BEAM-GAS AND BEAM-THERMAL PHOTON SCATTERING IN CEPC*

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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. Beam-Gas scattering (BG) and Beam-Thermal photon scattering (BTH), although not so serious as Radiative Bhabha scattering (RBB) and Beamstrahlung (BS), are also important components of the beam induced backgrounds at CEPC due to the beam lifetime. In this paper, we evaluated the beam-gas and beam-thermal photon scattering in simulation and designed 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 ~ 10^{34} cm^{-2} s^{-1}) is becoming more popular in the accelerator world [1]. The Circular Electron Positron Collider (CEPC) [2, 3] project in China is one of them.

Even if ultra-high vacuum pressure is usually required in beam pipes of particle accelerators, there are still a few gas molecules. Particles in the beam will be scattered by these gas molecules. And also accelerator components such as beam pipe etc., will emit a large number of thermal photons with different energies and directions due to thermal radiation. Scattering of thermal photons on electrons is known as Compton Effect. Beam particles will lose part of energy from the two effects of beam-gas and beam-thermal photon scattering. The resulting off-momentum particles constitute a potential source of background in the detectors.

The detector background might be too high to reconstruct the physical events if the lost particles are not well shielded. More serious situation 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, beam lifetime due to BG and BTH are firstly calculated, and the relevant events are generated by some specific Monte Carlo generators; the primary particles will be tracked inside the accelerator until they encounter the beam pipe; collimators are designed to shield the beam loss, and results are compared.

BEAM LIFETIME

After optimizing the lattice, and considering the beam-beam effect and errors, the energy acceptance is about 1.5%. If the energy loss of the beam particles are larger than the energy acceptance, these particles will be lost from the beam and might hit on the vacuum chamber. If this happens near the IR, detectors may be damaged by directly hitting or once-scattering of lost particles. Thus beam loss background should be analysed and prevented.

Beam lifetime due to beam-gas scattering (including elastic and inelastic scattering) can be calculated by (1) [4]:

$$\frac{1}{\tau} = \sigma \rho_{gas} c = \sigma c \frac{P}{k_B T} \tag{1}$$

And σ is the calculated scattering cross section, P is the vacuum pressure, k_B is Boltzmann constant, $k_B = 1.38064852e\text{-}23 J/K^{-1}$, T is temperature.

In CEPC, beam lifetime due to beam-gas elastic scattering (Coulomb scattering) is larger than 400 hours and can be ignored. Beam lifetime due to beam-gas inelastic scattering (bremsstrahlung) vs energy acceptance is shown in Figure 1:
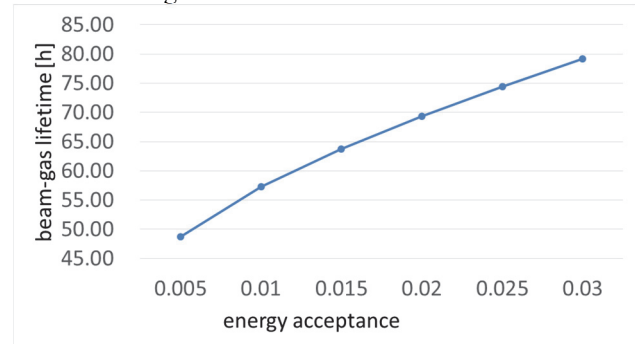

Figure 1: Beam lifetime due to beam-gas inelastic scattering (bremsstrahlung) vs energy acceptance.

It is assumed that the residual gas is CO in CEPC, and vacuum pressure is considered as 10^{-7} Pa. Beam lifetime due to beam-gas inelastic scattering (bremsstrahlung) is 63.8 hours.

Beam lifetime due to beam-thermal photon scattering can be calculated below in (2) [5, 6, 7]:

$$\frac{1}{\tau} = \rho_\gamma c \sigma_c f \tag{2}$$

With room temperature 27^{0}C (300K), ρ_γ is about $5.596e+14$ m^{-3}. c is speed of light. σ_c is the cross section, f is the ratio that in the number of scattering events which energy spread is larger than energy acceptance.

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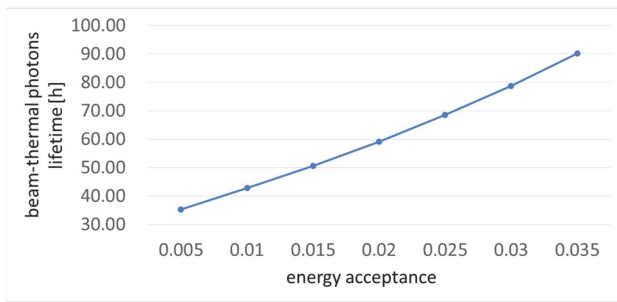MC1: Circular and Linear Colliders

T19 Collimation

Figure 2: Beam lifetime due to beam-thermal scattering vs energy acceptance.

For CEPC, beam-thermal photon scattering is 50.7 hours. Both beam-gas inelastic scattering and beam-thermal photon scattering should be taken into account for beam loss background.

BEAM GAS INELASTIC SCATTERING (BREMSSTRAHLUNG)

Beam particles are lost by inelastic scattering of residual gas molecules in the vacuum chamber of the machine, which can also be called bremsstrahlung. During this process, the particle emits a photon and loses energy. If the energy loss is large enough beyond the energy acceptance, particles are lost from the beam and can cause backgrounds to the detector.

To evaluate the level of beam lost particles, the scattering process will firstly be simulated by specific generator. Beam-gas inelastic scattering events are generated by Py_BG2 [8]. Figure 3 shows the energy spread distribution of 200000 events.
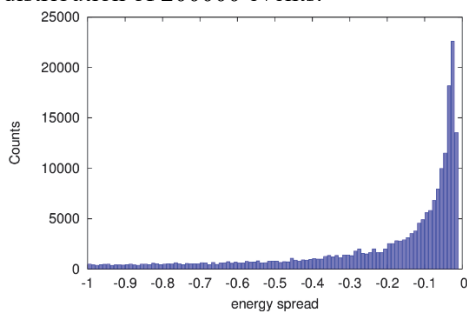

Figure 3: BG events in CEPC interaction region (IR).

Beam-gas inelastic scattering can happen at any position around the machine, but for Machine Detector Interface (MDI), background caused by beam-gas bremsstrahlung in the last 200m upstream of the IP can be serious. We have sliced up the 200m upstream region of the IP, and calculate the events number based on the beam lifetime. The events are generated from a Monte-Carlo generator and are placed at the entrance of the slice region. Due to the lost position of these particles are not clear when the scattering are occurred, these scattered particles must be tracked by accelerator tracking tools such as SAD [9] 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. The detector size in longitudinal is ±4.6m around the interaction point (IP) in the present design.

Figure 4 shows the lost particles statistics after tracking in ±6m around IP. Position at zero is the IP, while minus is the upstream of the beam and plus is the downstream.
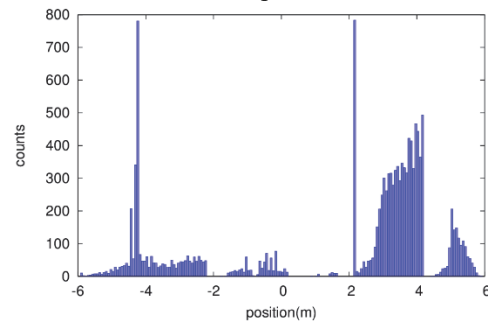

Figure 4: The distribution of lost particles positions due to Beam-Gas bremsstrahlung.

BEAM THERMAL PHOTON SCATTERING

Beam particles will also lose energy during scattering process of thermal photons on electrons. The resulting off-momentum particles is another potential source of background in the detectors. Beam-thermal photon scattering events are generated by Py_BTH [8]. Figure 5 shows the energy spread distribution of BTH events.
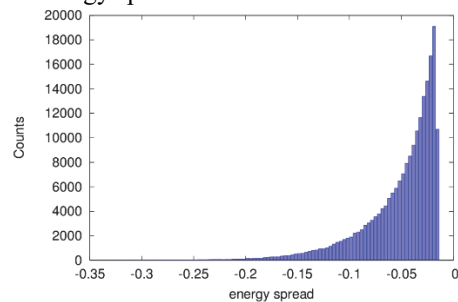

Figure 5: BTH events in CEPC interaction region (IR).

The simulation method is the same as with beam-gas bremsstrahlung. The distribution of lost particle positions after tracking is shown in figure 6.
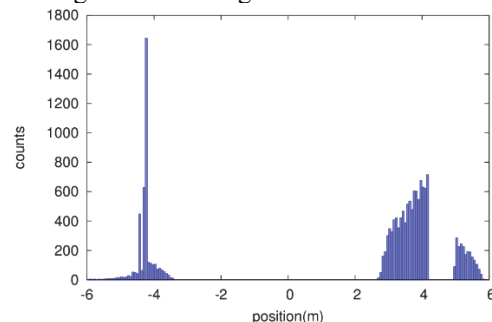

Figure 6: The distribution of lost particle positions due to Beam-Thermal photon scattering (minus position is the upstream of the beam and plus position is the downstream).

BEAM LOSS SHIELDING

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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:

- Aperture of collimator should be smaller than beam stay clear region: BSC_x=± (18 σ_x+3mm), BSC_y=± (22 σ_y+3mm)
- Impedance requirement: slope angle of collimator < 0.1 rad
- To shield large energy dispersive particles, phase between pair collimators: $\pi/2+n*\pi$
- 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 range from 1800 meters to 2300 meters.

With the collimators, the lost particles statistics due to beam-gas bremsstrahlung and beam-thermal photon scattering are kept at a low level as shown in Figure 7 and 8.
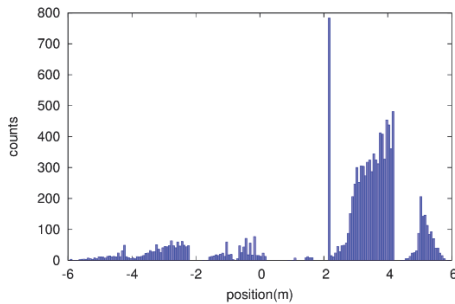

Figure 7: Lost particles statistics due to Beam-Gas bremsstrahlung with collimator half width settings of x = 5 mm for Higgs.
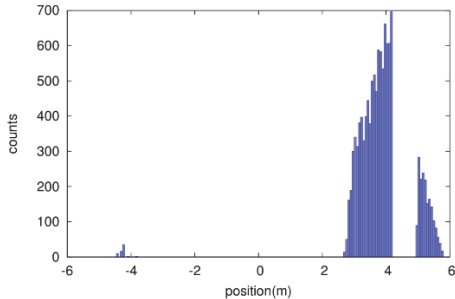

Figure 8: Lost particles statistics due to Beam-Thermal photon scattering with collimator half width settings of x = 5 mm for Higgs.

BEAM-GAS AND BEAM-THERMAL PHOTON SCATTERING IN Z FACTORY

In the above, the results are all for the CEPC double ring design of the Higgs factory. For the 45.5GeV Z factory, according to the off-momentum dynamic aperture after optimizing the CEPC lattice, and considering the beam-effect and errors, the energy acceptance is about 1.0%. Although the Z lattice is the same as the one in Higgs, the emittance is about 7 times lower. Thus the beam stay clear region will be small. The collimator design widths will be accordingly smaller than in the Higgs case. After optimization the collimators with half widths of x = 2.5 mm (~17σ_x) can be accepted.

In 45.5GeV Z factory, the Beam-Gas bremsstrahlung and Beam-Thermal photon scattering are still two important processes that will affect the beam lifetime at the level of ~ 57.26 and 70.17 hours respectively. The beam loss results with and without collimators are shown below in Figure 9 and 10:
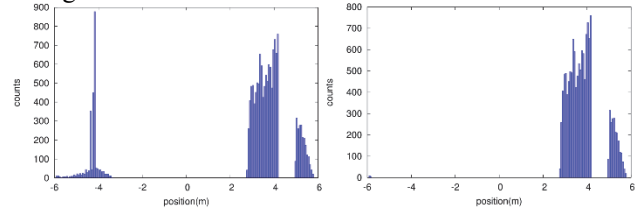

Figure 9: Lost particle statistics due to Beam-Gas bremsstrahlung without (left) and with (right) collimator half width settings of x = 2.5 mm for Z.
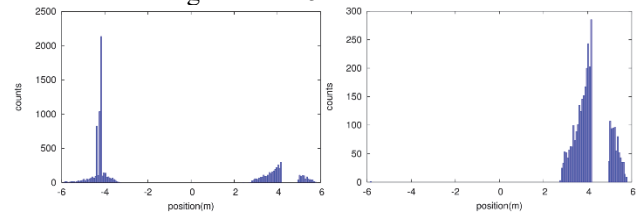

Figure 10: Lost particles statistic due to Beam-Thermal photon scattering without (left) and with (right) collimators half width x = 2.5 mm for Z.

As shown in Figure 9 and 10, with collimator half width settings of x = 2.5 mm, the beam loss caused by beam-gas bremsstrahlung and beam-thermal photon scattering has almost been eliminated upstream of the IP. Although the beam loss in the downstream part of the IP is still fairly large in the first turn, the radiation damage and the detector background are not as serious since the direction of the background particles is away from the detector.

CONCLUSION

The beam induced background – Beam-Gas scattering (bremsstrahlung) and Beam-Thermal photon scattering 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 has almost disappeared in the upstream of IP, and the event rate with collimators is acceptable for the CEPC detector.

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