Helium-3 thermal neutron detectors the Belle II commissioning detector for 2016 CAP congress

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- CP violation
- Precision measurements that may show deviations from the standard model.
- Rare or forbidden (by the standard model) decays.
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Belle II

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SuperKEKB aims to achieve a luminosity of $80 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$, more than 40 times the luminosity of its predecessor, KEKB.
Due to the high luminosity of SuperKEKB, it is important to understand the beam backgrounds in order to prevent damage to the Belle II detector.
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Two important beam background sources are:
- Beam-Gas - beam particles interact with an atom of gas in the beam pipe and are scattered into the detector.
- Beam-beam or Touschek - beam particles interact with other beam particles and are deflected out of the beam.
Helium-3 tubes

- One of UVic’s contributions to BEAST II is the thermal neutron detectors.
BEAST II

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- The thermal neutron detectors are stainless steel tubes, 8" long and 2" in diameter with a sense wire at the center.
- They are filled with 4atm of $^3$He and a small amount of CO$_2$.
- The amplifier system was designed and built by UVic’s electronics office.
**Helium-3 tubes**

When a thermal neutron interacts with an atom of $^3$He, a proton and a tritium are created:

$$\frac{3}{2}He + ^0_1n \rightarrow ^3_1H + ^1_1H + 760\text{MeV}$$

From GEANT4. Neutron starts at center of tube.
When a thermal neutron interacts with an atom of $^3\text{He}$, a proton and a tritium are created:

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- The tritium and proton ionize the $^3$He which produces a signal on the sense wire.
- The cross section of this reaction falls rapidly as a function of the neutron’s momentum.

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There are four Helium-3 tubes deployed in BEAST II.
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- $\phi=0$ (to the right)
- $\phi=90$ (above the beam pipe)
- $\phi=180$ (to the left)
- $\phi=270$ (below the beam pipe)
In May 2016, BEAST II machine studies were conducted at KEK.
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The goal of these studies was to seek evidence of Touschek and beam gas beam backgrounds, and determine how large an effect they had.
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The goal of these studies was to seek evidence of Touschek and beam gas beam backgrounds, and determine how large an effect they had.

The ultimate goal is to compare these results with simulation in order to verify the accuracy of the simulation.
Beam size studies

- Touschek beam losses are proportional to the inverse of the beam size.

When the beam size is infinite, there is no Touschek contribution. By plotting the rate in the helium-3 tubes vs the inverse of the beam size, it is possible to calculate the Touschek contribution for a given beam size and beam current.
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Low energy ring

**LER beam size study**

There is clear evidence of the Touschek effect.

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LER beam size study - conclusions

- Plotted here is $\text{Touschek}/(\text{Touschek} + \text{Other})$ at a beam size of $90\mu m$ calculated using fit information.
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LER beam size study - conclusions

- Plotted here is Touschek/(Touschek+Other) at a beam size of 90\(\mu\)m calculated using fit information.
- Touschek contribution in LER appears to be constant at about 60%.
The HER beam is older, and better vacuum scrubbed, and produces a lower rate in the tubes.
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Thus, the statistics are poor for the HER runs.
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- Thus, the statistics are poor for the HER runs.
- This is reflected in the quality of the fits.
If we believe the fit data, there is clear evidence of Touschek.

The Touschek contribution is about 5-20%
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- Coulomb scattering: beam particles deflect off atoms of gas in the beam pipe have no angular dependence.
- Bremsstrahlung: beam particles are slowed down by gas atoms has an angular dependence.

To make any angular effect more pronounced, the rate in each tube was divided by the average rate in that tube for that run.
Vacuum bump occurred at several different locations along the LER beam:
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- D02: L25, L26
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- D02: L18, L19, L20
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- D02: L20, L21, L22
- D02: L18, L19, L20
- D04, D05
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  - D02: L20, L21, L22
  - D02: L18, L19, L20
  - D04, D05
  - D07
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- D02: L25, L26
- D02: L23, L24
- D02: L20, L21, L22
- D02: L18, L19, L20
- D04, D05
- D07
- D10, D11
LER Vacuum bump in D02 L25 & L26, started at 2016-05-23 10:28:00
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LER Vacuum bump in D02 L23 & L24, started at 2016-05-23 11:30:00
LER Vacuum bump in D02 L25 & L26, started at 2016-05-23 10:28:00

LER Vacuum bump in D02 L23 & L24, started at 2016-05-23 11:30:00

LER Vacuum bump in D02 L20, L21 & L22, started at 2016-05-23 12:36:00
LER Vacuum bump in D02 L25 & L26, started at 2016-05-23 10:28:00

LER Vacuum bump in D02 L23 & L24, started at 2016-05-23 11:30:00

LER Vacuum bump in D02 L20, L21 & L22, started at 2016-05-23 12:36:00

LER Vacuum bump in D02 L18, L19 & L20, started at 2016-05-23 13:55:00

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LER Vacuum bump in D02 L25 & L26, started at 2016-05-23 10:28:00

LER Vacuum bump in D02 L23 & L24, started at 2016-05-23 11:30:00

LER Vacuum bump in D02 L20, L21 & L22, started at 2016-05-23 12:36:00

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LER Vacuum bump in D04 & D05, started at 2016-05-23 15:25:00
LER Vacuum bump in D02 L25 & L26, started at 2016-05-23 10:28:00

LER Vacuum bump in D02 L23 & L24, started at 2016-05-23 11:30:00

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LER Vacuum bump in D02 L18, L19 & L20, started at 2016-05-23 13:55:00

LER Vacuum bump in D04 & D05, started at 2016-05-23 15:25:00

LER Vacuum bump in in D07 L00, L01 & L02, started at 2016-05-23 16:50:00

LER Vacuum bump in D07 L00, L01 & L02, started at 2016-05-23 16:50:00
LER Vacuum bump in D02 L25 & L26, started at 2016-05-23 10:28:00

LER Vacuum bump in D02 L23 & L24, started at 2016-05-23 11:30:00

LER Vacuum bump in D02 L20, L21 & L22, started at 2016-05-23 12:36:00

LER Vacuum bump in D02 L18, L19 & L20, started at 2016-05-23 13:55:00

LER Vacuum bump in D04 & D05, started at 2016-05-23 15:25:00

LER Vacuum bump in D07 L00, L01 & L02, started at 2016-05-23 16:50:00

LER Vacuum bump in D10 & D11, started at 2016-05-23 17:40:00

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Helium-3 thermal neutron detectors the Belle II commissioning detector
LER vacuum bump - Conclusions

- Pressure increases in D02 have a large impact on the helium-3 tube rate.
- The impact decreases as the pressure bump was moved along D02 away from the IR.
- Pressure bumps at locations further down the beam pipe have little to no effect on the helium-3 tube rate.
- No obvious dependence on $\phi$ observed in the LER.
HER vacuum bump

- Vacuum bump occurred at several different locations along the HER beam:
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- D12
HER vacuum bump

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- D09
- D07
- D06
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- D12
- D09
- D07
- D06
- D05
Vacuum bump occurred at several different locations along the HER beam:

- D12
- D09
- D07
- D06
- D05
- D03
HER Vacuum Bump in D12, started at 2016-05-24 11:00:00
High energy ring

HER Vacuum Bump in D12, started at 2016-05-24 11:00:00

HER Vacuum Bump in D09, started at 2016-05-24 12:10:00
HER Vacuum Bump in D12, started at 2016-05-24 11:00:00

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HER Vacuum Bump in D12, started at 2016-05-24 11:00:00
HER Vacuum Bump in D09, started at 2016-05-24 12:10:00
HER Vacuum Bump in D07, started at 2016-05-24 13:00:00
HER Vacuum Bump in D06, started at 2016-05-24 15:35:00

\[ \text{He} \text{tube Rate} / \text{Mean(He} \text{tube Rate) \times \phi} \]
\[ \phi = 90 \]
\[ \phi = 180 \]
\[ \phi = 270 \]
HER Vacuum Bump in D12, started at 2016-05-24 11:00:00

HER Vacuum Bump in D09, started at 2016-05-24 12:10:00

HER Vacuum Bump in D07, started at 2016-05-24 13:00:00

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High energy ring

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HER Vacuum Bump in D06, started at 2016-05-24 15:35:00
HER Vacuum Bump in D05, started at 2016-05-24 17:05:00
HER Vacuum Bump in D03, started at 2016-05-24 17:35:00
Unlike the LER, pressure increases at any location cause an increase in the helium-3 tube rate.

As stated before, the HER beam is ‘cleaner’, and has a lower nominal pressure, so it is more sensitive to pressure increases.

Not dependence on $\phi$ observed.
Compare these results with simulation in order to assess the accuracy of the simulation.
Future work

- Compare these results with simulation in order to assess the accuracy of the simulation.
- Prepare Helium-3 tubes for phase 2 of BEAST.
Clear evidence of Touschek effect seen in the LER beam.
- Clear evidence of Touschek effect seen in the LER beam.
- Weaker evidence in the HER beam.
Clear evidence of Touschek effect seen in the LER beam.
Weaker evidence in the HER beam.
Coulomb beam gas seen in both beams.
Clear evidence of Touschek effect seen in the LER beam.

Weaker evidence in the HER beam.

Coulomb beam gas seen in both beams.

No evidence of bremsstrahlung radiation.
Special thanks to:

- Paul Poffenburger at UVic for advice on DAQ.
- Neil Honkanen at UVic’s machine shop for designing and building the amplifier system.
- Peter Lewis at the University of Hawaii for coordinating the BEAST II DAQ work.
- Hiroyuki Nakayama at KEK for coordinating with the accelerator folks.
- The accelerator control group at KEK for the nice, stable beams.