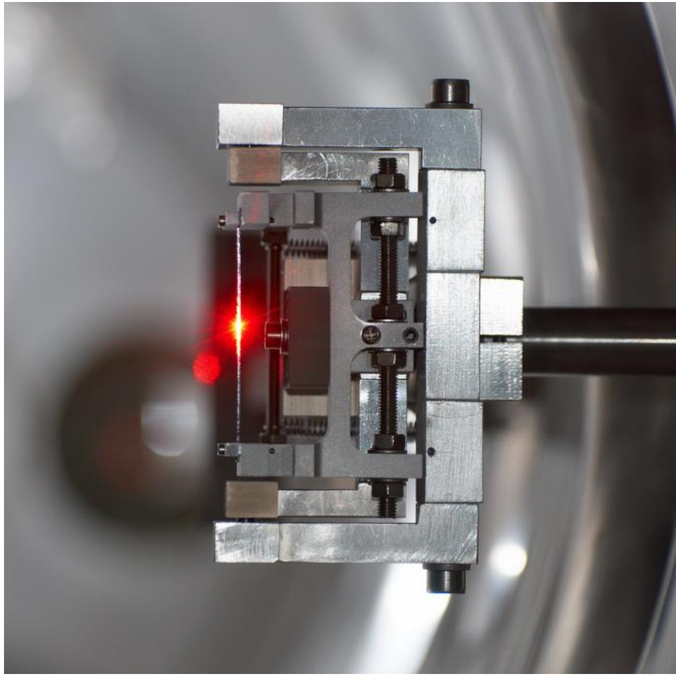
Status of UA9

Walter Scandale
for the UA9 Collaboration

Outline

- ❑ Concept of crystal collimation
- ❑ Recall of previous UA9 results
- ❑ Achievements in 2013
  - ✓ Preparing the crystal collimation test in LHC
  - ✓ Cerenkov detector for deflected proton flux measurement – CpFM
  - ✓ Systematic analysis of the data collected in H8
  - ✓ Routine to simulate crystal-particle interactions
- ❑ Extraction assisted by bent crystals
- ❑ Perspectives and plans



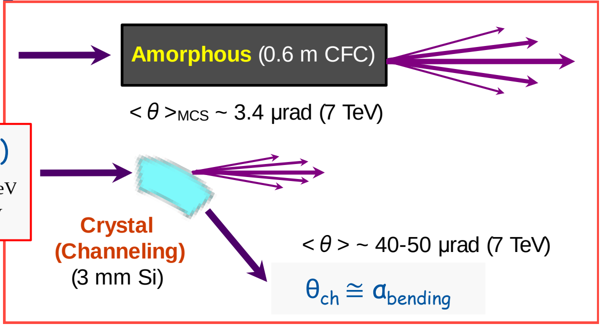
Crystal collimation concept

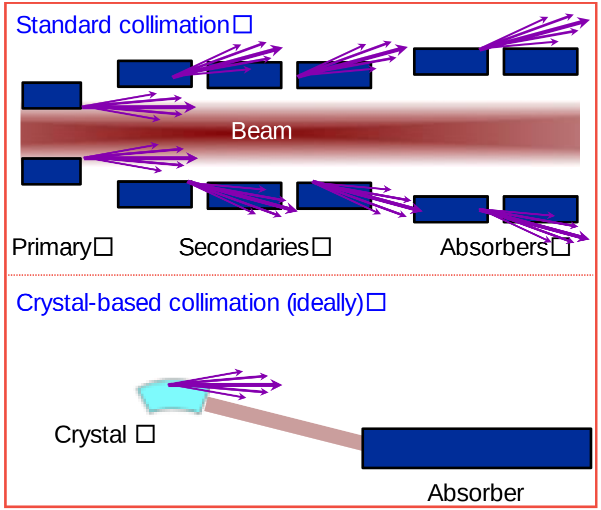
- Bent crystals allow deflecting particles by coherent interaction:
  - ✓ large angle deflection also at high energy
  - ✓ reduced interaction probability (e.g. diffractive events, ion fragmentation/dissociation)
  - ✓ reduced impedance (less secondary collimators, larger gaps)

  BUT
  - ✗ small angular acceptance
  - ✗ concentration of the losses on a single absorber
  - ✗ extrapolation to the highest energy not yet proven

$$\theta_c \cong \sqrt{2U_0/E}$$

$$\theta_c = \begin{cases} 10\,\mu rad @ 270\,\mathrm{GeV} \\ 2\,\mu rad @ 7\,\mathrm{TeV} \end{cases}$$



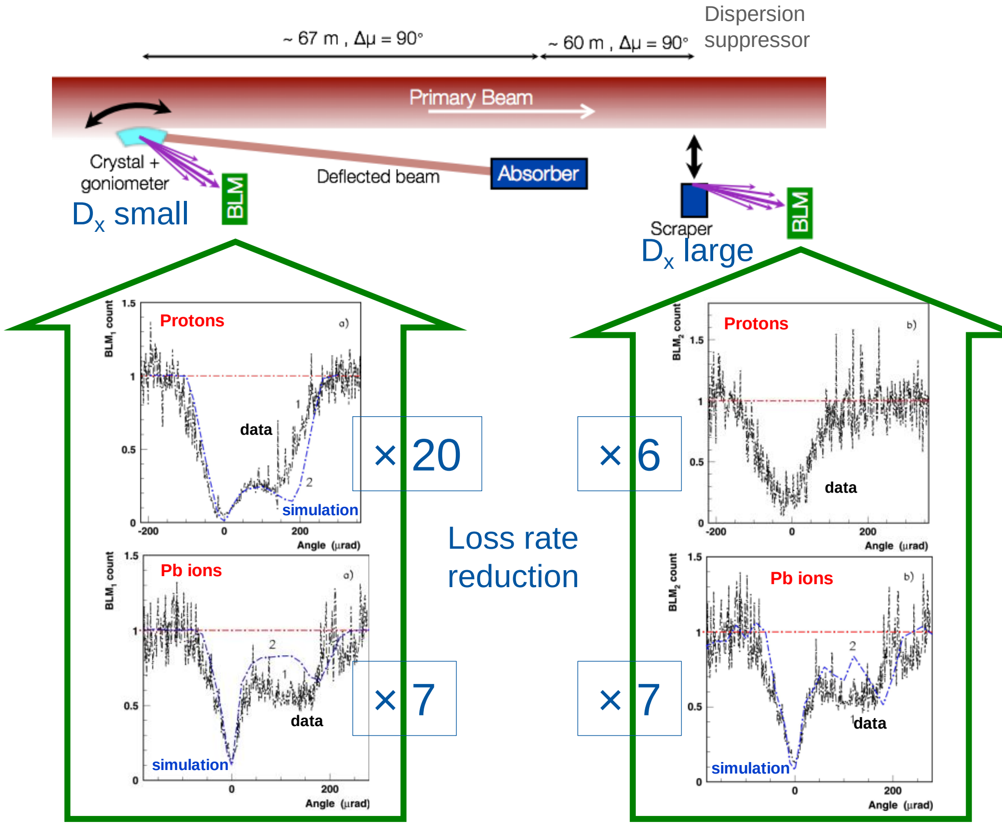


- The UA9 Collaboration is investigating how to use bent crystals as primary collimators/deflectors:
  - operational and machine protection concerns are considered in cooperation with the Collimation Team.

UA9-SPS: important results

Crystal collimation has been extensively tested in SPS:

- ✓ Alignment (linear and angular) of the crystal is fast and well reproducible.
- ✓ Consistent reduction of the losses when comparing the crystal in channeling and in amorphous orientation:
  - Loss rate reduction at the crystal: up to 20x for protons, 7x for ions.
  - Loss rate reduction in the dispersion suppressor: up to 6x for protons, 7x for ions.
  - and …



UA9-SPS: important results

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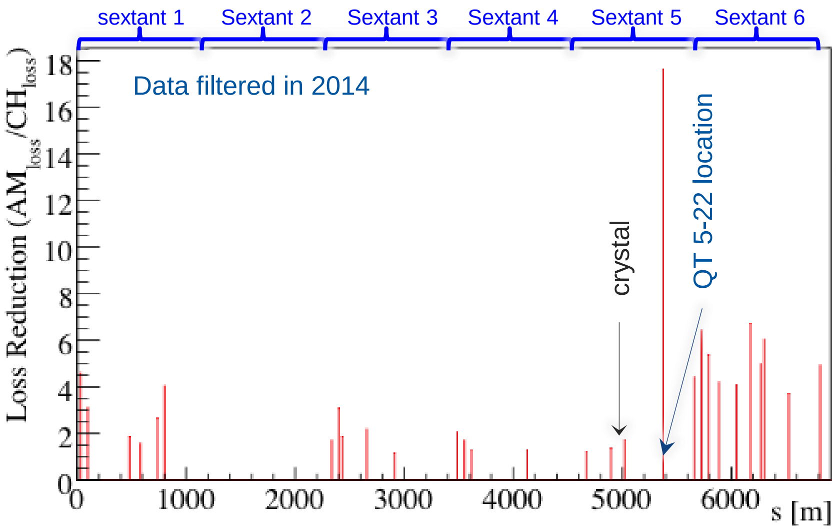
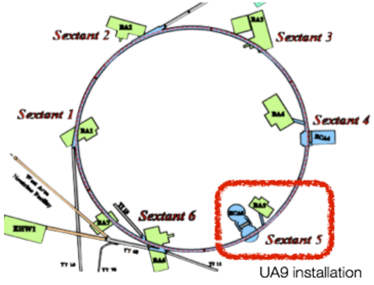
- Losses all around the accelerator ring: consistently reduced.

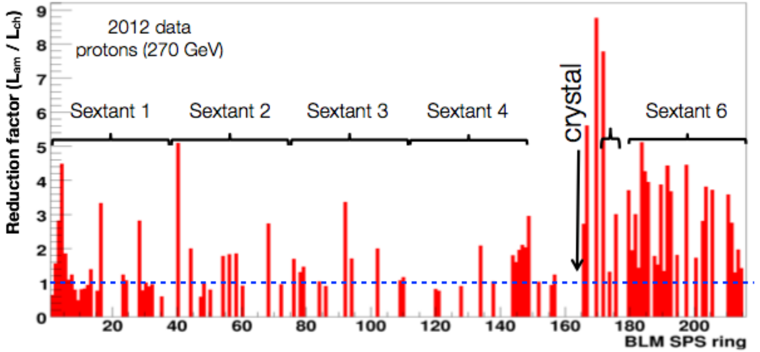




Subtract background &

drop the noisy BLM

rough data



Important steps of UA9

- **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)*.
  - ✓ 2012 ➙ Strong reduction of the off-momentum halo in crystal assisted collimation of the SPS beam. *(Physics Letters B, 714, no. 2-5, pp. 231–236)*.
  - ✓ 2013 ➙ Optimization of the crystal assisted collimation of the SPS beam. *(Physics Letters B, 726, no. 1-3, pp. 182–186)*
- **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➙ Cherenkov quartz detector in the SPS 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.
  - ✓ 2013➙ two crystals with their gonimeters installed in IR7 Beam 1 of LHC.

Scope of the tests in LHC

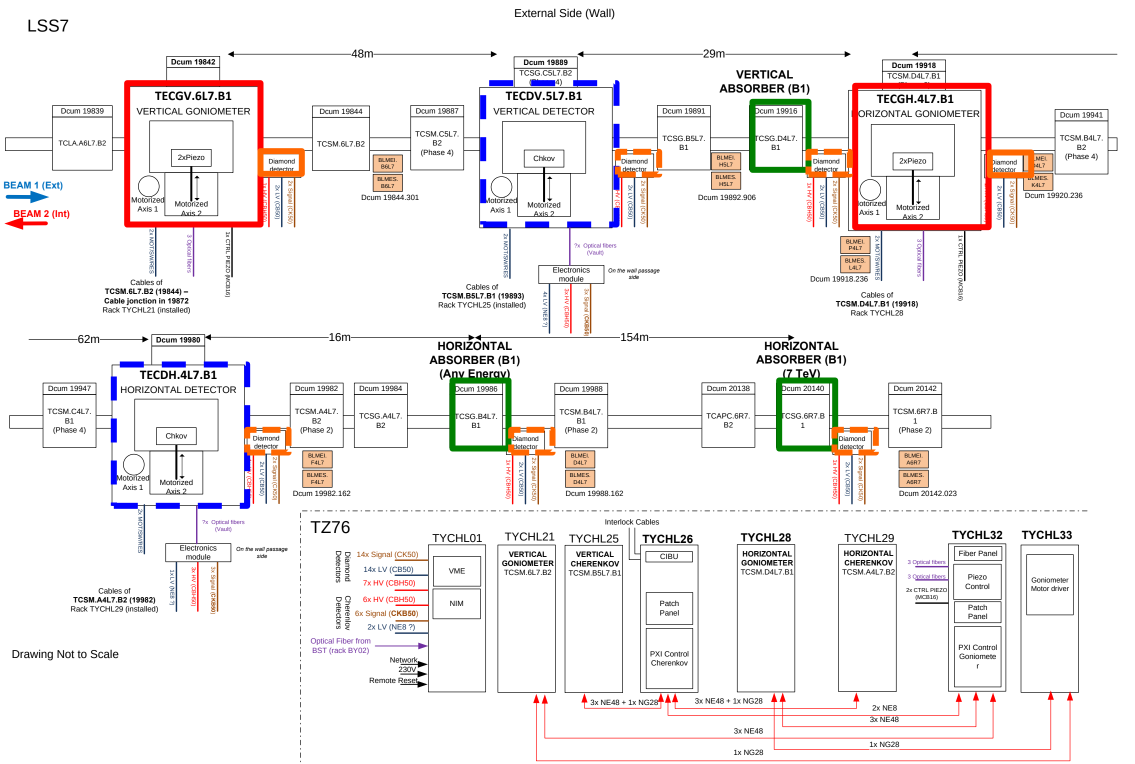
- Directly compare the cleaning efficiency of the collimation system with and without crystals.
- Address operational challenges (alignment, collimation for ramp/squeeze, …).
- Confirm the effectiveness of crystal collimation on ion beams.
- Check higher energy extrapolations.

STRATEGIES:

- Use of cleaning simulation to choose device positions and crystal parameters.
- Integration of the crystals in the existing collimation system:
  - ✓ installation of the equipment in IR7,
  - ✓ use of existing collimators (as absorbers) and instrumentation (BLMs).
- Simultaneous test of horizontal and vertical collimation.
- Careful design of dedicated interlocks – and later of collimation system settings and beam conditions – to avoid any possible machine protection concern.
- Operation under the control of the Collimation and the Operation Teams.

Layout of the LHC installation

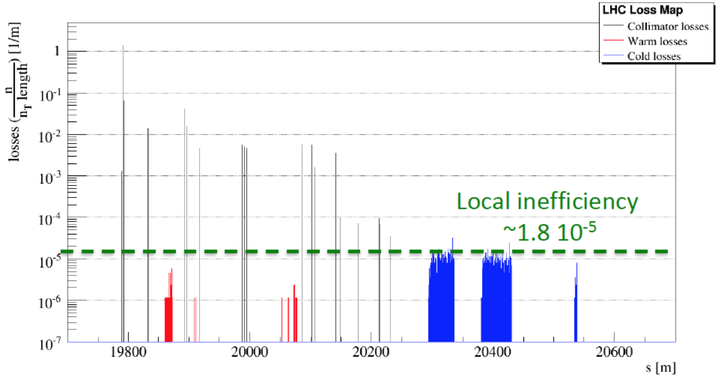
- 2 goniometers with crystals
  - ✓ Cables from phase-2 collimators + new optical fibers
  - ✓ 1 new support, 1 support from phase-2 collimator
- 3 absorbers (TCSGs – already installed)
- 2 Cherenkov detectors (not for installation during LS1)
  - ✓ 2 new supports
  - ✓ New signal and HV cables
  - ✓ New vacuum system cables
- 7 diamond BLMs (2 for installation during LS1)
  - ✓ New cables
- Control electronics to be installed in TZ76

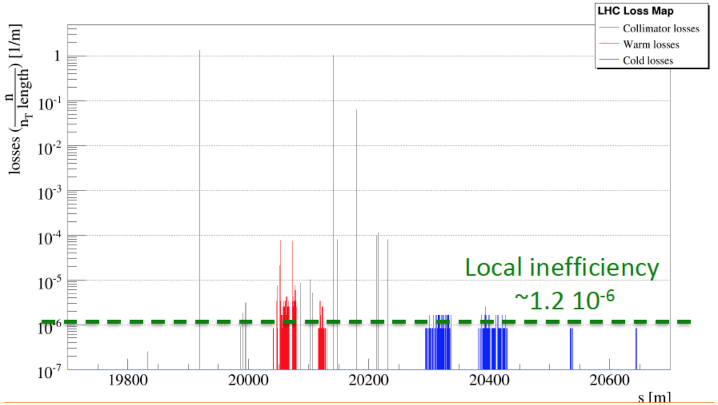


Courtesy of Jerome Lendaro

LHC collimation performance

- Complete tracking simulations of cleaning inefficiencies
  - ***important effort to debug, validate and extend the crystal simulation routine in SIXTRACK (accelerator tracking code)***
- Layout studied in cooperation with the Collimation Team*:
  - ✓ Semi-analytical analysis of channeled particle trajectories to identify candidate layouts
  - ✓ Evaluation of the cleaning efficiency and the safety margins as a function of different crystal parameters
- Chosen layout:
  - ✓ Vertical crystal: DCUM 19918, horizontal crystal: DCUM 19842
  - ✓ Crystal parameters: bending angle 50 μrad, length 4 mm
  - ✓ The simulated beam loss maps show that **local cleaning inefficiency is reduced by about 10 times** in the dispersion suppressor, with respect to the present system



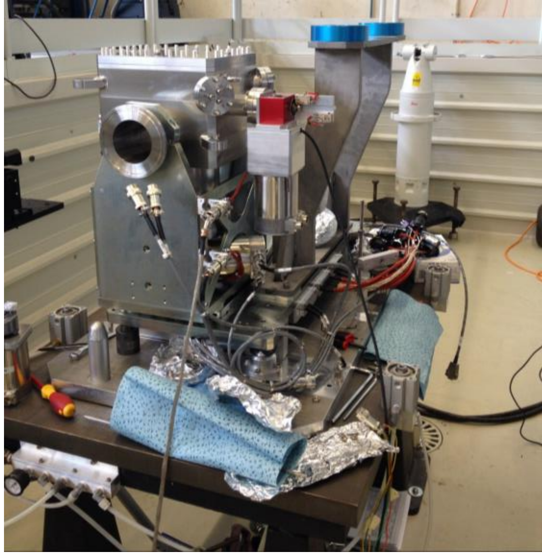


- *D. Mirarchi, S. Montesano, S. Redaelli, W. Scandale, A. Taratin, F. Galluccio: **FINAL LAYOUT AND EXPECTED CLEANING FOR THE FIRST CRYSTAL-ASSISTED COLLIMATION TEST AT THE LHC**, MOPRI110, PAC14.

The LHC goniometers

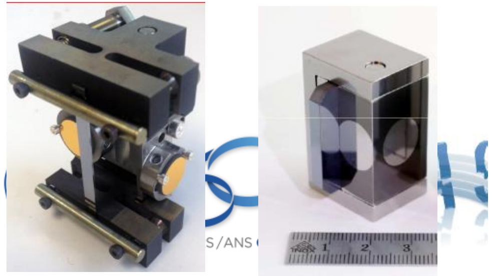
- Alignment of the crystal with respect to incoming particles is critical:
  - ✓ 1 μrad accuracy required at 7 TeV,
  - ✓ dynamic accuracy of the motion essential to obtain collimation during beam acceleration and β^* squeezing.

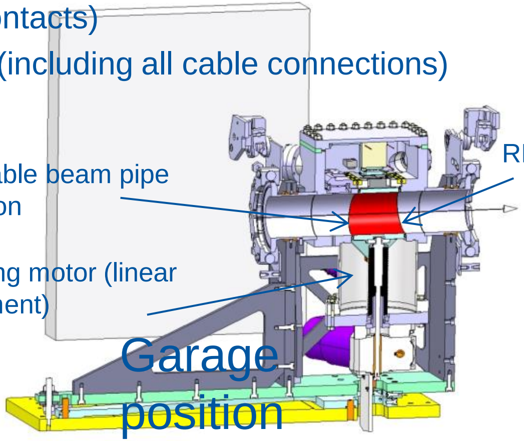
- Design of the goniometers in collaboration with industrial partners:
  - ✓ closed-loop piezoelectric angular movement (range: 20 mrad, accuracy 1 μrad)
  - ✓ motorized linear axis (60 mm stroke, 5 μm resolution)
  - ✓ integrated high-precision alignment system
  - ✓ no measured impact on machine impedance during normal LHC operation (movable beam pipe section with RF contacts)
  - ✓ quick-plugin on the collimator supports (including all cable connections)

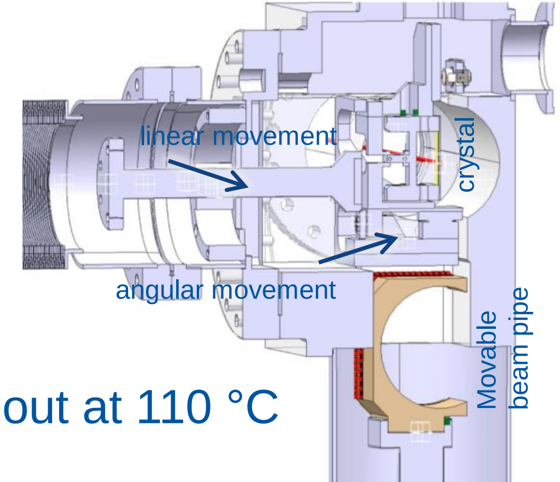


crystals

horizontal vertical



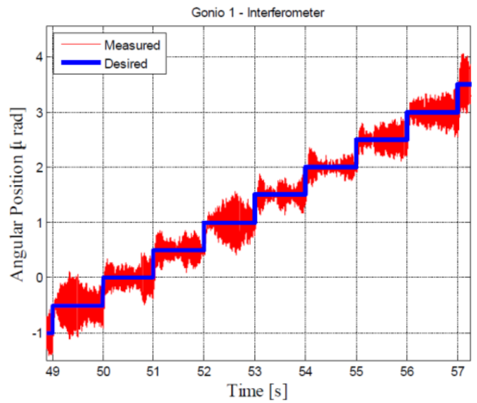




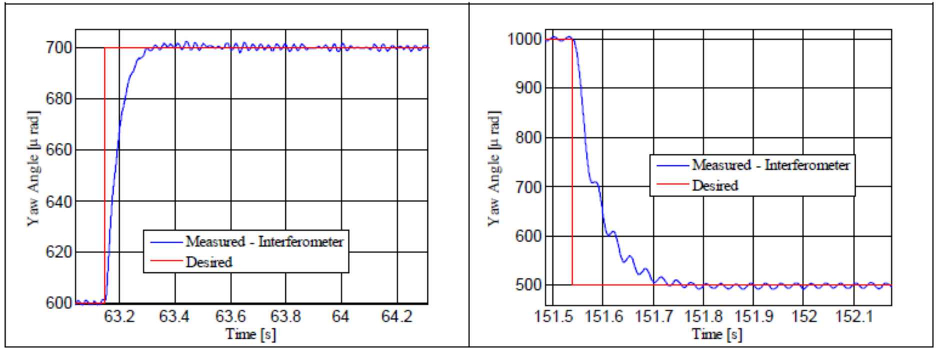
Bake out at 110 °C

Performance of the goniometers

- **Linear motion:**
  - ✓ 4 guides based on linear roller ceramic bearings
  - ✓ special cage (AISI 316L) to guarantee a minimal parasitic angle of 1 µrad/mm
  - ✓ elastic support on one guide to allow dilatation during bake-out



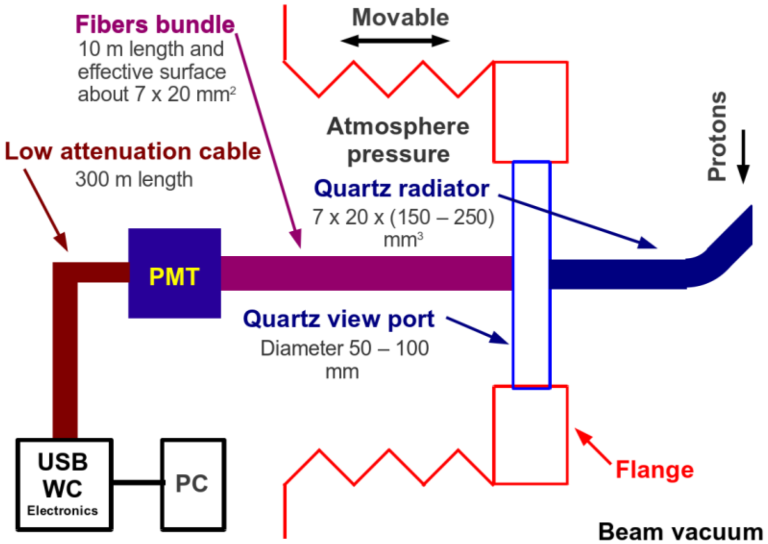
- **Angular motion:**
  - ✓ piezoelectric rotational stage including a feedback mirror and the crystal holder
  - ✓ closed-loop control based on 3 linear interferometric measurements (Attocube FPS3010)
  - ✓ From the acceptance tests:
    - +/- 0.5 µrad accuracy in angular position
    - 2% overshoot well below the specifications
    - settling time 100 msec

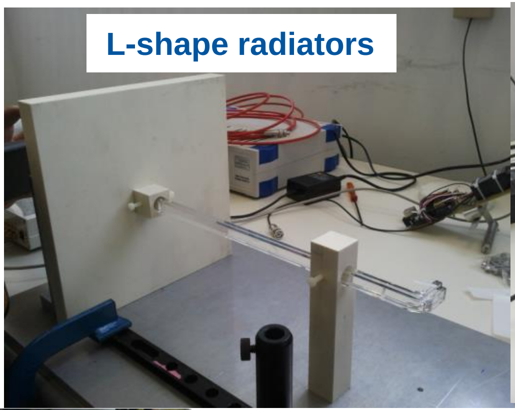


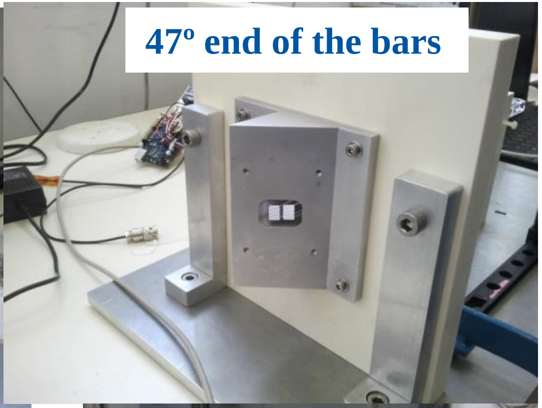
CERN | 60 YEARS/ANS CERN | UA9

Cherenkov proton flux monitor (CpFM)

- Exploit **Cherenkov radiation in fused silica** to count deflected particle, measure their time and – with segmentation – beam spot.

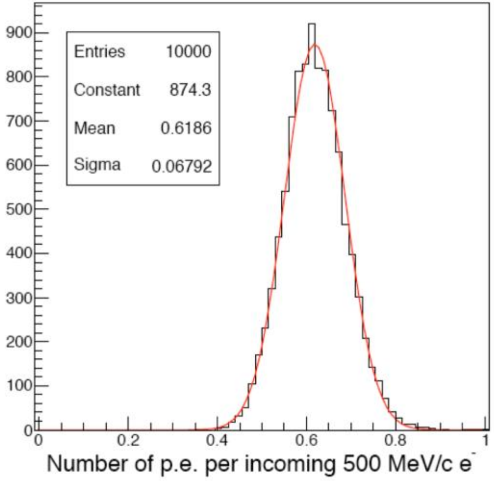






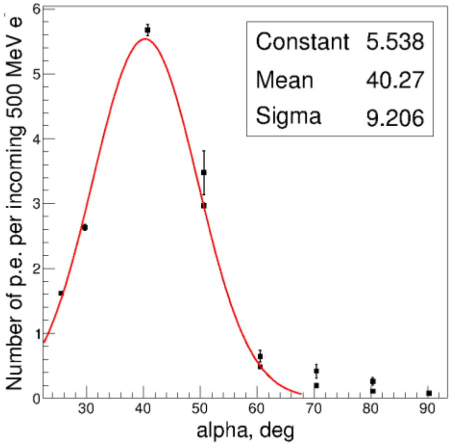
CpFM tests

L.Burmistrov et al, NSS/MIC proc. 2013 & NIPD proc. 2014

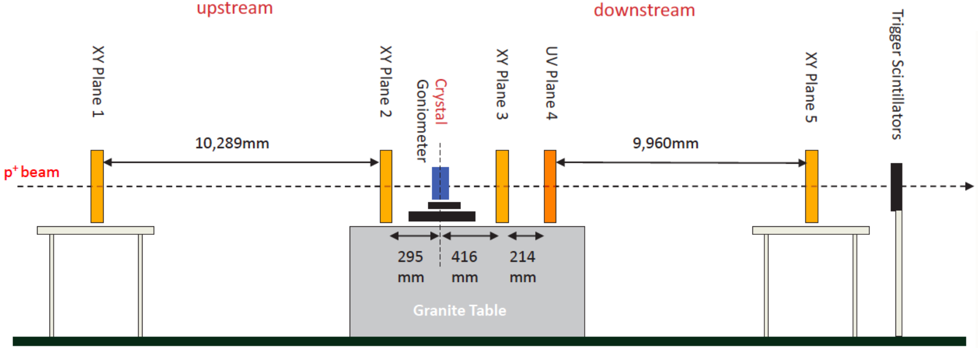


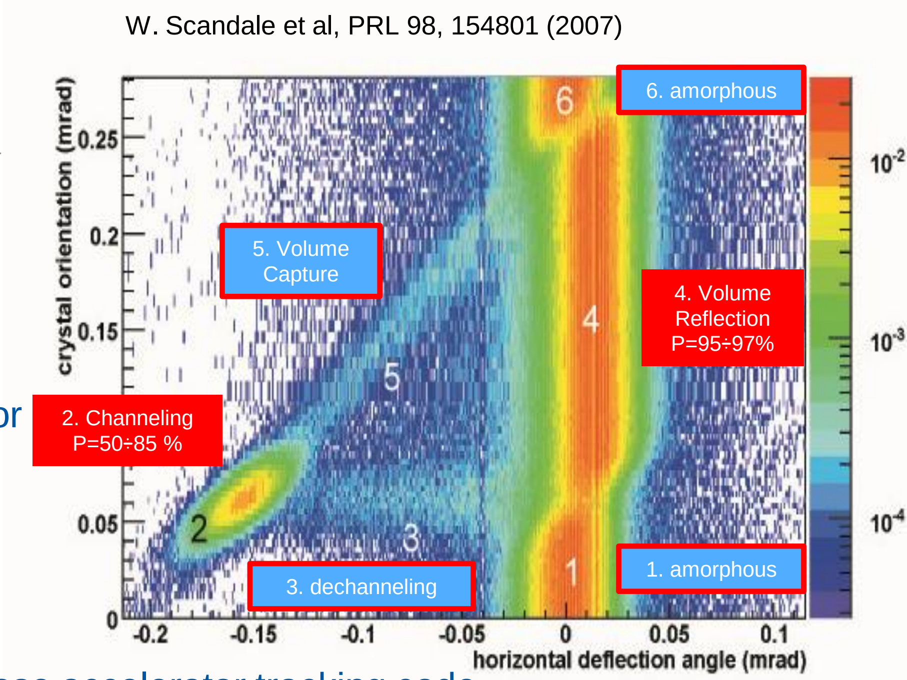
- Test at BTF-LNF
  - ✓ Measured CpFM charge (normalized on the charge of single p.e.) as a function of BTF calorimeter charge -> 0.6 photo-electrons per incident particles; linear response
  - ✓ **About 10% resolution** on number of incident particles (100)
  - ✓ Insertion of the viewport between quartz radiator and fiber bundle decreases the signal by a factor of 2 (brazing of the radiator to the viewport not mandatory)
- Test in H8 last week confirms data of BTF (analysis ongoing)
- Test in SPS due in 2015
- CpFM is compatible with LHC requirements (outgassing, radiation resistance, background…)
- Ongoing investigations on quartz-metal brazing technology in collaboration with industry

Intensity of light as a function of the particle radiator angle



Coherent interaction studies at H8





- ❑ Critical to characterize crystals for SPS or LHC
- ❑ Details are important for simulations in particle accelerator
  - ✓ MonteCarlo approach is fast but needs reliable scaling laws
  - ✓ Path integration is reliable but it is too slow for multi-turn
  - ✓ Path integration predicted volume reflection 20 years ago

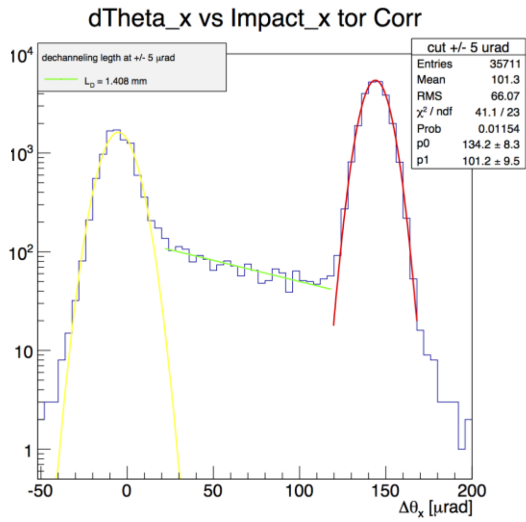
MonteCarlo method is used in SIXTRAC the general purpose accelerator tracking code

UA9 data have been used to improve reliability of MC routine

Simulations

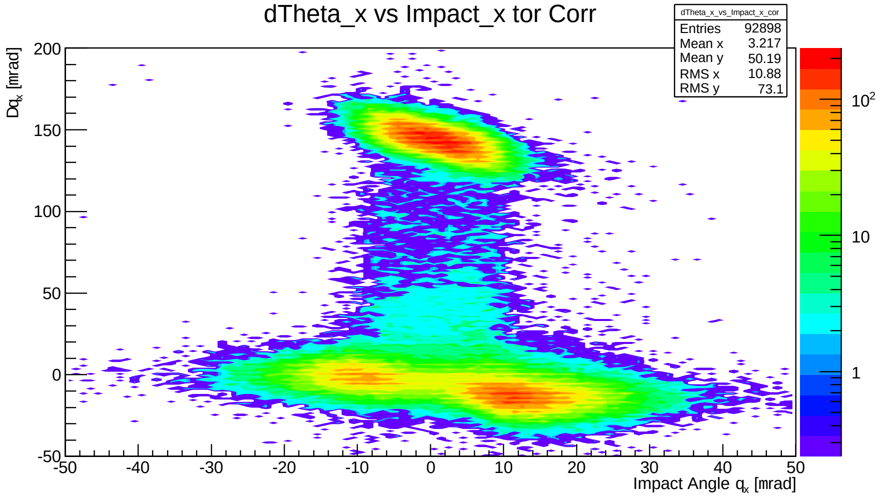
D,Mirarchi et al, ***CRYSCOL*** MonteCarlo code, MOPRI111, IPAC 2014

Data interpolation to compute probabilities of channeling, volume reflection, dechanneling

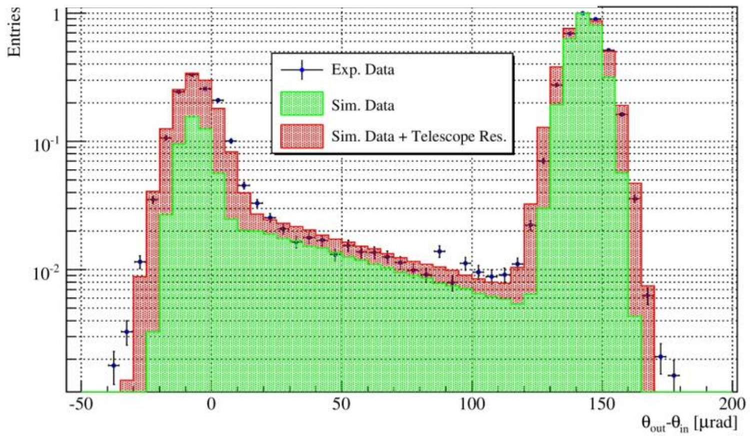


- measured and simulation data agreement better that 10 %
- more confidence on SIXTRACK predictions for SPS and LHC

High statistics data collected at fixed angle with STF45 crystal



Data versus simulation results with and without telescope resolution uncertainty



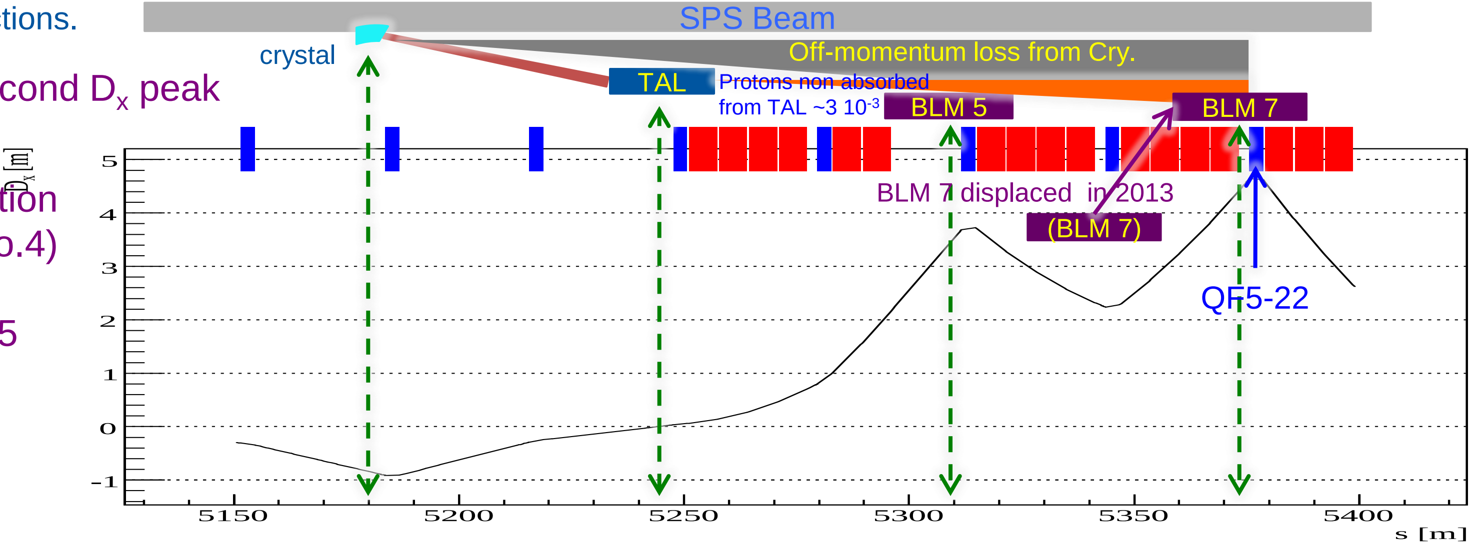
Collimation inefficiency in the SPS

- Beam loss rate at high D_x has two contributions:
  - ✓ diffractive protons coming from the crystal
  - ✓ protons non absorbed in the TAL
- Simulations of SIXTRACK + CRYSCOL (upgraded)
  - ✓ The two fractions are different at the two D_x peaks
  - ✓ Data collected in 2012 with low-sensitivity BLM agree with simulation predictions.

SIXTRACK + CRYSCOL simulation results with BLM7 at QF 5-22

Location	Crystal orientation	Losses from crystal	Losses from TAL	Total losses	Losses reduction
BLM5	AM	4.7 10^{-5}	1.2 10^{-3}	1.2 10^{-3}	~7
BLM5	CH	7.7 10^{-7}	1.7 10^{-4}	1.7 10^{-4}	
BLM7	AM	1.5 10^{-4}	4.2 10^{-5}	1.9 10^{-4}	~21
BLM7	CH	2.1 10^{-6}	6.9 10^{-6}	9.0 10^{-6}	

BLM7 displaced at the second D_x peak



- BLM7 measured reduction factor ~18 (see slide No.4)
- To be confirmed in 2015 with LHC-type BLM

Outlook on the future…

2014-2019

Inclusion of ERC-CoG ***CRYSBEAM*** project in UA9

Charged particle Coherent interactions

New phenomena, better measurements,

New crystal concept

Crystals on Accelerators

Collimation, beam scraping, **extraction**

Measurements at H8 and LNF BTF

Collimation detailed studies on SPS

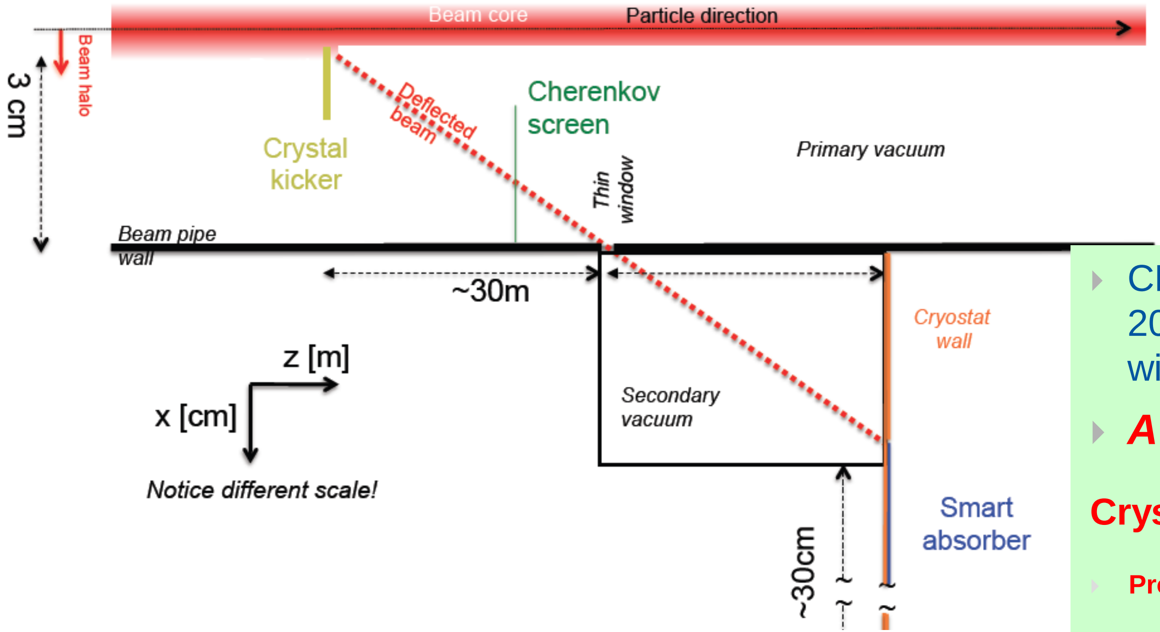
LHC crystal collimation validation

"Forward" physics & Cosmic rays

Crystal extraction from SPS and possibly LHC

LHC fixed target program (AFTER)

Conceptual layout of CRYSBEAM



- **Crystal kick about 1 mrad** technically feasible.
- ***Detection and timing*** of deflected/extracted beam at the vacuum/air interface with a detector based on ***Cherenkov*** light emission.
- **Instrumented** beam dump in air.

- CERN, INFN and UA9 discussed in June 2014 inclusion of ERC-CoG CRYSBEAM within the UA9 collaboration
- ***A new MoU in preparation***

Crysbeam GOALS

- **Produce crystals** with a large bending angle (a few mrad)
- **Test** them in the **North Area**
- Propose a scenario for the halo extraction in the SPS,
- **Test and characterize the halo extraction in the SPS**
- **Propose of a scenario for an extraction test in LHC**

UA9 requests for 2014

- UA9 would like to ask the SPSC support for the following beam requests
  - 20 days in H8 with proton microbeams at 450 GeV (recorded efficiency ~ 0.6)
    - Reserve crystals for LHC (1 strip, 1 QM)
    - Large bending crystal for extraction in the SPS (1 strip, 1 QM)
    - Multi-crystals for multi-reflection (array of 8/10/12)
    - Multi-strip for multi-reflection (array of 8/12/16)
    - Crystal with a 45° edge for focusing
    - Calibration of the Cherenkov detector
    - Calibration of diamond detectors
    - Fast electronics test for coincidence of Cherenkov & Diamond signals
    - Crystal with a cut for enhanced channeling efficiency
  - 7 days with ion (Ar or Pb) beams (recorded efficiency ~0.4)
    - PXR radiation
    - Probability of fragmentation
  - 5 dedicated days in the SPS (24 h runs in storage mode) (recorded efficiency ~ 0.7)
    - 0.5 mm long crystals (optimal at 270 GeV)
    - Multi-crystal and/or multi-strip
    - Test of a Cherenkov detector
    - Test with beam of a goniometer with angular piezo-electric actuator similar to the ones installed in LHC
    - Test of the reduced collimation inefficiency using the BLM 7 in the position close to QT 5-22
  - *Time for tests in LHC will allocated during the collimation LHC-MDs (see LMC minutes of 5 February 2014)*

UA9 publications in 2013/14

- Progress on Cherenkov detectors were presented in various conferences; *L.Burmistrov et al, NSS/MIC proc. 2013 & NIPD proc. 2014*
- Test of multi strip silicon deflectors were reported in Nuclear Instruments and Methods in Physics Research B 338 (2014) 108–111.
- Crystal with focusing effect was discussed in Physics Letters B 733 (2014) 366–372.
- Mirroring effect of ultra short crystals was shown in Physics Letters B, Volume 734, 27 June 2014, Pages 1-6.
- Stochastic deflection of positive particles in silicon crystal was presented in Physics Letters B 731(2014)118–121.
- Progress on data analysis and simulations were discussed in four paper submitted to the PAC 2014 (Particle Accelerator Conference in 2014).
- A master and a doctoral **thesis** have been completed in 2014.
- A PhD and a master thesis are in progress.

Acknowledgments

- The Collimation Team for the fruitful collaboration and the support to the UA9 Collaboration
- All the teams and the groups who helped to finalize the LHC installation proposal, including: EN/STI, EN/MEF, EN/HE, BE/ABP, TE/VSC, TE/MPE
- All the groups that supports the UA9 Experiment during data taking activities in SPS and in North Area, in particular: BE/OP, BE/RF

Thank you for your attention!