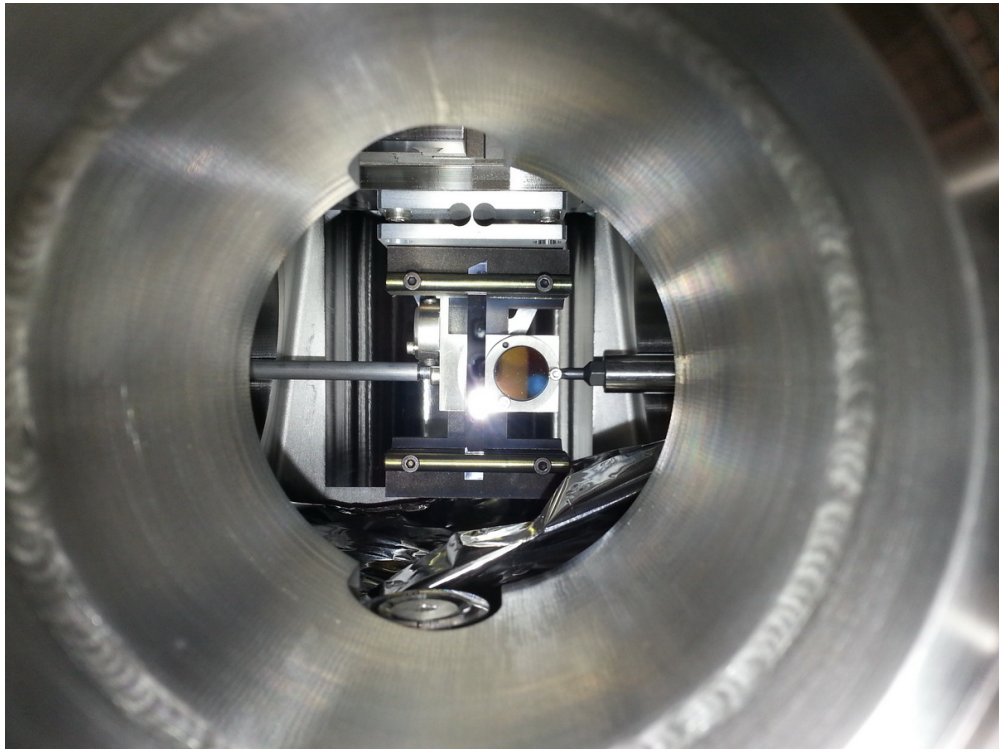
Outline

- Crystal Channeling
- Hadron beam collimation
- Crystal Collimation in SPS
- Crystal Collimation in LHC
- New Results
- Conclusion



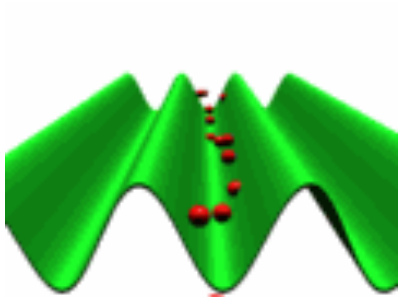
Strip silicon crystal. Installed on the horizontal goniometer in LHC.

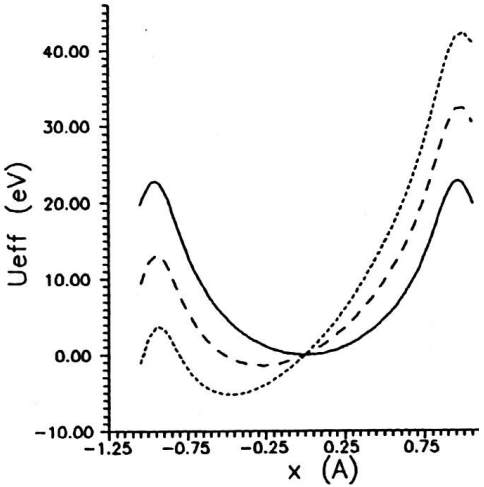
Crystal Channeling

Lindhard: “In the ipothesis of low impact angle, the potential generated by the crystalline plane can be approximated by a continouns potential.”

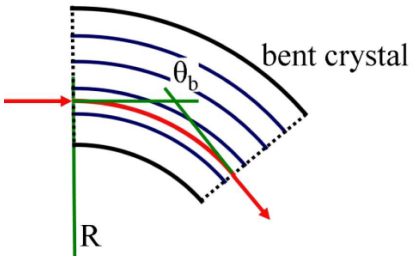
Channeling : Tansverse momenta < potential well.

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





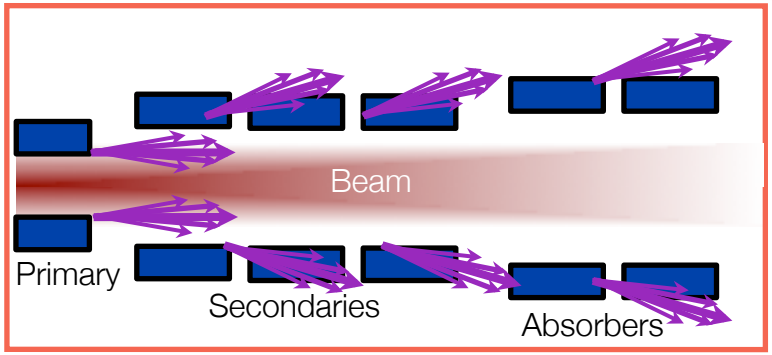
The particles are trapped in the channel, hence if a curvature is given to the lattice the particles direction will be modified by $\theta_b = l/R$



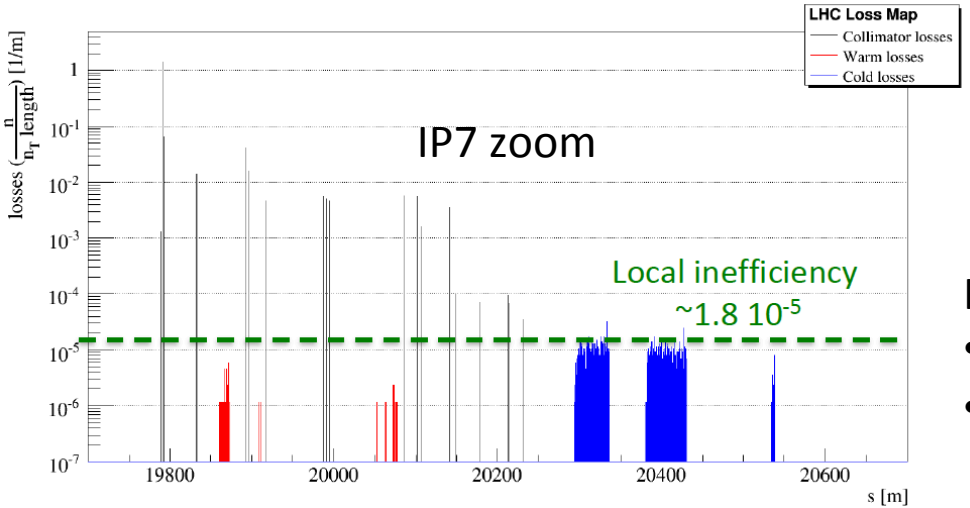
Interaction with nucleus and electrons of the crystal lattice => Dechanneling

Bent crystals shows other kind of coherent interaction Volume reflection and Volume Capture

Collimation System @ 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
- Optimize **background** in the experiments
  Minimize the impact of halo losses on (no big issue for the LHC)

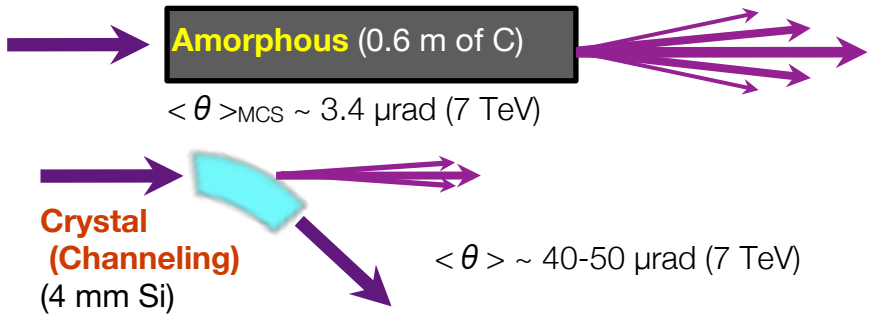


$$\text{Cleaning} = \frac{\text{losses on the first cold magnet}}{\text{losses on primary collimator}}$$

Issue :

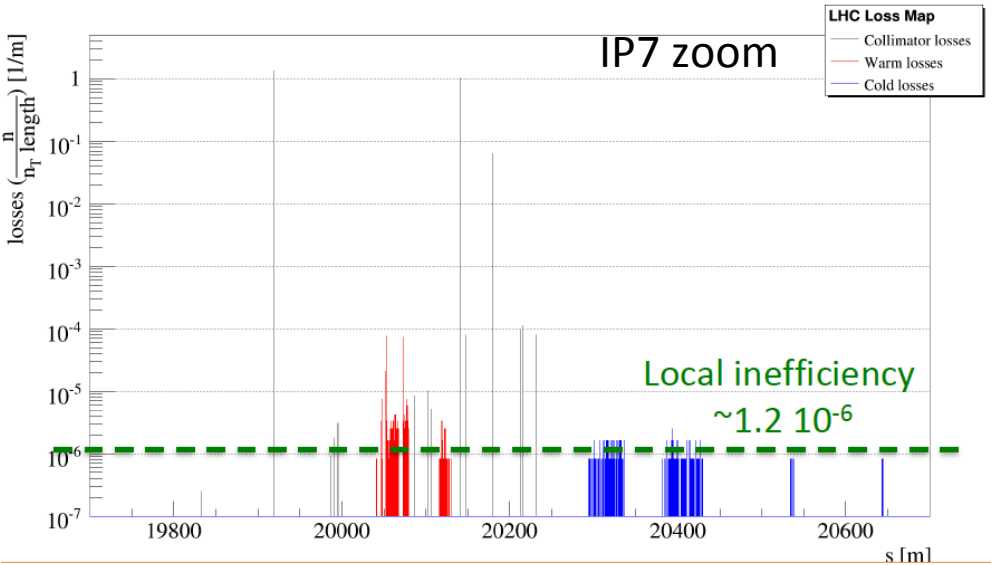
- Diffractive interaction
- Inelastic scattering

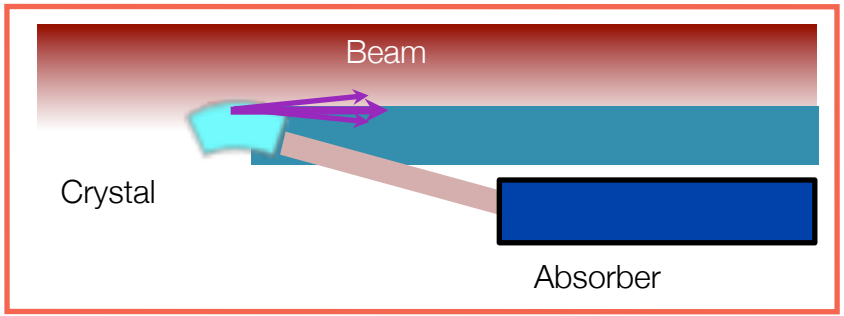
Crystal-assisted collimation



Promises of crystal collimation at the LHC:

- Improve **collimation cleaning** achieved with fewer collimators;
- Reduce electro-magnetic perturbations of collimators to the beams (**impedance**);
- Improve significantly the cleaning for **ion beams**.

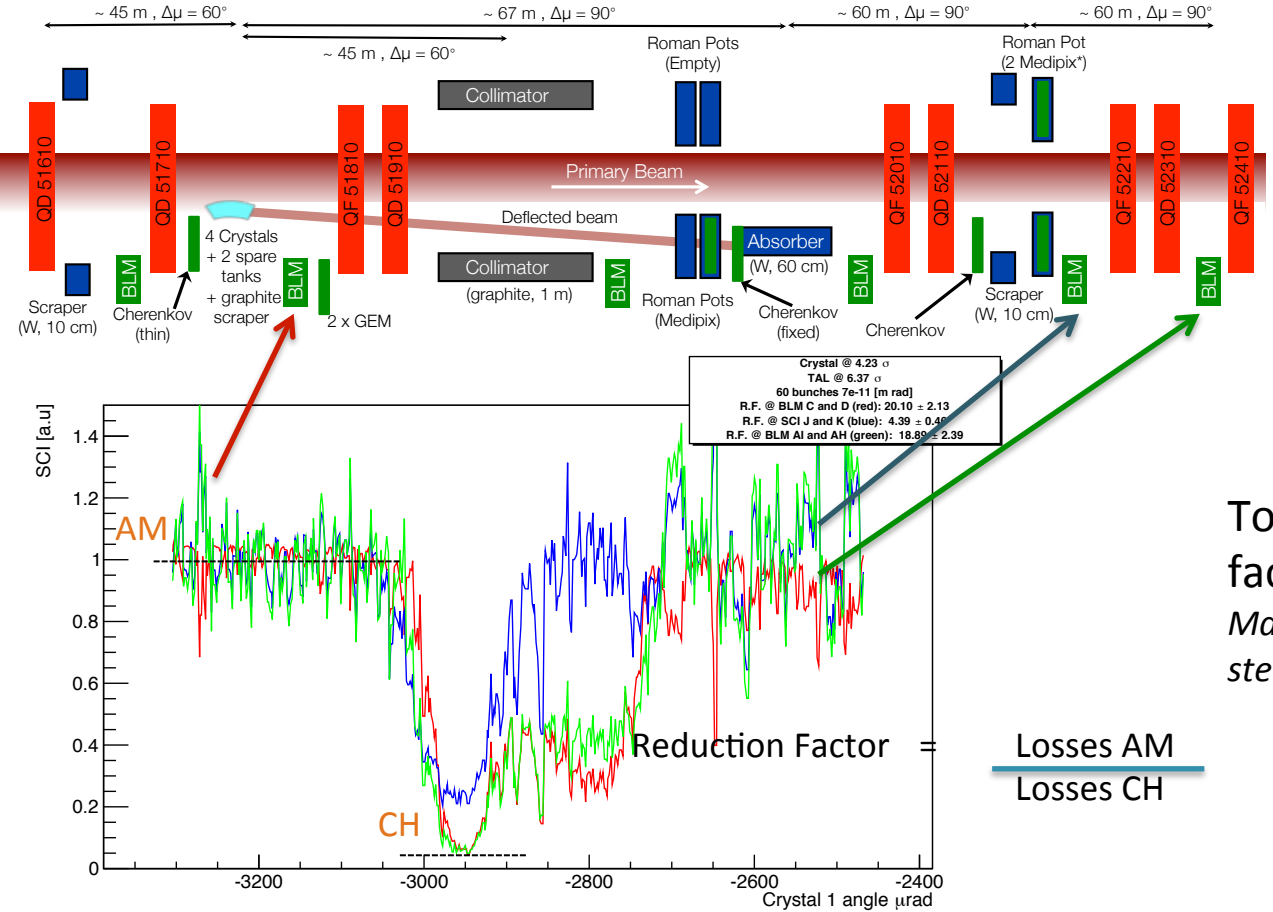




2 crystal installed in IP7

First LHC test successfully completed at injection energy

UA9 SPS collimation



Instrumentation Layout in LSS5 in the SPS

The system is well known by the collaboration

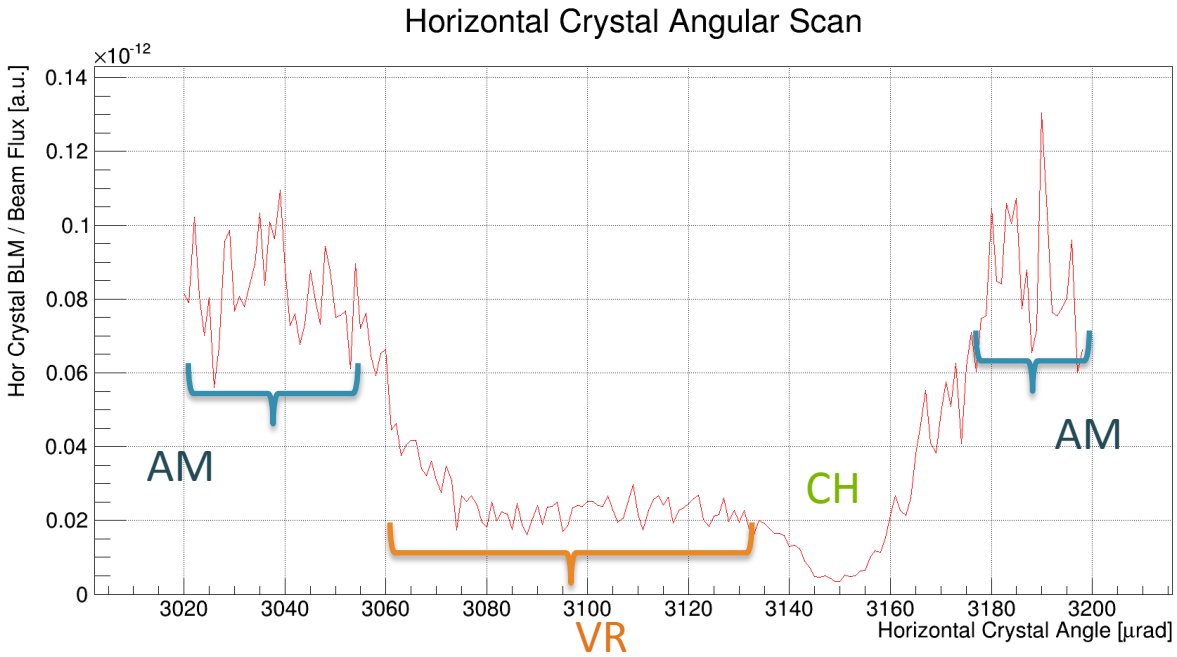
- Fast alignment
- Clear loss reduction in CH orientation

Today we observe a reduction factor near to 20

May be an inefficiency in absorbing the steered beam ➔ foreseen new study

Preliminary results H crystal

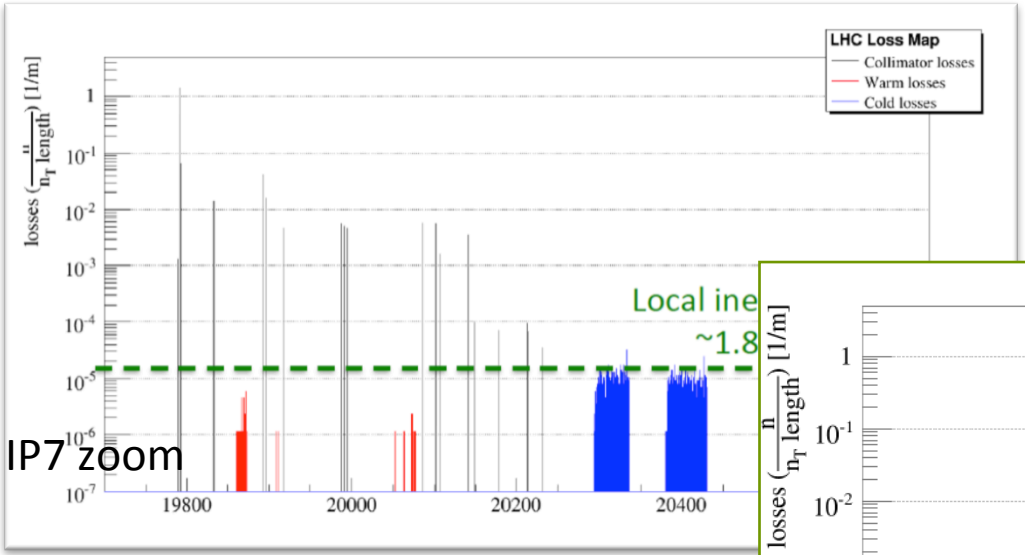
First observation of Channeling in the LHC (injection energy, 450 GeV)



Angular scan for horizontal crystal.

This scan was performed with all TCP.IR7 and TCSGs upstream the crystal retracted of 1 mm and 18 mm w.r.t. their nominal settings, respectively.

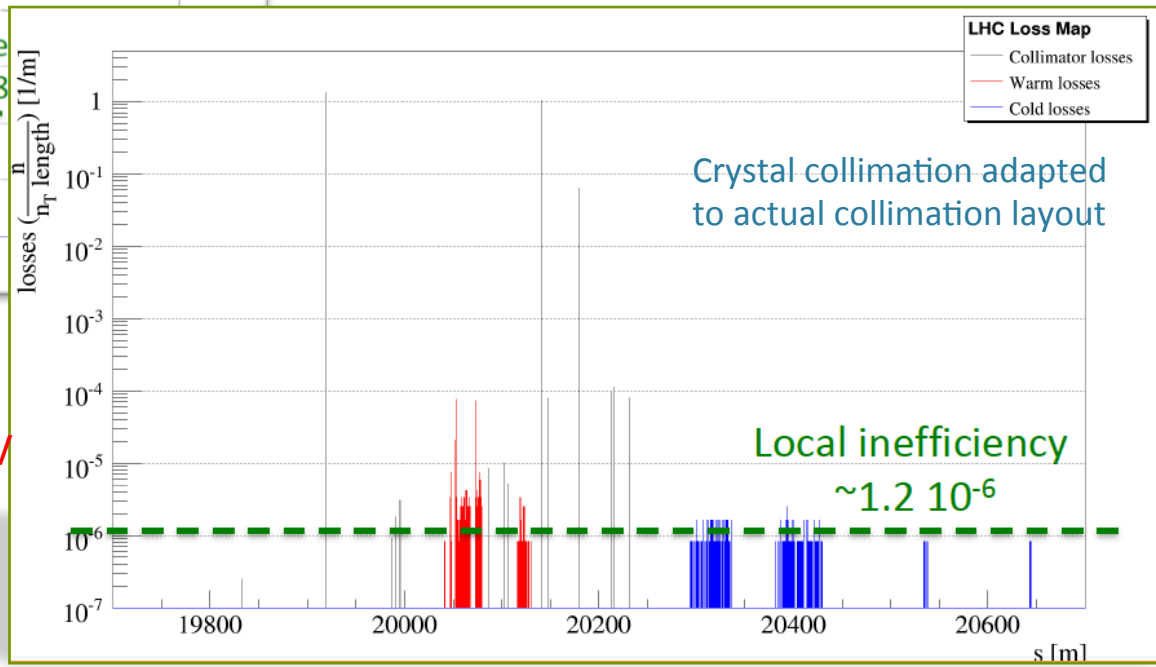
Prevision on LHC – flat top



Cleaning efficiency:

losess @ first cold magnet

losses @ fisrt primary collimator



Asked new MD slots for test @ 6,5 TeV
and with ions beam

SixTrack simulations – thanks to Daniele Mirarchi

Conclusion

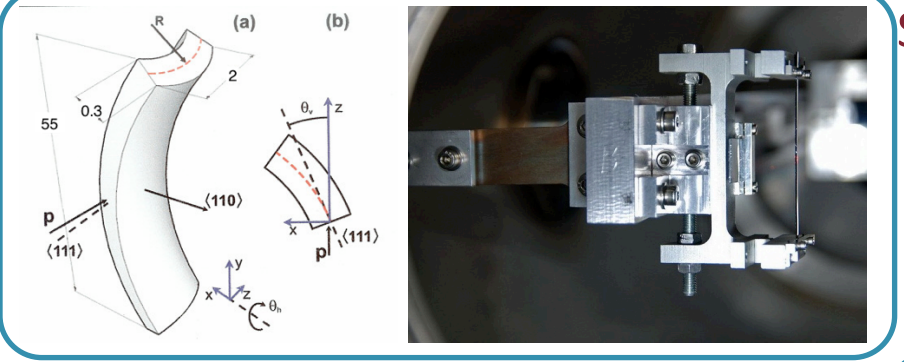
- ✓ All the results achieved by UA9 gave the chance to test the crystal-assisted collimation system on LHC
  in collaboration with CERN collimation team
- ✓ Very successful MD at LHC, all the measurements program was completed:
  - Channeling observed for the first time at the LHC for both crystals
  - Goniometers: important validation of new hardware (first test of technology)

Next UA9 Goal:

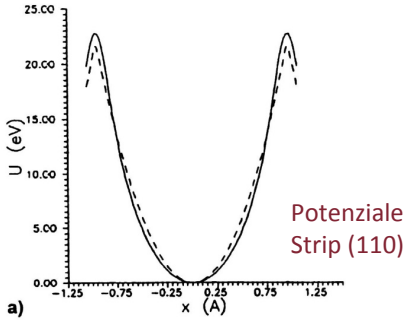
- ❑ Investigation on crystal-assisted collimation in LHC is now aimed to flat top energy (6,5 TeV), and ions beam.
- ❑ The opportunity of use the state of the art technology for beam extraction purposes is under investigation
  for both SPS and LHC
- ❑ The state of the art knowledge on the study of crystal extracted particle beam, let the collaboration develop new kind of detectors for beam monitoring
  see F. Iacoangeli talk tomorrow

BACKUP

Cristalli UA9

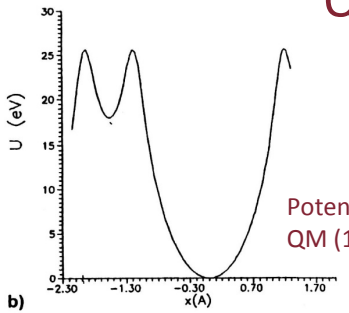


STRIP

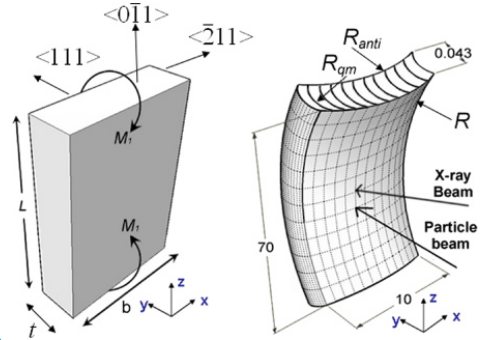


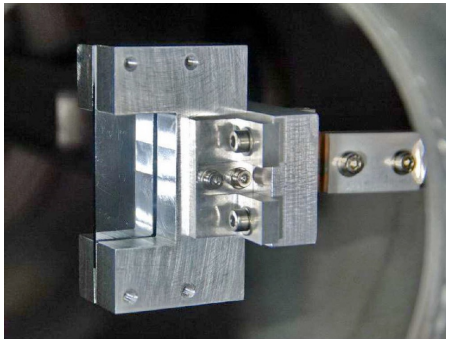
Potenziale
Strip (110)

QM



Potenziale
QM (111)





La curvatura viene impartita attraverso le forze anticlastiche, genarate dalla curvatura primaria che viene impartita meccanicamente.

UA9 Experiment

The UA9 Collaboration investigates how tiny bent crystals could assist and improve the collimation process in the Large Hadron Collider (LHC) at CERN in view of future ultra-high luminosity operation.

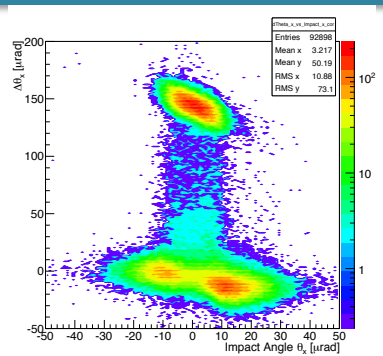
Required experimental measurment

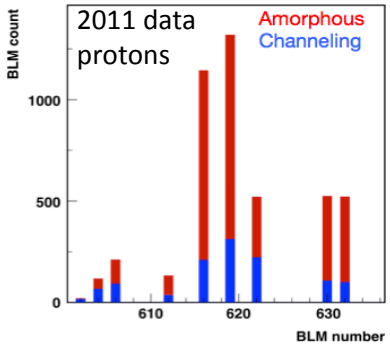
The characterization of high-energy particle interactions with a bent crystal is performed in SPS H8 extraction line.

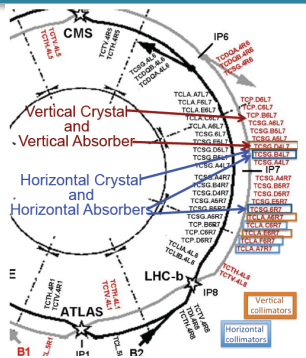
Crystal-assisted collimation is investigated at the CERN SPS with stored beams of protons or lead (Pb) ions of 120 or 270 GeV energy per charge.

Two crystals with their orienting goniometer devices have been installed in the Interaction Region IR7 in LHC.

A MD request has been presented for this year







Collimazione dei fasci adronici

Idealmente, note le equazioni che descrivono il moto delle particelle all'interno degli acceleratori, le particelle rimangono imperturabate sulla stessa orbita.

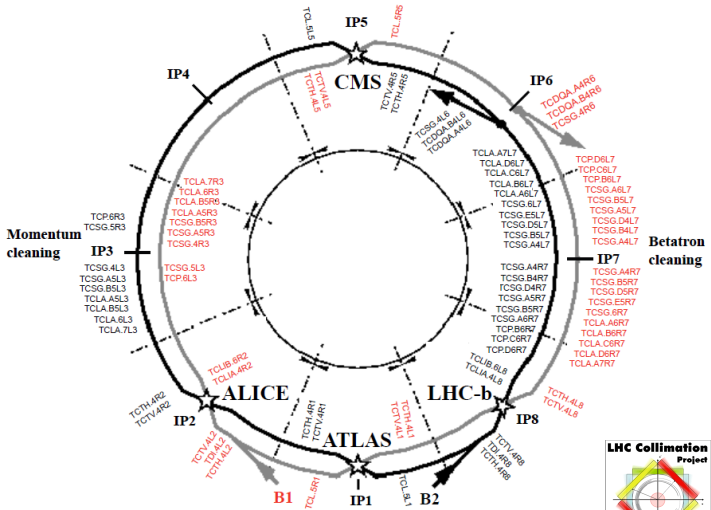
Le particelle <u>non</u> restano all'infinito sull'orbita di riferimento a causa di diversi effetti :

Interbeam Scattering	**Scattering con molecole di gas residue**	Effetti beam-beam	Perdite per errori di iniezione	Perdite per non sincronismo del dump	Errori occasionali e non prevedibili

Tali processi incrementano la popolazione dell'alone che provoca diversi problemi :

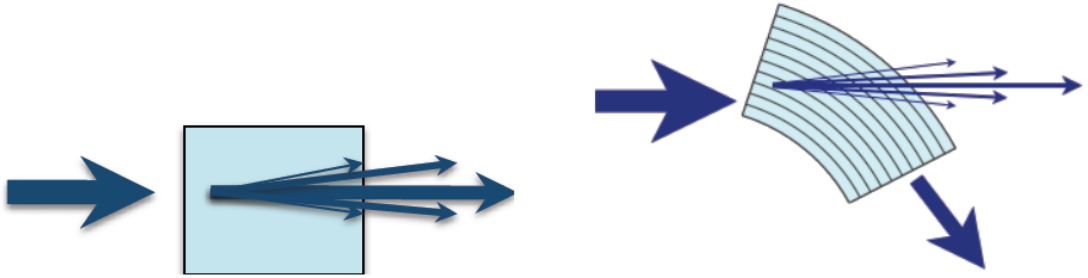
Effetti non lineari dei magneti, lontano dal centro	Interazione con restrizioni geometriche	Fondo per gli esperimenti a grande parametro d'impatto	Riduzione vita media apparati investiti	**Perdite su magneti superconduttori con possibile quench**

La **collimazione** serve a ridurre le perdite incontrollate delle particelle dell'alone nella macchina.



Introduction

UA9 collaboration is studying the possibility of steering particle beam with bent silicon crystal to improve the actual LHC collimation system.



Various studies are required to achive this goal :

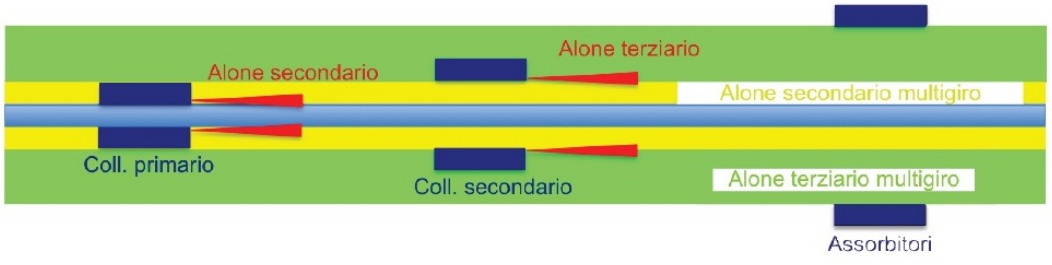
- Interaction characterization of charged particle with bent crystal
- Development of simualtion routine
- Experimental study of a crystal-assisted collimation system on SPS
- New detector development for beam flux measurment

UA9 just launched a working group with the CERN Extraction team to study an SPS beam extraction system with bent crystals.

Sistema di collimazione

Il sistema di collimazione attuale si basa sul multiplo scattering delle particelle dell'alone con i collimatori.

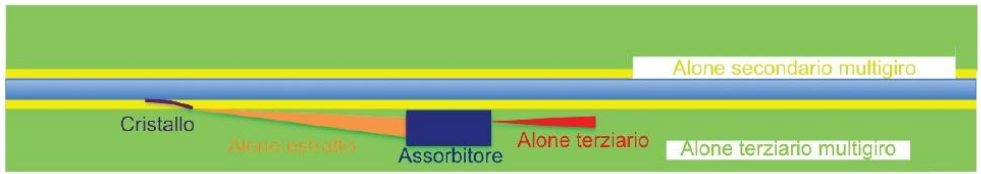
Le inefficienze di tale sistema sono dovute a
Effetti Diffrattivi
Interazioni Anelastiche

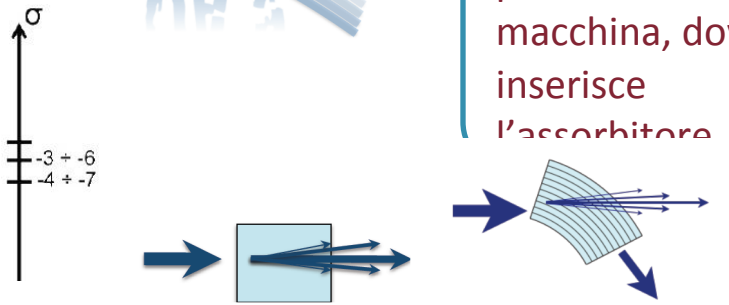


Questi effetti limitano la macchina in Corrente Totale Circolante e quindi la Luminosità.

Sfruttando il channeling dei cristalli il layout si riduce a due stadi. I vantaggi sono :

- Grande Angolo di Deflessione
- Riduzione Impedenza Complessiva
- **Riduzione Interazioni Anelastiche al primo stadio**





Consente di concentrare le perdite in un piccolo punto della macchina, dove si inserisce l'assorbitore

H8 Crystal test Beam

The UA9 collaboration is studying techniques to steer ultra-relativistic beams with bent crystals to improve the collimation of proton and heavy ion beams at the LHC.

Measurements of key crystals properties (bending angle, channeling efficiency, etc..) are performed on the SPS extraction line (H8) with 400 GeV/c protons before testing crystals with circulating beams.

Data analysis main goal:
Consistently analyze all the crystals tested in H8 (total of 15 between 2010-2012).

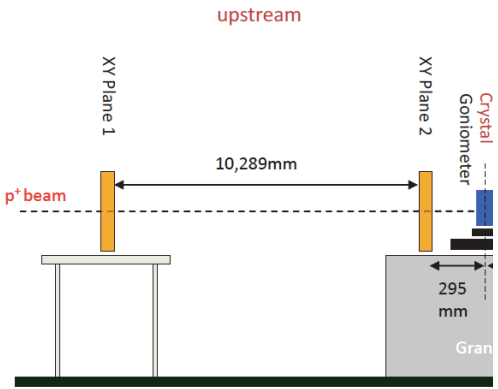
- Compile a comprehensive statistical treatment of different crystals
- Identify “fine” systematic effects (e.g., transitions)
- provide inputs to crystal code developers

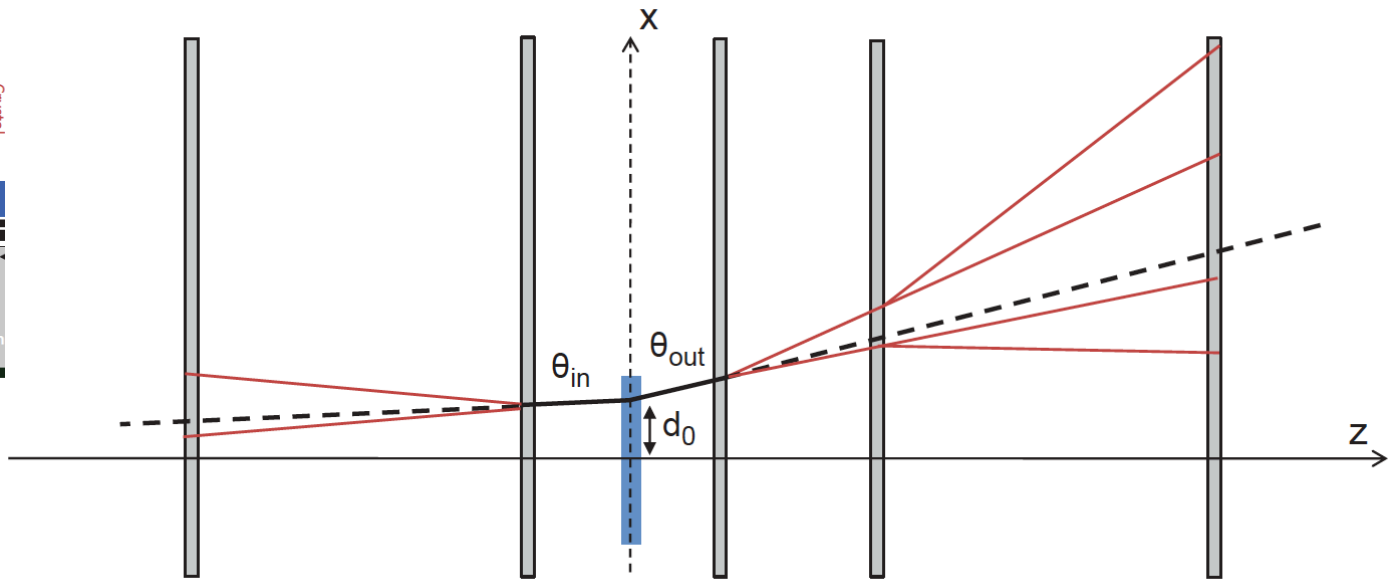
Immediate goal: compile list of experimental data for comparison with crystal simulations.

http://lhc-collimation-upgrade-spec.web.cern.ch/LHC-Collimation-Upgrade-Spec/H8_input.php

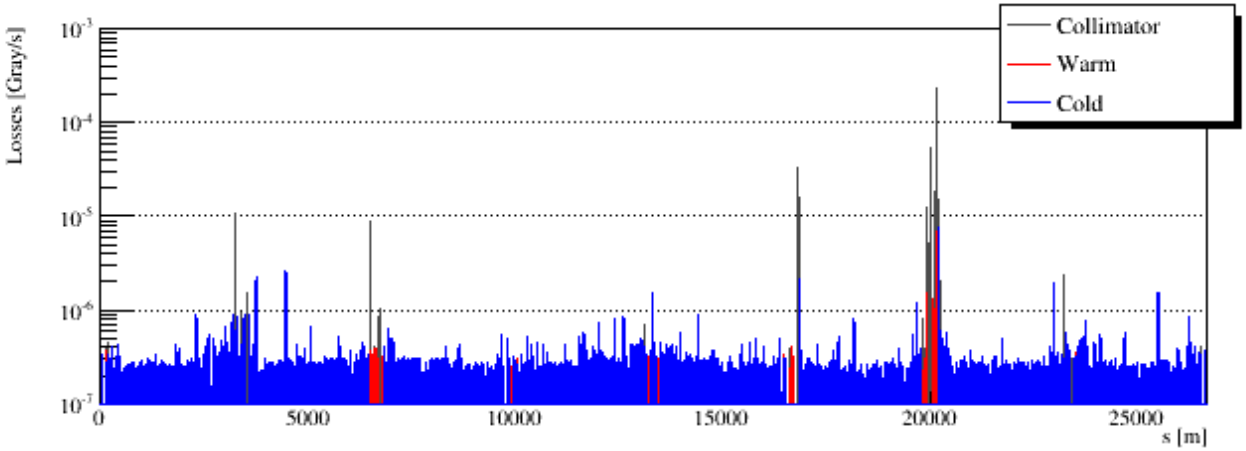
H8 experimental Layout

- Five silicon micro-strip sensors (active area 3.8x3.8 cm^2 in the x-y plane) are used to track the particles in the plane orthogonal to the beam direction before and after passing through the crystal.
- High precision goniometer is used to modify the crystal plane orientation with respect to the beam direction.

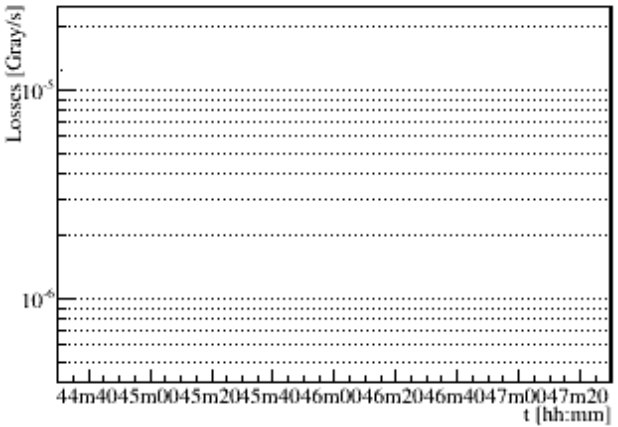


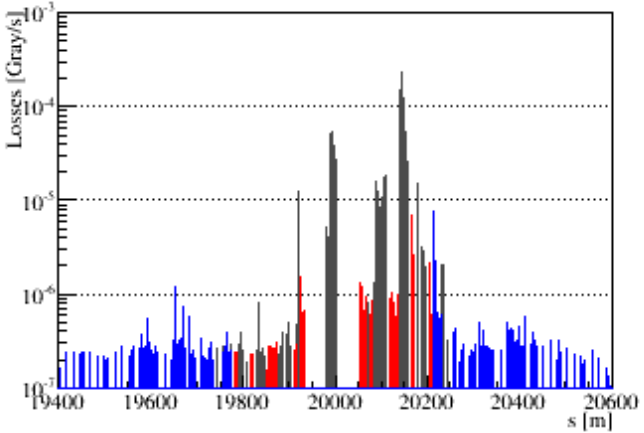


Loss Map Horizontal plane



Preliminary – pending detailed calibration

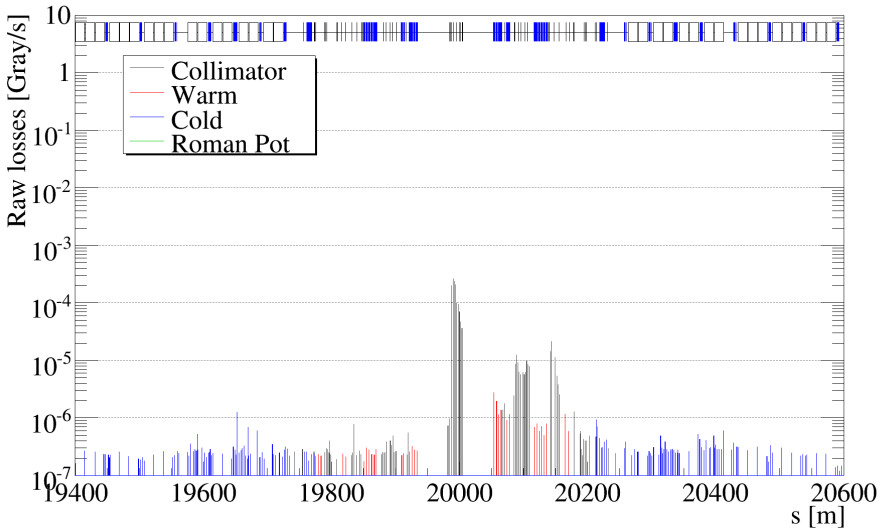


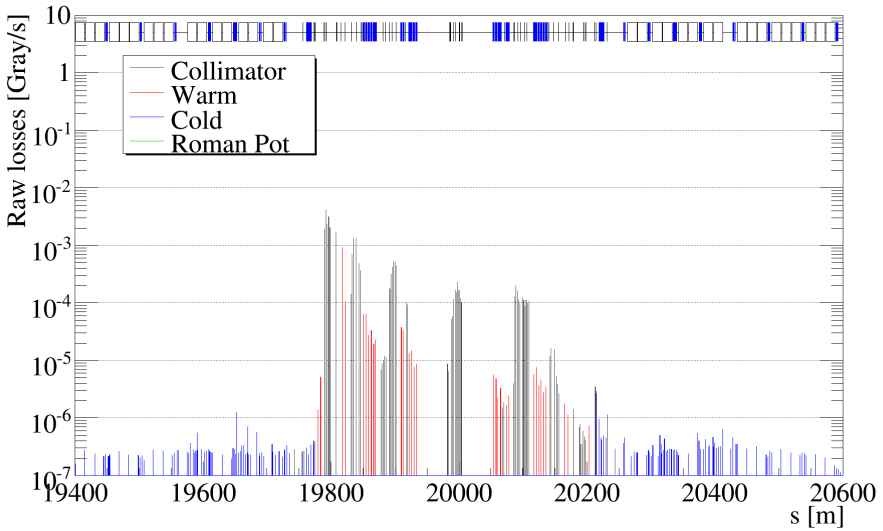


Raw data
The picture shows losses on the whole machine during an angular scan, with the reduced settings of collimators.

Daniele Mirarchi

Loss Map comparison

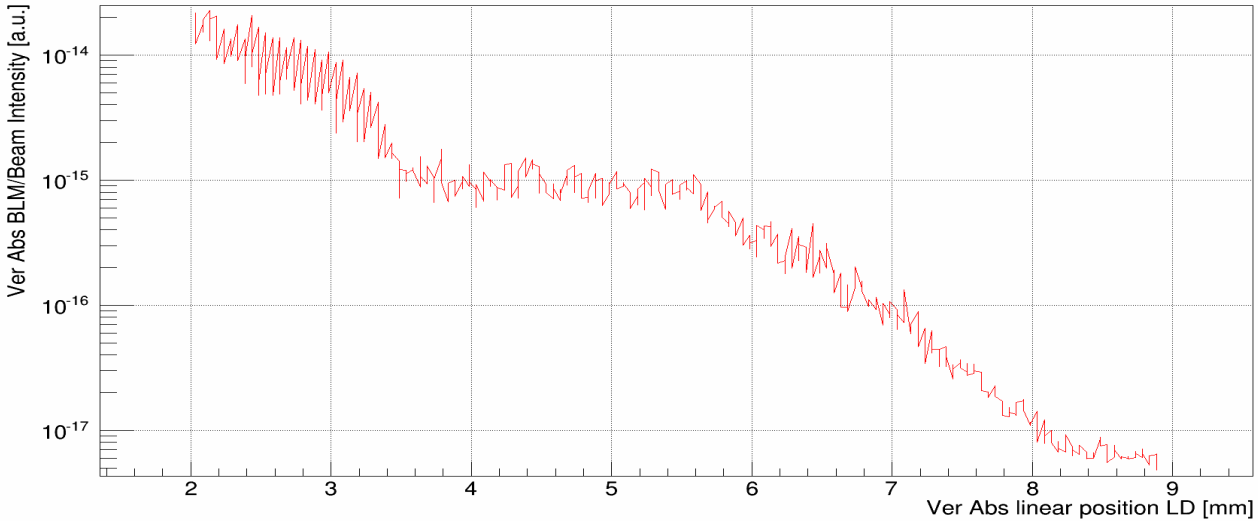




Preliminary – pending detailed calibration

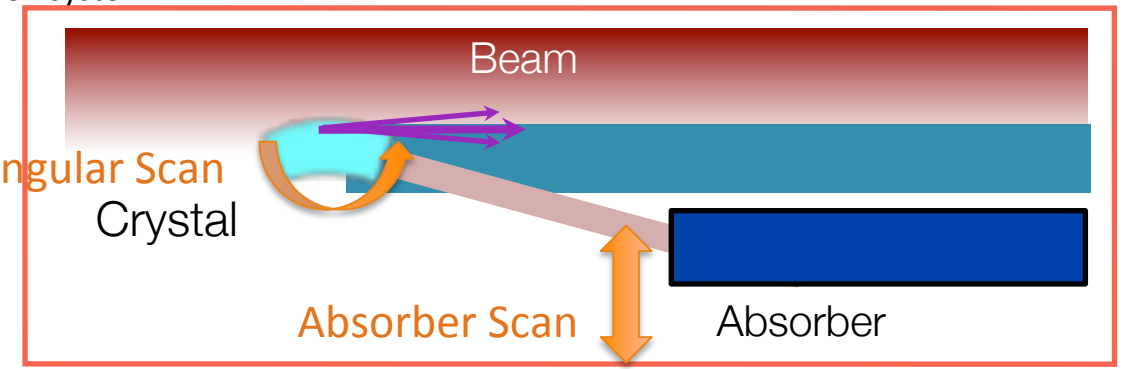
Preliminary results V crystal

Same measurement done on vertical plane with QM crystal.



List of measurements

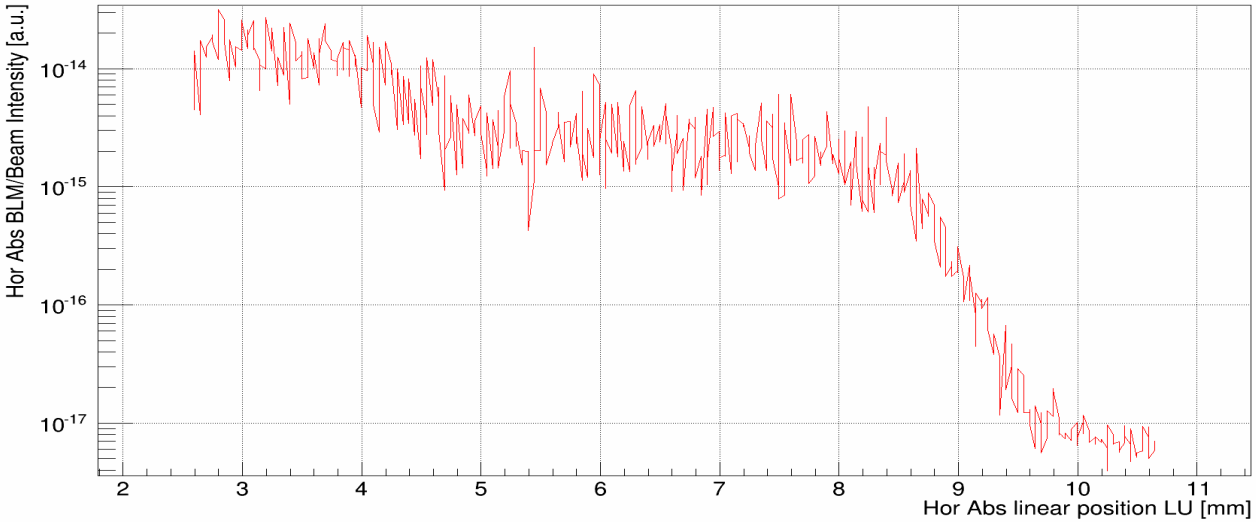
- Fast angular scan on whole goniometers range
  - Identification of channeling orientation
- detailed angular scan around angles determined with the measurement above
  - indication of optimal channeling orientation, scans repeated in different fills to test the system stability
  - measurement of nuclear interaction rate at the crystal, characterization of local losses for different working regimes
  - measurement of reduction of nuclear interaction rate (AM/CH) and measurement of crystal bending angle (extension of VR region)
- Crystal placed in optimal channeling orientation and linear scans with selected TCSG is performed
  - study the extracted beam profile, deflection angle, and multiturn channeling efficiency
  - validation of expected crystal orientation
- Loss map with reduced set of collimators in IR7 (all collimators upstream the crystal retracted of … sigma)
  - validation of working principle with reduced number of collimators
  - comparative studies w.r.t. present collimation system



Preliminary results H crystal

With the same reduced collimator layout and crystal fixed in CH, absorber scan has been performed.

The absorber is retracted and inserted again. Rising of losses downstream the absorber show the extracted beam and circulating beam interception.

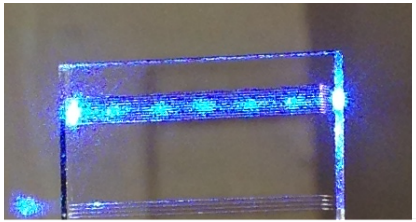


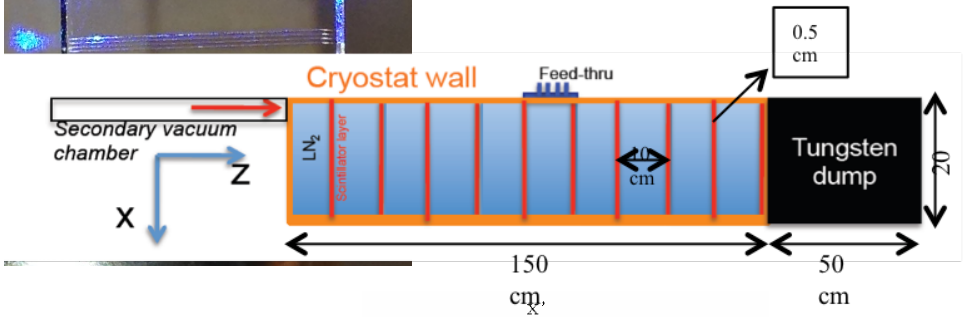
Nuove applicazioni del channeling

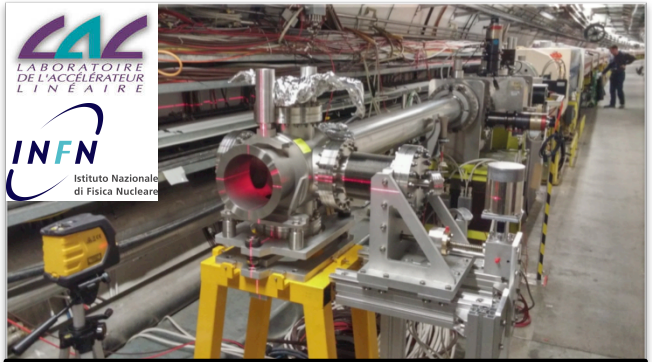
CRYSBEAM

Progetto ERC :

- Nuovo design dei cristalli (estrazione a 7 TeV)
- Sviluppo di nuovi rivelatori Cherenkov (monitorggio)
- Calorimetro assorbitore (cascate adroniche)





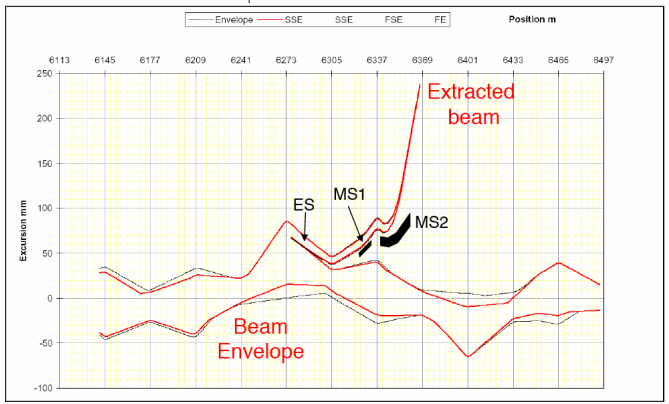


Integrazione del rivealtore CpFM per misure di modulazione di flusso

UA9-SE

L'obbiettivo è capire se si possa integrare un cristallo piegato per l'estrazione del fascio di SPS.

Un team di studio è stato creato al CERN insieme al gruppo dell'estrazione



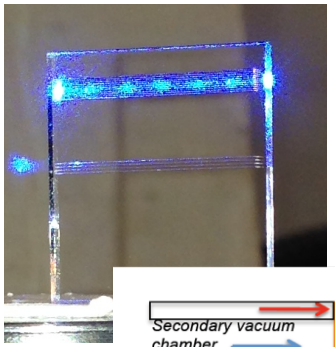
Applicazione per SHiP

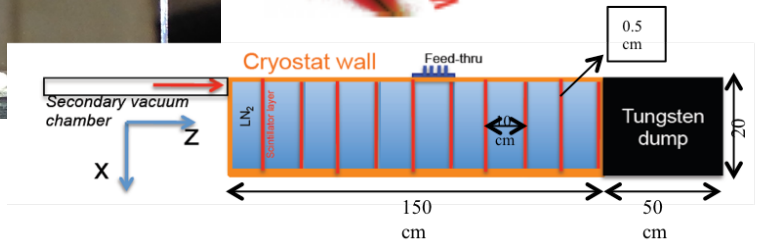
New application of crystal chenneling

CRYSBEAM

ERC project :

- New crystal design for LHC beam extraction (7 TeV beam extraction)
- Development of Cherenkov detector for beam monitoring (beam spot and timing)
- Smart absorber for high energy hadronic shower study





UA9-SE

A working group with CERN Extraction Team is investigating a new extraction system from SPS using a bent crystal.
The idea is to use a bent crystal instead of the actual electro-static septum.