Snowmass 2021 Letter of Interest: Belle II/SuperKEKB Upgrades & Overview

on behalf of the U.S. Belle II Collaboration

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Thematic Area(s):

■ (AF05) Accelerators for rare processes and precision measurements

Abstract:

We describe the planned upgrades of the SuperKEKB accelerator at KEK and additionally list all the Snowmass LOIs submitted on behalf of the Belle II Collaboration and U.S. Belle II. The upgrades will allow increasingly sensitive searches for possible new physics beyond the Standard Model in flavor, tau, electroweak and dark sector physics that are both complementary to and competitive with the LHC as well as other experiments.

In this Letter of Interest (LOI), we describe the planned upgrades of the SuperKEKB accelerator at KEK, and additionally list all the Snowmass LOIs submitted on behalf of the Belle II Collaboration and U.S. Belle II. The upgrades will allow increasingly sensitive searches for possible New Physics (NP) that are both complementary to and competitive with the LHC and other experiments. The physics progam and potential NP reach of Belle II are comprehensively described in the Belle II Physics Book,[1] which was the result of a collaboration between Belle II members and theorists which remains active and ongoing through the Belle II Theory Interface Platform (B2TIP). We continue to welcome new contributions from the theoretical and experimental community that may help expand the scope and reach of Belle II physics.

We have submitted additional Snowmass 2021 LOIs in several thematic areas to accompany this one. Each briefly summarizes the future prospects for the Belle II physics program which are expected to result from both the current configuration of the experiment as well as from planned upgrades:

- (AF05) Accelerators for rare processes and precision measurements
  - Belle II/SuperKEKB Upgrades & Overview
- (RF01) Weak Decays of b and c quarks (2 LOIs)
  - Belle II/SuperKEKB capabilities for B physics
  - Charm Physics at Belle II
- (RF06) Dark Sector at Low Energies
  - Dark sector studies at Belle II
- (RF01) Weak Decays of b and c, (RF02) Strange & Light Quarks, (RF03) Fundamental Physics in Small Experiments, (RF05) Charged Lepton Flavor Violation (electrons, muons and taus), (RF06) Dark Sector at Low Energies, (AF05) Accelerators for rare processes and precision measurements, (EF03) EW Physics: Heavy flavor and top quark physics, (EF04) EW Physics: EW Precision Physics and constraining new physics, (EF10) BSM: Dark Matter at colliders, (TF06) Theory techniques for precision physics, (TF08) BSM model building
  - Tau Physics and Precision Electroweak Physics with Polarized Beams at SuperKEKB/Belle II
- (RF07) Hadron Spectroscopy
  - Belle II/SuperKEKB capabilities for hadron spectroscopy
- (EF05) QCD and strong interactions: Precision QCD, (EF06) QCD and strong interactions: Hadronic structure and forward QCD, (RF03) Fundamental Physics in Small Experiments
  - QCD and Hadronization Studies at Belle II
- (CF[**??**]) Computation Frontier: ML/AI, analytic frameworks

  - Computing, Software, and Analysis capabilities for the Belle II Experiment

- (IF02) Photon Detectors, (IF03) Solid State Detectors & Tracking, (IF04) Trigger & DAQ, (IF05) Micro Pattern Gas Detectors, (IF06) Calorimetry, (IF07) Electronics/ASICS
  - Belle II Detector Upgrades

Belle II is an international collaboration of ~ 1000 members at more than 100 institutions in 26 countries; U.S. Belle II accounts for ~ 120 members at 18 U.S. universities and national labs. The primary systems responsibilities of U.S. Belle II include the iTOP (imaging Time Of Propagation) subdetector used for charged particle identification, the KLM (KLong Muon) subdetector, background commissioning detectors and computing operations.

SuperKEKB/Belle II was commissioned with colliding beams in 2018. The first physics run after installation of the vertex detector was in Spring 2019, followed by runs in Fall 2019 and Spring 2020. In spring 2020, SuperKEKB surpassed the highest recorded instantaneous luminosities of the B factories and LHC with a peak luminosity of 2.4 x 10^{34}cm^{-2}sec^{-1}. Belle II datataking has thus far operated smoothly with acceptable backgrounds and has routinely integrated ~ 1 fb^{-1} of data per day in Spring 2020. As of June 2020, Belle II has integrated 74 fb^{-1} of physics data at and slightly below the $\Upsilon(4S)$ resonance.

SuperKEKB is expected to be able to reach instantaneous luminosities of $\sim$ (1-2) x 10^{35}cm^{-2}sec^{-1} with the existing accelerator complex. However, in order to reach peak luminosities up to 6.5 x 10^{35}cm^{-2}sec^{-1}, an upgrade of the interaction region and the QCS superconducting final focus will be required. To handle the increased data rates which will result from these upgrades, a DAQ upgrade is currently under way. Also accompanying the machine upgrades are several planned detector upgrades, including a new pixel vertex detector and upgrades of the particle identification systems to optimally perform in the presence of the increased backgrounds, occupancies and radiation doses expected with the luminosity improvements. These detector upgrades are more fully described in several Snowmass LOI(s) submitted to the Instrumentation Frontier.

Belle II/SuperKEKB operations and upgrades over the next $\sim$ 1-2 decades are expected to factorize into several distinct epochs:

1. Intermediate luminosity, $\mathcal{L}_{peak} \sim 1$ x 10^{35}cm^{-2}sec^{-1}, $\mathcal{L}_{int} \sim 5$ ab^{-1}: The required upgrades of detector and machine for the intermediate luminosity epoch have been approved and baselined. They will be realized over the next few years.
2. High luminosity, $\mathcal{L}_{peak} \sim 6.5$ x 10^{35}cm^{-2}sec^{-1}, $\mathcal{L}_{int} \sim 50$ ab^{-1}: The high-lumi upgrade has been approved and incorporated into the SuperKEKB project. The technical design is currently under review.
3. Electron beam polarization at high luminosity: Currently in R&D, this upgrade would require modest additional hardware investments. With a goal of $\sim 70\%$ electron beam polarization, this upgrade would open unexplored NP discovery windows through a new and unique program of electroweak measurements of unprecedented precision involving beauty, charm and all three generations of charged leptons.
4. Ultra-high luminosity, $\mathcal{L}_{peak} \sim 2.5$ x 10^{36}cm^{-2}sec^{-1}, $\mathcal{L}_{int} \sim 200 - 250$ ab^{-1}: Currently in R&D.

References

[1] E. Kou *et al.*, The Belle II Physics Book (2018), https://arxiv.org/abs/1808.10567.