The Belle II Experiment: Status and Prospects

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on behalf of the Belle II collaboration
Belle II at SuperKEKB

Plan to collect $50 \text{ ab}^{-1}$ of collisions at and near $\Upsilon(4S)$
Successor to Belle at KEKB (1.05 ab$^{-1}$)

At $\Upsilon(4S), E_{CM} = 10.58$ GeV
7 GeV $e^-$ (HER; High Energy Ring)
4 GeV $e^+$ (LER; Low Energy Ring)

Nano beam scheme

\[
\mathcal{L} = \frac{\gamma \pm}{2e r_e} \left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right) I_{\pm \xi \pm y} \left(\frac{R_L}{R_y}\right) \beta_y^*
\]

5.9 $\rightarrow$ 0.3 mm
KEKB SuperKEKB

Physics motivations

- New physics search in $B, B_s, D, \tau$ decays
- Direct search for light new particles
- Precise measurement of Standard Model
- Hadron physics

Belle II collaboration

~1000 collaborators from 26 countries and regions
Belle II detector

Electromagnetic calorimeter
CsI(Tl), waveform sampling

Superconducting solenoid (1.5 T)

K_\ell and \mu detector
- Resistive plate chamber (outer barrel)
- Scintillator + MPPC (inner 2 barrel layers, end-caps)

Particle ID detectors
- TOP (Time-of-Propagation) counter (barrel)
- Aerogel RICH (forward end-cap)

Tracking detector
Drift chamber (He + C_2H_6) of small cell, longer lever arm with fast readout electronics

Silicon vertex detector
- 1\rightarrow2 layers DEPFET (pixel)
- 4 outer layers DSSD

Trigger and DAQ
Max L1 rate: 0.5\rightarrow30 kHz
Pipeline readout

GRID computing

Better performance even at the higher trigger rate and beam background
Major detector issues in the operation

- Detector lifetime (in particular TOP counter)
  - To keep the MCP-PMT QE within an acceptable level (QE/QE₀ > 80%) until 50 ab⁻¹, the Touschek and beam gas backgrounds, which increase with (beam current)², have to be kept constant by collimators, beam tuning, additional shielding, ...
  → TOP PMT hit rate could limit the luminosity.

- Permanent damage on PXD and SVD by accidental huge beam loss.

- Synchrotron radiation from HER beam on PXD
  → Should be carefully monitored not to irradiate PXD unnecessarily.

Projection of the QE degradation

Assume luminosity background (MC) + 1.2 MHz/PMT
Operation status in 2020

- SuperKEKB/Belle II was operated under Covid-19 pandemic while minimizing risk of infection:
  - Minimize person-to-person contact and avoid 3C
    - Remote control room shifts and expert shifts
    - Travel restrictions (~40 Belle II colleagues on-site)
    - Online meetings
  - Hygiene (face mask, alcohol disinfection, ventilation, …)

KEK campus

**Beam background** (SpeakApp)

**HV ctrl** (RocketChat)

Sub-system experts

Remote ctrl room shift

KCG (SuperKEKB CG)

BCG (Belle II Commissioning Group)
Accelerator operation summary

Beam background was kept below the limit.

$2.4 \times 10^{34} \text{ cm}^2/\text{s (WR)}$ at ~half beam current of KEKB

Try to squeeze $\beta_y^*$ down to 0.6 mm in this coming autumn run.
Integrated luminosity

Belle II data taking efficiency has been improved to 84%.

✓ Less DAQ errors and more prompt recovery from the errors by experts’ consistent effort

✓ Error analysis and monitor by ELK (Elasticsearch Logstash Kibana)

✓ More experienced shifters

✓ Controlled injection veto dead time (avg. 4.9%) as a result of injection background studies

Belle II Online luminosity

Exp: 7-8-10-12 - All runs

$\int L_{\text{Recorded}} dt = 74.10 [\text{fb}^{-1}]$

$1.3 \text{ fb}^{-1}/\text{day} \rightarrow$

ICHEP2020 dataset
34.6(3.2) fb$^{-1}$ on-(off-)resonance
Data analyses to be shown in ICHEP2020

**Performance assessment for the flavor physics program**

- $B^0$ lifetime $\rightarrow$ Talk by C. Praz
- $B$ flavor tagger $\rightarrow$ Talk by N. Rout
- Reconstruction of (semi-)leptonic $B$ decays with FEI $\rightarrow$ Talk by M. Milesi
- Search for $B \rightarrow K\ell\ell, X_s\ell\ell$ $\rightarrow$ Talk by Y. Sato
- $D^0$ lifetime, $D, D_s, \Lambda_c$ reconstructions $\rightarrow$ Talk by G. Casarosa

**Outset of flavor physics measurements**

(Need more statistics for publication)

- $B(\bar{B}\rightarrow D^{*+}\ell^−\bar{\nu})$, $V_{ub}$ and $V_{cb}$ $\rightarrow$ Talk by R. Cheaib; poster by S. Granderath
- $B$ and $A_{CP}$ of charmless $B$ decays $\rightarrow$ Talk by E. Ganiev
- $f_L$ in $B \rightarrow \phi K^*$ $\rightarrow$ Talk by N. Rout
- $\tau$-lepton mass $\rightarrow$ Talk by K. Inami

**Dark sector** with the data taken in 2018

$\rightarrow$ Talk by E. Graziani

- $Z'$ or LFV $Z'$ to invisible

\[ e^+ \xrightarrow{Z'} \mu, \nu, \chi \] \[ e^- \xrightarrow{\gamma} \] \[ e^+ \rightarrow e^+, Z', \mu, \nu, \chi \]

- Axion Like Particle

\[ e^+ \rightarrow e^+, \gamma^*, a \] \[ e^- \rightarrow e^-, \gamma^*, a \]

- $0.276 \text{ fb}^{-1}$; PRL 124 (2020) 141801

$1^{\text{st}}$ Belle II physics paper

- $0.445 \text{ fb}^{-1}$; Being submitted to PRL

$2^{\text{nd}}$ Belle II physics paper
Physics publication prospects in near future

- 140-240 fb\(^{-1}\) until Mar 2021 (depending on the operation budget)

**Flavor physics**

- \(|V_{cb}|\) from hadronic \(q^2\) moments
- Inclusive \(|V_{ub}|\) from lepton endpoint
- Inclusive and FEI tagged \(b \rightarrow s\gamma\)
- Inclusive \(B^+ \rightarrow K^+\nu\nu\)
- \(B^0\) lifetime and mixing
- 1\(^{st}\) combined Belle + Belle II analysis on BPGGSZ \(\phi_3\)
- \(D^0, D^+, D_s, \Lambda_c\) lifetimes
- \(B \rightarrow \Lambda_c + \) invisible
- \(\tau\)-lepton mass measurement
- \(\tau \rightarrow \ell + \) invisible(\(\alpha\)) search

\(\Rightarrow\) Talk by F. Tenchini

**Dark sector**

- Dark higgstrahlung
- Invisible dark photon
- Visible dark photon
- \(Z'\) or LFV \(Z'\) to invisible update
- \(Z' \rightarrow \mu\mu\)
- Inelastic dark matter
- Dark scalar
- ...

- \(~1\) ab\(^{-1}\) before long shutdown in 2022 to surpass BaBar and Belle

\(\Rightarrow\) Belle II will join in with the hunting for New Physics in earnest.
Projection toward 50 ab$^{-1}$

- Recently updated based on the past results.

\[ \beta_y^* \text{ (mm)} \quad 1.0 \quad 0.6 \quad 0.5 \quad 0.3 \]
Summary

- Belle II plans to collect 50 ab\(^{-1}\) to extensively search for New Physics in the flavor and dark sectors as well as to provide better understanding of the Standard Model and hadron physics.

- Accelerator and detector operation is in good shape: the world record of the peak luminosity 2.4 x 10\(^{34}\) /cm\(^2\)/s (KEKB record: 2.1 x 10\(^{34}\) /cm\(^2\)/s) was achieved with the acceptable beam background level.

- Collected 74 fb\(^{-1}\), and 1\(^{st}\) physics paper on dark sector was published, to be followed soon by other results on dark sector and flavor physics.

- In a few years, Belle II will join in with the hunting for New Physics in earnest.