Rare tau decays at Belle

-Recent results for tau LFV-

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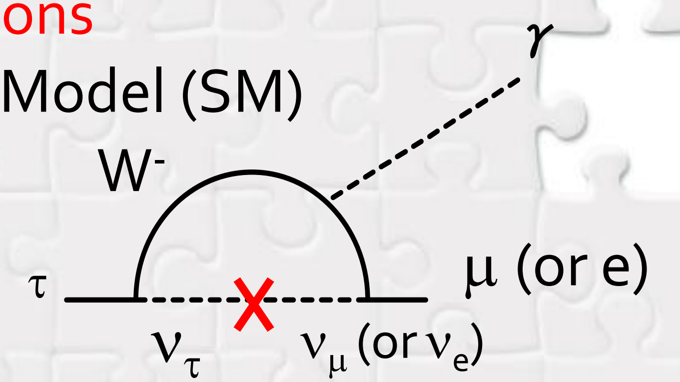
Introduction(1)

Lepton flavor violation (LFV) in charged leptons

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



-$Br(\tau \to \ell\gamma) < O(10^{-54})$

(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 ($\sim 10^{-8}$)

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

Tau lepton :

=The heaviest charged lepton

- Expected strong coupling to NP
- Many possible LFV decay modes
  - ✓Unusual charge combinations
  - ✓some decays include baryons

Muon:

- Huge samples: require high Intensity muon beams ($\sim 10^{-12}$)

$Br(\tau \to \mu\gamma)/Br(\mu \to e\gamma) \sim 10^{3-5}$ (?)

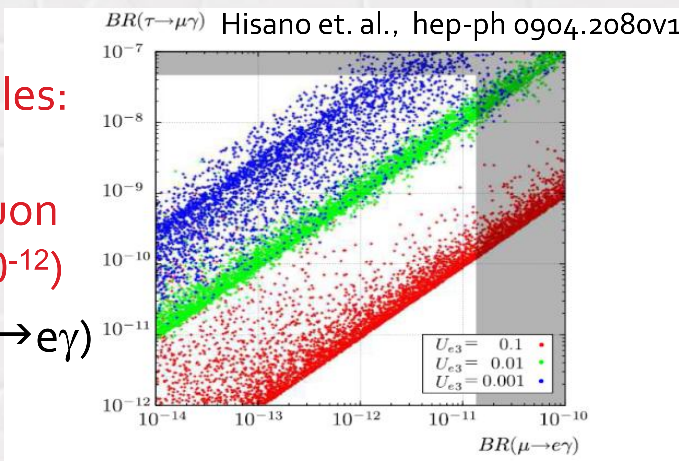


FIG. 7: $BR(\mu \to e\gamma)$ vs $BR(\tau \to \mu\gamma)$ in the $SU(5)_{RN}$ model.

Introduction(2)

By searching for various kinds of τ LFV, we can distinguish between NP models.

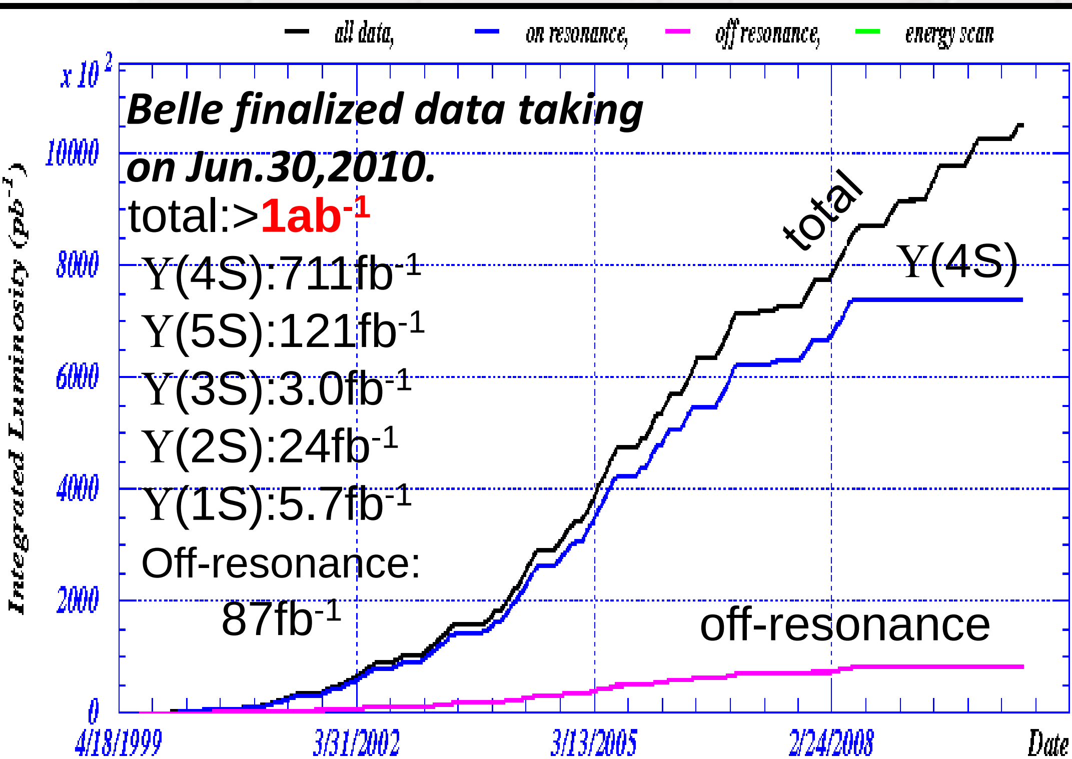
- $\tau \to \ell h h'$
  - $\tau^- \to \ell^- h^+ h'^-$: usual LFV → Higgs mediated model
  - $\tau^- \to \ell^+ h^- h'^-$: lepton number violating → Majorana ν model
- $\tau \to \Lambda h$
  - $\tau^- \to \bar{\Lambda} h^-$: B-L cons. → SUSY GUT model
  - $\tau^- \to \Lambda h^-$: B-L viol. → ??? New model ???

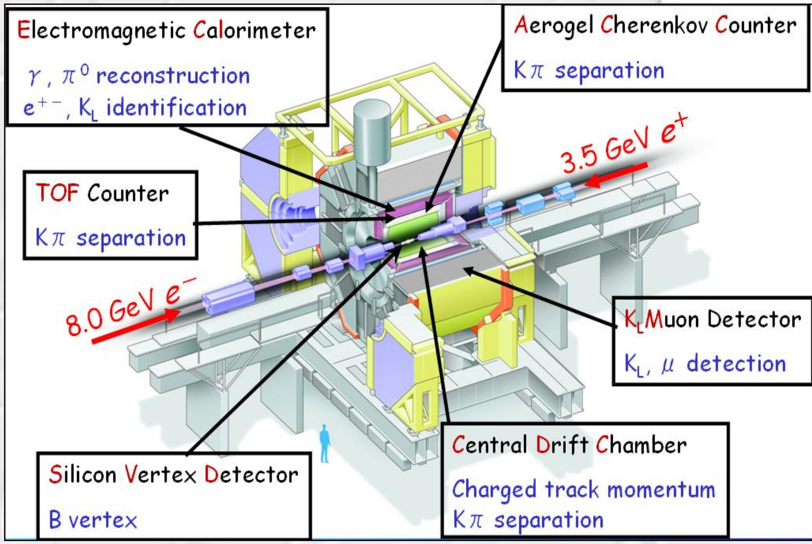
This summer we update the $\tau \to \ell h h'$ and $\tau \to \Lambda h$ searches with the full Belle data sample!

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!

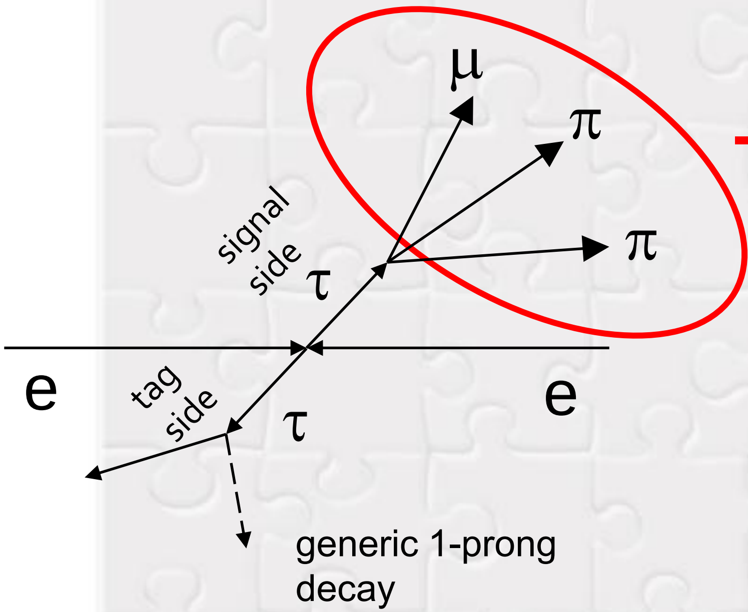
World-largest data sample!

~9×10^8 ττ at Belle

Analysis method

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

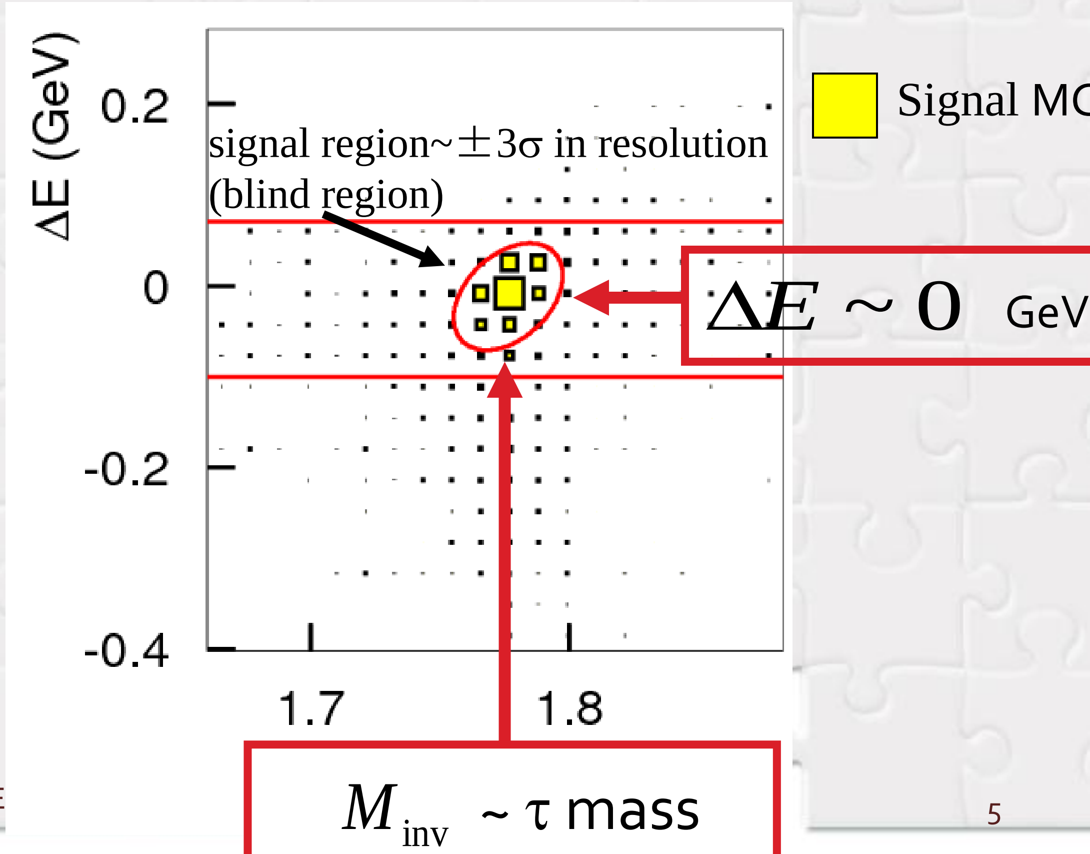
➡ clean environment



Signal Extraction

$$M_{inv} = \sqrt{E_{\mathrm{signal}}^2 - p_{\mathrm{signal}}^2}$$

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



Blind analysis
⇒Blind signal region

Estimate BG level
using sideband data and MC
If no excess is found,
set upper limits @ 90%CL
using the Cousin-Highland (CH)
frequentist counting method

Search for $\tau \to \ell h h'$

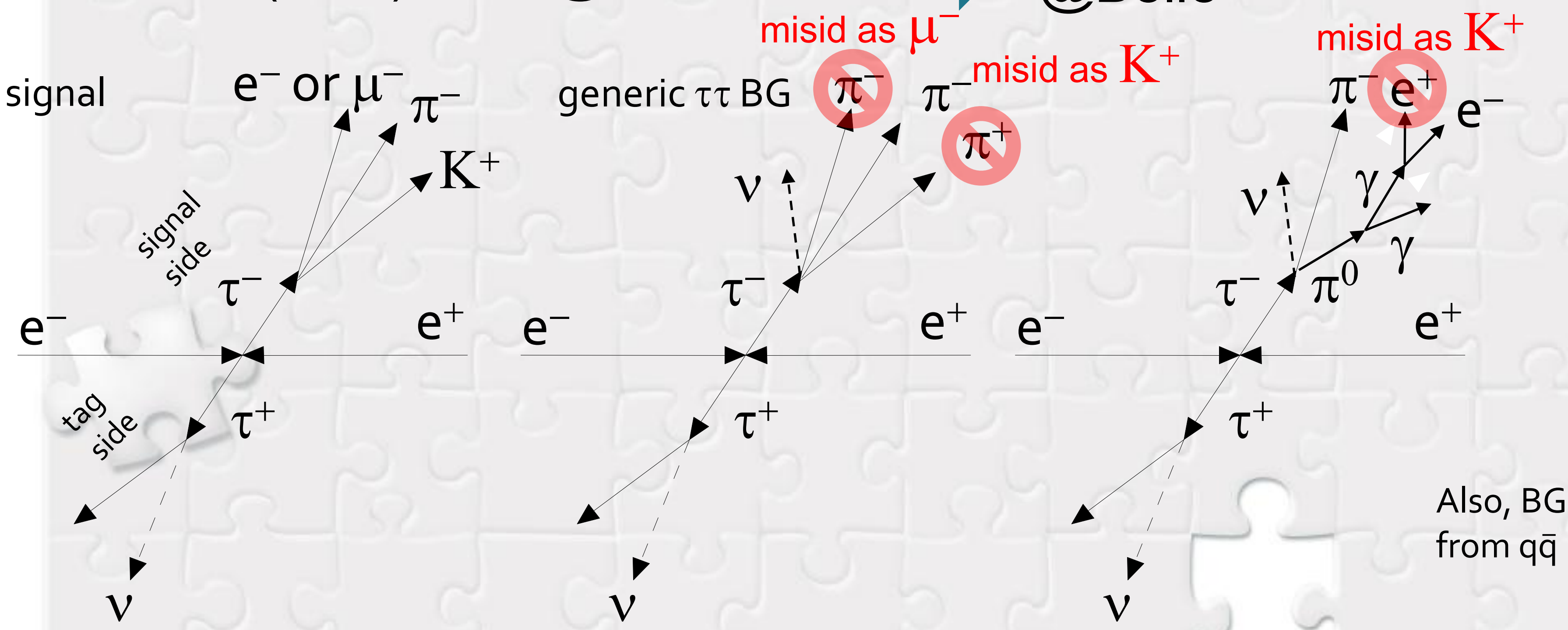
14 modes are investigated ($h, h' = \pi^{\pm}$ and $K^{\pm}$)

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

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



Missing momentum can help to reject this kind of BGs since signal has ν only on tag side.

BG rejection for $\tau \to \ell hh'$

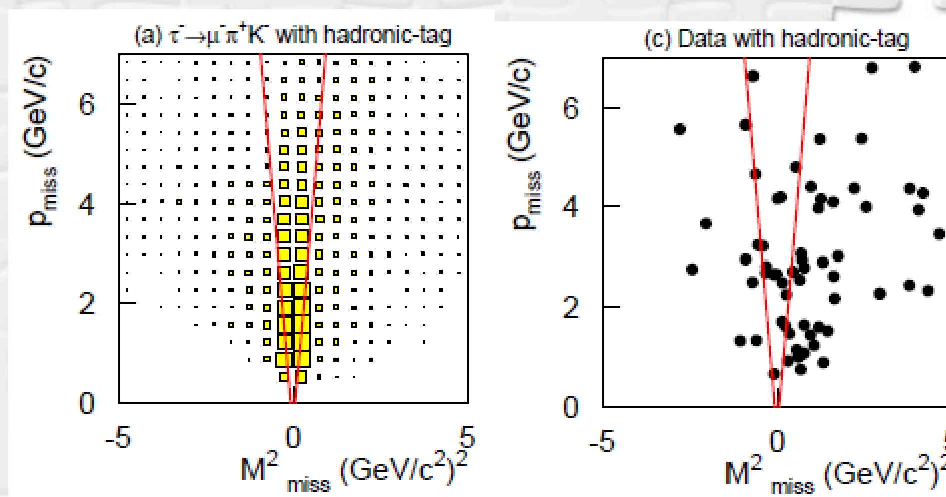
To reduce ττ and qq BG

- μπK mode

⇒ m_{miss}^2 -- p_{miss} correlation

2d selection

75% of eff. is kept while 75% of BG is rejected.



- ehh', μππ and μKK modes

⇒ m_{miss}^2 selection

90% of eff. is kept while 50% of BG is rejected.

To reduce ττ BG

- μπK mode

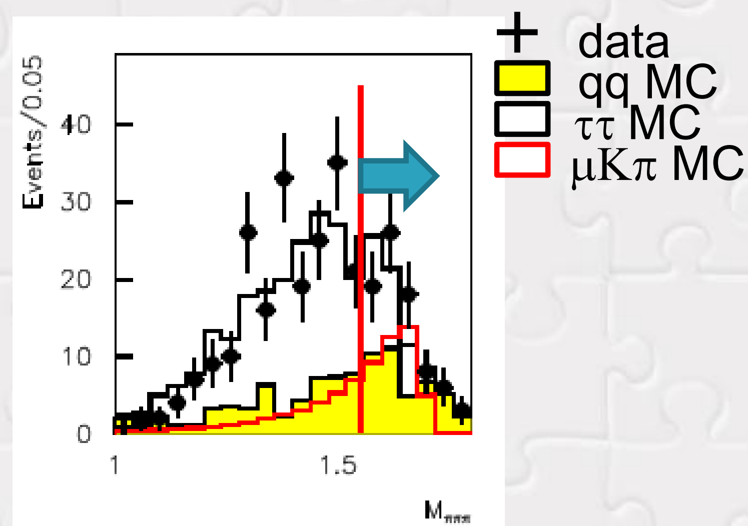
Dominant BG is from $\tau \to \pi\pi\pi\nu$ with a ππ combination misidentified as Kμ.

⇒$M_{\mu\pi K}$ is shifted into the τ-mass signal region while the original $M_{\pi\pi\pi}$ will be below the τ-mass due to the missing neutrino.

Assign πππ mass for selected events

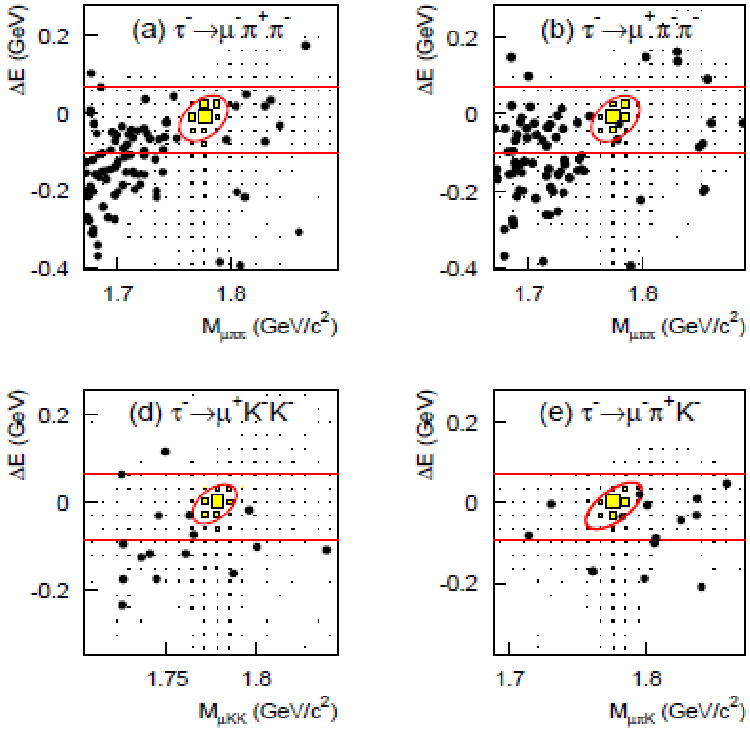
⇒ $M_{\pi\pi\pi}$>1.52 GeV/c²

65% of eff. is kept while 65% of BG is rejected.



Results for $\tau \to \ell hh'$

(preliminary)



In the signal region

1 event : in $\mu^+\pi^-\pi^-$ and $\mu^-\pi^+K^-$

no events: in other modes

$\Rightarrow$ no significant excess

Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{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

Set upper limits @90%CL:

$Br(\tau \to \ell hh') < (2.0\text{-}8.4) \times 10^{-8}$

(preliminary)

→most sensitive results

Improve our previous results by a factor of 1.8 on average

Search for $\tau \to \Lambda h / \bar{\Lambda} h$

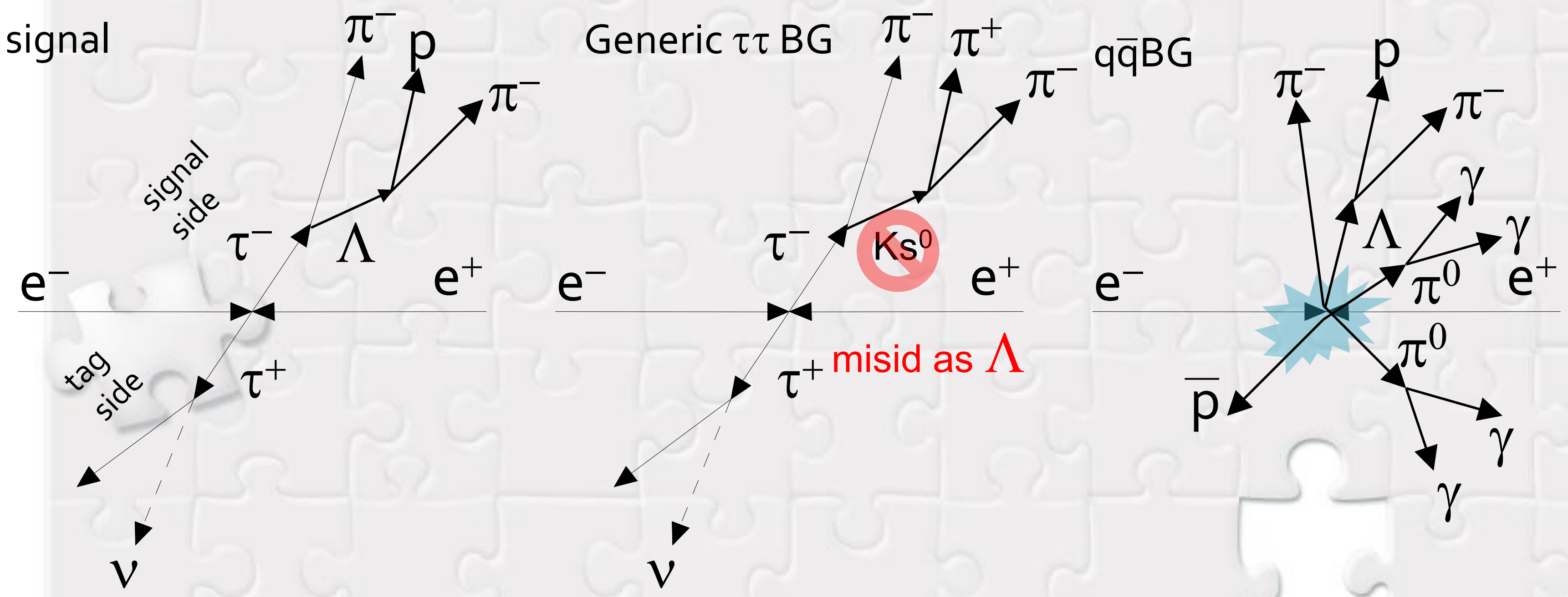
4 modes are searched for. (h=π and K)

- $\tau^- \to \bar{\Lambda} h^-$: (B-L) conserving decay
- $\tau^- \to \Lambda h^-$: (B-L) violating decay

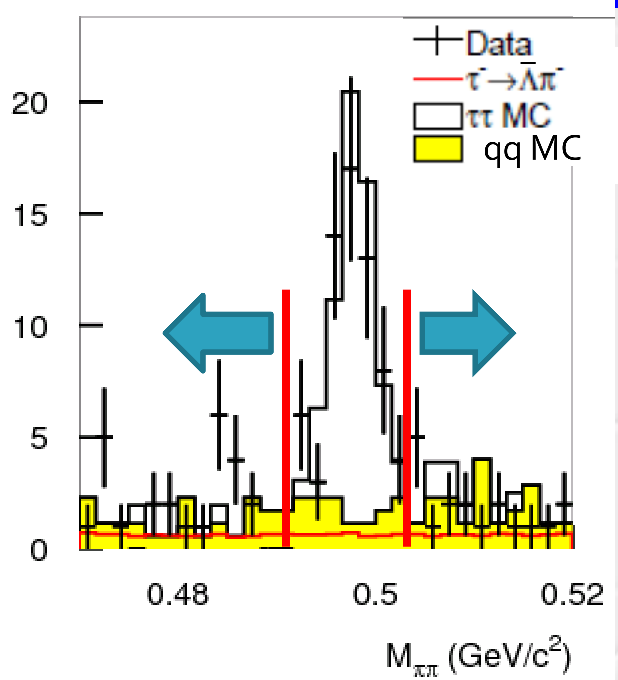
Current upper limits (no search for ΛK on Belle)

- Belle Br<(7.2-14)x10^{-8} @ 154fb^{-1}
- BaBar Br<(5.8-15)x10^{-8} @ 237fb^{-1}

update with 906fb^{-1} @Belle



BG rejection for $\tau \to \Lambda h / \bar{\Lambda} h$



<u>To reduce ττ BG including K_S^0</u>

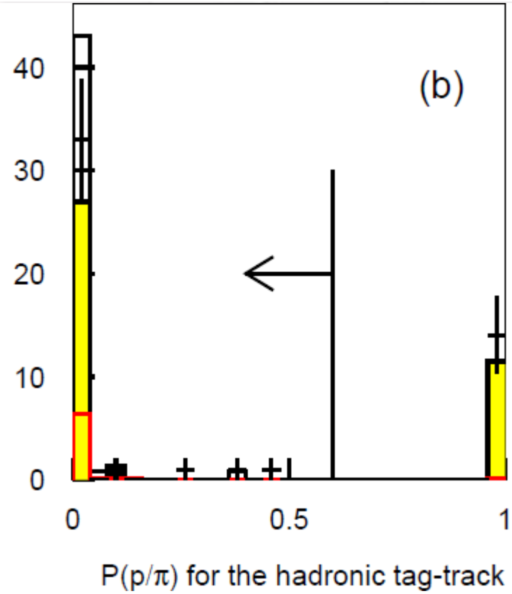
⇒ reconstruct K_S^0 and reject events that are likely to be K_S^0

85% of eff. is kept while
75% of Ks^0 BG events is rejected.

<u>To reduce $q\bar{q}$ BG including Λ</u>

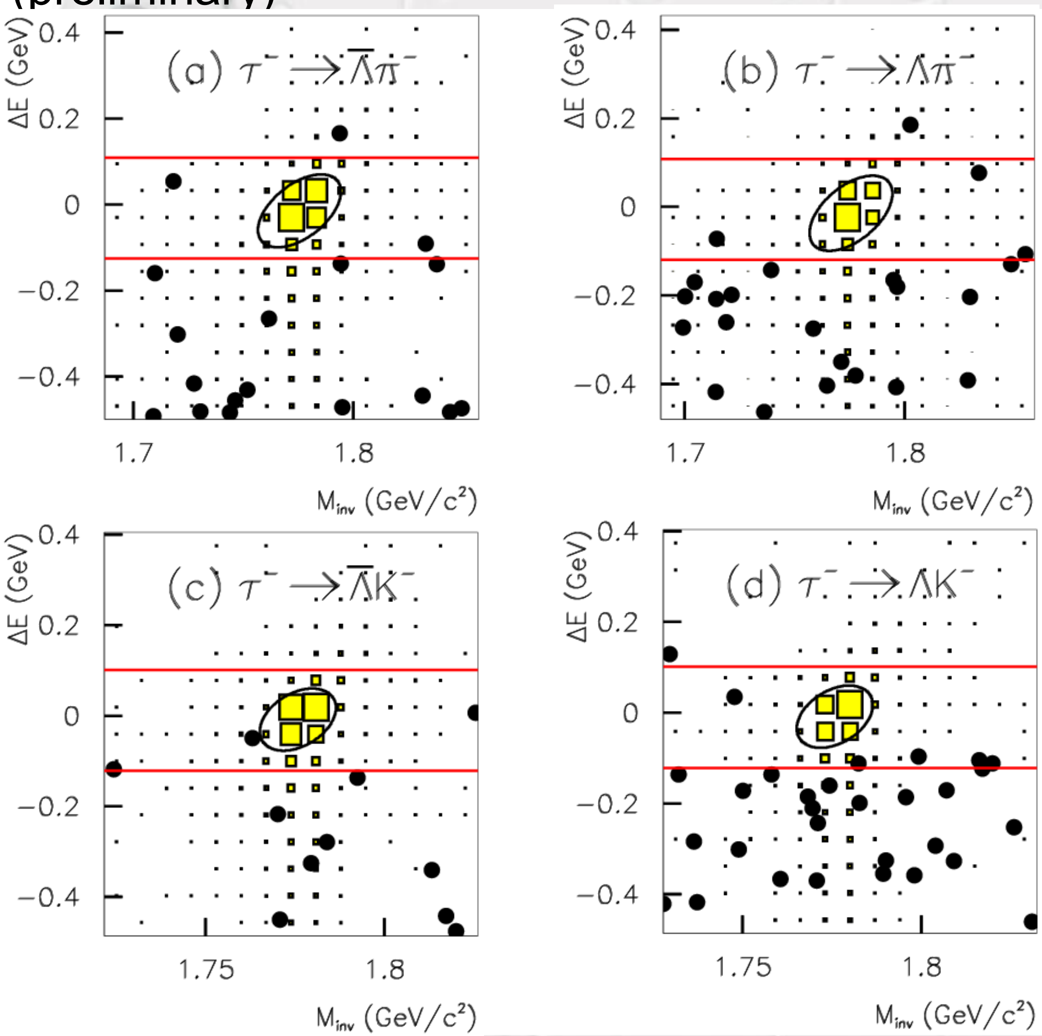
⇒ reject events with a proton in tag side (due to BN conservation, the events including a Λ tend to have baryon on the tag side.)

A third of $q\bar{q}$ BG events are rejected
while the eff. loss is negligibly small.



Results for $\tau \to \Lambda h / \bar{\Lambda} h$

(preliminary)



In the signal region

no candidate event are found

⇒ no significant excess

Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{obs}	s_{90}
$\tau^- \to \bar{\Lambda}\pi^-$	4.80	0.21 ± 0.15	8.2	0	2.3
$\tau^- \to \Lambda\pi^-$	4.39	0.31 ± 0.18	8.2	0	2.2
$\tau^- \to \bar{\Lambda}K^-$	4.11	0.31 ± 0.14	8.6	0	2.2
$\tau^- \to \Lambda K^-$	3.16	0.42 ± 0.19	8.6	0	2.1

Set upper limits@90%CL:

$Br(\tau^- \to \bar{\Lambda}\pi^-) < 2.8 \times 10^{-8}$ } (B-L) cons.
$Br(\tau^- \to \bar{\Lambda}K^-) < 3.1 \times 10^{-8}$

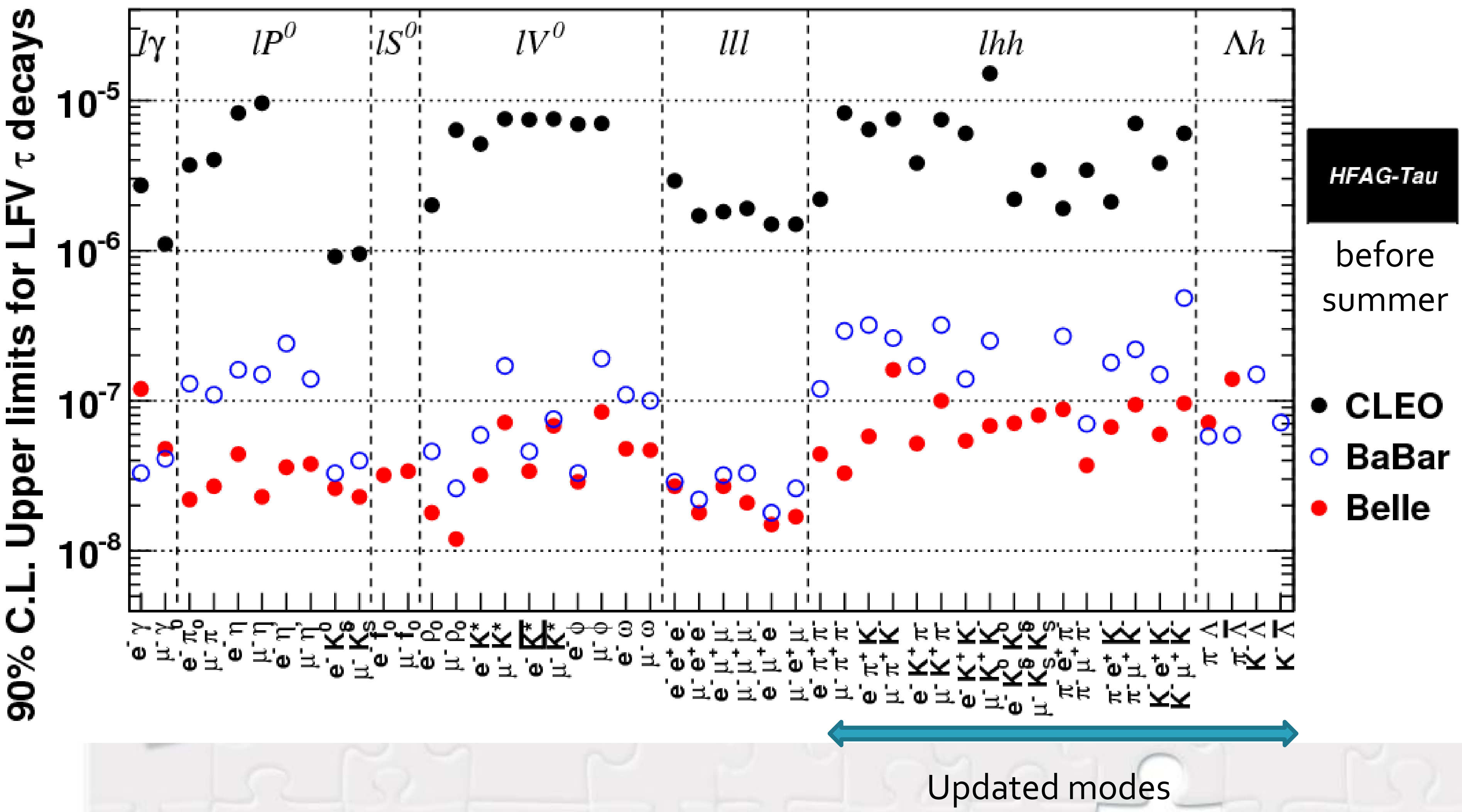
$Br(\tau^- \to \Lambda\pi^-) < 3.0 \times 10^{-8}$ } (B-L) viol.
$Br(\tau^- \to \Lambda K^-) < 4.2 \times 10^{-8}$

(preliminary)

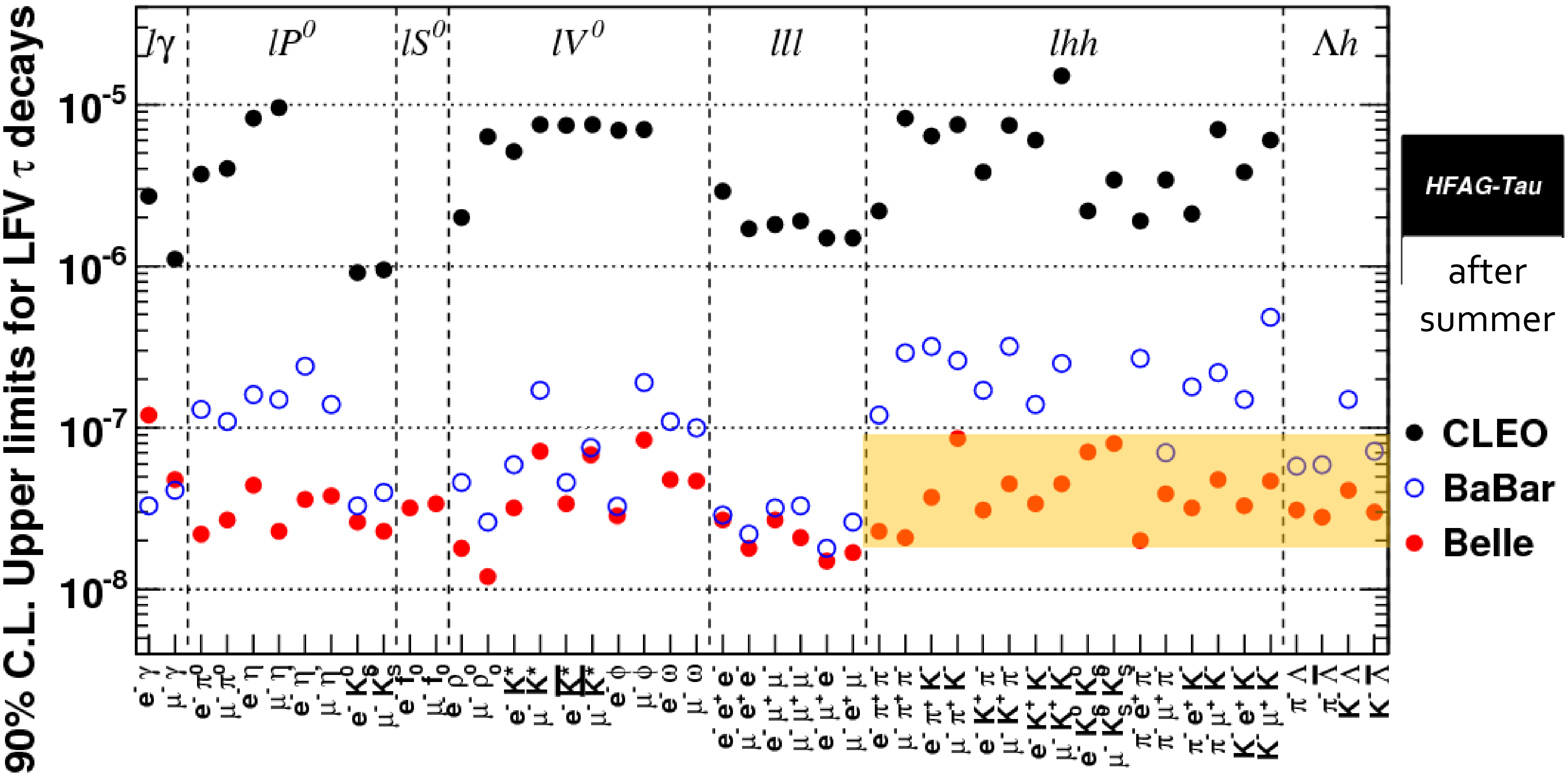
→most sensitive results

Around x(2-3) improvement from the previous BaBar results

Upper Limits on τ LFV Decay



New Upper Limits on τ LFV Decay



Reach upper limits around 10^{-8} ~100x more sensitive than CLEO

Update using full data samples will be finalized soon!

Summary

- Belle completed operation with a $1000 fb^{-1}$ data sample, which contains $\sim 10^9$ tau-pairs. This is the world's largest τ data sample.
- There are many kinds of τ LFV including lepton number (L) violation or violation of (B-L) violation, i.e., baryon number – lepton number.
  - $\tau \to \ell hh'$: $\tau^- \to \ell^- h^+ h'^-$ (L cons.)
    $\tau^- \to \ell^+ h^- h'^-$ (L viol.)
  - $\tau \to \Lambda h$: $\tau^- \to \bar{\Lambda} h^-$ (B-L cons.)
    $\tau^- \to \Lambda h^-$ (B-L viol.)
- By adding more data and studying the dominant BGs and optimizing the analyses to suppress these BGs, we have significantly improved τ LFV upper limits.

$Br(\tau \to \ell hh') < (2.0\text{-}8.4) \times 10^{-8}$ $Br(\tau \to \Lambda h) < (2.8\text{-}4.2) \times 10^{-8}$

(preliminary)

The most sensitive results for these modes.

- Almost all τ LFV modes have been investigated with the $0.9 ab^{-1}$ data sample. The last remaining ones are $\tau \to e\gamma / \mu\gamma$.

NEW					PREVIOUS				
$\tau^- \rightarrow$	lum	Eff.(%)	$N_{obs}/N_{BG}^{exp.}$	UL(x10^{-8})		lum	Eff.(%)	$N_{obs}/N_{BG}^{exp.}$	UL(x10^{-8})
$\bar{\Lambda}\pi^-$	906	4.8	$0/0.21 \pm 0.25$	2.8	Belle	154	12	$0/1.7 \pm 0.8$	13
					BaBar	237	12	$0/0.42 \pm 0.42$	5.9
$\Lambda\pi^-$	906	4.4	$0/0.31 \pm 0.18$	3.0	Belle	154	12	$0/1.7 \pm 0.8$	6.4
					BaBar	237	12	$0/0.56 \pm 0.56$	5.8
$\bar{\Lambda}K^-$	906	4.1	$0/0.31 \pm 0.14$	3.2	BaBar	237	11	$0/0.26 \pm 0.26$	7.2
ΛK^-	906	3.2	$0/0.42 \pm 0.19$	4.0	BaBar	237	9.5	$1/0.12 \pm 0.12$	15

NEW					PREVIOUS				
$\tau^- \rightarrow$	lum	Eff.(%)	$N_{obs}/N_{BG}^{exp.}$	UL($x10^{-8}$)		lum	Eff.(%)	$N_{obs}/N_{BG}^{exp.}$	UL($x10^{-8}$)
$\mu^-\pi^+\pi^-$	854	5.8	$0/0.63\pm0.23$	2.1	Belle	671	3.7	$0/1.12\pm0.38$	3.3
					BaBar	221	3.4	$3/2.99\pm0.41$	29
$e^-\pi^+\pi^-$	854	5.5	$0/0.55\pm0.23$	2.3	Belle	671	4.0	$0/0.34\pm0.15$	4.4
					BaBar	221	3.3	$0/0.81\pm0.13$	12
$\mu^-K^+K^-$	854	2.9	$0/0.51\pm0.18$	4.4	Belle.	671	2.4	$0/0.52\pm0.23$	6.8
					BaBar	221	2.2	$0/0.24\pm0.07$	25
$e^-K^+K^-$	854	4.3	$0/0.17\pm0.10$	3.4	Belle.	671	3.5	$0/0.11\pm0.08$	5.4
					BaBar	221	3.8	$0/0.22\pm0.06$	14
$\mu^-\pi^+K^-$	854	2.7	$1/0.72\pm0.27$	8.6	Belle.	671	2.6	$2/0.67\pm0.14$	16
					BaBar	221	2.9	$1/1.04\pm0.18$	26
$e^-\pi^+K^-$	854	4.0	$0/0.18\pm0.13$	3.7	Belle.	671	3.0	$0/0.33\pm0.19$	5.8
					BaBar	221	3.1	$1/0.14\pm0.06$	32
$\mu^-K^+\pi^-$	854	2.6	$0/0.64\pm0.23$	4.5	Belle.	671	2.6	$1/1.04\pm0.32$	10
					BaBar	221	3.0	$2/1.67\pm0.29$	32
$e^-K^+\pi^-$	854	4.1	$0/0.55\pm0.31$	3.1	Belle.	671	3.0	$0/0.57\pm0.19$	5.2
					BaBar	221	3.1	$0/0.32\pm0.08$	17

NEW					PREVIOUS				
$\tau^- \rightarrow$	lum	Eff.(%)	$N_{obs}/N_{BG}^{exp.}$	UL($\times 10^{-8}$)		lum	Eff.(%)	$N_{obs}/N_{BG}^{exp.}$	UL($\times 10^{-8}$)
$\mu^+\pi^-\pi^-$	854	6.6	1/0.33±0.16	3.9	Belle	671	3.8	0/0.73±0.25	3.7
					BaBar	221	3.3	0/1.46±0.27	7.0
$e^+\pi^-\pi^-$	854	6.6	0/0.37±0.18	2.0	Belle	671	3.9	1/0.10±0.07	8.8
					BaBar	221	3.4	0/0.41±0.10	27
$\mu^+K^-K^-$	854	3.0	0/0.25±0.13	4.7	Belle.	671	2.1	0/0.00+0.06 -0.00	9.6
					BaBar	221	2.1	1/0.07±0.10	48
$e^+K^-K^-$	854	4.6	0/0.06±0.06	3.3	Belle.	671	3.3	0/0.05±0.05	6.0
					BaBar	221	3.9	0/0.04±0.04	15
$\mu^+\pi^-K^-$	854	2.6	0/0.56±0.21	4.8	Belle.	671	2.6	1/1.37±0.21	9.4
					BaBar	221	2.9	0/1.54±0.25	22
$e^+\pi^-K^-$	854	4.0	0/0.46±0.21	3.2	Belle.	671	2.8	0/0.10±0.07	6.7
					BaBar	221	3.2	0/0.16±0.06	18