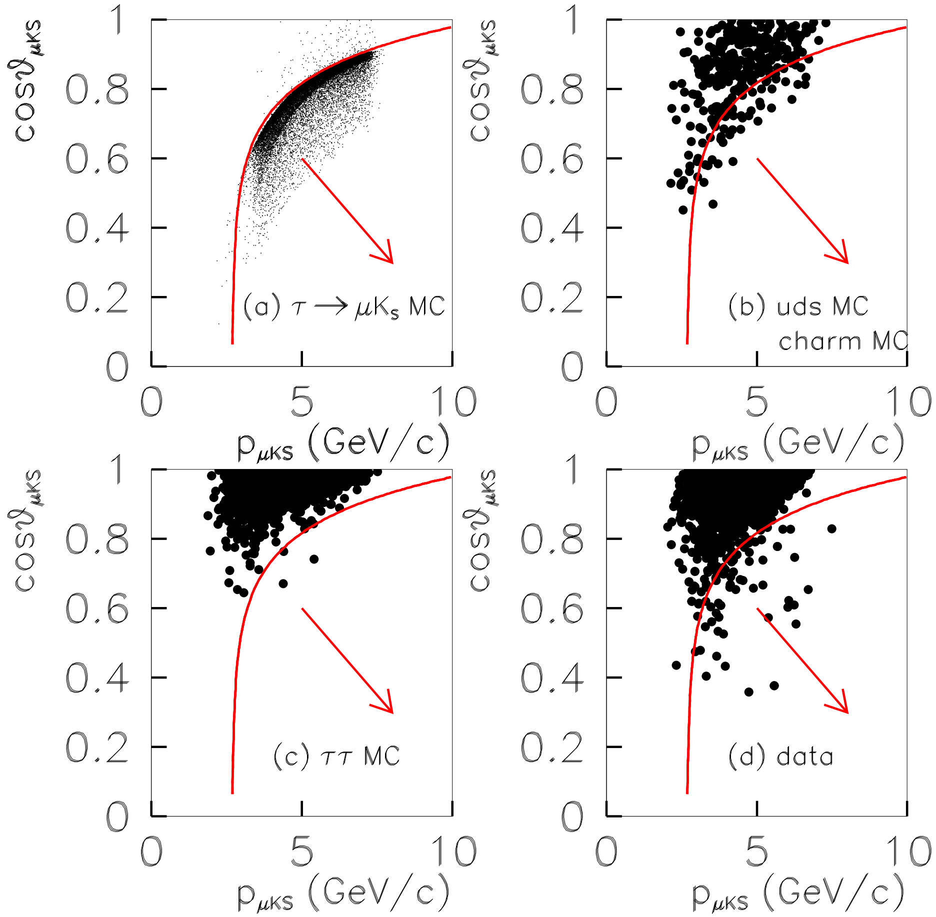
$\Rightarrow$ See plot on the right

Require $\cos\theta_{\ell K_S^0} < 0.14\log(p_{\ell K_S^0} - 2.7) + 0.7$

Eff. of $\cos\theta_{\ell K_S^0}$ vs. $p_{\ell K_S^0}$ cut for each MC

Signal 99%

$\tau\tau$ 0.7%, uds 16%



$\tau \to \ell K_S^0$ (2)

After events selections

ε = 11.8% for eK_S^0 mode

ε = 13.5% for μK_S^0 mode

Background:

$D^{(*)\pm} \to \ell^\pm \nu K_S^0$

$\pi^\pm K_S^0$

In signal region

— Expected background

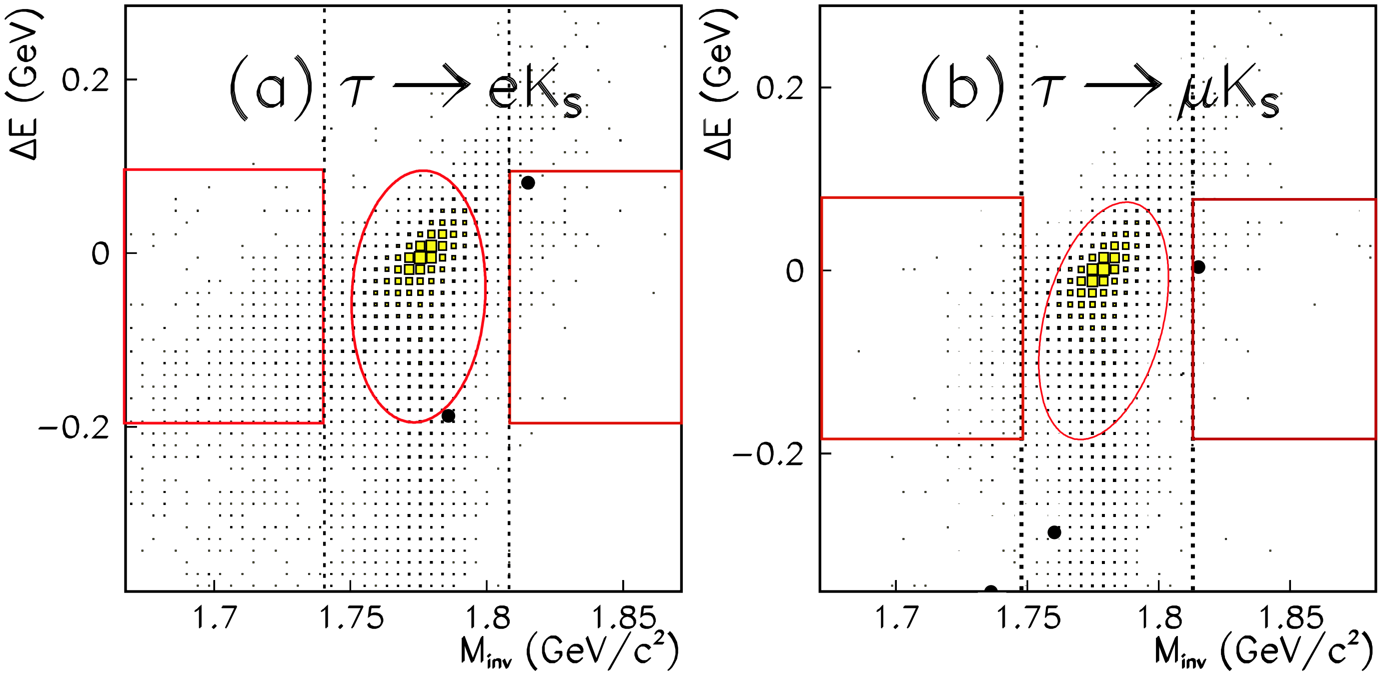
0.2 ± 0.2 events

— Data

No events in either mode

⇓

Set upper limits on branching fraction at 90% C.L.



$\mathcal{B}(\tau \to eK_S^0) < 5.6 \times 10^{-8}$ $\mathcal{B}(\tau \to \mu K_S^0) < 4.9 \times 10^{-8}$

(Preliminary, hep-ex/0509014)

Improved by a factor of 16 and 19 compared with CLEO

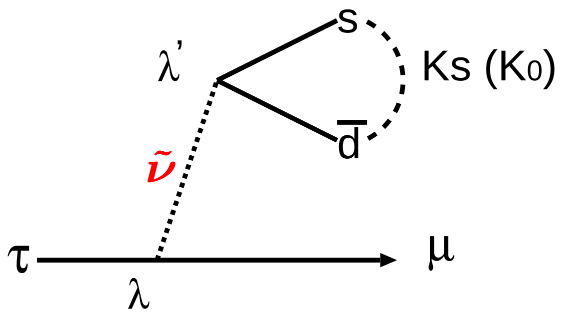
(Previous upper limits: $9.1(9.5)\times10^{-7}$ for $eK_S^0(\mu K_S^0)$)

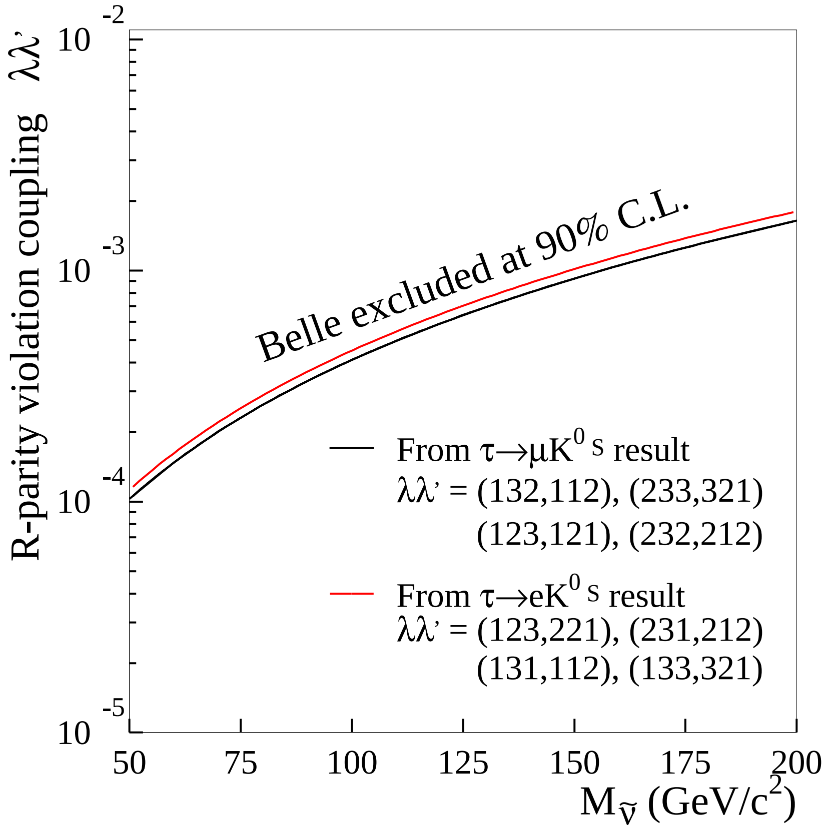
$\tau \to \ell K^0_S$ (3)

τ^- could decay into $\ell^- K^0_S$ mode via tree-level scalar neutrino ($\tilde{\nu}$) exchange by the $\lambda\lambda'$ couplings.
Using our results, the limits on the $\lambda\lambda'$ product as a function of the scalar neutrino mass ($M_{\tilde{\nu}}$) are given as (J. P. Saha and A. Kundu, PRD 66, 054021 (2002))

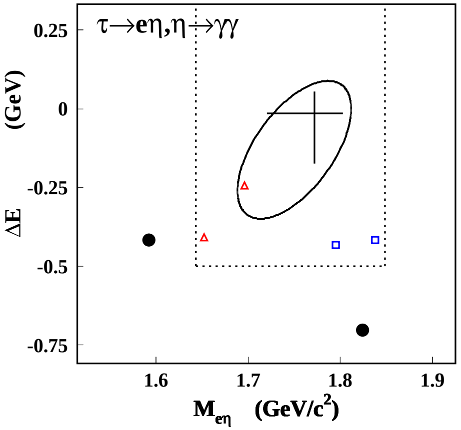
$\mathcal{B}(\tau \to e K^0_S) < 5.6 \times 10^{-8}$
$\Rightarrow |\lambda_{i31}\lambda'_{i12}|, |\lambda_{i31}\lambda'_{i21}| < 4.5 \times 10^{-4}(M_{\tilde{\nu}}/100\text{GeV/c}^2)^2$

$\mathcal{B}(\tau \to \mu K^0_S) < 4.9 \times 10^{-8}$
$\Rightarrow |\lambda_{i32}\lambda'_{i12}|, |\lambda_{i23}\lambda'_{i21}| < 4.1 \times 10^{-4}(M_{\tilde{\nu}}/100\text{GeV/c}^2)^2$
(i is the generation number.)

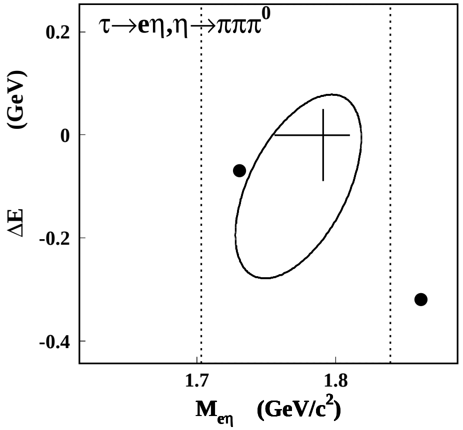




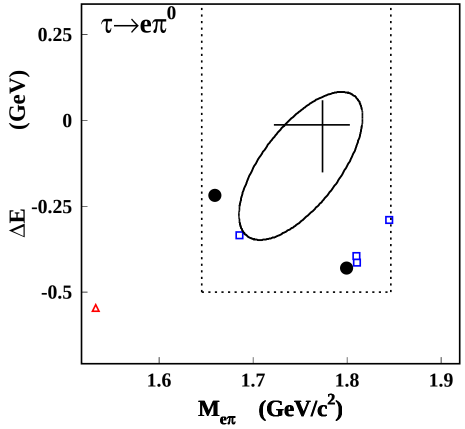
$\tau \to \ell\eta/\eta'/\pi^0$ (1)



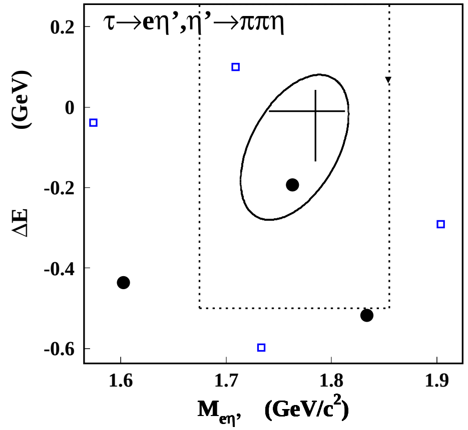
$\mathcal{B} < 4.0 \times 10^{-7}$



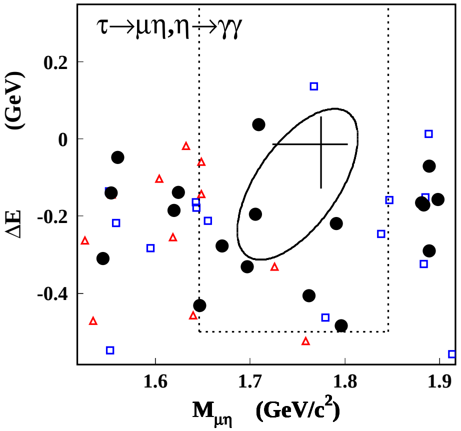
$\mathcal{B} < 5.8 \times 10^{-7}$



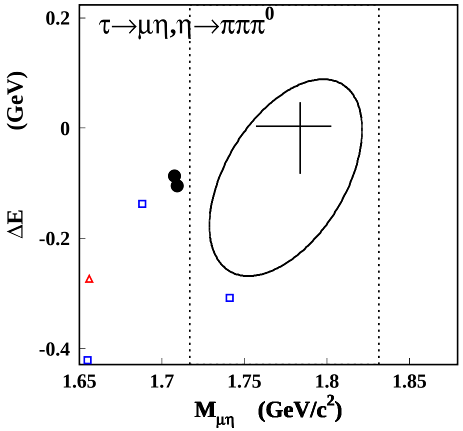
$\mathcal{B} < 1.9 \times 10^{-7}$



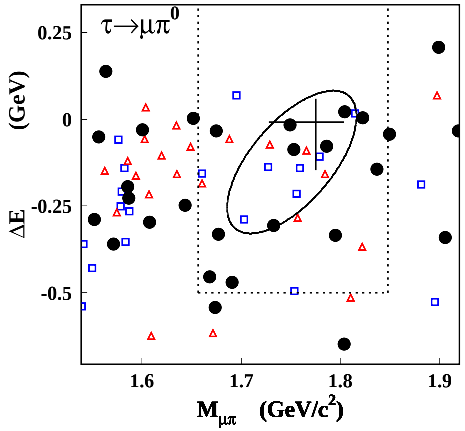
$\mathcal{B} < 10 \times 10^{-7}$



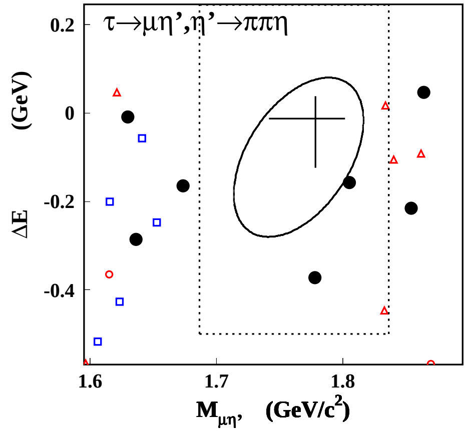
$\mathcal{B} < 4.0 \times 10^{-7}$



$\mathcal{B} < 5.8 \times 10^{-7}$



$\mathcal{B} < 1.9 \times 10^{-7}$



$\mathcal{B} < 10 \times 10^{-7}$

Combined $\mathcal{B}(\tau \to e\eta) < 2.3 \times 10^{-7}$

Combined $\mathcal{B}(\tau \to \mu\eta) < 1.5 \times 10^{-7}$

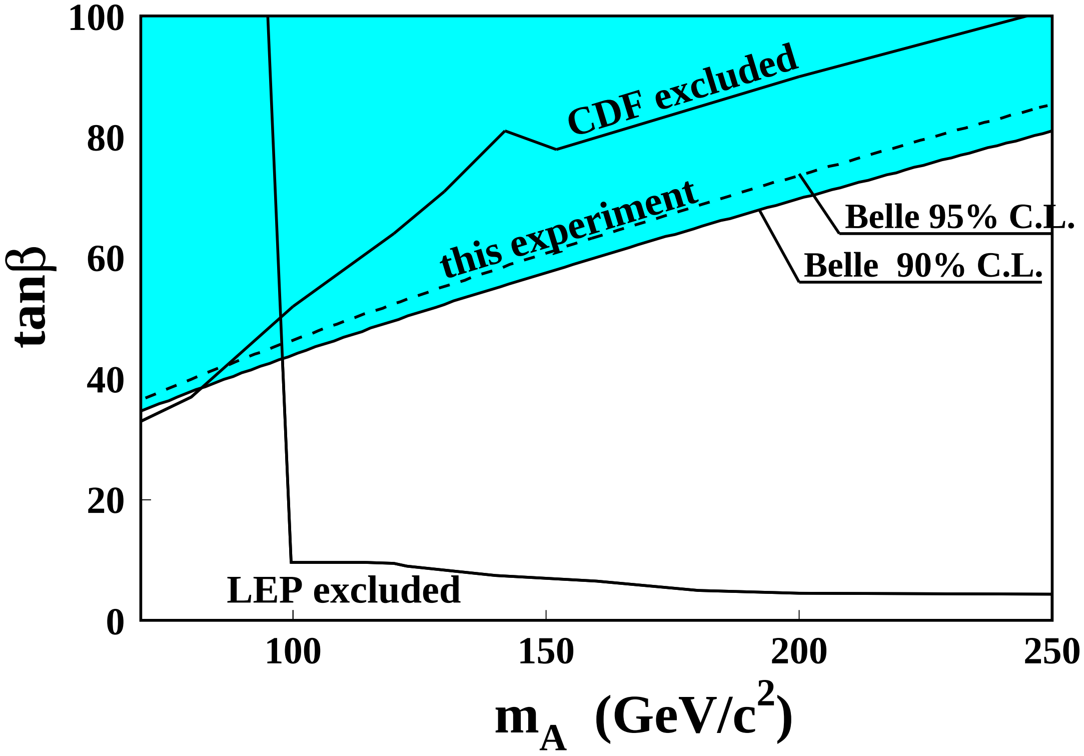
Dataset for this analysis @ 154 fb^{-1}

(PLB 622, 218 (2005)) ● data, △ $\tau\tau$, □ uds

$\tau \to \ell\eta/\eta'/\pi^0$ (2)

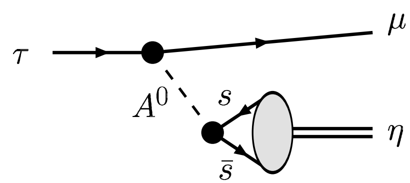
In MSSM at large $\tan\beta$, $\tau \to \ell\eta$ mode has a large braching ratio by Higgs mediated process

Constraint on $\tan\beta$ and M_A



$$\mathcal{B}(\tau \to \mu\eta) =$$
$$8.4 \times 10^{-7} \left(\frac{\tan\beta}{60}\right)^6 \left(\frac{100\mathrm{GeV}/c^2}{m_A}\right)^4$$

(M. Sher, PRD 66, 057301 (2002))



Comparison with $\mu\mu^+\mu^-$ and $\mu\eta'$

— enhanced as $(m_s/m_\mu)^2$

— color ($\times$ 3)

— larger phase space than η' and 3-body decay

(CDF results: $p\bar{p} \to h/H/Ab\bar{b} \to b\bar{b}b\bar{b}$ from RUN I (PRL 86, 4472 (2002))

(LEP results: LEP Higgs Working Group)

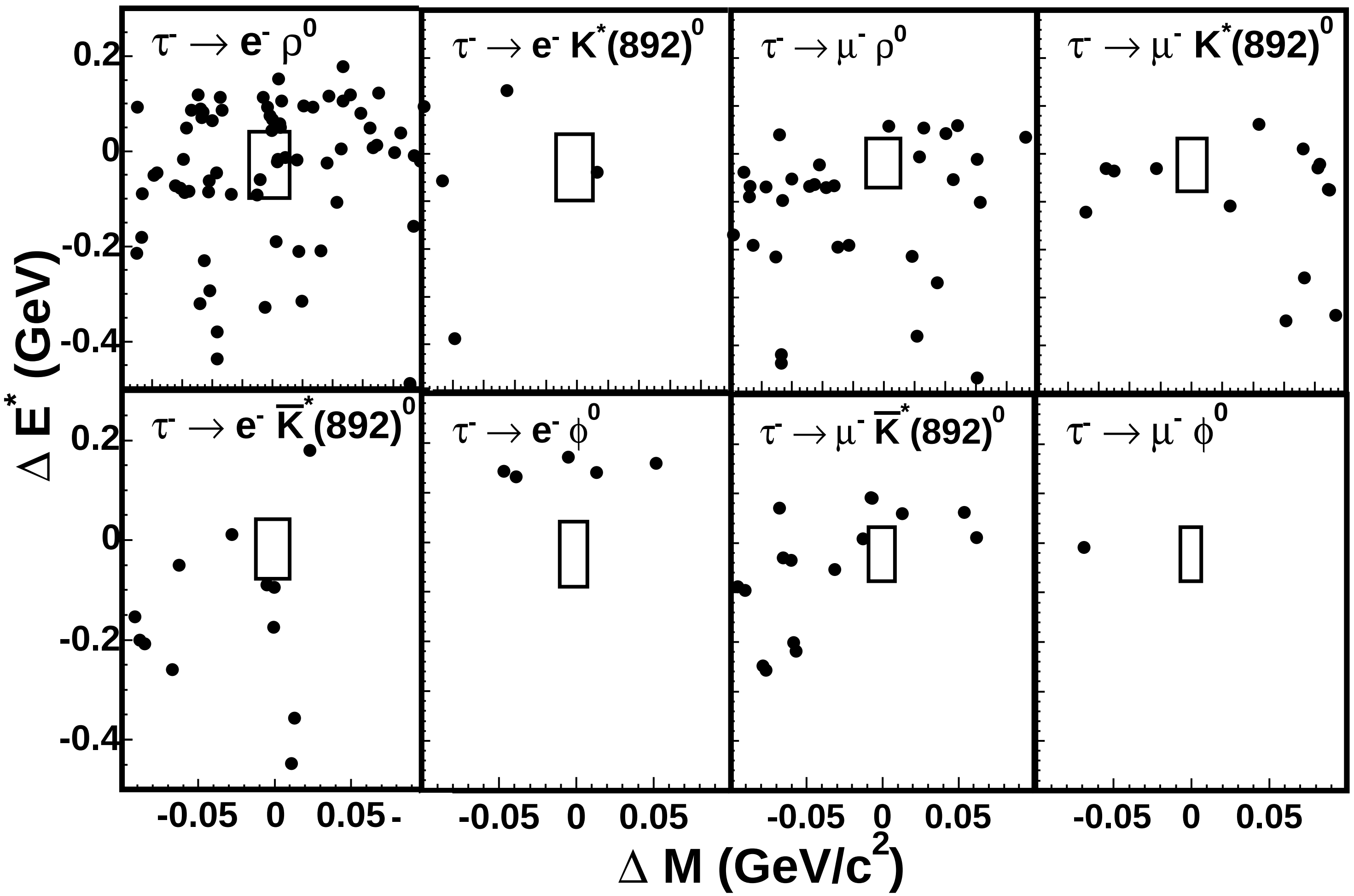
$\tau \to \ell V^0$

Dataset for this analysis @ 158 fb^{-1}

LFV decay into lepton and vector meson

$\mathcal{B} < (2.0\sim7.7)\times10^{-7}$

(Preliminary)



Background

for $\tau \to \mu V^0$

— $\tau\tau$ and uds

for $\tau \to e V^0$

— $\tau\tau$ and 2photon

($eeuu$, $eess$ etc.)

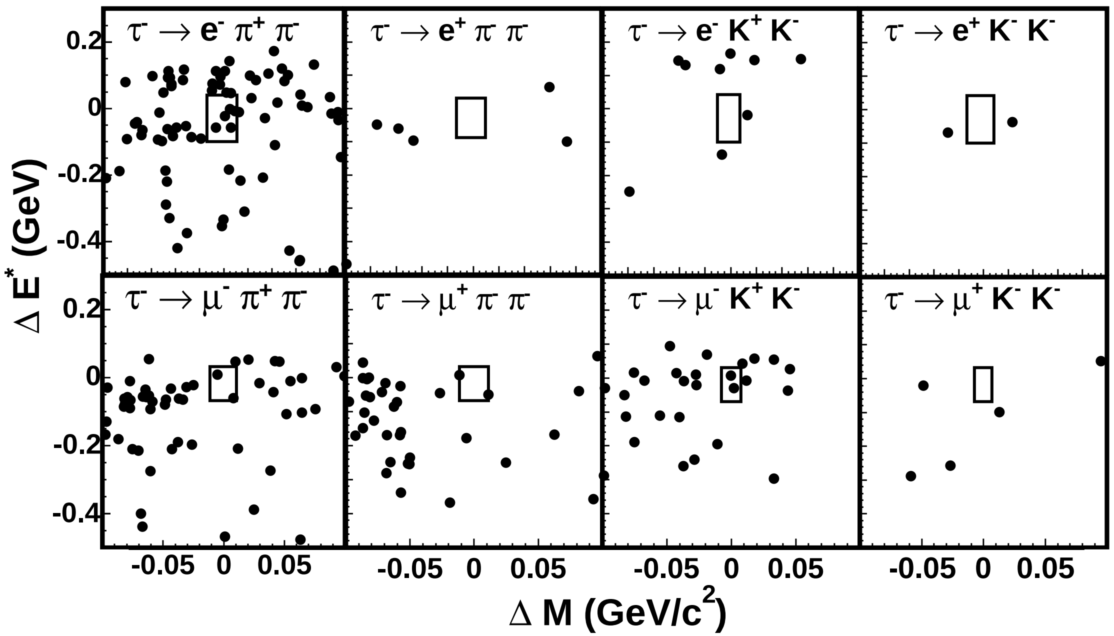
$\tau \to \ell h h'$

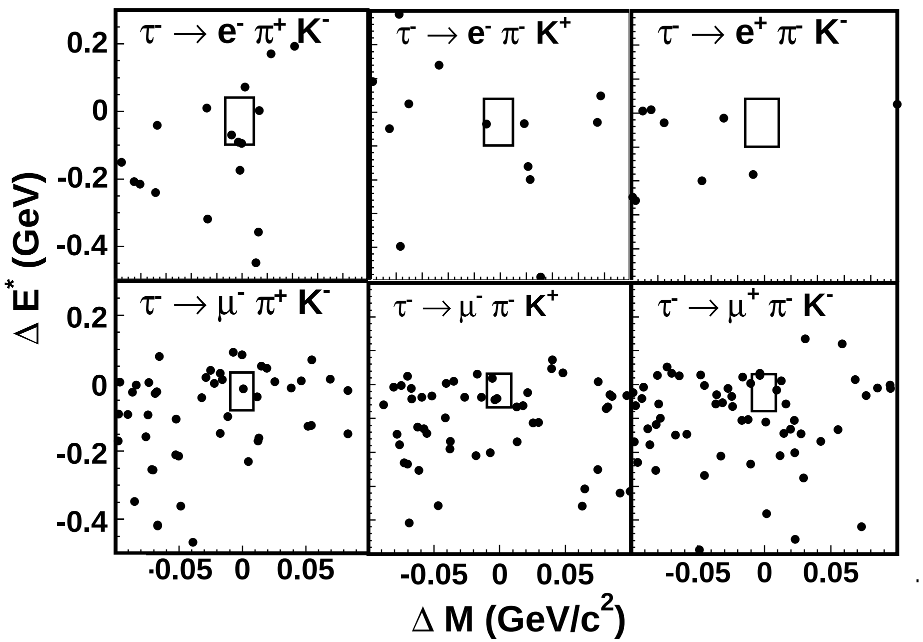
LFV decay into lepton and 2 meson ($h, h' = K^{\pm}$ or $\pi^{\pm}$)

(Including lepton number violation, e.g. $\tau^- \to \ell^+ h^- h'^-$)

$\mathcal{B} < (1.8 \sim 8.0) \times 10^{-7}$ (Preliminary)

Dataset for this analysis @ 158 fb^{-1}



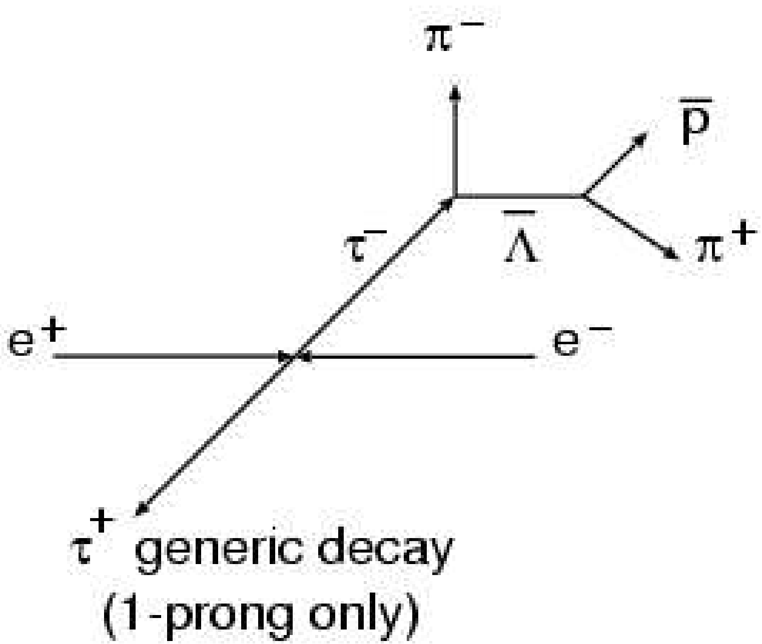


Background

$\tau\tau$, uds and 2photon

$\tau \longrightarrow \bar{\Lambda}\pi$ and $\Lambda\pi$ (1)

Search for τ decay with Lepton and Baryon number violation process
($\tau \longrightarrow \Lambda\pi, pK_S$, $p\gamma$, $p\pi^0$ and so on)
$\Rightarrow$ Important for cosmology (Baryon Asymmetry Universe)
$\Rightarrow$ Sensitive to new physics (SUSY etc.)



We consider two types from $\tau \longrightarrow \Lambda\pi$ decay

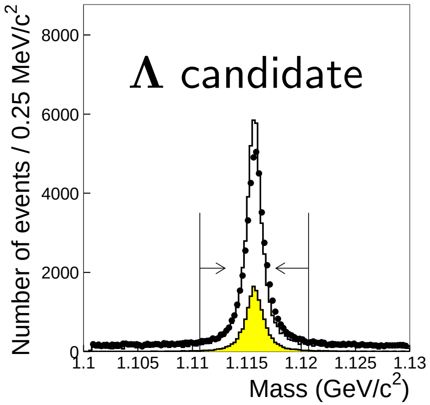
- $B - L$ conserving mode
$\Rightarrow \tau^- \longrightarrow \bar{\Lambda}\pi^-$ ($\bar{\Lambda} \longrightarrow \bar{p}\pi^+$)
- $B - L$ violating mode
$\Rightarrow \tau^- \longrightarrow \Lambda\pi^-$ ($\Lambda \longrightarrow p\pi^-$)

We can distinguish between these two modes using a charge between two pions

- $B - L$ conserving mode
$\Rightarrow$ Opposite charge
- $B - L$ violating mode
$\Rightarrow$ Same charge

$\tau \to \bar{\Lambda}\pi$ and $\Lambda\pi$ (2)

Dataset for this analysis @ 154 fb^{-1}

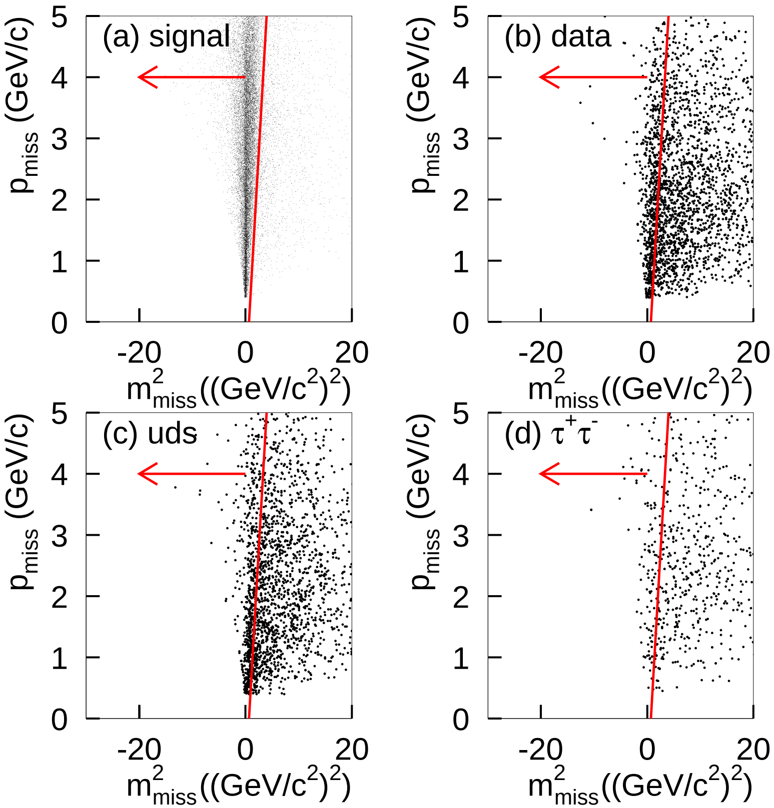


Event selection

- Λ selection using vertex informations and proton ID
- $p_{\rm miss} > 0.4$ GeV/c within the fiducial volume
- $10.5 > E^{CM}_{total} > 5.29$GeV
- $\cos\theta^{CM}_{tag-mis} > 0.0$
- Kaon and Proton veto against tag-side and π from $\tau \to \Lambda''\pi''$
- # of γ in signal side ≤ 1
- # of γ in tag side ≤ 2
- m^2_{miss} vs. p_{miss} cut

$\Rightarrow$ See plot on the right

Require $p^{lab}_{miss} > 1.5 m^2_{miss} - 1$



$\tau \to \bar{\Lambda}\pi$ and $\Lambda\pi$ (3)

After events selections

$\varepsilon = 11.8\%$ for both modes

Background:

uds: including real Λ

$\tau\tau$: fake Λ from 3-prongs decay

In signal region

— Expected background

1.7 ± 0.8 events in both modes

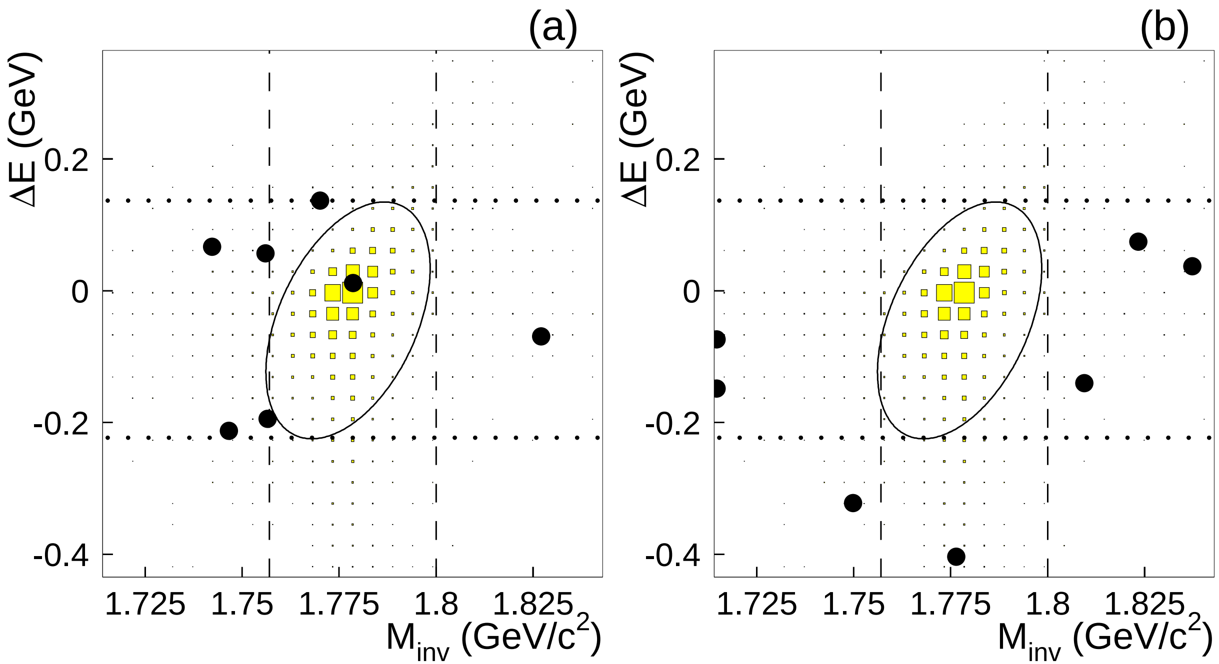
— Data

1 event for $B - L$ conserving mode

0 events for $B - L$ violating mode

$\Downarrow$

Set upper limits on branching fraction at 90% C.L.



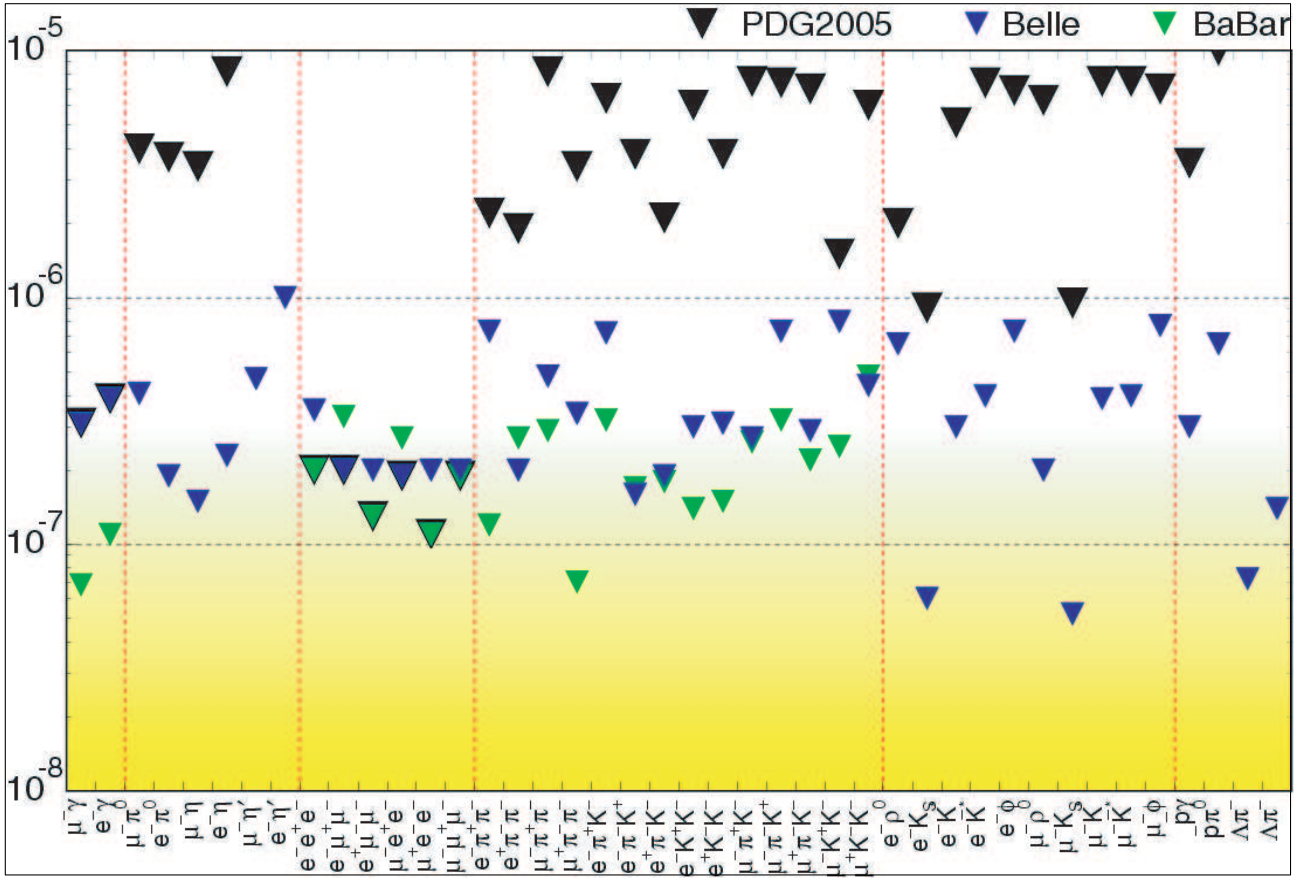
$\mathcal{B}(\tau \to \bar{\Lambda}\pi^-)) < 1.4 \times 10^{-7}$ ($B - L$ conserving)

$\mathcal{B}(\tau \to \Lambda\pi^-) < 7.2 \times 10^{-8}$ ($B - L$ violating)

(PLB 632, 51 (2006))

These results are the first searches ever performed.

Summary for LFV τ decay



We have searched for various LFV τ decay mode at Belle.

$\mathcal{B} < \mathrm{O}(10^{-5}\text{–}10^{-6})$ in PDG by CLEO $\Rightarrow$ $\mathcal{B} < \mathrm{O}(10^{-7}\text{–}10^{-8})$ by Belle

Updating LFV τ decay using full luminosity and get more stringent upper limits

Summary

We have searched for a lepton flavor violating τ decay at Belle.

No observation and sensitivity to lepton flavor violating τ decay branching fraction is approaching $\mathbf{10^{-7} \sim 10^{-8}}$ at Belle

$\Rightarrow$ Improvement of 1−2 orders over CLEO

$\Rightarrow$ Reached the level of some new physics

$\Rightarrow$ Provide constraints on the new physics models

We have just updated a search for LFV τ decays

$\Rightarrow$ Will show new results on this summer

B-factory is a good τ factory!

Thus, in additional to new physics search in B decay, we provide sensitivities to new physics via lepton flavor violation (and precision measurements also) in τ decay

Super B−factory (5∼10/ab)