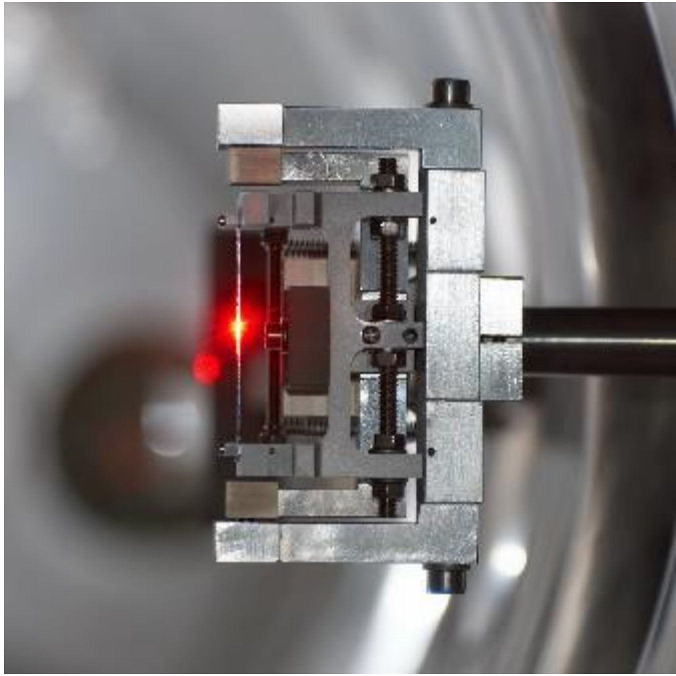
Status of UA9

W. Scandale on behalf of the UA9 Collaboration

- Outline of the measurements and tests in 2018
  - “double crystal” experiment
  - Slow extraction assisted by a bent crystal
    - Shadowing of the electrostatic septum
    - Non-resonant extraction
  - Crystal characterization in the H8 line of the North Area
  - Plans for the future
  - Publication list

In the entire year 2018 our reporting line was significantly modified:

- *The UA9 activity was scheduled in parasitic mode (masked time) both in H8 and in SPS*
- *The scientific plans and the experimental issues were discussed and approved in the frame of the technical departments*



Motivation for a double-crystal proof of principle in the SPS

"Parasitic fixed-target experiments" were proposed for LHC (see SPSC-EOI-012 and Eur. Phys. J. C (2017) 77: 828) based on:

- 1 bent crystal to separate the beam halo from the circulating beam
- 1 target + crystal assembly positioned along the deflected halo
  - to generate short living polarized particles, such as Λ_c , in the target
  - to let their magnetic moment precess in the bent crystal.

Magnetic moment of channeled particles should precess in a bent crystal

$$J_{spin} = \frac{g-2}{2} g J_{crystal}$$

See V.G. Baryshevskii, Pis'ma Zh. Tekh. Fiz.5, 182 (1979) and PLB 757 (2016) 426-9.

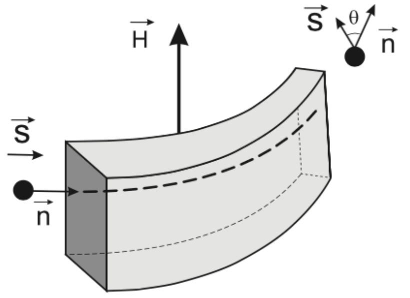


Figure 1. Spin rotation in a bent crystal

Tests in the SPS should clarify:

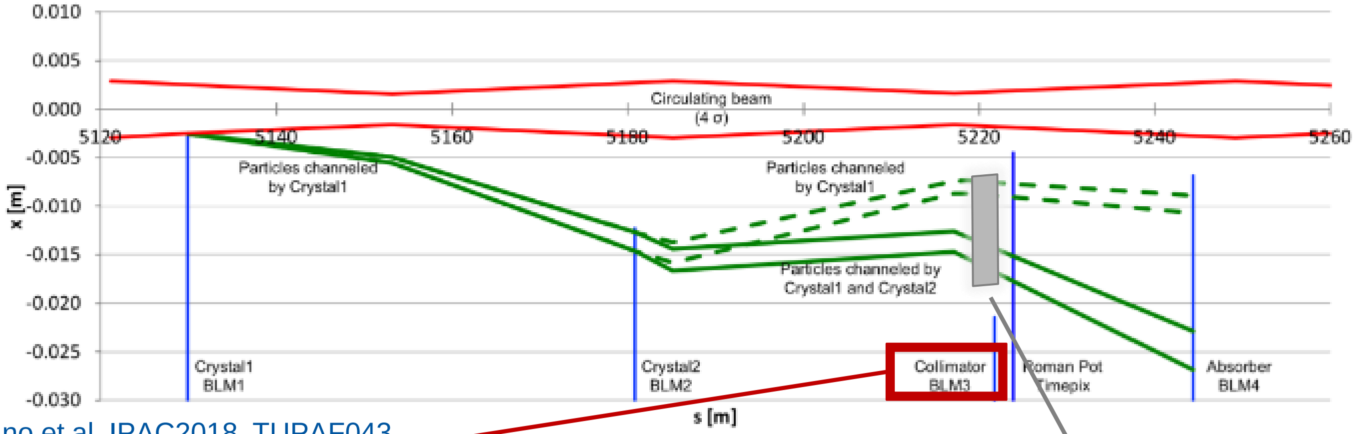
- Optimization of the double channeling process
- Control of the background
- Machine protection issues of interest for LHC

Minimal changes in the SPS UA9 layout provided a valuable test bench for the double-crystal scenario in LHC

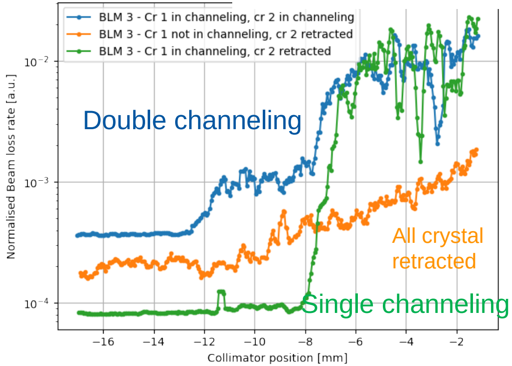
Observables:

- Efficiency of double channeling, with and without target
- Background estimate

First observed double channeling with a thin second crystal



S. Montesano et al, IPAC2018, TUPAF043



Scan of the beam peripheral

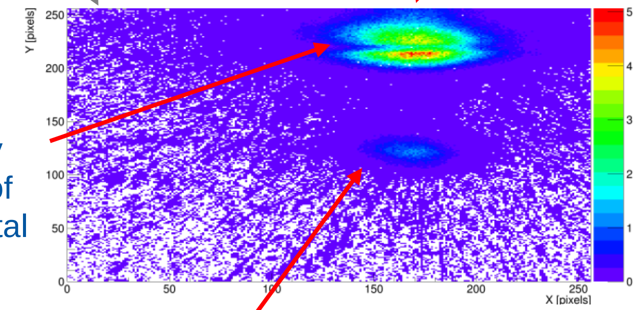
Only a small fraction of the first channeled beam could be channeled a second time because Crystal2 thickness = 0.5 mm, i.e. ~ ¼ expected beam spot

→ A WIDER crystal is needed

Pixel detector

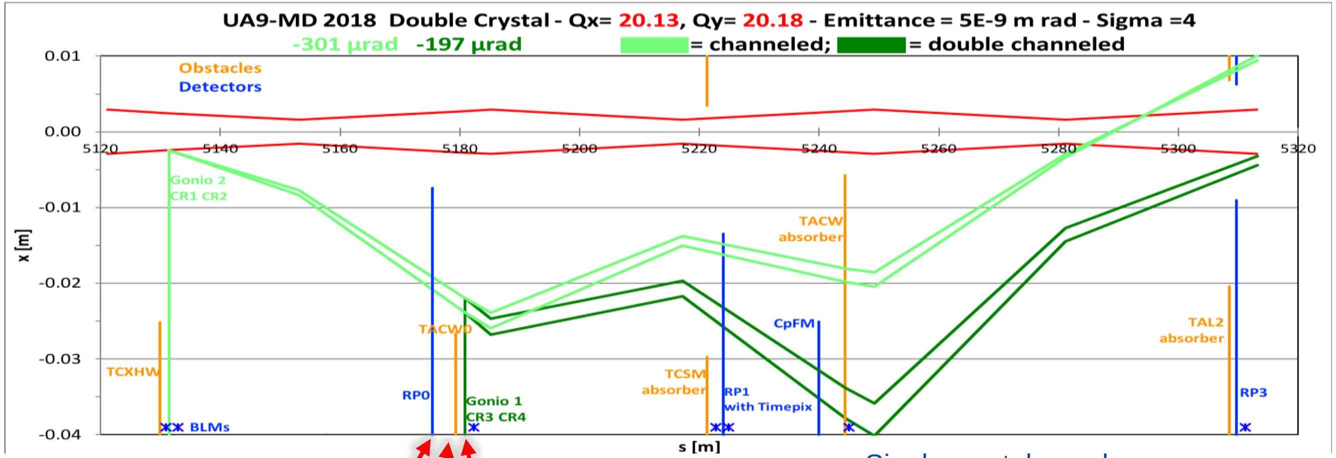
Part depleted by the channeling of the second crystal

Single deflected halo

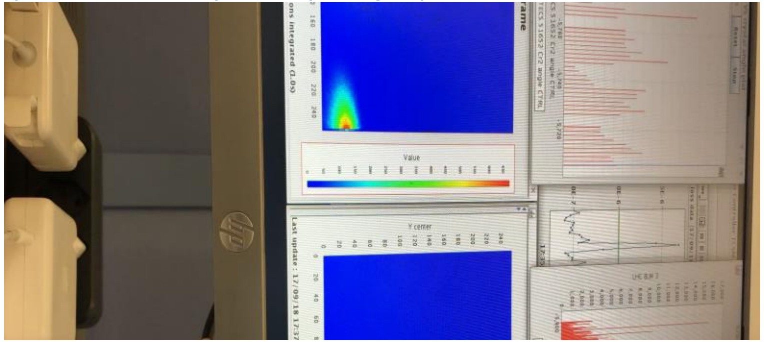


Double deflected halo

Layout upgrade and latest observation of channeling



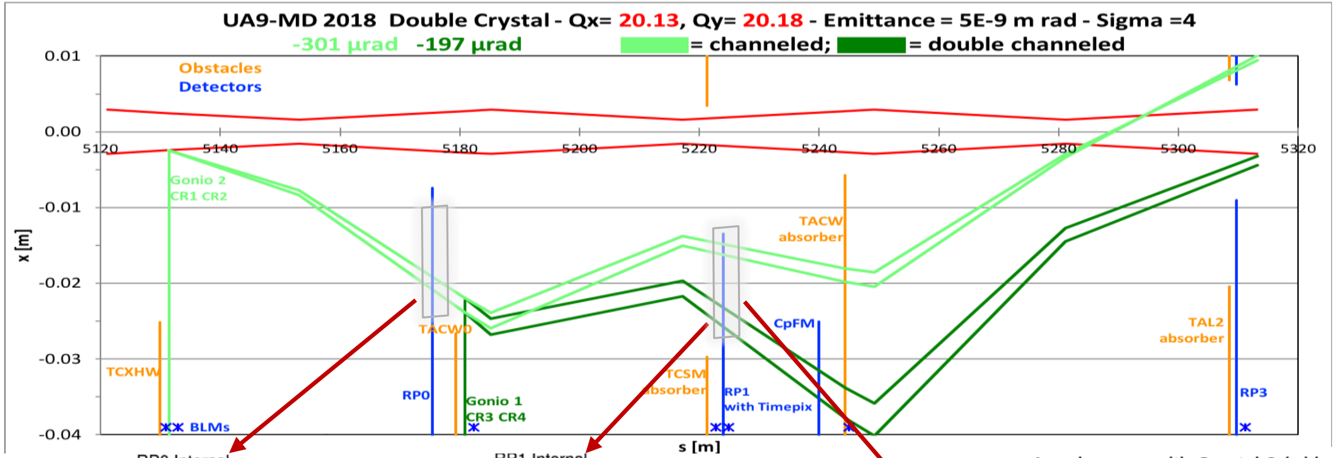
Single crystal angular scan:
Online observation from channeling to volume capture
θ_{Cr2} = 300 µrad
(Axes continuously self adjusting !!!!)

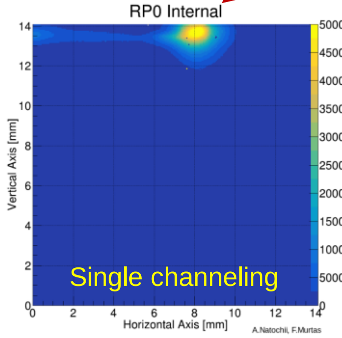


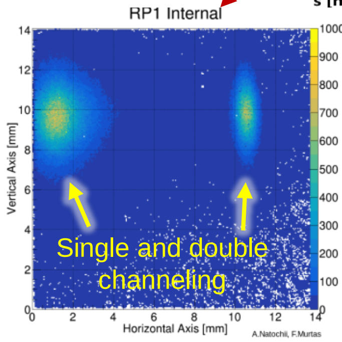
Added equipments:

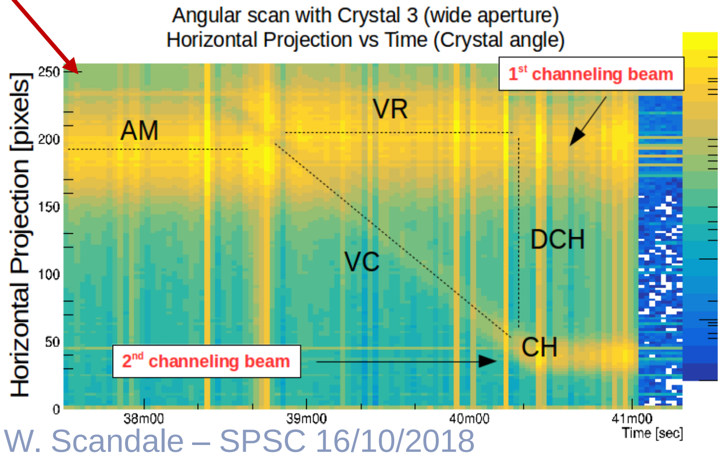
1. A 4-mm wide crystal installed in the downstream gonio
2. A new Roman Pot (RP0) equipped with Timpix2
3. A new Tungsten Absorber

Layout upgrade and latest observation of DOUBLE channeling





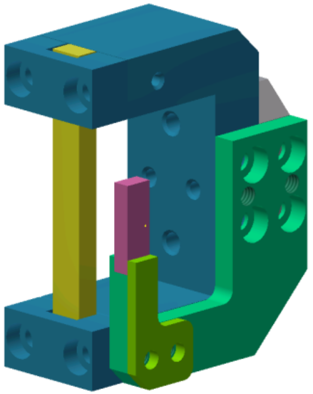




The UA9 in-vacuum detectors, Timepixes and CpFM, had crucial role to position and orient the second crystal

Next step: double channeling with a target

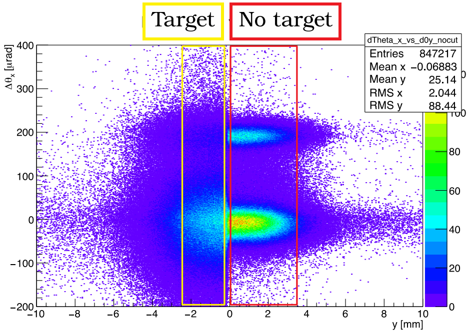
- A 3 mm long W target was inserted in SPS LSS5 in September 2018
- The W target totally shadows the second crystal
- Reference data have been taken in double channeling without the target, and final analysis is in progress
- We need now to complete the data set with same data with target in order to evaluate the process efficiency and the relative background



Extra run of 10 h requested in October/November 2018

TCP72 (PNPI) analysis procedure

Test of crystal with inserted target:



A similar crystal half covered by a Tungsten target, as measured at our H8 test-beam, and bending in the vertical direction

Crystal + ½ target assembly test in H8

Slow extraction studies at CERN SPS

- **Extraction flux ~4 x as today** (up to 4 x 10^{19} PoT/year) required for future Fixed Target programs at CERN SPS (i.e. Beam Dump Facility (BDF) and SHiP)
- At SPS it is expected that about **1% of extracted particles hit the Electrostatic Septum** (ES) wires creating radiative losses (measured value is 3.4±0.7%, Fraser, Slow Extraction Workshop 2017)

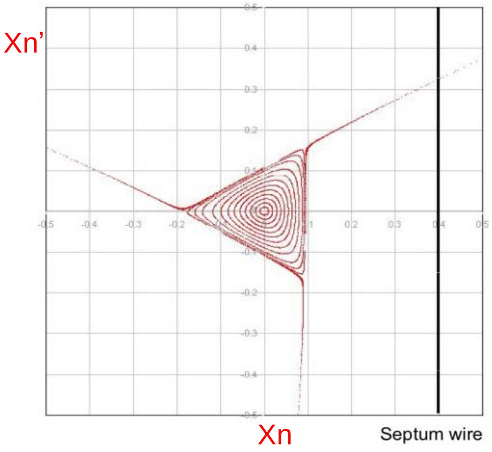
  → *showstopper for BDF from machine side*

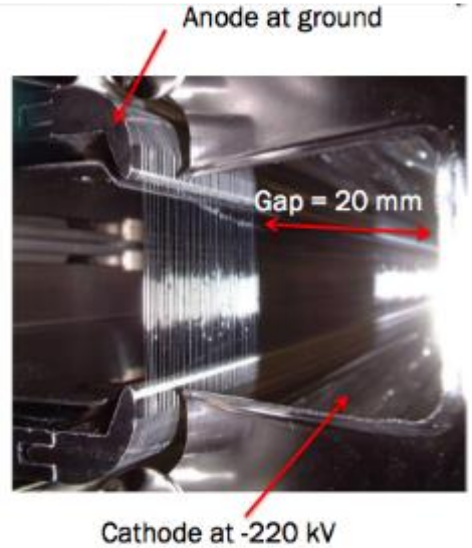
  - The irradiated wires tend to spark and may be damaged at the highest beam intensities
  - The secondary particle showers strongly activate the area downstream and can also affect the high voltage performance of the ES
- Ongoing studies to reduce the losses at the ES using bent crystals:
  - Crystal-assisted shadowing of the ES
  - Non-resonant extraction using bent crystals and a stochastic transverse beam excitation

Shadowing of the ES-septum with a bent crystal

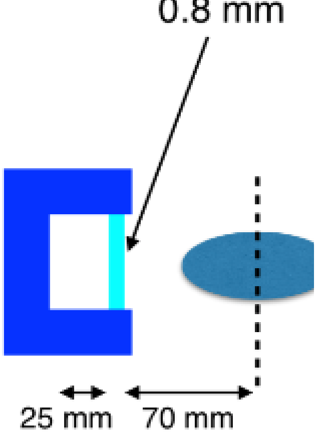
Joint activity with TE/ABT and EN/STI

Phase space during resonant extraction

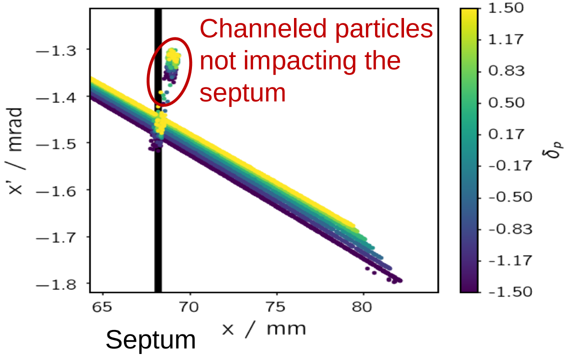




Schematic crystal shape for shadowing

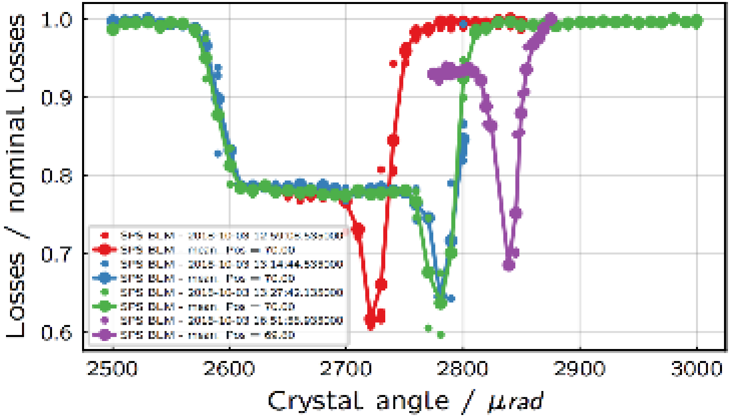


Protons are deflected 5m upstream of the ES, to avoid loss with the anode wires



- The crystal was installed in the recent TS in place of the already-tested passive diffuser 5 m upstream of the ZS
- in the very first tests of Oct 3rd with a 1-second 400 GeV spill

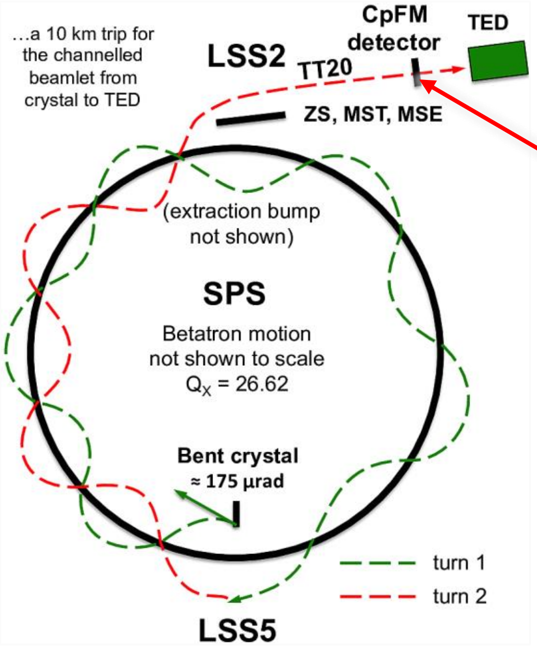
a loss reduction at the ZS of 40% was recorded.

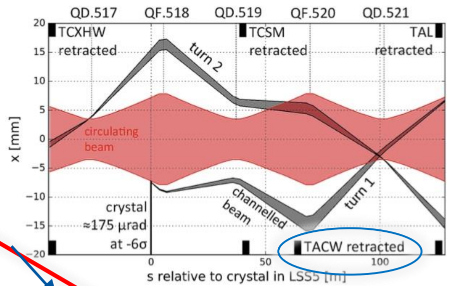


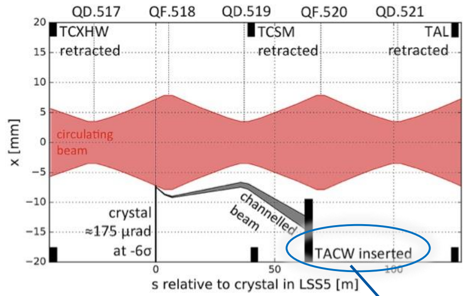
Crystal-assisted non-resonant slow extraction

Joint activity with TE/ABT and EN/STI

- Use the original UA9 infrastructure (goniometers with crystals, absorbers, detectors)
  + an on purpose Cherenkov detector (CpFM) down the extraction line TT20
- Non-local → UA9 Goniometers (LSS5) and Fixed Target Extraction Line are opposite in the SPS ring
- Stochastic → particle diffusion from the beam core was enhanced by means of the Transverse Adiabatic Damper (ADT, random transverse kicks) → different ADT excitation = different extraction rate

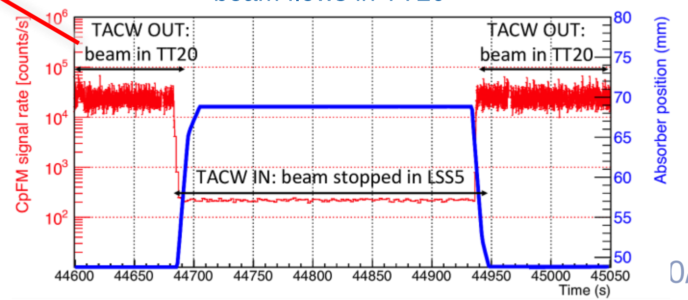






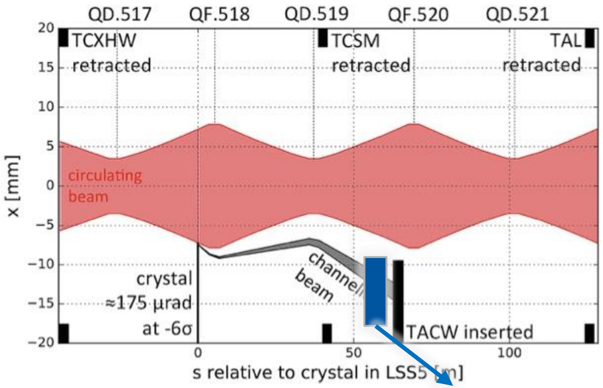
TACW retracted: the beam flows in TT20

TACW inserted: the beam is stopped

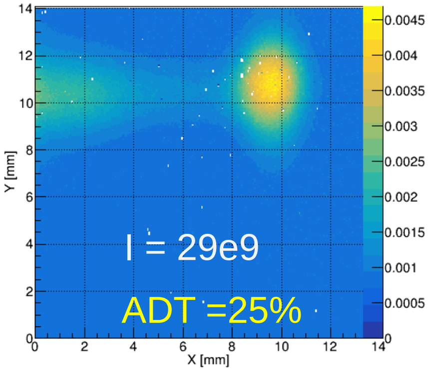


Halo density in channeling mode

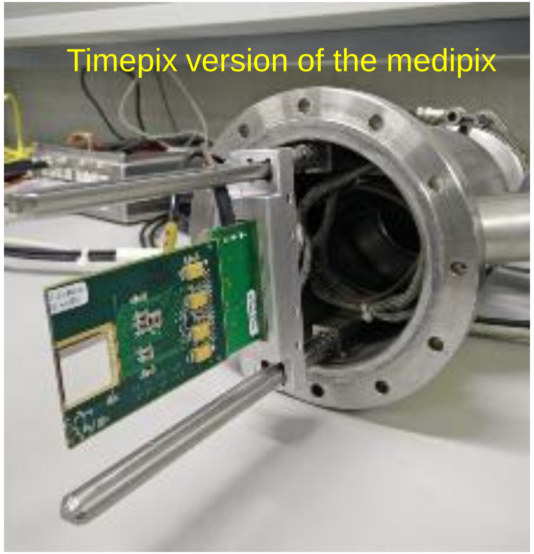
The halo density in channeling mode provides an accurate estimate of the beam loss at the ES septum for non-resonant extraction configuration.

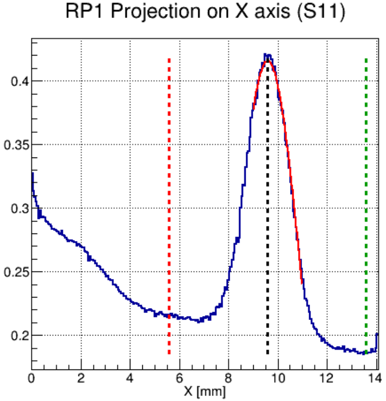


Medipix detector



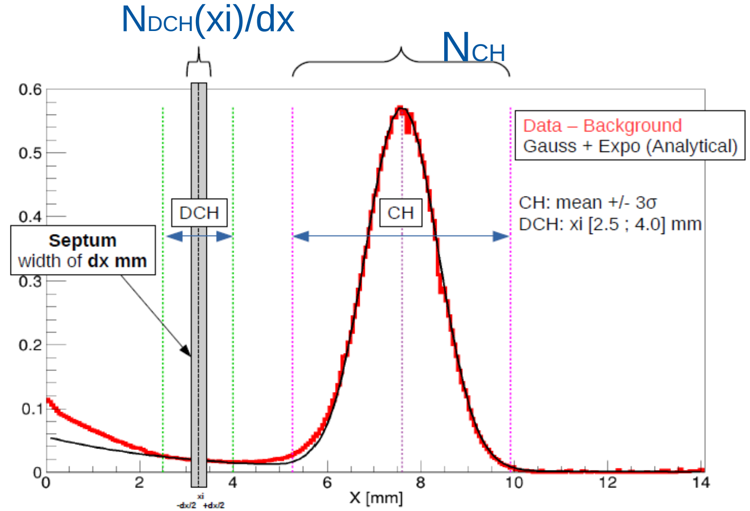
The ADT level changes the diffusion speed of the beam core to the halo region

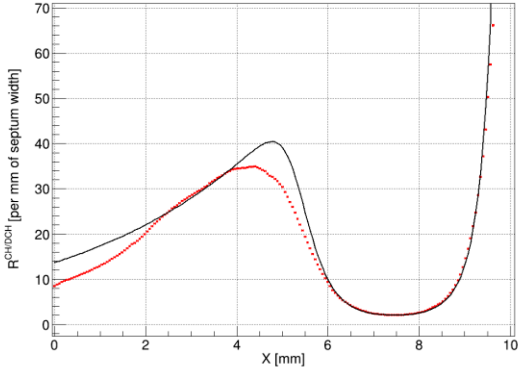




Projected halo density along the horizontal axis (self-normalized to the total No of impinging particles)

Estimating loss in crystal-assisted non-resonant extraction





$R^{CH/RCH}$ is the ratio of the extracted intensity by the ES loss (per mm of ES septum width)

Estimating the loss ratio in the ES septum

- Evaluate the particle per pixel impinging in the medipix
- Compute the particle flux per pixel column
- Subtract the background
- Compute the deflected flux N_{CH} (in the Gaussian peak)
- Chose the “septum” location (the grey area)
- The “septum” is at 3.5 mm from the core beam border for a close-to-minimal loss ratio
- The “septum” thickness is 0.2 mm
- Compute the “lost” flux N_{DCH} (in the grey area)
- The loss ratio expected in the septum is $R \approx N_{DCH} / N_{CH}$

Loss/Extr. Intensity = ~6 ‰

SPS North Area: key issues

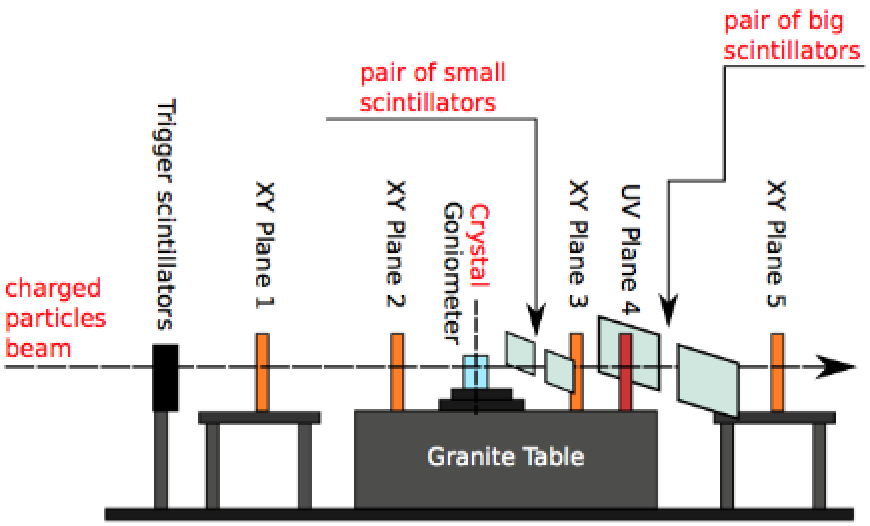


FIG. 1: Experimental layout in the H8 beam line.

- Upgrade of the telescope
  - Calibration of the Si-strip for lead-ion tracks
  - Alignment and fine-tuning of scintillation counters in view of investigating the shadowing process of an extraction septum with a crystal or an amorphous wire
- Procurement and test of crystals
  - Collimation crystals for LHC during LS2
  - Double crystal experiment in the SPS ring
  - Shadowing experiment in the SPS extraction channel
- Cross-section of inelastic nuclear interactions (INI)
  - LHC crystals as a quality indicator
  - Shadowing crystals for statistical purpose

SPS-North Area: Oct 2017 - Oct 2018

NA-H8 Test beam

47 days assigned in 7 runs : 15d main user, 32d parasitic

Effective time: ~ 45 % (~55 % lost for machine problems)

2017

Primary Xe Ion Beam

Main user

- *November 23^{th}-29^{th}* *(150 AGeV)*
- *December 4^{th}-7^{th}* *(40 AGeV)*

2018

Secondary Pion beam

(180 GeV)

Parasitic to TOTEM

- *April 9^{th}-18^{th}*
- *May 16^{th}-23^{rd}*
- *June 13^{th} – 18^{th}*
- *August 15^{th} – 22^{nd}*
- *September 12^{th} – 17^{th}*

2018

~~Primary proton beam~~

~~(400 GeV)~~

~~No protons delivered for microcollimator problem!!!~~

LHC strip crystals

- Massive effort to procure and qualify the crystals required in LHC and their spares for the RUN3 of Hi-Lumi ion operation
  - Quality-control criteria
    - crystal bending in the range 50 to 55 μrad
    - the torsion < 1 μrad/mm
    - long-term stability of the holder for repeated thermal cycles (LHC degassing procedure)
  - Evaluate the correlation between beam and X-ray measurements of the crystal bending angle and torsion

Results:

ACP Crystals (PNPI): 5 crystal prepared in 2018

- 5 fully characterized: final analysis is ongoing
- Additional prototypes

STF Crystals (INFN-Fe): 13 crystals prepared in 2018

- 6 fully characterized: final analysis is ongoing
- 3 not fully characterized. Ready for the end of the year if we will have additional H8 beam
- 3 preliminary prototypes
- 1 rejected

‘Crystal day’ due on Oct 19th to establish the LHC policy for LS2

UA 9

Other measurements in H8

Crystals for shadowing and "double crystal" experiment

- 3 crystals to assist the slow extraction from the SPS (electrostatic septum shadowing)
- 1 crystals for the double crystal experiment in the SPS

One focusing crystal

Four large angle crystals

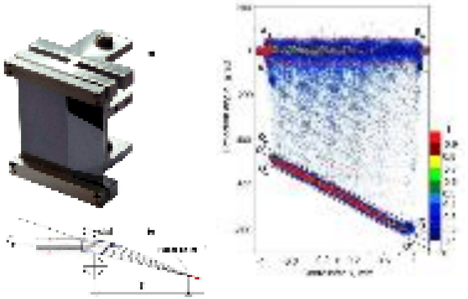
- «PL10»: angle ~3.4 mrad, length = 8 cm, width = 1 mm
- «PL10B»: angle ~12 mrad, length = 8 cm, width = 1 mm
- «PL11»: angle ~12 mrad, length = 8 cm, width = 5 mm
- «LCP61»: angle ~5 mrad, length = 1 cm, width = 1 mm

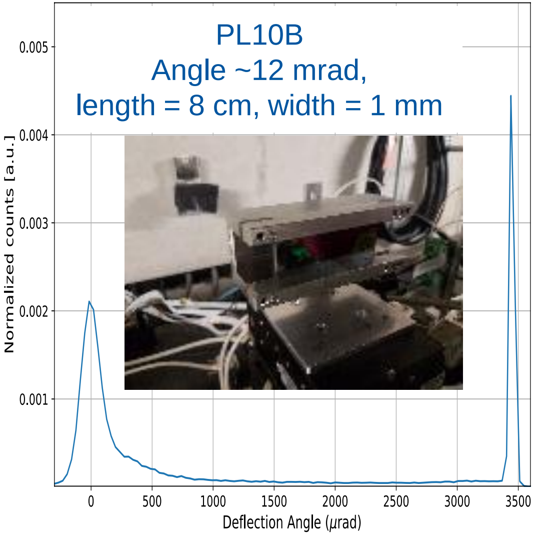
One self standing crystal (STF115) of 72 µrad

Two LHC crystals irradiated in HiRadMat at CERN in 2017

Eight crystals irradiated with 5 x 10^{20} fast neutrons (E> 1 MeV)

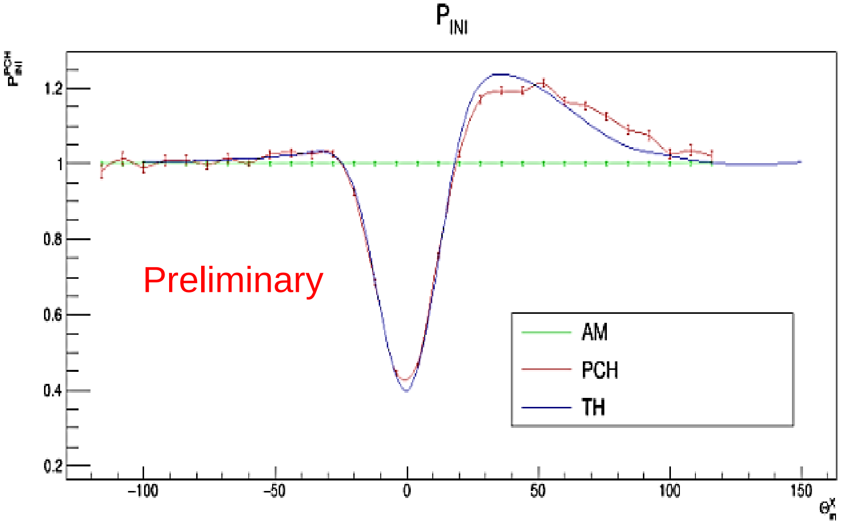
Focusing crystal



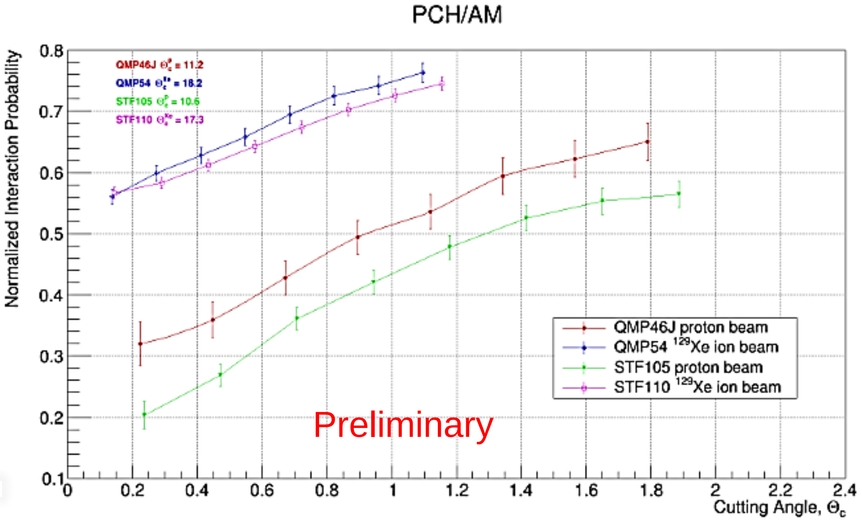


SPS North Area: Inelastic Nuclear Interactions (INI) studies

Objective: Study the Inelastic Nuclear Interaction probability with respect to the crystal orientation. Useful to understand the losses produced in a circular machine



Trend of INI probability of 180 GeV pions in a LHC crystals as a function of its orientation with respect to the beam



INI probability of heavy ions (150 GeV/n Xe) in channeling orientation for LHC silicon crystal. Comparison with INI of 400 GeV protons

Plans for 2019 and beyond

GOAL IN H8

1. Consider continuing the crystal tests at FNAL, LNF and Protvino during LS2
2. Build a portable telescope Timepix based
3. Continue procuring and testing crystals for LHC and SPS test runs during RUN3
4. Investigate correlation of crystal parameters measured with beam and with a X-ray source
5. New technology crystals in particular
   - large bending angle crystal with a sufficiently large efficiency for FT in LHC
   - focusing crystals for steering split halo-beam in LHC
6. Upgraded detector tests
   - In-vacuum Cherenkov detectors for the double crystal test in SPS and later for characterizing deflected ion beams in LHC
   - Next generation of Medipix for SPS

GOAL IN the SPS

1. Test and performance assessment of a crystal-assisted local/non-local non-resonant slow extraction, in view of reducing loss in the ES septum. Consider installing a more local setup or strong bumpers at the crystal to operate in cycled mode and more in-vacuum loss diagnostics
2. Pursue the shadowing test to bring immediate benefits for the daily SPS operation and ensure a safe extraction scenario for the high intensities required by the Beam Dump Facility
3. Investigate non-resonant extraction scenarios for LHC and beyond
4. Pursue investigation of beam splitting scenarios for FT physics in LHC

Modify the UA9 setup during LS2 to comply with the installation of a dump in LSS5, required for loss control during the SPS operation

Conclusive remarks

Main achievements of the UA9 collaboration

CRYSTAL COLLIMATION

- Crystal-assisted collimation fully demonstrated in the SPS; demonstration in progress in LHC
- Entire set of crystals for LHC collimation procured and tested in H8 (robust test procedure well assessed)
- Prototype goniometer for LHC procured and tested
- One final LHC goniometer procured, tested and installed
- Crystal-goniometer alignment issues identified and solved
- Beneficial effects of crystal collimation confirmed in the high-β TOTEM physics runs
  (first successful application of crystals in a collider physics run, ever demonstrated)

CRYSTAL EXTRACTION

- Proof of principle of a crystal-assisted non-local non-resonant slow extraction completed in the SPS
- Proof of principle of the shadowing mechanism demonstrated in the SPS extraction to TT20
  (Loss reduction at the electrostatic extraction septum observed during the SPS resonant extraction)
- Crystal-goniometer setup for shadowing conceived, built, installed and successfully tested in the SPS

PHYSICS BEYOND COLLIDER

- Double-channeling experiment in the SPS and the characterization of large bending angle crystal in H8 useful to solve the challenges for a full scale fixed-target experiment in the LHC.

INSTRUMENTATION

- Telescope to characterize the crystals in a beam line fully optimized and perfectly operational
- In-vacuum instruments well developed and optimized for collider operation with bent crystal

Acknowledgments

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

Publications and thesis

1) *"Focusing of a particle beam by a crystal device with a short focal length,", W. Scandale et al., NIMB 414 (2018) 104-106;*
2) *"Comprehensive study of beam focusing by crystal devices", W. Scandale et al., Phys. Rev. Accelerators and Beams 21 (2018) 014702;*
3) *"Study of inelastic nuclear interactions of 400 GeV/c protons in bent silicon crystals for beam steering purposes", W. Scandale et al., Eur. Phys. J. C (2018) 78:505.*

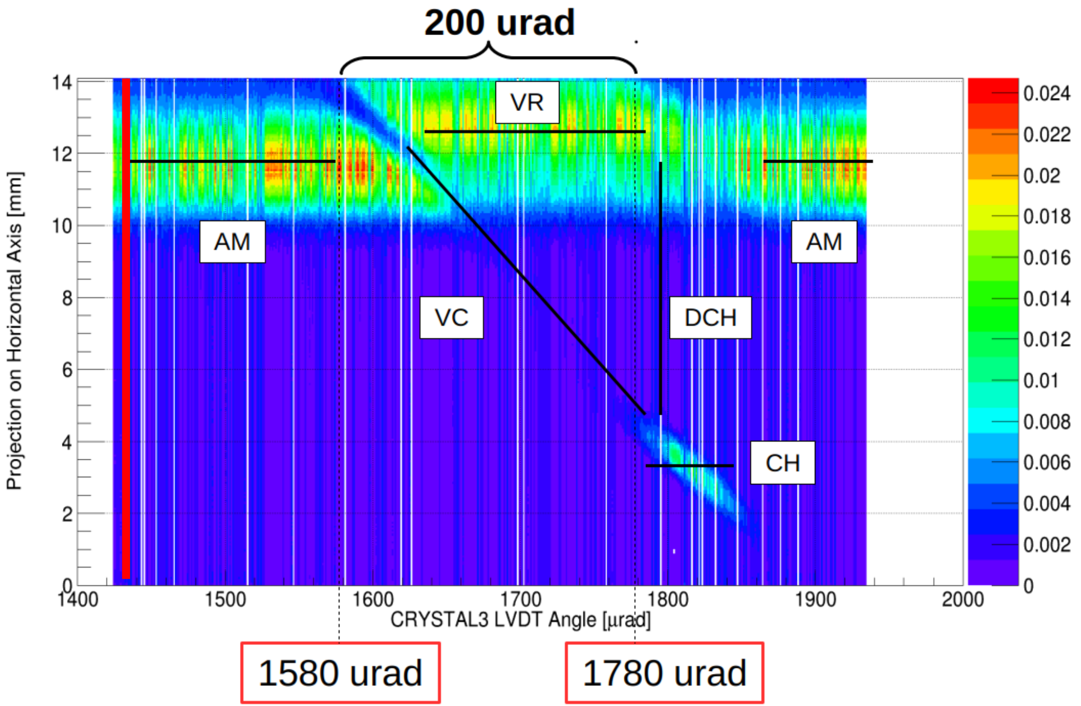
4 contributions to conferences IPAC 2018 and Channeling 2018

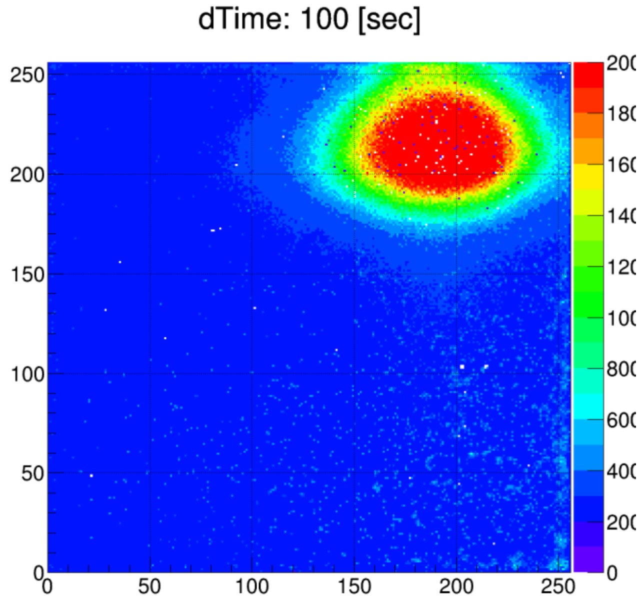
2 PhD thesis concluded and discussed in 2018

1 PhD thesis to be discussed in 2019

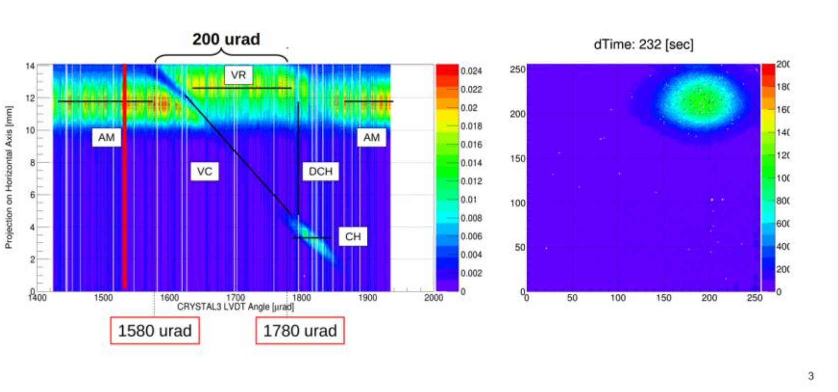
Thank you for your attention!

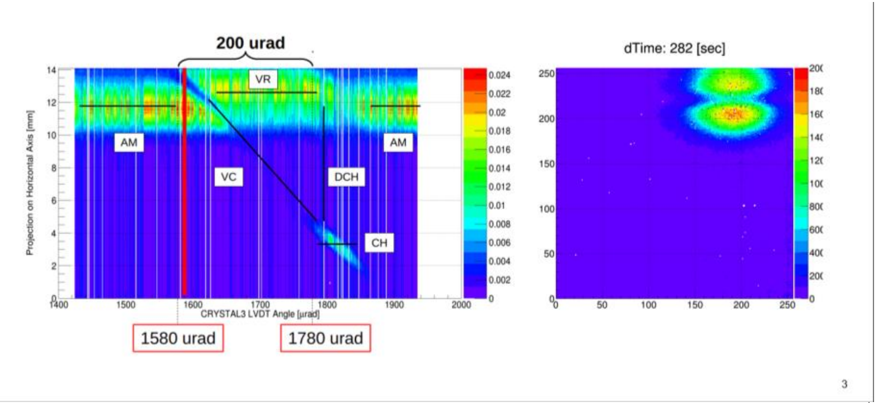
Double Channeling

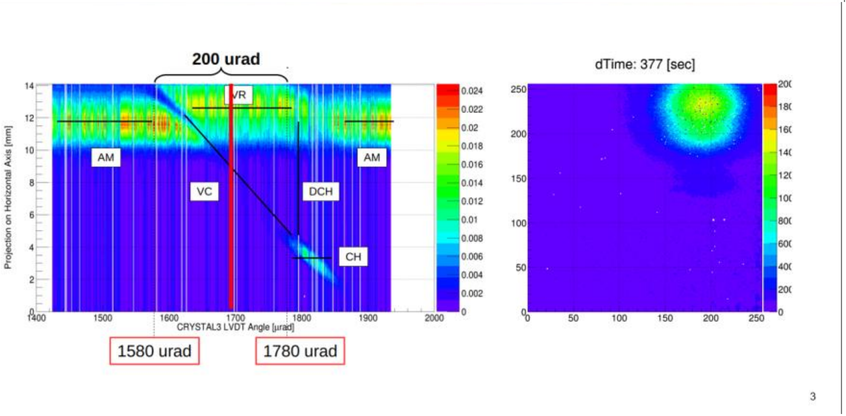


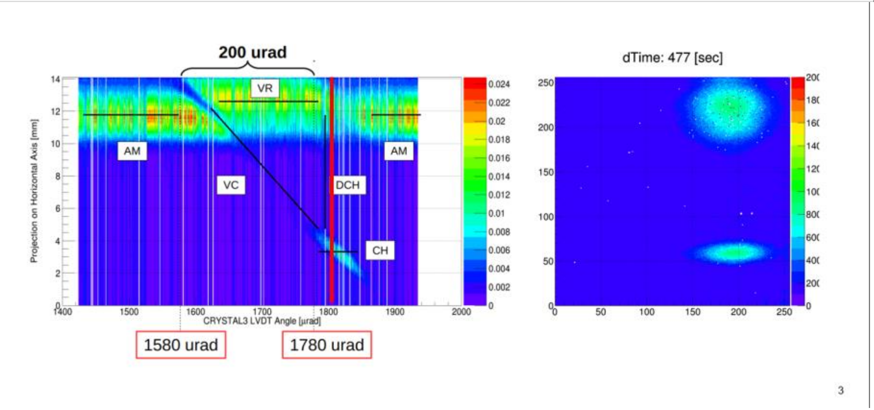


…more snapshots on double channeling

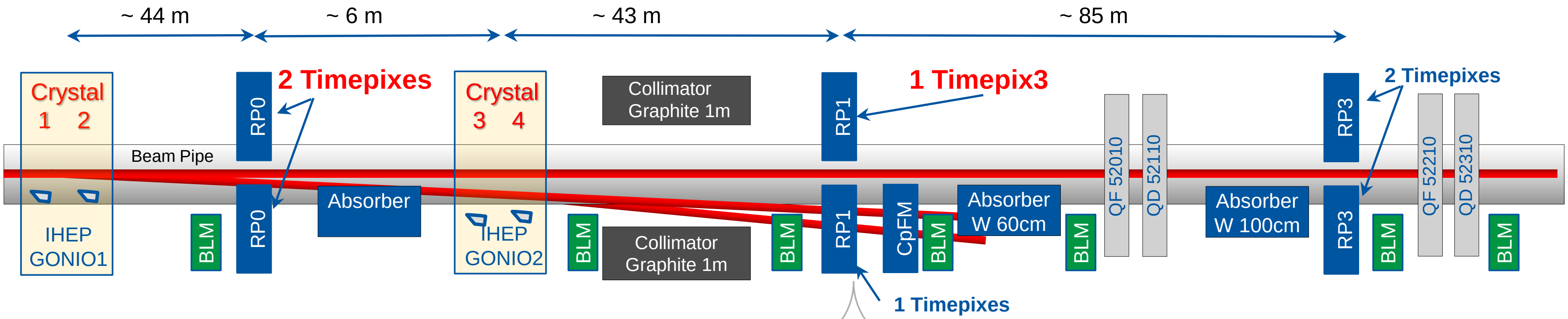








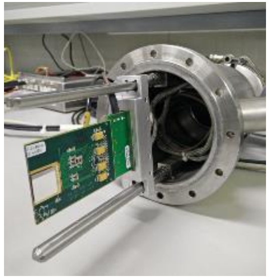
Medipix upgrade and latest observation of flux density distribution



We doubled the number of Timepix detectors

A third Roman Pot was installed in January 2018 with 2 Timepixes

A new Timepix3 has been installed in June on Roman Pot 1 external side



UA9