# *Special collimation schemes for reduced background during high-β physic run*

D. Mirarchi, R. Bruce, M. D'Andrea, H. Morales, S. Redaelli

On behalf of the LHC Collimation team

Acknowledgments:

EN-STI and EN-SMM hardware and controls, ALFA and TOTEM, BE-OP, impedance team, UA9 Collaboration provided the crystals installed in the LHC

# Outline

I. Collimation challenge and crystals
II. Standard and crystal collimation schemes
III. High beta physics run preparation
IV. High beta physics run results
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# Collimation challenge for high beta run

- **Very high background** in 2017 and May 2018 tests
  - ✗ Impossible to make measurements

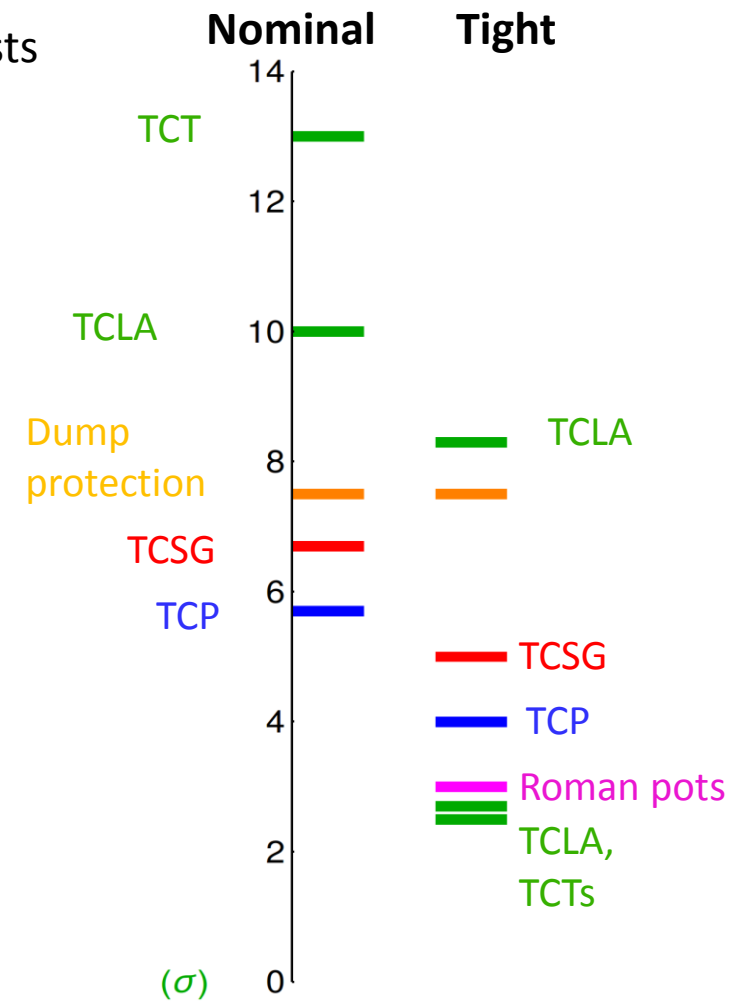
- **Solution proposed:**
  - ✓ Fit a **two-stage collimation** system **between 2.5 σ and 3 σ**
  - ✓ **Tungsten collimators** only for improved absorption
  - ✓ **Alternative** scheme using **crystals as primary stage**

**Primary stage at 2.5 σ**

**Secondary stage at 2.7 σ**

**Roman Pots at 3 σ**

*Tightest collimation ever in the LHC!*




***From R. Bruce at LMC #363***

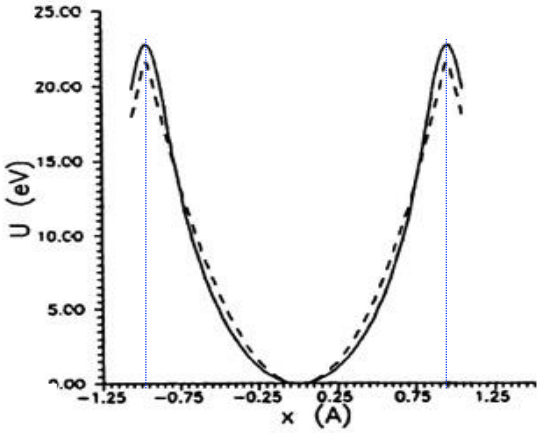
# Crystal channeling

**Potential** between a **particle** and an **atom** described by the **Thomas-Fermi model:** $V(r) = \frac{Z_i Z e^2}{r} \Phi(\frac{r}{a_{\mathrm{TF}}})$

**Continuous approximation** (small $\theta_{imp}$):

$$U_p(x) = Nd \iint_{-\infty}^{+\infty} V(x,y,z)dydz$$

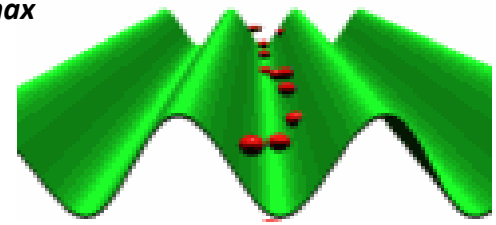
Potential seen by protons from crystalline planes




*If the protons* ***have $p_T < U_{max}$***

**Critical channeling angle**

$$\theta_c = \sqrt{\frac{2U_{max}}{pv}}$$



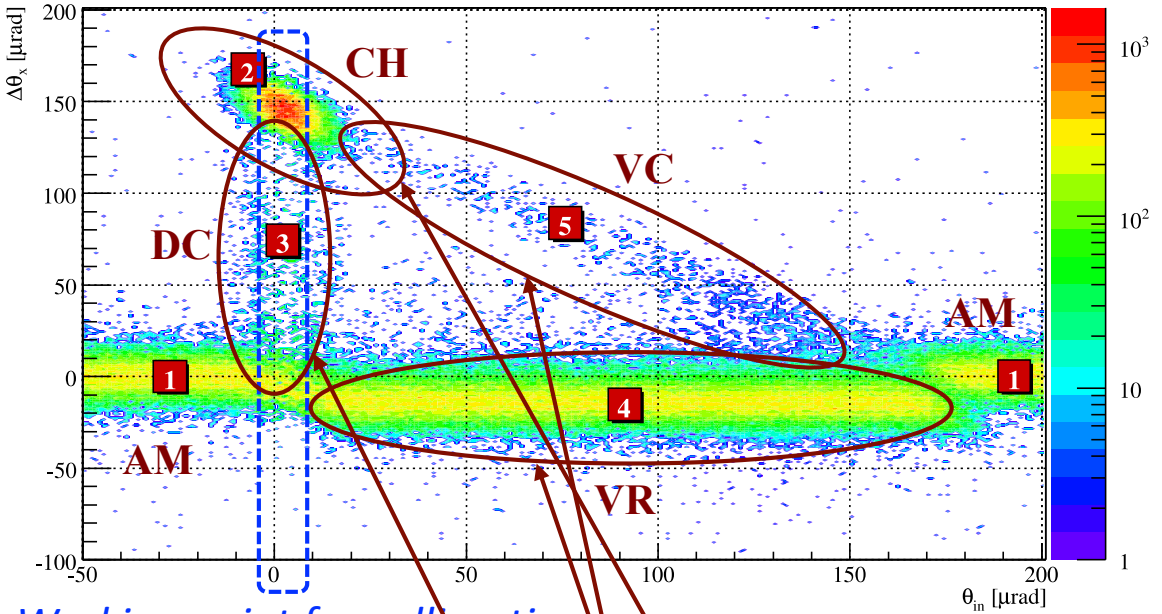
*Forced to oscillate in a relatively empty space*

***Typical values*** *at energies of our interest:*

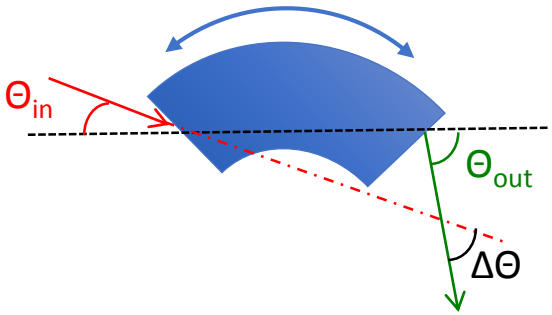
| Case | Energy [GeV] | $\theta_c$ [$\mu rad$] | $\lambda$ [$\mu m$] |
|---|---|---|---|
| SPS coast | 120 | 18.3 | 33.0 |
| SPS coast | 270 | 12.2 | 49.6 |
| H8 | 400 | 10.0 | 60.3 |
| LHC inj. | 450 | 9.4 | 64.0 |
| LHC top | 6500 | 2.5 | 243.2 |
| LHC top | 7000 | 2.4 | 252.3 |

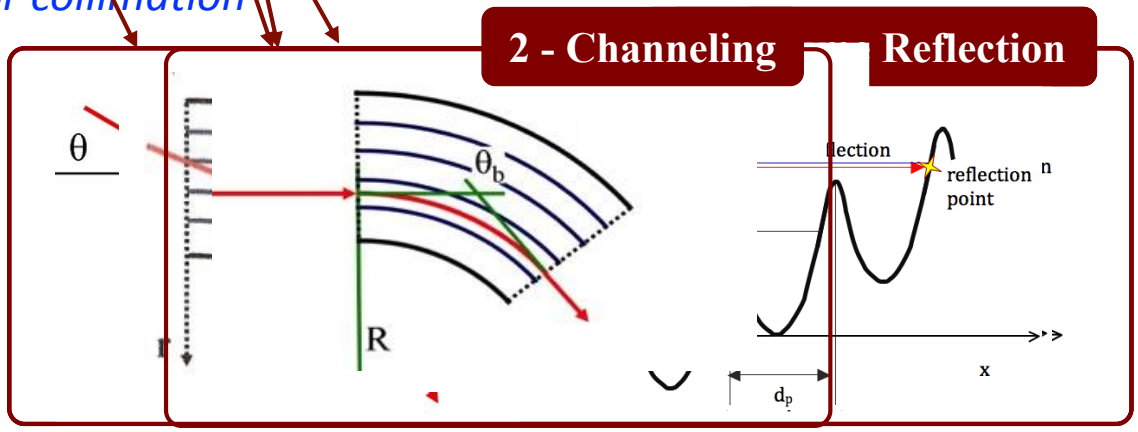
# Coherent processes in bent crystals

***From test beam*** *on the CERN-SPS extraction line H8 (in the framework of the UA9 experiment)*




*Working point for collimation*



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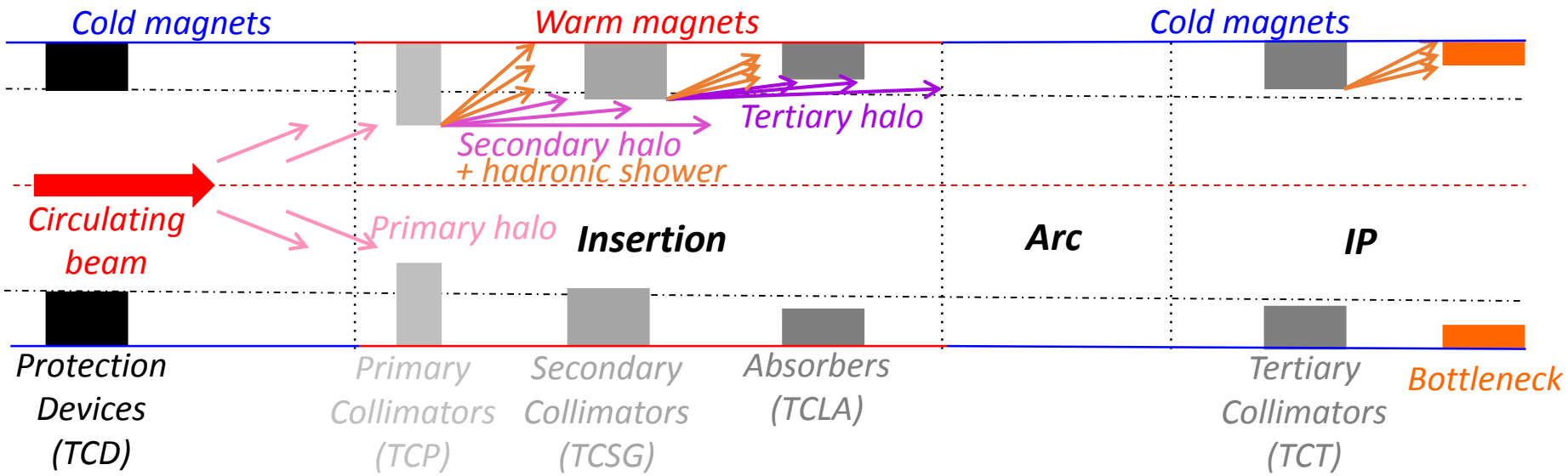
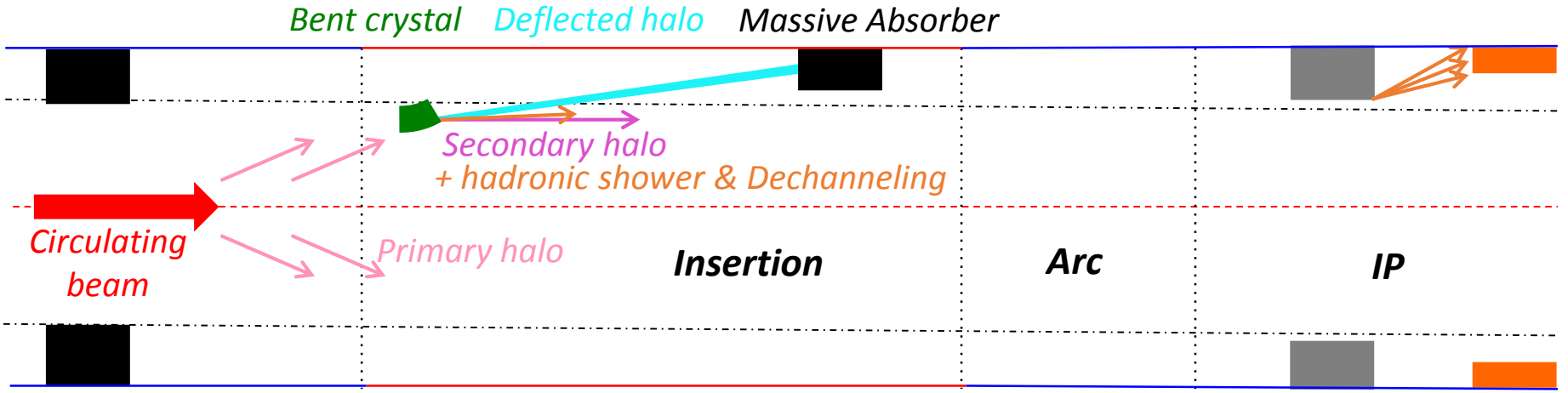
# Standard Vs Crystal collimation



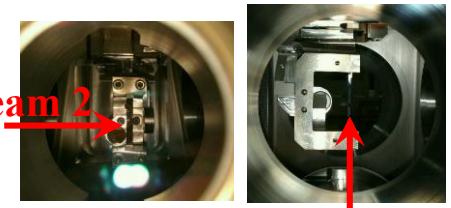



# Collimation layout in the LHC

**About 100 movable collimators** placed around the rings

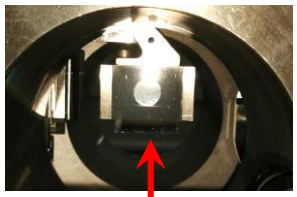
**Four crystals installed: two per beam, one per plane**

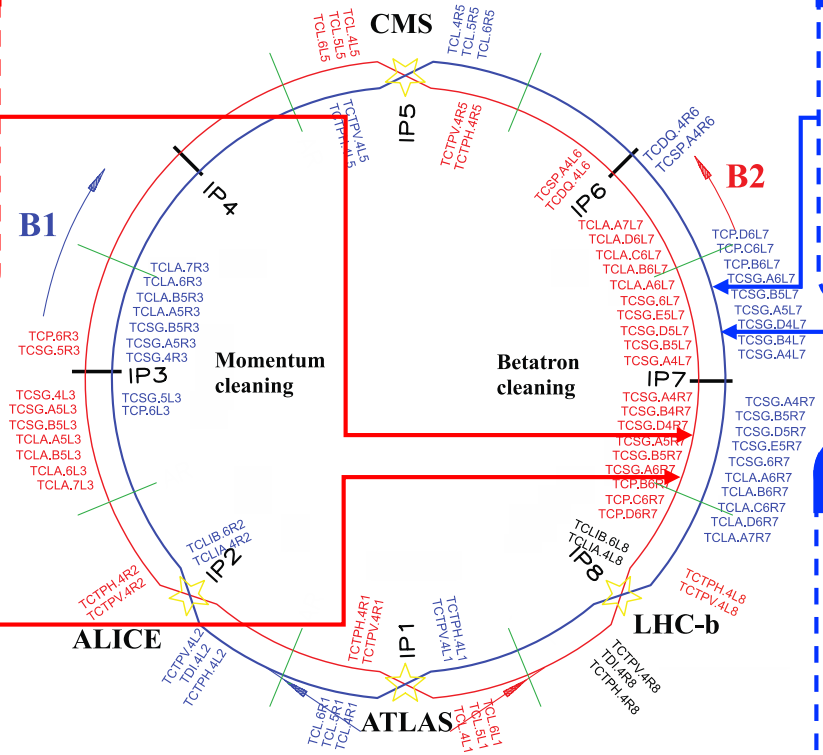
## TCPCH.A5R7.B2



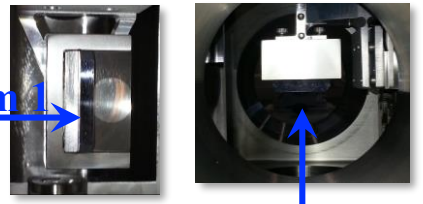

*Pics. Courtesy of Y. Gavrikov*

## TCPCV.A6R7.B2

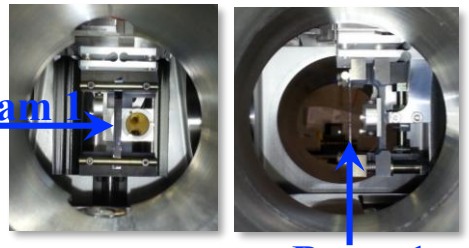



## TCPCV.A6L7.B1




## TCPCH.A4L7.B1



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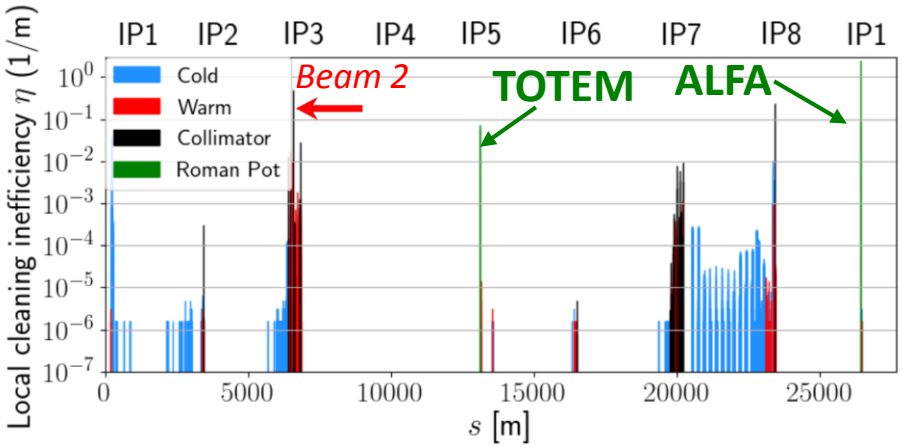
# Expected performance using tight coll.

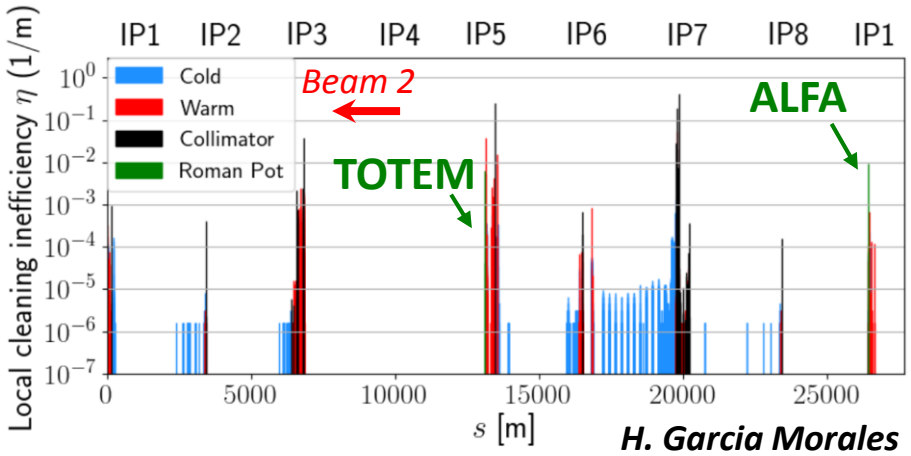
- **Tracking simulations** performed with SixTrack
  - Symplectic tracking plus **interaction radiation with matter**
    - Evaluation of **density of protons lost per metre**

- *Main question: can we reduce losses at the pots?*

***Old Collimation Scheme***
(Single stage cleaning)



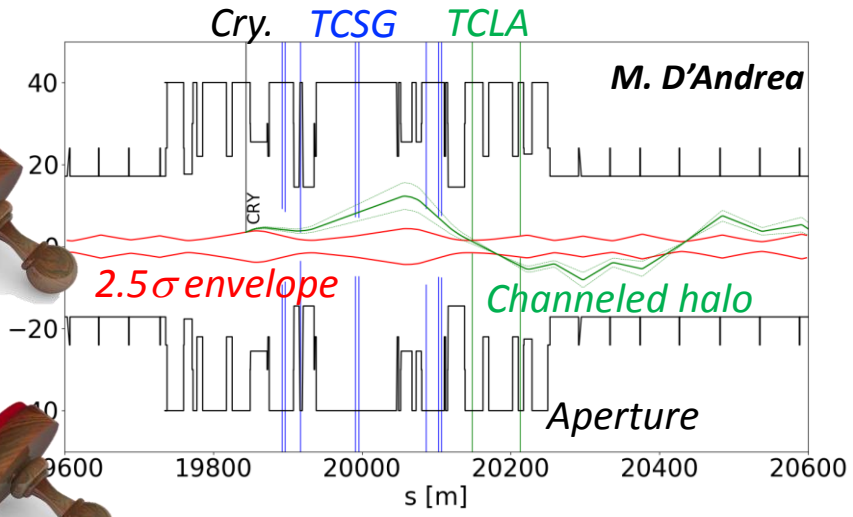

***Tight Collimation Scheme***
(Two stage cleaning)




***H. Garcia Morales***

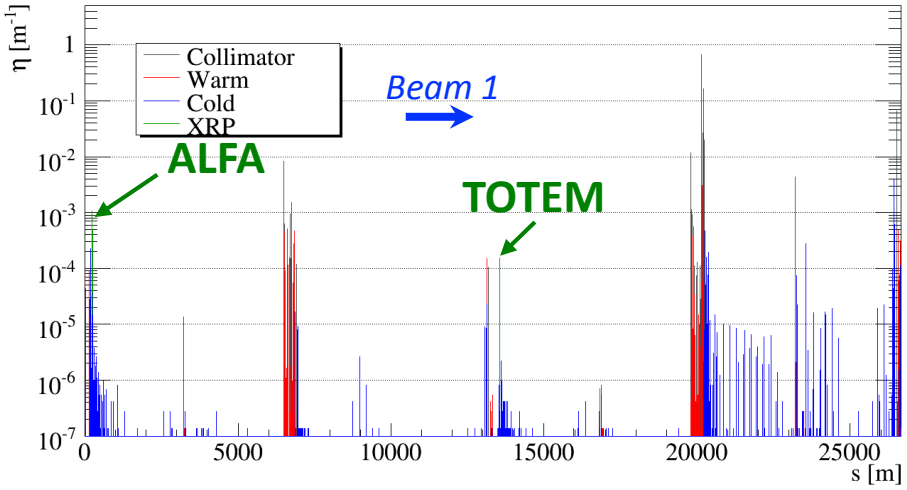
# Expected performance using crystals

**1** Can we intercept the channeled beam in these extreme conditions?

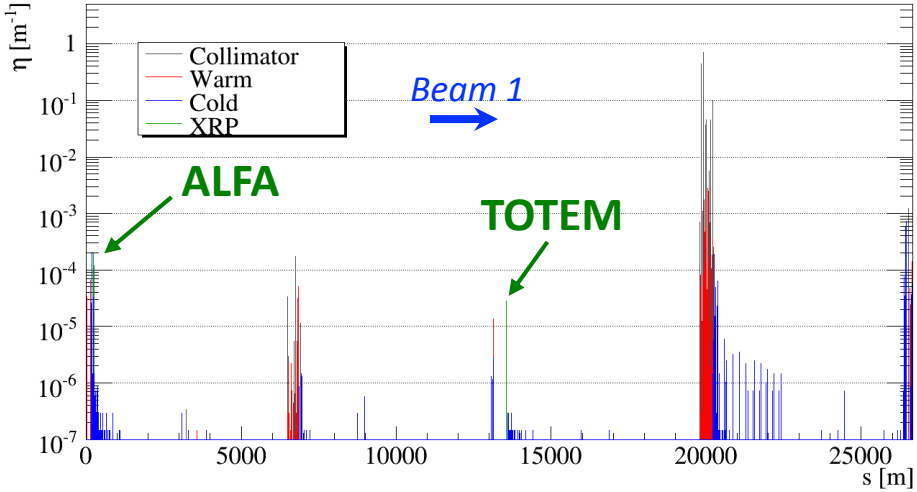



**2** Can we further reduce the background?

***Tight Collimation Scheme***



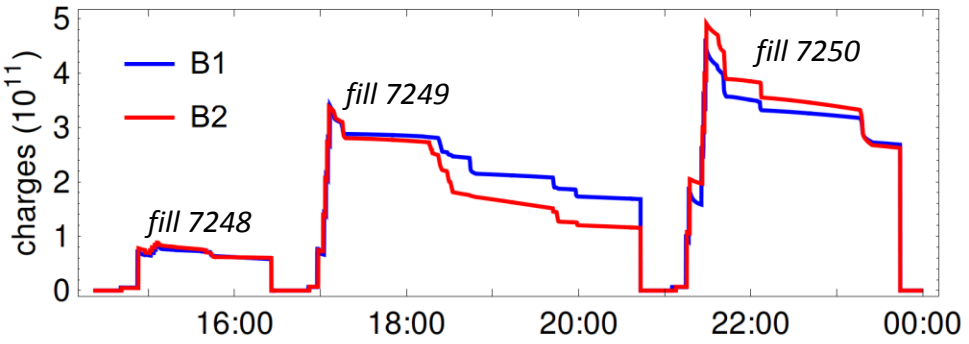

***Crystal Collimation Scheme***



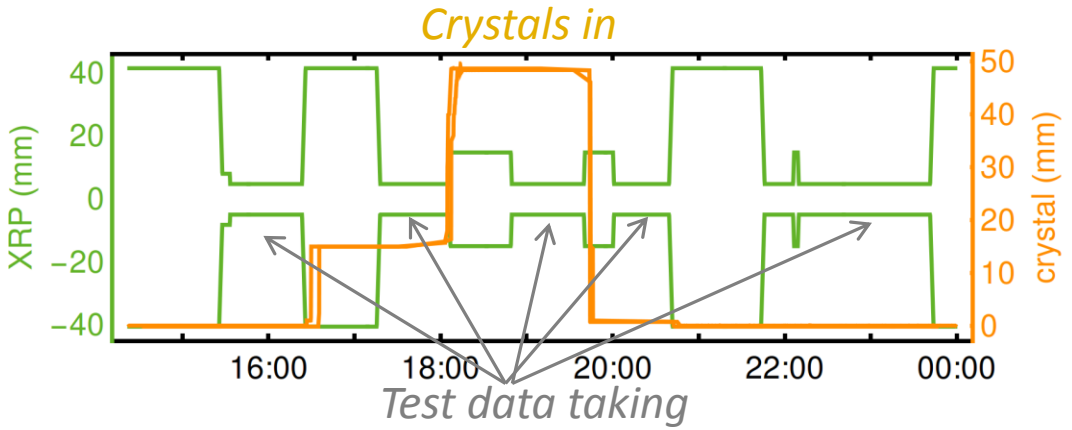
# Feasibility tests

1. Roman pot **data taking tested with both configurations** over three fills

   (Crystals tested taking over fill when PS was down)

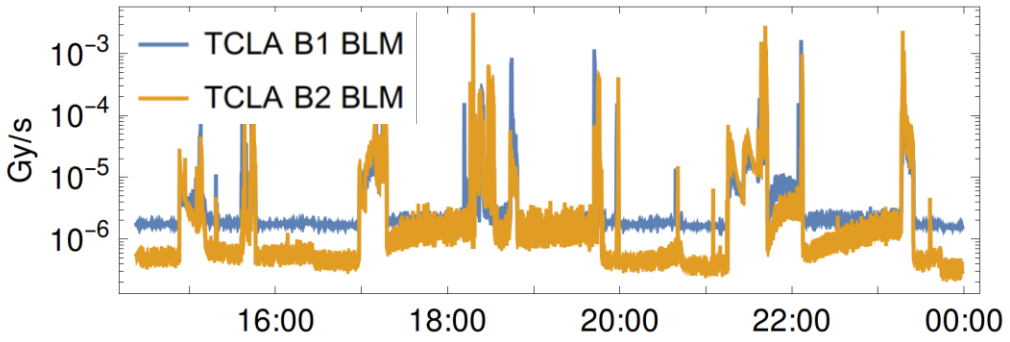



2. **Steady loss** rates observed at the "primaries", but **cleaned efficiently**



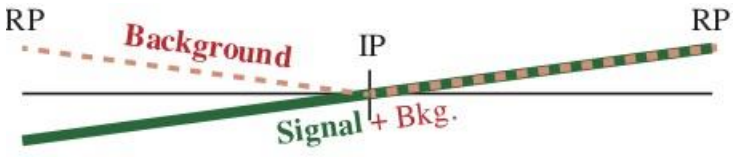

3. **Higher intensity** tried in 3rd fill led to **higher background**

**Mitigated by re-scraping the tails**

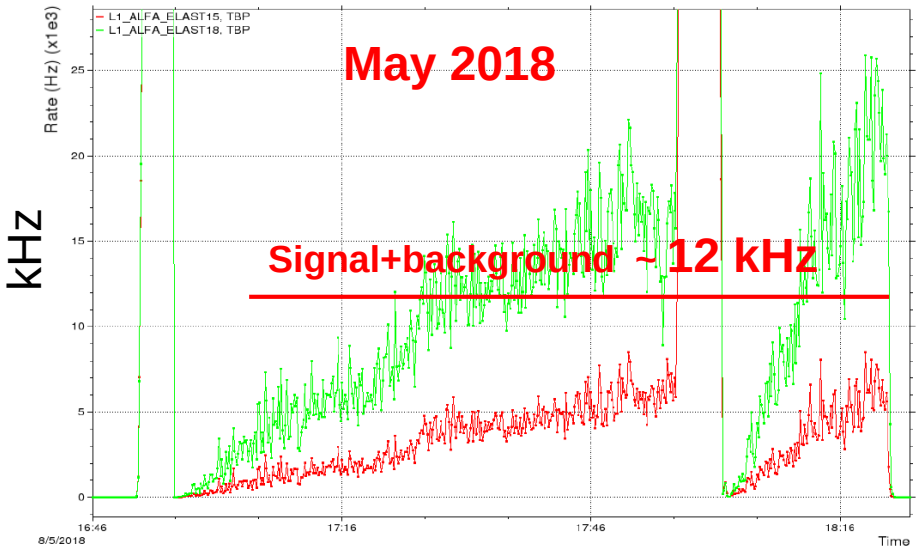


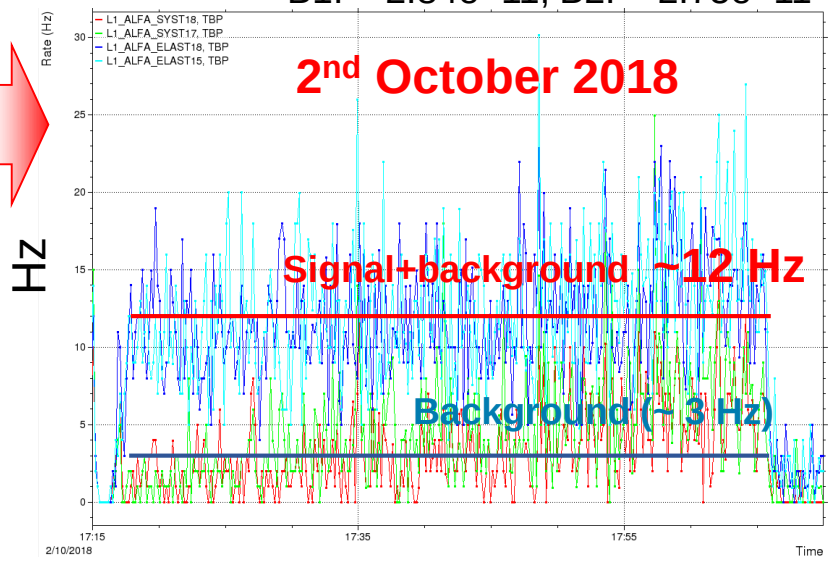
# Physics background evaluation

**Online plots courtesy of the ATLAS-ALFA Collaboration (M. Milovanovic)**




Bunch intensities (avg):
B1: ~ 7.11e+10, B2: ~ 6.87e+10
Beam intensities:
B1: ~ 2.84e+11, B2: ~ 2.75e+11



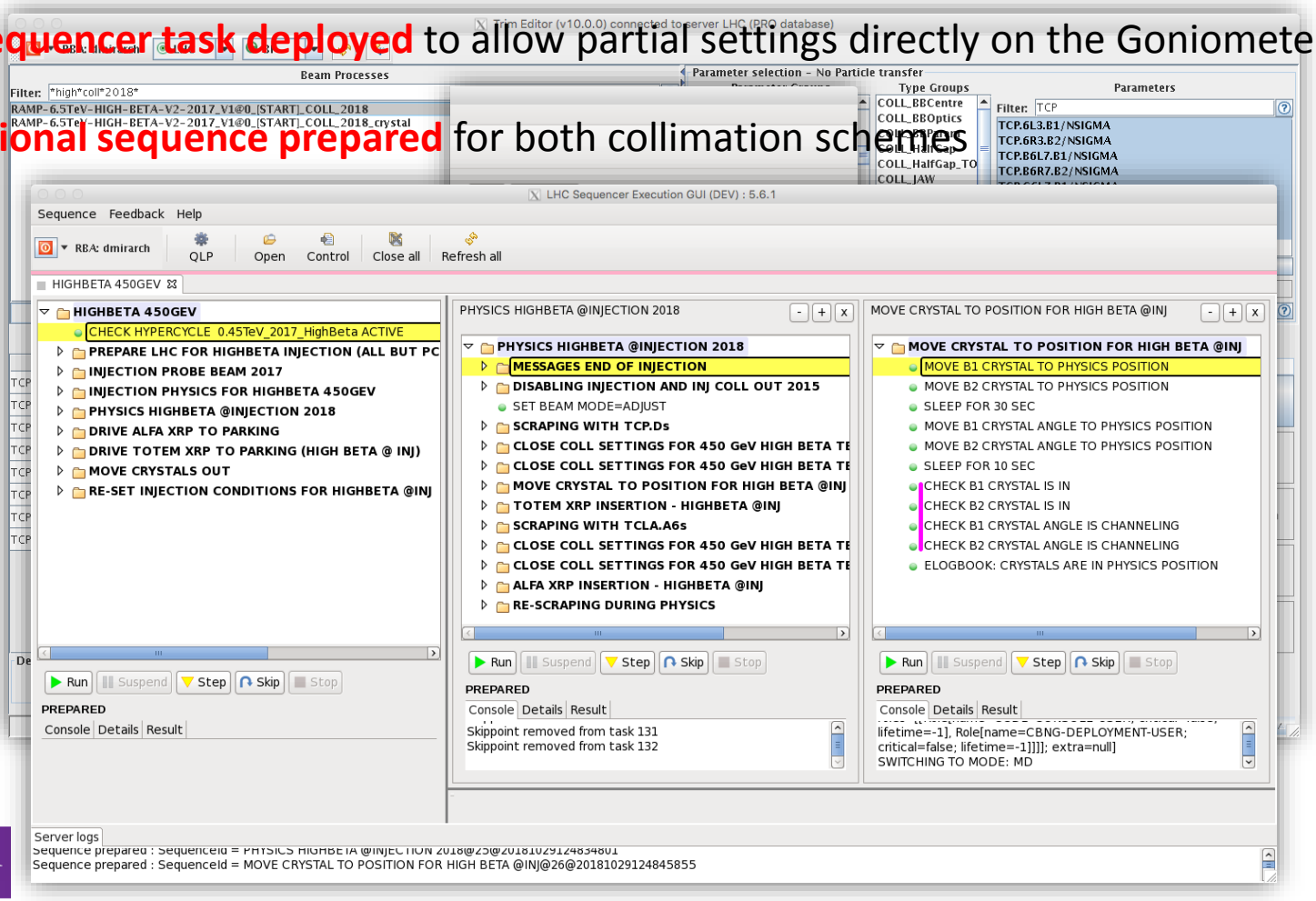

Online coincidence rates show orders of **magnitude reduced backgrounds using both schemes!**

***High beta physics run can take place!***

# Operational setting up

## Both collimation schemes prepared for operations

1. **Dedicated beam process** with setting of the entire system
2. **New sequencer task deployed** to allow partial settings directly on the Goniometer FESA class
3. **Operational sequence prepared** for both collimation schemes



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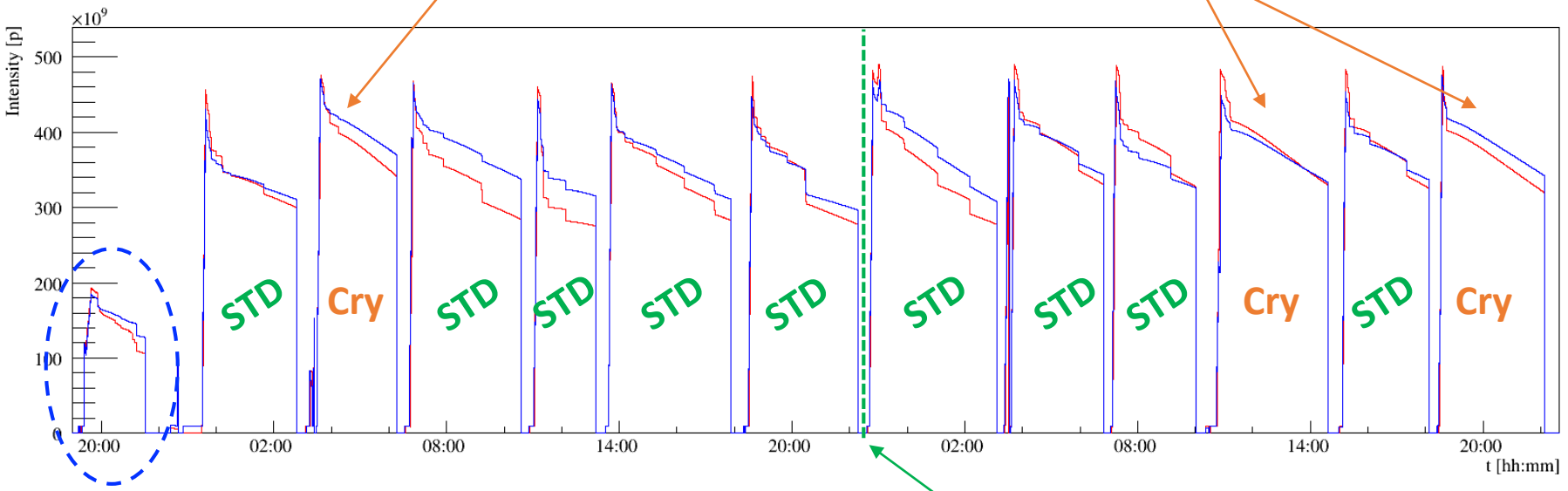
# Overview of the run

- **Promising results obtained during initial tests**

  → Decided to have the **crystals as a viable option** for the real physics run

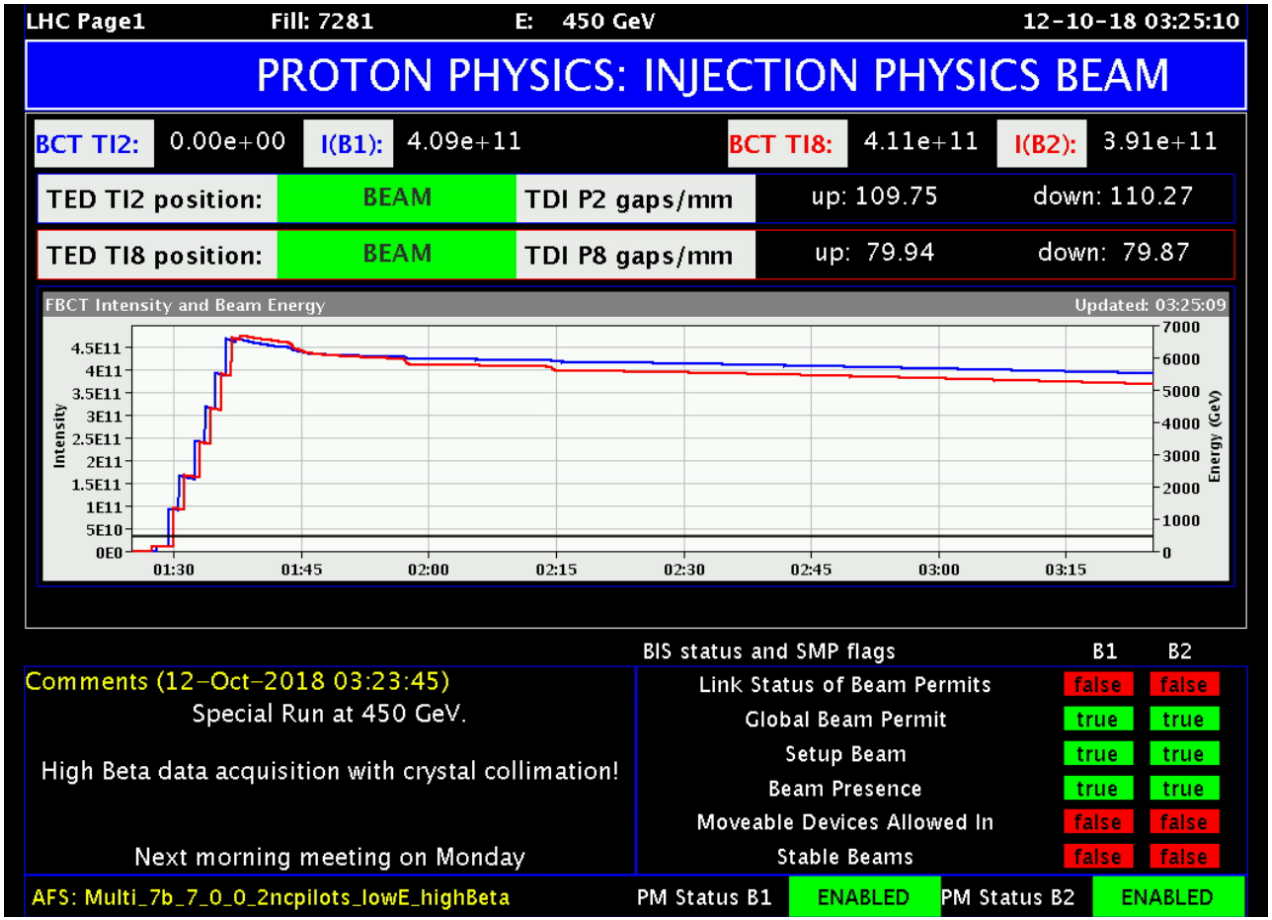
**NO NEED TO SCRAPING WITH CRYSTAL**




**1 setup fill:** confirmed alignment STD and Cry coll.

**Re-align needed for STD**
**Bad bkg to TOTEM following fills**

# First operational use of crystals!

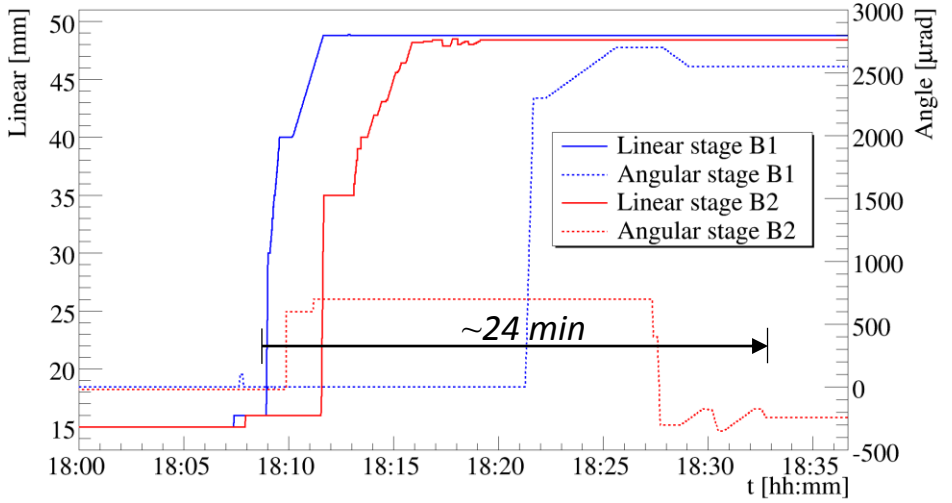



**First time ever that crystal collimation was used in a physics run**

**Very important milestone!**

# Operational performance of crystals

- **Setup** of the crystal collimation scheme took **less than 25 min** during initial setup fill!

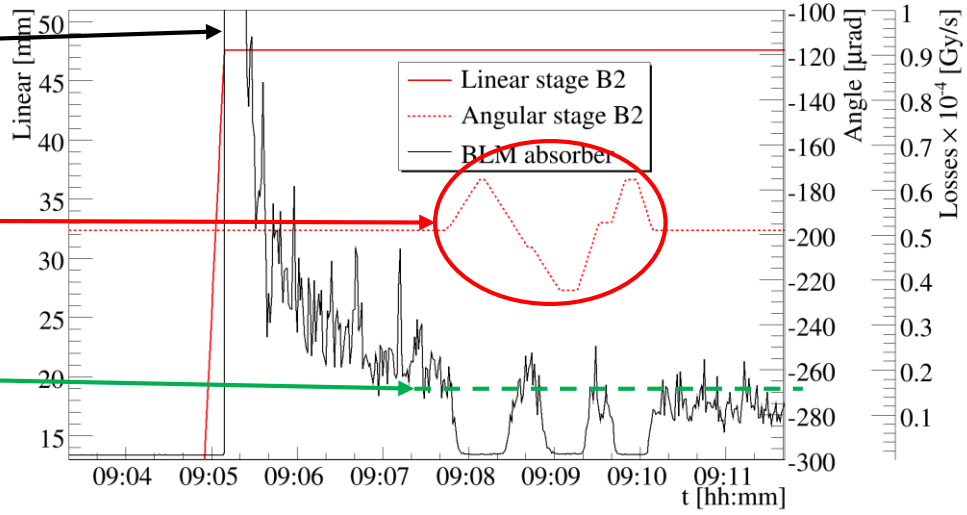



- **Crystals inserted through automated sequences directly in channeling orientation during operations!**

Beam touched as expected

Quick angular scan around channeling in the shadow of XRPs insertion

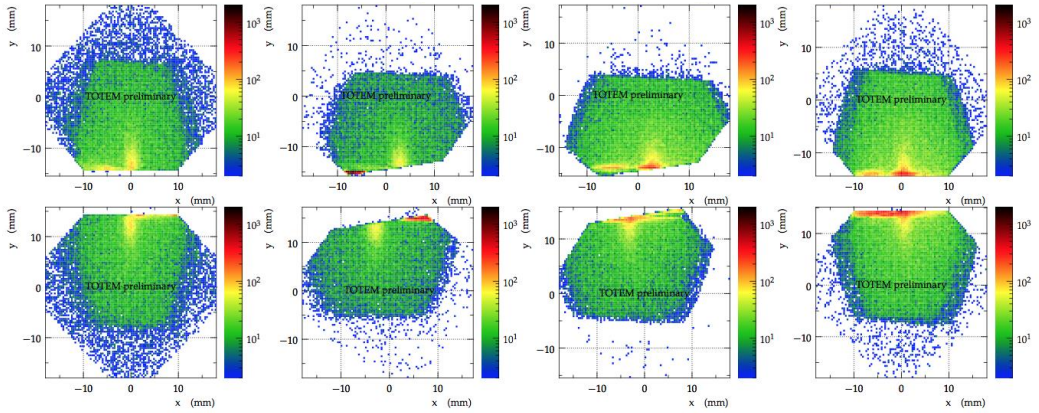
Crystals where inserted in channeling

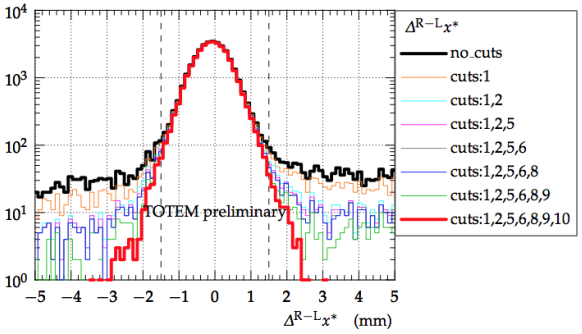


# Data quality from TOTEM

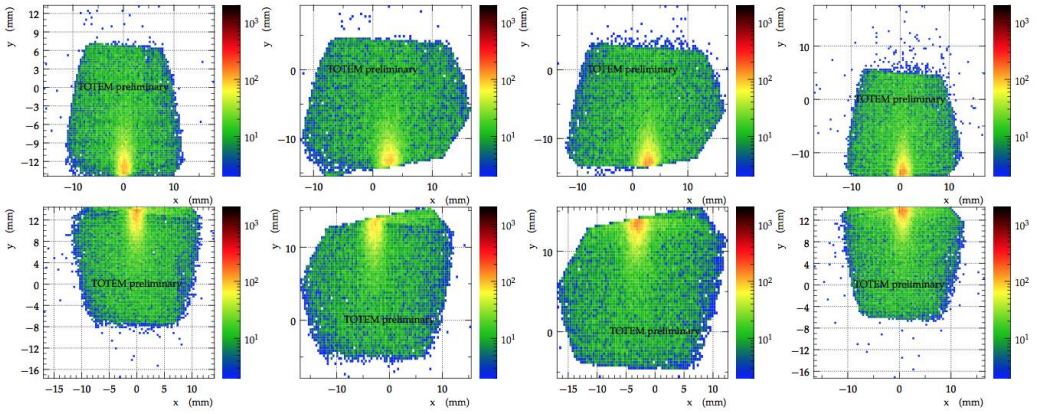
**PRELIMINARY DATA COURTESY OF J. CASPAR FOR THE TOTEM COLLABORATION**

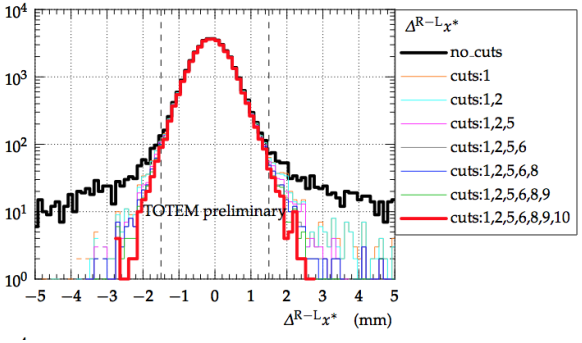
- **Tight collimation: background** at sensor edges, removed with **full off-line cut**




- **Crystal collimation: no background** evident, removed with **first off-line cut**



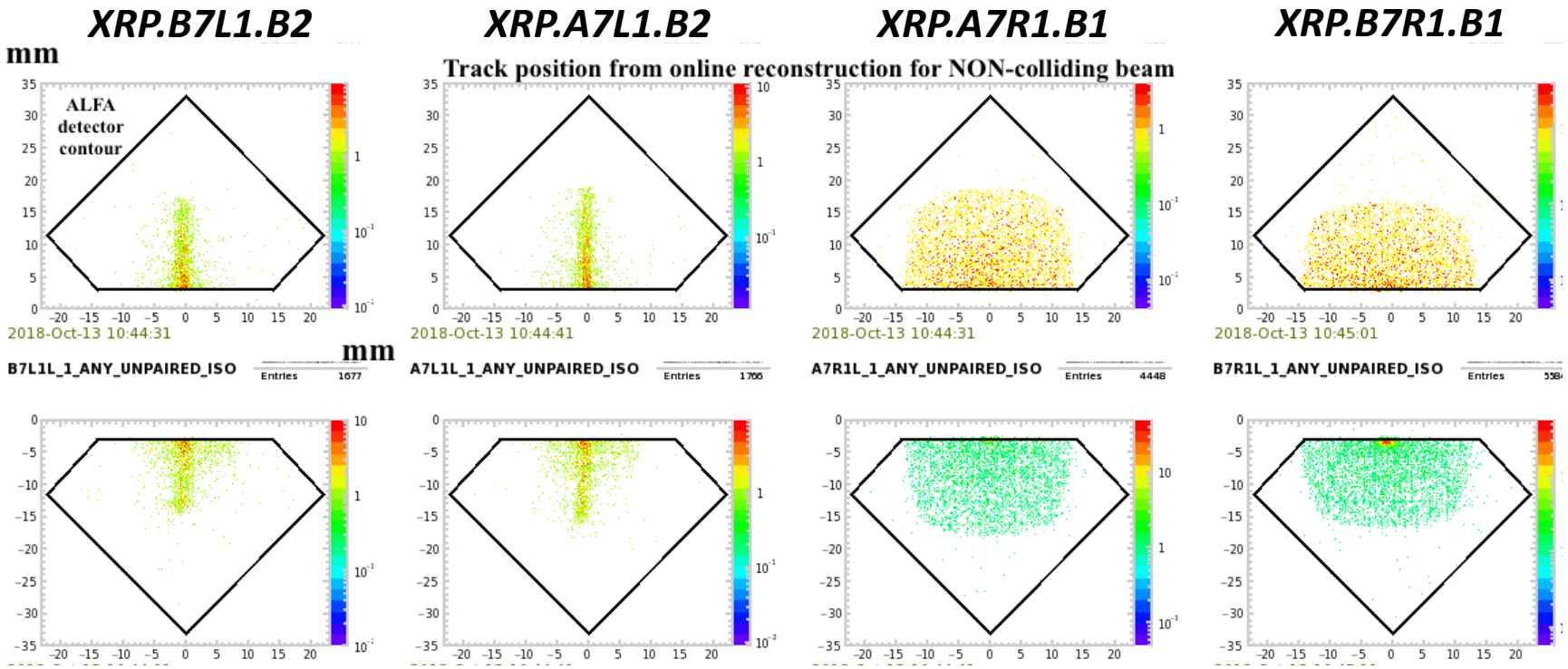



# Data quality from ALFA

**PRELIMINARY DATA COURTESY THE ATLAS-ALFA COLLABORATION**

- **Potentially problematic background distributions** with crystal collimation

  → Signal from non colliding bunches similar to elastic scattering signature (on B2 pots)

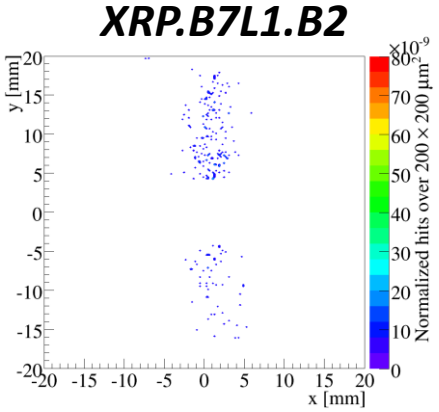


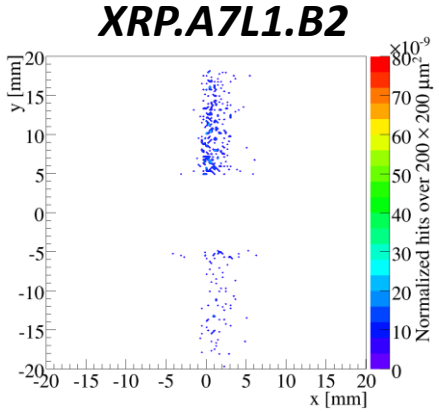

**Off-line analysis show that data collected could be used (LPC 29/10/18)**

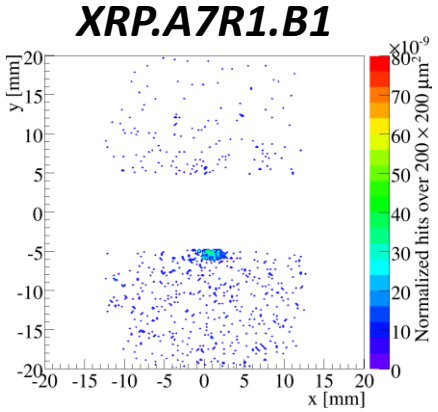
***0.5% and 1.5% physics background with tight and crystal collimation, respectively***

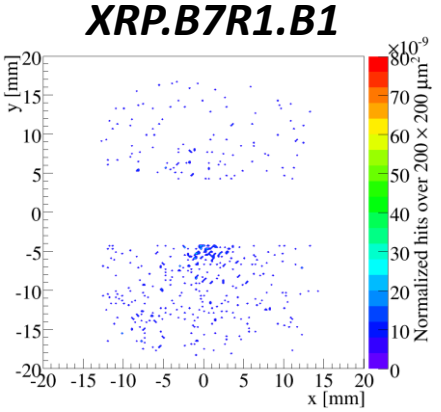
# Understanding ALFA background

**Very high statistics needed: 96x10$^6$ p simulated**




- **History of each particle reconstructed** to understand the hit pattern:

**Beam 2**

**3**
**Impact on TCLA.A5L3.B2**
closed at 2.7σ

**2**
**~10 turns**
in the machine

**1**
**Particles get dechanneled**
and escape from IR7

**4**
Emerge from TCLA
and **impact on ALFA-XRP**
at the same turn

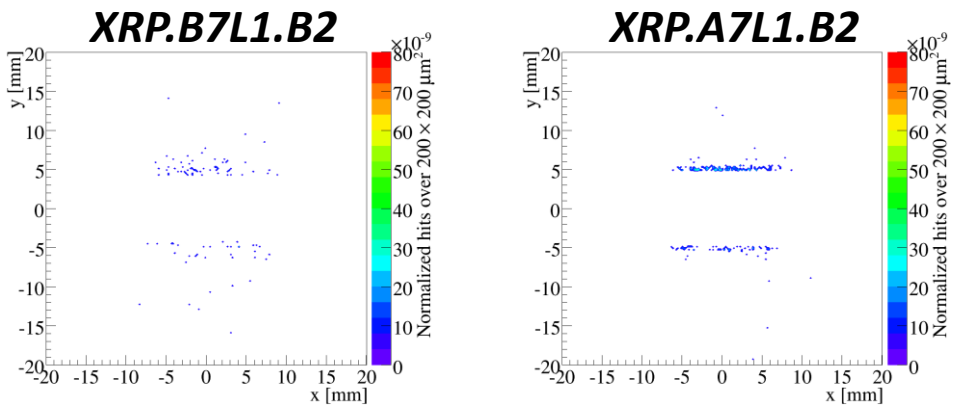
$$\Delta\mu_x^{XRP-TCLA} \sim 4^\circ \qquad \Delta\mu_y^{XRP-TCLA} \sim 244^\circ$$

$$\frac{\Delta y\,(\theta)}{\Delta x\,(\theta)} \propto \frac{\theta\sqrt{\beta_y^{TCLA}\beta_y^{XRP}}\;sin\left(\Delta\mu_y^{XRP-TCLA}\right)}{\theta\sqrt{\beta_x^{TCLA}\beta_x^{XRP}}\;sin\left(\Delta\mu_x^{XRP-TCLA}\right)} \sim 20$$

# Fixing ALFA background

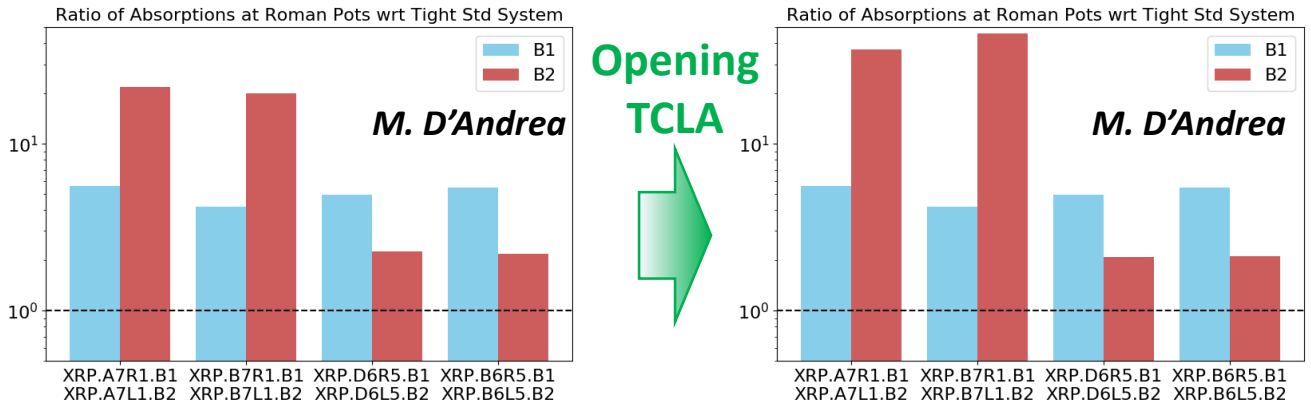
- Simulations performed with **TCLA.A5R3.B2 opened at 13 σ** as all other TCLAs in IR3

***Background distribution at problematic ALFA-XRP after TCLA retraction***




- **No changes** of distribution **in other pots** observed and even **larger gain in bkg rate** expected:

***Expected gain with respect to standard collimation (tight settings - 2.5 σ)***

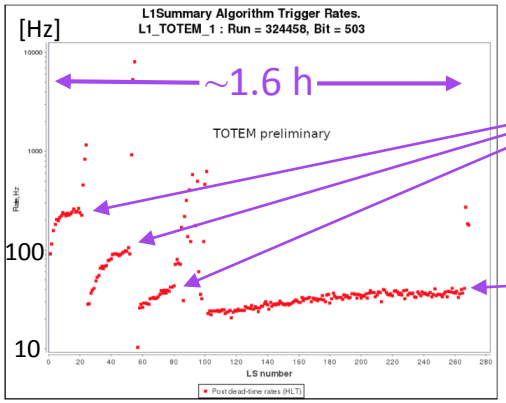



***Background distribution on Beam2 ALFA pots could have been easily modified!***

# Background rate from TOTEM

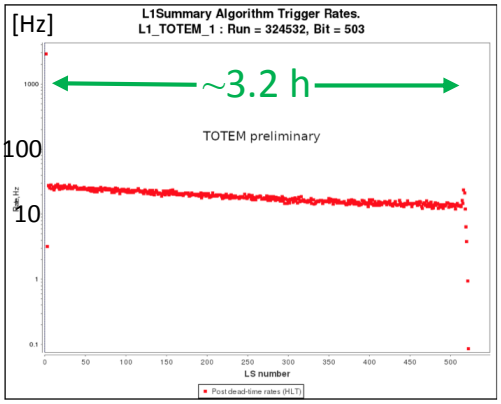
**PRELIMINARY DATA COURTESY OF J. CASPAR FOR THE TOTEM COLLABORATION**

- **Standard collimation:**




  - Frequent initial scraping needed to achieve a reasonable rate
  - Regular scraping needed due to the increasing rate

- **Crystal collimation:**

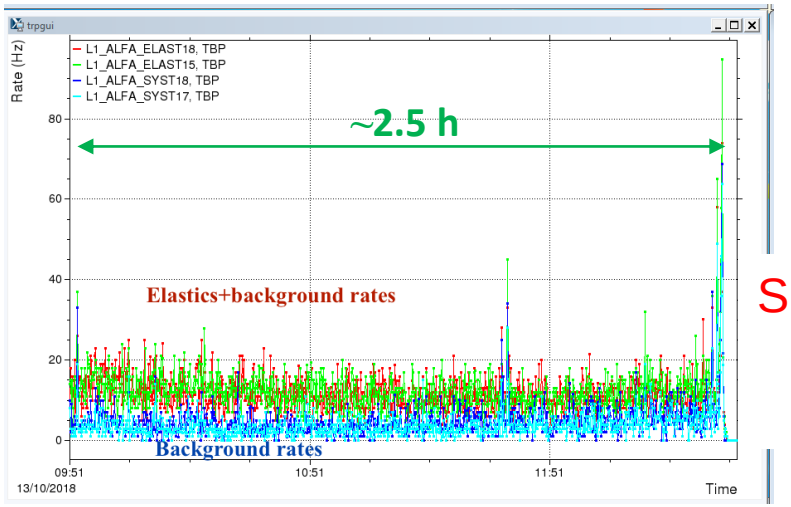



  - No need of scraping
  - Trigger rate follow luminosity

# Background rate from ALFA

**PRELIMINARY DATA COURTESY THE ATLAS-ALFA COLLABORATION**

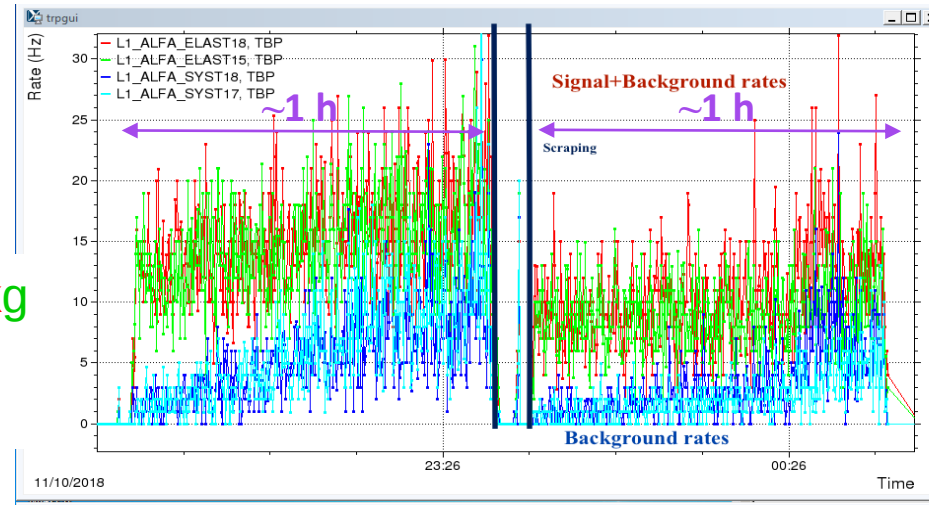
## Crystal collimation




Signal+Bkg

Bkg

## Standard collimation




***Same observations as for TOTEM: no need of scraping with crystals***

# Understanding background rate

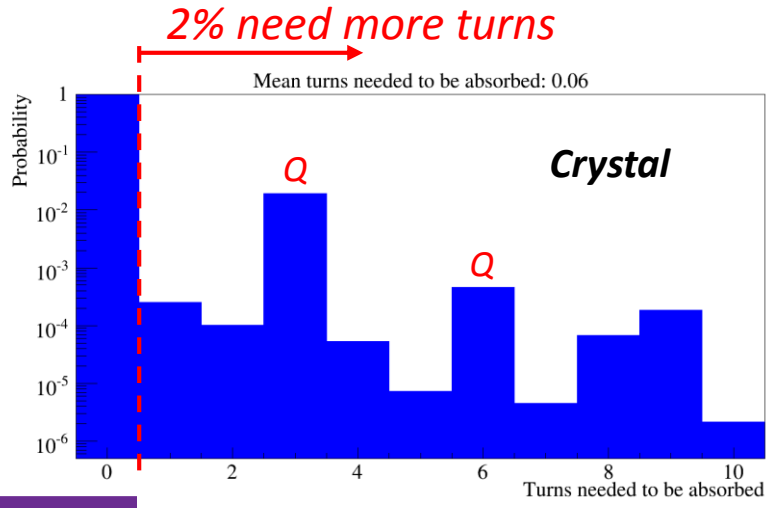
- **Two working hypothesis:**

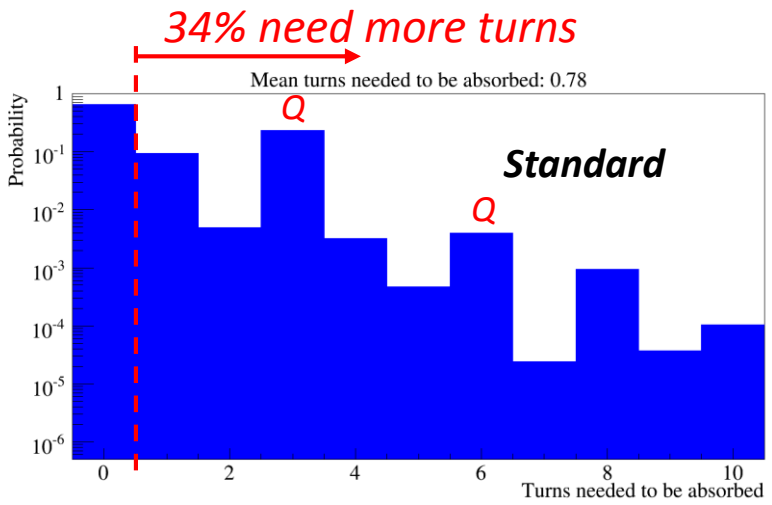
  1. **Background with crystals is so low that the is below BLM sensitivity**
     ↳ Inputs from experiments needed, as agreed at Collimation Working Group #235

  2. **Faster halo removal with crystals, able to digest larger diffusion rate**
     ↳ Evaluate the number of turns needed to remove a particle, using simulations

- **"Observable": number of turns between the hit on primary stage and absorption/lost**

*98% (66%) of particles absorbed in IR7 at the same turn in case of crystal (standard) collimation!*



# Outline

I. Collimation challenge and crystals
II. Standard and crystal collimation schemes
III. High beta physics run preparation
IV. High beta physics run results
**V. Conclusions**

# Conclusions

- Successful **reduction of background from kHz to Hz** one of the main **key to perform the run!**

- **Two collimation schemes conceived** using state-of-the-art simulation tools
  - ✓ **Both of them worked as expected**
  - ✓ Detailed **comparisons between simulations and data** on-going
  - ✓ **Reliable tools for possible future studies**

- **First feedback from experiments:**

| | TOTEM | | ATLAS-ALFA | |
|---|---|---|---|---|
| | **Tight coll.** | **Crystal coll.** | **Tight coll.** | **Crystal coll.** |
| **Bkg rate** | Re-scraping needed | Stable | Re-scraping needed | Stable |
| **Physics bkg** | <<1%/several% before/after partial re-alignment | <<1% | 0.5% | 1.5% |

# Outline

***Thanks for your attention***

# Outline

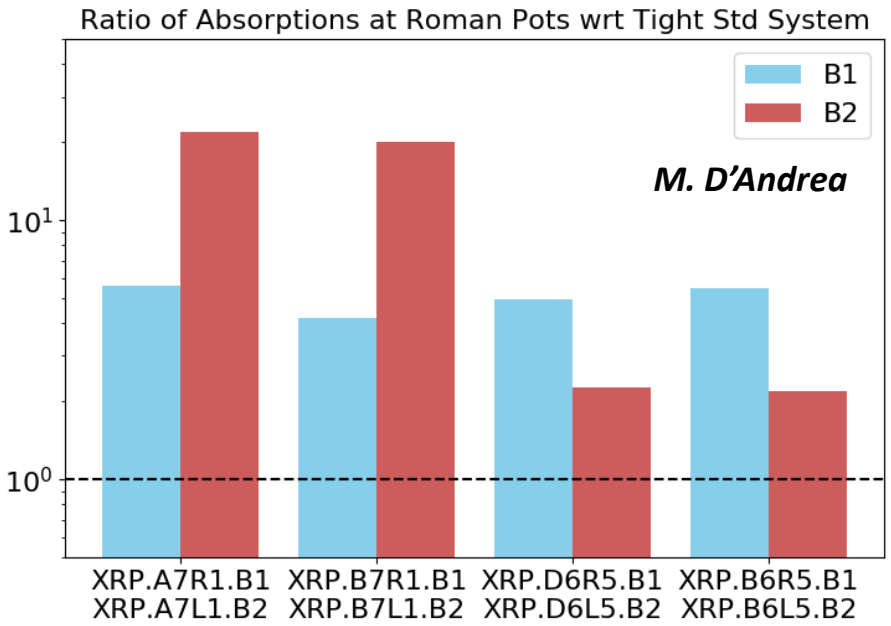
# Backup

# Setting optimization crystal collimation

- **Initial conditions:** setting used for **standard collimation but using crystal as primary**

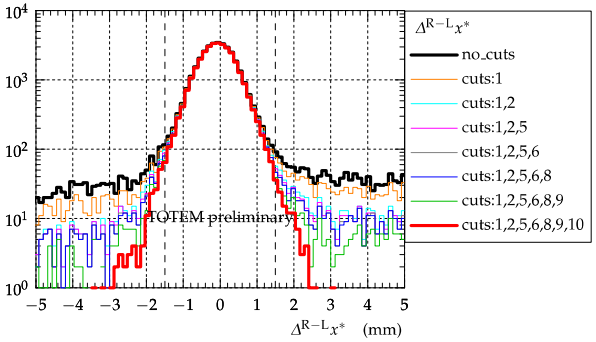
- **Main changes: relaxing the hierarchy while improving performance**
  - ✓ TCTPs in IR2 and IR8 in both beams opened (from 2.7σ to 13σ)
  - ✓ TCTPs in IR5 of Beam 1 and in IR1 of Beam 2 opened (from 2.7σ to 13σ)

*Expected gain with respect to standard collimation (tight settings - 2.5 σ)*

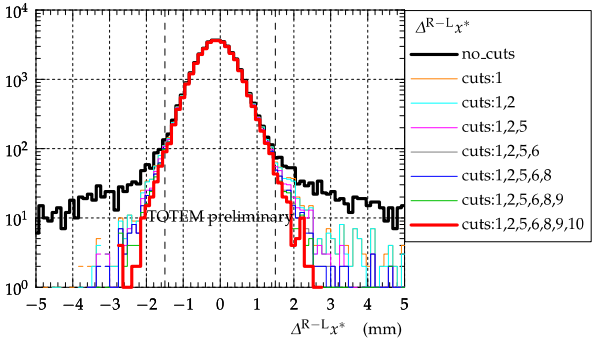


# Physics background TOTEM

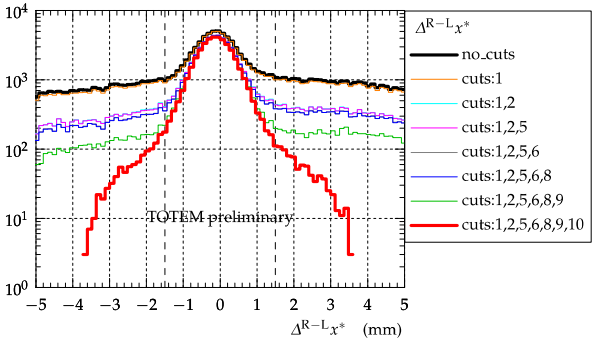
**PRELIMINARY DATA COURTESY OF J. CASPAR FOR THE TOTEM COLLABORATION**




- fill 7280 – standard collimation working well
  - background present (black curve has tails)
  - but treatable with offline cuts (red curve does not have tails)




- fill 7281 – crystal collimation
  - very little background present – most of it removed with the first offline cut




- fill 7286 – standard collimation with large background
  - even with all offline cuts background cannot be eliminated (red curve has significant tails)