Betatron collimation system insertions

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Configuration

- Using lattice V8 with modifications
- Many extra TCT around each experimental IR were required.
- Added the TCDQ in the dump insertion and have split the extraction kicker into 300 modules (required MAD-X modification).
- Multiple suggested collimator settings - scaled from the LHC or HL-LHC settings. This work uses a scaled LHC collimator configuration
- Usually simulate 100 million input protons.

Collimator settings

All simulations have used the following collimator configuration:

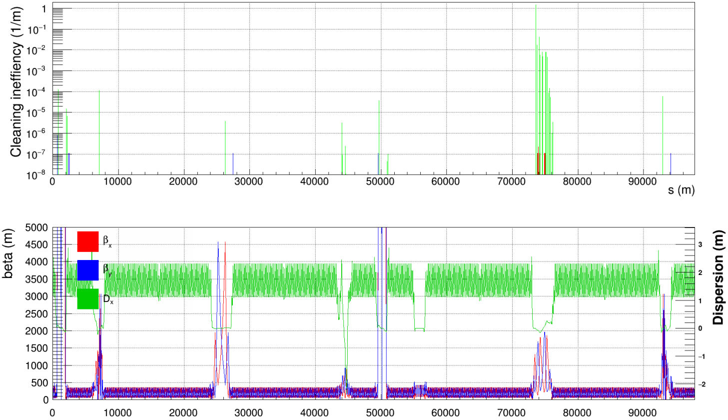
Collimator	Opening σ
TCP β	7.57
TCSG β	8.83
TCLA β	12.61
TCP δ	18.06
TCSG δ	21.67
TCLA δ	24.08
TCT	10.47
TCDQ	9.83
TCLD	35.14

Current status

Have looked at:

- betatron losses at collision: Horizontal and vertical halos.
- betatron losses at injection: Horizontal and vertical halos.
- betatron losses at collision with no skew TCP.
- Asynchronous dump.
- Asynchronous dump with TCDQ errors.
- Heavy ion losses

Betatron - collision - horizontal - full ring

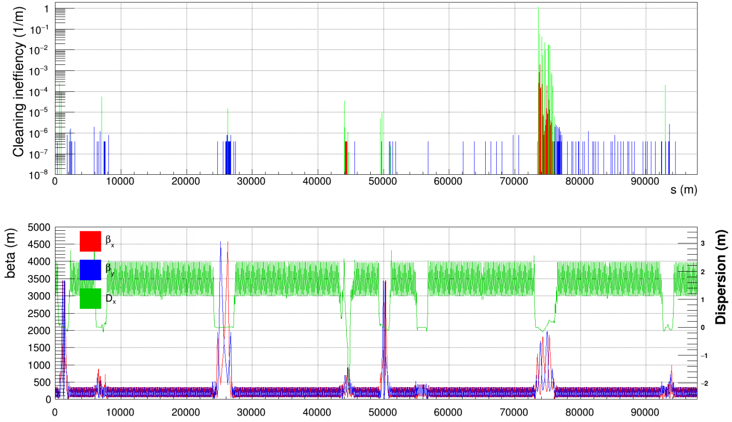


Betatron - collision - horizontal - no skew TCP

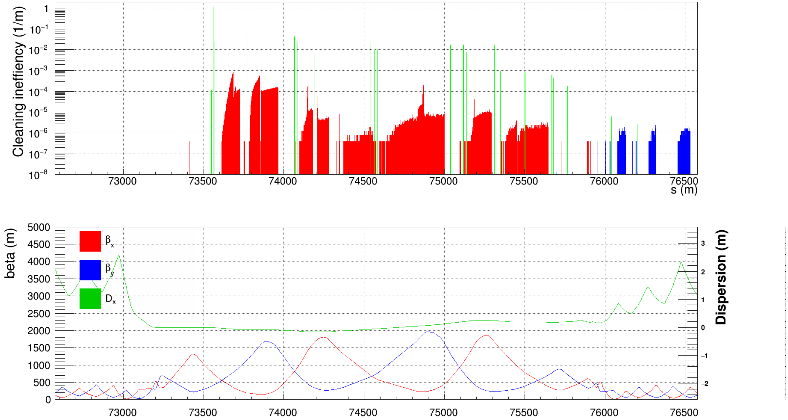
What happens if the skew TCP is removed? Not much - i.e. it is safe to remove at collision.

Betatron - collision - vertical - full ring

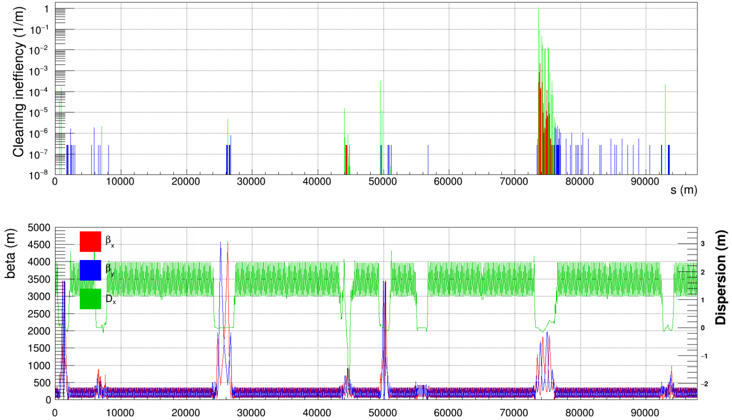
Betatron - injection - horizontal - full ring



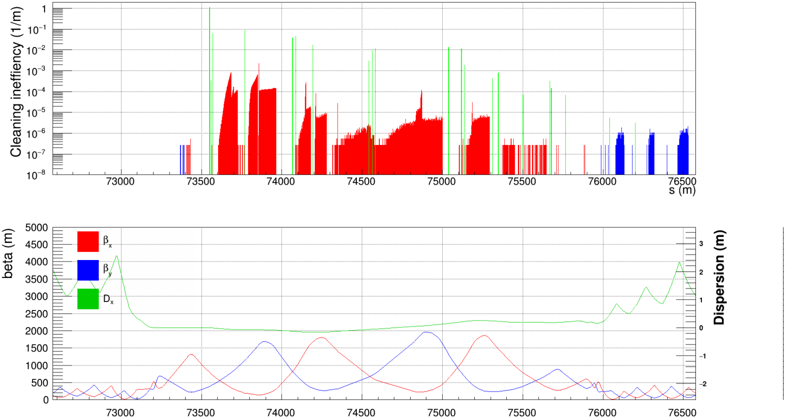
Betatron - injection - horizontal - betatron collimation



Betatron - injection - vertical - full ring



Betatron - injection - vertical - betatron collimation



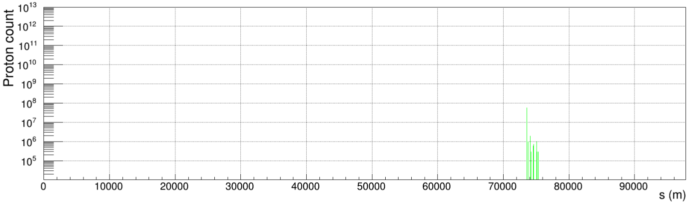
Betatron collimation summary

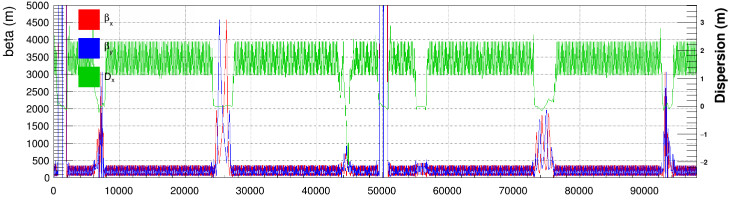
- Cleaning at top energy is mostly good for both the horizontal and vertical case.
- At injection due to the larger emittance and wider scattering angles the situation is not as good...
- The beam energy is lower, so there will be less energy deposited per proton. All depends on the injection quench limits.
- Protons are lost into potentially sensitive areas at injection. e.g. The injection and extraction kickers.
- More work needs to be done in looking at IR protection with the latest lattice - more than 1 set of TCTs is required (currently not in the baseline lattice).

Asynchronous dump

- One potential machine protection issue is the asynchronous dump.
- This is where the extraction kicker system either partially fires or fires at the incorrect time.
- This potentially could lead to the beam impacting with the machine aperture and collimation system instead of being extracted out of the ring to the dump.
- The current extraction system consists of 300 segmented extraction kickers.
- We simulate tracking for 3 turns, firing n kickers, then extracting the beam the following turn.
- This simulates a failure, and then a re-triggering of the system the following turn.
- Results do not show the cleaning inefficiency, but the total number of lost protons assuming a full nominal beam.
- Set a safe limit of 2 nominal bunches impacting a collimator.

Asynchronous dump - 1 kicker





Asynchronous dump - 2 kickers

Asynchronous dump - 3 kickers

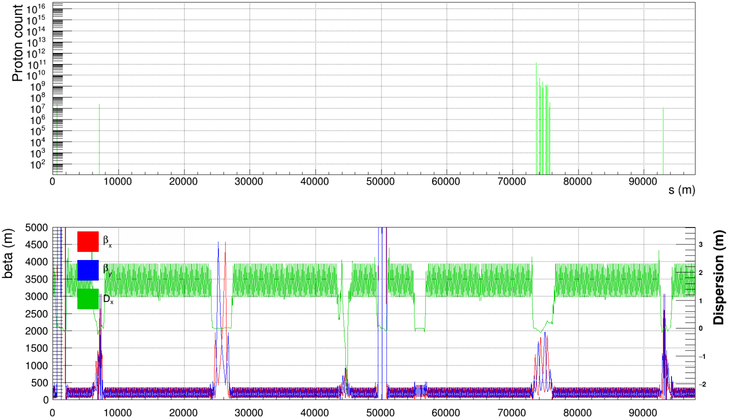
Asynchronous dump - 4 kickers

Asynchronous dump - 5 kickers

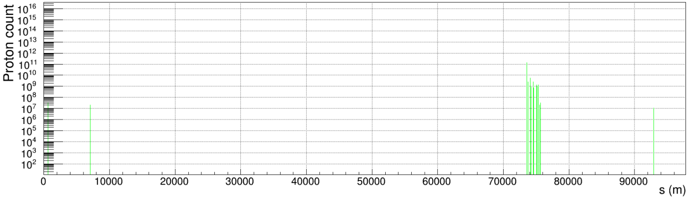
Asynchronous dump

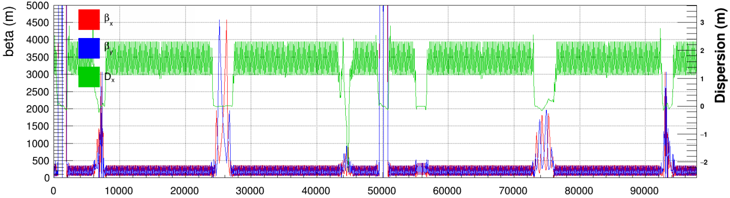
- As can be seen, 4 or more kickers firing will push the beam past the "safe" limit of 2×10^{11}.
- Currently 3 kickers or fewer can be considered "safe", but this does assume a perfect lattice and collimation system.
- Have a brief look at adding a gap error to the TCDQ (with 3 kickers firing).
- Open by 0.5 and 1.0mm to give a gap of 10.99σ and 12.16σ.
- Close by 0.5mm to give a gap of 8.66σ.

Asynchronous dump - open TCDQ 0.5mm



Asynchronous dump - open TCDQ 1.0mm





Asynchronous dump - close TCDQ 0.5mm

Asynchronous dump - Summary

- In summary, the system can be expected to survive 3 kickers pre-firing with a 2×10^{11} proton limit on a single collimator jaw.
- The addition of errors to the system (alignment, field, orbit, etc) could potentially cause this to decrease to 2, which will be investigated.
- With an increase gap size for the TCDQ, the beam safely hits the collimation system and does not impact the TCDQ (with 3 kickers firing).
- With a gap close of 0.5mm, the system is still safe, but the TCDQ becomes a secondary collimator, and this should be avoided.
- Currently with 3 kickers firing 1.51×10^{11} protons impact on the collimation system before the beam is extracted.
- Since these simulations have taken place, a new extraction system now exists, but the design is yet to be integrated into the main lattice. When this is done, new simulations will be performed.

Heavy ion losses

- No heavy ion loss maps have been simulated so far for the FCC-hh.
- Many code enhancements were required for this to take place - the required code was split over 3 different branches of SixTrack and FLUKA, which were all incompatible with each other and had to be manually merged together - a VERY time consuming process.
- Now up and running (just).
- Andrey is starting with Pb ion betatron loss maps at collision energy.

This is still in progress and will show an image if finished in time for next week (running right now).

Conclusion and future

- We have simulated the FCC-hh betatron collimation system at collision and injection energies. The system looks good at collision, but some aperture restrictions could exist at injection.
- Studies of the asynchronous dump failure have taken place with the conclusion being a failure of up to 3 kickers could take place with the current layout.

Many future enhancements can take place:

- Use the latest lattice layout.
- Create a better beam pipe description, including the dipole shape.
- Use new collimator layouts - shorter primaries, new material secondaries, and no skew TCP.
- Revisit the energy collimation system.
- Produce ion loss maps.