Search for Lepton Flavor Violating τ decays at Belle

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KEKB and Belle

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

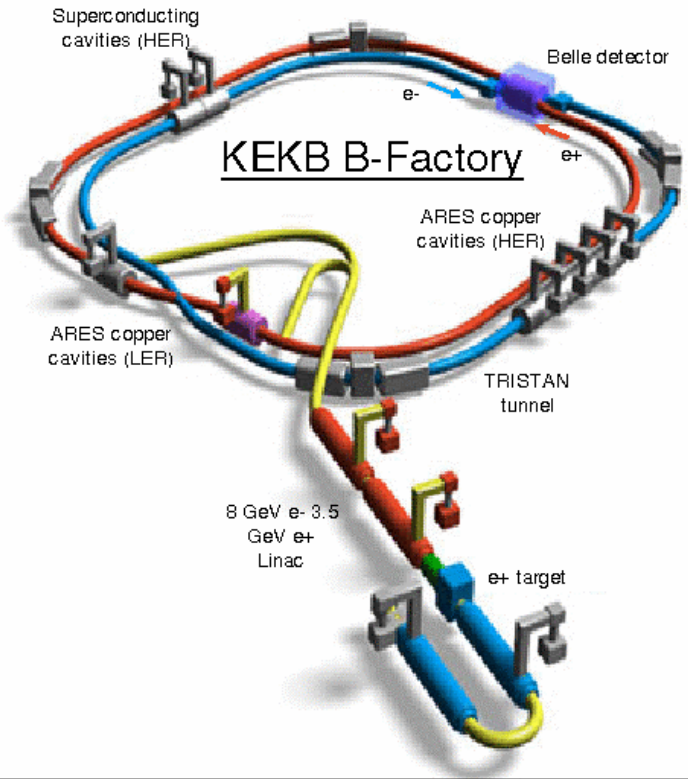
$\sigma(\tau\tau)$~0.9nb,σ(bb)~1.1nb

A B-factory is also a τ-factory!

Integrated luminosity: >1000 fb^{-1}

$\Rightarrow$>9x10^8 τ-pairs

(6~8x10^8 for this analysis)



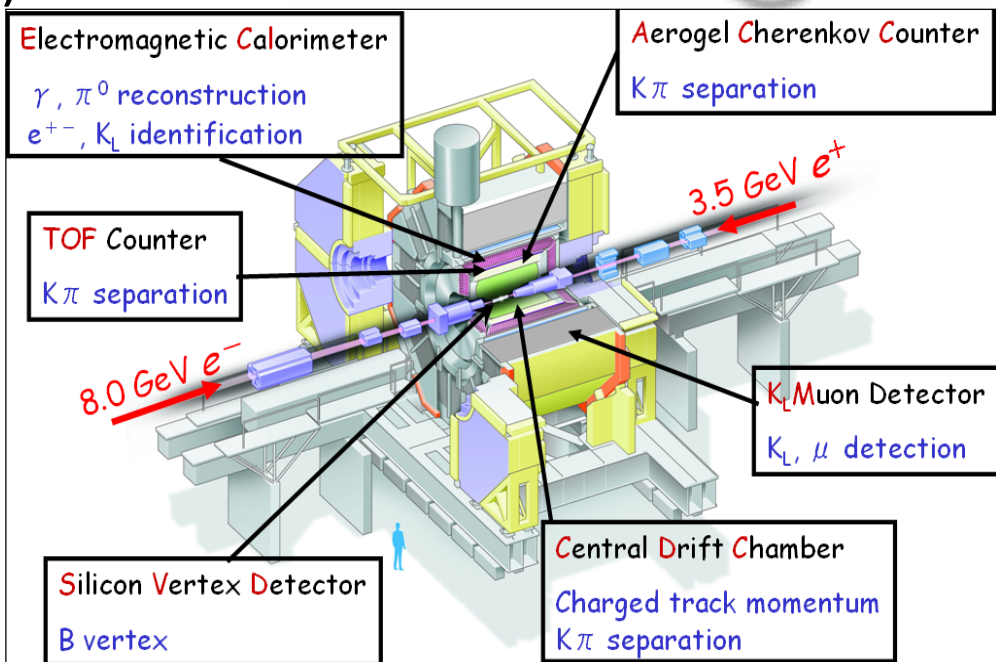
Belle Detector:

Good track reconstruction and particle identifications

Lepton efficiency:90%

Fake rate : O(0.1) % for e

O(1)% for μ



Lepton Flavor Violation

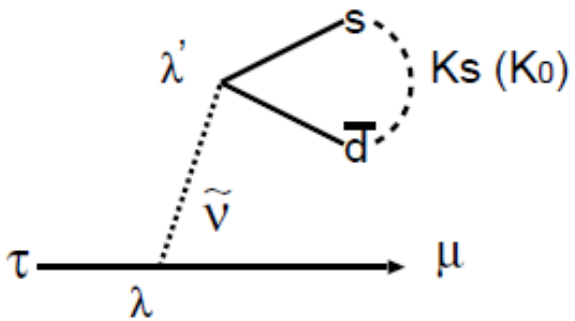
Lepton flavor violation (LFV) in charged lepton sector

Many extensions of the SM predict LFV decays.
Their branching fractions are enhanced as high as current experimental sensitivity

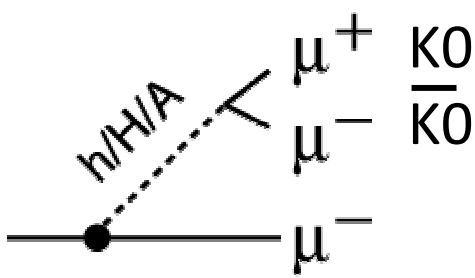
⇒Observation of LFV is a clear signature of New Physics (NP)

Tau lepton : the heaviest charged lepton

- Opens many possible LFV decay modes which depend on NP models



R-parity violation

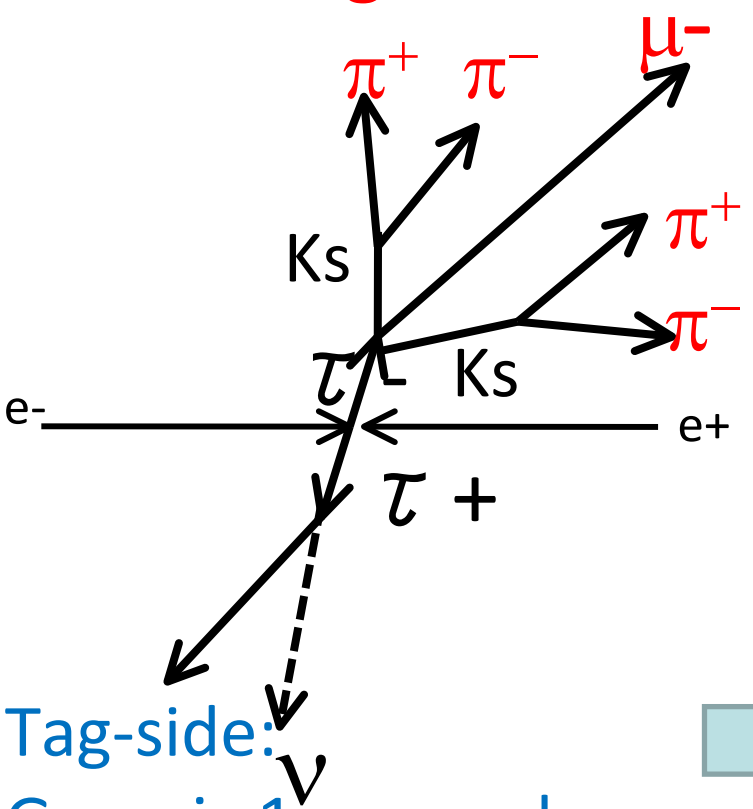


Higgs-mediation LFV

Event Selection

5-1 (3-1) prong events for lKsKs (lKs and 3leptons)

Signal side:



Tag-side:
Generic 1-prong decay
(Br(τ→1-prong+ν)~85%)

Select events with low multiplicity and separate two sides using thrust
- Signal (charged tracks from LFV)
- Tag (generic 1-prong decay)

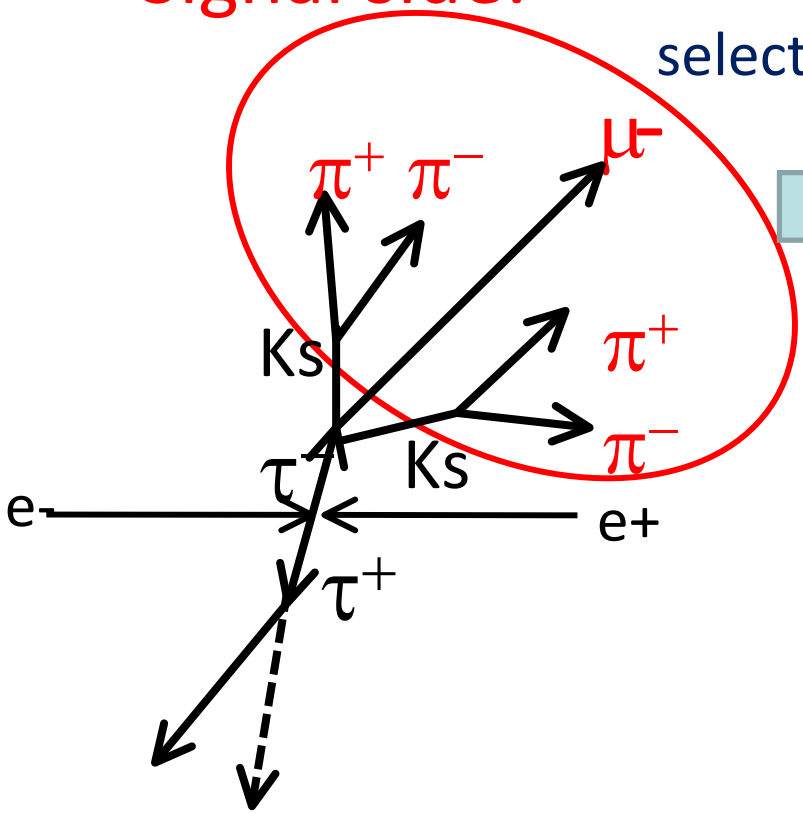
Reduce background events using PID, kinematical information

optimize the event selection for each mode separately

Analysis method

Signal side:

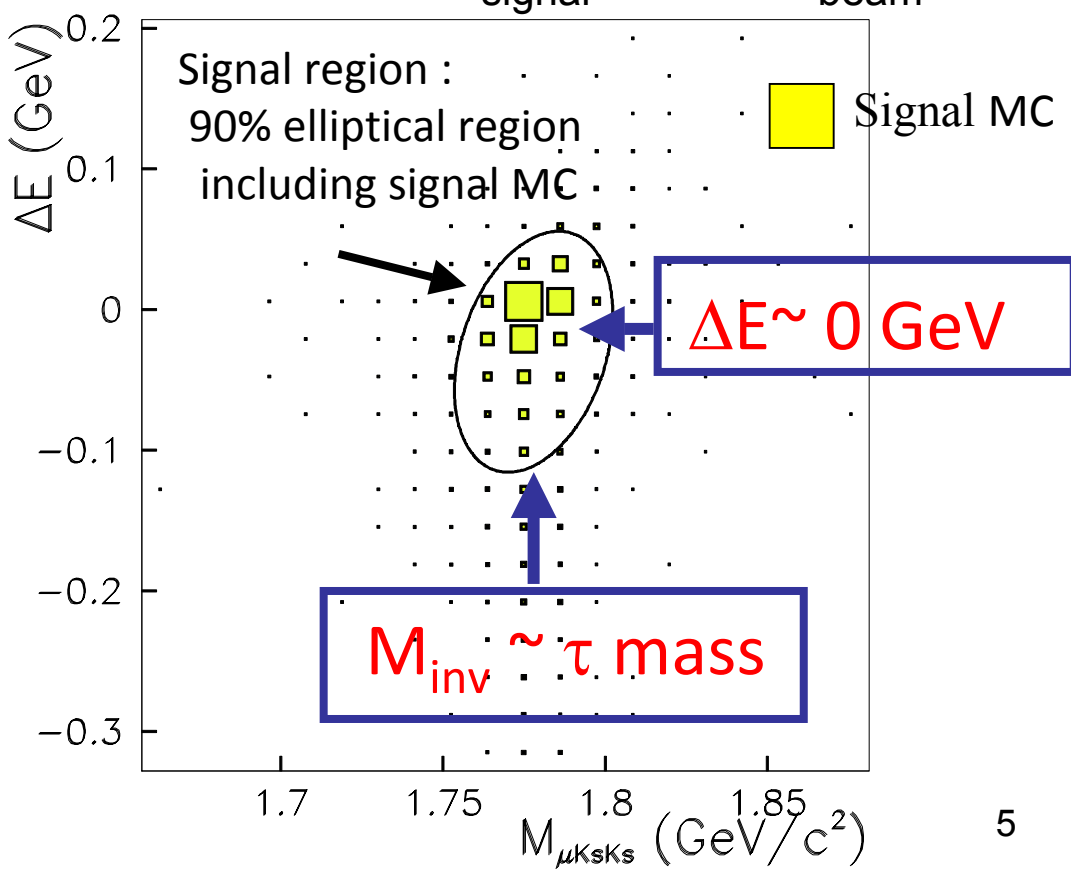
After event selection



Signal Extraction using particles in signal side

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

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



Blind analysis

⇒Blind signal region

Estimate number of BG using sideband data

Optimization of event selection

To find the LFV signature

→ we optimize the selection criteria to obtain a good sensitivity for the signal discovery, not for a lower UL.

To state 99% C.L. evidence

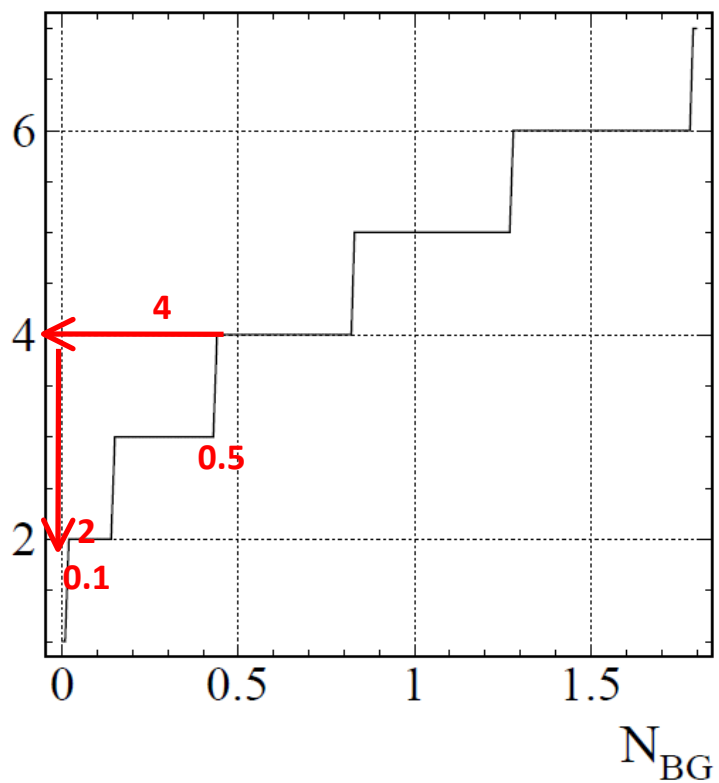
— Need 2events for N_{BG}~0.1

— Need 4events for N_{BG}~0.5

→ Diff. of effective efficiency is 2.

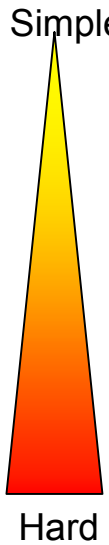
Unless the efficiency drops significantly, we set the criteria to reduce N_{BG} as much as possible.

Number of observed event, $N^{99}_{obs.}$ which we need for 99% CL evidence, as a function of Expected of BG, N_{BG}



Recent analysis

- $\tau \rightarrow lll$
- $\tau \rightarrow lK_s$
- $\tau \rightarrow lf_0$
- $\tau \rightarrow lhh'$
- $\tau \rightarrow l\gamma$



Difficulty of reducing the BG

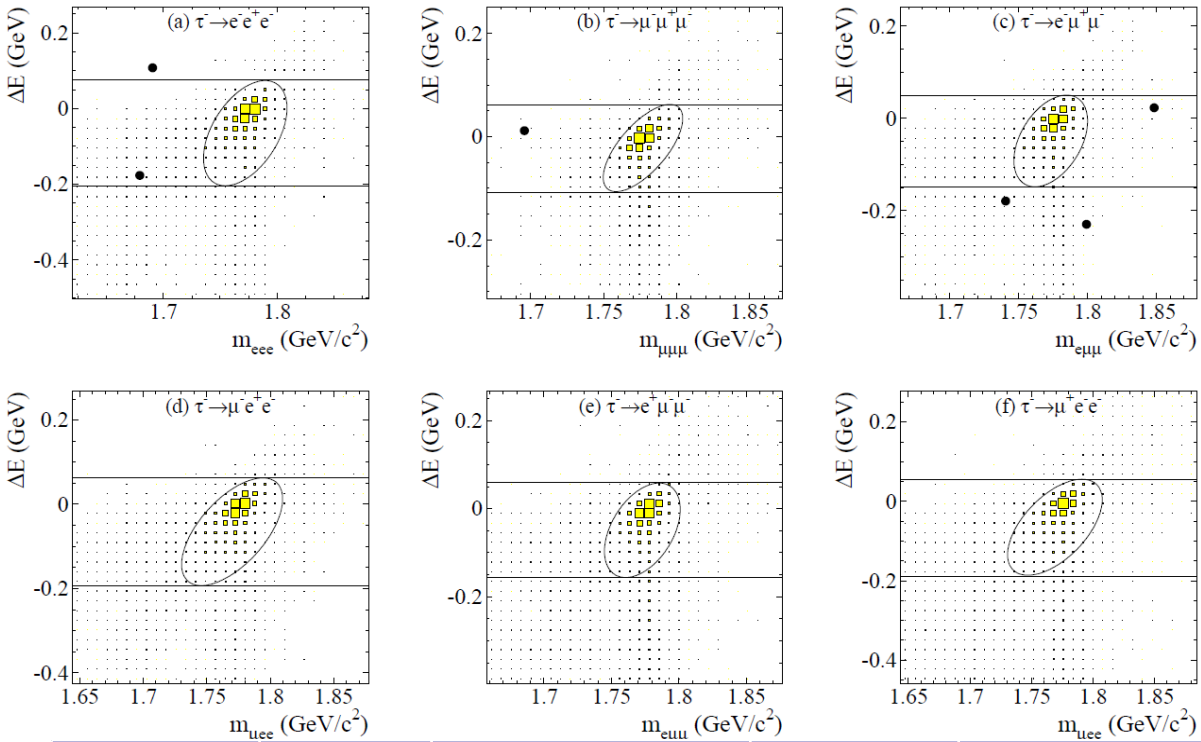
Dominant BG
μ: $\tau\tau$ and qq with π mis-ID
e: QED processes

- BG reduction with
  - Particle ID, Invariant mass cut
- Optimize for each final state individually
  - Introduce intelligent variables (likelihood, neural net etc.)

$\tau \rightarrow 3$leptons

[EPS2009,Preliminary]

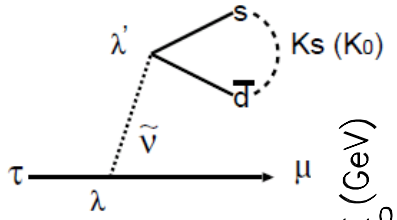
- Data: 782fb^{-1}
  - Prev.: 543fb^{-1}
- No event is found in the signal region.
- Remaining BG;
  Bhabha
  $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$
- B<(1.5-2.7)x10^{-8}
  - Improved the UL along with the luminosity from previous Belle result



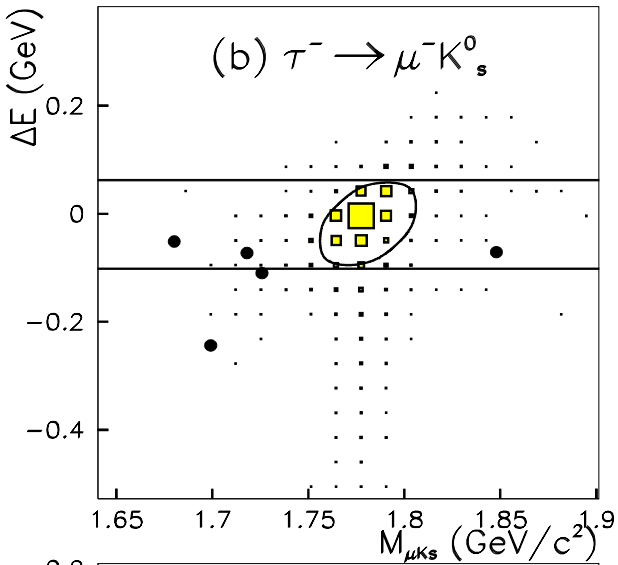
Mode	ε (%)	N_{BG}^{EXP}	σ_{syst} (%)	UL (x10^{-8})
$e^-e^+e^-$	6.0	0.21+-0.15	9.8	**2.7**
$\mu^-\mu^+\mu^-$	7.6	0.13+-0.06	7.4	**2.1**
$e^-\mu^+\mu^-$	6.1	0.10+-0.04	9.5	**2.7**
$\mu^-e^+e^-$	9.3	0.04+-0.04	7.8	**1.8**
$\mu^-e^+\mu^-$	10.1	0.02+-0.02	7.6	**1.7**
$e^-\mu^+e^-$	11.5	0.01+-0.01	7.7	**1.5**

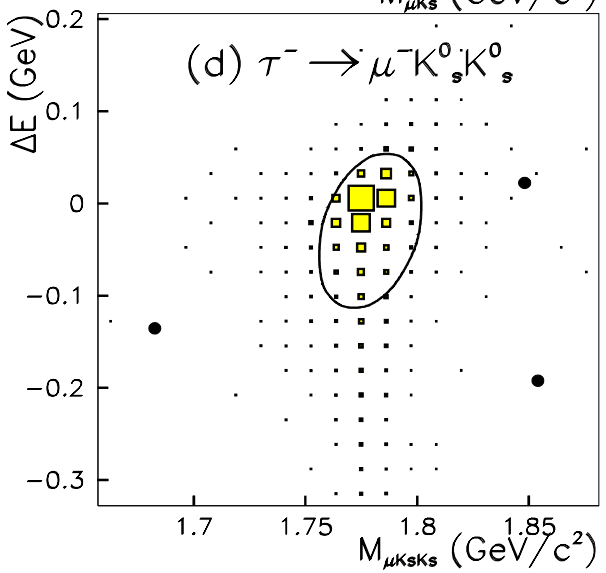
$\tau \rightarrow l K_s$ and $l K_s K_s$

- Accessible in R-parity violation [PRD66:054021,2002]
- Data: 671fb^{-1}
- Remaining BG:
  Fake lepton + real Ks from $e^+e^- \rightarrow qq$
- No events in signal region



Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{obs}	s_{90}	$\mathcal{B}$ ($\times 10^{-8}$)
$\tau^- \rightarrow e^- K^0_S$	10.2	0.18±0.18	6.6	0	2.25	2.6
$\tau^- \rightarrow \mu^- K^0_S$	10.7	0.35±0.21	6.8	0	2.10	2.3
$\tau^- \rightarrow e^- K^0_S K^0_S$	5.82	0.07±0.07	11.2	0	2.44	7.1
$\tau^- \rightarrow \mu^- K^0_S K^0_S$	5.08	0.12±0.08	11.3	0	2.40	8.0





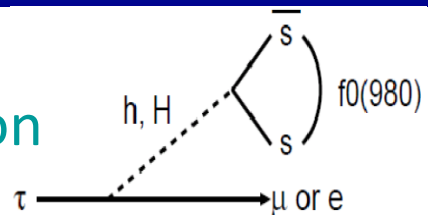
- $B(\tau \rightarrow l K^0 s) < (2.3\text{-}2.6) \times 10^{-8}$ at 90%CL
- $B(\tau \rightarrow l K^0 s K^0 s) < (7.1\text{-}8.0) \times 10^{-8}$

⇒ improve in a factor of (31-43) from CLEO [PRD66:071101R,2002]

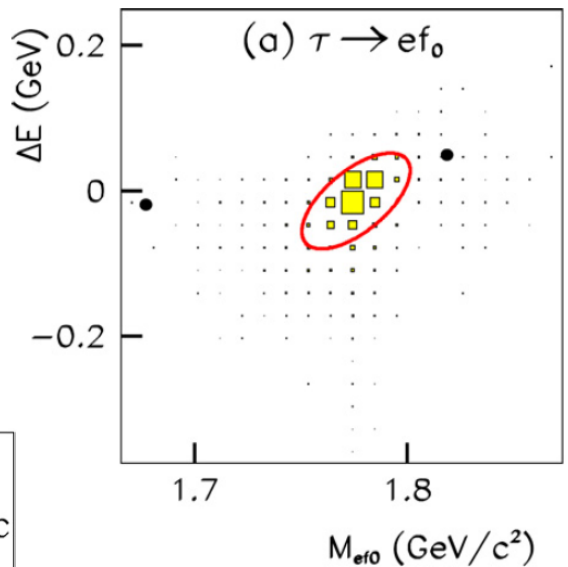
$\tau \rightarrow l f_0$

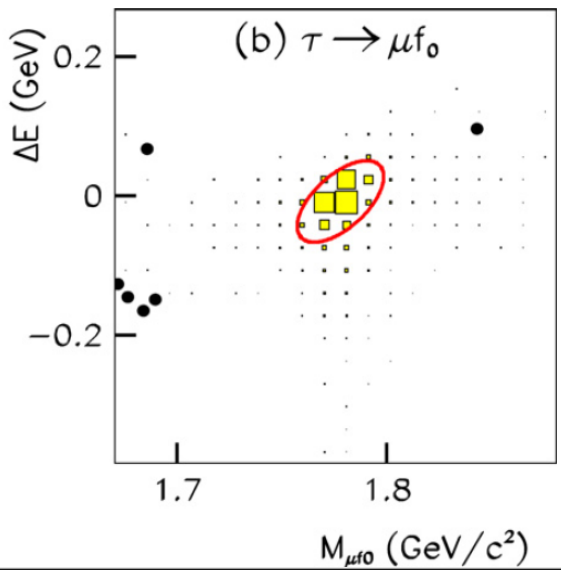
[PLB672:317,2009]

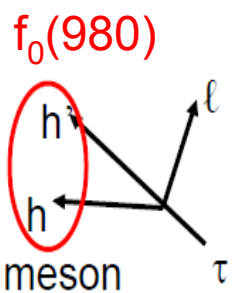
- Accessible level in Higgs mediation [PRD74:035010,2006]

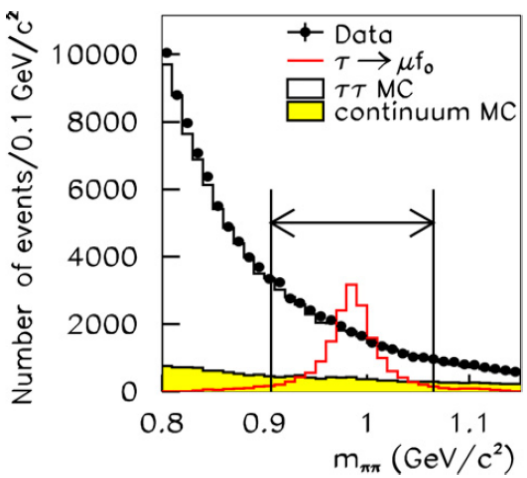


- Data: 671fb^{-1}
- $f_0(980) \rightarrow \pi^+\pi^-$ → Mass restriction reduces BG significantly.
- Remaining BG:
  $e^+e^- \rightarrow qq$ and e^+e^-qq
- $B(\tau \rightarrow l f_0) \times B(f_0 \rightarrow \pi^+\pi^-)$
  $< (3.2\text{-}3.4) \times 10^{-8}$









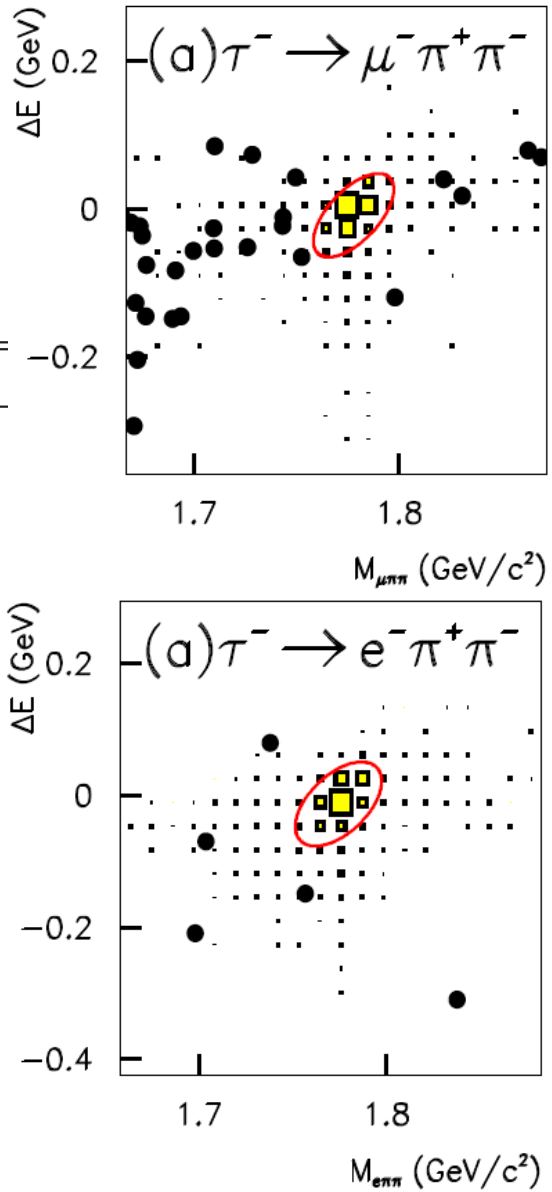
Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{obs}	s_{90}	$\mathcal{UL}(10^{-8})$
$\tau^- \rightarrow e^- f_0(980)$	5.80	0.10 ± 0.07	11.5	0	2.41	3.4
$\tau^- \rightarrow \mu^- f_0(980)$	6.02	0.11 ± 0.08	10.8	0	2.40	3.2

τ→lhh'

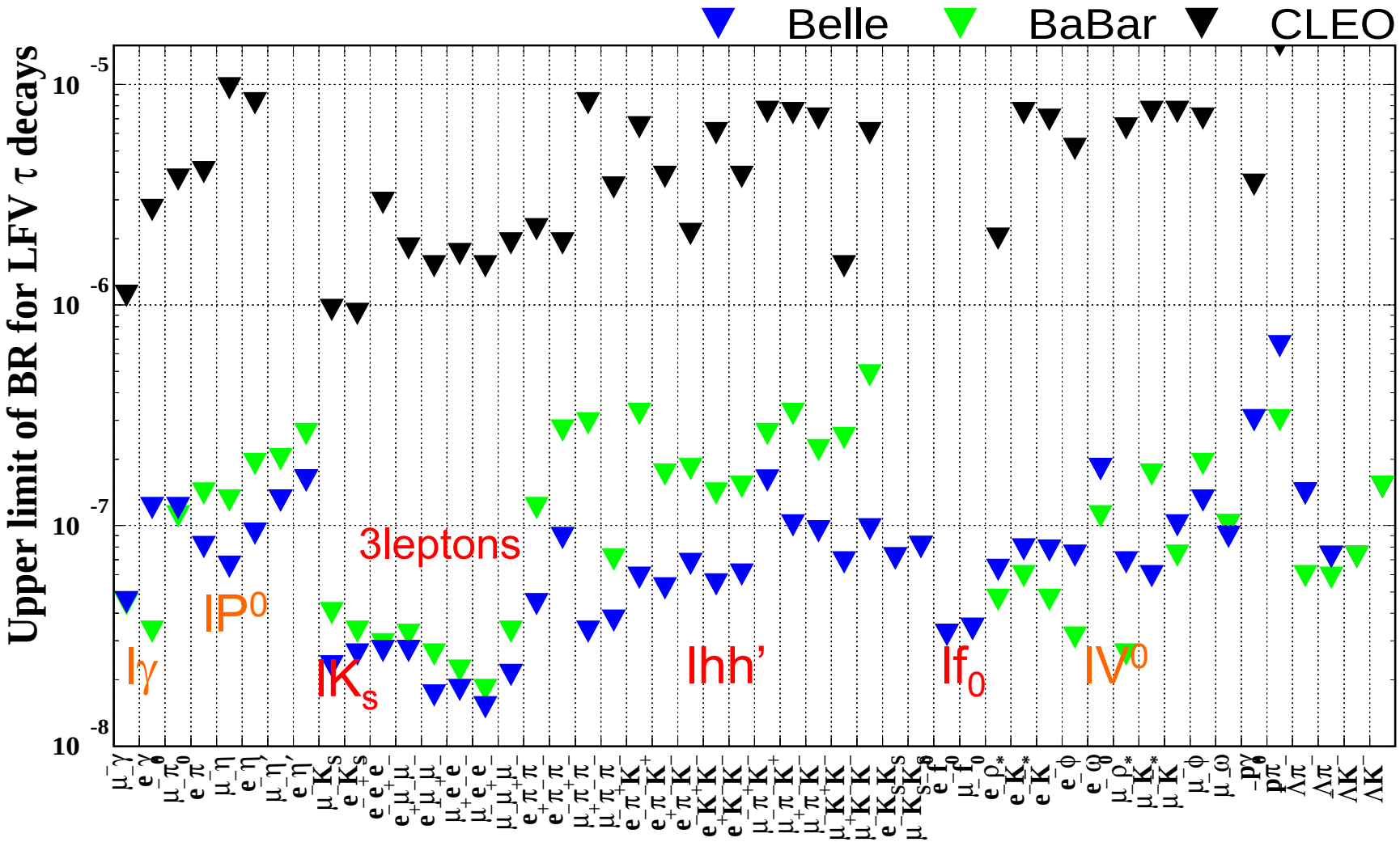
- Data: 671fb^{-1}
- Dominant BG:
  τ→πππν with mis-ID, e^+e^-→qq
- B<(3.3-16)x10^{-8}

arXiv:0908.3156 [hep-ex]

Mode	ε (%)	$N_{\rm BG}$	$\sigma_{\rm syst}$ (%)	$N_{\rm obs}$	s_{90}	$\mathcal{B}$ (10^{-8})
$\tau^- \to \mu^-\pi^+\pi^-$	3.69	1.12 ± 0.38	5.9	0	1.53	3.3
$\tau^- \to \mu^+\pi^-\pi^-$	3.84	0.73 ± 0.25	5.9	0	1.77	3.7
$\tau^- \to e^-\pi^+\pi^-$	3.99	0.34 ± 0.15	6.0	0	2.15	4.4
$\tau^- \to e^+\pi^-\pi^-$	3.91	0.10 ± 0.07	6.0	1	4.21	8.8
$\tau^- \to \mu^-K^+K^-$	2.40	0.52 ± 0.23	6.7	0	1.92	6.8
$\tau^- \to \mu^+K^-K^-$	2.07	0.00 ± 0.06	6.8	0	2.46	9.6
$\tau^- \to e^-K^+K^-$	3.50	0.11 ± 0.08	6.5	0	2.35	5.4
$\tau^- \to e^+K^-K^-$	3.28	0.05 ± 0.05	6.6	0	2.43	6.0
$\tau^- \to \mu^-\pi^+K^-$	2.63	0.67 ± 0.14	6.3	2	5.05	16
$\tau^- \to e^-\pi^+K^-$	3.02	0.33 ± 0.19	6.4	0	2.12	5.8
$\tau^- \to \mu^-K^+\pi^-$	2.60	1.04 ± 0.32	6.3	1	3.34	10
$\tau^- \to e^-K^+\pi^-$	2.98	0.57 ± 0.19	6.4	0	1.90	5.2
$\tau^- \to \mu^+K^-\pi^-$	2.61	1.37 ± 0.21	6.3	1	3.16	9.4
$\tau^- \to e^+K^-\pi^-$	2.83	0.10 ± 0.07	6.4	0	2.40	6.7



LFV results



- Reach the sensitivity of $O(10^{-8})$

Effect to physics models

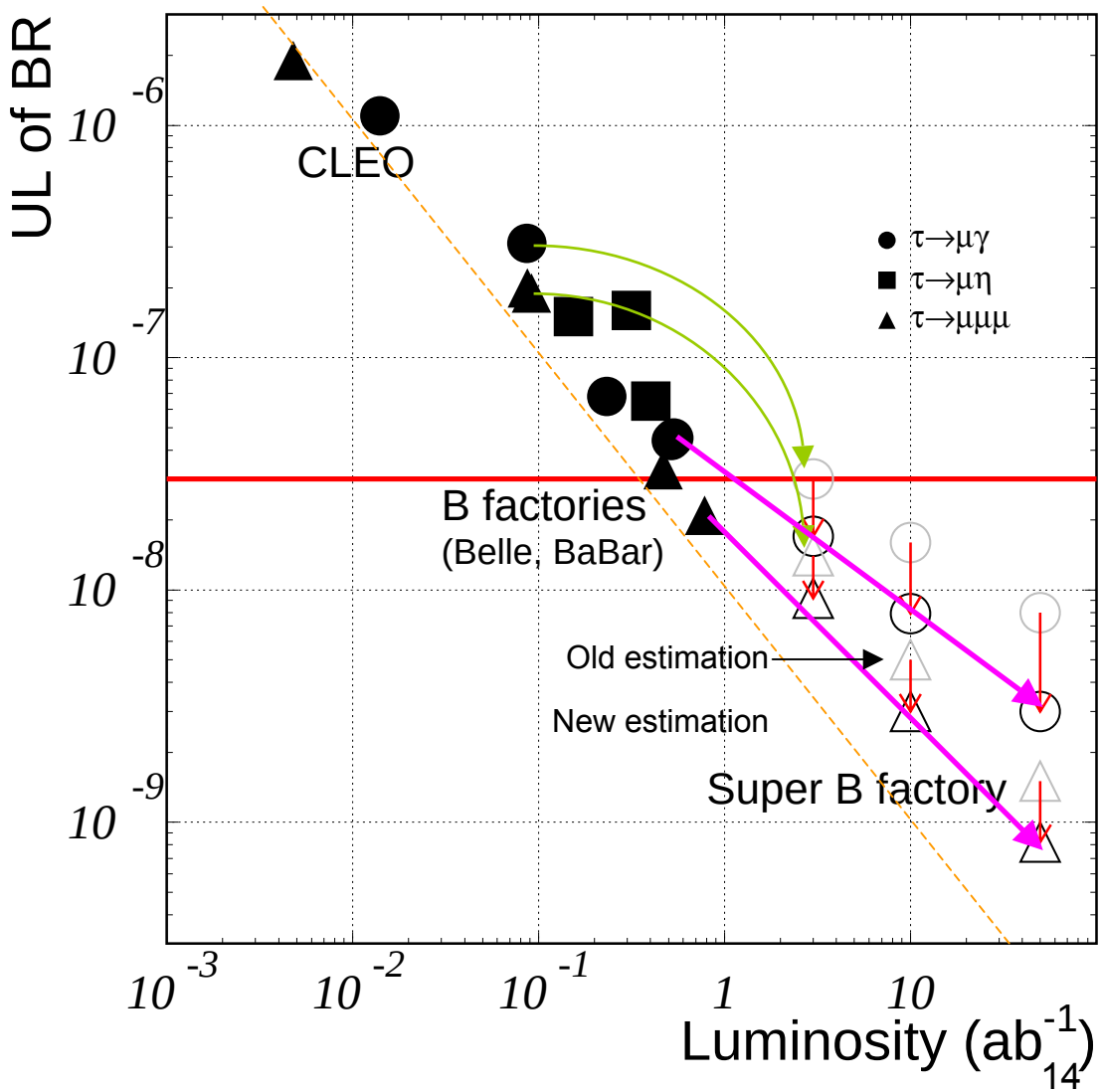
- Experimental results have already ruled out some parts of the parameter space.
  - Exclude large tanβ, small SUSY/Higgs mass

	reference	$\tau \to \mu\gamma$	$\tau \to \mu\mu\mu$
SM+ ν mixing	PRD45(1980)1908, EPJ C8(1999)513	Undetectable	
SM + heavy Maj ν_R	PRD 66(2002)034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547(2002)252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68(2003)033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66(2002)115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566(2003)217	10^{-10}	10^{-7}

  - Accessing other models and other parameter space

Future prospects

- In super B-factory, N_τ will be $>10^{10}$.
- Sensitivity depends on BG level.
  - Recent improvement of the analysis
    (BG understanding, intelligent selection)
    → Improve achievable sensitivity
- $B(\tau \to \mu\mu\mu) \sim O(10^{-10})$ at $50ab^{-1}$
- Improvement of BG reduction is important.
  - Beam BG
  - Resolution



Summary

- Search for LFV τ decays using ~10^9 τ decays
  - 48 modes are investigated.
- No evidence is observed yet.
- Upper limits on branching ratio around O(10^{-8})
  - B($\tau \rightarrow \mu\mu\mu$)<2.1x$10^{-8}$, B($\tau \rightarrow \mu K_S$)<2.3x$10^{-8}$, etc.
  - Exploring some new-physics parameters space.
  - Optimization for BG reduction is important.

- Plan
  - Finalize LFV search with full data set
  - Hadronic decay
    - Decay structure for hadronic decay with Kaon
  - Rare decay, CPV decay, EDM etc.

Luminosity

Peak Luminosity $2.1 \times 10^{34} cm^{-2} s^{-1}$

⇒ World record!!!

Integrated luminosity: >1000 fb^{-1}

⇒>9×10^8 τ-pairs

(6~8×10^8 for this analysis)