BEAM BACKGROUND SIMULATION FOR SUPERKEKB / BELLE-II

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Abstract

The Belle experiment is now being upgraded to the Belle II experiment designed for a 40 times higher luminosity. Such a high luminosity is realized by the SuperKEKB collider where beam-induced background rates are expected to be much higher than those of KEKB. This poses a serious challenge for the design of the machine-detector interface. We have thus carried out a GEANT4-based beam background simulation for Touschek effect. We describe the method of generating background particles and present the result of simulation.

SUPERKEKB AND BELLE-II

SuperKEKB, an upgraded of the KEKB collider, will provide a prove to search for new physics beyond the Standard Model, thanks to much larger data sample. The target luminosity of SuperKEKB, $80 \times 10^{34}\mathrm{cm}^{-1}\mathrm{s}^{-1}$, is 40 times higher than that of KEKB. The upgrade is based on so-called "Nano-beam scheme". The basic idea of this scheme is to squeeze the vertical beta function at the interaction point (IP). The vertical beta function at IP is 20 times smaller than KEKB. In addition, the total beam currents will be doubled to achieve 40 times higher luminosity. The basic parameter of SuperKEKB is summarized in Table 1

Belle II detector, an upgrade of the Belle detector, has better vertex resolution with new pixel detector, better particle identification performance with new type sensors, and better tolerance for the background particles. Details of the Belle II detector are described in [1].

Table 1: Basic parameters of SuperKEKB and the present KEKB.

(LER/HER)	KEKB achieved	SuperKEKB
Energy [GeV]	3.5/8.0	4.0/7.007
Beam current [A]	1.637/1.188	3.6/2.62
Number of bunch	1584	2503
ξ_y	0.129/0.090	0.0869/0.0807
σ_y^* [nm]	940/940	48/63
β_y^* [mm]	5.9/5.9	0.27/0.30
σ_x^* [μm]	147/170	10/10
β_x^* [mm]	1200/1200	32/25
Luminosity [10^{34} cm^{-2} s^{-1}]	2.108	80

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TOUSCHEK EFFECT

Touschek effect is the most dangerous background at SuperKEKB with "Nano-beam" scheme. The effect is an intra-bunch scattering. Elastic scattering between two particles in a same beam bunch changes their energy to deviate from the beam bunch, one with too much and the other with too little energy. The scattering rate of the Touschek effect is proportional to the inverse beam size, inverse third power of the beam energy, the number of bunches and second power of the bunch current. Since the beam size of SuperKEKB is much smaller than that of KEKB, background from the Touschek effect will become much higher.

The contribution from the LER is higher than the HER due to asymmetric beam energy. As shown in Table 1, we change the beam energy from (E_{HER},E_{LER}) = (8.5 GeV, 3.5 GeV) to (E_{HER},E_{LER}) = (7.0 GeV, 4.0 GeV). One reason that we change beam energy to be less asymmetric is to reduce the Touschek effect from the LER.

At SuperKEKB, simple extrapolation using the machine parameters predicts that Touschek background will increase by factor of $\sim$20 compared to that of KEKB. However, Touschek background is reduced than this prediction because we introduce improved countermeasures to cope with the background.

Touschek-scattered particles are lost by hitting the beam pipe inner wall while they propagate around the ring. If their loss position is close to the detector, generated shower might reach the detector. Fake hits generated by the background shower particles deteriorate the detector's physics resolution. Radiation dose by gammas or neutrons in the background shower damage the Silicon devices used in the detector.

To cope with Touschek background, there are two countermeasures: movable collimators and heavy-metal shield. The movable collimators located along the ring can stop the deviated particles before they reach close to the detector. Touschek background can be reduced effectively by collimating the beam horizontally from both inner and outer sides, since Touschek-scattered particles have too much or too little energy. At KEKB, we had horizontal collimation only from inner side. The heavy-metal shield is located outside the detector acceptance, between the beam pipe and inner detectors. The shield is made of Tungsten-alloy whose radiation length is short, and effectively stops the background showers before they reach the inner detectors.

TOUSCHEK SIMULATION

For generation and tracking, "SAD (Strategic Accelerator Design)"[2] and "TURTLE (Trace Unlimited Rays Through Lumped Elements)"[3] were used. Once scattered particles reach close to the interaction region, shower generation and detector responses are simulated with GEANT4.

In order to get scattering rate, we use Touschek scattering formula [4]. Scattering rate is dependent on position. We presume that it is inversely proportional to beam size. At the scattering point, only beam energy is changed.

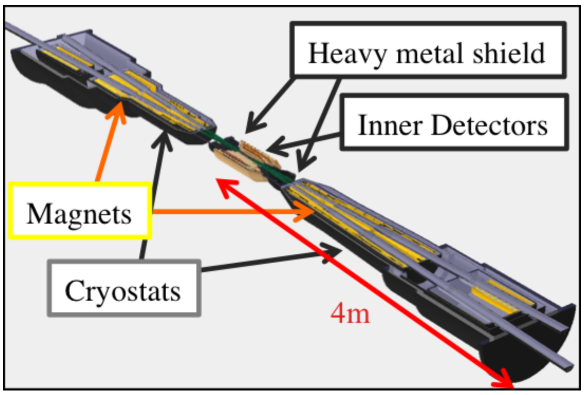

Figure 1: Interaction region geometry in GEANT4.

COLLIMATOR SETTINGS AND IR LOSS RESULT

Scattered particles are stopped by the collimators before they reach IR. We set movable collimators at the position where horizontal beta or dispersion is large. Collimation depth was chosen to avoid decreasing beam lifetime. The minimum width d_x is given by equations below:

$$d_x = \mathrm{Max}[d_{x\beta}, d_{x\eta}, d'_{x\beta}] \quad (1)$$

$$d_{x\beta} = n_x\sqrt{\epsilon_x\beta_x} \quad (2)$$

$$d_{x\eta} = \eta_x(n_z\sigma_\delta) \quad (3)$$

$$d'_{x\beta} = \sqrt{\frac{\beta_{x,\mathrm{mask}}}{\beta_{x,\mathrm{QC2}}}} r_{\mathrm{QC2}}. \quad (4)$$

Here, β_x is horizontal beta function, n_x, n_z are the parameters of dynamic aperture in number of sigma for horizontal position and energy respectively, η is dispersion, ϵ_x is horizontal emittance and r_{QC2} is beam pipe radius at QC2. These values of LER and HER are listed in Table 2.

Then, we set 8 collimators for LER and 11 for HER. Position and depth of the collimators are summarized in Table 3. Touschek background simulation for LER with SAD and the simulation for LER and HER with TURTLE were done. Both simulation result show that the LER Touschek loss rate in IR is ~1 GHz, and the loss position is ~1 m upstream of IP. It corresponds to about 0.3 % of total loss. Most of scattered particles are stopped by movable collimators. The particles lost at IR are mainly lost vertically. Vertical deviation was caused by the Touschek scattering at the opposite side of IP, where four vertical bending magnets are placed in order to cross HER. Vertical collimators might further reduce background, but we suffer from transverse mode coupling instability.

Loss rate of HER Touschek scattering at IR is much smaller than that of LER.

Table 2: Parameter list for collimation depth

	LER	HER
n_x	30	15
n_z	22	14
ϵ_x	3.2 nm	4.3 nm
σ_δ	0.00080	0.00066
r_{QC2}	35 mm	40 mm
$\beta_{x,\mathrm{QC2}}$	424 m	974 m

Table 3: Movable collimators for background study

LER s [m]	LER depth [mm]	HER s [m]	HER depth [mm]
956.17	12.34	2057.56	8.97
1710.94	12.31	1302.98	8.97
2463.72	12.34	549.89	8.97
2813.88	12.28	202.34	8.97
2872.80	12.98	156.64	8.97
2927.91	16.70	126.67	12.53
2947.61	17.60	91.16	14.35
2998.47	12.34	74.55	14.35
		48.35	6.21
		34.15	6.21
		17.7	10.82

IMPACT ON PIXEL DETECTOR

Using LER Touschek simulation result with SAD, pixel detector simulation were done. Pixel detector consists of two DEPFET pixel layers. Inner detector and outer detector are placed at a radius of 1.4 cm and 2.2 cm, and they have 8 and 12 ladders respectively. Illustration of the pixel detector's ladder is shown in Fig.3. The occupancies are given for readout time of the PXD, 20 μs. Simulation result shows that averaged occupancy is 0.18 %, and the number

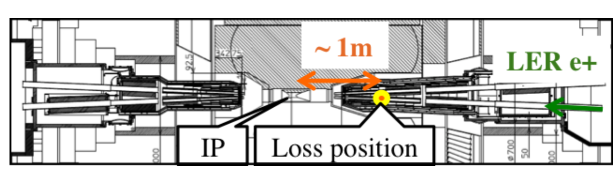

Figure 2: Illustration of loss position in IR

of neutron hit per readout time is 3.3 times. Occupancies for each ladder are listed in Table 4. It is below detector requirement, 2 - 3 %. This means that pixel detector occupancy from Touschek background is tolerable.

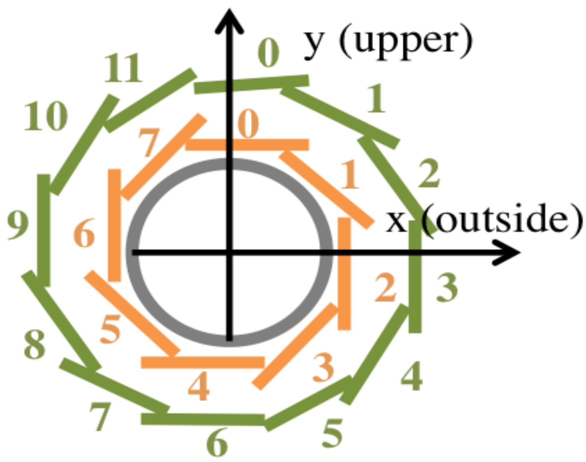

Figure 3: Illustration of the pixel detector's ladder.

Table 4: Occupancy from LER Touschek background.

	inner layer [%]		outer layer [%]	
ladder	forward	backward	forward	backward
0	0.23	0.21	0.19	0.18
1	0.20	0.19	0.26	0.23
2	0.22	0.22	0.32	0.27
3	0.19	0.18	0.36	0.30
4	0.19	0.18	0.32	0.27
5	0.15	0.14	0.22	0.19
6	0.13	0.12	0.14	0.12
7	0.14	0.13	0.13	0.12
8			0.11	0.10
9			0.10	0.10
10			0.12	0.10
11			0.15	0.15

REFERENCES

[1] Belle II Technical Design Report, http://xxx.lanl.gov/abs/1011.0352

[2] http://acc-physics.kek.jp/SAD/.

[3] D. C. Carey, K. L. Brown, Ch. Iselin,"DECAY TURTLE", http://www.slac.stanford.edu/pubs/slacreports/slac-r-246.html.

[4] A. Piwinski. The touschek effect in strong focusing storage rings, Mar 1999.