

DESIGN OF INTERACTION REGION AND MDI AT CEPC*

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Abstract

The CEPC is a proposed circular electron positron collider to study the Higgs boson more accurately. The interaction region and the machine detector interface must be well designed to make sure the machine and the detector can work well after they are integrated together. Important factors that will affect the design of the CEPC interaction region are reviewed, such as the beam induced background, the interference of the magnetic field between the machine and the detector, etc. Several rules are summarized to steer the design of the interaction region. The progress on the machine detector interface of CEPC are presented.

INTRODUCTION

The CEPC [1] is a proposed circular electron positron collider to study the Higgs boson more accurately. It will be operated at the center of mass energy of 240 GeV with an instantaneous luminosity of $2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. One of the most important advantages of the e^+e^- collider is that the produced Higgs events will be much cleaner than those produced at the proton collider, e.g. the LHC. However, if the interaction region (IR) isn't designed well, the potential of the e^+e^- collider will not be fully exploited. For instance, the luminosity might be highly suppressed by the detector solenoid field if the beam coupling is not well cancelled and the Higgs events might be "heavily polluted" by the beam induced backgrounds if the shielding of the IR is not well designed. Thus, the interface between the machine and the detector must be carefully designed to achieve the required luminosity and background level.

Two kinds of problems must be well understood to find reasonable solutions of IR design. Firstly, the mutual influence between the machine and the detector must be well studied. It includes the interference of magnetic field between detector solenoid and machine magnets, the sources of beam induced backgrounds and so on. Secondly, the interface between the machine and the detector, such as the mechanical supporting and the procedure to assemble the interaction region, must be well designed. In this paper, we present the recent progress of the IR design and machine detector interface (MDI) study of CEPC. The dominant sources of beam induced background have been studied and some preliminary results are obtained. A compensating solenoid and anti-solenoid will be used to suppress the influence on the beam status from the detector solenoid. A global design

of the interaction region is undergoing to balance the conflict of performance between the machine and the detector.

MAGNETS AND LAYOUT OF THE INTERACTION REGION

The luminosity is one of the most important parameters of CEPC. The accelerator design are trying to increase the luminosity as much as possible, however, the detector solenoid might decrease the luminosity. The luminosity is given by:

$$L = \frac{N_e^2 n_b f_0}{4\pi \sigma_x^* \sigma_y^*} FH \quad (1)$$

Here, N_e is the bunch population, n_b is the number of bunches, f_0 is the revolution frequency, σ_x^* and σ_y^* are the transverse size of bunches at the interaction point. F is the geometric luminosity reduction factor due to the crossing angle at the interaction point (IP). H is the hourglass factor giving the luminosity reduction due to the change of β^* along the bunch. To improve the luminosity of CEPC, the bunch size should be as small as possible, which means the final focusing magnets should be as close to the IP as possible. At current design, the distance between IP and the final quadrupole magnet L^* is set as 1.5 m. As a result, the final focusing magnets QD0 and QF1 will be inside the field of the detector solenoid. At CEPC, the bunch shape is set to be flat with large horizontal bunch size and very small vertical bunch size, which is helpful to reduced some kinds of beam induced backgrounds such as beamstrahlung meanwhile keep the multiply of σ_x and σ_y to be small. In this case, the detector solenoid will cause the coupling between the horizontal and vertical betatron motion and increase the bunch size in the vertical direction, which will further decrease the luminosity. To achieve the required luminosity, compensating solenoids are designed to cancel the beam coupling before the beam enter quadrupole magnets and anti-solenoids are designed around quadrupole magnets to prevent the beam coupling inside quadrupole magnets. Figure 1 shows the preliminary layout of the interaction region.

BEAM INDUCED BACKGROUNDS

The most important influence on the detector from the machine is the beam induced backgrounds. The major backgrounds at CEPC are the synchrotron radiation, the beam lost particles and the beamstrahlung.

Synchrotron Radiation

Because the beam energy of CEPC is very high and the number of beam particles in one bunch is very large, the synchrotron radiation (SR) emitted from the beam in the dipole and quadrupole magnets will be the most serious

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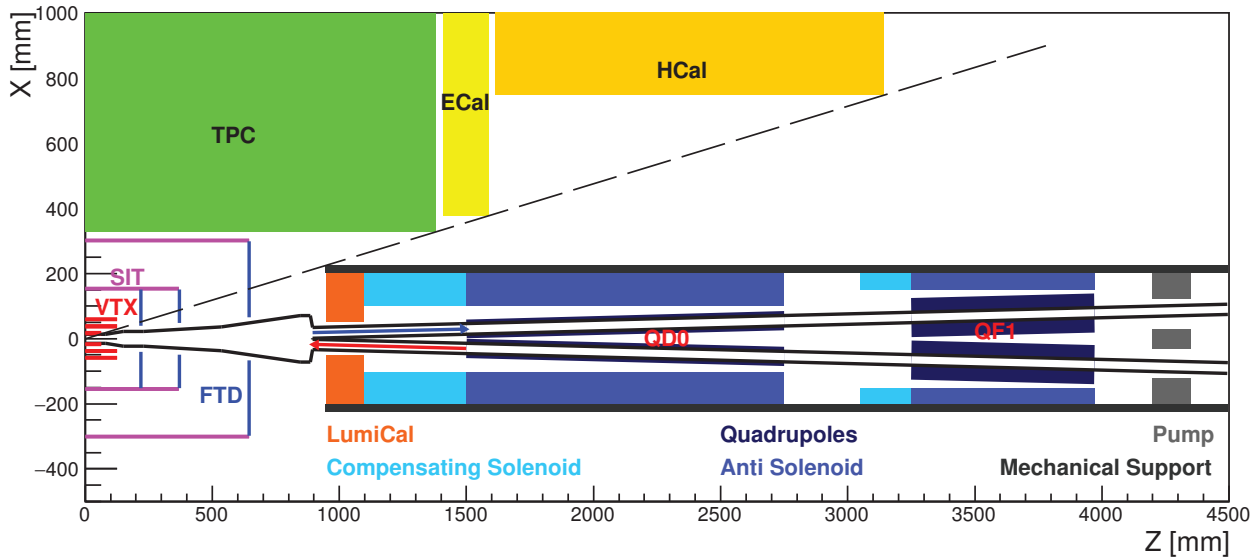


Figure 1: The preliminary layout of the interaction region. The L^* is set as 1.5 m at CEPC. Compensating solenoids are inserted before focusing quadrupole magnets to cancel the beam coupling. Ant-solenoids are around the quadrupole magnets to shield the field of the detector solenoid. There is a virtual boundary between the machine and the detector to suppress their mutual interference.

beam induced background at CEPC. The number and the energy spectrum of the photons that might enter the detector must be well evaluated to check whether the background level is acceptable to the experiments. The synchrotron radiation in the dipole magnets can be easily estimated with analytical formulas of classical electrodynamics. However, it's very difficult to estimate the synchrotron radiation in the quadrupole magnets because the field of the quadrupole magnets are non-uniform and the beam status will affect the radiation power significantly.

To study the synchrotron radiation from the dipole and quadrupole magnets uniformly, a Monte Carlo simulation program is developed based on Geant4 and BDSIM [2] to generate and track photons. In the simulation, the beam particles are generated with specific distributions in the phase space and are tracked along the relevant beam elements in which the SR photons will be emitted. For the synchrotron radiation in the quadrupole magnets, the tails of the beam density distributions should be pay more attention because the tail particles will produce more photons.

Preliminary results show that the SR rate is much higher than that can be tolerated by the detector. To cope with the synchrotron radiation, two kinds of treatments are used. One is to insert some collimator in the IR to absorb the SR radiation before they enter the detector region. Figure 2 shows the effects of preliminary designed collimator. The SR rate can be significantly suppressed by the collimator. The other is to modify the lattice design to reduce the radiation power of the synchrotron radiation in the IR. Further studies of these two methods are undergoing.

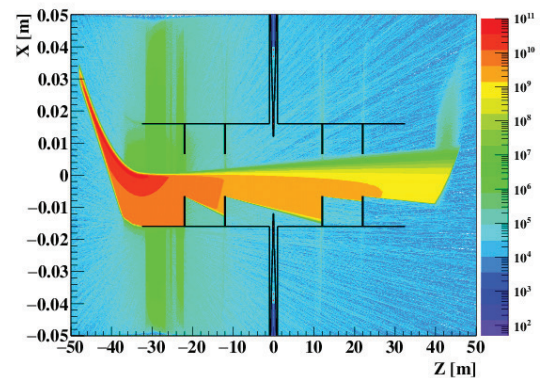


Figure 2: The preliminary design of collimator for the SR. The horizontal bold lines are beam pipe. The vertical line at $Z = 0$ m is the interaction point. Other vertical lines away from IP are collimator. The color represents the spacial distribution of number of photons from the last dipole magnet. The interactions between photon and materials have been considered in this Figure. The number of photons are suppressed by the collimator significantly.

Beam Lost Particles

The beam particles might lose a large fraction of energy through some scattering processes such as the radiative Bhabha, the beam gas scattering and so on. The energy acceptance of CEPC is designed to be 2%. If the relative energy loss of the beam particles are larger than 2%, these particles will be lost from the beam and some of these particles might hit the detector. In order to evaluate the beam lost particles, the energy loss of the beam particles in different

scattering processes are firstly simulated with proper Monte Carlo programs. For instance, the radiative Bhabha events are simulated with BBBREM [3]. Then, the particles with energy loss larger than 2% are tracked with an accelerator simulation program such as SAD [4]. The lost position and the four momentum of the lost particles will be record as the input of the detector simulation. Figure 3 shows the lost position of radiative Bhabha events in the interaction region of CEPC without any collimator. Most particles will loss at the position of final focusing magnets. The energy of these particles are usually very large and lots of secondary particles will be produced. Thus the hit density in the detector will be very high. In order to suppress the lost rate at IR, a set of collimator will be inserted into the main ring to stop the possible lost particles before they enter the IR.

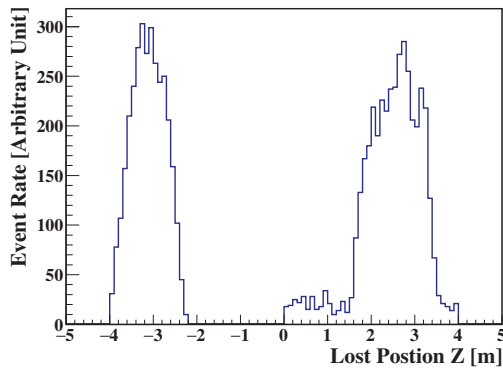


Figure 3: The lost position distribution of radiative Bhabha events at IR without collimator.

Beamstrahlung

To achieve the desired high luminosity, the electron and positron beams will be focused to very small bunch sizes at the IP. Trajectories of the charged particles in one bunch are bent by the induced electromagnetic field of the other crossing bunch of opposite charge. During this process, one kind of synchrotron radiation, called “beamstrahlung”, will be emitted. The beamstrahlung is usually characterised by the beamstrahlung parameter Υ :

$$\Upsilon = \frac{2}{3} \frac{h\omega_c}{E} \quad (2)$$

where $\omega_c = \frac{3}{2}\gamma^3 c/\rho$ denotes the critical energy of synchrotron radiation, ρ the bending radius of the particle trajectory and E the beam particle energy before radiation. The higher the Υ , the more beamstrahlung photons with higher energies will be emitted. Assuming Gaussian charge distribution for the beams, the average Υ [5] can be estimated as:

$$\Upsilon_{av} \approx \frac{5}{6} \frac{Nr_e^2\gamma}{\alpha(\sigma_x + \sigma_y)\sigma_z} \quad (3)$$

where r_e is the classical electron radius, γ the Lorentz factor of the beam particles, α the fine structure constant and σ_z

the bunch length. The value of Υ at CEPC is just about 5×10^{-4} . As a comparison, the Υ at ILC when it's operating at 250 GeV will be about 0.02. Thus, the beamstrahlung effect at CEPC is very small.

The photons emitted by beamstrahlung are usually very forward and will leave the IR along the beam pipe, thus these photons are usually harmless to the detector. However, a fraction of energetic beamstrahlung photons might further produce electron-positron pairs or even hadronic background by proper interactions. These kinds of backgrounds have evaluated with Guinea-Pig++ [6] and detector simulation for CEPC. Figure 4 shows the hit density at the vertex detector caused by the pair and hadronic backgrounds. The results shows that the event rate is acceptable for the CEPC detector.

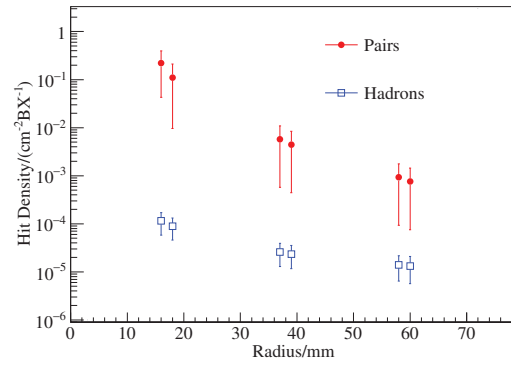


Figure 4: Hit density of pairs and hadronic backgrounds at 6 layers of the vertex detector with radii 16 mm, 18 mm, 37 mm, 39 mm, 58 mm and 60 mm. The hit rate is acceptable for the CEPC detector.

PROGRESS ON THE MACHINE DETECTOR INTERFACE

Besides the mutual influences between the machine and the detector, the mechanical interface between the machine and the detector are also very important. For CEPC, the heavy final focusing quadrupole magnets are very close to the IP. These magnets can't be supported by the detector because the detector will be opened regularly for maintenance. Thus, as shown in Figure 1, the mechanical supporting structure will be designed along the boundary in the accelerator side and the supporting point will be about 6 m (about half length of the detector) away from the IP along the central axis of the detector. It implies that the volume of the supporting structure might be very large and might conflict with the detector in space. To cope with the confliction in space, the final focus elements should be minimized as much as possible. Meanwhile, a global optimization considering the performances of both the machine and the detector is undergoing.

SUMMARY

The MDI problem is the key to make sure the machine and the detector are compatible with each other. The mutual

influence between the machine and the detector must be well understood to design the interaction region reasonable. Preliminary studies on the beam induced background and the magnet design have been done and some results are obtained. The global design of the interaction region that consider both the machine and the detector effects are being under going.

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