Lepton Flavor Violation at Belle and BelleII

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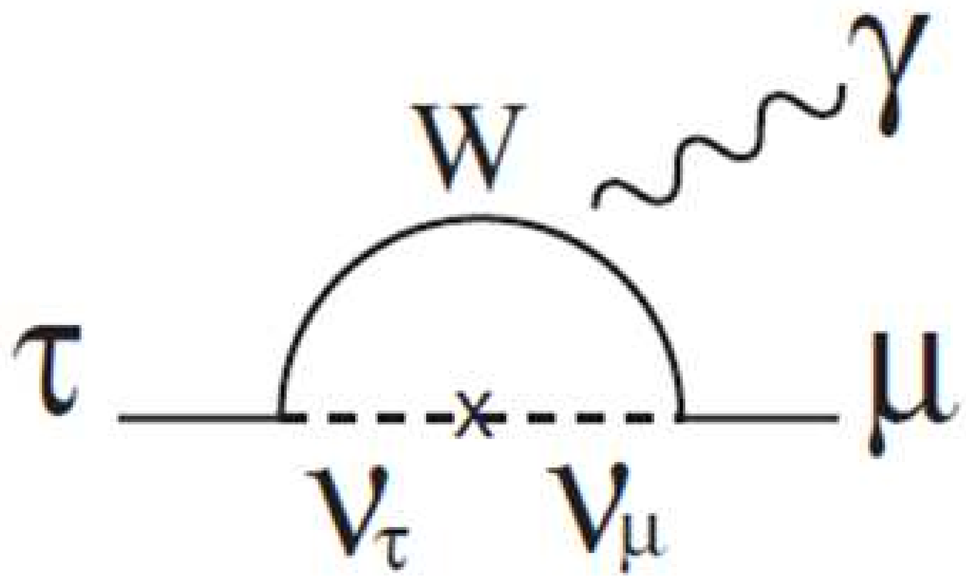
Outline

1. Introduction
2. LFV studies at B factories
3. Prospects for BelleII
4. Conclusions

Searches for New Physics (NP) in the Lepton Sector – I

In Standard Model (SM) Lepton Flavor Violation (LFV) is strongly suppressed:

$$\mathcal{B}(\tau^- \to \mu^- \gamma) \sim \mathcal{O}(10^{-54})$$



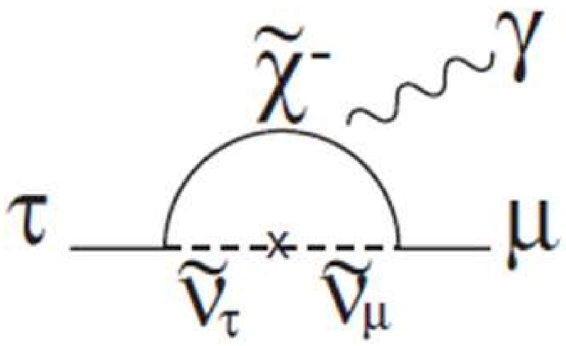
Effects of NP may enhance this probability

Searches for New Physics (NP) in the Lepton Sector – II

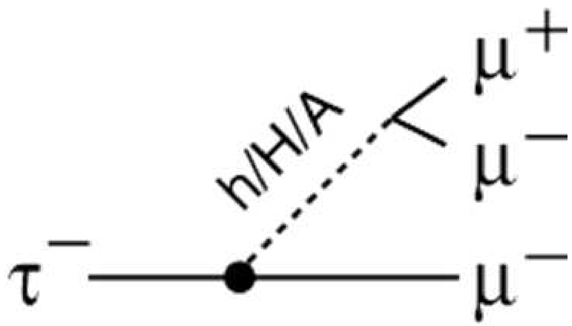
Neutrino oscillations, in particular $\nu_\mu \to \nu_\tau$ oscillations with a big mixing angle $\Rightarrow$ searches for large $\mu - \tau$ LFV, e.g., $\tau^- \to \mu^-\gamma$

In schemes with inverted hierarchy $\tau - e$ is also possible, e.g., $\tau^- \to e^-\gamma$

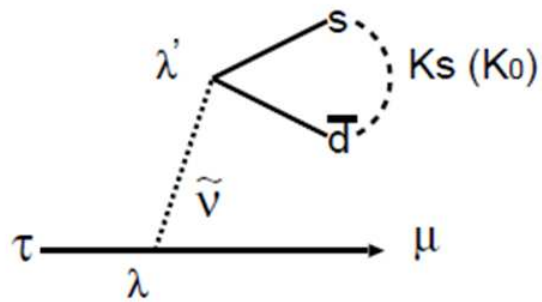
Many models consider SM extensions with enhanced LFV:
predicted $\mathcal{B}(\tau^- \to \mu^-\gamma)$ reach $10^{-8} - 10^{-7}$



SUSY



Higgs mediation



R-parity violation

Searches for New Physics (NP) in the Lepton Sector – III

For a muon, two LFV decays only are possible: $\mu^- \to e^-\gamma$ and $\mu^- \to e^-e^+e^-$

τ lepton is heavy $\Rightarrow$ A lot of decays possible!

It can decay to leptons only:

$\tau^- \to \mu^-\gamma$, $\tau^- \to e^-\gamma$,

$\tau^- \to \mu^-\mu^+\mu^-,\ \mu^-e^+e^-,\ \mu^-\mu^+e^-,\ \mu^-\mu^-e^+,\ \mu^+e^-e^-,\ e^+e^-e^-$

or to a mixture of leptons and hadrons:

$e^-h^0,\ \mu^-h^0,\ h = \pi,\ \eta,\ \eta',\ \rho,\ \omega,\ \phi,\ K^*(892),\ \ldots$

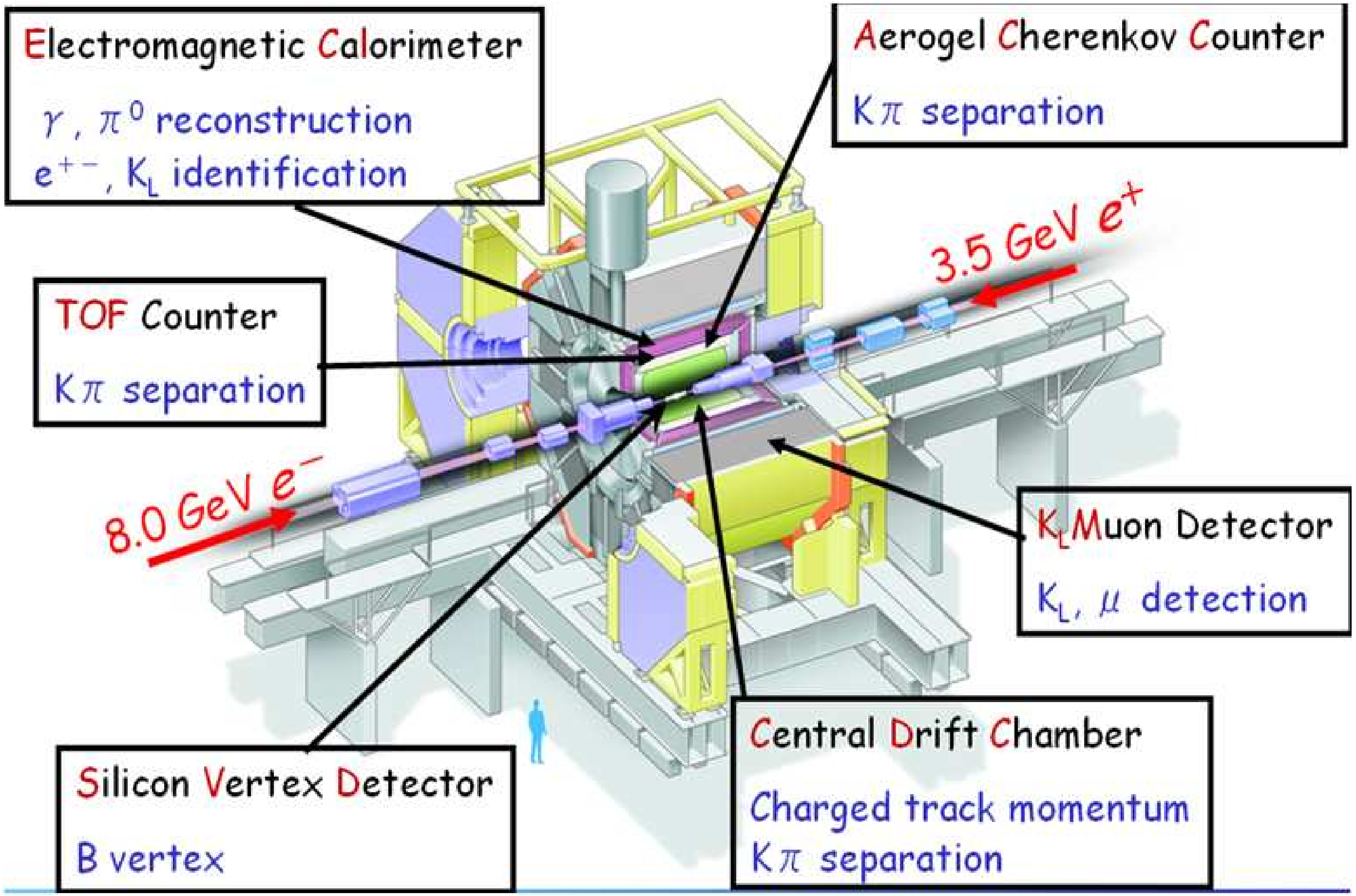
or to final states with baryons:

$\overline{p}\gamma,\ \overline{p}\mu^+\mu^-,\ p\mu^-\mu^-,\ \overline{p}h^0,\ \Lambda\pi^-,\ \ldots$

There have also been searches for l^-a^0, where a^0 is a light boson

In total, 61 various LFV modes have been searched for

Belle Detector



KEKB achieved a luminosity of $2.1 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Belle collected ~ 1 ab^{-1} or $\sim 10^9$ $\tau^+\tau^-$ events

How Do We Search for LFV τ Decays?

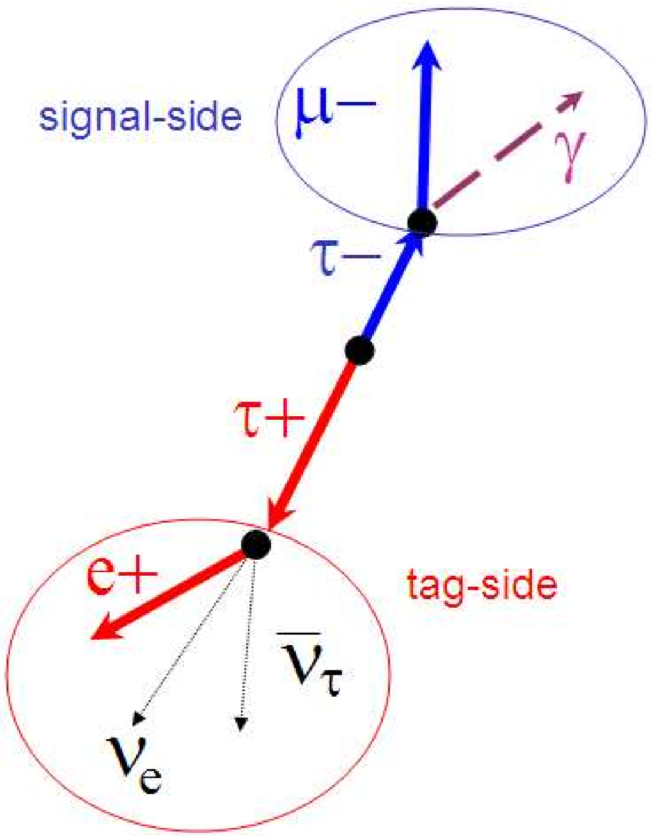
- At $\Upsilon(4S)$ (10.58 GeV) $\sigma(e^+e^- \to \tau^+\tau^-) = 0.92$ nb $\Rightarrow$ 100 fb^{-1} provides $N_{\tau\tau} = 92 \times 10^6$.
- We divide the event space by the plane perpendicular to the thrust axis into two hemispheres – "tag" side , in which some ordinary τ decay (usually 1-prong modes are selected) is observed and "signal" side , in which we try to completely reconstruct a neutrinoless LFV τ decay.
- Decays we are searching for are very rare ($\mathcal{P} < 10^{-7}$) $\Rightarrow$ mostly background (BG) is detected in the "signal" side. We apply various kinematical, topological and PID cuts to suppress BG.
- We compare various distributions in data (the sidebands) with MC to be sure that we completely understand BG (blind analysis)
- We calculate the branching ratio or place an upper limit: $\mathcal{B} = N_{\rm sig}/2N_{\tau\tau}\epsilon$, $N_{\rm sig}$ – signal yield, ϵ – acceptance

Important Technicalities

$$\mathcal{B} = \frac{N_{\rm sig}}{2N_{\tau\tau}\epsilon}$$

- ϵ is currently calculated assuming the uniform phase space distribution of the final particles
- Reasonable interpretation requires some model assumptions about the currents
- Interesting model-independent analysis for $\tau \to l_1 l_2 l_3$ in B.M. Dassinger, Th. Feldmann, Th. Mannel, S. Turczyk, JHEP 0710 (2007) 039
- Detailed analysis of $\tau^- \to \mu^-\mu^+\mu^-$ in A. Matsuzaki, A.I. Sanda, Phys. Rev. D77, 073003 (2008)

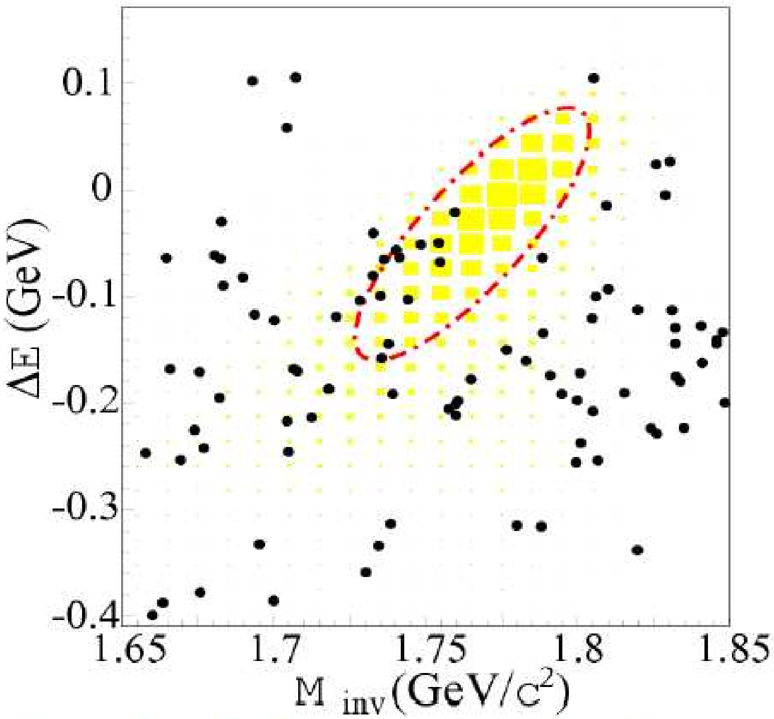
Search for $\tau \to \mu\gamma$ – I



$$m_{\rm inv} = \sqrt{E^2_{\mu\gamma} - p^2_{\mu\gamma}} \quad \Delta E = E^{\rm CM}_{\mu\gamma} - E^{\rm CM}_{\rm beam}$$

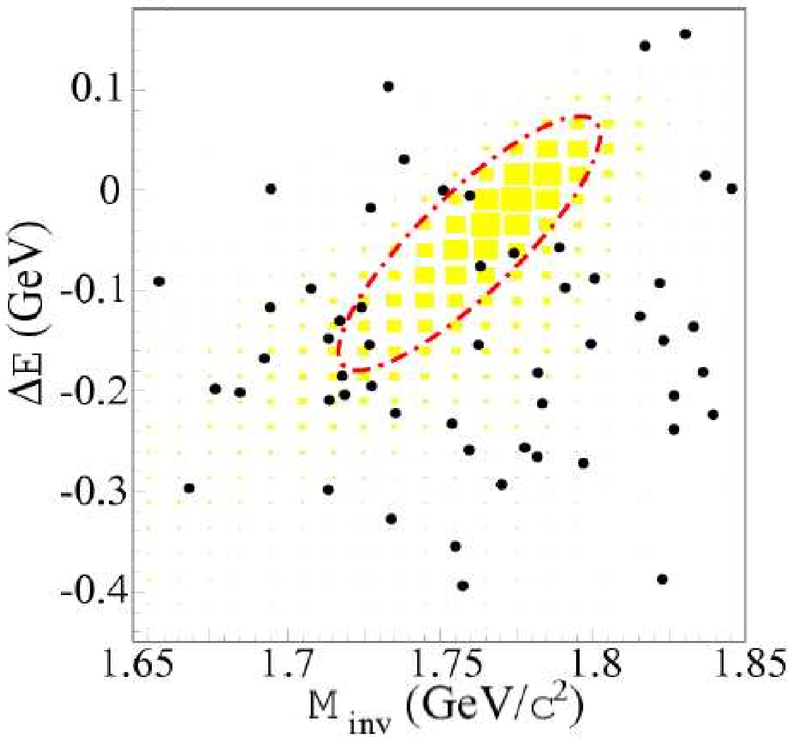
Search for $\tau \to \mu\gamma$ – II

τ→μγ



– Br<4.5x10^{-8} at 90%C.L.

τ→eγ



– Br<1.2x10^{-7} at 90%C.L.

Efficiencies: 5.1% for $\mu^-\gamma$ and 3.0% for $e^-\gamma$

K. Hayasaka et al., Phys. Lett. B666 (2008) 16

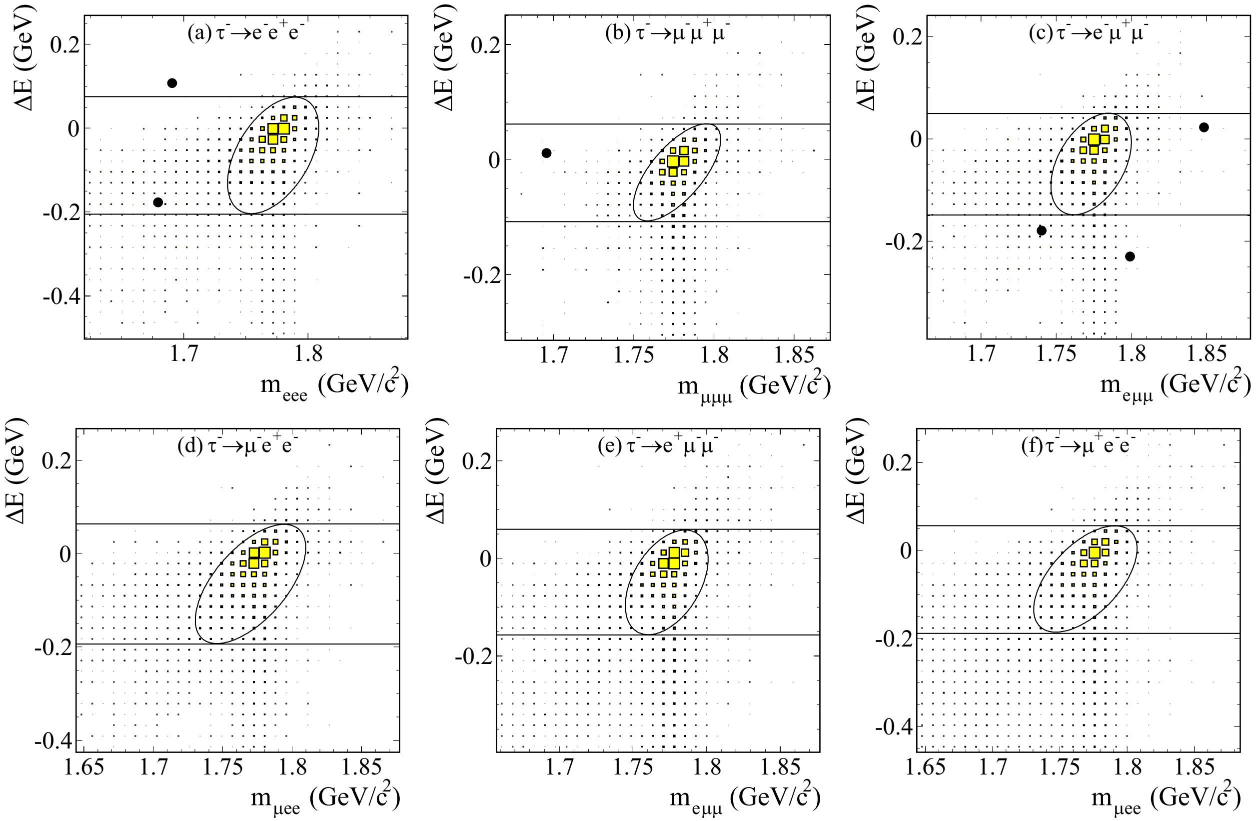
$\tau^- \to l^- \gamma$

τ^- mode	Belle		BaBar		CLEO	
	$\mathcal{B}, 10^{-8}$	$\int Ldt$,fb^{-1}	$\mathcal{B}, 10^{-8}$	$\int Ldt$,fb^{-1}	$\mathcal{B}, 10^{-8}$	$\int Ldt$,fb^{-1}
$\mu^-\gamma$	4.5	535	4.4	515.5	110	13.8
$e^-\gamma$	12	535	3.3	515.5	270	4.68

Belle K. Hayasaka et al., Phys. Lett. B666 (2008) 16

BaBar B. Aubert et al., Phys. Rev. Lett. 104 (2010) 021802

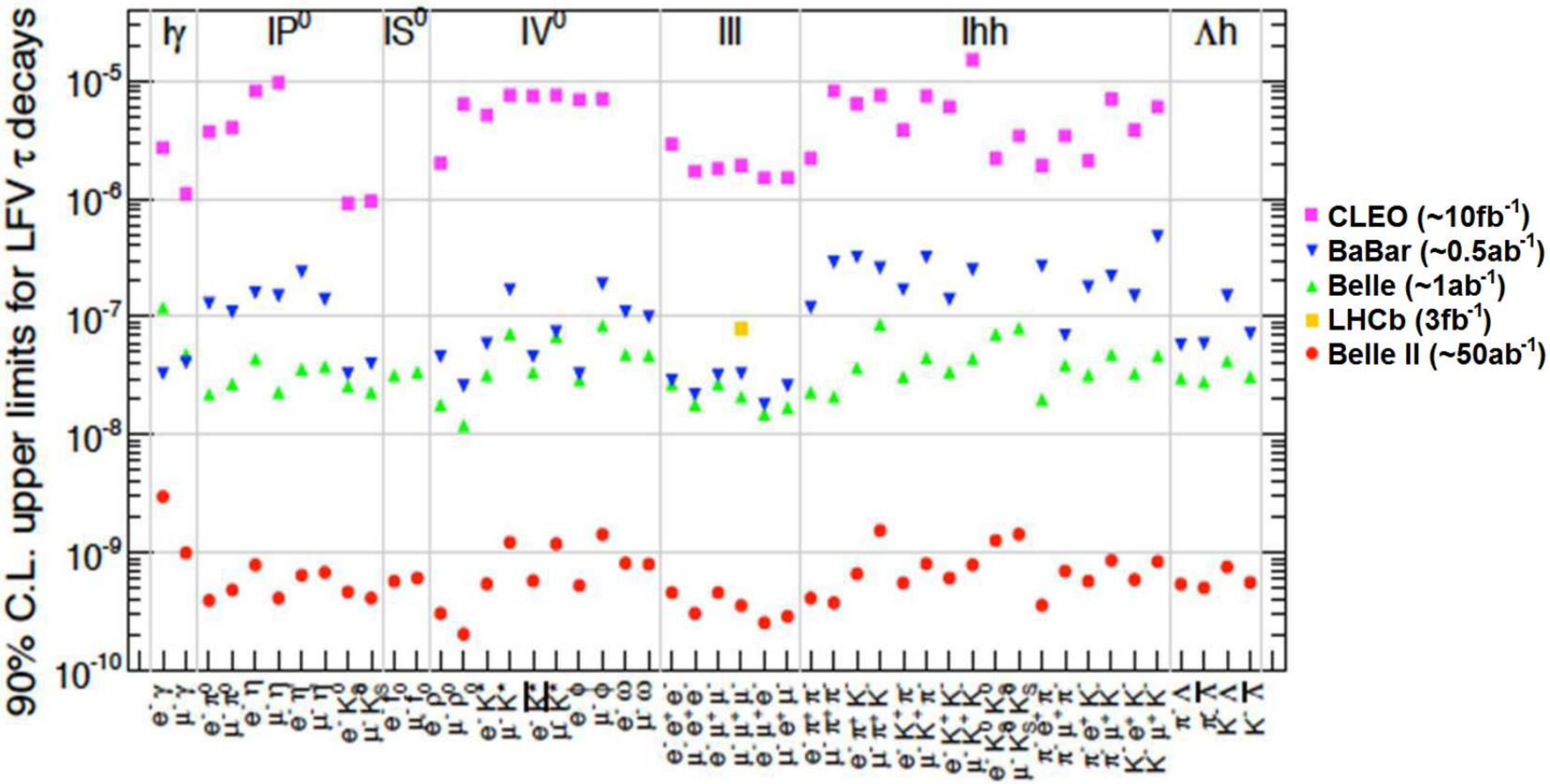
τ decays to Three Leptons



Efficiencies: (6.0-11.5)%, UL for $\mathcal{B}$: $(1.5\text{-}2.7)\times 10^{-8}$

K. Hayasaka et al., Phys. Lett. B687 (2010) 139

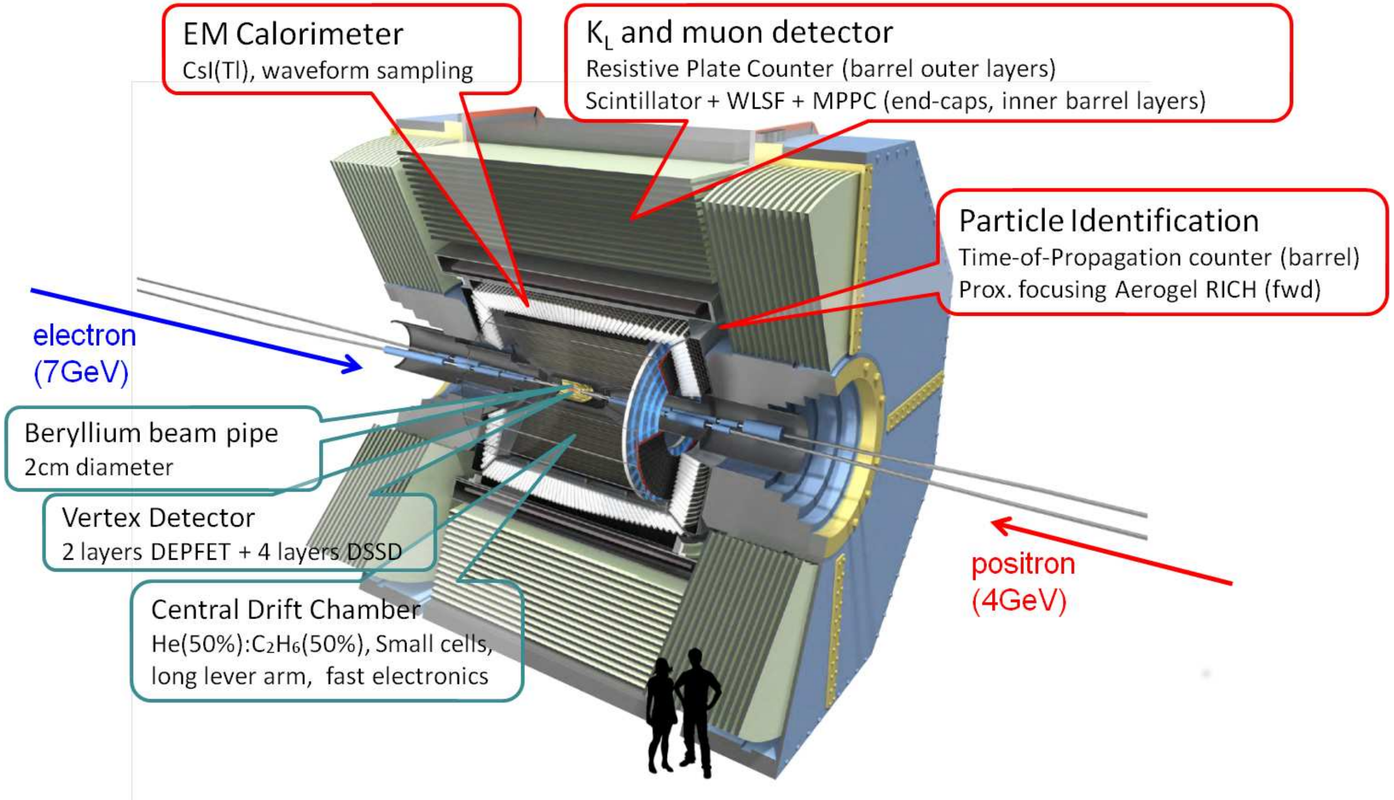
Current Upper Limits on LFV τ Decays



Progress of LFV Studies – $\tau^- \to \mu^- \gamma$

Group	Date	$\mathcal{L}$, fb^{-1}	$N_{\tau\tau}$, 10^6	$B_{\rm UL}^{90}$
MARK II	1982	0.017	0.048	5.5×10^{-4}
ARGUS	1992	0.387	0.374	3.4×10^{-5}
DELPHI	1995	0.07	0.081	6.2×10^{-5}
CLEO	2000	13.8	12.6	1.1×10^{-6}
Belle	2004	86.3	78.5	3.1×10^{-7}
BaBar	2005	232.2	207	6.8×10^{-8}
Belle	2006	535	477	4.5×10^{-8}
BaBar	2010	515.5	481.5	4.4×10^{-8}
BaBar & Belle	2006	767.2	684	1.6×10^{-8}

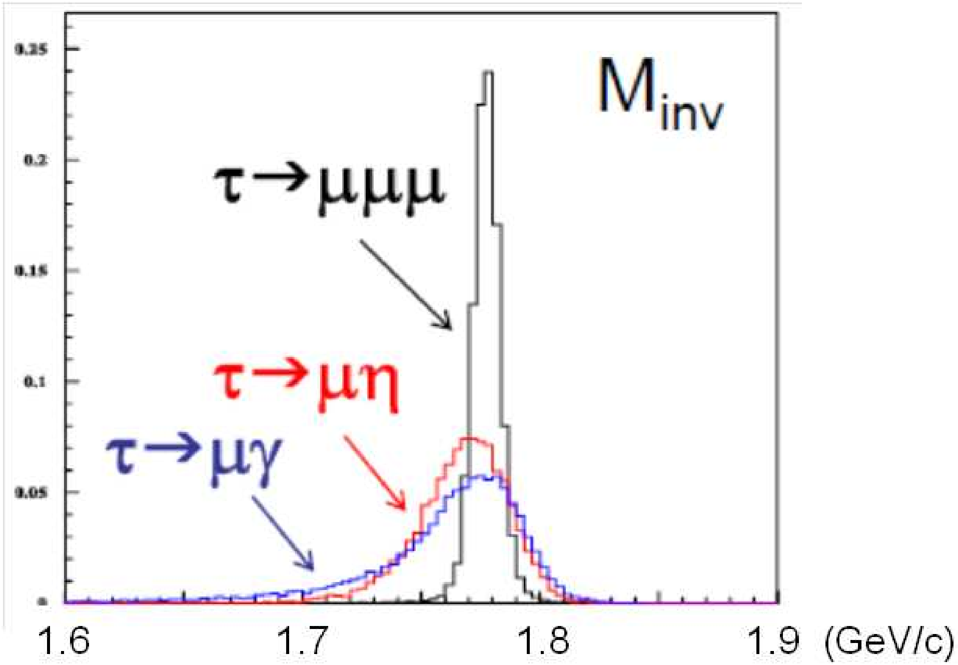
BelleII Experiment – I



The design luminosity of the upgraded KEKB is $8 \times 10^{35}\text{cm}^{-2}\text{s}^{-1}$

BelleII will start data taking in 2018 with a goal of 50 ab^{-1}

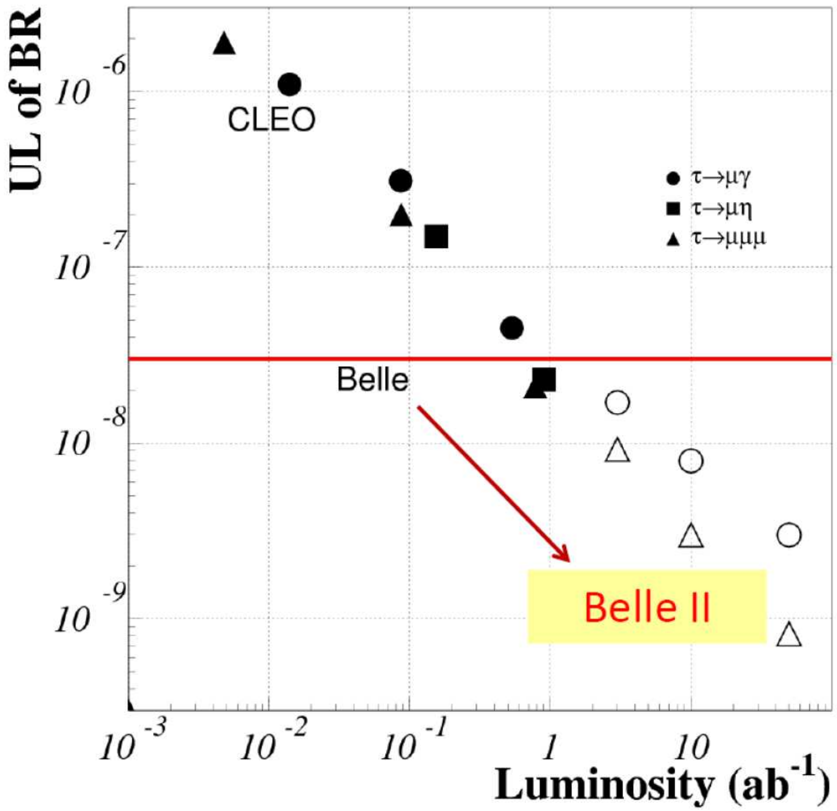
BelleII Experiment – II



Improvement of S/N is crucial (E_γ resolution, ϵ)

Prospects for the Future

- With 5×10^{10} $\tau^+\tau^-$ and $\epsilon \sim 3\%$: $\mathcal{B} < 10^{-9}$ for $N_{\rm ev} = 0$
- Background suppression needed (PID, higher ϵ, better $\Delta E_\gamma / E_\gamma$)
- $\tau \to l\gamma, \mu\eta(\gamma\gamma), l\rho$: BG $\neq 0$, $\mathcal{B} \propto 1/\sqrt{N}$
- $\tau \to lll, \mu\eta(\pi^+\pi^-\pi^0), \Lambda\pi$: BG $= 0$, $\mathcal{B} \propto 1/N$



Conclusions

1. Belle collected $\sim 10^9$ $\tau^+\tau^-$ events and reached $\mathcal{O}(10^{-8})$ sensitivity
2. In total, 46 decay modes have been searched for;
   the strongest limit achieved is $\mathcal{B}(\tau^- \to \mu^-\rho^0) < 1.2 \times 10^{-8}$ at 90%CL
3. With $\int Ldt = 50$ ab^{-1} BelleII will collect $\sim 5 \times 10^{10}$ $\tau^+\tau^-$ events
   - Sensitivity depends on a data sample
   - Background conditions are vitally important
   - Optimization of selection criteria to increase detection efficiency
   - For background-free modes like $\tau^- \to (3l)^-$ sensitivity is $\mathcal{O}(10^{-10})$
   - For $\tau^- \to l^-\gamma$ sensitivity is $\mathcal{O}(10^{-9})$