Tracking Simulation for FCC-ee Collider Top-up Injection

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Introduction

The Future Circular Electron – Positron Collider (FCC-ee) needs to produce record luminosities given the physics goals. Top-up injection is required for FCC-ee to maintain high beam intensity and luminosity. In this study beam behaviour, efficiency and optimisation at top-up injection scheme will be examined by particle tracking.

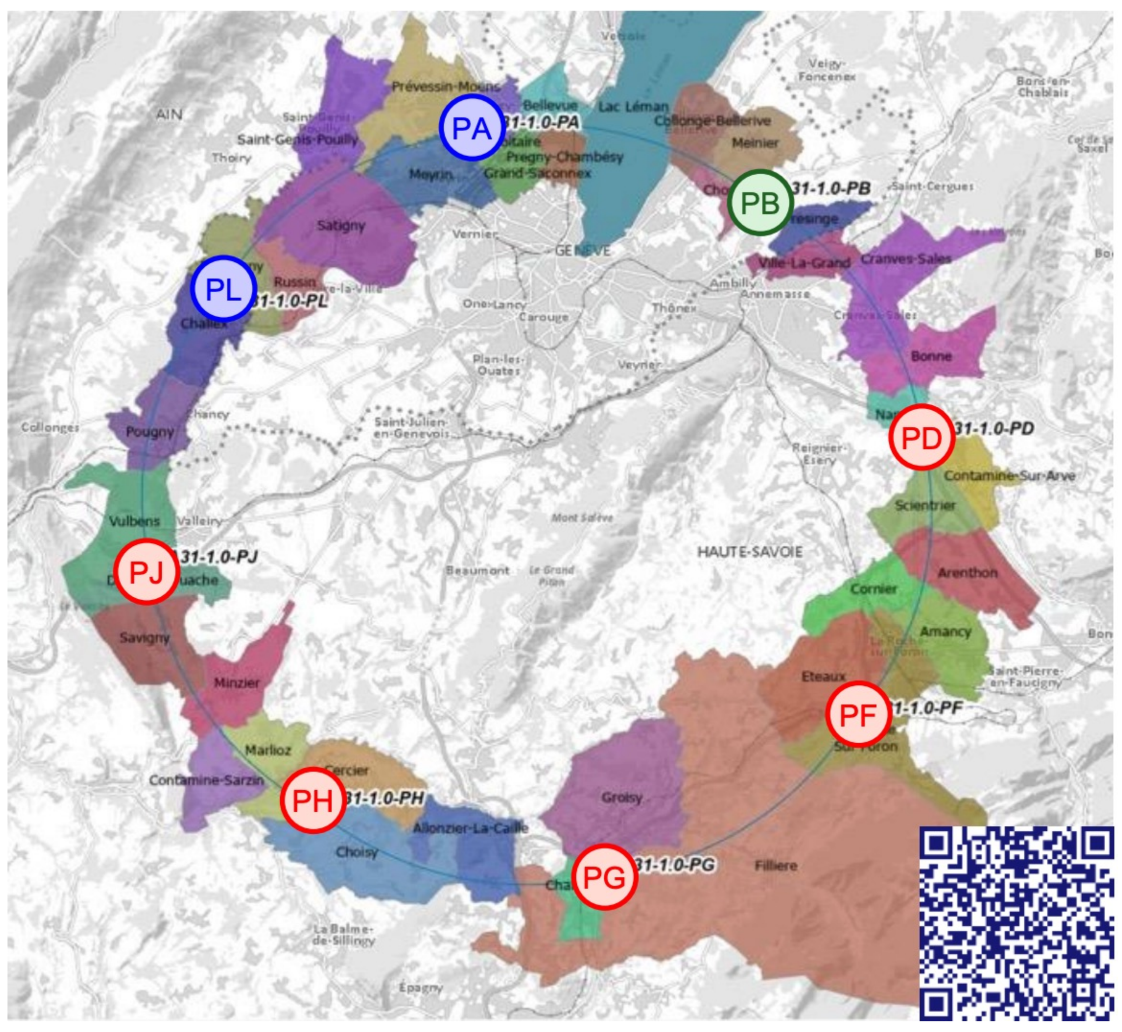

Figure 1: FCC implementation scenario [1]

On-axis Injection

Due to the several advantages such as faster damping time and lower radiation doses to experiments, on-axis injection is the currently considered scheme for the FCC-ee. In the case of on-axis injection, beam is injected into the chromatic closed orbit and damped into the circulating beam by the longitudinal oscillations.

The requirement on the dispersion, the off-energy of the injected beam and septum thickness is given by the following equality:

$$|D_x\Delta| = 5\sigma_{cir} + S + 5\sigma_{inj}$$

D_x: Dispersion at injection point

Δ: Energy offset of injected beam

σ: RMS beam envelope

S: Septum thickness

The 5σ beam envelopes of both circulating and injected beams with the beam bump created by two kicker magnets can be seen on Fig. 2.

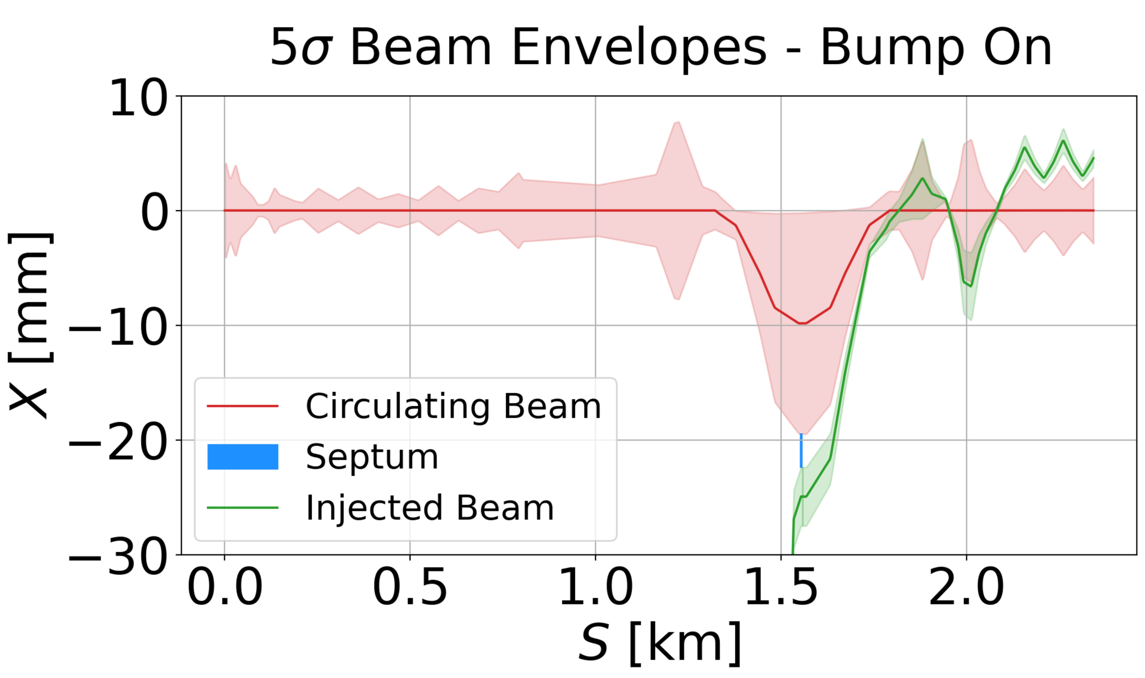

Figure 2: 5σ beam envelopes of injected (green) and circulating (red) beams at the injection section.

Particle Tracking with Synchrotron Radiation and RF

In this study tracking simulations were performed on Xsuite which requires the used lattice to be composed of thin elements. Therefore, the collider lattice was made thin using Madx. Several check of the thinned lattice was performed to validate that the thinning procedure doesn't have any effect on the design parameters of the lattice such as betatron tune, damping time and energy loss due to synchrotron radiation (SR).

One of the results of the mentioned checks can be seen on Fig. 3. Energy loss per turn is given as 39.1 MeV for Z-mode which agrees with the simulated value.

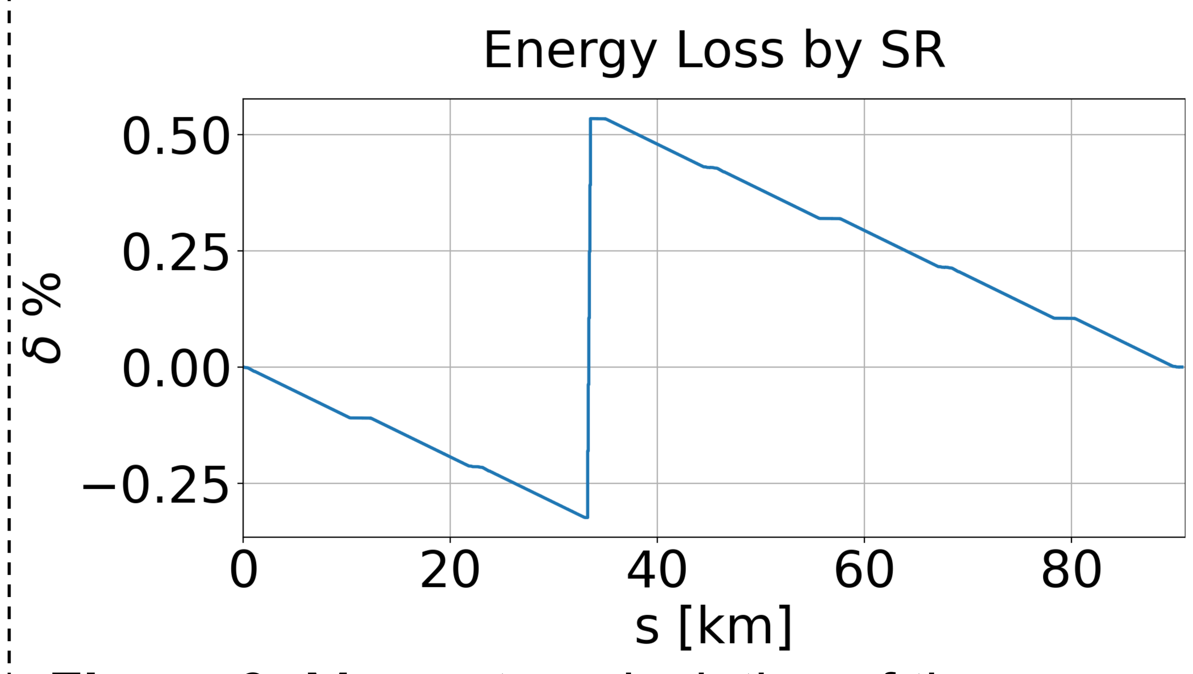

Figure 3: Momentum deviation of the reference particle due to the energy loss by synchrotron radiation.

$\delta = \frac{\Delta p}{p}$: Energy offset of the reference particle

s: Longitudinal position on the ring

To check the feasibility of on-axis injection, both the dynamic aperture and momentum acceptance of the collider ring was studied by particle tracking with synchrotron radiation and RF. For dynamic aperture study a grid of particles in $\Delta x - \delta$ space was tracked in the collider lattice for 800 turns. Boundary values of $\pm 20\sigma_x$ and $\pm 1.5\%$ were used for Δx and δ vales respectively. An example of such a dynamic aperture study result can be seen on Fig. 4.

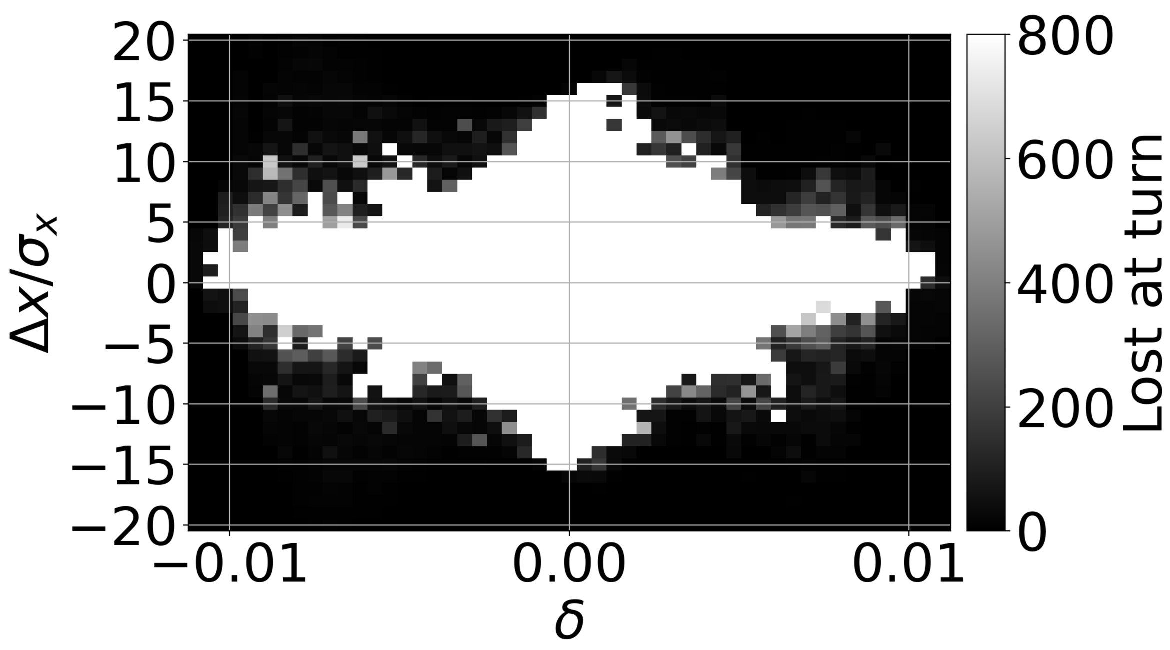

Figure 4: Dynamic aperture of the collider ring.

$\delta = \frac{\Delta p}{p}$: Energy offset of the tracked particle

Δx: Horizontal transverse offset

Transverse and Longitudinal Damping Times

Transverse and longitudinal damping times were checked by performing tracking simulations on the thinned collider lattice. Horizontal amplitude change of a tracked particle with an initial transverse offset can be seen on Fig. 5. An exponential fit was applied to extract the transverse damping time which was found to be 2334 turns.

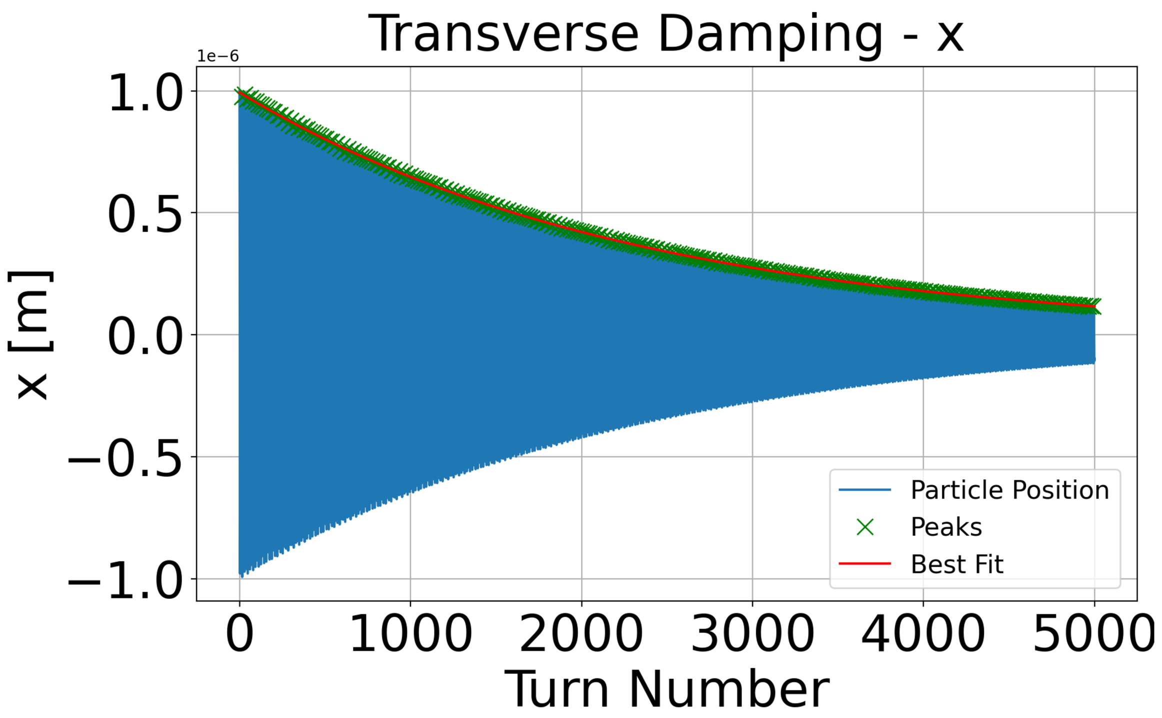

Figure 5: Transverse damping of a particle with an offset.

Longitudinal damping of an off-energy particle can be seen on Fig. 6. An exponential fit was applied to extract the longitudinal damping time which was found to be 1168 turns.

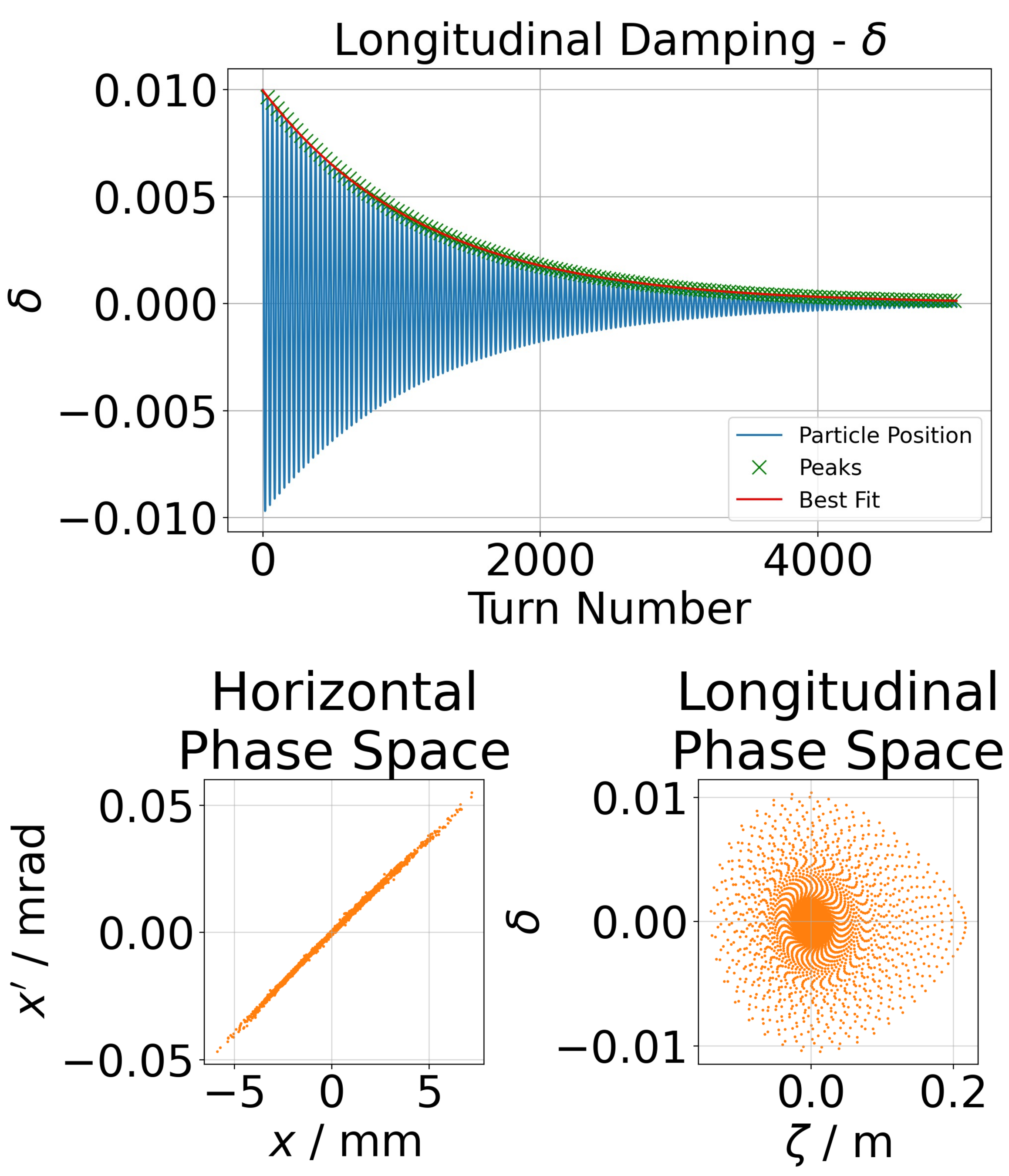

Figure 6: Longitudinal damping of an off-energy particle.

Further objectives:

- Optimizing injection lattice
- Optimizing injected beam parameters
- Studying mismatch on injection
- Defining hardware requirements
- Studying SR effect on septa and kicker

References:

1. J. Gutleber, FCC Week 2024 https://indico.cern.ch/event/1298458/contributions/5975655/