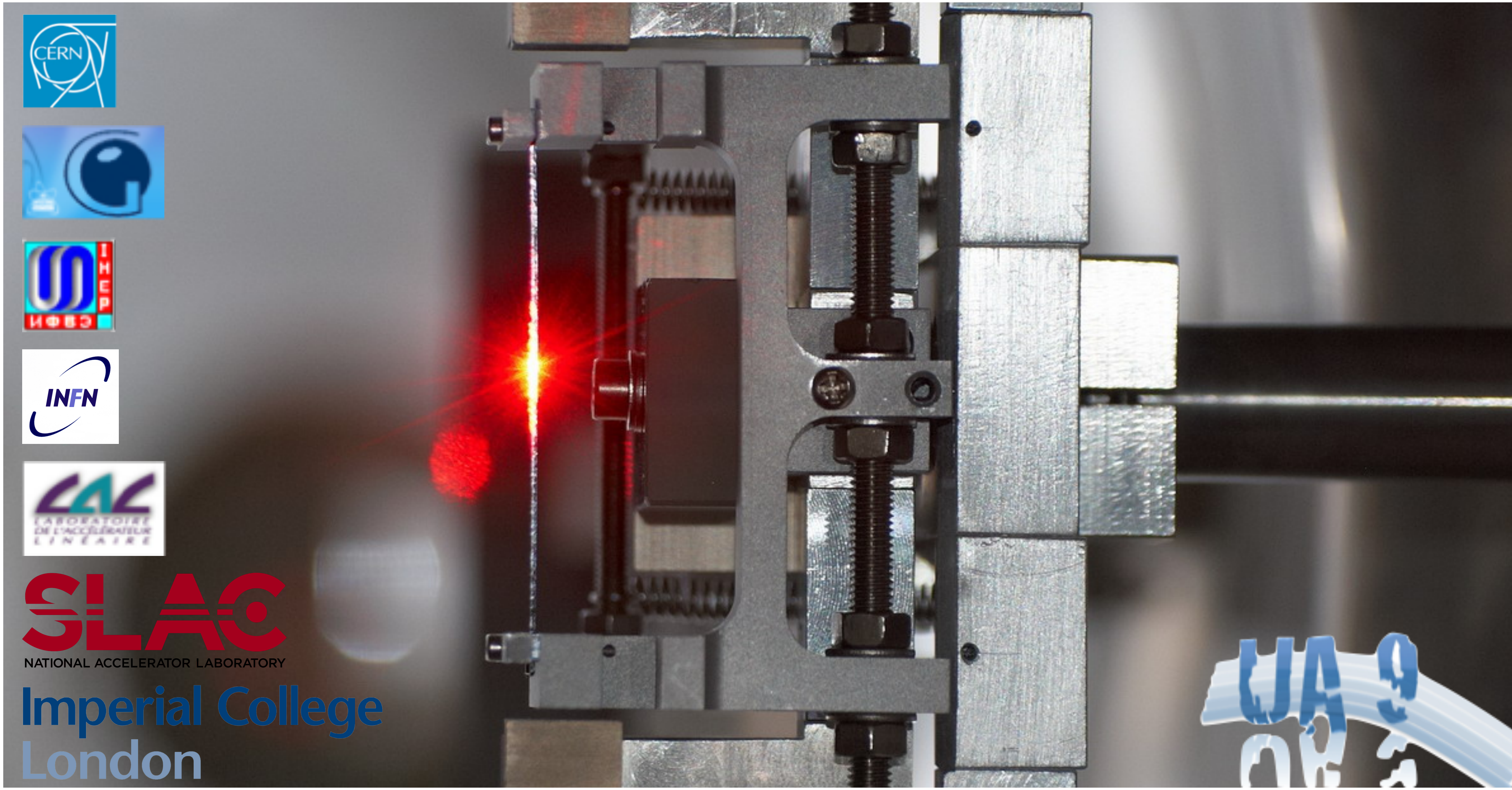


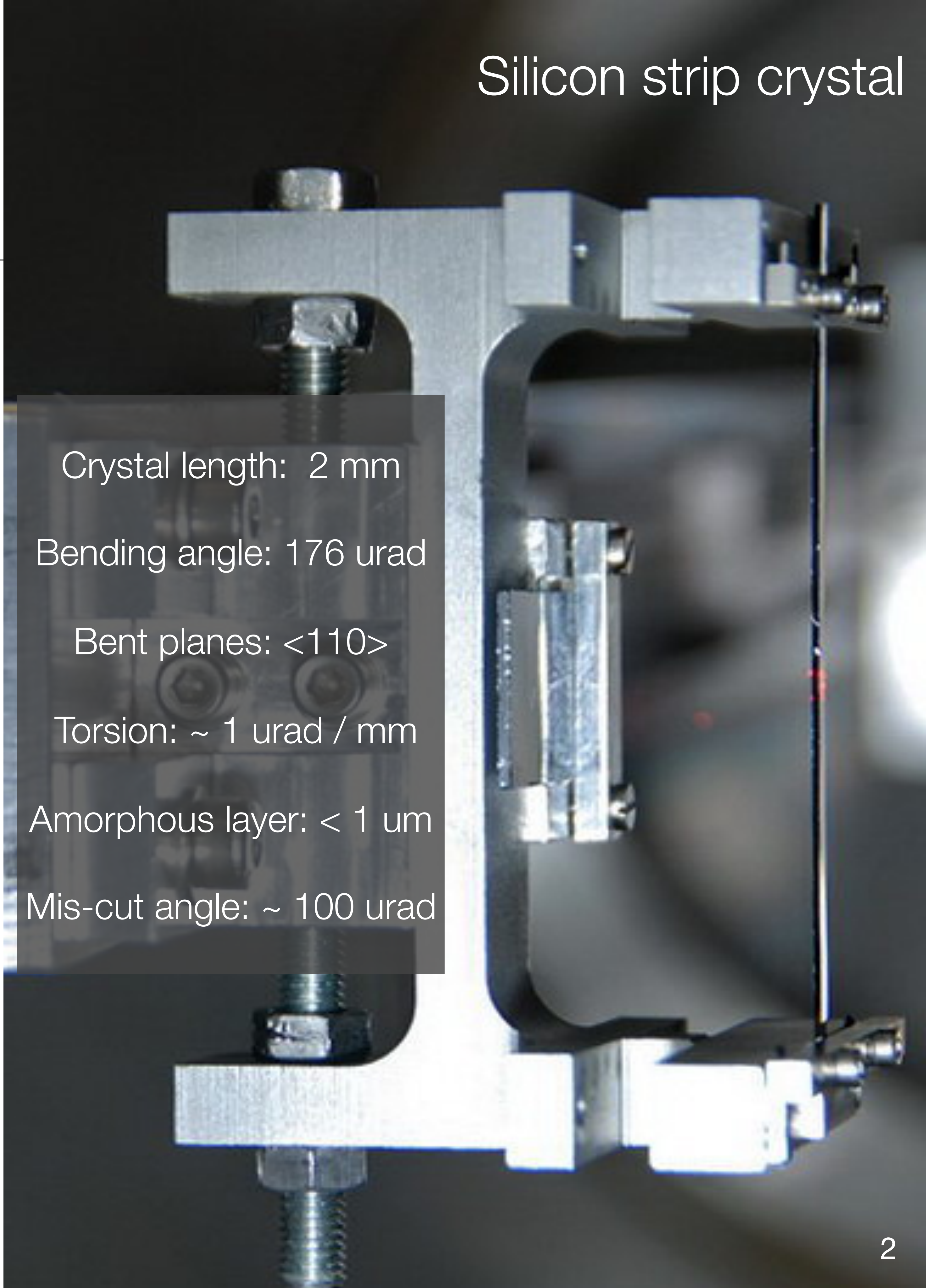
HB2012 - Beijing - 18 September 2012

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

Simone Montesano (CERN)
for the UA9 collaboration

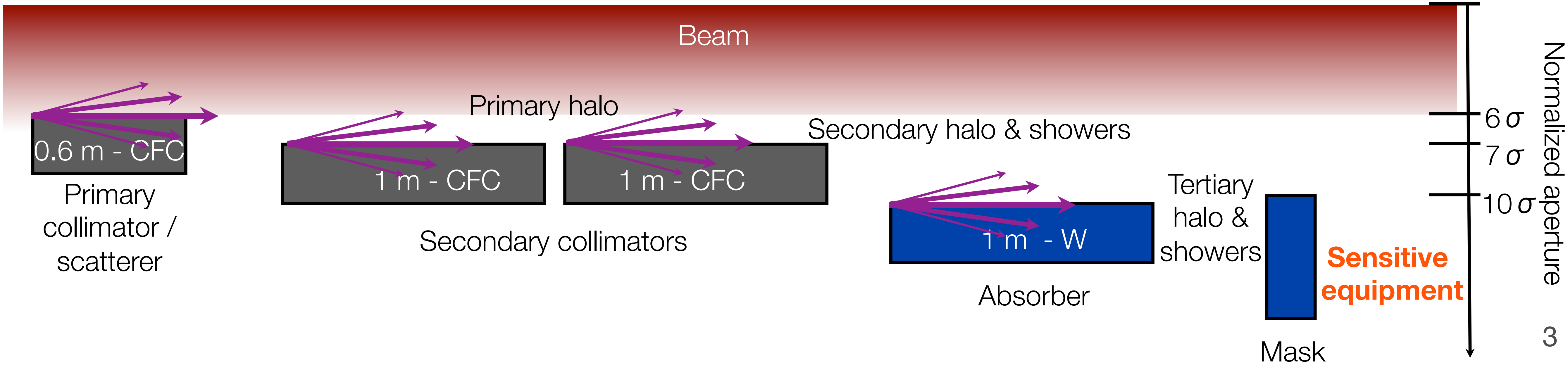
Outline

- Crystal collimation and the UA9 experiment
- Results from the UA9 experiment
- On going studies
- Toward the installation of a test system in LHC

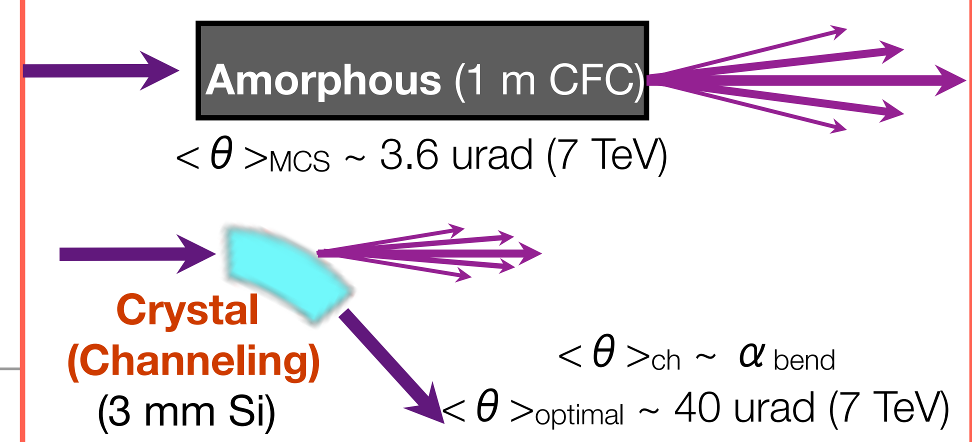


Multi-stage collimation system

- Diffusive primary halo intercepted by massive amorphous targets:
  - primary particles deflected by Multiple Coulomb Scattering (<θ> ~ 3.6 urad for graphite at 7 TeV), hadronic showers produced by interaction on the target (secondary halo)
  - secondary collimators and absorbers stop deflected particles & showers
  - tertiary collimators protect sensitive equipment from secondary halo
- Optimal performances reached (in LHC: 99.97% collimation efficiency in 2011)
- Limitations: single diffractive scattering, ion fragmentation/dissociation

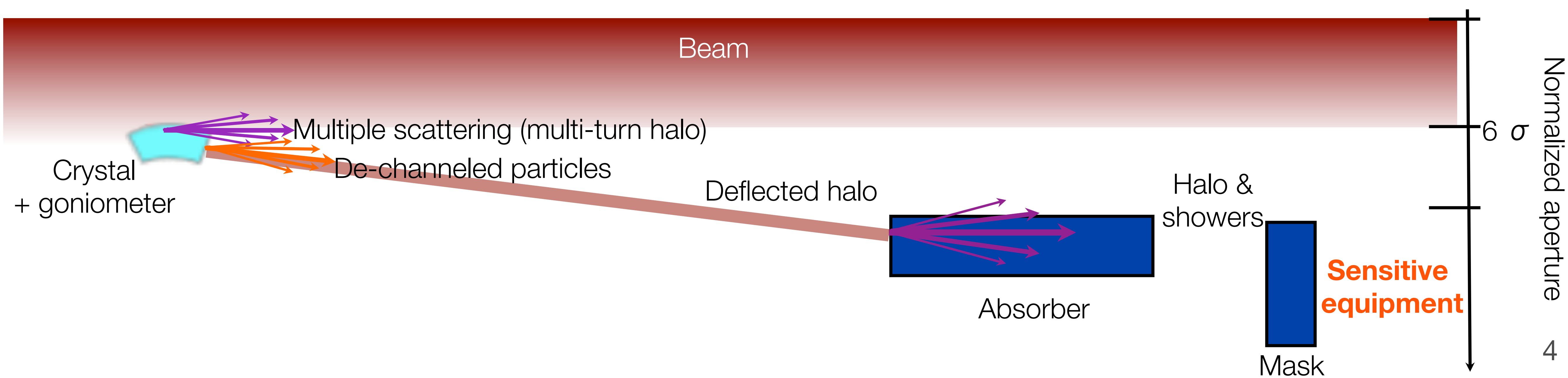


Crystal collimation system



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

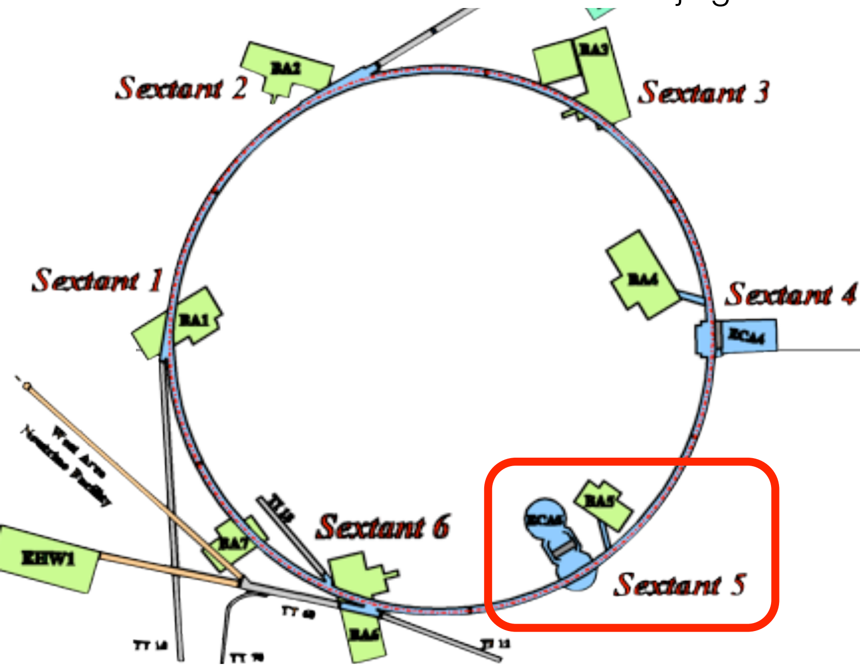
- Mechanically bent crystal as primary deflector.
- If crystalline planes are correctly oriented, particles are subjected to a coherent interaction (channeling):
  - small angular acceptance (19.45 urad for E = 120 GeV, 2.1 urad for E = 7 TeV)
  - localization of the losses on a single absorber, thanks to large deflection angle
  - reduced probability of diffractive events and ion fragmentation/dissociation.
- At present, there is no crystal-collimation system optimized for machine operation.



The UA9 experiment

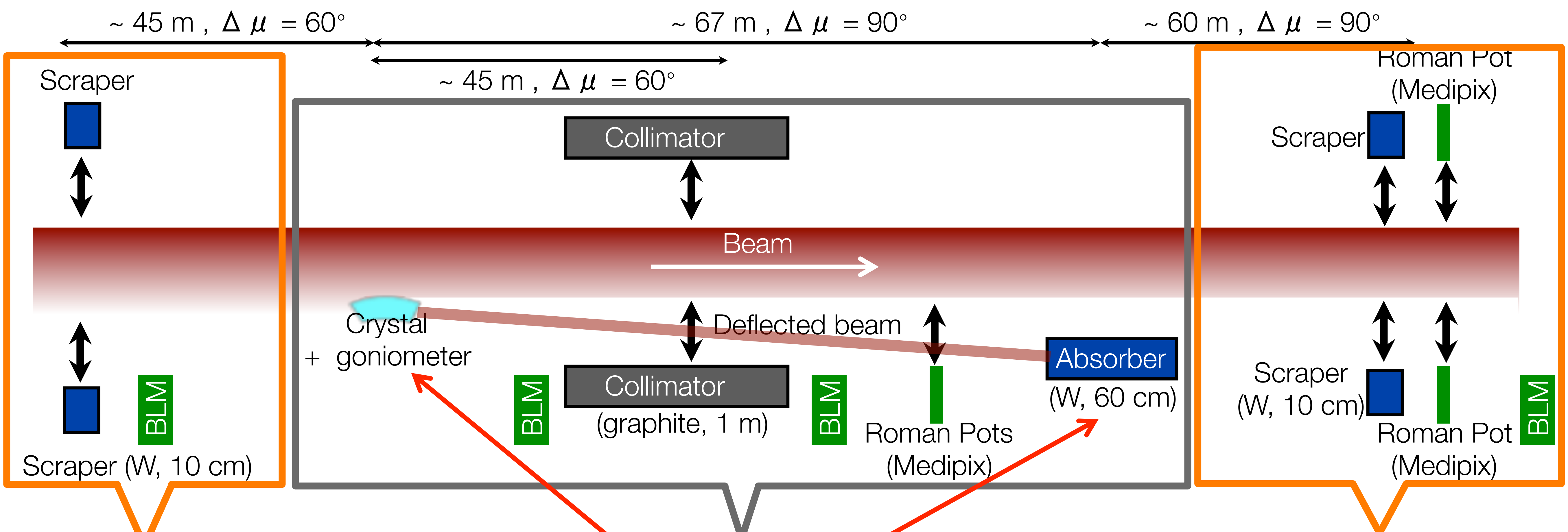
MISSION: Assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders.

- Test beams at CERN North Area (~ 3 weeks per year):
  - Study of 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→ 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 on-going)
- Working for future installation of a prototype system in LHC



SPS prototype system

- Test crystals and instrumentation suitable for an operational system.
- Study the properties of a crystal collimation system (proton or Pb ion beam in coast, E = 270 GeV/n)

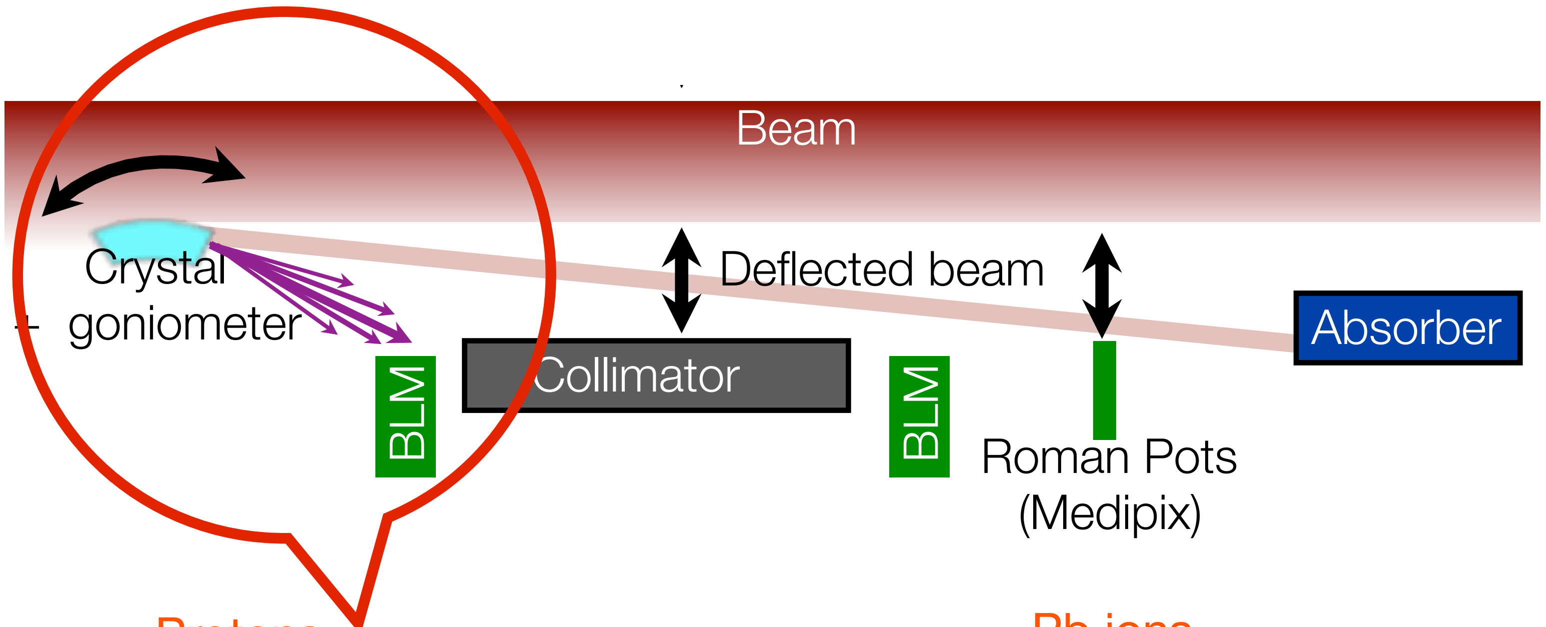


Installation for the measurements "far" from the collimation system

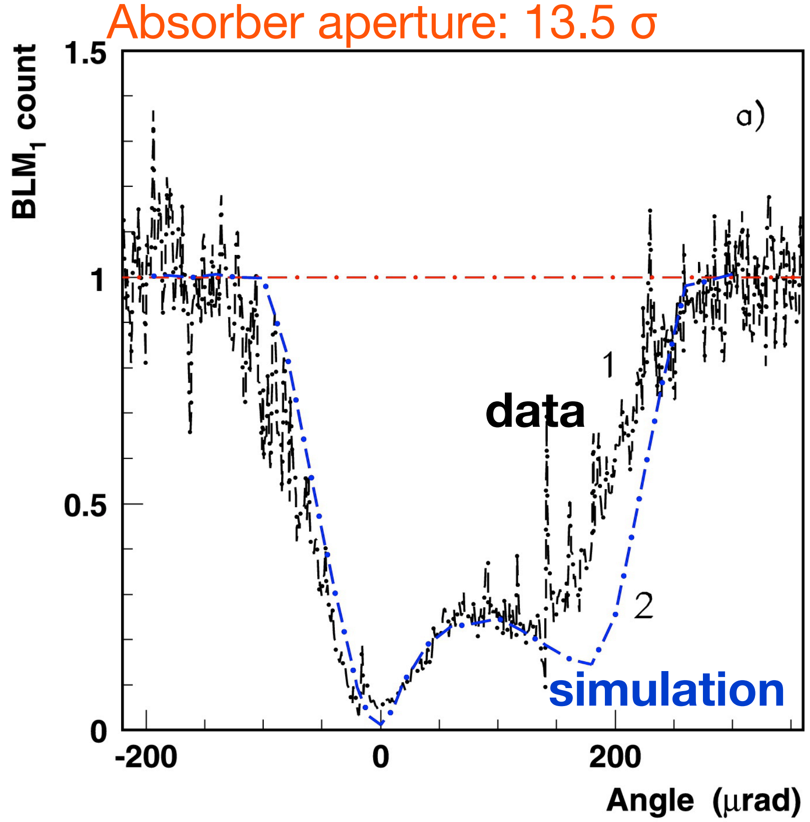
- Crystal collimation system
- Instrumentation for efficiency measurement

Installation in a high dispersion area for measurements on off-momentum halo

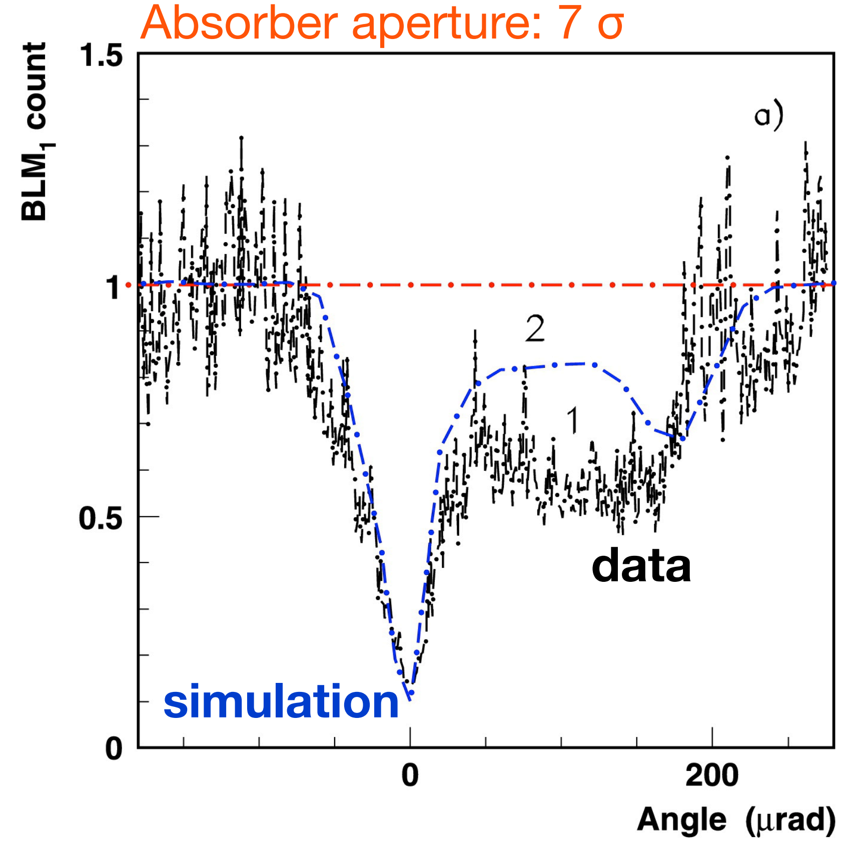
Results: local loss rate reduction



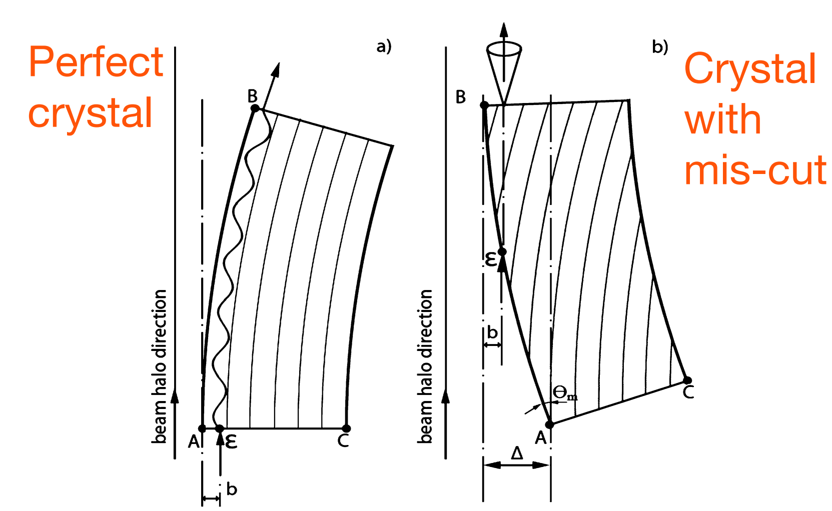
Protons
Crystal aperture: 9 σ
Absorber aperture: 13.5 σ



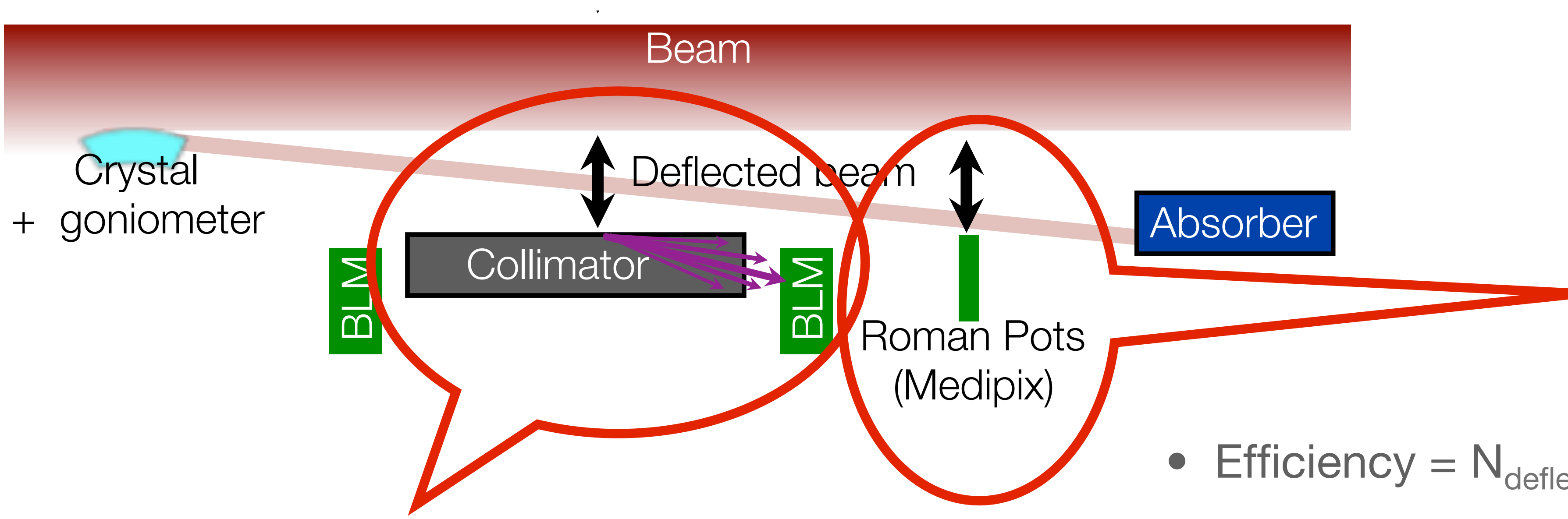
Pb ions
Crystal aperture: 3.5 σ
Absorber aperture: 7 σ

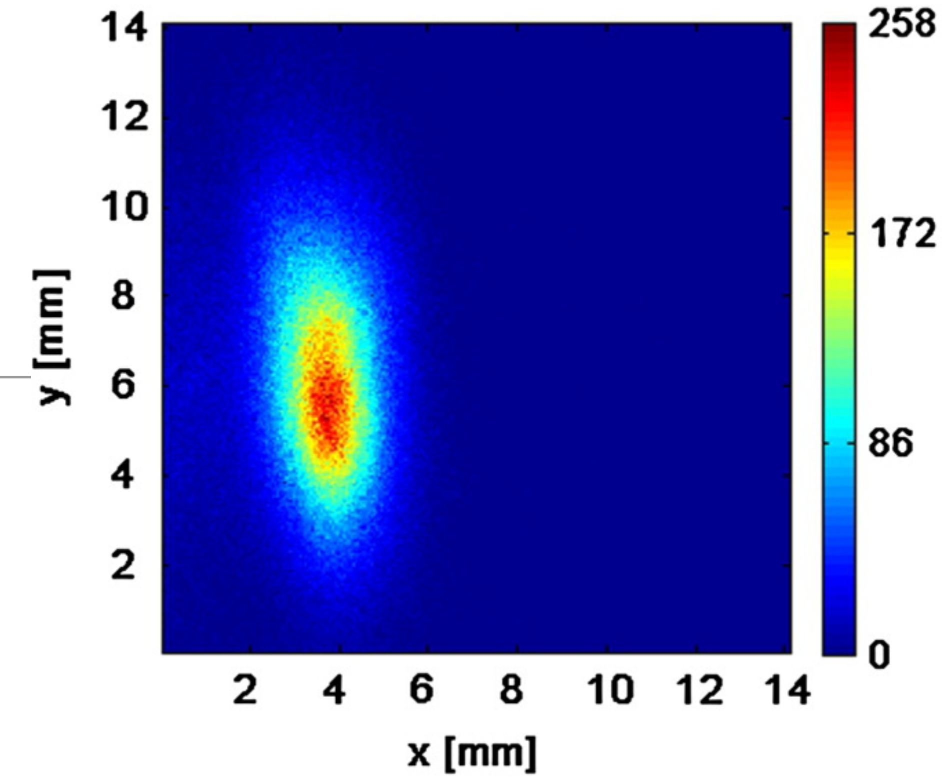


- Reduction of losses observed rotating crystal from “amorphous” to “channeling” orientation
  - very good reproducibility of loss rate profile and channeling angle
  - 5÷20x reduction for protons
    3÷7x reduction for Pb ions
- Small discrepancy between simulation and data
  - crystal imperfections (mis-cut angle) just implemented

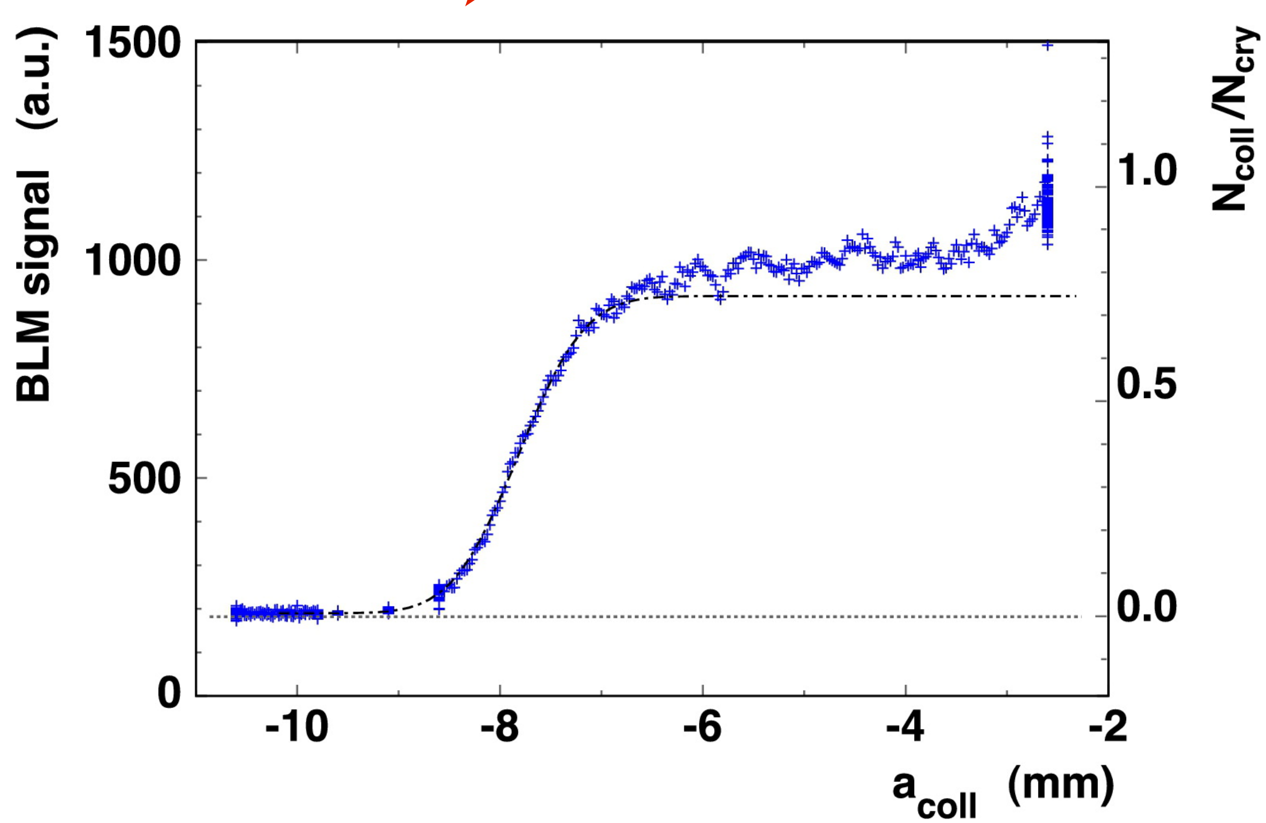


Results: extraction efficiency



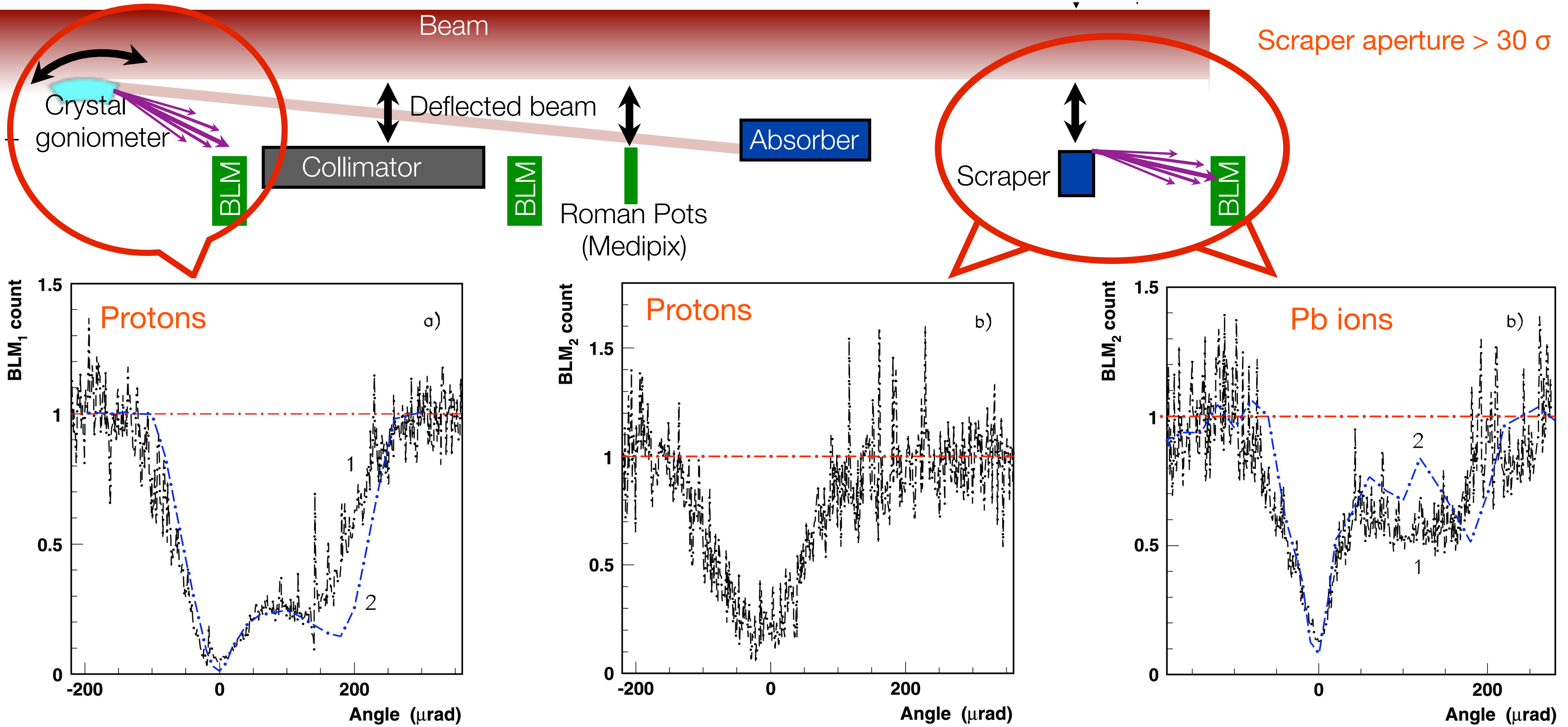


Extracted beam observed with the Medipix



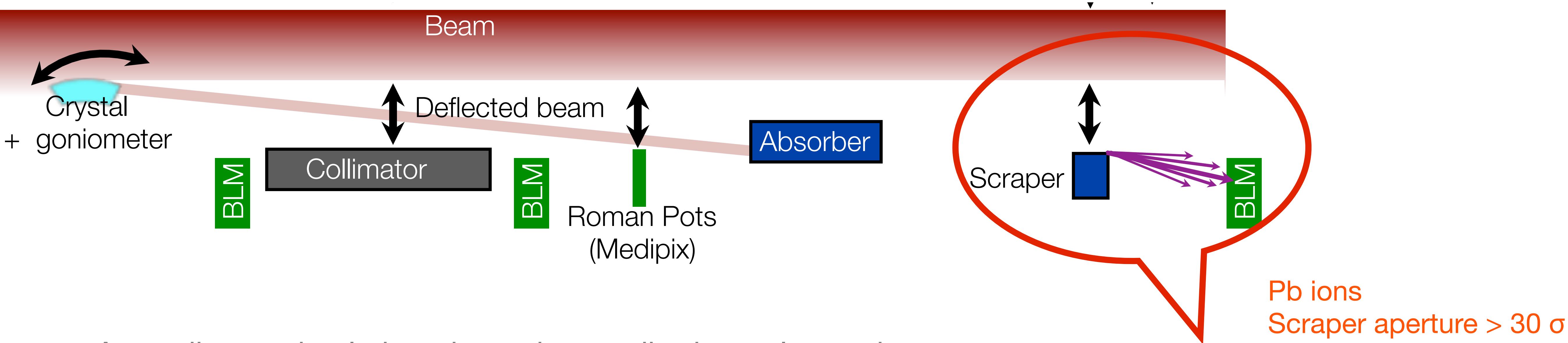
- Efficiency = $N_{deflected}$ / $N_{crystal}$
- Assumption:
  the number of particles intercepted by a moving object is proportional to the loss rate downstream the object
- Moving the collimator to intercept the deflected halo:
  - $N_{deflected}$ is proportional to the losses when intercepting the 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%

Results: off-momentum halo population reduction

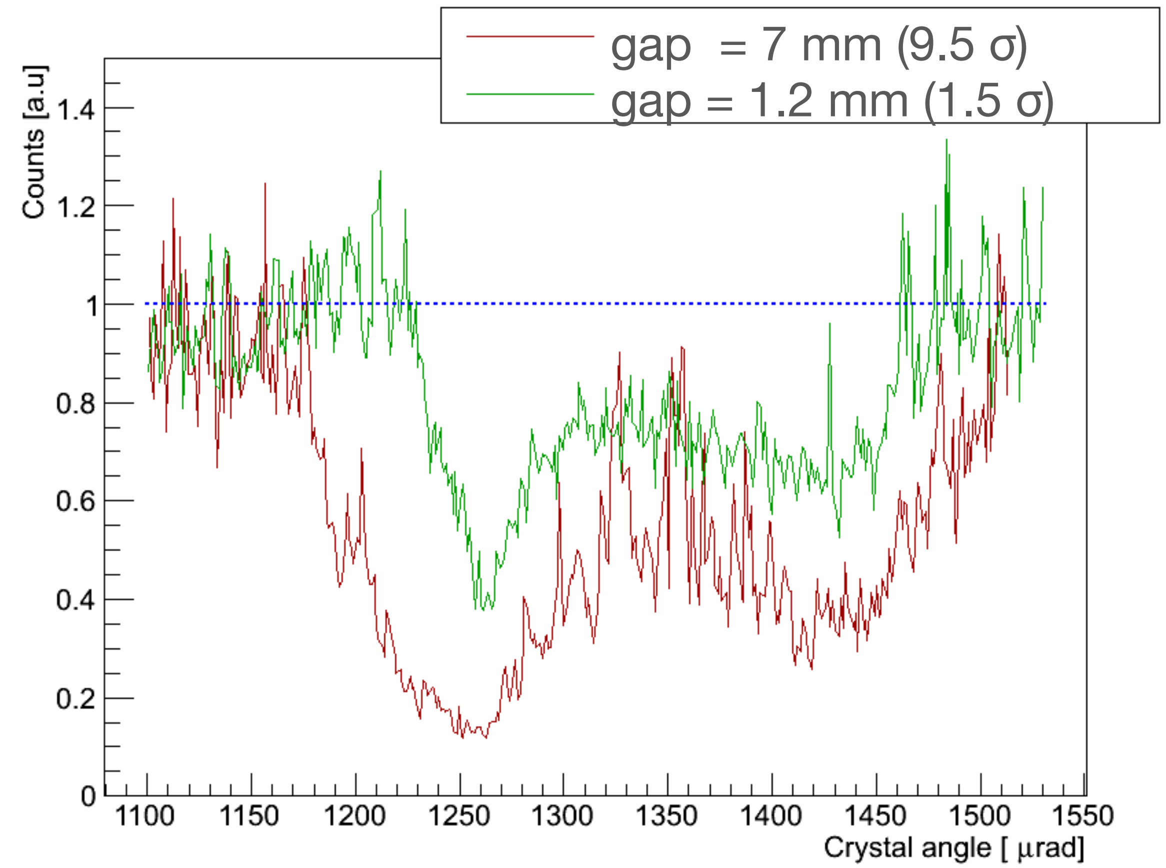


- Reduction of losses in the high dispersion area:
  - good correlation with the losses observed close to the crystal
- 2÷6x reduction for protons (less than in crystal region)
- 3÷7x reduction for Pb ions (equal to crystal region reduction)

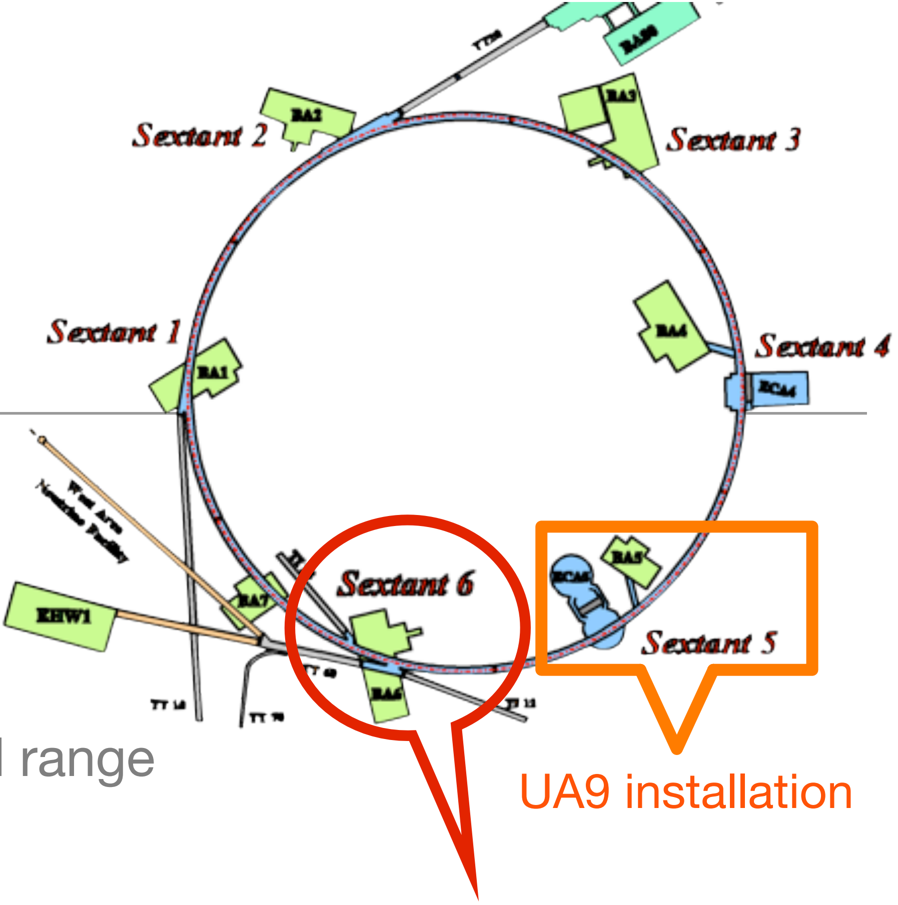
Studies: optimal aperture of the absorber



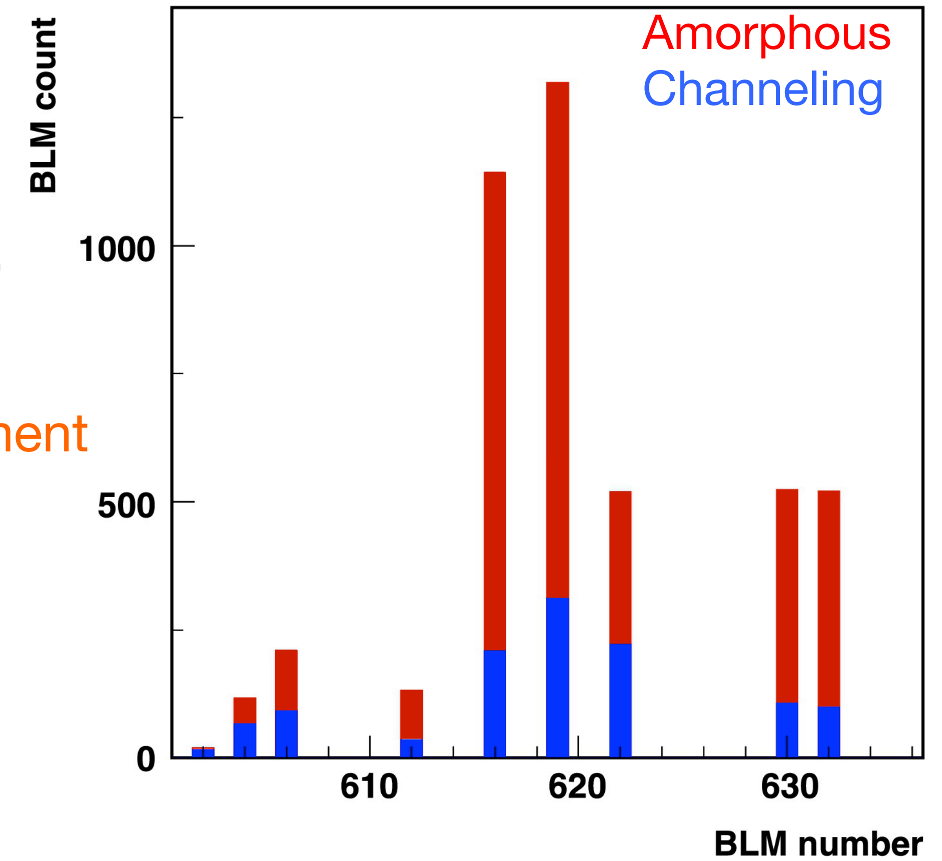
- According to simulation, the main contribution to losses in dispersive area is due particles back-scattered by the absorber:
  - Loss reduction in the dispersive area strongly dependent on the absorber aperture
- Identify the difference in aperture between crystal and absorber (= gap) that minimize the losses:
  - Preliminary results for ions: optimal gap is ~ 7 mm
  - Measurements for protons on going



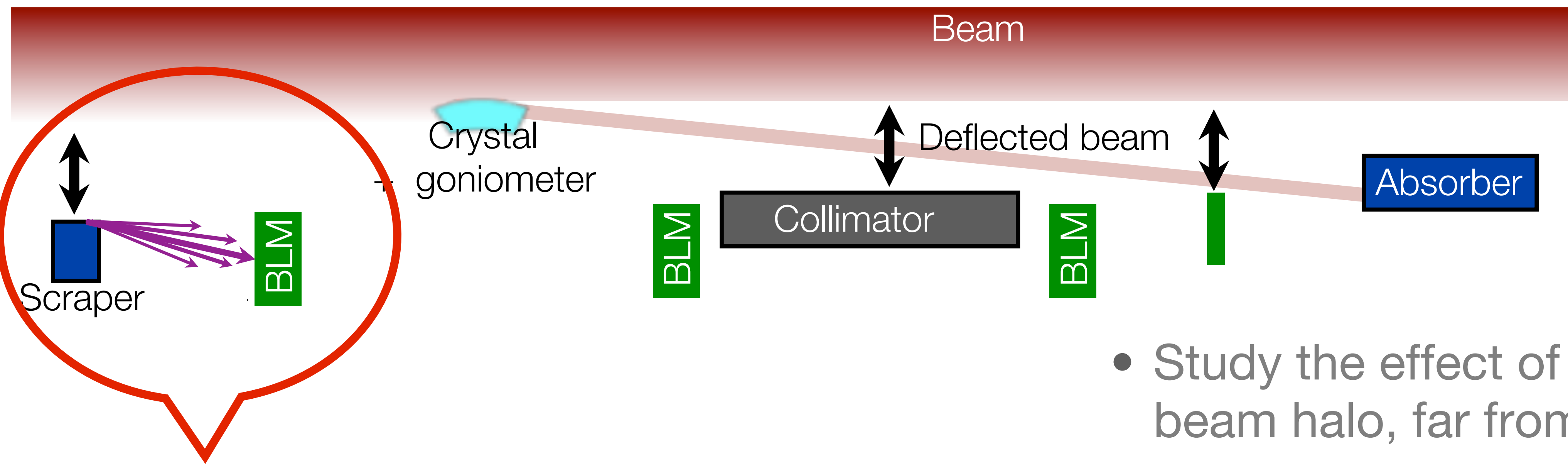
Studies: SPS ring loss maps

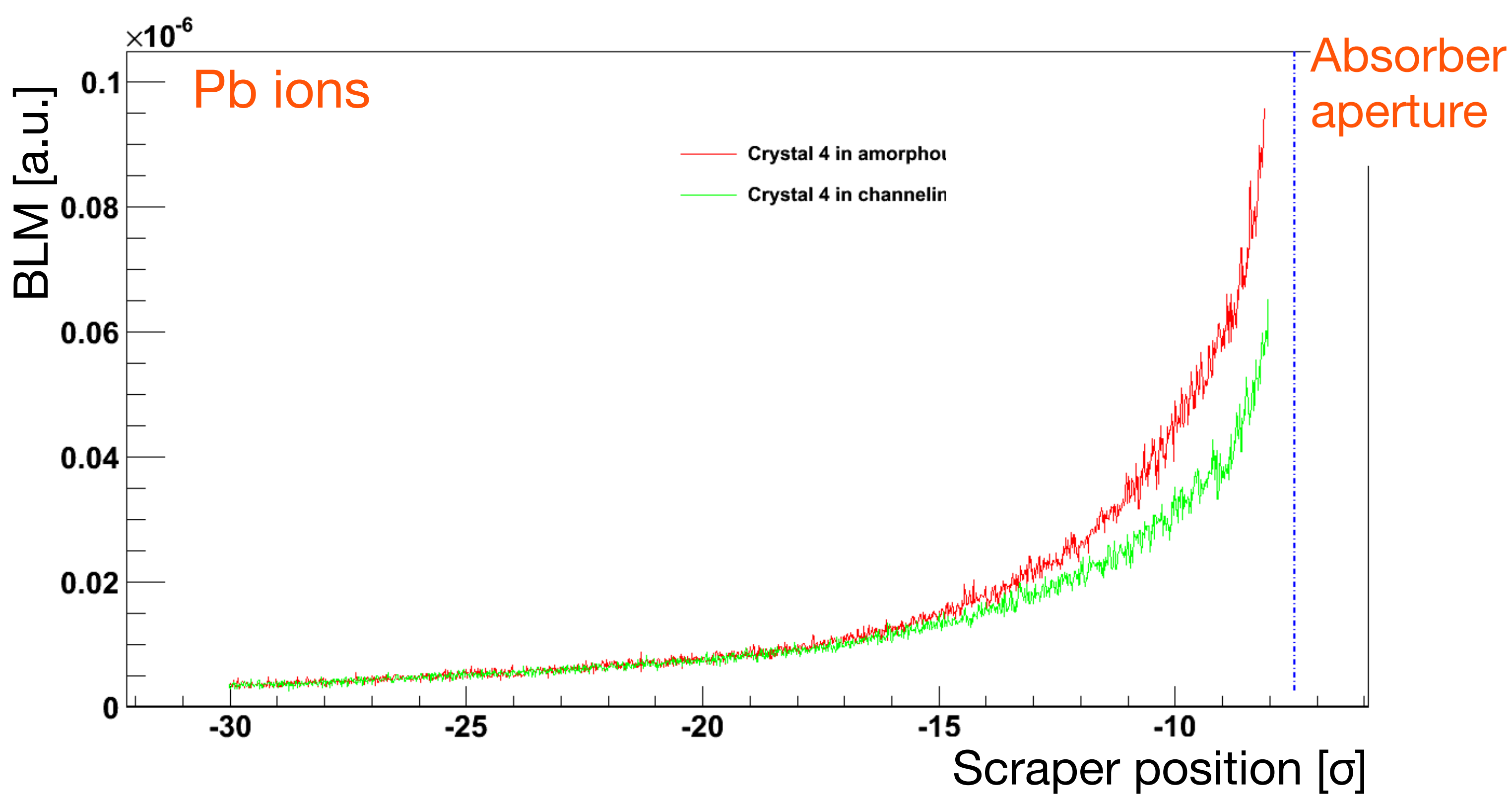


- “Loss maps” are the natural validation for collimation systems.
- Loss map measurement with the crystal collimation prototype is not trivial:
  - the SPS BLM system is not optimized to have high dynamical range
  - SPS losses are low and concentrated in very few regions (injection, extraction)
- Loss map measurement in 2011:
  - intensity increased from 1 bunch ($I = 1.15 \times 10^{11}$) to 48 bunches, beam loss rate artificially increased
  - Clear reduction of the losses in the sextant closer to the experiment
- Measurement tried in 2012:
  - total intensity: 3.3×10^{13}, 4 x 72 bunches with 25 ns spacing
  - unexpected loss increase for every small movement of devices (electron cloud?)
  - installation of a solenoid may allow for future measurement



Studies: halo profile "far from the crystal"



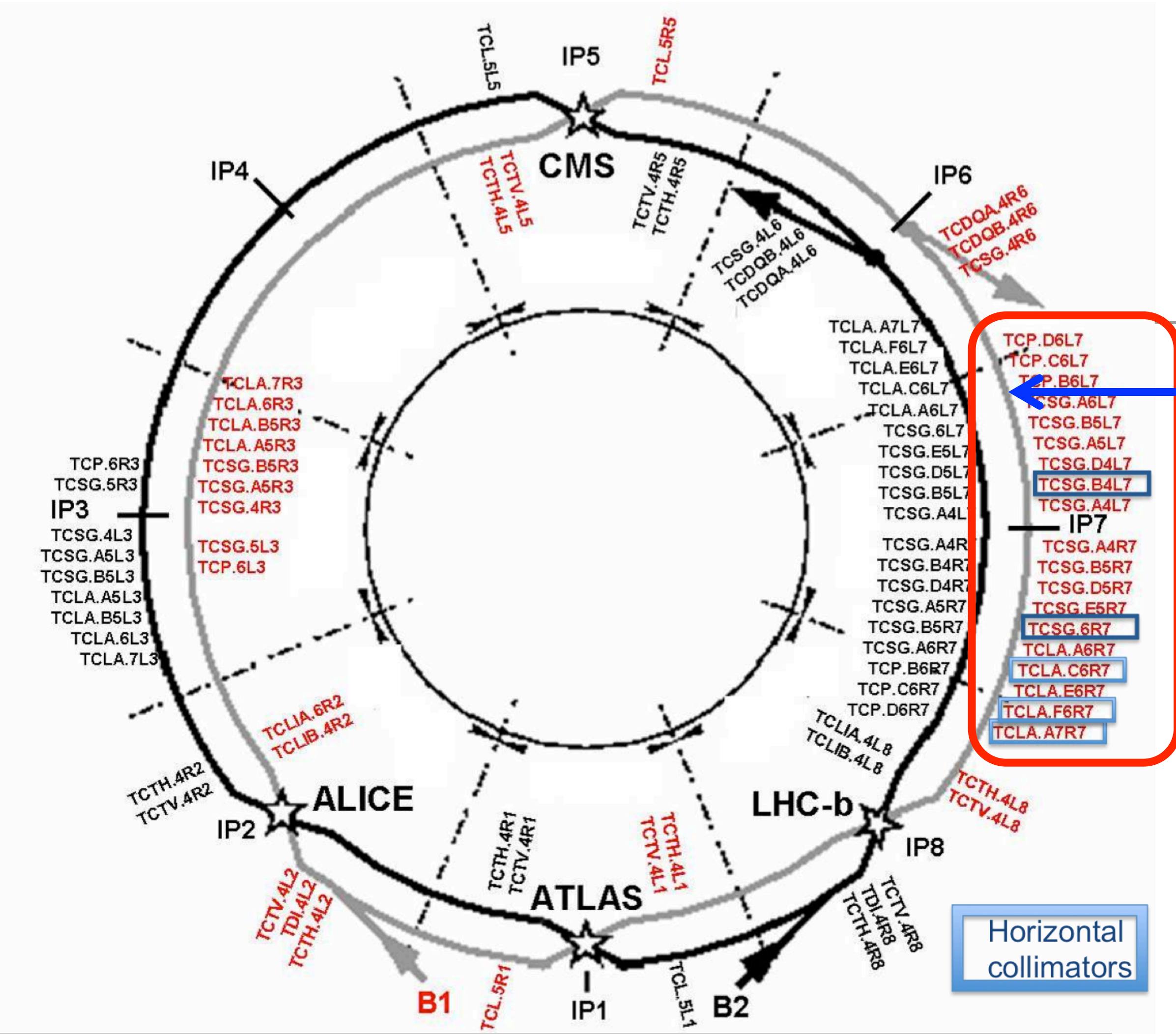


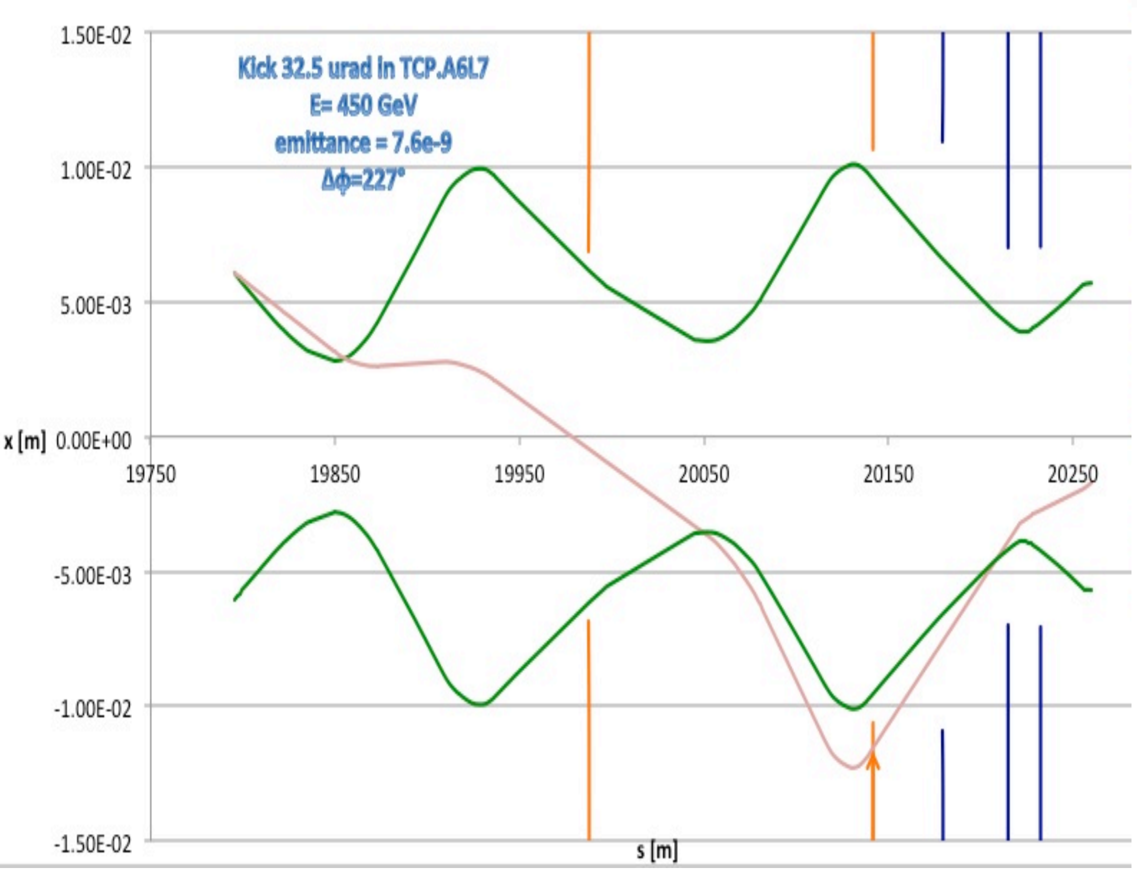
- Study the effect of crystal collimation on beam halo, far from the collimation region:
  - new scraper recently installed upstream the crystal
  - compare linear scans with crystal in channeling and amorphous position
  - Pb ions beam: small reduction of halo population for channeling orientation (signal close to detector baseline)
  - measurements for protons on-going

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
  - the next steps:
    - prepare the installation of at least one crystal in the LHC
    - demonstrate the extraction of the beam halo in the LHC
    - measure the possible improvements with respect to standard collimation

Toward LHC: layout

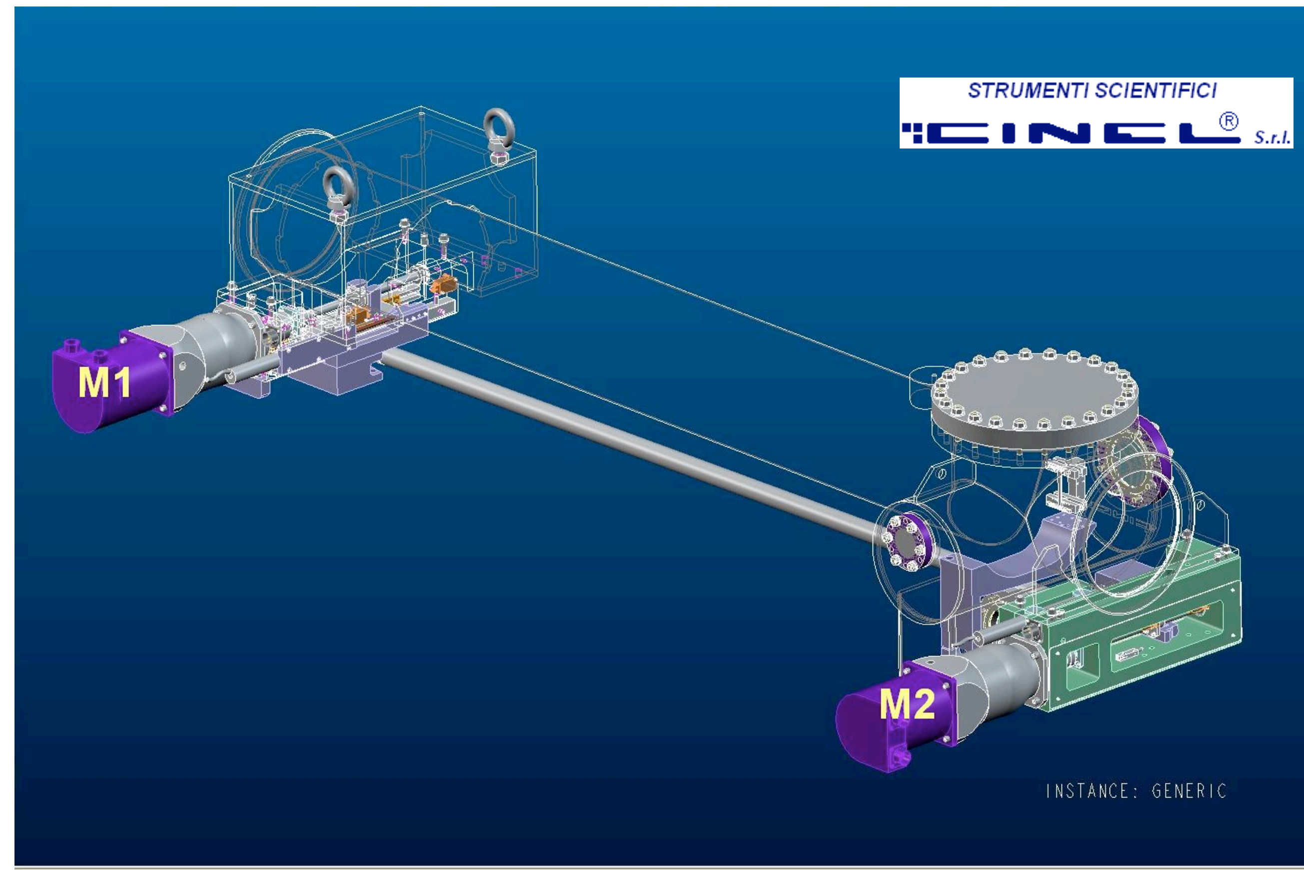


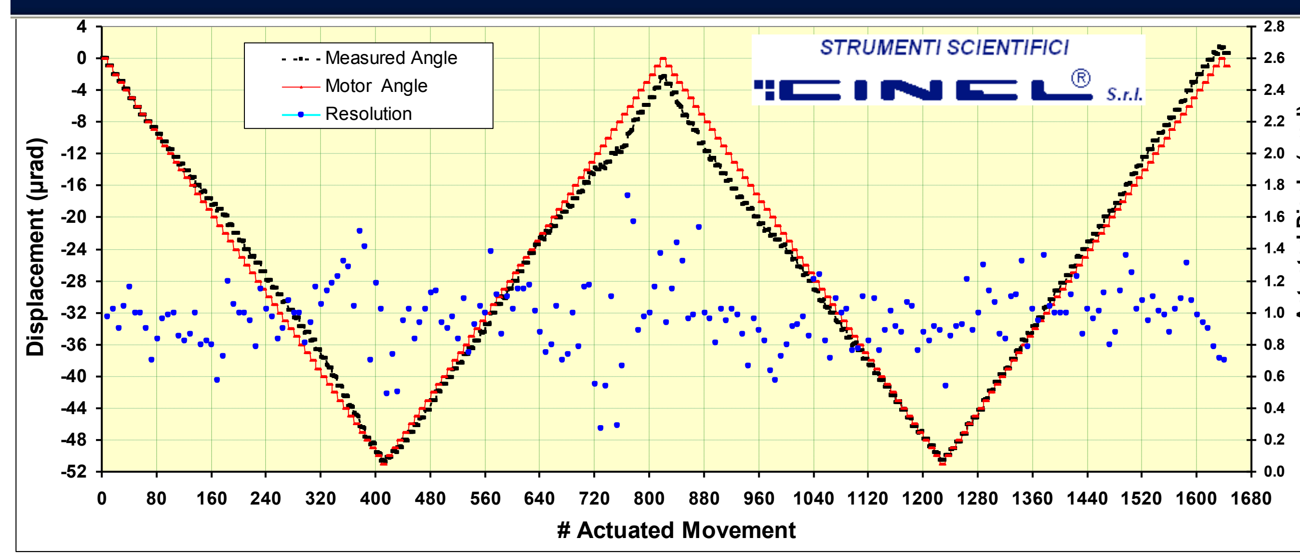


- Initial studies for the layout of the LUA9 experiment have considered:
  - only one beam (beam 1)
  - only one crystal (horizontal)
  - injection energy (450 GeV)
  - all standard collimation system in place
- Natural position for the crystal is close to the primary collimators (see arrow):
  - extracted beam absorbed by a secondary collimator with ~ 1 mm impact parameter
  - highest radiation area, tight space allowance
  - alternative possibilities are being studied

Toward LHC: R&D for a goniometer

- Acceptance for channeling defined by the critical angle $\theta_c = \sqrt{2U_0/E}$:
  - θ_c = 19.45 urad for E = 120 GeV
    θ_c = 10 urad for E = 400 GeV
    θ_c = 2.1 urad for E = 7 TeV
- Goniometer accuracy must be smaller than angular acceptance (i.e. < 2 urad):
  - SPS mechanical goniometer (IHEP, Russia) has resolution < 10 urad, an improved version has been built
  - mechanical device developed by industrial partner CINEL: static resolution meets expectations, test on going to assess accuracy in dynamic regime
  - piezoelectric device under development in collaboration with industrial partner ATTOCUBE.





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.

Publications & Acknowledgments

1. W. Scandale et al., First Results on the SPS Collimation with Bent Crystals. Phys. Lett. B 692 (2010) 78–82.
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7. W, Scandale et al., Observation of parametric X-rays produced by 400 GeV/c protons in bent crystals. Phys. Lett. B 701 (2011) 180–185.
8. W. Scandale et al., Comparative results on collimation of the SPS beam of protons and Pb ions with bent crystals. Phys. Lett. B 703 (2011) 547–551.
9. 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.

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
  - Possible future test at HiRadMat:
    - 440 GeV protons, max 288 bunches, 1.7×10^{11} protons per bunch
    - intensity comparable with worst accident scenario in LHC (asynchronous beam dump)
    - from very quick computation (only beam energy and silicon heat capacity): $\Delta T = 5$ K per bunch, $T_{melting}$ after ~ 280 bunches