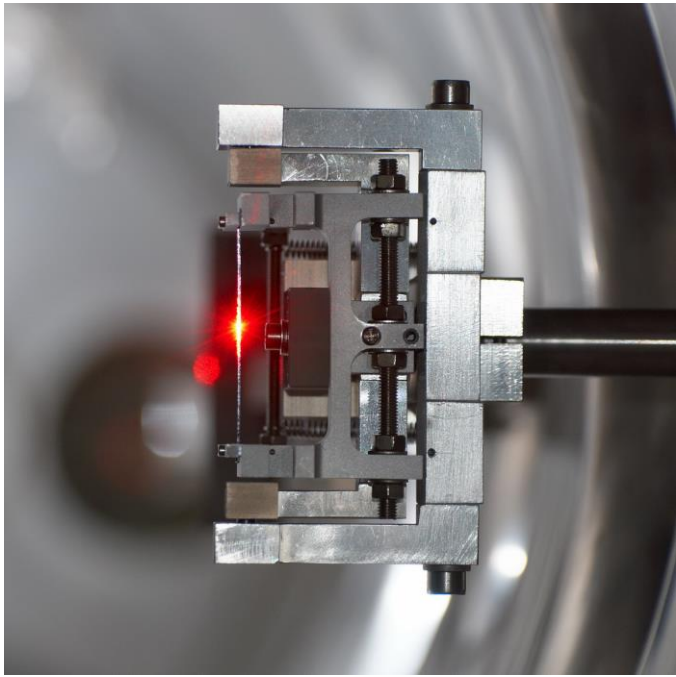
# Status of UA9

W. Scandale on behalf of the UA9 Collaboration

- Outline of the measurements and tests in 2017
  - in the SPS North Area
  - in the SPS
  - in LHC (in collaboration with the LHC Collimation Team)
- Beam requests for 2018



# SPS North Area: key issues

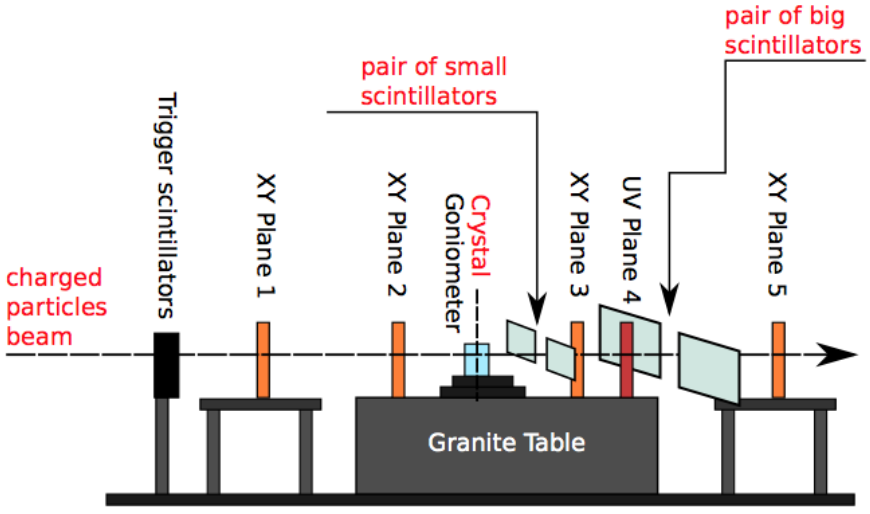



FIG. 1: Experimental layout in the H8 beam line.

- Procurement and test of crystals for
  - the crystal-assisted collimation in LHC
  - the double crystal experiment in LHC (bending angle > 10 mrad ⇒ see SPSC-EOI-012)
  - the double crystal experiment in the SPS
- Cross-section of inelastic nuclear interactions (INI) in LHC-type crystals
  - Special orientations (amorphous – planar channeling – axial channeling)
  - Close to the planar channeling orientation
- Detectors
  - Medipix
  - in-vacuum Cherenkov (CpFM)

# SPS-North Area: Oct 2016 - Oct 2017

## NA-H8 Test beam

53 days assigned in 5 runs : 46d main user, 7d parasitic

Effective time: ~ 50 % (~50 % lost for machine problems)

### 2016

~~Primary Pb Ion Beam (13 AGeV)~~

Main user

- *November 14th - 23th*

***Energy too low for reasonable measurements***

### 2017

Secondary Pion beam (180 GeV)

Main user

- *July 12th – 19th*
- *August 23rd – 30th*
- *September 15th – 21st*

Parasitic to TOTEM

- *May 15th – 24th*

### 2017

~~Primary proton beam (400 GeV)~~

Main User

- *May 8th – 15th*

***No protons delivered for micro-collimator problem***

# SPS North Area: upgrade of the tracker

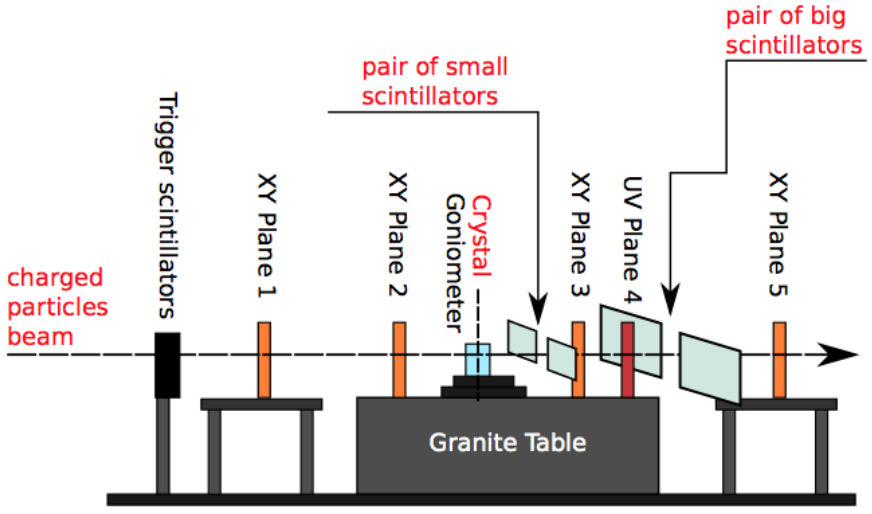



FIG. 1: Experimental layout in the H8 beam line.

- Optimization of Tracker, to test crystals with large deflection angle
  - Use only 4 sensor (drop plane 5)
  - New DAQ and reconstruction software
  - Angular resolution 5 ⇒ 15 μrad
  - Relative resolution not worsened
- Tracker commissioning with Xe Ions beam (October 2017)

Correlation of the bending angle values measured with beam and X-ray delayed to 2018 (x-ray source unavailable in 2017)

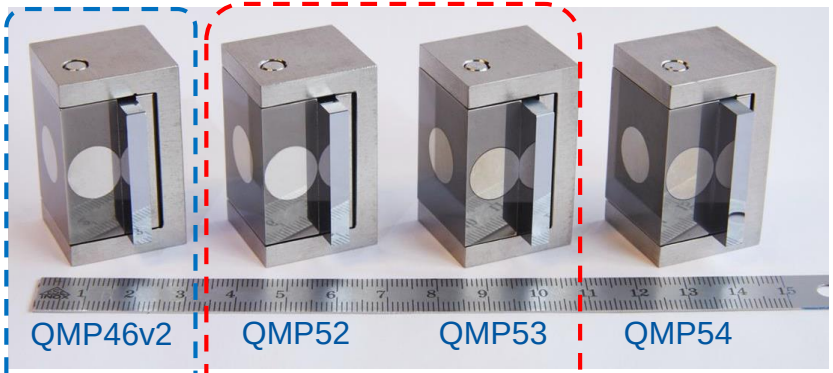
# SPS North Area: LHC quasi-mosaic crystals

4 QM crystals prepared by PNPI:

| Crystal | Angle μrad | Efficiency % | Efficiency % |
|---|---|---|---|
| **QMP46v2** | **56** ± 3 | 71 ± 3 | 68 ± 3 |
| **QMP52** | **55** ± 3 | 69 ± 3 | 66 ± 3 |
| **QMP53** | **55** ± 2 | 71 ± 2 | 65 ± 3 |
| **QMP54** | **56** ± 2 | 70 ± 3 | 66 ± 3 |
| | | Protons ± 5 μrad | Pions ± 5 μrad |

Holder size

| | |
|---|---|
| Dimentions HxWxL, mm | 40 x 30 x 25 |
| Weight, g | 96 ± 1 |
| Holder material | Titanium alloy grade V |




**December 2016**

- Crystal QMP46 has crushed against metal mechanism during goniometer test

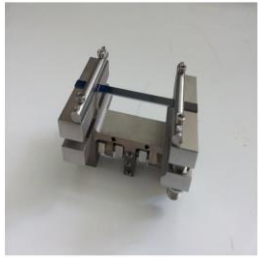
**May 2017**

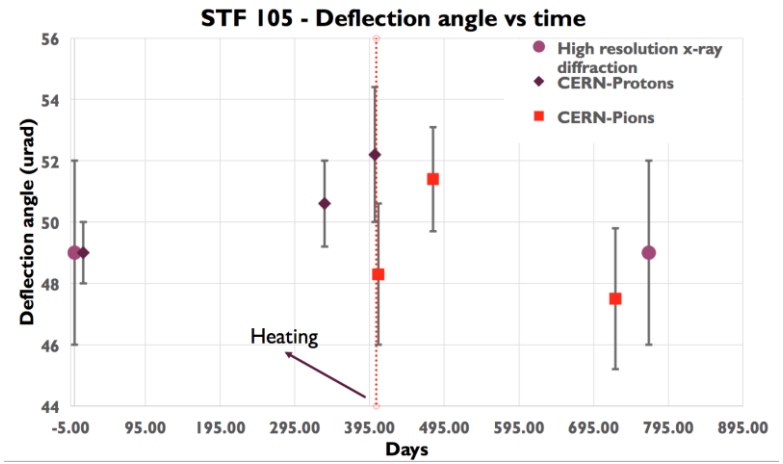
- QMP46v2 successfully recovered and re-bent

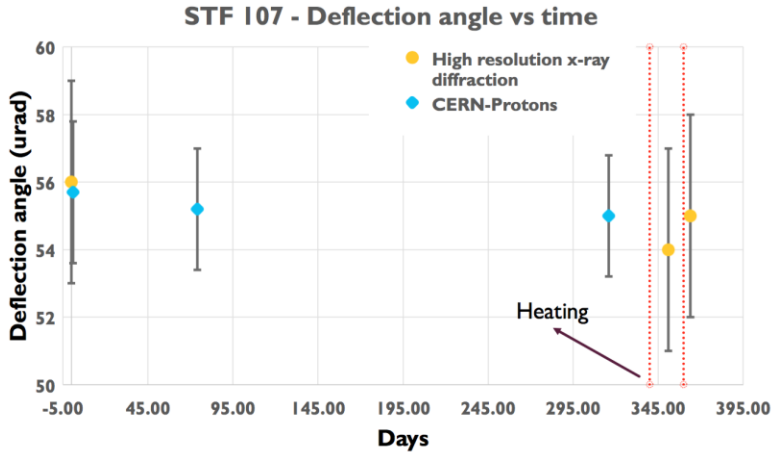
additional QM crystals required in 2018 in view of LS2

# SPS North Area: LHC strip crystals

## Tests of the new series of crystals with titanium holder





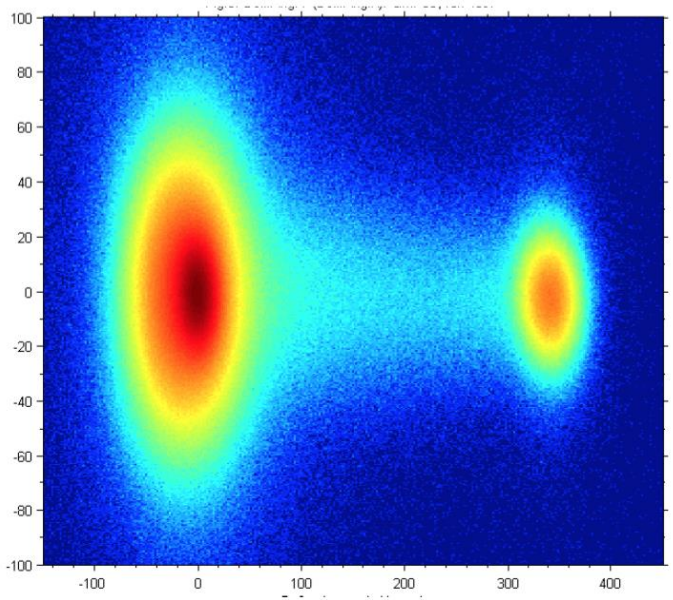

STF 110 measured only once in May 2017: bending angle 54 μrad, efficiency 70 %

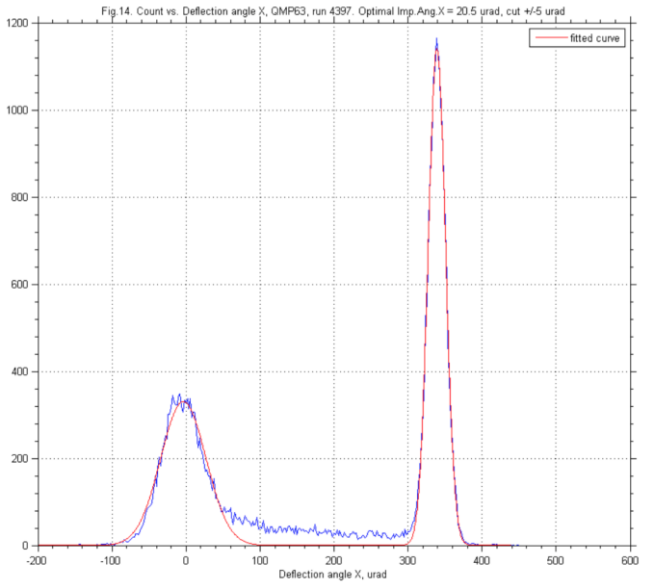
STF crystals in stand-by for additional thermal cycles and tests in 2018

# SPS North Area: QMP63 for SPS

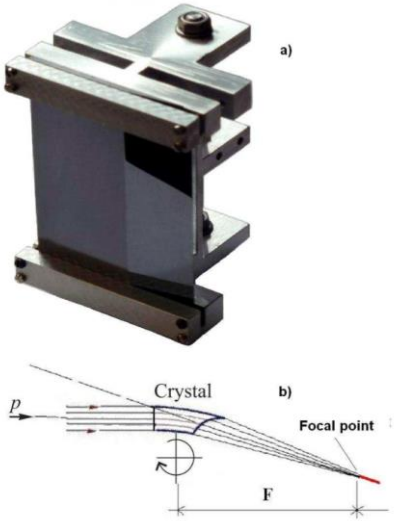
Large bending angle and length for a more realistic test of the **double crystal experiment in the SPS**

| | |
|---|---|
| Length: | 10 mm |
| Deflection angle | 340±5 μrad |
| Efficiency | 54 % |
| Torsion | 2 μrad/mm |



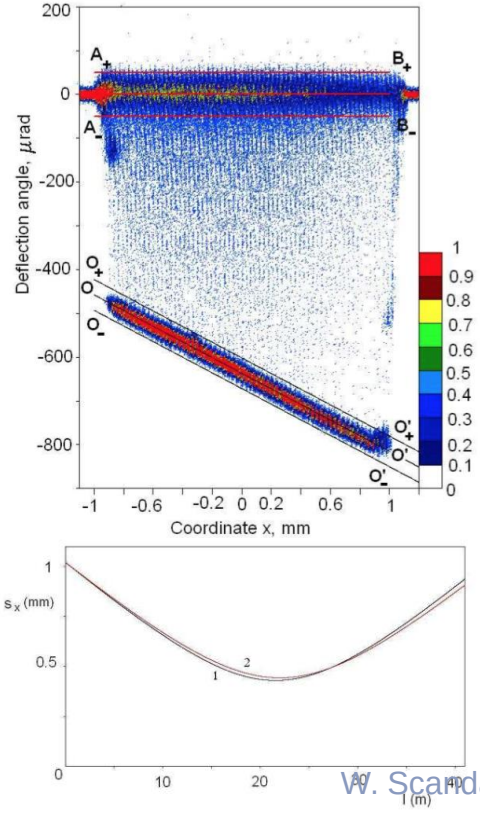



# SPS North Area: focusing crystals

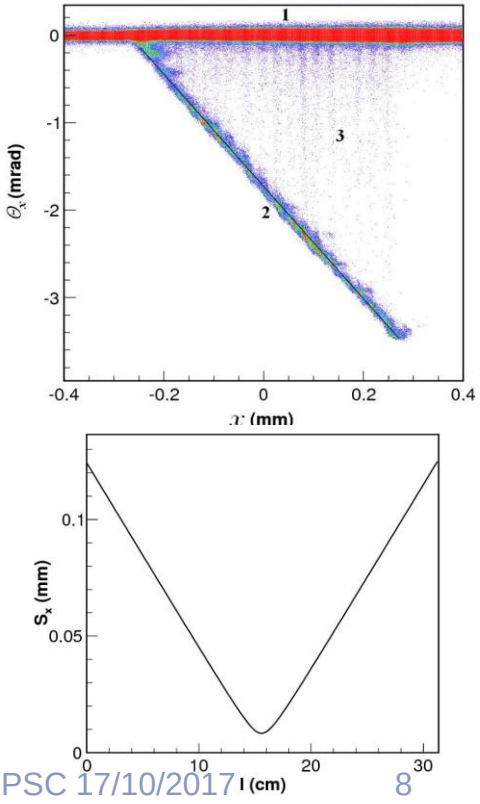



- Focusing crystals could be placed in the first position for the **double crystal experiment at the SPS**
- **matching the deflected beam to the size of the second crystal is the very challenging goal**

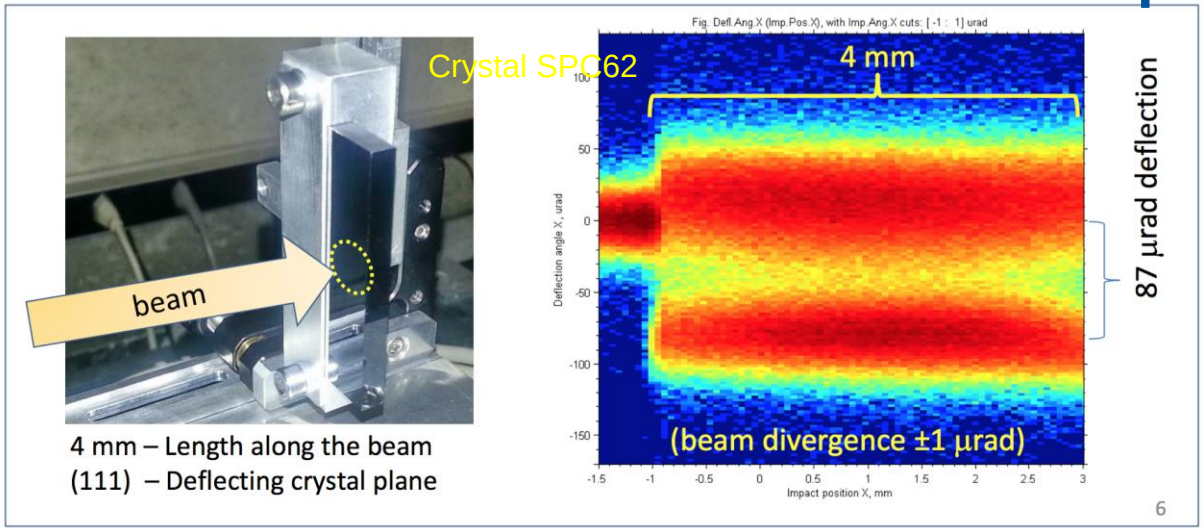
## Large efficiency crystal




## Very low focusing length

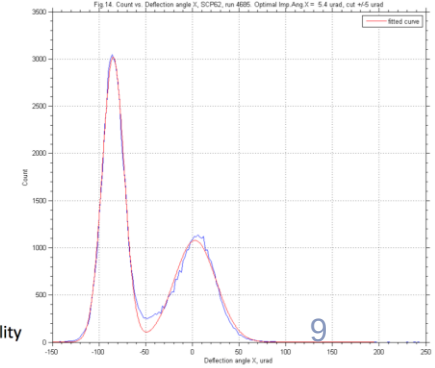


# SPS North Area: wide aperture crystals




**Wide aperture crystal SCP62**

Length: 4mm
Deflection angle: 85 **±3 urad**
Efficiency: 55%
Torsion: **<0.5 urad/mm**

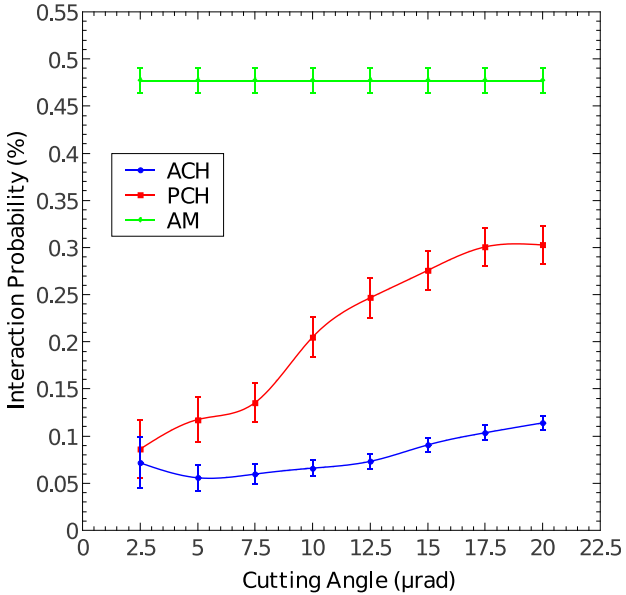


Results are the same as in 2016
Which is good sign for the long term stability

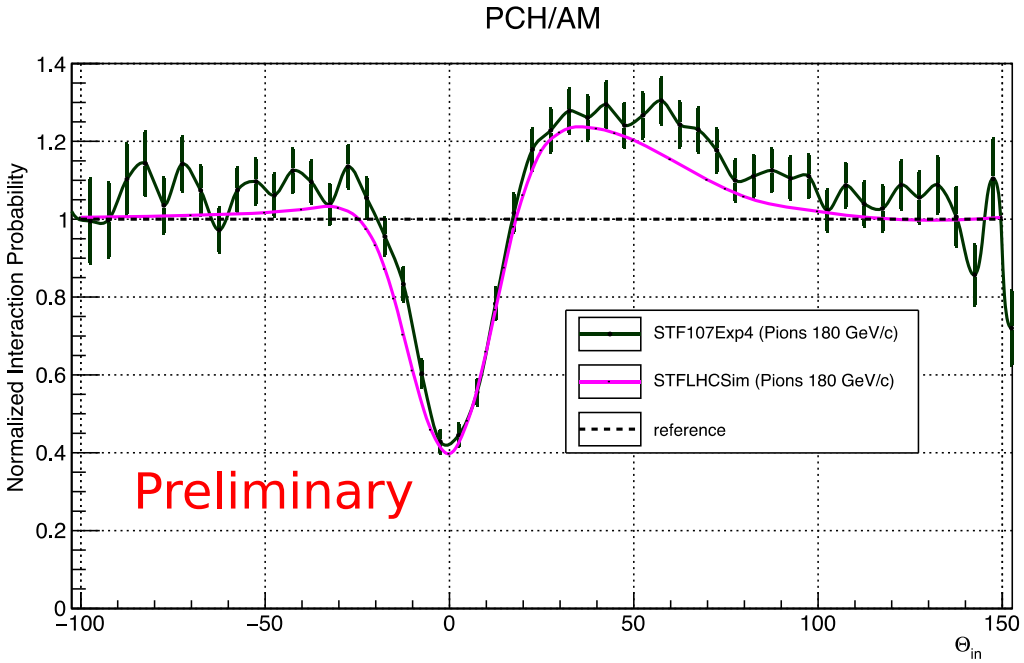
**Wide aperture crystals** are required for large size beam deflection, i.e.:

- for the double crystal tests
- for the **extraction** of resonant beam **by multi-volume-reflection**

# SPS North Area:
# Inelastic Nuclear Interactions (INI) studies



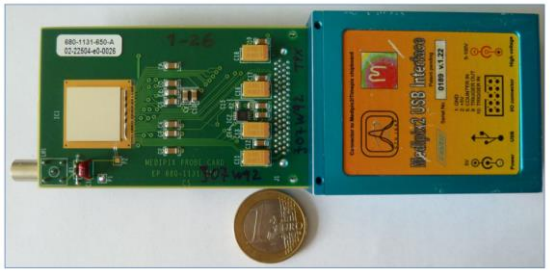

Absolute INI probability for amorphous, planar channeling, and axial channeling orientation of a bent silicon crystal



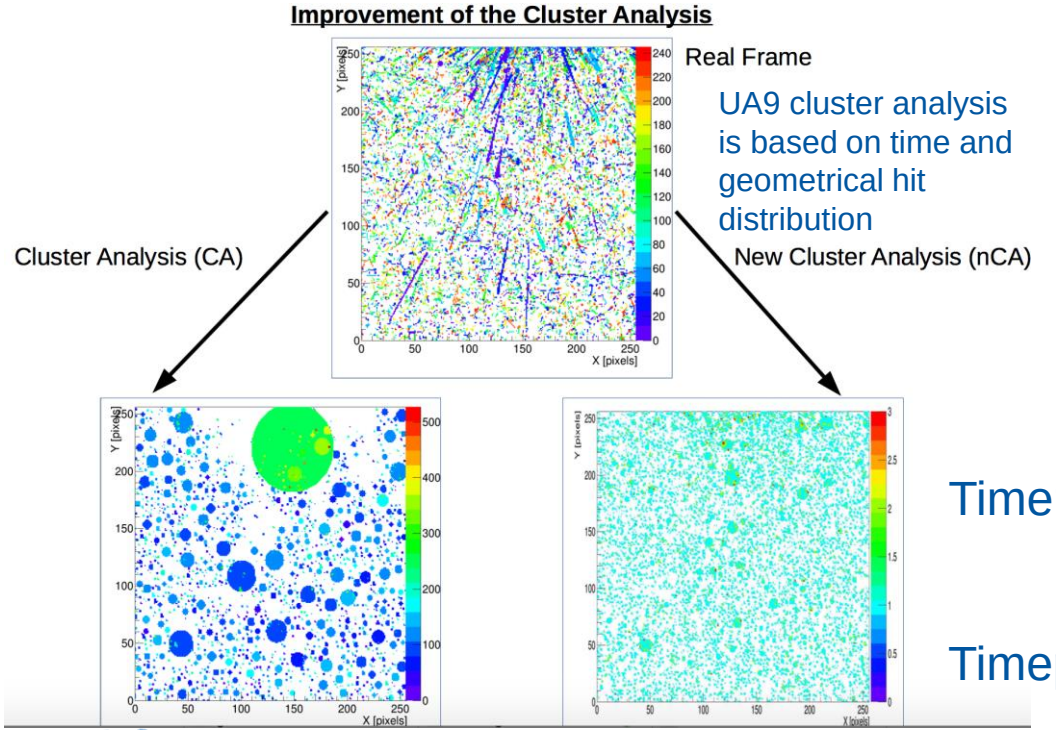

INI probability in an angular range close to the optimal planar channeling orientation ($\Theta_{in}$=0) **experimental data** versus **simulation**

New data with proton beam expected in 2018

# SPS North Area: MEDIPIX

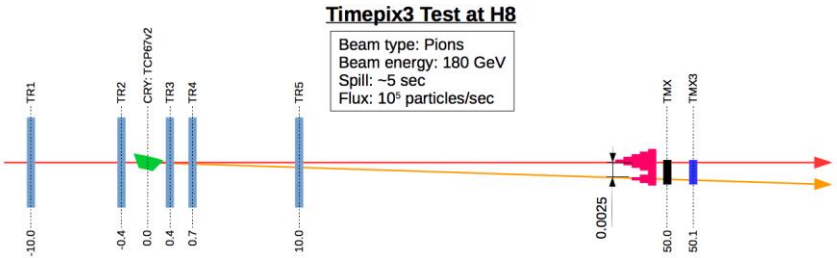


Goal: a realistic evaluation of the particle flux

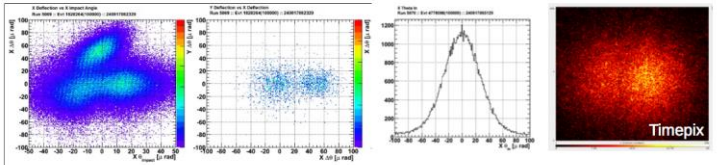



UA9 cluster analysis is based on time and geometrical hit distribution

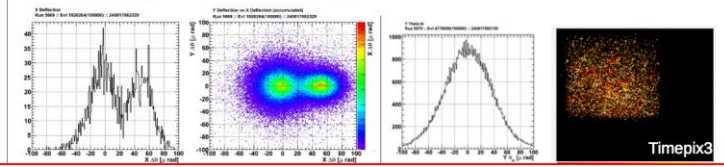
Goal: a large increase of the duty cycle in evaluating the particle flux




Timepix

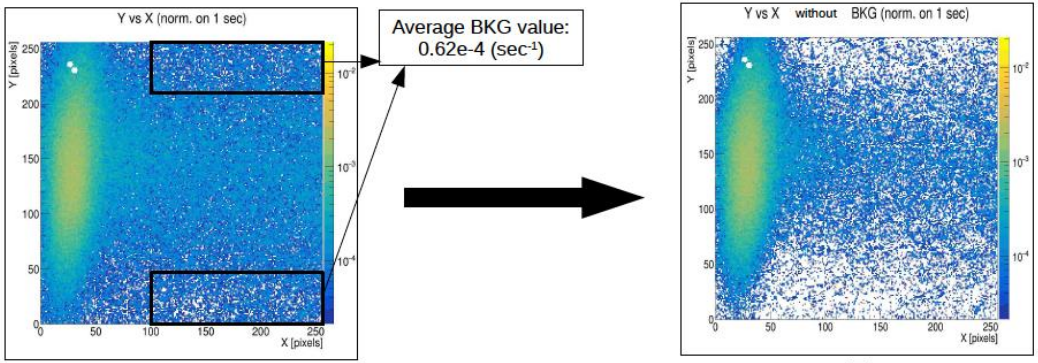



Timepix3




Full use of Timepix3 in UA9 expected in 2018

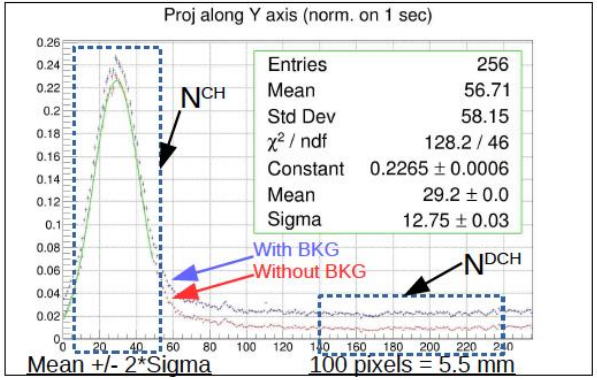
# SPS North Area: MEDIPIX




Goal: a realistic evaluation of the signal versus background

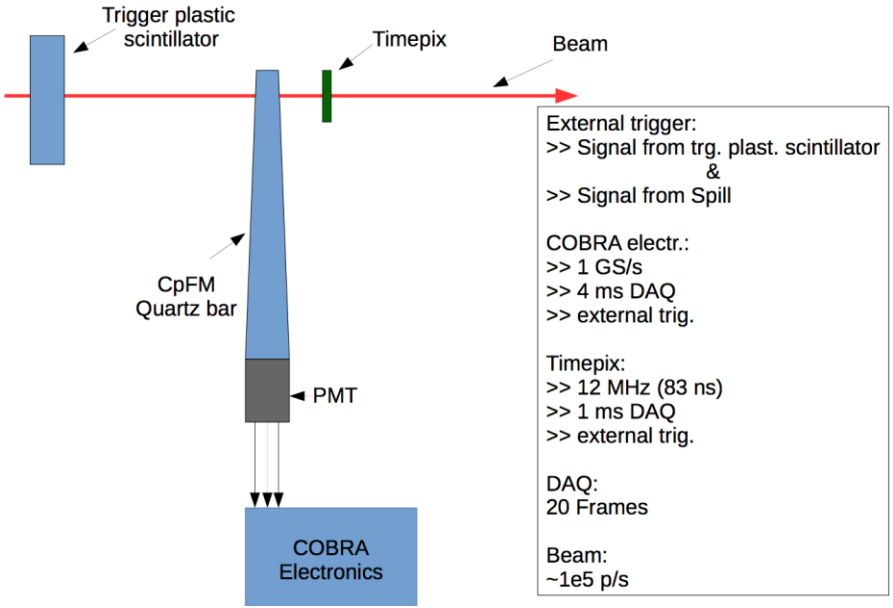
| | | |
|---|---|---|
| $N^{CH}$ | = 6.981502 | +/- 0.014395 |
| $N^{DCH}$ | = 0.166811 | +/- 0.000949 (mm$^{-1}$) |
| $N^{CH}/N^{DCH}$ | = 41.852768 | +/- 0.253259 |
| $\delta(N^{CH}/N^{DCH})$ | = 0.605119 % | |

In the **double crystal experiment** the MEDIPIX should be used to evaluate the **efficiency** and the **background** of the process



# SPS North Area: MEDIPIX and CpFM

**Timepix & CpFM (COBRA electronics). August 2017**




External trigger:
>> Signal from trg. plast. scintillator
&
>> Signal from Spill

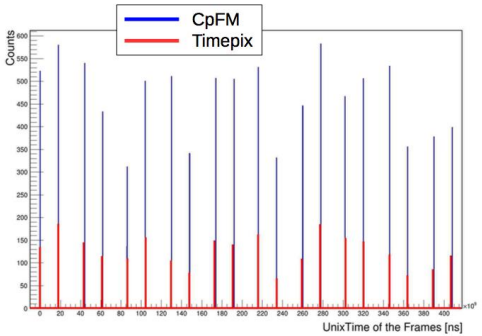
COBRA electr.:
>> 1 GS/s
>> 4 ms DAQ
>> external trig.

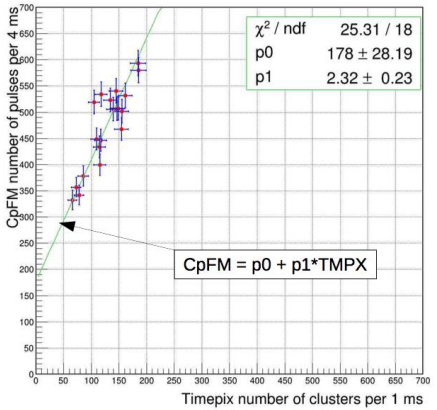
Timepix:
>> 12 MHz (83 ns)
>> 1 ms DAQ
>> external trig.

DAQ:
20 Frames

Beam:
~1e5 p/s

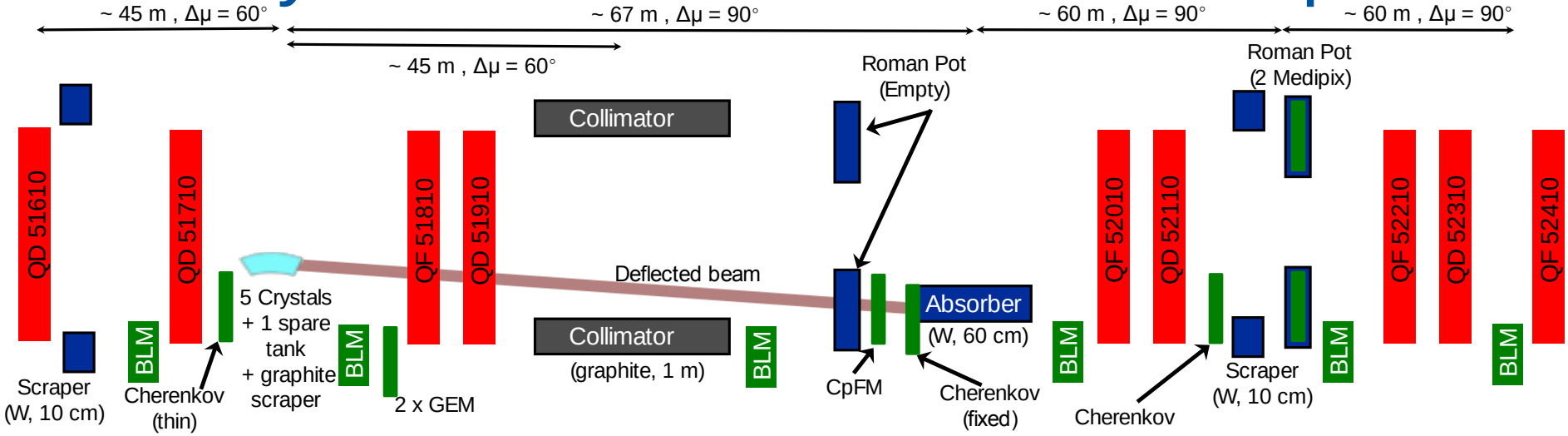
**Timepix & CpFM. Synchronization and lineatiry**



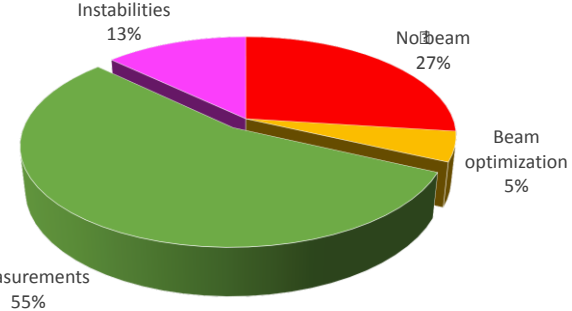

Goal: cross-calibration of the CpFM and the Medipix

# SPS: key issues from Oct 2016 to Sept 2017




- **Optics of double crystal process**
- **First successful test of double crystal process**
- **Effect of crystal miscut: performance of crystal 1 versus crystal 4**
- **Calibration of the CpFM** and the Medipix
- Source of beam instabilities

# SPS availability for UA9



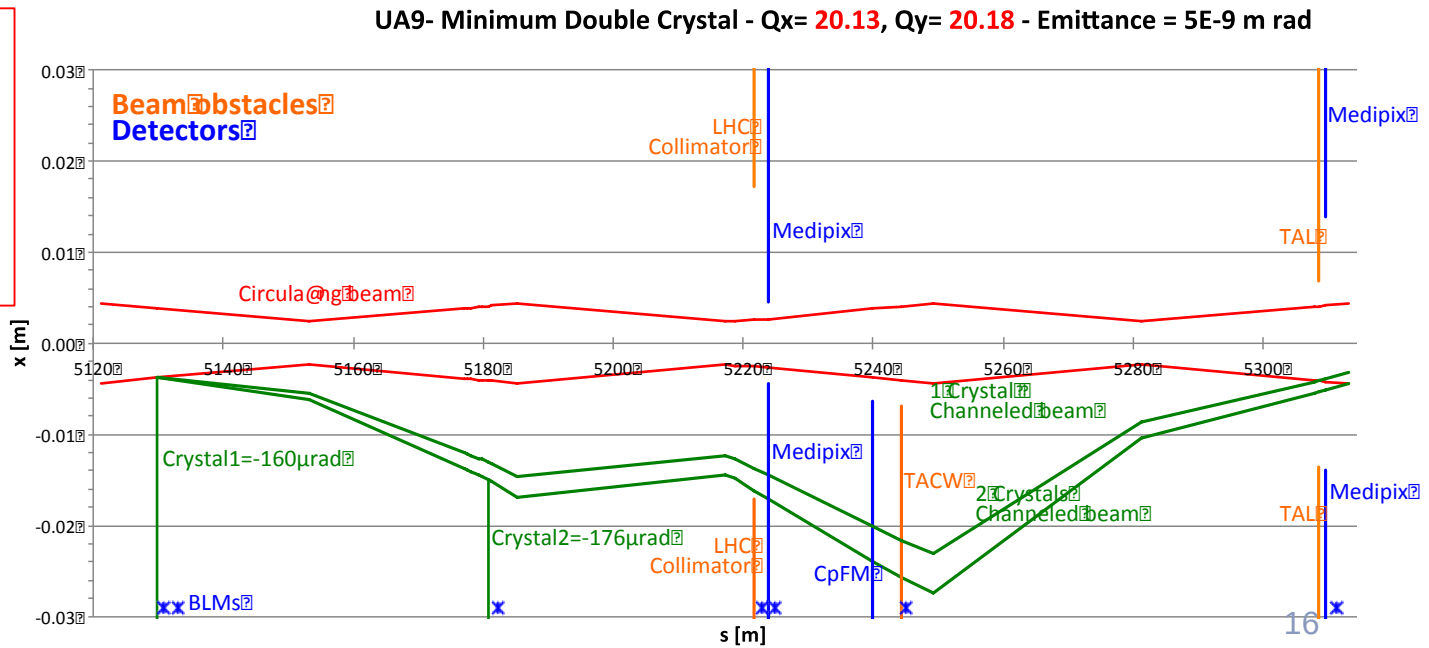

| Date | Total time [h] | No beam [h] | | Beam optimization [h] | | Measurements [h] | | Instabilities [h] | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| 18-Oct-16 | 24 | 6 | 25% | 0 | 0% | 17 | 71% | 1 | 4% | 1 Study of machine stability + data normalization 5 h<br>2 Medipix 2 h<br>3 Linear scans (angle measurement for CR4 and CR1) 4.5 h<br>4 CpFM scans 4.5 h |
| 23-Nov-16 | 21 | 6 | 29% | 2 | 10% | 11 | 52% | 2 | 10% | 0 LHC Collimator reset 1.5 h<br>1 Comparison Cr1 Cr4 4.5 h Debunched beam<br>2 Linear scans (angle measurement for CR4 and CR1) 2.5 h Debunched beam<br>3 CpFM scans + calibration 2.5 h Debunched beam |
| 30-May-17 | 23.5 | 10.5 | 45% | 0 | 0% | 10.5 | 45% | 2.5 | 11% | 1 ADT and diffusion 3 h<br>2 Q20 4.5 h<br>3 New crystals, Medipix and CpFM 3 h |
| 18-Sep-17 | 23.5 | 2 | 9% | 2.5 | 11% | 12.5 | 53% | 6.5 | 28% | 1 ADT and diffusion 3 h<br>2 CpFM 1.5 h<br>3 Channeling upstream crystal and characterization 4 h orbit off by 3 mm<br>3 Channeling downstream crystal and characterization 3 h orbit off by 3 mm<br>4 Medipix 1 h orbit off by 3 mm |
| Total | 92 | 24.5 | 27% | 4.5 | 5% | 51 | 55% | 12 | 13% | |

# SPS: optics for the two-crystal setup (April 2017)

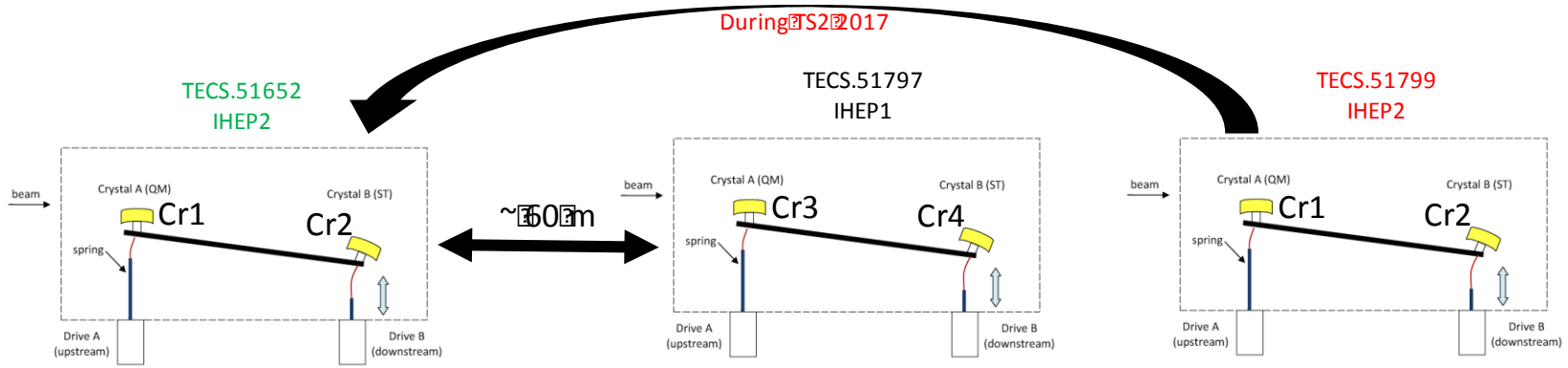
- Minimal addition of components
- Back-compatibility with collimation and extraction tests
- Correct phase advance of Crystal1, Crystal2 and absorber TACW at the tune value of $Q_x$ =20.xx
- Existing instrumentation sufficient to assess if the double-channeled beam can be produced

## Improvements for 2018

- Upgrade of instrumentation for advanced measurements
- Install another TACW-type absorber to operate at the nominal tune value of $Q_x$=26.xx

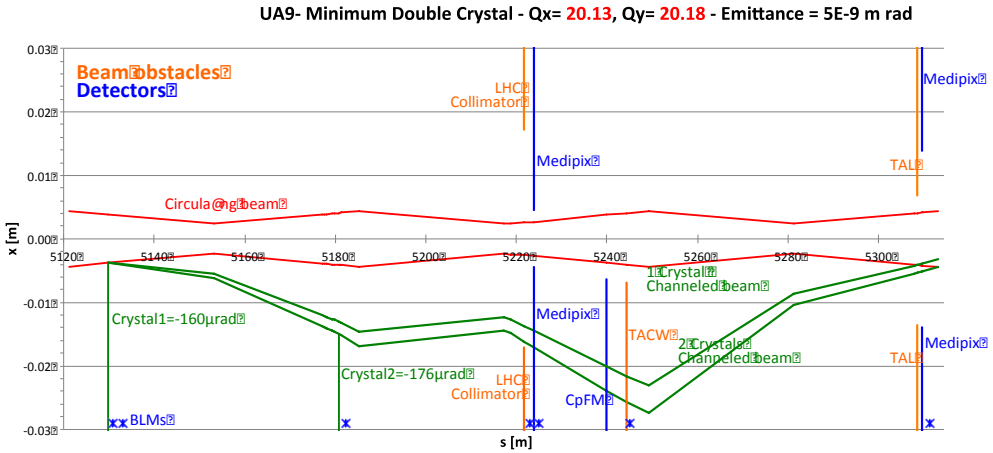


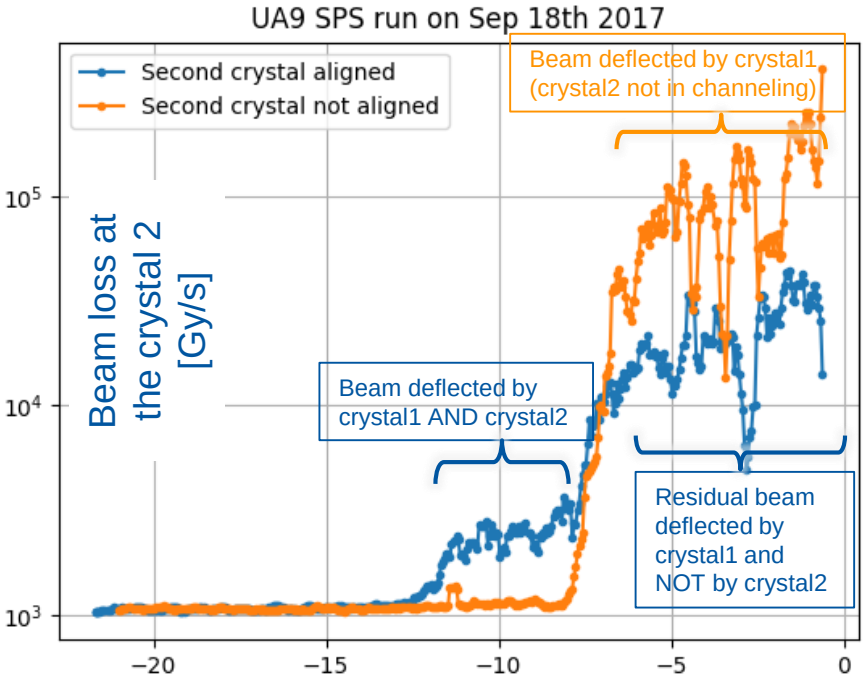
# SPS: double-crystal layout completed on July 5th




# SPS: first test of double-channeled beam

## 17-18 Sept 2017

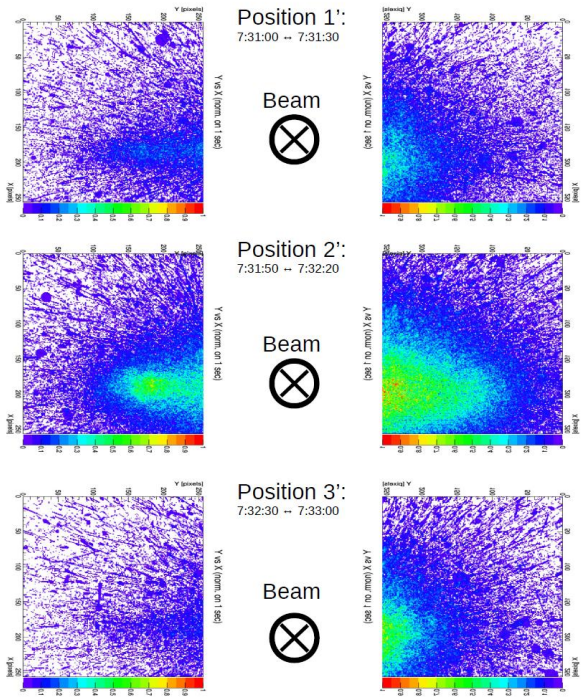


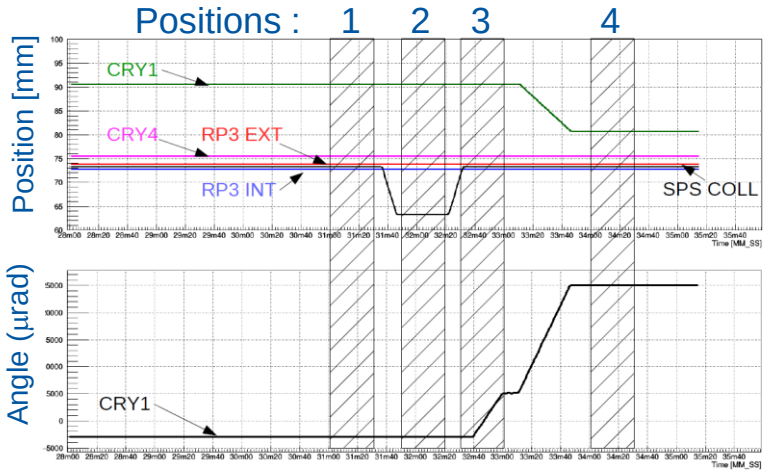



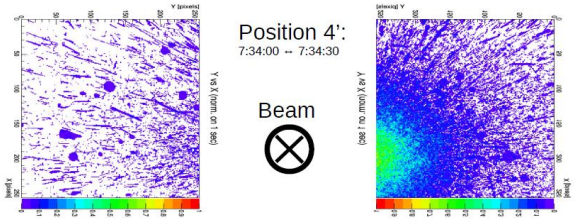
# SPS: double-channeled beam 17-18 Sept 2017

## Preliminary data collected with the Medipix detectors

RP3 EXT RP3 INT



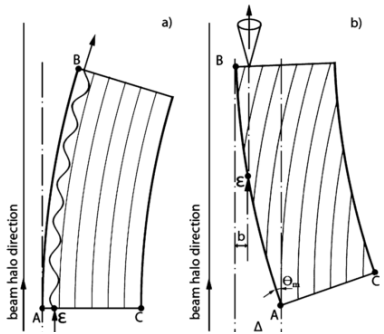

A new test is planned on 17 Oct 2017:

- improve the efficiency of the process by a better crystal positioning
- avoid multi-turn spots in the sensors by a better absorber positioning

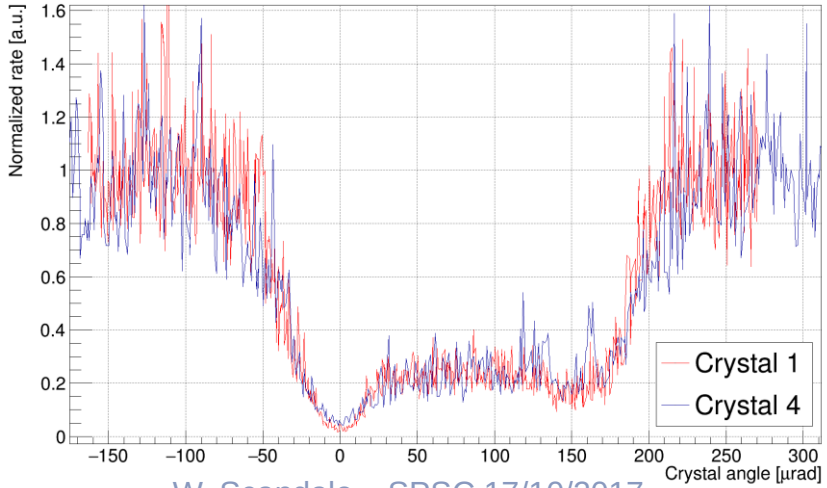
# SPS: crystals with different polishing

- The angle between the lattice and the surface of the crystal (mis-cut) can affect collimation performance
- Test with two strip crystals (INFN-FE) with identical geometry

| Crystal | Bending angle | Length (z) | Width (x) | Mis-cut angle | Torsion |
|---|---|---|---|---|---|
| 1 | 165 µrad | 1.87 mm | 0.5 mm | 6 µrad | < 1 µrad/mm |
| 4 | 176 µrad | 2.00 mm | 0.5 mm | 200 µrad | < 1 µrad/mm |




| | Crystal1 | Crystal4 |
|---|---|---|
| ΔCRY-TACW [mm] | 0.96 | 1.93 |
| Emittance [µ rad] | 6.00E-9 | 6.00E-9 |
| Crystal position [σ] | 9.19 | 4.23 |
| Date | 2016/10/18 | 2016/10/18 |
| Time GMT | 09:00:27 | 17:30:00 |



# Calibration of the CpFM with Pb-ions – Dec 2016

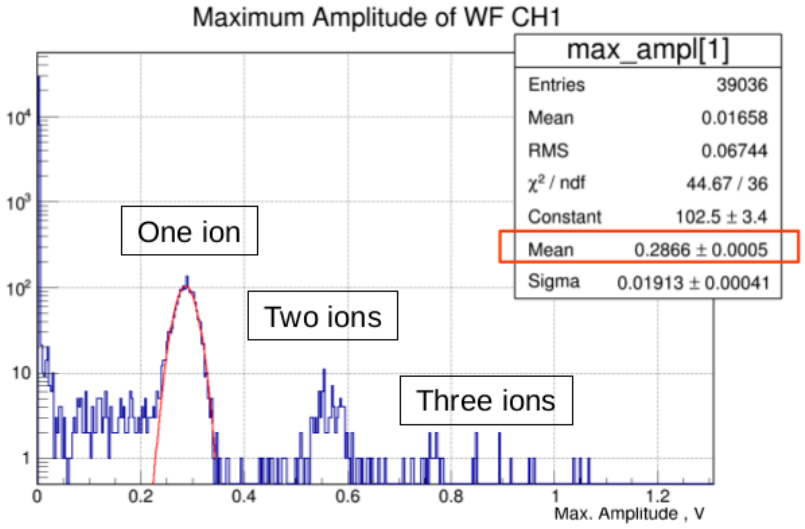
Pb-ions produce about 6724 times more light than protons

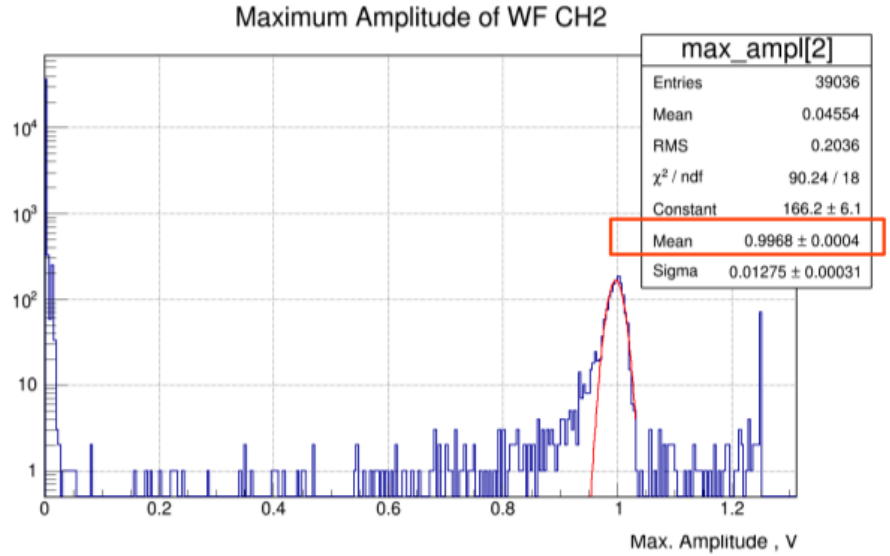
→ separate contribution of 1, 2, 3 ions individually

→ Compute the no. of photoelectrons per proton

Photoelectron yield efficiency

- 0.066 ± 0.043 (p.e. / proton) for CpFM1
- 0.218 ± 0.111 (p.e. / proton) for CpFM2
- Expected from simulations : 0.6 p.e./proton !




Actions during YETS 17 to improve the detector sensitivity:

Replace the two radiators with a single one

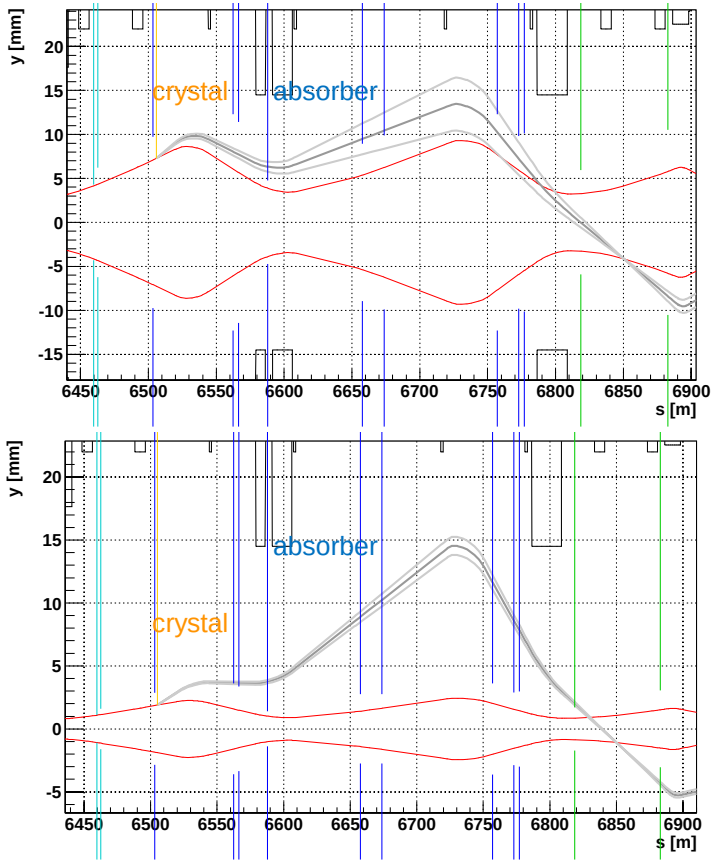
Remove the fiber bundle

# LHC: crystal installation in Ring 2

Semi-analytical studies has been provided to find the best location to install the crystal on beam 2 line.

The possible available location where evaluated wrt the clearance obtained at the absorber collimator

The grey line represent the envelope channeled beam extract from a 50 μrad bent crystal.
The lighter line represent the kick plus (and minus) a critical angle, hence the channeled beam size envelope is represented
The red lines represent the beam envelope

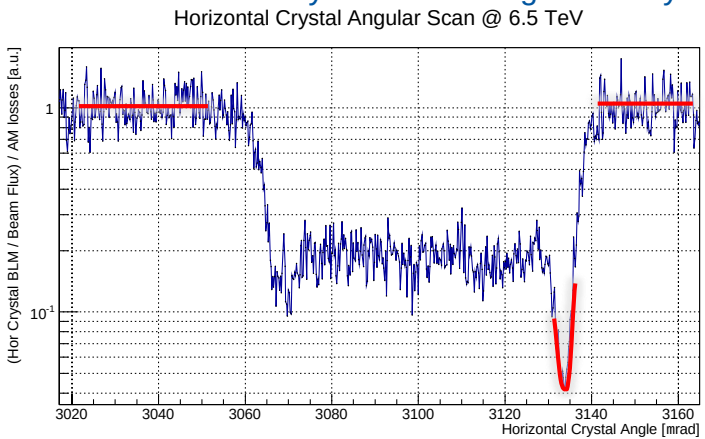


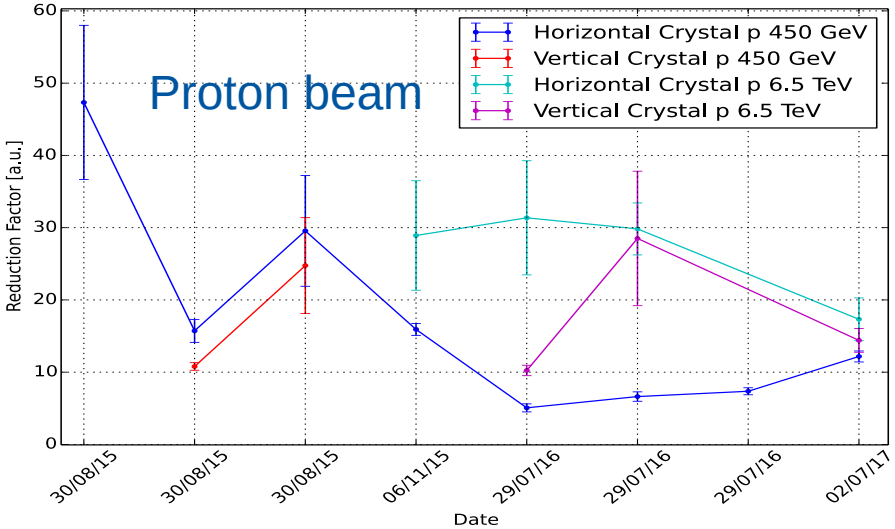
# LHC - Local Loss Reduction

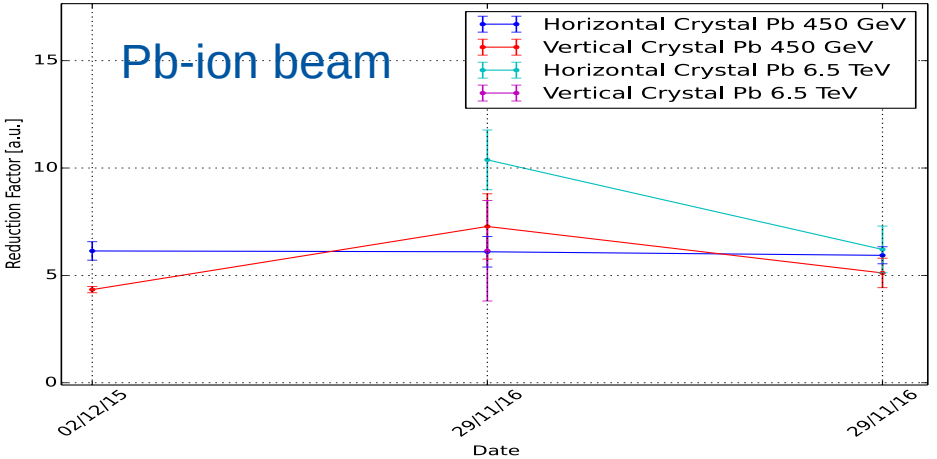
Crystal angular scans give information about crystal channeling efficiency

Channeling loss reduction with respect to amorphous on Ring 1.

Data collected in the years 2015-’16-’17.



# Requests for 2018

- Request in H8
- 18 days with 400 GeV protons
- 7 days with ions

## GOAL IN H8

1. Identifications of crystals for LHC and SPS runs
2. Correlation of the bending angle values obtained with beam and X-ray source
3. New technology crystals (large bending angle)
4. Focusing crystals for SPS
5. Calibration of Medipix and CpFM detectors for the double crystal test in SPS

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

## GOAL IN the SPS

1. Complete the studies started in 2017 on the double crystal test
2. Evaluate the efficiency and the background of the double crystal process
3. Extend the double crystal test by inserting the target in front of the second crystal in view of detecting the change of efficiency and background and of optimizing the performance

# Acknowledgments

Several CERN groups supported the UA9 activity, helping in the procurement, the installation and the operation:
EN/STI, EN/HE, EN/EA, BE/ABP, BE/OP, BE/RF,TE/ABT, TE/VSC, TE/MPE

## Publications and thesis

1) *"The CpFM, an in-vacuum Cherenkov beam monitor for UA9 at SPS"*, V. Puill et al., JINST 12 P04029 (2017);
2) *"Possibility of high efficient beam extraction from the CERN SPS with a bent crystal. Simulation results",* W. Scandale et al, Nuclear Instruments and Methods in Physics Research A 848 (2017) 166–169;
3) *"Measurement of multiple scattering of high energy protons in bent silicon crystals"*, W. Scandale et al, Nuclear Instruments and Methods in Physics Research B 402 (2017) 291–295.

One master thesis concluded

Two PhD thesis to be completed by 2017

The Department of Nuclear Physics and High Energy Physics of Taras Shevchenko National University of Kyiv (TSNUK) requested to join UA9 in 2018

Thank you for your attention!