Study of lepton flavor violation in the decay $\tau \to lll$

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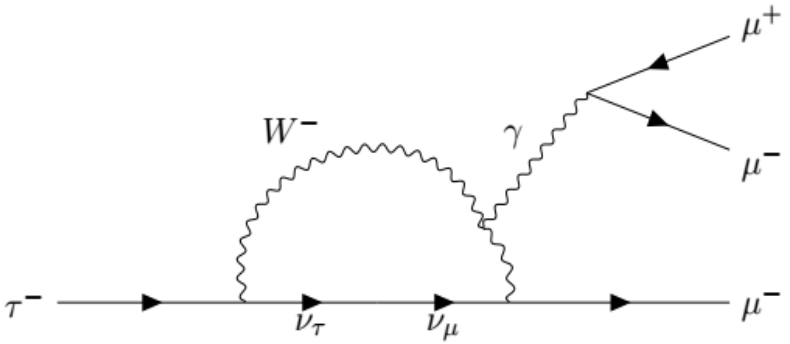
Physics Motivation

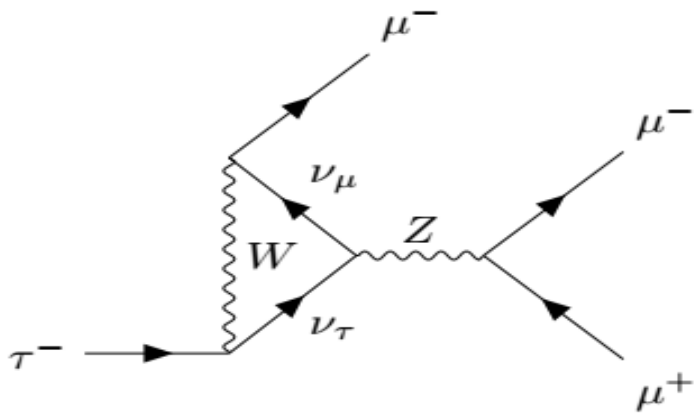
- **In quark sector:** flavor mixing is well established.
- **Neutrino mixing:** => lepton flavor symmetry is violated

  => How about charged lepton sector??

- **SM + neutrino mixing (in the SM):**



Br ~$(\Delta M_{ij}/M_W)^4$ <10^{-40}



Br ~$\log(M_i/M_j)$ ~10^{-14}

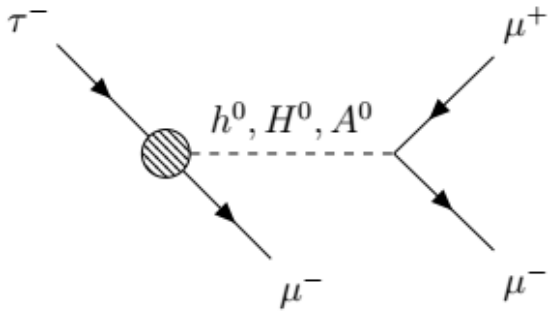
$\Rightarrow$ It is very small, if we find a signal -> new physics

Physics motivation

- Many extensions of the SM naturally introduces LFV at order **~10^{-7} -10^{-10} => can be detected with current experiments.**

Model	Ref.	$\tau \to \mu\gamma$	$\tau \to \mu\mu\mu$
SM + heavy majorana	PRD 66.034008	10^{-9}	10^{-10}
Non-universal *Z'*	PLB 547(3)252	10^{-9}	10^{-8}
SUSY + seesaw	PRL 89:241802	10^{-10}	10^{-7}
SM + 4th generation	arXiv.1006.5306	10^{-8}	10^{-8}

Eg. SUSY + seesaw

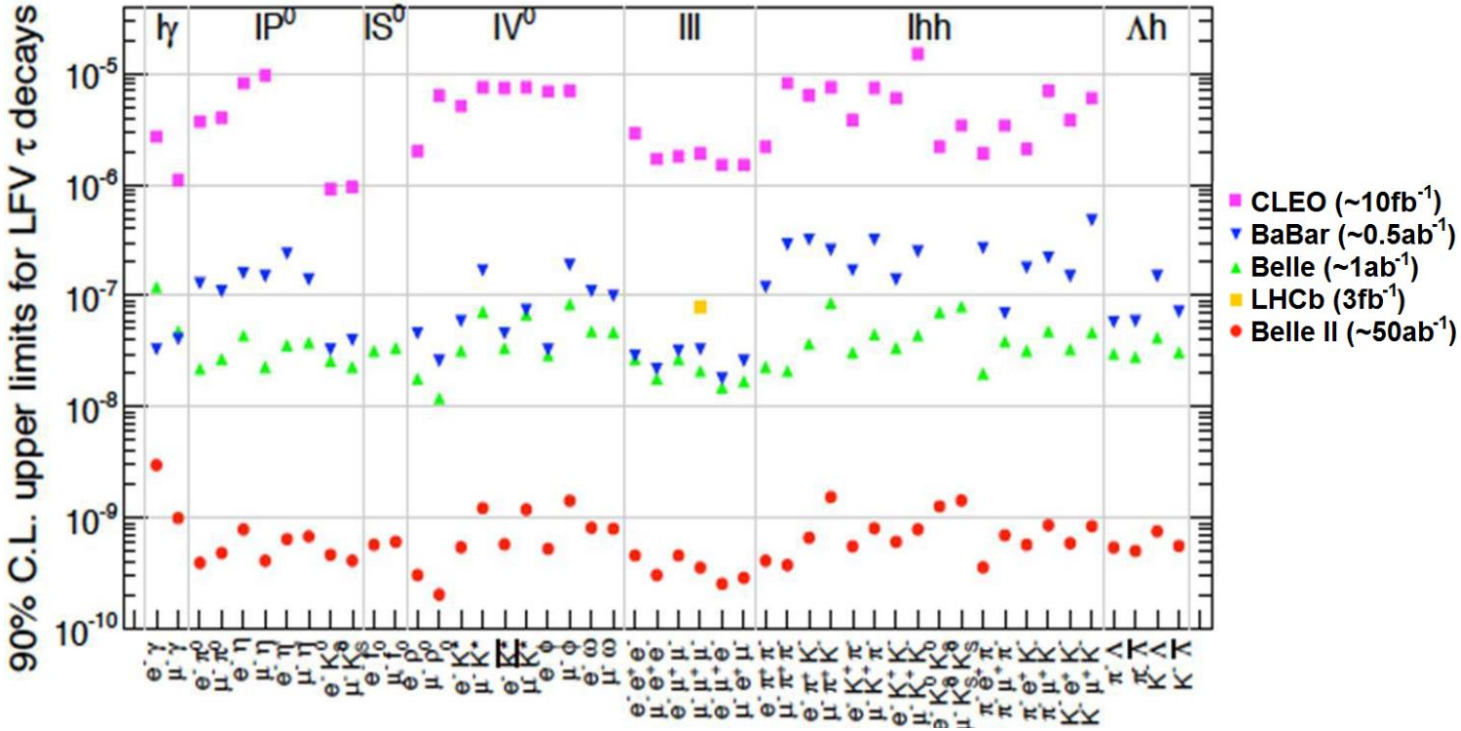


$Br(\tau \to \mu\mu\mu) < 10^{-7}$

- **Observe signal** => New physics.
- **Improve limits** => constrain parameters of theoretical modes

Search for LFV using τ

- τ – the heaviest charged lepton:
  - Various decay modes for LFV search, even decay to hadron.
  - Strength of interaction relate to new physics is naively expected to be mass-dependent.



Belle II results are simply projected from Belle results.

Search for LFV using τ

- $\tau \to l\gamma$ and $\tau \to lll$ are golden mode, which are expected to have the largest branching fraction.
- $\tau \to lll$ is more sensitive than $\tau \to l\gamma$ because of small background.

- Belle II will take 50ab^{-1} data,

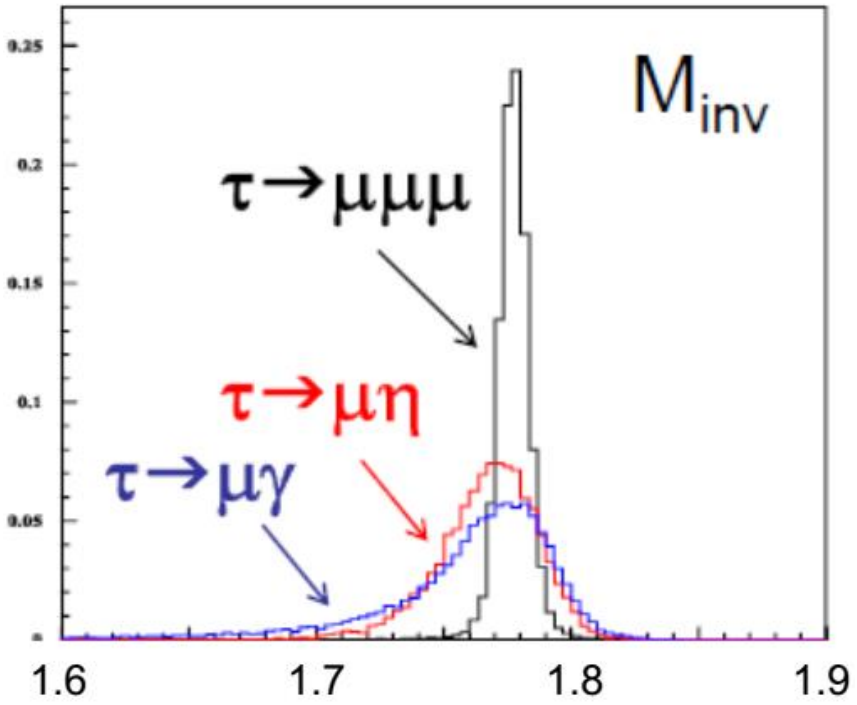
  $N_{\tau\tau}$~5x10^{10}

- The sensitivity:

  $+\ \tau \to l\gamma : \sim {}^{1}/_{\sqrt{L}}$

  $+\ \tau \to lll : \sim {}^{1}/_{L}$

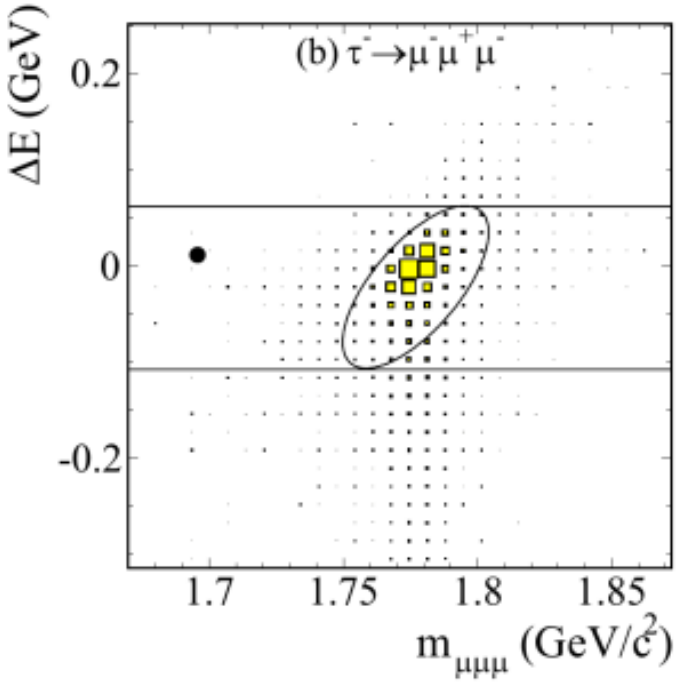
(good mass resolution and PID)



Search for LFV using τ

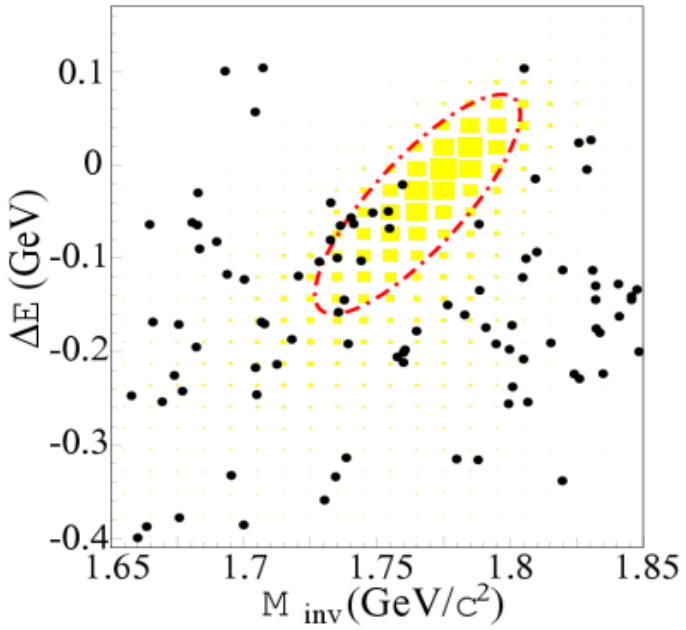
Belle results:

- Data: ~7×10^8 ττ



- Data; ~4.8×10^8 ττ

  $\tau \to \mu\gamma$



- $M_{\mu\mu\mu}$ is reconstructed mass of LFV τ decay.
- $\Delta E = E_\tau - E_{beam}/2$

Previous searches for decay $\tau \rightarrow \mu\mu\mu$

- The most stringent upper limits are set currently by the Belle and Babar.
- Final signal are observed in M-ΔE windows.

	BaBar (2010)	Belle (2009)
Data	468 fb^{-1} (426M $\tau^-\tau^+$)	782fb^{-1} (711M $\tau^-\tau^+$)
eff. (%)	6.6	7.6
$N_{observed}$	0	0
N_{bkg}	0.44±0.17	0.13±0.06
UL @90 C.L.	3.3×10^{-8}	**2.1×10^{-8}**

- LHCb @2014
  - τ from *b* and *c*-hadron decays
  - 3 fb^{-1} data (~90×10^9 τ^-)
  - Br <4.6×10^{-8} @90% C.L

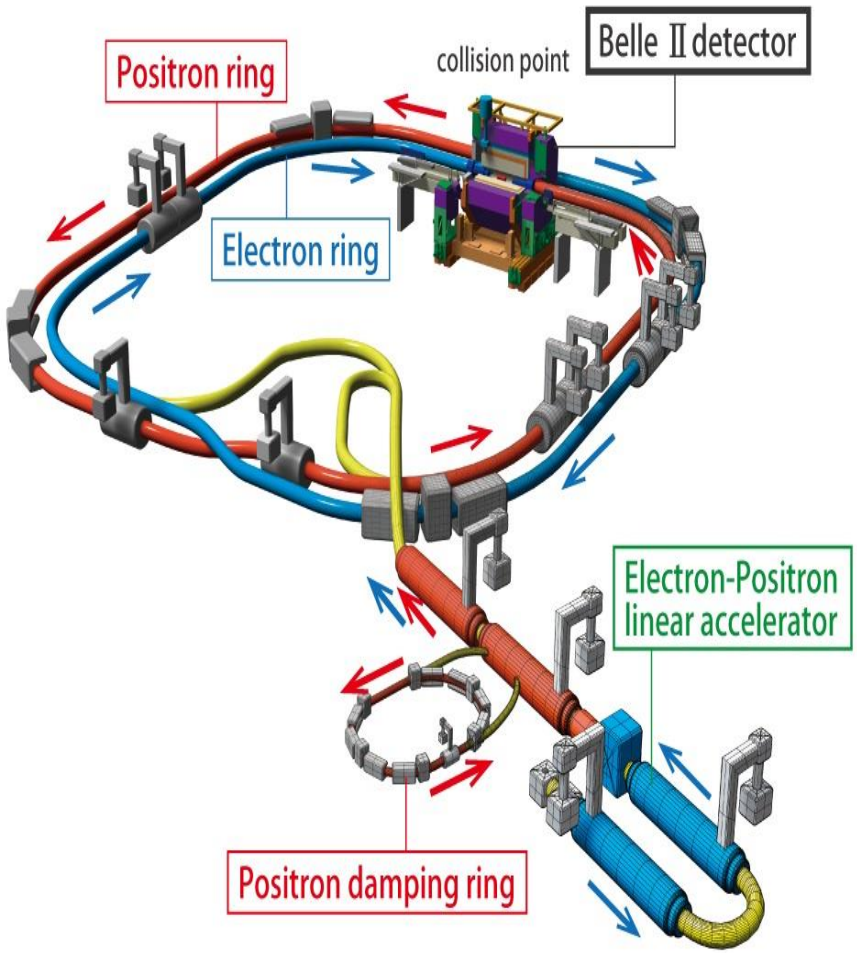
ATLAS @2016

τ from $W^- \rightarrow \tau^-\nu$

20.3fb^{-1} at 8TeV taken 2012. (241 x 10^6 τ^-)

Br <3.76×10^{-7} @90% C.L

Super-KEKB



- At High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki, Japan.
- E_{e^-} =7 GeV; E_{e^+}=4 GeV
- Upgrade of KEKB to increase luminosity by 40 times by:
  - Increase beam current
  - Reduce beam size

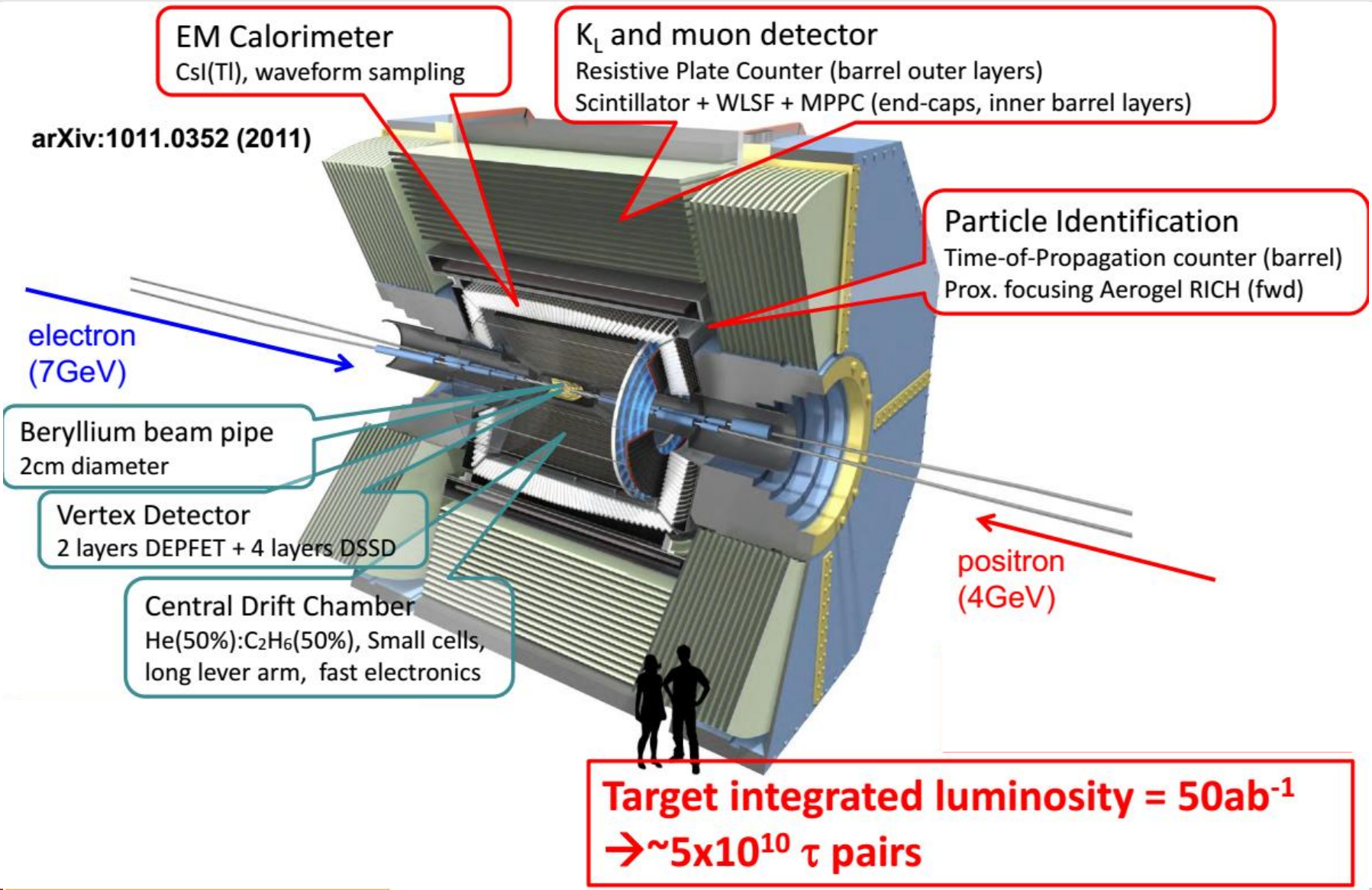
To get 40x luminosity of KEKB

Reduce beam size to a few 100 atomic layers!

Expected to take 50ab^{-1} data sample

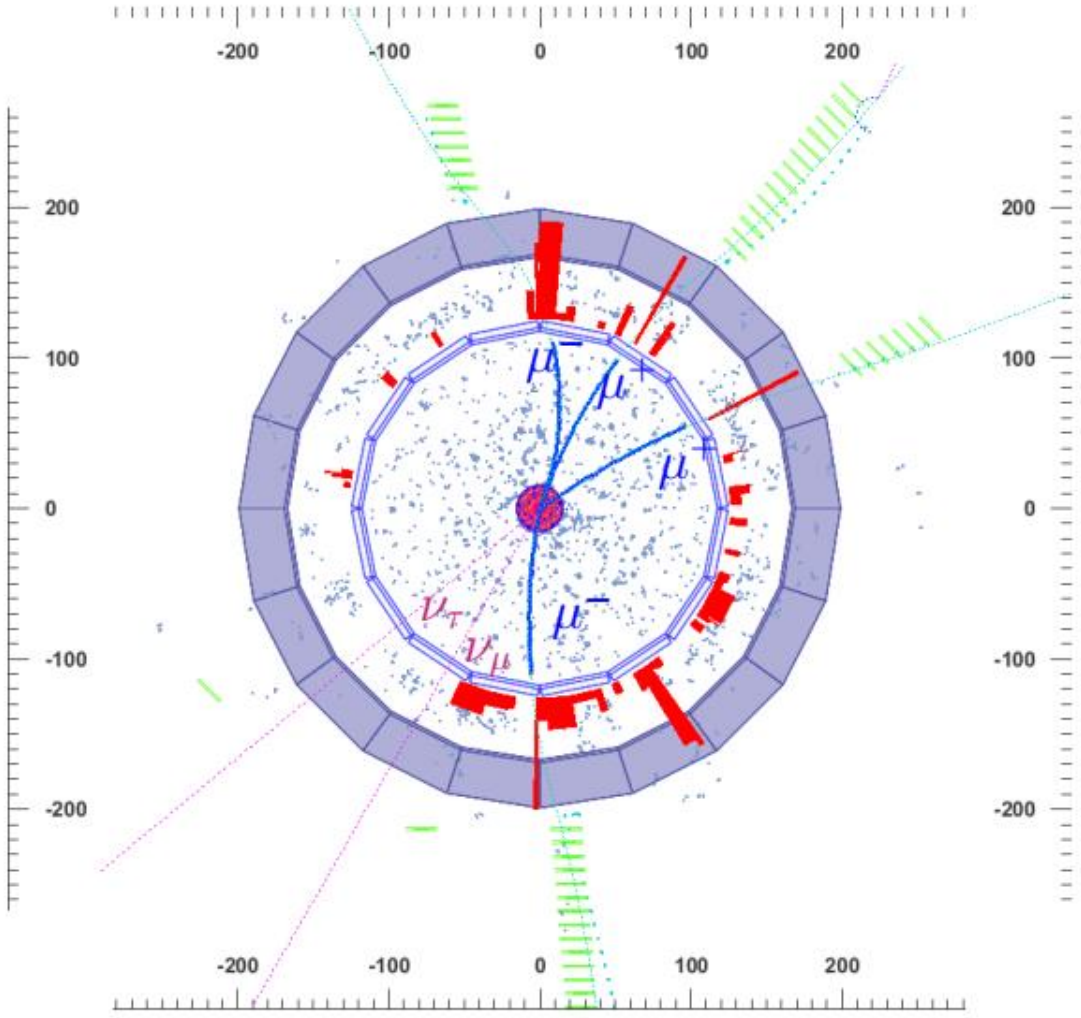
=> Detector will upgrade to cope with high beam background and improve measurement precision.

Belle II



Target integrated luminosity = 50ab^{-1}
→~5x10^{10} τ pairs

LFV study with decay $\tau \rightarrow \mu\mu\mu$

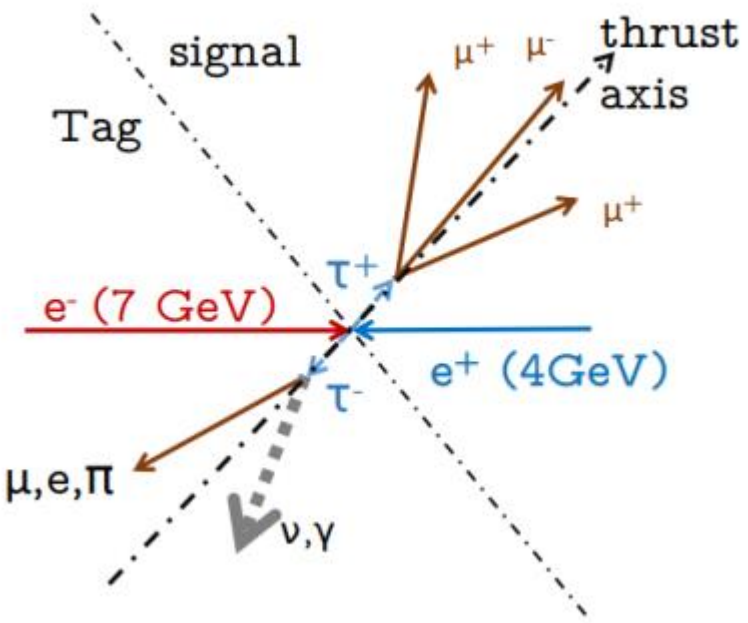


Analysis strategy

- Signal side contains 3 charged tracks.
- Tag side is 1 prog decay (Br~85%).

⇒Select 4-track events, $\sum charge$=0

- Apply general selection for all tag mode.
- Apply final selection tag-by-tag

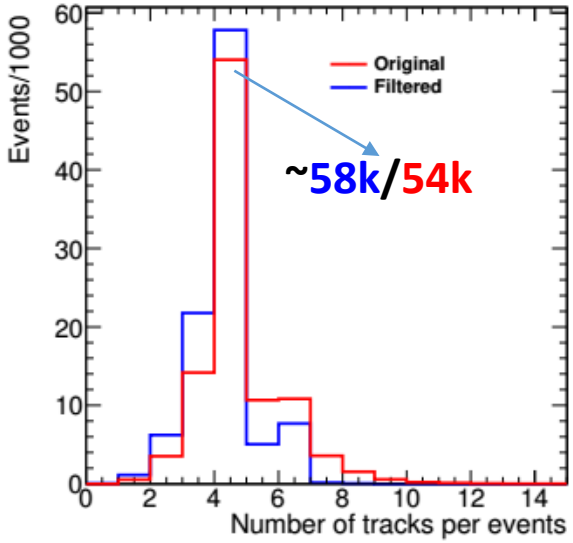


Track filter

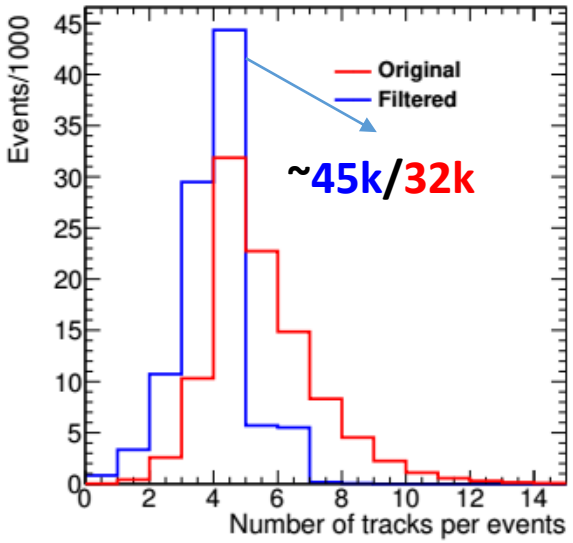
- Remove clone tracks, background tracks before reconstruction based one the impact parameters and number of hits.

#ntracks/events

4-track events are selected for the τ reconstruction



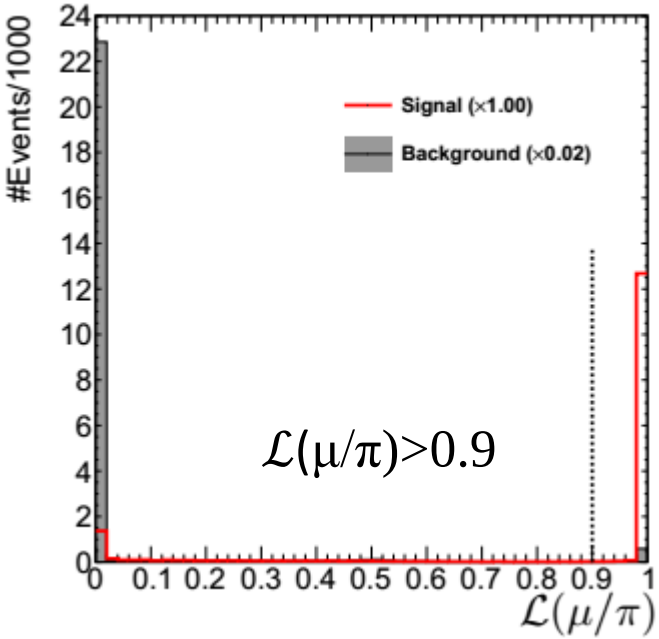
(a) Without beam background



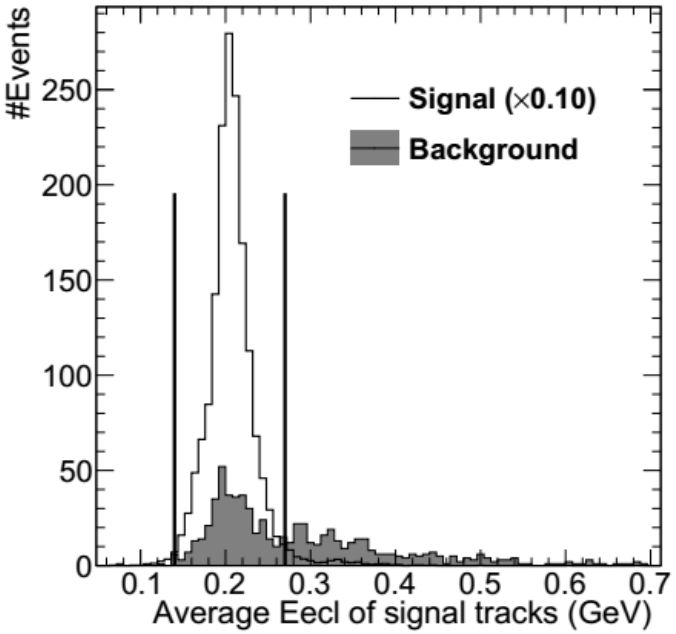
(b) With beam background

General selections

- Require μ-ID for one charged tracks



- Average energy deposited in ECL of charged tracks at signal side



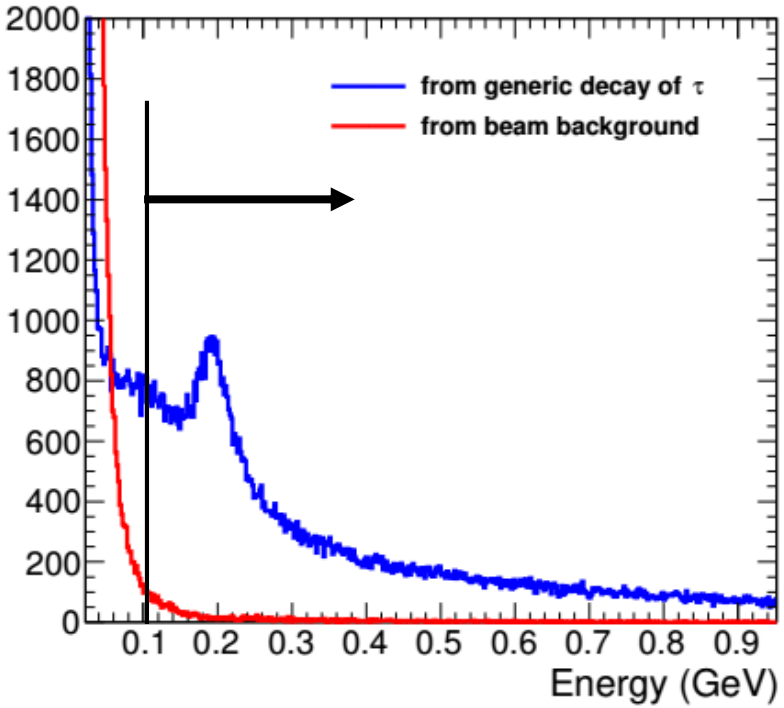
Background suppression

- 4-vector missing momentum: $P_{miss} = -P_{\tau} - P_{tag}$

  $P_{tag} = P_{charged\_Track\ or\ \rho}$ if tag is $\pi\nu$, $\mu\nu$, $\mu\nu$, $\rho\nu$

  $P_{tag} = P_{charged\_Track} + P_{gamma}$ if tag is $\pi\pi^0\pi^0\nu$
- $\overrightarrow{P_{miss}}$ is required to point into fiducial volume of detector.
- Magnitude selection will be different for each mode.

- Count N_{gamma} which has E>0.1 GeV.
- Maximum 1 gamma is allow at signal side.



Separate tag modes

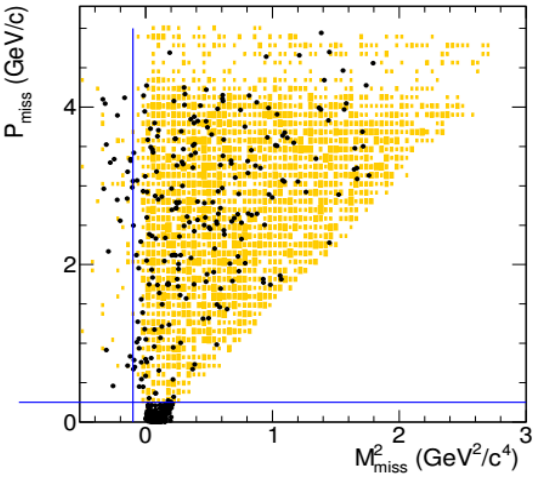
Tag modes	Branching fraction (%)	Conditions
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$	17.36	• $\mathcal{L}(e/\pi) > 0.1$ • $N_\gamma^{tag} \leq 1$
$\tau^- \to \mu^- \bar{\nu}_e \nu_\tau$	17.85	• $\mathcal{L}(\mu/\pi) > 0.8$ • $N_\gamma^{tag} \leq 1$
$\tau^- \to \pi^- \nu_\tau$	10.91	• $\mathcal{L}(\mu/\pi) < 0.8$ && $\mathcal{L}(e/\pi) < 0.1$ • there is no reconstructed π^0 • $N_\gamma^{tag} \leq 1$
$\tau^- \to \rho^- \nu_\tau$	25.51	• $\mathcal{L}(\mu/\pi) < 0.8$ && $\mathcal{L}(e/\pi) < 0.1$ • $\rho^- \to \pi^- \pi^0$ is reconstructed
$\tau^- \to \pi^- \pi^0 \pi^0 \nu_\tau$	10.85	• Remaining

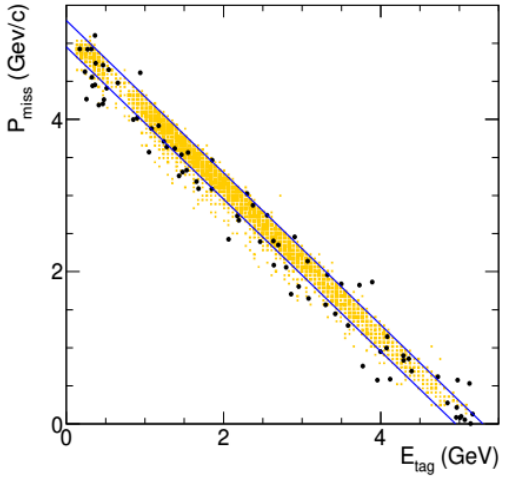
Tag-by-tag bkg suppression

- Using variables:
  - Reconstructed pi0, rho, for background suppression.
  - Missing information: M_{mis}^2 , P_{miss}
  - PID of the second charged track.
  - Eecl of charged tracks
  - Mass of two charged tracks (M_{ee})
  - P_{total}^{cms}

Selections for tag $\tau^- \to \mu^- \bar{\nu}_e \nu_\tau$

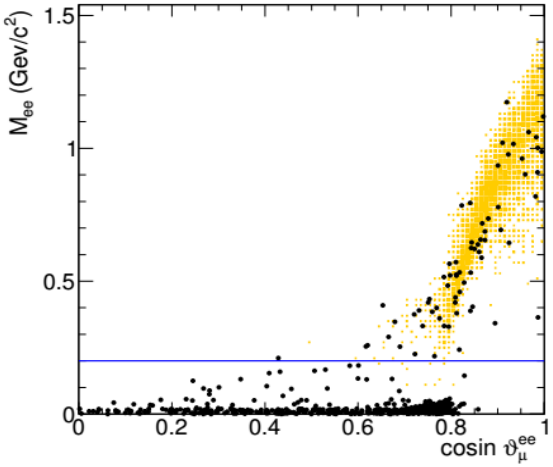
- Required 2nd μ-ID if a photon appears at tag side.
- Missing mass and momentum.

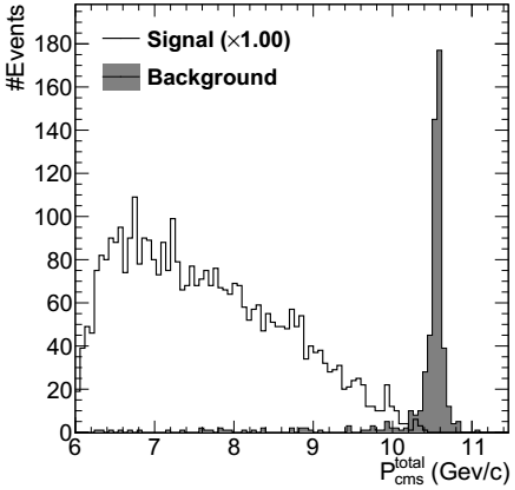




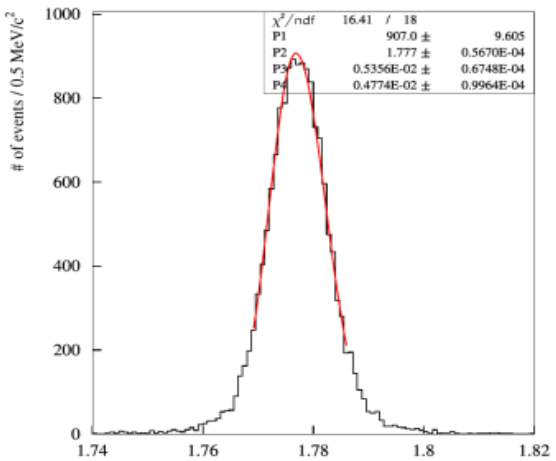
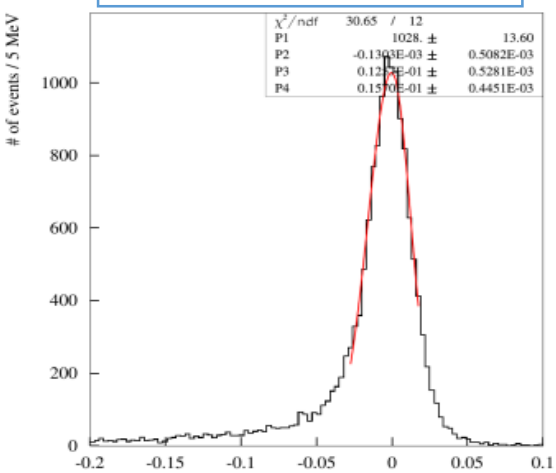
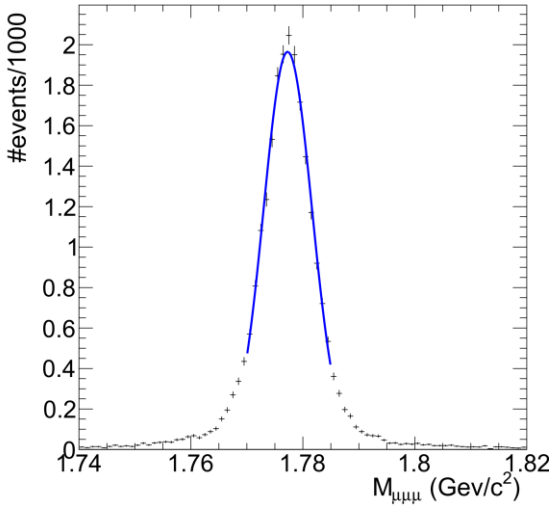
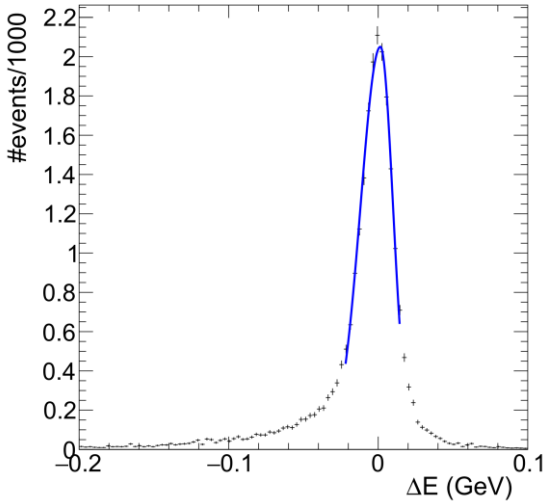
To suppress:

- Two- photon process: $e^+e^- \to \mu^+\mu^- e^+e^-$
- μ-pair process: $e^+e^- \to \mu^+\mu^- (\gamma \to e^+e^-)$



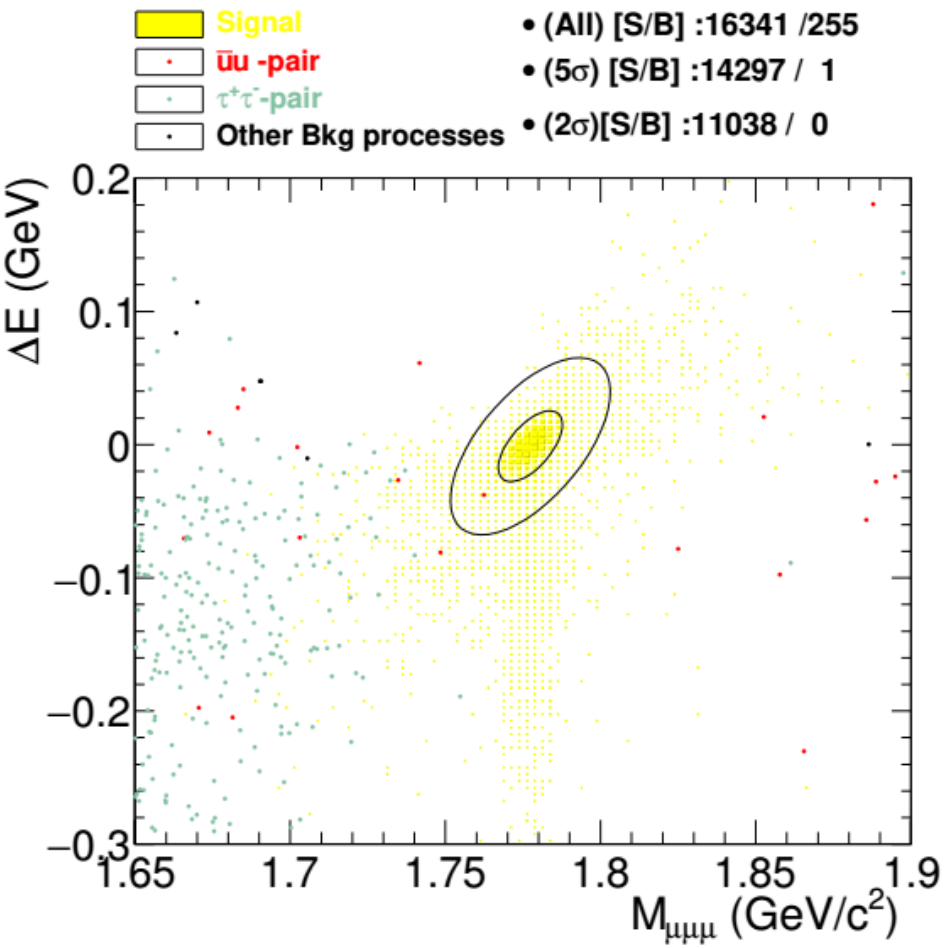


Mass and ΔE distribution

	$M_{\mu\mu\mu}$	ΔE
Belle (MC)		
Belle II (MC)		

Distributions of the Belle II are significantly narrower.

Signal analysis



- Select signal event in the 2σ region (11038 events).

eff. = 11.04 %

~1.5 times higher than that obtained at Belle.

- Estimated background by loosening the selections then propagate from 5σ to 2σ region.

$N_{bkg} = 0.13 \pm 0.06$

The same as belle result.

- Estimate the UL: $\mathcal{B}(\tau \to \mu\mu\mu) < \frac{N_{90}^{UL}}{2N_{\tau\tau}\epsilon}$

For 1 ab^{-1} with no observed event.

$\mathcal{B}(\tau \to \mu\mu\mu) < 1.1 \times 10^{-8}$ at 90% C.L

~2 times lower than the current limits.

Thank you very much

Back up

- LFV search with muon
  - Experimental set-up is simple and cheap (compared with tau exp).
  - Possible to produce intensity muon beams.
  - But number of decay channel for LFV is limited.