The Belle II Experiment: Status and Prospects
High Energy Accelerator Research Organization (KEK)
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39th International Conference on High Energy Physics

Jan, 2018
Beam pipe connection

EXPERIMENT 3, RUN 782, Event 2195
Belle II 2018/05/ 6 17:58 JST
B factory experiment

- Flavor physics
  - Verification of CKM mechanism
    - CKM matrix / unitarily triangle
    - CPV in B decays
  - Limits on BSM physics
    - B/D’s rare decays
    - $b \rightarrow s \gamma$, $b \rightarrow s l^+ l^-$
    - LFV $\tau$ decays
  - Exploring New particles
    - Four quark states

- Asymmetric High luminosity $e^+e^-$ collider can provide high statistics of
  - boosted B/D meson and also
  - $\tau$ lepton

Figure 2: First presentation [17] of the boosted-$\Upsilon$(4S) idea in 1987.
## SuperKEKB (nano-beam scheme)

**Beam current**

\[ L = \frac{\gamma_{e^\pm}}{2er_e} \left( 1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \left( \frac{I_{e^\pm} \xi e^\pm}{\beta_y^*} \right) \left( \frac{R_L}{R_{\xi_y}} \right) \]

- \( \sigma \): beam size
- \( \beta \): beam parameter

**Beam-beam parameter**

**Lower emittance beam DR for LER and RF gun**

<table>
<thead>
<tr>
<th></th>
<th>KEKB</th>
<th>SuperKEKB</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>( E_b )</td>
<td>( \begin{array}{c} 3.5 \ 8 \end{array} )</td>
<td>( \begin{array}{c} 4 \ 7.007 \end{array} )</td>
</tr>
<tr>
<td>Beam crossing angle</td>
<td>( \varphi )</td>
<td>( 22 )</td>
<td>( 83 )</td>
</tr>
<tr>
<td>( \beta ) function @ IP</td>
<td>( \beta_x^*/\beta_y )</td>
<td>( \begin{array}{c} 1200/5.9 \ 32/0.27 \end{array} )</td>
<td>( \begin{array}{c} 25/0.30 \end{array} )</td>
</tr>
<tr>
<td>Beam current</td>
<td>( I_b )</td>
<td>( \begin{array}{c} 1.64 \ 1.19 \end{array} )</td>
<td>( \begin{array}{c} 3.6 \ 2.6 \end{array} )</td>
</tr>
<tr>
<td>Luminosity</td>
<td>( L )</td>
<td>( 2.1 \times 10^{34} )</td>
<td>( 8 \times 10^{35} )</td>
</tr>
</tbody>
</table>
New Constraints by the nano-beam scheme

KEKB head-on (crab crossing)

**Nano-Beam SuperKEKB**

\[ \sigma_x^* = 100-150 \mu m \]
\[ \sigma_z^* = 6-7 \text{ mm} \]

**Hourglass requirement**

\[ \beta_y^* \geq \sigma_z \sim 6 \text{ mm} \]
\[ \beta_y^* \geq \frac{\sigma_x^*}{\phi} \sim 300 \mu m \]

**Reconstructed IP position**

\[ \sigma_{00} = 0.055 \text{ cm} \]

\[ \int L dt = 24 \text{ pb}^{-1} \]

\[ \text{Runs 1869-2047} \]

**KEKB**

\[ \beta \gamma = 0.42 : e^- (8 \text{ GeV}), e^+ (3.5 \text{ GeV}) \]

**SuperKEKB**

\[ \beta \gamma = 0.28 : e^- (7 \text{ GeV}), e^+ (4 \text{ GeV}) \]

In order to fit beam line in the tunnel, Belle II detector has rotated.

- Lower emittance beam \( \propto 1/E^2 \)
- Lower Synchrotron radiation loss

To realize nano-beam, we admit Lorentz boost factor down to 2/3 w.r.t. KEKB.

**LER (3.5 GeV \rightarrow 4 \text{ GeV})**:
- for longer Touschek lifetime \( \propto E^3 \)

**HER (8 \text{ GeV} \rightarrow 7 \text{ GeV})**:
- Lower emittance beam \( \propto E^3 \)
- Lower Synchrotron radiation loss
Detector layout (Belle -> Belle II)

- Belle II VXD R=14-140mm (Ks acceptance)
- Belle SVD R=20-88mm

SVD 4 layers (DSSD) → 2 DEPFET + 4 DSSD
CDC: small cell, long lever arm
ACC+TOF → TOP+ARICH (Better K/p separation)
ECL: waveform sampling
KLM: RPC → Scintillator+SiPM
(Endcap and inner two layer of Barrel for neutron BG)
Requirements on Belle -> Belle II upgrade

- 40 times higher Luminosity
  - Huge BG: need to control BG with 20 times level than Belle
    - Effective shielding and Collimator optimization
    - Higher rate capability of DAQ, Trigger and data transfer (max.: 30kHz)
    - To avoid signal pile-up, replacing with faster FE
  - SVD, CDC, ECL
- Keeping physics acceptance even if the beam crossing angle is changed from 22 to 83 mrad by the nano-beam scheme

Belle SVD
Pipe diameter at IP: 3 cm

Belle II VXD
Pipe diameter at IP: 2 cm

PXD (new)
Sub-detector installation

May 2016: TOP

Oct. 2016: CDC

Apr 2017
Belle roll-in

Aug. 2017: ARICH

Jan. 2017 BWD ECL

VXD: 2017 Nov.

2015 KLM
Belle II /superKEKB commissioning

- **Phase 1 (finished)**: Beam operation without final focus magnets and Belle II
  - Commissioning of beam transportation and vacuum scrubbing
- **Phase 2 (4 month)**: Start data taking with Beam collision
  - Target Luminosity $\sim 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ which is comparable with KEKB
  - No final VXD but one ladder/layer with background sensors
- **Phase 3 (2019)**: final detector configuration

![Timeline and Luminosity Graph](image)
Phase 2 VXD

Phase 2 VXD:
- Mechanical components are the same with phase 3
- 1 ladder/payer of PXD, SVD
  - BG hit rate, DAQ test and RoI tracking study
- BG sensors only for phase 2
  - To judge BG condition for phase 3 VXD

BG sensors in phase 2 VXD

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FANGS</td>
<td>Silicon pixel sensor : x-ray energy spectrum for SR</td>
</tr>
<tr>
<td>CLAWS</td>
<td>Scintillators w/ SiPMTs: Beam injection noise</td>
</tr>
<tr>
<td>PLUME</td>
<td>Two-side silicon pixel sensors: hit rate measurement in radially</td>
</tr>
<tr>
<td>Micro-TPC</td>
<td>Fast neutron from EM shower</td>
</tr>
<tr>
<td>He-3 tube</td>
<td>Thermal neutron</td>
</tr>
<tr>
<td>Scintillators + PIN diode</td>
<td>BG measurement around the final focus magnets</td>
</tr>
<tr>
<td>Diamond sensor</td>
<td>BG dose measurement @IP Aborting beam to protect VXD</td>
</tr>
</tbody>
</table>

Phase-2 VXD/BEAST setup

The Belle II Experiment: Status and Prospects
First hadronic event (26\textsuperscript{th} Apr.)

Bhabha like event

\textbf{Latest Machine achievement}

$L \sim 5.39 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

LER: 800mA
HER: 745mA
First studies

Hadron reconstruction (based on 5 pb\(^{-1}\) data) (corrected \(~\)0.5 fb\(^{-1}\))

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

\[ \pi^0 \rightarrow \gamma \gamma \]

Phase 2 Objective:
1. Luminosity measurement, hadronic events, B/D counting
2. Re-discovery of hadronic events (for calibration)
3. Performance measurements (tracking, neutrals, hadron ID, lepton ID, trigger)
4. Dark matter search
   e+e- \(\rightarrow\) \(\gamma\)X, e+e- \(\rightarrow\) \(\gamma\) (\(\gamma\gamma\))
5. BG measurement to confirm phase 3 operation

By reconstructing IP, the beam Size change in each beam optics has confirmed
Experimental targets on Belle II

1. Measuring CP violation with B meson
2. Fine verification of CKM mechanism which causes CP violation
3. Exploring new physics by high statics data

State of the art 2016

Belle II 50 ab⁻¹

Belle II physics report via Belle Theory Interface Platform (B2TIP) will be public soon. (https://confluence.desy.de/display/BI/B2TiP+WebHome#space-menu-link-content)
The Vertex Detector (Phase 3) can provide a factor 2 or more better impact parameter resolution in spite of lowered Lorenz boost. Phase 3 PXD installation in 2018.
Summary

• Phase 2 Belle II detector with superKEKB has completed in 2018 Mar.
• After the beam tuning, First beam collision has observed on 26\textsuperscript{th} Apr.
• Phase 2 Belle II operation is schedule from Apr. to middle of July 2018.
  – Phase 2 VXD equip 1 ladder/layer of PXD/SVD
  – DAQ, Trigger optimization
  – Event reconstruction parameter optimization
  – Rediscovery of heavy flavor
  – Performance measurement (tracking, particle ID, trigger)
  – Understanding/control BG
• Phase 3 operation with full Belle II detector is scheduled from next spring.
## Summary of detector performance.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Belle</th>
<th>Belle II</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B$ Vertex Reconstruction (typical)</td>
<td>$\sigma_x = 61 \mu m$</td>
<td>$\sigma_x = 26 \mu m$</td>
</tr>
<tr>
<td>Tracking</td>
<td>$p_t / p_t = 0.0019 p_t$ GeV/c $\oplus 0.0030 / \beta$</td>
<td>$p_t / p_t = 0.0011 p_t$ GeV/c $\oplus 0.0025 / \beta$</td>
</tr>
<tr>
<td>$K\pi$ ID</td>
<td>Kaon efficiency $\epsilon_K \approx 0.85$ with pion fake rate $\epsilon_\pi \approx 0.10$ for $p = 2$ GeV/c</td>
<td>$\epsilon_K \approx 0.90$ with $\epsilon_\pi \approx 0.04$ for $p = 2$ GeV/c</td>
</tr>
<tr>
<td>Calorimetry</td>
<td>$z_F / E = 0.0062 / E \oplus 0.318 / E \oplus 1.34%$</td>
<td>$z_F / E = 7.7%$ at 0.1 GeV, 2.25% at 1 GeV</td>
</tr>
<tr>
<td>Muon ID</td>
<td>Muon efficiency $\epsilon_{\mu} \approx 0.90$ with fake rate $\epsilon \approx 0.02$ for $p_t &gt; 0.8$ GeV/c tracks</td>
<td>$\epsilon_{\mu} = 0.92 - 0.98$ with $\epsilon = 0.02 - 0.06$ for $p &gt; 1$ GeV/c</td>
</tr>
<tr>
<td>L1 Trigger</td>
<td>500 Hz typical average, Efficiency for hadronic events $\epsilon_{hadron} \approx 1$</td>
<td>30 kHz max average rate, $\epsilon_{hadron} \approx 1$</td>
</tr>
<tr>
<td>DAQ</td>
<td>~5% dead time at 500 Hz L1 rate</td>
<td>&lt;3% dead time at 30 kHz L1 rate</td>
</tr>
</tbody>
</table>