Simulations for FCC: comparison between SixTrack and Fluka-SixTrack

M. Fiascaris - CoIUSM #73
Thanks to A. Mereghetti, S. Redaelli
Introduction

• The FCC-hh is designed to accelerate proton beams to 50 TeV: new energy regime!

• For the FCC studies we have taken advantage of the developments and experience built up for other projects (LHC, HiLumiLHC, EuCard). Several tools available for precise tracking simulations:
  ✦ Merlin: 6D tracking in thick lens + beam particle scattering used at LAL (work by J. Molson)
  ✦ SixTrack: 6D tracking in thin lens + beam particle scattering used at CERN
  ✦ SixTrack + Fluka: tracking engine of SixTrack + full MC functionalities of Fluka for beam machine interactions ongoing effort at CERN

• It is crucial to compare and validate the available simulation tools at the FCC energies.

• This talk is dedicated to the comparison of SixTrack with the SixTrack + Fluka coupling code (thanks a lot to A. Mereghetti).
Simulations setup

Tracking simulations (using lattice v14)

✦ Top energy (50 TeV), $\beta^* = 0.3$ m, $L^* = 36$ m
✦ Lattice - Baseline layout:
  ✦ two low-beta insertions (IPA, IPG)
  ✦ betatron cleaning after the extraction (IPD for B1)
  ✦ momentum cleaning insertion (IPJ for B1) -
    collimation not implemented
  ✦ two additional experiments in IPH and IPF (for
    now placeholders)

Collimation layout

➡ Implemented a three-stage betatron cleaning plus tertiary
  collimators in the experimental IRs
➡ No momentum cleaning, nor collimation in dump
➡ Collimator settings scaled from LHC design to account for the
  real FCC emittance ($\varepsilon_n = 2.2$).
Initial distributions

- All simulations for an horizontal annular halo at $7.6\sigma$ and a Gaussian distribution in the vertical plane. No energy errors.
- About $11 \text{ M}$ particles tracked for 200 turns $\rightarrow 7.6\text{M}$ particles absorbed

\begin{align*}
&x - x' \\
&y - y'
\end{align*}

\begin{align*}
&x, y \\
&x - y
\end{align*}
Sanity check: optics functions (beta functions, dispersion) are identical

**Optics functions**

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**SixTrack**

**SixTrack-Fluka**

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**Sanity check: optics functions (beta functions, dispersion) are identical**
Loss maps

**SixTrack**

![Graph showing local cleaning inefficiency $\bar{\eta}_c$ vs. $s$ [m] for SixTrack with collimators, cold losses, and warm losses.

**SixTrack + Fluka**

![Graph showing local cleaning inefficiency $\bar{\eta}_c$ vs. $s$ [m] for SixTrack + Fluka with collimators, cold losses, and warm losses.]

**Sharing of inelastic losses**
Loss maps

**SixTrack**

- Losses not observed with Fluka
- checked that the aperture is the same (arc)

**SixTrack + Fluka**

Sharing of inelastic losses
Loss maps

SixTrack

SixTrack + Fluka

 sharing of inelastic losses

<table>
<thead>
<tr>
<th></th>
<th>$N_{\text{coll}}$</th>
<th>$N_{\text{cold}}$</th>
<th>$N_{\text{warm}}$</th>
<th>coll (%)</th>
<th>cold (%)</th>
<th>warm (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SixTrack</td>
<td>7629630</td>
<td>3159</td>
<td>2438</td>
<td>99.927</td>
<td>0.04137</td>
<td>0.03193</td>
</tr>
<tr>
<td>Fluka-ST</td>
<td>7594095</td>
<td>1457</td>
<td>3085</td>
<td>99.940</td>
<td>0.01917</td>
<td>0.04060</td>
</tr>
</tbody>
</table>

Ratio of warm/cold losses very different! See zoom in IRD (next slide)
Maximum and average inefficiency in the two clusters of cold losses in the DS region

<table>
<thead>
<tr>
<th></th>
<th>CL1 $\eta_{\text{max}}$</th>
<th>CL1 $\eta_{\text{average}}$</th>
<th>CL2 $\eta_{\text{max}}$</th>
<th>CL2 $\eta_{\text{average}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SixTrack</td>
<td>$(5.2 \pm 2.6) \times 10^{-6}$</td>
<td>$(2.9 \pm 0.2) \times 10^{-7}$</td>
<td>$(2.0 \pm 0.5) \times 10^{-5}$</td>
<td>$(2.9 \pm 0.1) \times 10^{-6}$</td>
</tr>
<tr>
<td>Fluka-ST</td>
<td>$(5.3 \pm 2.6) \times 10^{-6}$</td>
<td>$(1.6 \pm 0.2) \times 10^{-7}$</td>
<td>$(1.1 \pm 0.4) \times 10^{-5}$</td>
<td>$(1.33 \pm 0.04) \times 10^{-6}$</td>
</tr>
</tbody>
</table>

- More warm losses with Fluka-coupling code
- Lower inefficiency in the DS for Fluka-coupling code
Loss Maps - IPG

**SixTrack**

Local cleaning inefficiency $\eta_c [1/m]$

- Collimator losses
- Cold losses
- Warm losses

**SixTrack + Fluka**

Local cleaning inefficiency $\eta_c [1/m]$

- Collimator losses
- Cold losses
- Warm losses

**Beta Function [m]**

- $\beta_x$
- $\beta_y$
- $D_x$

**Dx [m]**

- $D_x$

- $s [m]$

- $x \times 10^3$

- $y \times 10^3$
Loss Maps - IPJ

**SixTrack**

- Collimator losses
- Cold losses
- Warm losses

**SixTrack + Fluka**

- Collimator losses
- Cold losses
- Warm losses

Momentum cleaning insertions (collimation not implemented)
Loss maps - left of IPA

**SixTrack**

- Local cleaning inefficiency $\eta_c$ [1/m]
- $s$ [m]

**SixTrack + Fluka**

- Local cleaning inefficiency $\eta_c$ [1/m]
- $s$ [m]
Distribution of absorbed particles at collimators

Ratio Fluka/SixTrack

Horizontal TCP
Single diffractive events

Distribution of single diffractive interactions on collimators

In general Fluka predicts lower fraction of SD events (as observed for LHC simulations)
Conclusions

• Comparison of the available simulation tools at the FCC energy is a crucial step for the validation of our cleaning simulations.

• Found a good level of agreement between SixTrack and Fluka-SixTrack coupling code
  → comparable loss patterns
  → some differences (warm losses, fraction of SD events), similar to what observed for LHC simulations

• Level of agreement sufficient for the scope of our studies and gives us confidence on the reliability of cleaning simulations for further energy deposition studies.

• Comparison with Merlin ongoing (work by J. Molson).

• This exercise was also useful to setup all the tools for the SixTrack-Fluka coupling code (thanks to A. Mereghetti): now generalized to any machine and will soon be documented!