Status of SuperKEKB commissioning and Belle II detector construction

Peter M. Lewis on behalf of the Belle II Collaboration
University of Hawai`i at Manoa

5 August 2016
ICHEP Detector R&D and Performance session
Belle/KEKB

The $B$-factory at KEK (Tsukuba, Ibaraki, Japan)

- Targeted \textit{CP-violation} using a huge number of $B$ meson pairs
- Operated from \textbf{1999 to 2010}
- The KEKB accelerator delivered \textit{over 1ab}¹ to the Belle detector, a huge success (mostly at $Y(4S)$ resonance)
- Along with BaBar, \textbf{confirmed Kobayashi and Maskawa theories} about $CP$ asymmetries in $B$ decays, directly leading to 2008 Nobel Prize
- Collected additional unique datasets at $Y(1S)$, $Y(2S)$, $Y(5S)$ resonances, leading to \textbf{unexpectedly rich additional results} (some shown this week)
SuperKEKB

The super $B$-factory at KEK (2018 start)

- A planned **40-fold** increase in luminosity over KEKB (target: $8 \times 10^{35}$ cm$^{-2}$s$^{-1}$ instantaneous, 50ab$^{-1}$ integrated), due to major upgrades:
  - “**Nano-beam**” scheme (below)
  - Doubled beam currents
  - (large number of upgrades to RF, magnet, vacuum, etc. systems)
- First turns Feb. 10. 2016! Exciting times!

See Y. Onishi, ICHEP highlights, 8/08 12:10
SuperKEKB is the next luminosity frontier
Belle II major upgrades

Belle II at ICHEP:
Detectors:
- DEPFET: L. Andricek, Poster 8th 18:30
- SVD: A. Paladino, Detector 4th 17:00
- EMC: Y. Jin, Poster 6th 18:00
- iTOP: A. Schwartz, Detector 6th 14:30
- iTOP: K. Inami, Poster 6th 18:00
- CPU: M. Schram, Computing 4th 12:50

Physics:
- Prospects: B. Fulsom, Flavor 5th 14:30
- Dark: G. Inguglia, BSM 4th 17:40
- Bottomonia: K. Miyabayashi, Poster 6th 18:00

EM Calorimeter:
- CsI(Tl), waveform sampling (barrel)
- Pure CsI + waveform sampling (end-caps)

KL and muon detector:
- Resistive Plate Counter (barrel)
- Scintillator + WLSF + MPPC (end-caps)

Particle Identification
- Time-of-Propagation counter (barrel)
- Prox. focusing Aerogel RICH (Fwd)

Electron (7 GeV)

Beryllium beam pipe
- 2cm diameter

Vertex Detector
- 2 layers DEPFET + 4 layers DSSD

Central Drift Chamber
- He(50%):C2H6(50%), Small cells, long lever arm, fast electronics

Positron (4 GeV)
Commissioning of SuperKEKB
**Schedule: beam commissioning phases**

### Phase I (completed)

- Circulate both beams; no collisions
- Tune accelerator optics, etc.
- Vacuum scrub
- **Beam studies**

### Phase II (2017-18)

- First collisions
- Develop beam abort
- Tune accelerator optics, etc. (nano-beam)
- Detailed beam studies

<table>
<thead>
<tr>
<th>Year</th>
<th>Phase I</th>
<th>Phase II</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12</td>
</tr>
<tr>
<td>2017</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12</td>
</tr>
<tr>
<td>2018</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12</td>
<td><strong>Start!</strong></td>
</tr>
</tbody>
</table>

- First turns
- Beam studies
- **N**ow
- Final focusing magnets installed
- Belle rolls in
- Controlled panic
Commissioning requirements

SuperKEKB

- Real-time monitoring of beam conditions
- Quantify effects of tuning (for example, collimator adjustments) on beam loss
- Isolate the type and source of beam loss
- Inform beam loss simulations to optimize performance

Belle II

- Guarantee a safe-enough radiation environment for Belle II
- Mitigate beam backgrounds (with physical shielding, electronic gating, magnet tuning, etc.) around interaction point
- Inform beam background simulations so they are properly accounted for in physics analysis

We need a “commissioning detector”: a stand-in for Belle II to provide diverse real-time measurements of beam conditions...
Enter the BEAST

Primary detectors in BEAST II* for phase I:

<table>
<thead>
<tr>
<th>System</th>
<th>Institution</th>
<th>#</th>
<th>Unique measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIN diodes</td>
<td>Wayne St.</td>
<td>64</td>
<td>Neutral vs. charged dose rate</td>
</tr>
<tr>
<td>Time Projection Chambers</td>
<td>U. Hawaii</td>
<td>4</td>
<td>Fast neutron flux and tracking</td>
</tr>
<tr>
<td>Diamonds</td>
<td>INFN Trieste</td>
<td>4</td>
<td>Beam abort</td>
</tr>
<tr>
<td>He3 tubes</td>
<td>U. Victoria</td>
<td>4</td>
<td>Thermal neutron rate</td>
</tr>
<tr>
<td>CsI(Tl) crystals</td>
<td>U. Victoria</td>
<td>6</td>
<td>EM energy spectrum, injection backgrounds</td>
</tr>
<tr>
<td>CsI+LYSO crystals</td>
<td>INFN Frascati</td>
<td>6+6</td>
<td>Luminosity and EM rate</td>
</tr>
<tr>
<td>BGO crystals</td>
<td>National Taiwan U.</td>
<td>8</td>
<td>Fast injection backgrounds</td>
</tr>
<tr>
<td>CLAWS plastic scintillators</td>
<td>MPI Munich</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

*Belle had its own BEAST
Belle and the BEAST

Belle II will eventually roll in on a pair of railroad tracks
CAD rendering of detectors and central beam pipe only [not pictured: BGO crystals and diamond sensors]
BEAST operation: phase I

Real-time monitoring (via EPICS)

- BEAST systems and SuperKEKB conditions monitored by shifters (top)
- BEAST live monitors shared with SuperKEKB control room (bottom)
- BEAST liaison in SuperKEKB control room during key beam study days

Offline

- Collected ~20 TB of data throughout phase I
- Simulation of loss distribution and detectors ongoing
- Analysis ongoing; main goal is to inform simulations with data
Beam backgrounds and preliminary results from BEAST
Preliminary results

Touschek scattering

- Coulomb scattering between two particles in the same bunch
- Inverse lifetime is inversely proportional to the bunch size:
  \[
  \frac{1}{\tau_T} \propto \frac{1}{\sigma_x\sigma_y\sigma_z}
  \]
- To measure, **hold beam currents constant and vary beam size** [right]

He3 tube thermal neutron rate vs. inverse beam size (Touschek is linear component)
Preliminary results

Beam-gas

- Coulomb scattering off residual gas in beam pipe
- Phase I consisted of mostly **beam scrubbing**
- Scattering rate is proportional to current times pressure:

\[ R_{BG} \propto I \cdot P \]

- **To measure, heat vacuum pump to inject gas**

![Graph showing BGO deposited energy vs. current*pressure](image.png)
Preliminary results

Injection

- Charge is regularly injected into stored beam to counteract beam loss
- For <1ms after injection, **topped-off** bunches are messy; off-orbit particles can slam into pipe walls and spawn EM showers
- CLAWS (plastic scintillators) and CsI/LYSO crystals have time resolution to see **bunch-by-bunch structure**
- To measure, trigger on injection timing signal [right]
Preliminary results

Other

- Detailed spatial distribution from PIN diodes
- Directional fast neutrons from TPCs pointing to loss positions (right)
- Beam abort tuning for inner detectors in later phases using the diamond sensors
- Confirmation of integrated doses using dosimeters
- Effects of collimator positions
Status and milestones
SuperKEKB status and milestones

Phase I success

- Smooth startup. Compared to KEKB:
  - 2-3 times the currents after 3 months
  - Fewer machine troubles/downtime
- New hardware (RF, magnet and vacuum) systems are all working successfully
- Target 360-720mA*hours beam scrubbing met

Phase II

- Prepare for nano-beam: install focusing magnets, tuning and feedback systems, new damping ring
- Low beta tuning with upgraded BEAST

See Y. Onishi, ICHEP highlights, 8/08 12:10
Belle II status and milestones

Detector upgrades, very briefly:

- Time of propagation (TOP) Cherenkov detector modules all installed, testing ongoing (top)
- Drift chamber (CDC) strung and observing cosmics (bottom)
- VXD (inner pixel/strip silicon vertexing) completed successful beam test at DESY with full Belle II DAQ chain
- ECL (crystal EM calorimeter) electronics installed in summer, test with new firmware and software ongoing
- Aerogel Ring-Imaging Cherenkov (ARICH) endplate detector tiles cut, installation almost complete
- $K_L$ and muon system (KLM): installation of DAQ infrastructure in progress, first cosmics seen June 2016
BEAST II status and milestones

Phase I success

- **Measurements** of all primary beam backgrounds
- **Live feedback** to SuperKEKB informed injector tuning, verification of vacuum scrubbing progress, etc.
- Detailed **tuning and verification of simulation** essential for Belle II operation; ongoing
- Analysis ongoing; look for a **paper in late 2016**

Phase II

- **4 new detector systems** to be embedded in inner region of Belle (see additional slides)
- Physical integration with Belle begins **October 2016**
BEAST II status and milestones

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The BEAST cave without BEAST, July 2016
Breaking news: QCS-L (one of two final focusing magnets) installed this week!
Thank you!
Additional slides
BEAST II: from the top

Location

- Crossing point of electron beam and positron beam (interaction point, or “IP”)
- Belle II will roll into the same location in phases II+III

Structure

- Detectors mounted on non-magnetic fiberglass structure
- Aluminum central beam pipe
BEAST II: from the top

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Primary detectors in BEAST II for phase II:

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<td>KEK</td>
<td>6480</td>
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</tr>
<tr>
<td>“Micro” Time Projection Chambers</td>
<td>U. Hawaii</td>
<td>48</td>
<td>Fast neutron flux and tracking</td>
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<tr>
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...continued
BEAST II: the commissioning detector

Primary detectors in BEAST II for phase **II**:

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<tbody>
<tr>
<td>Belle II PXD</td>
<td>U. Bonn</td>
<td>2 ladders</td>
<td>Radiation tolerance for phase III</td>
</tr>
<tr>
<td>Belle II SVD</td>
<td>KEK</td>
<td>4 ladders</td>
<td>Radiation tolerance for phase III</td>
</tr>
<tr>
<td>FANGS</td>
<td>U. Bonn</td>
<td>15</td>
<td>Silicon pixel sensors (synchrotron x-ray spectrum)</td>
</tr>
<tr>
<td>PLUME</td>
<td>Strasbourg</td>
<td>2 ladders</td>
<td>Silicon pixel sensors (collimator adjustment)</td>
</tr>
</tbody>
</table>
TPCs

Data

- Pixel chip data is like taking multiple pictures of charge cloud as it drifts, with each “exposure” corresponding to a new slice of the cloud
- 3D reconstruction of ionization cloud from an alpha particle (color encodes total ionization collected per pixel)
- Right: 3D plot of three different characteristic event types in TPC
  - Alpha
  - x-ray
  - Neutron recoil
BEAST shifting room
BEAST in its cave
BEAST’s guts and decommissioning team, July 2016.