Tau physics at Belle

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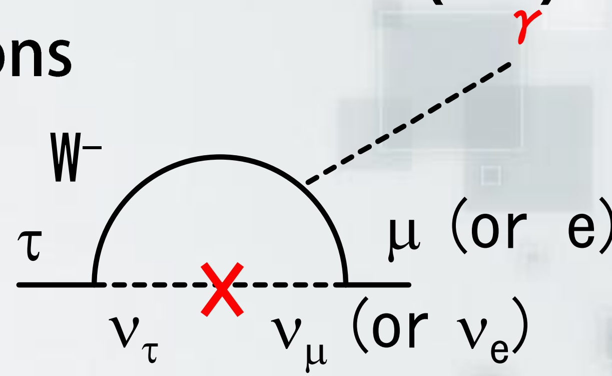
Introduction

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)

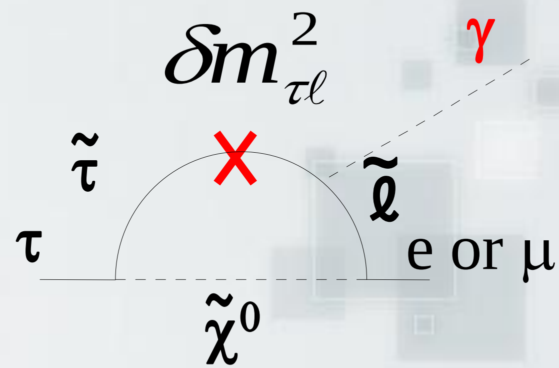
•Many extensions of the SM predict LFV decays.
→These branching fractions could be enhanced as high as current experimental sensitivity.

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

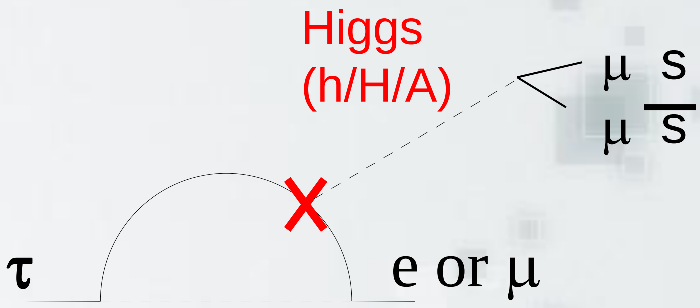


naturally induce LFV at one-loop due to slepton mixing

$\tau \to \ell\gamma$ 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

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

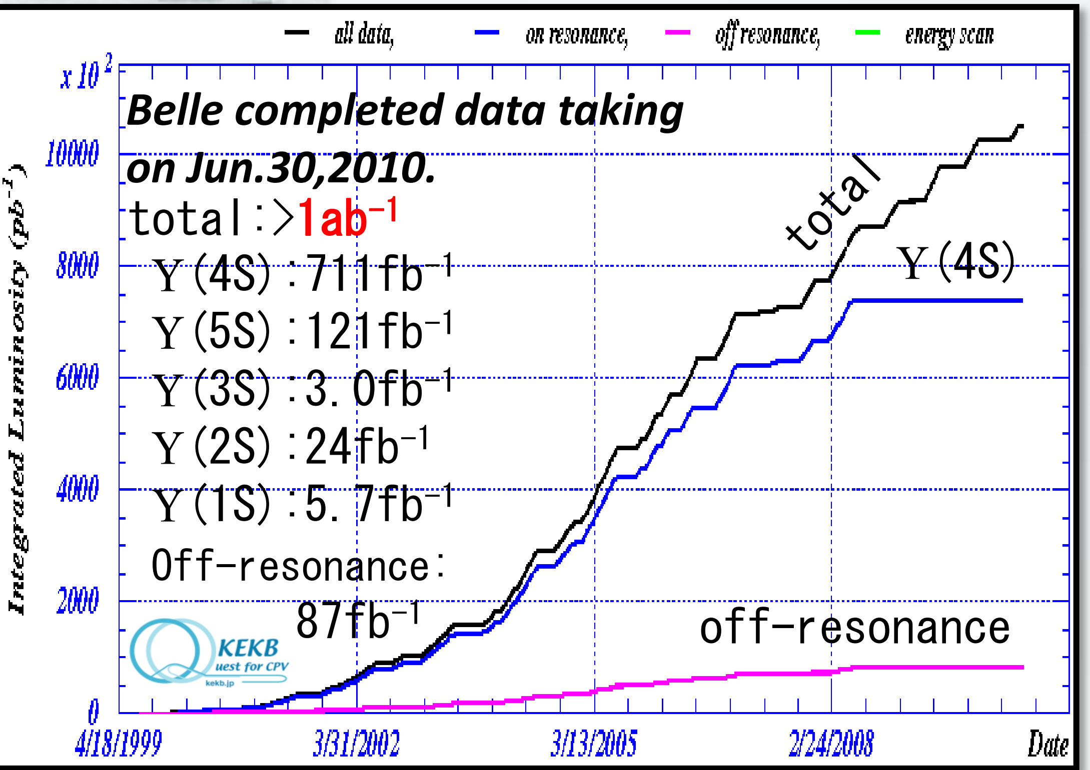
To distinguish which model is favored, various searches for τ LFV are important!

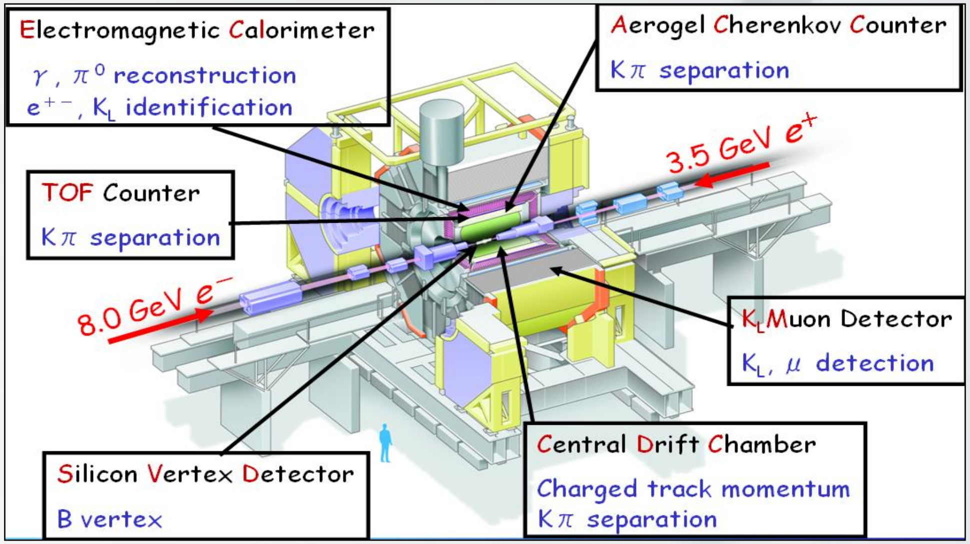
update $\tau \to \ell M^0$ ($M^0 = \pi^0, \eta, \eta'$, ρ^0, K^{*0}, $\overline{K^{*0}}$, ω, φ)

KEKB/Belle

B-factory: E at CM = Υ(4S)

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





Good track reconstruction and particle identification

	mID	eID
Efficiency	~85%	~90%
Fake rate	~3%	~0.1%

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

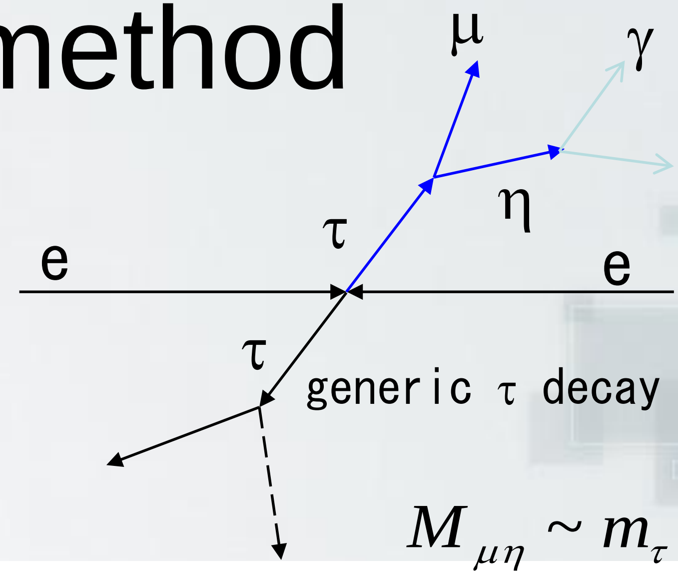
A B-factory is also a τ-factory!

World-largest data sample!

~9x10^8 ττ at Belle

Analysis method

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

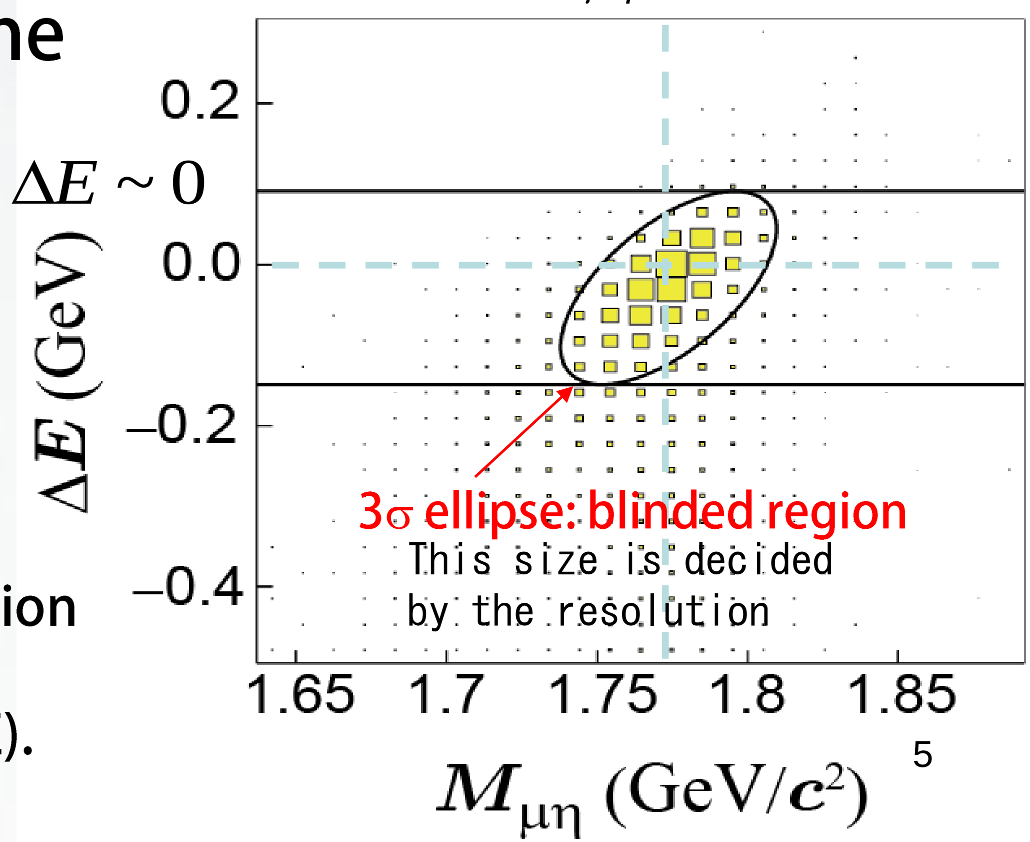


Signal extraction: $M_{\mu\eta}$-ΔE plane

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

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

Blind analysis
⇒Blind signal region



Estimate number of BG in the singal region using sideband data and MC
→UL is evaluated by F&C method (POLE).

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

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.)

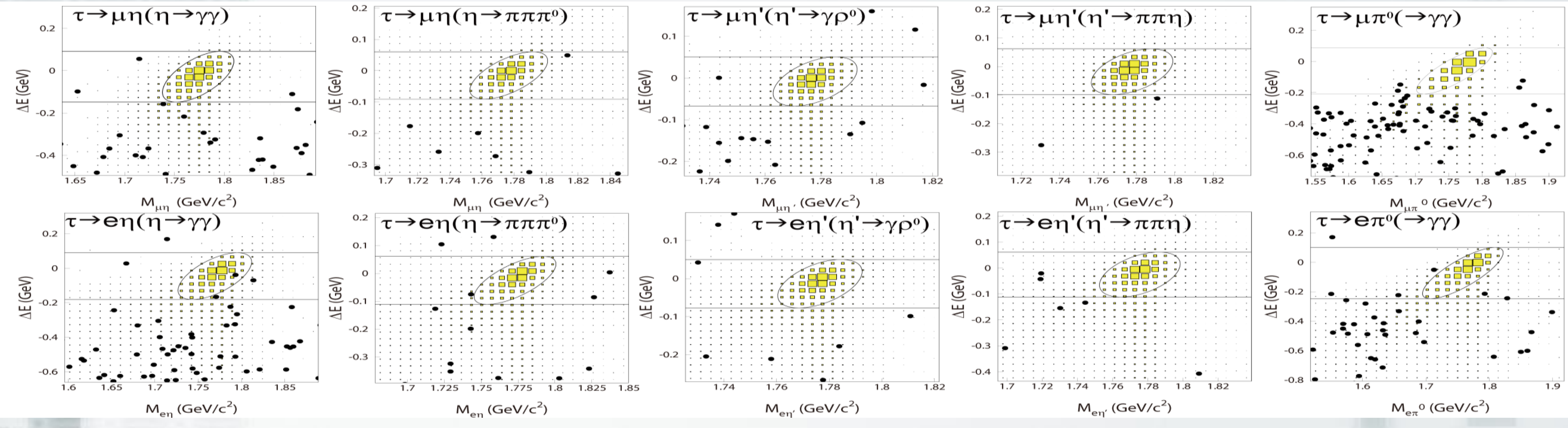
previous	new
commonly required $P_\ell^{CM}<4.5GeV/c$ →	$P_\mu^{CM}/\sqrt{s}<0.38$ for $\tau\rightarrow\mu\eta$
	not required for $\tau\rightarrow e\eta$
	$0.15<P_\mu^{CM}/\sqrt{s}<0.38$ for $\tau\rightarrow\mu\pi^0$
	$P_e^{CM}/\sqrt{s}<0.38$ for $\tau\rightarrow e\pi^0$

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

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

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

Belle preliminary



$\tau \to$	Eff.	N_{BG}^{exp}	UL ($\times 10^{-8}$)	$\tau \to$	Eff.	N_{BG}^{exp}	UL ($\times 10^{-8}$)
$\mu\eta(\to\gamma\gamma)$	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 ($401 fb^{-1}$)

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

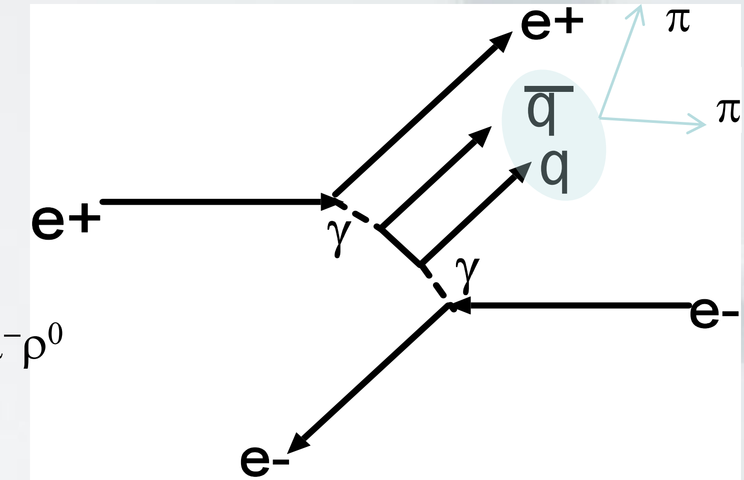
previous result

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

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

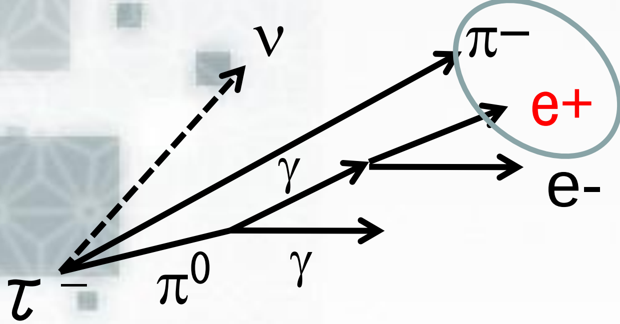
•Differently from ℓP^0, 2photon process could be large backgrounds for ℓ=e.

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



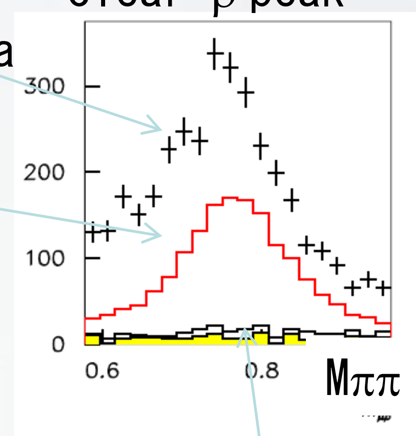
•New search with 854fb^{-1} data sample

•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 $e^-K^{*0}/\overline{K^{*0}}$ backgrounds because e/h(=π, K) separation is worse in low momentum region.



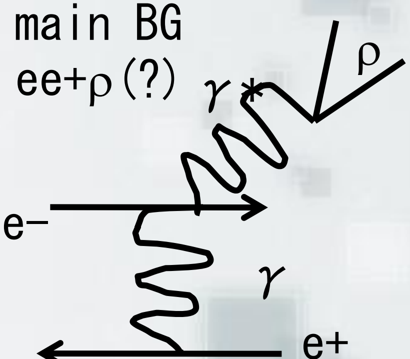
Fake K^{*0} due to miss KID

clear ρ peak



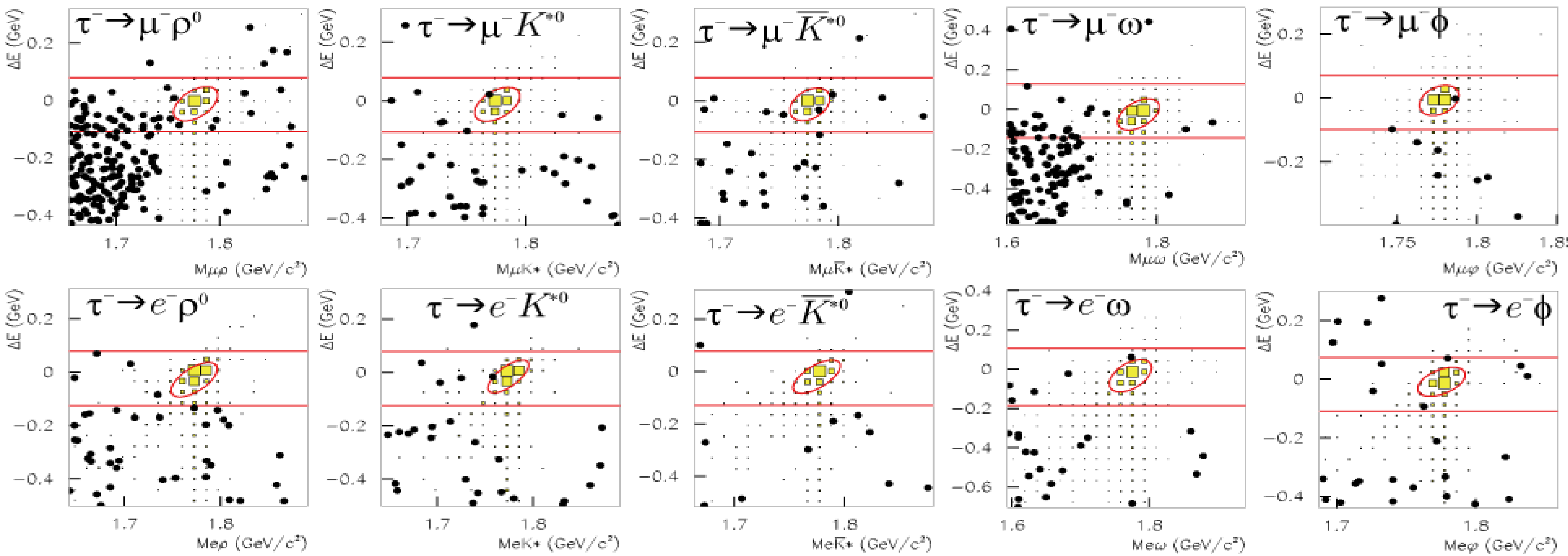
ττ and qq̄ MC

main BG ee+ρ(?)



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

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

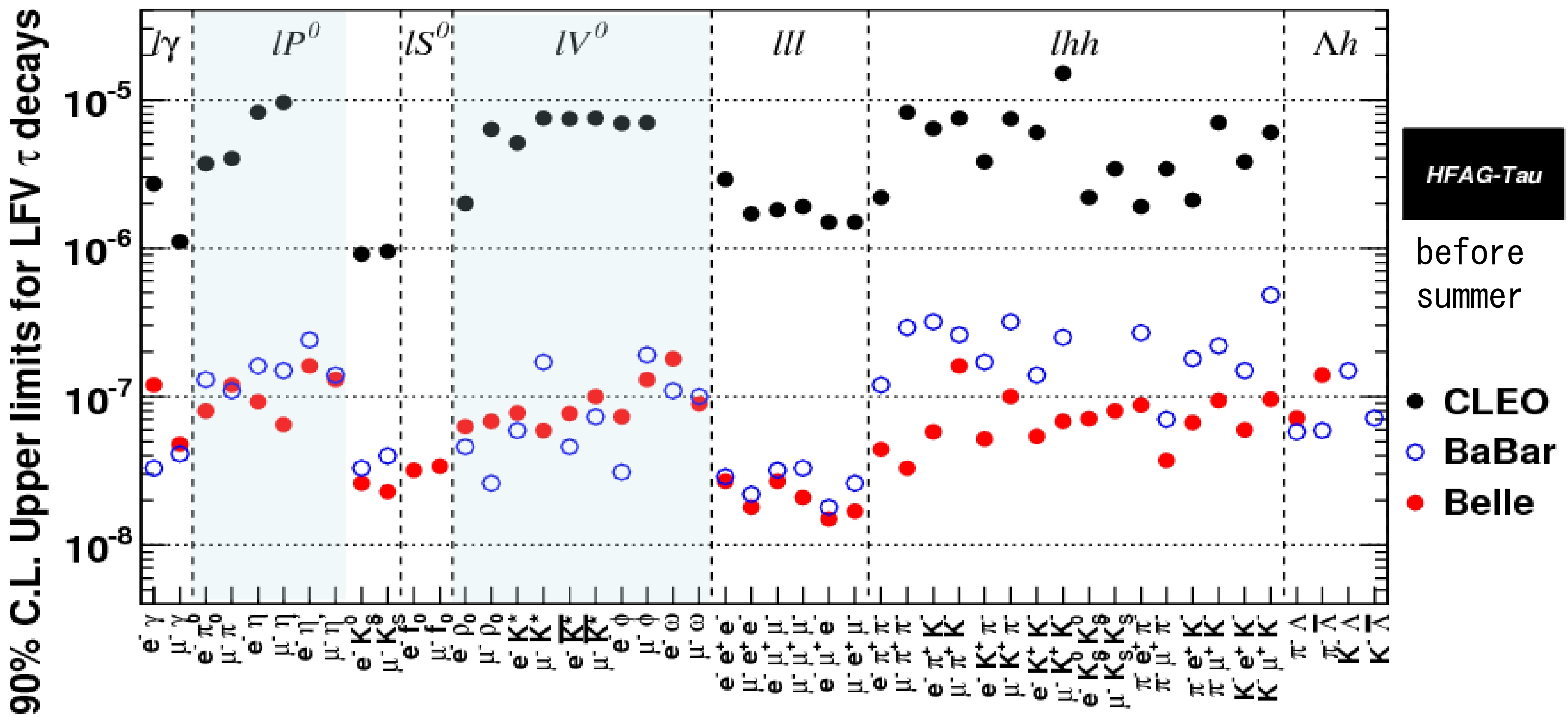


$\tau^- \to$	Eff.	N_{BG}^{exp}	UL ($\times 10^{-8}$)	$\tau^- \to$	Eff.	N_{BG}^{exp}	UL ($\times 10^{-8}$)
$e^- \rho^0$	7.6%	0.29 ± 0.15	**1.8**	$e^- K^{*0}$	4.4%	0.39 ± 0.14	**3.2**
$\mu^- \rho^0$	7.1%	1.48 ± 0.35	**1.2**	$\mu^- K^{*0}$	3.4%	0.53 ± 0.20	**7.2**
$e^- \phi$	4.2%	0.47 ± 0.19	**3.1**	$e^- \overline{K^{*0}}$	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**

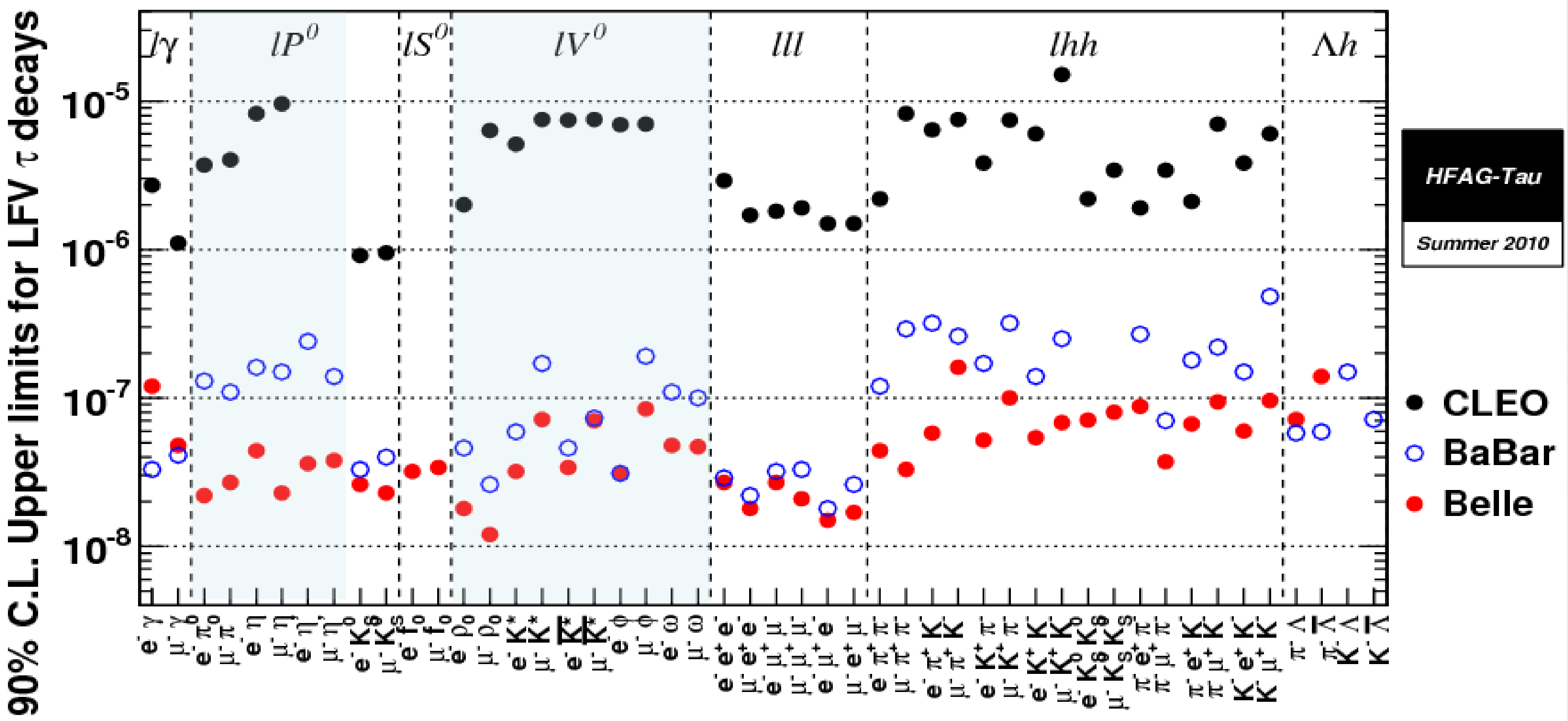
UL for $\tau \to \mu\rho^0$ is the most stringent among all the τ-LFV decays

Upper Limits on LFV τ Decay

Before this summer, …



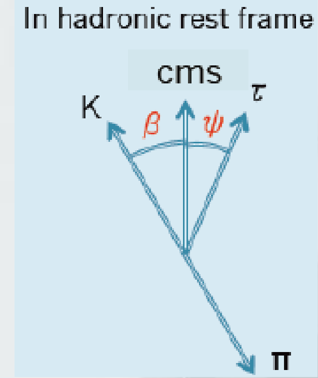
New Upper Limits on LFV τ Decay



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

100x more sensitive than CLEO's

CPV in $\tau \to \pi K_S \nu$



CP in the lepton sector should be conserved in SM
→CPV in the tau decay is a signature for NP.

Here, CPV by Higgs-exchange in NP is studied.

•Hadronic current into $K^0\pi$

$$J_\mu = \langle K^0(q_1)\pi(q_2)|\bar{u}\gamma_\mu s|0\rangle$$

$$= (q_1 - q_2)^\nu \left(g_{\mu\nu} - \frac{Q_\mu Q_\nu}{Q^2} \right) F_V(Q^2) + Q_\mu F_S(Q^2)$$

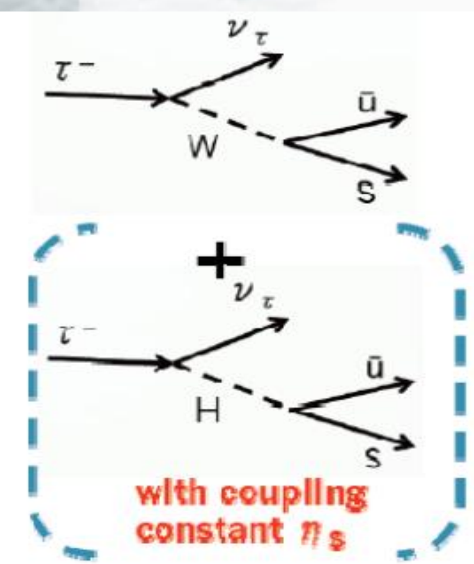
vector form factor (K*)

scalar form factor (K_0)

$$(Q^\mu = q_1^\mu + q_2^\mu)$$

Differential decay width

$$\frac{d\Gamma(\tau \to K\pi\nu)}{dQ^2 d\cos\theta d\cos\beta}$$
$$= (CP - \text{conserving} - \text{term})$$
$$+ C(Q^2)\cos\psi\cos\beta \times \mathrm{Re}(F_V \tilde{F}_S)$$



•Higgs-exchange is considered.

$$F_S \to \tilde{F}_S = F_S + \frac{\eta_S}{m_\tau} F_H$$

complex coupling
Im(η_S)~size of CPV

S-V interference
this include CPV term.

Experimentally, we evaluate

$$A_{\psi\beta}^{CP} = \langle \cos\psi\cos\beta \rangle_- - \langle \cos\psi\cos\beta \rangle_+$$

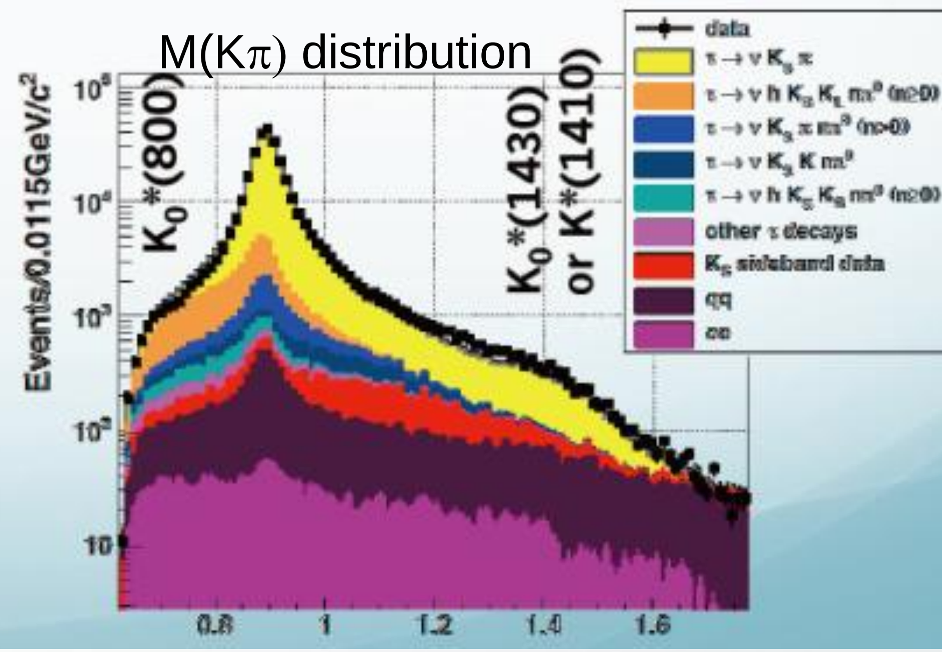
Event selection and $M_{K\pi}$ dist.

- data:700fb^{-1}

(previous analysis is performed by CLEO with 13fb^{-1} data sample)

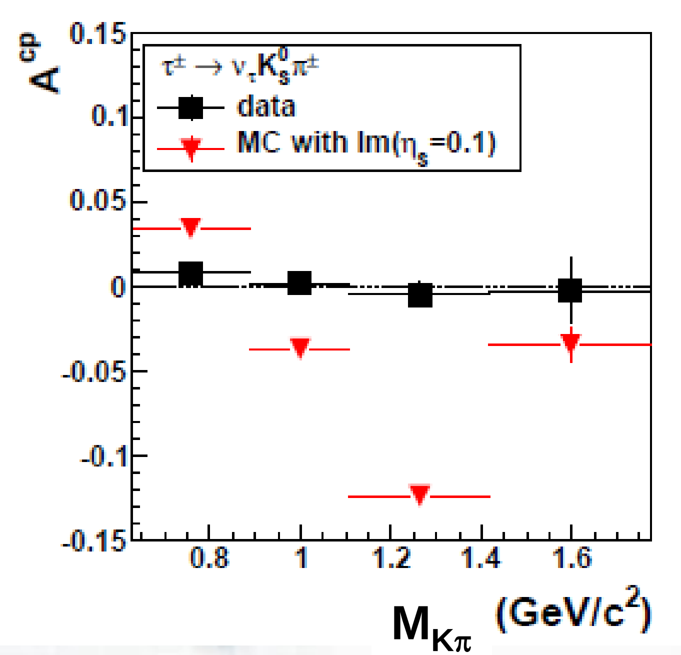
  - π(from primary vtx) and Ks^0(from sec. vtx) are selected.
  - missing is required.
  - tag side decay should be one prong decay.

→3x10^{5}events obtained (BG:23%)



Result for tau CPV measurement

- A^{CP} distribution

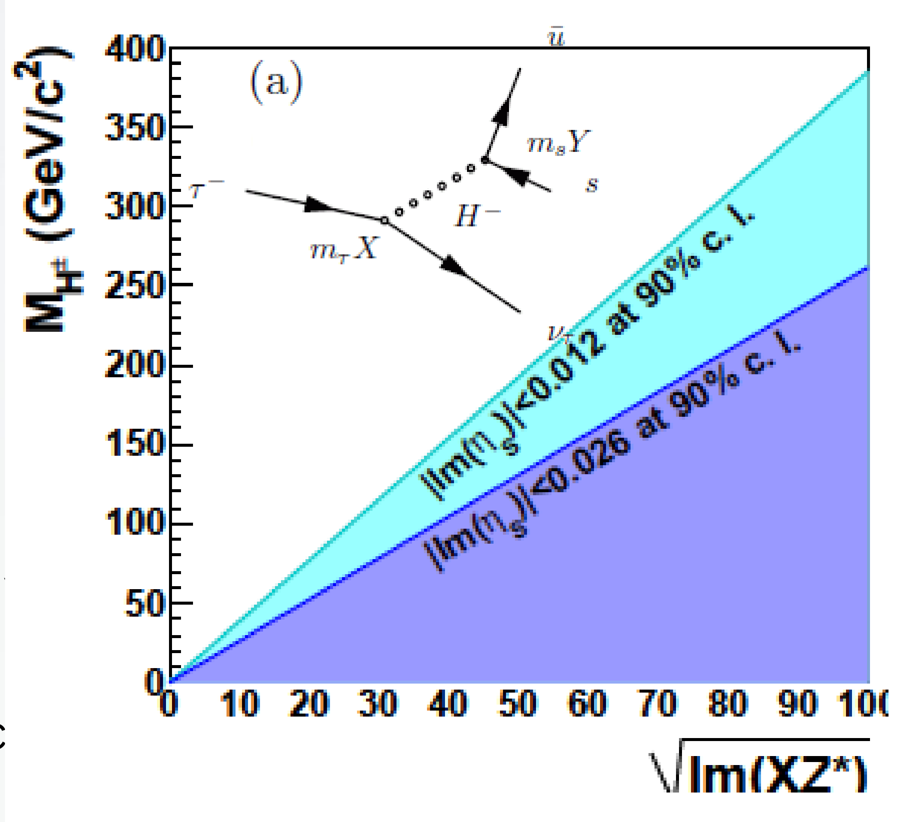


•0 consistent result
•γ-Z interference and detector effects are corrected using $\tau \to \pi\pi\pi\nu$ sample.

$A^{CP} \sim O(10^{-3})$

•Limits for multi Higgs doublet model

X,Z: complex coupling for Higgs
M_H:lightest charged Higgs mass



90%CL upper limit:

$Im(\eta_S)<(0.012—0.026)$

(depending on the model for form factors of S,

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

CPV in $\tau\to K_S\pi\nu$ is measured: 700fb^{-1} data sample (CLEO:13fb^{-1})

$M_{K\pi}$ (GeV/c^2)	A^{CP} (10^{-3})
0.625 − 0.890	5.2 ± 2.1
0.890 − 1.110	1.6 ± 1.7
1.110 − 1.420	−3.5 ± 4.7
1.420 − 1.775	9.6 ± 12.1

90%CL upper limits for CP parameter

$|\mathrm{Im}(\eta_S)|<(0.016—0.026)$ @90%CL

(improvement of one order is achieved from CLEO)

Belle preliminary

Belle started the analyses for the various modes using its full data sample!(~1ab^{-1})