LHC Operational Experience with Proton Beams

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HL-LHC Crystal Collimation Day, 19 October 2018, CERN

Outline

I. Methods for Crystal Characterization

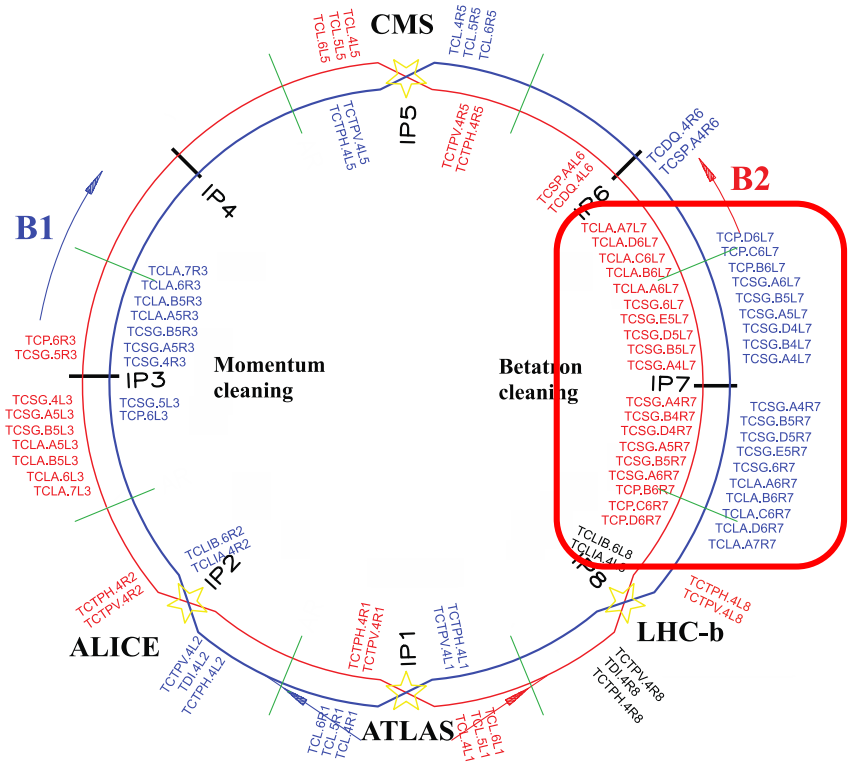
II. Observations with Protons

III. Crystal Collimation in Dynamical Phases

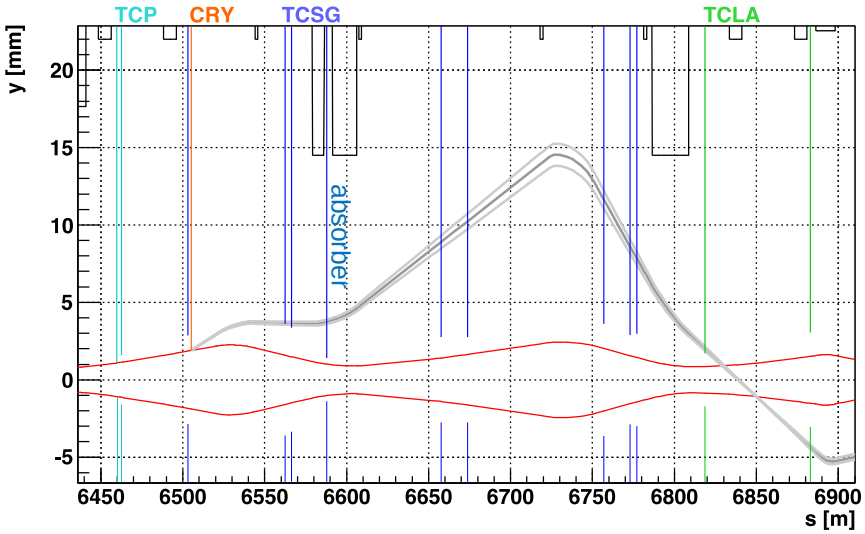
IV. Conclusions

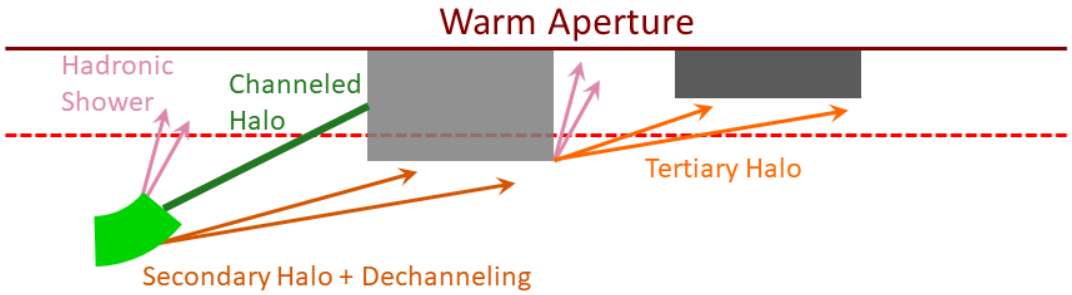
Outline

Crystal Collimation Layout

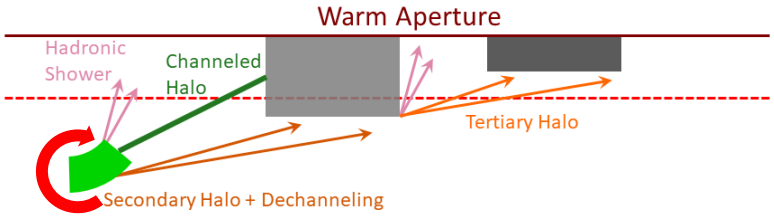


Four crystals installed in IP7: one per plane per beam





Angular Scan



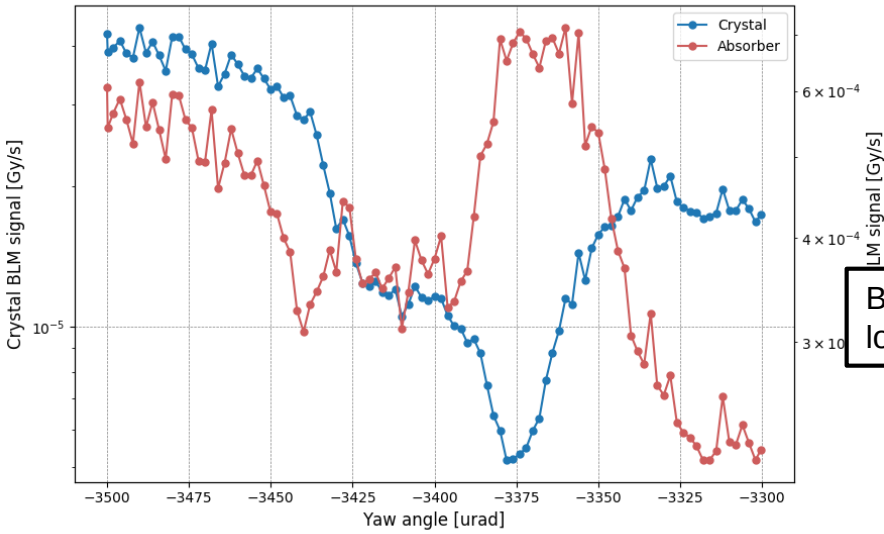
The crystal device is aligned to the beam halo and rotates around its axis

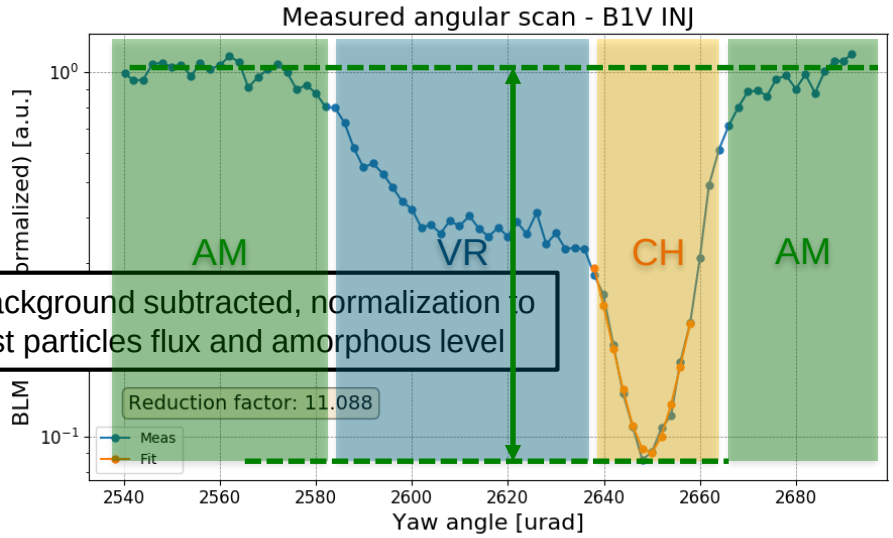
What we look at:

- decreased losses at the crystal
- increased losses at the absorber

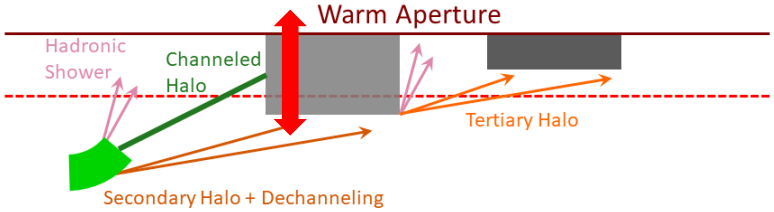
What we look for:

- optimal channeling orientation
- reduction factor

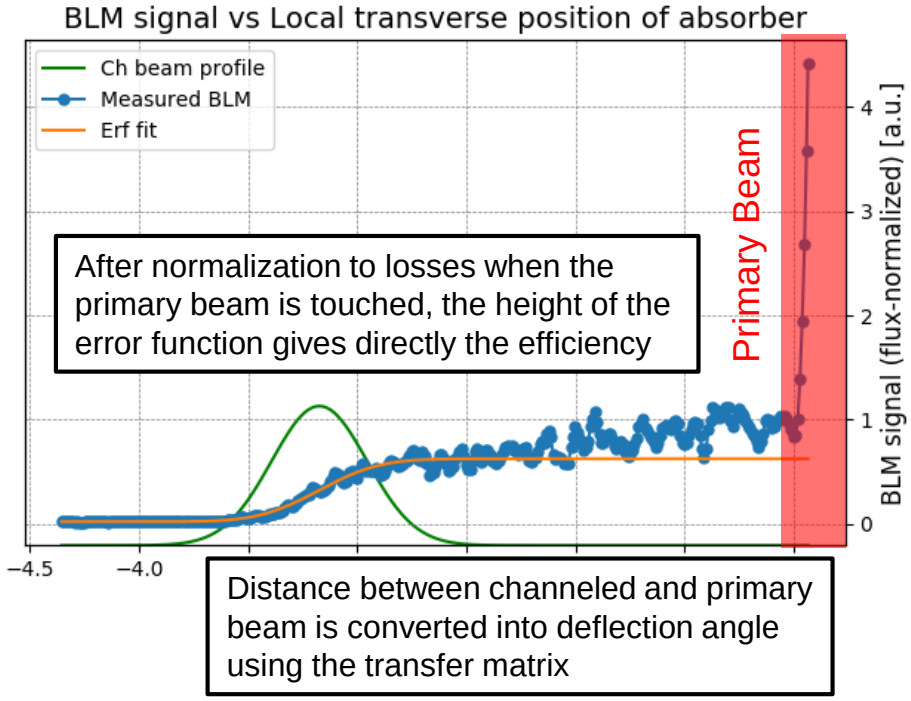




Linear Scan



The absorber is retracted and inserted until it touches the primary beam, with the crystal in channeling orientation



What we look at:

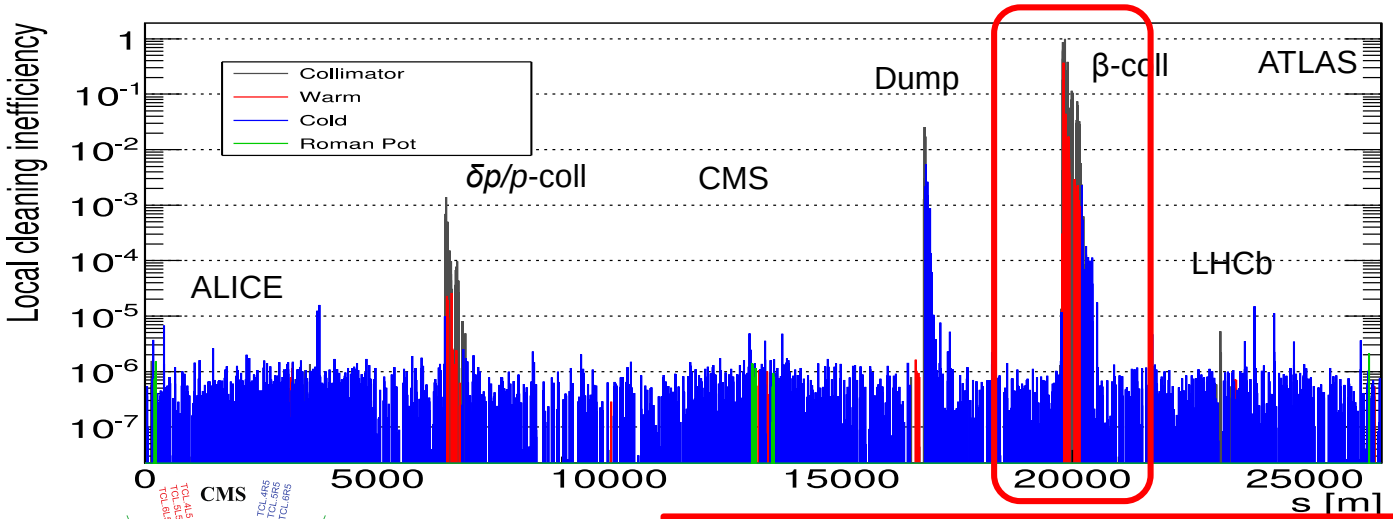
- losses at the absorber as a function of its transverse position

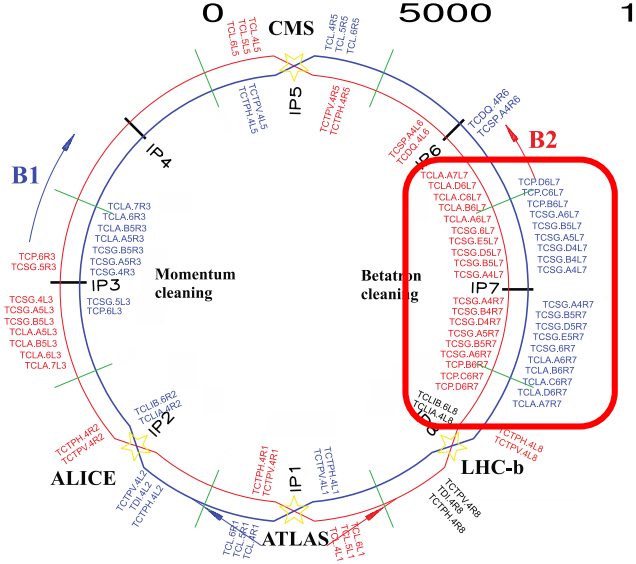
What we look for:

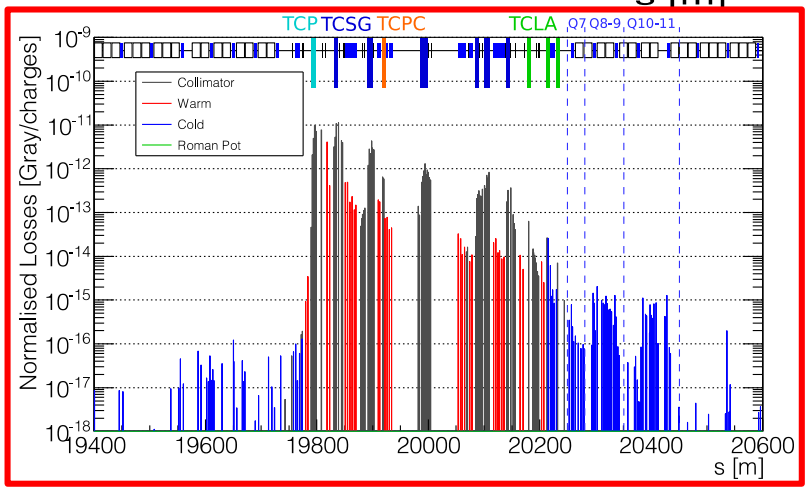
- multiturn channeling efficiency
- characterization of channeled beam and crystal bending angle

Loss Maps

The beam is blown up with ADT (transverse white noise) to generate controlled losses around the machine







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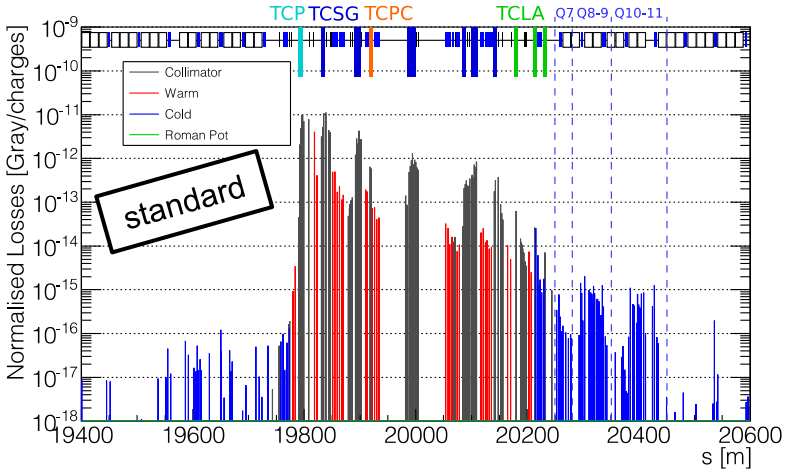
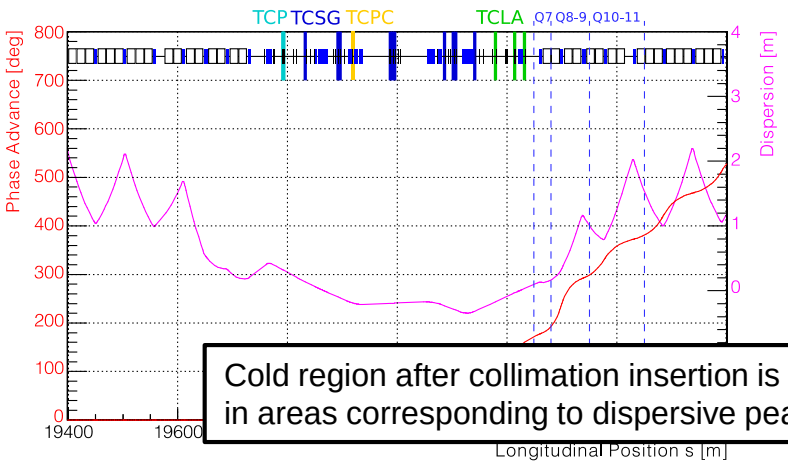
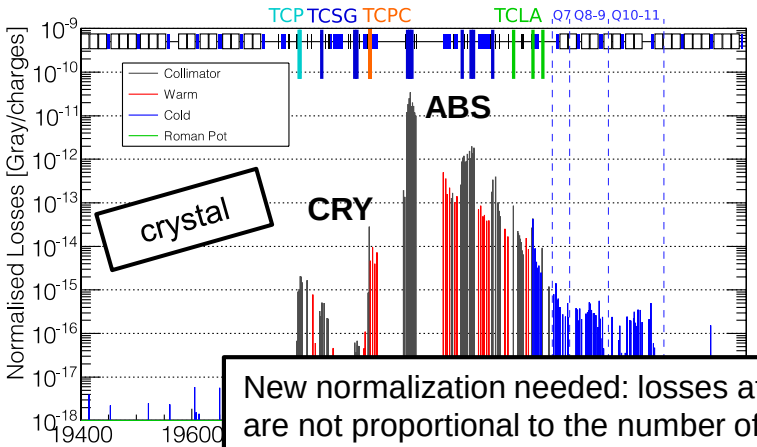
Crystal and Std Collimation Comparison

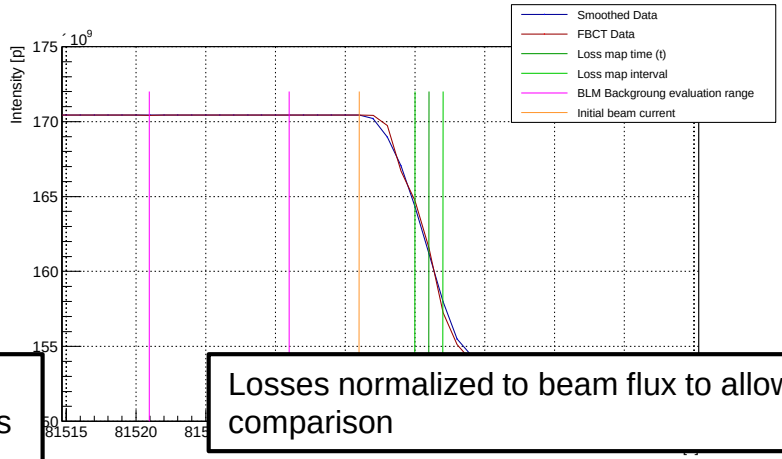




Cold region after collimation insertion is divided in areas corresponding to dispersive peaks



New normalization needed: losses at crystal are not proportional to the number of particles entering the collimation system



Losses normalized to beam flux to allow direct comparison

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II. ***Observations with Protons***

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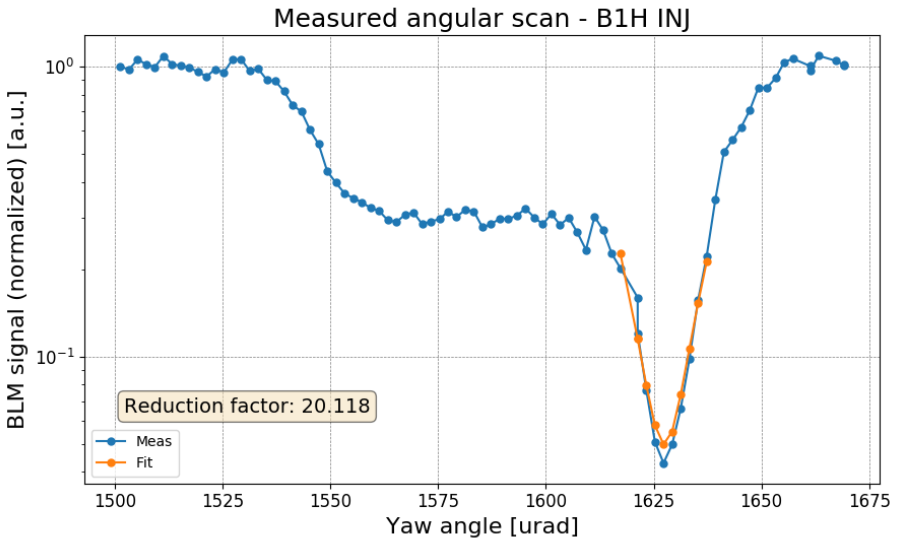
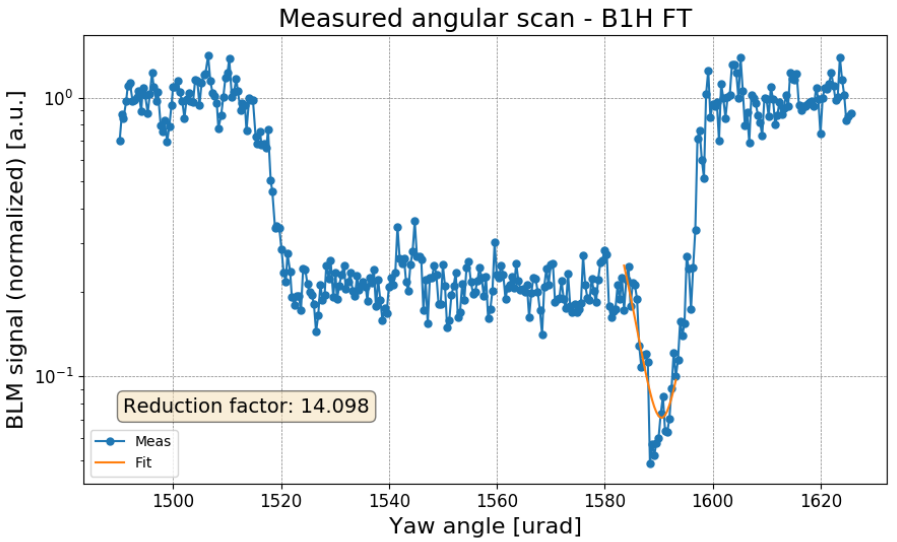
IV. *Conclusions*

Channeling Observations

Channeling was successfully observed for the first time at LHC energies in 2015 and then re-established in subsequent measurements in the following 4 years

Setup is quick and measurements are highly reproducible thanks to the high goniometer precision





B2H Crystal Goniometer Replacement

B2H crystal was replaced during 2017 YETS due to an issue with the alignment during installation

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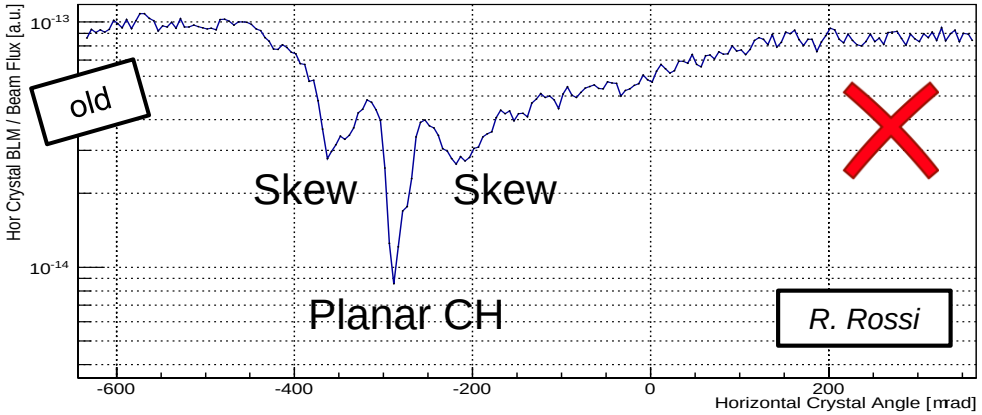
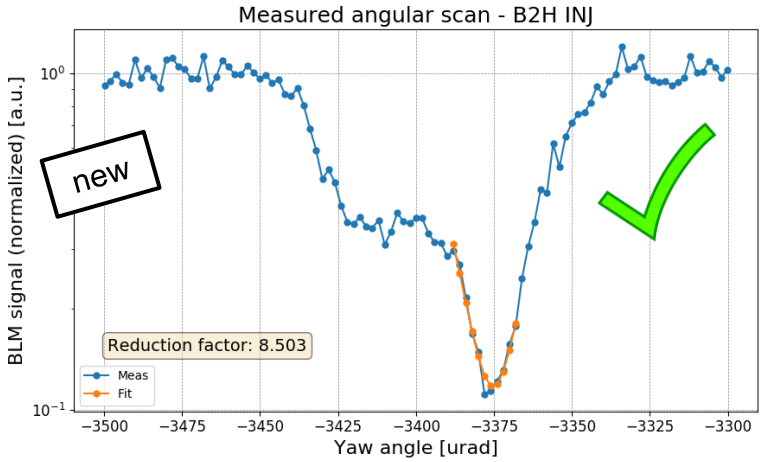




Impossible to correct remotely with present hardware: the whole device was replaced

Measurements with B2H performed this year and currently under analysis

Measured Bending Angle Overview

Crystal	Bending Angle [μrad]
B1H	63.2 ± 1.7
B1V	39.8 ± 2.3
B2V	56.5 ± 1.5

B2H not reported: analysis ongoing

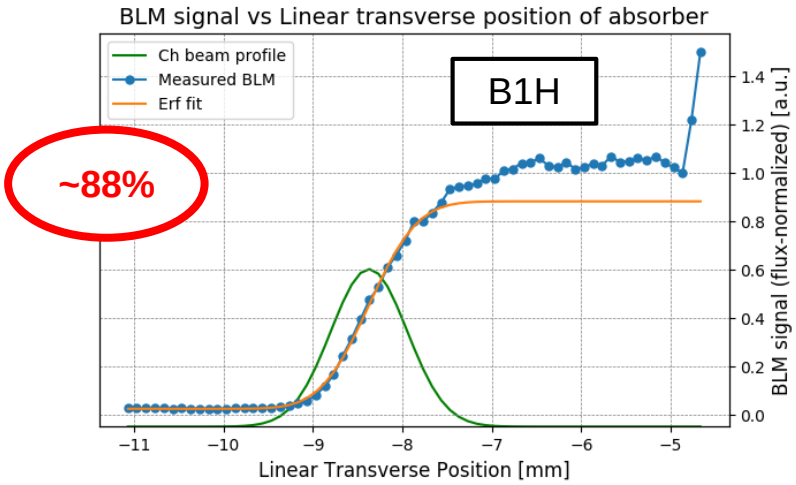
Crystals installed in B1 turned out to be not optimal for LHC operations: experience with these crystals allowed to better establish specifics for future installations

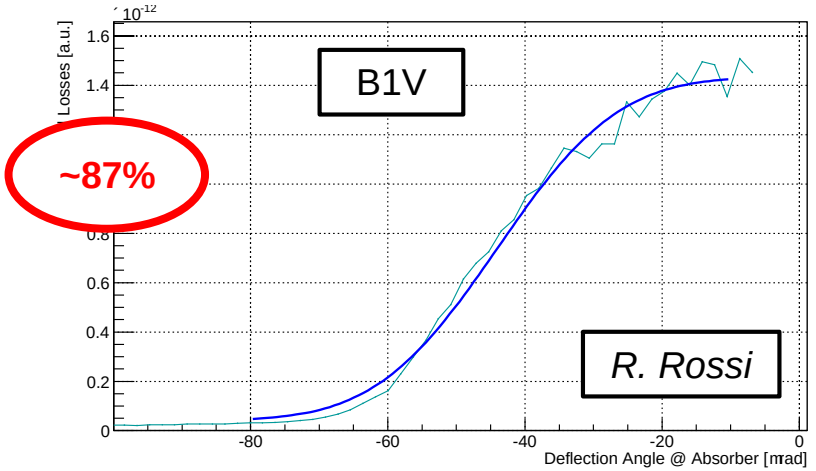
B1H has a larger bending angle: the radius is closer to the critical value

In this condition, dechanneling at flat top is enhanced and efficiency is reduced

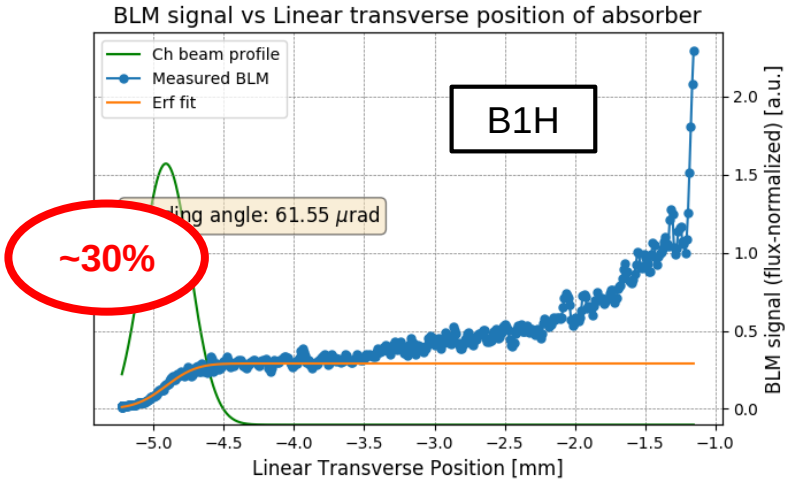
Effects of Bending Radius on CH Efficiency

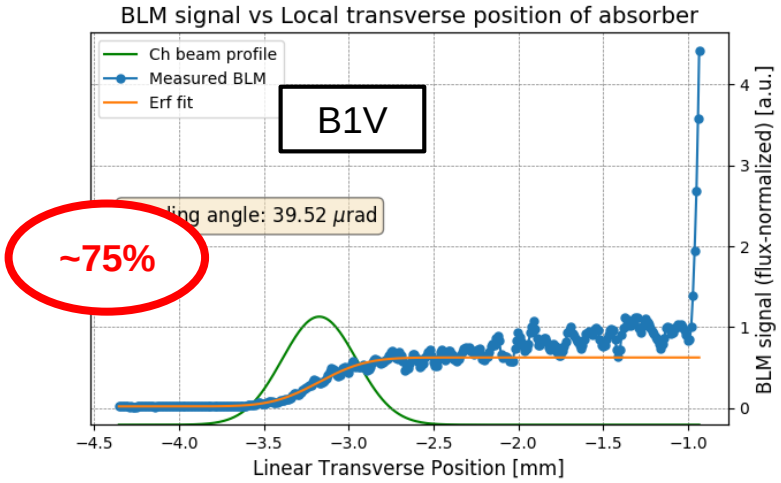
Injection:



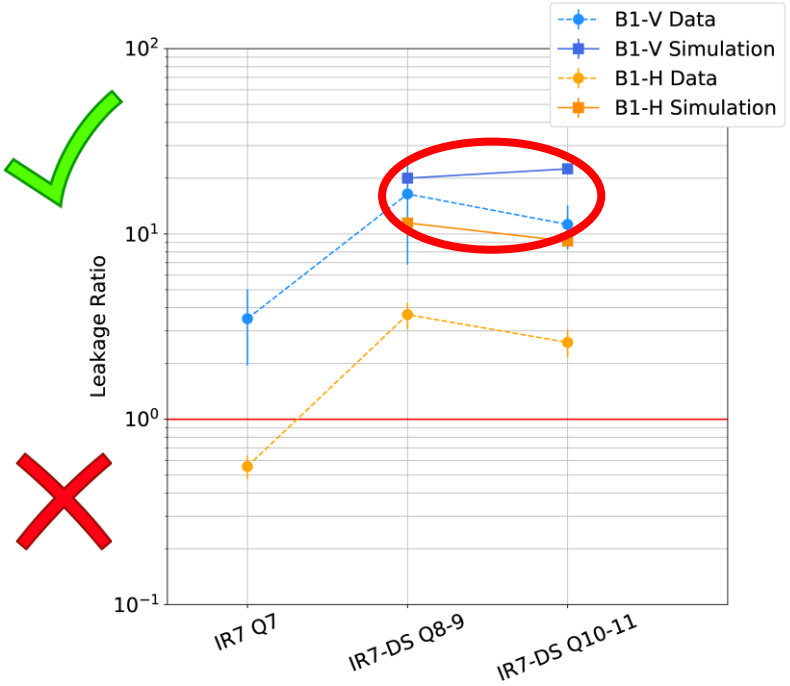


Flat top:

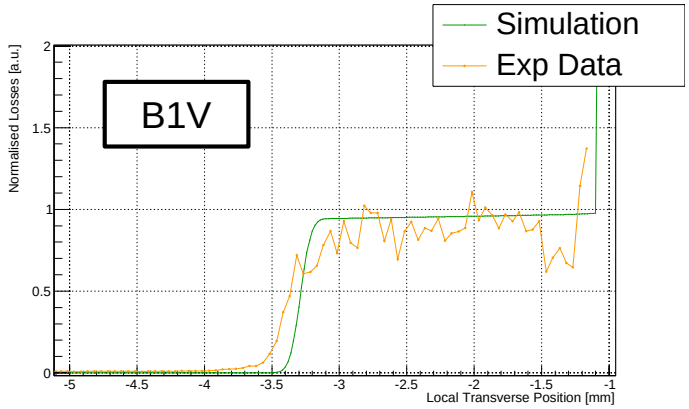


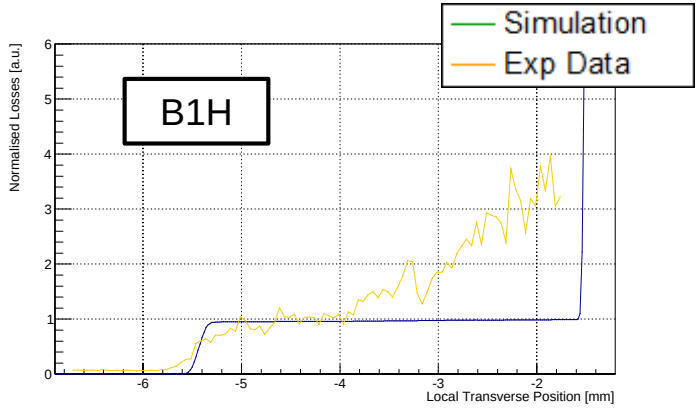


Cleaning Inefficiency with Protons



- Significant improvement (factor ~10) observed in the DS for B1V
- Analogous results observed for B2V
- No significant improvement observed on B1H (possibly due to high dechanneling)
- Comparison with simulation shows good agreement for B1V and a significant difference for B1H
- No analytical description for bending radius close to critical value: not reproducible in simulations





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Crystal Collimation in Dynamical Phases

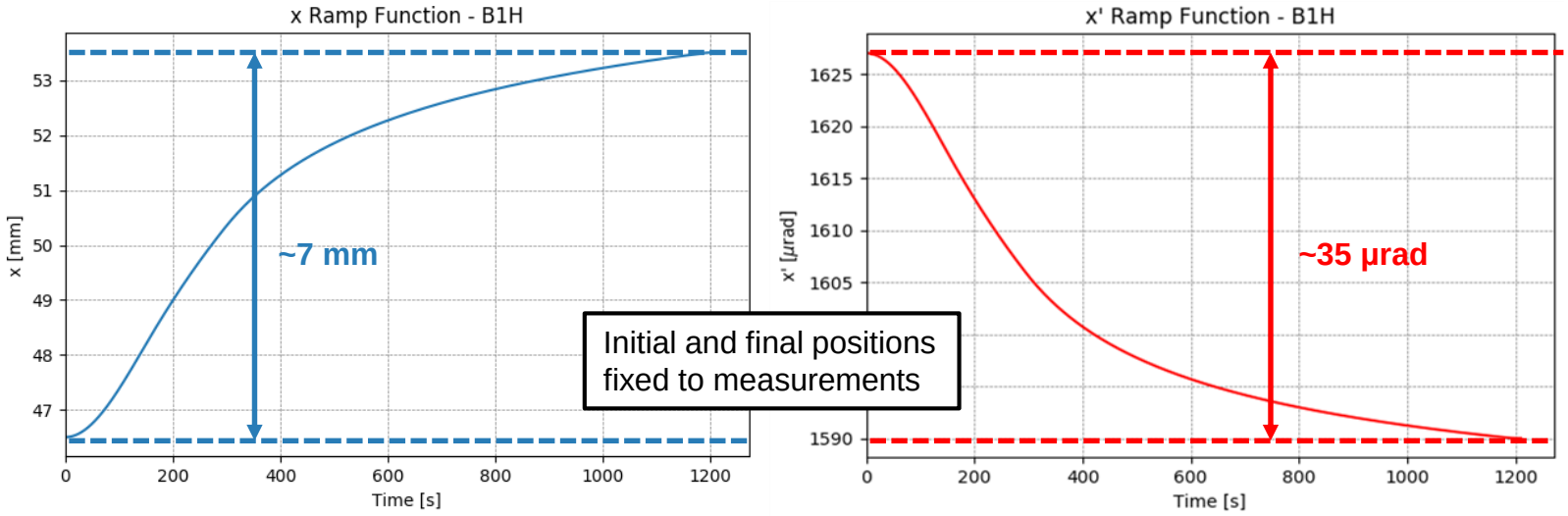
In order be used during operations, crystals need to be kept in channeling orientation during dynamical phases such as the energy ramp

Challenges:

- shrinking of beam size and change in angular distribution due to adiabatic dumping
- change in critical angle (from ~10 µrad to ~2 µrad) and acceptance

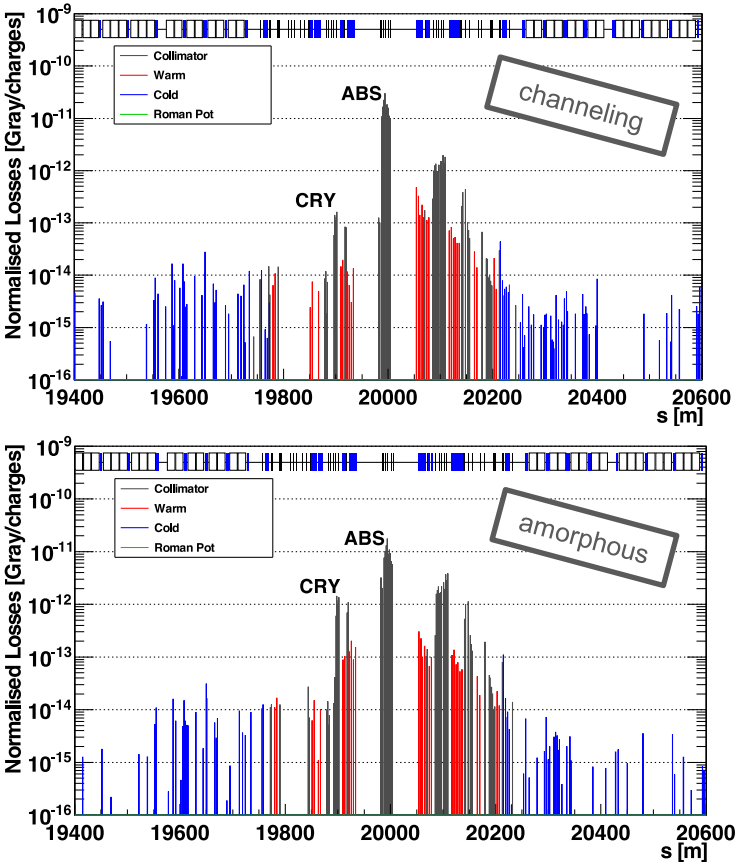
Functions need to be prepared to move the crystals: same formula used for standard collimators, but adapted also for rotational stage

$$x(t) = x_c - \left[n_{inj} + \frac{n_{ft} - n_{inj}}{\gamma_{ft} - \gamma_{inj}}\left(\gamma(t) - \gamma_{inj}\right)\right]\left[\tilde{\sigma}_{inj} + \frac{\tilde{\sigma}_{ft} - \tilde{\sigma}_{inj}}{\gamma_{ft} - \gamma_{inj}}\left(\gamma(t) - \gamma_{inj}\right)\right]\frac{1}{\sqrt{\gamma(t)}}$$



First Ramp Attempt with B1H

First attempt in 2016: channeling conditions evaluated during the ramp (continuous loss maps) by the ratio of losses at crystal and absorber



Well under control (ratio < 10^{-2}) for the whole ramp!

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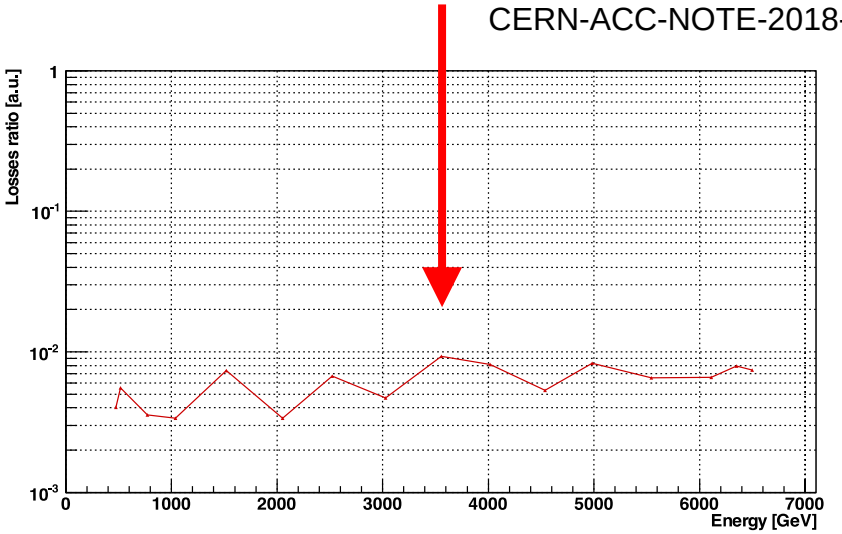

Second attempt this year with all four crystals: analysis ongoing

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Conclusions

- **Crystal channeling was successfully established during 4 years of testing**
  - **procedure is quick**
  - **measurements are highly reproducible thanks to high precision goniometer hardware**
- B1 crystals turned out not optimal for LHC operations, but still useful for studies
  - better grasp of crystal specifics for future installations
  - quantitative evaluation of small bending radius effects on dechanneling population
- Crystals with larger bending radius (B1V, B2V) show good agreement between simulations and measurements
- Discrepancies observed for B1H are believed to be caused by the extreme conditions in terms of bending radius
  - no analytical description of enhanced dechanneling
- **Channeling conditions were successfully maintained during the energy ramp, paving the path for potential operational use**
  - **second attempt performed this year with all four crystals, analysis ongoing**
- Detailed characterization of the newly installed B2H crystal is ongoing

Thank you for your attention