SEARCH FOR NEW PHYSICS IN CHARGED LEPTON FLAVOR VIOLATING PROCESSES AT THE BELLE II EXPERIMENT

Marcela García,* **Ivan Heredia.***
*The Center for Research and Advanced Studies of the National Polytechnic Institute (CINVESTAV-IPN)

ABSTRACT

In particle physics, lepton flavor violating (LFV) processes are known to take place in the neutral sector due to neutrino oscillations. However, these processes have not been observed in the charged sector yet. If they were observed, they would lead to new physics scenarios, as they are strongly suppressed in the Standard Model.
The Belle II experiment will collect the world largest τ lepton sample in the upcoming years, making it suitable to explore the properties of the τ lepton and search for cLFV.
We have explored the cLFV decay with missing energy, $\tau \longrightarrow \ell + \alpha$, where α stands for an undetected long-lived particle predicted by new physics theories and $\ell = e, \mu$.
In addition, we have been searching for the golden channel $\tau \longrightarrow \ell + \gamma$, where $\ell = e, \mu$.

BELLE II EXPERIMENT

Electron-positron asymmetric beams collider.

- CMS energy $\sqrt{s} \approx m_{\Upsilon(4s)} \approx 10.58$ GeV.
- Target luminosity of 6.5x10^{35} cm^{-2} s^{-1}(x30 Belle).
- Goal: 50 ab^{-1} (~2031). (x50 Belle).

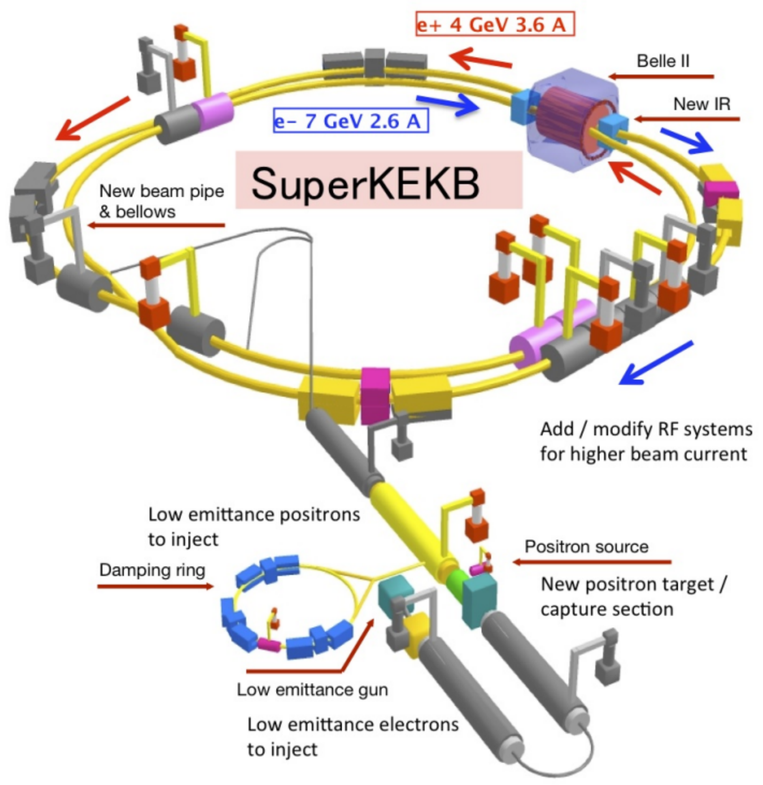

Figure: SuperKEKB.[1]

- Phase 3 data: > 400 fb^{-1} collected so far.

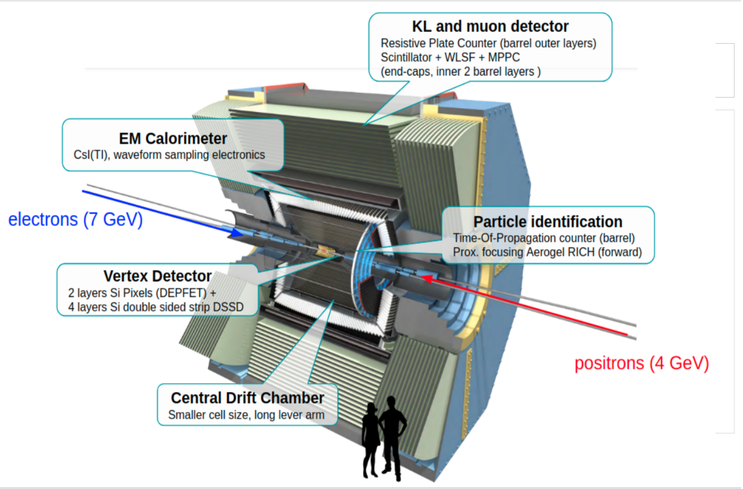

Figure: Belle II detector. Major upgrade of Belle.[1]

- Among the members of 123 institutes (26 countries) in Belle II, there is Cinvestav, UAS and UNAM in Mexico.

TAU LEPTON

In the Belle II experiment mostly B mesons are produced
$\Rightarrow$ Super B-factory.
Moreover,

- $\sigma(e^-e^+ \longrightarrow B\bar{B})$ = 1.05
- $\sigma(e^-e^+ \longrightarrow \tau^-\tau^+)$ = 0.919

$\Rightarrow$ Also a τ-factory.
The Belle II experiment will offer fantastic possibilities to study τ physics with high precision.

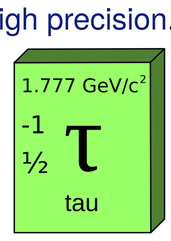

Figure: τ lepton

TAU PHYSICS AT BELLE II

In Belle II, we are measuring the properties of the τ, performing precision tests, and searching for new physics.

- τ mass measurement (8.76 fb^{-1}).
  2020: 1777.28 ± 0.75 ± 0.33 MeV/c^2.

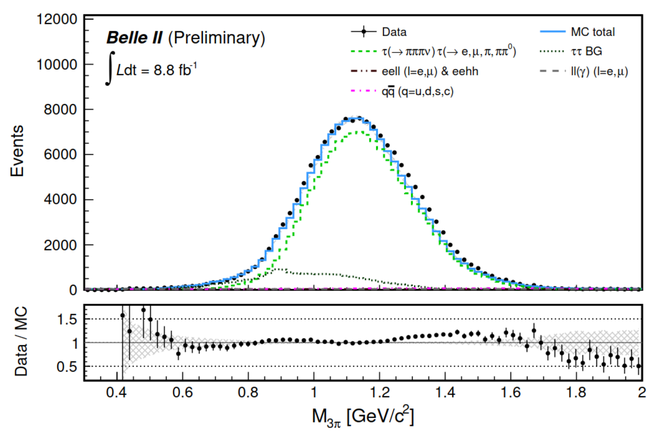

Figure: Mass of the 3π system.[2]

The distribution of the pseudomass is fitted to an empirical edge function to estimate τ mass:

- $F(M_{min}, \vec{P}) = (P_3 + P_4 \cdot M_{min}) \cdot tan^{-1}[(M_{min} - \mathbf{P_1})/P_2] + P_5 \cdot M_{min} + 1$
- $M_{min} = \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi})}$

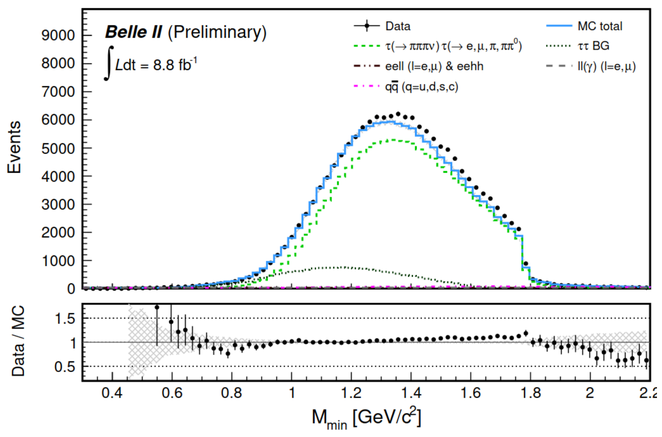

Figure: Pseudomass technique.[2]

Belle τ lifetime: τ_τ = 290.17 ± 0.53 ± 0.33 fs.[3]

- Belle II: Improvement of the resolution (2 narrower) w.r.t. to Belle.

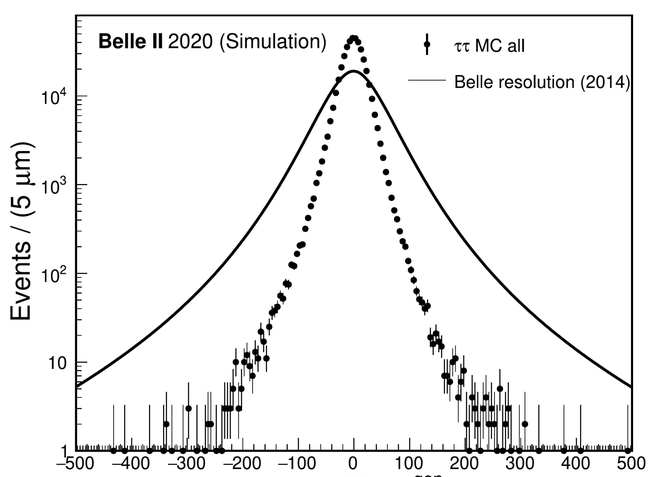

Figure: Resolution. Ref: IPA2022(Tau physics program at Belle II)

- Searches of violation of LFU.

LFV

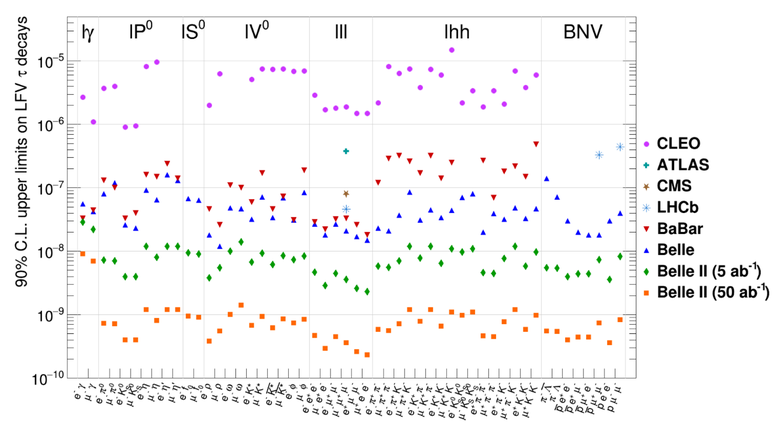

Figure: Since the τ is the most massive lepton, it is possible to search for more than 40 different cLFV processes.[4]

TAU TO LEPTON ALPHA

- ARGUS 1995: 476 pb^{-1}, Belle II 2022: 68fb^{-1}.
- The search is in a 3x1 prong topology.

The idea is to search for a 2 body decay: The momentum of the signal lepton will manifest as a peak in the τ rest frame, as compared against the SM $\tau \longrightarrow \ell\nu\bar{\nu}$ (bkg).
However, cannot access the τ rest frame directly due to missing particles. $\Rightarrow$ τ pseudo rest frame.

- $E_\tau \approx E_{CMS}/2$
- $\vec{e}_\tau \approx -\vec{e}_{3-prong}$

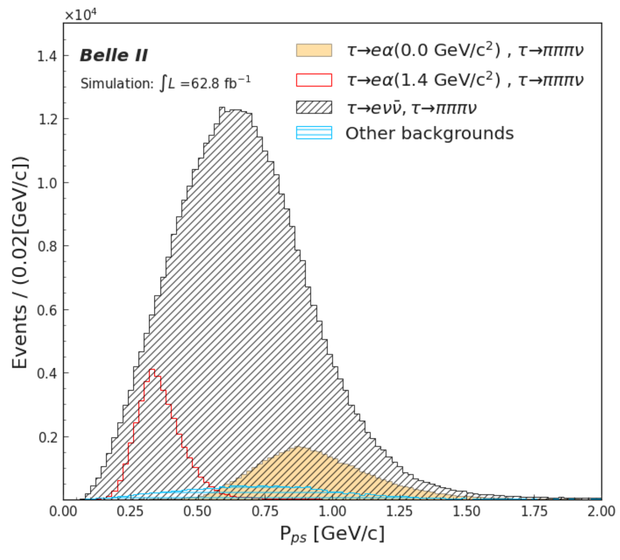

Figure: τ pseudo rest frame distribution for e channel.[5]

UL calculation:

- $F(x) = \frac{\epsilon_\alpha}{\epsilon_{l\nu\bar{\nu}}} \cdot N_{l\nu\bar{\nu}} \cdot R \cdot f_\alpha(x) + N_{l\nu\bar{\nu}} \cdot f_{l\nu\bar{\nu}}(x) + N_{bkg} \cdot f_{bkg}(x)$

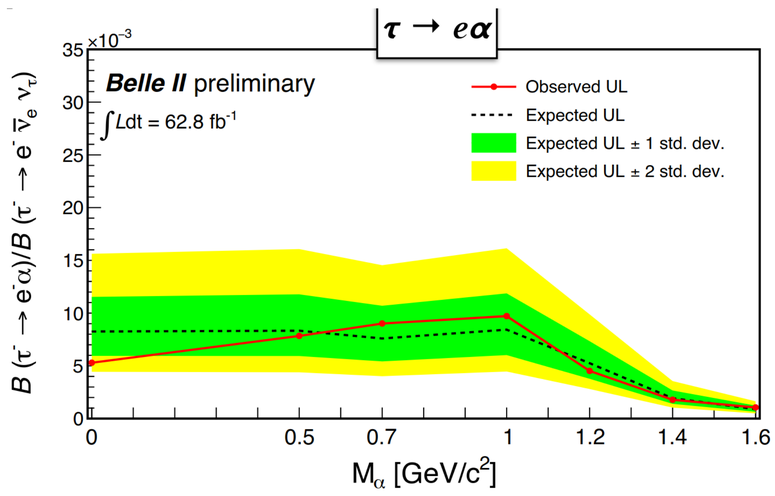

Figure: UL results as a function of the mass of the α particle, for e channel. Ref: ICHEP 2022 (New limit on $\tau \longrightarrow \ell$ + invisible.)

- **Paper in final stage review.**

TAU TO LEPTON GAMMA

This process is expected to have a Br ~ O(10^{-54}), however, new physics scenarios predict BR ~ $10^{-9(-10)}$.
$\Rightarrow$ Belle II will be able to reach these predictions in the next years.
Current limits,

- Belle 2021: BR($\tau \longrightarrow \mu\gamma$) < 4.2 x 10^{-8} 90% C.L.[6]
- BaBar 2009: BR($\tau \longrightarrow e\gamma$) < 3.3 x 10^{-8} 90% C.L.[7]

The signal will manifest as a peak in the 2D plane:
$\Delta E = E_{\mu\gamma}^{CM} - E_{beam}^{CM}$, $M_{inv}^{\mu\gamma} = \sqrt{(E_{\mu\gamma})^2 - (p_{\mu\gamma})^2}$.
In Belle II, we expect to improve the limit for 1 ab^{-1}: $BR(\tau \longrightarrow \mu\gamma)/2$, and for 50 ab^{-1} to improve for 2 orders of magnitude.

- Similar procedure is used to search for $\tau \longrightarrow \ell\ell\ell$.

REFERENCES

[1] arXiv:1808.10567
[2] arXiv:2008.04665
[3] PhysRevLett.112.031801
[4] arXiv:2203.14919
[5] BELLE2-NOTE-PL-2021-011
[6] JHEP10(2021)019
[7] PhysRevLett.104.021802