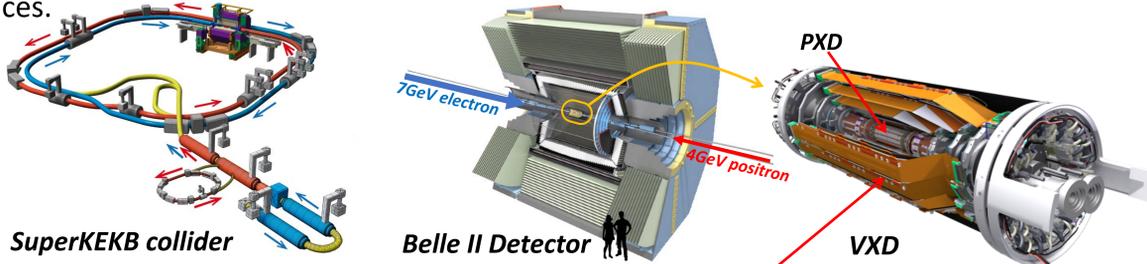


Beam background study for the Belle II Silicon Vertex Detector

Belle II Silicon Vertex Detector

The Belle II experiment is conducted at SuperKEKB, an asymmetric e^+e^- collider at KEK, Japan. SuperKEKB will achieve the unprecedented luminosity of $8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ by squeezing the beams down to a vertical size of 50 nm and doubling the beam currents. Physics data taking with the complete Belle II detector started in March 2019.

The Silicon Vertex Detector (SVD) consists of 4 layers of double-sided silicon strip sensors at radii of 39, 80, 104, 135 mm. Together with the PiXel Detector (PXD), the SVD composes the Vertex Detector (VXD), used to track charged particles and determine their production vertices.



	spring 2019*	Design
e^+ beam current [A]	~0.6	3.6
e^- beam current [A]	~0.6	2.6
Luminosity [$\text{cm}^{-2}\text{s}^{-1}$]	~ 5×10^{33}	8×10^{35}

* typical beam condition during physics run

SVD
Readout pitch: 50-75 μm in r- ϕ direction,
160-240 μm in z direction
Thickness: 300-320 μm

Beam Background

The intense luminosity of SuperKEKB will be accompanied by harsh beam background environment. The main effects predicted on the SVD are the following.

- Radiation damage
 - MC prediction $\sim 0.1 \text{ Mrad/yr}$, $\sim 2 \times 10^{11} n_{\text{eq}} \text{ cm}^{-2}/\text{yr}$
 - Tolerable limit 10 Mrad, $10^{13} n_{\text{eq}} \text{ cm}^{-2}$ in 10 years
- Deterioration of tracking performance due to fake hits
 - MC prediction $\sim 1\%$ occupancy
 - To keep good tracking performance, **Occupancy $\lesssim 2\text{-}3\%$**

Beam backgrounds arise from beam collision or single e^\pm beams. During spring 2019, because of low luminosity, SVD background has been dominated by the latter contribution. Since studies done during commissioning in 2016 and 2018 has shown that the simulation results of single-beam backgrounds are not fully reliable, actual measurement of them is crucial for the estimation of background level on the design condition. The results from single-beam background studies in spring 2019 run are shown below.

BG Decomposition

Single-beam backgrounds mainly originate from *Beam-Gas* and *Touschek* scatterings of storage beams. Since the scattering rates show different dependencies on beam parameters, the backgrounds can be decomposed by measurements with different beam density (n_b and σ_y scans).

Beam-Gas scattering

Coulomb scattering and Bremsstrahlung between beam particles and residual gas
Rate $\propto N_{\text{gas molecules}} \times N_{e^\pm} \propto PI$

Touschek scattering

Intra-bunch scattering of e^\pm
Rate $\propto (e^\pm \text{ density}) \times N_{e^\pm} \propto \frac{I}{\sigma_y n_b} \cdot I$

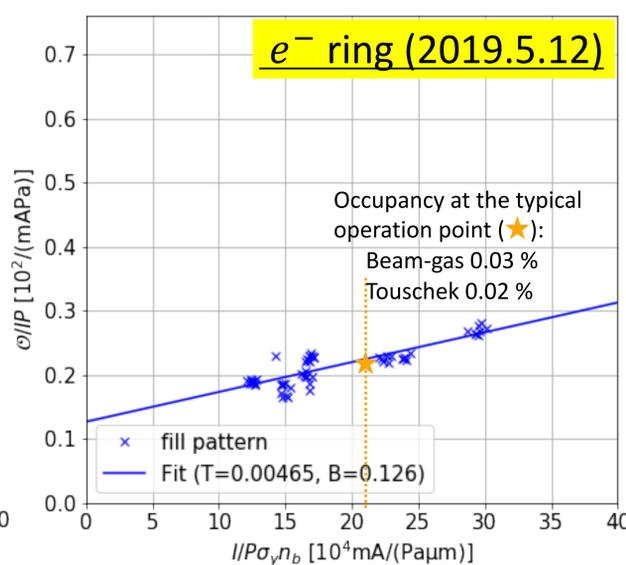
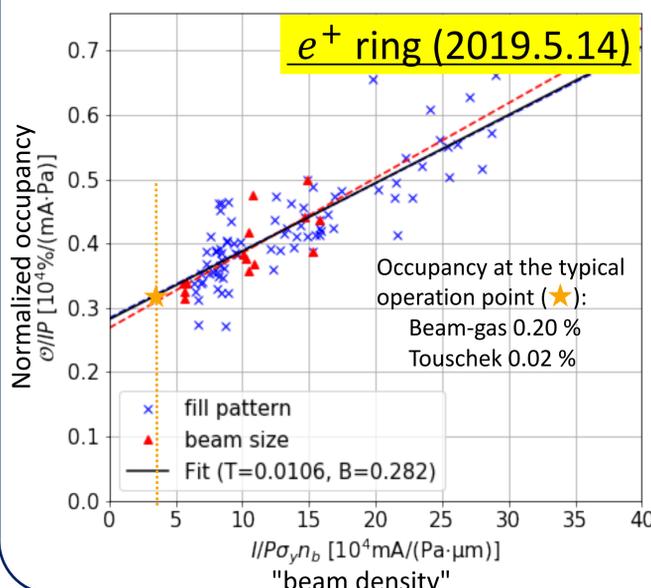


Model:

$$\mathcal{O}(I, P, \sigma_y, n_b) = B \cdot PI + T \cdot \frac{I^2}{\sigma_y n_b}$$

\mathcal{O} : background level observable **Quantities**
 I : beam current σ_y : beam size
 P : pressure n_b : number of bunches
 B, T : fit parameters

The results of the n_b and σ_y scans for SVD are plotted on $\frac{I}{P\sigma_y n_b} - \frac{\mathcal{O}}{PI}$ planes, where the above model is translated into a linear function: $\frac{\mathcal{O}}{PI} = B + T \cdot \frac{I}{P\sigma_y n_b}$, as shown below. The observed behavior of the single-beam backgrounds is consistent with the beam-gas and Touschek model. On a typical beam condition in spring 2019 run, the e^+ beam-gas has been the dominant background source.



Data-MC Comparison

Measured background rates are compared to the MC prediction assuming the same beam condition. The simulated e^- Touschek rate being strangely low, huge discrepancy is observed between data and MC.

SVD Occupancy in the innermost layer

(on a typical beam condition in spring 2019)

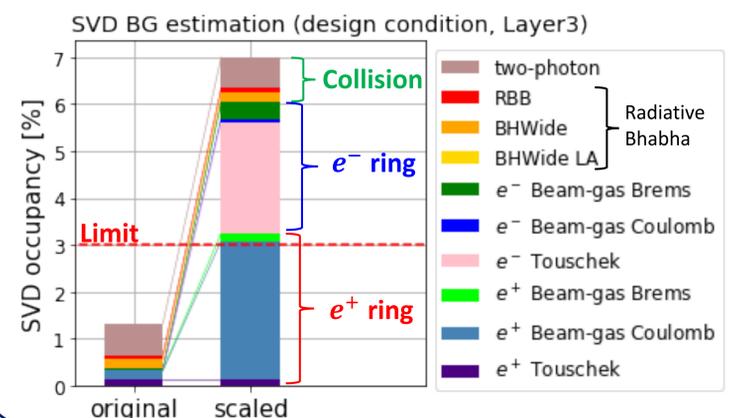
type	data	MC	data/MC
e^+ Beam-gas	0.20 %	0.012 %	16
e^+ Touschek	0.024 %	0.022 %	1.1
e^- Beam-gas	0.027 %	0.0016 %	17
e^- Touschek	0.021 %	1.6e-5 %	1300

Extrapolation to the design luminosity

The above comparison indicates MC prediction is not accurate enough to estimate single-beam background rates. The background rate on the design condition has been estimated by rescaling prediction of design MC by the data/MC factors shown above:

$$(\text{Scaled MC})_{\text{design}} = MC_{\text{design}} \times (\text{data/MC})_{2019\text{Spring}}$$

The estimated SVD occupancy exceeds the limit from tracking performance due to two main sources: e^- Touschek and e^+ Beam-gas Coulomb. Since the estimation of e^- Touschek rate is highly uncertain due to the huge scaling factor, we should understand the data-MC discrepancy for more reliable extrapolation. On the other hand, e^+ Beam-gas Coulomb has already been dominant background source in spring 2019. It should be mitigated by adding collimators and improving vacuum.



Summary

The Belle II Silicon Vertex Detector started physics data taking in March 2019. During spring 2019 run, the beam backgrounds seen in the SVD has been consistent with the assumption of beam-gas and Touschek backgrounds. The dominant background for the SVD has been e^+ Beam-gas, which should be mitigated by additional collimators and improvement of vacuum to achieve the design luminosity. e^- Touschek background shows huge data-MC discrepancy, which results in large uncertainty of the estimated background rate on the design condition. The discrepancy should be understood for more reliable extrapolation. It is also important to measure collision backgrounds, which will increase considerably approaching the design luminosity.