PROTON CROSS-TALK AND LOSSES IN THE DISPERSION SUPPRESSOR REGIONS AT THE FCC-hh*

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Abstract

Protons that collide at the interaction points of the FCC-hh may contribute to the background in the subsequent detector. Due to the high luminosity of the proton beams this may be of concern. Using DPMJET-III to model 50 TeV proton-proton collisions, tracking studies have been performed with PTC and MERLIN in order to gauge the elastic and inelastic proton cross-talk. High arc losses, particularly in the dispersion suppressor regions, have been revealed. These losses originate mainly from particles with a momentum deviation, either from interaction with a primary collimator in the betatron cleaning insertion, or from the proton-proton collisions. This issue can be mitigated by introducing additional collimators in the dispersion suppressor region. The specific design, lattice integration, and the effect of these collimators on cross-talk is assessed.

INTRODUCTION

The Future Circular Collider (FCC-hh) aims to accelerate and collide two counter rotating 50 TeV proton beams at two major and two minor experiments. The FCC-hh layout is shown in Fig. 1. The nominal and ultimate luminosities of the FCC-hh are $5 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and $30 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ respectvely. Given this high proton energy and luminosity, collision debris must be properly handled. Here we assess the cross-talk, *i.e.* the effect on the downstream detector from the collision debris. The debris comprises mostly of photons, pions, protons, other charged hadrons, and muons, in order of abundance. Photons are ignored for cross-talk studies as they will not reach the next detector. The number of pions produced is significant, however together with other charged hadrons these do not have the required rigidity to be transported in the accelerator, and are therefore lost almost immediately in aperture restrictions. Muons are of concern as they have a large mean free path and can travel kilometres in dense materials - this is discussed in [1]. Here we focus on protons, of particular interest in cross-talk studies because they may be transported by the accelerator to the proceeding detector.

PROTON CROSS-TALK

Using the upgraded version of the DPMJET-III [2] event generator within FLUKA [3], we simulate the proton collisions at interaction point A (IPA), with vertical crossing. These protons have a large energy range, as shown in Fig. 2.

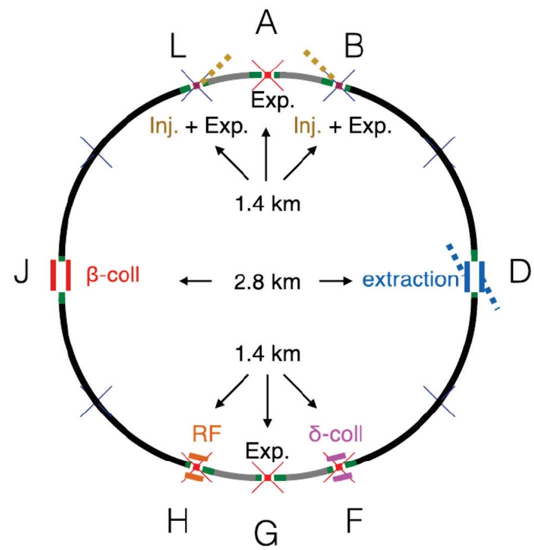

Figure 1: FCC layout. The main experimental interaction regions are located at A and G, and the low luminosity ones at L and B.

We separate these protons into two regimes, elastic protons which have an energy greater than 49.95 TeV, and inelastic which have an energy less than this.

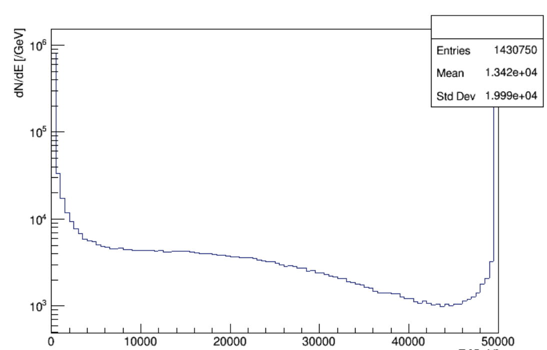

Figure 2: Proton energy distribution 3 m downstream of IPA for 10^6 pp collision events.

Using PTC [4] and MERLIN [5] we perform tracking of both elastic and inelastic protons to assess the cross-talk. The elastic protons nearly all reach IPB, as their energy and position spread is similar to that of the machine proton bunch. This will lead to some emittance growth. The inelastic protons are more interesting. At nominal luminosity under 2 inelastic protons will reach IPB per IPA bunch crossing, at ultimate settings this rises to ≈ 9. The mean energy of these

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protons is 49.89 TeV. It is unlikely that these few protons will be of concern in terms of cross-talk.

LOSSES

Inelastic protons are mostly lost in the short straight section, and dispersion suppressor (DS) regions post IPA. The energy correlation loss map for inelastic protons is shown in Fig. 3. These simulations treat all apertures as black absorbers. The power loss map is shown in Fig. 4. We see that the majority of low energy protons are lost in aperture restrictions close to the IP as expected, only higher energy protons travel as far as the dispersion suppressor, where they are nearly all lost. Power loss on the D1 and D2 separation and recombination dipoles is large, FLUKA studies of energy deposition and shielding is foreseen in the near future. As the losses in the DS (after s ≈ 800 m) region comprises of higher energy protons, these are of concern.

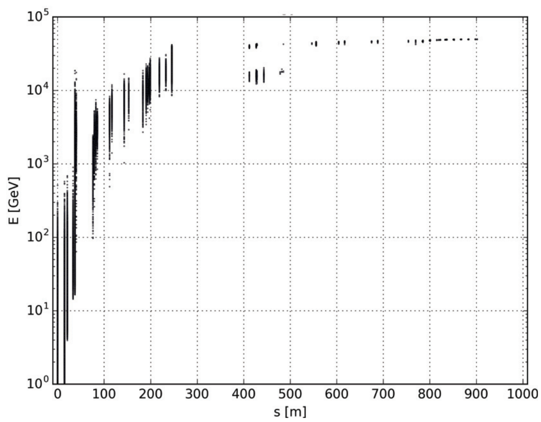

Figure 3: Inelastic proton energy correlation loss map per element. The TAS is located at 40 m, D1 at 230 m, D2 at 425 m, the dispersion suppressor region begins around 800 m, and s = 0 is IPA.

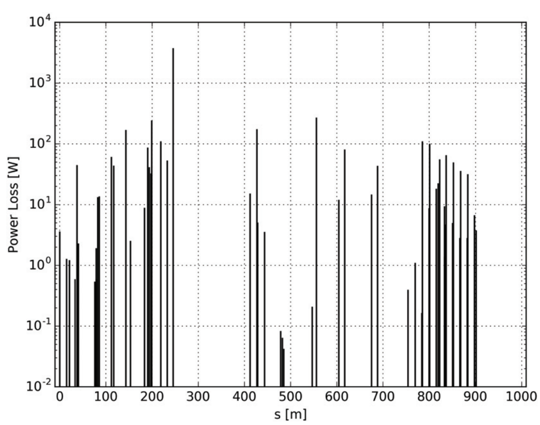

Figure 4: Inelastic proton power loss map per element.

DISPERSION SUPPRESSOR PROTECTION

The cold dispersion suppressor regions in the FCC-hh are a critical point in the optics since they are a bottleneck for off-momentum particles, as the dispersion is rapidly rising [6].

To reduce the losses in the cold regions to a cleaning inefficiency of $\approx 3 \cdot 10^{-7}$ [7] a new dispersion suppressor collimation system has been integrated into the current lattice. This collimation system consists of two 'TCLD' collimators, one in cell 8 and one in cell 10 of the dispersion suppressor at the point where the dispersion is rapidly rising. With the additional collimators in place it can be shown that the cold losses from off-momentum beam particles can be managed. Particle showers induced by these protons impacting upon the collimator jaws are therefore the main concern [8].

The DS regions in the current FCC-hh lattice version 7 have been modified to include drift space for the placement of the TCLD collimators in front of the first quadrupole in cell 8 and cell 10. Important for the positioning is a relatively small β function and a rising dispersion. This gives the possibility of a bigger jaw gap so not to violate the collimation hierarchy, while still being able to intercept the off-momentum particles.

Simulation of the dispersion suppressor region losses with the additional collimators has been done in two steps. First, using the MERLIN code [5] to generate and track the primary protons, in order to ensure that all relevant particles get caught by the collimation system, and to create a distribution of particles that hit the collimator for shower simulations. Second, using the FLUKA simulation code [3] with a simplified geometry of the DS regions that includes a model of the first downstream quadrupole, to simulate the shower development and energy deposition in the cold magnet coils.

The main focus of these studies has been on the DS region after the betatron cleaning insertion (IPJ) since this has been identified as the region with the biggest cold losses during short beam lifetime scenarios. This is not the case for nominal physics operation; here the largest losses come from collision debris around the experiments (IPA, IPG). To ensure that a DS collimation design similar to the one under investigation for IPJ can also be used around the experiments, simulations with collision debris particles have been carried out.

ENERGY DEPOSITION SIMLUATIONS

MERLIN was used to track the collision debris inelastic protons, including the TCLD collimators in the DS region post-IPA. This provides an input distribution for FLUKA shower and energy deposition studies. Treating aperture restrictions as black absorbers MERLIN simulations confirm that the TCLDs post-IPA intercept all remaining inelastic protons. For the shower simulations only cell 8 has been considered, as the load on the collimator in cell 10 is smaller and therefore also the energy deposition in the downstream magnets should be less. A 1 m long collimator has been placed in the drift before the quadrupole as close to the beginning of the drift as possible, considering space for cryostat connections. This gives the shower particles space to move away from the beam axis and potentially hit the magnet yoke instead of the coils. A 3D model of the geometry is shown in Fig 5.

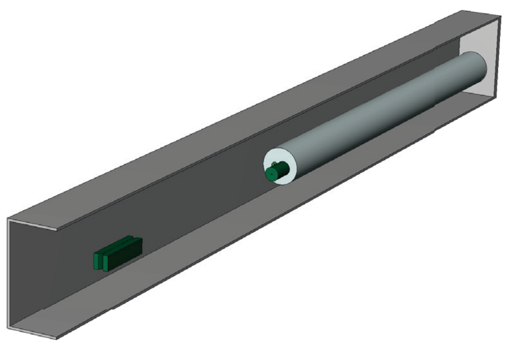

Figure 5: 3D FLUKA model used for shower simulations in the dispersion suppressor. The green objects are first the TCLD collimator, followed by a 50 cm long mask, both made of Inermet180. Following this is the first quadrupole in the DS. The particles are loaded 63 cm before the collimator.

Since the collimator has to act as an absorber, Inermet180 has been chosen as the jaw material, this is also used in the absorbers currently installed in the LHC. The half-gaps for the collimators were set to 35 σ. This has proven to be tight enough to intercept the particles, but wide enough not to violate the collimation hierarchy. As the momentum collimation system in the FCC-hh is a work in progress, there is a possibility that the momentum cleaning hierarchy might be violated. This has to be investigated when the momentum cleaning insertion is finalized. For the quadrupole a simple model with coils consisting of a mixture of 50% niobium-3-tin and 50% copper is used. Additionally simulations including a mask of 50 cm Inermet180 directly in front of the magnet have been performed. Figure 6 shows the maximum energy deposition along the length of the quadrupole.

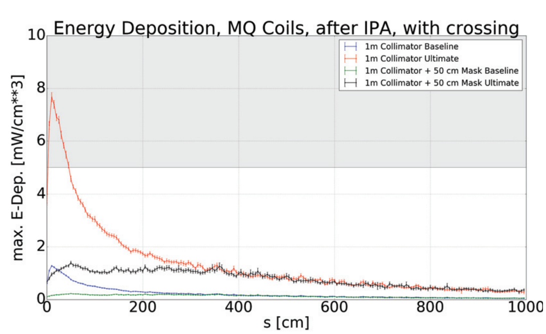

Figure 6: Maximum energy deposition per cm^3 in 5 cm bins along the first quadrupole in cell 8 after IPA for baseline and ultimate configuration.

Without a mask the energy deposition rises rapidly in the first few centimeters of the magnet. The mask is able to stop almost all particles that hit the face of the magnet coils, and the main losses come from shower particles that travel through the beampipe and hit the magnet on the inside. Considering magnet limits of $\approx$ 5 - 10 mW cm^{-3} [9] protection without the mask should be sufficient for the baseline configuration of the FCC-hh. For ultimate parameters however the mask is required to provide sufficient protection, this includes consideration of errors of up to a factor of 2. The mask could also provide flexibility for future luminosity upgrades.

CONCLUSION

Proton cross-talk has been assessed in the FCC-hh using DPMJET-III in FLUKA as an event generator, as well as PTC and MERLIN for tracking and loss location simulations. It has been found that elastic protons will all reach the proceeding IP, causing some emittance growth. The inelastic protons reach the next IP at a rate of 2 - 8 protons (at IPB) per IPA bunch crossing. This is deemed negligible. What is of concern is the loss of inelastic protons in the short straight section and dispersion suppressor post-IP. The inner triplet quadrupoles, recombination, and separation dipoles are the subject of detailed energy deposition and shielding studies to ensure adequate performance. Losses in the dispersion suppressor thus become the main concern. For the dispersion suppressors around the experiments a simple collimation design consisting of two 1 m Inermet180 collimators is enough to stop the cold magnets from quenching. When including a simulation error of a factor of 2, a 50 cm mask is enough to compensate. Further studies must be performed to ensure that the momentum collimation hierarchy is not violated. With the dispersion suppressor collimators in place post-IP, the inelastic proton cross-talk is negated.

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