$^3$He neutron detectors in Belle II

Caleb Miller, Samuel de Jong, Micheal Roney

University of Victoria

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Introduction

- Motivation
  - SuperKEKB
  - Understanding Simulation with BEAST II
  - $^3$He as a neutron detector
- Phase 1 commissioning of SuperKEKB
  - Beam Gas and Touschek Scattering
  - Calibration of $^3$He tubes
  - Implications for Belle-II
- Phase 2 commissioning of SuperKEKB
  - Plans and status
Motivation

- SuperKEKB will deliver $e^+e^-$ collisions with 10.58 GeV COM energy
  - $e^+$ at 4 GeV
  - $e^-$ at 7 GeV
- The luminosity goal of SuperKEKB is $8 \times 10^{35} cm^{-2} s^{-1}$
  - 40x the luminosity of KEKB
- Commissioning of the accelerator will take place in three separate phases
  - Phase 1: Beam gas and Touschek studies, no collisions (Completed 2016)
  - Phase 2: Collisions begin with Belle-II in place, no vertex detectors (February 2018)
  - Phase 3: Vertex detectors installed, Physics runs begin (Late 2018)
- Simulations for the running of Belle II and SuperKEKB were made with a combination of SAD and GEANT4
  - SAD: Strategic Accelerator Design
Motivation

- During the running of Belle II high energy collisions will produce a range of particles including neutrons.
- Neutrons in particular can be hard on silicon based electronics:
  \[ ^{30}\text{Si} + n \rightarrow ^{31}\text{Si} + \gamma \rightarrow ^{31}\text{P} + \beta^- + \gamma \] (1)
- Introduction of phosphorus increases n-doping which changes the response of detectors.
- Neutron rate measured with thermal neutron detectors and compared to simulation.
In order to test the accuracy of the simulations a group of small detectors were designed for deployment during beam commissioning and make corrections as needed.

Collectively the group is known as BEAST II:
- Beam Exorcism for A Stable Experiment

BEAST II was deployed in phase 1 with a variety of detectors and is being deployed in phase 2 with a new set of detectors.
BEAST II in Phase 1

$^3\text{He}$ Crystals
Diamonds
CLAWS
BGO
PIN
TPC

$^3\text{He}$ tube 0
$^3\text{He}$ tube 1
$^3\text{He}$ tube 2
$^3\text{He}$ tube 3

e$^{-}$
e$^{+}$

Centre of SuperKEKB rings
$^{3}\text{He} + n \rightarrow ^{3}\text{H} + ^{1}\text{H} + 764\text{keV}$
Neutron Capture Cross-Section

Cross Section (barns) vs. Incident Energy (MeV)
A preamp is attached directly to each tube.

Signal is then sent ≈30m from the tubes to a receiver module.

The analog signal is then digitized with CAEN V1724 and sent to the control room.
Beam Gas and Touschek Scattering

- During the running of SuperKEKB various backgrounds are produced
- The main contributions to neutrons are:
  - Interactions with residual gases in the beam pipe
  - Interaction within beam bunches causes Touschek scattering
  - $e^+e^-$ interactions release radiative Bhabhas (not present in phase 1)
- When scattered electrons or photons hit the beam pipe wall, showering events occur
- Phase 1 studies compared neutron rates from beam gas and Touschek contributions to simulated rates
Pressure Bumps during Phase 1

- Gasses adsorbed on getter pumps were released in a controlled manner into the beam line on several occasions for dedicated measurements.
- These bumps were ideal for studying the beam gas contribution to neutron rate.
Beam Size Scan

- In order to study the Touschek contribution to backgrounds various beam diameters were sent through BEAST II
GEANT and Calibration

- After phase 1 the tubes were returned to UVic for final calibration
- UVic has a 168 GBq AmBe source encased in a cube of graphite 1.89m/side

\[
^{241}\text{Am} \rightarrow ^{237}\text{Np} + ^4\text{He} + \gamma \quad (3)
\]
\[
^9\text{Be} + ^4\text{He} \rightarrow ^{12}\text{C} + n + \gamma \quad (4)
\]

- Thermal rates were measured with the full system used at KEK and compared to a GEANT simulation
Calibration Results

Helium-3 tube rate (Hz)

Distance from source (cm)

Simulation
Channel 0 ($\phi=0$)
Channel 1 ($\phi=90$)
Channel 2 ($\phi=180$)
Channel 3 ($\phi=270$)
Phase 1 Measured Rates divided by Simulation

Figure: ratio of rates detected vs simulated rates
Effect of Correction in Neutron Sensitive Detector

![Graph showing unscaled and scaled data for neutron sensitive detector.](image)
SuperKEKB Phase 2

- Belle-II was rolled onto the beam line in April
- Phase 2 $e^+e^-$ collisions without vertex detectors will begin next year
The return of BEAST

- $^3\text{He}$
- TPC
- CLAWS
- FANGS
- PLUME
- PIN
- Diamonds
- PXD
- SVD
Phase 2 plans

- Upgrade cabling to LSZH requirements
- Make use of radiative Bhahbas to determine if simulation error is present in SAD or GEANT4
- Confirm neutron rates are acceptable for installation of vertex detector
Conclusions

- $^3$He neutron detectors were able to successfully measure beam backgrounds in Phase 1 commissioning and correct simulation
- Preparations for Phase 2 are on track
  - Components start shipping end of June
  - Installation begins end of October
- $^3$He will continue to provide unique insight into the SuperKEKB beam conditions
Backup Slides
Figure 2.3: Cross section of the Belle II detector. The forward direction is on the right, and is the direction the electron beam travels. The whole detector is 5 m tall, and approximately symmetric in $\phi$ [3].
<table>
<thead>
<tr>
<th>2013/July/29</th>
<th>LER</th>
<th>HER</th>
<th>unit</th>
</tr>
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<tbody>
<tr>
<td>E</td>
<td>4.000</td>
<td>7.007</td>
<td>GeV</td>
</tr>
<tr>
<td>I</td>
<td>3.6</td>
<td>2.6</td>
<td>A</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>2,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bunch Current</td>
<td>1.44</td>
<td>1.04</td>
<td>mA</td>
</tr>
<tr>
<td>Circumference</td>
<td>3,016.315</td>
<td></td>
<td>m</td>
</tr>
<tr>
<td>$\varepsilon_x/\varepsilon_y$</td>
<td>3.2(1.9)/8.64(2.8)</td>
<td>4.6(4.4)/12.9(1.5)</td>
<td>nm/pm</td>
</tr>
<tr>
<td>Coupling</td>
<td>0.27</td>
<td>0.28</td>
<td>%</td>
</tr>
<tr>
<td>$\beta_x^<em>/\beta_y^</em>$</td>
<td>32/0.27</td>
<td>25/0.30</td>
<td>mm</td>
</tr>
<tr>
<td>Crossing angle</td>
<td>83</td>
<td></td>
<td>mrad</td>
</tr>
<tr>
<td>$\alpha_p$</td>
<td>3.18x10^{-4}</td>
<td>4.53x10^{-4}</td>
<td></td>
</tr>
<tr>
<td>$\sigma_b$</td>
<td>8.10(7.73)x10^{-4}</td>
<td>6.37(6.30)x10^{-4}</td>
<td></td>
</tr>
<tr>
<td>$\nu_c$</td>
<td>9.4</td>
<td>15.0</td>
<td>MV</td>
</tr>
<tr>
<td>$\sigma_z$</td>
<td>6.0(5.0)</td>
<td>5(4.9)</td>
<td>mm</td>
</tr>
<tr>
<td>$\nu_s$</td>
<td>-0.0244</td>
<td>-0.0280</td>
<td></td>
</tr>
<tr>
<td>$\nu_s/\nu_y$</td>
<td>44.53/46.57</td>
<td>45.53/43.57</td>
<td></td>
</tr>
<tr>
<td>$U_0$</td>
<td>1.86</td>
<td>2.43</td>
<td>MeV</td>
</tr>
<tr>
<td>$\tau_{x,y}/\tau_s$</td>
<td>43.2/21.6</td>
<td>58.0/29.0</td>
<td>msec</td>
</tr>
<tr>
<td>$\xi_x/\xi_y$</td>
<td>0.0028/0.0881</td>
<td>0.0012/0.0807</td>
<td></td>
</tr>
<tr>
<td>Luminosity</td>
<td>8x10^{35}</td>
<td></td>
<td>cm^{-2}s^{-1}</td>
</tr>
</tbody>
</table>
SuperKEKB luminosity projection

**Goal of Belle II/SuperKEKB**

- Integrated luminosity: \((ab^{-1})\)
- Peak luminosity: \((cm^{-2}s^{-1})\)

Calendar Year

- 9 months/year
- 20 days/month
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>
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<tbody>
<tr>
<td>PIN diodes</td>
<td>Wayne St.</td>
<td>64</td>
<td>Neutral vs. charged dose rate</td>
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<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></td>
</tr>
<tr>
<td>BGO crystals</td>
<td>National Taiwan U.</td>
<td>8</td>
<td>Luminosity and EM rate</td>
</tr>
<tr>
<td>CLAWS plastic scintillators</td>
<td>MPI Munich</td>
<td>8</td>
<td>Fast injection backgrounds</td>
</tr>
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</table>

*Belle had its own BEAST
BEAST II: the commissioning detector

Primary detectors in BEAST II for phase II:

<table>
<thead>
<tr>
<th>System</th>
<th>Institution</th>
<th>#</th>
<th>Unique measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIN diodes</td>
<td>KEK</td>
<td>64</td>
<td>Neutral vs. charged dose rate</td>
</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>
<td>Diamonds</td>
<td>INFN Trieste</td>
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<td>Ionizing radiation rate</td>
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<tr>
<td>He3 tubes</td>
<td>U. Victoria</td>
<td>4</td>
<td>Thermal neutron rate</td>
</tr>
<tr>
<td>CLAWS plastic scintillators</td>
<td>MPI Munich</td>
<td>82 ladders</td>
<td>Fast injection backgrounds</td>
</tr>
</tbody>
</table>

...continued
### BEAST II: the commissioning detector

Primary detectors in BEAST II for phase II:

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<tr>
<th>System</th>
<th>Institution</th>
<th>#</th>
<th>Unique measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belle II PXD</td>
<td>U. Bonn</td>
<td>2 ladders</td>
<td>Radiation tolerance for final physics runs</td>
</tr>
<tr>
<td>Belle II SVD</td>
<td>KEK</td>
<td>4 ladders</td>
<td>Radiation tolerance for final physics runs</td>
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<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>
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</table>