Snowmass 2021 - Letter of Interest

Tau Physics and Precision Electroweak Physics with Polarized Beams at SuperKEKB

Collaboration: Belle II/SuperKEKB

Thematic Area(s):

■ (RF01) Weak Decays of b and c ■ (RF02) Strange & Light Quarks ■ (RF03) Fundamental Physics in Small Experiments ■ (RF04) Baryon & Lepton Number Violation ■ (RF05) Charged Lepton Flavor Violation (electrons, muons and taus) ■ (RF06) Dark Sector at Low Energies

Corresponding Author(s):

Swagato Banerjee (University of Louisville)

Authors:

John Micheal Roney (University of Victoria)
Name B (Institution)
Name C (Institution)

Abstract:

The upgraded Belle II experiment at the world's highest luminosity collider, the SuperKEKB, offers unique opportunities to study fundamental features of Tau lepton and Electroweak Physics, which are extremely sensitive to new physics effects beyond the Standard Model. Polarized beams with the projected luminosity at SuperKEKB can probe parity violating components of neutral couplings of both quarks and leptons to new particles up to unprecedented precision.

- New Physics Searches with Precision Neutral Current Measurements

  One of the mysteries in particle physics that is unexplained for more than two decades now is a three-sigma discrepancy between the left- right asymmetry measured at the Stanford Linear Collider and the forward-backward asymmetry measured by the experiments at the Large Electron Positron collider at CERN. This kind of unique physics opportunity is not covered by any other present-day experiments and can not be achieved again until FCCee-generation machines have integrated significant amounts of luminosity at the Z- pole, maybe in 2040s'.

  At 10.58 GeV, polarized e- beam yields product of the neutral axial-vector coupling of the electron and the vector coupling of the final state fermion via Z- interference.

  Left-right asymmetry (ALR) of neutral vector coupling (gv) to each of the five fermion flavors (f): b, c, , , e

- New Physics Searchers with Precision Charged Current Measurements

  – Charged current universality

    gmu/ge, gtau/gmu, gtau/ge

  – Largest off-diagonal element of CKM Matrix

    There is a 3σ discrepancy between the measured value of $|V_{us}|$ and the unitarity prediction.

  – Scalar contributions to hadronic currents in τ decays

    This is quite interesting because it can manifest as second class current, which connects with the extended Higgs sector

  – Lepton flavor violation in τ decays:

    Lepton flavor violation (LFV) is unambiguous signature of new Physics. Belle II expects to probe (LFV) decays in τ decays down to few parts in $10^{-9} - 10^{-10}$. While the signal does not depend on the beam polarization, several of the dominant Standard

Model backgrounds do exhibit strong asymmetry to beam polarization, and thus can be reduced with polarized beams. The "irreducible background" would be cut by 70% for a 39% loss in signal efficiency. This would result in approximately a 10% improvement in the sensitivity.

One of the most important aspect of having the polarization is the possibility to determine the helicity structure of the LFV coupling from the final state momenta distributions.

- Dark sector
  - Light or dark extra gauge bosons

    SuperKEKB with polarization would be uniquely sensitivity to "Dark Sector" parity violating light neutral gauge bosons especially when Zdark is off-shell and with a mass between roughly 10 and 35 GeV or even up to the Z0 pole, or couples more to the 3rd generation.

  - Dark photon

    $\tau^- \to \mu^- A' \bar{\nu}_\mu \nu_\tau$ with $A' \to e^- e^+, \mu^- \mu^+$

- Electric dipole and anomalous magnetic moment of τ:

BaBar+Belle	2 ab^{-1}	$\lvert d_\tau^\gamma \rvert \leq 4.4 \times 10^{-19} e \cdot cm$
Super B/Flavor factory	15 ab^{-1}	$\lvert d_\tau^\gamma \rvert \leq 1.6 \times 10^{-19} e \cdot cm$
Super B/Flavor factory	75 ab^{-1}	$\lvert d_\tau^\gamma \rvert \leq 7.2 \times 10^{-20} e \cdot cm$

Various observables of the τ's produced on top of the Υ resonances, such as cross-section and normal polarization for un-polarized electrons or longitudinal and transverse asymmetries for polarized beams, can be combined in order to increase the sensitivity on the magnetic moment form factor. In the case of polarized electrons, we identify a special combination of transverse and longitudinal τ polarization's able to disentangle this anomalous magnetic form factor from both the charge form factor and the interference with the Z-mediating amplitude. For an integrated luminosity of $15ab^{-1}$ one could achieve a sensitivity of about 10^6, which is several orders of magnitude below any other existing high- or low-energy bound on the magnetic moment. Thus one may obtain a QED test of this fundamental quantity to a few % precision.

References: