DETECTOR BEAM BACKGROUND SIMULATIONS FOR CEPC

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Abstract

Detector backgrounds of different sources expected at the Circular Electron Positron Collider are reviewed. Their potential impacts on the interaction region design and detector performance are discussed. The backgrounds originating from beam-beam interactions are evaluated with Monte Carlo simulation and preliminary results are presented.

INTRODUCTION

The Circular Electron Positron Collider (CEPC), proposed by the Chinese High Energy Physics community, is designed to operate at the center-of-mass energy of $\sqrt{s} = 240$ GeV, with an instantaneous luminosity of 2×10^{34} cm^{-2}s^{-1}. The CEPC e^+e^- collider will produce millions of clean Higgs events over a period of 10 years, allowing for detailed studies of the properties of the Higgs boson discovered at the LHC experiments [1,2].

To fully exploit the physics potential of machine and to optimise the detector performance, it is important to understand the detector backgrounds at the CEPC, which is among the most critical issues for the project. Different sources of backgrounds can give rise to either primary particles that enter the detector directly or generate secondary debris that ultimately hit the detector. It is mandatory to study thoroughly those backgrounds and their impacts on detector performance with Monte Carlo simulation. In this report, results of the main backgrounds from the beam-beam interactions, including beamstrahlung, electron positron pair production, hadronic backgrounds and radiative Bhabha events, are presented and their impacts on the CEPC detector are discussed. Other critical backgrounds, in particular synchrotron radiation, beam-gas interactions and beam loss, are important topics for future studies.

THE INTERACTION REGION LAYOUT

The interaction region (IR) of the CEPC consists of the beampipe, the surrounding silicon detectors, the luminosity calorimeter and the interface to the last final focus quadrupoles, namely QD0 and QD1. Its preliminary IR layout is depicted in Figure 1. The current design features a rather short focal length of $L^* = 1.5$ m, *i.e.* the distance between QD0 and the interaction point (IP). Such short L^* allows for the realisation of high luminosity without large chromaticity corrections, but at the same time it imposes certain constraints on the CEPC detector layout and can have significant impact on the choice of detector technologies. Therefore thorough understandings of the effects of the short L^* on both detector and machine performance will be a critical topic for future studies.

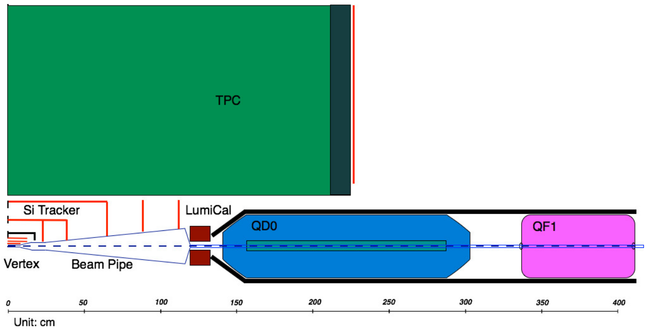

Figure 1: Preliminary layout of the interaction region for the CEPC.

BACKGROUNDS FROM THE BEAM-BEAM INTERACTIONS

At the IP of the e^+e^- collider, the two crossing bunches of opposite-charge attract each other, called "Pinch Effect", which is illustrated in Figure 2. The self-focusing effect during this process leads to higher luminosity for head-on collisions. However, the charged particles deflected by the strong forces will emit radiation called "beamstrahlung". The actual beam-beam effects can be estimated with Monte Carlo simulation, which shall take into account the dynamically changing bunch effects, reduced particle energies and their impacts on the fields. The GUINEA-PIG [3] program has been adopted to simulate the beam-beam interactions for the CEPC. The machine and beam parameters used as the input into the program are listed in Table 1.

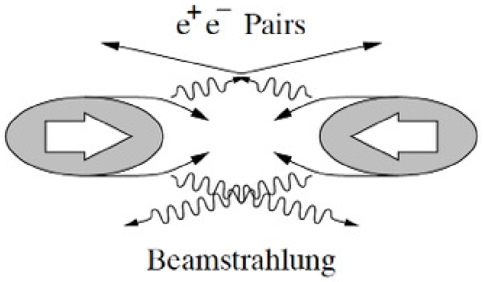

Figure 2: Illustration of the Pinch Effect between two crossing bunches of opposite-charge.

The main backgrounds from the beam-beam interactions are beamstrahlung, electron positron pair production,

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ISBN 978-3-95450-172-4

Table 1: Input CEPC Beam and Machine Parameters to the GUINEA-PIG Simulation Program

Machine Parameters	**Unit**	**Value**
$E_{\rm cm}$	GeV	240
Particles per bunch		3.7×10^{11}
Beam size σ_x/σ_y	μm	73.7/0.16
Beam size σ_z	μm	2260
Emittance $\varepsilon_x/\varepsilon_y$	mm·mrad	1595/4.8

hadronic background and radiative Bhabha events. Preliminary results from each of the sources are presented in the following.

Beamstrahlung

Due to the Pinch Effect, the trajectories of the particles in the bunches are bent and they emit beamstrahlung photons. The beamstrahlung photons can have potentially large impacts on the beam energy spread and the luminosity spectrum of the CEPC machine. However, as illustrated in Figure 3, the beamstrahlung photons are dominantly produced with very low transverse momentum and small polar angle along the beam axis. They are negligible background for the CEPC detector.

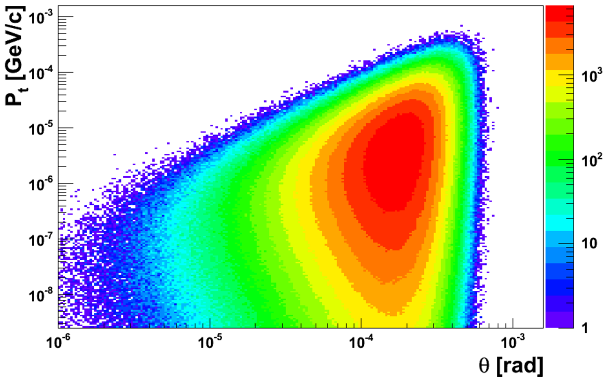

Figure 3: Transverse momentum distribution vs polar angle of the beamstrahlung photons for the CEPC.

Pair Production

The electron-positron pairs can be produced with either coherent or incoherent processes:

- **Coherent Production**: e^+e^- pairs produced via the interaction of virtual or real photons (e.g. beamstrahlung photons) with the coherent field of the oncoming bunch. The particles can be highly energetic but dominantly produced with small angle and confined in the beampipe.
- **Incoherent Production**: e^+e^- pairs produced via the interactions involving two real and/or virtual photons. Most of the particles are confined in the beampipe with the strong detector solenoid field. But a small fraction of the particles are with high transverse momenta and large polar angles and can enter the detector. Incoherent pair production is considered as one of the most important background sources for the CEPC detector.

Figure 4 shows the transverse momentum distribution vs. the polar angle of the incoherent e^+e^- pairs, after deflection through beam-beam interaction. It also shows the sharp kinematic edge (green band in the figure) developed by the pairs. Any detector component, including the detector beampipe, must be placed away from the particles in that region to avoid introducing particle shower. In addition, it is necessary to introduce mask to protect the CEPC detector from secondaries created by the pair-produced particles interaction with the quadrupole.

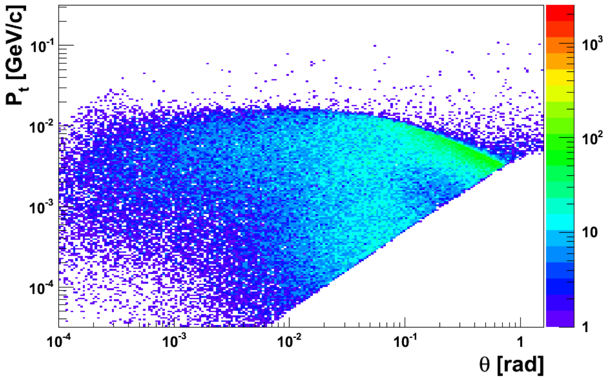

Figure 4: Transverse momentum distribution vs the polar angle for the particles from the incoherent e^+e^- pair production. Events are integrated over 50 bunch crossings.

Hadronic Background

The interaction of photons can also produces quark pairs (e.g. the $\gamma\gamma \to q\bar{q}$ process), forming hadronic background events. But fortunately the production rate of this type of events is orders of magnitude smaller than the dominant e^+e^- pair production. To evaluate the effects, the energetic photons produced from the beam-beam interactions using GUINEA-PIG are passed to PYTHIA [4] for generation of the hard interaction, followed by hadronisation. Preliminary results confirm that most of the hadronic background events are of low energy and small polar angle, which make them negligible for the CEPC detector. However, there is a very small fraction of events, in which jets can be produced with sufficiently large transverse momenta (called “mini-jets”). Their exact impacts on the CEPC detector, in particular the calorimeter, needs to be studied with detailed detector simulation.

Radiative Bhabha Events

Radiative Bhabha scattering ($e^+e^- \to e^+e^-\gamma$) events can be dominant background for $B-$factories (see the

SuperKEKB report in the same proceeding), but become less important for high energy electron positron colliders. Their effects have been studied with GUINEA-PIG, and cross-checked with BBBREM [5]. The preliminary result demonstrates that they are negligible background for the CEPC detector. Nevertheless radiative Bhabha scattering provides an important handle to determine precisely the machine luminosity. It has been planed to perform more detailed studies with the BHWIDE [6] program dedicated for large angle scattering, and the general-purpose generator WHIZARD [7].

RADIATION LEVELS

The radiation backgrounds can degrade the performance of the CEPC detector. Among the sub-detectors, the vertex detector that will be constructed with silicon pixel sensors and placed closest to the IP, will be most vulnerable to the radiation backgrounds. The radiation damage, characterised as Total Ionisation Dose (TID) and Non-Ionising Energy Loss (NIEL), has to be estimated reliably to guide the design of the silicon pixel sensors. The NIEL contribution from the particles originating from the beam-beam interactions is presented in 1MeV equivalent neutron fluence and shown in Figure 5.

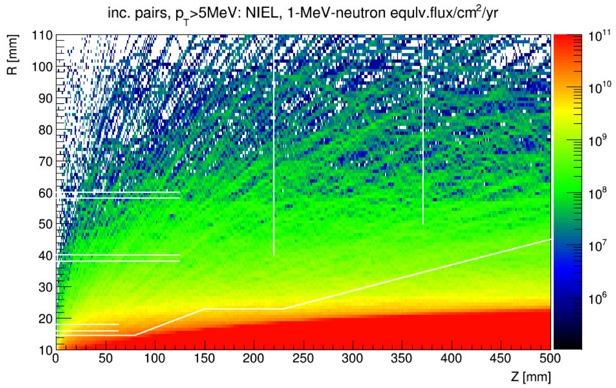

Figure 5: The NIEL distribution introduced by the particles originating from the beam-beam interactions. The white lines indicate the positions of the barrel layers of the vertex detector, the first two forward disks of the silicon tracker and the beampipe for the CEPC.

The first layer of the vertex detector of the CEPC detector will be positioned at $r = 1.6$ cm from the IP. The averaged hit density at this distance is estimated to be $0.2/\text{cm}^2/\text{BX}$. The corresponding annual values for NIEL and TID are estimated to be 10^{11} $\text{n}_{eq}/\text{cm}^2$ and 100 kRad, respectively. In both NIEL and TID calculations, a safety factor of 5 has been taken into account.

OPTIMISATION OF THE VERTEX DETECTOR LAYOUT

The low hit density presented in the first layer and benign radiation levels may make it possible to place the vertex detector layer closer to the IP. Shortening the distance from the first measurement to the IP can reduce the extrapolation uncertainty, hence enhance the performance of heavy-flavour tagging, which can improve precision measurement of the Higgs branching fractions. Therefore it becomes important to find out other limiting factors and make sure such improvements could be realised. From the detector background point of view, it must avoid direct hitting of the synchrotron radiation photons on any detector component. In addition, as it has been already pointed out, the beampipe must be places sufficiently far away from the kinematic edge ("Pair Edge") developed by the e^+e^- pair production. The current beampipe position and the "Pair-Edge" are shown in Figure 6, assuming a solenoid magnetic field of 3.5 Tesla for the CEPC detector. It shall be feasible to place the beampipe closer by ∼1 mm, and the first vertex detector layer accordingly. This change needs to be validated and justified with further studies and the impacts on final physics results need to evaluated with full detector simulation in future studies.

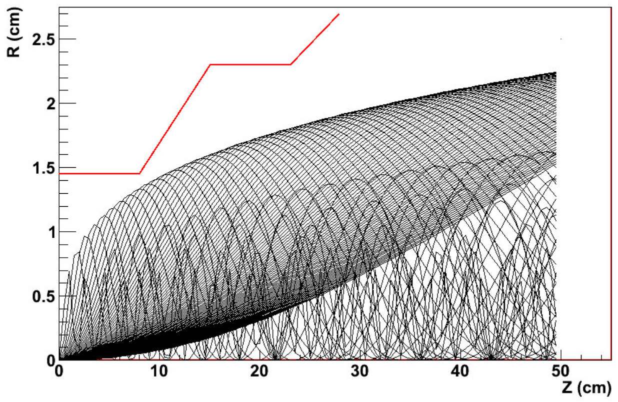

Figure 6: "Pair Edge" developed by the e^+e^- pair production within a solenoid magnetic field of 3.5 Tesla and projected to the R-Z plane. The read line indicates the current beampipe position.

SUMMARY

The proposed Circular Electron Positron Collider (CEPC) will offer great opportunities to perform precision measurement of the recently discovered Higgs boson. To fully exploit the physics potential and to optimise the detector performance, it is critical to understand thoroughly the detector backgrounds from different sources. Preliminary results on the detector backgrounds from the beam-beam interactions are obtained and their potential impacts on detector performance have been briefly discussed. It is important to refine those estimations and include more background sources in future studies.

ISBN 978-3-95450-172-4

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ISBN 978-3-95450-172-4