FCC-hh collimation system

J. Molson on behalf of the FCC-hh collimation team.

October 17, 2018
Role of the collimation system

- Assuming 10600 bunches, $1 \times 10^{11}$ particles per bunch for protons, 3.3TeV injection energy, and 50TeV collision energy, we have:
  - 8480 MJ stored energy at collision
  - 560MJ stored energy at injection (more than at the LHC collision energy).

- Currently we have an estimated quench limit of $5mW/cm^3$ at collision energy and $15mW/cm^3$ at injection.

- We need an efficient and robust collimation system to ensure safe operation of the machine.

- It also must protect against fast equipment failures, reduce experimental backgrounds, and prevent activation of the machine in general.

J. Molson on behalf of the FCC-hh collimation team.

FCC-hh collimation system
Machine layout

- 2 dedicated collimation insertions - for betatron and momentum cleaning.
- Experimental insertion protection
- Injection protection
- Dump protection
- Dispersion suppressor protection
Vast updates have taken place to the SixTrack code since the meeting last year.

Now much more robust for FCC-hh simulations.

Previously many different branches of SixTrack existed for different needs.

The FLUKA coupling and heavy ion tracking branches were both merged into the main SixTrack release.

These provided the ability to track any baryon species generated by FLUKA and also contained the new online aperture check code which is required to simulate the FCC-hh beam screen.

Memory allocation inside SixTrack was fully re-worked. Now there are no limits - previously one could face issues where the FCC lattice was too big to fit into the internal arrays in SixTrack.

This also allows arrays such as those relating to particles to change size whilst the code is running.
Lattice status and configuration

- **Lattice used**: the current master branch on gitlab with some additional extras.
- The beam screen and aperture used are the current up to the current values.
- **Extra Collimators (TCTs, TCDQs)** have been added into the lattice where required.
- **Dump insertion** has the extraction kickers added.
- **Run at injection and collision energy** - use the nominal collision settings: 30cm $\beta^*$ with the crossing angle enabled.
Run with the latest SixTrack and FLUKA coupling versions - use 100m particles and track for 200 turns.

The loss map output when using the FLUKA coupling is normalised to the energy per bin, not the particle number.

Usually a magnetic rigidity cut of 30% is applied - i.e. $dp = -0.3$, but in some cases this is removed.

Collimator material fragmentation products can also be tracked.

### Collimation and simulation configuration

<table>
<thead>
<tr>
<th>Family</th>
<th>Half gap $\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP $\beta$</td>
<td>7.6</td>
</tr>
<tr>
<td>TCSG $\beta$</td>
<td>8.8</td>
</tr>
<tr>
<td>TCLA $\beta$</td>
<td>12.6</td>
</tr>
<tr>
<td>TCP $\delta$</td>
<td>10.8 $\rightarrow$ 18.0</td>
</tr>
<tr>
<td>TCSG $\delta$</td>
<td>13.0 $\rightarrow$ 21.7</td>
</tr>
<tr>
<td>TCLA $\delta$</td>
<td>14.4 $\rightarrow$ 24.1</td>
</tr>
<tr>
<td>TCT</td>
<td>10.5</td>
</tr>
<tr>
<td>TCLD</td>
<td>35.1</td>
</tr>
<tr>
<td>TCDQ</td>
<td>9.8</td>
</tr>
</tbody>
</table>
Collision - Horizontal halo loss map - full ring

J. Molson on behalf of the FCC-hh collimation team.
Collision - Horizontal halo loss map - betatron collimation insertion

Exact allowable cold loss rate is currently under study - see the next talk by M. Varasteh.

J. Molson on behalf of the FCC-hh collimation team.
Collision - Skew - with skew TCP - betatron collimation insertion

J. Molson on behalf of the FCC-hh collimation team.

FCC-hh collimation system
Collision Skew halo - without skew TCP - betatron collimation insertion

J. Molson on behalf of the FCC-hh collimation team.

FCC-hh collimation system
From previous studies, we have found that the power load on the skew TCP was too high.

It was proposed that the skew TCP collimator could be removed.

As can be seen, this leads to an increase in losses just before the DS collimators.

Also the primary collimator becomes one of the metallic secondaries. This could have robustness issues, and if required, further studies should be made on this.

Possible that this is ok - skew losses from LHC experience are small relative to horizontal and vertical.

The collimator position must be moved, or a stricter limit on the beam lifetime for skew losses should be used.
Should be good for up to 3 of 300 kickers pre-firing with the old design.

Will be re-run with the updated lattice and extraction region when available.
• Simulations with collimator errors have been performed at collision (15cm $\beta^*$) - as expected the cleaning performance decreases.
• Waiting for the updated lattice to be released with new magnet error tables before re-running with magnetic field errors.
Lead ion lossmaps have also been performed at collision energy (15cm $\beta^*$) using the FLUKA coupling.
Adding TCLDs cures the cold loss issues.

More simulation configurations will be studied.
Collimation at injection

- At injection the momentum collimation will be the most critical.
- Any un-captured beam will be lost at the start of the ramp within a short time - this is unavoidable.
- Current baseline is 1% of the beam will be un-captured → 5.6MJ will be lost.
- The aim is to spread this out over 10 seconds and stay below any additional limits.
- With the current collimator and RF settings, the beam is collimated at 33 seconds after the start of the ramp, with a ramp rate of 1.45x the maximum acceptable. The ramp rate will need to be slightly reduced at the start of the ramp.
- Simulate the momentum collimation by injecting a beam with a fixed dp offset so that it just touches the primary collimator.
- Will show with the momentum TCP cut reduced to 10.8σ.

J. Molson on behalf of the FCC-hh collimation team.
Injection - -dp offset - full ring

J. Molson on behalf of the FCC-hh collimation team.

FCC-hh collimation system
Injection - -dp offset - energy collimation insertion

J. Molson on behalf of the FCC-hh collimation team.

FCC-hh collimation system
Momentum collimation

- With the current master lattice, the energy cut difference between the beam pipe aperture and the collimation system is $\approx 160\,\text{MeV}$. This results in the beam impacting the pipe instead of the collimators ($18\sigma$ momentum TCP).

- To fix this, the dispersion at the collimator must be increased and/or the collimator jaw gap size should be reduced as shown in the above simulation - (limited by the betatron system cut).

- Unfortunately closing the collimators also causes impedance issues at collision. This is currently under study.

- Optics improvements are ongoing with reduced dispersion at peaks in the DS and higher dispersion in the momentum collimation (A. Chance).

- Alternative optics for momentum cleaning studied (collaboration with A. Chance, FNAL)
Summary

- The collimation system is in good shape for cleaning performance at collision energy.
- Potential issues may remain at injection for the energy collimation system, but a path to fixing these issues is clear.
- Other areas that will require further study include placement of the skew TCP collimator, debris leakage through collimators (mask placement), collimator impedance limits, and simulations with magnetic field errors.
- Larger and more precise simulations are now frequently performed, including heavy ion simulations with tracking of debris via the SixTrack-FLUKA coupling.
- Hope to re-run with the latest lattice.
- Good progress has been made!

J. Molson on behalf of the FCC-hh collimation team.