FCC-hh: Collimation system design

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with S. Redaelli
Outline

• Introduction
• Baseline layout assumptions
• Tracking simulations setup and first results
• Cleaning optimization from normalized halo populations
• Next steps
• Conclusions
Roles of the LHC collimation cleaning

- **Halo cleaning** versus quench limit
- Passive **machine protection**
  First line of defense in case of accidental failures
- **Concentration of losses/activation** in controlled areas
  Avoid many loss locations around the 27-km tunnel
- **Reduction of total doses** on accelerator equipment
  Provide local protection to equipment exposed to high doses (like the warm magnets in cleaning insertions)
- **Cleaning of physics debris** (collision products)
  Avoid SC magnet quenches close to the high-luminosity experiments

Clearly it’s a long way to achieve all of that for the FCC! First studies must be targeted to achieve a conceptual design that addresses the main cleaning challenge, taking into account impedance and machine protection aspects.
FCC collimation: our initial approach

- Very good performance of the collimation system so far (up to 140 MJ): **solid solution** to start with!

- For a first conceptual solution in a short time scale, start-up from a **scaled-up system** derived from the present one:
  - Scale the optics and insertion length
  - Keep current collimation system layout (ie. same half-gaps and positioned at same phase advance)

  ➡ Scaled version of LHC IR7 provided by Rogelio ✔

  Straight section of ~ 2.7 km (factor 5 wrt LHC)

**Note:**

Initially aimed at scaling factor of 7 to keep exactly same settings as in the LHC in $\sigma$ units and same gaps in mm

Could only have factor 5 $\rightarrow$ gaps about 0.8 of LHC ones for same $\sigma$ settings

For the rest of the optics the scaling factor is $\sqrt{(50/7)} = 2.6$
FCC betatron cleaning

LHC IR7

FCC IR2 (scaled LHC IR7)

FCC - phase

Mu x
Collimator Mu x
Mu y
Collimator Mu y

Collimators phase advance (FCC and LHC)

LHC Collimators
FCC Collimators

thanks to the optics team!
Simplified cleaning analysis

- High level of accuracy in LHC loss maps is the result of years of experience and operations.
- In view of FCC studies we need to go one step backward, reviving the performance studies done at the time of the LHC system design.

Cleaning inefficiency

\[ \eta_c(A_i) = \frac{N_p(A > A_i)}{N_{abs}} \]

- depends on collimator settings
- no need for machine aperture model

→ Included new performance plots for momentum cleaning performance studies
Tracking simulation setup

- Using a toy madx-lattice provided by the optics team:
  - 2 low-beta insertions
  - 2 cleaning insertions: betatron cleaning + place-holder for momentum cleaning
- Simulations so far include betatron cleaning only! No collimation in experimental IRs and dump implemented yet.
- No aperture model yet - no loss maps around the ring and in cold magnets
• Implemented a three-stage cleaning with 19 collimators, with the following settings:

<table>
<thead>
<tr>
<th>Collimator Type</th>
<th>Number of Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP</td>
<td>3</td>
</tr>
<tr>
<td>TCSG</td>
<td>11</td>
</tr>
<tr>
<td>TCLA</td>
<td>5</td>
</tr>
</tbody>
</table>

* same settings as for LHC nominal (6/7/10 \(\sigma\)) expressed in \(\sigma\) units for the FCC-hh emittance of 2.2 \(\mu\)m

* note: half-gaps in mm are a factor of 0.83 the LHC ones
Simulation setup: initial distributions

Annular halo setup with predefined impact on primary collimators

Horizontal halo at $7.6\,\sigma$
Gaussian distribution in $y$ plane
Simulation results: first impacts

Distributions of first impacts on the primary collimators (in the collimator frame)

Impact parameter (in units of $\sigma$) on primary horizontal collimator

10 $\mu$m
Inelastic impacts on collimators

Distribution of inelastic impacts on the primary collimators in x - y planes
Distributions at collimators

Distribution of inelastic interactions at collimators

Distribution of absorbed particles at collimators
Cleaning inefficiency

First preliminary results on cleaning from normalized halo population

Cleaning inefficiency vs. radial amplitude

\[ \eta_c(A_i) = \frac{N_p(A > A_i)}{N_{abs}} \]

- number of particles above amplitude \( A_i \)
- number of particles absorbed in coll. system

Cleaning inefficiency vs. \( \Delta p / p \)

off-momentum halo population
Scan of TCP-TCSG retraction

- Performed a scan of simulation varying the retraction $\Delta(TCP\text{-}TSCG)$, keeping fixed:
  - TCP’s at 7.6 $\sigma$
  - TCLA’s at a 3 $\sigma$ retraction
  - scanned values: $\Delta(TCP\text{-}TCSG) = 0.1, 0.2, 0.75, 1.0, 1.5, 2.5, 5, 10 \sigma$

Fraction of particles absorbed in primaries / secondaries vs. retraction

Results on following slides for horizontal halo
Δ(TCP-TCSG) scan: cleaning inefficiency

How is the cleaning inefficiency affected by the Δ(TCP-TSCG) retraction?

Minimum around 0.5-0.7 for A = 9 - 12 σ
In practice retraction will be determined by mechanical and optics tolerances
$\Delta$(TCP-TCSG) scan: cleaning inefficiency

Off-momentum halo distribution

zoom

\begin{align*}
\eta(\Delta p/p) & = a \Delta(TCP-TCSG) + b \\
\Delta p/p & = 0.8, 0.5, 0.2, 0.05, 0.02
\end{align*}
Next: DS collimators

From HL-LHC simulations: loss maps

Critical location: losses in the cold dispersion suppressor are a fundamental limitation of the current system.

Need to catch losses close to the first dipoles where dispersion starts growing.
Present system: make space for a room temperature collimator replacing one 15m long dipole with two 5.5m long 11T dipoles.

Appropriate solutions must be foreseen early on into the FCC lattice design!
Next: DS collimators

HL-LHC with DS collimators

FCC-hh IR2 current optics

dispersion not well behaved
should be fixed before we add TCLDs

Need support from optics team for dispersion collimators as well as for momentum cleaning insertion
Plan to implement collimators in the experimental insertions next.

Similarly we will add dump protection elements that must fit into the collimation hierarchy.
Collimator settings

- In the simulations performed so far, used the nominal settings (6/7/10 $\sigma$ for TCP/TCSG/TCLAs in IR7).

- However, if we scale the settings from the HL-LHC baseline (see CERN-ACC-2014-0044) we obtain the following:

<table>
<thead>
<tr>
<th>HD-LHC</th>
<th>FCC-hh - case 1</th>
<th>FCC-hh - case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP</td>
<td>5.7</td>
<td>7.2</td>
</tr>
<tr>
<td>TCS</td>
<td>7.7</td>
<td>9.7</td>
</tr>
<tr>
<td>TCDQ</td>
<td>9.0</td>
<td>11.4</td>
</tr>
<tr>
<td>TCT</td>
<td>10.9</td>
<td>13.7</td>
</tr>
<tr>
<td>aperture</td>
<td>12.3</td>
<td>aperture</td>
</tr>
</tbody>
</table>

- Case 1: same settings as HL-LHC in $\sigma$ units (for $\varepsilon = 3.5$ µm), re-expressed in $\sigma$ units for $\varepsilon = 2.2$ µm
- Case 2: same settings as HL-LHC in mm, expressed in $\sigma$ units for $\varepsilon = 2.2$ µm
Conclusions

• Started collimation design studies with a “conservative approach” based on a scaled-up version of the present system.
  • Results should tell us how far we can go with current state-of the art

• Simulation tools are well set-up and we performed first systematic studies of betatron cleaning with SixTrack.
  • Tools ready to start iterative process with other teams!

• Next steps:
  • address issue of dispersions suppression losses (optics/layout)
  • implementation of collimation layout in experimental insertions
  • implementation of collimation layout in momentum cleaning insertion
  • setup aperture models for first loss maps
  • aperture calculations for feedback on hierarchy choices
EXTRAS
**IR3: Momentum cleaning**
- 1 primary (H)
- 4 secondary (H)
- 4 shower absorber (H,V)

**IR7: Betatron cleaning**
- 3 primary (H,V,S)
- 11 secondary (H,V,S)
- 5 shower absorber (H,V)

**Local cleaning at triplets**
- 8 tertiary (2 per IP)

Passive absorbers for warm magnets
Physics debris absorbers
Transfer lines
Injection and dump protection

> **100 movable collimators**

**Two jaws (4 motors) per collimator**
Achieved performance - IR7

IR7

0 TCLDs

IR7

2 TCLDs, cells 8 & 10

R. Bruce
Achieved performance - IR7

- Simulations SixTrack + FLUKA with 2 TCLDs in cells 8 and 10 (0.8 m W jaws):
  Gain factor \(\sim 10\) in peak power in superconductors.
  \textit{Note that quench limits of new dipoles are \(>2\) larger than for present ones}

- Physics debris with ion collisions: gain up to a factor 50 (0.5 m W jaws).
- Final decision for installation should be based on Run 2 experience, leaving time to address \textbf{loss rate scenarios} and \textbf{quench limits} at \(\sim 7\) TeV.
<table>
<thead>
<tr>
<th></th>
<th>LHC</th>
<th>HL-LHC</th>
<th>Baseline</th>
<th>Ultimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity ([10^{34}\text{cm}^{-2}\text{s}^{-1}])</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Bunch distance [\text{ns}]</td>
<td>25</td>
<td>25</td>
<td>25 (5)</td>
<td>25 (5)</td>
</tr>
<tr>
<td>Background events/bx</td>
<td>27</td>
<td>135</td>
<td>170 (34)</td>
<td>680 (136)</td>
</tr>
<tr>
<td>Bunch charge ([10^{11}])</td>
<td>1.15</td>
<td>2.2</td>
<td>1 (0.2)</td>
<td>1 (0.2)</td>
</tr>
<tr>
<td>Norm. emitt. ([\mu\text{m}])</td>
<td>3.75</td>
<td>2.5</td>
<td>2.2(0.44)</td>
<td>2.2(0.44)</td>
</tr>
<tr>
<td>IP beta-function [\text{m}]</td>
<td>0.55</td>
<td>0.15</td>
<td>1.1</td>
<td>0.3</td>
</tr>
<tr>
<td>IP beam size ([\mu\text{m}])</td>
<td>16.7</td>
<td>7.1</td>
<td>6.8 (3)</td>
<td>3.5 (1.6)</td>
</tr>
<tr>
<td>RMS bunch length [\text{cm}]</td>
<td>7.55</td>
<td>7.55</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Turn-around time [\text{h}]</td>
<td></td>
<td></td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Crossing angle ([\sigma_{\phi}])</td>
<td>12</td>
<td>Crab. Cav.</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>
Δ(TCP-TCSG) scan: vertical halo

Results for annular halo in vertical plane

Note: fewer scan points
Minimum in radial amplitude plot at 0.5 for A = 9 \( \sigma \)
No minimum in off-momentum halo distribution
HL-LHC Simulations

**Horizontal halo**

- Cleaning inefficiency, $\eta(A_0)$
- Radial Aperture, $A_0$ [$\sigma$]
- Comparison between without DS coll and with DS coll

**Vertical halo**

- Cleaning inefficiency, $\eta(\Delta p/p)$
- Comparison between without DS coll and with DS coll