Lepton Flavor Violating τ Decays at B-factories

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Introduction

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LFV in SUSY

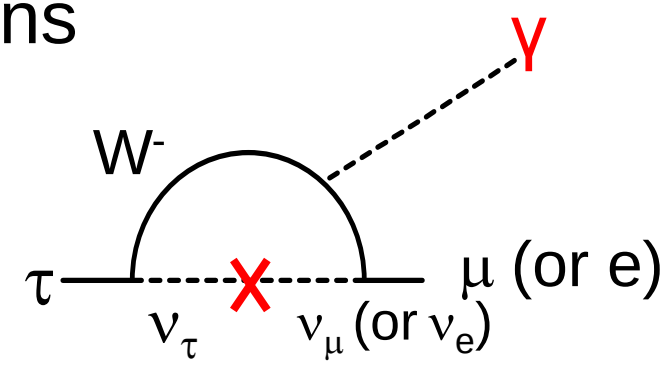
Introduction

Lepton flavor violation (LFV) in charged lepton

⇒negligibly small probability in the Standard Model (SM) even including neutrino oscillations

- Br($\tau \to l\gamma$) <O(10^{-54})
- Br($\tau \to 3$leptons) <O(10^{-14})

(PRL95 41802(2005), EPJC8 513(1999))



Many extensions of the SM predict LFV decays with enhanced branching fractions that could be accessible at current experimental sensitivities

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

Tau lepton :

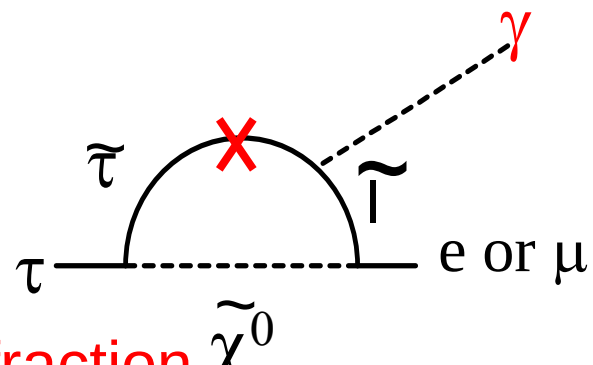
- The heaviest charged lepton
- Many possible LFV decay modes

⇒Ideal place to search for LFV

LFV in SUSY

SUSY is the most popular candidate among new physics models

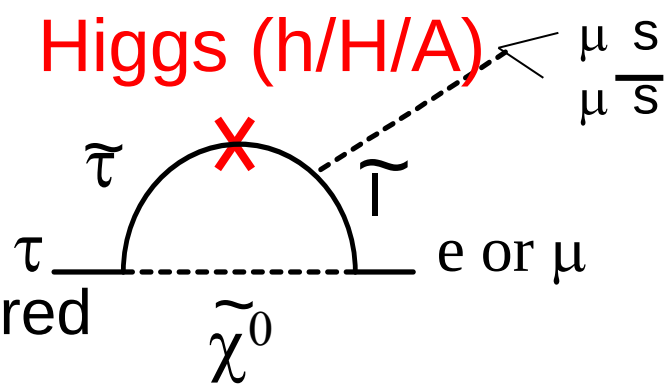
induce naturally LFV at one loop due to slepton mixing



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

When sleptons are much heavier than weak scale

LFV mediated by neutral Higgs boson (h/H/A)



Higgs coupling is proportional to mass

$\Rightarrow$ $\mu\mu$ or $s\bar{s}$ ($K\bar{K}$, η, $f_0(980)$…) are favored

Model independent searches for various LFV modes are very important

Analysis

B-factories

Analysis method

Signature of signal and background

B-factories

B-factoies : E at CM = Y(4S)

e^+(3.5 (3.1) GeV) e^-(8 (9) GeV) for KEKB (PEP II)

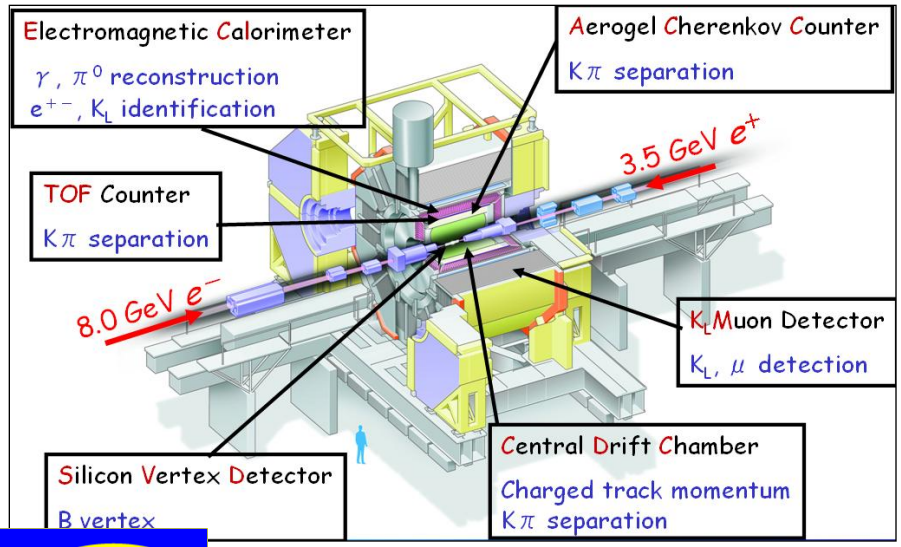
$\sigma(\tau\tau)$~0.9nb,$\sigma(bb)$~1.1nb

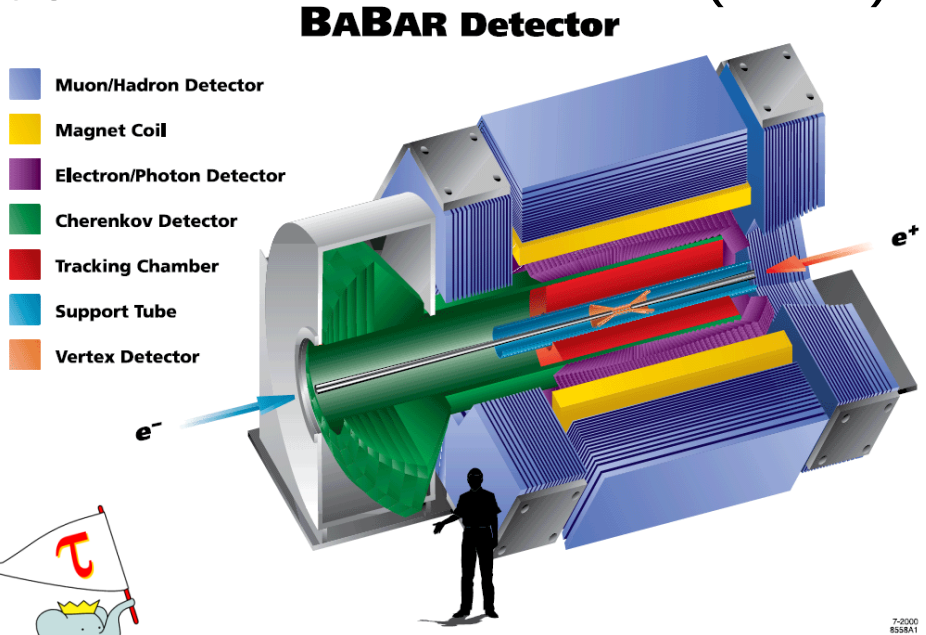
A B-factory is also a τ-factory!

Detector: Good track reconstruction and particle identification

Lepton ID ~ (80-90)%

Fake ID ~ O(0.1-1)%





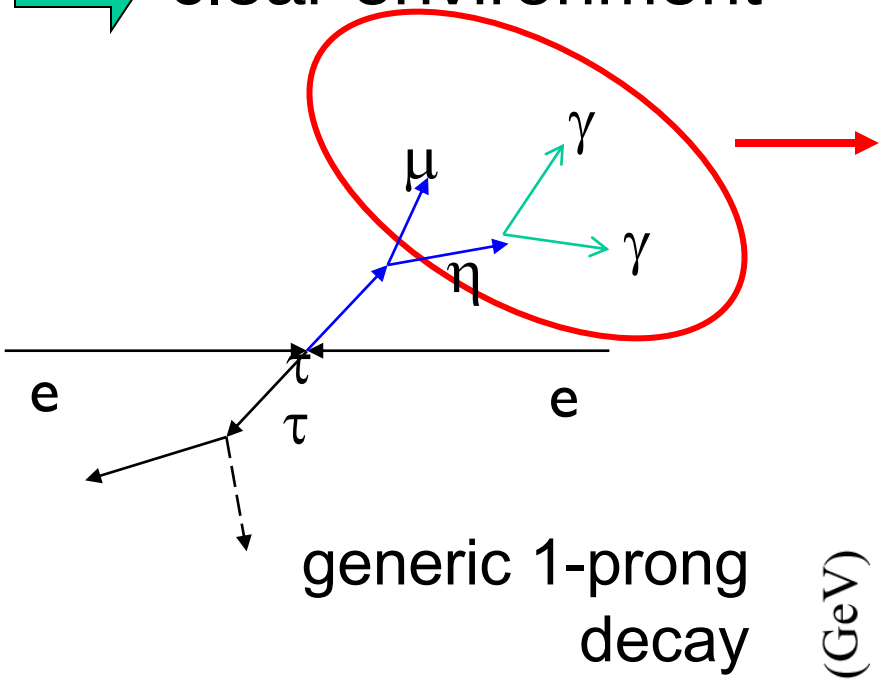
~9×10^8 $\tau\tau$ at Belle

~4.8×10^8 $\tau\tau$ at BaBar

Analysis method

$e^+e^- \rightarrow \tau^+\tau^-$

clear environment

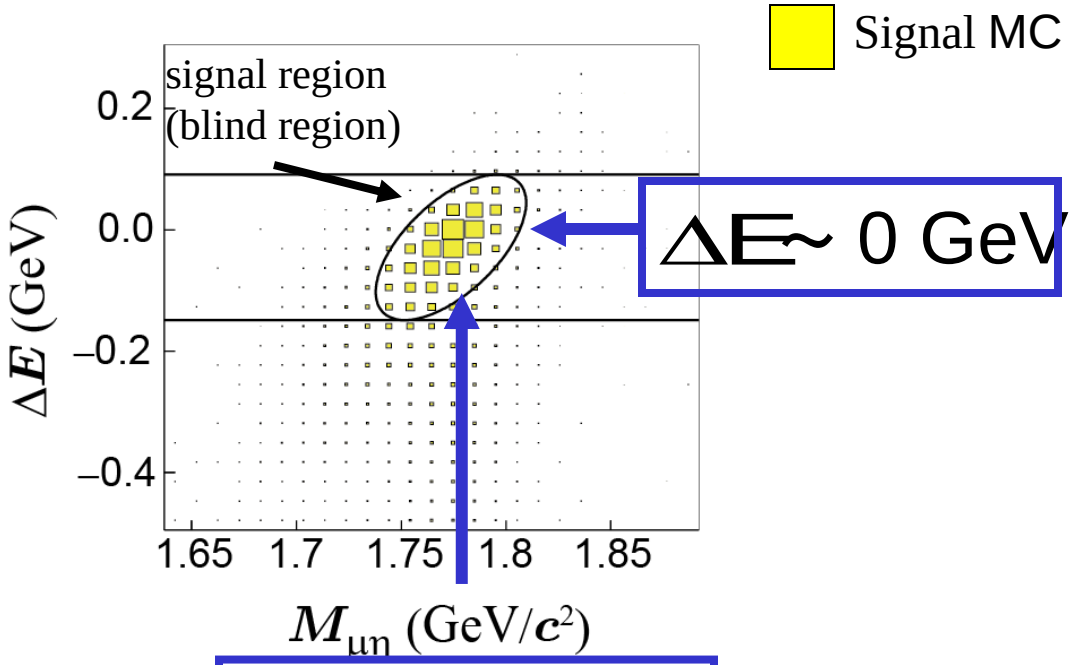


generic 1-prong decay

Signal Extraction

$$M_{inv} = \sqrt{E^2_{signal} - p^2_{signal}}$$

$$\Delta E = E^{CM}_{signal} - E^{CM}_{beam}$$



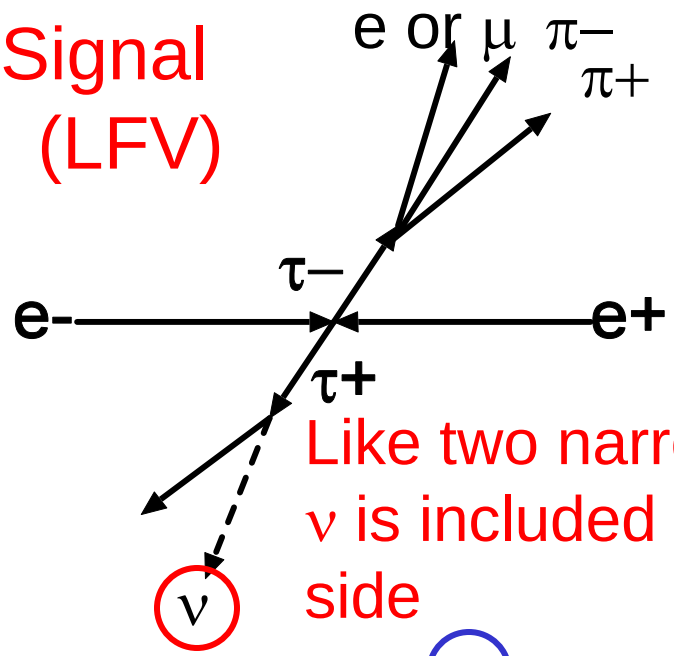
Blind analysis

⇒Blind signal region

Estimate number of BG using sideband data and MC

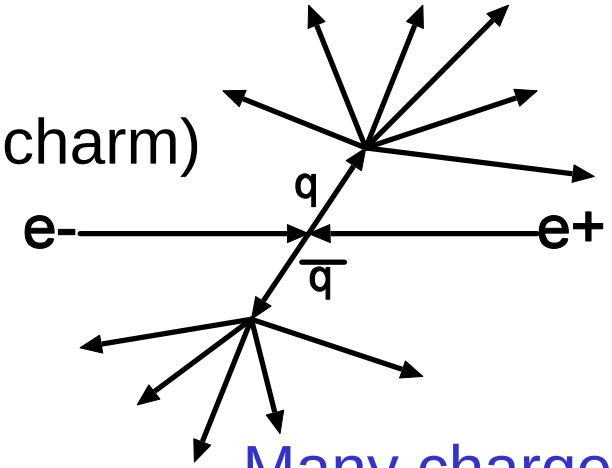
Signature of signal and background

Signal (LFV)



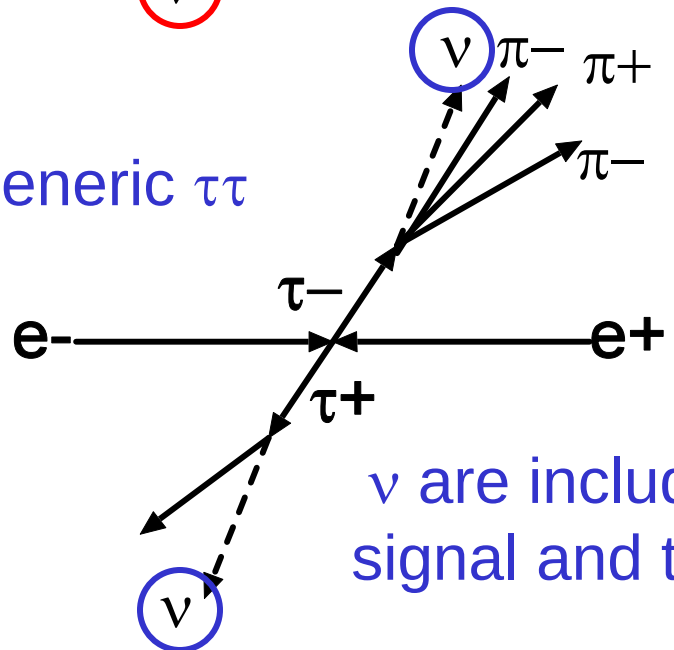
Like two narrow jets
ν is included in only tag side

$q\bar{q}$ (uds, charm)



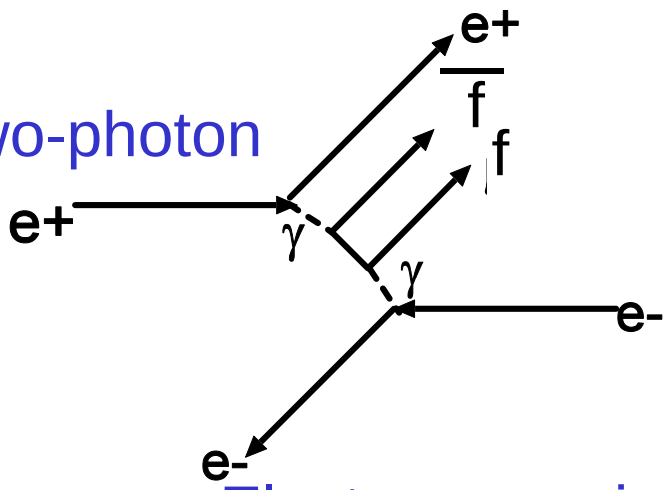
Many charged tracks and γ

Generic ττ



ν are included in signal and tag side

Two-photon



Electrons are included in signal and tag side

Recent Results

l + γ

l + pseudoscalar meson

l + Vector meson

l + hh' (=$K^{\pm}$ or $\pi^{\pm}$)

$\tau \to l\gamma$

$\tau \to \mu\gamma, e\gamma$ (PLB666,16(2008))

Data: 492M τ pairs

$Br(\tau \to \mu\gamma) < 4.5 \times 10^{-8}$ at 90%C.L.

$Br(\tau \to e\gamma) < 1.2 \times 10^{-7}$ at 90%C.L.

$\tau \to \mu\gamma, e\gamma$ (PRL104,021802(2010))

Data: 482M τ pairs (including Y(2,3S) data)

Use Neural network for event selection

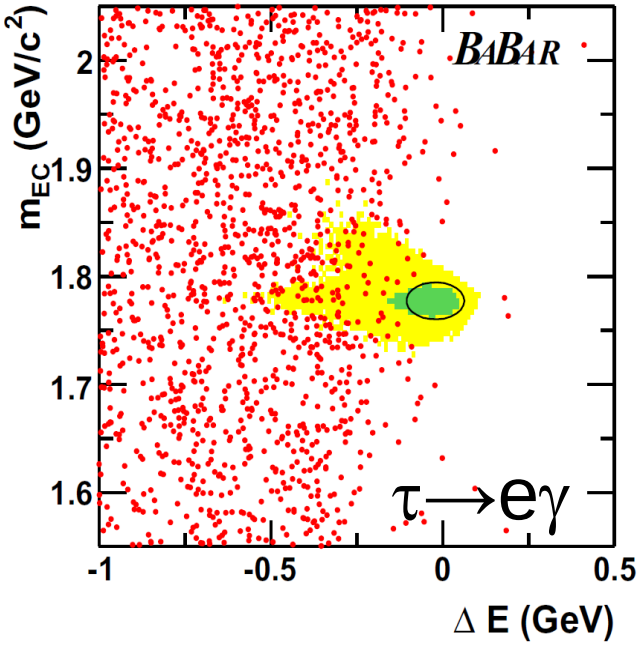
Decay modes	2σ signal ellipse		ε	UL ($\times 10^{-8}$)	
	obs	exp	(%)	obs	exp
$\tau^{\pm} \to e^{\pm}\gamma$	0	1.6±0.4	3.9±0.3	3.3	9.8
$\tau^{\pm} \to \mu^{\pm}\gamma$	2	3.6±0.7	6.1±0.5	4.4	8.2

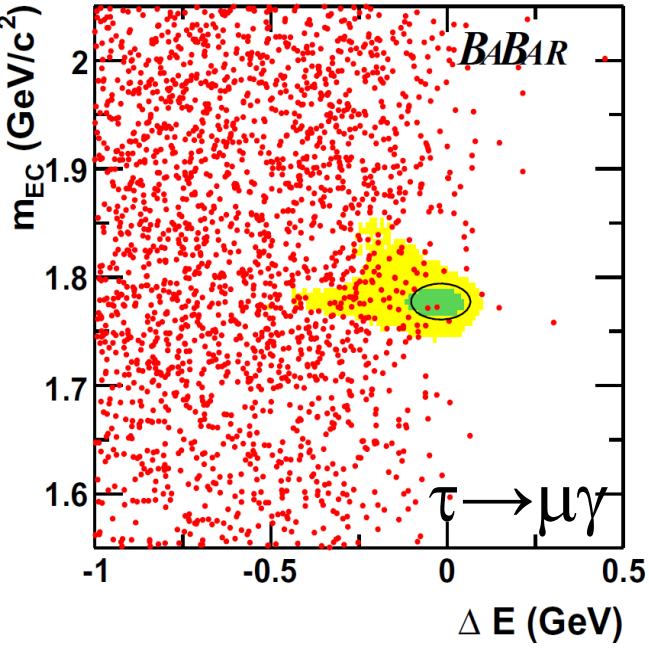
$Br(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$ at 90%C.L.

$Br(\tau \to e\gamma) < 3.3 \times 10^{-8}$ at 90%C.L.

Many remaining BG events from $e^+e^- \to \tau^+\tau^-\gamma$

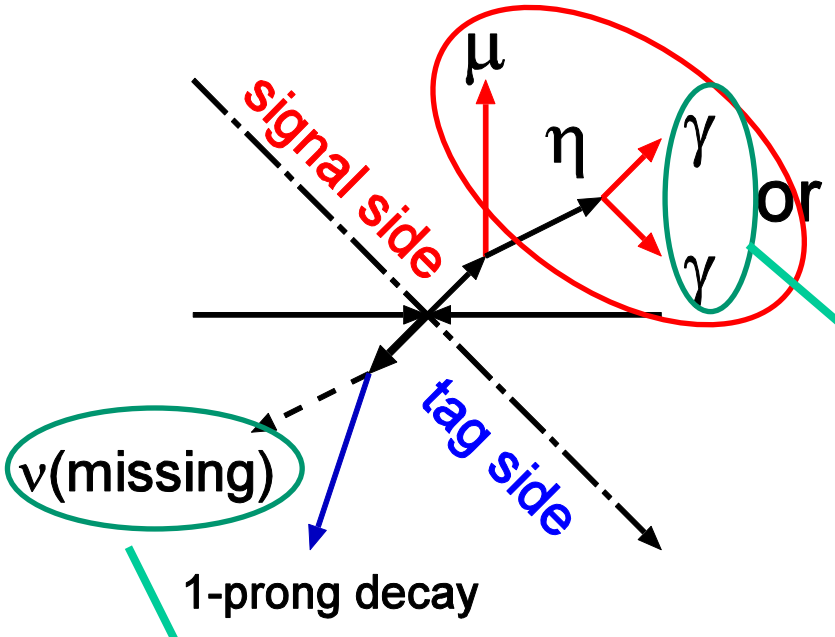
sensitivity is limited by the background



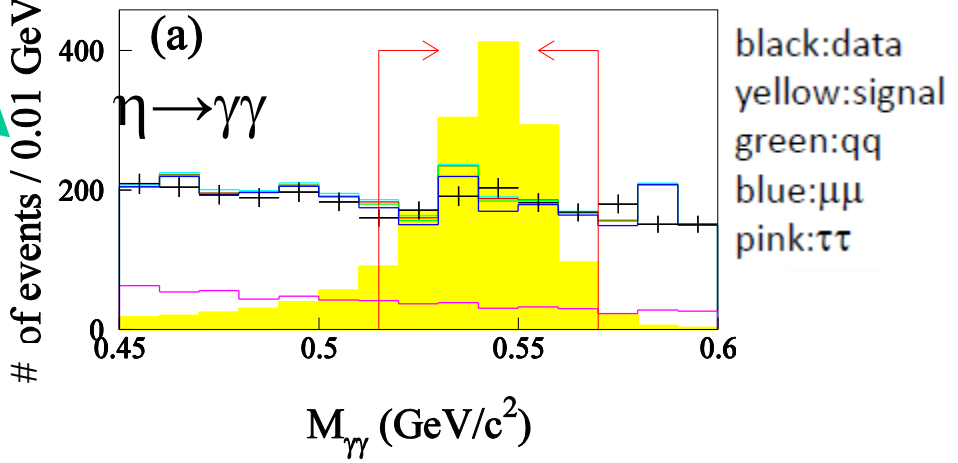


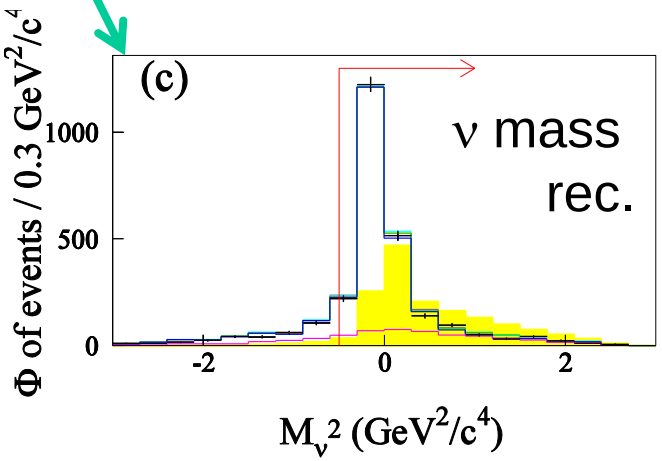
$\tau \to l P^0$ (1)

Previous results
(6.5-16)x10^{-8}@Belle 401fb^{-1}
Update with 901fb^{-1} @Belle



Signal side
- lepton (e or mu)
- pseudoscalar meson
- $\eta \to \gamma\gamma$, $\pi^+\pi^-\pi^0$
- $\eta' \to \eta(\to\gamma\gamma)\pi^+\pi^-$, $\rho\gamma$
- $\pi^0 \to \gamma\gamma$





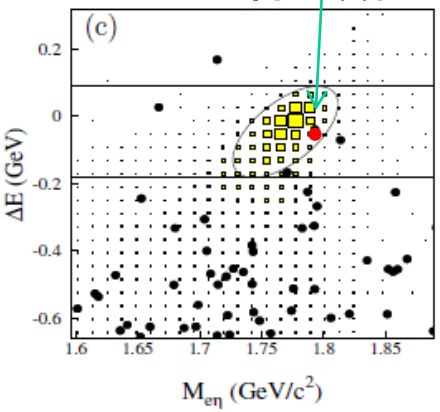
To improve sensitivity, we changed event selection mode by mode

For example $\mu\eta(\to\gamma\gamma)$: Neural Net
increase higher eff in x1.5
while keep low BG (<1)

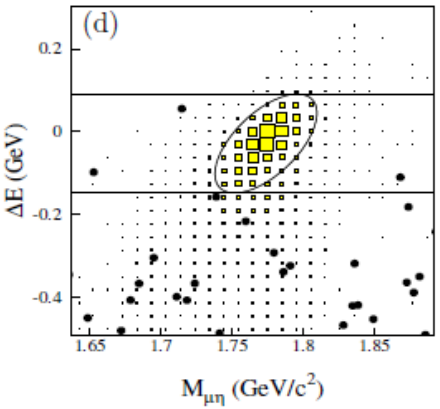
$\tau \to lP^0$ (2)

one observed event in data

$\tau \to e\eta(\to\gamma\gamma)$



$\tau \to \mu\eta(\to\gamma\gamma)$



No excess

After event selection

Expected # of BG (0.0-1.4)events

- 1 event $e\eta(\to\gamma\gamma)$
- 0 events others

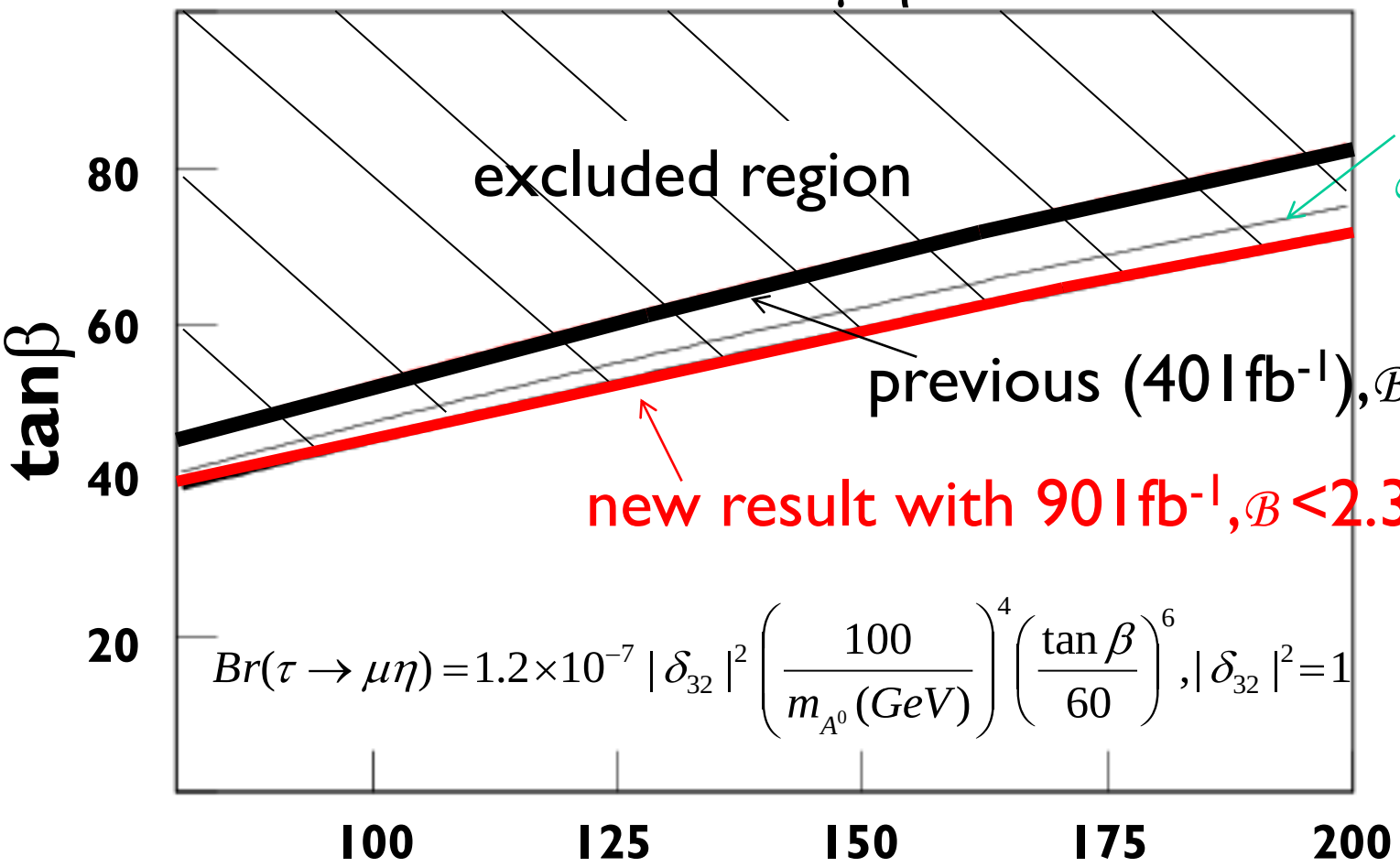
$Br(\tau \to lP^0) < (2.2\text{-}4.4) \times 10^{-8}$ @90%C.L.(preliminary)

Improve x(2.1-4.4) from prev.

$\tau\to$	Eff.	N_{BG}^{exp}	UL(10^{-8})	$\tau\to$	Eff.	N_{BG}^{exp}	UL(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
$\mu\eta(\to\pi\pi\pi^0)$	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**

$\tau \rightarrow lP^0$ (3)

Constraint on new physics parameters from $\tau \rightarrow \mu\eta$ results

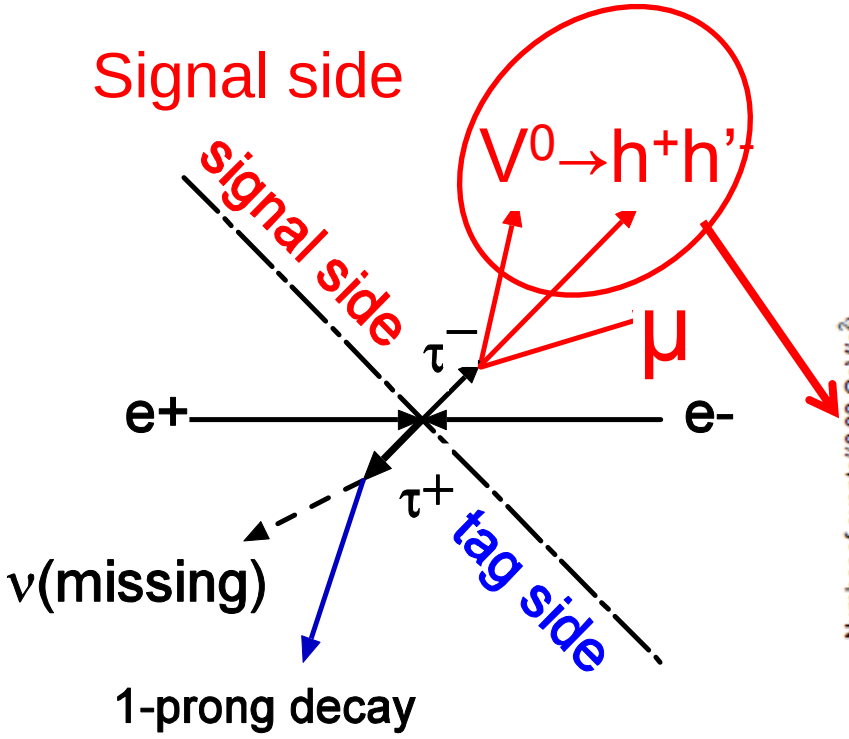


M.J.Herrero et al, JHEP06(2008)079

$\tau \to l V^0$ (1)

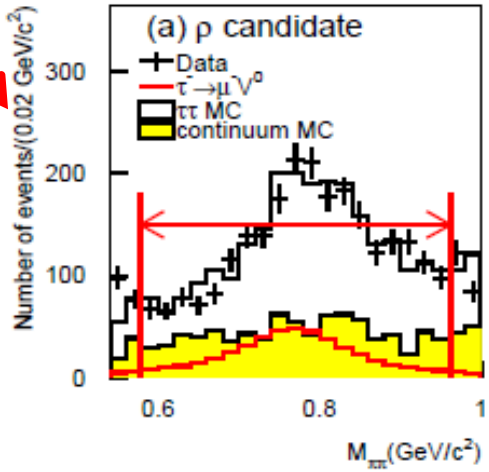
Previous results
- Belle:543fb^{-1} Br<(6.3-18)x10^{-8}
- BaBar:(384-451)fb^{-1} Br<(2.6-19)x10^{-8}

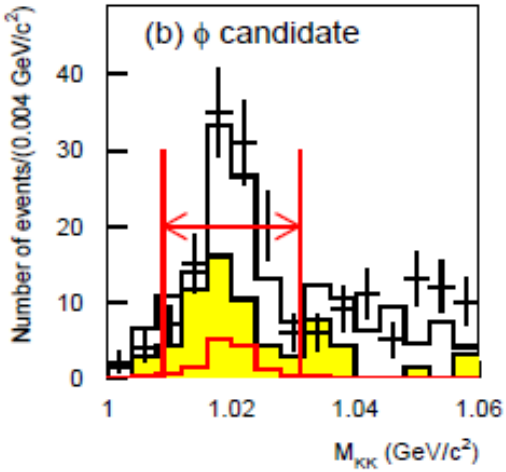
Update with 854 fb^{-1} of data@Belle



- lepton (e or μ)
- Vector meson (ρ,ϕ,ω,K^{*0},$\overline{K}^{*0}$)

$\Rightarrow$final state h^+h^-($h=\pi/K$)
($+\pi^0$ for ω only)



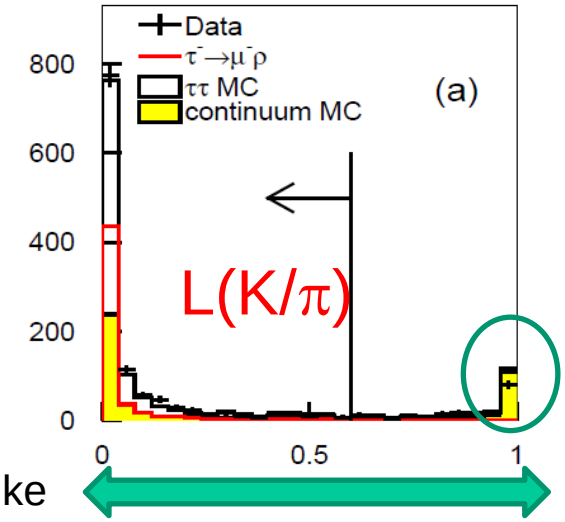


By detailed BG study,
we apply the event selection mode by mode

$\tau \to l V^0$ (2)

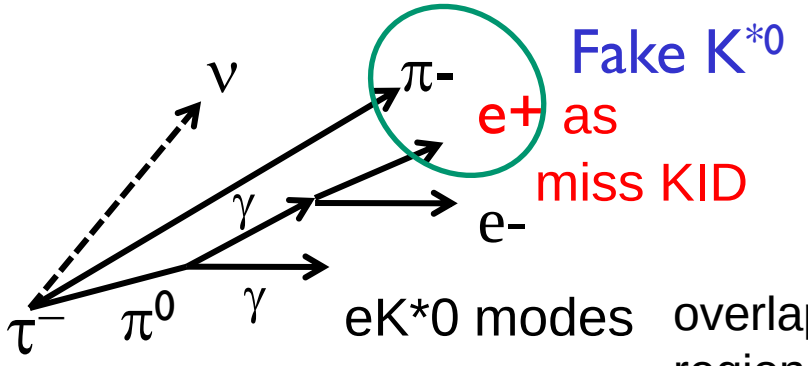
For example, we apply event selections as

- μV^0 modes
  Dominant BG
  $K \to \mu\nu$ in continuum events
  $\Rightarrow$ apply K-veto to μ-track
  as $L(K/\pi) < 0.6$



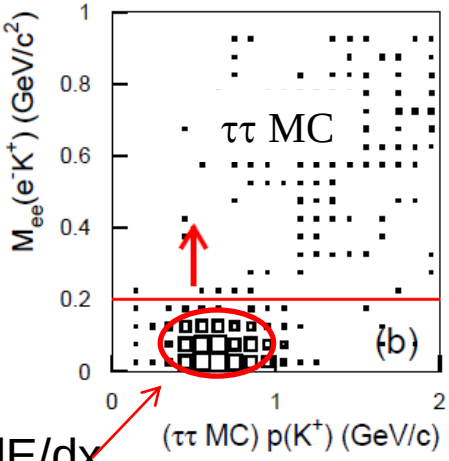
$K \to \mu\nu$ in continuum events

- $e\rho$, eK^{*0}, $e\bar{K}^{*0}$ modes
  BG from $\tau^- \to h^- \pi^0 (\to \gamma\gamma) \nu_\tau$ with $\gamma \to ee$ conversion

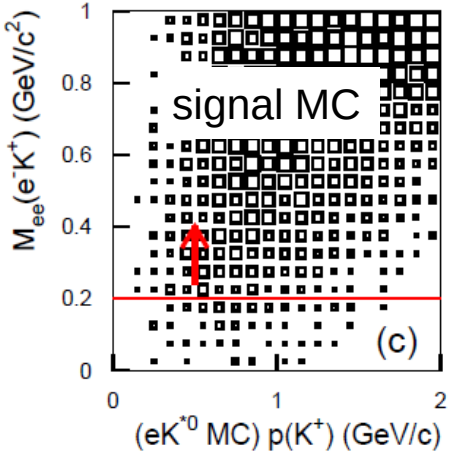


Fake K^{*0} as miss KID

eK*0 modes



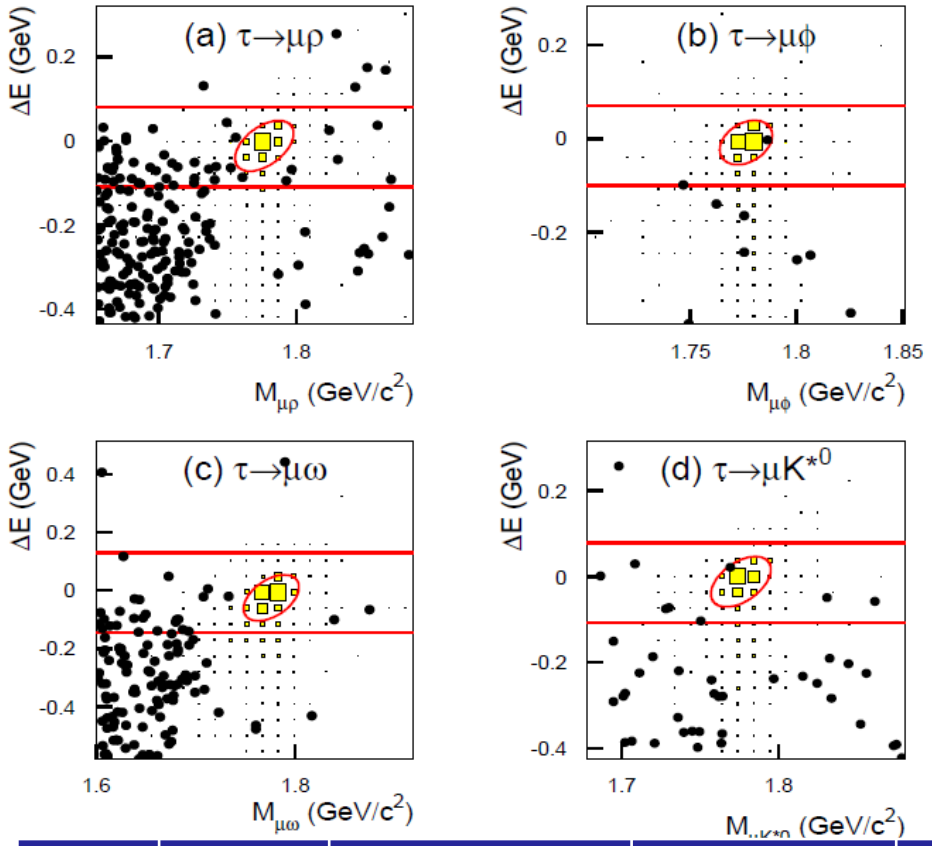
overlap dE/dx region btw. e and K



better or similar eff. than prev. while keep low BG

PLB 699 251, (2011)

$\tau \to l V^0$ (3)



After event selections

Expected # of BG

(0.1-1.5) events

No excess between data and expected BG

- 1 event $\mu\phi$, μK^{*0}, $\mu\overline{K}^{*0}$
- 0 events others

$Br(\tau \to l V^0) < (1.2\text{-}8.4) \times 10^{-8}$ @90%C.L.

⇒Improve up to x 5.7 from previous results

$\tau^- \to$	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**	μ^-K^{*0}	3.4%	0.53±0.20	**7.2**
$e^-\phi$	4.2%	0.47±0.19	**3.1**	e^-K^{*0}	4.4%	0.08±0.08	**3.4**
$\mu^-\phi$	3.2%	0.06±0.06	**8.4**	μ^-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**

$\tau \to lhh'$ (1)

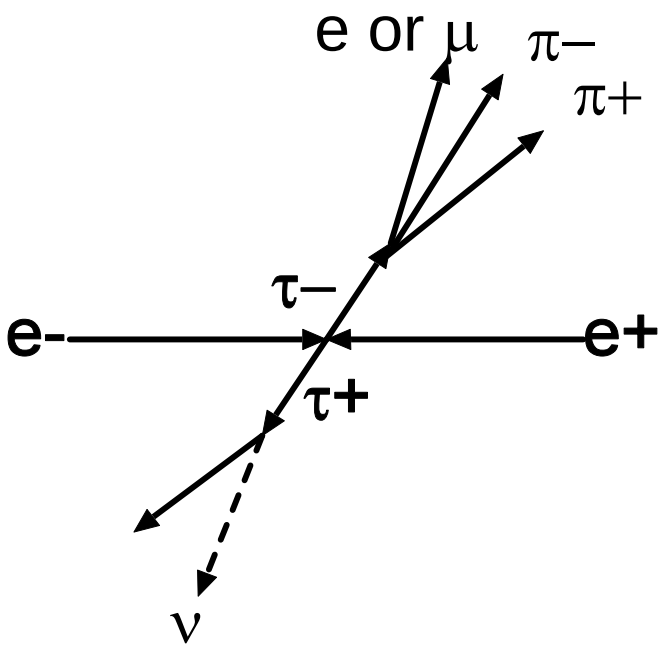
lhh' modes: 14 modes are investigated ($h,h'=\pi^{\pm}$ and $K^{\pm}$)

- lepton flavor violation ($\tau^- \to l^- h^+ h'^-$) 8 modes
- lepton number violation ($\tau^- \to l^+ h^- h'^-$) 6 modes

Current upper limits

- Belle Br<$(4.4\text{-}16)\times10^{-8}$ @ $671fb^{-1}$
- BaBar Br<$(7\text{-}48)\times10^{-8}$ @ $221fb^{-1}$

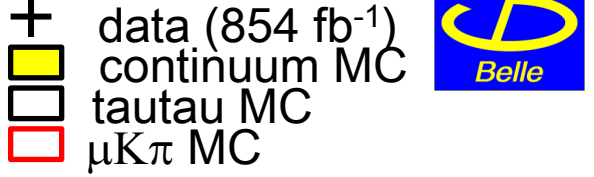
update with $854fb^{-1}$ @Belle



Basically same signature as $\tau \to lV^0(\to hh')$ modes while BGs are increased due to no meson reconstructions

Apply similar event selections to lV^0 selections and additional tighter cuts

$\tau \rightarrow lhh'$ (2)



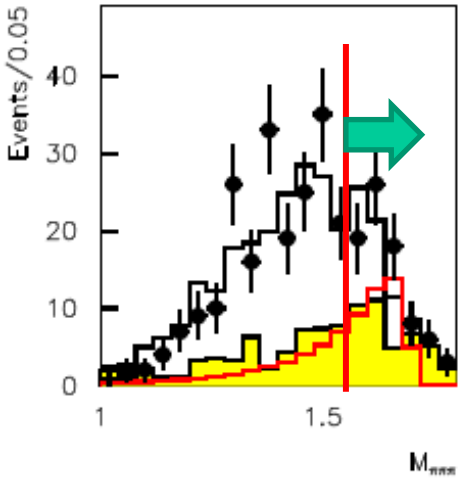
For μπK modes

main remaining BG events from $\tau \rightarrow \pi\pi\pi\nu$ decays with missID ππ as K and μ

⇒shift to bigger mass than tau mass due to $\pi \rightarrow K$ mass assignment

Assign ππ mass in BG and μKπ

⇒ $M_{\pi\pi\pi}$>1.52 GeV



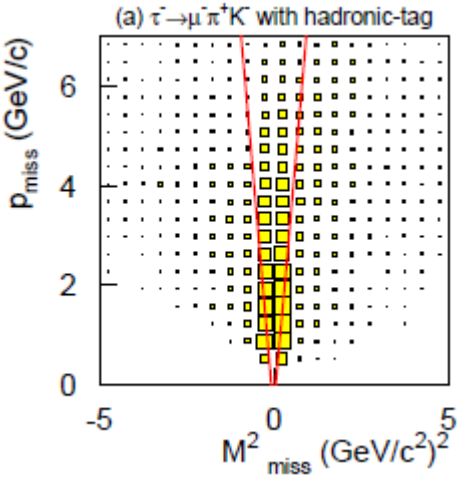
To reduce ττ and continuum BG

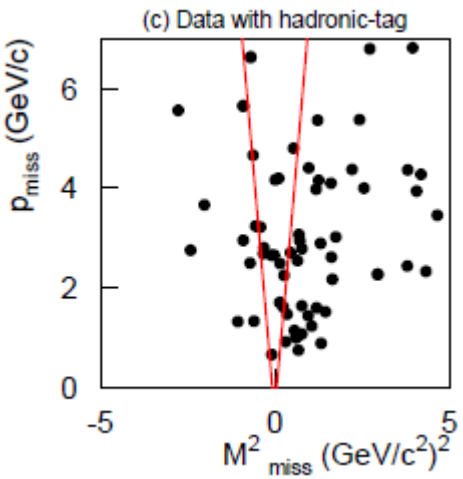
- μπK modes

⇒ m^2_{miss} vs. p_{miss} correction cut

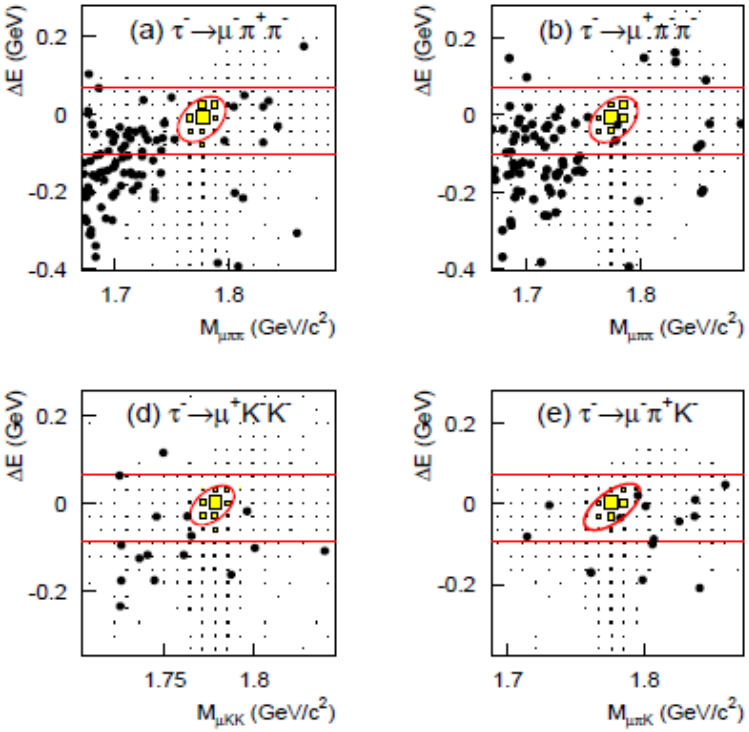
- ehh', μππ and μKK modes

⇒ m^2_{miss} cut





τ→lhh' (3)



1event : μ+π−π− and μ−π+K-
no events: others
⇒ no significance excess
between data and BG

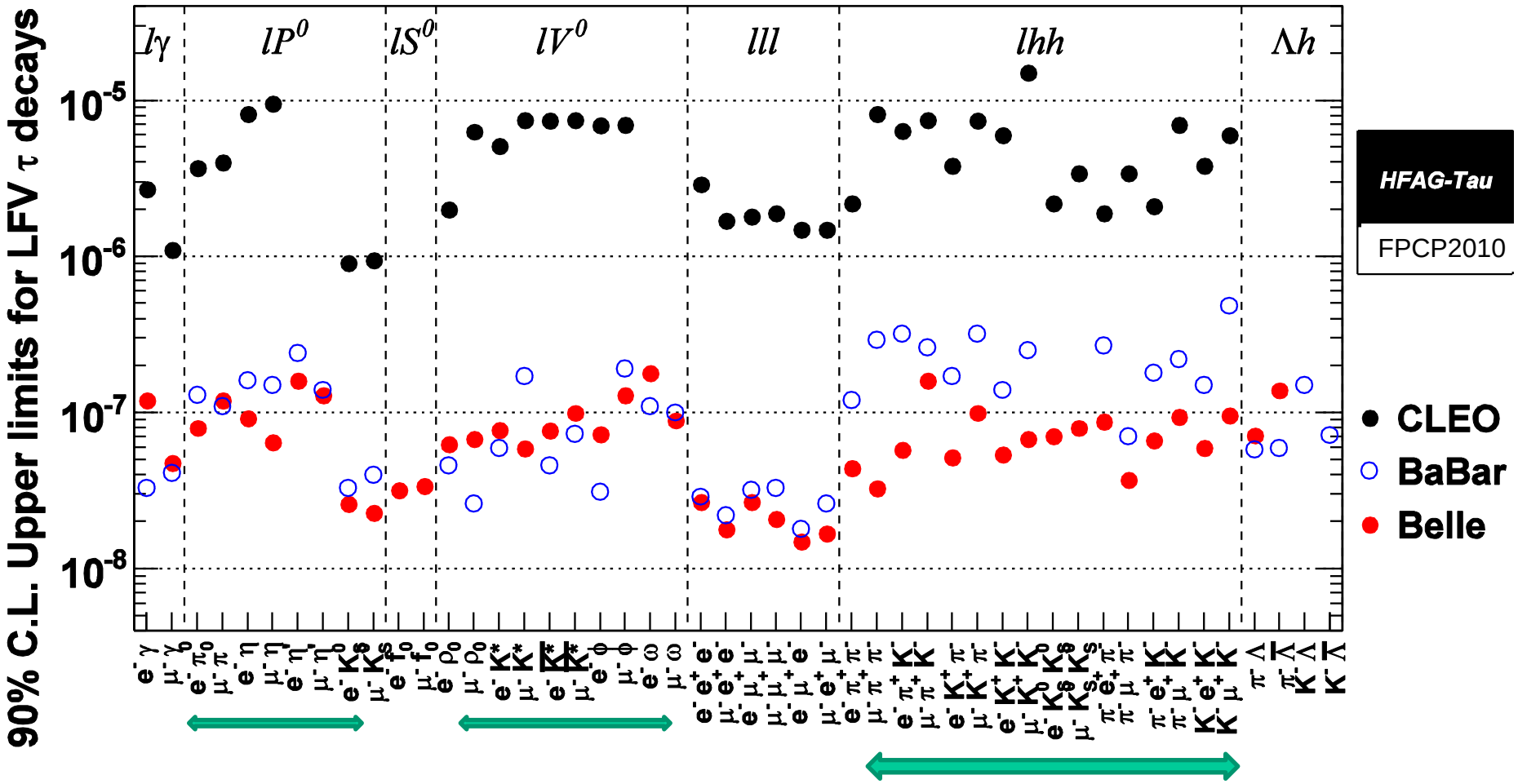
Set upper limits as
Br(τ→lhh')< (2.0-8.4)x10^{-8}
(preliminary)

Improve UL from our prev. results by factors of 1.8 on the average

Mode	ε (%)	$N_{\rm BG}$	$\sigma_{\rm syst}$ (%)	$N_{\rm obs}$	s_{90}	$\mathcal{B}$ (10^{-8})
$\tau^- \to \mu^-\pi^+\pi^-$	5.83	0.63 ± 0.23	5.3	0	1.87	2.1
$\tau^- \to \mu^+\pi^-\pi^-$	6.55	0.33 ± 0.16	5.3	1	4.02	3.9
$\tau^- \to e^-\pi^+\pi^-$	5.45	0.55 ± 0.23	5.4	0	1.94	2.3
$\tau^- \to e^+\pi^-\pi^-$	6.56	0.37 ± 0.18	5.4	0	2.10	2.0
$\tau^- \to \mu^-K^+K^-$	2.85	0.51 ± 0.18	5.9	0	1.97	4.4
$\tau^- \to \mu^+K^-K^-$	2.98	0.25 ± 0.13	5.9	0	2.21	4.7
$\tau^- \to e^-K^+K^-$	4.29	0.17 ± 0.10	6.0	0	2.28	3.4
$\tau^- \to e^+K^-K^-$	4.64	0.06 ± 0.06	6.0	0	2.38	3.3
$\tau^- \to \mu^-\pi^+K^-$	2.72	0.72 ± 0.27	5.6	1	3.65	8.6
$\tau^- \to e^-\pi^+K^-$	3.97	0.18 ± 0.13	5.7	0	2.27	3.7
$\tau^- \to \mu^-K^+\pi^-$	2.62	0.64 ± 0.23	5.6	0	1.86	4.5
$\tau^- \to e^-K^+\pi^-$	4.07	0.55 ± 0.31	5.7	0	1.97	3.1
$\tau^- \to \mu^+K^-\pi^-$	2.55	0.56 ± 0.21	5.6	0	1.93	4.8
$\tau^- \to e^+K^-\pi^-$	4.00	0.46 ± 0.21	5.7	0	2.02	3.2

Upper Limits on LFV τ Decay

Upper limits @ FPCP2010

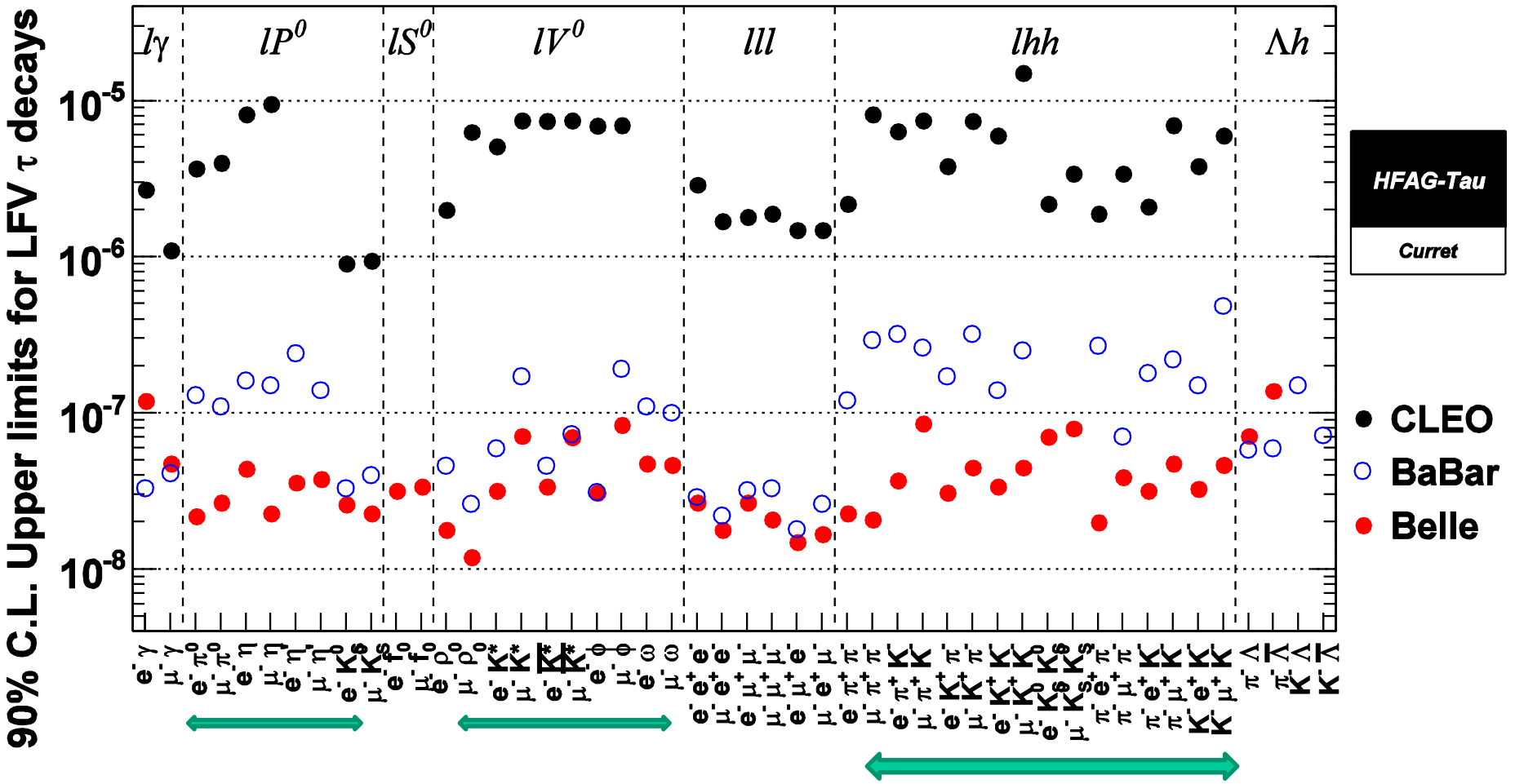


New Upper Limits on LFV τ Decay

Reach upper limits around 10^{-8}

Improve by factor ~100 from CLEO

Belle and BaBar are updating using full data samples



Future Prospects

LFV Sensitivity for future prospects

Belle Ⅱ・Super B-factory:(10~50) ab^{-1}

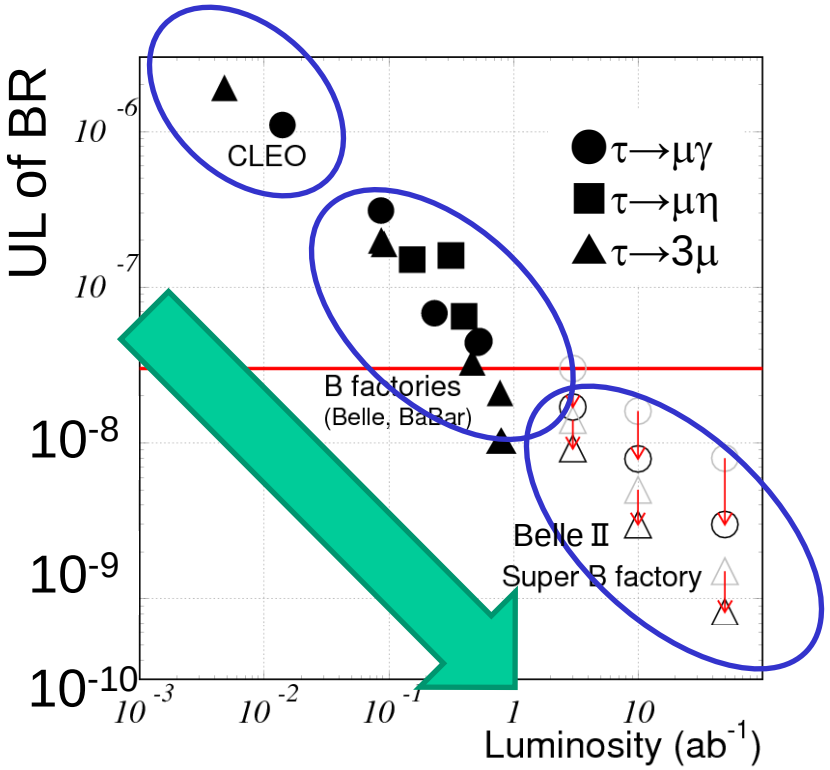
LFV sensitivity

depends on background level

- $\tau \rightarrow l\gamma$,

  ⇒ Sensitivity currently limited due to background from $\tau^+\tau^-\gamma$ events

scale as ~$1/\sqrt{L}$ ⇒ Br~O($10^{-(8\text{-}9)}$)



- $\tau \rightarrow$ 3leptons, l+meson

  Negligible background at $1ab^{-1}$ due to good particle identification and mass restriction to select meson

scale as ~$1/L$ ⇒ Br~O($10^{-(9\text{-}10)}$)

Summary

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Lepton flavor violation is a good signature of NP.

We have searched for LFV τ decays using a large data sample obtained by B-factories

No LFV signals are observed yet

⇒Set limits of branching fraction around $O(10^{-8})$

- Improve sensitivity by factor ~100 from CLEO

⇒ rejected BG effectively while keeping high efficiencies due to detailed BG studies and new approach of event selections

We are updating final results including LFV and hadronic tau decays using full data samples

Sensitivities of LFV search will reach $O(10^{-9\sim10})$ at Belle Ⅱ/Super B with 50 ab^{-1}