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BEAM LOSS BACKGROUND AND COLLIMATOR DESIGN IN CEPC DOUBLE RING*

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Abstract

The Circular Electron Positron Collider (CEPC) is a proposed Higgs factory with center of mass energy of 240 GeV to measure the properties of Higgs boson and test the standard model accurately. Beam loss background in detectors is an important topic at CEPC. Radiative Bhabha scattering and beamstrahlung effects are dominant mechanism of the beam induced backgrounds at CEPC due to the beam lifetime. In this paper, we evaluated the beam loss background in simulation and designed a series of collimators to suppress the radiation level on the machine and the detector.

INTRODUCTION

With the discovery of the Higgs boson at around 125GeV, a circular Higgs factory design with high luminosity ($L \sim 10^{34}$ cm^{-2} s^{-1}) is becoming more popular in the accelerator world [1]. The Circular Electron Positron Collider (CEPC) [2] project in China is one of them.

Radiative Bhabha scattering (RBB) and beamstrahlung (BS) are important components of the beam induced backgrounds at CEPC due to the beam lifetime (RBB~100min, BS~60min) [3]. Beam loss is due to scattering processes off of particles and materials which can induce energy loss.

The occupancy of the detector might be too high to reconstruct the physical events if these lost particles are not well shielded. More serious is that some critical devices of the machine and the detector might be damaged very soon if so many loss particles hit the devices directly. In order to suppress the radiation level on the machine and the detector, the loss particles background must be well evaluated and the shielding must be well designed.

In this paper, RBB and BS events are initially created by a Monte Carlo generators; the initial particles are then tracked until they encounter a beam pipe or collimators; collimators are designed to prevent the lost particles, and results are compared.

BEAM LOSS BACKGROUND

The off-momentum dynamic aperture after optimizing the CEPC lattice is about 1.6%. Considering the beam-beam effect and errors, the energy acceptance of CEPC should be smaller and can be considered as 1.5%. If the energy loss of the beam particles are larger than 1.5% of the beam energy, these particles will be lost from the beam and might hit the vacuum chamber. If this happens near the IR, detectors may be damaged by the lost particles. Thus beam loss background should be analysed and prevented.

Radiative Bhabha Scattering

To evaluate the level of beam loss, the scattering process will be simulated by specific generators. For instance, the radiative Bhabha scattering [4] is simulated by BBBrem [5] or Py_RBB [6]. Figure 1 shows the energy spread distribution of 200000 generated radiative Bhabha scattering events.

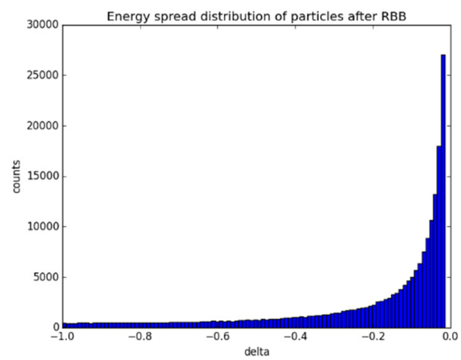

Figure 1: RBB events in CEPC interaction region (IR).

The location of particle loss makes it unclear when the scattering occurred, these scattered particles must be tracked by accelerator tracking tools such as SAD [7] to determine the lost position. The particles will be flagged as lost if the transverse position of the particles touch the inner wall of the beam pipe. Particles might be lost at any position along the accelerator, however, only the particles lost near the IP are important. The position and coordinate in phase space of lost particles are recorded, which is shown in Fig. 2 for the first two turns. The information at the lost position of the lost particles will be used as the input of the Geant4 [8] simulation to evaluate the radiation level on the detector.

Most particles get lost in the detector immediately after the collision due to their large energy loss, which can be seen from the blue histogram in Fig. 2. A few particles with high energy are lost near the IP after one revolution for a small energy loss. Although a pretty large fraction of events are lost in the downstream region, the radiation damage to the detector components is tolerable since most of these particles are confined within a small angle exiting the detector. This part of beam loss will not strike any detector components.

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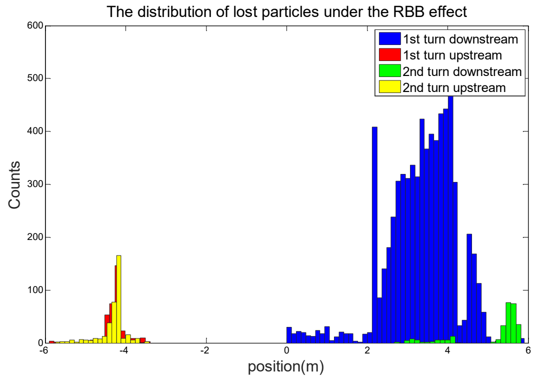

Figure 2: The distribution of lost particles positions due to radiative Bhabha scattering.

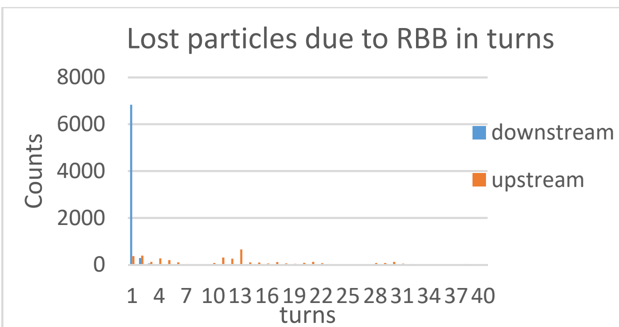

Figure 3: The statistic of lost particles in multi-turn tracking due to radiative Bhabha scattering.

Compared to the one turn's tracking, more particles get lost in the upstream region of the IR. The events lost in the upstream region are more dangerous for they are likely to permeate into the detector components, even when considering the small flying angle with respect to the longitudinal.

Beamstrahlung

Beamstrahlung events have been generated with Guinea-Pig++ (Generator of Unwanted Interactions for Numerical Experiment Analysis Program Interfaced to GEANT)[9] or Py_BS [6]. Below in Fig. 4 is the energy spread distribution of 200000 beamstrahlung events. From Telnov's formula of beam lifetime due to beamstrahlung [10], one can get the relationship between the cross section and energy spread [6].

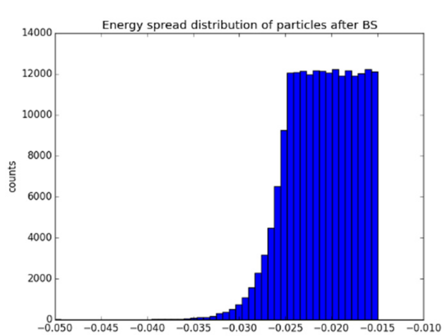

Figure 4: Beamstrahlung events in the CEPC IR.

Due to the energy spread distribution close to the energy acceptance and not having a large tail, the beam loss particles do not appear in the downstream of the first turn tracking in SAD but do appear in multi-turn tracking (Fig. 5).

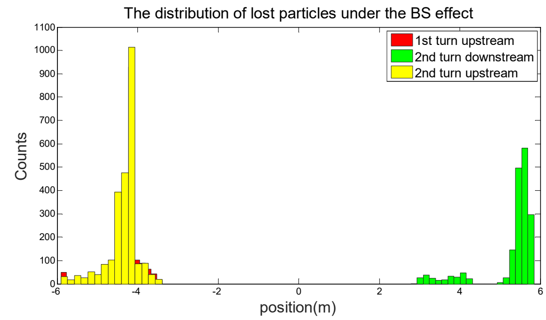

Figure 5: The distribution of lost particles positions due to beamstrahlung for the first two turns tracking.

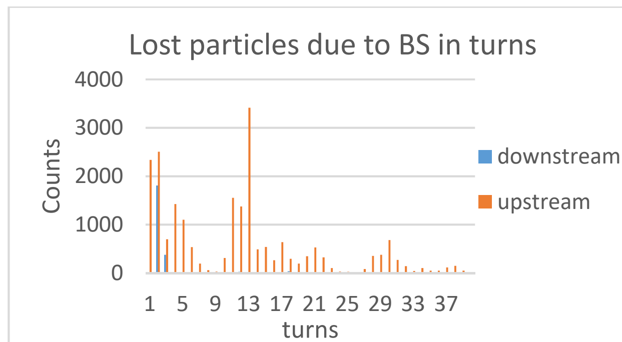

Figure 6: The statistic of lost particles in multi-turn tracking due to beamstrahlung.

COLLIMATOR DESIGN

The collimator can be inserted into the beam line to reduce the number of particles lost in the IR. The aperture of the collimator should be as small as possible to absorb lost particles as much as possible, however, the beam core shouldn't be affected by the collimator. Thus there should be some limitations and optimizations on the design of the collimator.

Collimators design in the ARC section are chosen, and several requirements should be satisfied:

1) Aperture of collimator should be smaller than beam stay clear region: BSC_x=± (18 σ_x+3mm), BSC_y=± (22 σ_y+3mm)
2) Impedance requirement: slope angle of collimator < 0.1 rad
3) To shield big energy spread particles, phase between pair collimators: π/2+n*π
4) Collimator design should be in large dispersion region to shield big energy spread particles:

$$\sigma = \sqrt{\varepsilon\beta + (D_x\sigma_e)^2}$$

Four collimators are used in this design, only for horizontal plane (APTX1, APTX2, APTX3 and APTX4). Two of them (APTX1 and APTX2) are located in the upstream of the IP, and the others (APTX3 and APTX4) are located in the downstream of the IP. The distance to IP

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range from 1800 meters to 2300 meters. Table 1 shows the four collimators design parameters.

Table 1: Collimators Design Parameters

	APTX1	APTX2	APTX3	APTX4
Position	D1I.1897	D1I.1894	D1O.10	D1O.14
Distance to IP (m)	2139.06	2207.63	1832.52	1901.09
β_x (m)	113.83	113.83	113.83	113.83
D_x (m)	0.24	0.24	0.24	0.24
Phase	356.87	356.62	6.65	6.90
BSC/2 (m)	0.00968	0.00968	0.00968	0.00968
Range of half width allowed (mm)	2.2~9.68	2.2~9.68	2.2~9.68	2.2~9.68

The number of particles lost in IR can be significantly suppressed when the aperture of the collimator are reduced. As shown in Fig. 7, vertical collimators are not needed.

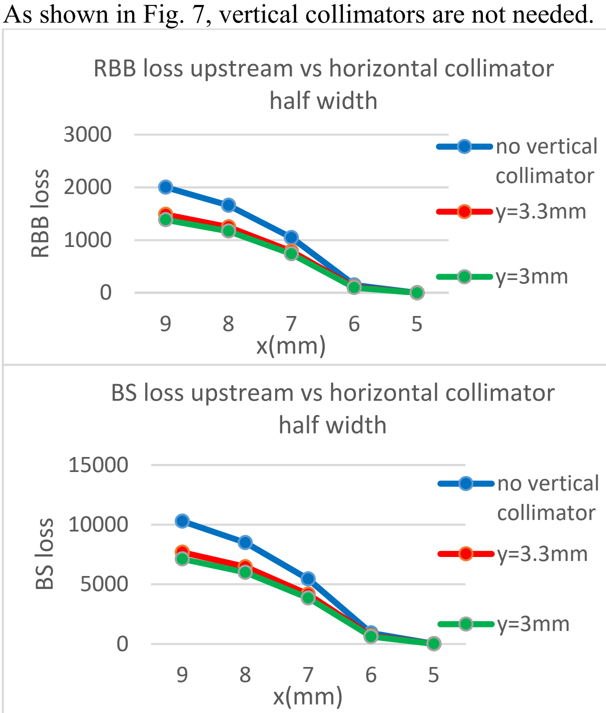

Figure 7: Scan result of RBB and BS loss as the function of the half width of horizontal collimators.

The half width of the collimators are set as 5mm (~13σ_x) in horizontal plane. The collimators will not have effect on the beam quantum lifetime.

Compared with the results shown in Fig. 3 and Fig. 6, the lost particles upstream of the IP have been reduced to zero with the system of collimators. Although the beam loss in the downstream of the IP is still pretty large in the first turn tracking, the radiation damage and the detector background are not as serious as the loss rate for the relative small flying angle to the ideal orbit (Fig. 8).

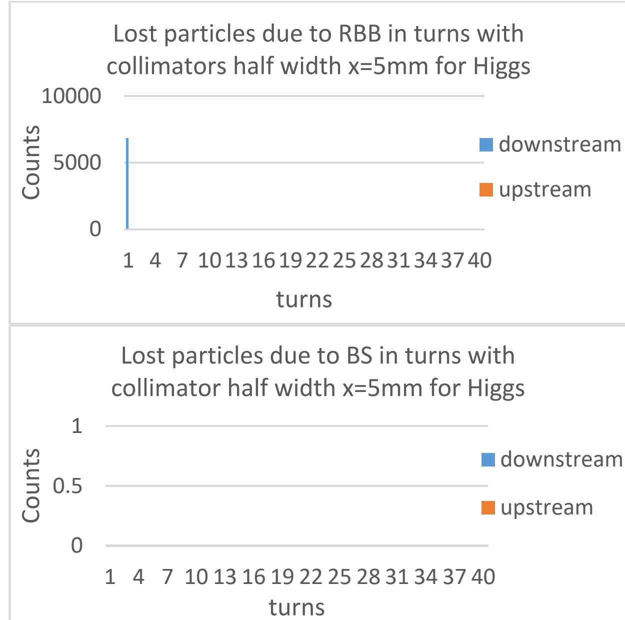

Figure 8: Lost particles statistic due to RBB and BS in multi-turn tracking with collimators half width x=5mm for Higgs factory.

CONCLUSION

The most important beam induced background – radiative Bhabha scattering and beamstrahlung have been evaluated for CEPC double ring scheme. Collimators are designed in the upstream around 2000 meters far from IP, to avoid other backgrounds generation. Beam loss particles have disappeared in the upstream of IP, and the event rate with collimators is acceptable for the CEPC detector.

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