Prospects for tau lepton physics at Belle II

David Rodríguez Pérez
Universidad Autónoma de Sinaloa
México
on behalf of Belle II colaboration

Flavor Physics and CP Violation
FPCP 2019 conference
University of Victoria
Victoria BC, Canada, May 2019

Outline

1) Overview of SuperKEKB and Belle II experiment

2) Prospects for tau lepton physics at Belle II

3) Status and schedule

4) Summary and outlook

Motivation

Why a flavor factory?
A flavor factory searches for New Physics (NP) by measuring phases, CP asymmetries, inclusive decay processes, rare leptonic decays and absolute branching fractions.

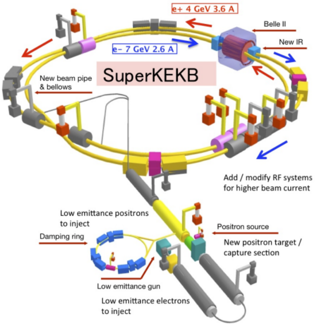
Why an e^+e^- machine?
– Low backgrounds, high trigger efficiency, excellent γ and π^0 reconstruction, high flavor-tagging efficiency with low dilution.

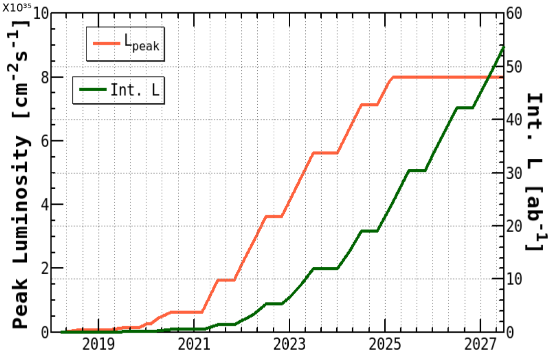
– Due to low backgrounds, negligible trigger bias, good kinematic resolutions. Dalitz plots, missing energy and mass analyses are straightforward.

– A better systematic from those at LHCb to almost every τ channel. If true NP is seen by one of the experiments, confirmation by the other would be important.

B factory - SuperKEKB

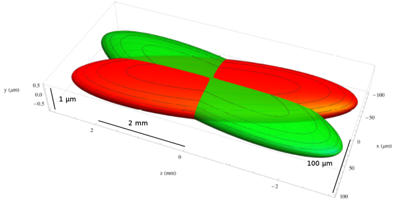
- Peak luminosity: 8×10^{35} cm^{-2}s^{-1}
- Int. luminosity Goal: 50 ab^{-1}



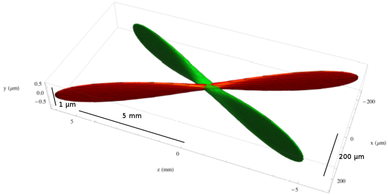


Instantaneous luminosity - Nano-beam scheme

KEKB



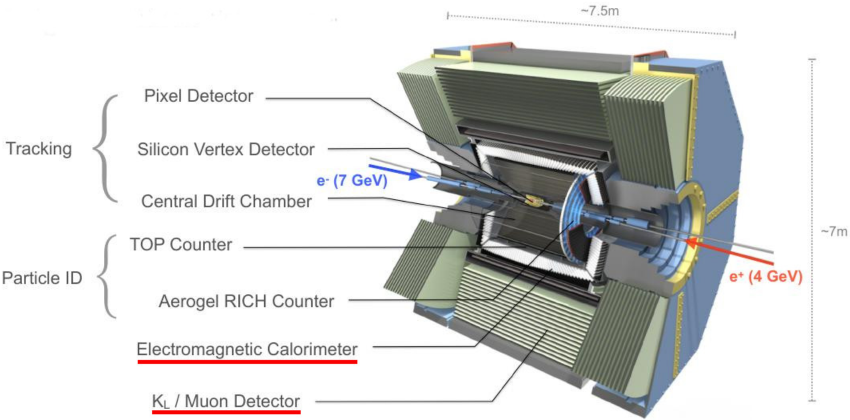
SuperKEKB



Parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
beam energy	E_b	3.5	8	4	7	GeV
CM boost	β_γ	0.425		0.28		GeV
half crossing angle	φ	11		41.5		mrad
horizontal emittance	ϵ_x	18	24	3.2	4.6	nm
emittance ratio	κ	0.88	0.66	0.37	0.40	%
beta function at IP	β_x^* / β_y^*	1200/5.9		32/0.27	25/0.30	mm
beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam parameter	ξ_y	129	90	0.0881	0.0807	
beam size at IP	σ_x^* / σ_y^*	100/2		10/0.059		μm
Luminosity	L	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

Beam related background is expected to be 20 times higher than Belle:
Radiative Bhabha, Touschek, Beamgas scattering

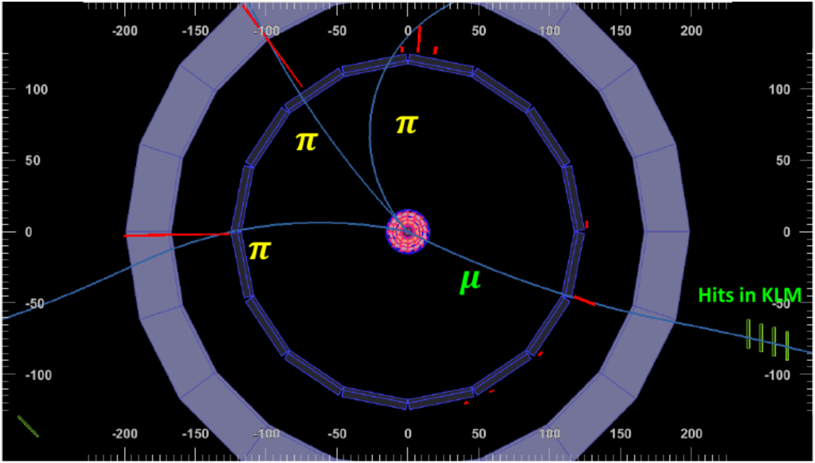
Belle II detector



First Belle II result in tau physics

τ pair candidates with $3\pi\nu$

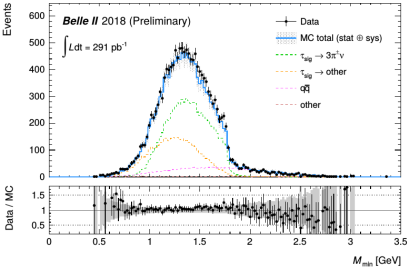
Phase 2 lasted from April 26^{th} to July 17^{th}, 2018

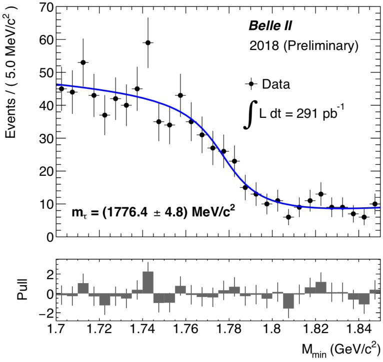


τ rediscovery

First re-measurement of tau mass, following the method developed by the ARGUS collaboration (PLB 292 (1992) no. 1, 221-228) the pseudomass M_{min} is obtained for each $\tau \to 3\pi\nu$ candidate, defined by

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





Search for τ Lepton Flavor Violation

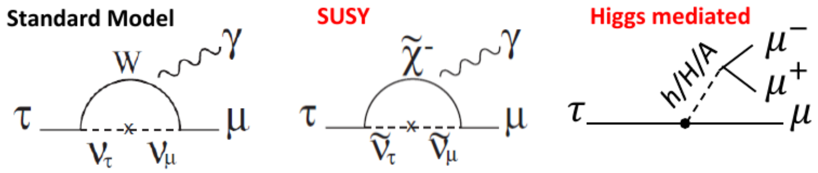
Search for τ LFV

Lepton Flavor Violation is highly suppressed in the Standard Model even if neutrino oscillation is taken $\mathrm{Br} < \mathrm{O}(10^{-45})$, experimentally unreachable.

Many extensions to SM predict to enhance LFV to be observable in current experiment facilities $\mathrm{Br} < \mathrm{O}(10^{-8})$

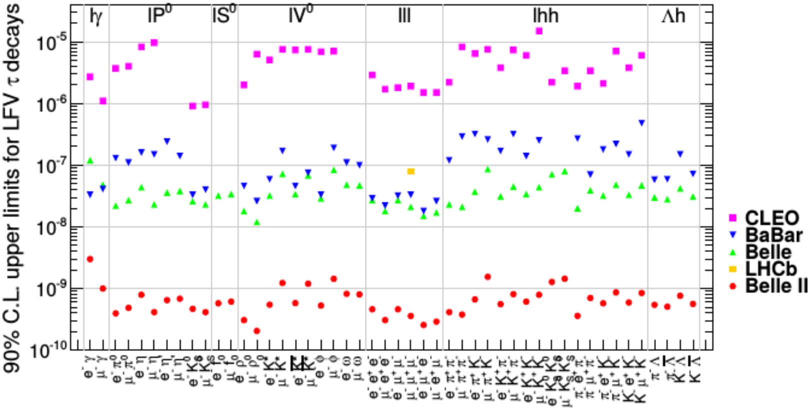
Observation of LFV is a clear signature of the New Physics

Many possible LFV decay modes related to the NP models



Upper limits at B factories

Current estimation with Belle II statistics: $\sim 10^{-2}$ lower

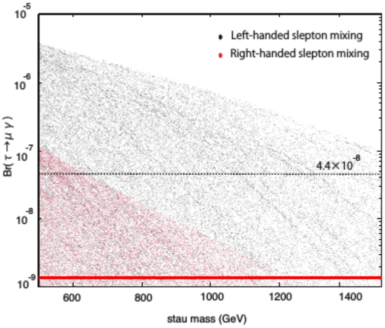


Many decay modes are reachable in Belle II

Theoretical prediction for $\tau \to \gamma\mu$

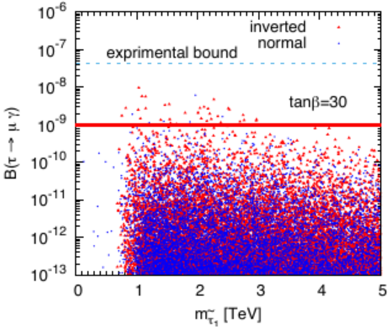
When the most recent experimental results are considered,
MSSM cannot make $\tau \to \gamma\mu$

Non-minimal SUSY SM



$M_{bino} = 250$ GeV   tan $\beta = 30$
$M_{wino} = 500$ GeV   LH slepton mix $= 0.2 \sim 2$ TeV
$M_{higgsino} = 1$ TeV   RH slepton mix $= 5$ TeV

CMSSM



$M_0 > 0.5$ TeV $\mu > 0$

$M_{1/2} < 10$ TeV $|A_0| < 3$

These models predict $\tau \to \gamma\mu$ with reachable BR by Belle II

The Belle II Physics Book, arXiv: 1808.10567

Charge-Parity Violation in τ hadronic decays

CP violation in $\tau \to K_s\pi^\pm\nu_\tau + n\pi^0$

Due to CP violation in the kaon sector, $\tau \to K_s\pi^\pm\nu_\tau$ decays in the SM have a nonzero decay rate asymmetry:

$$A_\tau = \frac{\Gamma(\tau^+ \to K_s^0\pi^+\bar{\nu}_\tau) - \Gamma(\tau^- \to K_s^0\pi^-\nu_\tau)}{\Gamma(\tau^+ \to K_s^0\pi^+\bar{\nu}_\tau) + \Gamma(\tau^- \to K_s^0\pi^-\nu_\tau)}$$

SM prediction: $(3.6 \pm 0.1) \times 10^{-3}$

I. Bigi and A. I. Sanda, Phys. Lett. B 625, 47 (2005).

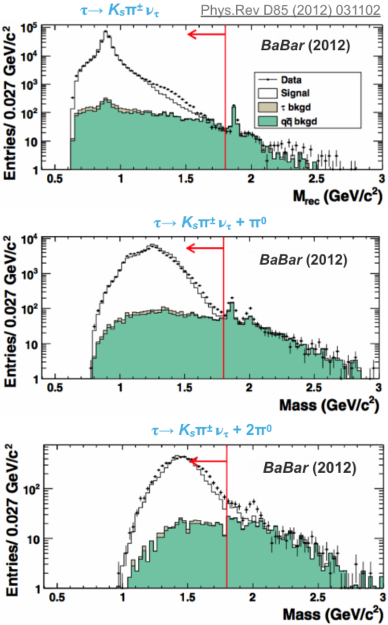
Y. Grossman and Y. Nir, JHEP 2012.4 (2012).

BaBar results:

$(-3.6 \pm 2.3 \pm 1.1) \times 10^{-3}$

2.8σ discrepancy from SM

An improved A_τ measurement is a priority at Belle II

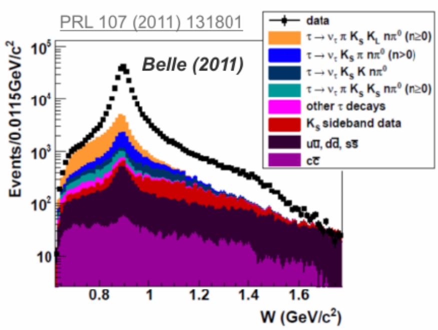


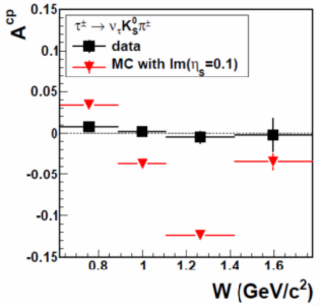
CP violation in $\tau \to K_s \pi^{\pm} \nu_\tau$

CP violation could also arise from a charged scalar boson exchange and it would be detected as a difference in a decay angular distributions:

$$A_i^{CP} = \frac{\iint_{Q^2_{1,i}}^{Q^2_{2,i}} \cos\beta \cos\psi \left(\frac{d\Gamma_{\tau^-}}{d\omega} - \frac{d\Gamma_{\tau^+}}{d\omega}\right) d\omega}{\frac{1}{2} \iint_{Q^2_{1,i}}^{Q^2_{2,i}} \left(\frac{d\Gamma_{\tau^-}}{d\omega} + \frac{d\Gamma_{\tau^+}}{d\omega}\right) d\omega} \simeq \langle \cos\beta \cos\psi \rangle^i_{\tau^-} - \langle \cos\beta \cos\psi \rangle^i_{\tau^+},$$

$$d\omega = dQ^2 d\cos\theta d\cos\beta$$





with 50 ab^{-1} of data, Belle II (Belle, 699 fb^{-1}) is expected to provide a $\sqrt{70}$ more precise measurement:

$|A_{CP}| < (0.4 - 2.6) \times 10^{-4}$

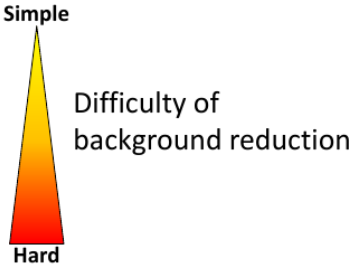
but the stat errors will go as sqrt of the luminosity ratio.

Lepton Flavor Violation analysis

Analysis strategy

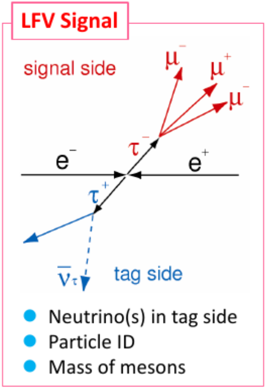
- Rare decay search:
  - Understand background and reduce as much as possible
- Search various decay modes:

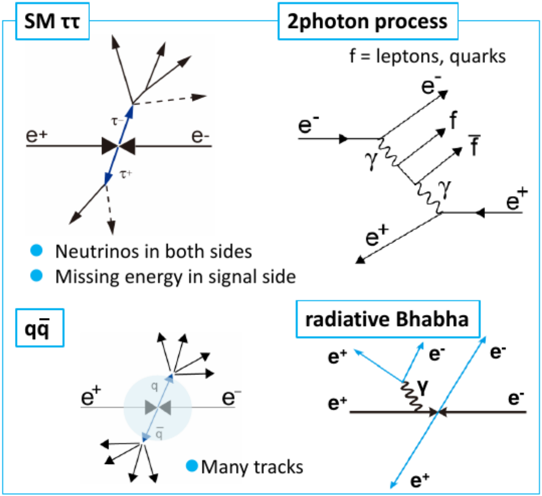
  - $\tau \to \ell\ell\ell$
  - $\tau \to \ell K_s, \Lambda h$
  - $\tau \to \ell V_0(\to hh')$
  - $\tau \to \ell P^0\ (\to \gamma\gamma)$
  - $\tau \to \ell hh'$
  - $\tau \to \ell\gamma$



- Analyze the modes from simple selections to hard ones for background reduction
  - Provide feedback to next analysis of similar final state

Signal and background





Major BG differs between LFV decay channels

Extraction of τ pairs

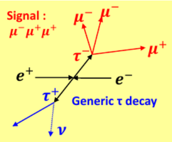
Huge *tau* pair samples are collected by tagging method

$$e^+e^- \to \tau^+ \text{ (tag side)}$$
$$\tau^- \text{ (signal side)}$$

Event shape helps to reduce backgrounds significantly

$$T = \frac{\sum |\vec{T} \cdot \vec{p_i}|}{\sum |\vec{p_i}|}$$

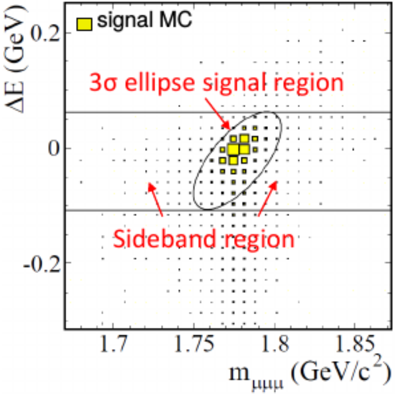
Thrust vector, minimizing T, shows sphericity of an event



Signal extraction: $m_{\mu\mu\mu} - \Delta E$ plane

$$m_{\mu\mu\mu} = \sqrt{E^2_{\mu\mu\mu} - p^2_{\mu\mu\mu}} \sim m_\tau$$
$$\Delta E = E^{CM}_{\mu\mu\mu} - E^{CM}_{beam}$$

Number of background is estimated using sideband data and MC



Status

Phase 3 has started!!

Summary and Outlook

- Belle II is beginning its **Phase 3** run. This will fully commission the detector, and there will be early physics.
- There are challenges: background is high, β_y is still high and current is still low.
- Tau physics potential is huge, there is much better vertexing and particle ID than in Belle.

Backup

Belle II timeline