First experience of crystal collimators during LHC special runs and plans for the future

M. D'Andrea, V. Avati, R. Bruce, M. Butcher, M. Di Castro, M. Deile, B. Dziedzic, H. Garcia Morales, Y. Gavrikov, J. Hiller, S. Jakobsen, J. Kaspar, K. Korcyl, I. Lamas Garcia, A. Masi, A. Mereghetti, D. Mirarchi, S. Redaelli, B. Salvachua Ferrando, P. Serrano Galvez, M. Solfaroli Camillocci, N. Turini

Acknowledgements:
HL-LHC Project
ATLAS (ALFA) and TOTEM collaborations
UA9 collaboration and PNPI
CERN BE-ABP, BE-CEM, BE-OP and SY-STI groups

64th ICFA Advanced Beam Dynamics Workshop (HB2021)
4th October 2021

Outline

I. Introduction

II. Collimation challenges and schemes

III. Crystal performance during special physics run

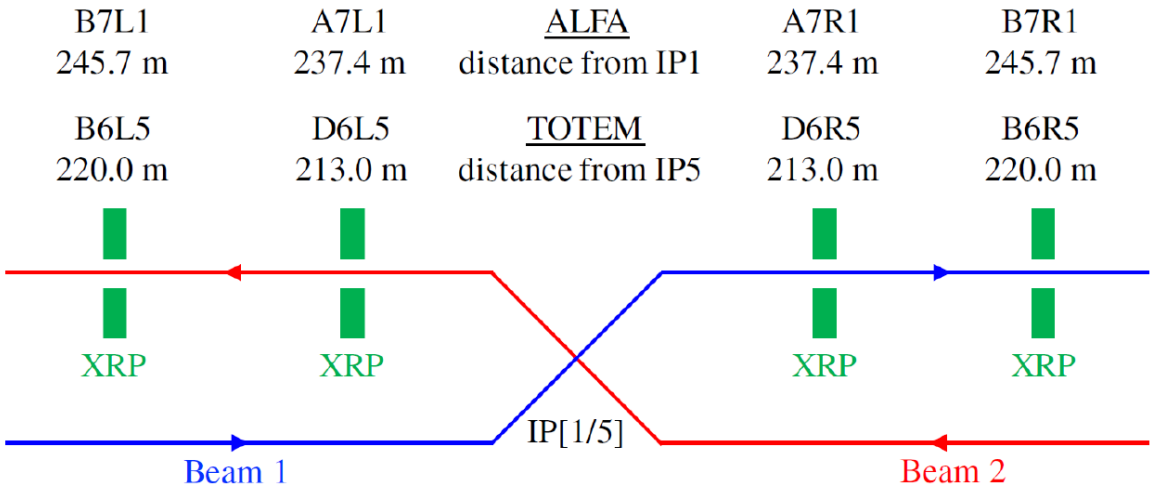
IV. Future plans for crystals

V. Conclusions

For more details:
D. Mirarchi et al., Phys. Rev. Applied 14, 064066 (2020)

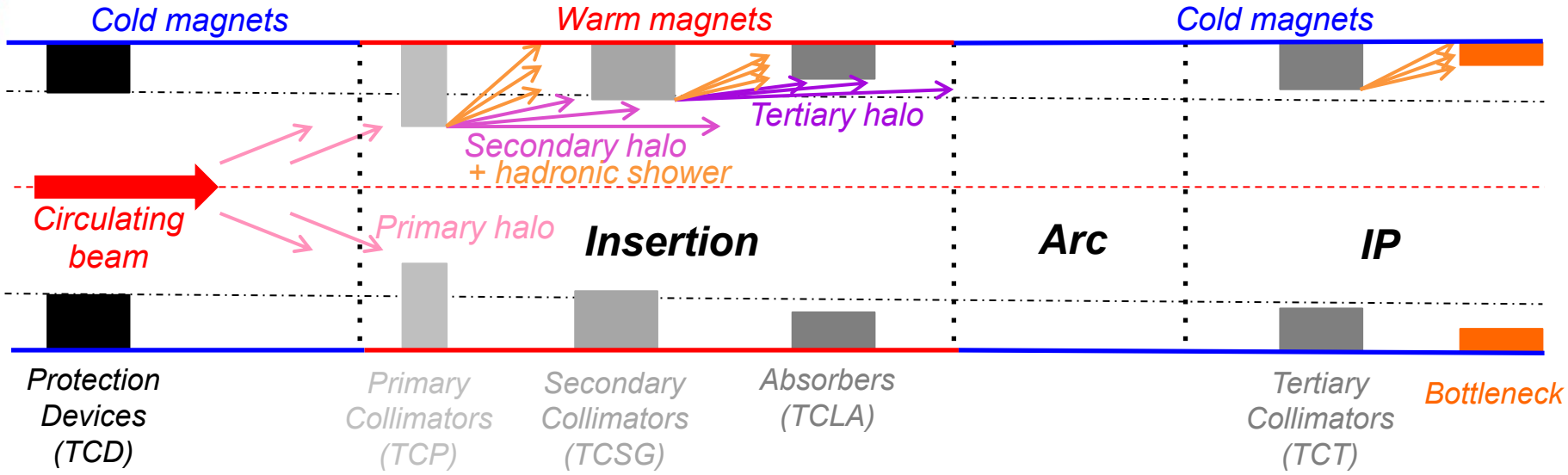
LHC operation and special runs with protons

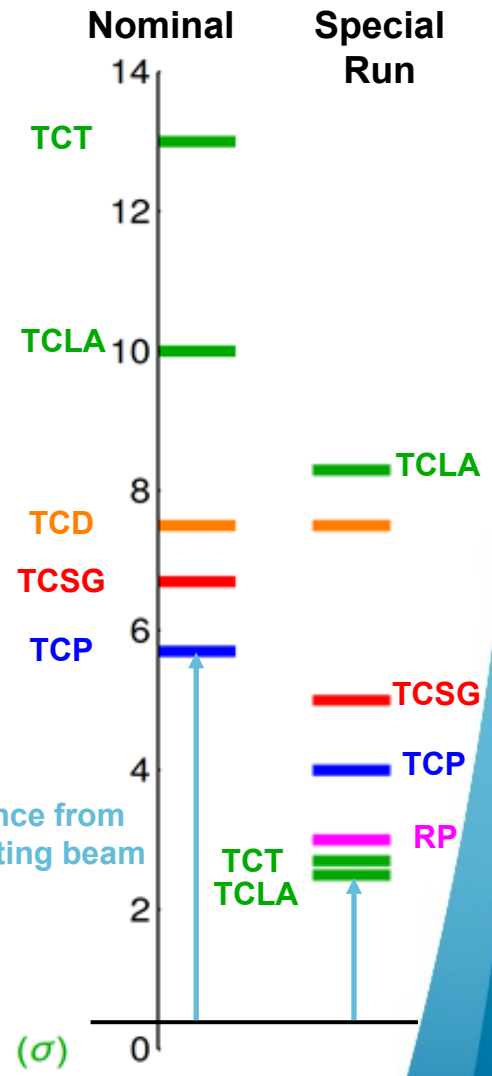
- **Standard LHC operation** with proton beams: ~10^{14} protons per circulating beam at 6.5 TeV
- **Special physics run** in October 2018 requested by Forward Physics community:
  - **Low intensity and energy**: ~10^{11} protons per beam at 450 GeV
  - **Higher β^*** (optical function at Interaction Points, IPs)
- **Goal**: measurement of **proton-proton elastic cross section** and extrapolation of **nuclear part at low momentum transfer**



- Detectors housed in movable (vertical) Roman Pots by **ATLAS (ALFA)** and **TOTEM** collaborations
  - **As close as possible to circulating beams**
  - **Target distance: 3 σ (r.m.s. beam width)**
- Dedicated **optics** and **collimation** settings needed to reduce detector background…

Collimation challenges for the special run

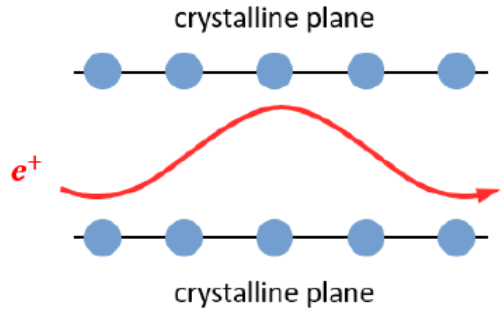


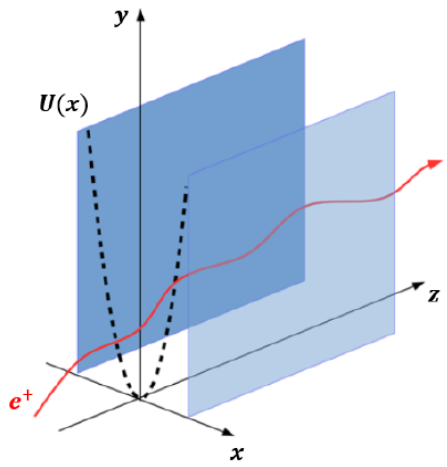


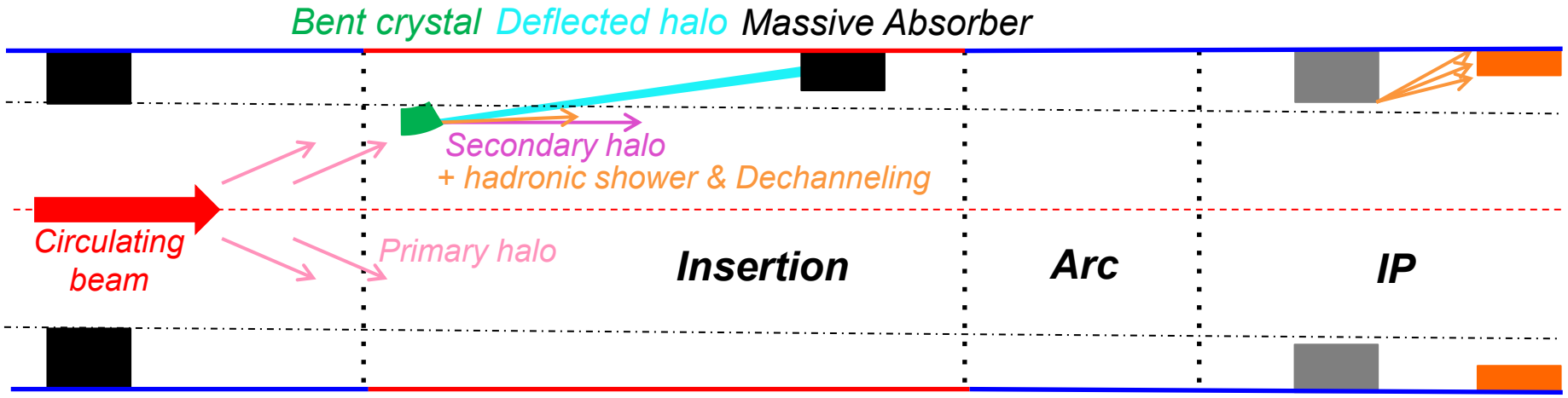
- **Standard collimation system**: multiple collimators to progressively outscatter halo particles until absorbed
  - ↳ Outscattered particles generate **background at detectors** close to the beam
- **Dedicated scheme** devised to achieve acceptable background
  - ↳ **Tightest settings and margins ever used at LHC!**
- Possible other solutions explored in parallel…

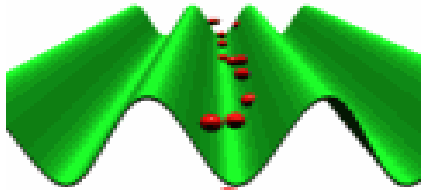
Principles of crystal collimation

- Crystals can trap charged particles in potential well between highly ordered atomic planes: **channeling**
- **Bent crystals** can efficiently **steer halo particles**: equivalent magnetic field of **hundreds of Tesla** at the LHC top energy
- 4 Silicon crystals installed in IR7: studied to **improve LHC beam cleaning**
- Identified as **suitable alternative for special physics run**







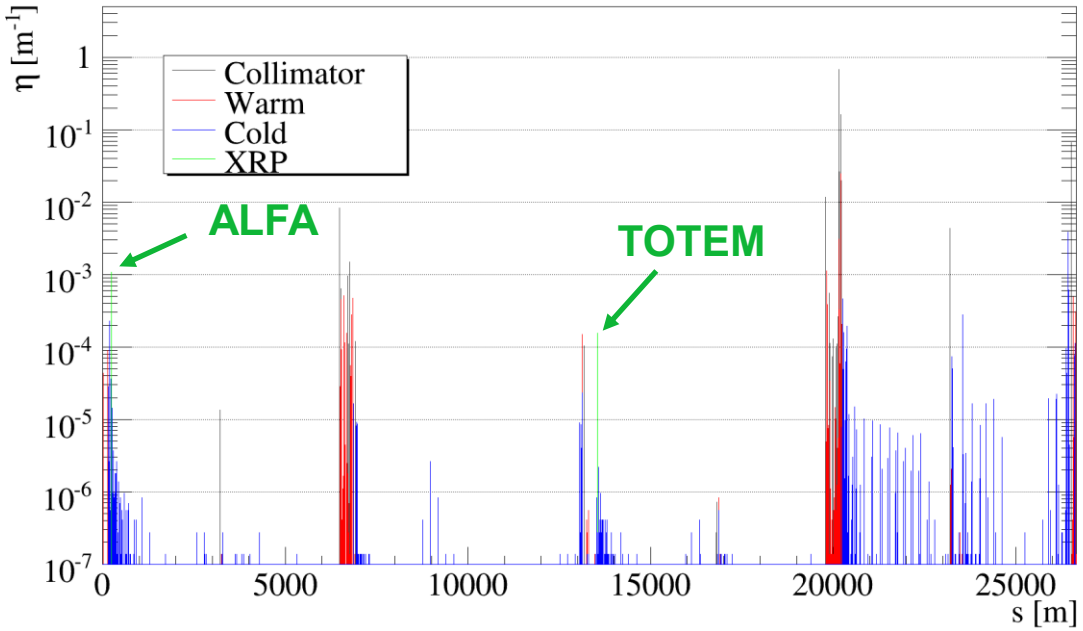


Preparatory crystal collimation studies

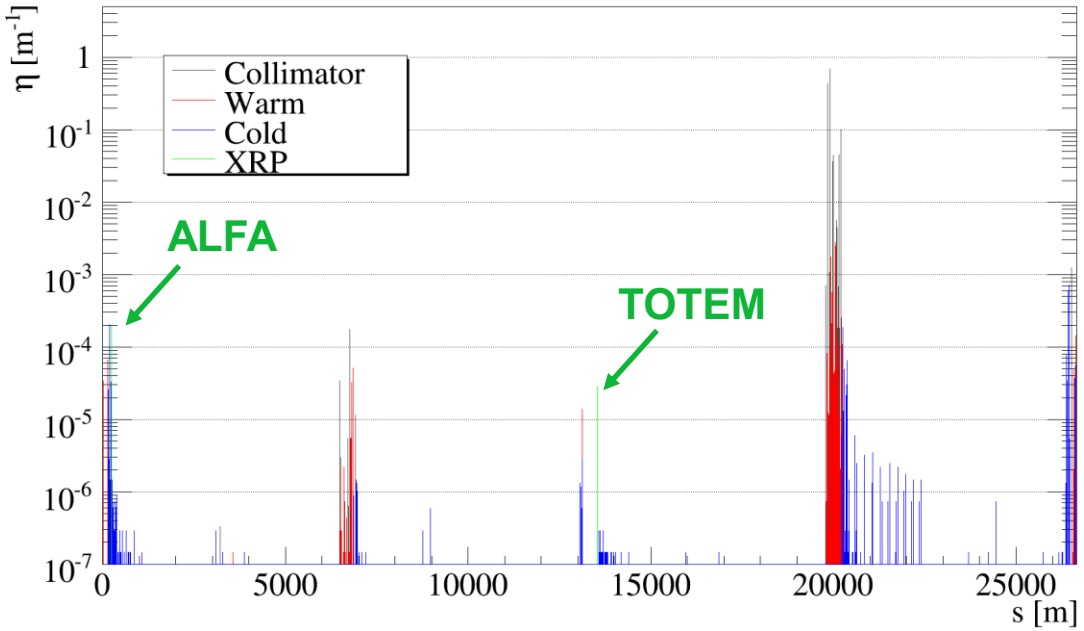
- Crystal collimation settings optimized and performance evaluated via **simulation campaign**

  More relaxed margins and potentially improved performance thanks to more efficient halo removal

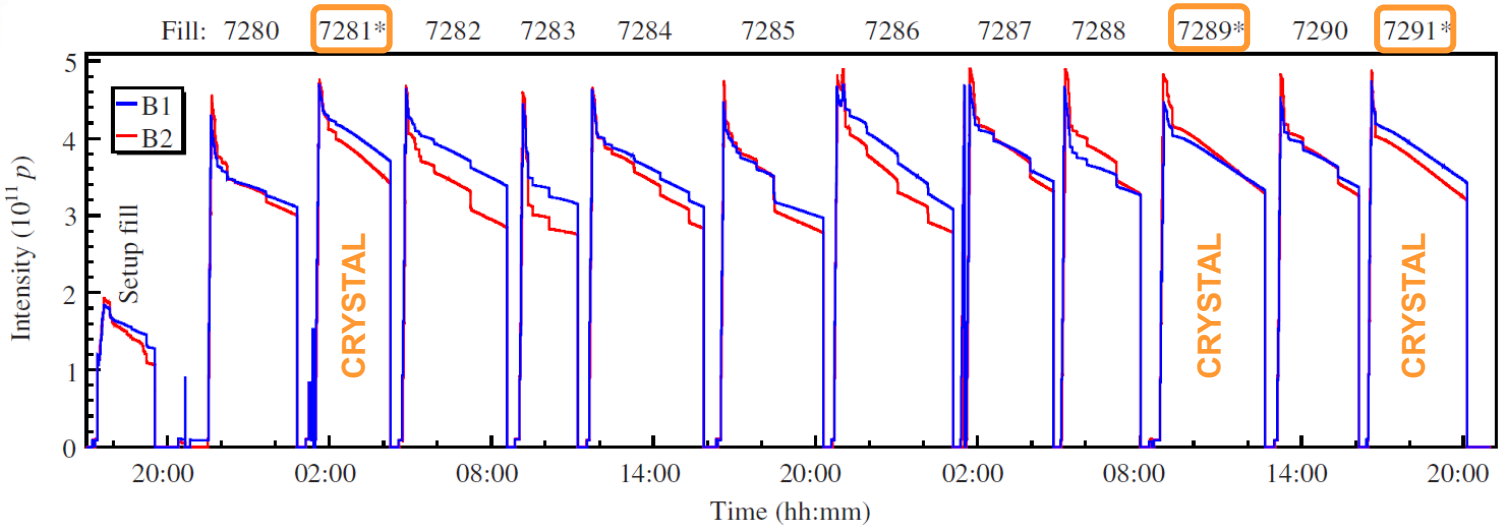
Standard collimation

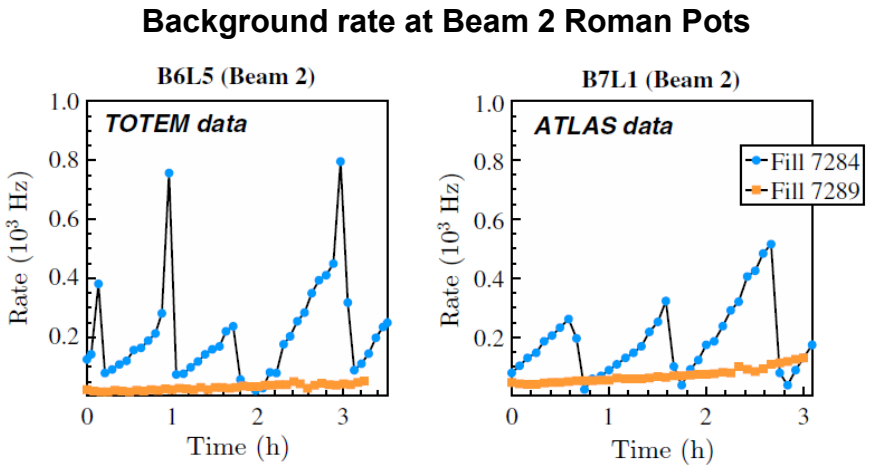


Crystal collimation



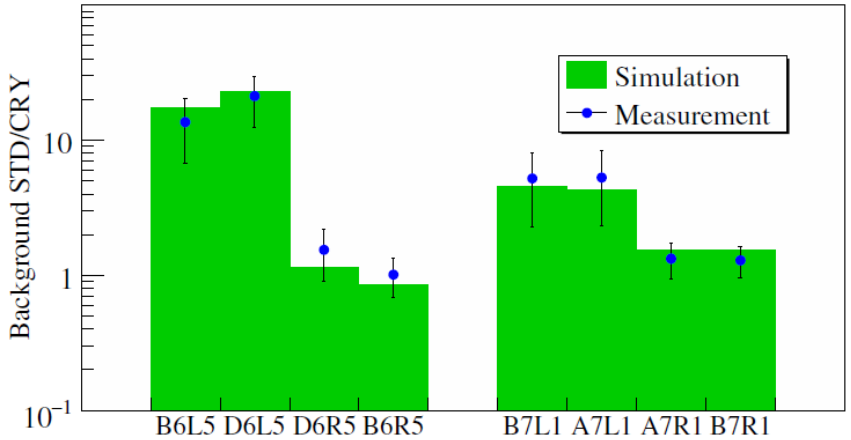
Overview of the special physics run



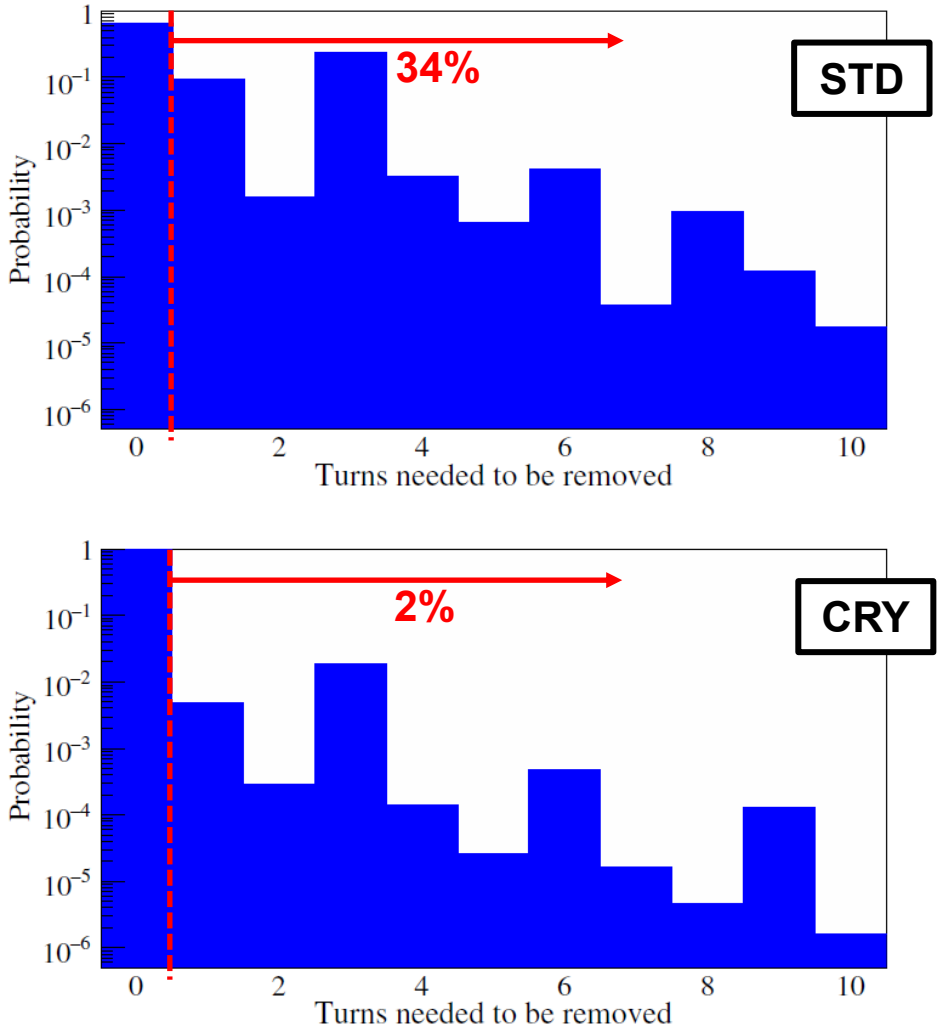


- Crystals deployed with **automatic sequence** directly in optimal channeling
- **Standard scheme**: frequent **rescraping** needed to mitigate **background rate increasing** over time (~6 min once every hour)
- **Crystal scheme**: **no scraping required**

  → **10% more efficient data taking with crystals**
- Measured background in **good agreement with simulations** (with detailed modelization of detectors and layout)



Background rate analysis in simulations



- **Is the crystal scheme able to dispose of halo particles faster?**
- Extensive simulation studies to verify **number of turns required to remove** particles after first interaction with collimation system

Less turns required on average to remove halo particles with crystals

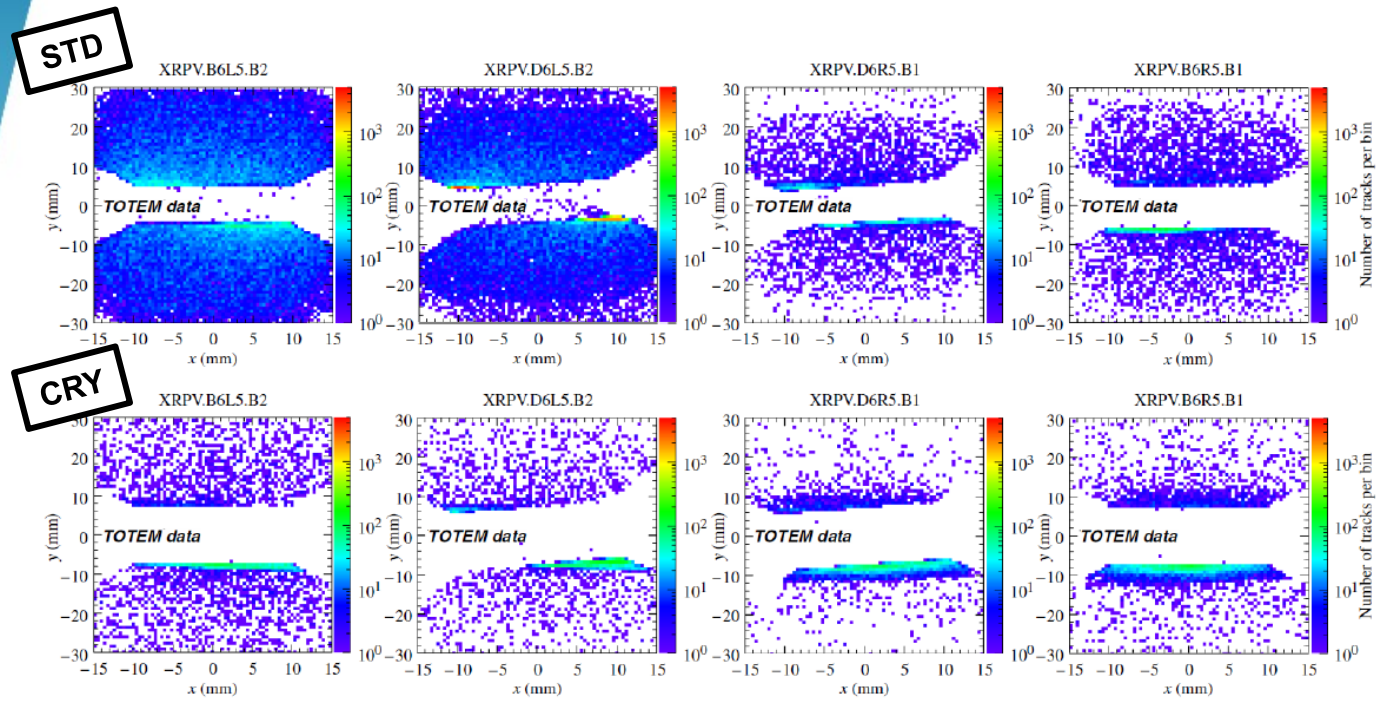
↓

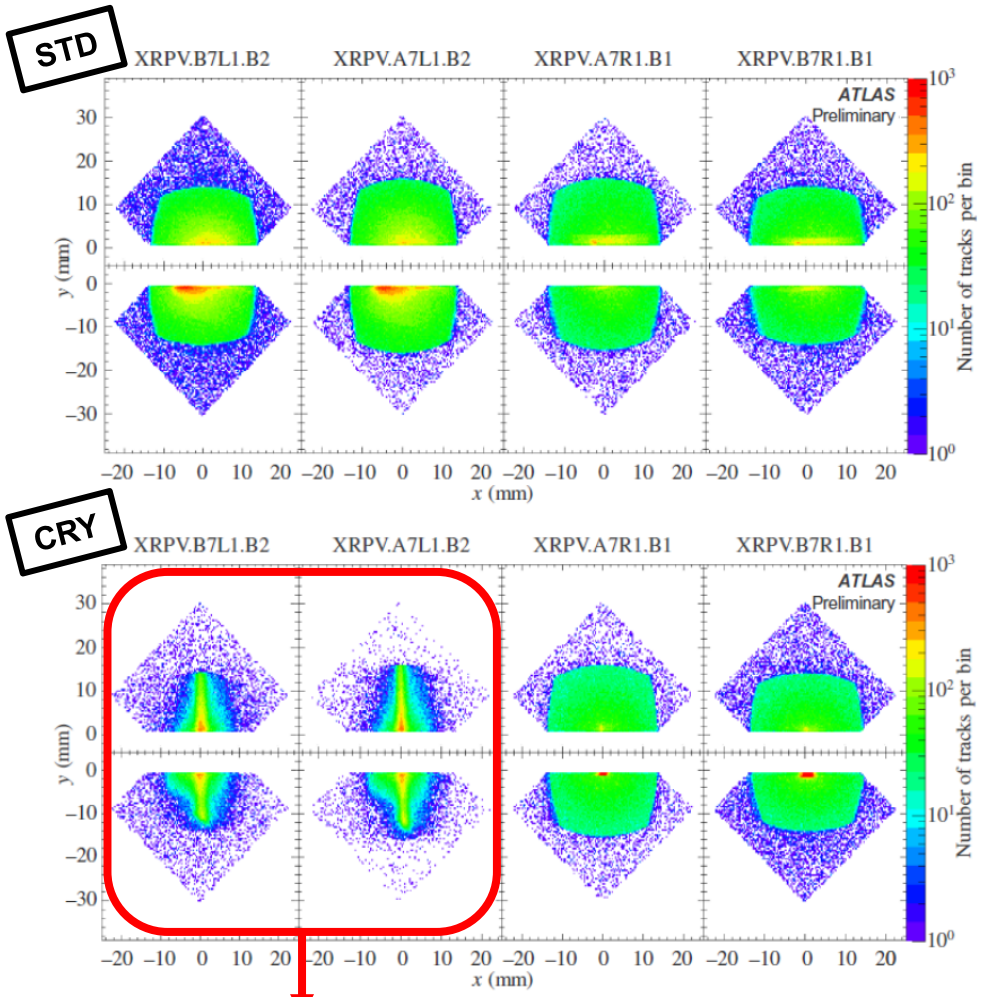
Slower multiturn halo population

↓

Reduced background rate at detectors

Background hit pattern at Roman Pots



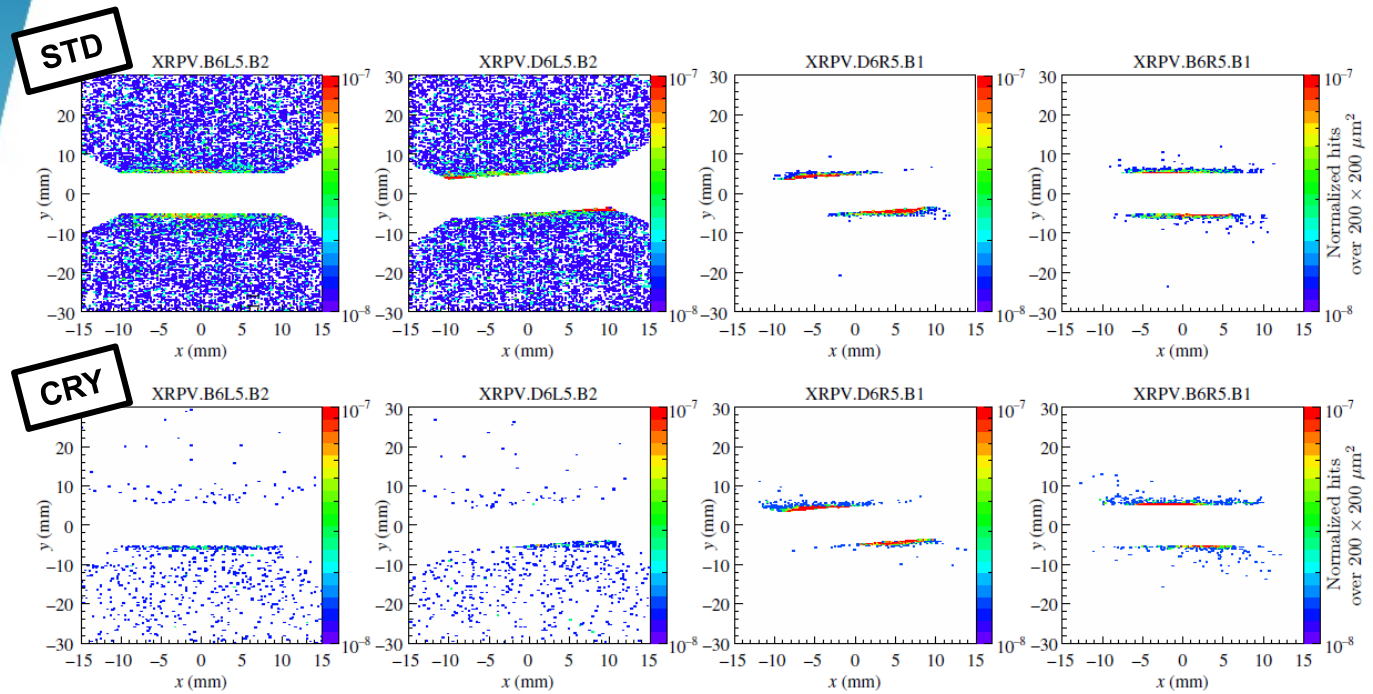


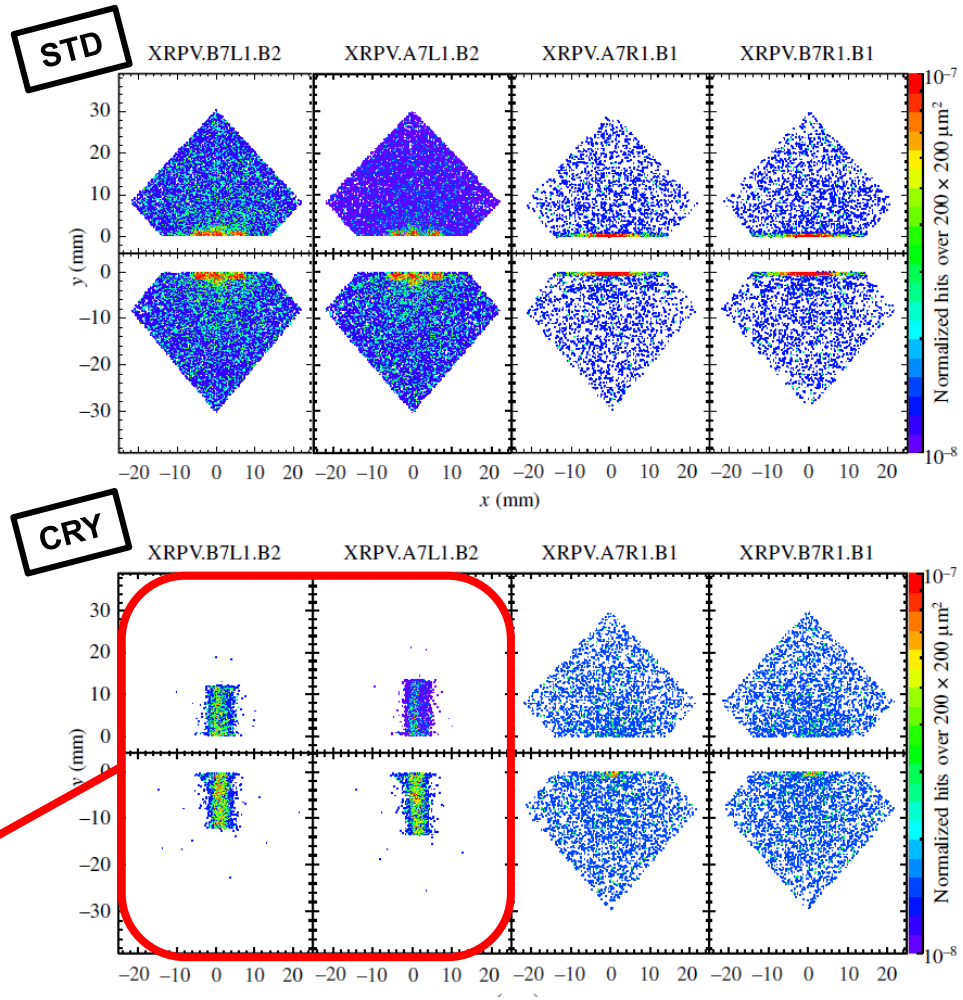
- Suppression of structures due to multiturn halo hitting detector edges when crystals are used

→ **More efficient background subtraction in offline analysis**

Potentially problematic pattern at ALFA Beam 2 Roman Pots

Pattern comparison with simulations



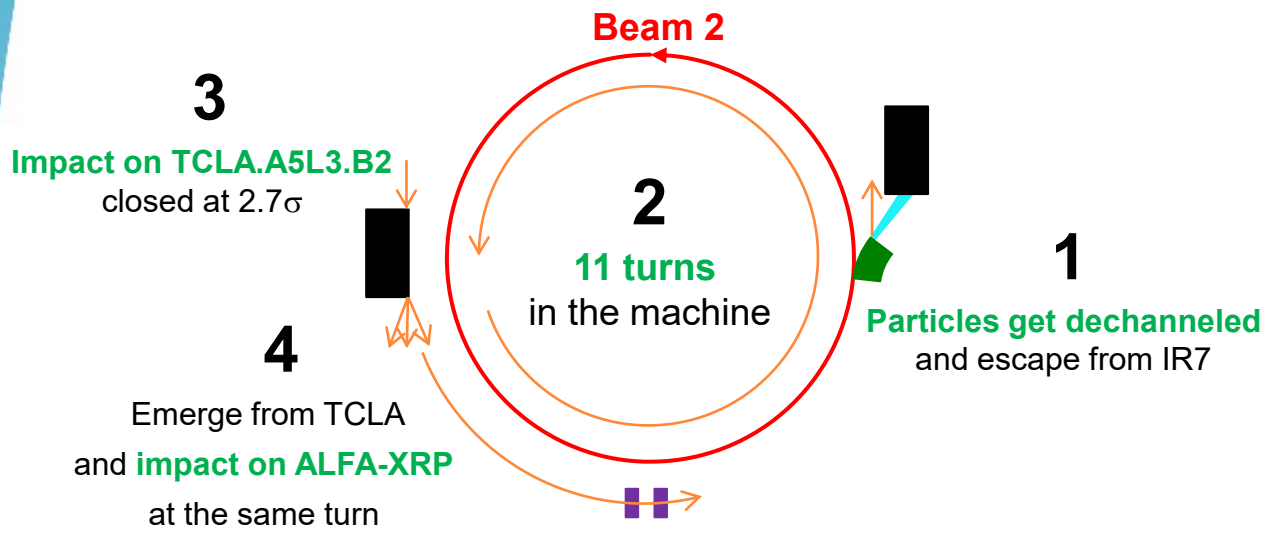


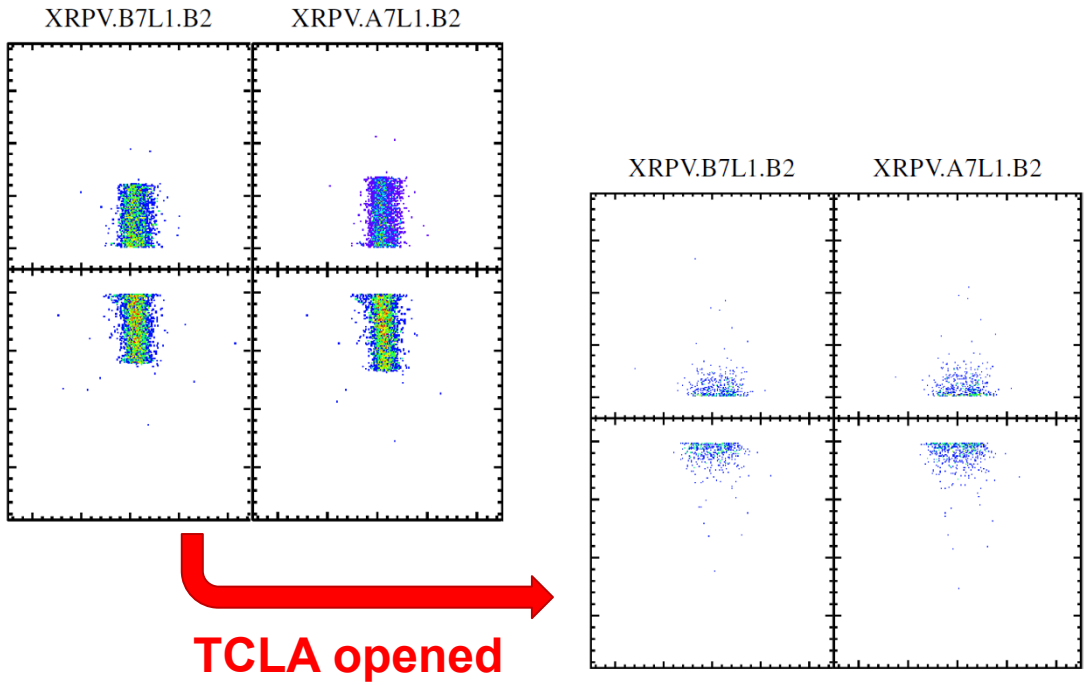
- **Very good qualitative and quantitative agreement** (after accurate modelization of detectors and layout)

Pattern further analyzed in simulations

ALFA pattern analysis in simulations

- **What is the origin of the pattern observed at AFLA Beam 2 Roman Pots?**
- High-statistics simulations (10^8 particles) to study history of particles hitting detectors
- Particles can escape crystal before acquiring full deflection: **dechanneling**



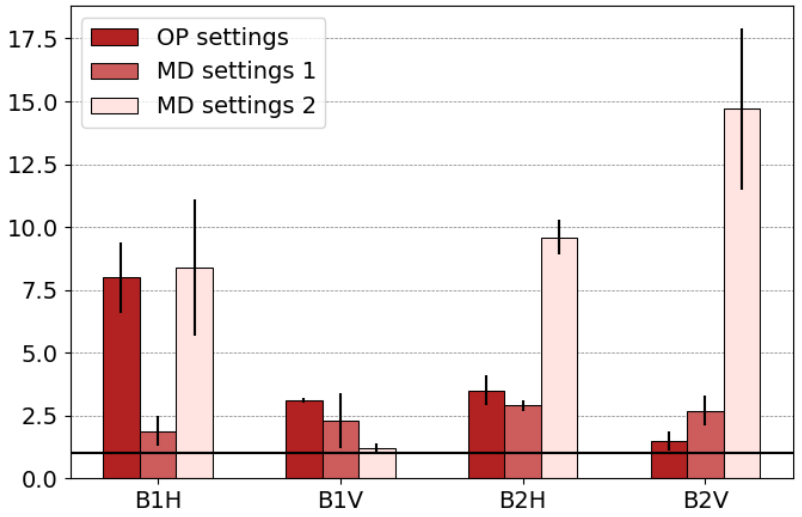


- **Pattern could be optimized in future runs**

Crystal collimation for HL-LHC

- **Outcome of low-intensity special physics run was crucial milestone** to show maturity and reliability of the system
- **Upcoming HL-LHC upgrade**: increased stored energy requires **upgrade of present collimation system** to reduce losses at limiting locations (cold region of IR7)
- Crystal collimation in operation with high-intensity proton beams still challenging: special absorber required to withstand power deposition of channeled halo

Global leakage ratio STD/CRY in IR7 with Pb ion beams



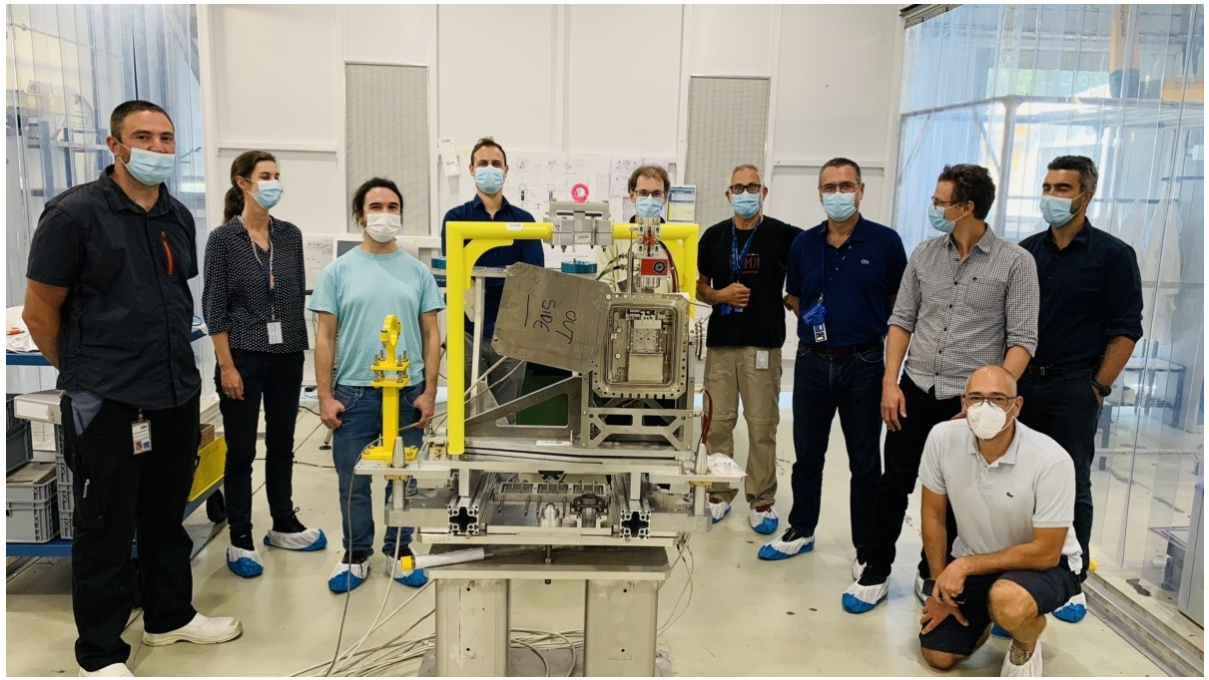
- Standard secondary collimator can **safely absorb channeled halo with high-intensity ion beams**: crystal collimation can be used
- Operational tests with high-intensity Pb ion beams in 2018: **different configurations tested for use in operation**

Demonstration of reduced leakage at limiting locations of the machine

Crystal collimation included in HL-LHC baseline for operation with Pb ion beams as of Run 3 (starting 2022)

Conclusions

- **First use of crystal collimation in a physics run** at the LHC during the 2018 special run with high β*: **background** at ALFA and TOTEM detectors **significantly reduced** thanks to faster halo removal
- Crystals deployed efficiently directly in optimal channeling orientation: **reliability of hardware and control systems**
- **Results in agreement with simulations**: confidence in predicting power and potential for further optimization in future runs



- **Crucial milestone**: together with demonstrated performance with Pb ion beams, contributed to **inclusion of crystal collimation in HL-LHC baseline**
- More applications to **advanced techniques of beam extraction/manipulation** and to **fixed target experiments** (Physics Beyond Colliders) currently under study

Thank you for your attention!

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