EVALUATION OF THE DETECTOR BG FOR SuperKEKB

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Abstract

SuperKEKB is the upgrade plan of the current B-factory experiment with the KEKB accelerator at KEK. Its luminosity is designed to be 8×10^{35}/cm^2/s (40 times higher than KEKB) and the integrated luminosity is expected to be 50 ab^{-1}. In SuperKEKB, it is important to evaluate the beam induced BG and design the interaction region (IR) to assure the stable detector operation. To estimate the beam induced BG, we construct the beam-line simulation based on the GEANT4 simulation. To study the particle BG features, we did the background studies during the 2009 fall Belle runs. In this paper, we report the BG evaluation for SuperKEKB.

IR DESIGN FOR SUPERKEKB

For the next generation B-factory experiment in Japan, SuperKEKB, the high luminosity e^+e^- asymmetric collider at the B mesons CM energy, is planed as an upgrade of the current KEKB [1]. It is designed to achieve a luminosity of 8×10^{35}/cm^2/s, 40 times higher than the highest luminosity record at KEKB, by employing higher beam currents and smaller interaction point (IP) beam sizes.

For SuperKEKB, we deign that the 7 GeV electrons stored in the high-energy ring (HER) and the 4 GeV positrons in the low-energy ring (LER) collide at IP with a finite crossing angle of 83 mrad. The large crossing angle helps to separate quickly the two beams and to position the final quadrupole magnets closer to IP to achieve small β-functions at IP. We have separated quadrupole magnets for the two beams on each side in this design. Parameters are listed in Table 1, here x and y directions are defined as the horizontal and vertical directions, respectively.

In the higher luminosity machine operations, the higher beam-induced background to the Belle II detector is expected. To assure the stable detector operations under such high luminosity experiments, the IR design based on the beam-induced background estimations compared to the present level is important.

In this paper, we discuss the expected beam-induced background at SuperKEKB. Note that all expectations strongly depend on the beam optics. Then the numbers will be updated after fixing the beam optics and the IR design.

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Table 1: SuperKEKB Beam Parameters

	LER	HER	Unit
Beam Energy	4.0	7.0	GeV
β^*_x / β^*_y	32 / 0.27	25 / 0.41	mm
ϵ_x / ϵ_y	3.2 / 12.8	2.4 / 8.4	nm / pm
IP beam size (x)	10.2	7.75	μ m
IP beam size (y)	0.059	0.059	μ m
Bunch length	6	5	mm
Beam current	3.60	2.62	A
Crossing angle	83		mrad
Luminosity	8×10^{35}		cm^{-2} s^{-1}

EVALUATION OF POSSIBLE BEAM-INDUCED BACKGROUNDS

In this section, we describe the possible background sources in SuperKEKB: synchrotron radiation (SR) from upstream of the high energy ring (HER), backscattering of SR from HER downstream, scattering of the beam on residual gas[1], Touschek scattering, radiative Bhabha scattering, and electron-positron pair production via the two photon process $e^+e^- \to e^+e^-e^+e^-$.

SR from Upstream (SR Upstream)

It is important to evaluate the upstream SR background to design the IP-chamber to protect the inner detectors of the pixel detector(PXD) and the silicon vertex detector (SVD). Here we design the IP-chamber to avoid the direct SR hit from HER to the detector. Figure 1 shows a rough sketch of the current IP-chamber design for SuperKEKB. The baseline design of the IP chamber is similar to the current IP-chamber [2]. In SuperKEKB, as shown in the figure, there are crotched structures both left and right sides, since IP chamber is connected to the two separate quadrupole magnets in both ends.

In SuperKEKB, the polarity of the last bend is designed so that SR fan from the bend do not directly hit the central part of the IP chamber. Then we expect SR from the last bend is stopped by the crotched part. For further detailed estimations, we also perform GEANT4 based beam-

[1]In what follows, we will use the expression 'beam-gas scattering' or just 'beam-gas' for this kind of scattering.

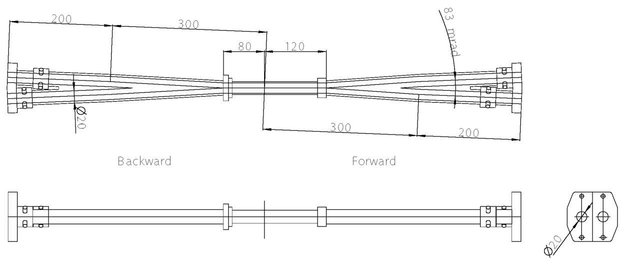

Figure 1: Picture of IP chamber.

line simulations, since the SR background level depends on the HER current, beam-optics (magnet positions, magnetic field strength, and beam orbits), and the geometry of the IR components. As a result, no direct SR hits from HER are expected by assuming the current beam optics and IP-chamber design.

Backscattering of SR from Downstream (SR Backscattering)

The final focusing magnet for the HER downstream side is called 'QCS-R', where R stands for the right hand side. The magnet QCS-R provides the final focusing of the LER beam. In the current KEKB case, it also works as a bending magnet to separate the outgoing HER beam from the LER. Then, strong SR is emitted because of this bending. These strong SR emissions once destroyed the SVD.

On the other hand, in SuperKEKB case, two separate quadrupole magnets are located in both R and L sides, and beam orbits of both incoming and outgoing beams are on center of the magnets. Then we expect much lower background than current KEKB. Based on the optics calculations, we expect 1/800 of the current KEKB backscattering SR at SuperKEKB. To confirm this, careful simulation studies will also be necessary after fixing the beam optics.

Beam-Gas

Beam-gas scattering (bremsstrahlung and Coulomb scattering) changes the momenta of beam particles, which then hit the walls of vacuum chambers and magnets. Then shower particles are produced and caused one of the major sources of the beam-induced background. The effect of this background depends on the beam current, the vacuum pressure in the ring, and strength of the magnets.

In SuperKEKB, the beam currents will be $\sim$2 times higher than KEKB. Except for IR, the vacuum level and the overall magnet-field strength will be the same levels as current. Then we expect the same order (a few times higher) beam-gas background dose. However, the vacuum level at IR ($\pm$2m region from IP) will be 100-1000 times higher than the current, and we locate much higher magnetic field final focus magnets around IP, it is important to evaluate these effects. In addition, in SuperKEKB IR, due to the little space around IP, the thickness of the IP-chamber mask to shield the shower particle backgrounds from Beam-gas and Touschek will be only 1-2X_0, a careful beam-gas background evaluation is necessary.

Touschek

Touschek scattering is intra-bunch scattering. It changes the momenta of beam particles, and the beam particles hit the vacuum chambers and magnets walls. Then shower particles are produced. This background is proportional to the beam bunch current, the number of bunches, and the inverse of the beam size. In SuperKEKB, the beam size will be $\sim$1/20 of current, then the Touschek background is expected to be the major background source.

The contribution from the HER can be ignored, because the rate of Touschek scattering is proportional to E^{-3}, where E is the beam energy, and also to the bunch current density, which is less than in the LER because the HER current is smaller than the LER current.

Based on the expected beam-life time, we expect the Touschek background from LER to be $\times$20-30 of current KEKB. The detailed Touschek background estimation based on the beam-line simulation is important.

Radiative Bhabha Scattering

The rate of the radiative Bhabha events is proportional to the luminosity. Photons from the radiative Bhabha scattering propagate along the beam axis direction and interact with the iron of the magnets. In these interactions, neutrons are copiously produced via the giant photo-nuclear resonance mechanism [3]. These neutrons are the main background source for the outer-most detector, the K_L and muon detector (KLM) in the instrumented return yoke of the spectrometer. Detail simulation studies are important to design the IR.

In addition, in the radiative Bhabha events both electron and positron energies decrease. If we employ the shared QCS magnets for incoming and outgoing beams like current KEKB, the scattered particles are over-bent by the QCS magnets. Then the particles hit the wall of magnets where electromagnetic showers are generated. In the SuperKEKB case, we use two separate quadrupole magnets

and both orbits for incoming and outgoing beams are center of the Q-magnets. Then we expect the radiative Bhabha background due to the over-bent electrons and positrons will be low. Based on the beam optics calculation, we estimate 1/40 of current KEKB background in SuperKEKB.

EVALUATION OF THE BACKGROUND LEVEL BASED ON THE BEAM-BACKGROUND STUDY

To understand the particle shower beam-induced background features, we perform background studies during the 2009 fall Belle runs. To evaluate the Beam-Gas scattering, we perform the vacuum bump studies, here we change the vacuum level of the each section of the ring. To study the

Touschek effect, we vary the overall beam size. In these studies, we use single LER or HER beam.

Vacuum Pump Study

To study the Beam-Gas scattering background effect, we vary the vacuum level of one of the sections in the HER or LER ring. We compare the SVD PIN diode current, CDC current, or TOF hit rate and vacuum level of the each section. The all of above sub detector background levels depend on the vacuum level of the last Arc. or just upstream straight sections. But there is no strong correlations between the detector background level and the other section vacuum level. It shows that the vacuum level from the last Arc to the upstream straight section of the IR determines the Beam-Gas background level.

On the other hand, we also vary the vacuum level of the IP in this background study. Figure 2 shows the results of (a) CDC current, (b) SVD PIN diode, (c) HER beam life time, and (d) vacuum level of the IP. This study indicates that the bad IP vacuum level affects to the beam life time, but not affects to the detector background level.

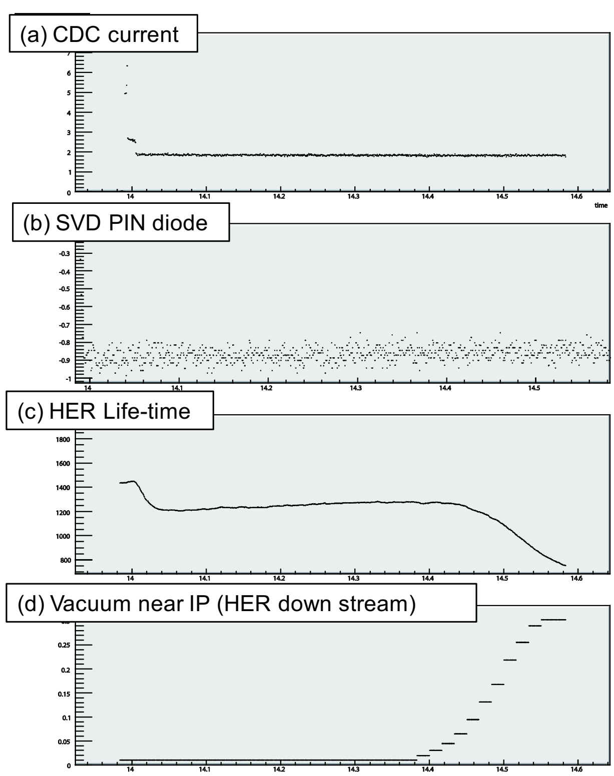

Figure 2: Measured values at the IP.

Touschek Study

To study the Touschek effect, we vary the HER or LER beam size. Figure 3 shows the scatter plots of (a) 1/beam size vs 1/lifetime, and (b) 1/lifetime vs CDC current. Since CDC currents is proportional to the life time, we estimate the expected Touschek background level based on the expected beam life, as shown in the previous section.

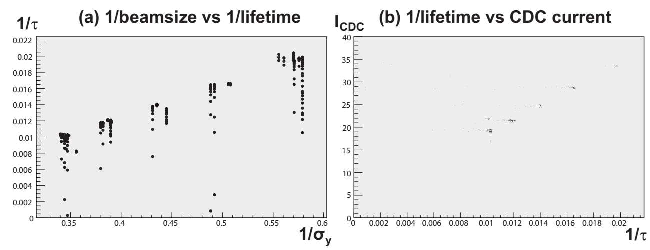

Figure 3: Results of the LER Touschek background study: (a) 1/beamsize vs 1/lifetime, and (b) 1/lifetime vs CDC current.

SUMMARY

We have evaluated the detector background level for SuperKEKB. Based on the beam-line simulations, optics calculations, and BG studies, we estimate that there are

1. No direct SR hits from HER to the detector,
2. 1/800 of backscattering SR,
3. A few times higher beam-gas BG, and
4. 20-30 times higher Touschek BG

in SuperKEKB.

Since all expectations strongly depend on the beam optics, the numbers will be updated after fixing the beam optics. We need further detailed beam-line simulations to finalize the IR design.

REFERENCES

[1] S. Kurokawa and E. Kikutani, Nucl. Instr. and Meth. A**499** (2003) 1.

[2] R. Abe *et al.*, Nucl. Instrum. Meth. A**535** (2004) 558.

[3] Particle Data Group, C. Amsler *et al.*, Phys. Lett. B**667** (2008) 1.