Beam Background/MDI recent status

Hiroyuki Nakayama (KEK) on behalf of Beam Background and MDI group

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• Catastrophic losses and collimator damage
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New Background Measurement Campaigns
Carried out by Andrii Natochii, Hiro Nakayama, Kodai Matsuoka, Keisuke Yoshihara

- June 16: 2020, LER/HER single-beam and luminosity BG studies
  https://elog.belle2.org/elog/BCG/896

- June 16, April 27: D02H2 collimator scan in LER
  https://elog.belle2.org/elog/Collimator/30
  https://elog.belle2.org/elog/Collimator/13

- June 10: D01H3 collimator scan in HER
  https://elog.belle2.org/elog/BCG/871

- March 23: Horizontal beam orbit scan at vertical LER collimators:
  https://elog.belle2.org/elog/BCG/636

- First fully successful study in almost 1 year
  (December 2020 study suffered from TMCI / beam instabilities)
- Very valuable to gauge beam-gas / Touschek evolution and update rate extrapolations
- Up to $L = 2.6 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ → improved the luminosity background measurement?
- High beam currents will also allow us to check for beam instabilities
- TOP, PXD, TPC groups showed preliminary analysis results at B2GM, hope for more in time for BPAC
- Vary the neutron flux into Belle II from the tunnel → check neutron sensitivity of Belle II detectors
- To inform injection background simulation
2021ab background status

• Summary: Recent background rates in Belle II acceptable – all well below administrative limits and therefore not limiting beam currents

• Main background concerns in short term are catastrophic losses and stable operation (see p.14-17)

Note: “3 MHz/PMT” is the limit for the sum of single beam and injection backgrounds. It does not include the luminosity background.
Storage backgrounds: near term outlook

- TOP group already analyzed bkg composition using June 16th 2021 campaign
- On average, the total single beam bkg increased by a factor of $1.23 \pm 0.06$ over 2020
  - Compared at fixed beam parameters
- LER Touschek increased by factor $2.35 \pm 0.11$ → reduce with targeted collimation?
- The data/MC ratios of luminosity background are $0.76 \pm 0.08$ on average (was $0.98 \pm 0.04$ in 2020).
  This is an unexpected discrepancy with simulation, but consistent with other detectors.
  Analysis artifact? Good news if correct.

Needs to understand - affects design luminosity outlook
Storage backgrounds: long term outlook

- Preliminary summary by Sven May 2021. To be updated based on June 2021 studies. Still assuming \( L = 8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1} \) and original design optics, collimation.

- Extrapolation assumptions: 1) Collimator settings re-optimized for an optimal tradeoff between beam lifetime and backgrounds at design optics.

- Vacuum pressure of 1nTorr in both rings.

Table 2: Background forecast for each Belle II detector at a luminosity of \( 8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1} \). Injection background is not yet included. The TOP rate forecast includes the vacuum scrubbing uncertainty for the beam-gas component. A tentative 5 MHz TOP PMT rate limit on single-beam backgrounds is part of the new 2021 run plan and will allow for higher luminosities. We expect to replace 224 short-lifetime PMTs in 2022, and a second round of replacements during the 2026 interaction region upgrade appears likely.

<table>
<thead>
<tr>
<th>Detector</th>
<th>Expected rate or occupancy</th>
<th>Maximal acceptable rate or occupancy</th>
<th>Current prognosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>PXD, layer 1</td>
<td>1%</td>
<td>3%</td>
<td>OK</td>
</tr>
<tr>
<td>SVD, layer 3</td>
<td>4%</td>
<td>( \sim 3% ) (*)</td>
<td>OK</td>
</tr>
<tr>
<td>CDC</td>
<td>100-200 kHz / wire</td>
<td>&gt; 200 kHz /wire (not clearly established)</td>
<td>uncertain</td>
</tr>
<tr>
<td>ECL</td>
<td>n/a</td>
<td>n/a (main effect of backgrounds is on energy resolution)</td>
<td>OK</td>
</tr>
<tr>
<td>ARICH</td>
<td>50 hits/event</td>
<td>&gt; 500 hits/event</td>
<td>OK</td>
</tr>
<tr>
<td>TOP, slot 3-9 (ALD type PMTs)</td>
<td>2-7 MHz / PMT for non-luminosity component (lower estimate based most recent vacuum scrubbing extrapolation)</td>
<td>3-5 MHz / PMT for non-luminosity component</td>
<td>need two PMT replacements (2022, 2026) for 5 MHz</td>
</tr>
<tr>
<td>KLM Scintillators</td>
<td>2-2000 Hz/cm^2</td>
<td>~1 % drop in muon identification efficiency for nominal rates</td>
<td>OK</td>
</tr>
<tr>
<td>KLM RPCs</td>
<td>0.1-2 Hz/cm^2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(*) will be relaxed by a factor of about 2 (TBC) with hit time selection.
Initial motivation: significantly affects neutron production in tunnel close to Belle II, and thereby EKLM
But also found to have subtle effects on other Belle II detectors
First feedback: TOP ~ no effect, PXD: ~20% reduction in occupancy, CDC: ~20% hit rate increase
• Diamonds, PXD, SVD, CDC, TOP: Four of five storage background components have data/MC of order 1!
• KLM and ARICH included into common analysis for first time. Still need refinement at detector level.
• Puzzle: luminosity background 20-25% lower than predicted. Now also seen in TOP (but not yet included on this page).
• Plan: Include 2021 measurements. Add ECL. Improved error analysis. Latest bugfixed3 MC (see previous page) for all detectors.
• Then the study is complete and will be published.
• We use these data/MC factors to correct extrapolations of backgrounds to design luminosity.
• Systematic errors are small for Lumi and LER (largest backgrounds), reducing the extrapolation uncertainty.
Neutron shielding

• Neutrons generated both inside and outside Belle II
  • New background MC samples w/ truth can be used by detector groups to study their neutron sensitivity

• Neutron background reduction can reduce SEU rates of CDC/TOP FPGAs

• Shielding design for 2022 installation urgent → new inter-detector group formed
  • Neutron dosimeters installed to assess the situation
  • Strategy is to install as much polyethylene as possible
  • Background group will simulate preliminary /conceptual designs
Cavern Neutrons

• Greatly improved understanding
  • Spectral and directional measurements with TPCs (fast neutron detectors)
  • EKLM hit distributions
  • New far beamline “cavern backgrounds” included in simulation
  • Corrected simulation of beam particle interaction with collimator jaw (see p.6)

• Most neutrons from two mechanisms
  • RBB photon hotspots
  • Touschek losses at collimators
Neutrons part II

- Armed with this improved knowledge, performed experiment to verify
- Achieved 40% EKLM Touschek neutron reduction via modified collimation
- Also directly observed the reduced fast-neutron flux in the tunnel with the TPCs
- This confirms the Touschek-collimator neutron hypothesis
- Not only does Belle II need more shielding... also the simulation lacks shielding material that actually exists, in different places → we plan to fix the leading issues
Are inner Belle II detectors seeing delayed neutrons from injection background losses at collimators?

- Utilizing new 2Hz Poisson trigger which extends into injection veto period.
- CDC occupancy evolves during one revolution (10 μs) evolves on ms time scales
- In the first bin (<0.5ms after injection) there’s a significant delayed component
- MeV neutrons originating from the horizontal collimator D01H5?
Injection Backgrounds

- Two new efforts
  - Natochi: Simulation of injection background now *can* produce IR backgrounds
  - Schwenker: Machine learning can identify injection backgrounds with rather good accuracy

- What we still need
  - Validation of simulated injection backgrounds vs inj. parameters
  - Identify most predictive parameters
  - Method for extrapolating injection backgrounds
Catastrophic beam loss abort events in 2021b
(which caused QCS quenches)

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>qf status</th>
<th>Beam Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/19 (MO) Owl</td>
<td>1:07</td>
<td>QC1LE</td>
<td>HER 820 mA</td>
</tr>
<tr>
<td>5/10 (MO) Day</td>
<td>14:26</td>
<td>QC1LP, QC1RP</td>
<td>LER 910 mA</td>
</tr>
<tr>
<td>5/23 (SU) Owl</td>
<td>8:24</td>
<td>QC1LP, QC1RP</td>
<td>LER 840 mA</td>
</tr>
<tr>
<td>5/28 (FR) Owl</td>
<td>3:21</td>
<td>QC1RP</td>
<td>LER 840 mA</td>
</tr>
<tr>
<td>6/2 (WE) Swing</td>
<td>20:13</td>
<td>QC1LP, QC1RP</td>
<td>LER 840 mA</td>
</tr>
<tr>
<td>6/6 (SU) Day</td>
<td>16:06</td>
<td>QC1LP, QC1RP</td>
<td>LER 840 mA</td>
</tr>
</tbody>
</table>

BOR/BCM

Most of them are caused by huge beam loss in LER, several turns before the abort.

Dangerous for Belle II inner sensors. In some cases, diamonds on IP beam pipes saw >1500mrad (saturated) and PXD was damaged.

This event caused a severe damage on LER D2V1 collimator.
Severe damage on LER D02V1 collimator after the huge beam loss on June 6\textsuperscript{th}

- After the huge beam loss event on June 6\textsuperscript{th}, LER BG increased significantly
- D02V1 collimator jaws were severely damaged (deep scar on the bottom jaw)
- We lost 3~4 days for the collimator replacement work and the baking runs

Understanding the cause of huge beam loss events is essential for the stable operation at high beam currents. Where in the ring the beam abnormality initially occurs? Adding more sensors to the key collimators will help to understand the initial beam loss position.
Where’s the location of initial beam loss?

- By comparing beam loss timing among several sensors along the ring, we can find the possible area of initial beam loss.

- If we can add new beam loss sensors at some important collimators, it will help us pin-down the initial beam loss position of dangerous aborts.
Even faster beam abort: CLAWS

• 4+4 CLAWS sensors (on QCSL and QCSR) are used to issue beam aborts (since May 26th, 2021)

• **Thanks to CLAWS, abort kicker can be fired faster by ~4.4us on average**
  • For some LER aborts, CLAWS are outperformed by LER RF D5-F, which is located at better ring position
  • Adding new beam loss sensors (upstream of IP) might be able to make abort even faster
Summary

• Steady state beam backgrounds in 2021b mostly acceptable for Belle II
  • TOP PMT replacement still expected in 2022, of course
  • Catastrophic losses / abort events dangerous for inner detectors

• Storage background simulation becoming increasingly accurate
  • Up to factor ~2 effects from machine tuning need study
  • Systematic overestimate of luminosity bkg in all detectors (~20-25 % effect) not yet understood

• Long term extrapolations (large uncertainties related to collimation): most detectors safe
  • CDC and TOP uncertain \( \rightarrow \) more work needed
  • ECL not really studied but “probably fine”

• Good progress on neutron studies, shielding design is starting
• Promising new efforts on injection backgrounds
• New background studies performed in mid June, analysis ongoing
Background Publications Status

Submitted
• A. Natochii et al., *Improved simulation of beam backgrounds and collimation at SuperKEKB*, PRAB

Review by authors / authorship process ongoing
• Z. Liptak et al., *Measurements of Beam Backgrounds in SuperKEKB Phase 2*, NIMA
• M. Hedges et al., First deployment of novel vector tracking nuclear recoil detectors for directional neutron measurements at SuperKEKB, NIMA
• J. Schueler et al., *Directional cavern neutron background measurements at SuperKEKB*, NIMA

Just started / planned
• Phase 3 paper: simulation, data/MC up to now, BG19c forecast, NIMA.
• Snowmass paper: background forecast + mitigation plan to reach 2026. *Now due March 15, 2022*