FCC-ee interaction region backgrounds

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The FCC-ee machine induced backgrounds on the two proposed detectors (CLD and IDEA) have been studied in detail. Synchrotron Radiation (SR) considerations dictate the Interaction Region (IR) optimization. An asymmetric IR design limits the final bend critical energy to 100 keV. Masks placed before the final focus quadrupole protect the detector from direct hits, and a shield placed around the beam pipe from secondary particles, keeping the effect of SR on the detector to negligible levels. The most important source of background is expected to be the Incoherent Pair Creation (IPC). Its effect has been studied in full simulation and reconstruction, and it was shown that it will not pose a problem for the detector, even if conservative estimations for the time resolution of the detector sensors are assumed. Moreover, the $\gamma\gamma \rightarrow$ hadrons, radiative Bhabhas and beam-gas interaction induced backgrounds were studied. All were found to have small to negligible effect on the detector. Overall, the FCC–ee interaction region backgrounds are not expected to compromise the detector performance.

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1. Introduction

The FCC-ee is a proposed electron–positron collider to be built in CERN. It is foreseen to operate at four different centers-of-mass, at 91.2 GeV, 160 GeV, 240 GeV and 365 GeV, and it will reach a peak luminosity of 2.3×10^{36} cm^{-2}s^{-1} at $E_{\mathrm{cm}} = 91.2$ GeV. FCC-ee should share the same footprint with its hadronic counterpart, FCChh. Their Conceptual Design Reports (CDR)[1] were published in January 2019. Two Interaction Points (IP) are foreseen, where electrons and positrons will collide under a rather large crossing angle of 30 mrad. The crab waist scheme will be employed.[2] A detailed description of the Interaction Region (IR) can be found elsewhere.[3] The main sources of background expected in FCC-ee are the Synchrotron Radiation (SR), beamstrahlung induced backgrounds, radiative Bhabhas and background due to beam–gas interactions. SR is the main driver of the design of IR.

2. Synchrotron Radiation Background

The SR that may affect the detector comes from the last bending magnet and the final focus quadrupoles. The effect of SR can be partially suppressed by bending the beams mostly after the IP. This way, the critical energy of the last bend is kept ≤ 100 keV (at $E_{\mathrm{cm}} = 365$ GeV). Still $\sim 10^{12}$ photons per beam are expected to be produced at the last bend (at $E_{\mathrm{cm}} = 365$ GeV), therefore masks that will protect the detectors from direct hits from SR photons will be placed in the last 100 m from the IP. However, a fraction of the last bend ($\sim 10^7$ photons) and final focus

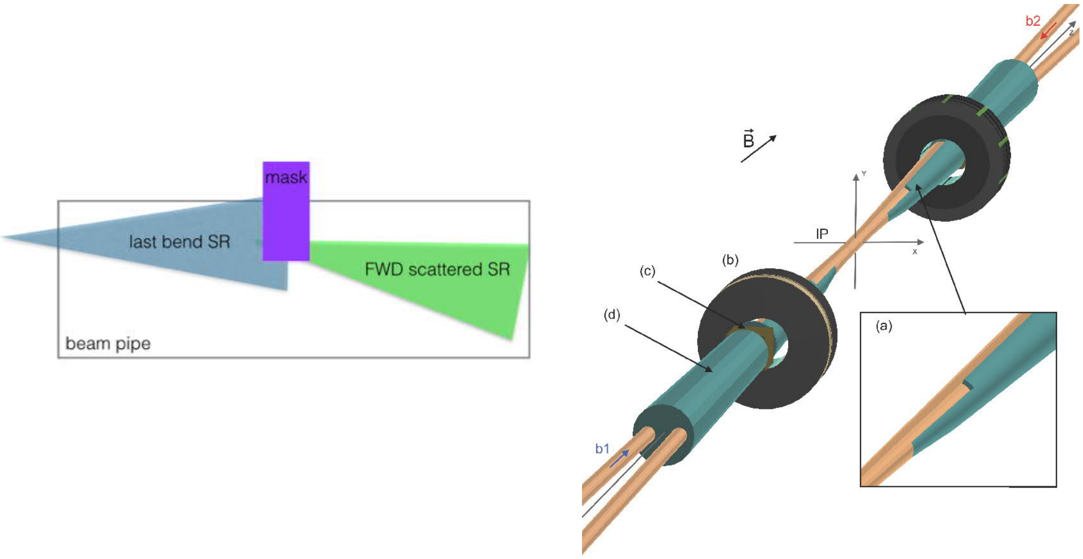

Fig. 1. (Color online) Left: Sketch of the SR mask. A fraction of the impinging photons (especially the ones close to the tip) will be scattered off towards the IP. Right: Sketch of the implementation of the interaction region in GEANT4. The tungsten shielding of the beam pipe appears in turquoise blue.

quadrupoles produced SR photons will scatter off the mask and potentially shower into the detector area. In order to limit the secondaries reaching the detector, a tungsten shield has been placed around the beam pipe (Fig. 1).

3. Beamstrahlung Induced Backgrounds

The beamstrahlung induced background is generated from the electromagnetic force that the two approaching bunches exert to each other. This beam–beam interaction leads to the production of hard bremsstrahlung photons. The produced photons might scatter with each other, or interact with the collective field of the opposite bunch. Then, an effect similar to pair creation can occur, that will lead to the production of incoherent or coherent electron–positron pairs respectively. The Coherent Pair Creation (CPC) is strongly focused on the forward direction, and is negligible at FCC. On the contrary, the Incoherent Pair Creation (IPC) is expected to be one of the main sources of background. Particles from IPC are also focused on the forward direction, however some of them feature enough P_T or polar angle to create hits in the detector (mainly the vertex detector (VXD)). An even larger contribution arises from IPC particles that are backscattered in the IR elements and coming back to the tracker. Results will be discussed in Sec. 4. The Guinea Pig (GP)[4] event generator has been used to generate these backgrounds at $\sqrt{s}$ of 91.2 and 365 GeV. Their kinematics are illustrated in Fig. 2.

The particles seen at $\theta \sim 15$ mrad correspond to those that are emitted at a very small angle, in the direction of the outgoing beams. The dense region at higher θ corresponds to e^- (e^+) particles that are emitted in the direction of the outgoing e^+ (e^-) beam and that are deflected towards larger polar angles, by the electromagnetic field of the bunch.

Apart of e^+e^- pairs, the photon scattering can give rise to hadrons. Fragmentation will occur, ending up potentially to jets in the detector. This is also a considered source of background in the detector. These interactions have been simulated with

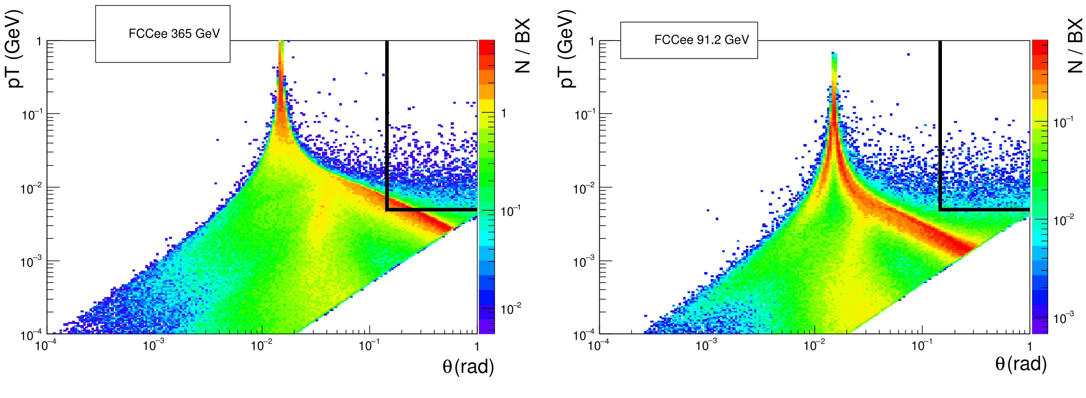

Fig. 2. pT versus polar angle of the generated e^+e^- particles. Only the particles within the top right corner, indicated with the black solid lines, will reach the innermost layer of the vertex detector in a 2T field.

Table 1. Number of $\gamma\gamma \to hadrons$ events per bunch crossing for $\gamma\gamma$ center-of-mass energies exceeding three different thresholds, $\sqrt{\hat{s}_{\text{min}}}$. Values given for FCC-ee operating at, respectively, the Z peak and the $t\bar{t}$ threshold.

$\sqrt{\hat{s}_{\text{min}}}$ [GeV]	Events Z	Events top
2	0.00063	0.0078
5	0.00029	0.0043
10	0.00015	0.0027

a combination of GP (determining the energy spectrum of the interacting photons) and Pythia6[5] (producing and fragmenting the partons). Table 1 summarizes the number of hadronic events obtained per bunch crossing, for $\sqrt{\hat{s}}$, the energy in the center-of-mass of the two photons, above given minimal values. Within the phase-space considered, this background appears to be very small.

4. Full Simulation Study of the Effect on the Detectors

The IR elements (beam pipe, tungsten SR shield, luminosity calorimeter (LumiCal), higher-order mode absorbers, solenoids) have been implemented in full simulation. The simulation framework used is DD4hep.[6] A realistic magnetic field map, combining the fields of the main detector solenoid (2T) and the compensating solenoid scheme[3] has been used. Both FCC-ee proposed detectors, CLD and IDEA,[1] share the same IR. In this section we will focus in the background effect on the vertex detector and the trackers.

4.1. *Synchrotron radiation*

The results discussed in this section concern the top working point ($\sqrt{s} = 365$ GeV). The photons emerging from the tip of the mask are the relevant sample for the full simulation studies. It was shown that proper shielding around the beam pipe can reduce the effect of the SR background on the FCC-ee detectors to almost negligible levels (Fig. 3). Overall, the shield reduces the number of hits per bunch crossing from 3.3×10^4 to ~ 400. Considering the follow assumptions for the calculation of the occupancy:

- Cluster multiplicity = 5 for pixels and = 2.5 for strips,
- Pixel pitch $25 \times 25\ \mu\text{m}^2$ for vertex detector, $1 \times 0.05\ \text{mm}^2$ for strips,
- Safety factor 3 (SF = 1 for IDEA's drift chamber (DCH))

then the maximum recorded occupancy is $\sim 10^{-4}$. With the term maximum we mean the occupancy obtained at the hottest area of the subdetector.

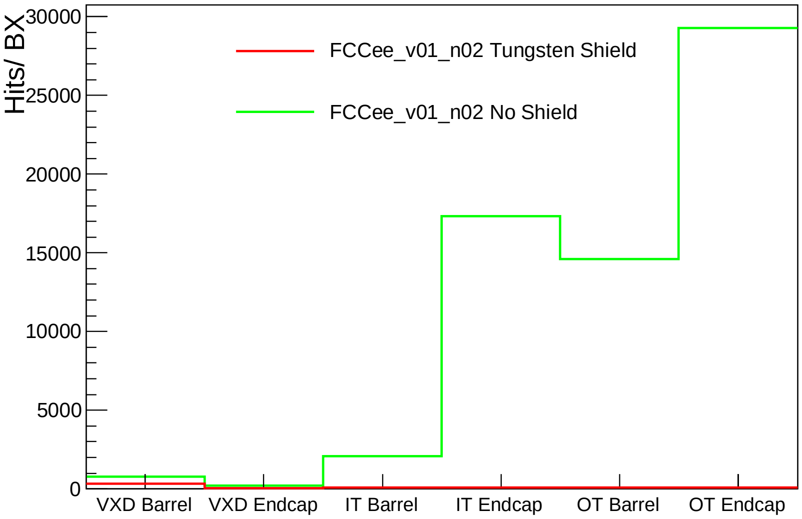

Fig. 3. (Color online) Comparison of hits per bunch crossing (BX) in each subdetector part with (red) and without tungsten shield (green).

Table 2. CLD subdetector's maximum occupancies.

$\sqrt{s}$ [GeV]	91.2	365
Vertex detector barrel	$\sim 10^{-5}$	$\sim 4.5 \times 10^{-4}$
Vertex detector endcap	$\sim 3.8 \times 10^{-5}$	$\sim 4 \times 10^{-4}$
Tracker endcap	$\sim 1.8 \times 10^{-5}$	$\sim 1.6 \times 10^{-4}$

4.2. *Beamstrahlung induced*

In this section, we summarize the obtained occupancy due to IPC in the various subdetectors. In Table 2 we summarize the maximum occupancies for the CLD vertex detector and tracker.

The occupancy per bunch crossing is rather low for the vertex detector and the silicon tracker, even at their hottest areas. However, at $\sqrt{s} = 91.2$ GeV where the bunch spacing is 20 ns, we will may be have to integrate over several bunch crossings. Assuming a time resolution for the vertex detector pixel sensors of 1 μs, a value that seems within reach at the timescale of FCC-ee, the occupancy stays $\leq 6 \times 10^{-4}$.

The occupancy obtained in IDEA's DCH due to IPC is 2.9% at $\sqrt{s} = 365$ GeV and 1.1% $\sqrt{s} = 91.2$ GeV. Based on experience from the MEG2[8] drift chamber, this occupancy is believed to be at a manageable level.

4.3. *Radiative Bhabhas*

Radiative Bhabhas will be lost from the beam downstream the IP. They might reach the next IP and therefore is a potential source of background. The Bhabhas are generated with GP and then tracked with SAD[7] along the ring. At $E_{\rm cm} = 91.2$ GeV

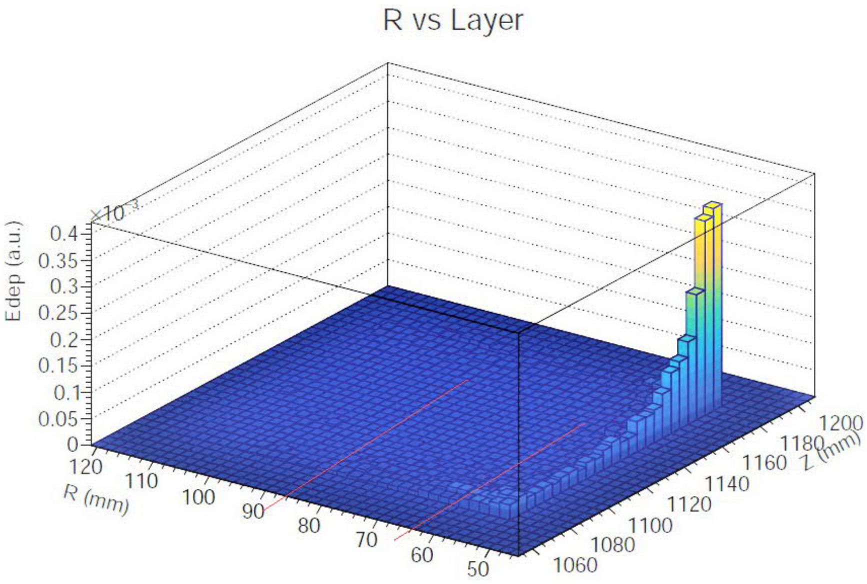

Fig. 4. (Color online) Energy deposits at LumiCal due to the IPC. The two red lines are roughly indicating the fiducial volume.

all Bhabhas are lost 70 m downstream the IP, while for $E_{\mathrm{cm}} = 365$ GeV the Bhabhas are lost all over the ring. A 20% of the particles is expected to reach the second IP, and potentially affect the detector. The spectrum of particles reaching the second IP has been fully simulated. Preliminary results show that this background is expected to be very small.

5. Background on the LumiCal

The IR backgrounds effect on LumiCal have also been studied in full simulation. The main focus is on $\sqrt{s} = 91.2$ GeV, where the requirements on the precision of the luminosity measurement are more strict ($\Delta L/L \sim 10^{-4}$). The SR is effectively suppressed by the beam pipe shielding to a negligible level. During LEP operation, the main source of background for the LumiCal was coming from false coincidences due to off momentum particles coming from beam-gas scattering. Full simulation studies of the effect for the FCC-ee shown a negligible effect, which is explained by the much higher vacuum quality. The loss rate inside a region of $\pm\,2.1$ m from the IP, assuming a vacuum of 10^{-9} mbar of N_2 at 300 K, is found to be ~ 2 MHz per beam. A first study of the effect on the LumiCal was performed, using a straight line extrapolation of the produced particles to the face of the opposite LumiCal. The rate of fake coincidences, before any angular or energy cuts, is estimated to be below 10^{-7} per bunch crossing, which is negligible compared to the expected Bhabha rate of 6.4×10^{-4} per bunch crossing. The main source of background at the LumiCal is also the IPC, where ~ 300 MeV of energy deposited per bunch crossing on each arm is expected. However, the energy deposits are mainly concentrated at inner radius at the rear of the device, mostly outside the fiducial volume (see Fig. 4).

6. Conclusions

We have performed full simulation studies of the various sources of background expected in the FCC-ee IR. The obtained occupancies are low, with the exception of the drift chamber. Track reconstruction studies in vertex detector and silicon tracker indicated that the pattern recognition performance is not compromised from the presence of backgrounds. Work on drift chamber tracking is currently ongoing. Concerning LumiCal, most of the energy is deposited outside the fiducial volume, thus a clever clustering algorithm should be able to cope with it. A study have been undertaken to prove this point. Overall, the results of the background studies indicate that the backgrounds are not expected to compromise the detector performance.

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