Tau physics prospects at Belle II

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For Belle II collaboration

SuperKEKB and Belle II experiment

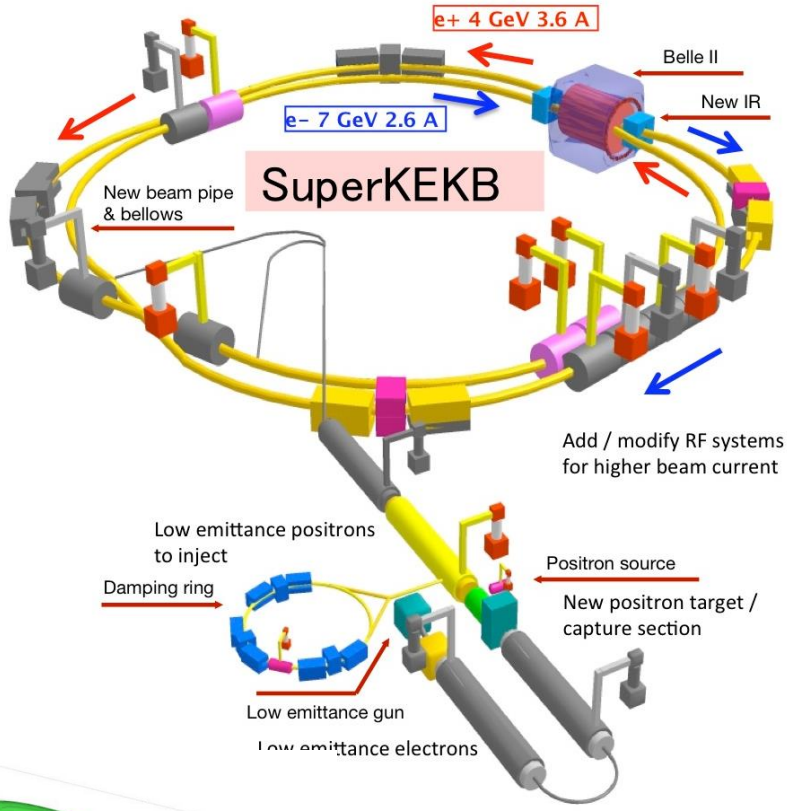
- Advanced B factory
- Asymmetric energy e^+e^- collider
  - At $\sqrt{s}$=10.58GeV

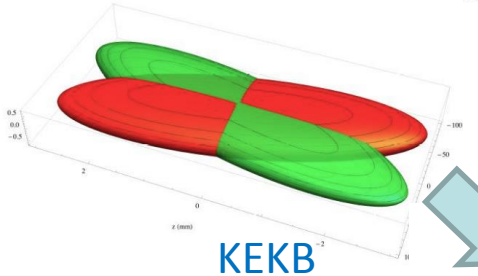
  $\sigma(\tau\tau)$~0.9nb, $\sigma(bb)$~1.1nb

  A B-factory is also a tau-factory!
- Challenges to higher luminosity
  - Narrower beam at IP
  - Higher beam current
  - Detector works with higher beam background and trigger rates

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

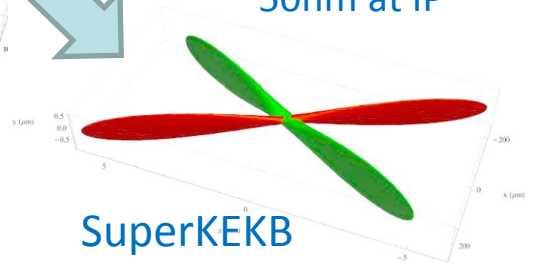
  - x50 higher than previous B factory





KEKB

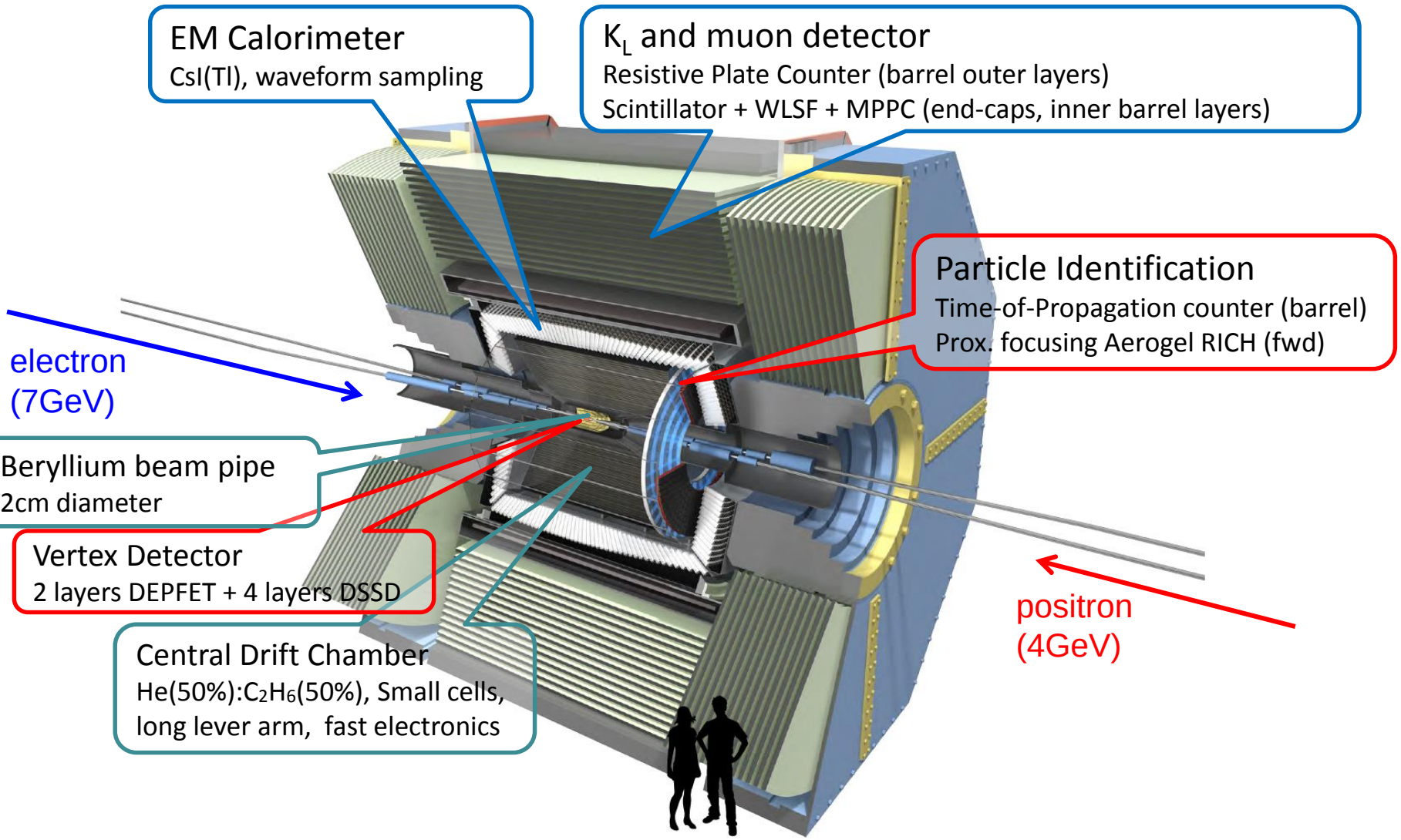
"Nano beam"
Vertical beam size is 50nm at IP



SuperKEKB

Belle II detector

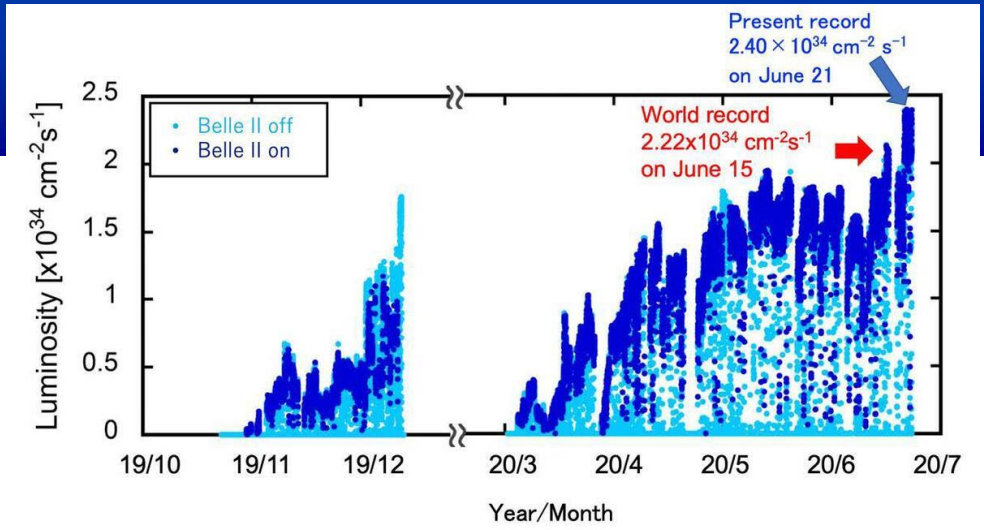
General purpose, forward/backward asymmetric acceptance

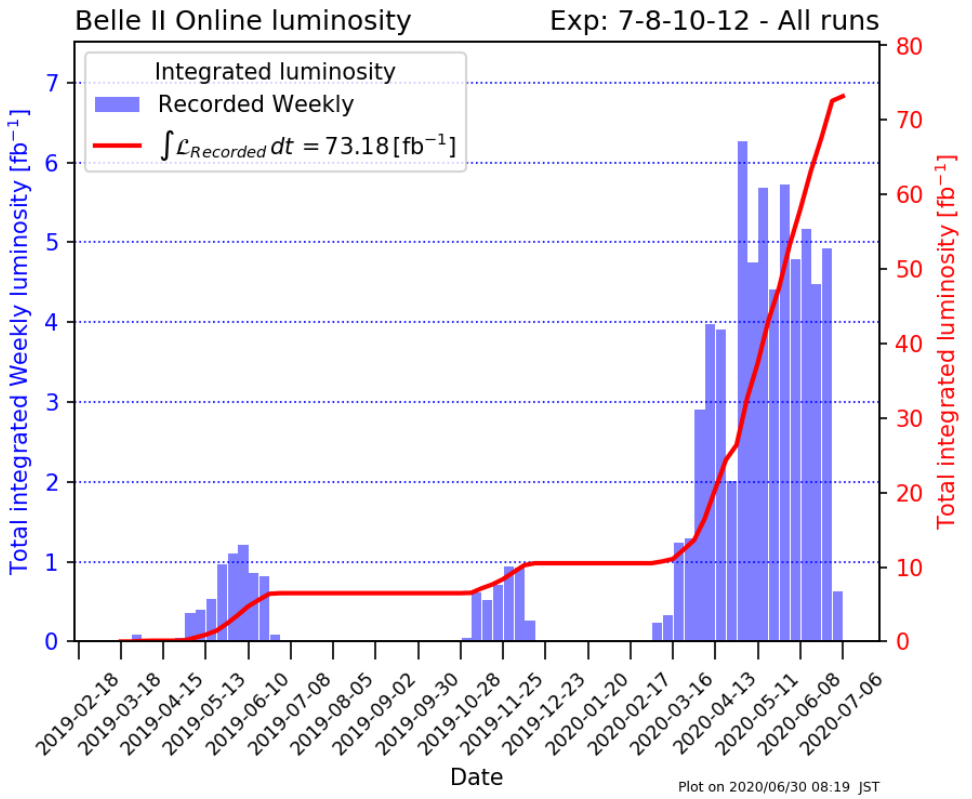


Status

- Physics data taking started in March 2019.
  - Performed luminosity tuning during the data taking
- Achieved world record
- L = 2.4x10^{34} cm^{-2} s^{-1}.

- Data collected stably
  - High beam background env.
- Integrated luminosity; 73fb^{-1}
  - Physics analysis for ICHEP2020; ~8.8fb^{-1}





Tau physics program

- The world largest number of tau-pair events in e^+e^- collisions offer data for tau physics analyses with high precision.

- Lepton flavor violating decays
  - $\tau \to \mu\gamma$, $e\gamma$, $\mu\eta$, $e\eta$, $p\gamma$, $\Lambda\pi$, lll, ..., $l+\alpha$ (→ talk by F. Tenchini)
- Electric Dipole Moment (CP/T violation)
- CP violation in tau decay; $\tau \to K_s \pi\nu$
- Tau mass, ν_τ mass, Lifetime
- Test of Universality
- Hadronic decays
  - Search for second class current; $\tau \to \pi\eta\nu$
  - Mass spectrum in $\tau \to \pi\pi^0\nu$
  - ...

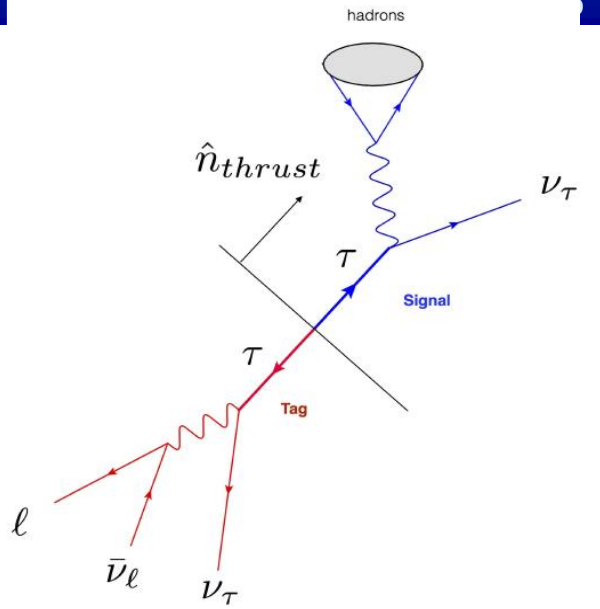
New physics search

Precise test of Standard Model

Tau mass measurement

Signal: $\tau \to 3\pi$

Tag: $\tau \to e, \pi, \mu, \pi\pi^0$



- Performed tau mass analysis using early Belle II data (8.8fb^{-1})
- Select $\tau \to 3\pi\nu$ + 1-prong topology events and measure tau mass using the "pseudomass" technique developed by ARGUS

$$M_{min} = \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi})} \leq m_\tau$$

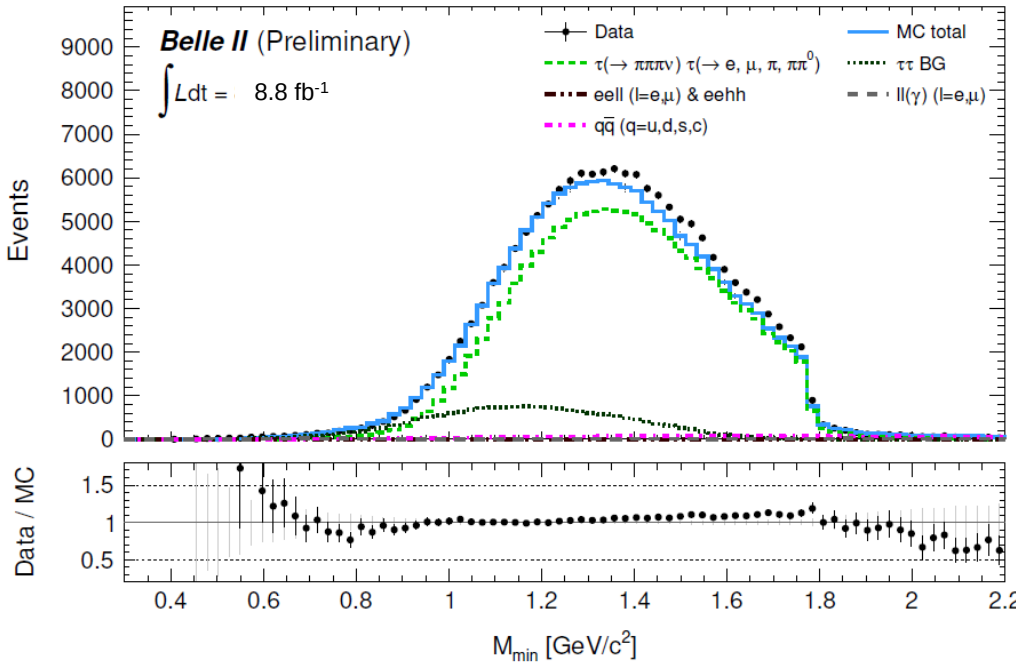
  - Current best value by Belle;

    1776.61 ± 0.13 ± 0.35 MeV

    - Phys. Rev. Lett. 99, 011801 (2007)
  - Tau pair production at threshold energy shows better result.

    BESIII; 1776.91 ± 0.12 ± 0.13 MeV

    - Phys. Rev. D 90, 012001 (2014)
- Clear shoulder in the data
  - Well rediscovered tau-pair events at Belle II.

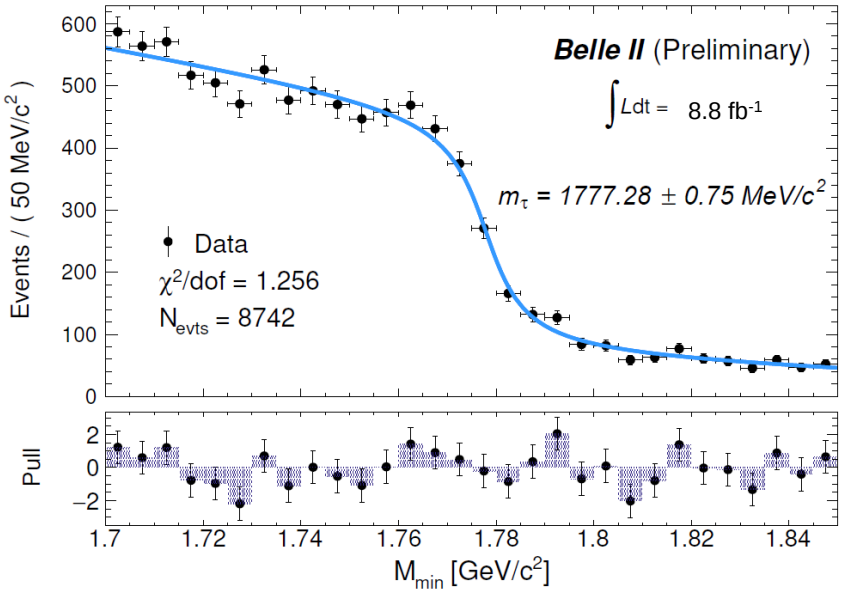


Tau mass measurement

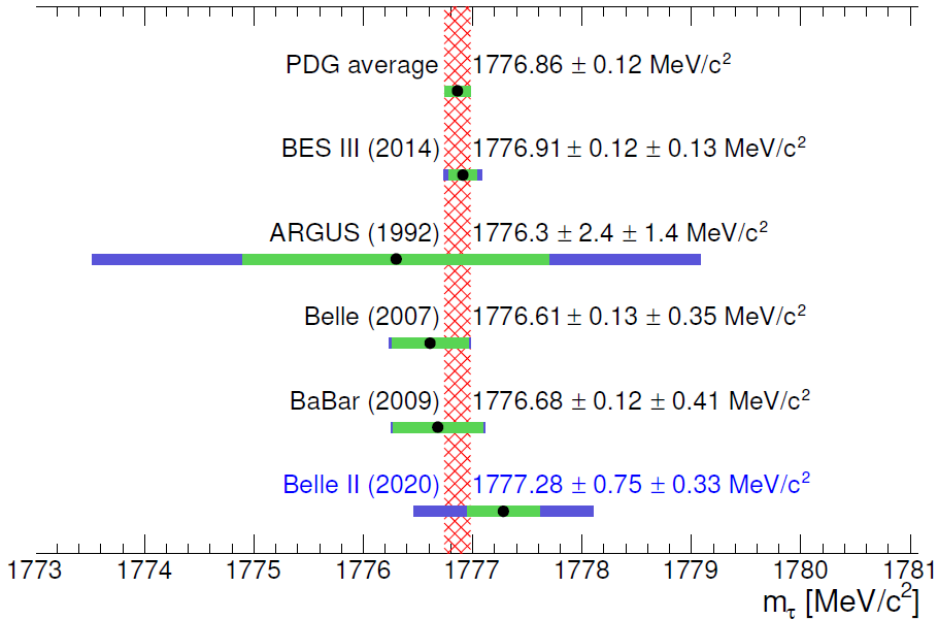
- Extract mass by fitting to a empirical edge function
- Preliminary result;

1777.28 ± 0.75 (stat) ± 0.33 (syst) MeV/c^2

  - Similar systematic error with previous B factory results
  - Can improve using more data and more precise corrections, then achieve best precision among pseudomass measurement.



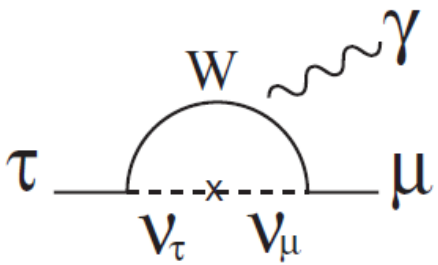
Systematic uncertainty	MeV/c^2
Momentum shift due to the B-field map	0.29
Estimator bias	0.12
Choice of p.d.f.	0.08
Fit window	0.04
Beam energy shifts	0.03
Mass dependence of bias	0.02
Trigger efficiency	≤ 0.01
Initial parameters	≤ 0.01
Background processes	≤ 0.01
Decay model	≤ 0.01
Tracking efficiency	≤ 0.01



Lepton Flavor Violation in tau decay

In the Standard Model, LFV is highly suppressed.

Impossible to access; Br<O(10^{-54})

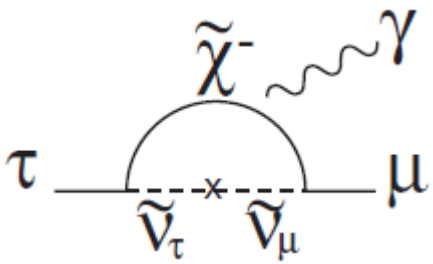


Many extensions of the SM predict LFV decays.
Their branching fractions are enhanced as high as current experimental sensitivity

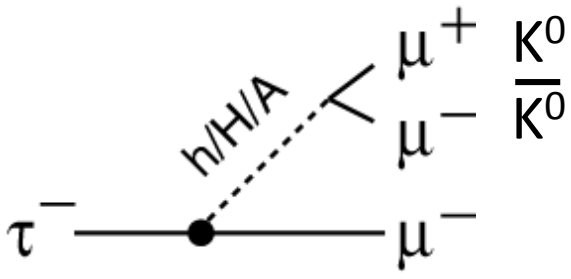
⇒Observation of LFV is a clear signature of New Physics (NP)

Tau lepton : the heaviest charged lepton

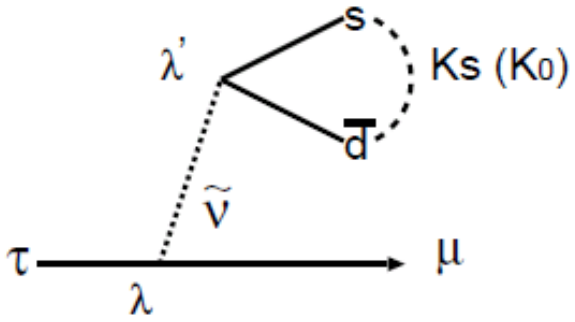
- Opens many possible LFV decay modes which depend on NP models



SUSY



Higgs-mediation LFV

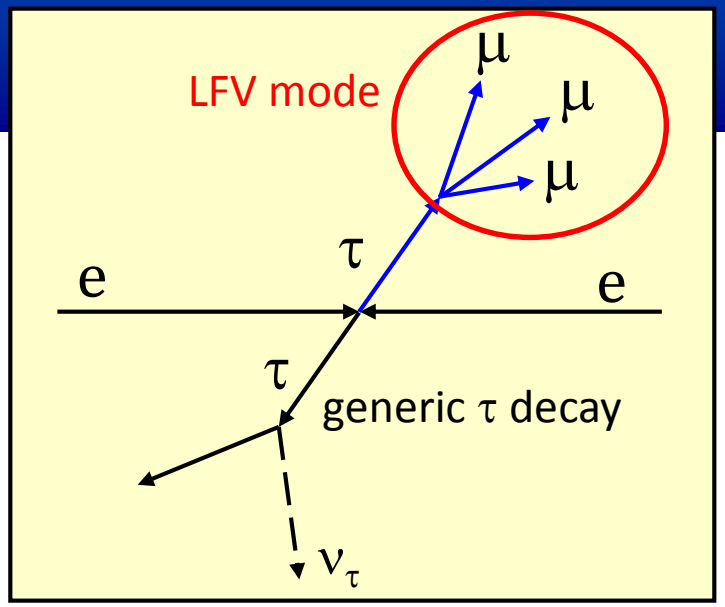


R-parity violation

Tau LFV analysis

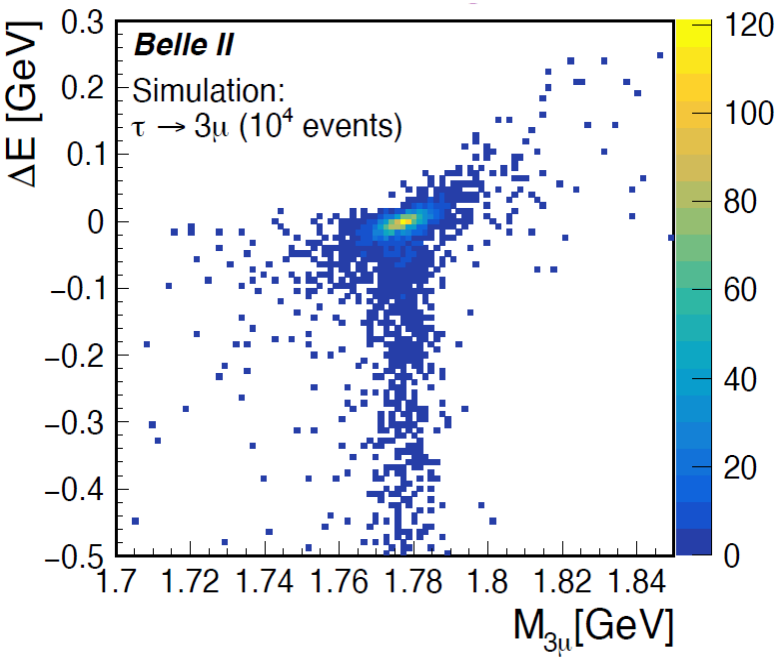
- $e^+e^- \to \tau^+\tau^-$ Br~85%
  - 1 prong + missing (tag side)
  - $\mu\mu\mu$ (LFV mode, signal side)

Fully reconstructed

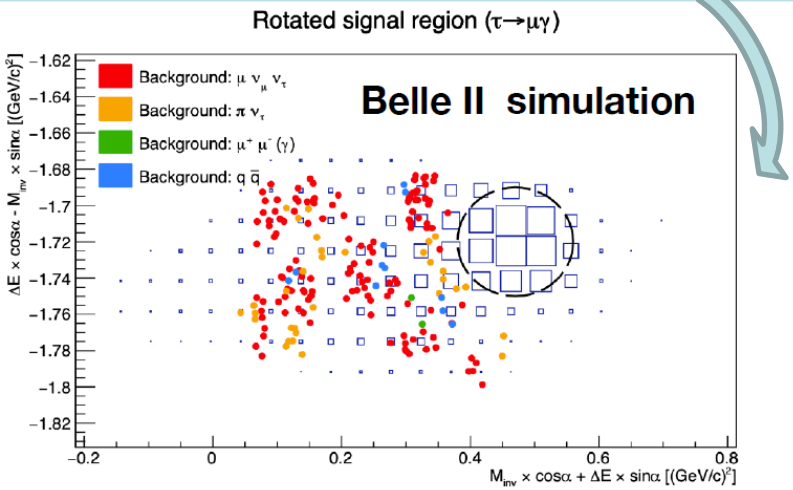


Signal extraction: $M_{3\mu}$–ΔE plane
(or rotated signal plane to reduce correlation)

Evaluate background from side band

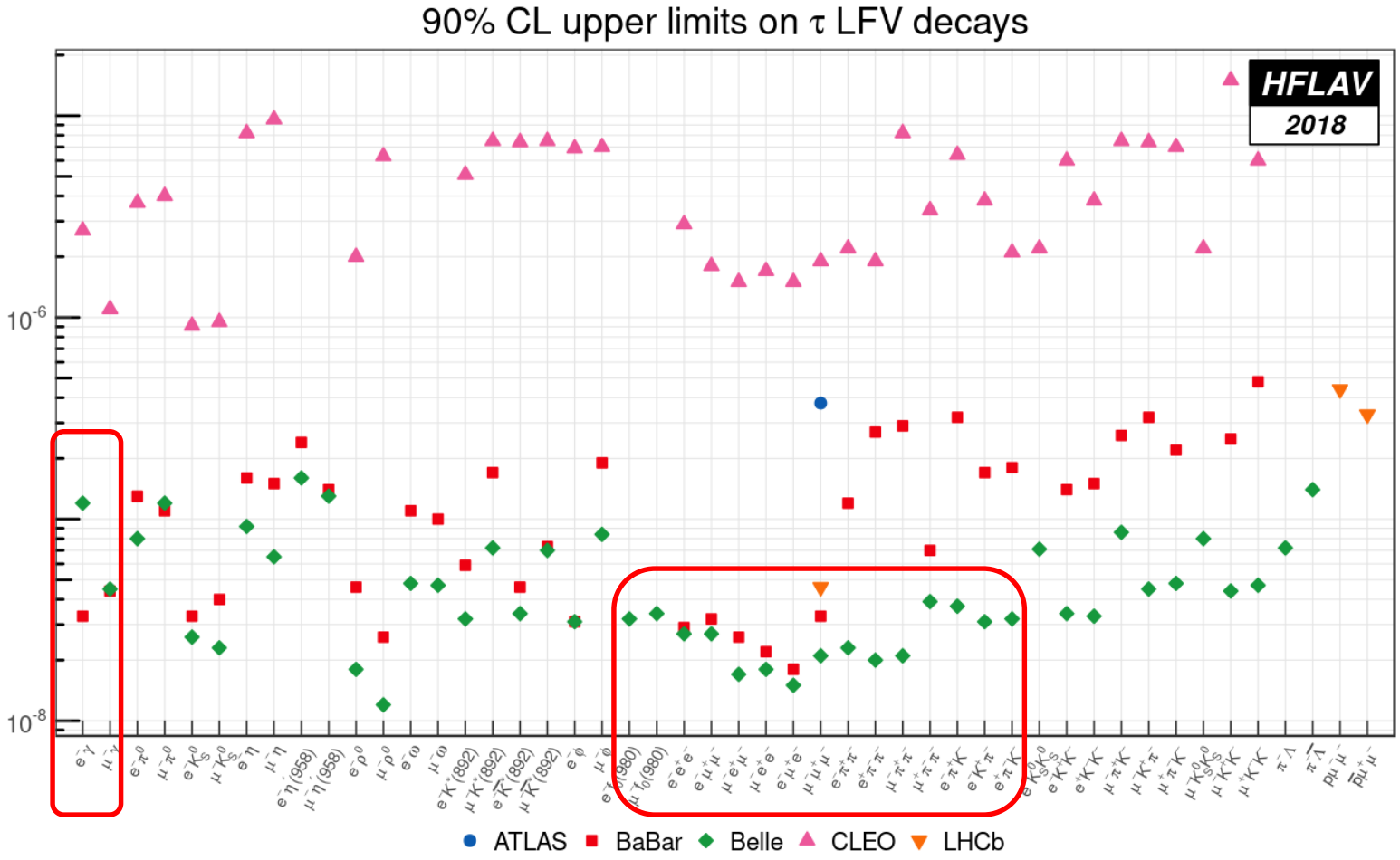


BG contribution is small for 3lepton modes because of good PID performance, however non-negligible for l+γ modes



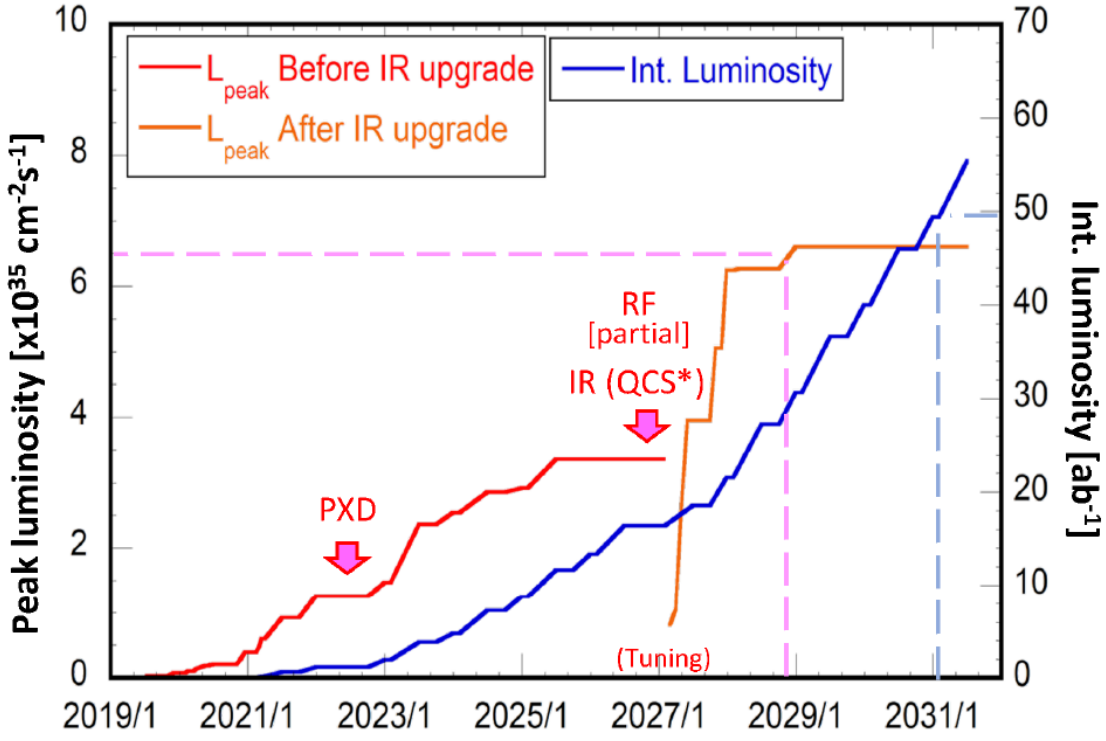
The Belle II Physics Book arXiv:1808.10567v2

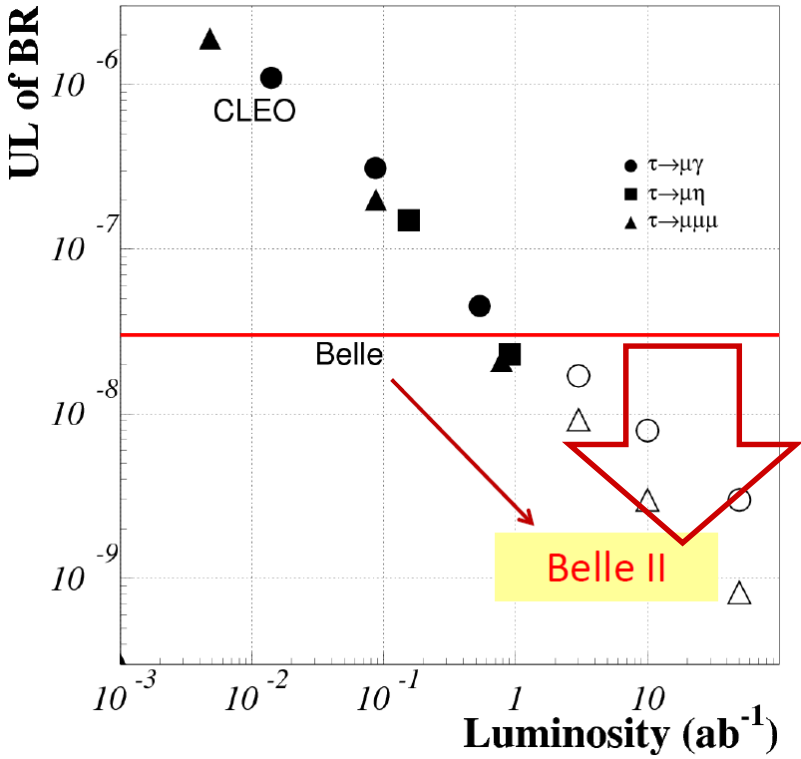
Upper limits on LFV τ decays



- Belle, Babar reached O(10^{-8}) branching ratio, LHCb improving the result
- $\tau \rightarrow$ 3 leptons, l+mesons (to charged particles) show better sensitivity because of less background, compared to $\tau \rightarrow l\,\gamma$.

Future prospects at Belle II





- Will collect 50ab^{-1} data by ~2031, with upgrading detector and accelerator
- B(τ→μμμ)~O(10^{-10}) at ~50ab^{-1}
- Background suppression is key issue.
  - Understanding of background (beam BG, fake PID etc.)
    - → Improvement of reconstruction algorisms
  - Intelligent event selection by machine learning technique

Summary

- Belle II experiment started
  - Achieved world record luminosity; $L = 2.4 \times 10^{34}\ cm^{-2}\ s^{-1}$
  - Accelerator tuning is on going and more data will be recorded.
- Also started actual physics analyses
  - Tau mass measurement by early data shows clear tau rediscovery signal and promising sensitivity.
  - Preliminary result; $M_\tau = 1777.28 \pm 0.75\ (stat) \pm 0.33\ (syst)\ MeV/c^2$
- Belle II will collect $\sim 5 \times 10^{10}\ \tau$ pairs
  - Tau LFV searches will reach the higher sensitivity compared to the previous experiments
  - The background free modes, such as $\tau \rightarrow 3$ leptons, can be reached to $O(10^{-10})$ branching ratio sensitivity.
- More precise result with more data

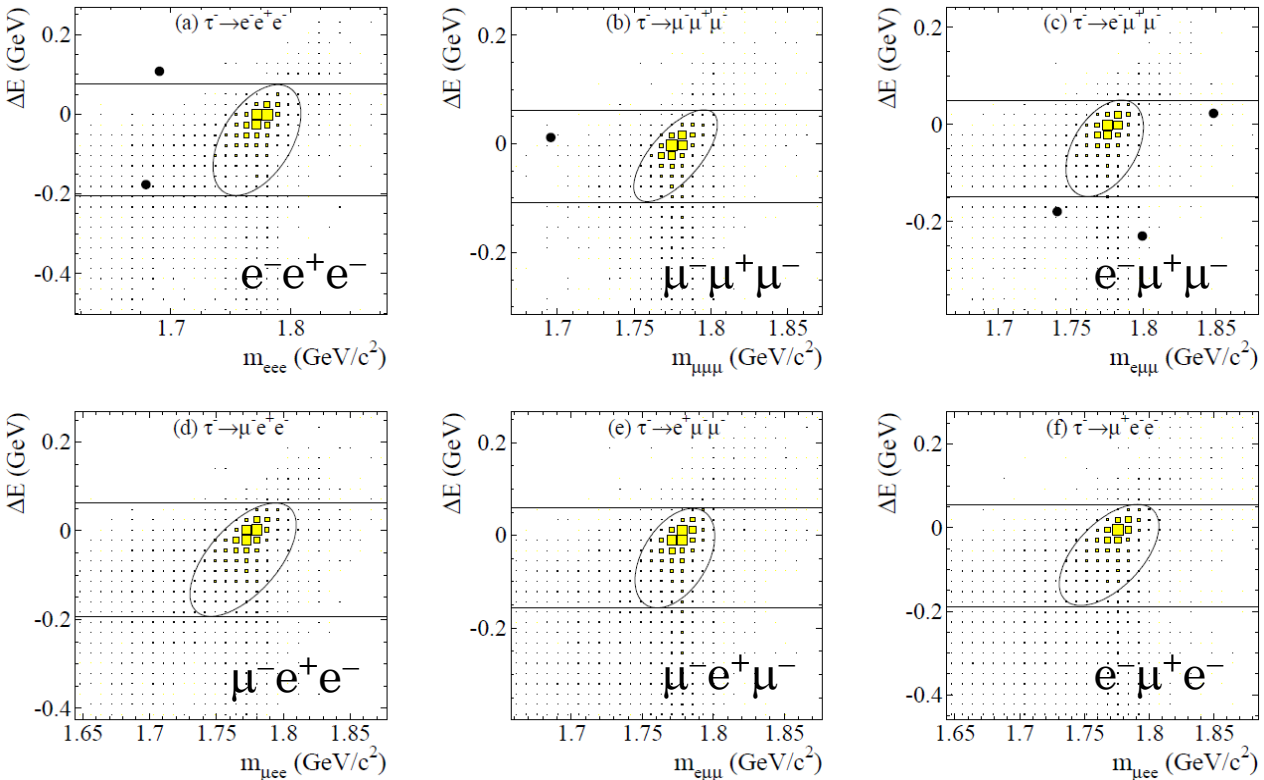
Stay tuned!

Search for τ→3leptons at Belle

- Data: ~7x10^8 ττ
- No event is found in the signal region.
- Br<(1.5-2.7)x10^{-8} at 90% CL.
- Almost BG free
  - Because of good lepton ID

Phys.Lett.B 687,139 (2010)

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



τ→μγ, eγ at BaBar

Phys.Rev.Lett.104:021802,2010

- Data: 470fb^{-1}+31fb^{-1}@Υ(3S)+15fb^{-1}@Υ(2S)
  - (963±7)x10^{6} τ decays
- New kinematical cuts
  + Neural Net discri.
  → Improve S/N
- Dominant BG:
  τ→lνν + radiation
  (irreducible BG)

Decay modes	2σ signal ellipse		ε	UL (×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

- B(τ→μγ)<4.4x10^{-8}
- B(τ→eγ)<3.3x10^{-8}