Commissioning and Operation Status of Belle II and SuperKEKB

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Heavy Quarks and Leptons 2018
SuperKEKB
SuperKEKB and Belle II

**e^+ 4GeV 3.6 A**

**e^- 7GeV 2.6 A**

**Target: L = 8x10^{35}/cm^2/s**

- Colliding bunches
- Damping ring
- Low emittance gun
- Low emittance positrons to inject
- Low emittance electrons to inject
- Replace short dipoles with longer ones (LER)
- TiN-coated beam pipe with antechambers
- Redesign the lattices of HER & LER to squeeze the emittance
- Add / modify RF systems for higher beam current
- New superconducting final focusing quads near the IP
- New IR
- New positron target / capture section
- Positron source

\[ L = \frac{\gamma \pm \left( 1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \left( 1 - \frac{\xi_{y\pm}^*}{\sigma_y^*} \right)}{2e \varepsilon_{y\pm}} \left( \frac{R_L}{R_y} \right) \]
Key points for SuperKEKB

• Smaller beam size with moderate current
  – Nano beam option
    • Very low emittance
    • Stronger final focusing magnet closer to IP

• Complete new LER ring
  – New antechamber to reduce electron cloud
  – New longer and more bending magnets

• Optimized HER parameters (KEKB ring)

• Complete new IR
Why nano beam?

• Bunch luminosity is limited by several reasons.
  – Beam-beam tune shift limit.
  – Bunch lengthening.
  – Higher bunch current → damage hardware component
  – $1.2 \times 10^{31}$ cm$^{-2}$sec$^{-1}$ at KEKB
    • It is not so high as compared with other machines.

• Higher luminosity means larger number of bunches.
  – Factor 2 at TRISTAN
  – Factor $\sim50$ or more thanks for pretzel scheme at CESR and LEP
  – Factor $\sim1600$ thanks for double rings at KEKB and PEPII
    (also BEPC II, LHC).

• We only need to improve the number of bunches by factor of three.
  – 5000 ($\sim1600$ at KEKB) is real maximum due to RF frequency.

• Super bunch (nano beam) idea improves number of bunches, significantly.
The beam beam shift could not exceed 0.09 even for higher bunch current and even with the crab cavity.
Super bunch (Nano beam)

Each sub bunch collides on opposite sub bunch separately. It means that number of bunches increases significantly.

To achieve this scheme, $\sigma_x$ should be much smaller than $\sigma_z$ and rather large crossing angle should be applied. Lower emittance and lower $\beta$ function at IP are required.
Nano beam collision

- Vertical beam size is much smaller.
  - 2 μm $\rightarrow$ 50 nm
- Collision area is much smaller.
  - Even if bunch lengths are similar.
  - $\sim$10 mm $\rightarrow$ $\sim$0.5 mm
Belle II
Requirements for Belle II detector

Target luminosity: \( L = 8 \times 10^{35}/\text{cm}^2/\text{sec} \)

**Larger beam-related background ( \( \times 20 \))**
- Finer granularity
- Better timing separation

**High trigger rate ( \( \times 20 \))**
- Pipeline readout

**Improvements**
- Better particle ID devices
- Better vertex resolution
Belle II Detector

- **K_L and muon detector:**
  - Resistive Plate Counter (barrel outer layers)
  - Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

- **EM Calorimeter:**
  - CsI(Tl), waveform sampling (baseline)
  - (opt.) Pure CsI for end-caps

- **Japan, USA, Slovenia, Italy**
  - Particle Identification
  - Time-of-Propagation counter (barrel)
  - Prox. focusing Aerogel RICH (fwd)

- **Russia, USA, Italy, Japan**

- **Russia, Italy, Korea, Canada, Japan**

- **Japan, Germany**

- **Beryllium beam pipe**
  - 2cm diameter

- **Vertex Detector**
  - 2 layers DEPFET + 4 layers DSSD

- **Germany, Czechia, Spain, Saudi Arabia, China, Austria, Poland, Italy, India, Australia, Japan**

- **Central Drift Chamber**
  - He(50%):C_2H_6(50%), Small cells, long lever arm, fast electronics

- **Japan, Taiwan, ...**

- **Positron (4 GeV)**
Belle II Collaboration

25 countries/regions
108 institutions
~750 researchers

Europe

- Austria: 10
- Czechia: 7
- France: 22
- Germany: 138
- Israel: 5
- Italy: 65
- Poland: 12
- Russia: 38
- Slovenia: 14
- Spain: 5
- Ukraine: 4

Asia

- Saudi Arabia: 1
- Australia: 33
- China: 37
- India: 31
- Japan: 133
- Korea: 40
- Malaysia: 5
- Vietnam: 2
- Taiwan: 27
- Thailand: 1
- Turkey: 3

America

- Canada: 26
- Mexico: 13
- USA: 84
### SuperKEKB/Belle II schedule

<table>
<thead>
<tr>
<th>Calendar year</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan FY</td>
<td>JFY2016</td>
<td>JFY2017</td>
<td>JFY2018</td>
<td>JFY2019</td>
</tr>
<tr>
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<td>Summer shutdown (power saving)</td>
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<td>Power saving after mid July 2018</td>
<td>Summer shutdown (power saving)</td>
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**Phase 1 (w/o final focusing Q, w/o Belle II):**
- Accelerator system test and basic tuning,
- Vacuum scrubbing,
- Low emittance tuning, and
- Beam background studies

**Phase 2 (w/ final focusing Q, w/Belle II but background monitors instead of vertex detectors):**
- Verification of nano-beam scheme
  - target: $L > 10^{34} \text{ cm}^2\text{s}^{-1}$
- Understand beam background especially in vertex detector volume

**Phase 3:**
- Full Belle II operation
  - 9 months / year
Phase 1 operation in 2016

- Without Belle II and the final focusing magnets (QCS)
  - No collisions
  - Several sensors to measure the beam background.
- Hardware check and vacuum scrubbing
  - 0.85A and 1A were successfully stored in the electron and positron rings.
After Phase 1

Roll-in on April 11th, 2017

Construction and installation of the final focusing magnets (QCS) were done.

Damping ring construction and commissioning were performed, also.
Before Phase 2

Global cosmic ray run under 1.5 T magnetic field

Drift chamber performance

Cosmics Preliminary 2017

Final construction and installation of ARICH

Partial vertex detector and beam background monitors were installed in the CDC.
Phase 2 operation from March

- It started with Belle II just two months ago.
  - The beam currents are increasing gradually.
  - The beams have been squeezed gradually (smaller $\beta^*$).
- First collision occurred just one month ago.
Events for first collision on April 26, 2018

First hadronic event
More Events

Bhabha event

BB like event

KLM is working.

ARICH is working.
Present status

• Belle II is still the debugging and calibration stage.
  – SuperKEKB needs a lot of time for squeezing beams and other machine tuning (reducing the beam background).

• Present luminosity
  – Peak $L \sim 1.3 \times 10^{33} \text{cm}^{-2}\text{sec}^{-1}$
  – Integrated $L \sim 100 \text{ pb}^{-1}$

• At least,
  – $K_s$, $K^*$, $\Lambda$, $D$ and $D^*$ peaks can be seen for charged tracks.
  – $\pi^0$ and $\eta$ peaks can be seen for gammas.
  – $R_2$ distribution for hadronic events is reasonably good.
    • The beam energies are consistent with $Y(4S)$ peak.
  – Longitudinal vertex distribution is smaller.
Mass peaks for charged tracks and gammas

![Graph showing mass peaks for charged tracks and gammas.](Image of graph)
The longitudinal component of the interaction vertex

- The distribution is much smaller than the bunch length.
- The nano beam scheme is working!!!
Preparation for Phase 3 operation

• Phase 2 operation will continue until July 17th.

• After that, full vertex detector will be installed.
  – Now, the construction is full swing.
SuperKEKB luminosity projection

It is a very long term project and various opportunities for the upgrade

Goal of Belle II/SuperKEKB

Integrated luminosity (ab⁻¹)

Peak luminosity (cm⁻²s⁻¹)

9 months/year
20 days/month

We are here, now.
Summary

• After several years construction, Belle II successfully observed first collision events from the SuperKEKB machine on April 26th, 2018.
  – But, it is just the starting point of a long experiment.
• The vertex detector will be installed this summer.
  – The phase 3 operation will start in February, 2019.
• Fruitful physics will come soon.
  – Belle II collaboration is still growing.
  – Please join us.
Backup
World highest luminosity

40 times higher than present record

$L = 8 \times 10^{35}/\text{cm}^2/\text{sec}$