

# LUMINOSITY- AND BEAM- INDUCED BACKGROUNDS FOR THE FCC-ee INTERACTION REGION DESIGN

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## Abstract

A preliminary study on machine induced backgrounds has been performed for the proposed FCC-ee interaction region (IR) and proto-detector. Synchrotron radiation has the strongest impact on the present design of the IR and both radiation from dipoles and quadrupoles have been taken into account. The effect of luminosity backgrounds like  $\gamma\gamma \rightarrow$  hadrons and pair production have also been studied. The impact of background particles on the detector occupancy has also been studied in full simulation.

## 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 350 GeV, and it will reach a peak luminosity of  $207\text{-}90 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-2}$  in two interaction points, at  $E_{cm} = 91.2 \text{ GeV}$ . FCC-ee will provide a very clean environment, ideal for precision measurements. However, we still expect some machine and beam-beam induced backgrounds that may affect the detectors. In these proceedings, we will focus on the aforementioned backgrounds.

## FCC-EE DETECTOR INTERACTION REGION

The design of the FCC-ee machine-detector interface poses a great challenge. It is mainly driven by the luminosity requirements. Those requirements imply a very small vertical emittance ( $\beta^* \sim 1 \text{ pm}$  for  $E_{cm} = 91.2 \text{ GeV}$ ), which demands an  $L^* \sim 2.2\text{-metre}$ . That means that the final focus magnet elements are located inside the tracker's magnetic field ( $B=2 \text{ T}$ ), see Fig. 1, which necessitates their shielding. It is provided by a shielding solenoid around the final quadrupole. Due to the very high luminosity of the collider, in particular at  $E_{cm} = 91.2 \text{ GeV}$ , a crossing angle of  $2 \times 15 \text{ mrad}$  has been introduced together with the crab waist scheme [1]. The fact that the collision will take place with a crossing angle inside the detector's magnetic field, could lead to an emittance blow up during the 2-metre that the beam travels when it exits the quadrupole until it reaches the Interaction Point (IP). For that concern, a compensating solenoid providing a high magnetic field will be placed after the shielding one, so that the field integral seen by the beam will be zero. A full discussion of the FCC-ee interaction region magnets is given in [2].

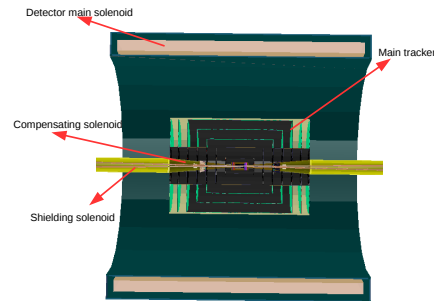


Figure 1: FCC-ee proto-detector layout and elements of the interaction region

In these proceedings, full simulation studies of a Geant4 [3] implementation of the FCC-ee proto-detector model FCCee\_o1\_v01 will be presented. The model consists of the FCC-ee interaction region elements, around of which, a modified CLIC detector<sup>1</sup> [4] has been placed. At the time these proceedings were written, the design of the FCC-ee interaction region was still evolving.

## SOURCES OF BACKGROUND AT FCC-EE

There are two main categories of background in the FCC-ee detector, the machine and the luminosity induced. The former is due to the operation of the accelerator and includes the Synchrotron Radiation (SR) and the beam gas interactions. The latter is arising from the interaction of the two very intense FCC beams close to the IP.

The SR that may affect the detector comes from the closest bending magnets and final focus quads. The produced photons might scatter in the IR and create hits on the detectors. It is expected to be the dominant source of background in the FCC-ee detector.

The luminosity 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

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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 below. 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.

### $e^+e^-$ PAIRS

The Guinea Pig (GP) [5] event generator has been used to generate the luminosity induced backgrounds at  $\sqrt{s}$  of 91.2 GeV and 350 GeV. The collider parameters given to GP have been taken from [6]. The  $P_T$  versus polar angle of the produced  $e^+e^-$  particles is illustrated in Fig. 2 for the 350 GeV option. Particles that are on the top right of the black line would cross the innermost VXD layer. This line should not touch the dense core of the distribution. The GP generated files were then simulated using ILCSoft [7]. Figure 3 shows the hit density in various layers of the VXD obtained for  $E_{cm} = 350$  GeV. Assuming a pixel pitch of  $20 \mu\text{m}$  and an average cluster size of 5, the expected occupancy in the innermost layer will reach  $\sim 10^{-5}$ . The bunch spacing being  $\sim 4 \mu\text{s}$  at that energy, given relatively fast sensors (readout time in order of  $\sim 1 \mu\text{s}$ , one would expect that the induced occupancy wouldn't pose problems to pattern recognition.

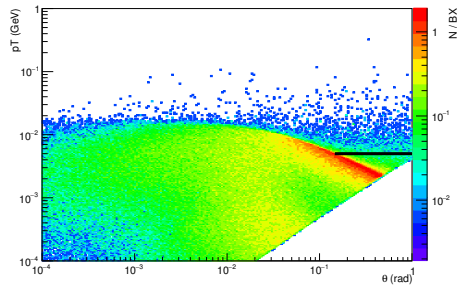


Figure 2:  $P_T$  versus polar angle at  $e^+e^-$  pairs center of mass at 350 GeV. One can see also the first VXD layer

Apart of the VXD innermost layer, the pairs are expected also to affect the forward tracking detectors for very shallow angles. Figure 4 shows the hit density in the first and second Inner Tracker Endcaps (ITE) disk, as well as in the last VXD Endcap disk. One can observe a relatively high hit density for small radii, especially in the VXD Endcaps. Locally the occupancy may reach  $\sim 10^{-4}$ . It decreases rapidly with the increase of the radius, and this maximal occupancy would be a factor of O(5) lower if the VXD disk coverage does not extend below 140 mrad from the beam line. Given fast and granular sensors, such values of occupancy will not create problems.

The highest expected occupancy for running at  $\sqrt{s}$  of 91.2 GeV is observed again at VXD Endcaps for very shallow angles, and can reach  $\sim 3 \times 10^{-6}$  per bunch crossing. This is a

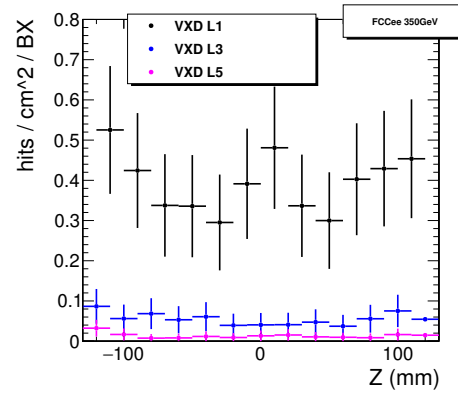


Figure 3: Number of hits per  $\text{cm}^2$  per bunch crossing in 3 layers of the VXD as a function of Z

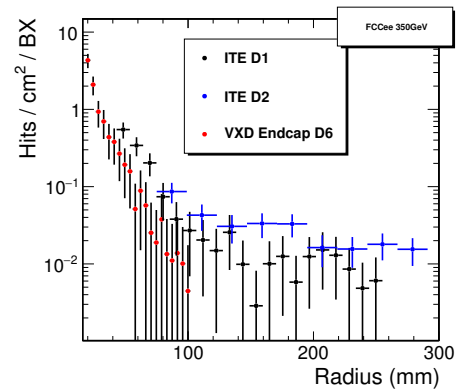


Figure 4: Number of hits per  $\text{cm}^2$  per bunch crossing on the ITE disks 1 and 2, and on the sixth VXD Endcap, as a function of radius

small value, however one should keep in mind that the bunch spacing will be 7.5 ns (or 2.5 ns), therefore the detectors will integrate over many bunch crossing. So fast sensors with a readout of  $\sim 1 \mu\text{s}$  will be required.

### $\gamma\gamma \rightarrow$ HADRONS

Hadrons coming from  $\gamma\gamma$  interactions are expected to create additional jets in the calorimeters and hits in the trackers. These interactions have been simulated with a combination of GP (which determines the energy spectrum of the interacting photons) and Pythia6 [8] (which produces and fragments the partons). Table 1 summarises the number of hadronic events obtained per bunch crossing, for a  $\gamma\gamma$  center-of-mass energy above the cut given in the first column. This background is small, and corresponding occupancies are negligible compared to those induced by the pair-production background.

### SYNCHROTRON RADIATION

The detector elements will be shielded from SR by adding a mask inside the beampipe, at  $\sim 2.1$ -metre from the IP. The mask is expected to stop most of the SR from hitting directly the detector, however a number of photons are expected to be

Table 1: Events per bunch crossing, for a  $\gamma\gamma$  center-of-mass energy above the cut given in the first column.

$\sqrt{\hat{s}}$ (GeV)	Number of events
2	0.004
5	0.002
10	0.001

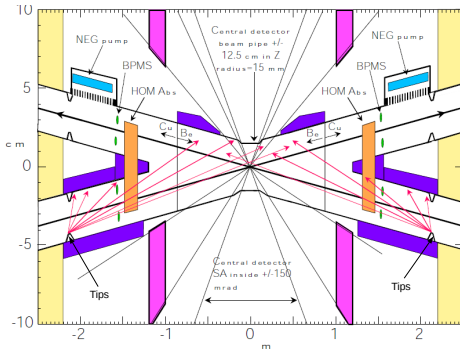


Figure 5: Schematic representation of the FCC-ee interaction region. One can see the tips of the SR shielding mask. With red lines are shown the forward scattered photons that might reach the detector. With blue colour is illustrated the Tantalum used as a shield from the scattered SR

forward scattered on the tip of the mask and then reach the detector, see Fig. 5. The suppression of the scattered SR will be achieved by a combination of a thin ( $\sim 5 \mu\text{m}$ ) gold coating inside the central part of the Beryllium beam pipe, and a Tantalum (or Lead) shield (0.5–2 cm thick) on the outer part (seen in blue colour in Fig. 5). The gold coating, being inside the tracking fiducial volume, should be sufficiently thin in order not to significantly degrade the impact parameter resolution, therefore the vertexing/flavour tagging abilities of the detector. The Tantalum shield is outside the tracker volume; however, one should be careful and leave an open window in front of the luminosity calorimeter (LumiCal). It has been shown through full simulation studies that if the Bhabha electrons (use for the luminosity measurement) are crossing the Tantalum shield before reaching the LumiCal, the obtained energy resolution would be significantly lower. The work for designing an optimal shield, that wouldn't affect the detector performance, is currently on-going.

A full simulation study of the scattered photons from the tip of the mask has been performed. SR, without the Ta shield, is the dominant source of background on the detector, producing 20–40 times more hits than  $e^+e^-$  pairs. Those hits have different distribution than pairs-produced hits since the photons are scattered from the tip of the mask in rather large angles. On the other hand, it was found that Tantalum shield can substantially reduce the number of photons that create hits in the detector. Figure 6 summarises the number of hits per subdetector due to SR with and without the shield.

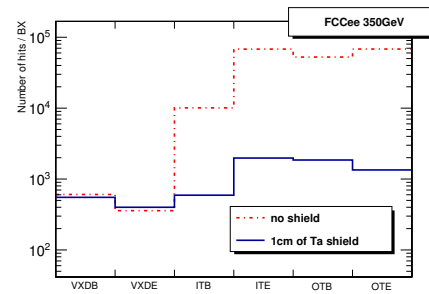


Figure 6: Hits per subdetector per bunch crossing, in the vertex detector (VXD) barrel (B) and endcap (E), Inner Tracker (IT) barrel and endcap, Outer Tracker (OT) barrel (B) and endcap (E))

## CONCLUSIONS

The effects of some of the machine and luminosity backgrounds on the FCC-ee detector have been examined. The obtained hit densities per bunch crossing are rather low. Given reasonably fast and highly granular detectors, it seems that the induced occupancy will not be worrying. Figure 7 shows the total number of hits per subdetector expected, as well as the individual contribution from each background source examined here. Work is on-going to study the effect of other accelerator induced background, like beam-gas interactions and electrons from radiative bhabhas.

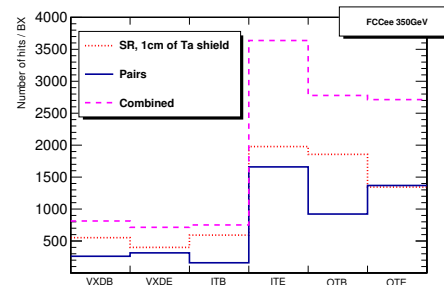


Figure 7: Hits per subdetector per bunch crossing.

## ACKNOWLEDGEMENT

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