Search for lepton flavour violating tau decay and lepton-number violation B decay at Belle

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(on behalf of the Belle Collaboration)

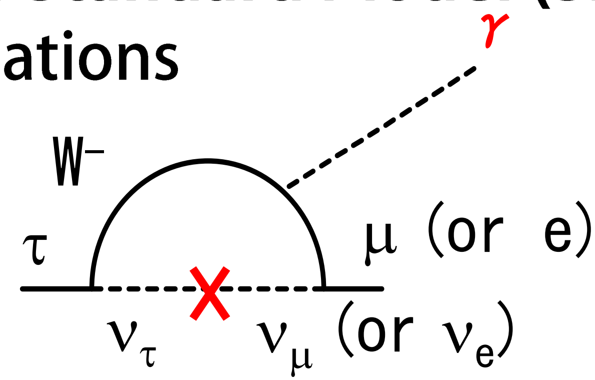
Introduction

Lepton flavor violation (LFV) in charged leptons

⇒ **negligibly small probability in the Standard Model (SM)**
even taking into account neutrino oscillations

$$Br(\tau \to \ell\gamma)_{SM} \propto \left(\frac{\delta m_\nu^2}{m_W^2}\right)^2 < 10^{-54}$$

(EPJC8 513 (1999))



Observation of LFV is a clear signature of New Physics (NP)

- Many extensions of the SM predict LFV decays.

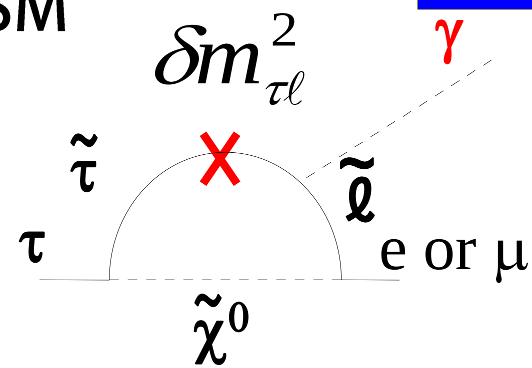
→These branching fractions could be enhanced as high as current experimental sensitivity.

Tau lepton :
- The heaviest charged lepton
- Many possible LFV decay modes

⇒Ideal place to search for LFV

LFV in SUSY

SUSY is the most popular candidate for BSM among new physics models

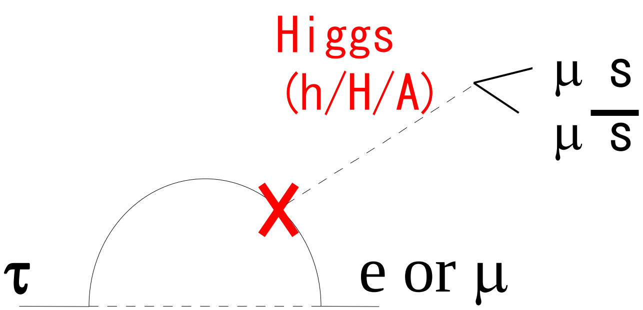


naturally induce LFV at one-loop due to slepton mixing

$\tau \to \ell\gamma$ mode has the largest branching fraction in SUSY-Seesaw (or SUSY-GUT) models

When sleptons are much heavier than weak scale

LFV associated with a neutral Higgs boson (h/H/A)



Higgs coupling is proportional to mass

$\Rightarrow \mu\mu$ or $s\bar{s}$ (η, η' and so on) are favored and Br is enhanced more than that of $\tau \to \mu\gamma$.

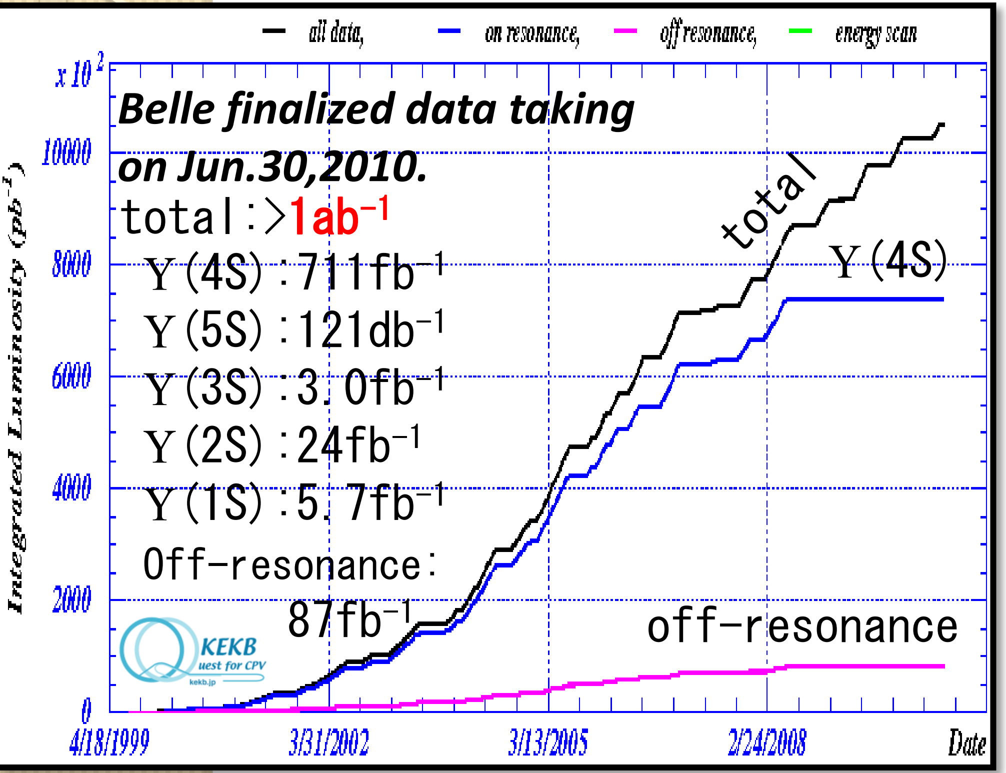
To distinguish which model is favored, various searches for τ LFV are important!

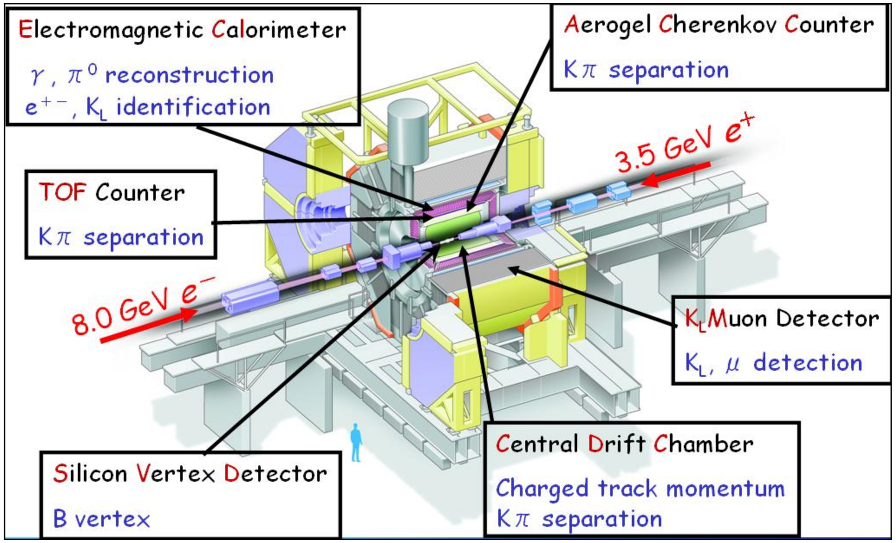
update $\tau \to \ell M^0$ ($M^0 = \pi^0, \eta, \eta'$, ρ^0, K^{*0}, $\bar{K}^{*0}$, ω, ϕ)

KEKB/Belle

B-factory: E at CM = Υ(4S)

e^+(3.5 GeV) e^-(8 GeV)





Good track reconstruction and particle identification

Lepton ID ~ (80-90)%

Fake ID ~ (0.1-3)%

$\sigma(\tau\tau)$~0.9nb, $\sigma(b\bar{b})$~1.1nb

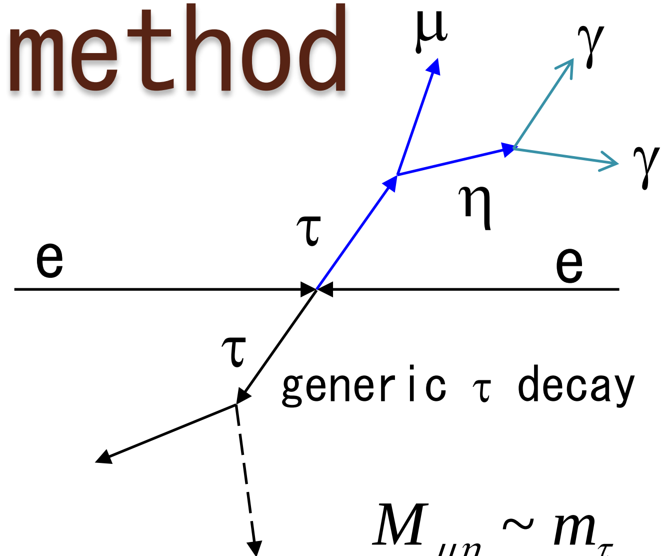
A B-factory is also a τ-factory!

World-largest data sample!

~9x10^8 ττ at Belle

Analysis method

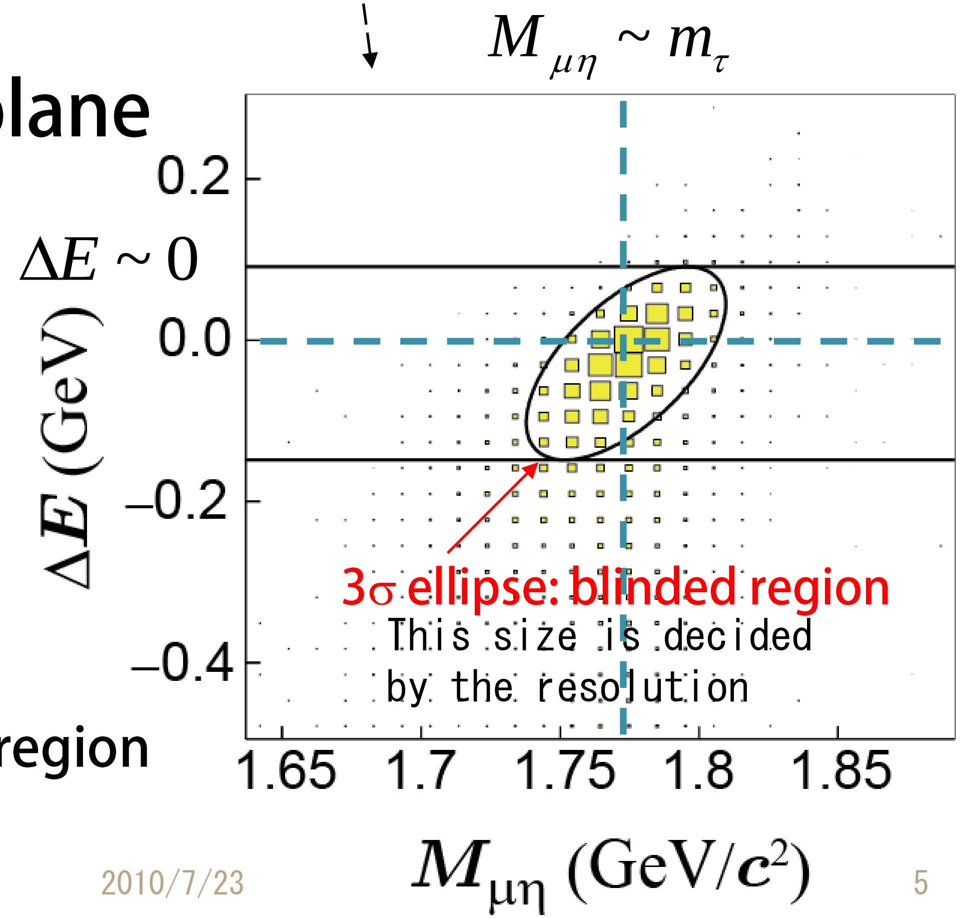
- $e^+e^- \rightarrow \tau^+\tau^-$
  - $\tau^+ \rightarrow$ 1 prong + missing (tag side)
  - $\tau^- \rightarrow \mu + \eta$ (signal side)
    - $\eta \rightarrow \gamma + \gamma$



Signal extraction: $M_{\mu\eta}$-ΔE plane

$$M_{\mu\eta} = \sqrt{(E_{\mu\eta}^2 - p_{\mu\eta}^2)}$$

$$\Delta E = E_{\mu\eta}^{CM} - E_{beam}^{CM}$$

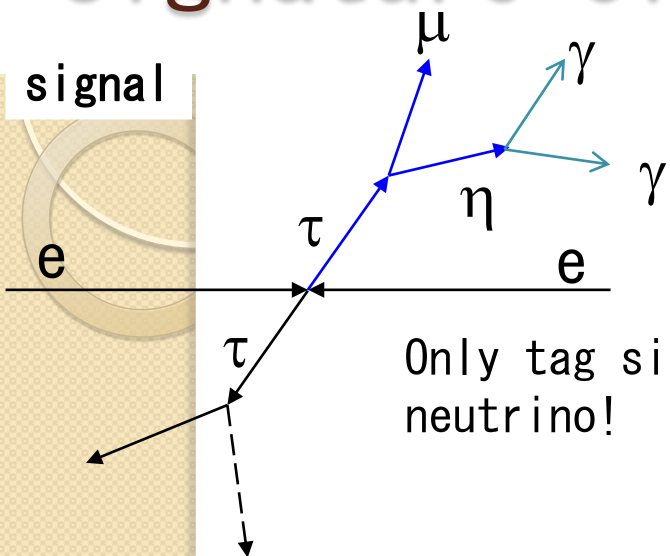


Blind analysis
⇒Blind signal region

Estimate number of BG in the singal region using sideband data and MC

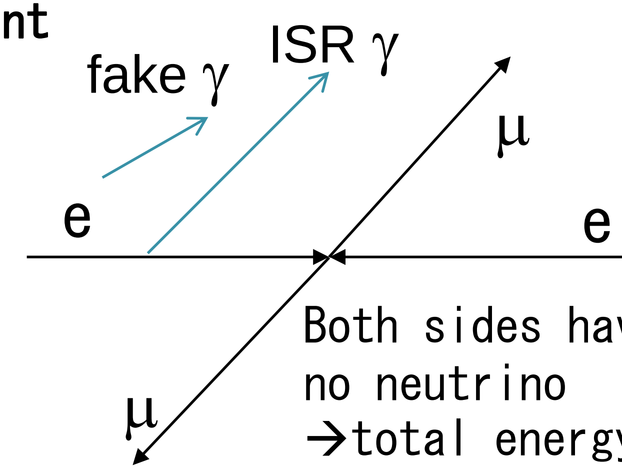
Signature of signal and background

signal



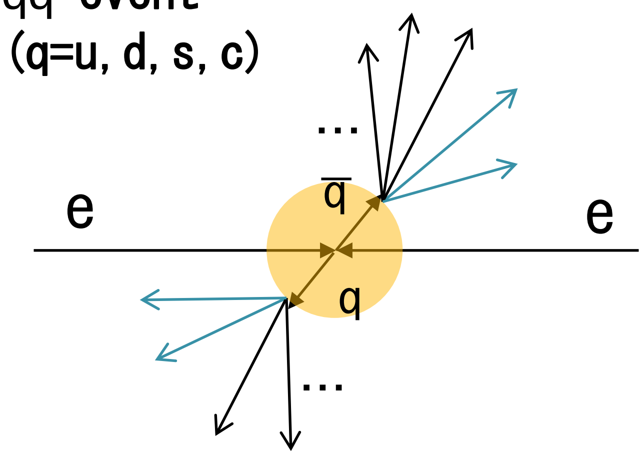
Only tag side has
neutrino!

μμ event



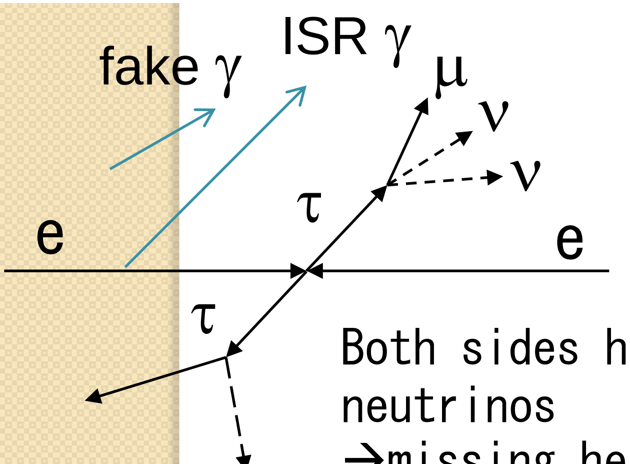
Both sides have
no neutrino
→total energy is
equal to beam energy.

$q\bar{q}$ event
(q=u, d, s, c)



Both sides have
many tracks and photons.
→No. of photons
decreases this kind of BG's.

SM ττ event



Both sides have
neutrinos
→missing helps us
to reject this kind of BG's.

Search for $\tau \to \ell P^0 (=\pi^0, \eta, \eta')$

BELLE

previous result

Data : 401 fb^{-1} @ Belle,   339 fb^{-1}@BaBar

(PLB648,341(2007)) (PRL98,061803(2007))

•To obtain high detection efficiency,

$\eta(\eta')$ is reconstructed from $\gamma\gamma(\rho^0\gamma)$ as well as $\pi\pi\pi^0(\pi\pi\eta)$.

$\mathcal{B}<(0.8\text{-}2.4)\times10^{-7}$ at 90%CL

•**New search with 901fb^{-1} data sample**

- To obtain better resolution, $\eta(\eta')$-momentum is evaluated by $\eta(\eta')$-mass-constrained fit.
- Differently from the previous analysis, selection criteria are set mode by mode.

ex.)　previous　→　new

commonly required $P_\ell^{CM}<4.5GeV/c$ → $P_\mu^{CM}/\sqrt{s}<0.38$ for $\tau\to\mu\eta$

$P_e^{CM}/\sqrt{s}<0.38$ for $\tau\to e\eta$

$0.15<P_\mu^{CM}/\sqrt{s}<0.38$ for $\tau\to\mu\pi^0$

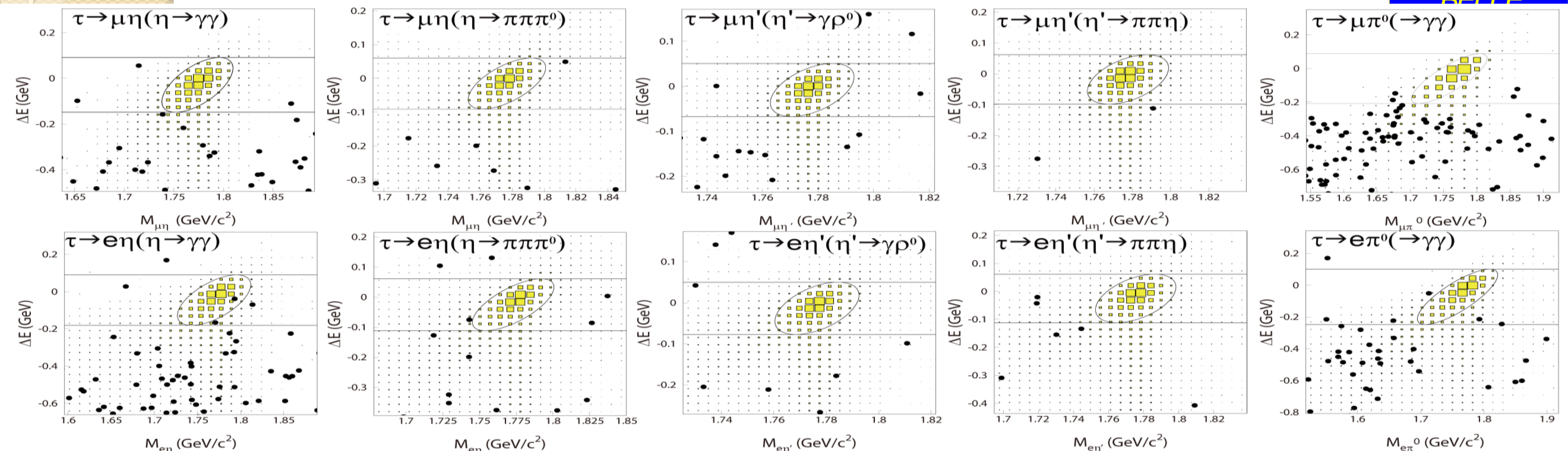
$P_e^{CM}/\sqrt{s}<0.38$ for $\tau\to e\pi^0$

- For $\tau\to\mu\eta$, Neural network (NN) selection is also introduced.

Finally, the efficiency is higher than previous (around 1.5x in average), while <1 background level is achieved.

Result for $\tau \to \ell P^0 (=\pi^0, \eta, \eta')$

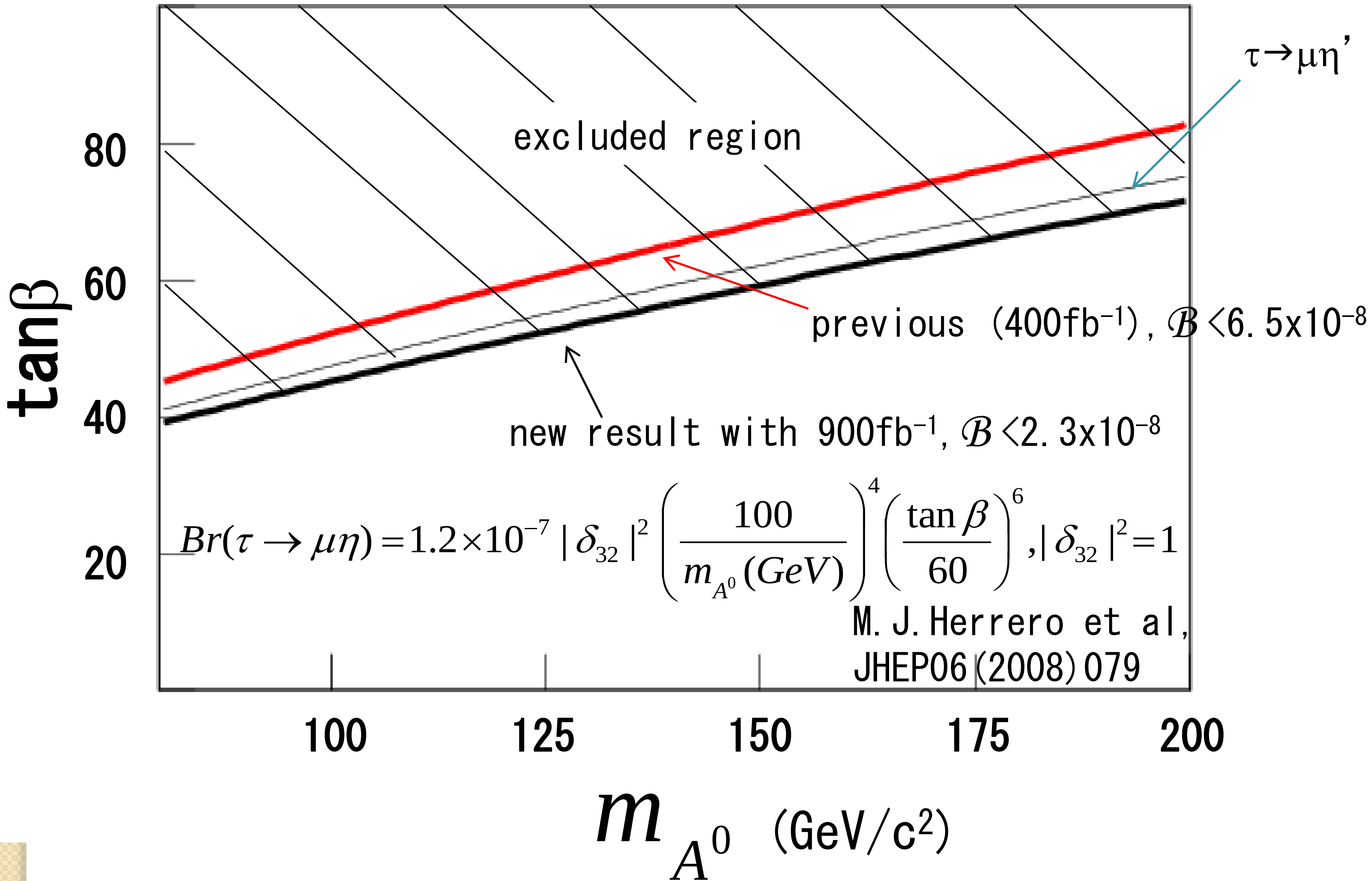
Belle preliminary



$\tau\to$	Eff.	N_{BG}^{exp}	UL ($\times10^{-8}$)	$\tau\to$	Eff.	N_{BG}^{exp}	UL ($\times10^{-8}$)
$\mu\eta(\to\gamma\gamma)$	8.2%	0.63±0.37	3.6	$\mu\eta'(\to\pi\pi\eta)$	8.1%	0.00+0.16−0.00	10.0
$\mu\eta(\to\pi\pi\pi^0)$	6.9%	0.23±0.23	8.6	$\mu\eta'(\to\rho^0\gamma)$	6.2%	0.59±0.41	6.6
$\mu\eta$(comb.)			2.3	$\mu\eta'$(comb.)			3.8
$e\eta(\to\gamma\gamma)$	7.0%	0.66±0.38	8.2	$e\eta'(\to\pi\pi\eta)$	7.3%	0.63±0.45	9.4
$e\eta(\to\pi\pi\pi^0)$	6.3%	0.69±0.40	8.1	$e\eta'(\to\rho^0\gamma)$	7.5%	0.29±0.29	6.8
$e\eta$(comb.)			4.4	$e\eta'$(comb.)			3.6
$\mu\pi^0(\to\gamma\gamma)$	4.2%	0.64±0.32	2.7	$e\pi^0(\to\gamma\gamma)$	4.7%	0.89±0.40	2.2

→(2.1-4.4) times more stringent results than previous ($401 fb^{-1}$)

SUSY parameters from $\tau \to \mu\eta$



$$Br(\tau \to \mu\eta) = 1.2\times10^{-7}\,|\delta_{32}|^2 \left(\frac{100}{m_{A^0}(GeV)}\right)^4 \left(\frac{\tan\beta}{60}\right)^6, |\delta_{32}|^2 = 1$$

M. J. Herrero et al, JHEP06 (2008) 079

search for $\ell V^0(=\rho^0, K^{*0}, \overline{K^{*0}}, \omega, \phi)$

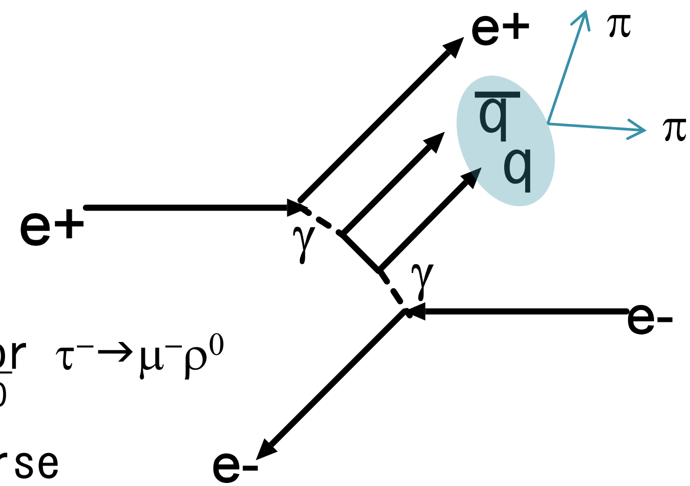
previous result

Data : 543 fb^{-1} @ Belle, 451 fb^{-1}@BaBar

(PLB664,35(2008)) (PRL100,071802(2008),PRL103,021801(2009))

•Differently from ℓP^0, 2photon process could be large backgrounds for ℓ=e.

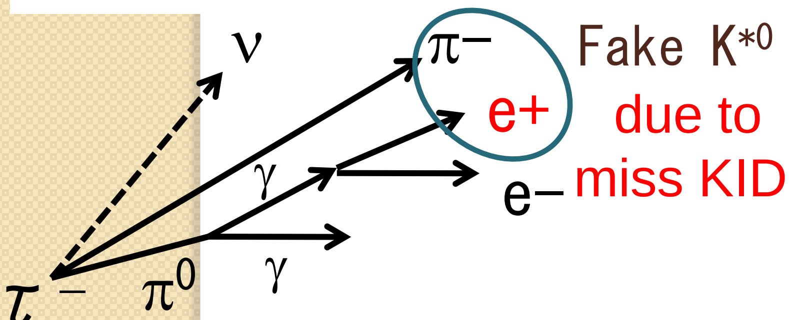
$\mathcal{B}<(0.3\text{-}1.9)\times10^{-7}$ at 90%CL

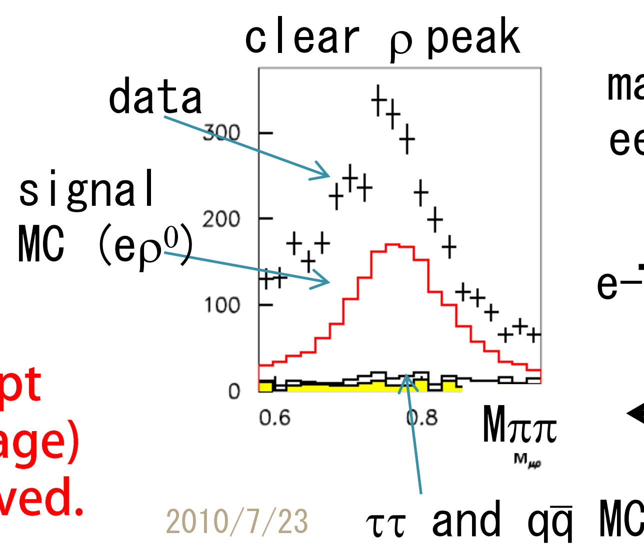


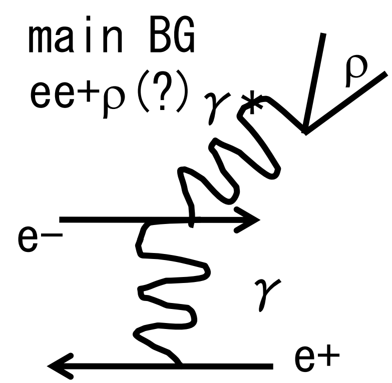
•New search with 854fb^{-1} data sample

•Detailed background study:

It turns out that not only 2photon process but also ee+X process become large background for $\tau^-\to\mu^-\rho^0$ and $\tau^-\to\pi^-\pi^0\nu$ with γ-conversion becomes e^-K^{*0}/K^{*0} backgrounds because e/h(=π, K) separation is worse in low momentum region.

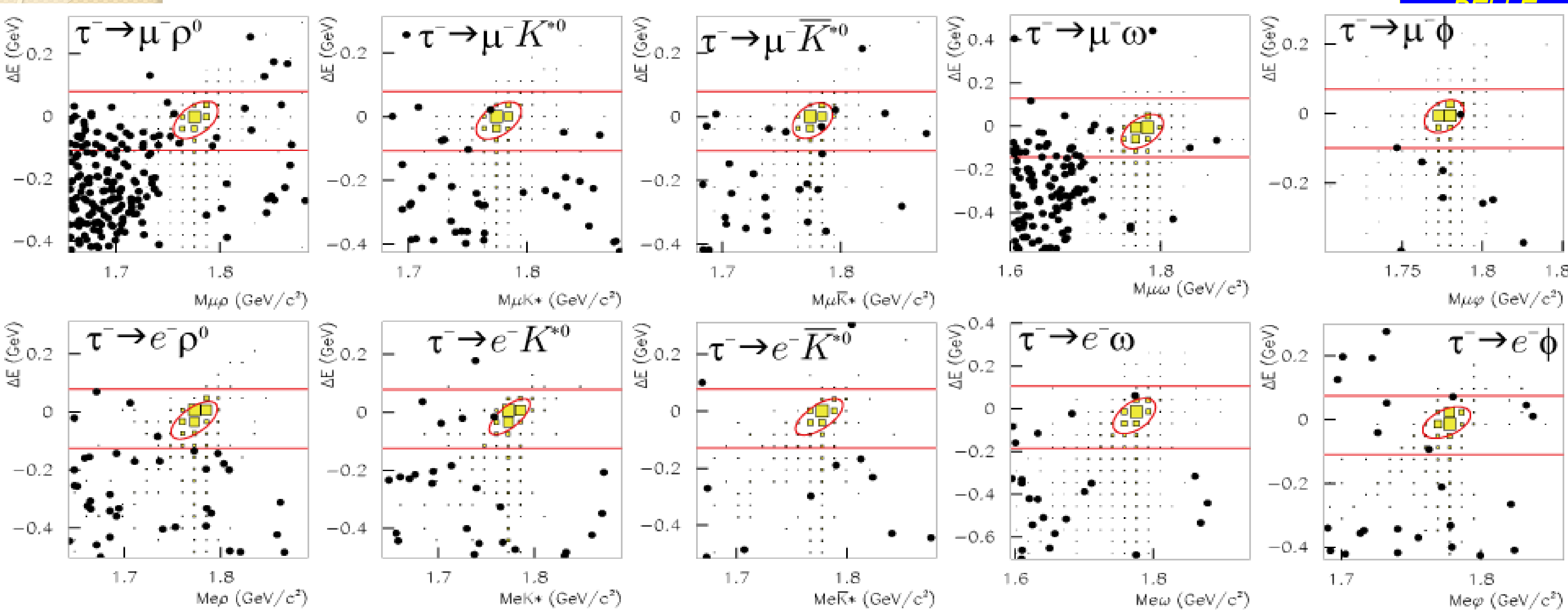






Finally, higher or similar efficiency is kept (around 1.2x in average) while similar background level is achieved.

Result for $\ell V^0 (=\rho^0, K^{*0}, K^{*0}, \omega, \phi)$

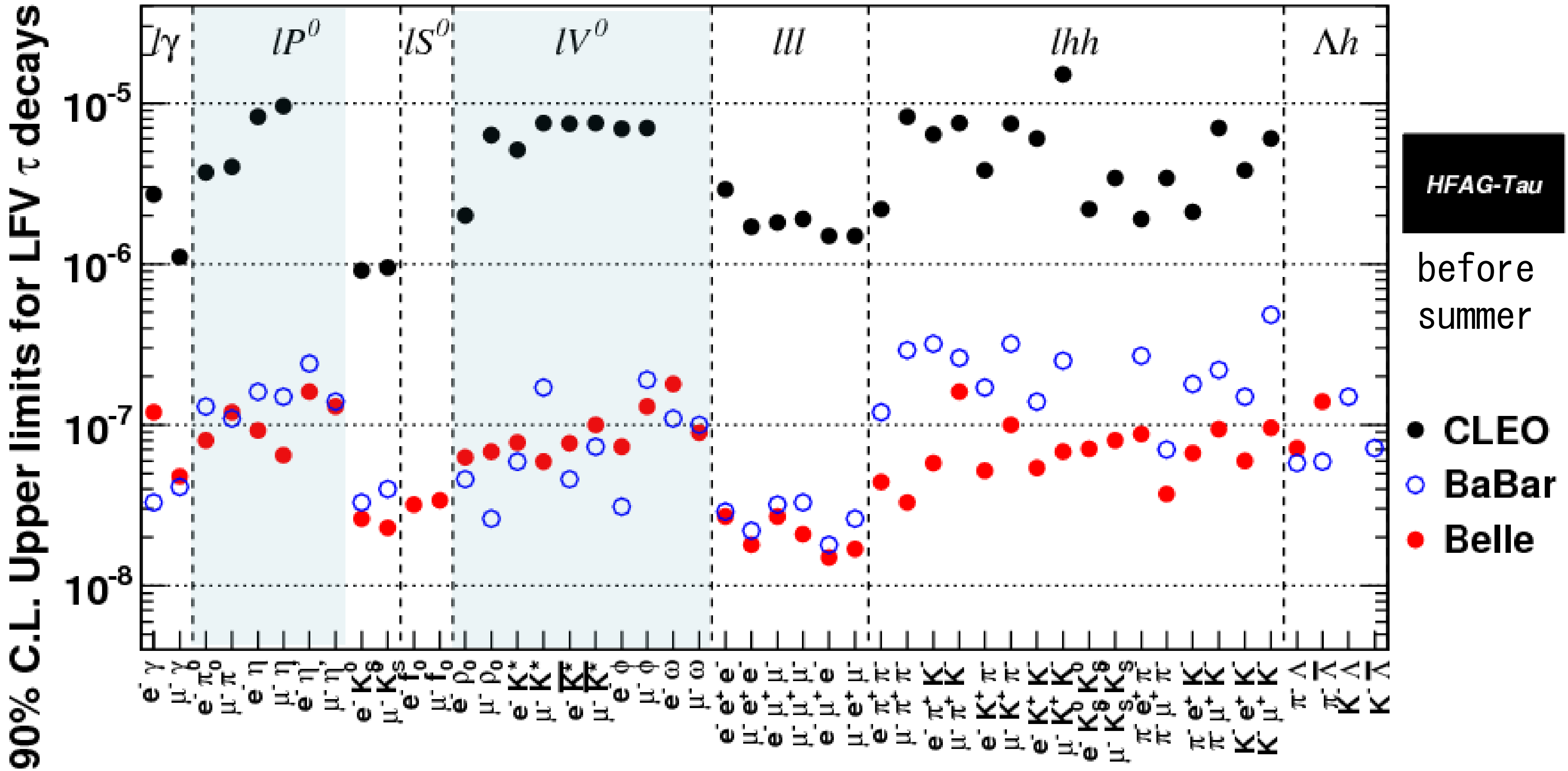


$\tau^- \rightarrow$	Eff.	N_{BG}^{exp}	UL $(\times 10^{-8})$	$\tau^- \rightarrow$	Eff.	N_{BG}^{exp}	UL $(\times 10^{-8})$
$e^- \rho^0$	7.6%	0.29±0.15	**1.8**	$e^- K^{*0}$	4.4%	0.39±0.14	**3.2**
$\mu^- \rho^0$	7.1%	1.48±0.35	**1.2**	$\mu^- K^{*0}$	3.4%	0.53±0.20	**7.2**
$e^- \phi$	4.2%	0.47±0.19	**3.1**	$e^- \overline{K^{*0}}$	4.4%	0.08±0.08	**3.4**
$\mu^- \phi$	3.2%	0.06±0.06	**8.4**	$\mu^- \overline{K^{*0}}$	3.6%	0.45±0.17	**7.0**
$e^- \omega$	2.9%	0.30±0.14	**4.8**	$\mu^- \omega$	2.4%	0.72±0.18	**4.7**

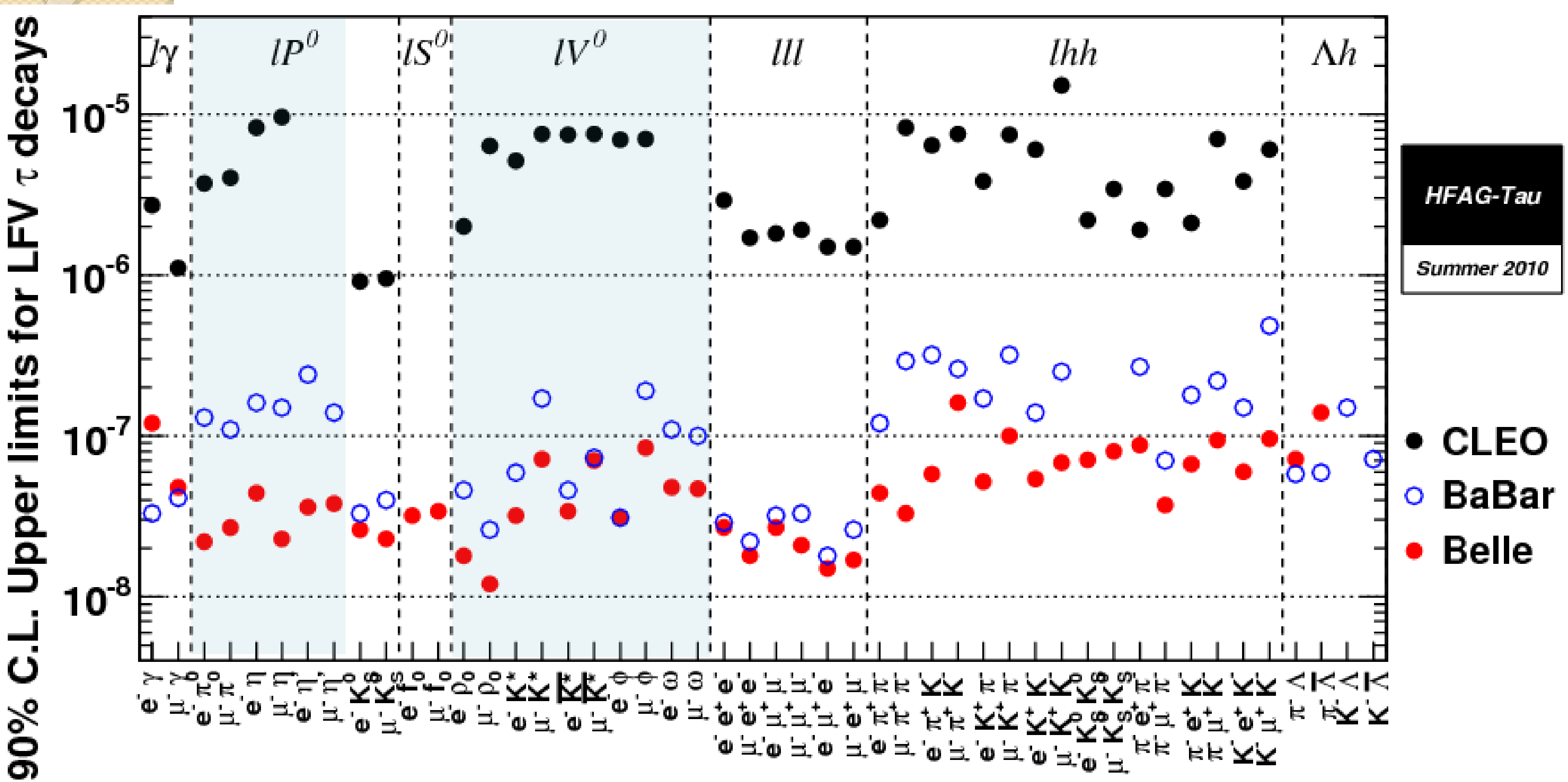
UL for $\tau \rightarrow \mu \rho^0$ is the most stringent among all the τ-LFV decays

Upper Limits on LFV τ Decay

Before this summer, …



New Upper Limits on LFV τ Decay



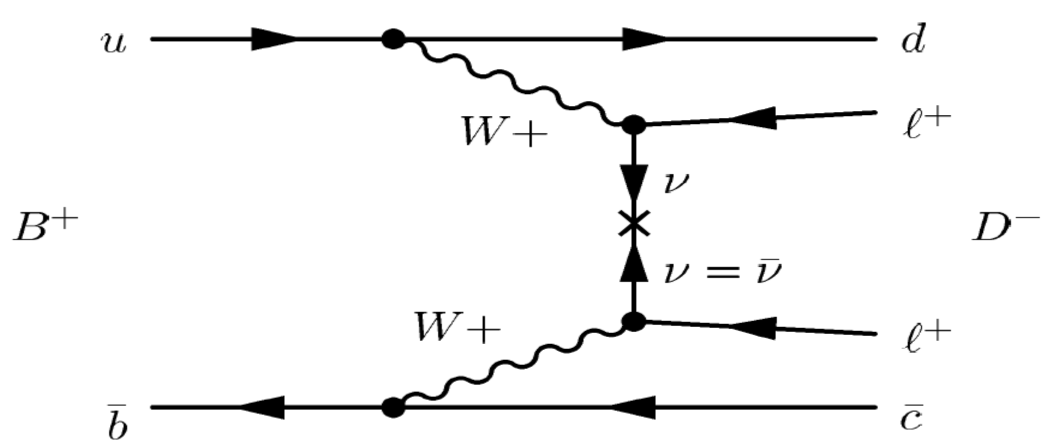
Our sensitivity reaches $O(10^{-8})$!

100x more sensitive than CLEO's

Search for $B^+ \to D^- \ell^+ \ell^+$

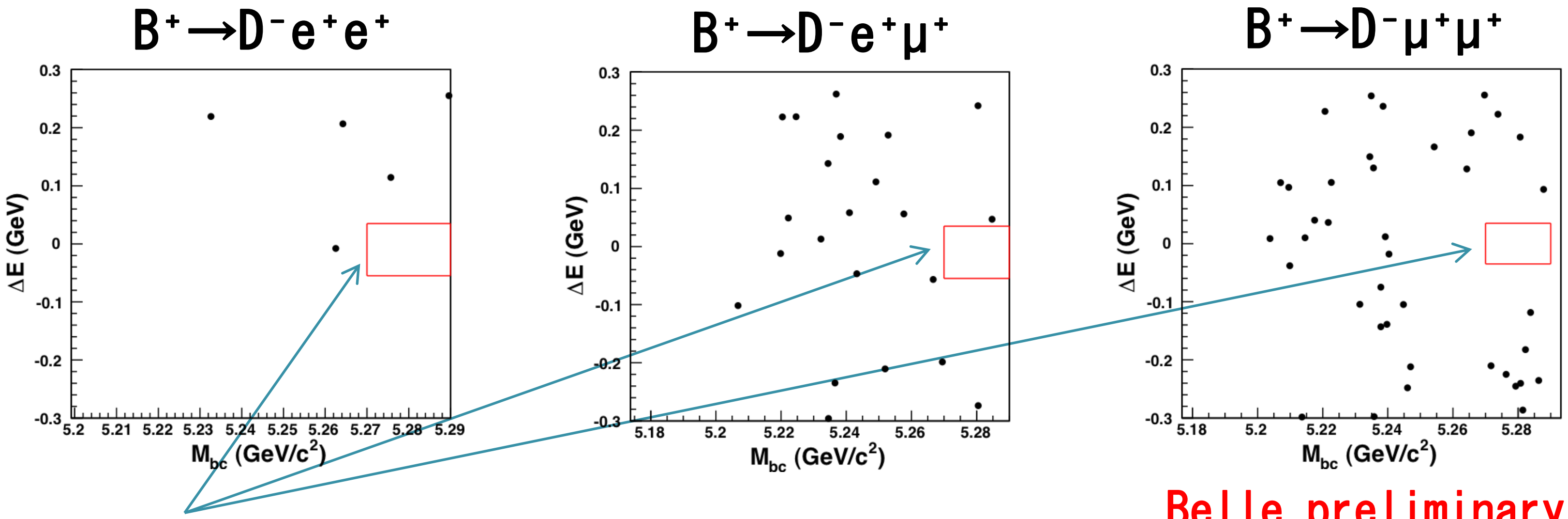
- Majorana ν allows a lepton number violating process, $B^+ \to h^- \ell^+ \ell^+$ ($h = \pi, K, \rho, K^*, D, \cdots$), while Dirac ν forbids it.
- Due to size of CKM matrix element, $B^+ \to D^- \ell^+ \ell^+$ will be the most sensitive.

Belle has been searched for $B^+ \to D^- \ell^+ \ell^+$ with 7.7×10^8 B^+B^- data sample.
$(\ell, \ell) = (e, e), (e, \mu), (\mu, \mu)$
This is a first search!



- Blind analysis
- Likelihood selection is introduced.
  - missing energy
  - z-helix distance between $\ell\ell$
  - $\cos\theta_B^*$
  - Modified FW moments
- Counting method (POLE)

Result for $B^+ \to D^- \ell^+ \ell^+$



Belle preliminary

Blinded region: no event is found after opening it

$B^+ \to$	Eff.	sys	N_{BG}^{exp}	UL ($\times 10^{-6}$)
$D^- e^+ e^+$	1.2%	8.6%	0.18±0.13	**2.7**
$D^- e^+ \mu^+$	1.3%	10.1%	0.83±0.29	**1.9**
$D^- \mu^+ \mu^+$	1.8%	8.8%	1.44±0.43	**1.1**

This first measurement would be nice guideline
for experiments(such as Belle2, LHC..) and theoretical activities.
We are planning to extend our analysis to other LV charmful B decay.

Summary

Lepton flavor violation is a good signature of NP.

We have updated search for τ LFV decays into $\ell+M^0(=\pi^0,\eta,\eta',\rho^0,K^{*0},\overline{K^{*0}},\omega,\phi)$ using the world-largest data sample obtained by KEKB/Belle

No LFV signals are observed yet and we set limits of branching faction around $O(10^{-8})$.

→Improve sensitivity by factor ~100 from CLEO

- UL for $\tau\to\mu\rho^0$ is the most stringent among all the τ-LFV decays
- not only much larger data samples but also more effective BG rejection after detailed examination of the BG

Lepton number violating B decay is a good signature of Majorana/Dirac neutrino discrimination.

First search for LV charmful B decay with 7.7×10^8 B^+B^- data sample

90%CL upper limits for the branching fraction is set as

$$\mathcal{B}(B^+\to D^-\ell^+\ell^+)<(2.7,1.9,1.1)\times10^{-6}\ @90\%CL$$

where $(\ell,\ell)=(e,e),(e,\mu),(\mu,\mu)$. Belle preliminary

Belle is starting the analyses for the various modes using its full data sample!($>1ab^{-1}$)

Theoretical prediction for $B^+ \to D^- \ell^+ \ell^+$

A. The case of light neutrinos ($m_N < m_\pi$)

$$Br(B^+ \to D^- \ell^+ \ell^+) \sim 1.2 \times 10^{-31} \left(\frac{U_{N\ell}^2 m_N}{1 \text{ eV}} \right)^2$$

C. The case of heavy neutrinos ($m_N > m_{B_c}$)

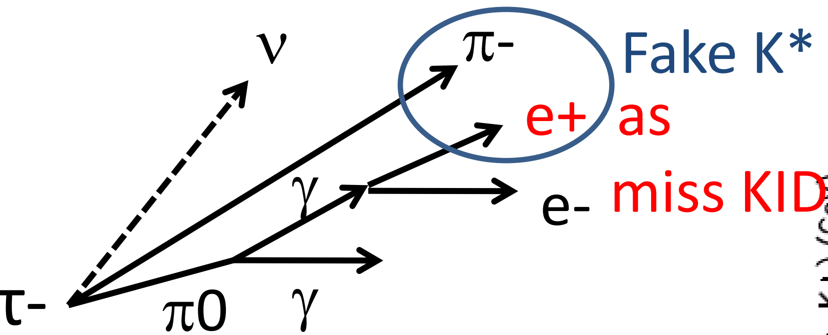
$$\text{Br}(B^+ \to D^- \ell^+ \ell^+) \approx 1.1 \cdot 10^{-22} \times \left(\frac{100 \text{ GeV}}{m_N} \right)^2 \left(\frac{|U_{N\ell}|^2}{10^{-2}} \right)^2 .$$

Probing Majorana neutrinos in rare K and D, ~D_s, B, B_c meson decays.
G. Cvetic, Claudio Dib, (Santa Maria U., Valparaiso) , Sin Kyu Kang, (Seoul, Nat. U. Technol.) , C.S. Kim, (Yonsei U. & IPAP, Seoul) . May 2010. 26pp.
e-Print: **arXiv:1005.4282** [hep-ph]

eK*, e$\overline{K}$*, eρ modes

Other BG for eK*, e$\overline{K}$* and eρ
⇒ Event with γ-conversion

For example, eK*mode
τ-→π-π0ν
with γ conversion from π0

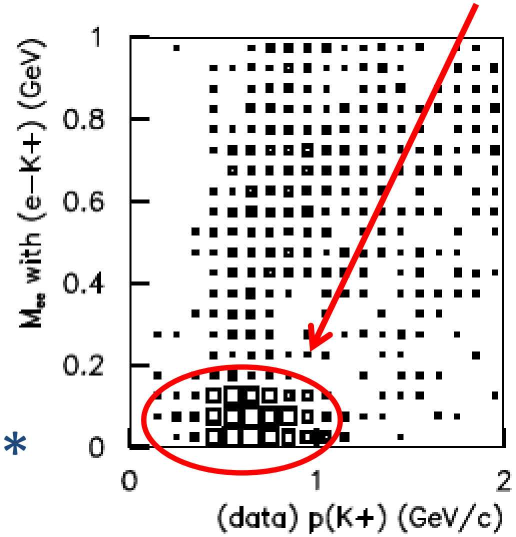


To reduce events

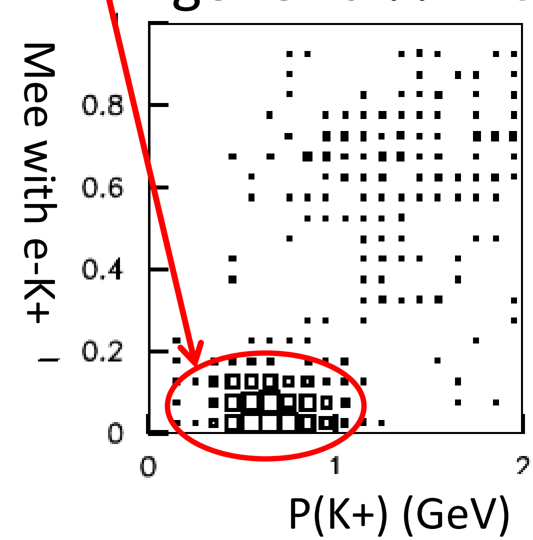
- Mee using eK > 0.2 GeV
- Mee from V0 daughter > 0.2 GeV

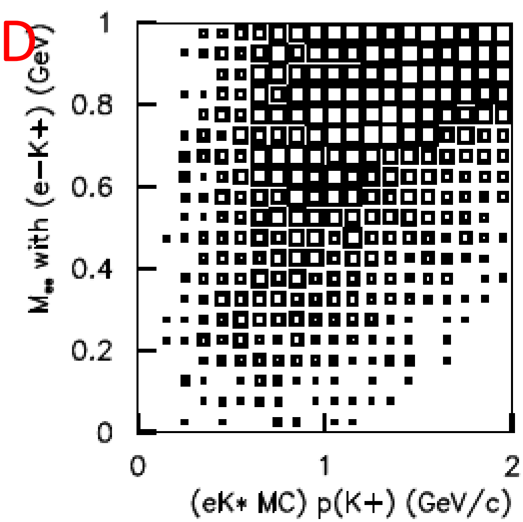
data

γ-conversion

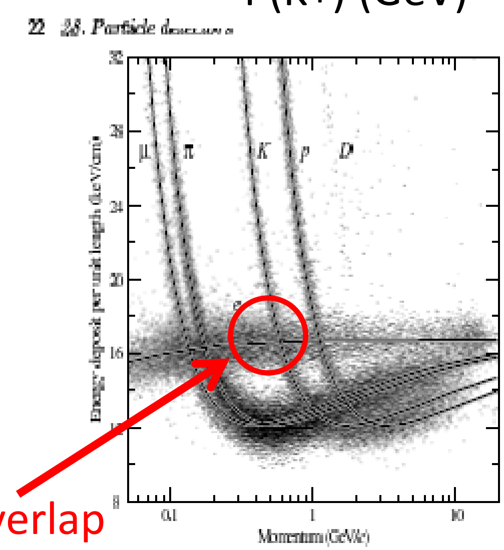


generic ττ MC





eK* MC



overlap dE/dx region between e and K