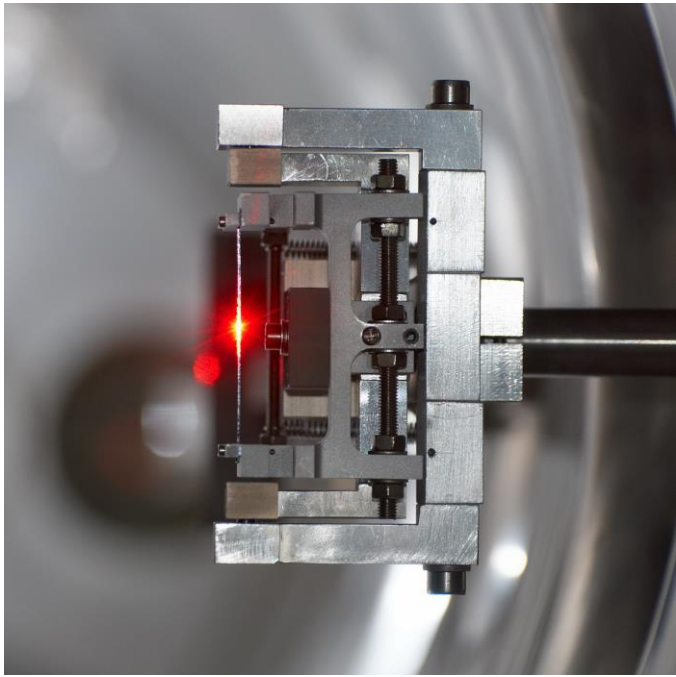
Status of UA9

W. Scandale on behalf of the UA9 Collaboration

- Introduction
- Measurements and tests in the SPS North Area
- Measurements and tests in the SPS
- Test in LHC
- Requests for 2016



Crystal collimation

$\theta_{ch} \cong \alpha_{bending}$

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

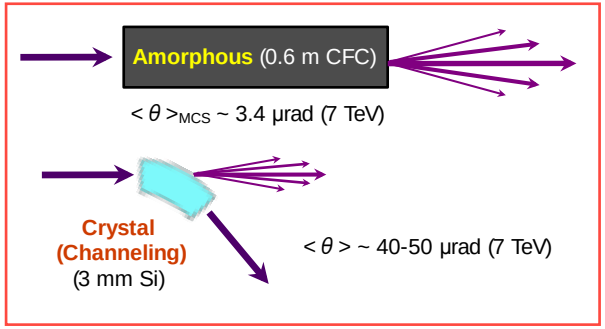
$q_c = \begin{cases} 10\,mrad@270\ GeV \\ 2\,mrad@7\ TeV \end{cases}$

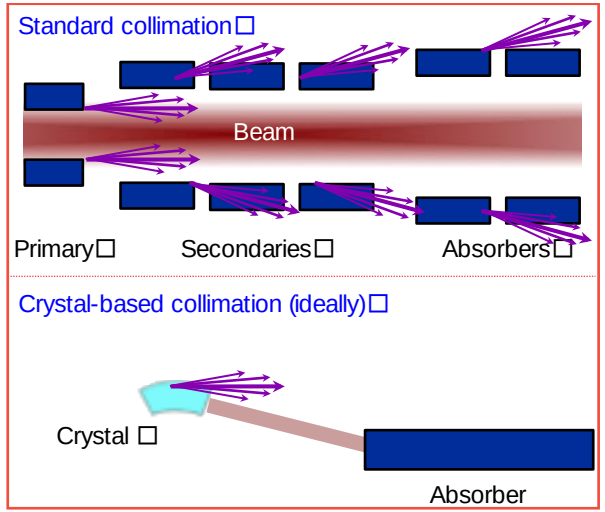
- Bent crystals allow deflecting particles by coherent interaction:
  - ✓ large angle deflection also at high energy
  - ✓ reduced interaction probability (e.g. diffractive events, ion fragmentation/dissociation)
  - ✓ reduced impedance (less secondary collimators, larger gaps)

  BUT

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

- 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
  - three installations (since 2014): LHC, SPS, SPS North Area (H8)





Timeline of the UA9 Experiment

- Test with extracted beams at the SPS North Area (few weeks per year):
  - ✓ Crystal – beam interactions
  - ✓ Measurement of crystal properties before installation in CERN-SPS and LHC
- Prototype crystal collimation system in the SPS (~ 4 / 5 days per year):
  - ✓ 2009 → First results on the SPS beam collimation with bent crystals *(Phys. Lett. B, 692, 78–82)*.
  - ✓ 2010 → Comparative results on collimation of the SPS beam of protons and Pb ions with bent crystals *(Phys. Lett. B, 703, 547–551*).
  - ✓ 2012 → Strong reduction of the off-momentum halo in crystal assisted collimation of the SPS beam *(Phys. Lett. B, 714, 231–236)*.
  - ✓ 2013 → Optimization of the crystal assisted collimation of the SPS beam *(Phys. Lett. B, 726, 182–186)*
  - ✓ **2014 → Observation of strong leakage reduction in crystal assisted collimation of the SPS beam *(Phys. Lett. B, 748, 451–454).***
  - ✓ **2015 → Test and validation with beam of the LHC-type goniometer.**
- Prototype crystal collimation system in the LHC (16h in 2015):
  - ✓ 2006 → First of a crystal-assisted collimation layout *(Assmann, Redaelli, Scandale EPAC2006).*
  - ✓ 2011 → Letter of Intent (CERN-LHCC-2011-007 / LHCC-I-019 10/06/2011).
  - ✓ 2012 → First goniometer industrially produced suited for the LHC requirements.
  - ✓ 2014 → Two crystals with their goniometers installed in IR7 Beam 1 of LHC (EDMS 1329235)
  - ✓ **2015 → Test of the crystal-assisted collimation with beam at 450 GeV.**

Schedule from Oct 2014 to Oct 2015

NA-H8 Test beam

62 days assigned in 8 runs : 44d main user, 18d parasitic

Effective time: ~ 70 % (~30 % lost for machine problems)

2014

Secondary Pion beam (180 GeV)

Main user

- *October 13th - 19th*
- *December 8th - 15th*

Parasitic to TOTEM

- *November 18th - 21th*

2015

Primary Ar Ion Beam (150 AGeV)

Main user

- *February 11th - 15th*

Parasitic to PROBA-V (*75 AGeV*)

- *April 1st - 7th*

2015

Primary proton beam (400 GeV)

Main User

- *April 27th - May 13th*
- *June 4th - 10th*

Parasitic to TOTEM

- *June 10th - 15th*

SPS tests

4 SPS runs of 24 h with 270 GeV proton beam

28-10-2014 – 25-11-2014 – 7-07-2015 – 14-10-2015

Effective time ~ 70 %

SPS North Area: experimental setup

UA9 Standard setup + new detectors for I.N.I. studies

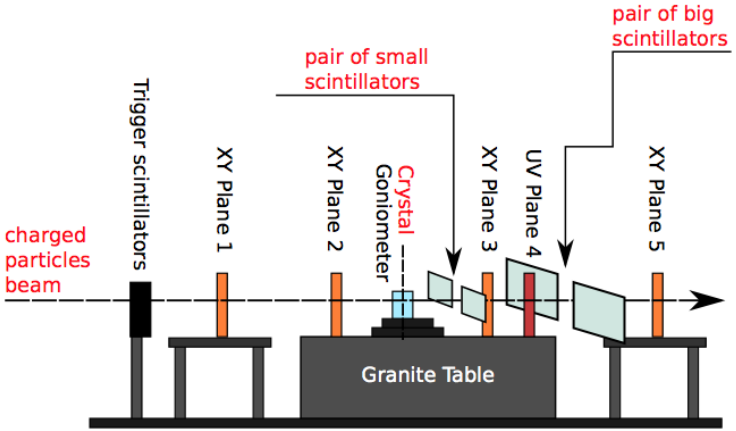
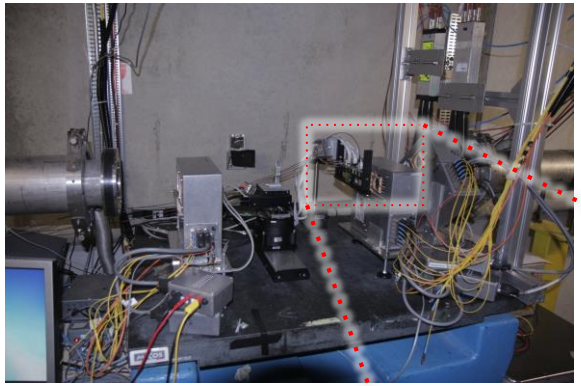
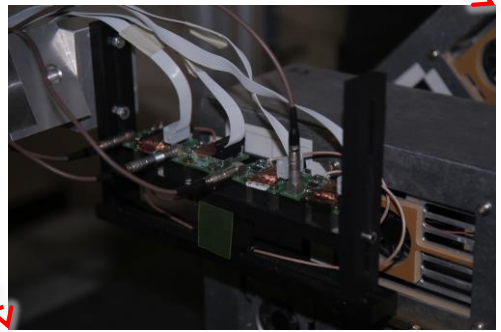


FIG. 1: Experimental layout in the H8 beam line.





fast scintillators and electronics (2 *ns* coinc. gate)

SPS North Area: LHC twin crystals

Test of twins of Crystals already installed (recently successfully tested) in LHC

- 1 QMP Crystal (PNPI): very good results
- 1 STF Crystal (INFN-Ferrara): possible crystal deformations problems due to the titanium holder

Bending angle of the ST76 strip crystal as a function of time

Date of the test in H8 (beam species)	Bending angle [µrad]
October 15th, 2014 (pions)	70.9
December 10th, 2014 (pions)	81.2
February 11th, 2015 (Ar ions)	77.0
February 14th, 2015 (Ar ions)	63.2
February 15th, 2015 (Ar ions)	63.3
At fabrication in June 2013	51

Bending angle of the QM33 quasimosaic crystal

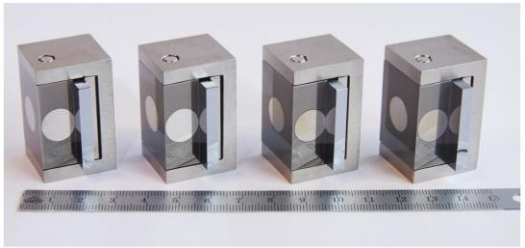
Measured bending angle [µrad]	38 ± 2
At fabrication in 2014	44

SPS North Area: new LHC crystals

4 QMP Crystals (PNPI)

Tested before and after LHC standard heating process

QMP46, QMP53 - to be used for installation
QMPXX-bo - crystal after bake-out
QMP52 - is spare crystal for installation
QMP54 - crystal for demonstration purpose



Crystal	run	Beam divergence ±5 urad		
		Deflection angle	Efficiency	Angular cuts
		urad	%	urad
QMP46	2737	**51.3**	69.8	(-6 ..+4)
QMP46	2791	**51.4**	67.4	(-9..+1)
QMP46	2798	**52.1**	70.5	(-12..-2)
QMP46-bo	3078	**50.2**	71.2	(-14 ..-4)
QMP52	2655	**54.0**	67.5	(-12..-2)
QMP52-bo	3063	**53.5**	69.4	(-9 ..+1)
QMP53	2664	**54.9**	71.1	(-1 ..+9)
QMP53-bo	3043	**54.5**	71.4	(-6 ..+4)
QMP54	2805	**58.2**	69.8	(-10..+0)
QMP54-bo	3101	**54.8**	69.5	(-5 ..+5)

2 STF Crystals (INFN-Fe)

Tests with a new titanium holder shows encouraging results about the Crystal deformations problems

	Bending angle [μrad]		Channeling efficiency		Torsion	
	±2.5 μrad	±5 μrad	±2.5 μrad	±5 μrad	p0 (offset)	p1 (torsion)
STF105	49.64	49.48	0.778	0.739	-0.6161± 0.4271	1.457± 0.5125
STF106	40.95	40.64	0.773	0.739	-0.03649± 0.3675	0.279± 0.4523

SPS North Area: Inelastic Nuclear Interaction

Goals:

- Frequency & probability of I.N.I. in Crystals for different orientation: AM, VR, CH and AX
- I.N.I. reduction factor: AM vs CH, CH vs AX
- I.N.I. probability in crystals with different bending radius
- Benchmarks for Ions simulations crystal routine

Measurements on ST Crystals, QM Crystals & LHC Crystals

Preliminary results:

Measurements with protons:

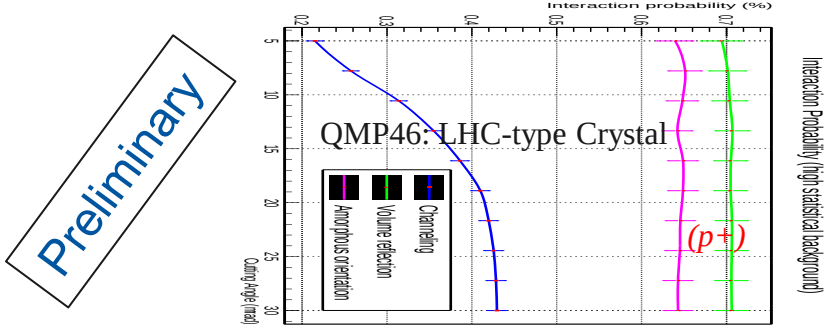
- Confirmations of the previous results (2010 UA9 paper)
- **First evidence of AX-CH I.N.I. reduction**

Measurements with Ar Ions:

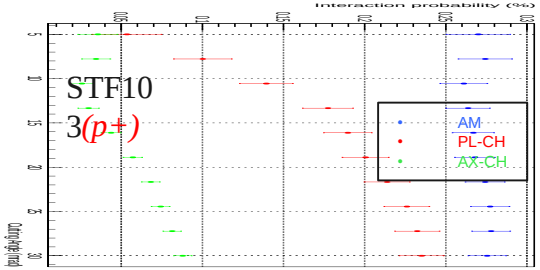
- New results never obtained before

Feature measurements with Pb Ions (next November)

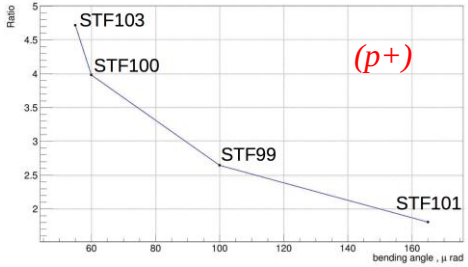
I.N.I. reduction in Planar CH



I.N.I.: Axial CH vs Planar CH



AM/CH I.N.I. vs bending R



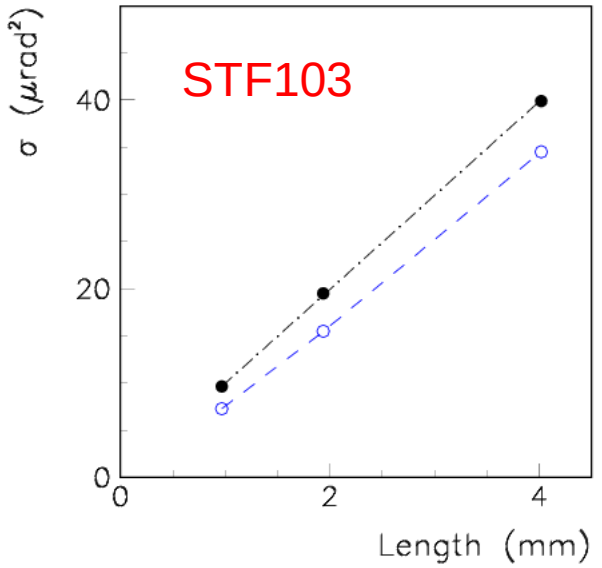
SPS North Area: Multiple Scattering

The dependence of the mean square deflection angle of multiple scattering on the crystal length

- experiment with 400 GeV/c protons (●)
- theoretical values performed by Gaussian fits of the Moliere distributions (○)

Crystal orientation w.r.t. the beam direction:

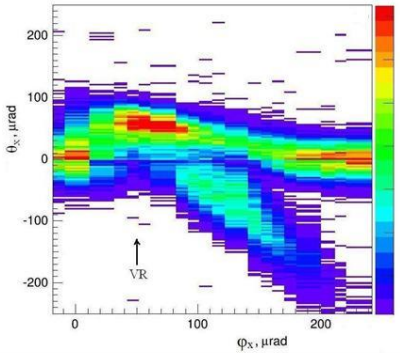
- 20 mrad from the crystal axes, in the plane direction
- 3 mrad from the crystal plane



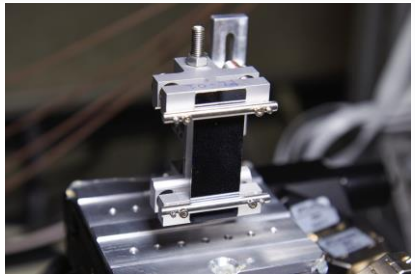
SPS North Area: new crystals tested

Large angle deflection: **Multi-strip crystal**

(p+) 400 GeV

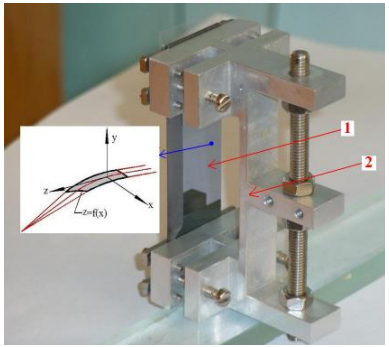


Large angle deflection:
Long Crystal (20 mm)
α = 0.25 mrad

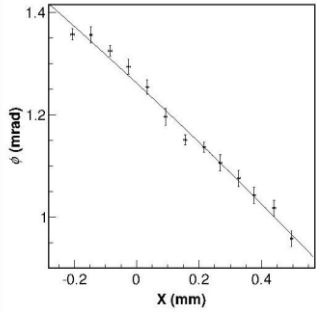


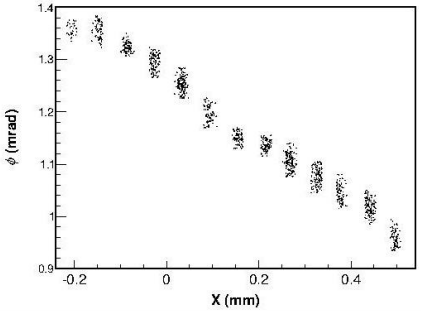
Focusing crystal device

(p+)
400 GeV

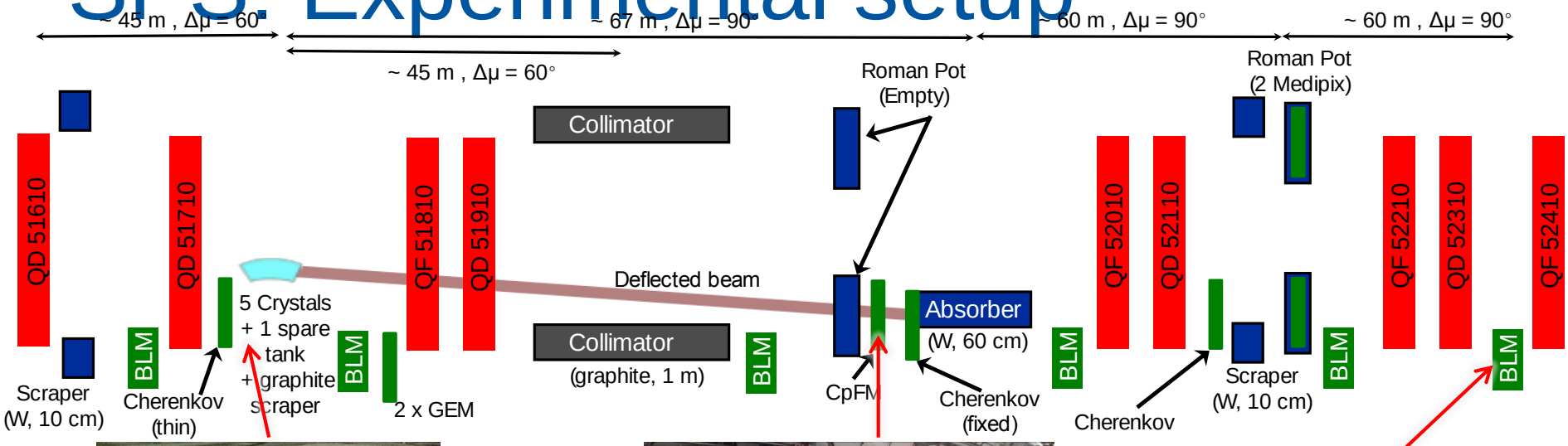


Linear dependence of
bending angle vs transversal coordinate





SPS: Experimental setup



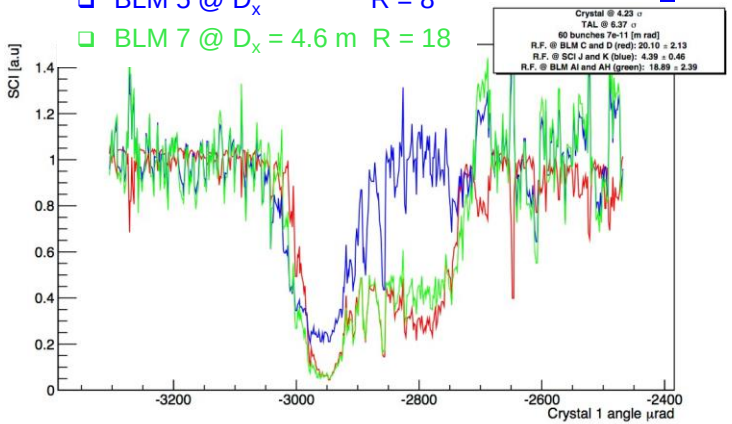
SPS: leakage reduction in the dispersive area

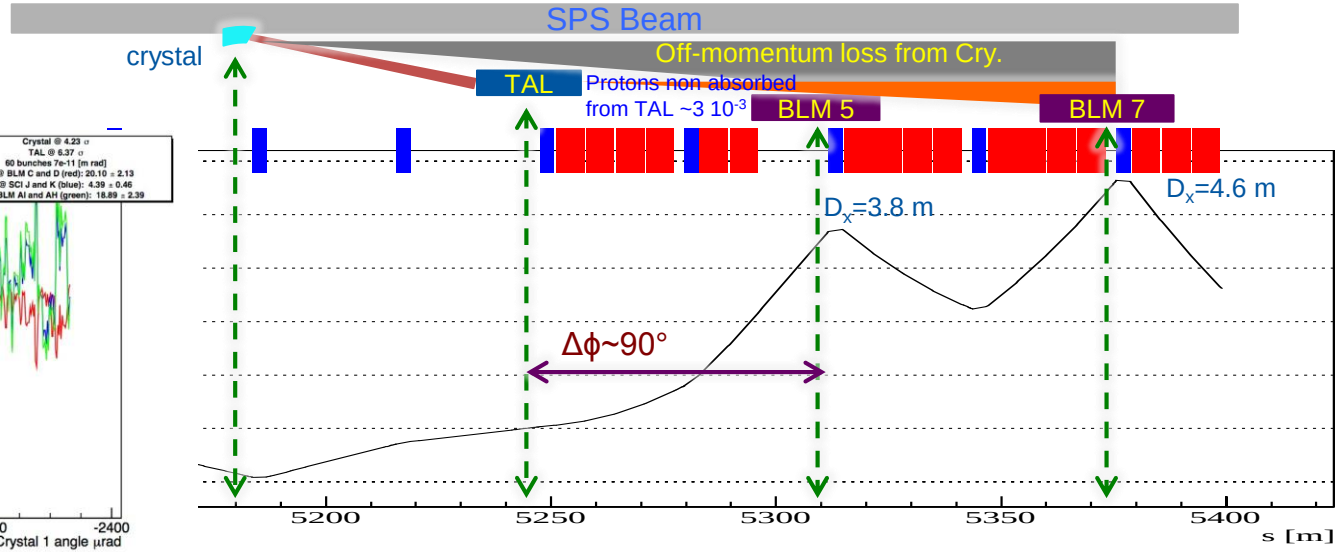
- Beam loss rate at high D_x has two contributions:
  - ✓ diffractive protons coming from the crystal
  - ✓ protons non absorbed in the TAL
- Simulations of SIXTRACK + CRYSCOL (upgraded)
  - ✓ The two fractions are different at the two D_x peaks
  - ✓ Data collected in 2012 with low-sensitivity BLM agree 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	$2.1\ 10^{-6}$	$6.9\ 10^{-6}$	$9.0\ 10^{-6}$	

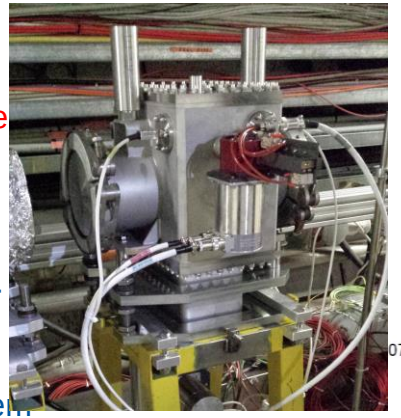
Measured loss reduction factor
- BLM @ the crystal R =18
- BLM 5 @ D_x R = 8
- BLM 7 @ D_x = 4.6 m R = 18



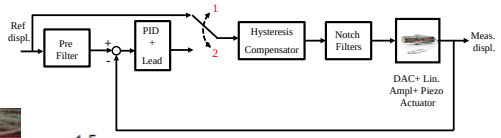


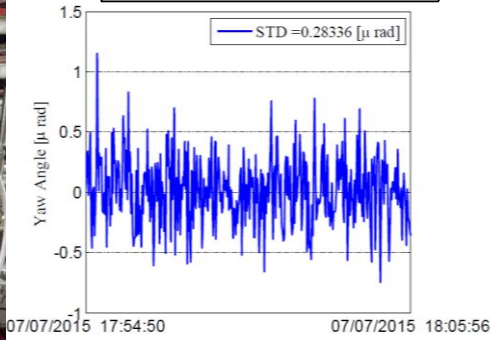
SPS: LHC-type goniometer

- LHC-type goniometers:
  - sophisticated control system developed on the laboratory te bench device
  - the goniometer installed in SPS was used for the first test with the beam in July
- The performance and the reliability of the goniometer is fully verified:
  - closed-loop control system allows to compensate for mechanical vibrations and noise on the measurement system
  - unprecedented resolution (< 0.5 μrad)
  - good angular stability (STD < 0.3 μrad)
  - successful test of the reproducibility in operation with beam (<< θ_c = 10 μrad)
- The operation of the devices in LHC has been approved after the beam test in SPS!

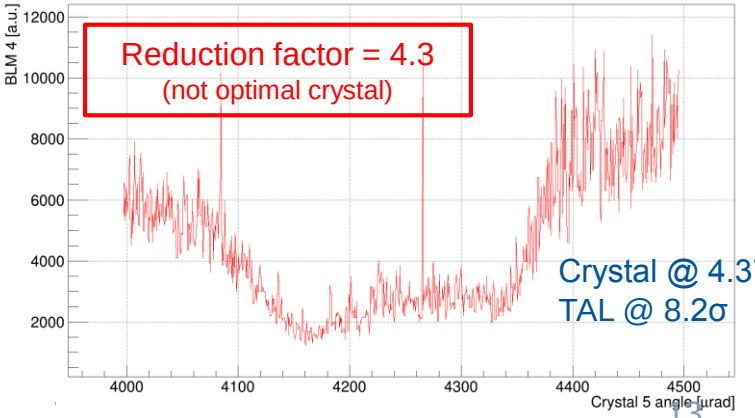


Angular stability with crystal fixed orientation



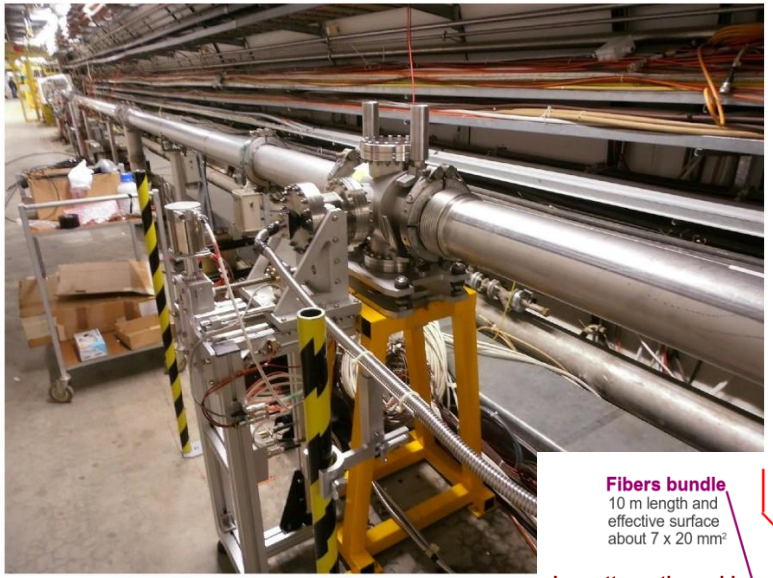


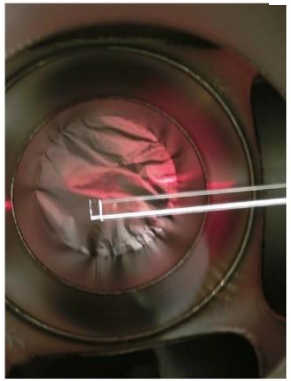
Angular scan 0.5μrad/s

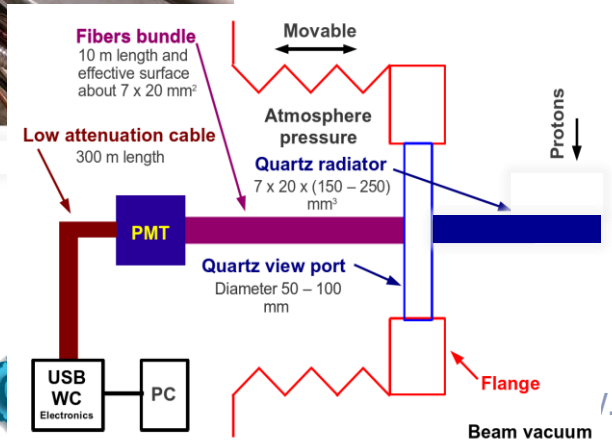


SPS data collected on July 2015

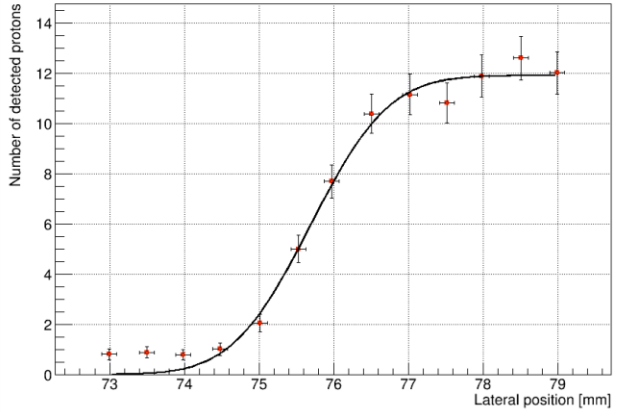
SPS: test of the CpFM detector





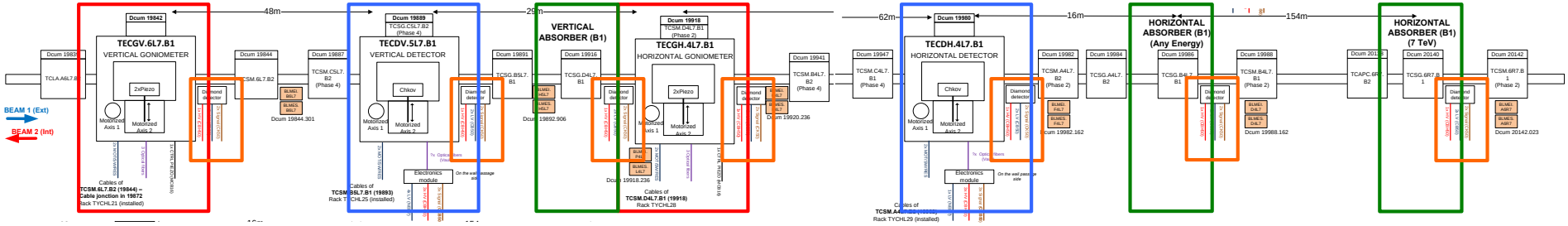


Scan of a 270 GeV proton beam in the SPS



- Error-function interpolation with Gaussian derivative ➔ σ = 1.2 +/- 0.2 mm.
- Distance crystal - CpFM = 58,48 m
- angular spread of the channeled beam at 2σ = 21. +/- 2 μrad
- in good agreement with the critical angle at 270 GeV.

LHC: experimental setup

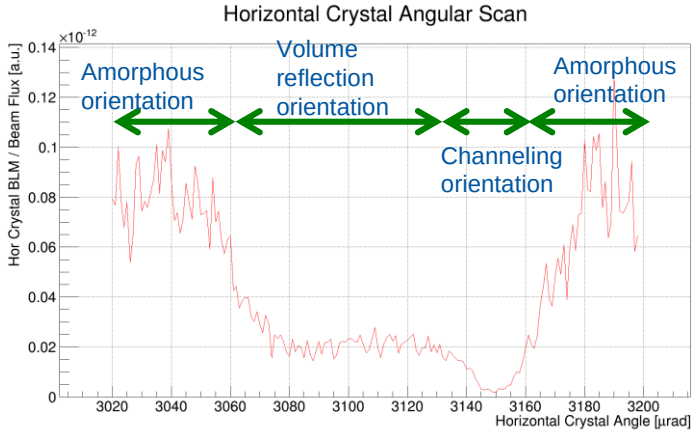


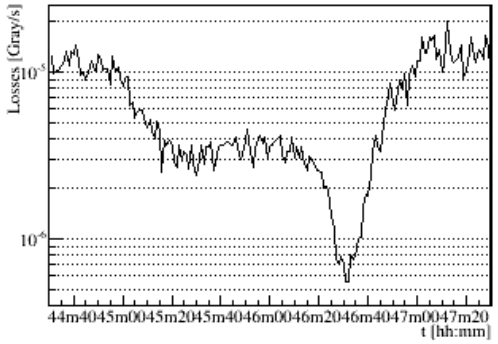
- Full crystal collimation prototype system designed in collaboration with the collimation team:
  - ✓ Development of a crystal simulation routine for the SIXTRACK tracking code
  - ✓ Semi-analytical analysis of channeled particle trajectories to identify candidate layouts
  - ✓ Evaluation of the cleaning efficiency and the safety margins as a function of different crystal parameters

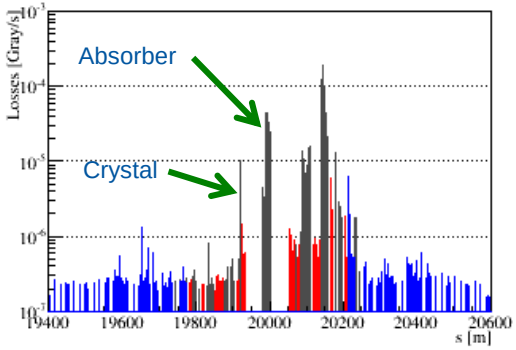
- Experimental setup installed in 2012:
  - 2 piezo-electrical goniometers (horizontal + vertical) with 2 crystals (50 μrad, 4 mm)
  - 3 existing secondary collimators (TCSG, 2 horizontal, 1 vertical) as absorbers
  - space reserved for 2 in-vacuum detectors (à la CpFM)
  - 2 diamond detectors + cables for 5 additional ones

LHC: collimation in the horizontal plane

- Crystal collimation setup:
  - Crystal at ~ 5.6 σ (1 σ = 1.53 mm)
  - Collimators upstream the crystal are retracted
  - TCSGs at 7 σ, TCLAs at 10 σ (nominal position)
- Repeated angular scans:
  - Channeling orientation identified in 2 hours beam time
  - Channeling orientation reproducible within few μrad from fill to fill.
  - Loss reduction factor in channeling w.r.t. amorphous orientation: ~ 39.
  - Redistribution of the losses from the crystal to the absorber
- Scan with TCSG:
  - Deflection angle: ~ 60 μrad
  - Extracted beam size: RMS = 436 μm

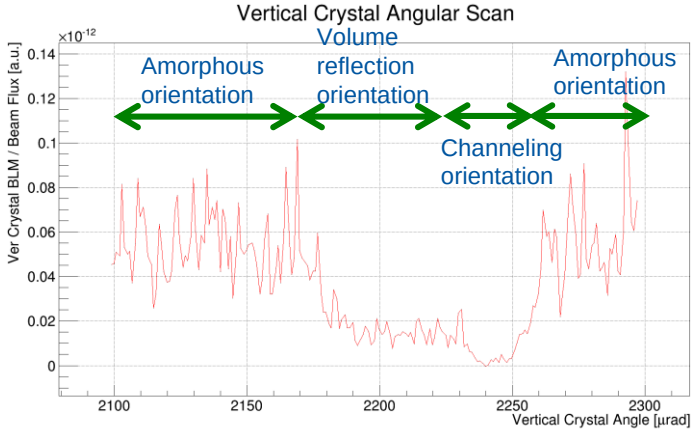


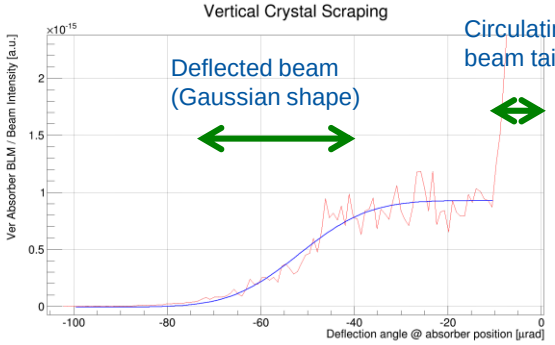


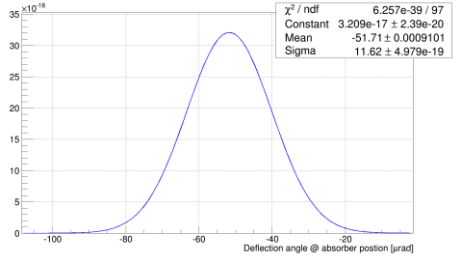


LHC: collimation in the vertical plane

- Crystal collimation setup:
  - Crystal at ~ 5.4 σ (1 σ = 1.19 mm)
  - Collimators upstream the crystal are retracted
  - TCSGs at 7 σ, TCLAs at 10 σ (nominal position)
- Angular scans:
  - Channeling orientation identified and reproducible within few μrad from fill to fill.
  - Loss reduction factor in channeling w.r.t. amorphous orientation: ~ 115.
- Scan with secondary collimator:
  - Deflection angle: ~ 52 μrad
  - Extracted beam size: RMS = 584 μm







Requests for 2016

- Request in H8
- 20 days with 450 GeV protons
- 7 days with Ar or lead ions

- Request in the SPS
- 3 days with 270 GeV protons
- 1 day with lead ions

GOAL IN H8

1. Stability of LHC-type holders for strip crystals
2. Calibration of the quartz radiator for LHC
3. Inelastic nuclear interactions with Pb ions
4. Multistrip /multi-crystals for SPS
5. Calibration of Timepix for SPD
6. Long crystals for large curvature
7. Focusing crystals for SPS
8. PXR detector for protons and ions

GOAL IN the SPS

1. Disentangle off-momentum loss produced in the crystal from absorber leakage
2. Cherenkov detector for the deflected flux of halo particles
   - Evaluate the collimation efficiency through the deflected flux rate
   - Analyze the time profile of the deflected flux
   - Collimation efficiency for lead-ions
3. Test collimation in ramping mode changing the store energy
4. Multistrip /multi-crystals versus single crystals

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Thank you for your attention!