Tracking studies for Pb ion crystal collimation

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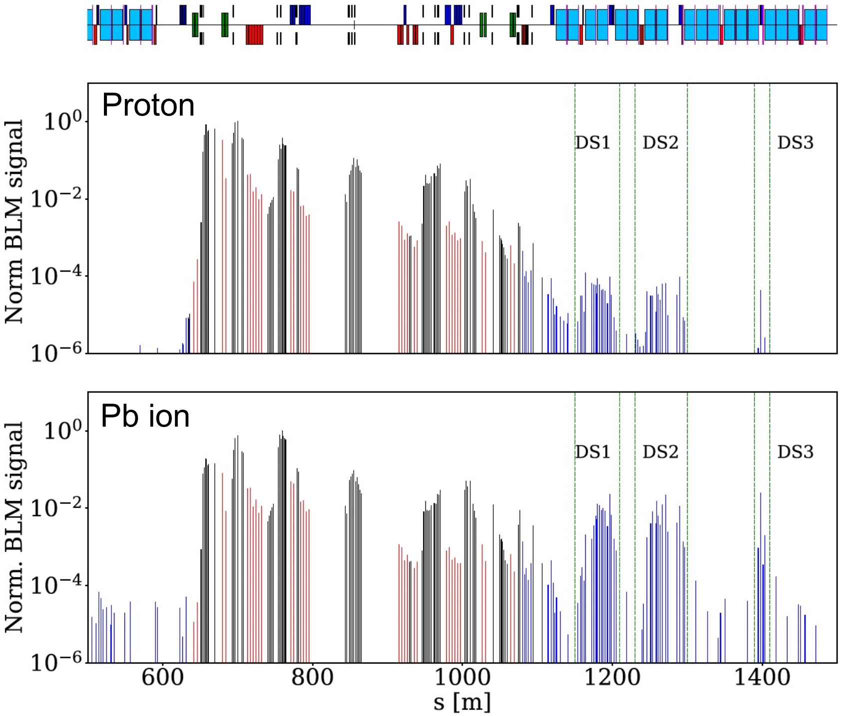
Heavy-ion collimation

Due to fragmentation, the collimation cleaning in the LHC was found to be approximately 2 orders of magnitude less efficient for Pb ions than for protons.



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New challenges

The estimated power load for design losses is three times higher than the quench limit.

Numerous dumps have been triggered in the 2018 10 Hz events.

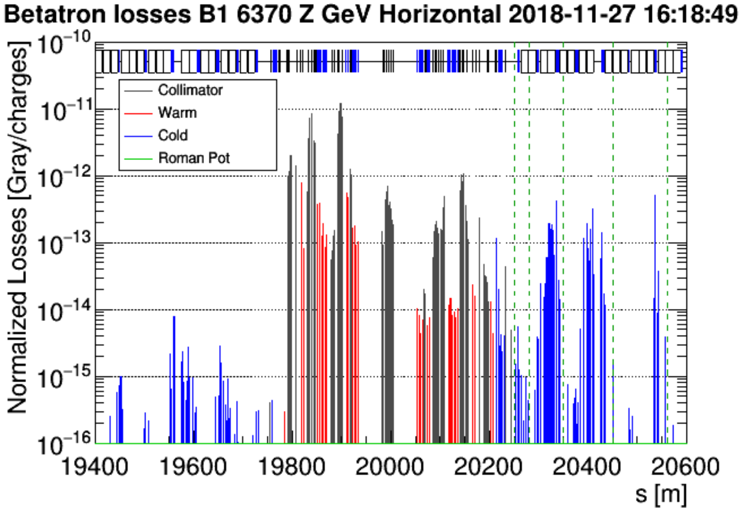
The stored beam energy is planned to increase from 13 MJ to 20 MJ.

Previously planned mitigation through TCLD collimators, requiring the installation of 11 T dipoles, has been deferred

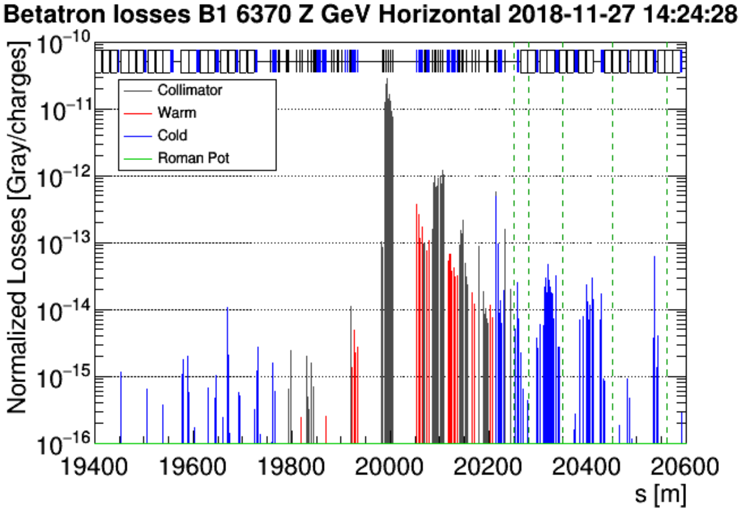
Deployment of crystal collimation as a solution to overcome possible limitations.

Experimental evidence of crystal efficiency

During the 2018 MDs, the insertion of crystal collimators have proved to improve the cleaning performance



Standard collimation



Crystal collimation

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Experimental evidence of crystal efficiency

Global leakage ratio: $\frac{\max \eta_c^{STD}}{\max \eta_c^{CRY}}$

where $\max \eta_c^{STD}$ and $\max \eta_c^{CRY}$ are the maximum cleaning inefficiency for the standard and crystal collimation.

Results of 2018 cleaning measurements with Pb ions

Crystal	Maximum normalized BLM signal [a.u.]		Global leakage ratio
	Standard	Crystal	
B1H	$(5.81 \pm 1.03) \cdot 10^{-13}$ Q8-9	$(7.30 \pm 0.15) \cdot 10^{-14}$ Q8-9	8.0 ± 1.4
B1V	$(1.95 \pm 0.07) \cdot 10^{-13}$ Q8-9	$(6.39 \pm 0.05) \cdot 10^{-14}$ Q12-13	3.1 ± 0.1
B2H	$(2.76 \pm 0.39) \cdot 10^{-13}$ Q12-13	$(7.89 \pm 0.78) \cdot 10^{-14}$ Q8-9	3.5 ± 0.6
B2V	$(2.25 \pm 0.01) \cdot 10^{-13}$ Q8-9	$(1.46 \pm 0.36) \cdot 10^{-13}$ Q8-9	1.5 ± 0.4

Recently replaced

Recently replaced

M. D'ANDREA

Crystal collimation layout

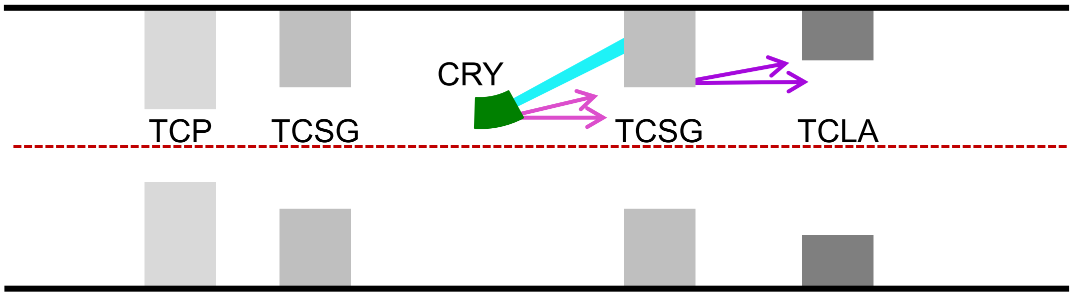
- There are four crystal collimators (one for each beam plane):
  - The vertical crystal collimators have been exchanged in LS2 to new devices with an improved design.
  - The remaining two old devices in the horizontal plane will be exchanged in the upcoming YETS
- Crystal collimators are in the HL-LHC baseline for Pb ions.

Crystal	Bending angle
TCPCH.A4L7.B1	65.6 µrad
TCPCV.A6L7.B1	46.3 µrad
TCPCH.A5R7.B2	36.3 µrad
TCPCV.A6R7.B2	48.7 µrad

Run III Pb operational settings

In the foreseen heavy-ion operational setting, the crystals are placed "adiabatically" 0.25 σ tighter than the primary collimator in the existing collimation system.

The rest of the collimation system is kept at the 2018 settings.



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Motivation

To…

…efficiently study crystal collimation for Pb ions

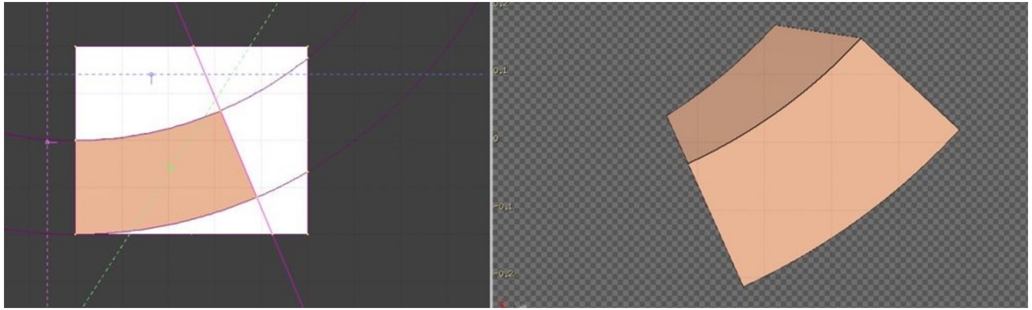
…explore better collimation configurations with crystal collimators

…predict future setups

⇨ a well-built and benchmarked simulation framework for heavy ions is needed.

Simulation framework implementation

- The simulation framework relies on the existing SixTrack-FLUKA coupling and makes use of the crystal routine in FLUKA.
- Four strip crystals have been defined and inserted in the FLUKA Element Database for the LHC.
- Relevant files have been created to link the crystals to the accelerator lattice.
- Crystal models have been updated to the latest measurements.

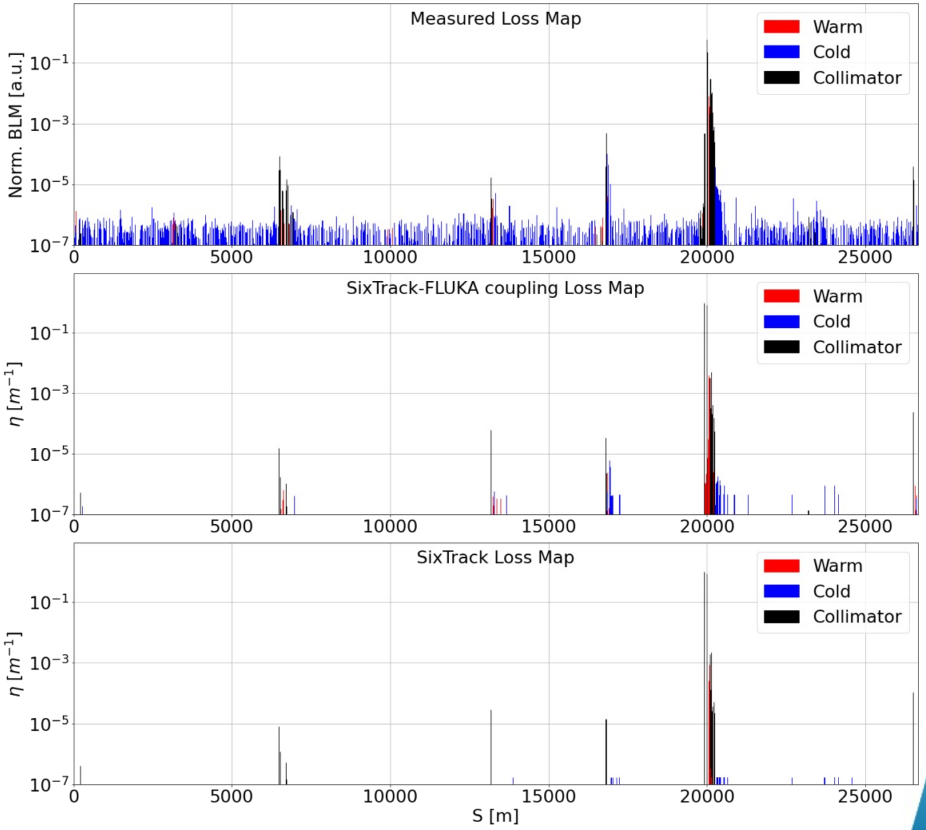


Benchmark of the simulation framework

Framework benchmark
Proton

The framework has been benchmarked with the 2018 6.5 TeV proton run at flat-top in the horizontal plane.

	IR1	IR2	IR5	IR8
β^* [m]	1	1	1	3
Beam separation [mm]	-0.550	1.400	0.550	-1.000
Crossing angle IR [μrad]	160	200	160	-250



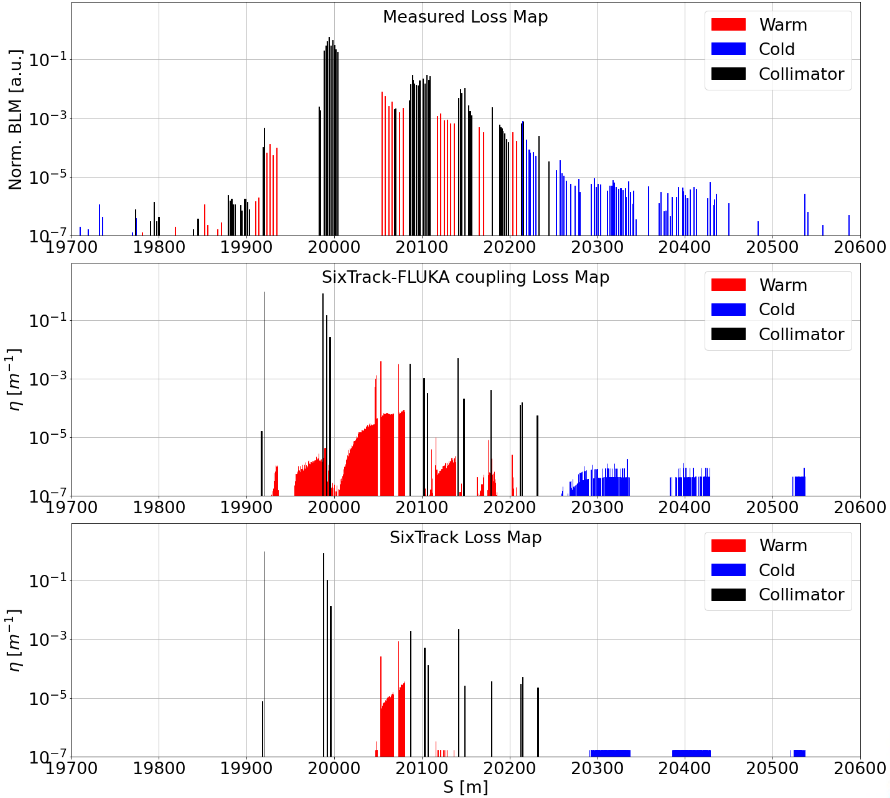
Framework benchmark
Proton

IR7:

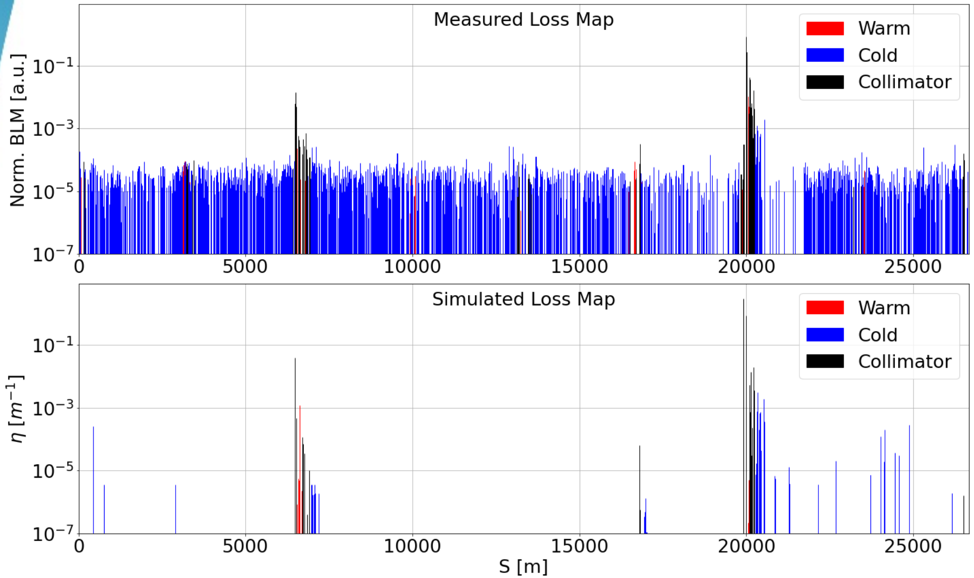
The results have been compared both with experimental data and the standalone SixTrack simulation.

Overall, good agreement in terms of loss pattern.

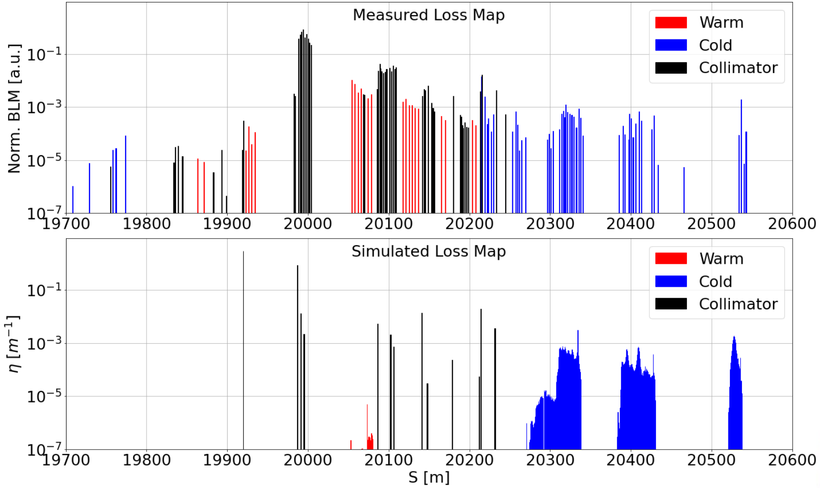
A different volume reflection treatment has been observed from the two tools. This is under investigation.



Framework benchmark
Pb ion



IR7:



For Pb ions, the benchmark has been done for the 2018 6.37 Z TeV MD.

The order of magnitude of cold loss is well-reproduced in the DS region.

Applications:
1) Simulation framework used for optimization

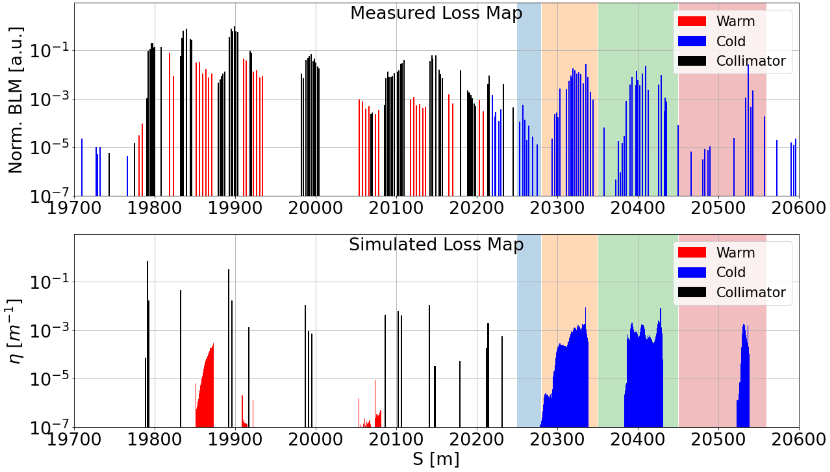
Crystal operational scenario comparisons

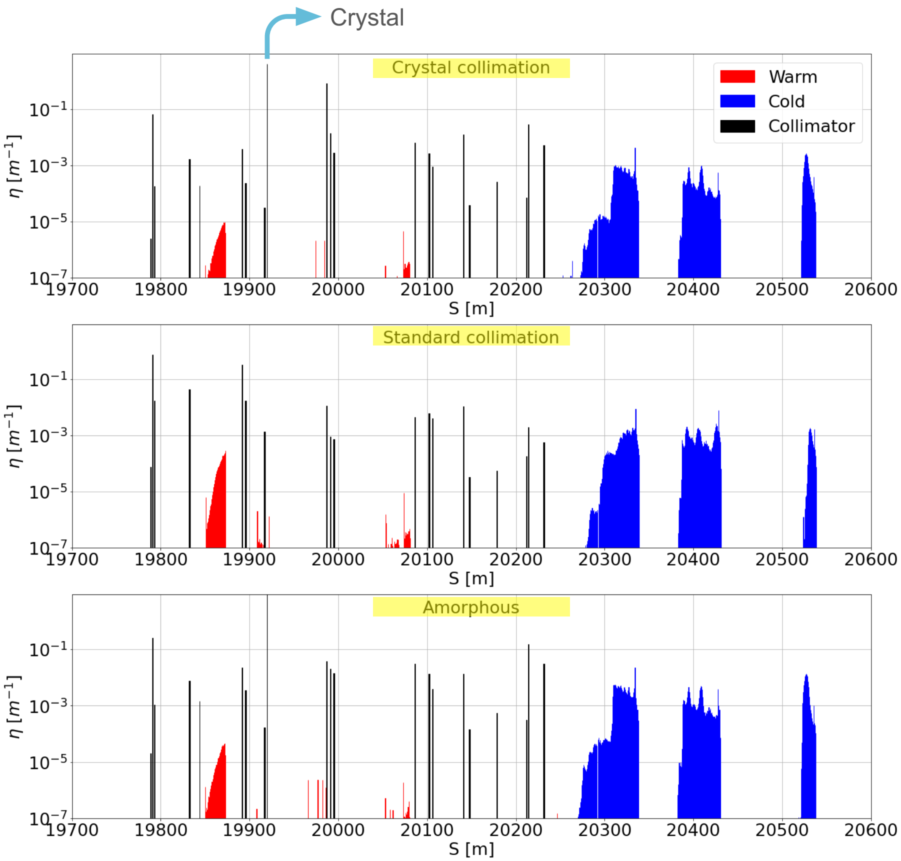
- The framework has also been used to compare different operational scenarios:
  - Standard collimation setup
  - Collimation setup with crystal in optimal orientation
  - Collimation setup with crystal in amorphous orientation
- The simulations follow the configuration of the 2018 physics Pb ion run.
- These simulations are useful to
  - evaluate the improvement of a collimation system with crystals starting from simulated data,
  - understand the risk in case of crystal failure.

Crystal operational scenario comparisons

Beam 1:

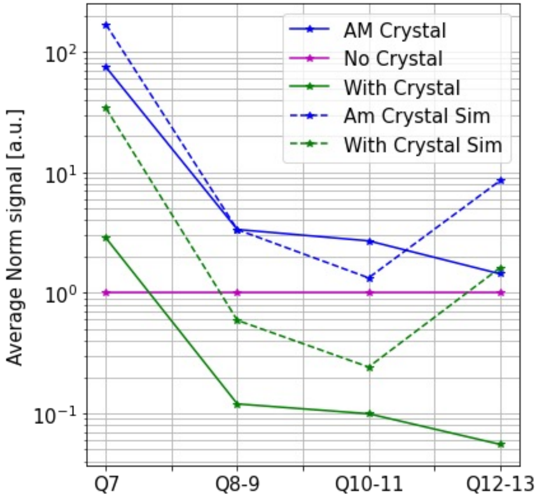
Standard collimation



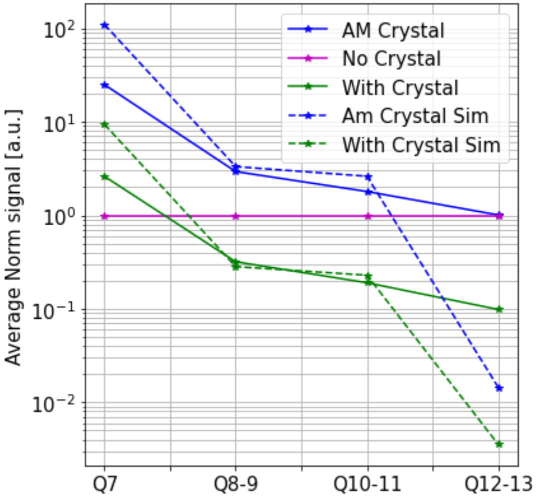


Crystal operational scenario comparisons

Beam 1 horizontal



Beam 2 horizontal



Dashed lines are the corresponding simulations for the measurement shown in the same color.

- Losses are normalised with respect to the respective simulated or measured data with the standard setup (purple).
- General trend and the worsened amorphous performance are reproduced by simulation.
- It can be concluded that the amorphous configuration gives significantly worse performance. However, it is also not an extreme result for the machine.

Applications:
2) Simulation framework used to understand

Perfect absorber study

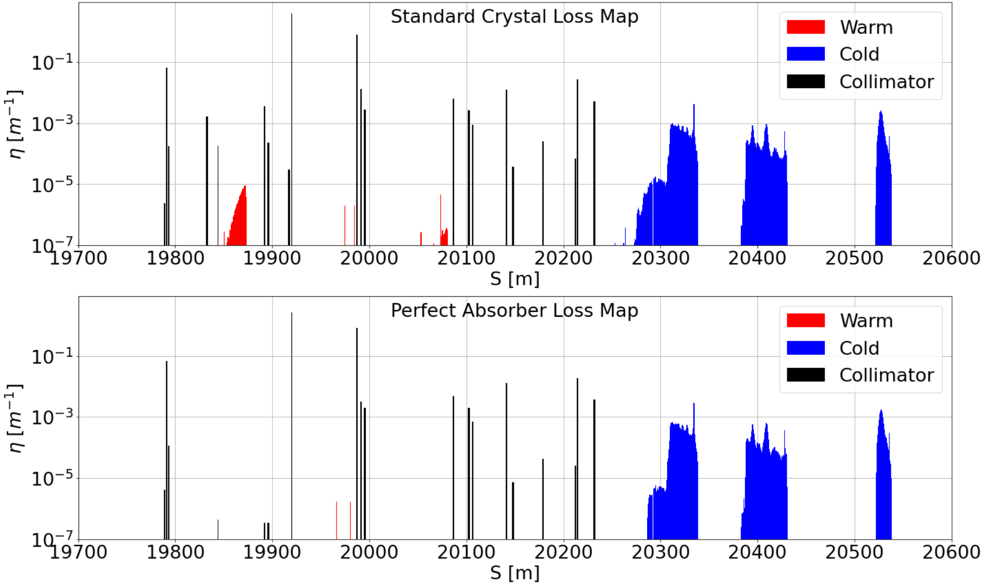
In order to understand the contribution of particles leaking directly from the crystal to the DS,

a simulation with all collimators set to perfect black absorbers except for the crystal has been carried out

Perfect absorber study

The small changes in the DS region while using the black absorber setup indicate that direct leakage from the crystal is by far dominating in Pb cleaning.

This conclusion has also been reached by FLUKA.*

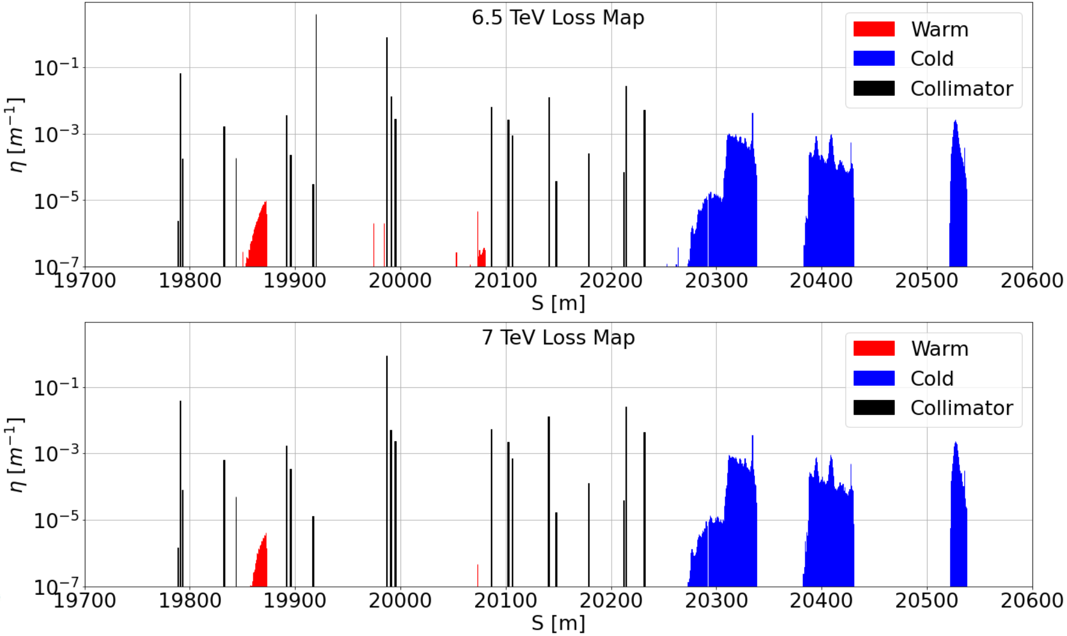


**More details in talk by J.B. Potoine (this session)*

Applications:
3) Simulation framework used to predict

7 TeV Pb ion simulations

- The simulation framework has also been used to simulated 7 Z TeV Pb ions



The IP separations differ between the two simulations

Conclusions

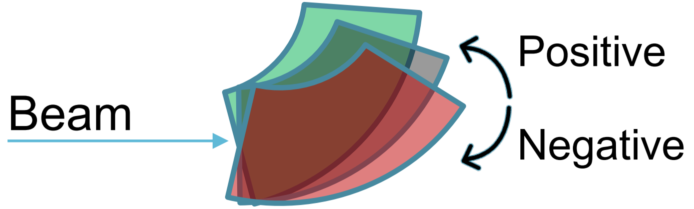
- A simulation framework has been built for heavy-ion crystal collimation.
- The loss pattern simulated has been benchmarked for protons and Pb ions with satisfactory results and can be used to study and optimize the performance in future configurations.
- The tool has been used to reproduce the enhanced collimation efficiency coming from the crystal collimator for Pb ions.
- Thanks to this simulation framework, it was possible to understand that direct leakage from the crystal contributes greatly to DS losses.
- Future scenarios such as 7 Z TeV Pb ions have been simulated successfully with crystals.

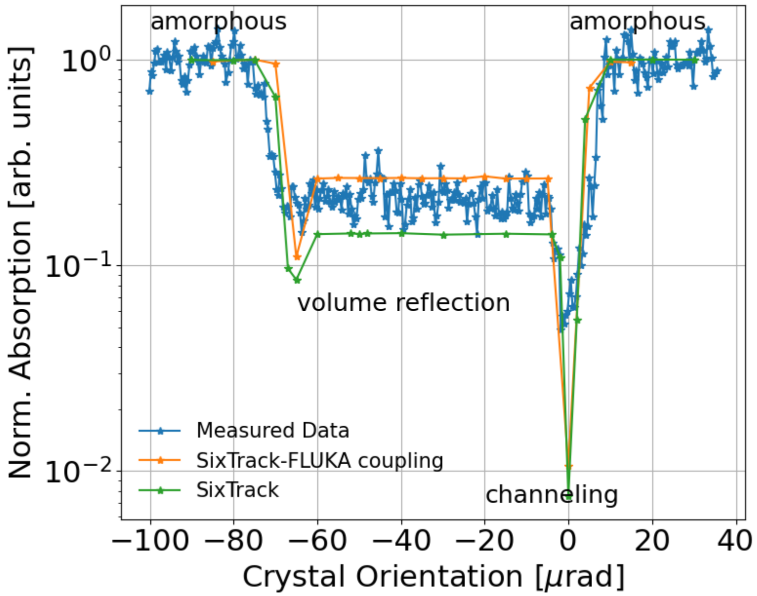
Thank you!

Backup

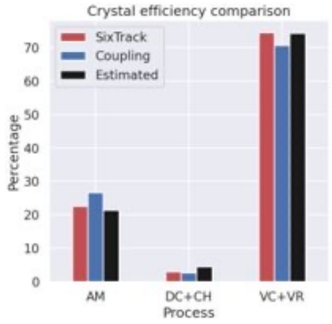
Proton angular scan benchmark

- In an angular scan the orientation of the crystal is changed with respect to the beam direction.
- The particle absorption is recorded as a function of orientation angle.
- The absorption is normalised to the one obtained when the crystal at an amorphous orientation.
- The two tools have been compared and the main discrepancy is in the volume reflection section which necessitate further investigation.





Proton single pass comparison



Simulations has been carried out to compare the coupling and the standalone SixTrack crystal treatment at 6.5 TeV, where the particles only pass through the crystal once.