Collimation aspects of the PSI beams in the LHC

A. Abramov, R. Bruce, A. Gorzawski, N. Fuster-Martinez, J. Molson, S. Redaelli

GF meeting – CERN 25.03.2019

Outline

1. Results of the PSI MD in the LHC and first understanding 

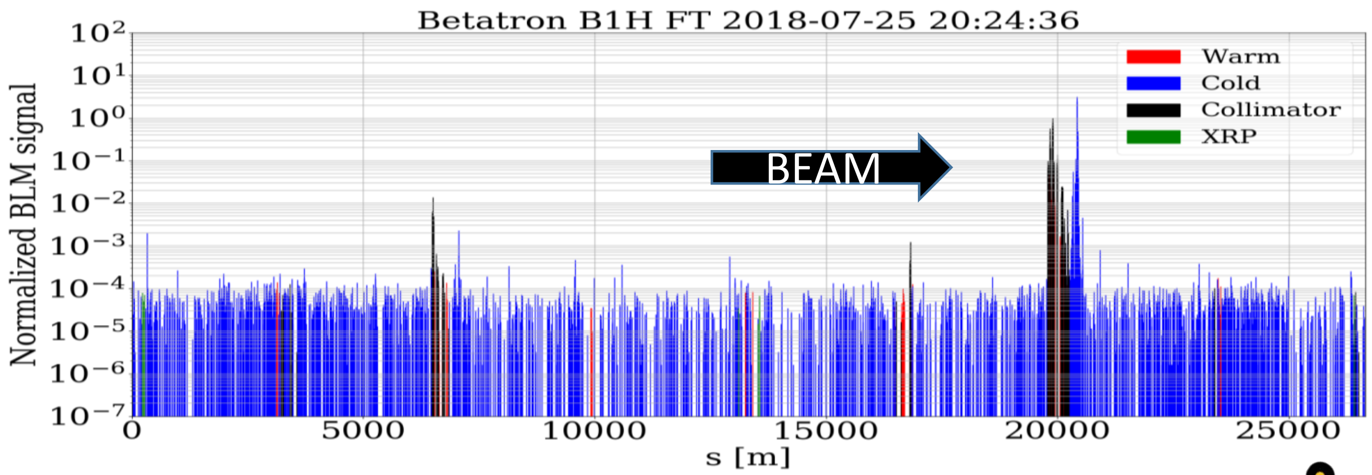
2. Proposed mitigation techniques 

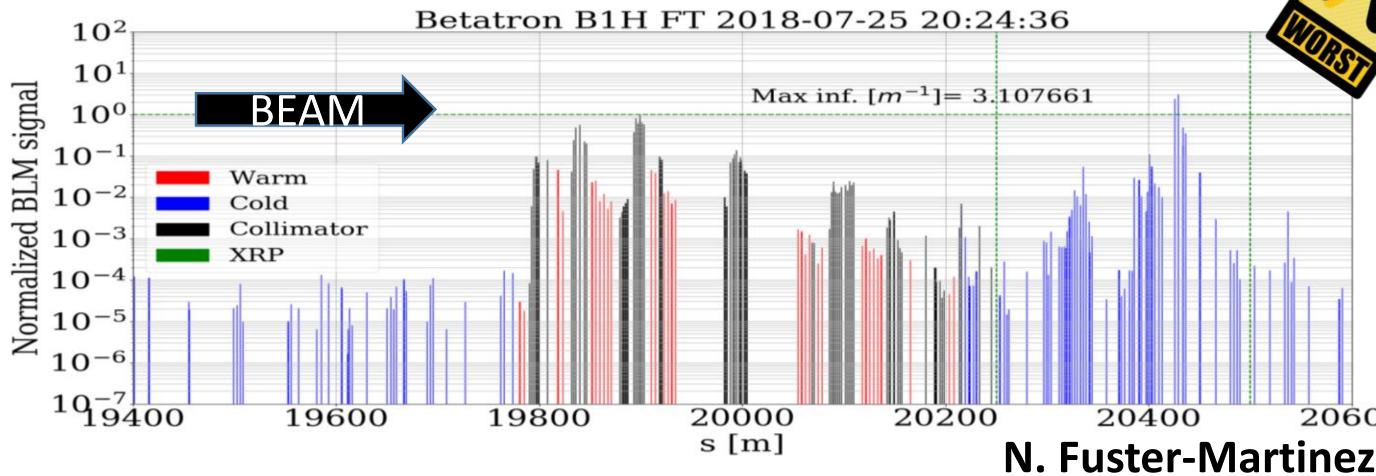
3. **Available software tools**
4. **Quantitative results of simulations**
5. **First intensity limit estimates**

Collimation of the PSI beams during the PSI MD

Collimation performance with PSI beams in the LHC

- The first experience of PSI beam collimation was acquired during MD3284 [1].
- Loss map measurements were performed for injection and flat top.
- **The highest losses in both cases were recorded in cell 11**.
- Severe losses were observed in the cold magnets of the dispersion suppressor of IR7 for flat top.
- **With 24 low-intensity bunches a dump was triggered after only 2 minutes at flat top**.
- **Loss map was taken with only 6 low-intensity bunches**.



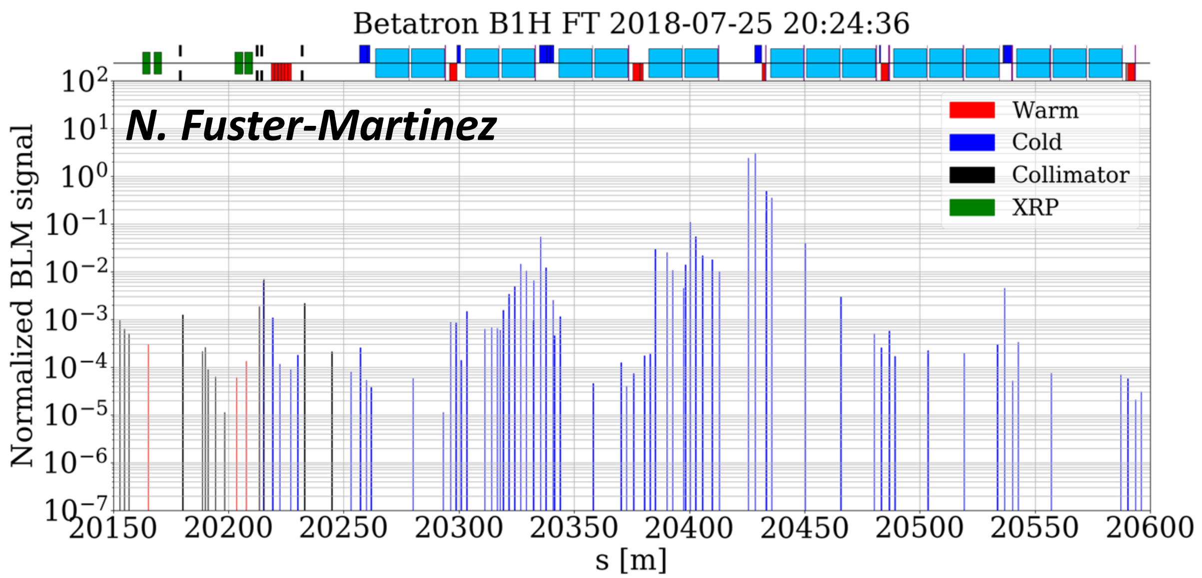


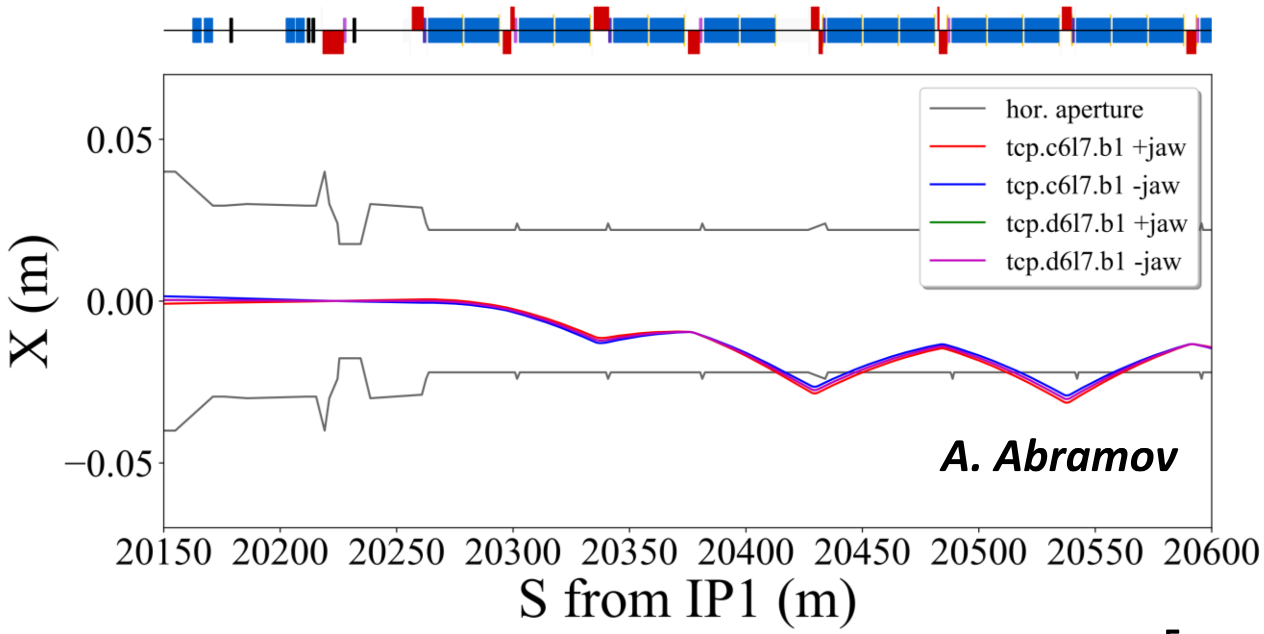
N. Fuster-Martinez

[1] **M. Schaumann**, https://indico.cern.ch/event/781222/

Understanding the losses

- The most likely explanation of the extreme losses in the DS is **that the primary collimators can strip the electron from PSI in the halo without fragmenting them.**
- The resulting **off-rigidity fully-stripped ions are lost on the cold aperture in the DS** where the dispersion ramps up.
- Simulations of equivalent off-momentum trajectories in MADX backs this theory and predicts the loss location with good accuracy.





Mitigation strategies

- With the current collimation configuration the losses greatly limit the possible intensity reach. Mitigation strategies considered include:

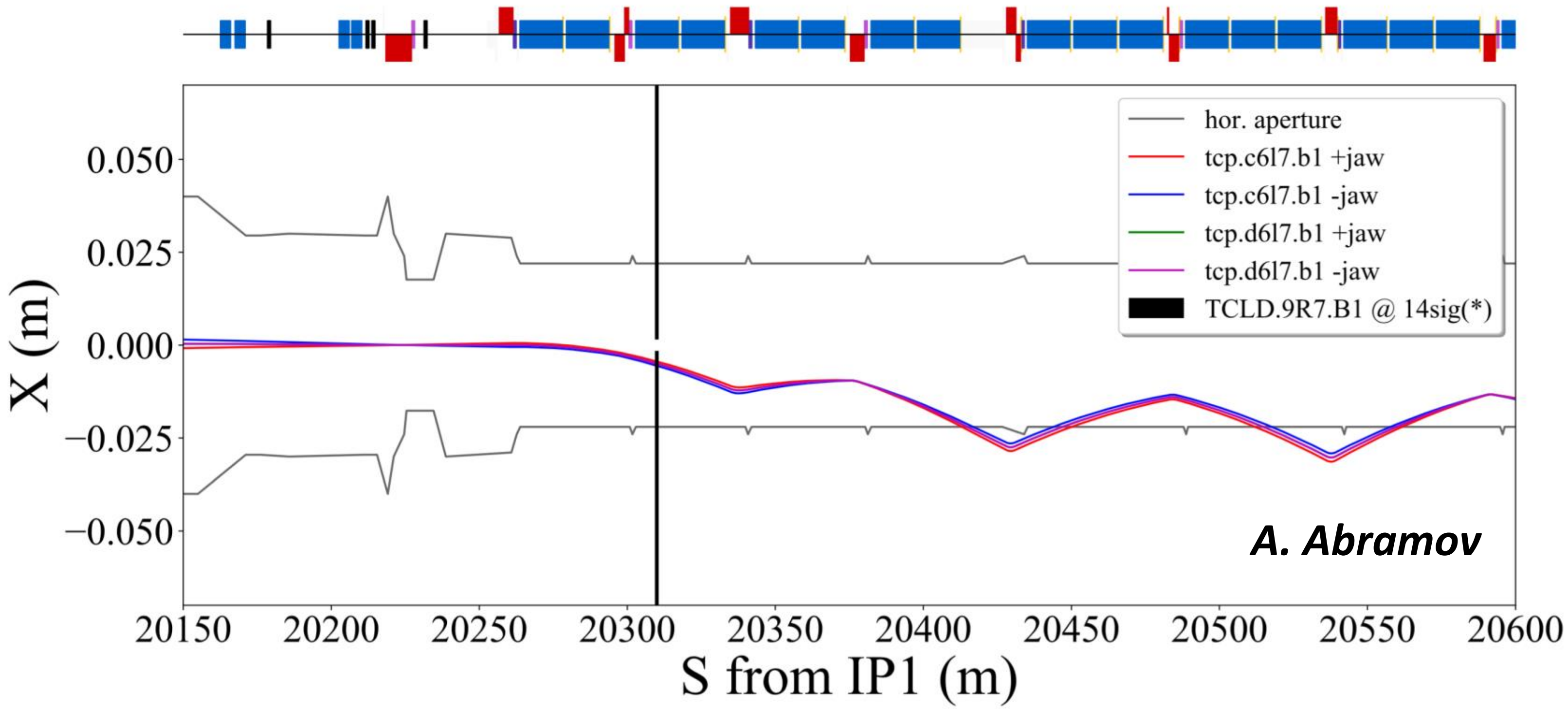
Dispersion suppressor collimator (TCLD)

Crystal collimation

Orbit bump

Mitigation strategies - TCLD

- The plan is to install a dispersion suppressor collimator (TCLD) during LS2.
- The location of the **TCLD was changed from cell 8 to cell 9 in December 2018**.
- In cell 8 the collimator wasn't expected to intercept the losses, but **in cell 9 it there is a good outlook that it will**.
- At present, without energy deposition studies, it is not possible to quantify the intensity limit with the TCLD in as the load on the collimator will likely be very high.



Preliminary plot with the TCLD at the nominal opening of 14 sigma

More detailed studies later in Fluka results…

Mitigation strategies - other

- **Crystal collimation**
  - Another potential strategy is to use crystal collimators.
  - It is theorized that both partially stripped and fully stripped ions can be channeled onto an absorber before they leave the warm collimation insertion.
  - In addition to this, the channeling is expected to suppress the interaction cross-sections.
  - **MD4166 was approved to test this concept, but never took place due to technical problems**.
- **Orbit bump**
  - Orbit bumps are used to move cold losses from BFPP in the DS of experimental insertions to a more favorable location like the connection cryostat.
  - Such a bump can be considered for the DS of IR7.
  - **May not be needed if the TCLD is found to be effective**.

Simulations

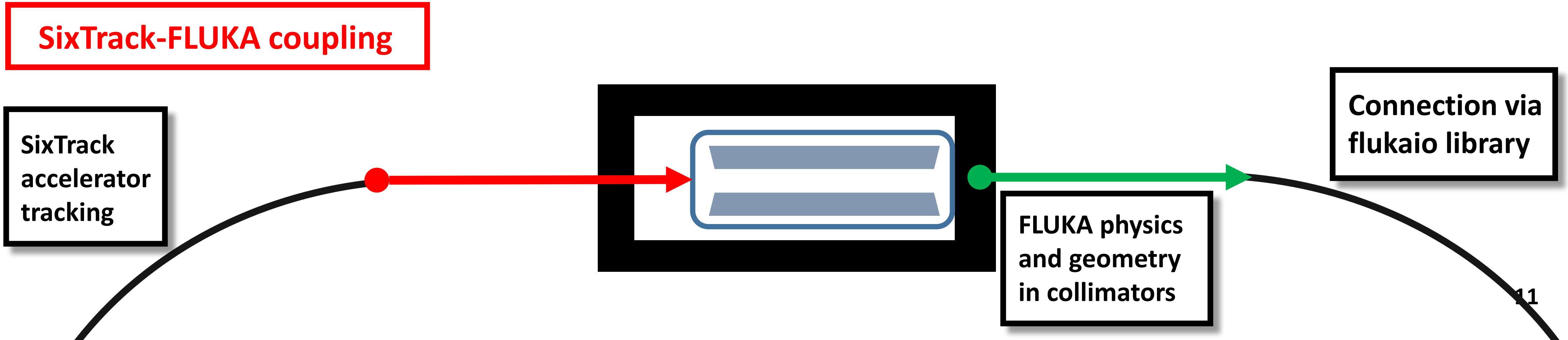
Tools and first quantitative results

Simulation methods

- Due to **the bound electrons and additional physics interactions involved**, it is **not currently possible to perform direct collimation cleaning** efficiency studies for PSI beams.
- As a start, attempt to recreate the measured loss maps as accurately as possible using available tools and some assumptions, e.g. **all beam ions fully stripped by the primary collimator.**
- In addition, work towards integrating support for PSI tracking and physics interactions to existing radiation transport frameworks.

SixTrack – FLUKA active coupling

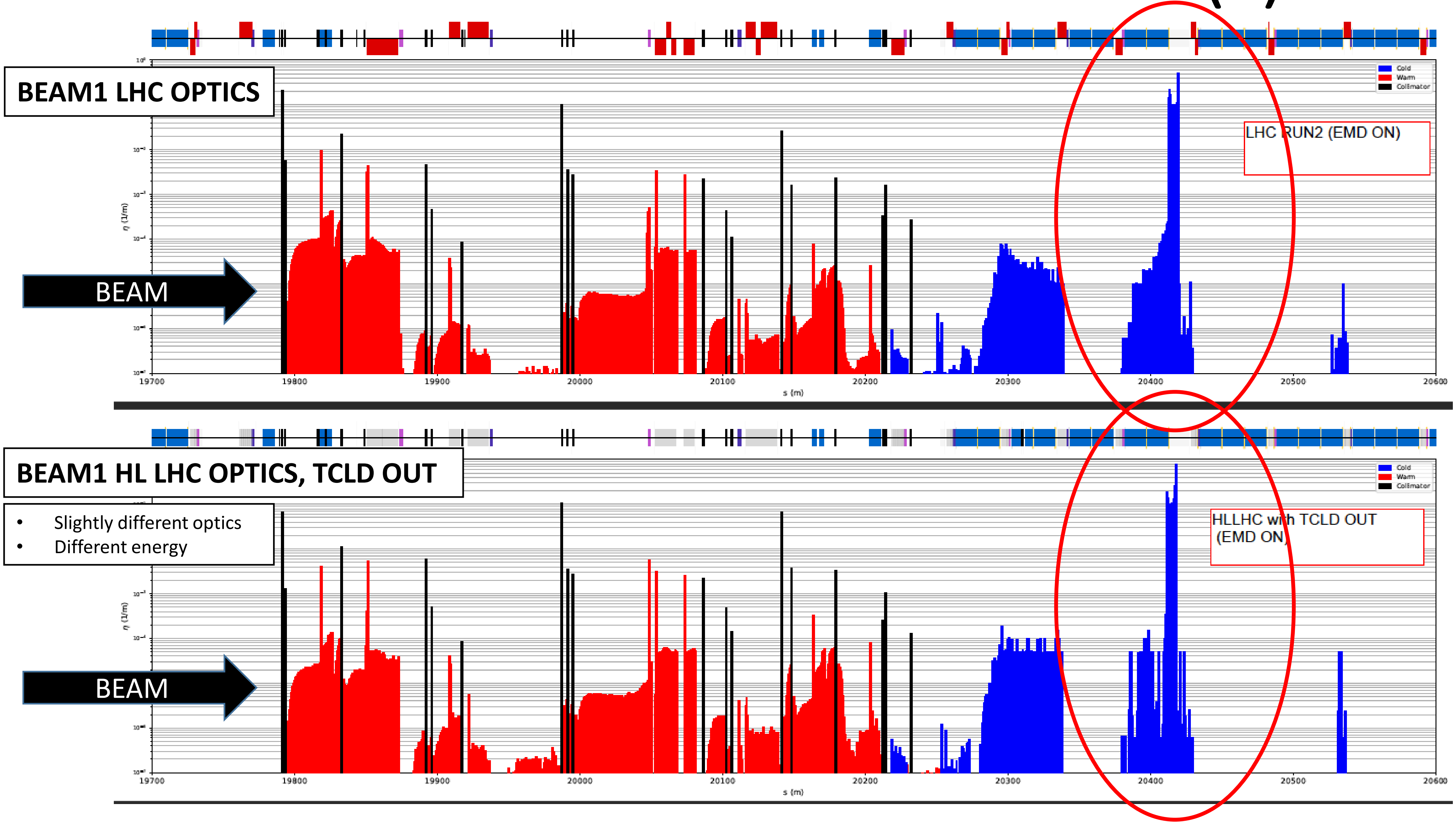
- The SixTrack-FLUKA coupling combines tracking in SixTrack and Monte Carlo simulation of physics interaction inside the collimators in FLUKA.
- One of the trusted standard frameworks for collimation studies.
- Supports arbitrary ions species.
- Available immediately.
- **Does not currently support partially stripped ions, but there are some ideas of extending it.**
- *The plan is to **perform studies using off-rigidity fully-stripped ions starting at the primary collimator**, similar to the MADX studies.*



Sixtrack – Fluka Simulation setup

- **Optics for** Beam1 Horizontal at Flat Top (worst cleaning inefficiency…)
  - Run2 LHC optics (as the one used for the PSI MD test in 2018) at **6.5 TeV**
  - HL-LHC v1.2 (**with TCLD in cell 9**) at **7 TeV**
- **Sixtrack**:
  - Machine setup for **208/81+ at 6.5TeV/7 TeV**
  - Initial particle distribution 208/82+ but with an energy of 81+
  - Tracking start at the front of the **horizontal TCP**
- **Fluka**
  - Energy cuts ~100GeV
  - With Electro-magnetic Dissociation enabled for IONs

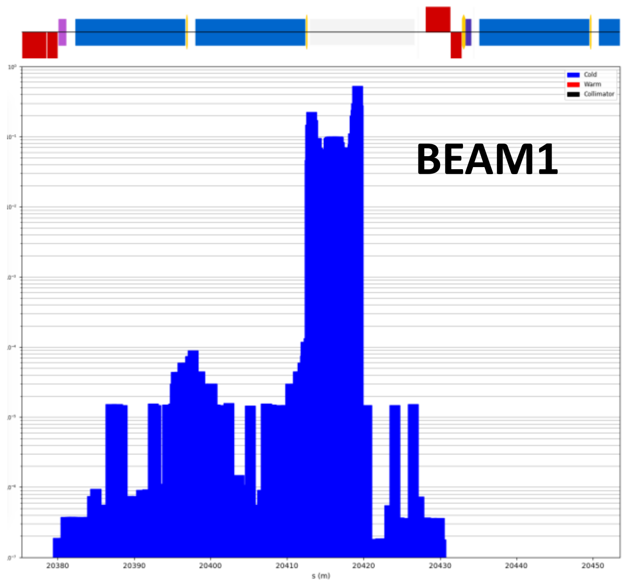
Sixtrack – Fluka Simulation results (1)

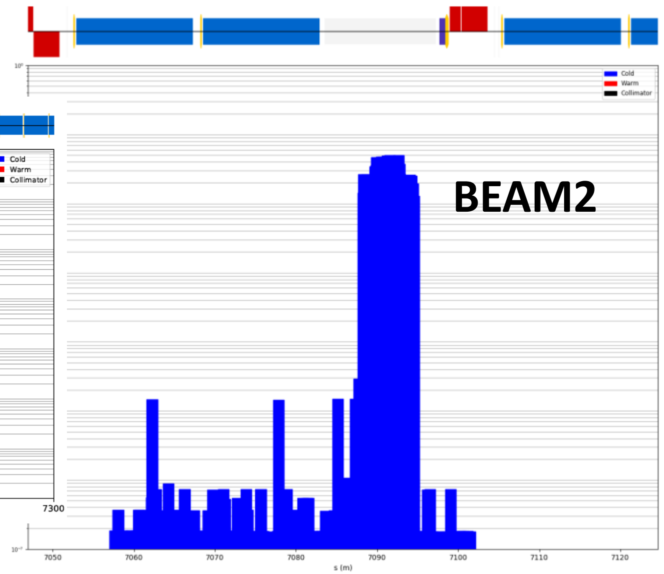


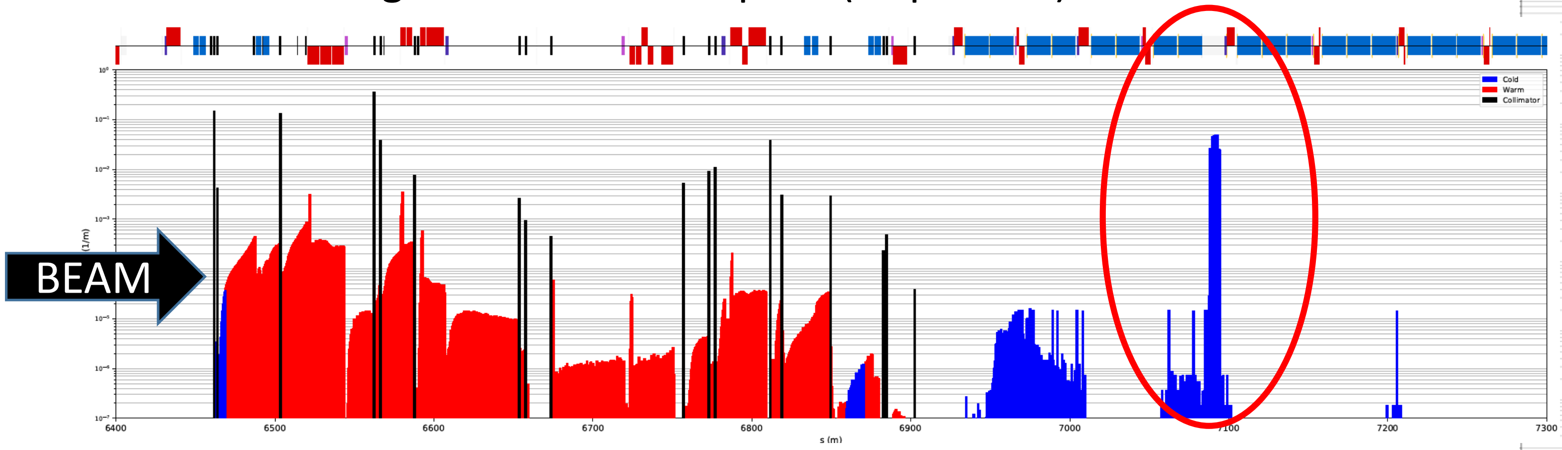
- Slightly different optics
- Different energy

Sixtrack – Fluka Simulation results (2)

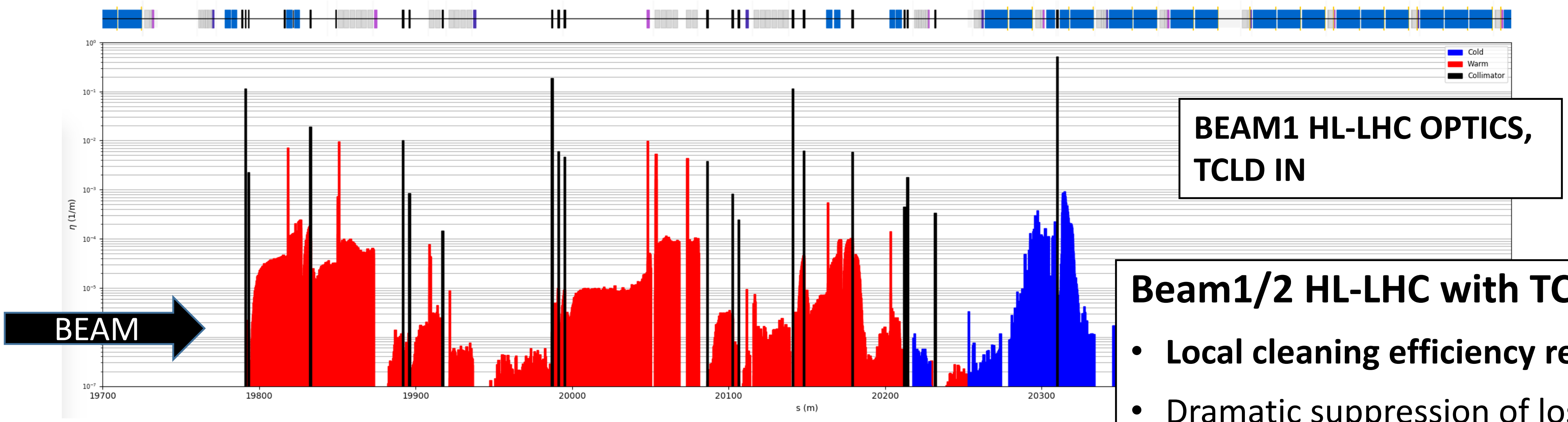
- **Beam1 LHC** / HLLHC (with TCLD out)
  - Reproduced the measured loss map
  - Highest peak identified in around the interconnection between SC dipole and DS (s=20413m)
    - **Great agreement with the measurement and simple MADX trajectory estimate!**
- **Beam2 LHC**
  - No measurement available
  - **Loss peak localized downstream wrt to Beam1**, into the other end of the DS (cell 11)
    - Slight difference in optics (dispersion)!





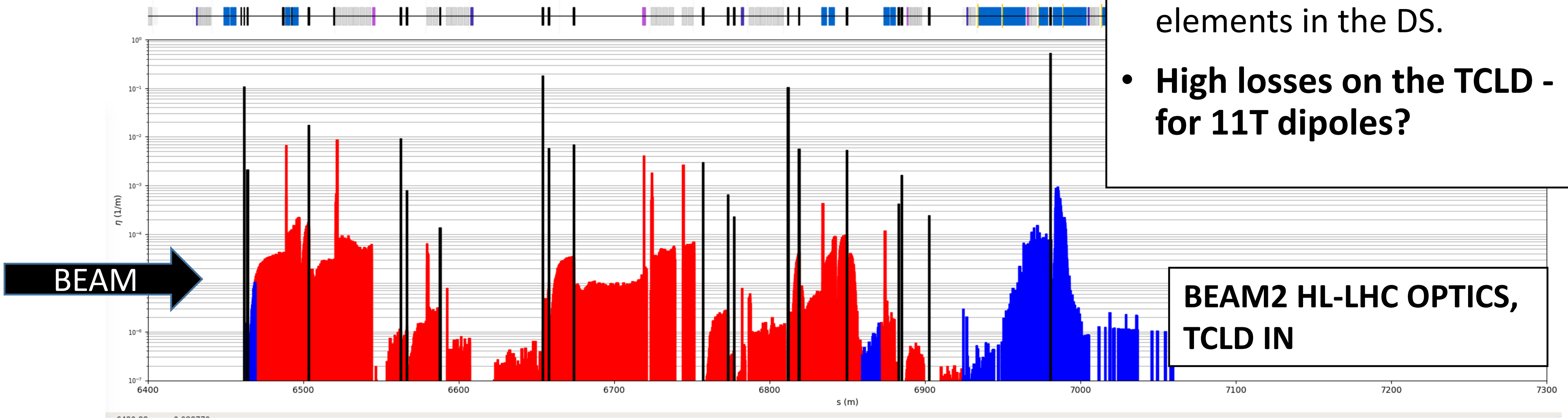


Sixtrack – Fluka Simulation results (3)



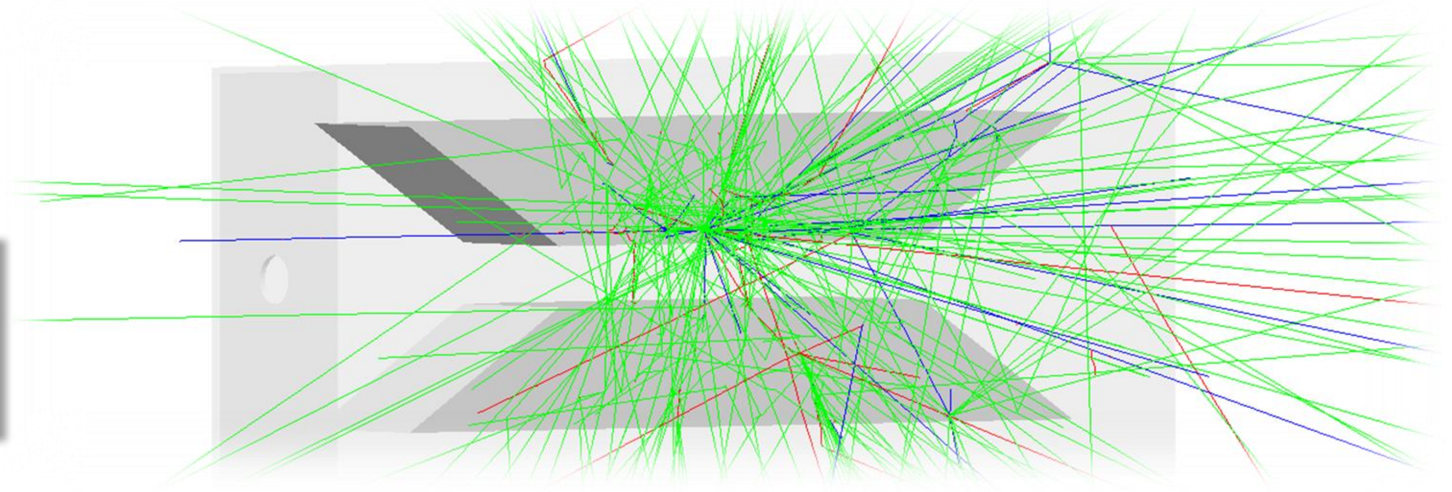
Beam1/2 HL-LHC with TCLD inserted:

- **Local cleaning efficiency restored** (cell 11)
- Dramatic suppression of losses on cold elements in the DS.
- **High losses on the TCLD - quench limits for 11T dipoles?**



Geant4 / BDSIM

- **Geant4 natively supports the definition of ions with non-zero electron occupancy**, but no relevant charge-changing physics processes are currently available.
- A stripping physics process and the other necessary physics configurations are being implemented in BDSIM and can later be integrated into a new Geant4 release.
- Can tie in with other processes like crystal channeling for ions and PSI laser excitation and de-excitation being developed for BDISM/Geant4.
- It is possible to couple Geant4/BDSIM to SixTrack and utilize those processes on a per-element basis.



Visualisation of an example particle interaction in BDSIM

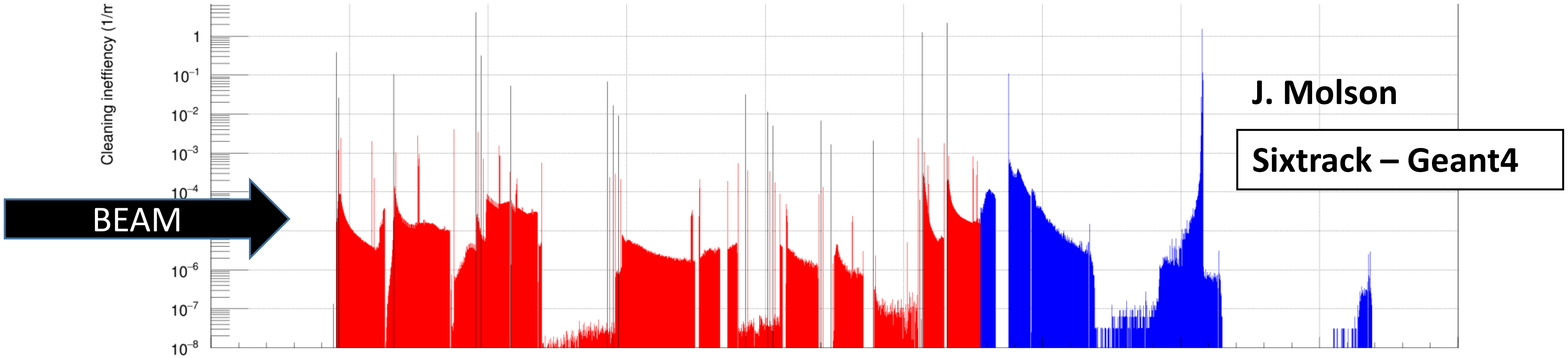
Sixtrack – Geant4

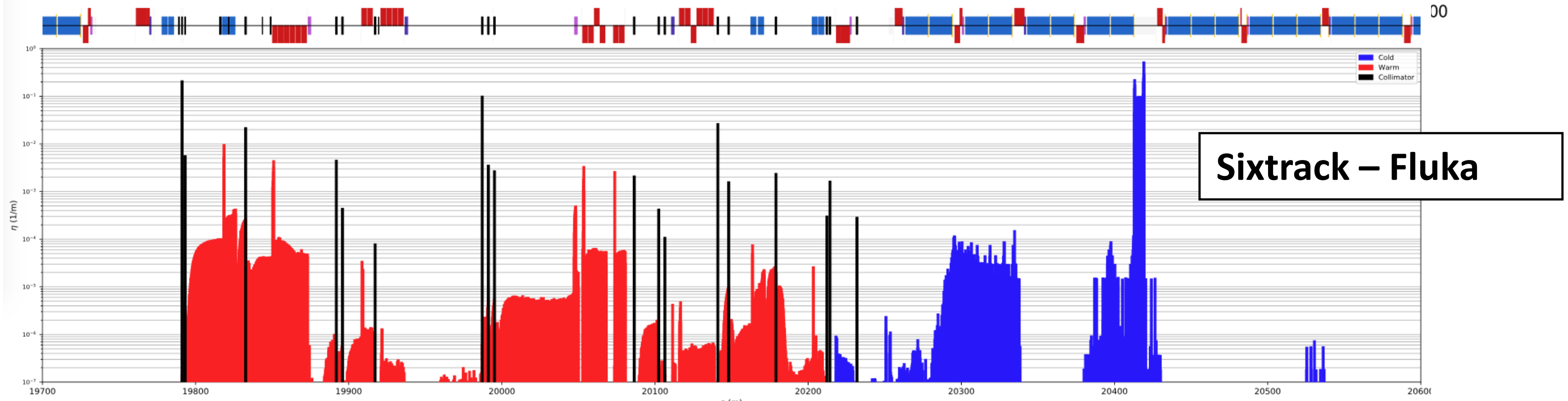
Beam1 LHC, **first preliminary results**:

Qualitative agreement with measurements and Fluka-Sixtrack.

- First look with the same energy cuts and particles transported back to Sixtrack

- More benchmarking needed – on more standard cases!





Intensity limits

Quench limits for the 11T dipoles

- **VERY Preliminary estimation!**
- for **7 Z TeV** , **5 x10^{-7} mJ/cm3** deposed in the 11T magnet per **ONE ion** (Z>80) interacting with TCLD
  - Fluka calculation *A.Lechner et al. for normal lead cleaning for HLLHC*
  - For the GF the impact distribution may differ resulting in different value
- Quench limit for 11T dipoles assumed to be **70mW/cm3.**
- Assuming a minimum beam life time of **12 mins** (HLLHC base line).
- We come with an estimate for the max beam intensity **about 3x10^{11} ions**.
  - More than HL-LHC baseline beam -> hope for no intensity limit (wrt 11T magnets).
- Energy deposition on TCLD collimator still to be investigated
  - **Preliminarily ~10kW expected**, probably no showstopper but to be studied.
- **For better understanding – dedicated Fluka studies in the TCLD region needed!**

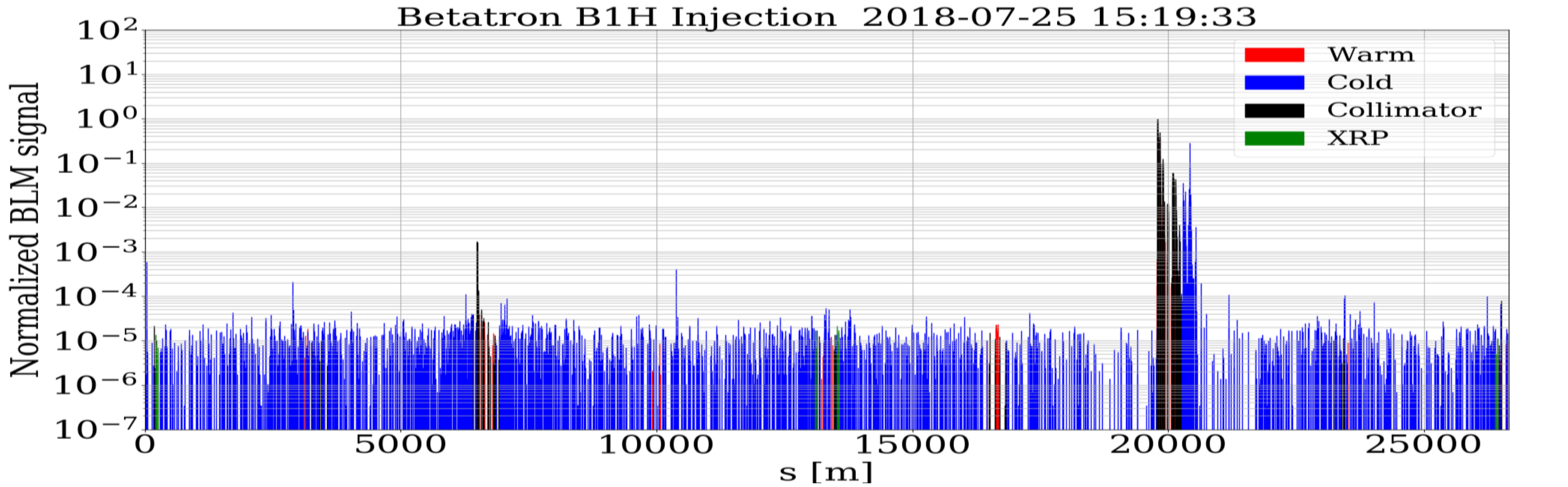
Summary

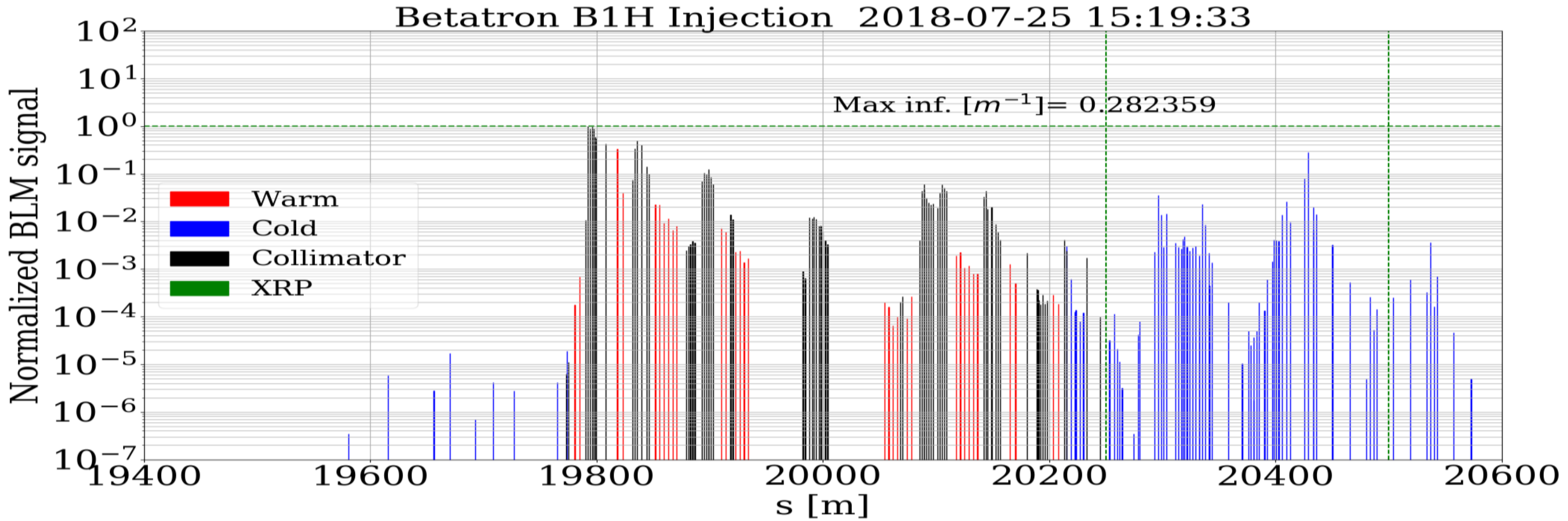
- In the first test with PSI in the LHC **the collimation cleaning performance was observed to be prohibitively low for operation with high-intensity beams**.
- **Analysis of the measured loss maps and simulations have helped identify** the reason for the inadequate cleaning – **the stripping action of the primary collimators.**
- Several mitigation strategies are being investigated – **TCLD collimator**, crystal collimation and an orbit bump.
- First, **preliminary estimates** on the losses on the 11T dipoles indicate **no additional intensity** limits (wrt to the HL-LHC baseline)

Backup slides

Appendix - Injection B1H

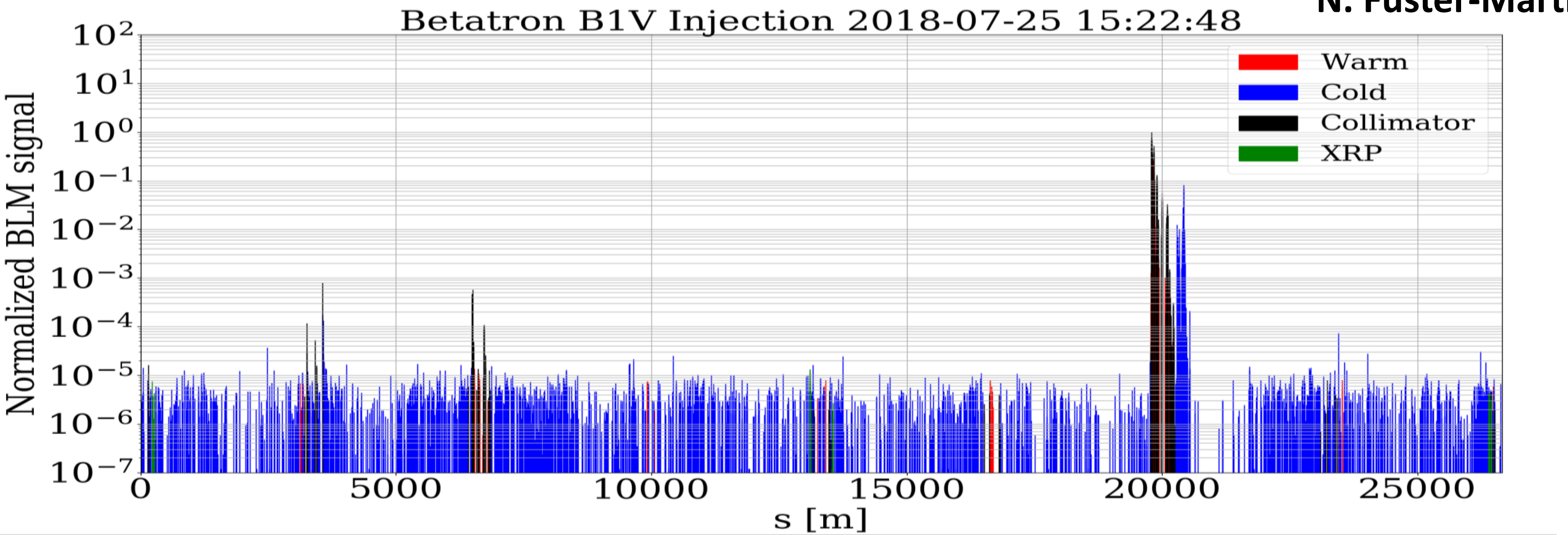
N. Fuster-Martinez

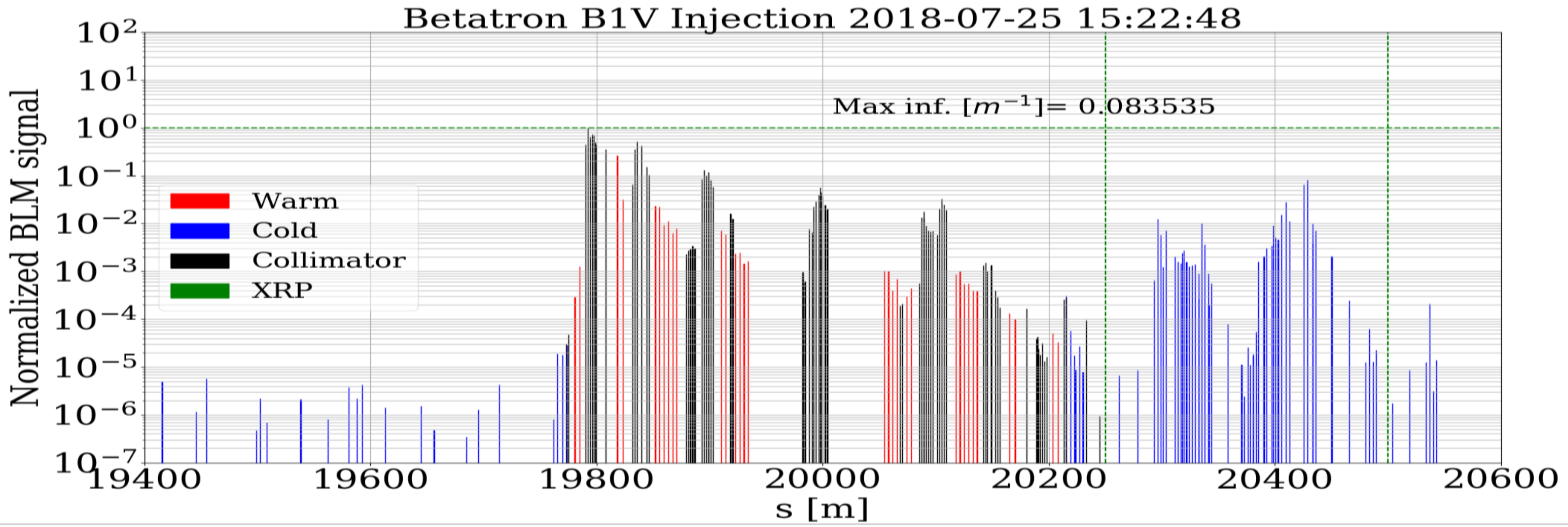




Appendix - Injection B1V

N. Fuster-Martinez





Appendix - Flat top B1V

N. Fuster-Martinez