

TRACKING SIMULATION FOR BEAM LOSS STUDIES WITH APPLICATION TO FCC

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Abstract

We present first results on FCC-ee beam losses using a tracking simulation tool originally developed and successfully applied to Flavor Factories designs.

After a brief description of the tool, we discuss first results obtained for FCC-ee at top energy, both for the Touschek effect and radiative Bhabha scattering.

INTRODUCTION

CERN recently launched in a worldwide collaboration the new study for a design of a “Future Circular Collider” FCC with a circumference of about 100 km to be built in the CERN area; the target is a hadron collider (FCC-hh) at centre-of-mass energies close to 100 TeV with possible intermediate step of a e^+e^- collider (FCC-ee) in the centre-of-mass energy range of 90 – 400 GeV [1].

One of the challenges for FCC is to reach very high luminosities in combination with low or at least acceptable backgrounds and radiation levels in the interaction regions. To reach this goal, the interaction region design needs to cope with both the machine and detector constraints in a balanced machine detector interface (MDI) design. This is obtained by studies that include the simulation of the accelerator-related detector backgrounds, which can be divided in two main sources: losses of beam particles (the main focus of this paper) and synchrotron radiation [2]. Particle effects that cause beam losses can be generated either by single beam effects, mainly Touschek and beam-gas scattering all around the ring, or by beamstrahlung, radiative Bhabha, e^+e^- pairs production, referred to as *IP backgrounds*. At FCC all these effects need dedicated studies.

The timeline of the FCC design study aims for CDRs to be ready by the end of 2018. In the present stage the lattice design and beam parameters are evolving; the beam loss rates are expected to vary accordingly. We present here the tools that will be used to perform these studies for all the optics and at the different energies, together with the first results.

TOOL FOR MDI SIMULATIONS

To perform the tracking simulations of beam losses for the Machine Detector Interface studies we have started from the tool developed for the Flavor Factories [3], with the plan to adapt and upgrade it to the requirements of FCC. This is an on-going work and first results are presented here. We started to evaluate the Touschek and radiative Bhabha processes for the current optics.

The work can be subdivided in two different steps:

- read the machine lattice description and generate the twiss and aperture files;
- track the beam particles with the proper Monte Carlo depending on the effect under investigation.

MACHINE LATTICE

The starting point of the studies is the machine lattice layout in the form of the MAD-X input files [4]. As a first step, we run the MAD-X program to produce the twiss file which contains the magnetic lattice description.

The beam loss estimates presented in the following sections have been obtained for the currently proposed lattices [5-6]. Parameters relevant for these studies are listed in Table 1.

Table 1: FCC-ee Parameters Relevant for Beam Losses Estimate

parameter	unit	
Beam Energy	GeV	175
Total length	km	100
Particles/bunch	10^{11}	4
Energy Spread	10^{-3}	2.6
Emittance x/ y	nm / pm	2.1 / 4.3
β_x^* / β_y^*	m	0.5 / 0.001
Emittance x/ y	nm / pm	2.1 / 4.3

The horizontal and vertical physical apertures are defined by means of an external file. As a start, we have assumed here a constant physical aperture of 2 cm and 4 mm in the horizontal and vertical planes, respectively. More reliable predictions will be possible when the apertures in the machine and in particular in the IP region have been defined. Our main focus here is on the discussion of the methods and trends, rather than on lifetime and loss rate numbers that may still change a lot.

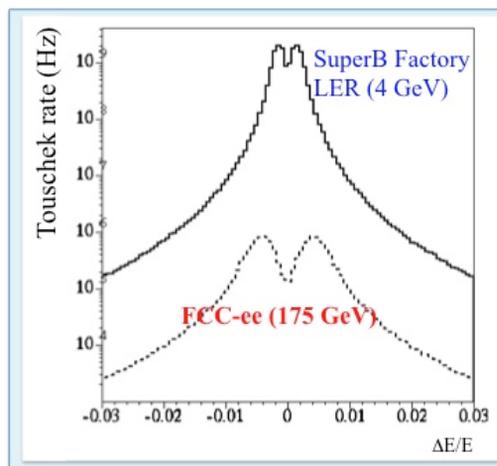


Figure 1: Rate of Touschek particles for FCC-ee (dotted line) compared to SuperB LER (black line).

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BEAM PARTICLE LOSSES

The driving process for particle beam loss in lepton colliders depends on the machine parameters and in particular on the beam energy, beam density and energy spread. For the FCC-ee case, and in particular at the top beam energy of 175 GeV, we expect that beamstrahlung will be the dominant loss effect, followed by radiative Bhabha scattering, $e+e-$ pair production, beam-gas and Touschek. Beamstrahlung and Touschek are strongly dependent on energy acceptance (see Fig. 1 for the Touschek case).

Simulations with particle tracking provide accurate predictions for the losses and their location, as well as their contribution to the beam lifetimes.

Touschek Losses: First Results for FCC-ee

The Touschek effect [7] is generated by the Coulomb scattering between particles in a stored bunch that induces an energy exchange between the transverse and longitudinal motion; in this process small transverse momentum fluctuations are transformed into significant longitudinal fluctuations by the relativistic Lorentz factor in the transformation. Off-momentum particles can exceed the RF momentum acceptance, or they may hit the aperture when they are displaced by dispersion. The Touschek effect depends on many parameters, e.g. the beam energy, bunch density, momentum acceptance. The effect scales with $1/\gamma^3$, and is therefore particularly important for low energy storage rings. In Fig. 1, where the Touschek rate is plotted as a function of $\Delta E/E$, we see that in fact the prediction for SuperB [8] at 4 GeV is much higher than for FCC-ee at 175 GeV. We do not expect that losses from the Touschek effect will be a major problem at the highest FCC-ee energies. We plan to continue with simulation of the Touschek effect to be able to provide quantitative predictions at all FCC-ee energies considered.

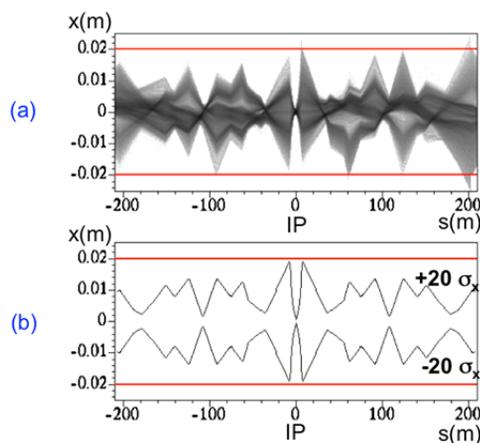


Figure 2: (a) Touschek trajectories and (b) on-energy beam envelope at $20 \sigma_x$ in the FCC-ee Final Focus region.

The Touschek simulations for FCC-ee have been performed considering Touschek scattering for $\Delta E/E$ in

the range between 0.3 and 4.0 %. The loss rate was determined assuming an RF acceptance (bucket height) of 3% in the current simulations. Touschek scattering was simulated for the whole ring. The scattered particles were tracked for a full turn, from -100 km up to the IP, at $s = 0$ m, see Fig. 3. Macro-particles are tracked through each small elements slice for many turns. The slicing is important to get correct estimates for elements in which the beam density changes significantly within the element. An update of the simulation code is planned to interface it with ROOT [9] for plotting and more direct use of twiss parameters provided by MAD-X for the tracking of primaries.

Figure 2 shows in the upper part the Touschek trajectories in the FCC-ee Final Focus region ($|s| < 200$ m), and on the lower part the on-energy beam envelope at $20 \sigma_x$.

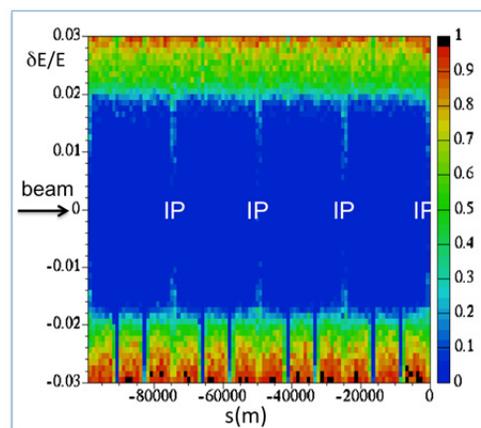


Figure 3: Loss probability for Touschek particles around the ring (x-axis) as a function of the momentum acceptance (y-axis).

The momentum aperture of the FCC may also be limited by the chromatic behavior of the lattice. In Fig. 3, we show the loss probability for Touschek scattered particles around the ring (x-axis) as a function of the momentum acceptance (y-axis). A zoomed view upstream the IR is given in Fig. 4.

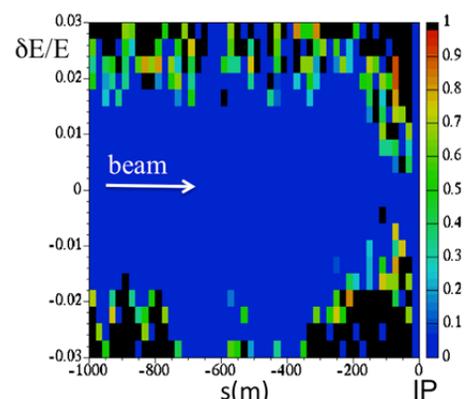


Figure 4: Zoomed view of the loss probability for Touschek particles upstream the IR (x-axis) as a function of the momentum acceptance (y-axis).

Radiative Bhabha: First Results for FCC-ee

Radiative low angle Bhabha scattering has a large cross section which makes it the dominant process for collision losses. The loss rate is directly proportional to the luminosity. The very high luminosities planned for the FCC-ee, imply also very high radiative Bhabha loss rates. This is also well known from the SuperB studies where this effect was studied in great detail. The dominant loss mechanism is that one of the particles radiates a photon of an energy larger than the momentum acceptance.

The impact of radiative Bhabha scattering as background process is determined by tracking. The tracking is done for the e^+e^- particles resulting in the collision, and in addition for the radiated high energy photons which may produce secondary particles including neutrons. Radiative Bhabha scattering occurs only at the IP. We distinguish two cases:

- Bhabha final states particles have large energy deviation;
- Bhabha final states particles have small energy deviation, so that they can be lost after few machine turns.

In the first case spent particles get lost immediately, close to detectors. These particles are well simulated with the BBBREM [10] generator and then tracked into detectors with GEANT4 [11]. There is little dependence on the machine lattice, only the Final Focus design really matters. In the second case a multi-turn tracking code is needed to simulate spent particles from the IP through the ring. At SuperB, as well as SuperKEKB [12] it has been found that most of these particles get lost in the first, or, in a small percentage, in the second turn.

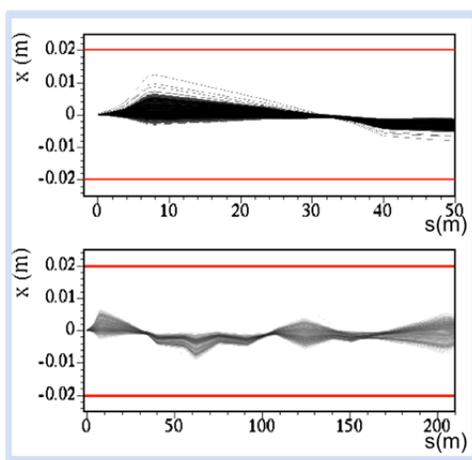


Figure 5: FCC-ee radiative Bhabha trajectories downstream the IP.

Figure 5 shows first tracking simulations for radiative Bhabha trajectories, assuming a constant physical aperture of 2 cm through the FCC-ee IR using the same Monte Carlo tracking code as used for SuperB studies with the FCC-ee lattice described in the Machine Lattice section. The upper plot shows a zoomed view for the first

50 m downstream the IP, and the lower plot shows the off-energy particles up to 200 m. Fig. 6 shows the IP energy acceptance for the off-energy particles resulting from simulation from the first to the tenth machine turn.

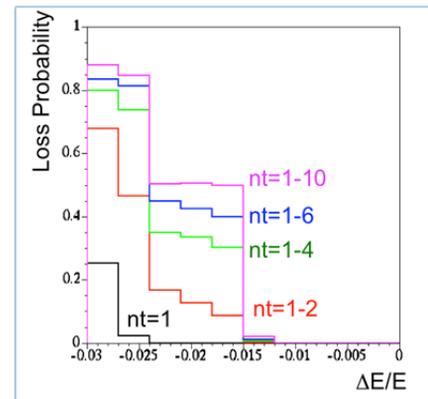


Figure 6: FCC-ee IP energy acceptance for the off-energy particles tracked for ten turns.

CONCLUSIONS

The design of the IR is critical for the success of a collider. A careful trade-off between the constraints of the machine and detectors has to be found. Simulations of all relevant effects that produce machine backgrounds are essential, and they should be as realistic as possible.

We have been setting up software tools for dedicated beam loss studies with detailed tracking simulations and started to apply them to the FCC-ee IR designs under study.

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