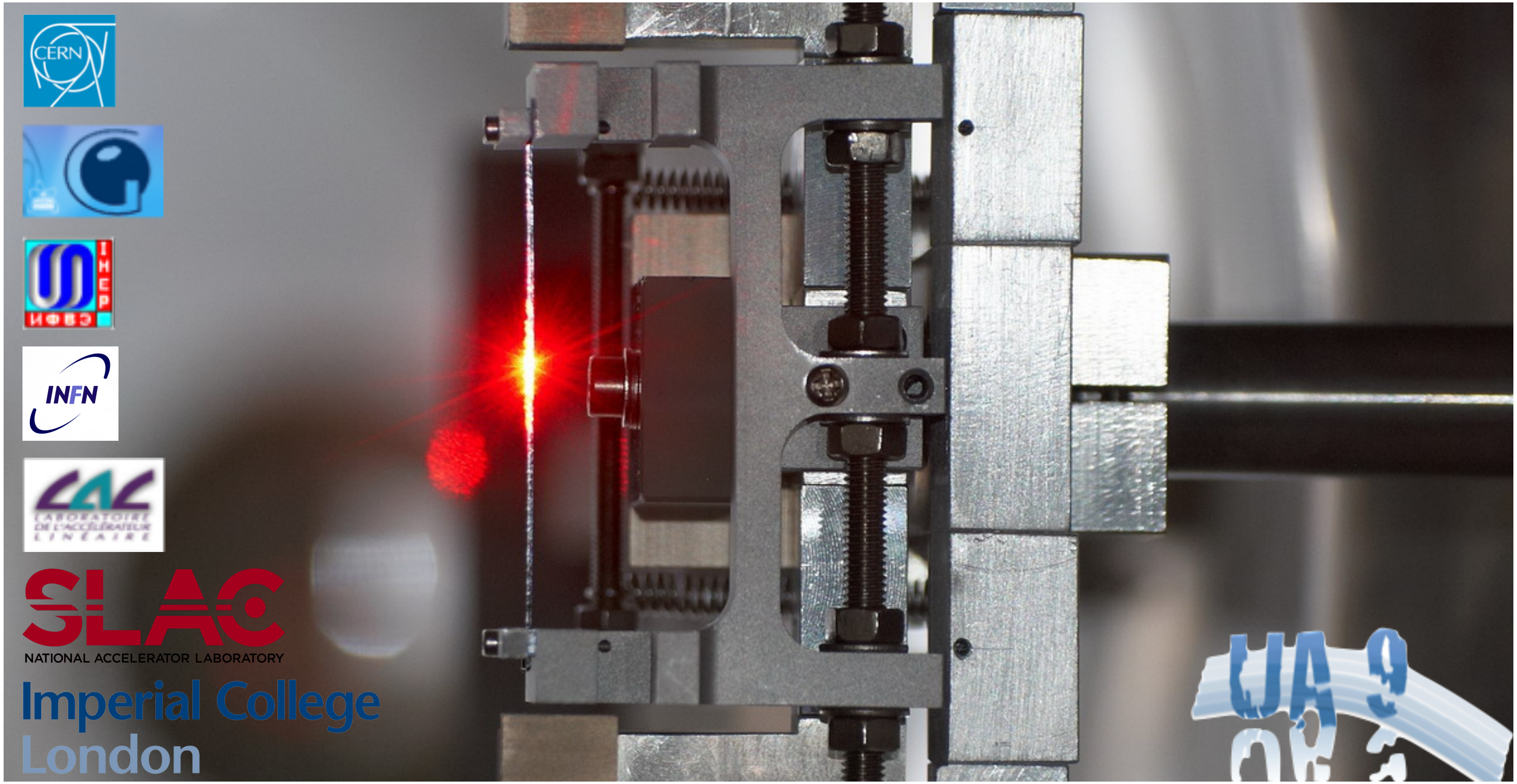


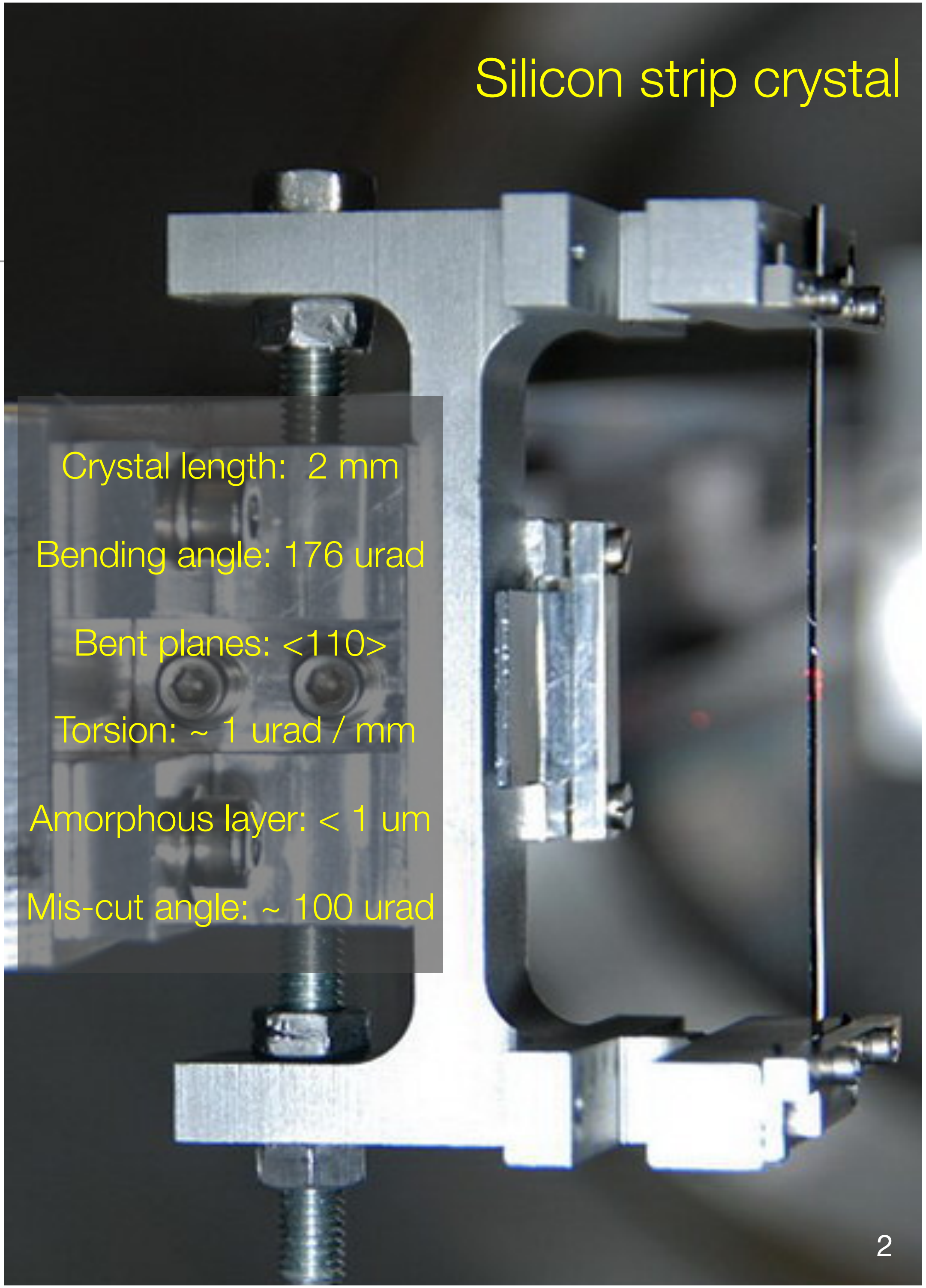
SPSC, 23 October 2012

Status and Results of the UA9 Crystal Collimation Experiment at CERN-SPS

Walter Scandale (CERN, LAL, INFN)
for the UA9 collaboration

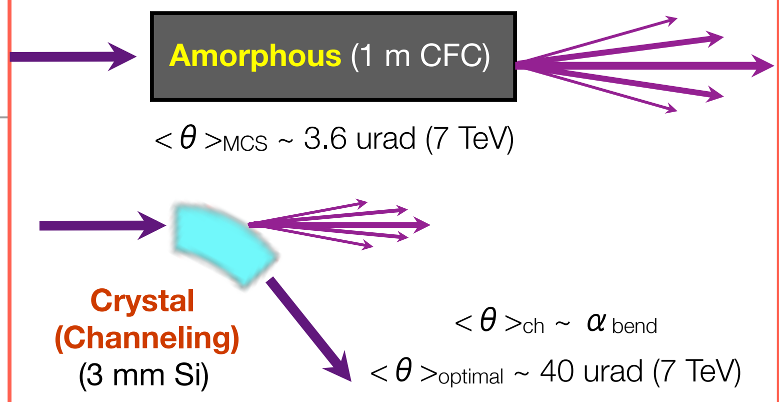
Outline

- Crystal collimation and the UA9 experiment
- UA9 layout in 2012
- UA9 results in 2012
- Toward the installation in LHC
- Conclusions



Crystal collimation concept

UA9 MISSION: investigate bent crystals as primary collimators in hadron colliders.



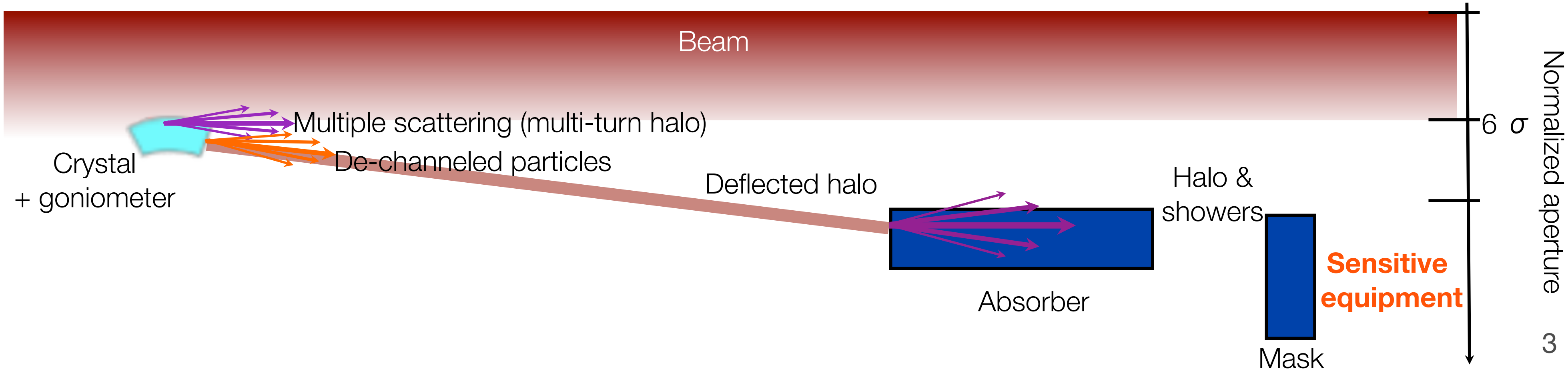
R.W. Assmann, S. Redaelli, W. Scandale, "Optics studies for a possible crystal-based collimation system for the LHC", EPAC 2006

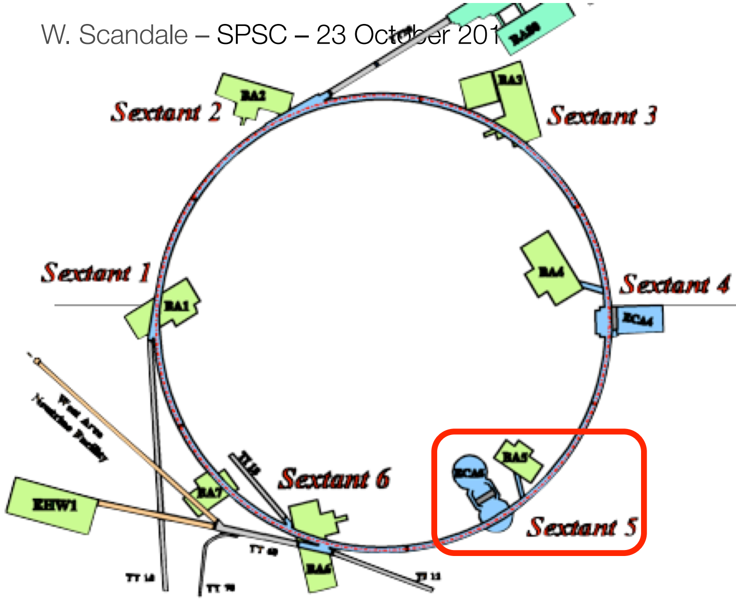
- Mechanically bent crystal instead of amorphous primary deflector.
- Particles are subjected to a coherent interaction (channeling):
  - reduced loss rate close to the crystal
  - reduced probability of diffractive events and ion fragmentation/dissociation

  BUT
  - small angular acceptance $2 \times \theta_c$ depending on the beam energy
  - localization of the losses on a single absorber, thanks to large deflection angle

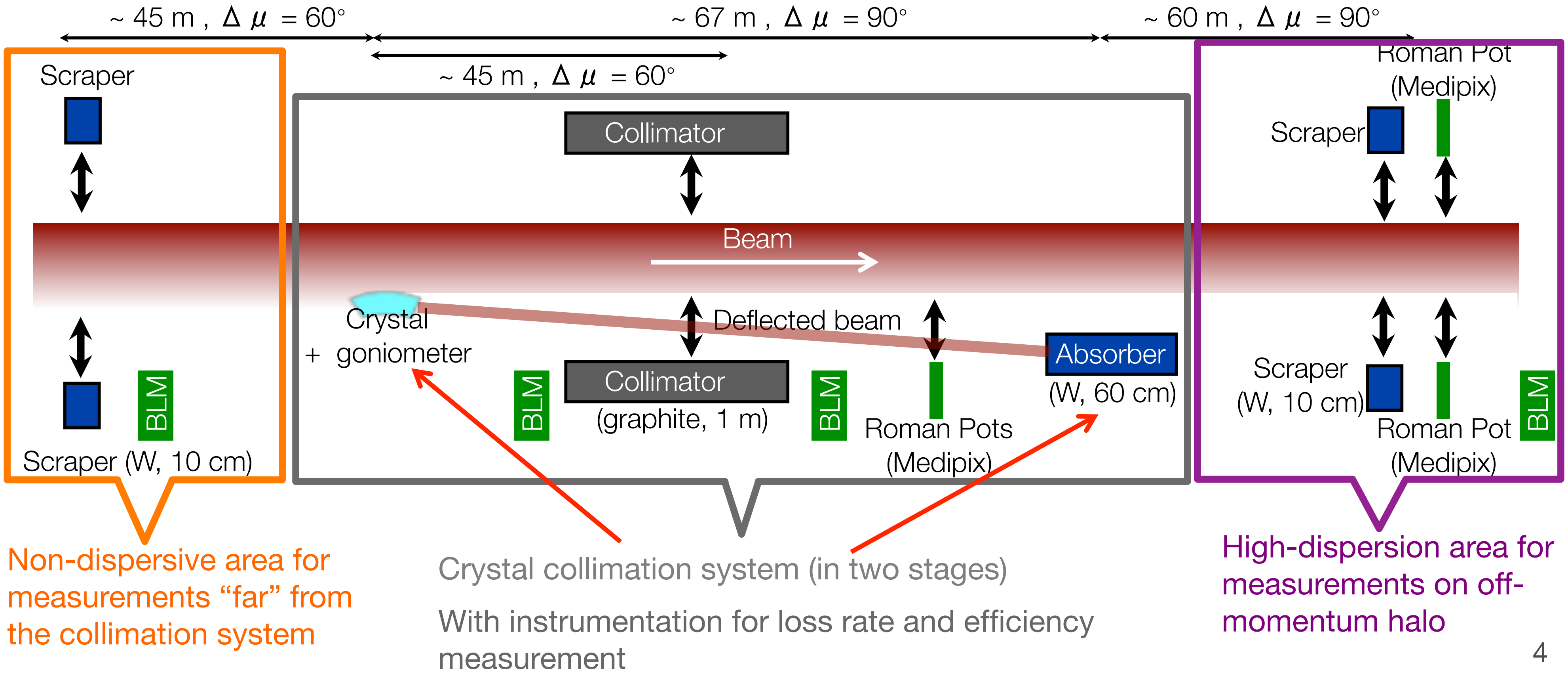
$$\theta_c = \sqrt{\frac{2U_{max}}{E}}$$

Energy	θ_c [μrad]
120 GeV	18.26
270 GeV	7.30
450 GeV	9.42
3.5 TeV	3.38
7 TeV	2.39

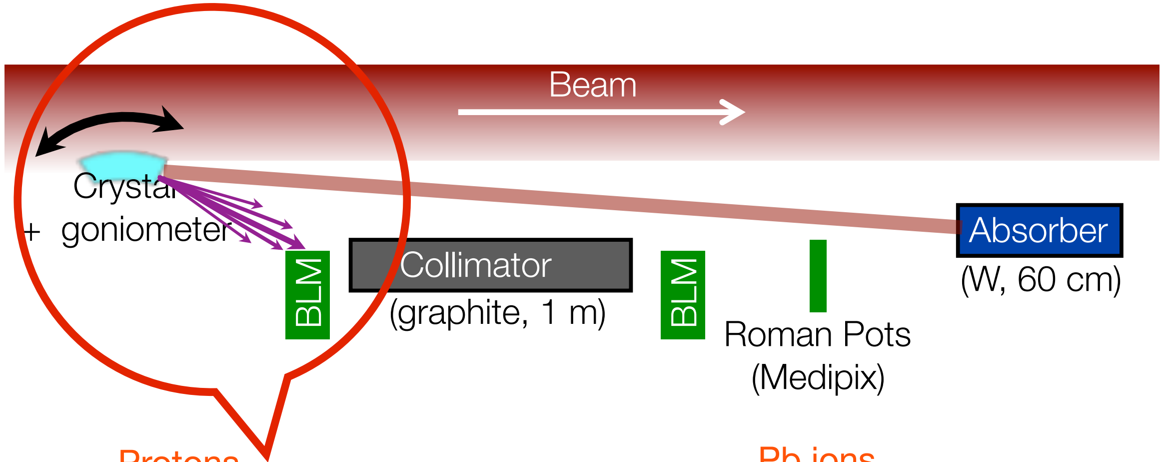




UA9 layout in 2012

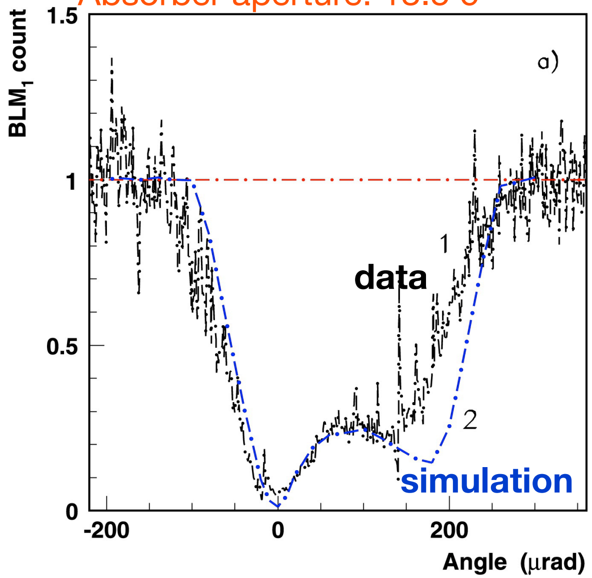


Loss rate reduction in the crystal area

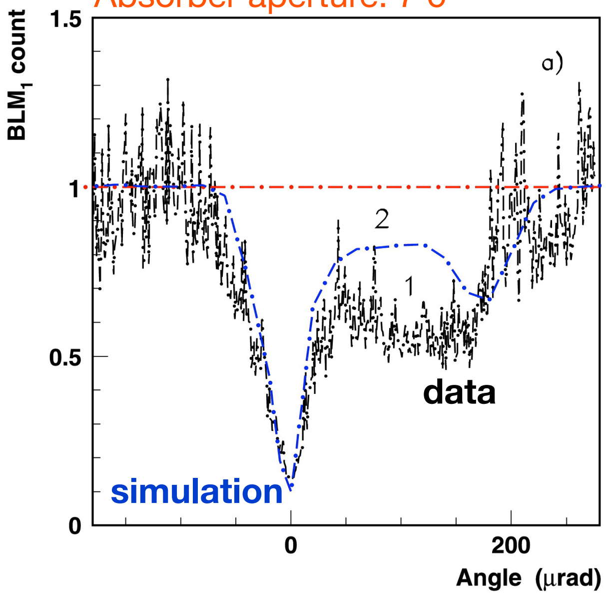


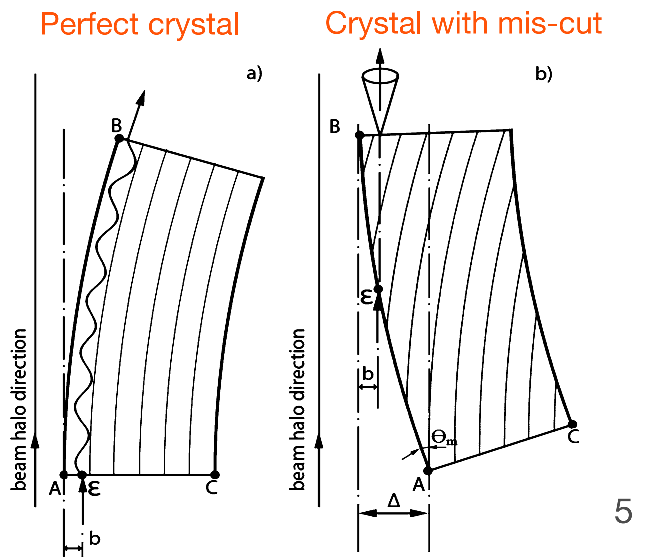
- Large loss reduction factor from "amorphous" to "channeling" orientation
  - 5÷20x reduction for protons
    3÷7x reduction for Pb ions
  - Best performance using a 1 mm long crystal
- Small discrepancy data/simulation
  - Mis-cut crystal modeled in simulation

Protons
Crystal aperture: 9 σ
Absorber aperture: 13.5 σ

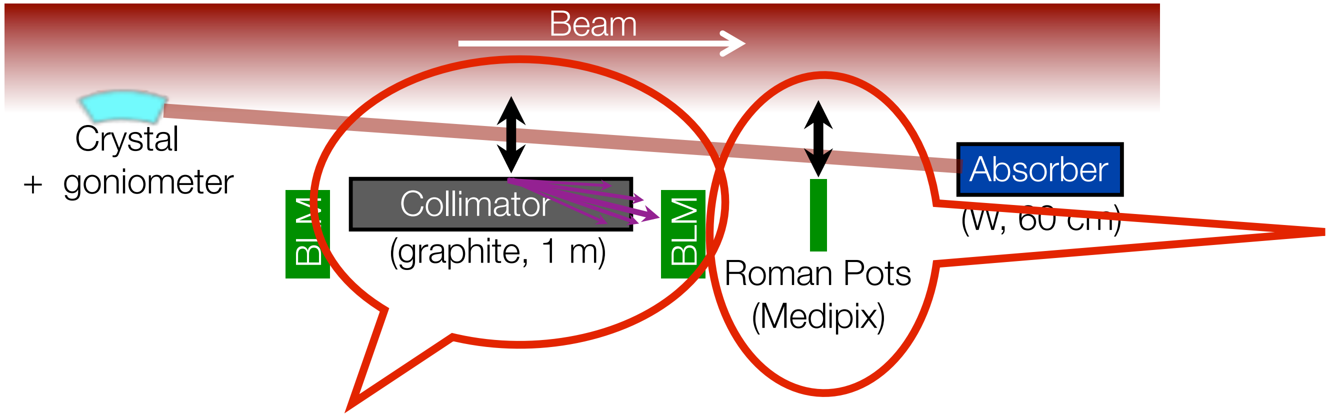


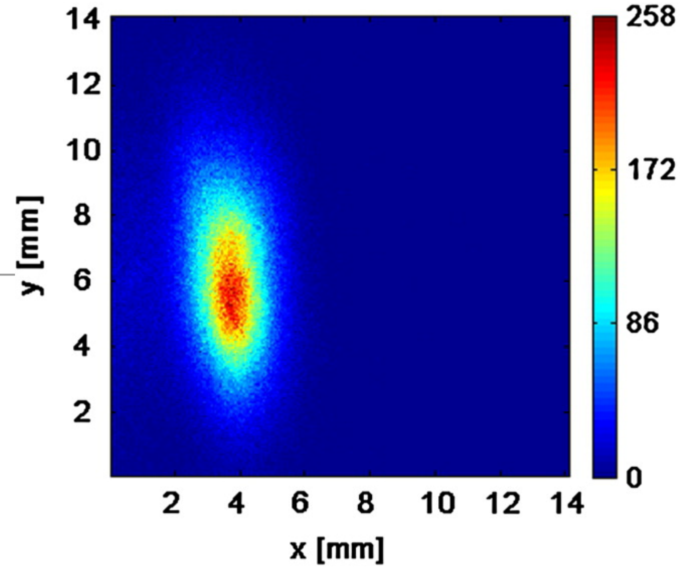
Pb ions
Crystal aperture: 3.5 σ
Absorber aperture: 7 σ



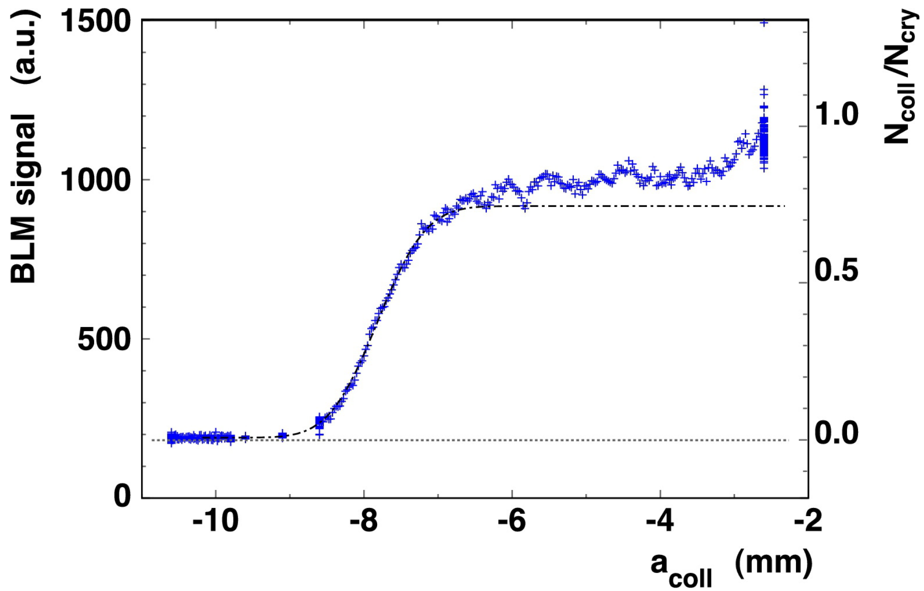


Extraction efficiency



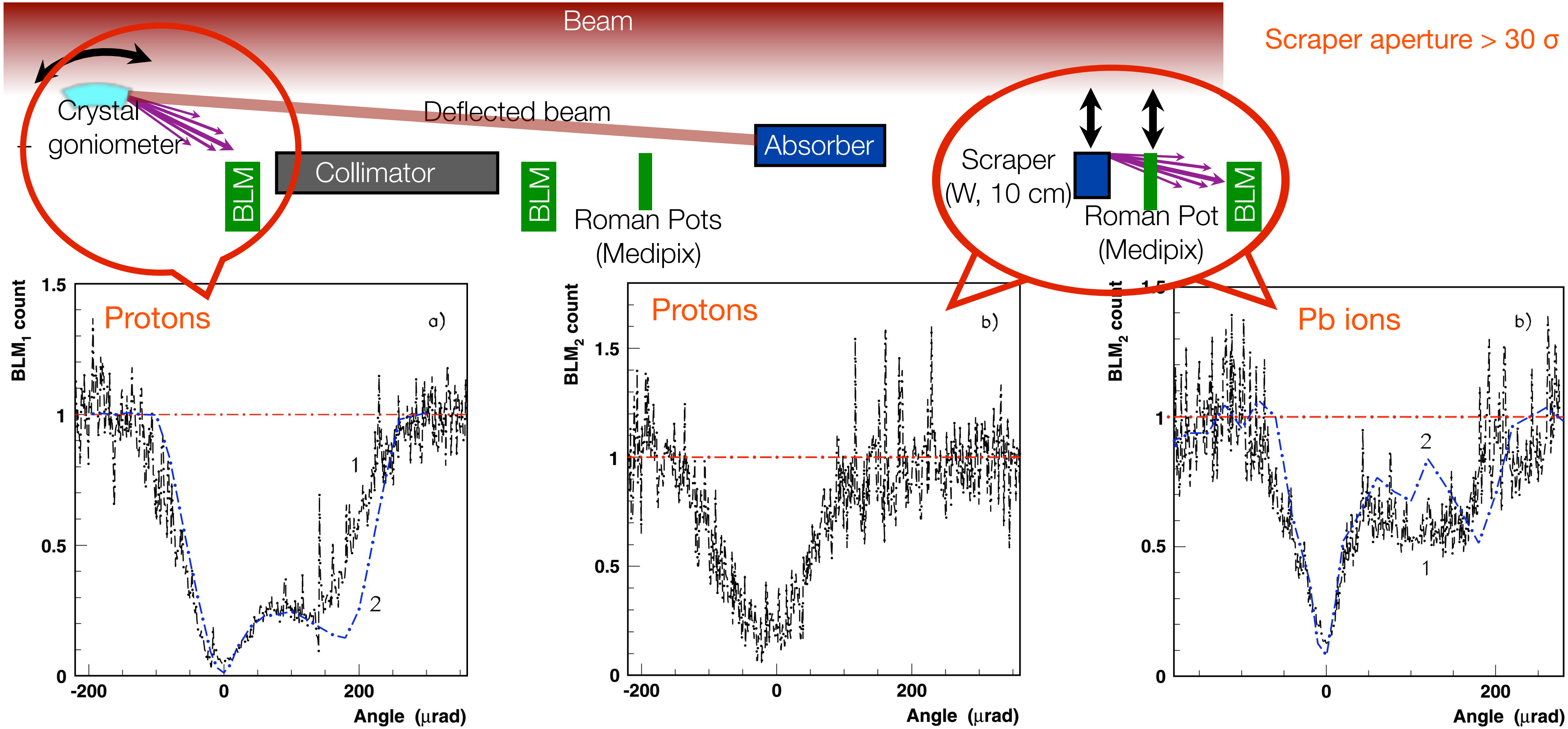


Extracted beam observed with the Medipix



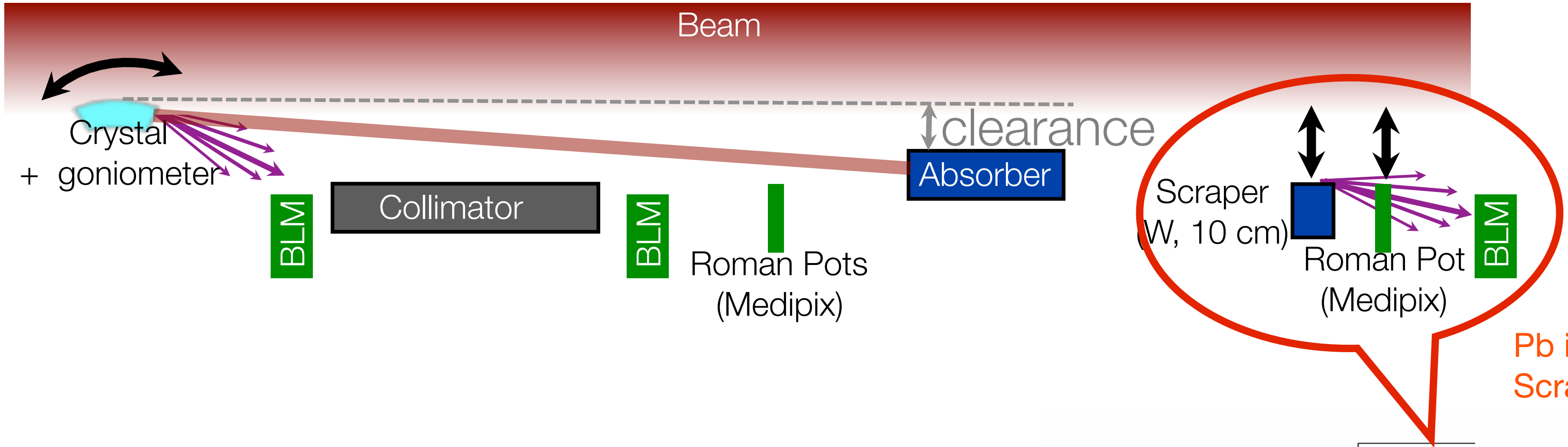
- Efficiency = $N_{deflected}$ / $N_{crystal}$
- Assumptions:
  - the number of particles intercepted by a moving object is proportional to the loss rate downstream the object
    - $N_{deflected}$ is proportional to the losses when intercepting the whole deflected beam
    - $N_{crystal}$ is proportional to the losses when the collimator is the primary aperture
- efficiency for protons: 70÷80%
- efficiency for Pb ions: 50÷70%

Reduction of the off-momentum halo population

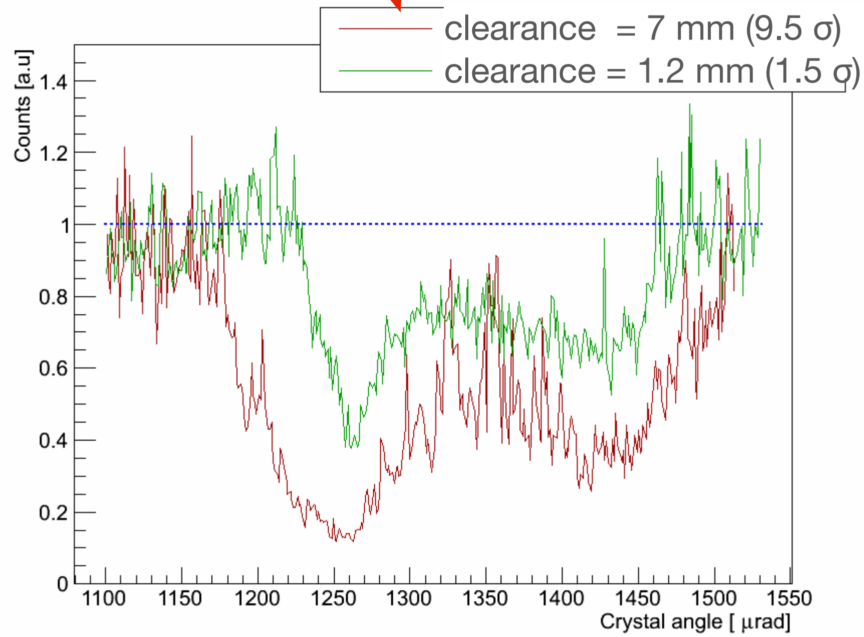


- ❑ excellent correlation with the losses observed at high-dispersion and at the crystal
- ❑ 2÷6x reduction for protons (less than in crystal region)
- ❑ 3÷10x reduction for Pb ions (equal to crystal region reduction)

Clearance between the crystal and the absorber

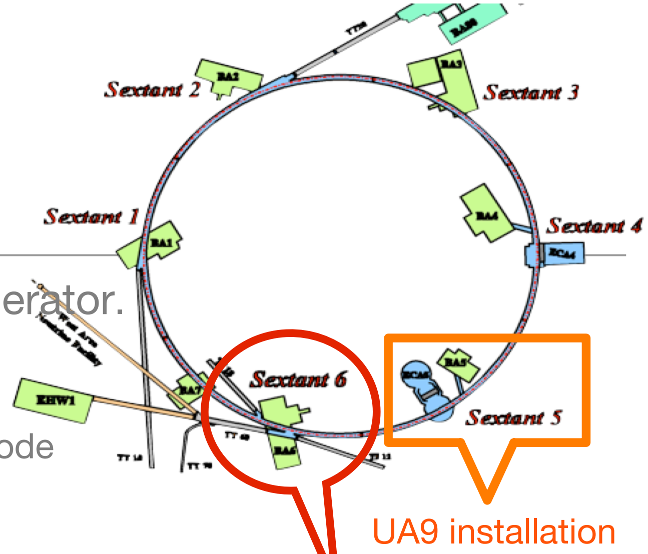


Pb ions
Scraper aperture > 30 σ



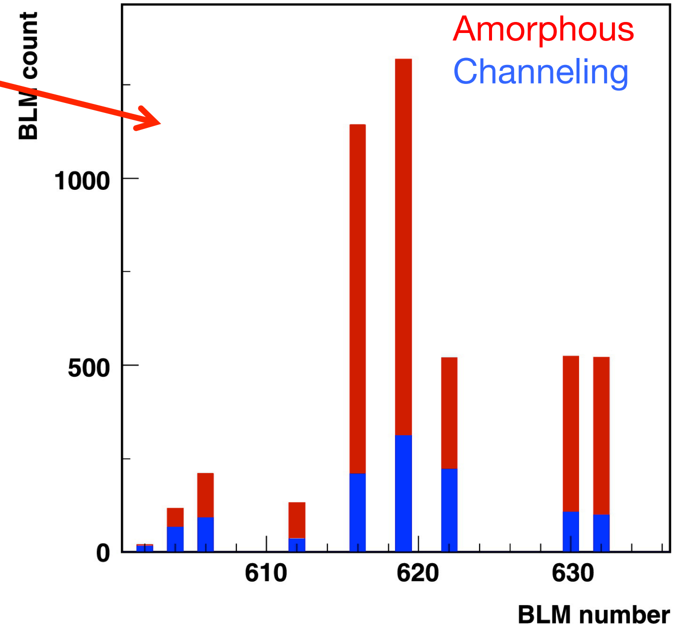
- According to simulation, losses in dispersive area
  - are due particles back-scattered by the absorber
  - depend on the difference in aperture between crystal and absorber (= clearance)
- To minimize the loss rate in the dispersive area for ions and protons the optimal clearance is ~ 7 mm

Loss maps

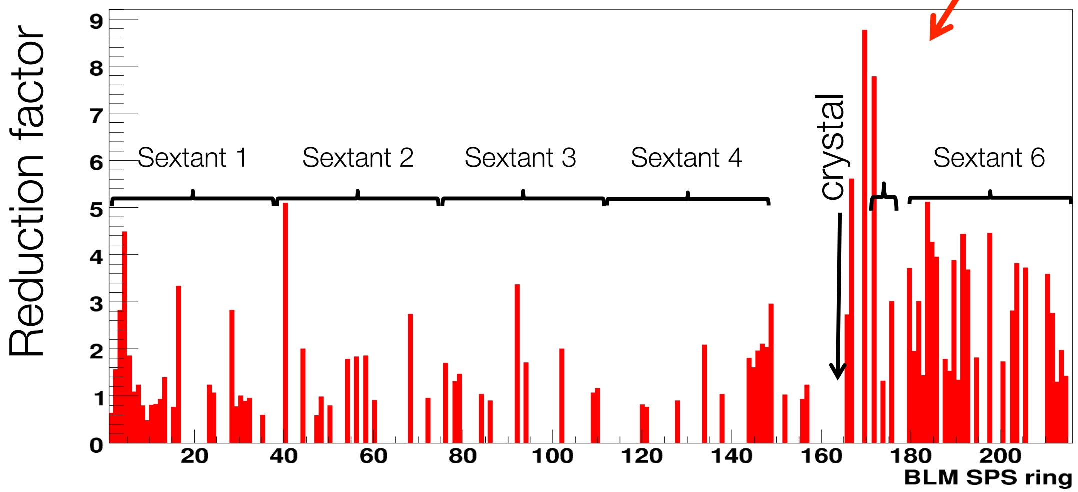


Loss maps are beam loss monitor rates registered along the accelerator.

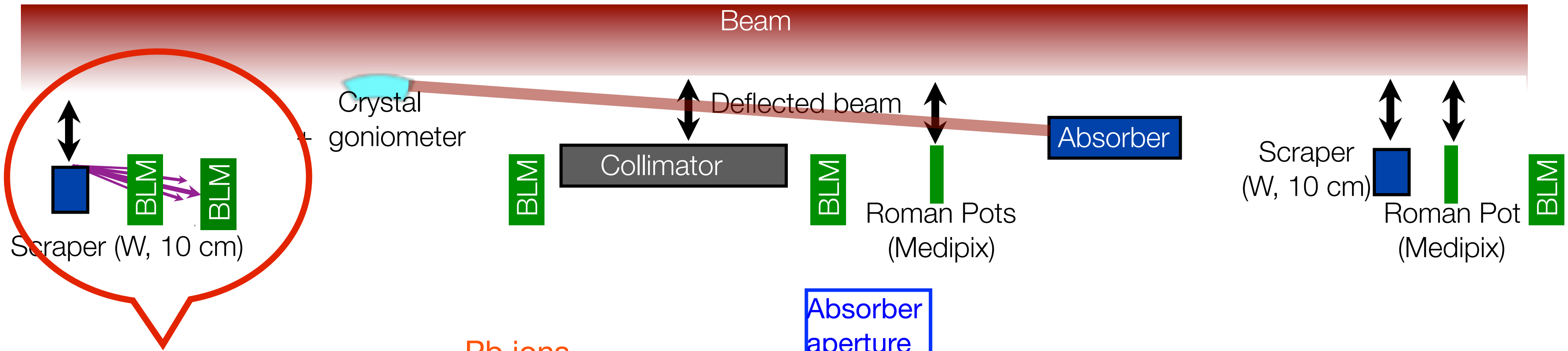
- Loss map measurement is not trivial in UA9:
  - the SPS BLM system is optimized for high-intensity operation in pulsed mode
  - UA9 operates at low intensity and low loss rate.
- Loss map measurement in 2011:
  - intensity increased from 1 bunch (I = 1.15 x 10^{11}) to 48 bunches,
  - Clear reduction of the losses in the Sextant 6 next to the experiment

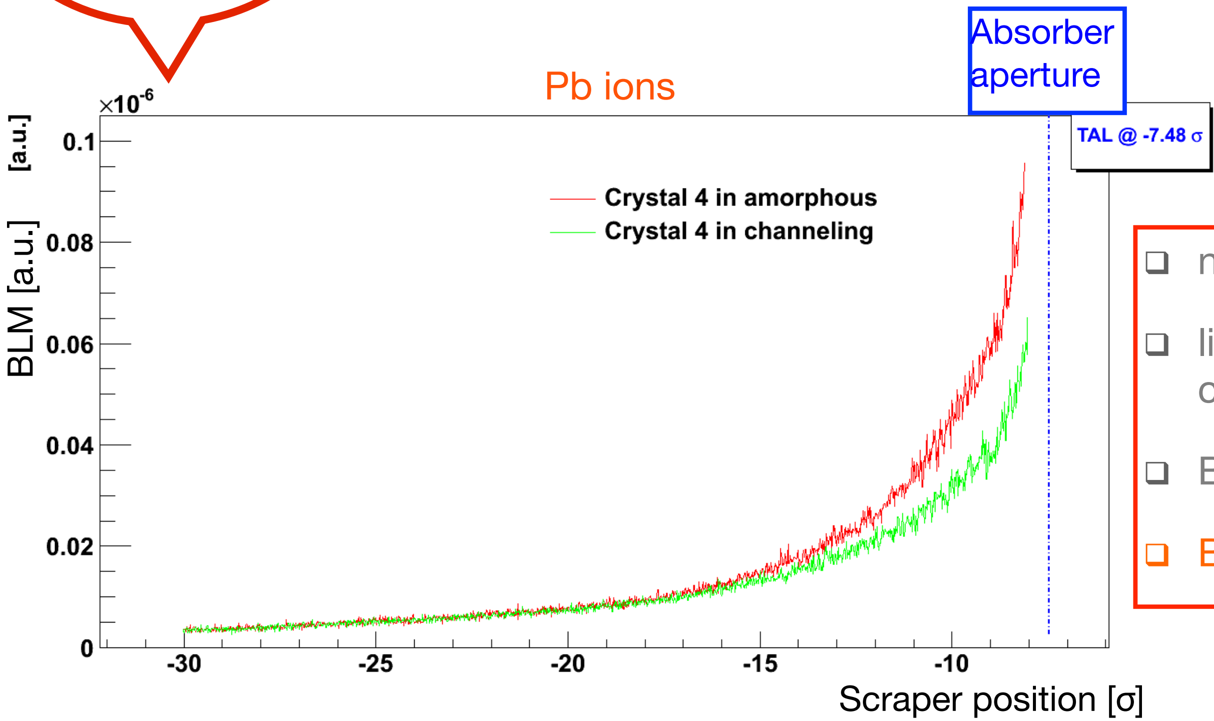


- Loss map measurement in 2012:
  - total intensity: 3.3 x 10^{13}, 4 x 72 bunches with 25 ns spacing
  - Loss reduction in the entire ring (in the reliable BLMs)



Halo profile “far from the crystal”



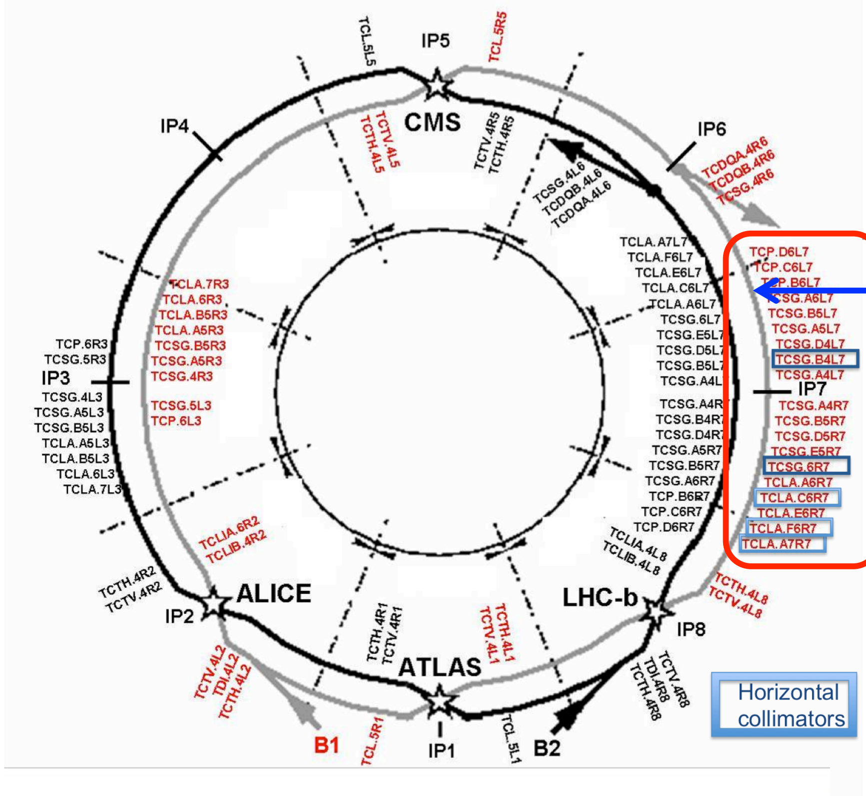


- ❑ new scraper upstream the crystal
- ❑ linear scans of the scraper with crystal in channeling and amorphous position
- ❑ BLM signal close to detector baseline
- ❑ BLM rate reduced with Pb-ions

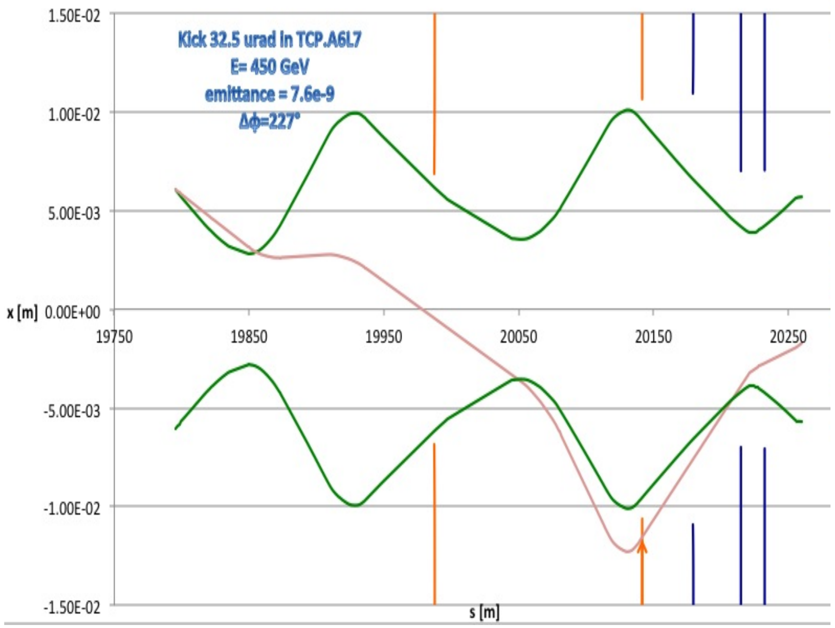
Toward installation in LHC

- In September 2011, a letter of intents was presented to the LHCC, asking to extend UA9 to the LHC:
  - new experiment (LUA9) recommended by the LHCC and accepted by the accelerator directorate
  - goals:
    - demonstrate the extraction of the beam halo in the LHC
    - measure the possible improvements with respect to standard collimation
  - the UA9 Collaboration together with the LHC collimation team (leader S. Redaelli) will conduct the test.

Toward LHC: layout



H & V crystals



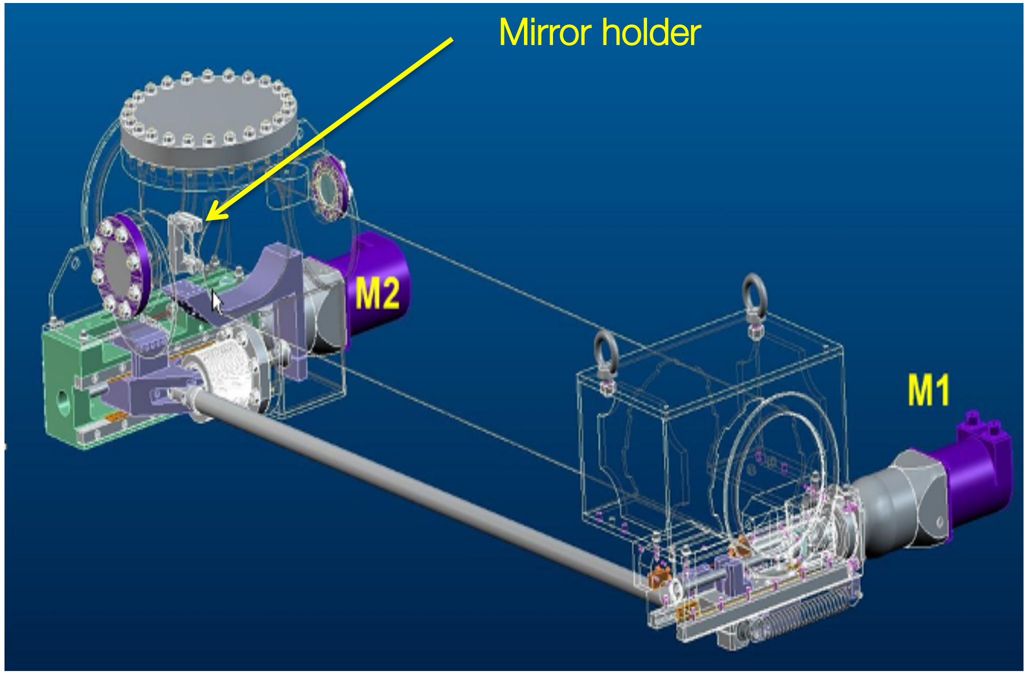
- ❑ Layout of the LUA9 experiment
  - ◆ only one beam (beam 1)
  - ◆ two crystal (horizontal and vertical)
  - ◆ two detector stations (horizontal and vertical)
    - ○ Mini-Roman pot with a segmented detector
    - ○ Cherencov detector in vacuum
  - ◆ initially/later:
    - ○ test at steady/ramping energy
    - ○ standard collimation system in-place/retracted
- ❑ Crystal located close to the primary collimators (see arrow):
  - ❑ extracted beam absorbed by a secondary collimator
  - ❑ highest radiation area, tight space allowance

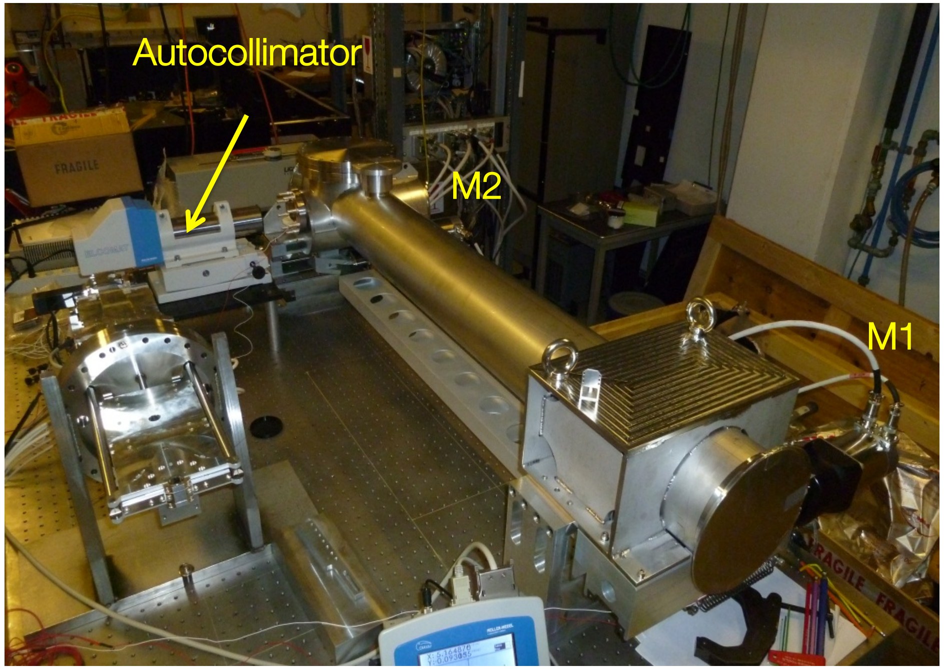
Toward LHC: R&D for a goniometer

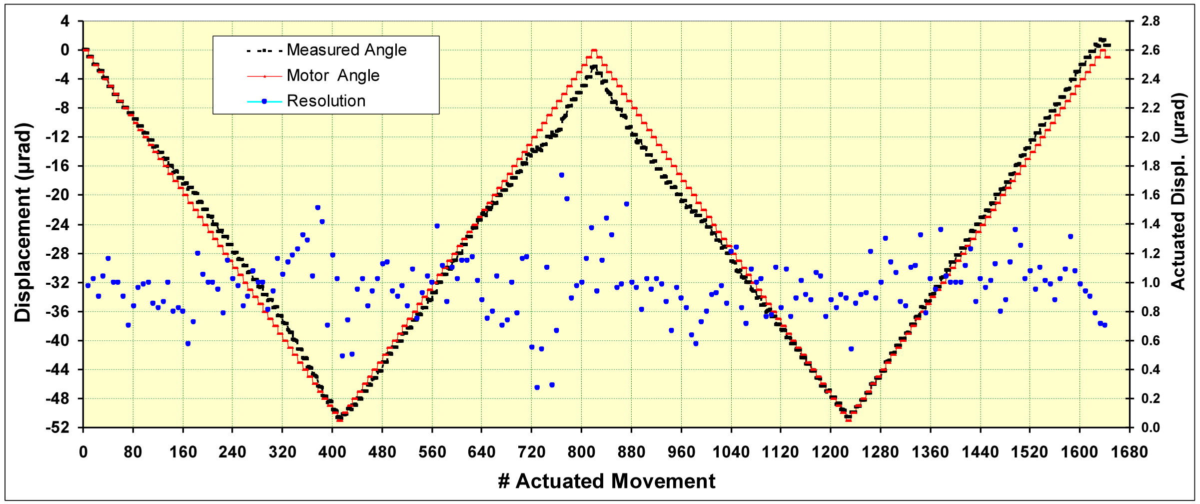
- ❑ Acceptance for channeling defined by the critical angle $\theta_c = \sqrt{2U_0/E} = 2.4$ µrad (7TeV)
- ❑ Goniometer accuracy must be smaller than angular acceptance:
  - ❑ Total angular range : >10 mrad
  - ❑ "Resolution": <0.1 μrad
  - ❑ "Accuracy": < 1 μrad
    - ◆ Maximum tilt inaccuracy: < 1 μrad
    - ◆ Linear resolution: 5 μm
  - ❑ Total linear range: 40 mm
- ❑ Possible solutions
  - ◆ mechanical goniometer à la "SPS (IHEP, Russia)" has resolution < 10 urad
  - ◆ mechanical device developed by industrial partner CINEL for the SPS:
    - static resolution and accuracy meet the LHC specifications
    - test on going to assess accuracy in dynamic regime
  - ◆ piezoelectric device under development in collaboration with industrial partner ATTOCUBE.

CINEL goniometer for the SPS

M1: Angular deflection (144 mm stroke)
M2: Angular and linear displacement (88 mm stroke)
M1 & M2: Linear displacement

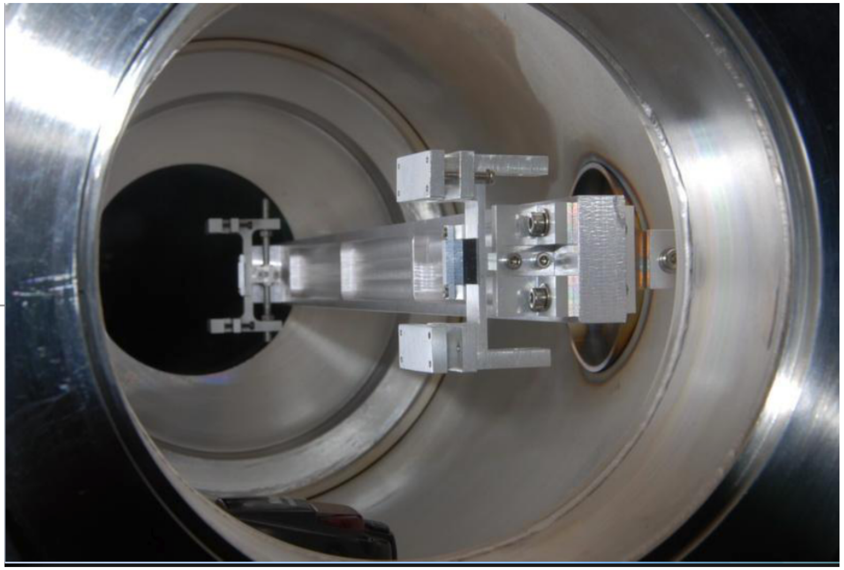






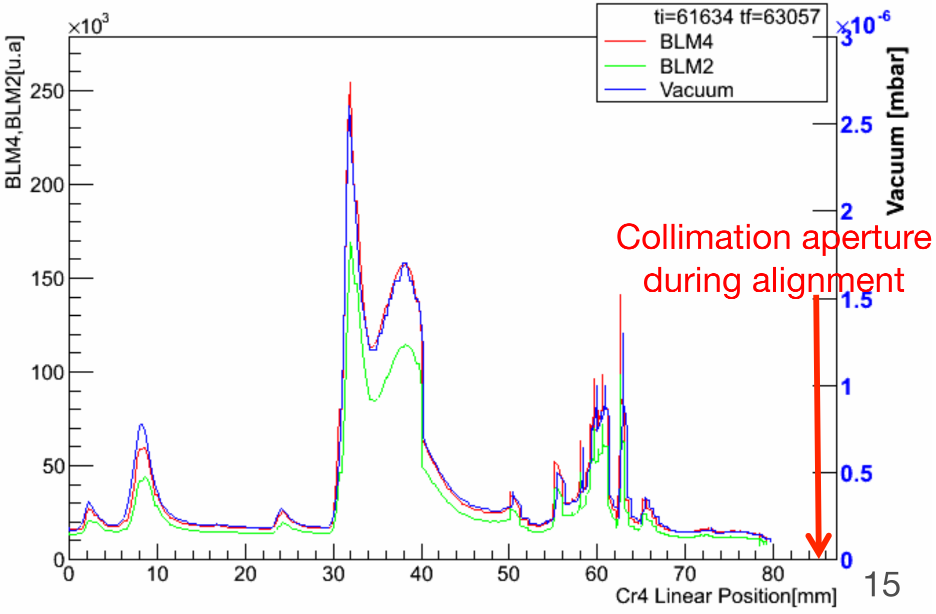
	M1 test - M2 at rest	M2 test - M1 at rest
Repeatability	0.22 μrad	0.96 μrad
Backlash	0.11 μrad	0.68 μrad
Resolution (10 steps)	Average = 0.998 μrad Std Dev = 0.078 μrad	Average = 0.978 μrad Std Dev = 0.185 μrad
Dynamical overshoot	LHC Motor	500%
	Nanotec Motor	200%

Electron cloud?

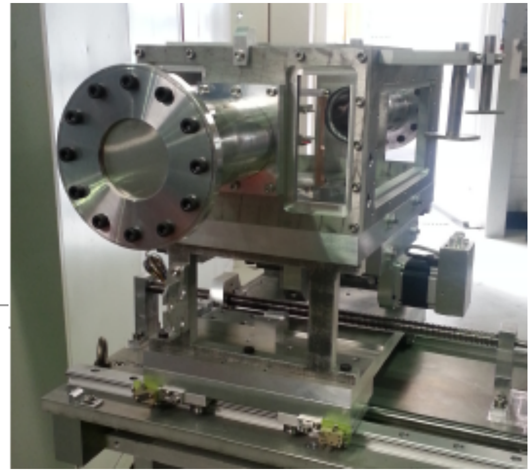


- In order to register loss maps:
  - total intensity: 3.3 x 10^{13},
    4 x 72 bunches with 25 ns spacing
- During the initial alignment of the crystals with the beam, unusual local loss patterns observed, most probably due to electron cloud formation:
  - losses well correlated with crystal transversal position
  - losses extremely correlated with vacuum pressure
  - 50 cm aluminum bar in the goniometer
- To check the nature of the effect
  - solenoid installed around goniometer tank
  - mitigation of the e-cloud effect observed

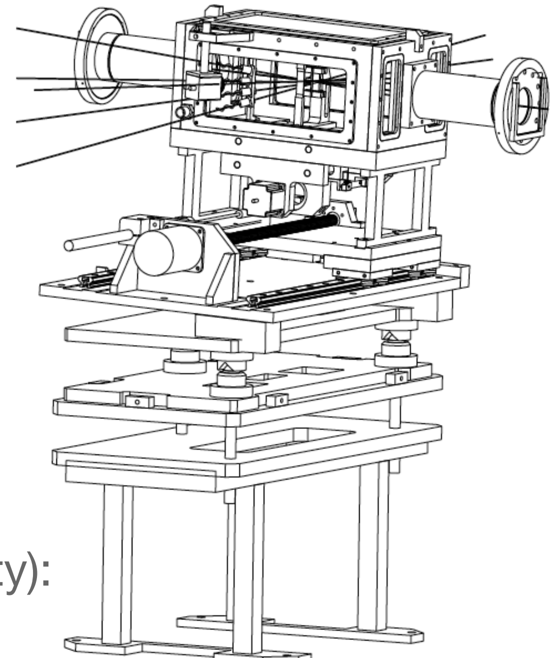
Coating of the LHC tank required



Crystal damage



- Radiation resistance:
  - IHEP U-70 (Biryukov et al, NIMB 234, 23-30): 70 GeV protons, 50 ms bunch of 10^{14} p every 9.6 s, several minutes irradiation, channeling efficiency unchanged
  - NA48 (Biino et al, CERN-SL-96-30-EA): 450 GeV protons, 2.4 s spill of 5×10^{12} p every 14.4 s, one year irradiation, channeling efficiency reduced by 30%
  - LHC: 7 TeV protons, 3×10^{14} p per fill
  - test HRMT16-UA9CRY under approval at HiRadMat facility:
    - 440 GeV protons, max 288 bunches, 1.7×10^{11} protons per bunch
    - intensity comparable with worst accident scenario in LHC (asynchronous beam dump)
    - Simulation with only beam energy and silicon heat capacity): $\Delta T = 5$ K per bunch, $T_{melting}$ after ~ 280 bunches



Courtesy of Frederic Loprete

Summary of the UA9 findings

- Test with extracted beams at CERN North Area (~ 3÷5 weeks per year):
  - Crystal – beam interactions
  - Measurement of crystal properties before installation in CERN-SPS
- Prototype crystal collimation system installed in CERN-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→ Direct measurement of a strong reduction of the off-momentum halo in crystal assisted collimation of the SPS beam *(Physics Letters B, 714(2-5), 231–236).*
  - 2012→ Direct observation of the halo population reduction far from the crystal, SPS loss maps, optimized apertures for collimation system elements, … (data taking still on-going)
- Working for future installation of a prototype system in LHC
  - 2006→ First of a crystal-assisted collimation layout *(Assmann, Redaelli, Scandale EPAC2006).*
  - *2008*→ Medipix in a Roman pot
  - 2009→ Cherencov quartz detector in the primary vacuum
  - 2011→ Letter of Intent (CERN-LHCC-2011-007 / LHCC-I-019 10/06/2011)
  - 2012→ First goniometer industrially produced suited for the LHC requirements.

Conclusion

- The UA9 experiment is studying the possibility to use crystals as primary obstacle in collimation systems.
  - Test beam measurements demonstrate the possibility to efficiently deflect particles at high angles using bent crystals.
  - Using a prototype crystal collimation system in the CERN-SPS:
    - collimation of the beam reliably obtained for proton and lead ion beams
    - losses in the collimation system and in the closest high dispersion area reduced when using a crystal target instead of an amorphous one
    - new measurements to estimate loss reduction in the whole accelerator ring and to optimize the parameters of the system
  - The team is preparing the installation of a minimal crystal collimation system in the LHC.

UA9 request for 2013

We ask the SPSC to support our request of a 24 h shift in the SPS with Pb-ions to test the CINEL gonimeter with beam

Publications & Acknowledgments

1. W. Scandale et al., Strong reduction of the off-momentum halo in crystal assisted collimation of the SPS beam. Phys. Lett. B, 714 (2012), 231–236.

The EN/STI group at CERN is providing extraordinary support to UA9.
The BE/OP-BI-RF groups carefully prepare the SPS to allow for our measurements.

We specially thank our funding agencies, reference Committees and Referees.