Status of the Belle II experiment (and its first results)

Rencontres de Moriond 2019 (QCD)
La Thuile, March 25th 2019
**The Belle II detector**

**Electromagnetic calorimeter (ECL):**
CsI(Tl) crystals, waveform sampling

**Vertex detectors (VXD):**
- 2 layer DEPFET pixel detectors (PXD)
- 4 layer double-sided silicon strip detectors (SVD)

**Central drift chamber (CDC):**
He(50%):C$_2$H$_6$ (50%), small cells, fast electronics

**K$_L$ and muon detector (KLM):**
- Resistive Plate Counters (RPC) (outer barrel)
- Scintillator + WLSF + MPPC (endcaps, inner barrel)

**Trigger:**
- Hardware: < 30 kHz
- Software: < 10 kHz

**Magnet:**
1.5 T superconducting

**Particle Identification (PID):**
- Time-Of-Propagation counter (TOP) (barrel)
- Aerogel Ring-Imaging Cherenkov Counter (ARICH) (FWD)

DEPFET: depleted p-channel field-effect transistor
WLSF: wavelength shifting fiber
MPPC: multi-pixel photon counter
The Belle II experiment: a timeline

<table>
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<tr>
<th>Calendar year</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
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<td>JFY2017</td>
<td>JFY2018</td>
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**Phase 1**
- MR startup
- MR renovation for phase 2, including installation of QCS and Belle II
- DR installation & startup
- DR commissioning

**Phase 2**
- w/ QCS
- w/ Belle II (no VXD)
- HER start
- LER start

**Phase 3**
- w/ full Belle II
- VXD installation

First phase 3 data are being taken as we speak!
What is “phase 2”?

Pilot run with limited vertexing
→ Background monitor detectors
  replacing most of the silicon tracker
→ One full octant of PXD+SVD
( 2 + 4 layers)
The first Belle II results

Phase 2 lasted from April 26\textsuperscript{th} to July 17\textsuperscript{th}

→ 0.5 fb\textsuperscript{-1} of collisions at Y(4S)
→ 0.55 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1} maximum luminosity

Goals

→ Verify the nano-beam collision scheme
→ Commission the detector
→ Produce some physics result?
The accelerator
Super-KEKB target

Final goal: 40x KEKB luminosity

Peak lumi = $8 \times 10^{35}$ Hz/cm$^2$

Int. lumi = 50 ab$^{-1}$

Reach KEKB peak lumi
Reach Belle integrated lumi

Int. L [ab$^{-1}$]

Peak Luminosity [cm$^{-2}$s$^{-1}$]

2019 2021 2023 2025 2027
\[ L = \frac{\gamma \pm}{2er_e} \left( 1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \left( \frac{I \pm \xi y \pm}{\beta_y^*} \right) \left( \frac{R_L}{R_{\xi y \pm}} \right) \]

**Lorentz factor**

**Beam current**

**Beam-beam factor**

**Beam aspect ratio**

(Flat beam \( \sim 1-2\%\))

**Vertical beta function at IP**

**Geometrical corrections**

(Hourglass effect...)

**Brute force:** Increase the current \((x2)\)

**Precision:** denser beams, smaller \(\beta^*\) \((x20)\)
Nano-beam scheme

1) Large Piwinski angle by **large** $\theta$ and **small** $\sigma_x$

$$\phi = \frac{\sigma_z}{\sigma_x} \tan\left(\frac{\theta}{2}\right) \approx \frac{\sigma_z}{\sigma_x} \frac{\theta}{2}$$

2) Very small $\beta$

$$\beta_y^* \approx \frac{\sigma_x}{\theta} \ll \sigma_z$$

3) Non-linear optics (suppress beam-beam resonances)

$\sigma_y^* = 940$ nm

$\beta_y^* = 5.9$ mm

$\sigma_x^* = 147/170$ $\mu$m

$\sigma_y^* = 48/62$ nm

$\beta_y^* = 0.27/0.3$ mm

$\sigma_x^* = 10.1/10.7$ $\mu$m
Measuring a nanometric beam

- How to measure the vertical size of the beams?
  - Measure the luminosity with our fast diamond detector while the machine people moves the beam vertically.

![Graph showing the vertical size of beams with different beta values over time.

SuperKEKB/Belle II
2018 (preliminary)

- $\beta_y = 8$mm
- $\beta_y = 6$mm
- $\beta_y = 4$mm
- $\beta_y = 3$mm

less than 500 nm achieved
Interaction region size

Beam spot ~ 10 times smaller than KEKB
The detector
Vertexing: impact parameter resolution

MC (Belle II) and Cosmics (Belle)

Fit function:

\[ \sigma = \sqrt{a^2 + \frac{b^2}{p\beta\sin(\theta)^{3/2}}} \]

- Belle SVD2 cosmic (Data) BN715
  - \( a = 17.4 \pm 0.3 \, \mu m \)
  - \( b = 34.3 \pm 0.7 \, \mu m \, \text{GeV}/c \)

- Belle II single track events (MC)
  - \( a = 9.6 \pm 1.4 \, \mu m \)
  - \( b = 16.2 \pm 1.9 \, \mu m \, \text{GeV}/c \)
Vertexing: impact parameter resolution

Belle II data: bhabha events

- measured 12.1 μm, expected ~10 μm
- PXD contribution is crucial
Tracking

\[ K_S \rightarrow \pi^+ \pi^- \]

\[ \Lambda \rightarrow p \pi^- \]

\[ J/\psi \rightarrow e^+ e^- \]

\[ J/\psi \rightarrow \mu^+ \mu^- \]
Calorimetry

\[ e^+ e^- \rightarrow \mu^+ \mu^- \gamma \]

**Belle II**

2018 (Preliminary)

\[ \int L \, dt = 261 \text{ pb}^{-1} \]
An example of combined Particle ID

\[ \phi \rightarrow K^+ K^- \]

No kaons identified

Both kaons identified

TOP + dE/dx from the drift chamber
Some physics: $\tau$ rediscovery

$\tau \rightarrow 3\pi \nu$ Mass

First re-measurement of the tau mass

$\tau \rightarrow 3\pi \nu$ Pseudo-Mass
Some physics: Full reconstruction

Recursive reconstruction algorithm:
→ Reconstruct $B^0$ or $B^+$ in 5000+ modes (tag B)
→ Essential reconstruct events with missing energy
Conclusions

The Belle II experiment has successfully concluded the phase 2 pilot run:

→ Basic detector performance is satisfactory
→ Nano-beam scheme has been realized

Phase 3 is starting

→ Full physics run
→ 20 fb\(^{-1}\) by the summer 2019

Any physics out of phase 2?

→ Yes!

→ Search for **axion-like particles** in ee → γγγ
→ Search for Z' in ee → 4l
Backup
What is “phase 3”?  

Phase 3 = (almost) final setup for physics  
→ 4 full layers of silicon strips  
→ 1 + 1/6 full layers of pixel  
→ full installation approx in 2020
Particle Identification

The TOP is a “DIRC in the time domain”

→ Cherenkov light trapped and propagated to the readout in a wide bar of fused silica
→ The Cherenkov angle is measured by the time of propagation rather than the ring image on the PMT surface
Visualizing the Cherenkov rings

Belle II TOP 2018 (Preliminary)

$D^*$ kinematically tagged kaon

$p = 2.14$ GeV/c

$\theta = 110.4^\circ$

Pion PDF

$log L(\pi) = -234.11$

Belle II TOP 2018 (Preliminary)

$D^*$ kinematically tagged kaon

$p = 2.14$ GeV/c

$\theta = 110.4^\circ$

Kaon PDF

$log L(K) = -199.51$

Belle II TOP 2018 (Preliminary)

$D^*$ kinematically tagged kaon

$p = 2.14$ GeV/c

$\theta = 110.4^\circ$

Proton PDF

$log L(p) = -249.96$
Super-KEKB: energy and limitations

Super-KEKB is technically an accumulation ring
→ All the acceleration phase is done in the LINAC
→ RF only to sustain the beams (continuous injection!)

Current max \( E_{cm} \) = \(~11.02\) GeV, a bit above \( Y(6S) \)
Achievable max \( E_{cm} \) = \(~11.24\) GeV, at \( \Lambda_b \Lambda_b \) threshold

![SuperKEKB PF/AR Injector](image-url)
The TOP counter at Belle II

TOP implementation in Belle II:
→ 16 modules (or slots) arranged around the interaction point
→ Each module is made of two identical bars of fused silica glued together
→ Backward side: expansion prism, PMTs and readout
→ Forward side: spherical mirror
QWG 2019! May 13-17 Torino

https://agenda.infn.it/conferenceDisplay.py?confId=15632
IP size

Belle case 1999 data

(c)

-20000  -10000  0  10000  20000

-1.0 cm  1.0 cm

Z (μm)
Belle case 1999 data

(c)

[Graph showing data points and annotations]

Belle II 2018 (preliminary)

Median = -0.015 cm

σz = 0.055 cm

Entries / [10^1 cm]

[Histogram with data distribution]