# *Snowmass 2021 Letter of Interest:* Belle II Detector Upgrades


on behalf of the U.S. Belle II Collaboration

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## Thematic Area(s):

■ (IF02) Photon Detectors
■ (IF03) Solid State Detectors & Tracking
■ (IF04) Trigger & DAQ
■ (IF05) Micro Pattern Gas Detectors
■ (IF06) Calorimetry
■ (IF07) Electronics/ASICS

## Abstract:

We describe the planned near-term and potential longer-term upgrades of the Belle II detector at the SuperKEKB electron-positron collider in Tsukuba, Japan. These 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. We encourage the instrumentation frontier community to contribute and study upgrade ideas as part of the Snowmass process.

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. Primary U.S. Belle II responsibilities include the imaging Time Of Propagation subdetector ( iTOP) used for charged particle identification, the K-Long Muon subdetector (KLM), beam background mitigation, computing operations, and data production.

SuperKEKB/Belle II was commissioned with colliding beams in 2018. In spring 2020, SuperKEKB surpassed the highest recorded instantaneous luminosities of the B factories and LHC with a peak instantaneous luminosity of $\mathcal{L}_{\text{peak}} = 2.4 \times 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$. SuperKEKB is expected to be able to reach $\mathcal{L}_{\text{peak}}$ of (1-2) $\times\ 10^{35}\,\text{cm}^{-2}\text{s}^{-1}$ with the existing accelerator complex. In order to reach $\mathcal{L}_{\text{peak}} = 6.5 \times 10^{35}\,\text{cm}^{-2}\text{s}^{-1}$, however, an upgrade of the interaction region and the QCS superconducting final focus will be required. In order to handle expected increases in data rates, a DAQ upgrade is currently under way. Accompanying the machine upgrades are planned Belle II detector upgrades, on three time scales:

1. **short term**, $\mathcal{L}_{\text{int}} = 5\,\text{ab}^{-1}$: year 2022, during planned shutdown for pixel detector replacement. This upgrade is well defined and only minimal additions are possible. The upgraded detector must tolerate $\mathcal{L}_{\text{peak}} = 1 \times 10^{35}\,\text{cm}^{-2}\text{s}^{-1}$.
2. **medium term**, $\mathcal{L}_{\text{int}} = 50\,\text{ab}^{-1}$: approximately year 2026, during shutdown for interaction region upgrade. Detector upgrade proposals exist, but are not yet well defined, alternatives are still possible. The upgraded detector must tolerate $\mathcal{L}_{\text{peak}} = 6.5 \times 10^{35}\,\text{cm}^{-2}\text{s}^{-1}$/
3. **long term**, $\mathcal{L}_{\text{int}} = 200\,\text{ab}^{-1}$: years $> 2032$. Studies have started to explore upgrades beyond the currently planned program, such as beam polarization and ultra-high luminosity. The upgraded detector must tolerate $\mathcal{L}_{\text{peak}} = 2.5 \times 10^{36}\,\text{cm}^{-2}\text{s}^{-1}$.

Table 1 shows the currently planned short and medium-term Belle II detector upgrades. The U.S. groups plan participation in iTOP, KLM, and DAQ upgrades, and have proposed the "STOPGAP" system to increase the geometric TOP acceptance. There is also U.S. interest in studying the feasibility of replacing the drift chamber with a time projection chamber (TPC) with charge readout via Micropattern Gasous Detectors (MPGDs).

For long-term ($> 2032$) upgrades, plans are much more uncertain. In addition to further investigation of the medium-term upgrade technologies, the following options have been discussed within the collaboration to date:

- PXD, SVD, CDC: These detector will likely require long-term upgrades. The medium-time-scale (2026) proposals should be extended.
- TOP replacement: Replacement of quartz bars with scintillator and MCP-PMT with SiPM or LGAD.
- Instrumenting TOP gaps with STOPGAP, a time of flight detector using scintillators and LGAD or SiPM phodetectors. This can improve the geometrical acceptance by 6%.

The medium and long term upgrades are highly relevant to the 2021 Snowmass process. We encourage the wider instrumentation community participating in Snowmass to contribute and study existing or new upgrade ideas for Belle II.

| Subdector | Function | 2022 upgrade | 2026 upgrades proposed to date |
|---|---|---|---|
| PXD | Vertex Detector | 2 layer upgrade | 1) New DEPFET<br>2) SOI<br>3) CMOS monolithic sensors |
| SVD | Vertex Detector | — | 1) Thin, double-sided strips, w/ new frontend<br>2) Merge PXD and SVD, CMOS monolithic sensors |
| CDC | Tracking | Upgrade FE if ready | 1) Keep current detector, upgrade FE electronics<br>2) Replace with TPC w/ MPGD readout |
| TOP | PID, barrel | Repl. conv. MCP-PMTs | 1) Replace not-life-extended ALD MCP-PMTs<br>2) Partial "STOPGAP" (see below) |
| ARICH | PID, forward | — | 1) Replace HAPPD with Silicon PhotoMultipliers<br>2) Replace HAPPD with Large Area Picosecond Photodetectors |
| ECL | $\gamma$, $e$ ID | — | 1) Add pre-shower detector in front of ECL<br>2) Replace ECL PiN diodes with APDs |
| KLM | $K_L$, $\mu$ ID | — | 1) Replace 13 barrel layers of legacy RPCs with scintillators<br>2) On-detector upgraded scintillator readout<br>3) Timing upgrade for K-long momentum measurement |
| Trigger | | Firmware improvements | Not defined yet, depend on detector upgrades |
| DAQ | | 1) 2021: PCIe40 readout upgrade<br>2) Add 1300 cores to HLT | Add 1900 cores to HLT |

Table 1: Known short and medium-term Belle II subdetector upgrade plans, starting from the radially innermost. The current Belle II subdetectors are the Silicon Pixel Detector (PXD), Silicon Strip Detector (SVD), Central Drift Chamber (CDC), Time of Propagation Counter (TOP), Aerogel Rich Counter (ARICH), EM Calorimeter (ECL), Barrel and Endcap K-Long Muon Systems (BKLM, EKLM), Trigger and Data aquistion (DAQ). DAQ includes the high level trigger (HLT).