SIMULATION OF THE FCC-HH COLLIMATION SYSTEM

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Abstract

The proposed CERN FCC-hh proton-proton collider will operate at unprecedented per-particle (50 TeV) and total stored beam energies (8.4 GJ). These high energies create the requirement for an efficient collimation system in order to protect the accelerator components and experiments.

In order to verify the performance of proposed collimation system designs, loss map simulations have been performed using the code Merlin. Results for the current baseline layout are presented for both betatron and off-momentum loss maps.

INTRODUCTION

The FCC-hh will collide protons at a centre of mass energy of 100 TeV, and like the Large Hadron Collider (LHC), there is also the possibility to collide heavy ions. Due to its nature as a discovery machine, the desired parameter set is expected to exceed the current LHC in every aspect. In order to maximise the physics discovery potential, both high energies and high luminosities are required. These requirements give a parameter set that involves a very high stored beam energy. In order to protect the machine components, including the superconducting magnets, and the experimental detectors, an efficient collimation system is a core design requirement. Relevant parameters for a collimation system are shown in table 1, with a comparison to the equivalent LHC and the High luminosity upgrade (HL-LHC) parameter set.

Table 1: A table showing parameters relevant to collimation system designs for the LHC, the high luminosity upgrade, and the nominal FCC-hh baseline [1]. The interaction energy is the available energy when a proton collides with a fixed target nucleon in a collimator.

Parameter	LHC	HL-LHC	FCC
Proton energy (GeV)	7000	7000	50000
Number of bunches	2808	2808	10600
Protons per bunch ($\times 10^{11}$)	1.15	2.2	1
Stored energy (MJ)	360	690	8400
Interaction energy (GeV)	115	115	306

Due to the high stored beam energy, an efficient collimation system must be developed to prevent any stray halo protons from colliding with the cold regions of the machine. The higher stored beam energy will require a more efficient collimation system over the LHC, and thus lessons learned from the LHC experience must be incorporated into the design.

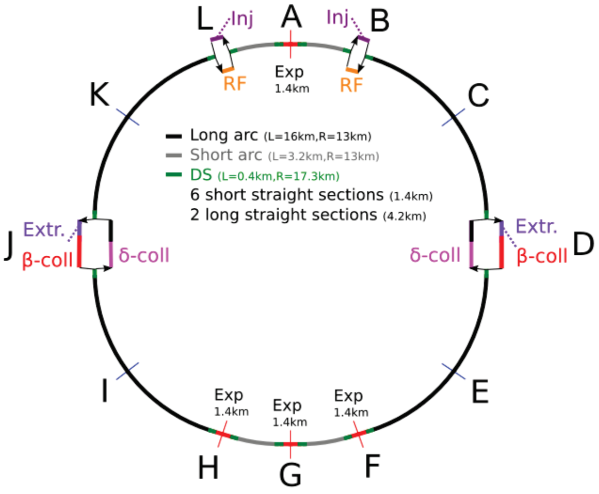

Figure 1: The current (V6) baseline FCC-hh accelerator layout.

THE FCC-HH COLLIMATION SYSTEM LAYOUT

Separate Betatron and momentum cleaning insertions

The current baseline FCC-hh lattice includes two cleaning insertions in the extended straight sections, IRD and IRJ. Unlike the LHC system, where each IR was dedicated to one type of cleaning, e.g. betatron or energy, the FCC baseline system will provide betatron cleaning for one beam, and momentum cleaning for the other beam in each IR, as shown in figure 1. Due to the high stored beam energy, and the potential for asynchronous beam dumps, the betatron cleaning insertion is placed directly after the beam dump system. If an asynchronous beam dump does occur, the betatron system can act as an additional protection system for the sensitive cold arc magnets.

The rational for placing the energy collimation system in the other beam, is that a clean radiation environment can be provided for the extraction kicker magnet power supplies, which must be placed close to the extraction magnets. Due to this the energy collimation insertion is placed at the opposite end of the straight insertion to the extraction system in the other beam. Directly opposite the extraction system is a FODO beam transport line in order to provide a lower radiation environment. The optics for these two insertions are shown in figures 3 and 5

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Betatron collimation system

The current FCC betatron cleaning system is a scaled version of the LHC IR7 betatron system. The rational for doing this is that the current LHC system is known to operate effectively, and settings used for the LHC can be transferred over to the FCC. Collimator jaw gap sizes are set to be similar physical values as in the LHC - these are known to be achievable. The sigma settings are scaled to take into account the increased beam energy and the reduced normalised emittance, and the change in beta functions in the insertion due to the scaling. The optics of the betatron collimation insertion are shown in figure 3 along with a loss map. The beam dumping system can be seen to directly proceed the betatron cleaning insertion at 23 to 24km from IPA.

Energy collimation system

The creation of an energy collimation system follows the same thought process as the betatron system. The LHC system is taken and scaled up to the FCC energy, allowing the same collimator placement and settings. Since there is additional empty space due to the lack of the beam dumping system, a FODO beam transport line is used to match the collimation section to the rest of the accelerator. This can potentially be used for beam diagnostics. The optical layout is shown in figure 3 along with a loss map. The jaw settings have been configured to cut in δp at 1×10^{-3}, in order to protect the arc.

SIMULATION CODES

Multiple codes exist for performance evaluations of collimation systems. For general proton loss distributions, and not energy deposition studies, two main codes exist. These are Sixtrack [2, 3] and Merlin [4]. Sixtrack is the primary CERN code for performing loss map simulations. Merlin is a C++ accelerator physics library initially designed for the International Linear Collider beam delivery system. It has been adapted for circular machines, and has previously been used to simulate loss maps for the LHC [5,6]. It has also been used for simulations of the high luminosity upgrade [7] for the LHC. It contains enhancements for collimation physics at FCC energies [8].

The usage of both Sixtrack and Merlin allows for cross checks [9] between the two codes. The following results use the Merlin code.

COLLIMATION SYSTEM SIMULATIONS

All simulations are performed with the FCC-hh lattice version 6. The common parameters between the betatron and energy collimation simulations are shown in table 2.

Betatron collimation system performance.

The collimation system performance is evaluated in the same manner as for previous LHC studies. A matched bunch of protons is injected into the lattice such that they slightly graze the primary collimator jaw in the betatron collimation insertion with a maximum impact factor for $1 \mu m$. For this work a simulation of a horizontal loss map is performed. The injected bunch has no energy spread, and is a cut ring in x and x', and point-like in y and y'. The loss map for the full FCC ring is shown in figures 2 and 3.

Table 2: Collimation simulation parameters common to both the betatron and energy collimation system simulations.

Paramter	Value
Proton energy	50 000 GeV
β^*	0.3 m
ϵ_n	2.2 μrad
Particle count	6400000
Turn count	200
Loss resolution	0.1 m
Betatron primary (TCP)	7.57 σ
Betatron secondary (TCSG)	8.83 σ
Betatron Tertiary (TCLA)	12.61 σ
Energy primary (TCP)	18.06 σ
Energy secondary (TCSG)	21.67 σ
Energy tertiary (TCLA)	24.08 σ
Experimental IR protection (TCT)	10.47 σ

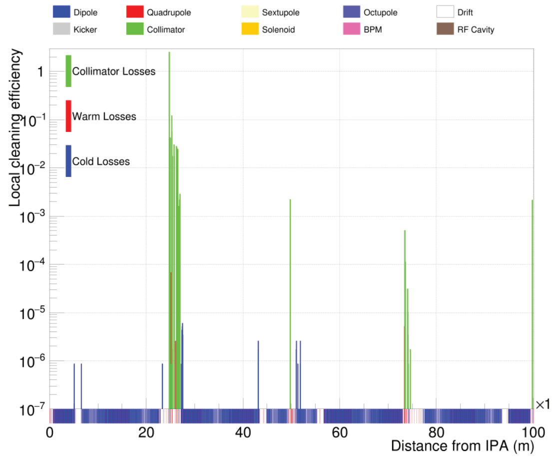

Figure 2: An image showing a loss map for the FCC-hh betatron collimation system using a horizontal beam halo, showing the full accelerator ring.

The majority of losses are confined to the collimation system, but there is some leak through to the cold superconducting magnets. This is expected, since the system is a simple scaling of the LHC insertion. As with the LHC, the main area of cold region losses is the dispersion suppressor directly following the collimation insertion. Here the dispersion rapidly rises to match the arc values, and due to this dispersion any sufficiently off momentum protons are lost in this confined area.

Energy collimation system performance.

The energy collimation system is evaluated by injecting a bunch with a spread in energy and allowing it to impact with

Figure 3: An image showing a loss map for the FCC-hh betatron collimation system using a horizontal beam halo, showing the betatron collimation insertion.

the primary energy collimator. The distribution is normal in x,x' and y,y'. The transverse distribution is cut at 1σ so that protons do not have sufficient amplitude to impact with the betatron collimation system. An impact factor cut of $1\mu m$ is also provided in transverse space at the collimator jaw. The longitudinal distribution is also a normal distribution, and the proton energy was selected to be either $\pm 1 \times 10^{-3}$.

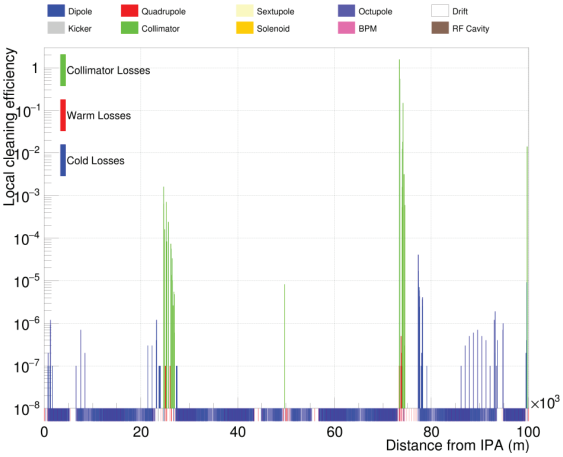

Figure 4: An image showing a loss map for the FCC-hh energy collimation system, showing the full accelerator ring.

As with the betatron system, the main region of cold losses is the dispersion suppressor at the end of the insertion region. Here the diameter of the beam pipe is reduced, and the dispersion rises rapidly at the start of the arc.

CONCLUSIONS

The current FCC collimation system performance has been simulated with the code Merlin. The collimation system as currently implemented does not fulfil the required cleaning efficiency required to prevent quenches of the cold superconducting magnets, especially in the cold dispersion suppressor regions. A cleaning inefficiency of $\approx 10^{-7}$ is targeted for the cold regions the machine. Methods are now currently under investigation to reduce the losses in these critical regions.

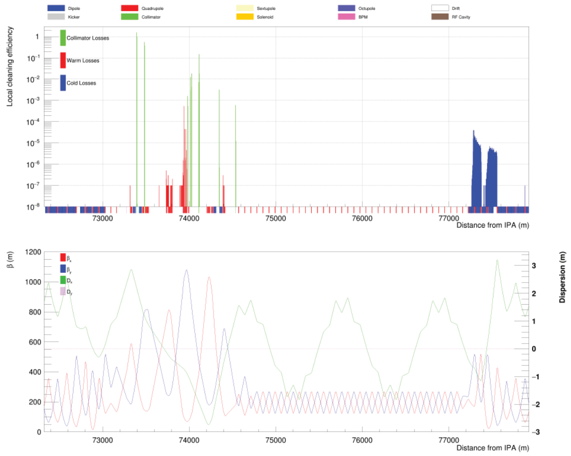

Figure 5: An image showing a loss map for the FCC-hh energy collimation system using an off-momentum beam halo, showing the energy collimation insertion.

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