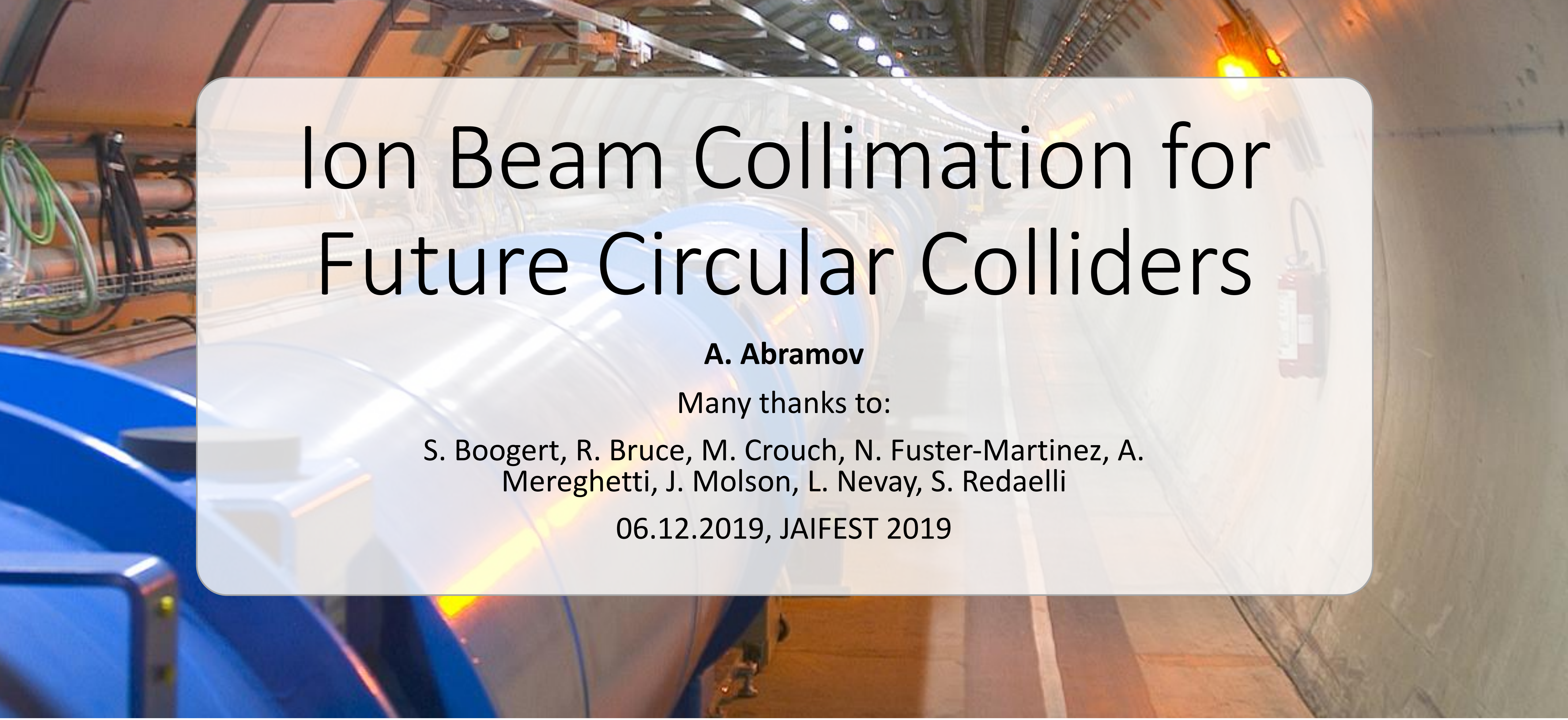


Ion Beam Collimation for Future Circular Colliders

A. Abramov

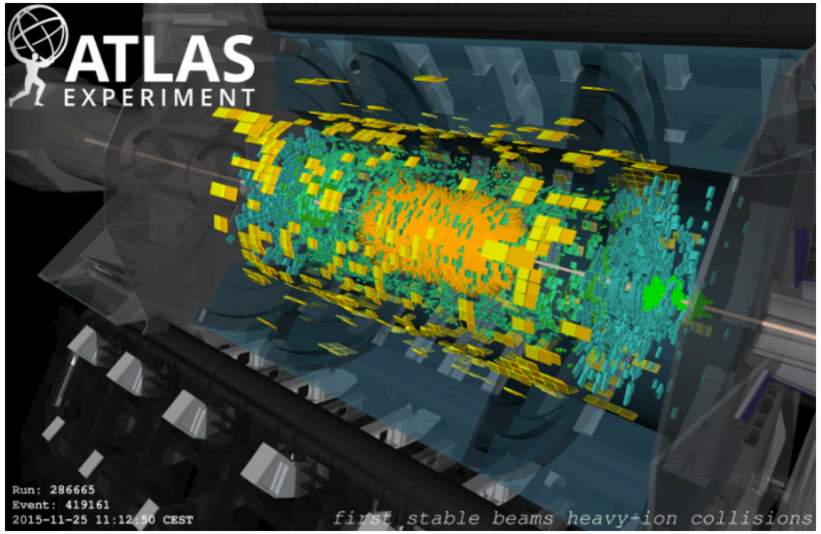
Many thanks to:

S. Boogert, R. Bruce, M. Crouch, N. Fuster-Martinez, A. Mereghetti, J. Molson, L. Nevay, S. Redaelli

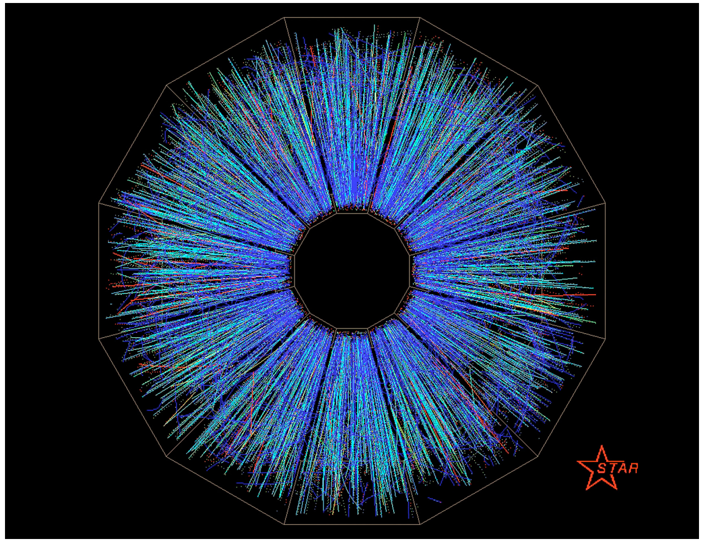
06.12.2019, JAIFEST 2019

Ion beams in hadron colliders

- Ion collision are used to study quark-gluon plasma (QGP).
- Two ion colliders currently operational:
  - Relativistic Heavy-Ion Collider (RHIC) at BNL.
  - Large Hadron Collider (LHC) at CERN.
- RHIC is a dedicated ion collider, while the LHC operates with ions for a limited period every run.
- Future hadron collider designs such as the HE-LHC, FCC-hh and SppC all include ion collider options by design.



LHC



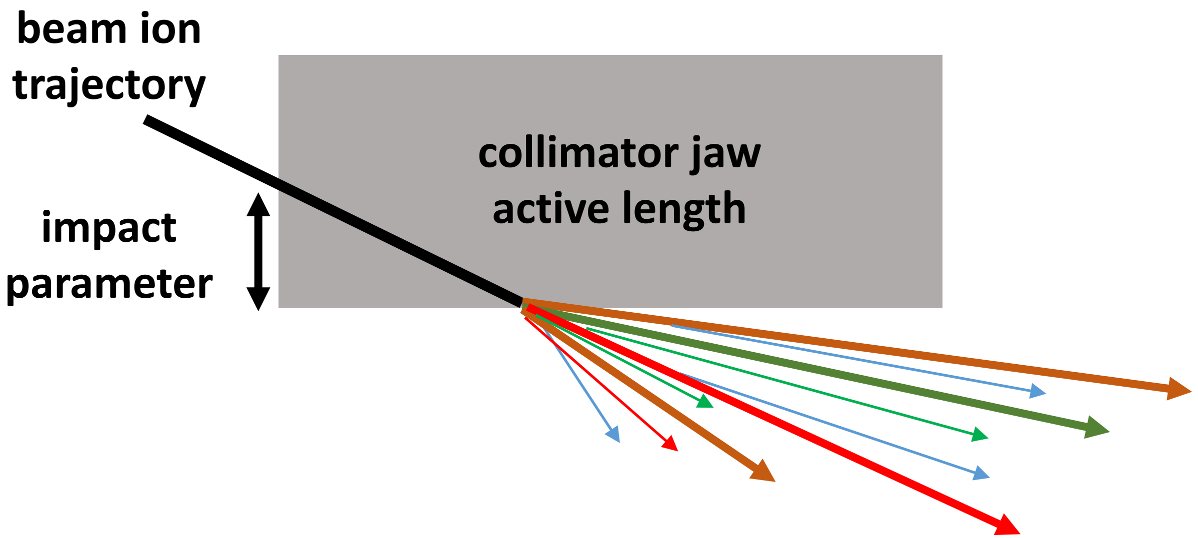
RHIC

Collimation of heavy-ion beams

- Beam ions can undergo nuclear fragmentation and electromagnetic dissociation (EMD) inside the primary collimators.
- The distance traversed inside the collimator strongly affects the fragment spectrum and hence the collimation cleaning efficiency.

$$\mathrm{EMD_m} : {}^{208}\mathrm{Pb}^{82+} + {}^{12}\mathrm{C} \rightarrow {}^{208-m}\mathrm{Pb}^{82+} + {}^{12}\mathrm{C} + \mathrm{mn}$$

$$\mathrm{Fragmentaion} : {}^{208}\mathrm{Pb}^{82+} + {}^{12}\mathrm{C} \rightarrow {}^{\mathrm{A_X}}\mathrm{X}^{\mathrm{Z_X}} + {}^{\mathrm{A_Y}}\mathrm{Y}^{\mathrm{Z_Y}} + N_\mathrm{n}\mathrm{n} + N_\mathrm{p}\mathrm{p}$$

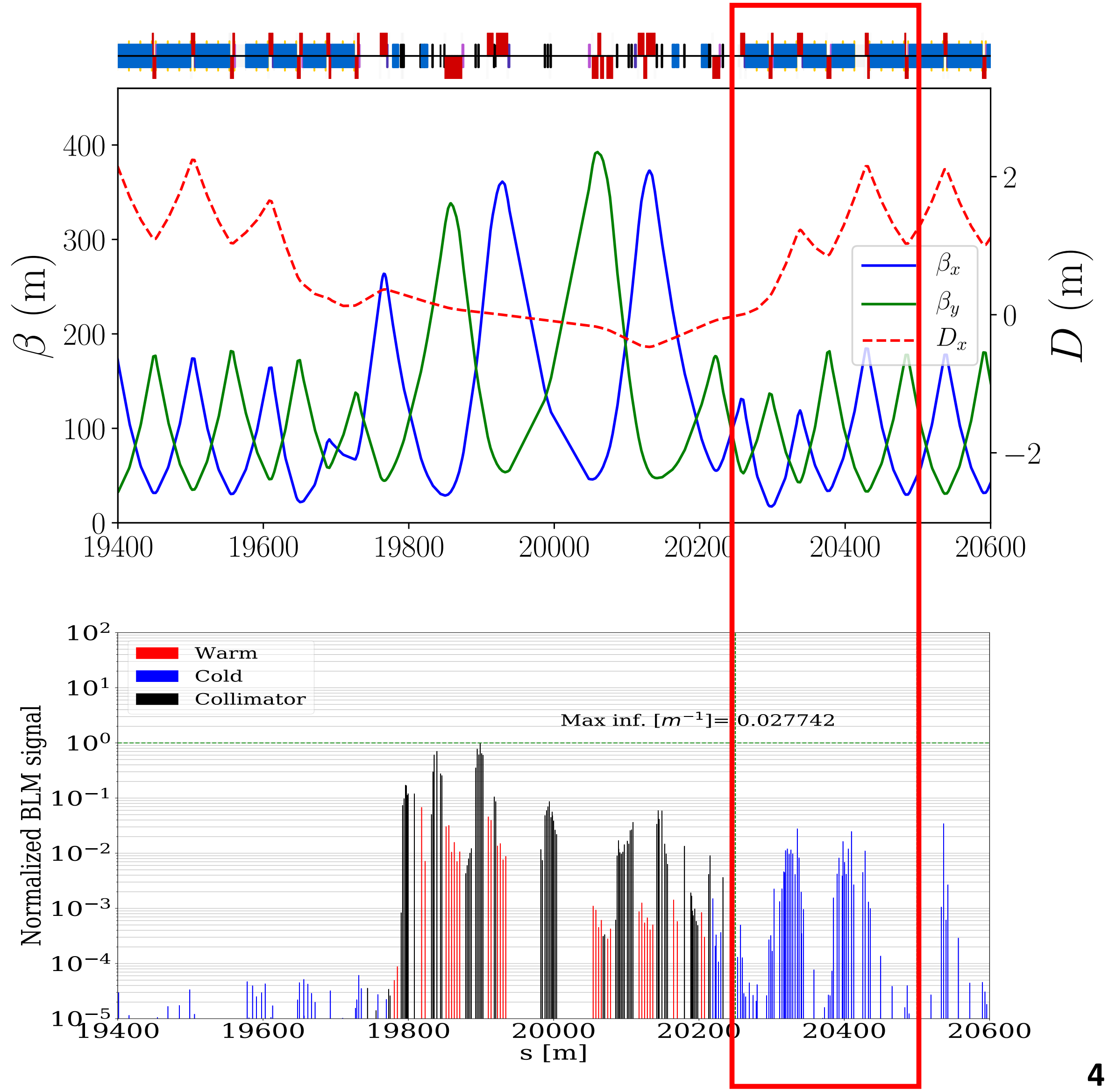


Collimation of heavy-ion beams

- Secondary ions leaving the warm collimation insertions pose a risk to the downstream dispersion suppressor.
- In the LHC, the collimation cleaning efficiency is one of the limiting factors for ion beam intensity.

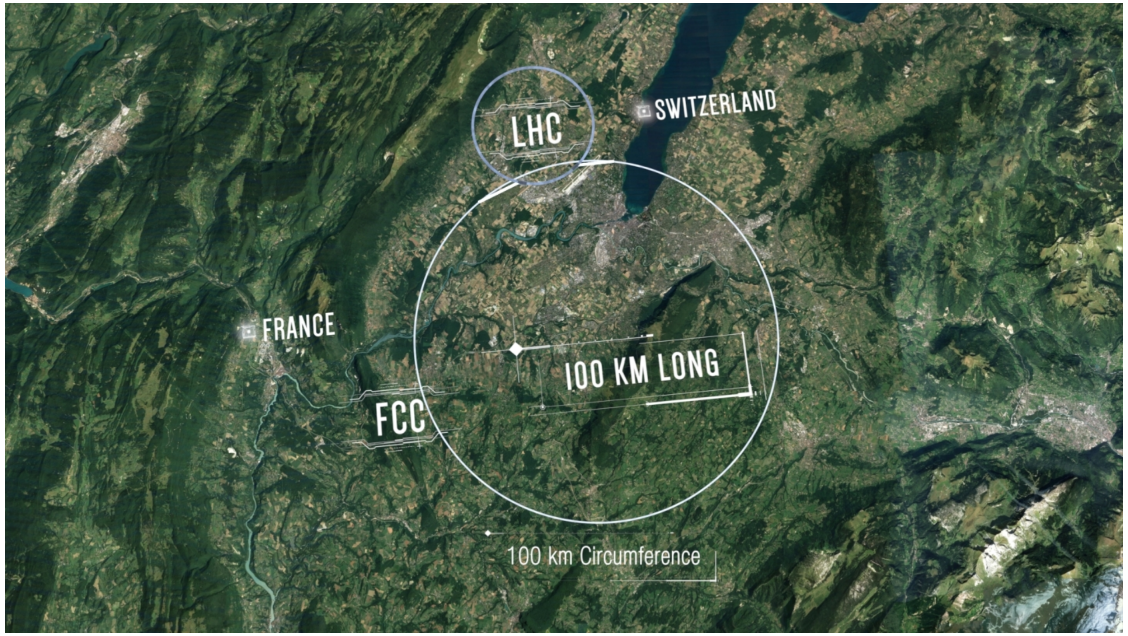
Optics for LHC IR7

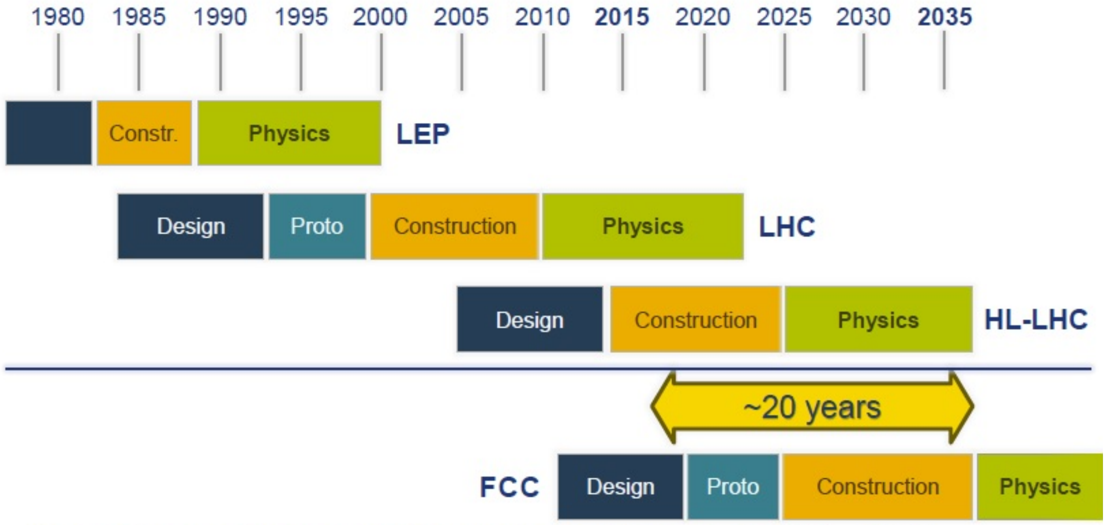
Measured loss map For LHC IR7



The Future Circular Collider (FCC)

- A study focused on a post-LHC energy frontier collider to be built at CERN.
- Three possible collider versions explored – hadron (FCC-hh), lepton (FCC-ee) and lepton-hadron (FCC-he).
- FCC-hh includes ion operation in the baseline design.

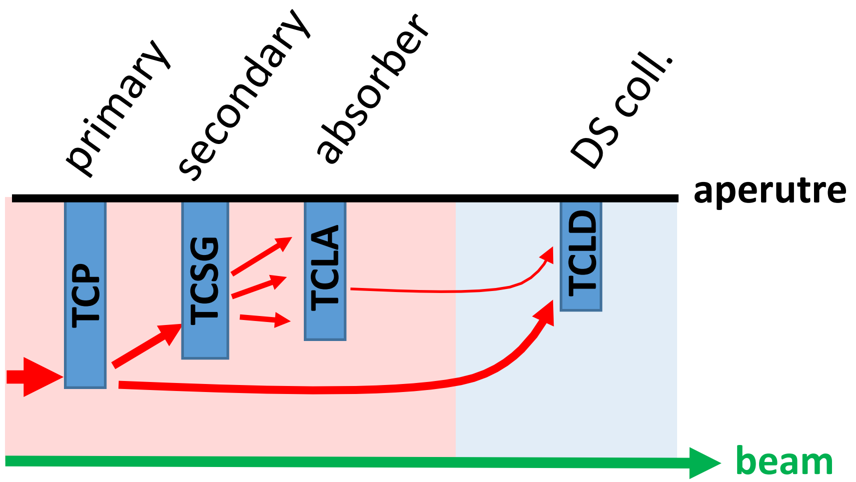




Introduction

- The FCC-hh includes a multi-stage collimation system:
  - Designed to clean the beam halo and protect the ring from beam losses.
- Heavy-ion operation involves additional challenges:
  - Ion collimation efficiency in the LHC is a ~2 orders of magnitude worse for ion than for protons
  - The stored ion beam energy in the FCC-hh is a factor ~25 larger than in the LHC.

β-coll.



FCC-hh layout

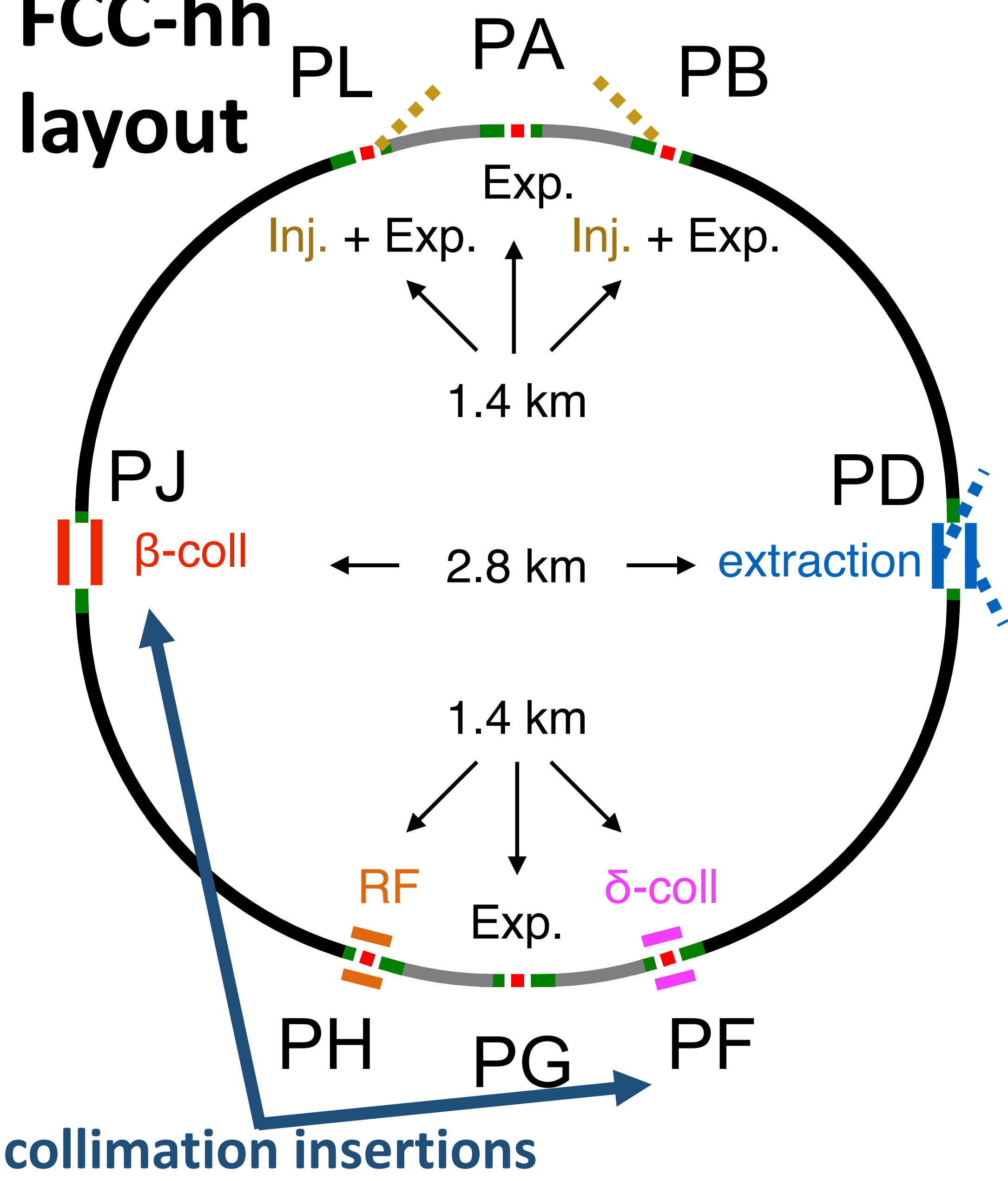
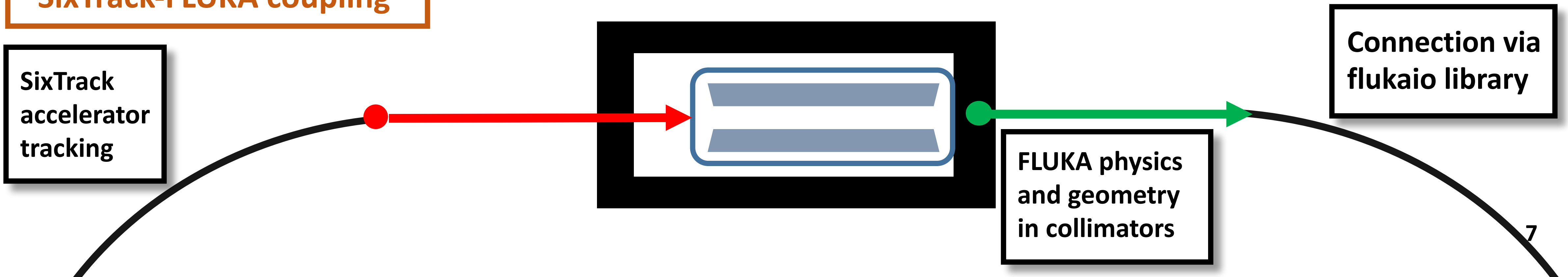


*Figure from FCC-hh long CDR

Simulation tools

- Studying ion collimation requires specialised tools:
  - Beam ions can undergo nuclear fragmentation and electromagnetic dissociation in the primary collimator, producing multi-species secondary ion beams.
- The simulations are performed using the **<u>SixTrack-FLUKA active coupling</u>**.
  - Thanks to A. Mereghetti, J. Molson, P. Hermes and the FLUKA team at CERN
- Combination of tracking and physics interactions:
  - Symplectic tracking in the accelerator magnetic lattice is performed by SixTrack.
  - Monte Carlo simulation of beam ion interaction with the collimators is performed in FLUKA.

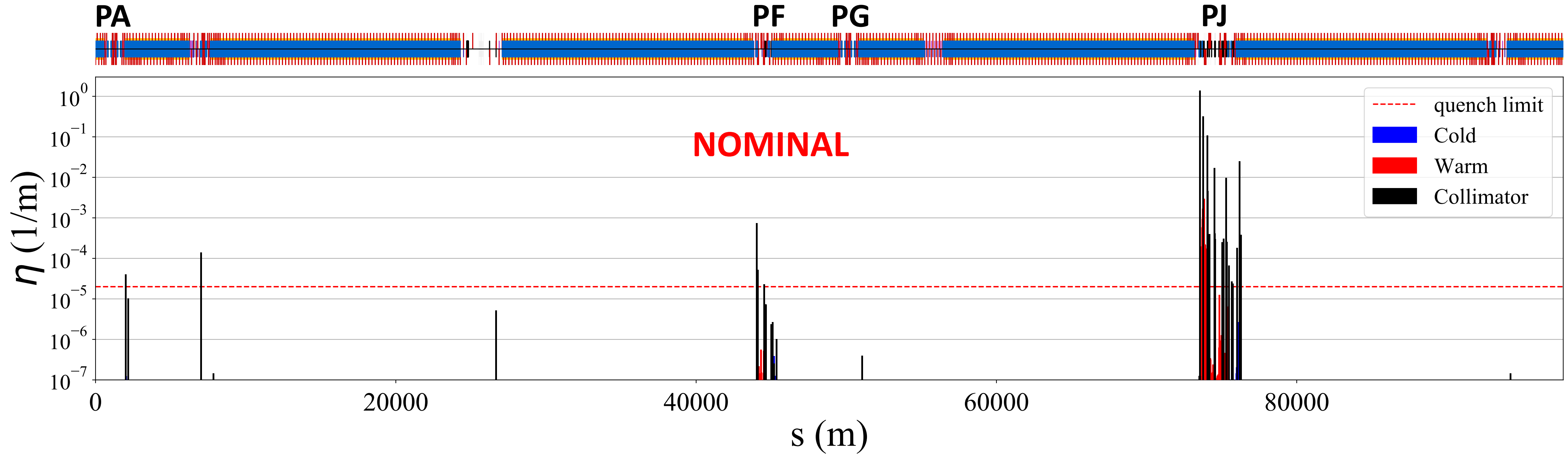
SixTrack-FLUKA coupling

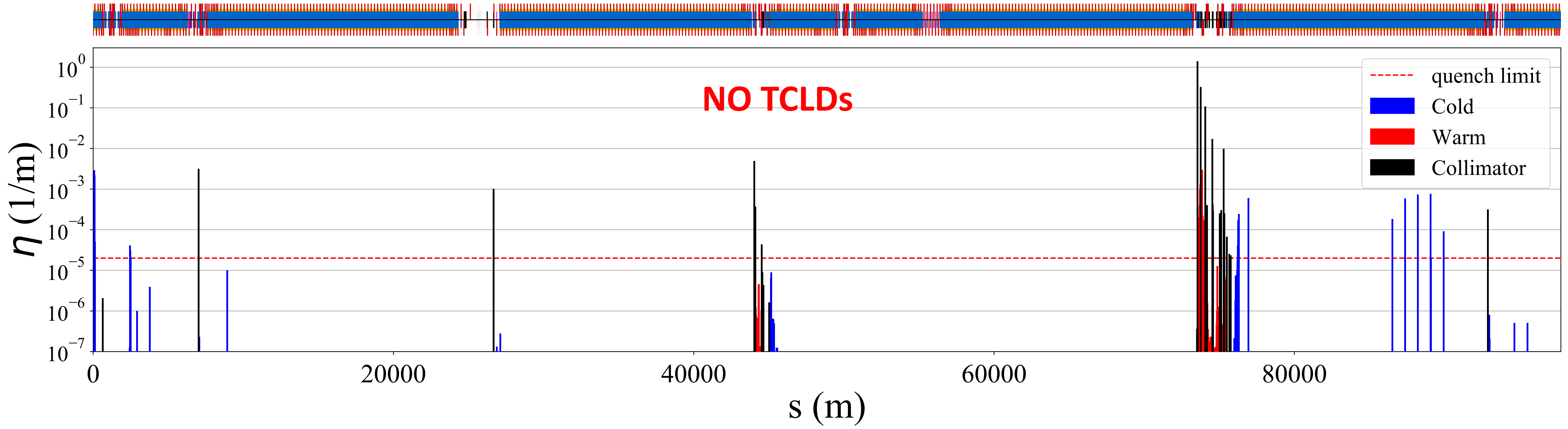


Simulation

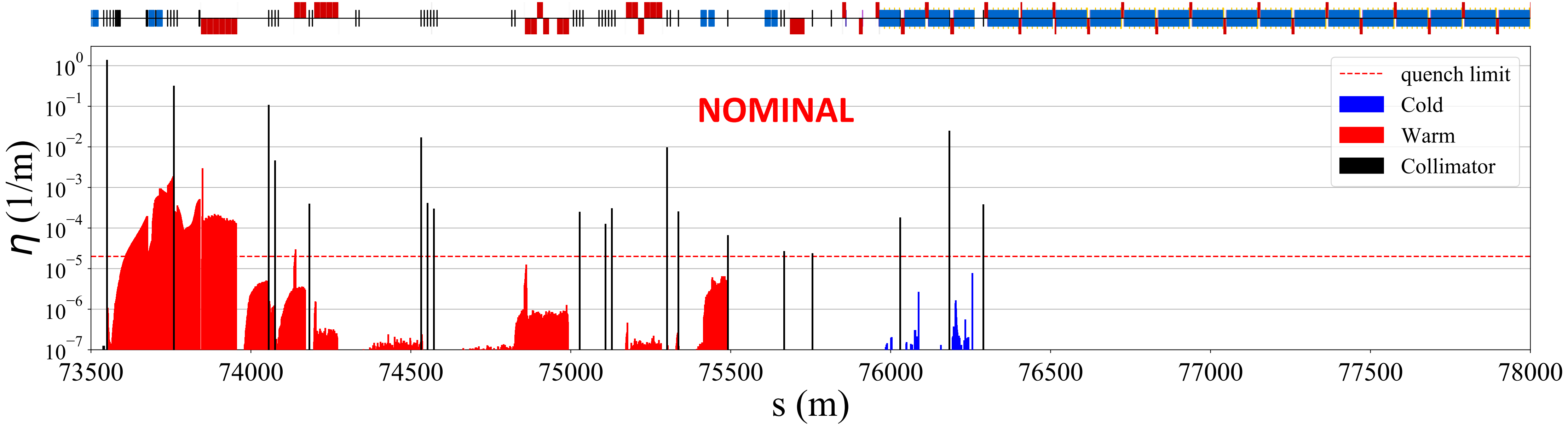
- Study the collimation system performance for Lead (Pb) ion beams:
  - Investigate the most demanding cases – betatron collimation in collision mode and off-momentum collimation in injection mode.
  - Evaluate the performance of the dispersion suppressor collimators (TCLDs)
- Simulation procedure:
  - Perform loss studies for Beam 1 in the horizontal (B1H) using a halo beam.
  - Compare the results against an estimate of the quench limit.
  - Analyse in more detail the losses in dispersion suppressor (DS).

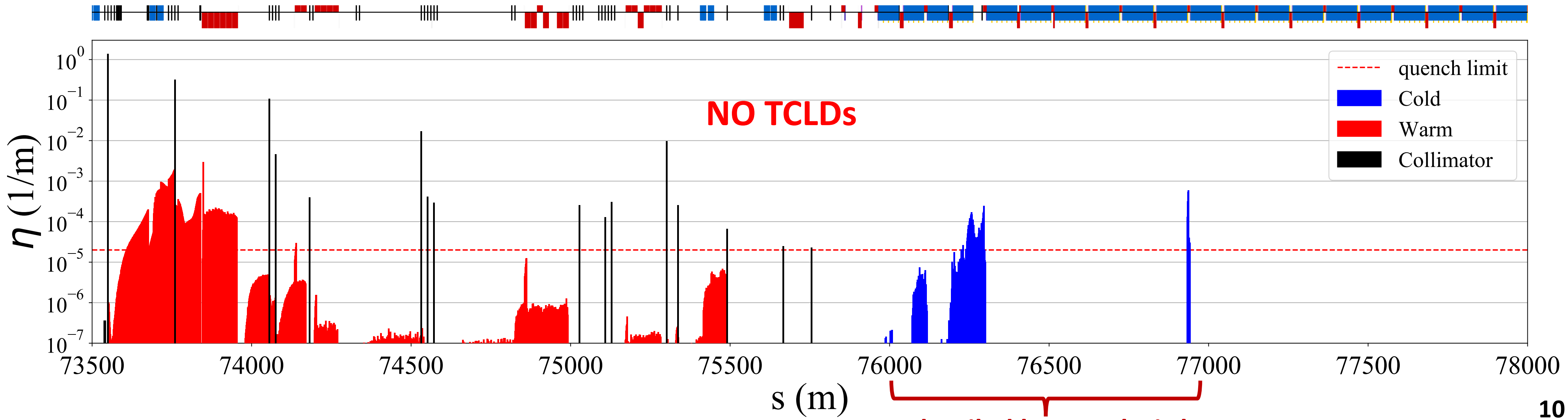
FCC-hh betatron cleaning at collision – B1H





FCC-hh Betatron cleaning at collision – B1H

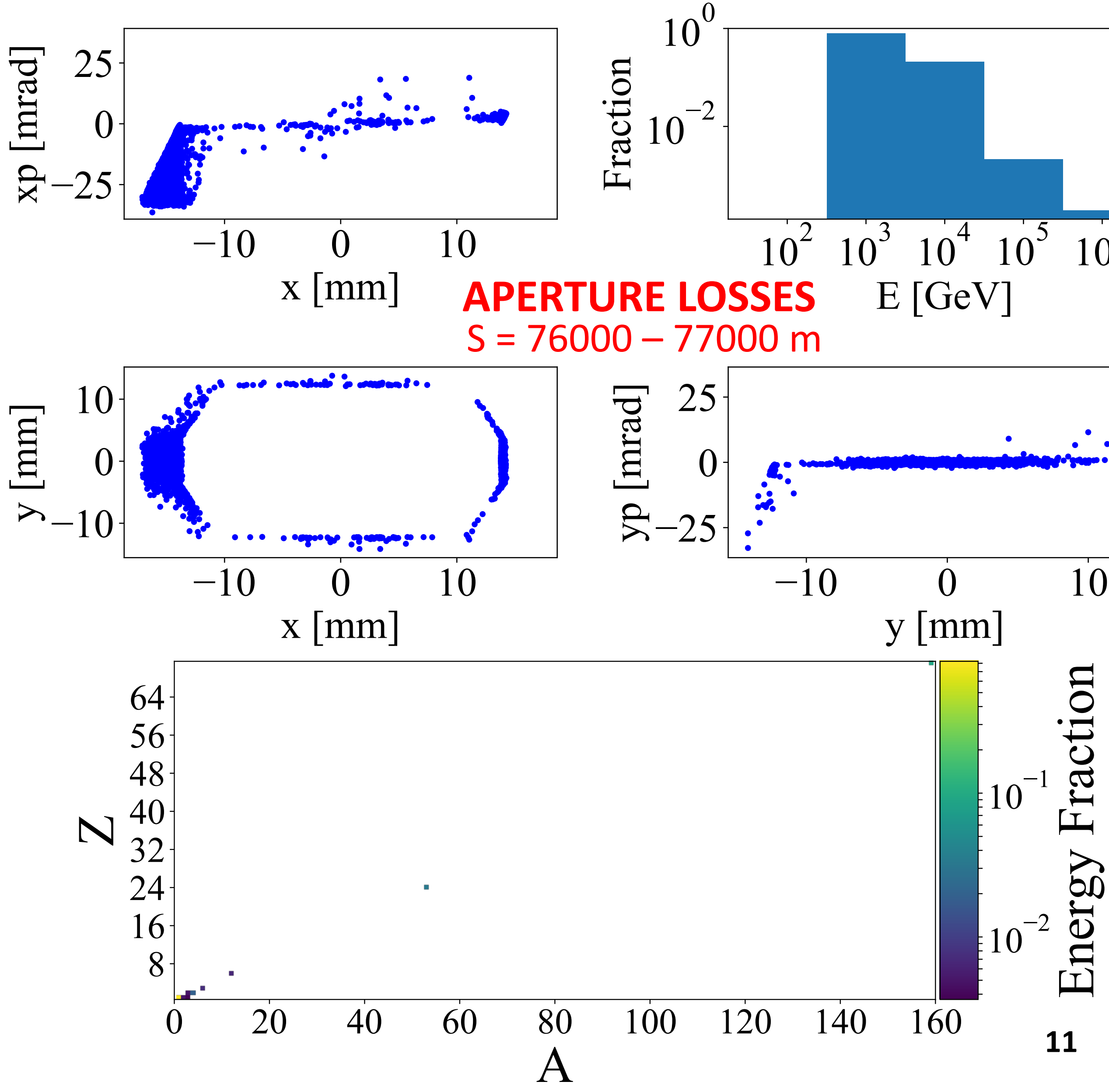




detailed loss analysis later

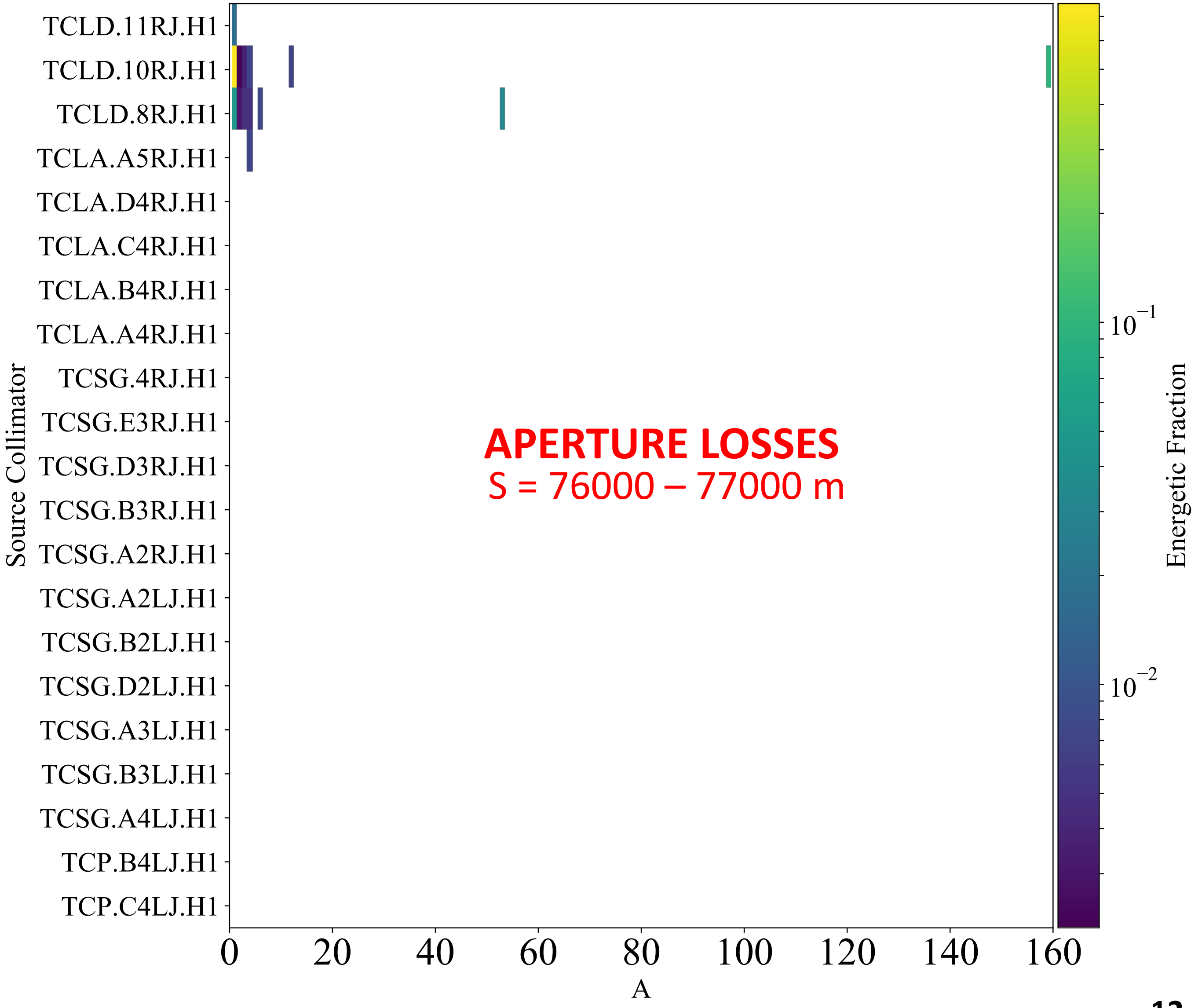
FCC-hh DS losses analysis – B1H in collision

- The dispersion suppressor of the betatron cleaning insertion is one of the critical areas for losses.
- Analysis of the losses on the cold aperture shows more losses on the inside of the ring.
- Light ion fragments make up most of the losses on the aperture.



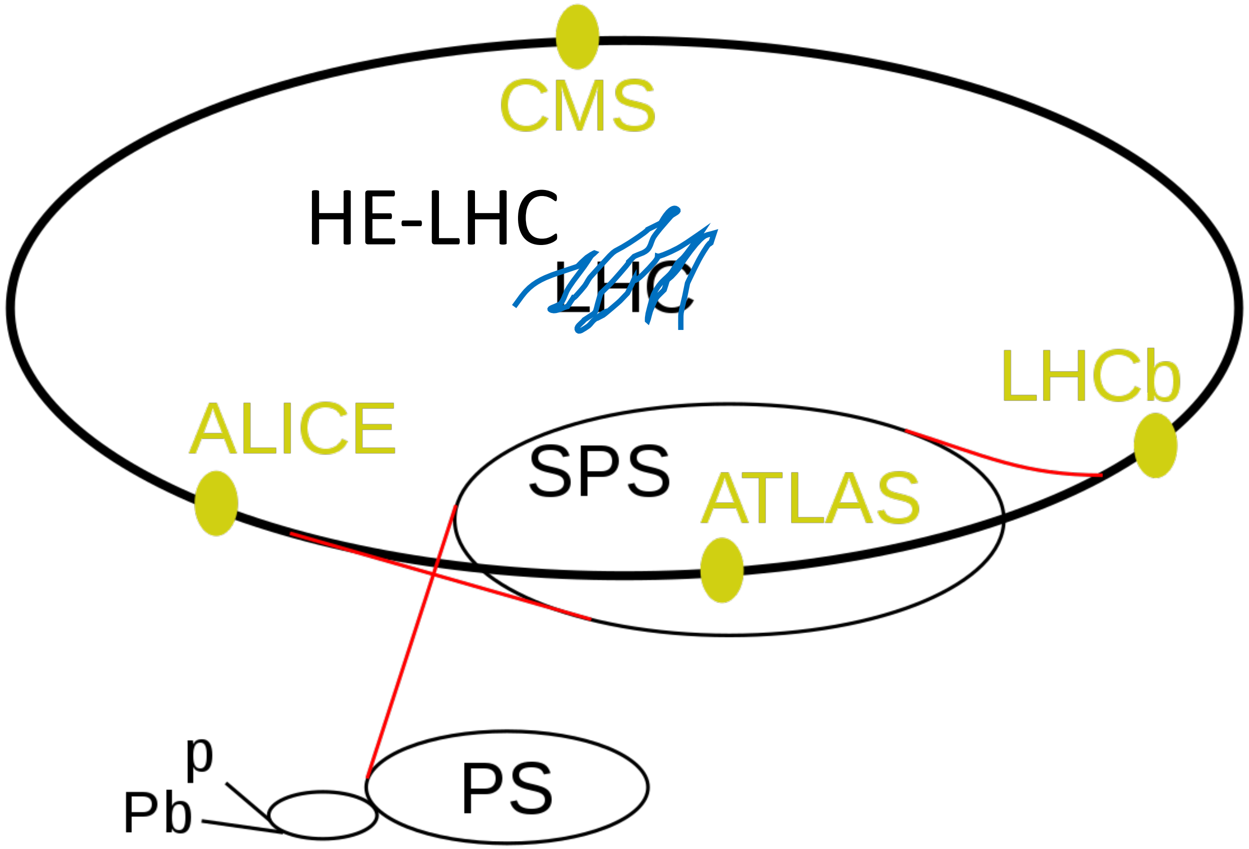
FCC-hh DS losses analysis – B1H in collision

- Connect the aperture losses to the collimator where they originated.
- All the fragments coming from the TCPs and TCSGs are successfully intercepted by the TCLDs.
- The dominant contribution to energy lost in the DS are light fragments leaking out from the TCLDs

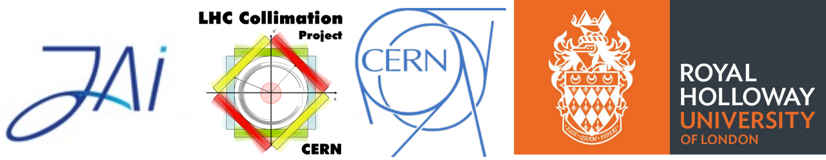


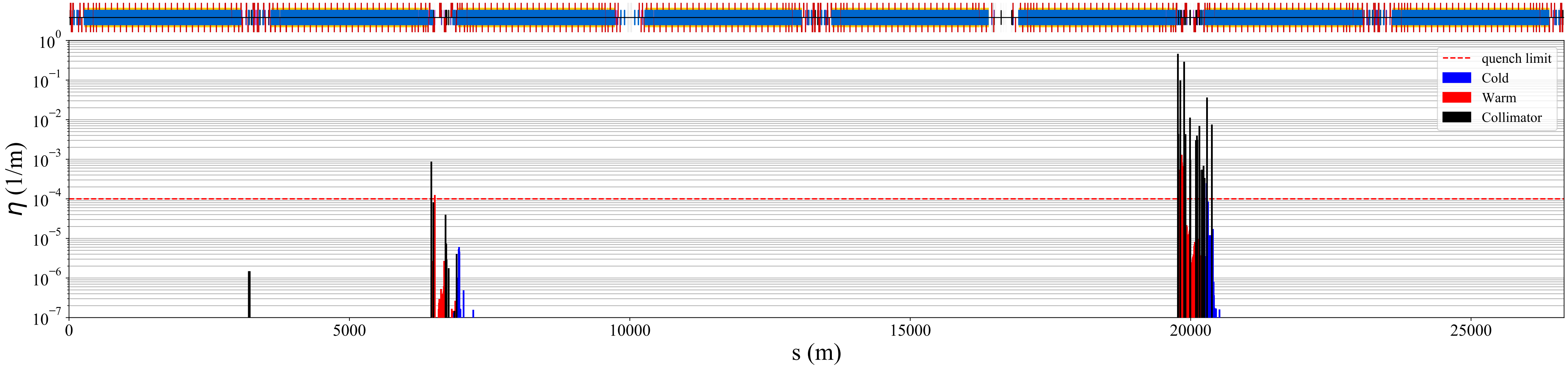
The High-Energy LHC (HE-LHC)

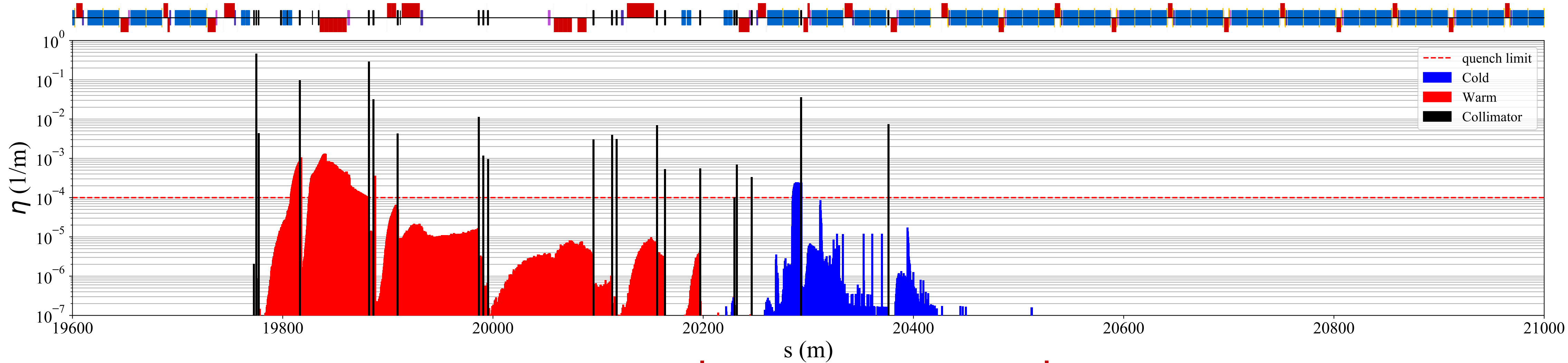
- An alternative proposal for a post-LHC hadron collider.
- Use the LHC infrastructure, but with FCC-hh technology, such as magnets.
- Also includes DS collimators, but due to space constraint, changes in the layout and optics were required.



HE-LHC betatron cleaning at collision – B1H





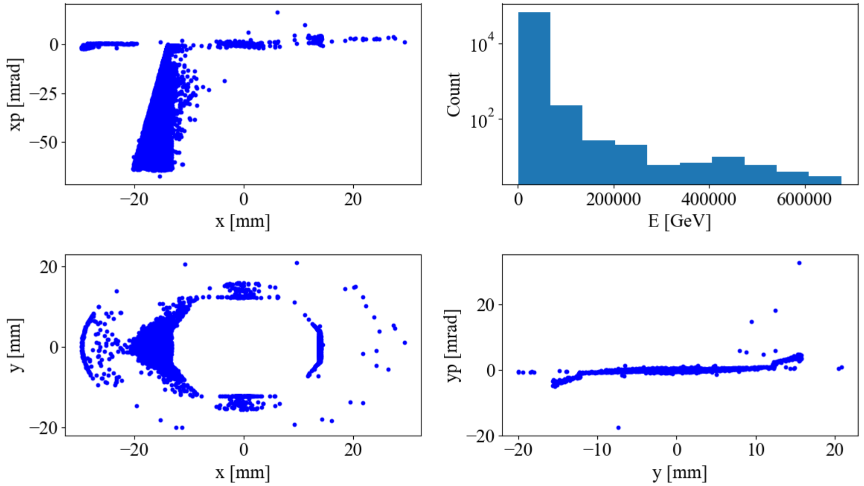


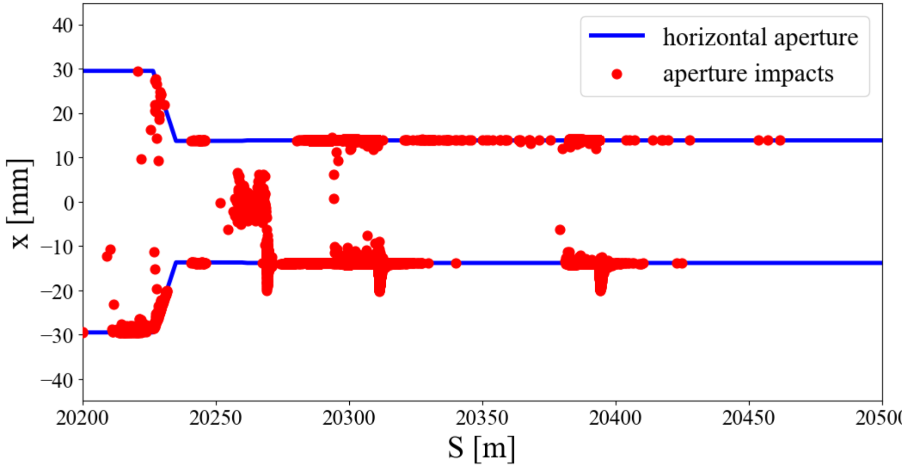
detailed loss analysis later

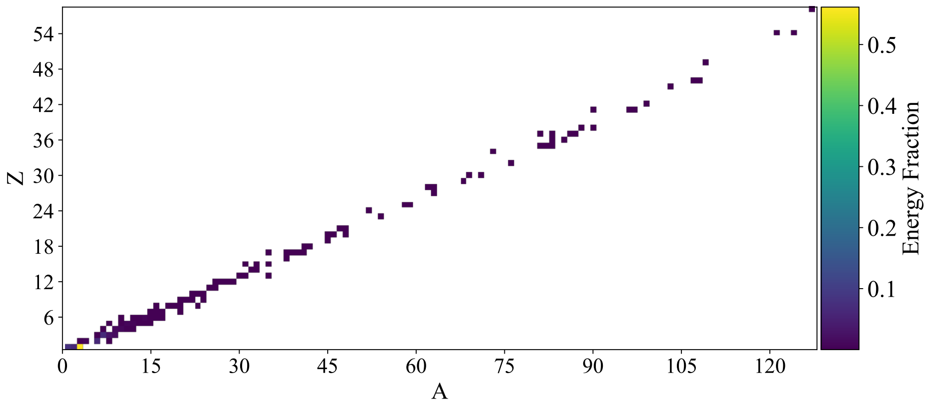
HE-LHC DS losses analysis – B1H in collision

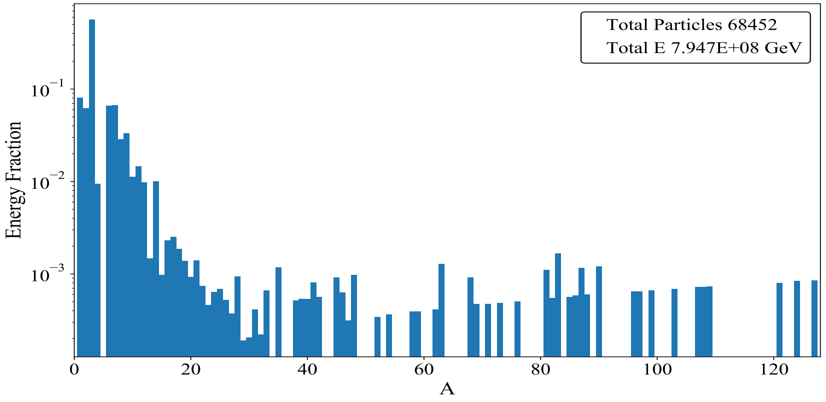
- A large cold loss spike with a magnitude above the estimated quench limit is observed just upstream of the first TCLD for B1H (also for B1V).
- Performed detailed investigation of the cold losses in the DS.

APERTURE LOSSES
S = 20200 – 20500 m



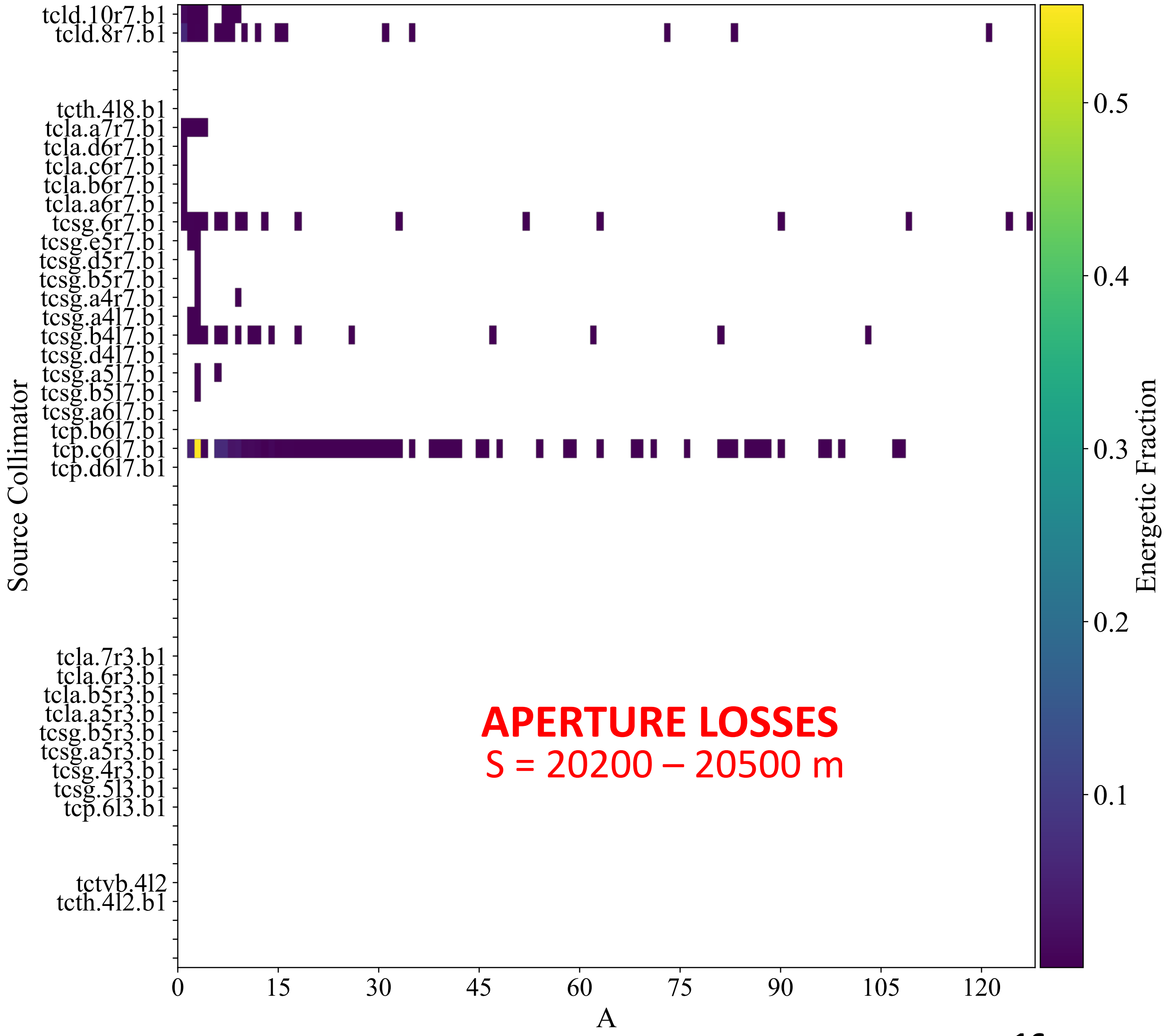






HE-LHC DS losses analysis – B1H in collision

- Analysing the DS losses shows that the largest energetic fraction comes from light fragments originating in the primary collimator.
- Based on the results, a couple of mitigation strategies are investigated:
  - Tightening the openings of secondary collimators and absorbers.
  - Using an asymmetric primary collimator opening.
  - Using an orbit bump to shift the losses onto the TCLD.



Conclusions

- The study of ion collimation for the FCC-hh shows good cleaning performance. Beam losses can be sustained without quenching within the specification for 12 minute beam lifetime.
- Ion collimation in the HE-LHC is also found to be adequate, with some areas where additional investigation is required.
- The TCLD collimators are shown to be critical for ion operation as they intercept heavy-ion fragments coming from warm collimation insertion upstream.
- Further energy deposition studies are necessary to fully asses the quench risk.