Crystal collimation of hadron beam at CERN, the UA9 experiment

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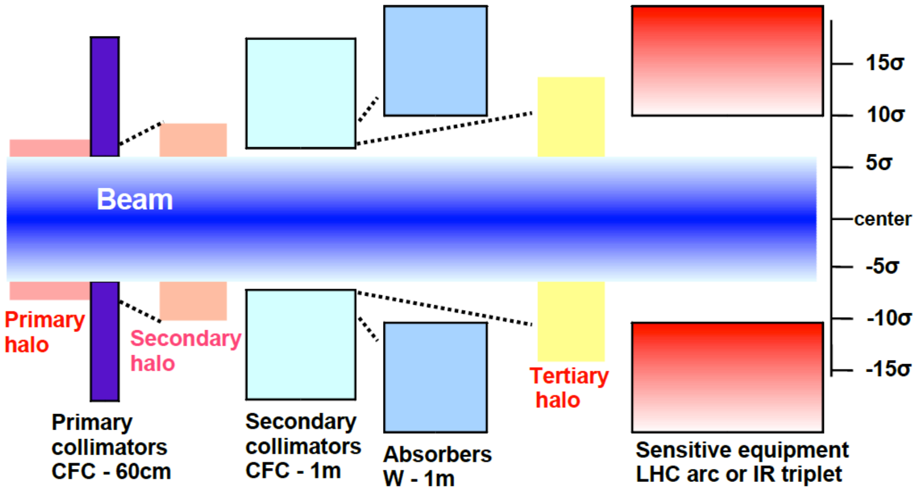
IFAE 2011
Perugia

Collimation at colliders

- Passive protection for fast losses
- Cleaning and absorption for slow losses
- Defense against radiation
- Reduction of physics background



High luminosity requires (eventually) high currents

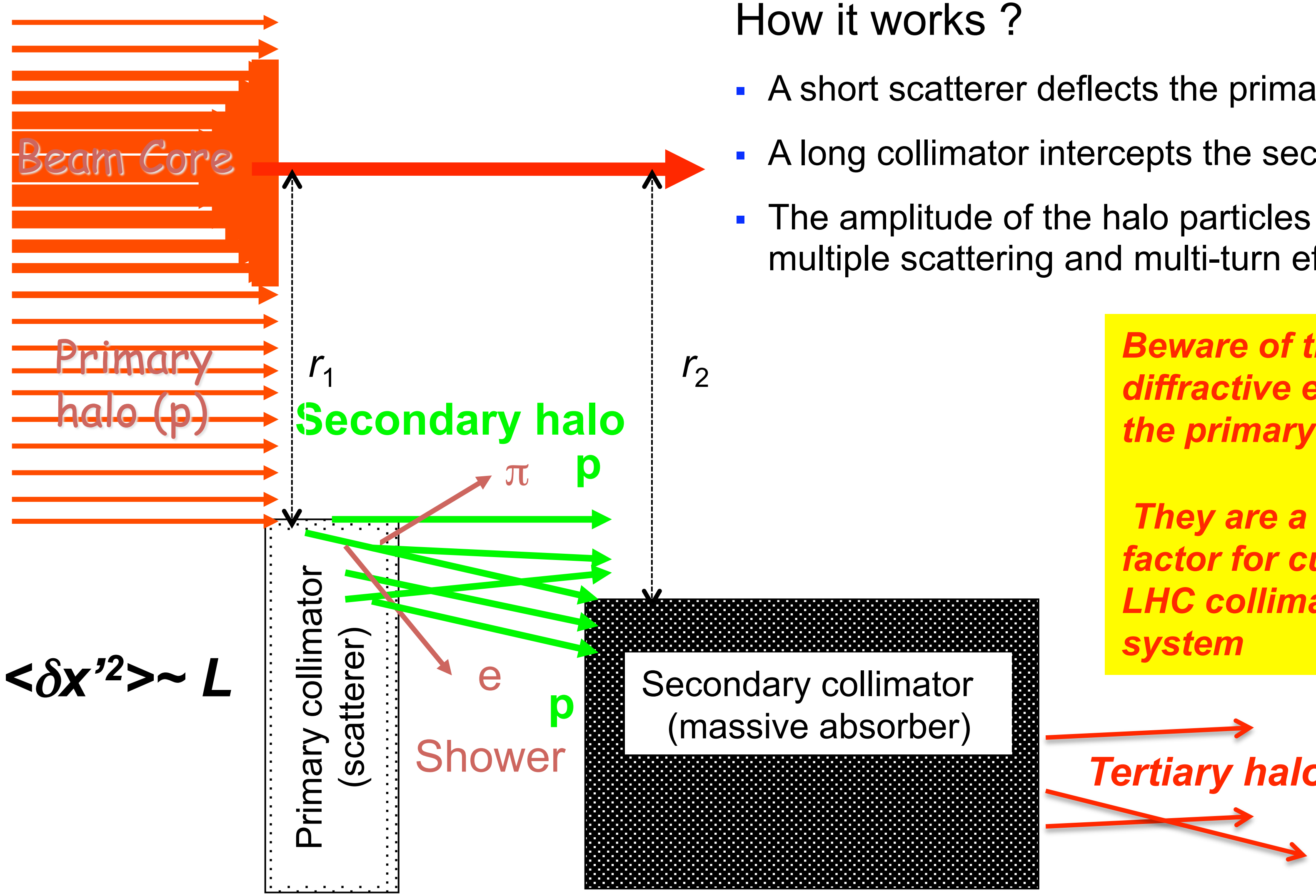
At 7 TeV 1/50.000 proton lost makes a SC magnet quench!

Cleaning Efficiency

Traditional concept

How it works ?

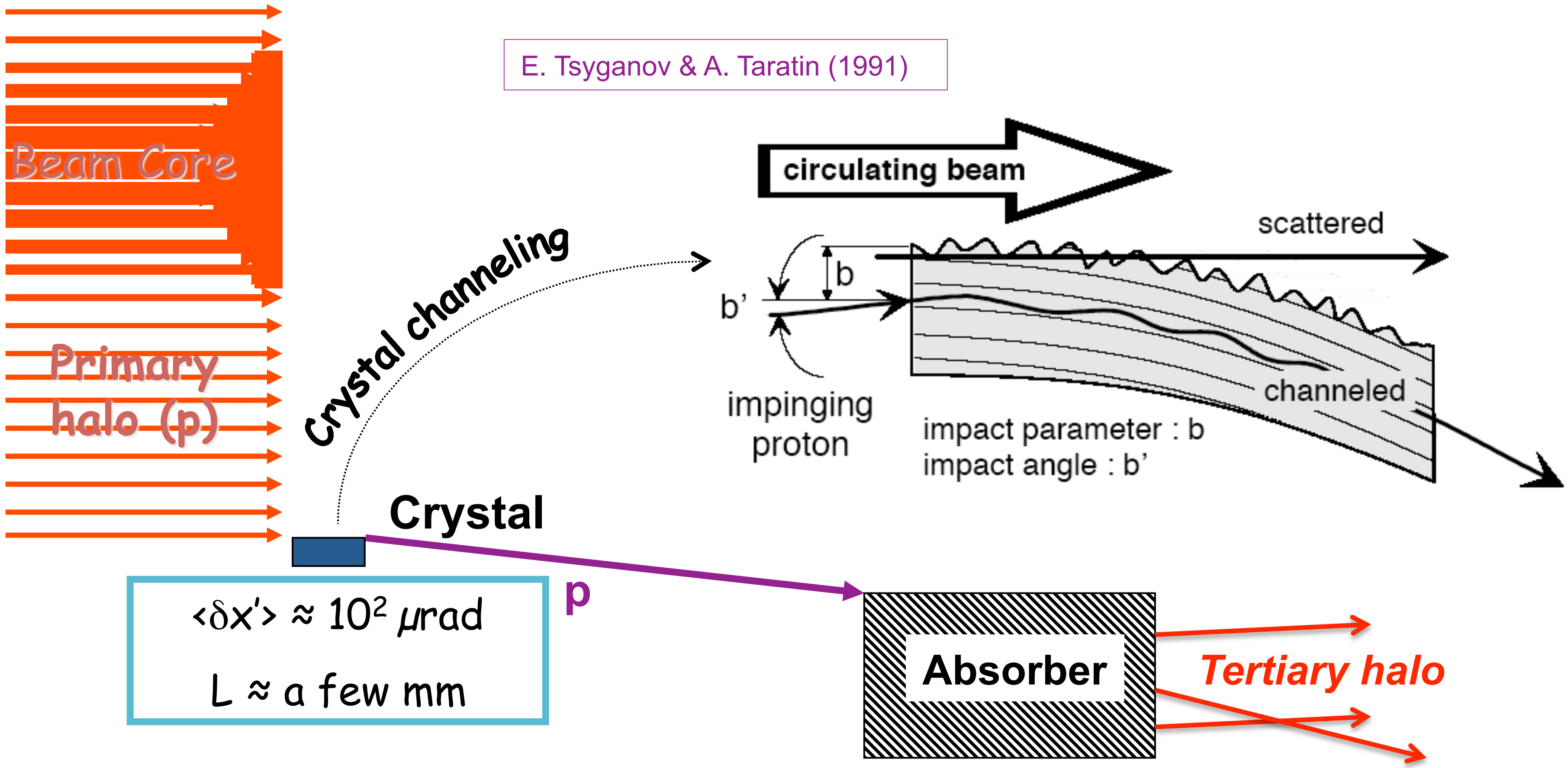
- A short scatterer deflects the primary halo
- A long collimator intercepts the secondary halo
- The amplitude of the halo particles increases via multiple scattering and multi-turn effects.



Beware of the diffractive events in the primary

They are a limiting factor for current LHC collimation system

A new idea!



- **Coherent deviation of the primary halo**
- **Very small probability of inelastic interaction in the crystal**

- ***Larger collimation efficiency***
- ***Less impedance***
- ***Reduced tertiary halo***

Crystal channeling

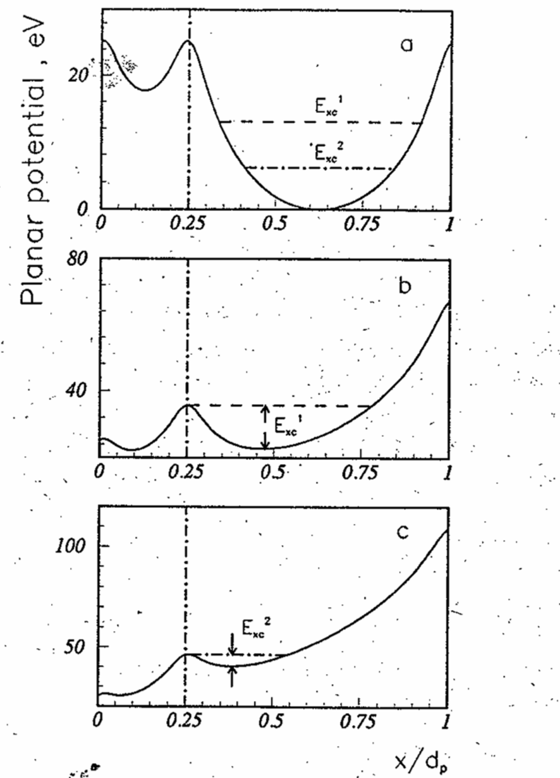


Fig.2. The continuum potential of the (111) silicon channel (a), and the effective planar potential for the crystal bent with the average curvature (b) and with the maximum one (c) at the bending angle of 8.9 mrad. The critical transverse energies of particles E^1_{xc}, E^2_{xc} for the wide channels in the bent crystal are shown by the dashed and dot-dashed lines, accordingly, in fig.2b and fig.2c. The same values of E_{xc} in the straight channel potential are shown in fig.2a.

5

J. Lindhard, Phys. Lett. 12, 126 (1964)
E. Tsyganov , Fermilab, TM-682 (1976)

Charged particle entering crystal with angle wrt lattice place smaller than a critical angle

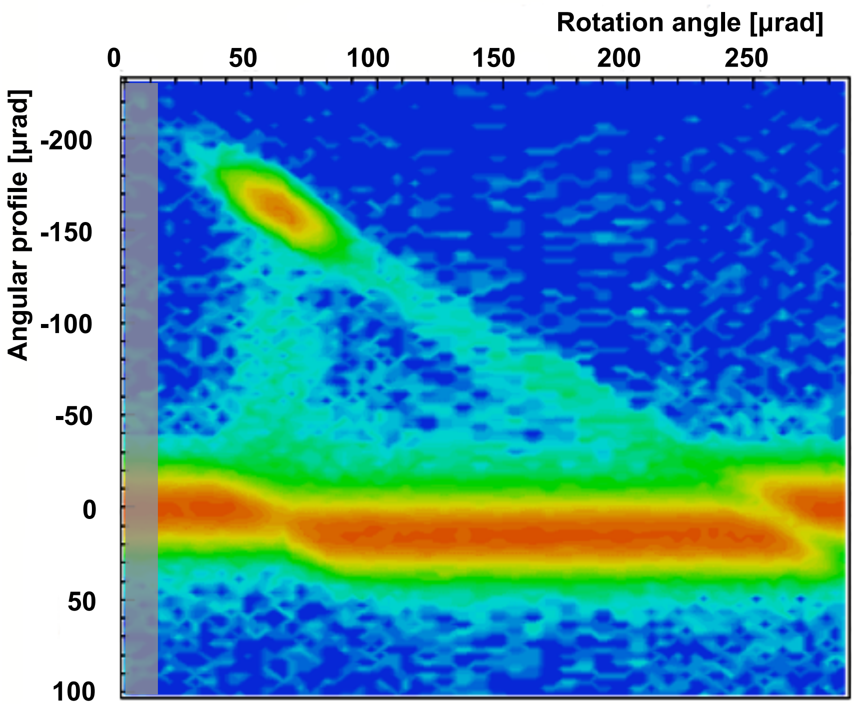
$$\theta_{IN} < \theta_C = \sqrt{\frac{2U}{E}}$$

Oscillation within the lattice planes!
Particles trapped!

If the crystal is BENT, additional centrifugal potential.
Charged particles are deflected!

In silicon (110) 400 GeV protons
$\theta_c \sim 10\ \mu\text{rad}$

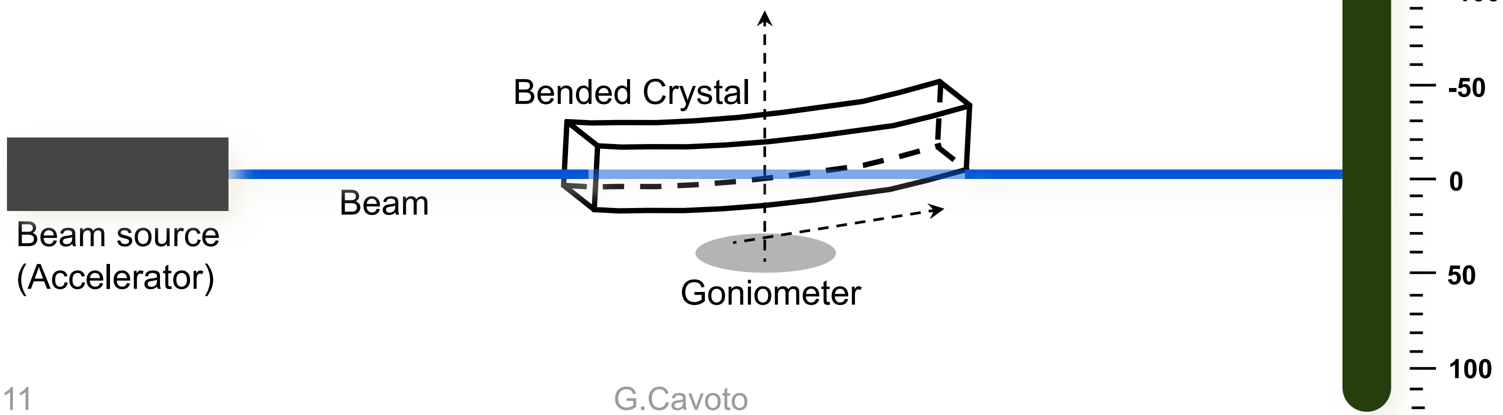
Crystal behaviour



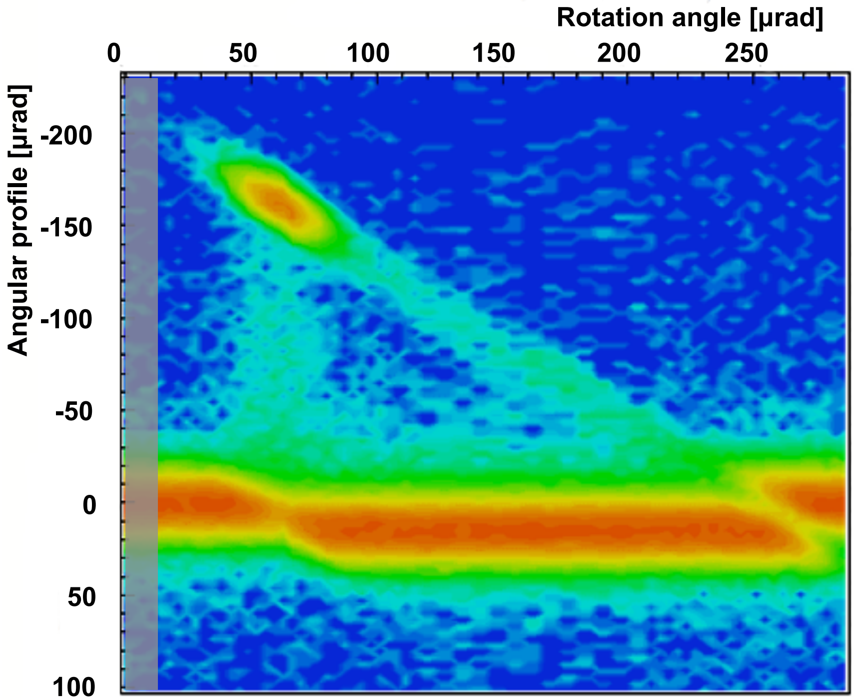
Amorphous
behavior

W. Scandale et al. PRL 98, 154801 (2007)

W. Scandale et al. PRST 11, 063501 (2008)



Crystal behaviour



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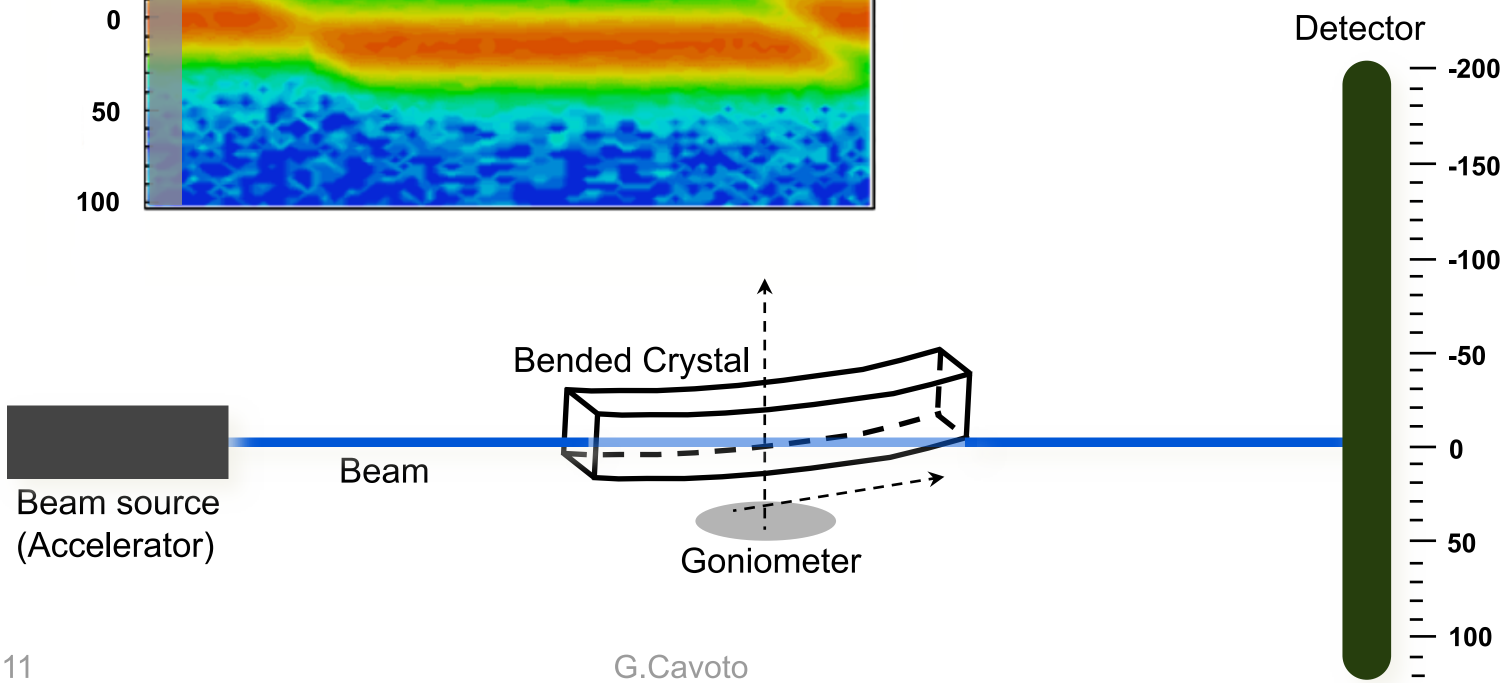
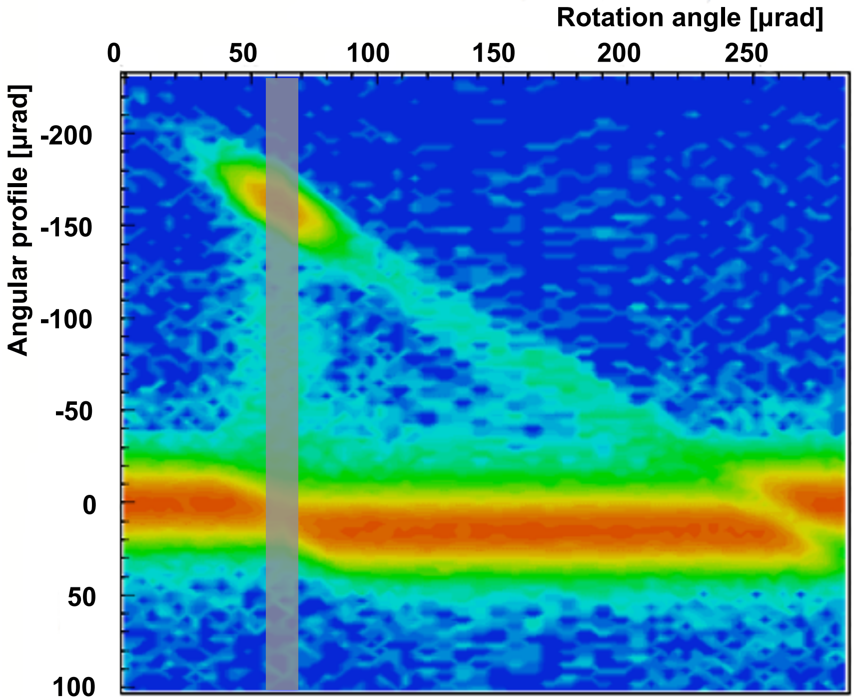


Crystal behaviour



Channeling
behavior

W. Scandale et al. PRL 98, 154801 (2007)

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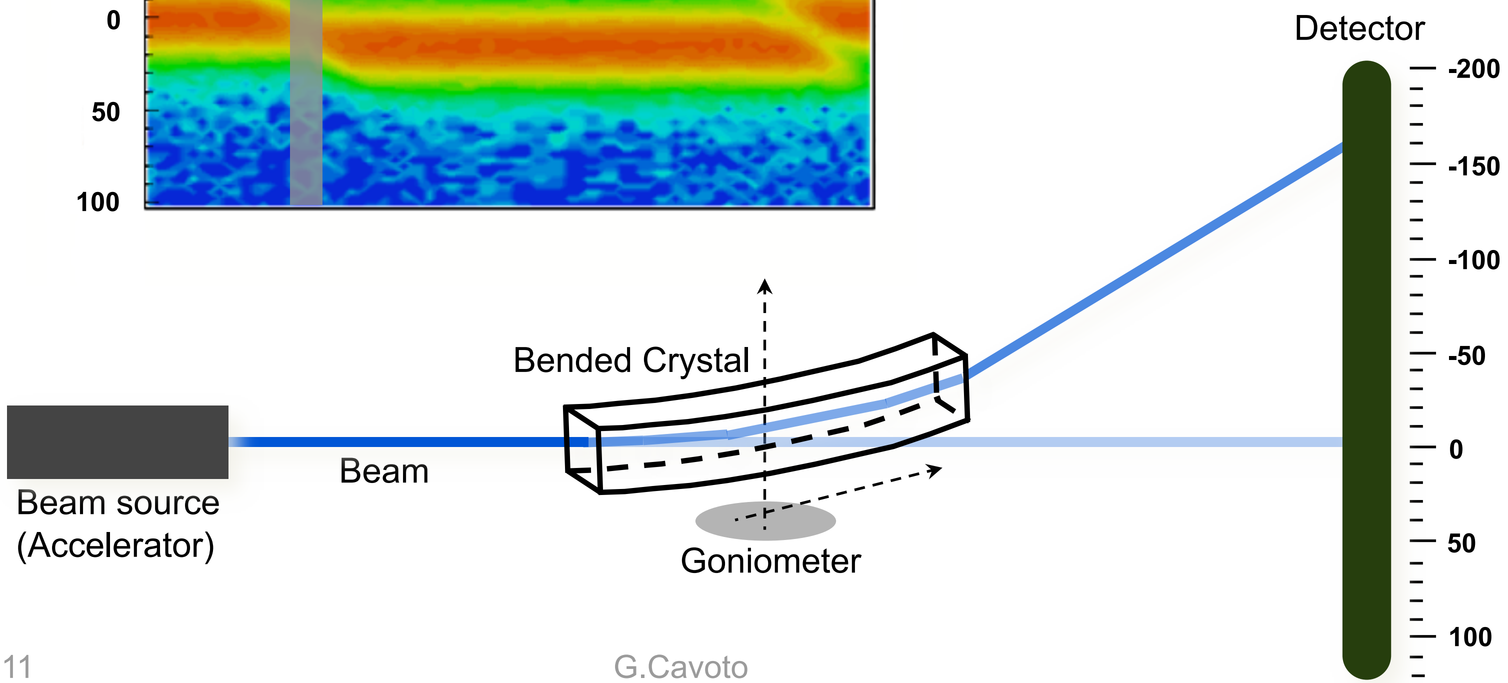
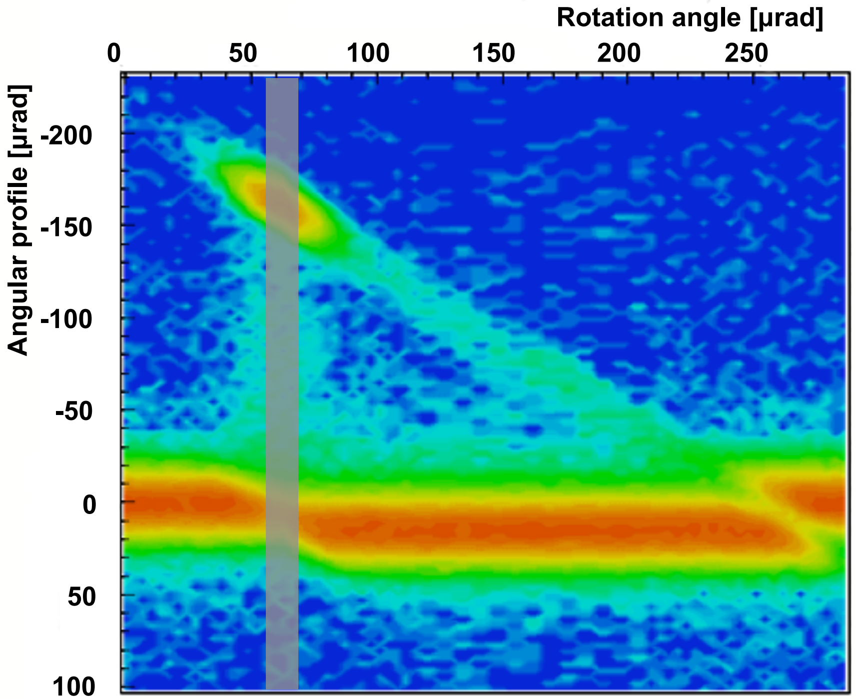


Crystal behaviour



Channeling behavior

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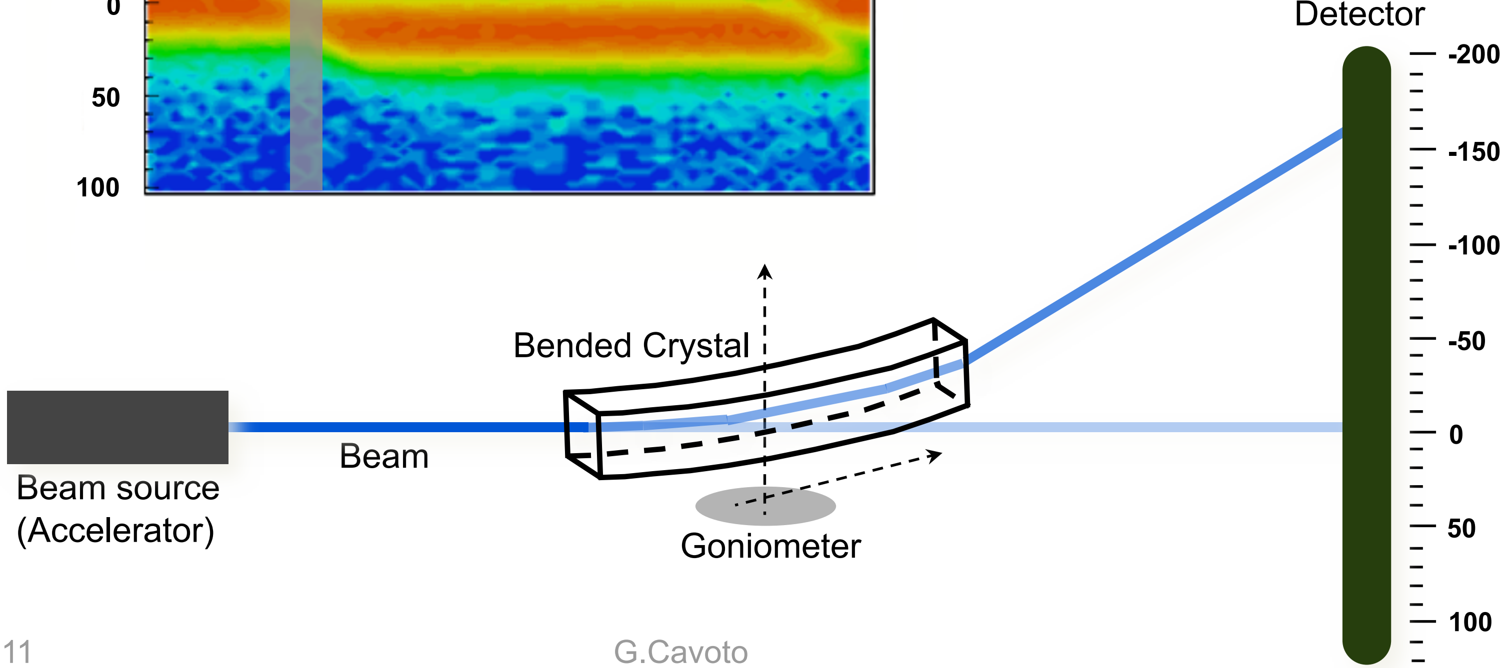
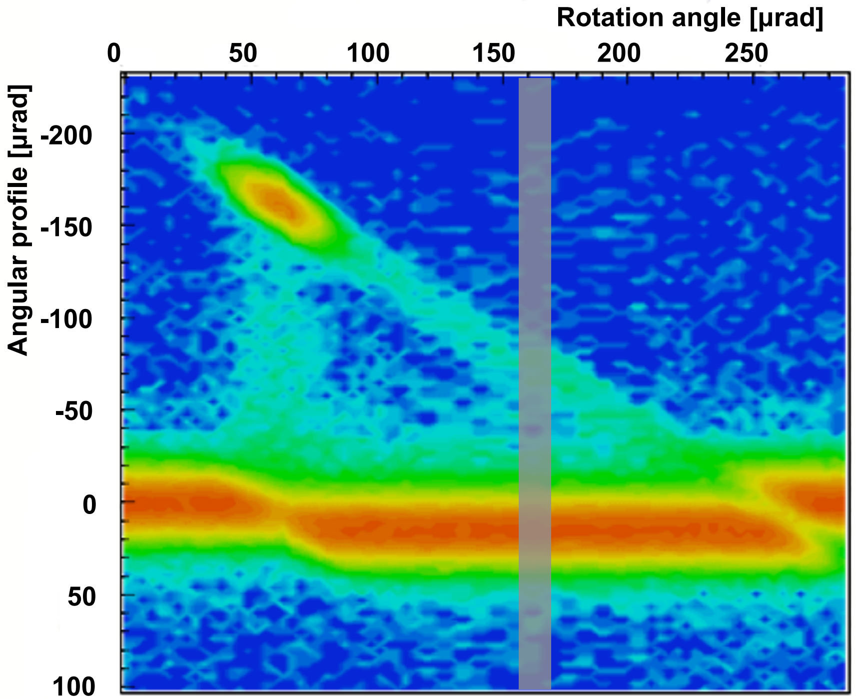


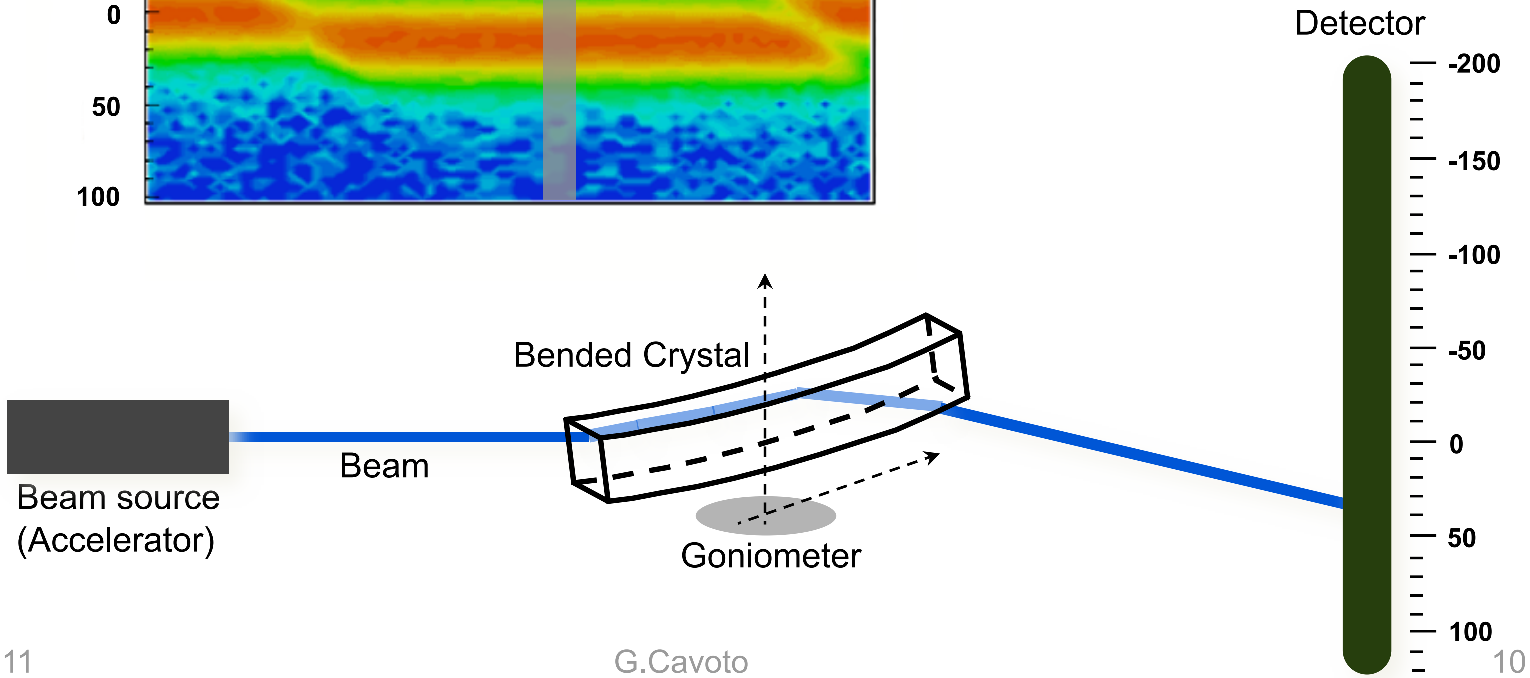
Crystal behaviour



Reflection behavior

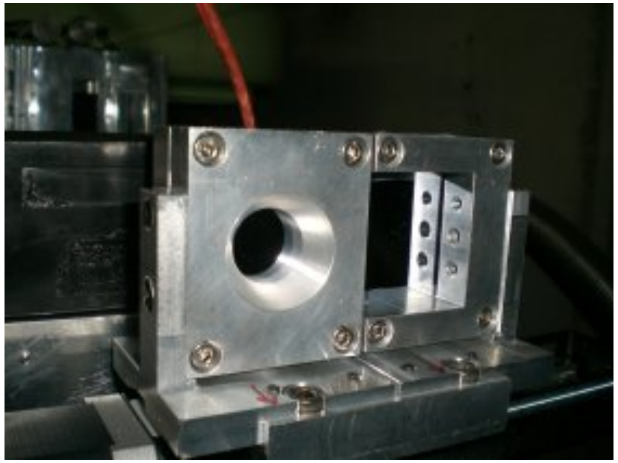
W. Scandale et al. PRL 98, 154801 (2007)

W. Scandale et al. PRST 11, 063501 (2008)

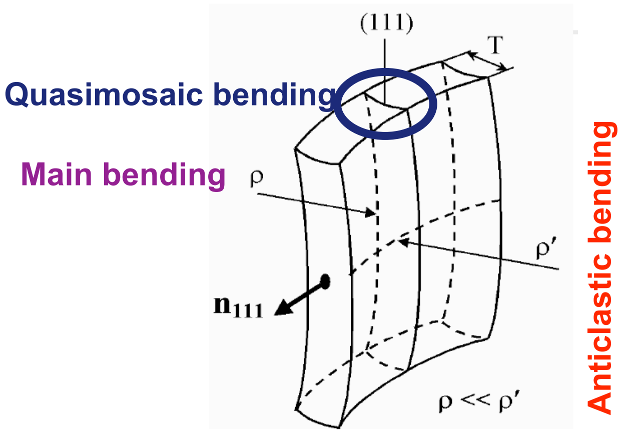


Crystals

Quasimosaic crystals

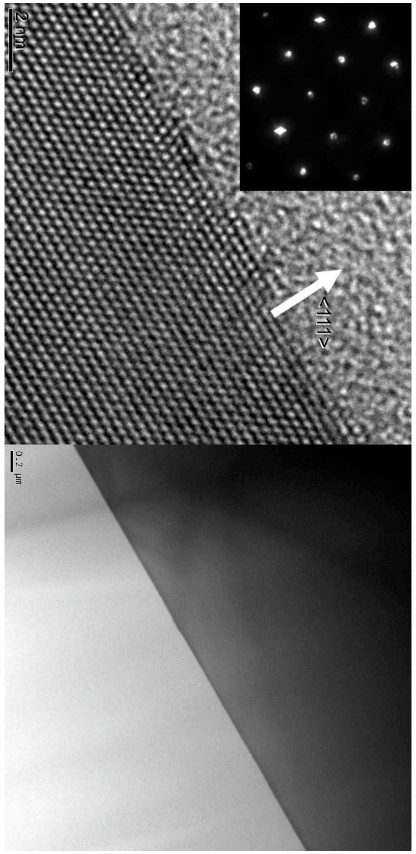


O.I.Sumbaev - PNPI (1957)



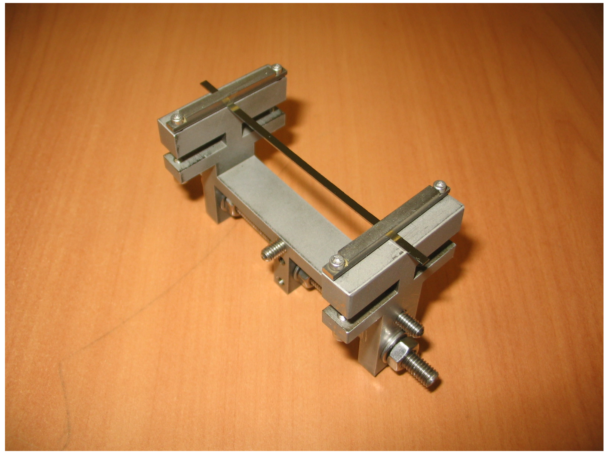
- Bending driven solely by anisotropy

Chemical etching

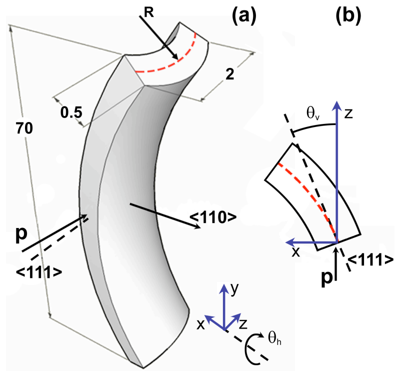


S. Baricordi *et al*., Appl. Phys. Lett. 91, 061908 (2007)

Strip crystals



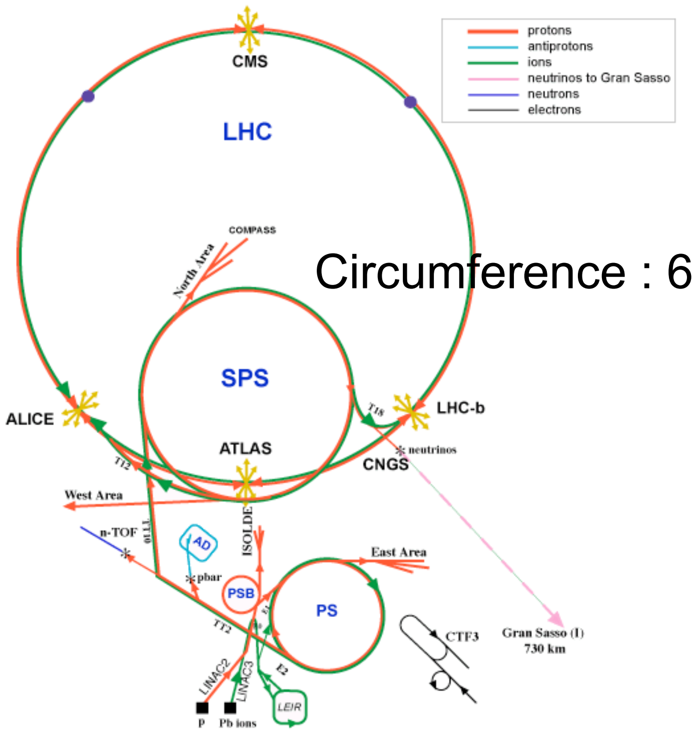
A. G. Afonin *et al*., JETP Lett. 67, 781 (1998)



- Bending driven by 2-D elasticity law

UA9 @ SPS

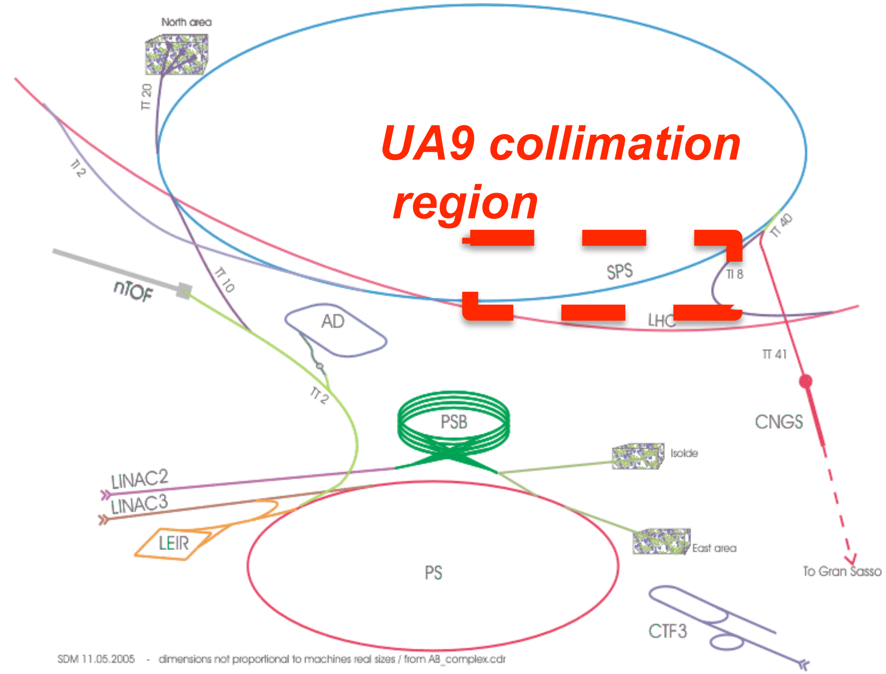
CERN Accelerators
(not to scale)



Circumference : 6.9 km

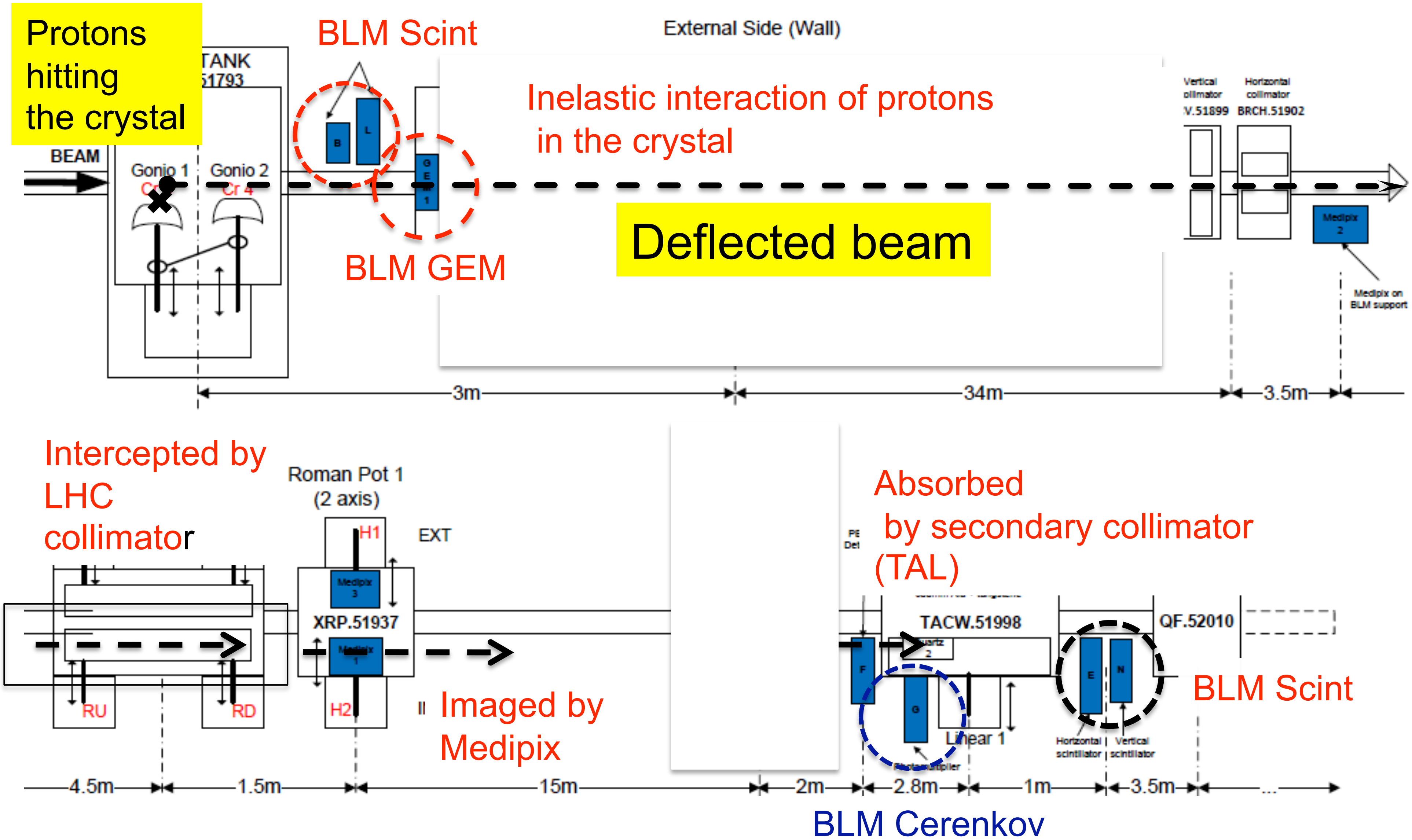
LHC: Large Hadron Collider
SPS: Super Proton Synchrotron
AD: Antiproton Decelerator
ISOLDE: Isotope Seperator OnLine DEvice
PSB: Proton Synchrotron Booster
PS: Proton Synchrotron
LINAC: LINear ACcelerator
LEIR: Low Energy Ion Ring
CNGS: Cern Neutrinos to Gran Sasso

An international collaboration
60 people
CERN, Italy, Russia,UK, US
[INFN FE, LNF,LNL, NA, RM]

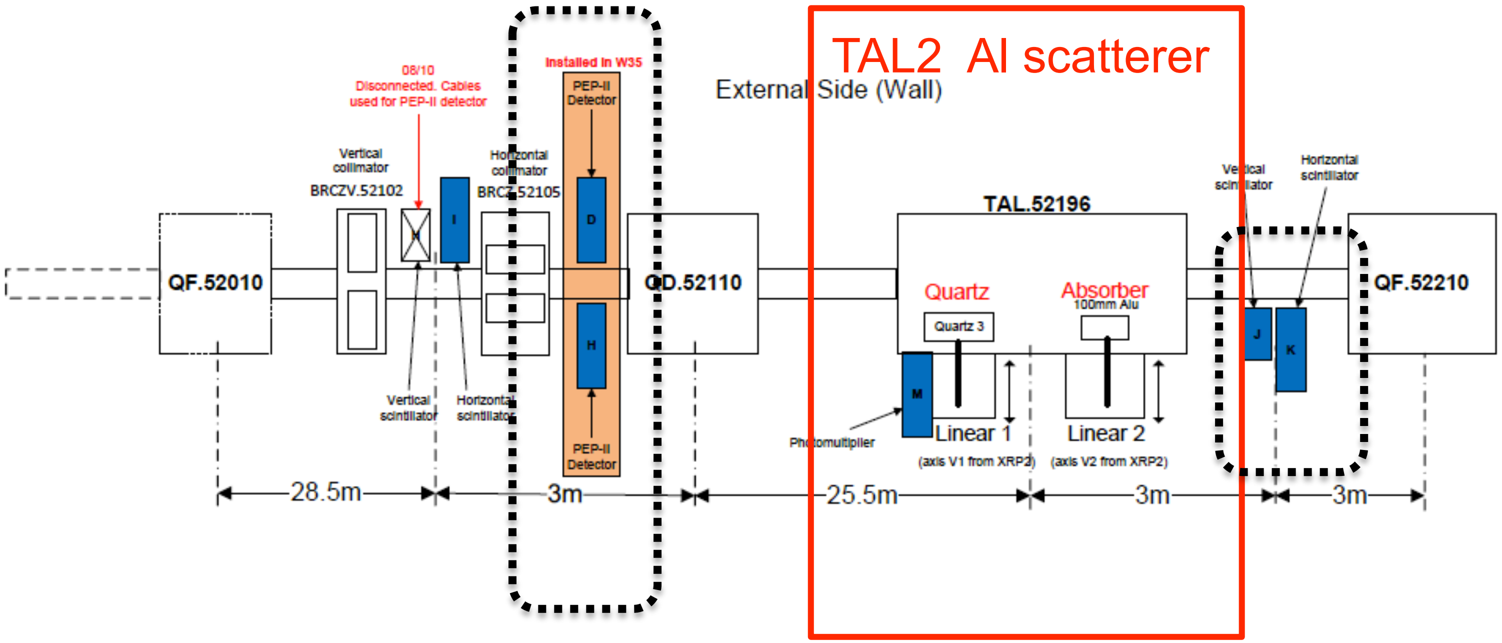


Data-taking during dedicated ***M***achine ***D***evelopment days with SPS beam in coast mode (~5 in a year, in 2010
4 with protons and 1 with Pb ions
Extracted beam (microbeam at H8) tests.

Collimation region



Out of collimation region



New scatterer + BLM (scint, Cerenkov, ionization ch.) in highly ***dispersive*** region to detect

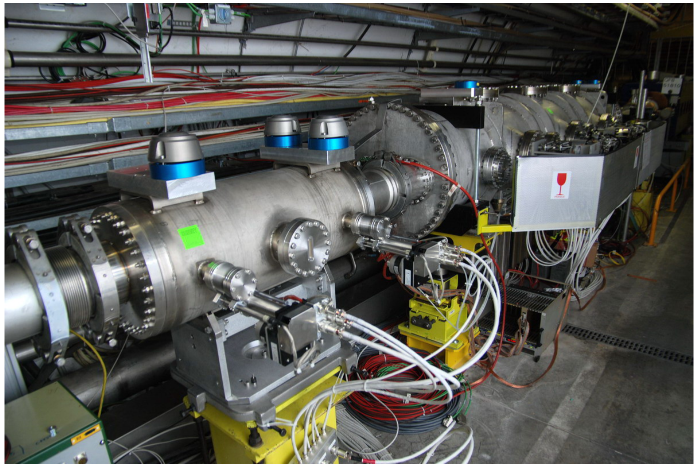
1) **off-momentum particles** (produced in the crystals) which are displaced lateraly
2) any not absorbed secondary halo

Observe the spray rate as a function of scatterer lateral position

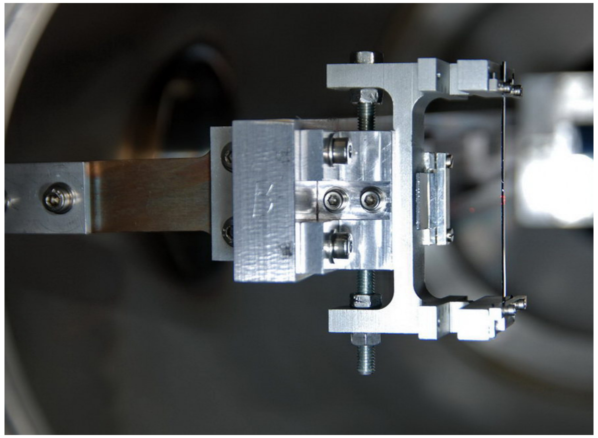
SPS UA9 devices

IHEP tank with goniometers

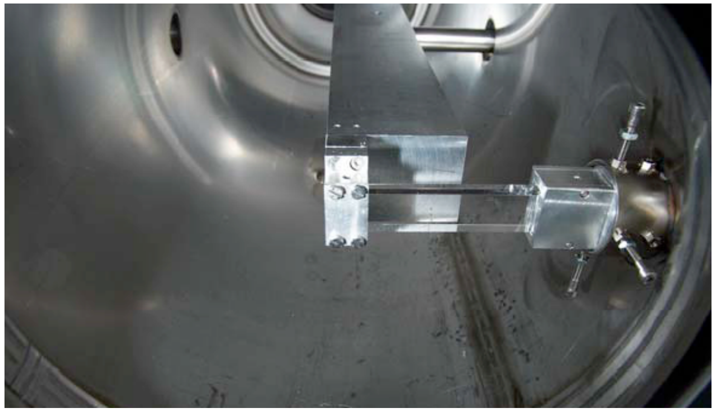
Angular resolution ± 10 μrad



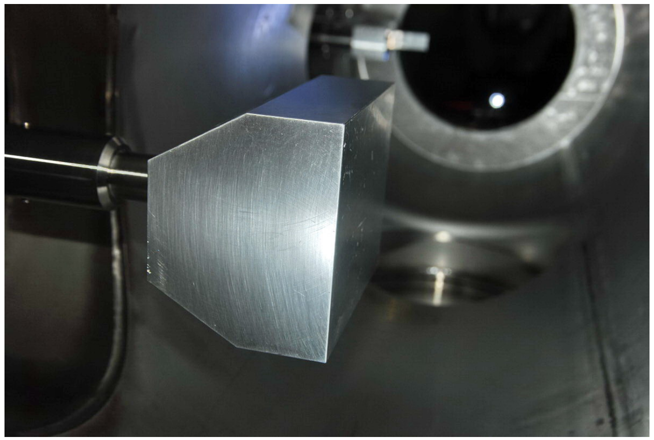
Strip crystal in IHEP tank



TAL absorber & Quartz Cerenkov detector



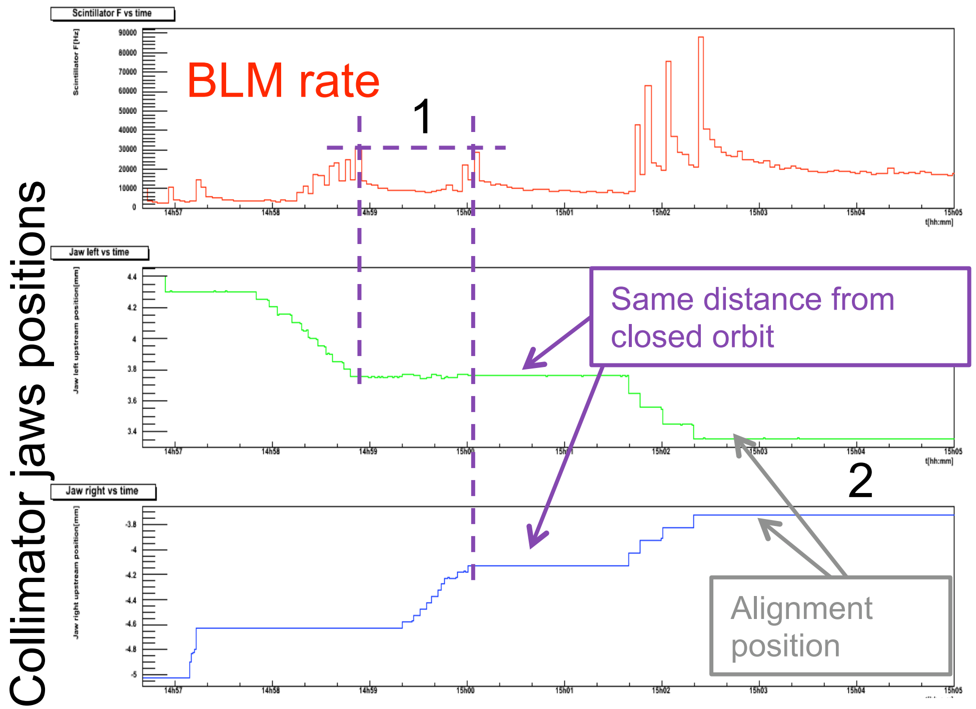
TAL2 Al scatterer



High quality mechanical devices, accurate motion system

Alignment procedure

1) Search of the closed orbit, 2) redefine the beam at how many sigma we want.



Crystal and all UA9 movable devices are aligned during each fill.

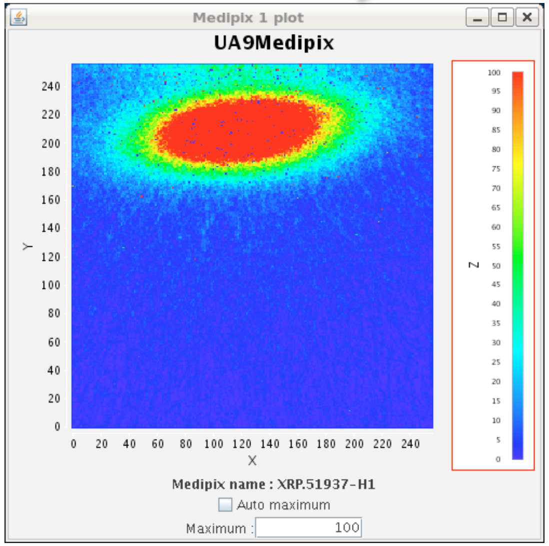
Standard and fast procedure to find channeling configuration and collimation!

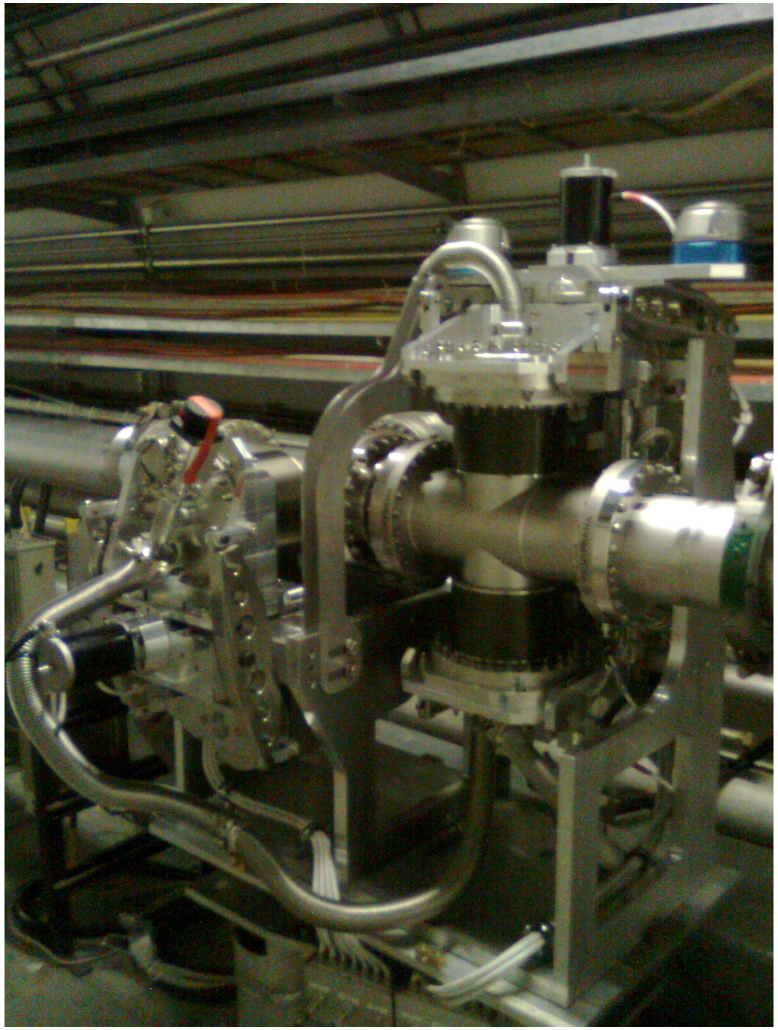
Roman pots

- Movable device housing detectors in secondary vacuum
  - Used to ***acquire images of channeled beam***
  - Relevant to measure channeled beam direction (from centroid) and flux of proton of channeled beam

Vertical displacement

Horizontal displacement

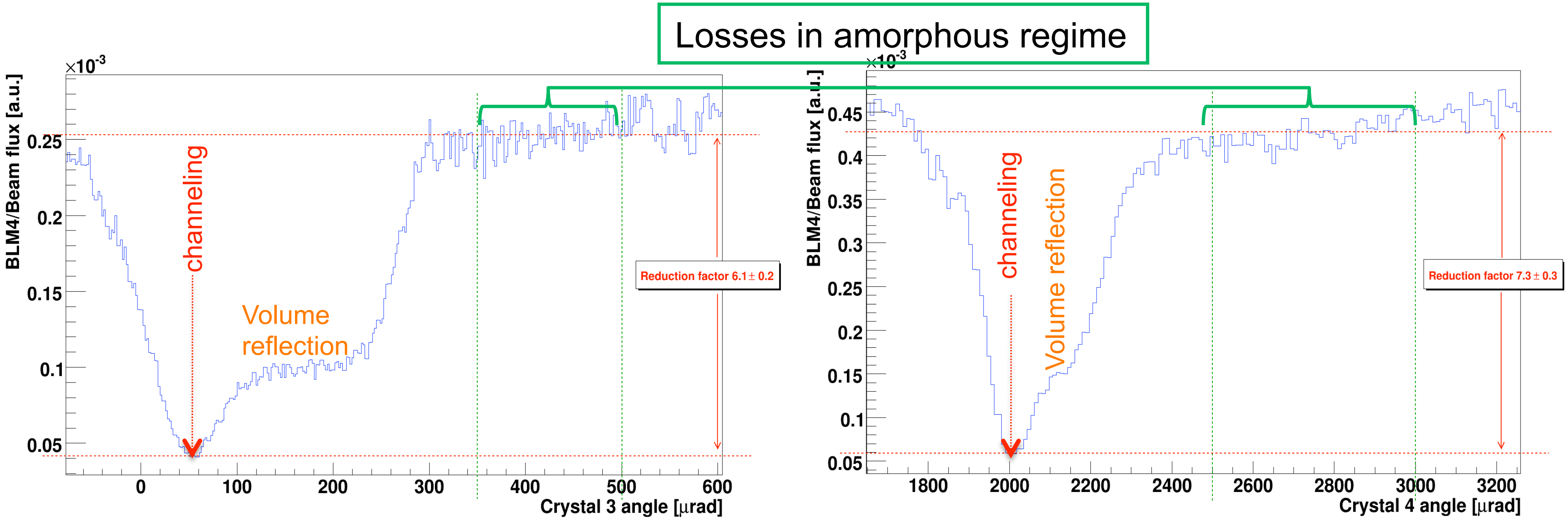




Online picture with Medipix

Angular scans

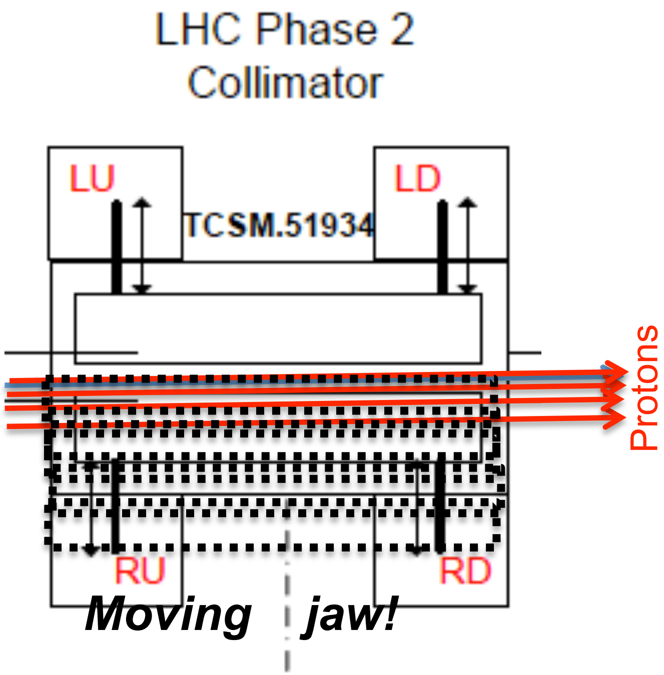
- <u>Reduction factor</u> of the inelastic losses due to inelastic interactions in channeling versus amorphous orientations.
  - Measured with LHC-BLM and GEM detectors
  - Very reproducible in several scans and fills

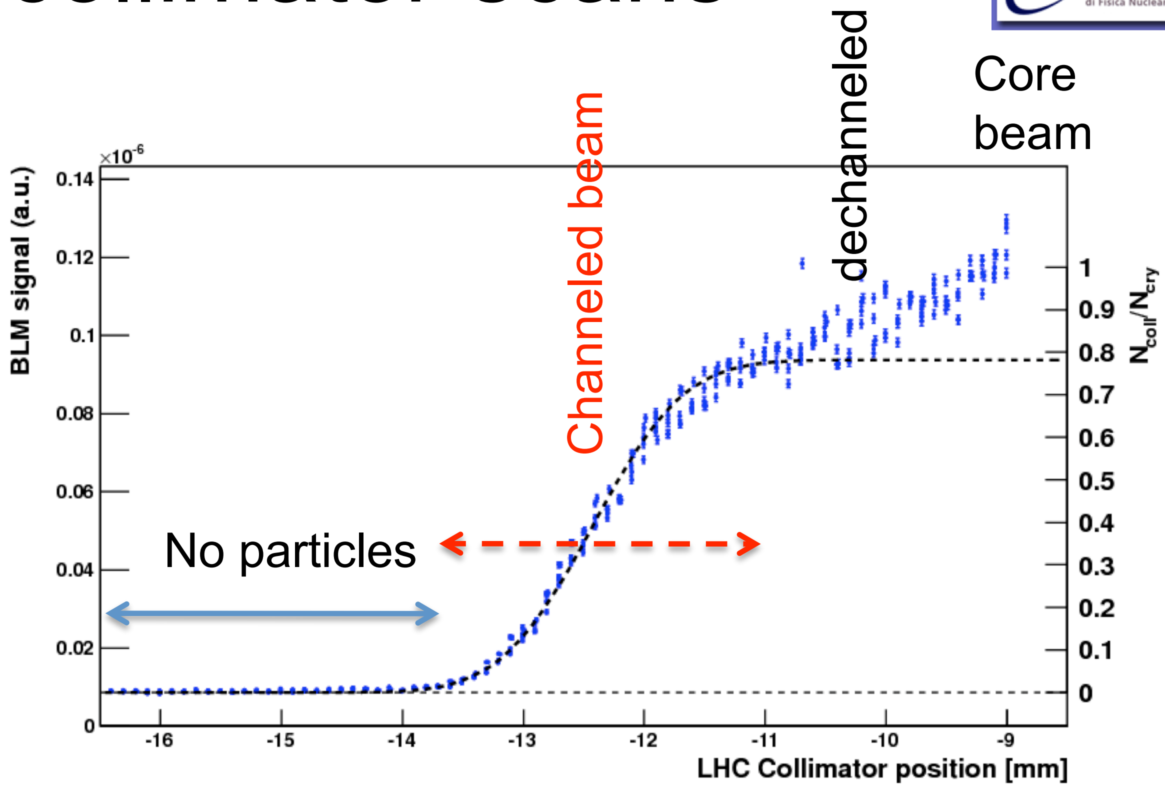


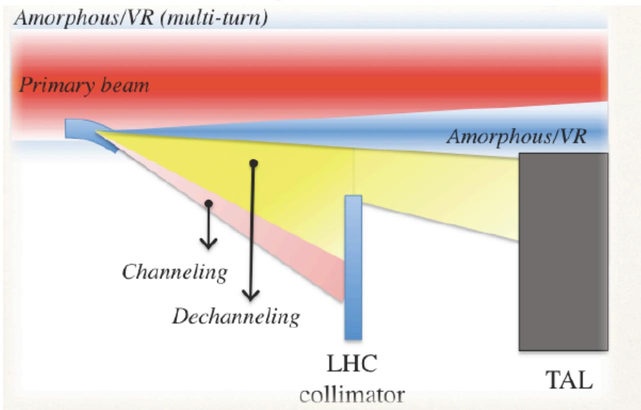
Depending on crystals 5 – 9 reduction factor (protons)
NEW: measurement also with Pb ions: 2-4 factor

Still off with respect to simulation

LHC collimator scans







Measurement of channeled beam position and width

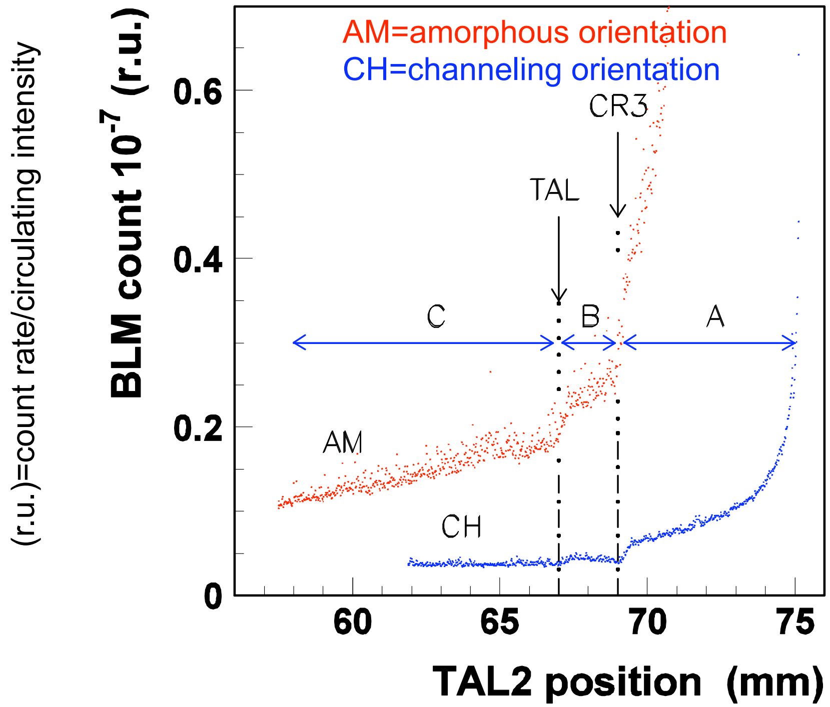
» σ_{beam} **~0.6mm**

Comparison of plateau with core beam

» **Deflection efficiency ~80%,**

Close to expectation (92% and 0.33mm)

Collimation leakage

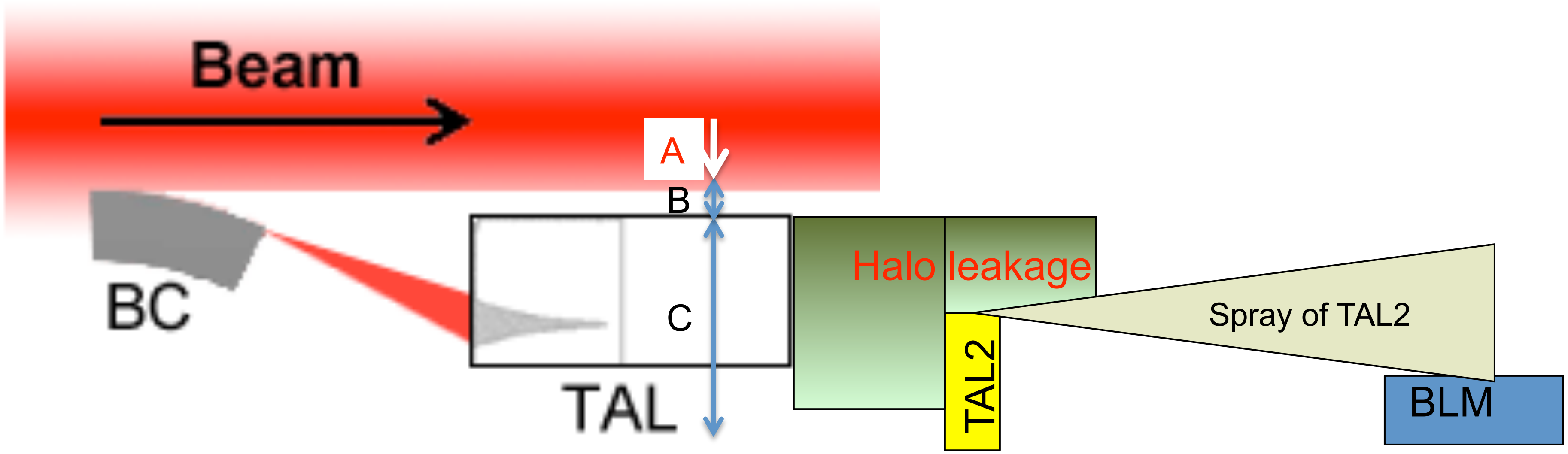


Paper in preparation

A: beam tails (off-momentum and betatronic)

B: multiple Coulomb scattering area

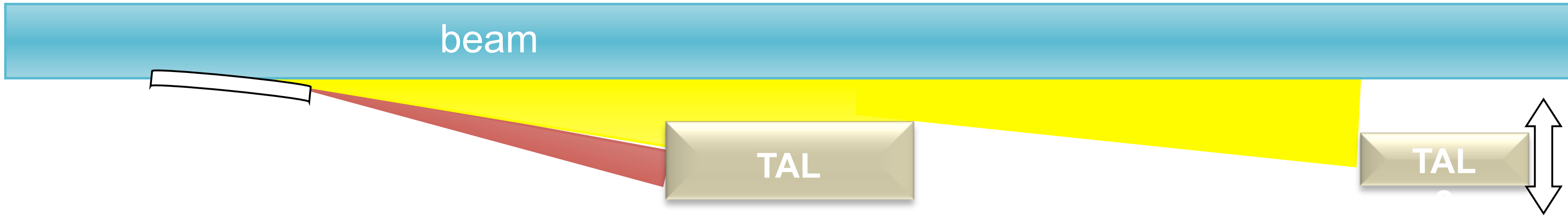
C: shadow of the TAL absorber
Reduction of TERTIARY HALO almost 5 times larger !
Better cleaning efficiency

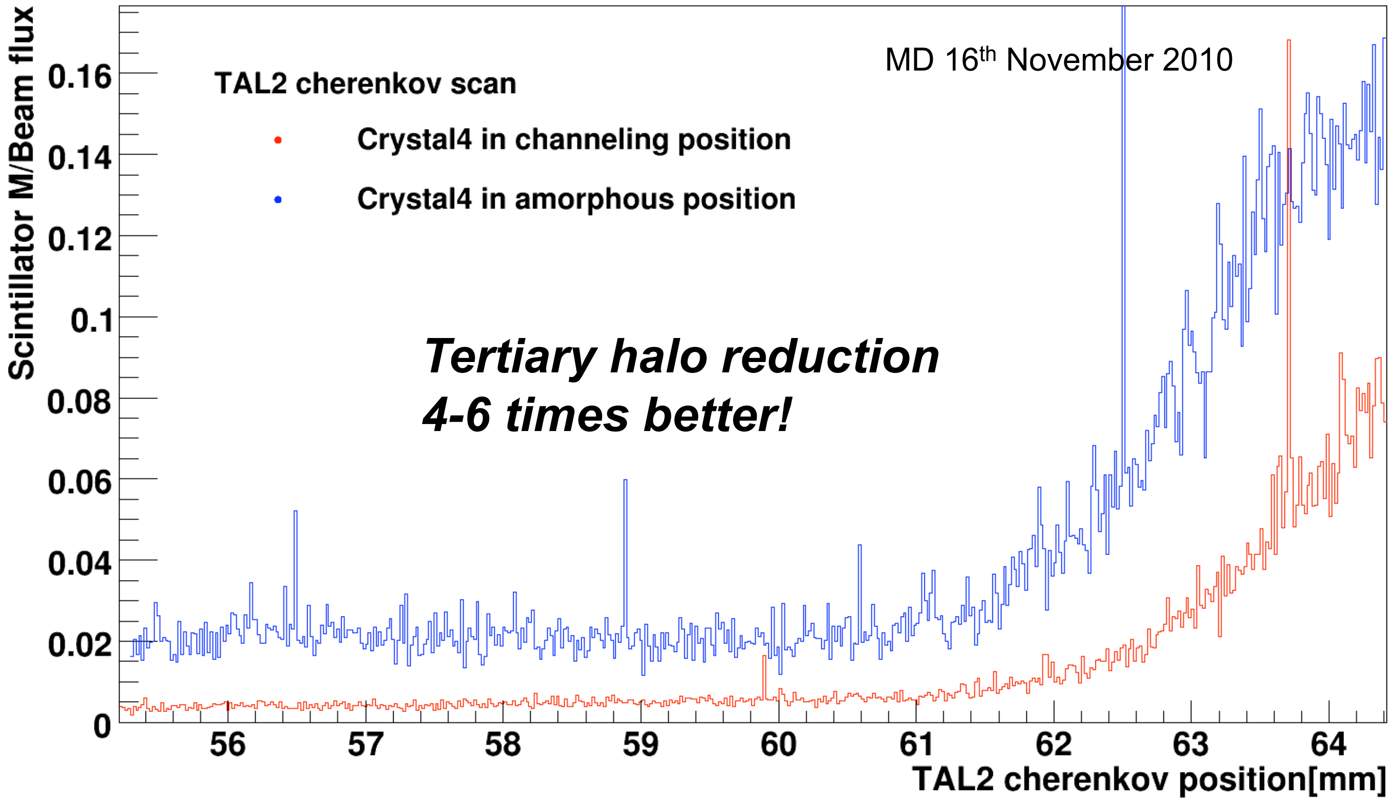


Collimation leakage with ions

Paper in preparation

Only one set of scans made by Cherenkov detector mounted on TAL2.





Summary & Outlook

Summary of 2010 SPS test

Crystal collimation works very well based on *channeling process*

Optimal crystal alignment easily detected and achieved

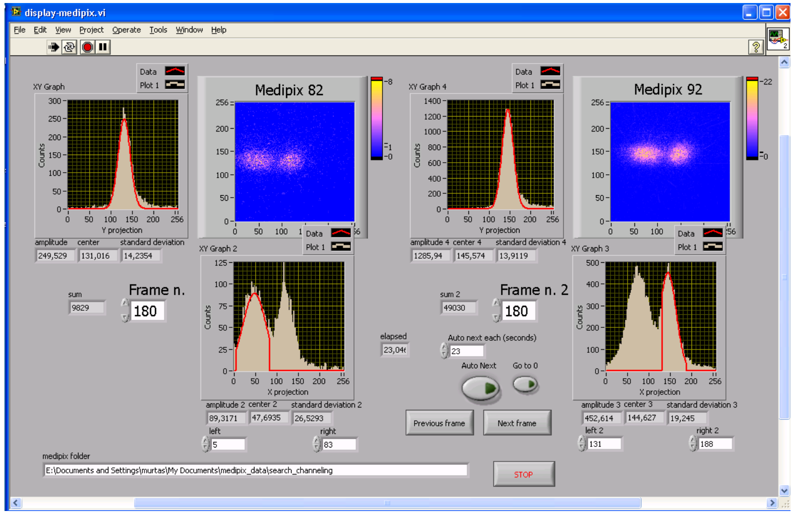
Nuclear loss rate (including **diffractive**) strongly depressed in channeling versus amorphous orientation.
Observed ***for both protons and ions***!

Estimate of cleaning efficiency of collimation region

Leakage is a factor 5 better in aligned orientation versus amorphous

Next for 2001:
Better goniometer accuracy
Thinner Cerenkov detector to resolve proton pile-up
More accurate analysis of tertiary halo [new Medipix]
disentagling betatron from synchrotron tertiary halo

Crystal test station at SPS H8



Silicon strip telescope and gas chamber
to characterize new crystals

Si, (110 plane), miscut: 22 μrad
Deflection angle: 100 μrad
size: 55x5x2 mm^3
Torsion : holder can regulate torsion within 0.2 μrad/mm

Study more exotic crystals
for different collimation scheme

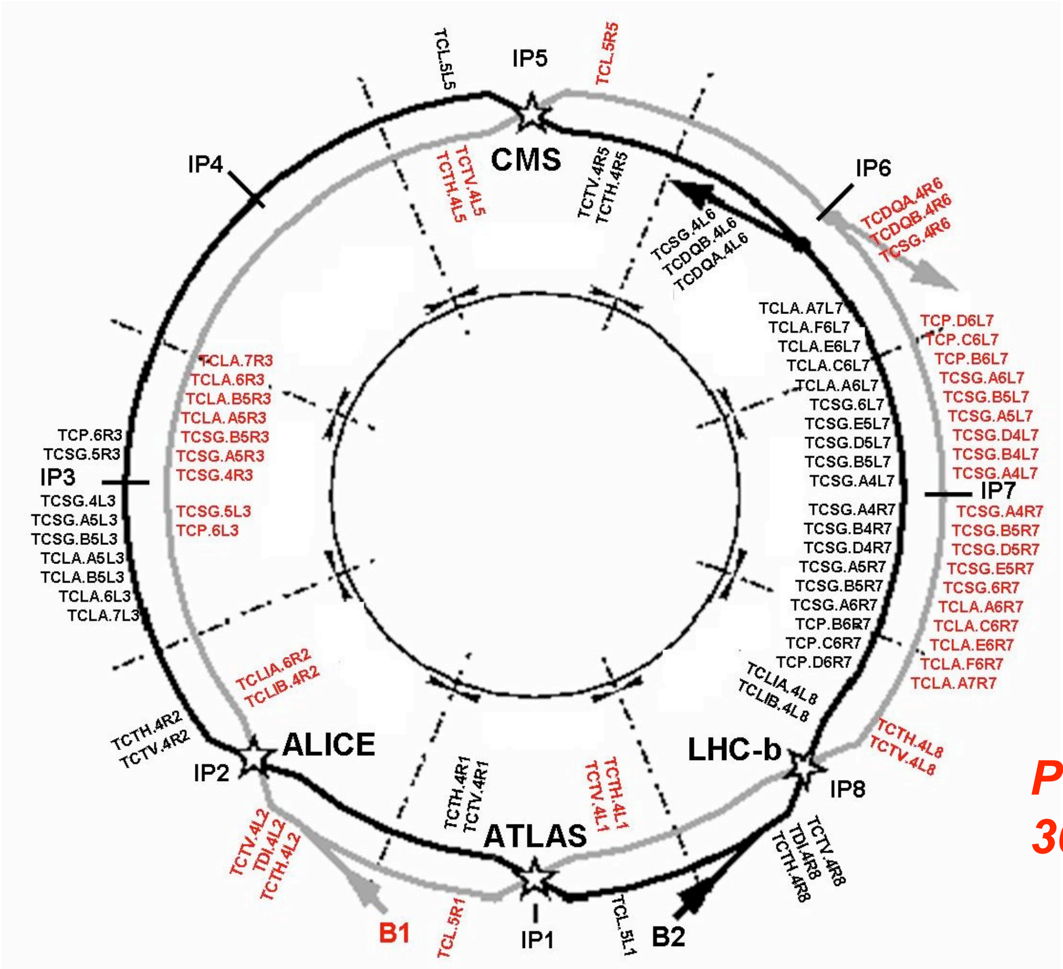
Thin Crystals

Study new particle coherent interaction effects

PXR

Study ion Pb_{82} channeling

LHC Phase 2 collimation



Overall ~150 collimator locations in LHC and transfer lines

Two warm insertions dedicated to collimation:

- IR3 **momentum cleaning**
- IR7 **betatron cleaning**

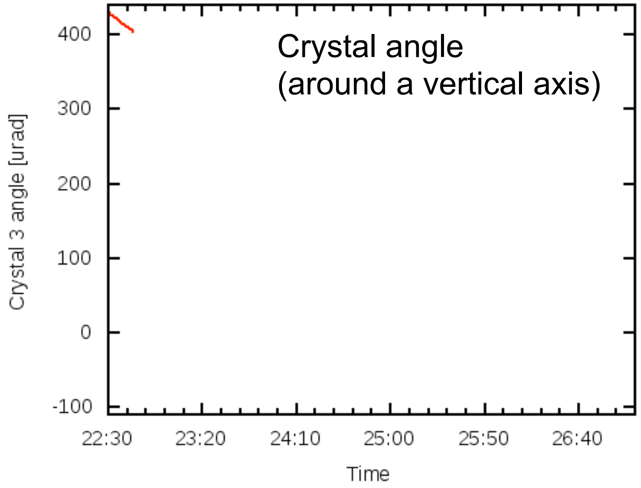
Layout has been optimized for phase 1

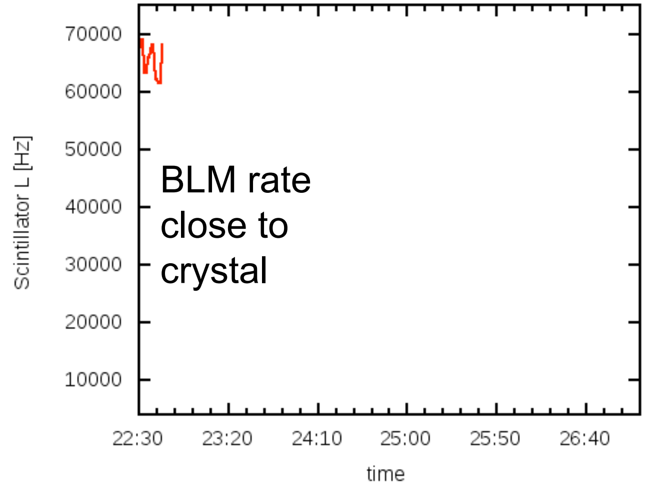
Phase 1 means
30-40% of nominal beam intensity

Assman. R. et al, "The final collimation system for the LHC", EPAC 2006

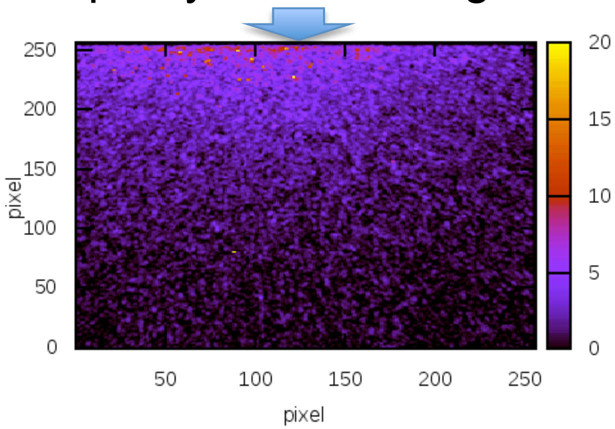
Letter of Intent for LHCC in preparation
Plan is to install a crystal collimation region on LHC in 2012

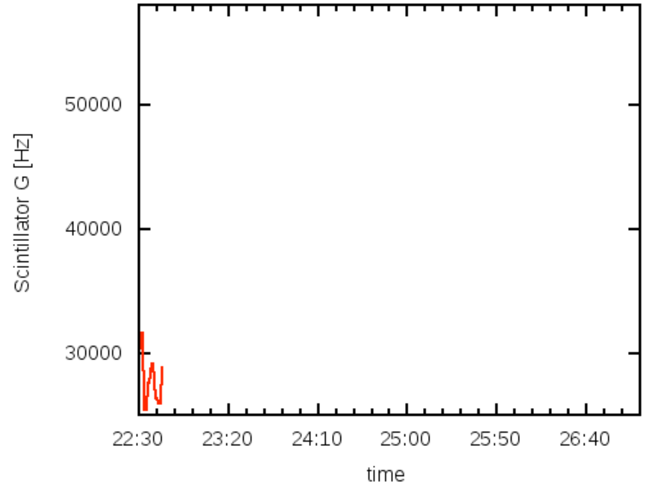
Rotating crystal in the beam





Periphery of circulating beam





Appearance of 120 GeV/c proton beam deflected by crystal channeling

Road-map for a test in LHC

Parameters	Obtained in 2009	Obtained in 2010	Required for LHC	
Channeling efficiency	75	80	90÷95	★★
Nuclear loss reduction	5	5-10	20÷30	★★
Goniometer: angular accuracy [μrad]	30÷40	10	1÷2	★
Crystal bend [μrad]	140÷150	150÷170	50÷100	★★★
Crystal torsion [μrad]	20÷30	0.1÷1 (*)	0.1÷1	★★★
Amorphous layer on crystal	About zero	About zero	About zero	★★
Collimation leakage reduction	-	5	Should be analyzed	★★

(*) On external beam test

Backup