

BEAM BACKGROUND AND MDI DESIGN FOR SUPERKEKB/BELLE-II

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Abstract

The Belle experiment, operated at the asymmetric electron-positron collider KEKB, had accumulated a data sample with an integrated luminosity of more than 1 ab^{-1} before the shutdown in June 2010. We have started upgrading both the accelerator and the detector, SuperKEKB and Belle-II, to achieve the target luminosity of $8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$. With the increased luminosity, the beam background will be severe. The development of Machine-Detector Interface (MDI) design is crucial to cope with the increased background and protect Belle-II detector. We will present the estimation of impact from each beam background sources at SuperKEKB and our countermeasures for them, such as collimators to stop Touschek-scattered beam particles, Tungsten shield to protect inner detectors from shower particles, and dedicated beam pipe design around interaction point to stop synchrotron radiation, etc.

INTRODUCTION

The Belle experiment, operating at an asymmetric electron positron collider KEKB, finished its operation in June 2010. The Belle experiment had accumulated a data sample corresponding to an integrated luminosity of 1 ab^{-1} . KEKB recorded the worlds highest peak luminosity, $2.1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. Numerous results of the Belle experiment have confirmed the theoretical predictions of the Standard Model. Especially, measurement of large CP violation in the B meson system has demonstrated that the Kobayashi-Maskawa (KM) mechanism is the dominant source of CP-violation in the standard model,

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, $80 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, is 40 times higher than that of KEKB. The upgrade is based on so-called “Nano-beam scheme”, which is first proposed by SuperB project planned in Italy [1]. The basic idea of this scheme is to squeeze the vertical beta function at the interaction point (IP). The luminosity of the collider is expressed by the following formula, assuming flat beams and equal horizontal and vertical beam size for two beams at IP:

$$L = \frac{\gamma_{\pm}}{2er_e} \left(\frac{I_{\pm} \xi_{y\pm}}{\beta_{y\pm}^*} \right) \frac{R_L}{R_{\xi_y}}, \quad (1)$$

where γ , e , and r_e are the Lorentz factor, the elementary electric charge and the electron classical radius, respectively. I , ξ_y , β_y^* are the beam current, the beam-beam parameter and the vertical beta function at IP. The suffix \pm specifies the positron (+) or the electron (-) beam. The pa-

rameters R_L and R_{ξ_y} represent reduction factors for the luminosity and the vertical beam-beam parameter, which arise from the crossing angle and the hourglass effect. At SuperKEKB, the vertical beta function at IP is 20 times smaller than KEKB in the Nano-beam scheme. 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 [2].

Table 1: Basic parameters of SuperKEKB and KEKB. The former number is for the LER and the latter for the 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 [$\text{cm}^{-2} \text{ s}^{-1}$]	2.1×10^{34}	80×10^{34}

BEAM BACKGROUND SOURCES

At SuperKEKB with higher luminosity, the beam-induced background will also increase. Major background sources at SuperKEKB are shown in this section.

Touschek Effect

The first background source is Touschek effect, which is the most dangerous background at SuperKEKB with “Nano-beam” scheme. Touschek effect is an intra-bunch scattering. Coulomb 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, 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. At SuperKEKB,

simple extrapolation using the machine parameters predicts that Touschek background will increase by factor of ~ 20 compared to that of KEKB. However, Touschek background is reduced than this prediction because we introduce improved countermeasures to reduce 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.

Beam-gas'Uattering

The second background source is the beam-gas scattering by the residual gas atoms. Coulomb scattering changes the direction of the beam particle, and bremsstrahlung scattering decrease the energy of the beam particles. Scattering rate of the beam-gas scattering is proportional to the vacuum level and the beam current. At SuperKEKB, the beam currents will be ~ 2 times higher than that of KEKB, and the vacuum level except for the interaction region will be the same level as KEKB. Therefore we have been expected the same order of magnitude (a few times higher) beam-gas background in the past publications[2]. However, our latest simulation study reveals that Coulomb scattering rate is higher by factor of ~ 100 than that of KEKB, since IR beam pipe aperture is smaller and the maximum vertical beta function is larger. Beam-gas scattered particles are lost by hitting the beam pipe inner wall while they propagate around the ring, just like Touschek-scattered particles. The countermeasures used for Touschek background, movable collimators and the heavy-metal shield, are also effective to reduce beam-gas background. Especially, vertical movable collimator is essential to reduce Coulomb scattering background. Transverse Mode Coupling (TMC) instability caused by the vertical collimator should be carefully examined since vertical beta function is larger than horizontal beta function,

01 Circular Colliders

A02 Lepton Colliders

Synchrotron Tadiation

The third background source is synchrotron radiation (SR) emitted from the beam. Since the SR power is proportional to the beam energy squared and magnetic field squared, the HER beam is the main source of this type of background. The energy of SR is few keV to tens of keV. At the first stage of Belle, the inner layer SVD was severely damaged by x-rays with $E \sim 2\text{keV}$ from HER. To absorb the synchrotron radiations before they reach the inner detector (PXD/SVD), the inner surface of the Beryllium beam pipe are coated with gold plate. The shape of IR beam pipe is designed to avoid direct SR hits at the detector.

Radiative Bhabha Rrocess

The fourth background source is Radiative Bhabha process. Photons from the radiative Bhabha process 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. These neutrons are the main background source for the outermost detector, the KL and muon detector (KLM) instrumented in the return yoke of the spectrometer. The rate of neutron production by the radiative Bhabha events is proportional to the luminosity, which is 40 times higher than that of KEKB. Additional neutron shield in the tunnel to stop those neutrons is necessary. Both electron and positron energies decrease after radiative Bhabha process. If we employ the shared QCS magnets for incoming and outgoing beams as in KEKB, the scattered particles are over-bent by the QCS magnets. The particles then hit the wall of magnets and electromagnetic showers are generated. In the SuperKEKB case, we use two separate quadrupole magnets and both orbits for incoming and outgoing beams are centered in the Q-magnets. We therefore expect the radiative Bhabha background due to over-bent electrons and positrons will be small.

Two Rhoton'Rrocess

The fifth background source is very low momentum electron-positron pair backgrounds produced via the two-photon process: $ee \rightarrow eeee$. In SuperKEKB, the radius of the innermost detector is less than that of KEKB since we introduce the pixel detector close to the IP. The two-photon background rate increases roughly as $1/r^2$. MC simulations and machine studies at KEKB in 2010 has shown that the two-photon BG rate on the PXD is less than our requirement.

Beam-beam Dackground

A beam bunch interacts with the electric field of the other bunch when they collide at the IP. A beam particle is kicked by this interaction and the kick force is almost proportional to the distance from the center of the bunch at $x/\sigma \ll 1$. Beam-beam interaction results in non-Gaussian shape of beam tail, therefore it might increase the background rate

such as synchrotron radiation. It is not easy to estimate this interaction precisely, because the interaction is a non-linear force and numerical simulation needs huge CPU power. Anyway, simulation study is being performed.

MACHINE DETECTOR INTERFACE DESIGN

Final Focusing Magnets

At SuperKEKB, beam crossing angle is 83 mrad, which is about four times larger than that of KEKB. This value is determined mainly by considerations related to the optics of the interaction region, magnet design, and background.

With a large crossing angle, the final focus quadrupole magnets can be independent for the two beams, which has the merit of reducing the detector background due to synchrotron radiation and radiative Bhabha process. Another merit of a larger crossing angle is that the final focus quadrupole magnets can be placed closer to the IP, which contributes to widening the dynamic aperture. Dynamic aperture is one of the most serious issues for SuperKEKB in the Nano-Beam scheme. A narrow dynamic aperture shortens the beam lifetime from the Touschek effect and the lost particles cannot be replenished by the injector if the lifetime is too short.

Interaction Region Design

Figure 1 shows comparison of interaction region design between KEKB and SuperKEKB. At SuperKEKB, the beam pipe radius gets smaller (from 15mm to 10mm) and the beam crossing angle gets larger (from 22mrad to 83mrad). As a consequence, the branching of the beam pipe gets much closer to the interaction point and beam pipe fabrication becomes more complicated.

In addition, since we install a new pixel detector just outside the beam pipe, the additional read out cables and cooling pipes for the pixel detector make space allocation problem much more difficult.

Beam Pipe at the Interaction Point

The beam pipe at the interaction point is made of Beryllium for inside acceptance angle and stainless-steel for outside acceptance. Inner wall of the beam pipe is coated with gold plating ($10\mu\text{m}$) to absorb SR hits. The largest heat source in this section is caused by the image current. Since Beryllium is reactive, we would like to avoid cooling by water. Instead, a normal paraffin liquid such as $\text{C}_{10}\text{H}_{22}$ is the candidate coolant. We allow paraffin and vacuum to touch both sides of welding. As a result, fabrication of Beryllium part is simpler and less expensive.

Beam Pipe at the Branching Part

The beam pipe at the branching part is made of Tantalum, effective to stop background showers with short radiation length. Diameter of the incoming beam pipe is col-

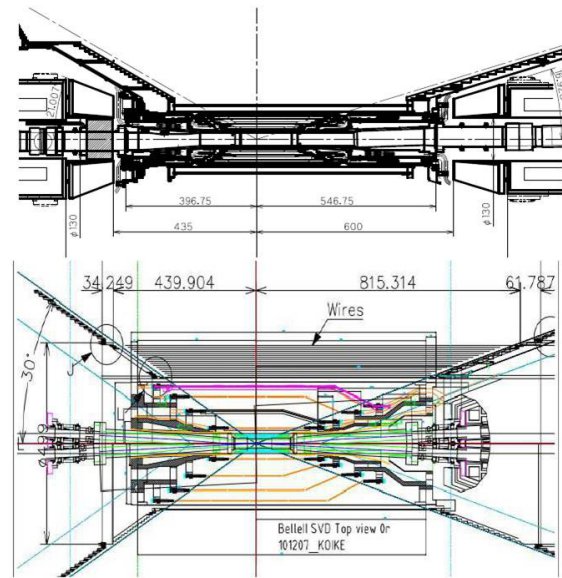


Figure 1: Interaction region design of KEKB (upper) and SuperKEKB (lower).

lated from 20mm to 9mm. This collimation part stops most of SR photons parallel to the beam and almost no direct SR hits on the Beryllium part of the beam pipe. Simulated SR hit rates on the PXD or SVD are far below required level. HOM energy is not trapped around interaction point and escapes through the outgoing beam pipe, since the outgoing beam pipe is not collimated. The ridge (or saw-tooth) structure on the collimation part prevents reflected SR photons to hit Beryllium part of the beam pipe.

Heavy-metal Shield

Cone-like structure of Tungsten-alloy surrounding the branching part of the beam pipe stops background showers with short radiation length. The average thickness is $1 \sim 2\text{cm}$, which is enough to reduce background down to the tolerable level. It is not possible to put more material, since the total weight is too heavy to be supported by the mechanical structure.

REFERENCES

- [1] P. Raimondi, talk given at the 2nd SuperB workshop, Frascati, 2006.
- [2] Belle II Technical Design Report, <http://xxx.lanl.gov/abs/1011.0352>