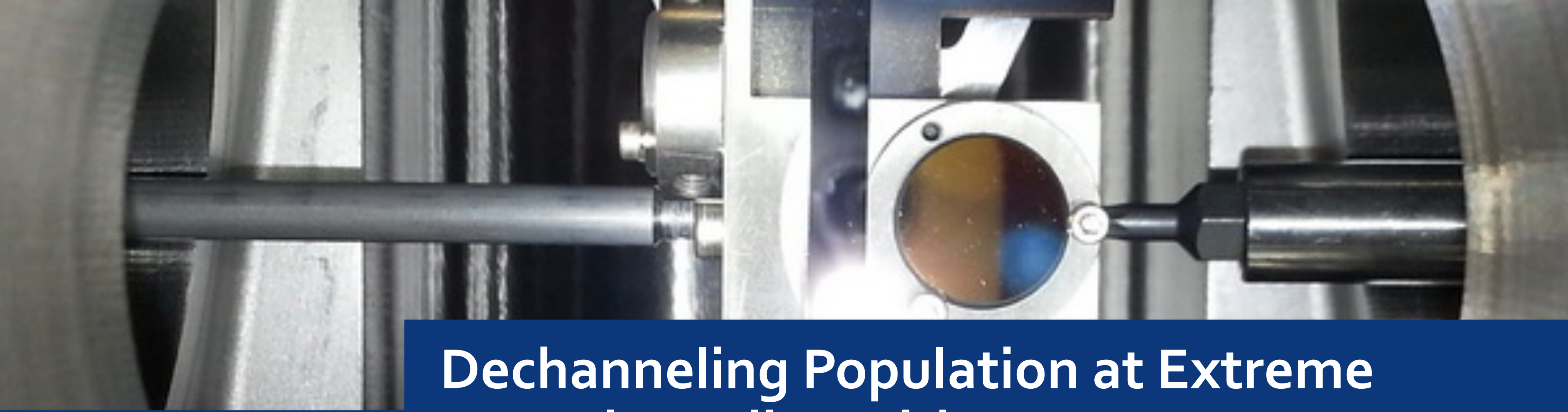


Dechanneling Population at Extreme Crystal Bending with 6.5 TeV Proton Beam

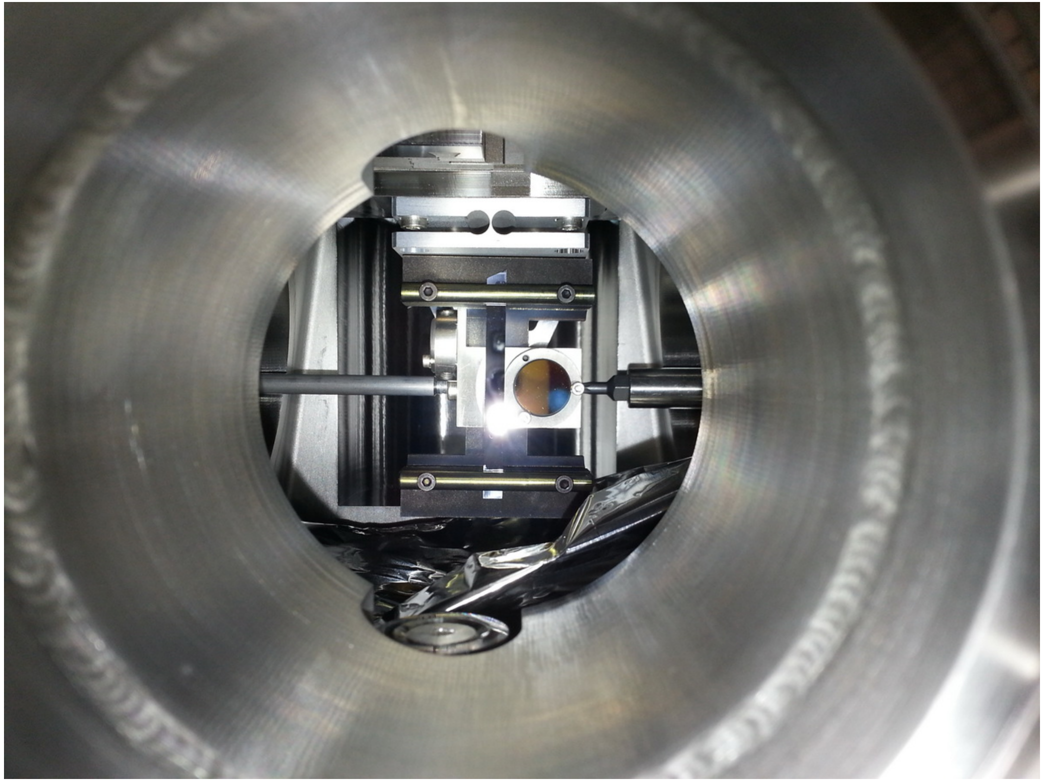
24/09/2018 – Channeling 2018

Roberto Rossi

Daniele Mirarchi, Stefano Redaelli, Walter Scandale

Outline

- Crystal Hadron Channeling
- Applications
  - Hadron beam collimation @ LHC
  - Crystal collimation for HL-LHC
- Experimental layout @ LHC
- Observations
  - Crystal angular scans
  - Collimator linear scans
    - Comparison with Simulation
  - Cleaning Performance
    - Comparison with Simulation
- Conclusions



Strip silicon crystal. Installed on the horizontal goniometer in LHC.

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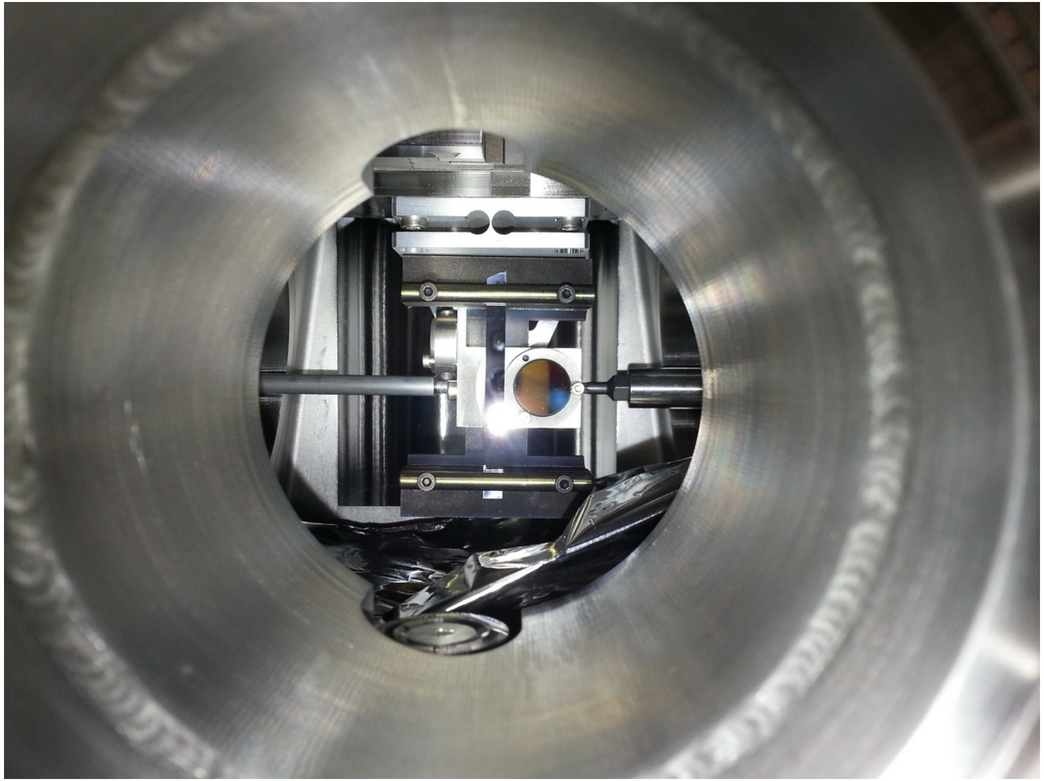

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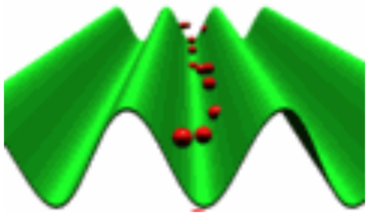
Channeling : Tansverse momenta < potential well

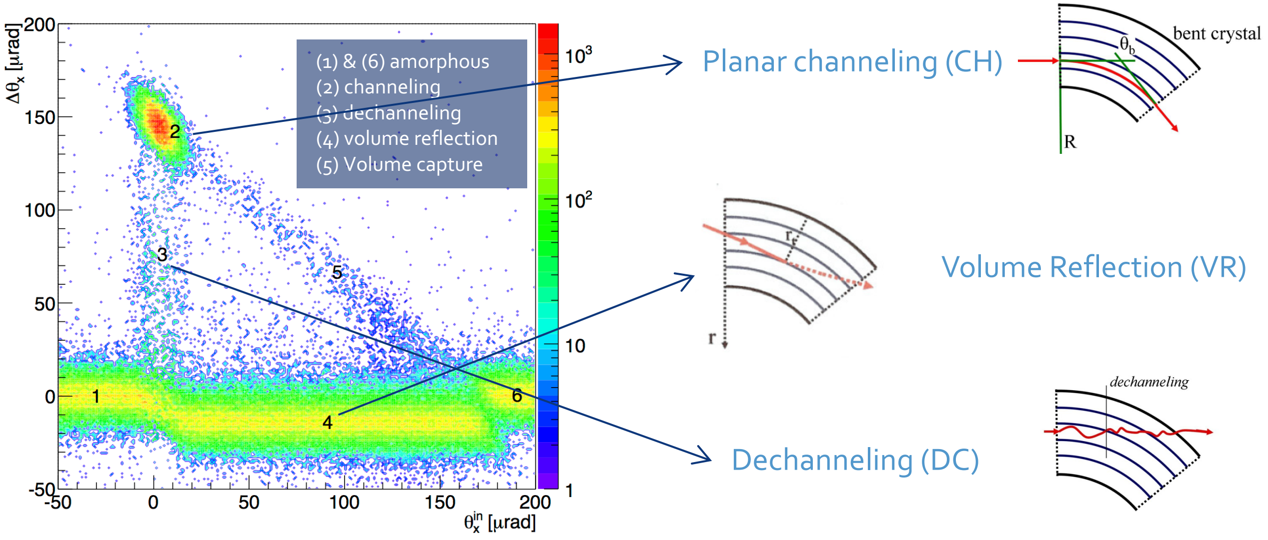
Critical angle

$$\theta_c = \sqrt{\frac{2U_{max}}{pv}}$$

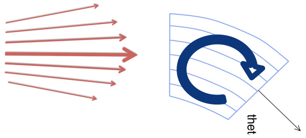
Case	Energy [GeV]	θ_c [μrad]
SPS coast	120	18.3
SPS coast	270	12.2
H8	400	10.0
LHC inj.	450	9.4
LHC top	6500	2.5
LHC top	7000	2.4



The particles are trapped in the channel, hence if a curvature is given to the lattice the particles direction will be modified by $\theta_b = l/R$

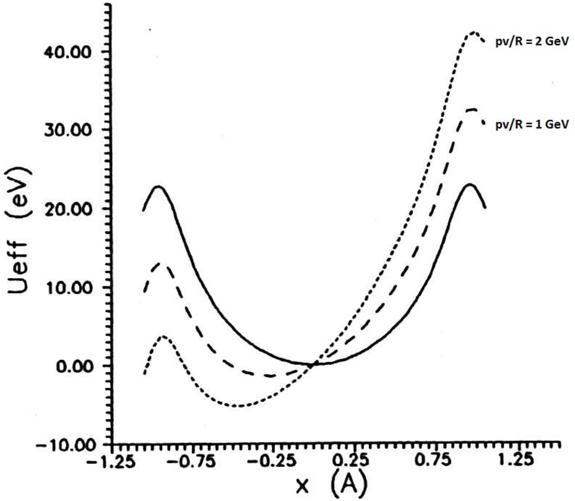


Single pass measurements with 400 GeV protons.
Strip crystal (110) with a bending of 144 μrad.



Critical Radius

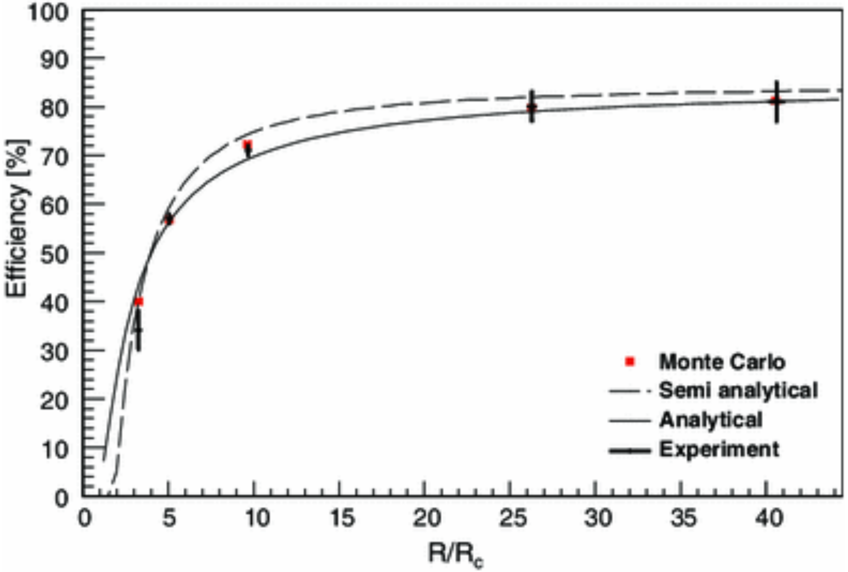
The crystalline planar potential asymmetry increase as the ratio of the particles energy and the crystal bending radius (R)



A critical radius (R_c) can be defined

$$R_c = \frac{pvx_{\max}}{2U_{\max}} \Rightarrow \theta_c^b = \theta_c\left(1 - \frac{R_c}{R}\right)$$

[2] E. Bagli et al., **Steering efficiency of a ultrarelativistic proton beam in a thin bent crystal,** Eur. Phys. J. C, 74 (1) (2014), pp. 1-7



The crystal channeling efficiency is a function of the ratio R/R_c

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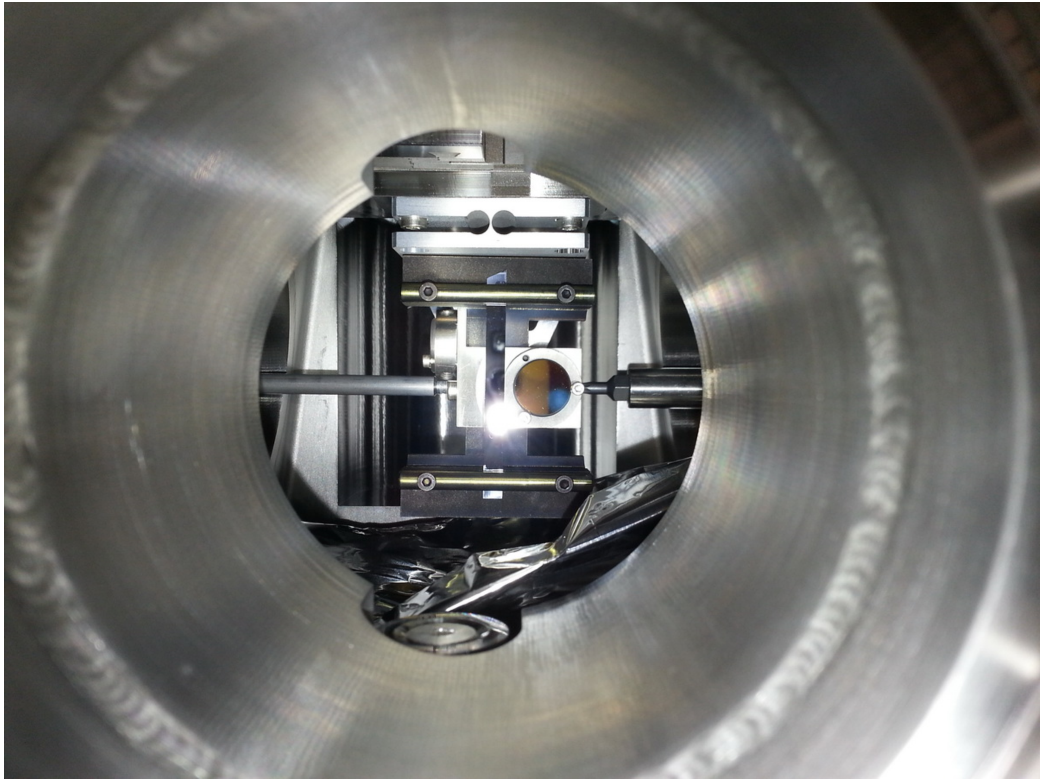


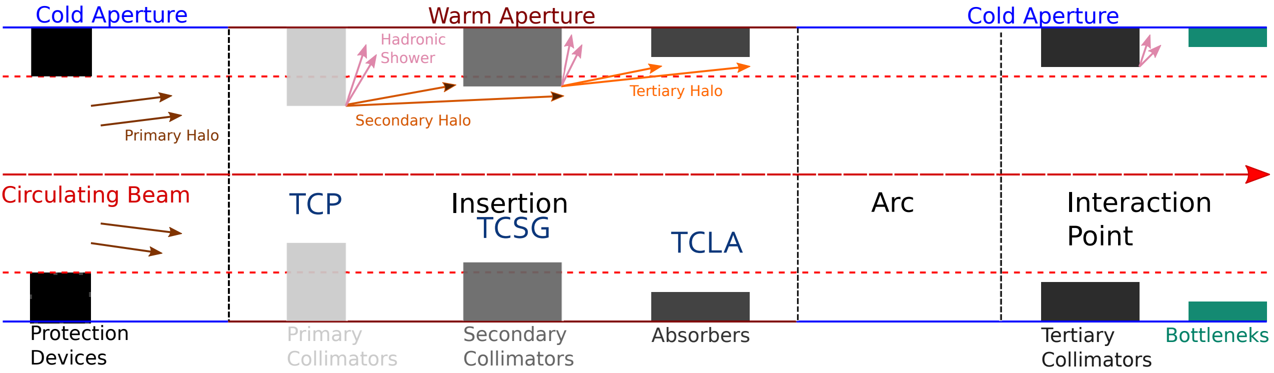
Strip silicon crystal. Installed on the horizontal goniometer in LHC.

Collimation System in LHC

To protect the superconductive magnets from high energy deposition induced by lost particles

<u>Collimation system is needed!</u>

$\eta = 10^{-4}$ is the actual performance in LHC



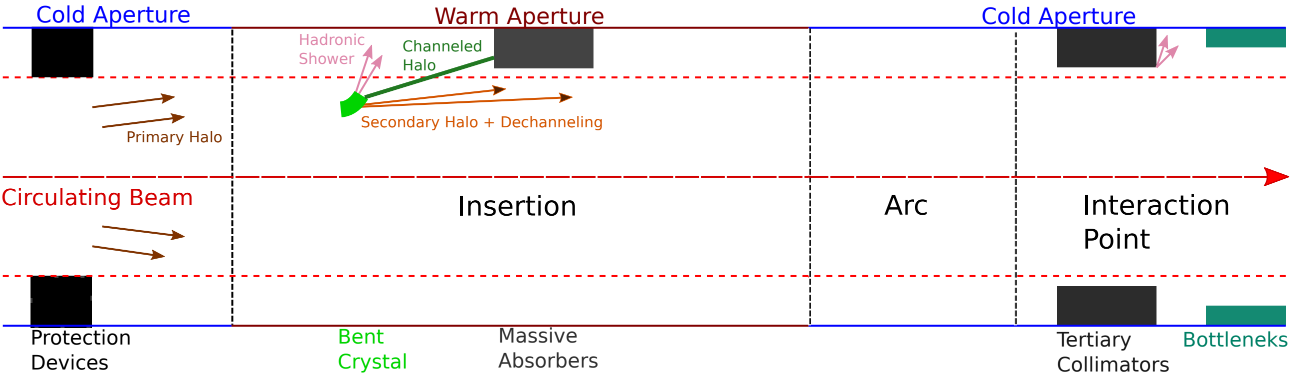
- **Halo cleaning**: reduce the risk of magnet quenches
- **Concentration of losses/activation** in controlled areas
  Avoid many hot locations around the 27km-long tunnel

Multistage system of 50 collimators per beam.

LHC: only machine where collimation must be used continuously in operation

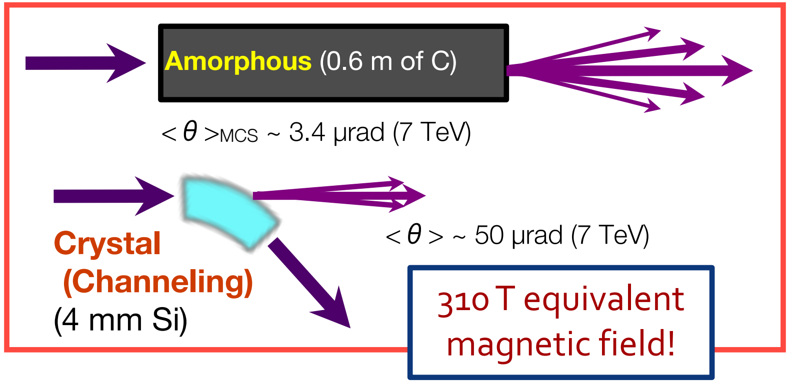
<u>The cleaning inefficiency</u> with ions <u>drops to 10^{-2}!</u>

Crystal Collimation



Advantages of crystal collimation at the LHC:

- Improve **collimation cleaning** (by a factor 10);
  Reducing off-momentum losses in DS
- Lower **impedance**;
  Less collimators at larger gaps



Crystal collimation *could improve the ion cleaning* and is one of the R&D subject for HL-LHC upgrade

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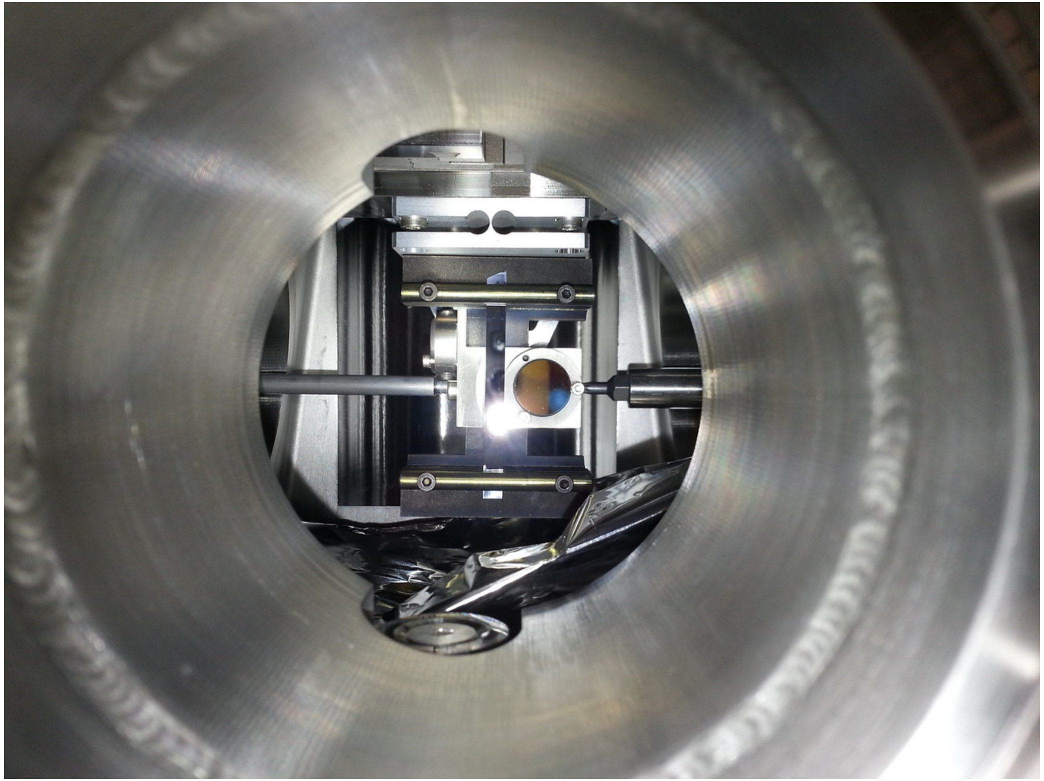

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Crystal Collimation Layout

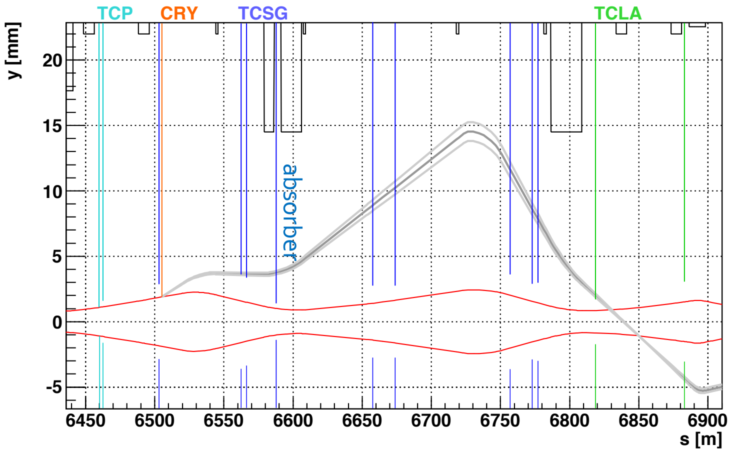
Semi-analytical studies and full tracking simulations has been provided to find the best layout for the LHC test stand.

The major requirements (for both injection and flat top) have been studied [1]:

1. Intercept the channeled halo with enough clearance by the TCSGs downstream
2. Respect the aperture constraints
3. Collimation cleaning performances optimisation

Crystal request defined before 2014 restart:

- Bending angle: 50 μrad
- Length: 4 mm



		θ_b [μrad]		
R[m]		40	50	60
l [mm]	3	~~75~~	~~60~~	~~50~~
	4	~~100~~	80	~~66.7~~
	5	~~125~~	~~100~~	~~83.3~~

R_c~15.6 m @6.5 TeV

[1] D. Mirarchi, et al., **Design and implementations of crystal collimation test stand at the Large Hadron Collider**, Eur. Phys. J. C, 77 (6) (2017), p. 424

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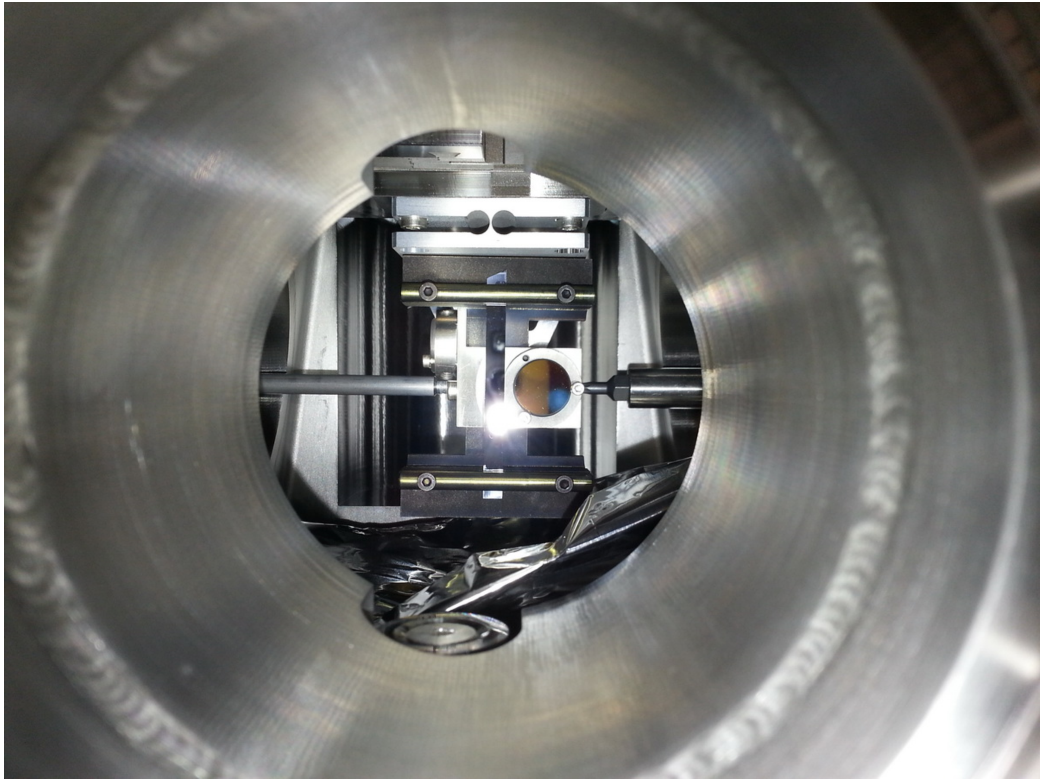
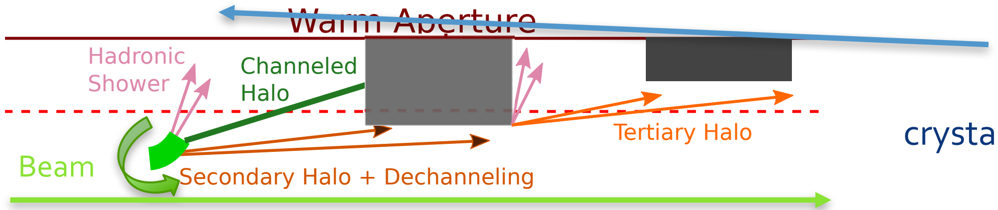


Strip silicon crystal. Installed on the horizontal goniometer in LHC.

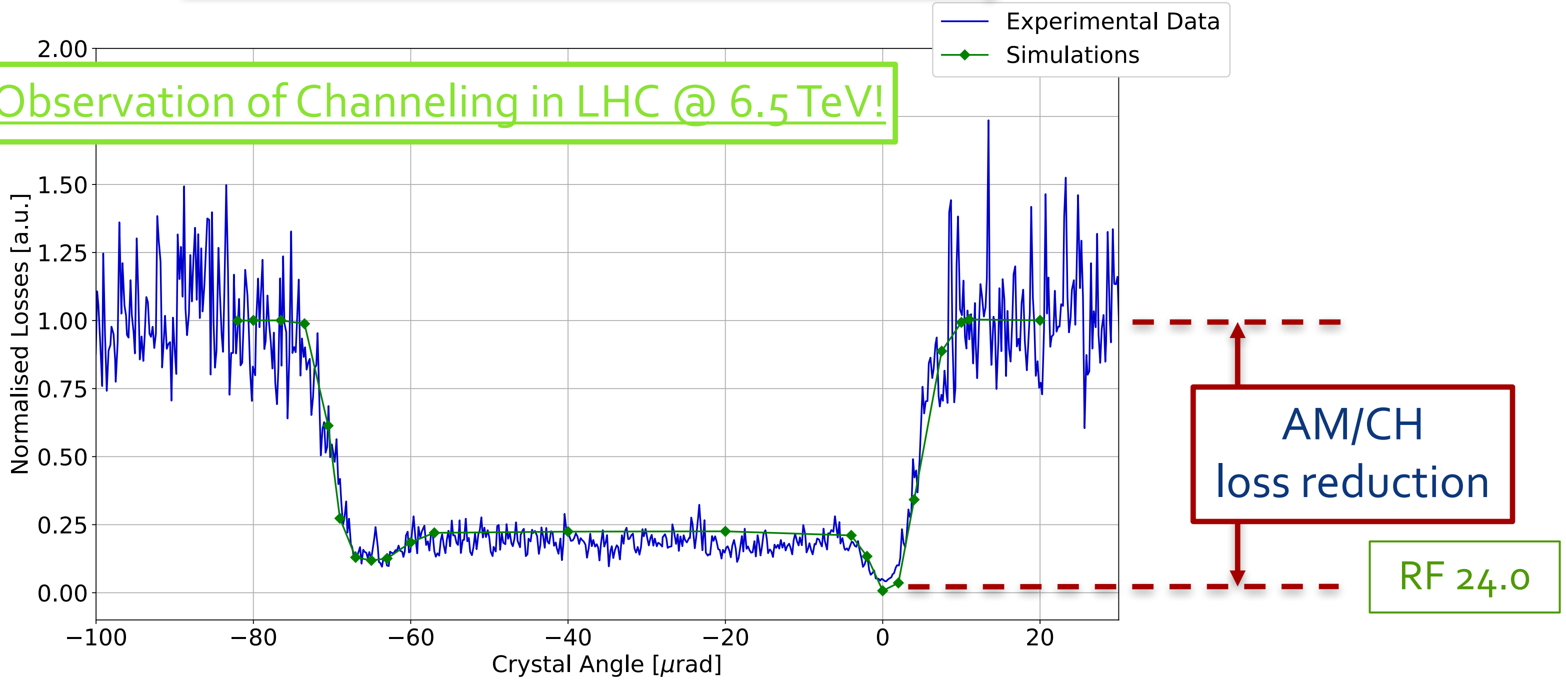
Channeling Observation

1. Angular Scan



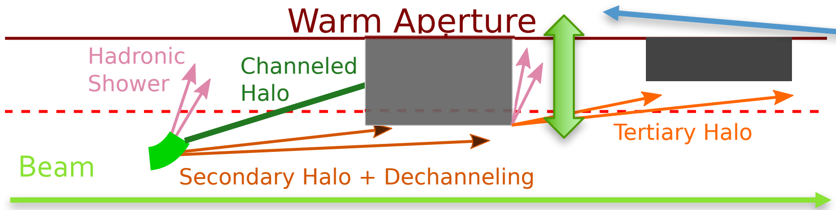
local losses
vs
crystal angular orientation

First Observation of Channeling in LHC @ 6.5 TeV!

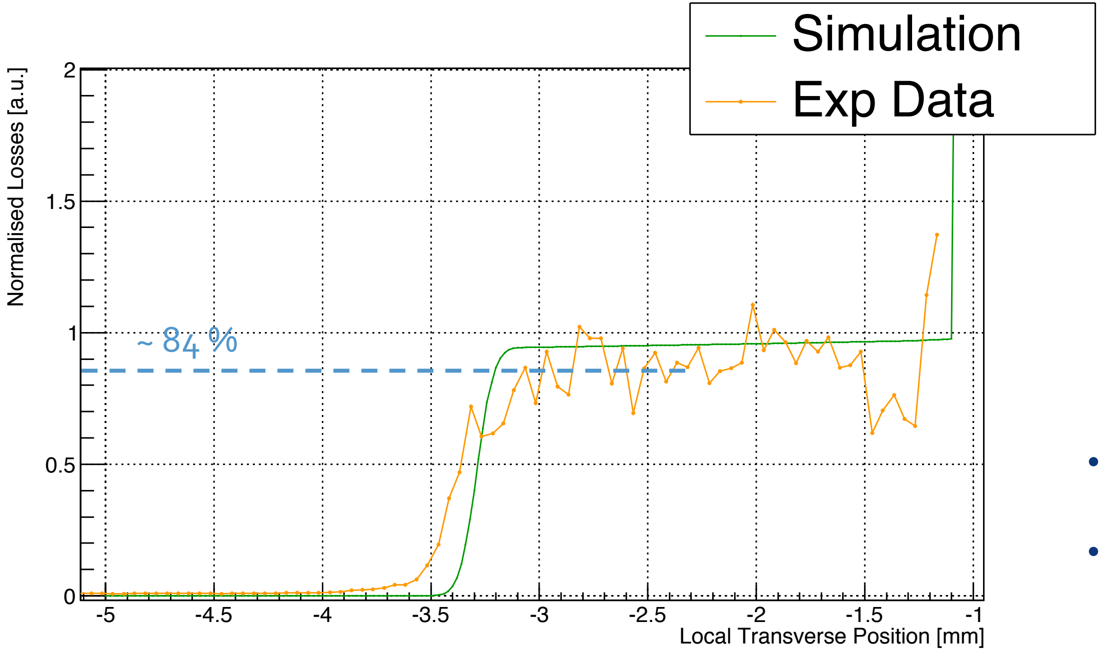


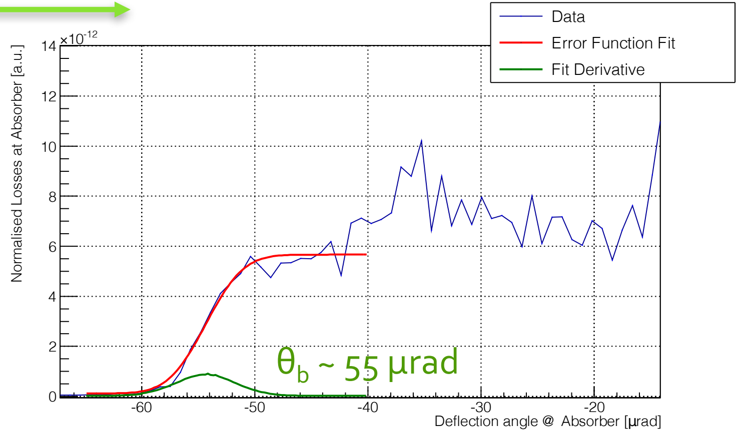
Channeling Observation

2. Absorber Scan



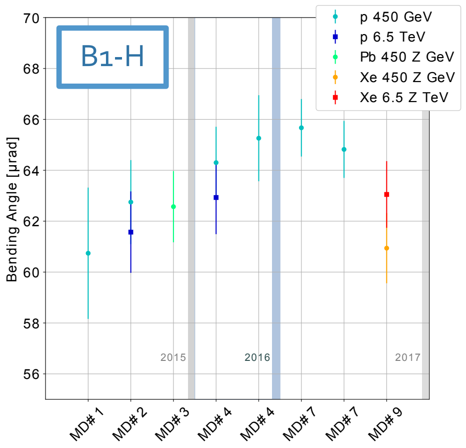
local losses
vs
collimator transverse position

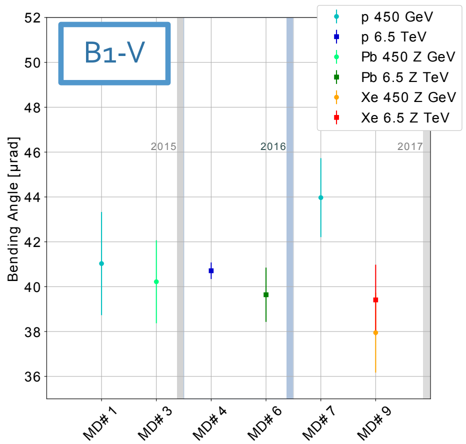




- With Transport Matrix can be evaluated the deflection angle
- Losses at channeling plateau, normalised to the primary beam spike, can evaluate the multiturn channeling efficiency

B1 Angles





Crystal	Reduction Factor						Bending Angle [μrad]
	p		Pb		Xe		
	Injection	Flat Top	Injection	Flat Top	Injection	Flat Top	
B1-H	17.5 ± 2.9	26.9 ± 5.5	6.1 ± 0.5	8.3 ± 1.2	8.4 ± 0.6	6.4 ± 1.1	63.2 ± 1.7
B1-V	17.8 ± 3.6	17.7 ± 3.9	5.6 ± 0.8	6.2 ± 2.3	5.8 ± 0.7	3.9 ± 0.5	39.8 ± 2.3
B2-H	10.6 ± 2.5	–	–	–	–	–	52.1 ± 1.6
B2-V	19.6 ± 0.5	20.1 ± 0.3	–	–	8.8 ± 1.0	8.2 ± 0.8	56.5 ± 1.5

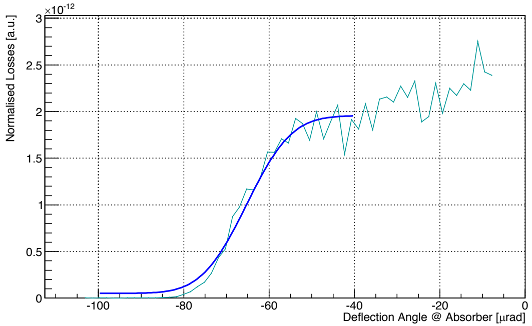
Crystals on B1 out of specs

Collimator Scan Measurements

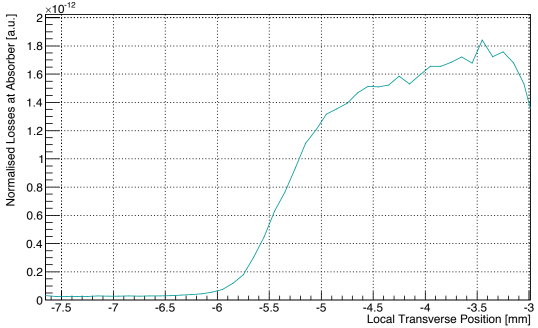
R_c~1.1 m @450 GeV   The crystals are equivalent in injection measurements

Injection

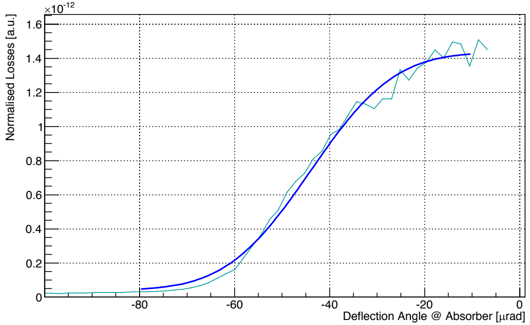
B1-H: θ_b = 63 µrad, R = 63 m



B2-V: θ_b = 56 µrad, R = 71 m



B1-V: θ_b = 40 µrad, R = 100 m



Multi-turn Channeling Efficiency

~71%

~83%

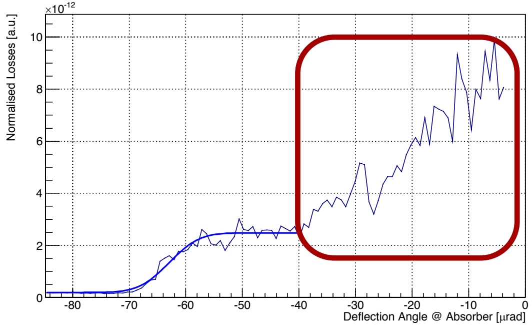
~87%

Collimator Scan Measurements

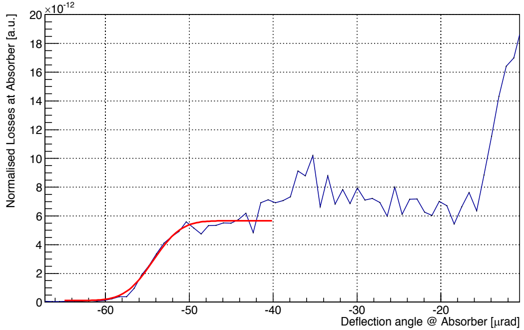
R_c~15.6 m @6.5 TeV

Flat Top

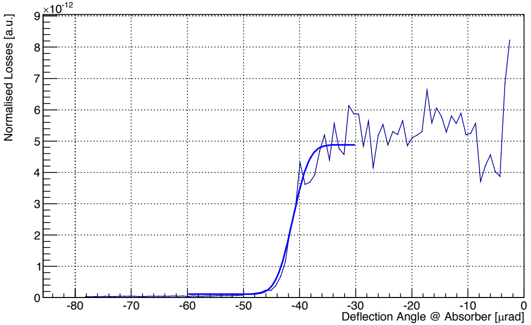
B1-H: θ_b = 63 µrad, R = 63 m*



B2-V: θ_b = 56 µrad, R = 71 m



B1-V: θ_b = 40 µrad, R = 100 m



Multi-turn Channeling Efficiency

~27%

~72%

~84%

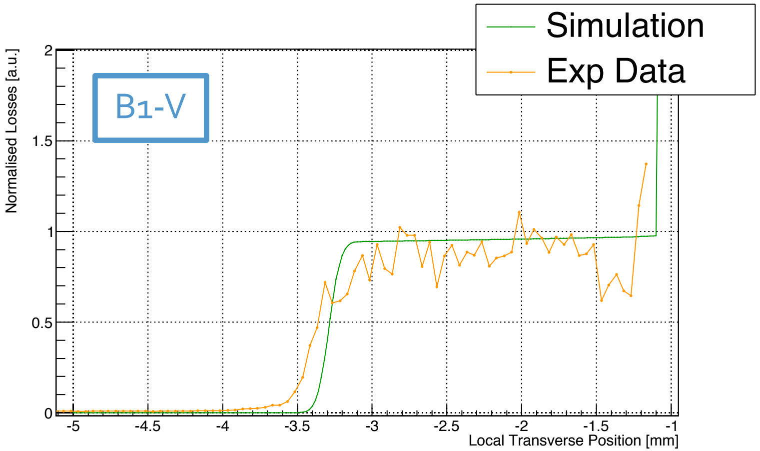
* ~4 critical radius

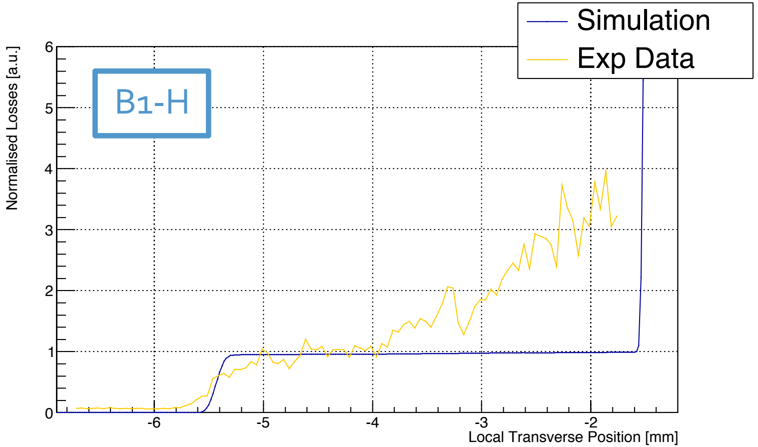
Collimator Scan Simulations

In collimator scan simulations, it is evident that the dechanneled population at lower deflection angles is higher in B1-H.

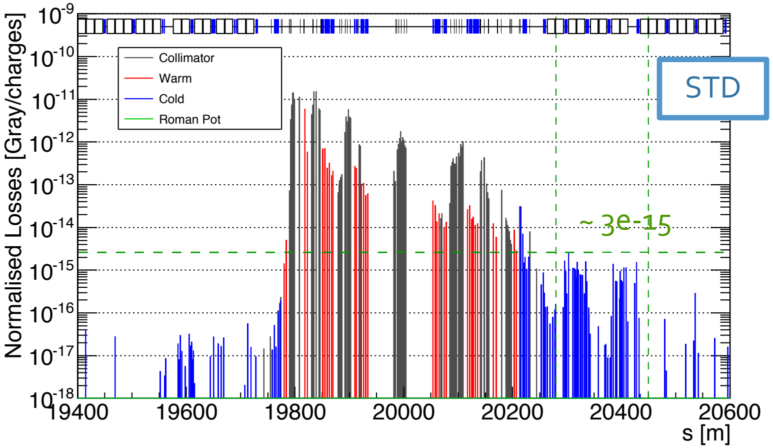
The main difference we can found between the two condition is the bending angle of the two crystals.

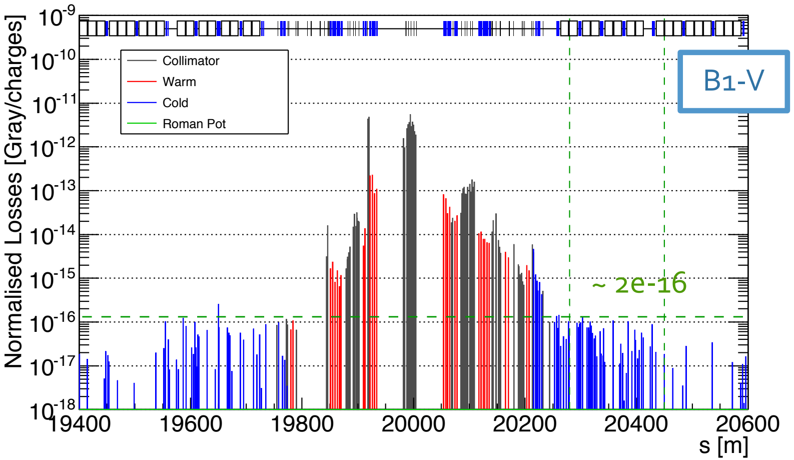
In this regime nuclear dechanneling is enhanced and there is no analytical description (simulation discrepancies)

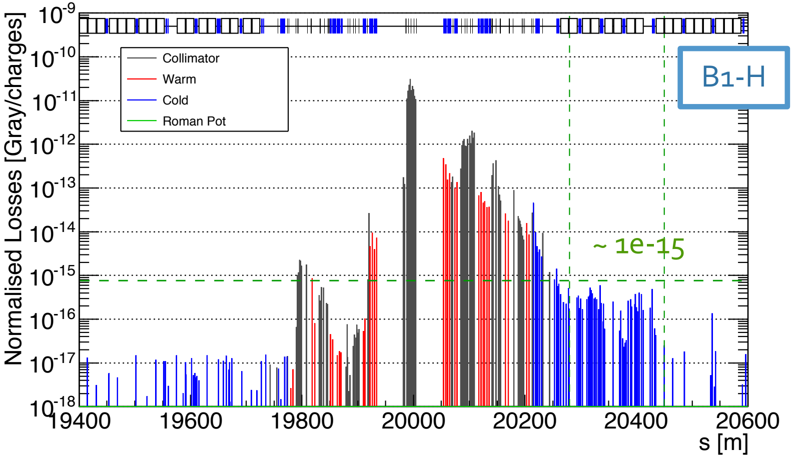




Proton Cleaning Measurements

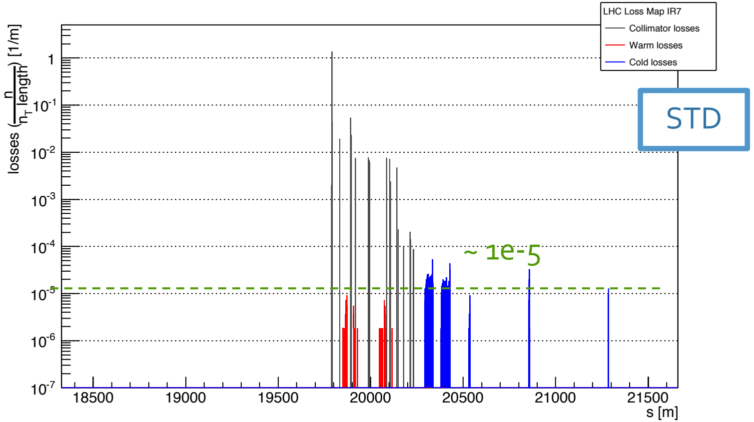


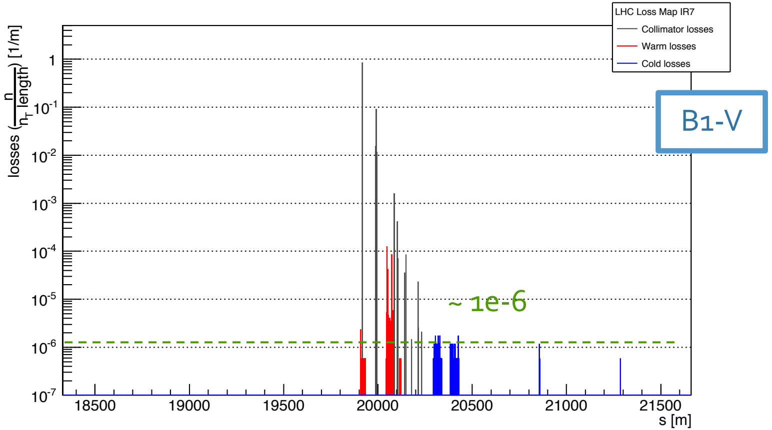




- B1-V is improving the collimation cleaning by a factor > 10
- B1-H shows more losses in dispersive area (closer to standard collimation)

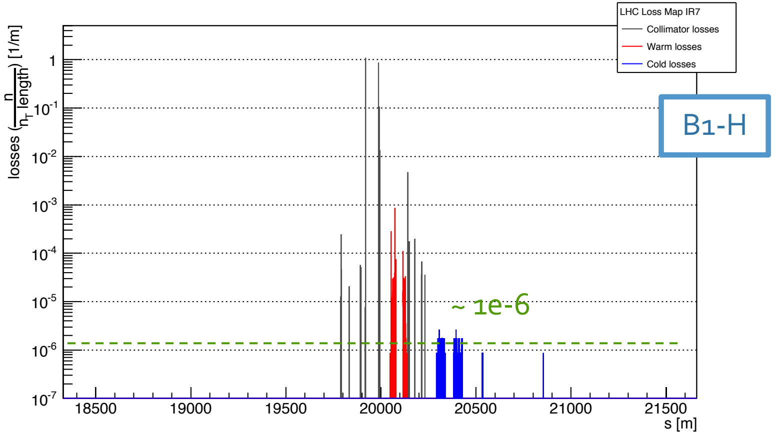
Proton Cleaning Simulations





Comparing cleaning simulations to measurements

- good agreement with data is found in vertical plane: same factor 10 improvement
- important difference is observed in the horizontal plane with respect to data



Dechanneled particles at low deflection are lost in the dispersive area

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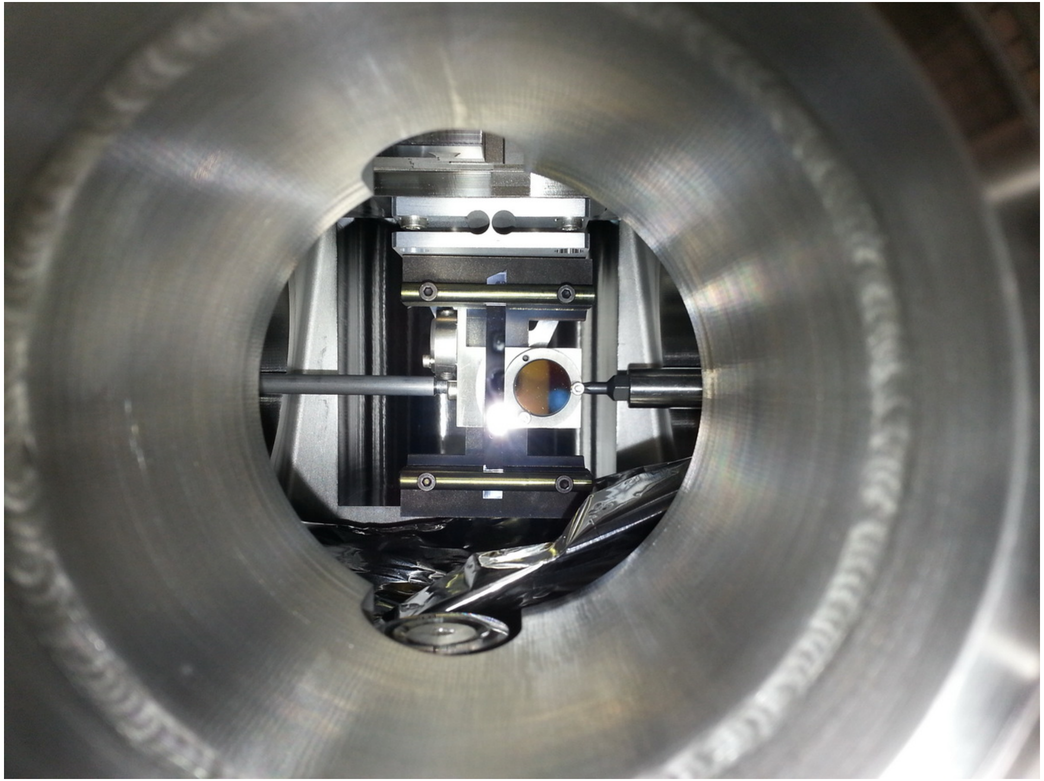

Strip silicon crystal. Installed on the horizontal goniometer in LHC.

Conclusions

- ✓ Crystals too close to critical radius (~ 4 times) shows a enhancement of dechanneled particles at low deflections
- ✓ At LHC 6.5 TeV, B1-H crystal is too close to critical radius
  - In linear scans is observed a reduced efficiency due to dechanneling enhancement
  - In proton cleaning measurements B1-H showed reduced performance compared to B1-V
- ✓ Simulations benchmark confirmed the hypothesis
  - Good agreement with experimental data for B1-V ($>6R_c$)
  - Allowed good understanding of B1-H features