Review of the experimental results for the crystal assisted collimation in the UA9 experiment

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For the UA9 Collaboration

Outline

I. Crystal Channeling theory
II. Crystal collimation concept
III. Experimental apparatus
IV. Experimental results
V. Conclusions

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Crystal Channeling theory

We can describe the potential between a particle and an atom by the Thomas-Fermi model:

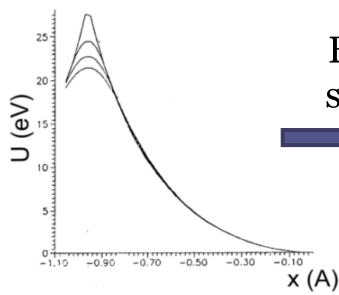
$$V(r) = \frac{Z_i Z e^2}{r} \Phi(\frac{r}{a_{TF}})$$

Where $\Phi(r/a_{TF})$ is the Moliére screening function

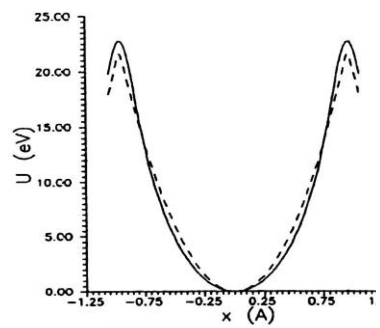
We can make the continuous approximation by Lindhard: $U_p(x) = Nd \iint_{-\infty}^{+\infty} V(x,y,z)dydz$

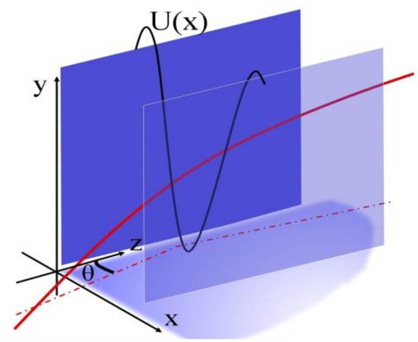
We can get the potential seen by protons from the crystalline plane:

By single plane: (plus thermal agitation)



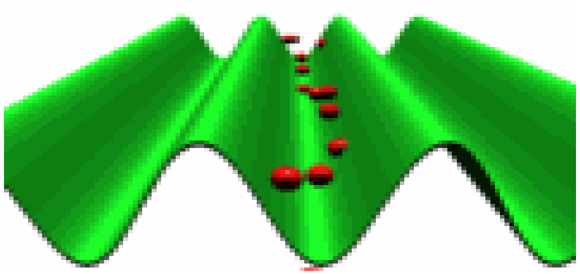
By two planes superimposed





So:
If the particles have $p_T < U_{max}$
Can be channeled

Protons forced to oscillate between crystalline planes



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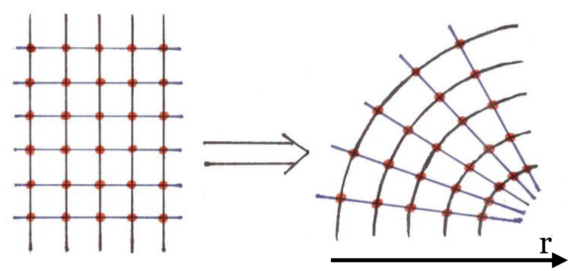
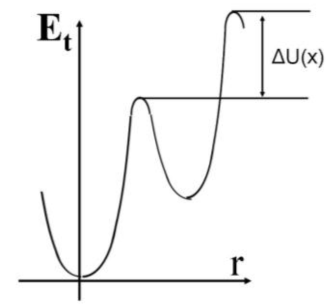
Crystal Channeling theory

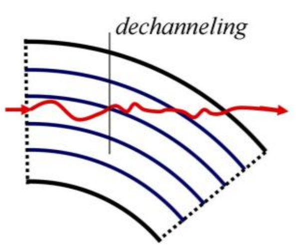
The potential between the particles and the planes is modified bending the crystal as:



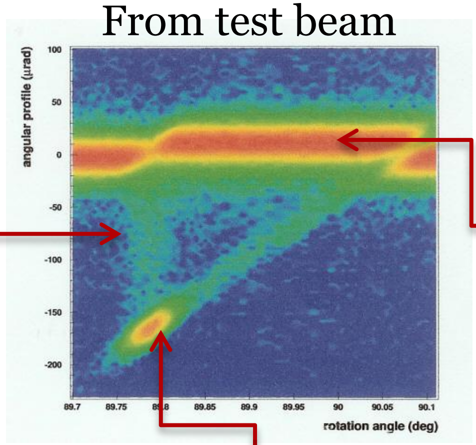


Hence the particle can undergo:

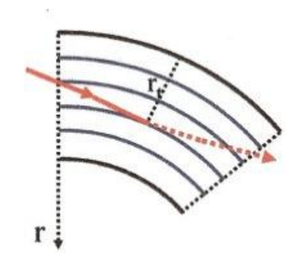
Dechanneling



From test beam



Volume Reflection

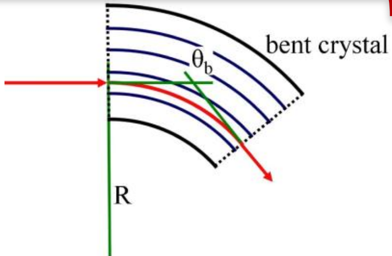


Eff = 95÷97%

$\sigma_{VR} = 5\ \sigma_{CH}$

Desired **deflection** if channeled for all the path

Eff = 50÷85%



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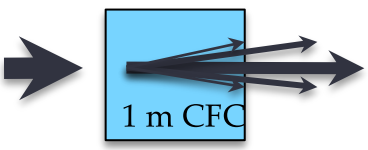
Crystal collimation concept

Basic limitation of the amorphous collimation system: **inelastic interaction**

Diffractive events (p) Fragmentation and dissociation (pb^+)	➢ Small deflection ➢ Not negligible $\Delta p/p$	*Escape from the collimation insertion and lost on the magnets*

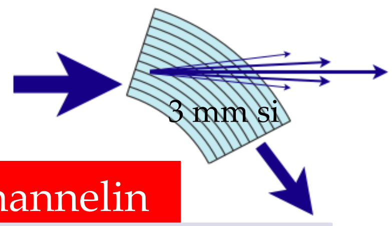
New system based on two stages, the first composed of a bent crystal and the second by an absorber

Crucial difference:



amorphous

$<\theta>_{MCS} \cong 3.6 \mu rad$ @ 7 TeV



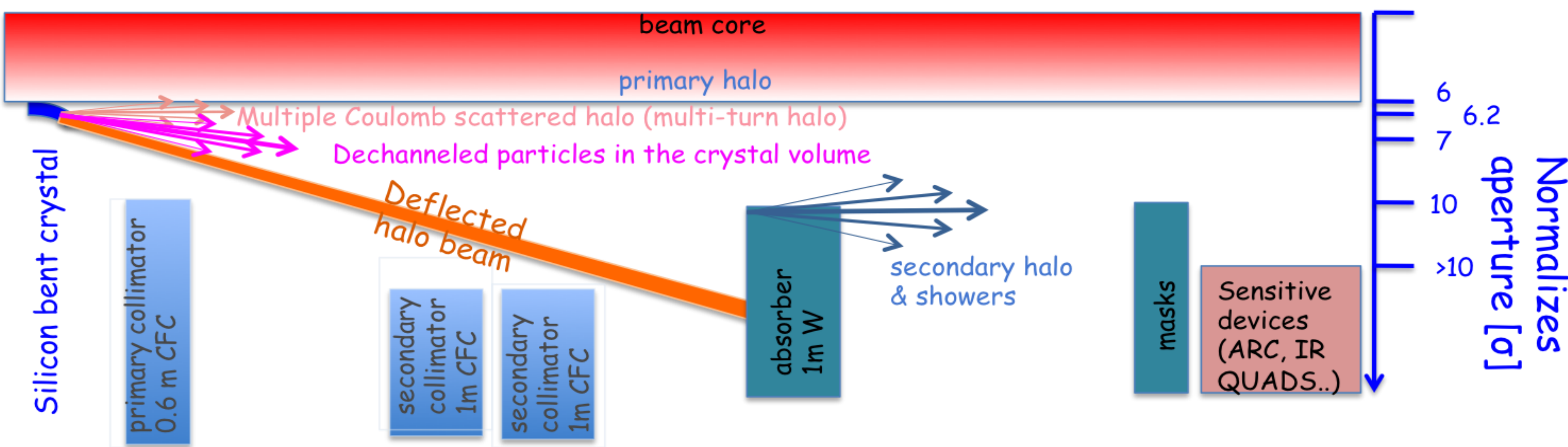
channelin

$\theta_{optimal\ @7TeV} \cong 40\ \mu rad$

Principal gains:

- Reduction of inelastic int.
- Big deflection angle after 1st stage
- Impedance reduction

Increasing in L



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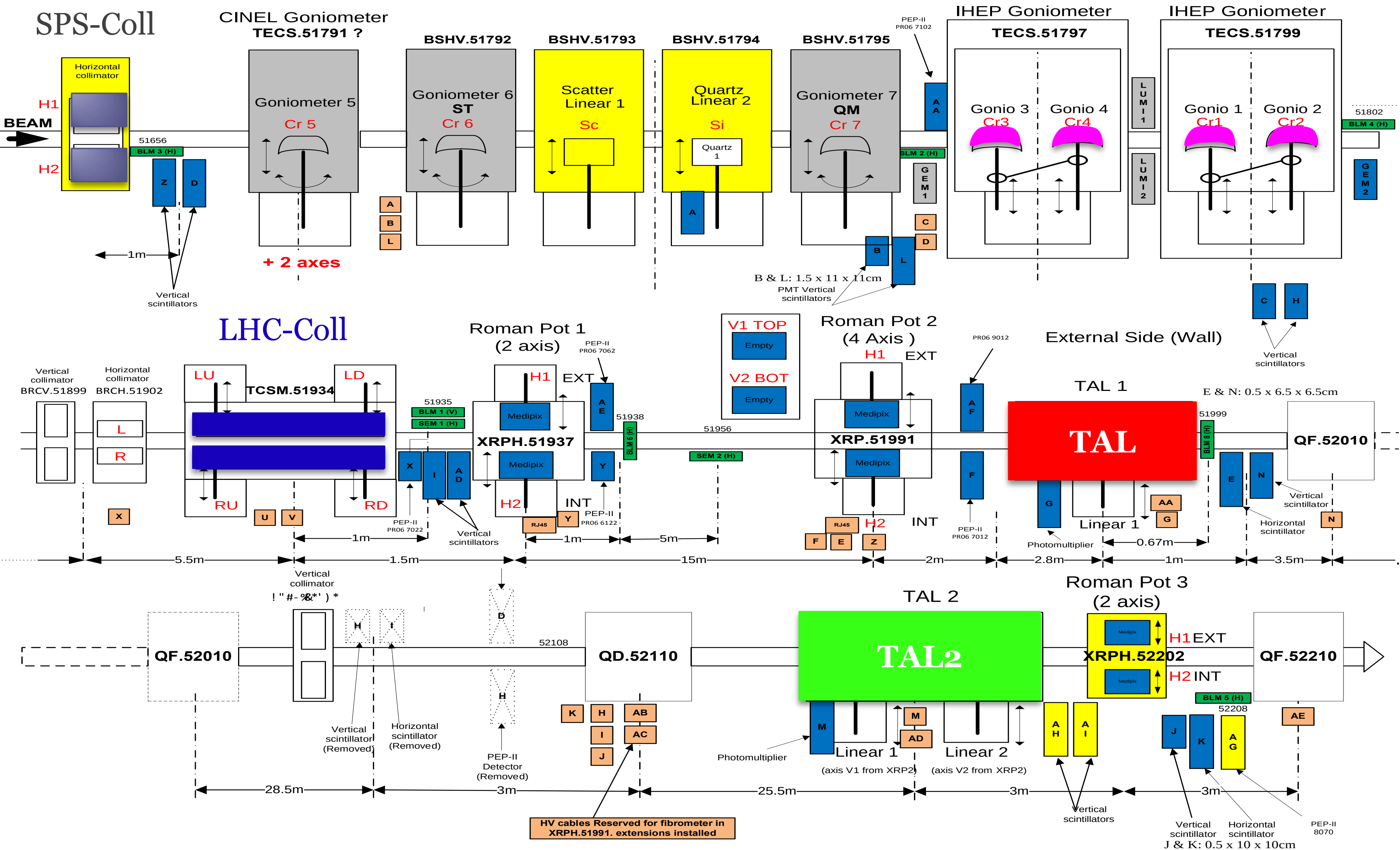
Experimental apparatus



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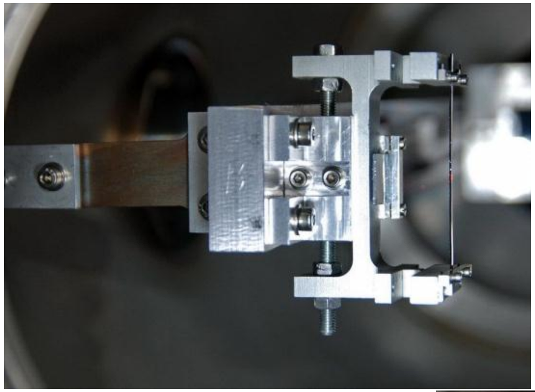
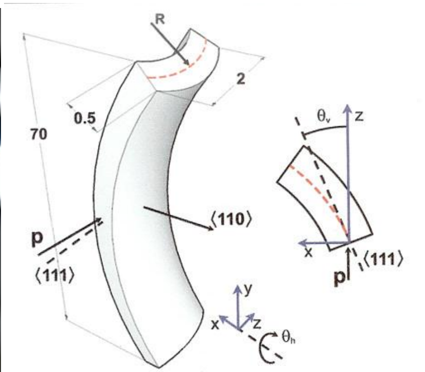
Experimental apparatus

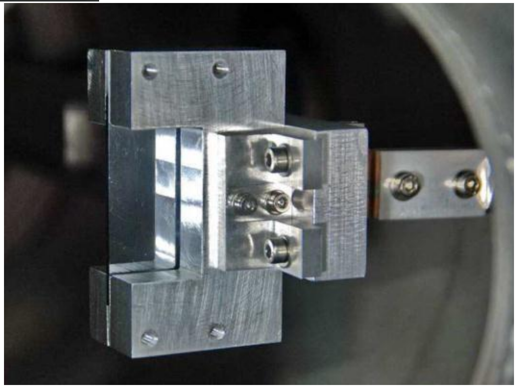
Si Crystals:

- ✓ Two Strip Crystal (1&4)
- ✓ Two Quasi Mosaic Crystal (2&3)





Bending given by anticlastic forces



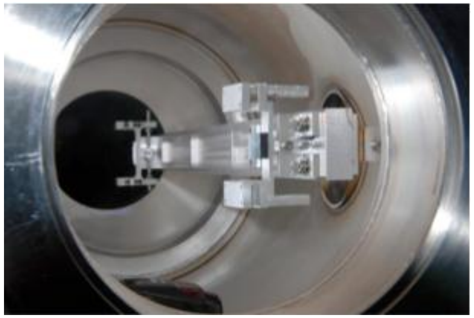
In the SPS:

- Crystal length ~2mm,
- Bending 150÷180 μrad
- Torsion: ~ 1 urad / mm
- Amorphous layer: < 1 um
- Miscut angle: ~ 100 urad

Goniometers:

$$q_c = \sqrt{\frac{2U_{max}}{E}}$$

Energy	θ_c [μrad]
120 GeV	18.26
450 GeV	9.42
3.5 TeV	3.38
7 TeV	2.39



Needed high precision and repeatability ~10 μrad for SPS, ~1÷2 μrad for LHC

Outline

Experimental results

Main UA9 goals and steps

Test beams in the North Area (~ 3 weeks per year on the H8 line):

- Crystal characterization before the installation in the SPS

Test of crystal assisted collimation in the SPS(~ 5 days per year)

- 2009 : First results on the SPS beam collimation with bent crystals
  (Physics Letters B, vol. 692, no. 2, pp. 78–82).

- 2010 : Comparative results on collimation of the SPS beam of protons and Pb ions with bent crystals
  (Physics Letters B, vol. 703, no. 5, pp. 547–551).

- 2011 : Strong reduction of the off-momentum halo in crystal assisted collimation of the SPS beam
  (Physics Letters B, 714(2-5), 231–236)

- 2012 : Halo population reduction far from the crystal, SPS loss maps, optimized apertures for collimation system elements, … (data taking still ongoing)

Towards the future installation of a prototype system in the LHC

Experimental results

Done different tests to investigate the crystal assisted collimation properties:

- Angular scan → Local nuclear interaction rate study
- LHC-Collimator scan → Measurement of the multiturn channeling eff.
- Scraper linear scans → Study of the escaping tertiary halo
- Losses around the ring → SPS Loss Map

Tests made in the SPS with p and Pb ions

- ✓ Beam intensity: from single bunch up to 288 bunches in COAST (nominal LHC bunch)
- ✓ Energy 120 & 270 GeV

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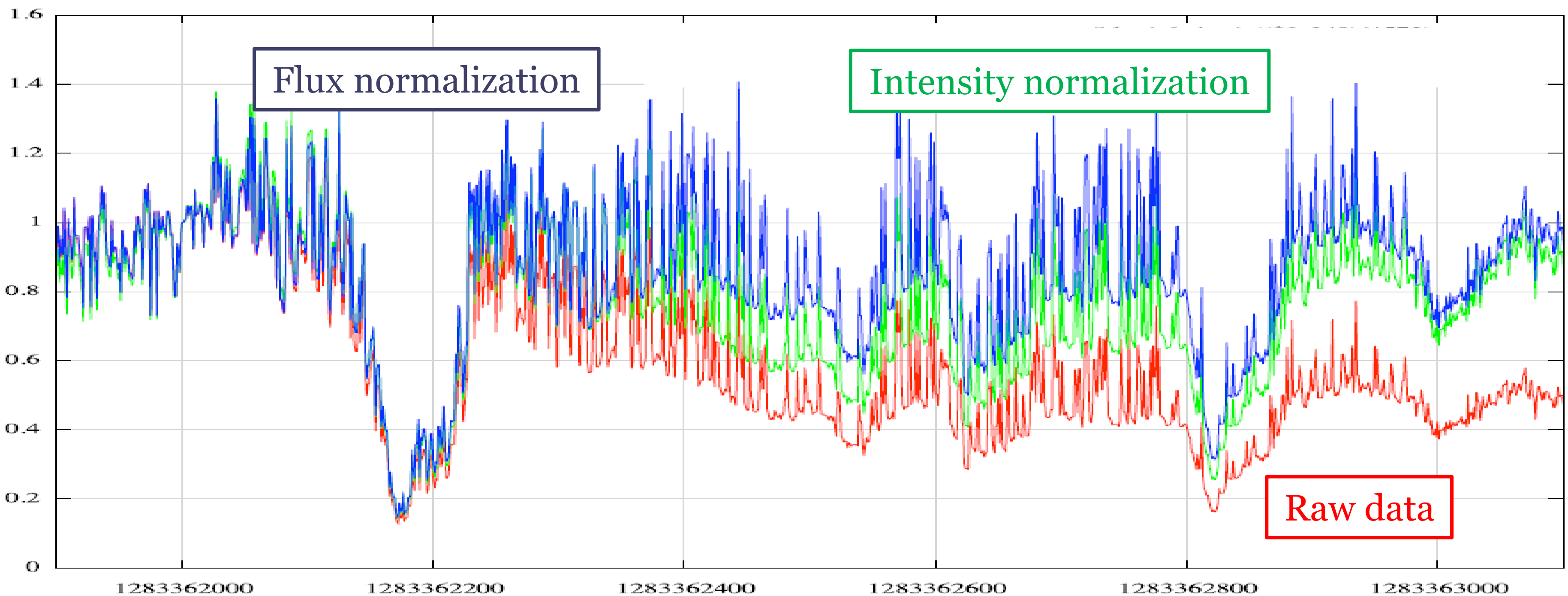
Experimental results

Crucial point for all the analysis: what is the right normalization?

If we assume that the flux is proportional to the intensity → At first order we can normalize with the circulating intensity in SPS



i.e. if the beam life time changes : We have to use directly the beam flux!!
(Derivate of beam intensity measured by BCT)

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Experimental results

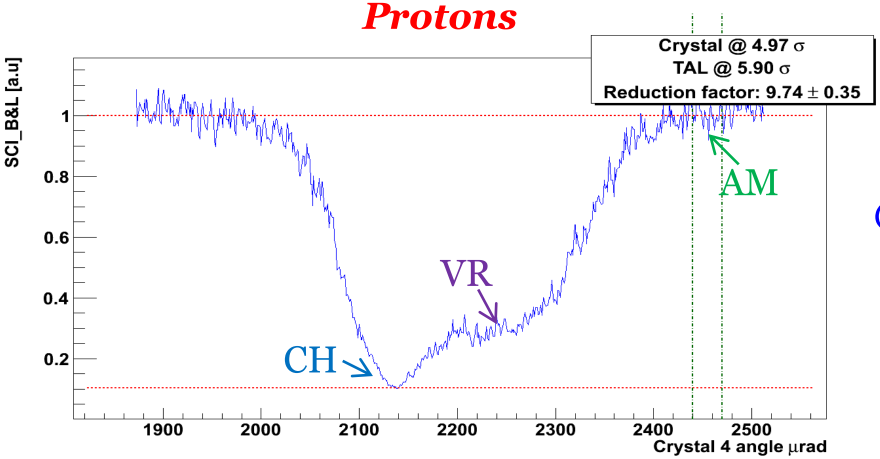
Angular scans:

What we want to do: Study of nuclear interaction rate (at the crystal location)

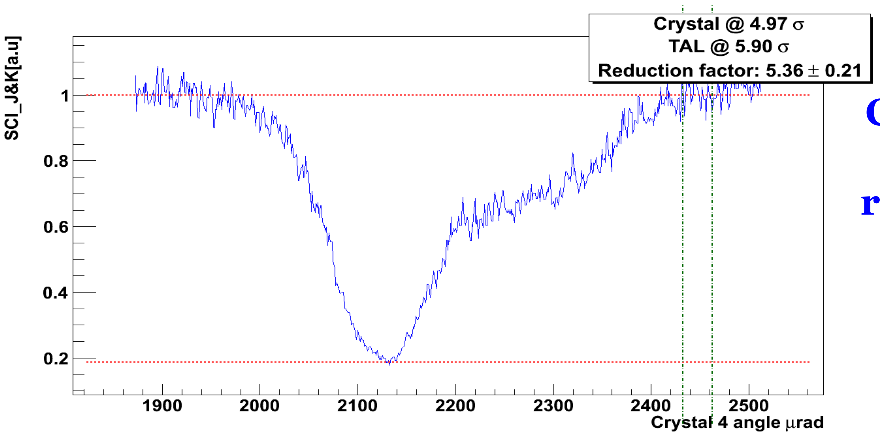
Observable: reduction factor between the normalized losses in channeling and amorphous orientation

Example of angular scan with p and pb^+

Protons

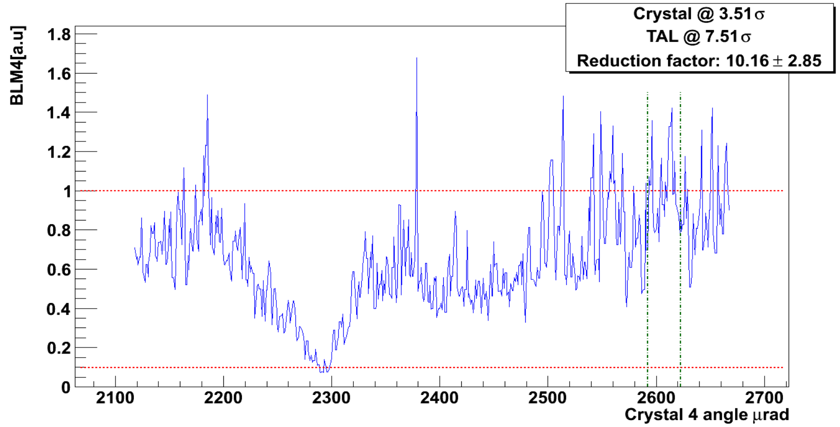


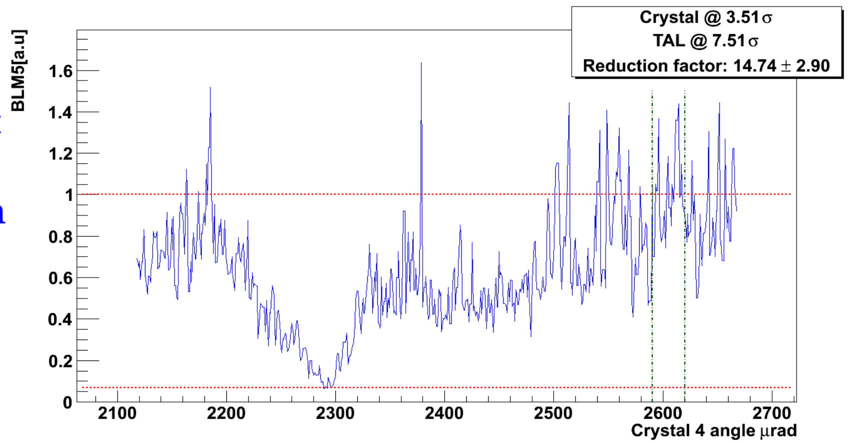
@ crystal



Coherent losses reduction @ high disp. area

Ions





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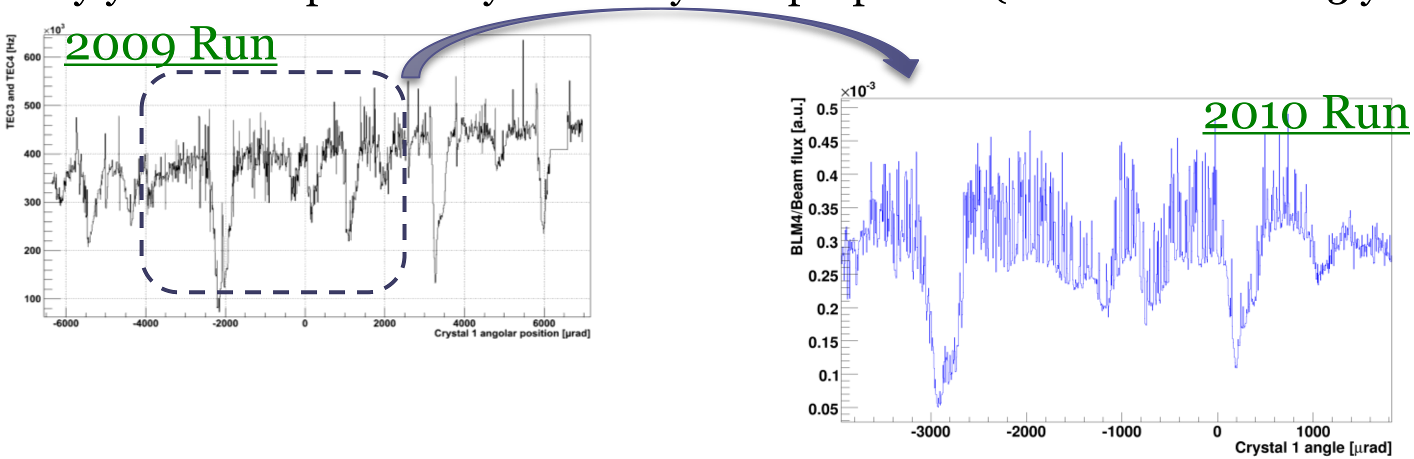
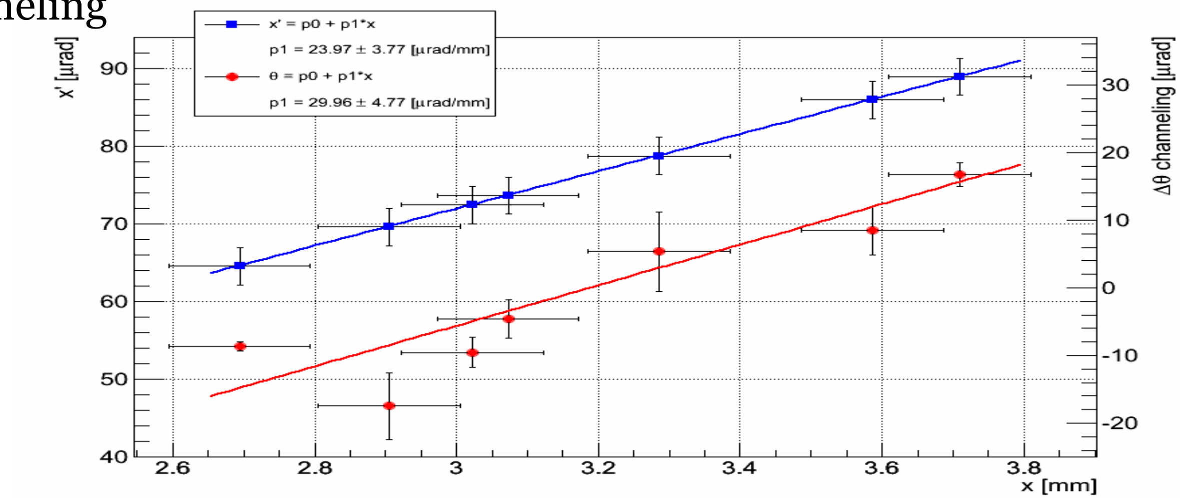
Experimental results

Angular scans:

- ✓ Checked every year the repeatability of the crystals properties (still stables after 3 years of tests)



- ✓ Checked the good agreement between the changes in the aperture and in the crystal orientation to get in channeling



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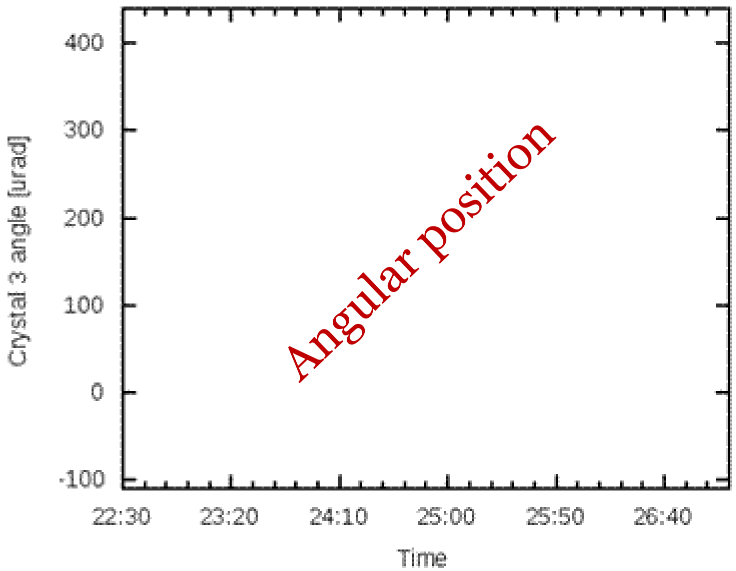
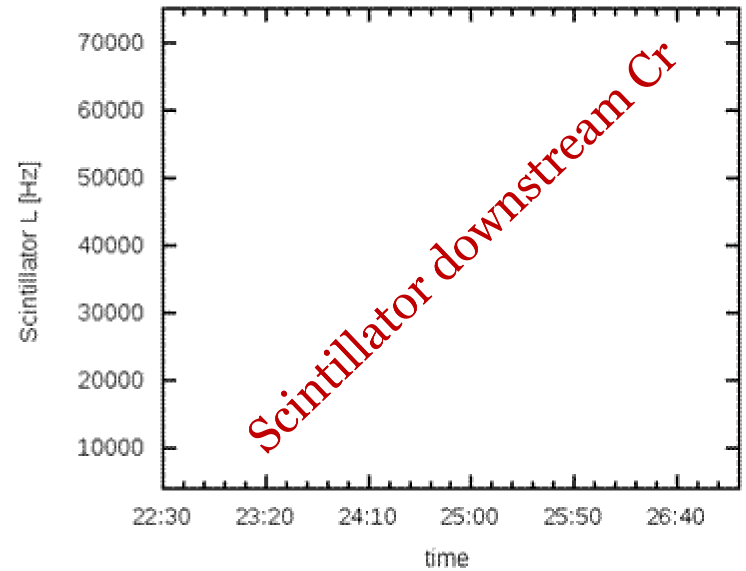
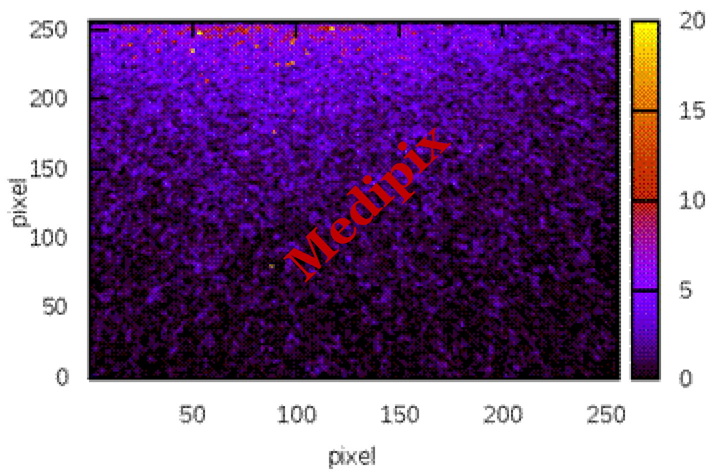
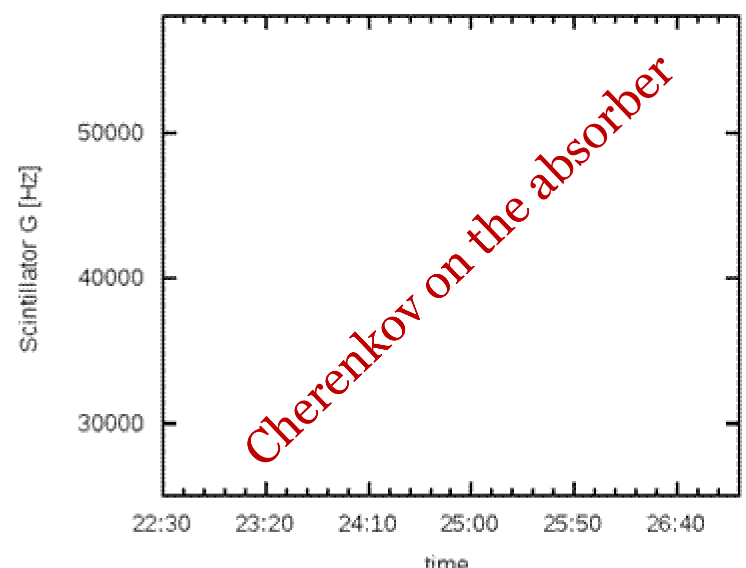
Experimental results









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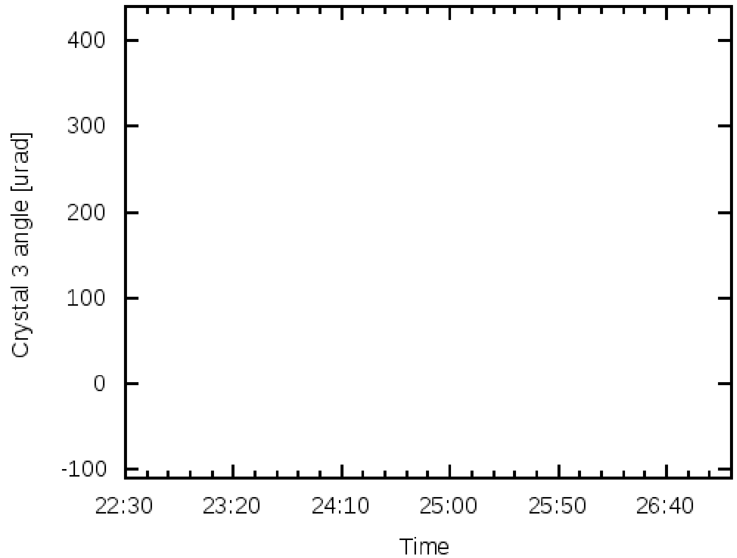
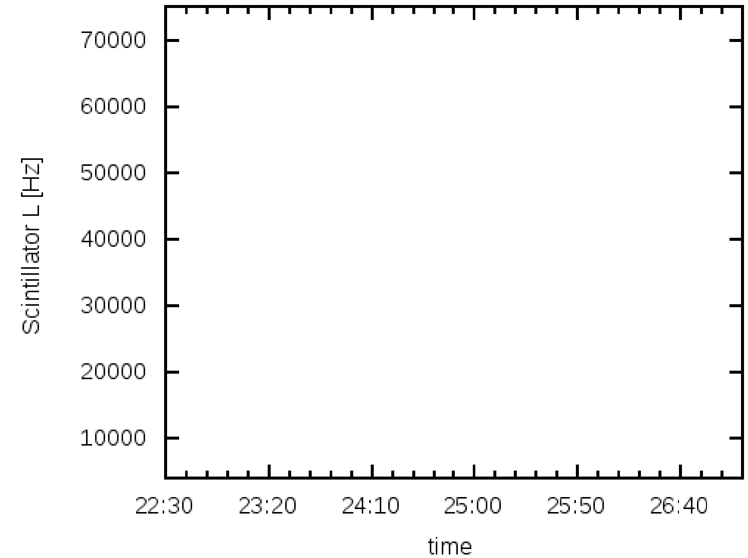
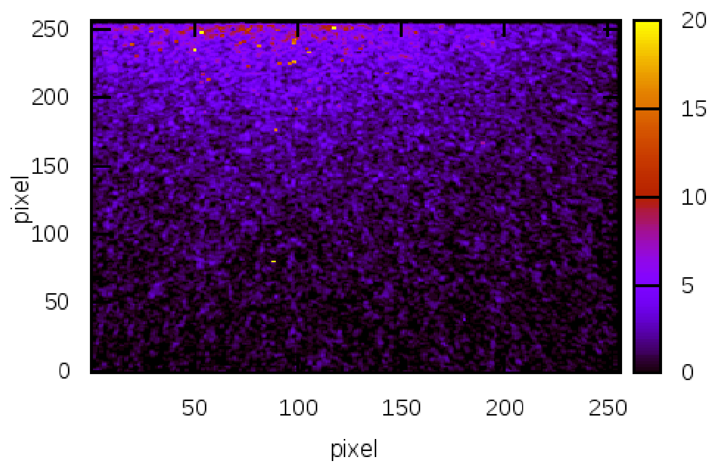
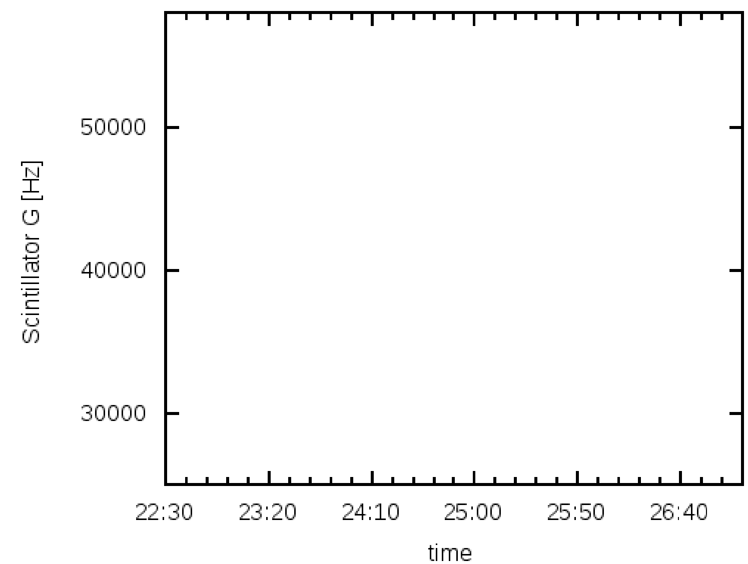
Experimental results









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Experimental results

LHC-Collimator scans:

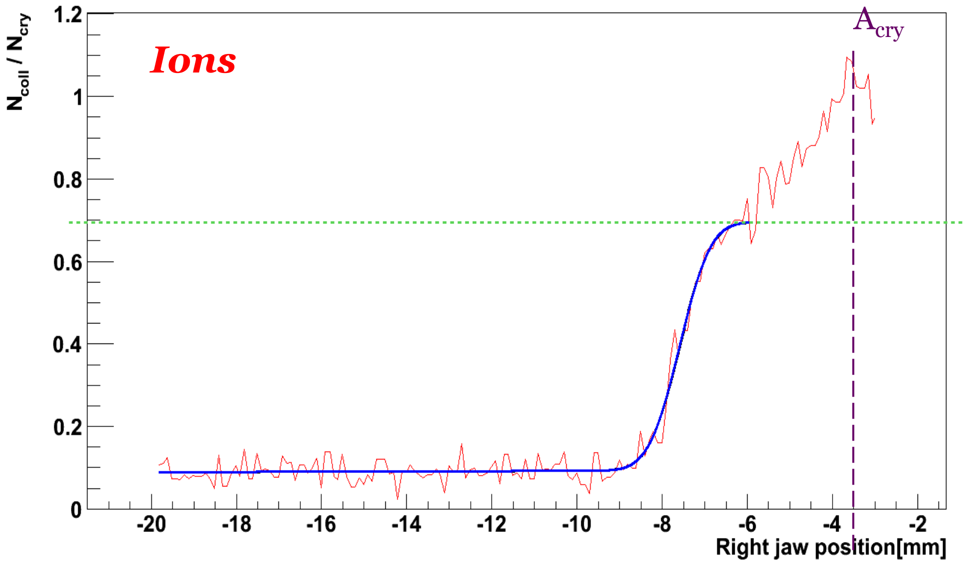
What we want to do: Measure the crystal channeling efficiency

Observable: Shower created by gradual collimator insertion, detected by his downtream detectors

Valid if we assume:

1. BLM signal $\propto N_{coll}$
2. If $A_{coll} = A_{cry} \rightarrow N_{coll} = N_{cry}$

Where N are the particles at collimator/crystal and A the aperture



Evaluation of the multiturn channeling efficiency:

With protons: ~80%   *With ions: ~70%*

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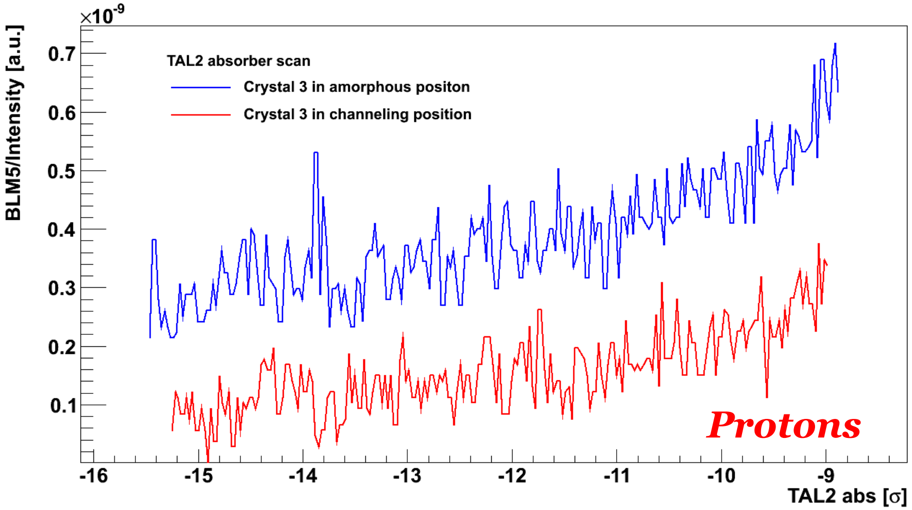
Experimental results

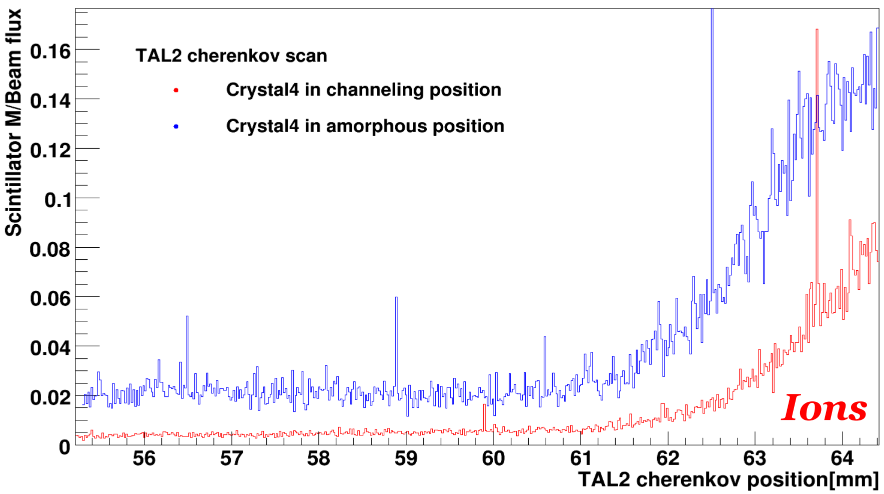
Scrapers linear scans:

What we want to do: Study of tertiary halo reduction

Observables: • High dispersive area:

- ➢ Shower created by gradual insertion of 10cm Al, detected by his downtream detectors
- ➢ Signal of cherenkov detector, gradually inserted





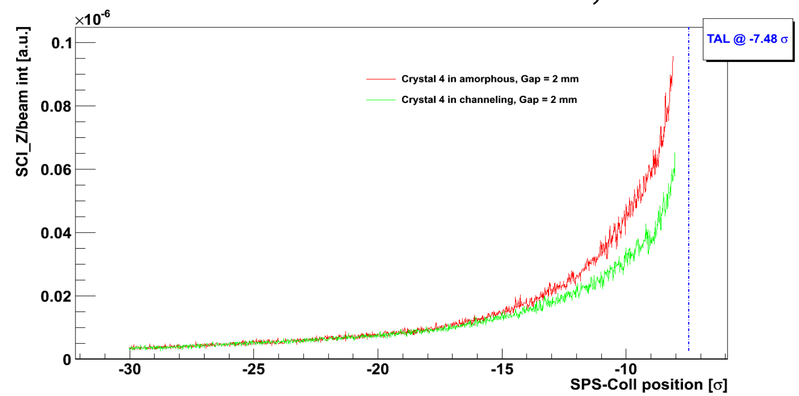
Experimental results

Scrapers linear scans:

What we want to do: Study of tertiary halo reduction

Observables: • Before the crystal (to check what comes back to the collimation insertion):

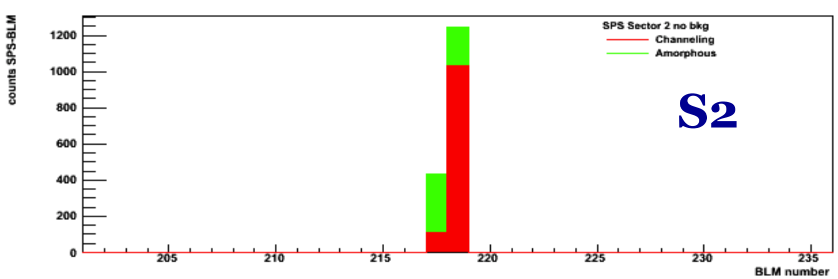
➢ Shower created by gradual insertion of an SPS-Collimator, detected by his downtream detectors

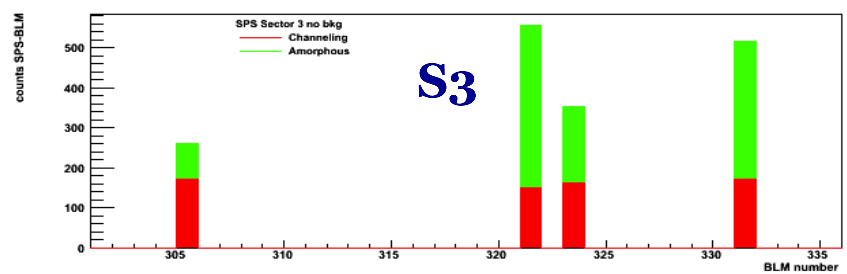


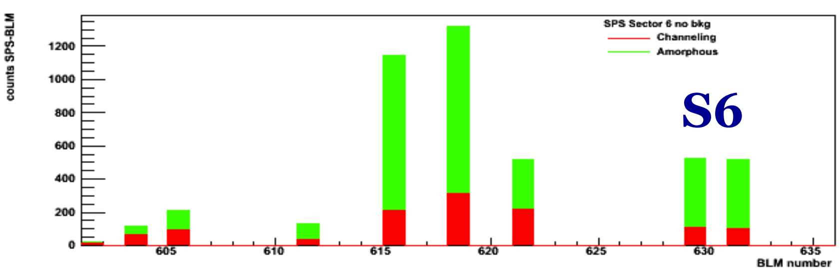
Preliminary SPS Loss Map:

Only few BLMs sensitive to the losses (48 bunch)

✓ Visible reduction in all of them







Used beam of 4 batches in the last MD to redo it

➢ analysis still ongoing

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Conclusions

The good results achieved made possible the approval by the LHCC to move from the SPS to the LHC

Main results achieved in the past tests:

- ✓ reduction of nuclear interaction rate at the primary collimator of ~10 in case of protons and lead ions
- ✓ multiturn channeling efficiency of: ~80% with protons, and ~70% with lead ions
- ✓ reduction of the tertiary halo in the high dispersion area of: ~5 with protons, and ~10 with lead ions
- ✓ preliminary SPS Loss Map with visible losses reduction around the whole ring

Stable crystal properties over 3 years of tests!

More interesting results are coming!!

(like, SPS complete Loss Map, system parameters optimization, ...)

Working still ongoing on hardware (crystals, goniometers, ...) to be installed in the LHC (LS1), and simulations of the first tests in the LHC using Six-Track to choose the best system configuration

We are confident in even better results in the LHC since is more stable than the SPS, leading to a possible not negligible step in the collimation efficiency

Backup

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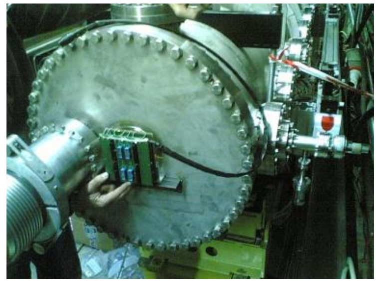
Experimental apparatus

Detectors:

- *Out of the beam pipe*

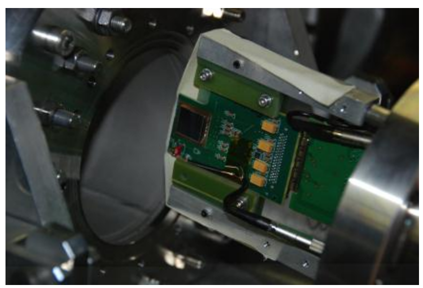


GEM, 128 pad, 10x10cm^2

Plastic scintillator, ~10x10x1cm^3

BLM-LHC Type, 2πx4.5x50cm^3

- *Secondary vacuum*



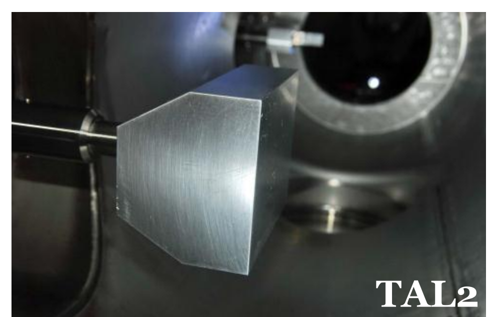
Medipix, 256x256 pixel, 55x55 μm^2 each

- *Primary vacuum*

Quartz, Cherenkov radiator

Absorbers:

- TAL, 60cm W
- LHC-Coll Phase II
- TAL2, 10cm Al



LHC-Coll