



*HL-TCC Technical Coordination Committee  
35<sup>th</sup> meeting, August 3<sup>rd</sup>, 2017  
CERN, Geneva, CH*



# ***Summary of latest collimator MDs for HL-LHC***

*S. Redaelli, O. Aberle, D. Amarin, S. Antipov, G. Azzopardi, A. Bertarelli, N. Biancacci, R. Bruce, F. Carra, M. Fitterer (SLAC), N. Fuster, H. Garcia, I. Lamas and O. Aberle (for the STI team), L. Lacny, T. Markiewicz (SLAC), D. Mirarchi, A. Masi (for the controls team), A. Mazzacano, A. Mereghetti, E. Métral, A. Rossi, R. Rossi, B. Salvachua, B. Salvant, W. Scandale (for the UA9 collaboration), G. Sterbini (for the BBLR team), G. Valentino (Malta University), D. Valuch, J. Wagner, ... and many more.*



*The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.*



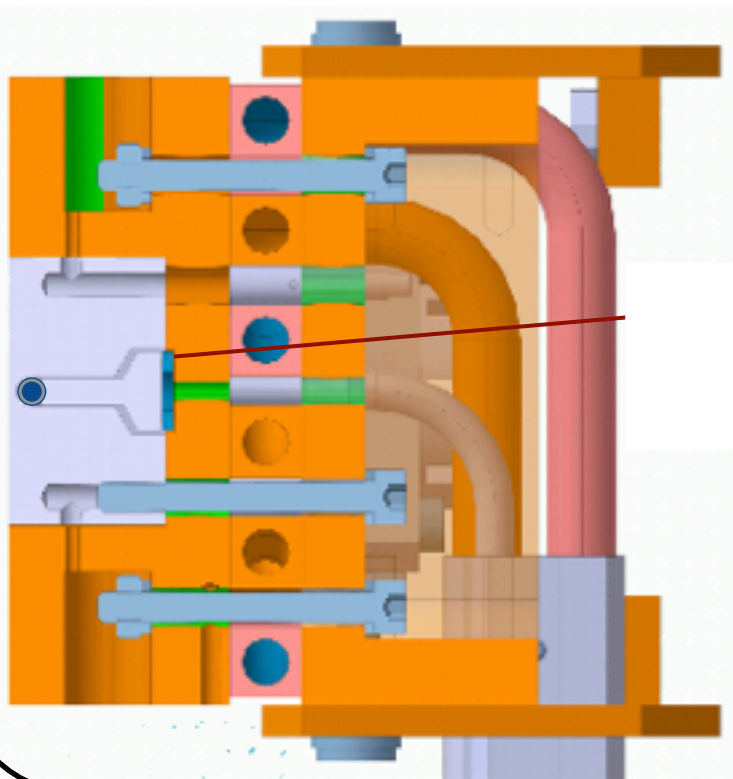
Main collimation works in EYETS2016

1. Low-impedance collimator prototype for HL-LHC (TCSPM)
2. Two collimators with wire for long-range beam-beam compensation studies (TCTPW)
3. 2 crystal primaries on beam 2
4. *Consolidated design of primary collimators: added BPMs (TCPP)*

*MoGr jaws with three surfaces for impedance checks (MoGr, Mo and TiN)*



TCTPW for beam-beam compensation studies



*Tertiary collimator with embedded wire for LRBB MDs*

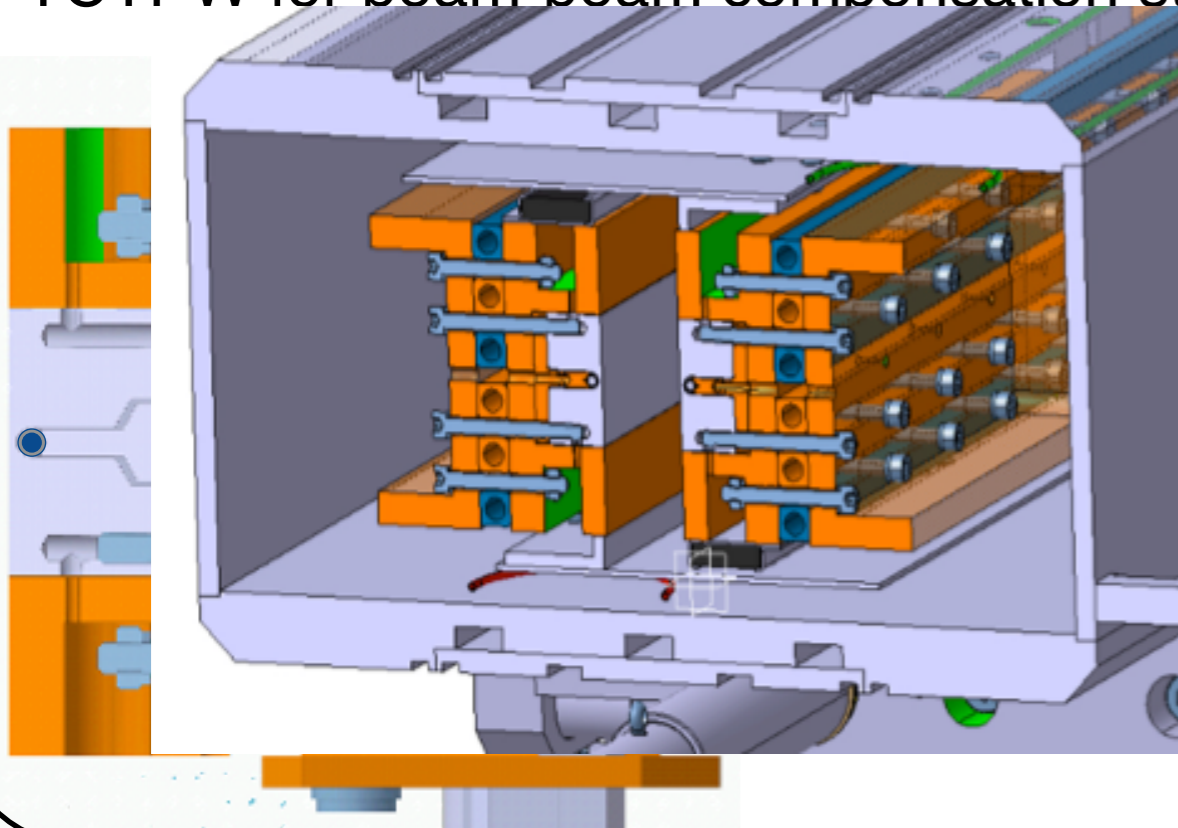
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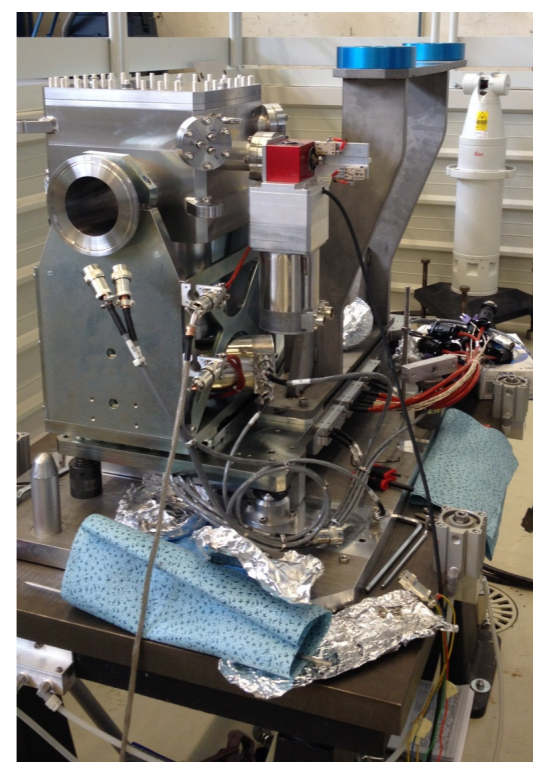
*MoGr jaws with three surfaces for impedance checks (MoGr, Mo and TiN)*



TCTPW for beam-beam compensation studies



*or wire*



*Goniometers for bent crystals: completely new installation for B2 (h+v)*

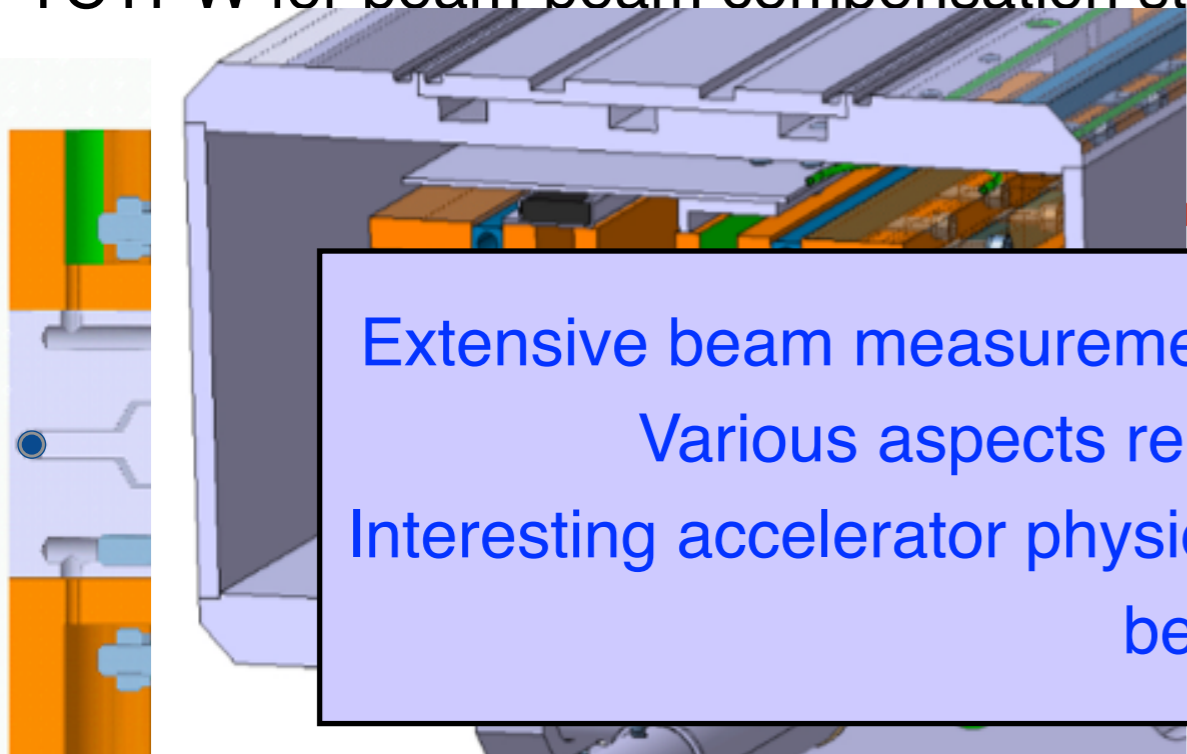
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TCTPW for beam-beam compensation studies



First HL-LHC hardware seeing beam??

Extensive beam measurement program proposed to MD coordination team!  
Various aspects relevant for feedback to LS2 production.  
Interesting accelerator physics cases made possible by new hardware, even beyond WP5 (ex. BBLR).



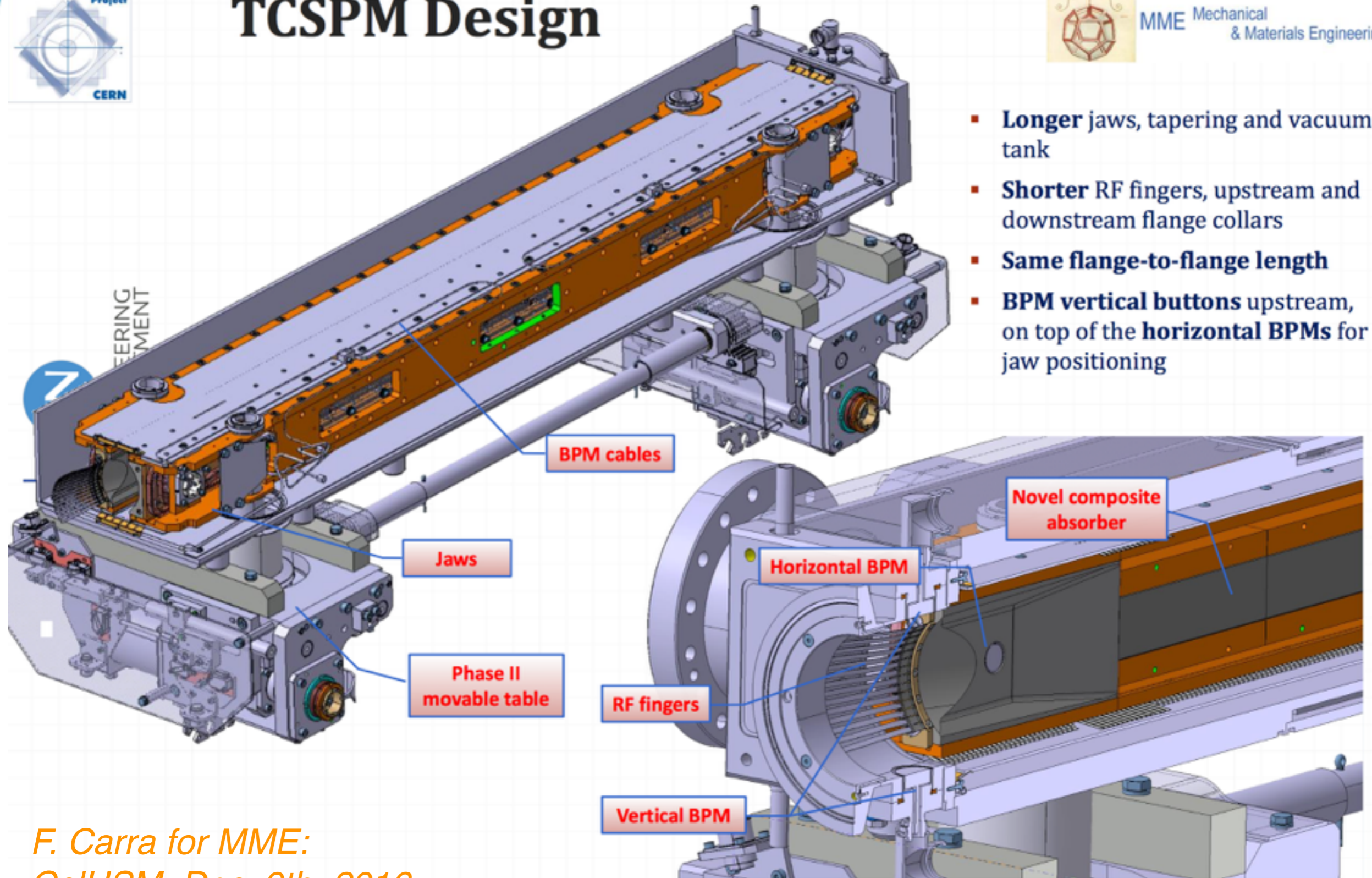
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- **Introduction**
- **Recap. of new collimators**
- **Performance with beam and MD results**
- **HiRadMat results with SLAC “RC”**
- **Conclusions**

- All people and teams that make the installation possible, in particular to EN/STI.  
EYETS2016: 6 new collimator devices installed!  
This was a huge amount of work.
- Collimator production teams:
  - Industrial production at CINEL
  - Prototype production in-house
  - Crystals (UA9), goniometers, electronics
- Planning and EYETS teams.
- BE/OP
- MD coordination for the beam time allocation.
- HiRadMat coordination team.
- HL-LHC project team for the support.

## TCSPM Design

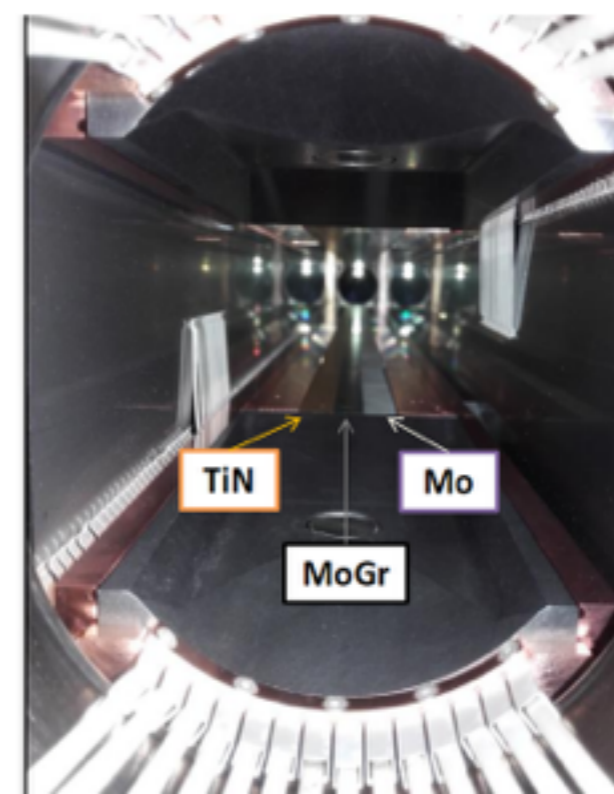
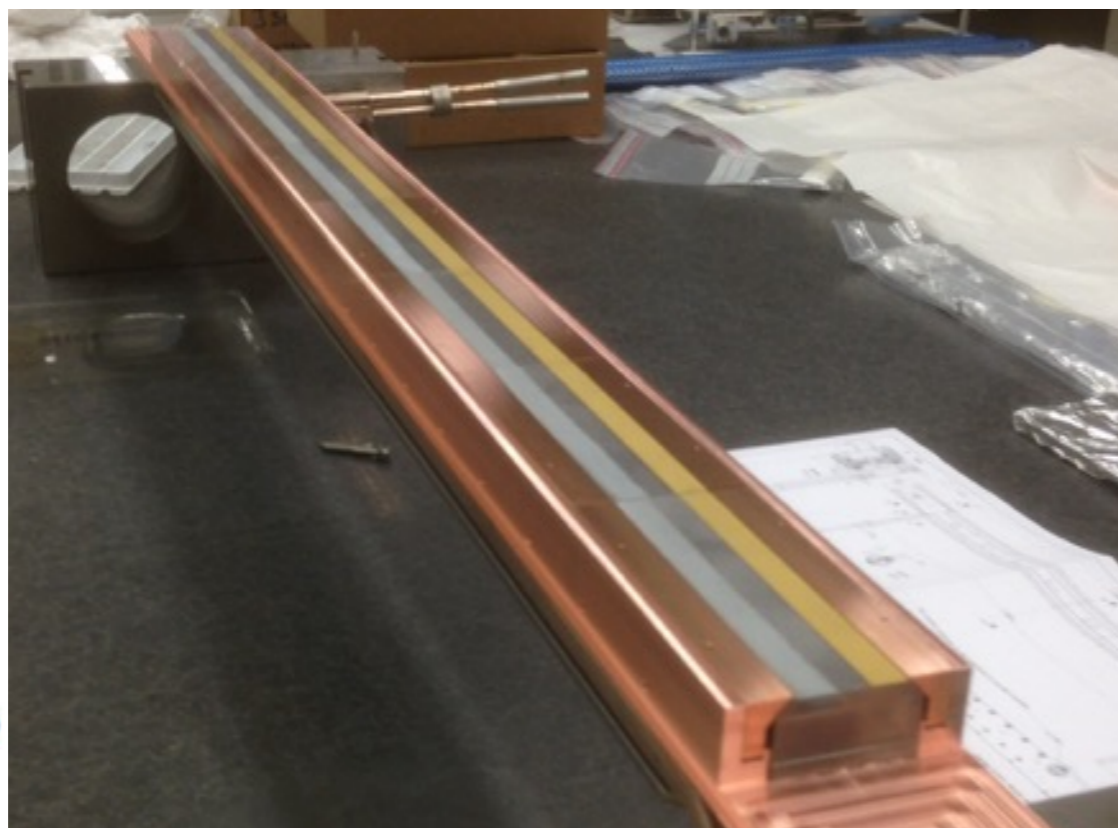
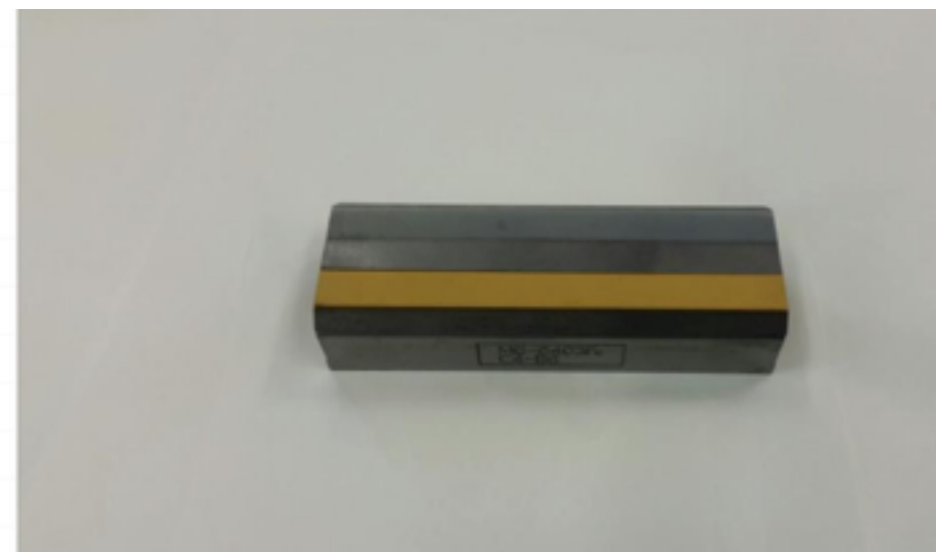
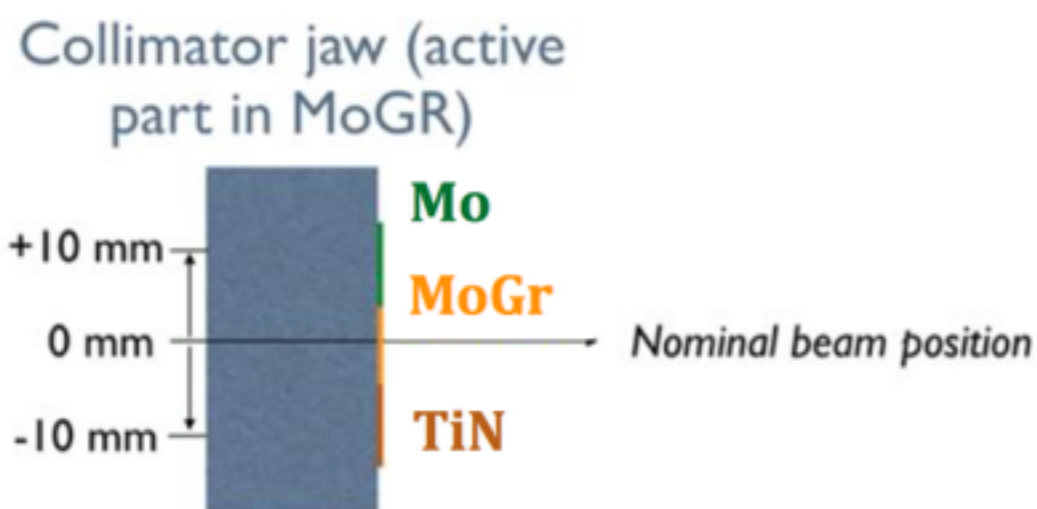


- **Longer jaws**, tapering and vacuum tank
- **Shorter RF fingers**, upstream and downstream flange collars
- **Same flange-to-flange length**
- **BPM vertical buttons** upstream, on top of the **horizontal BPMs** for jaw positioning

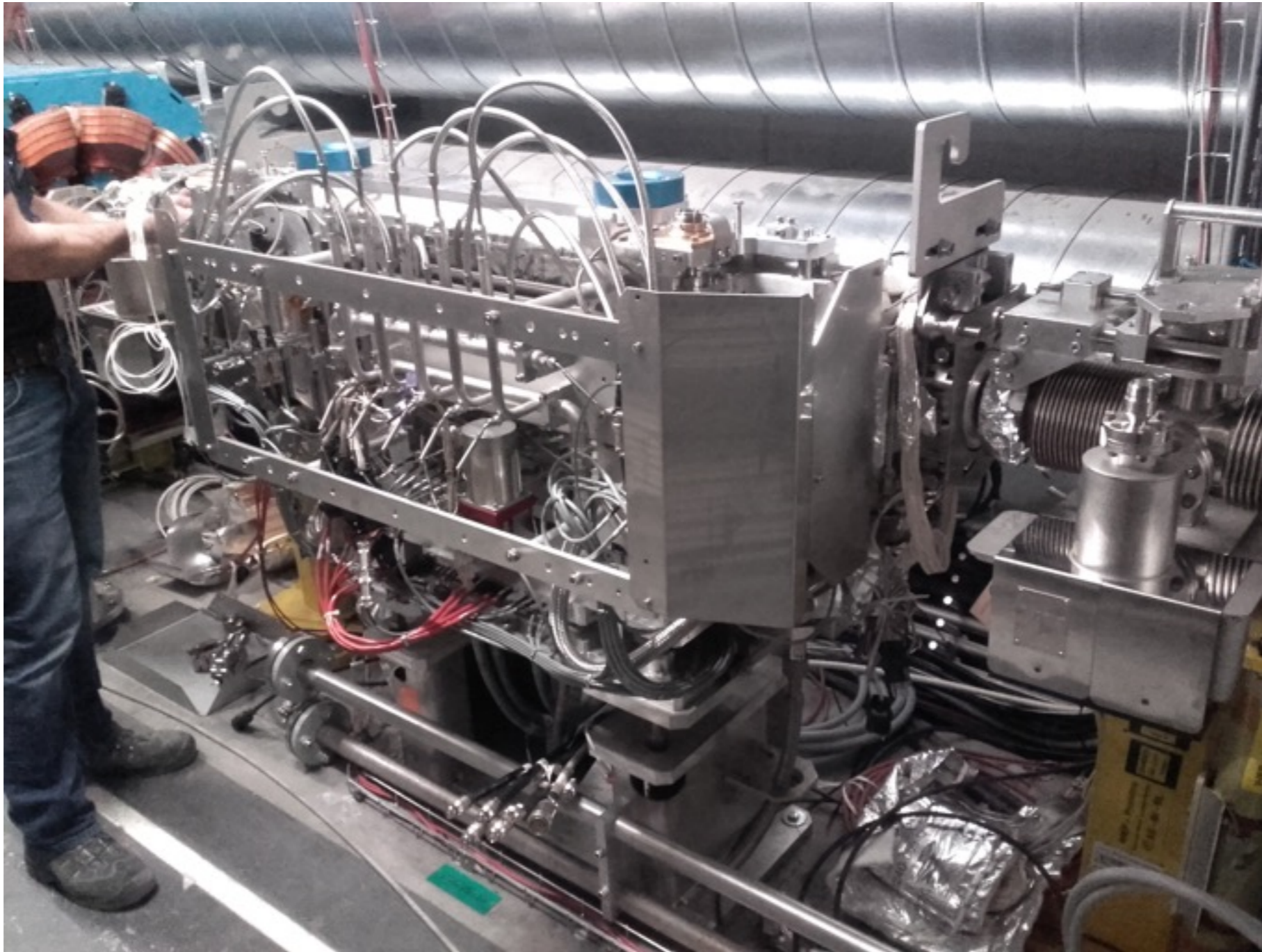
*F. Carra for MME:  
CoLUSM, Dec. 9th, 2016*

# Prototype for LHC beam tests

Idea: Test 3 different surface resistivity values (2 coatings)  
Collimator “5<sup>th</sup> axis” shift jaws transversally across the beam  
Very challenging, but feasible.  
Unique opportunity to test different coatings at LHC

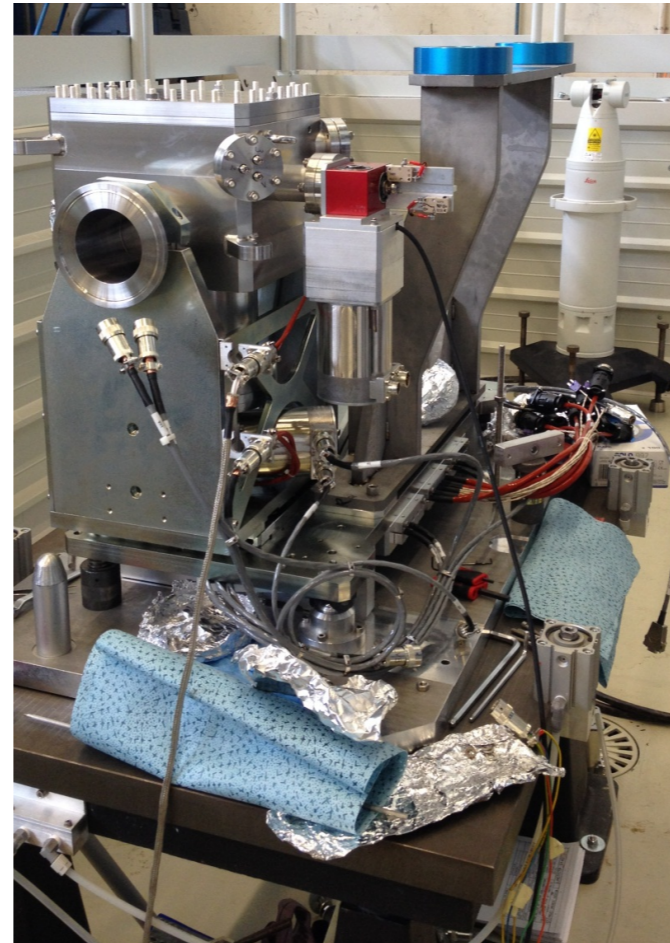
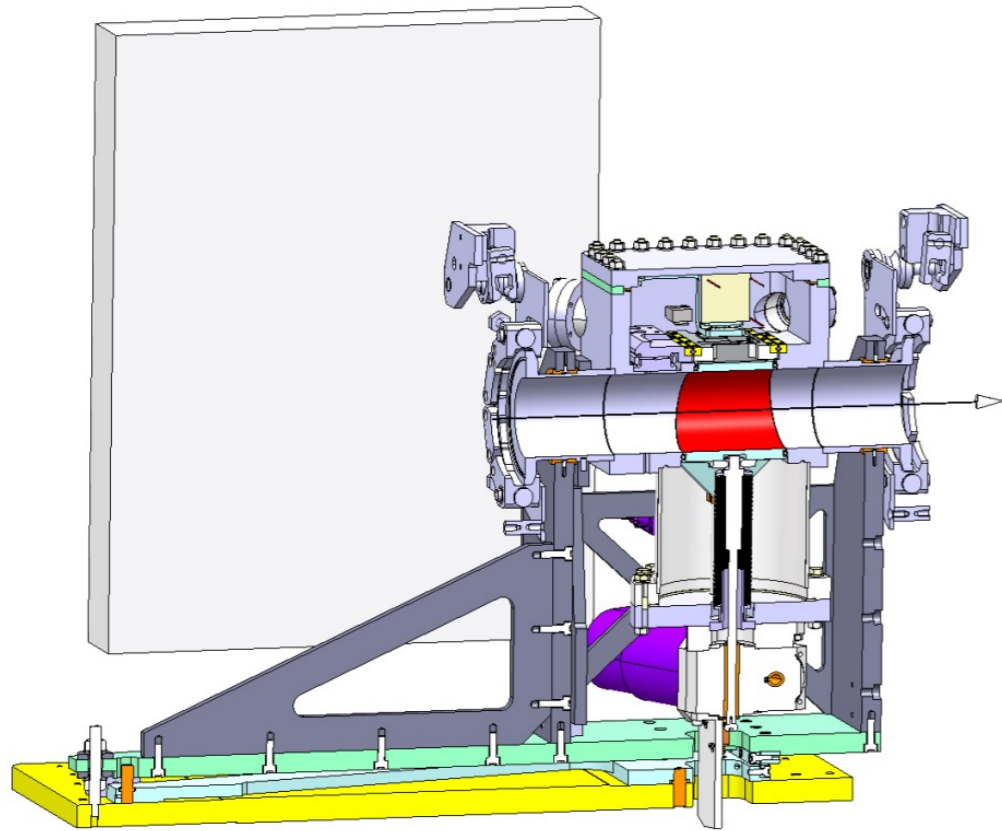






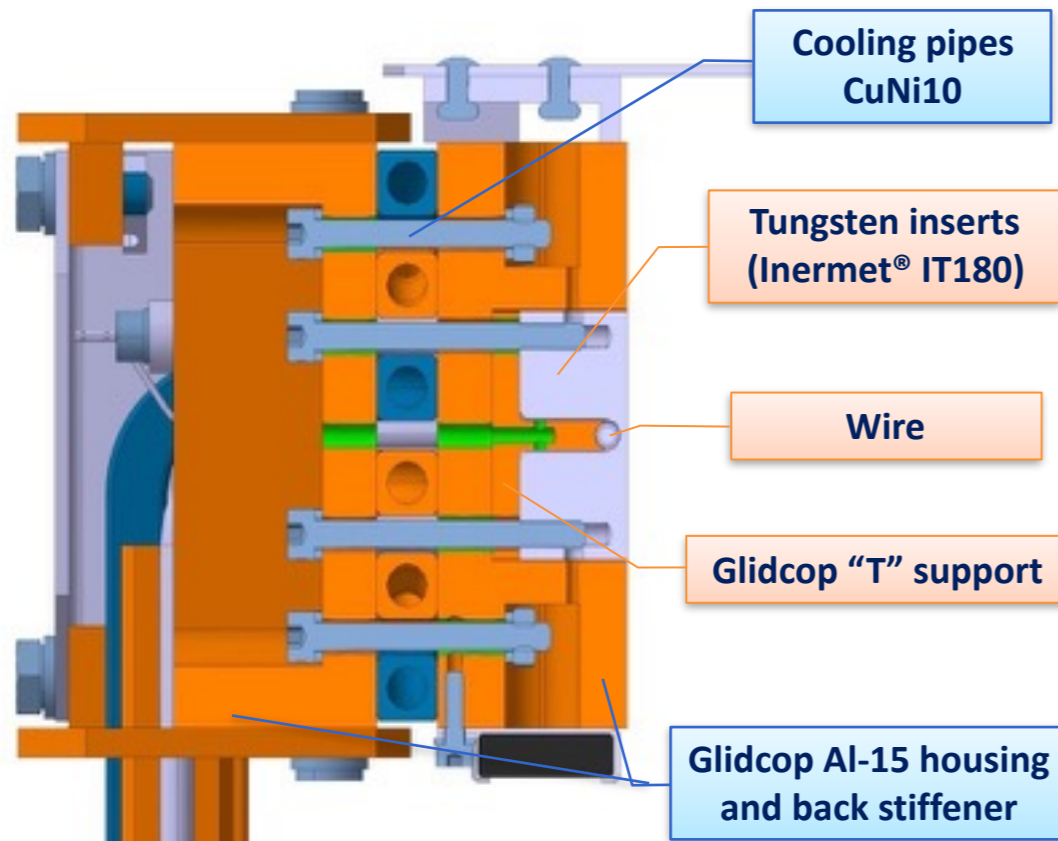
*Courtesy  
Inigo Lamas*

Successful installation and operation after vacuum crisis reported here on March 29<sup>th</sup>. Many thanks to joint efforts of EN/MME, EN/STI, TE/VSC, BE/BI and BE/ABP.



Goniometers: EN/STI development with industry.  
Crystals provided by the UA9 collaboration.  
Chosen 2 quasi-mosaic produced in Russia.  
*(B1: 1 Italian and 1 Russian crystal)*

Both new crystals installed, after a hiccup with the angular range of the vertical crystal (range reduced after bake-out, required design change).



1. Complex and quite unique design
2. 4 units produced thanks to a “production option” for new collimators on top of the LS1 contract of TCTPs
3. IR5: this design replaces operational collimators (TCTP/TCL)
4. IR1: 1 TCTP slot + a new slot (See A. Rossi, 33rd HL-TCC)
5. Crucially rely on “5th axis” to transversally align wire to the beam

## Specs and design

1. Primary functionality as tertiary collimator to be ensured.
2. Mechanically, challenging to be closer to surface than  $\sim 3$  mm.
3. Specs for current by F. Zimmermann and R. Steinhagen: **350 A** (taking into account larger-than-desired distance from beam), 19th CoLUSM, 01/03/2013
4. Design and thermo-mechanical aspects: 27th CoLUSM, 16/08/2013
5. Validation prior to installation: 80th CoLUSM, 09/12/2016 + report to TCC in March (A. Rossi)

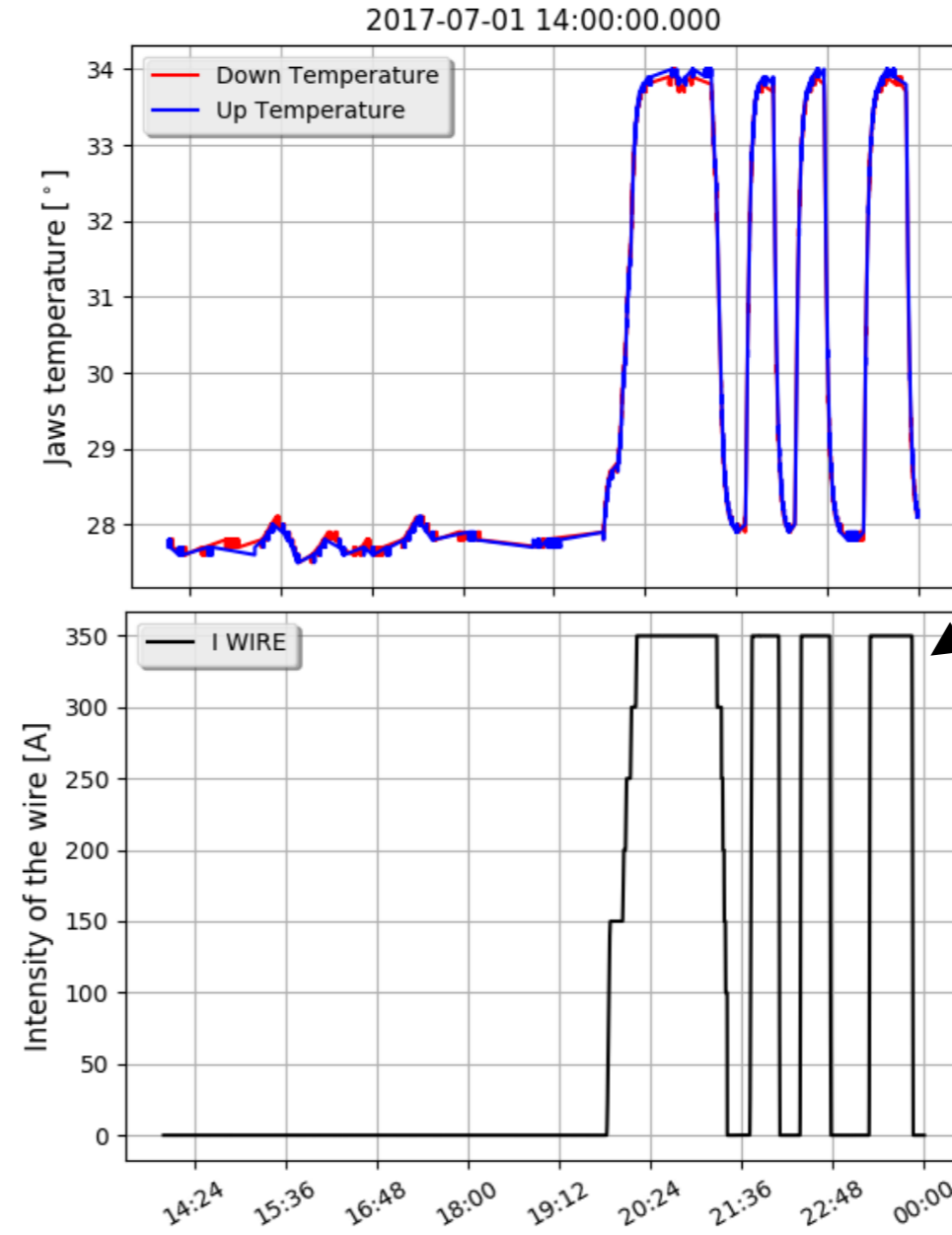
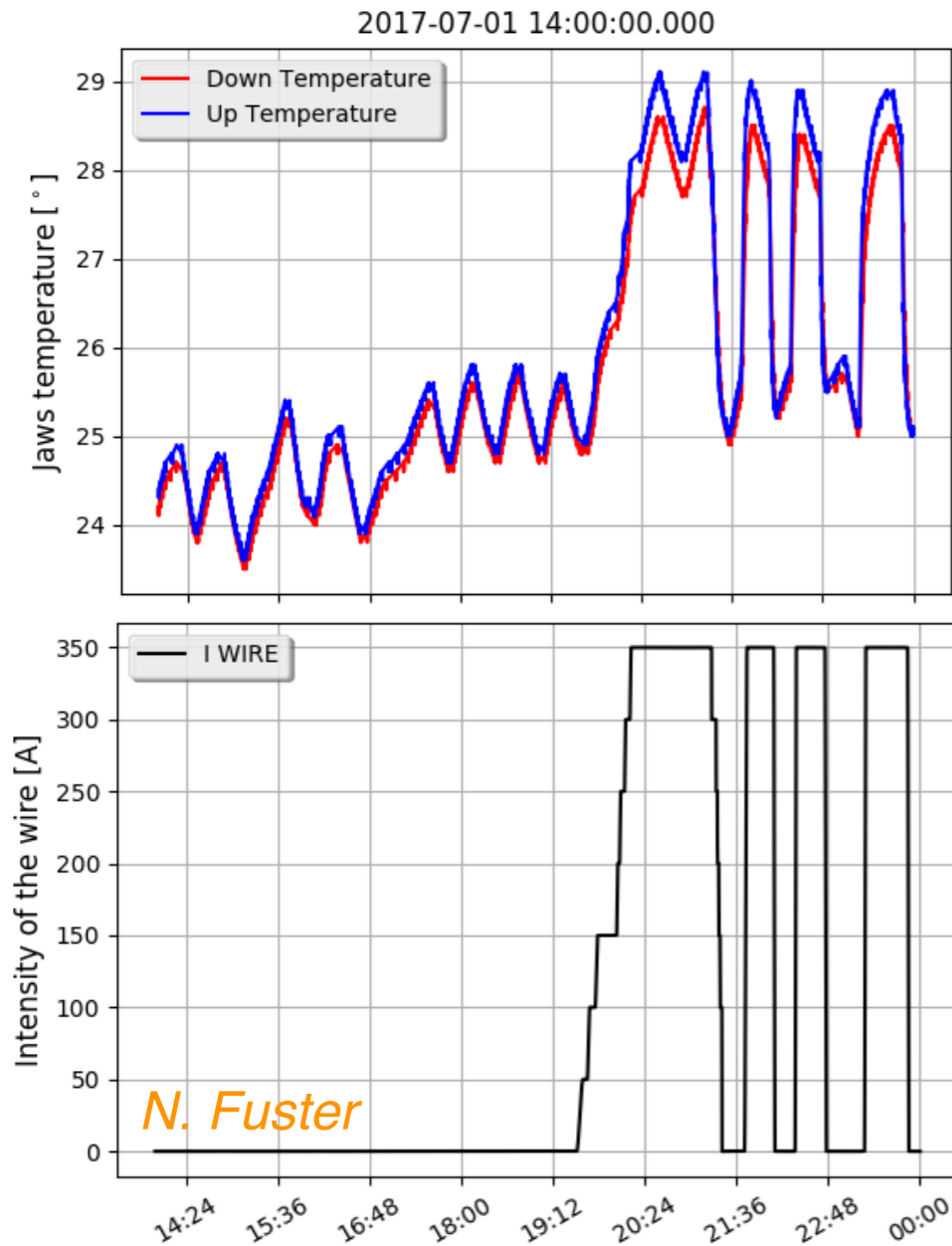


# Outline



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- **Performance with beam and MD results**
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Preliminary analysis collected and presented to the ColUSM meeting last Friday ([link](#)).  
See 33rd TCC for BBLR results with wire collimators.



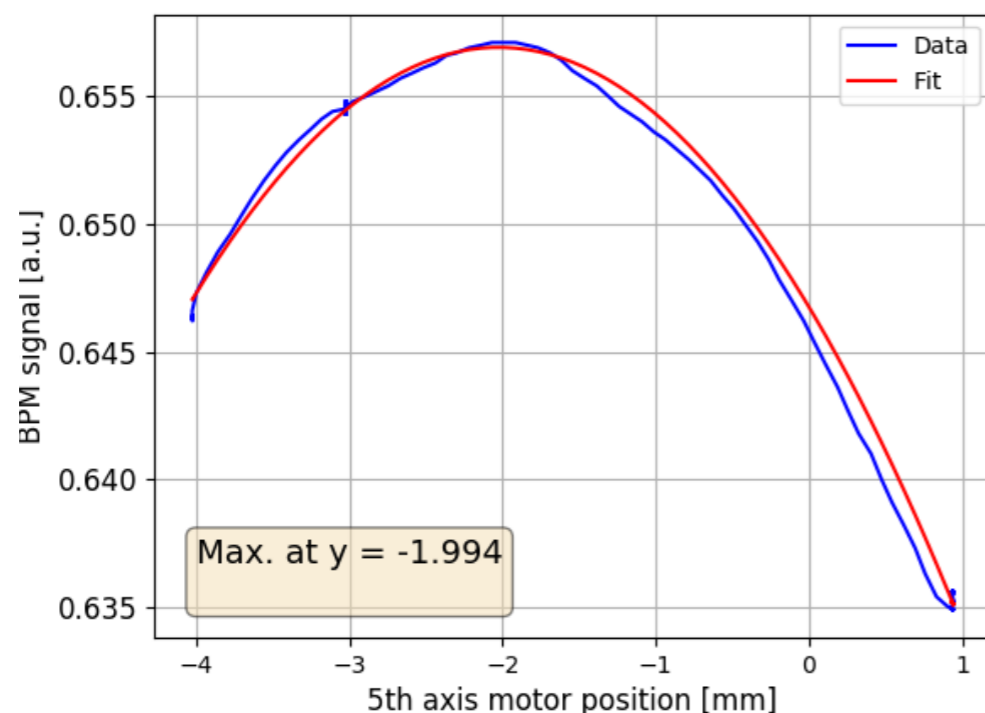
*Operated throughout the MD at maximum current.*

Verified without and with beam that the current in the wire does not perturb collimator motors, position measurements and BPMs.

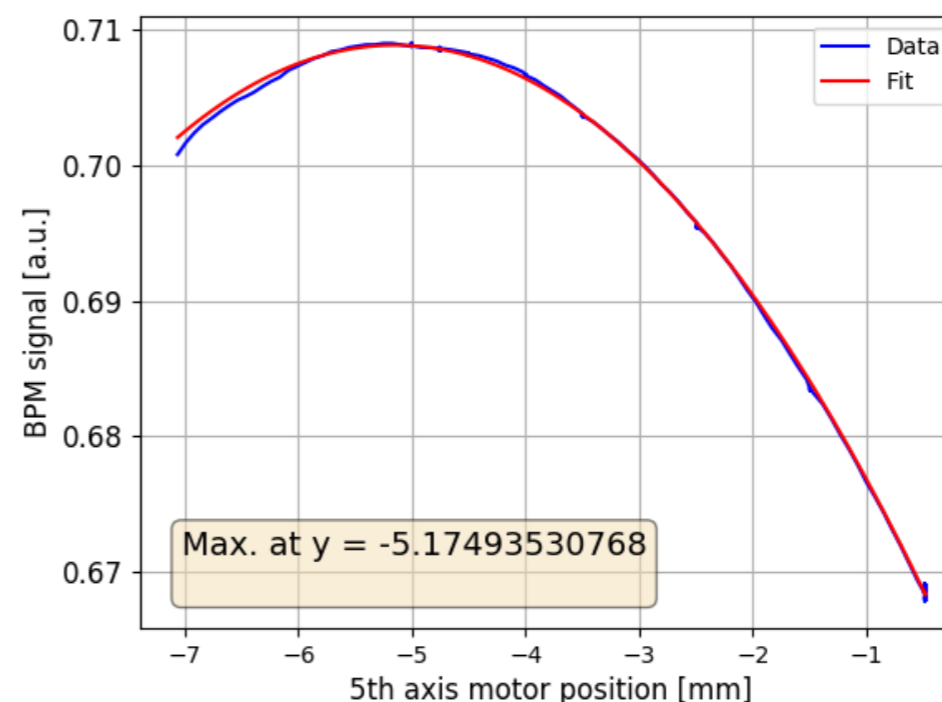
Excellent hardware performance during the tests with beam!

*Reminder — responsibility wire powering : TE/EPC + BE/BI (with support BE/OP)*

## TCTPH.4R5.B2



## TCL.4L5.B2

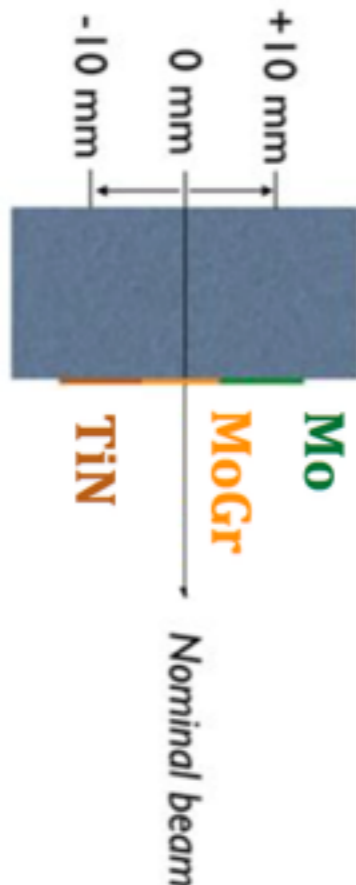
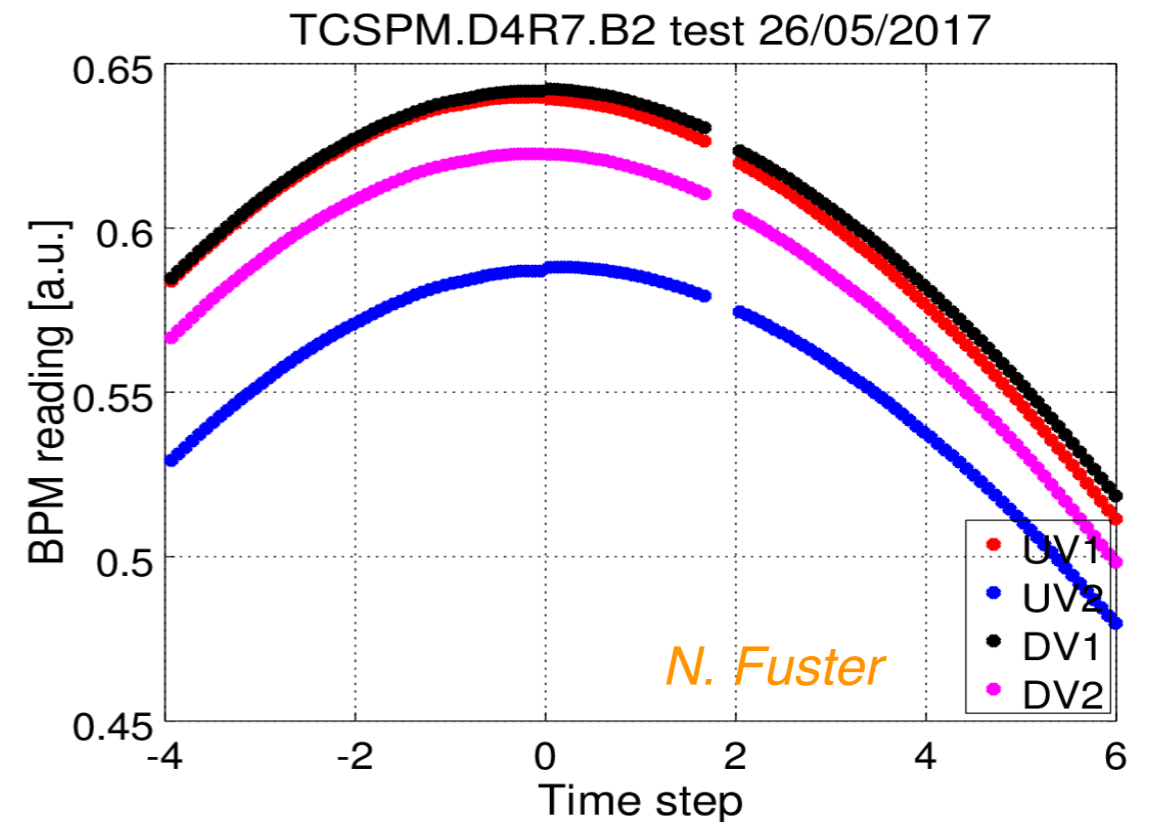
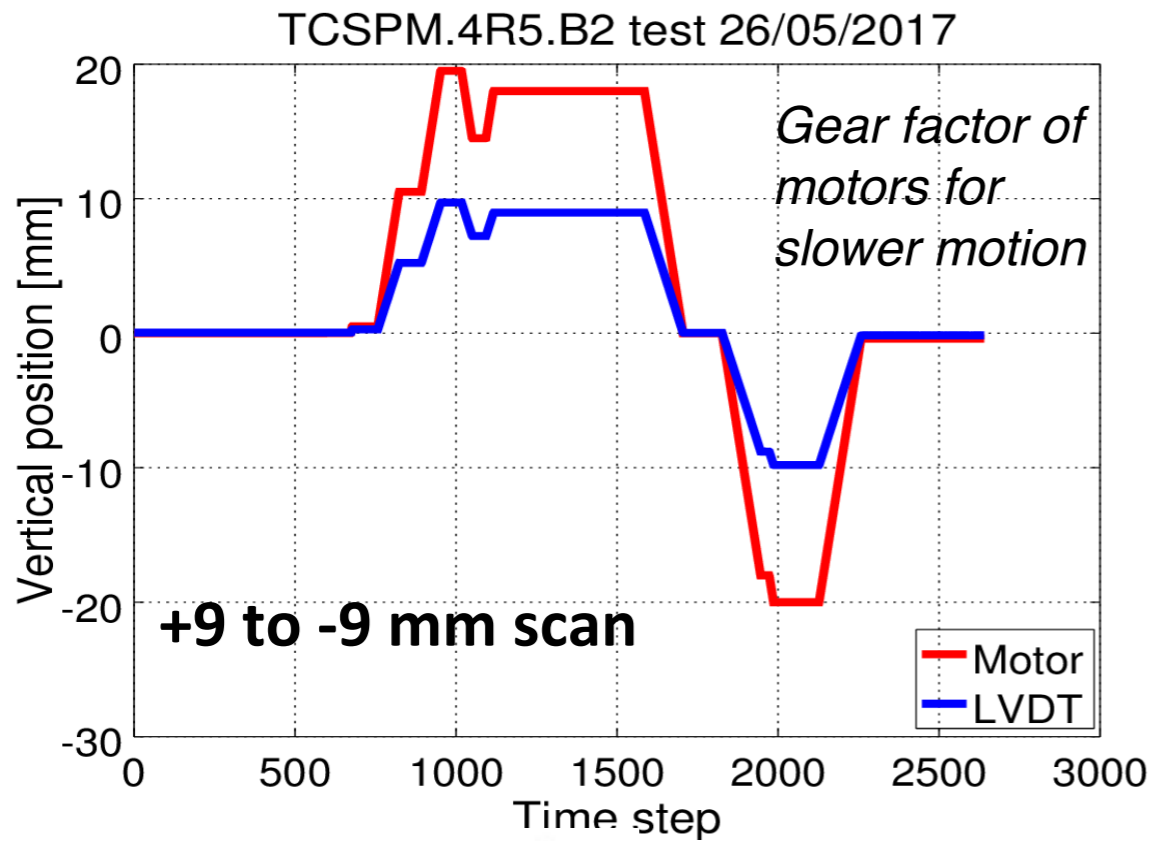


*N. Fuster*

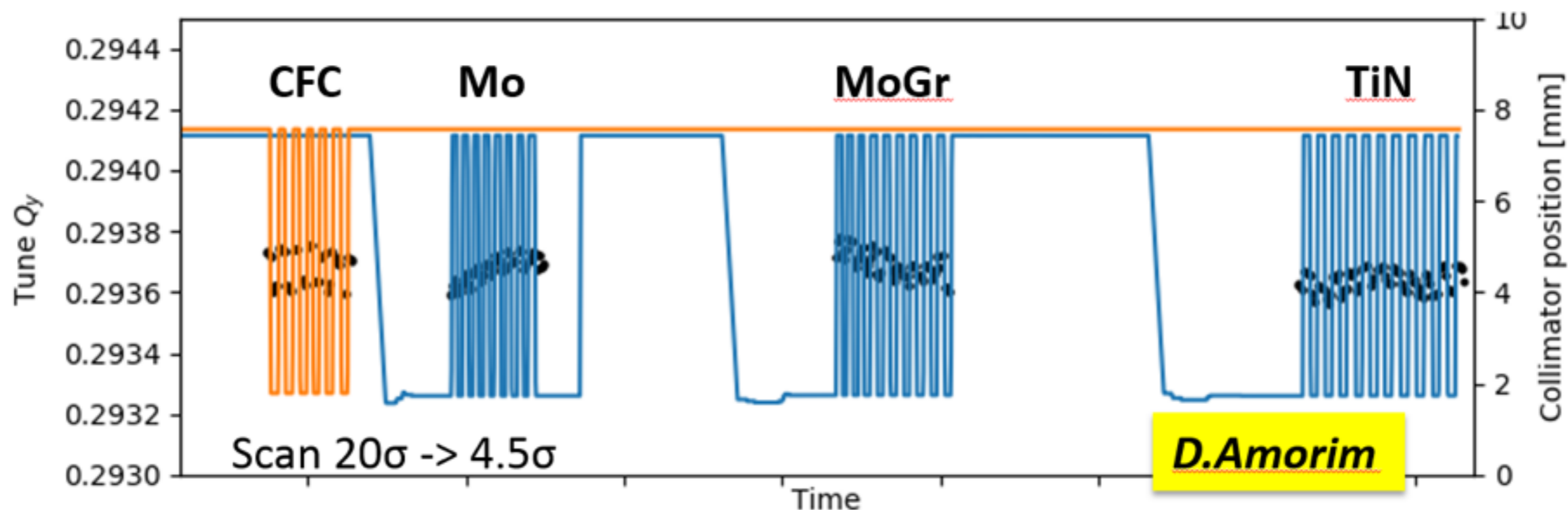
Alignment of the vertical wire position to the beam:

- Checked before MD that reference settings are recovered after changes
- Proposed alignment procedure by using BPM signal worked well during MD, confirmed by beam measurement (see by G. Sterbini at 33rd HL-TCC)
- Puzzling results: larger offset than foreseen for TCL; some differences between upstream and downstream sides. To be understood.

Transverse settings achieved: **5.5 sigmas on the “weak beam”!**



Average offset between upstream and downstream:  
**0.0065 mm compatible with expected offset of 0 mm**



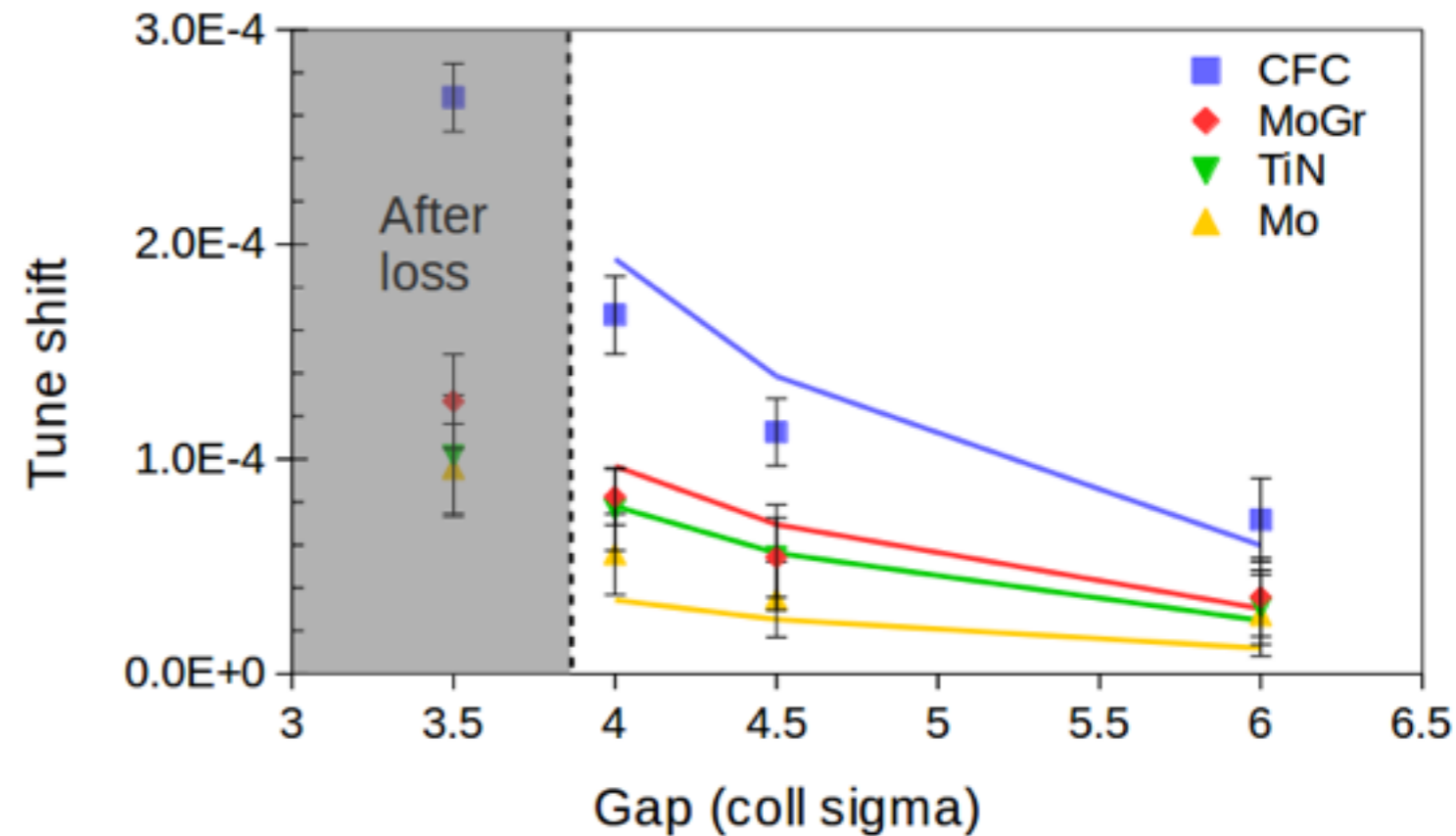
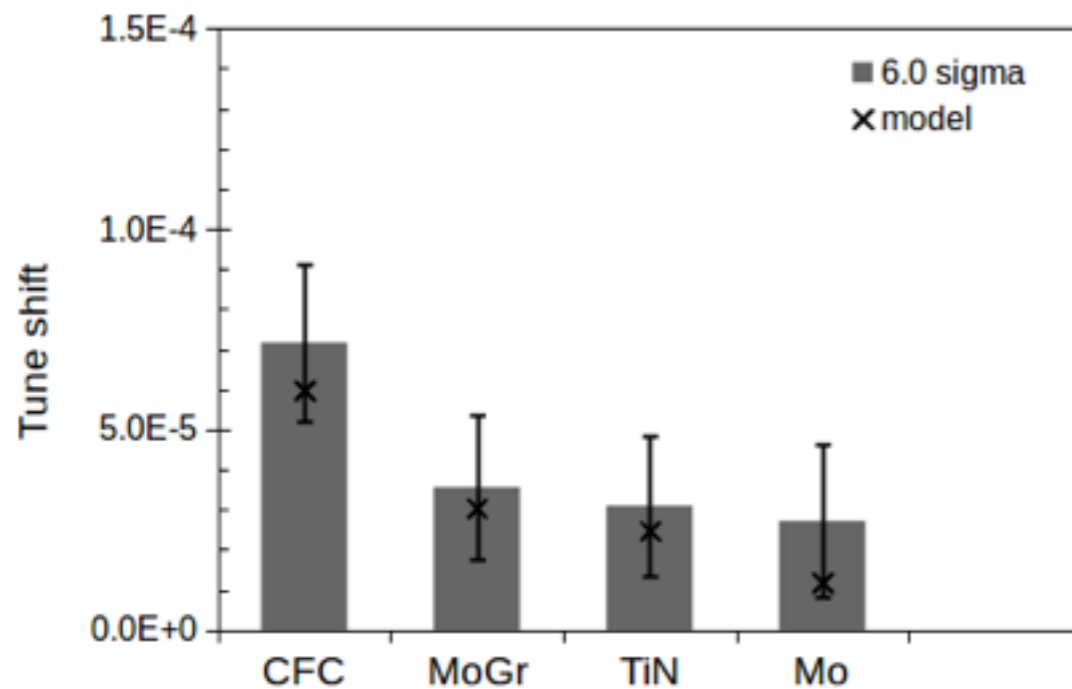
(Updated) procedure:

- Align centre of one facet to the beam
- Rapid scans in/out between extreme positions (avoid tune drifts!)
- Kicks with transverse damper synchronised to catch the tune deltas

Remarks:

- Direct comparison to adjacent "TCSP" made of CFC
- We are looking at very small tune shifts!





S. Antipov

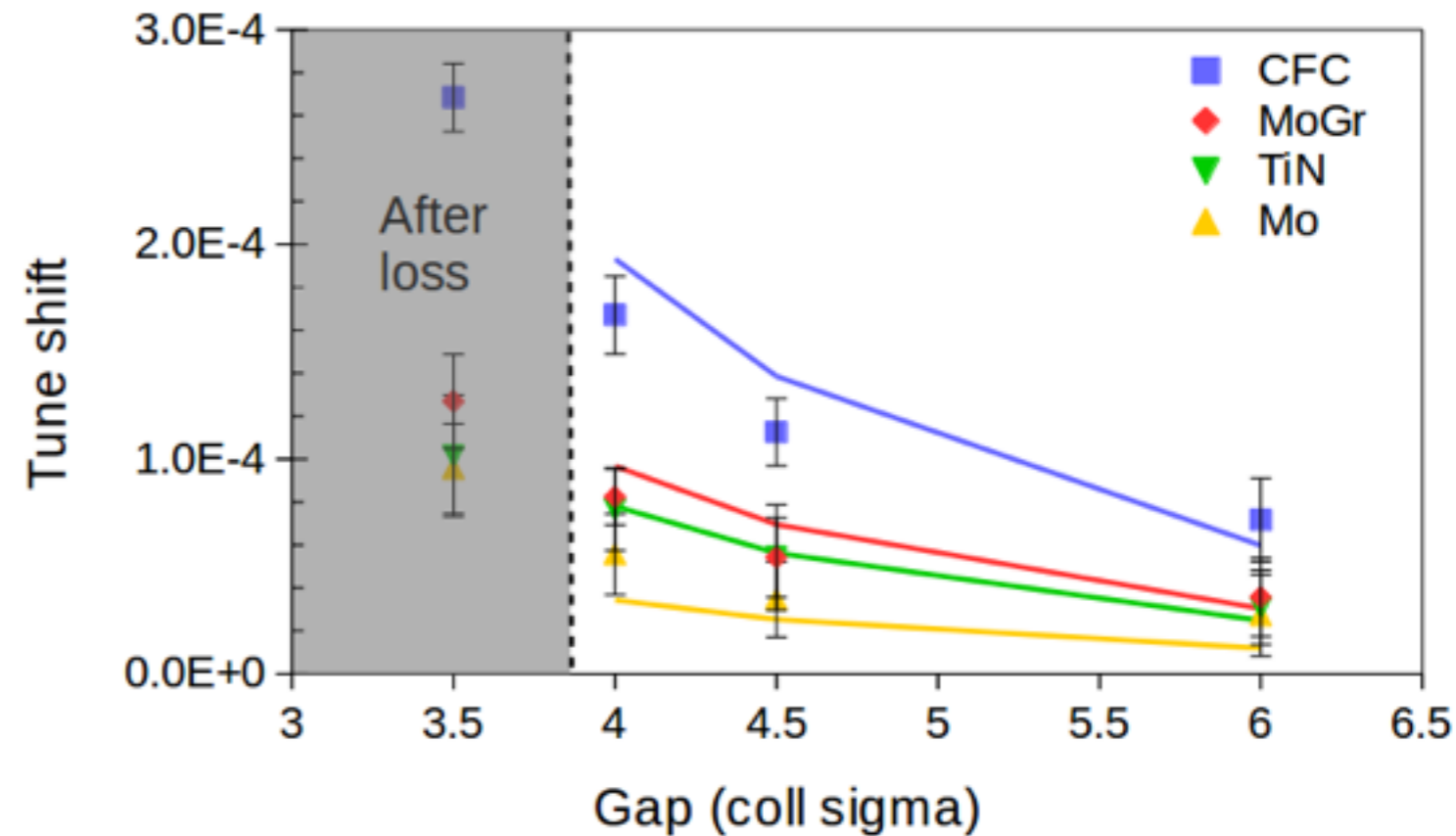
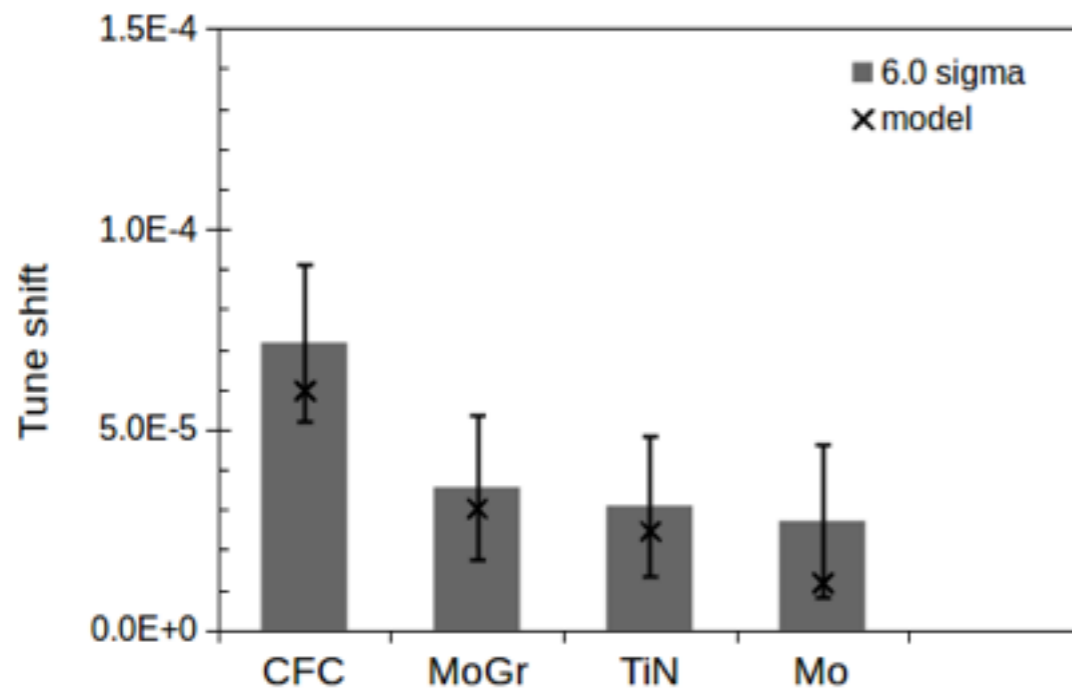
Preliminary conclusions (work still in progress)

- Good agreement against expectations
- Small difference close to operational settings, could be amplified with smaller collimator gaps.

Remark:

Laboratory measurements (see TCC, March 2017) indicated a different behaviour: in one case the MoGr improvement was not as expected.

Beam measurements confirm the gain from coating! Under investigation...



S. Antipov

Preliminary conclusions (work still in progress)

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- Small difference close to operational settings, could be amplified with smaller collimator gaps.

Remark:

Laboratory measurements (see TCC, March 2017) indicated a different

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Beam mea

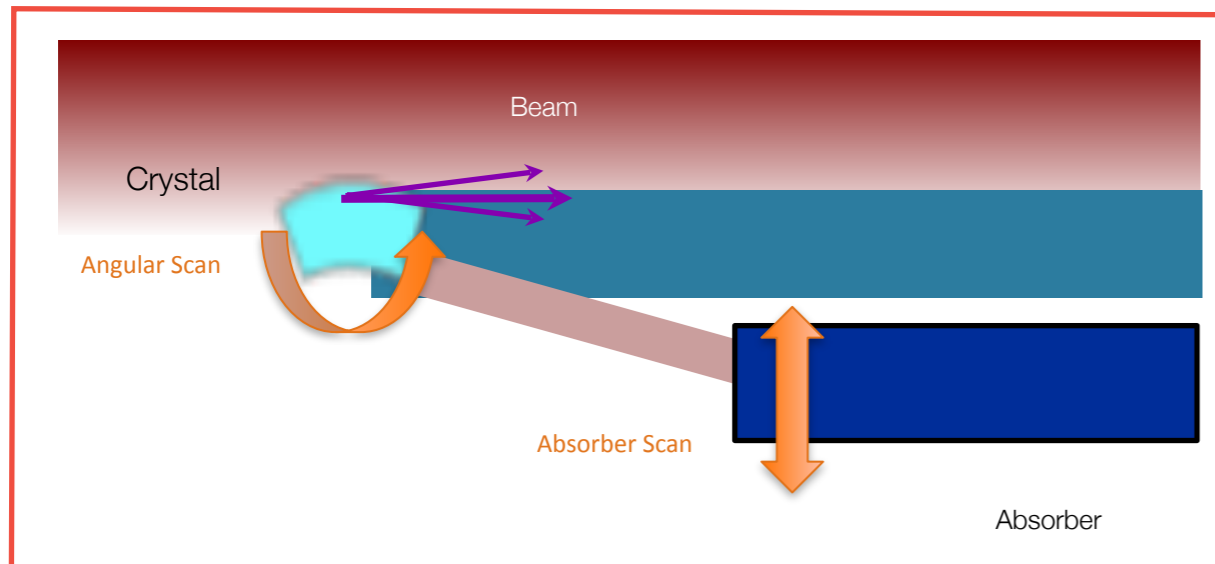
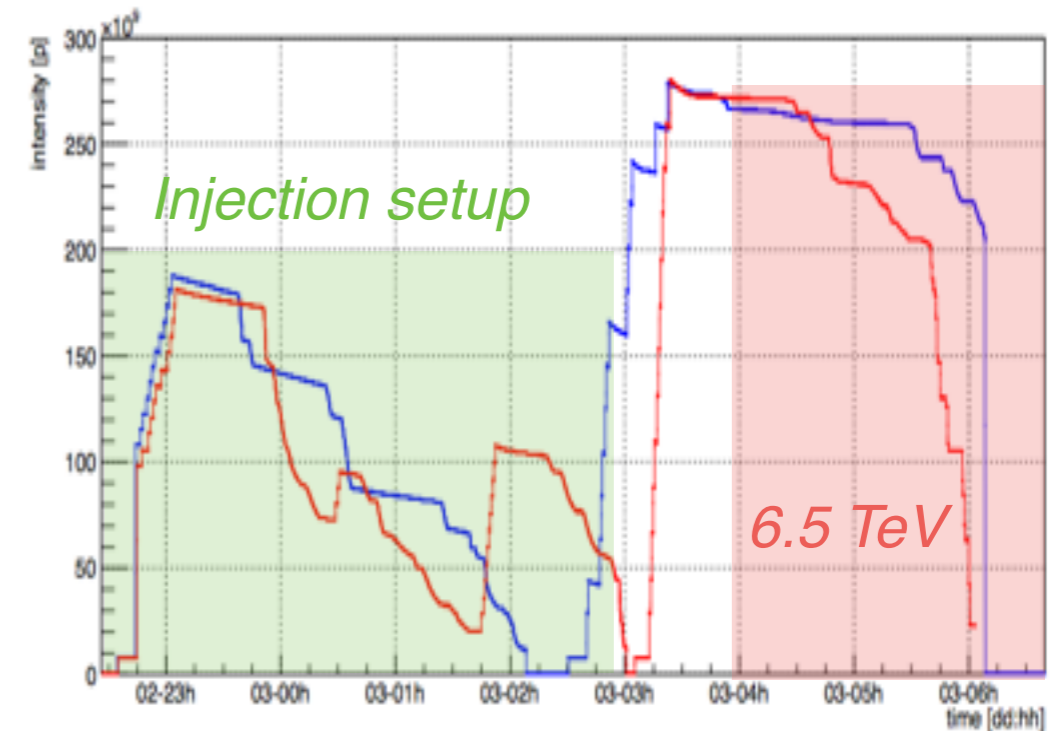
*Followup meeting on Friday 11<sup>th</sup> (CoLUSM): review of models and decision on the 8 TCSP slots to be equipped in LS2 with low-impedance design.*

# (Part of) MP participants

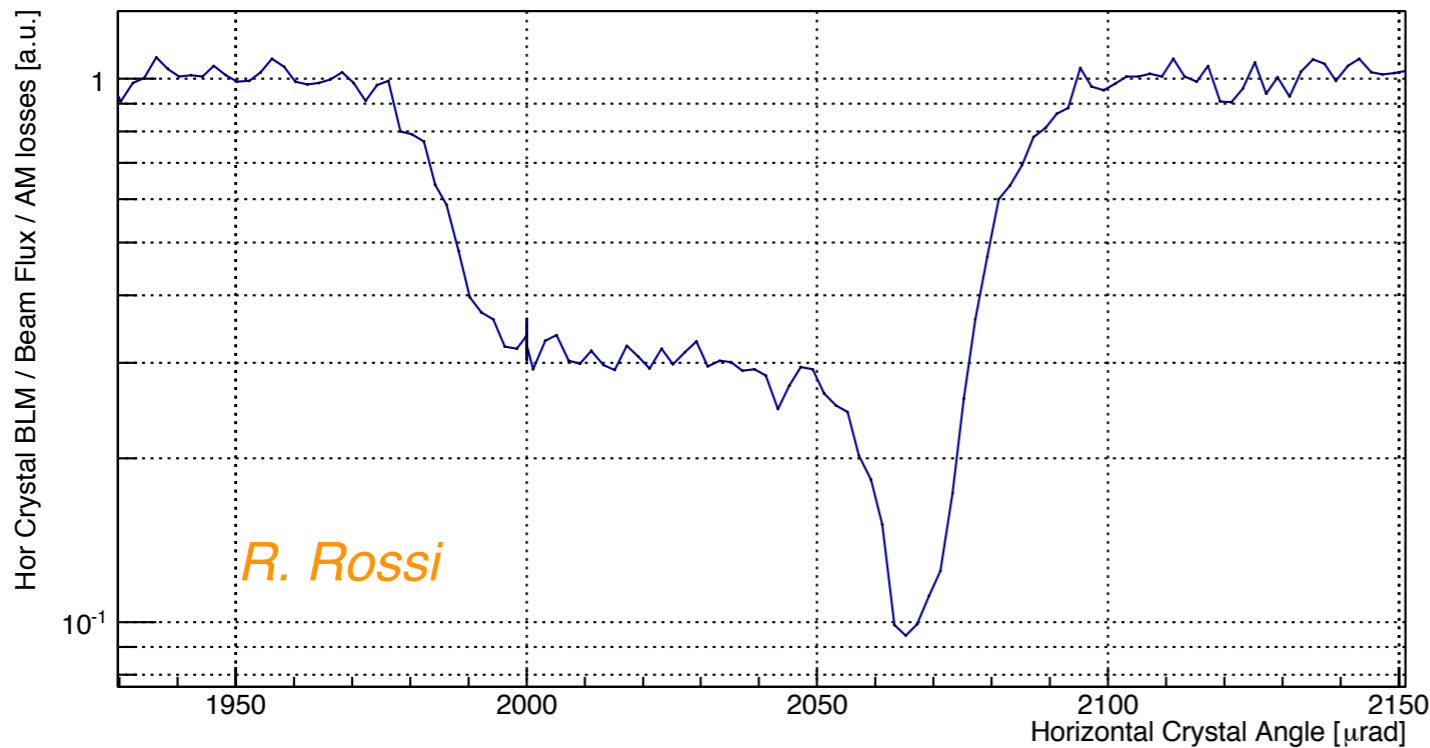
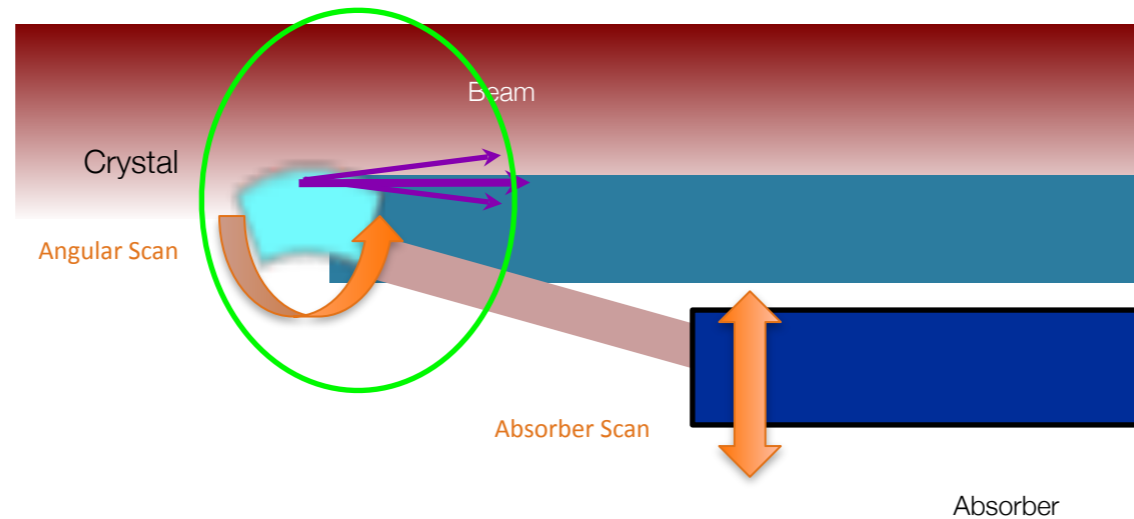


- The main goals for first tests (MD block1)
- ❑ Assess new goniometers and crystals for B2
  - ❑ Characterise new crystals' performance
    - Injection and top energy
  - ❑ Assess reproducibility of B1 system (parasitic)
  - ❑ *Preliminary: collimation cleaning at 6.5 TeV, new optics 2017 with small  $\beta^* = 1m$*

*Beams during MD: efficient!*



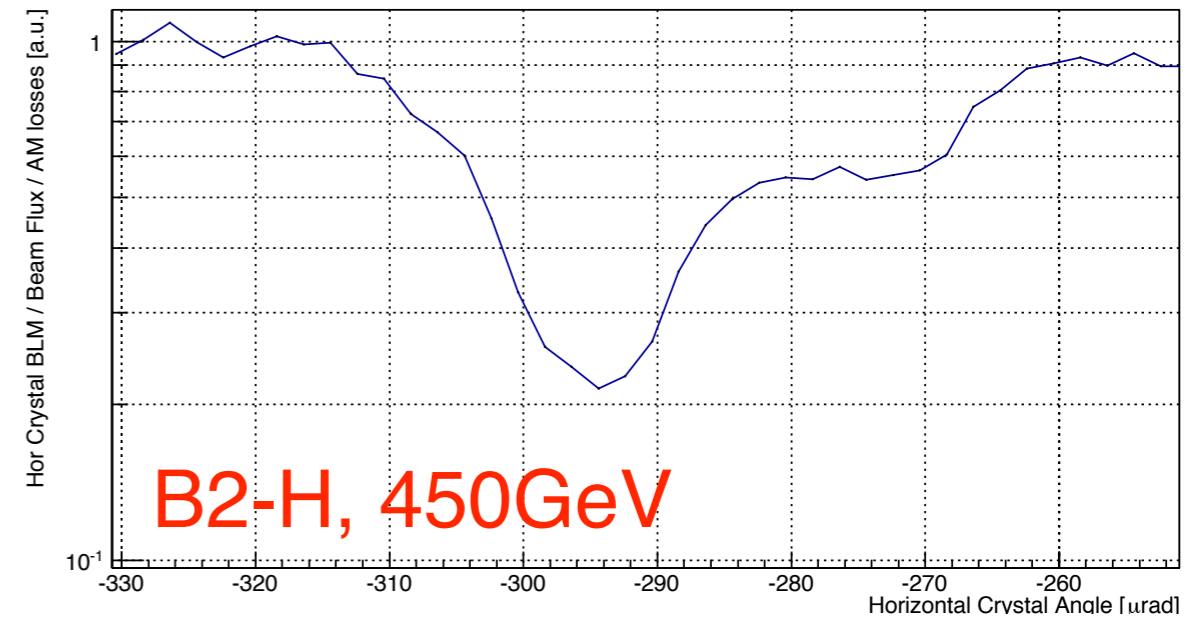
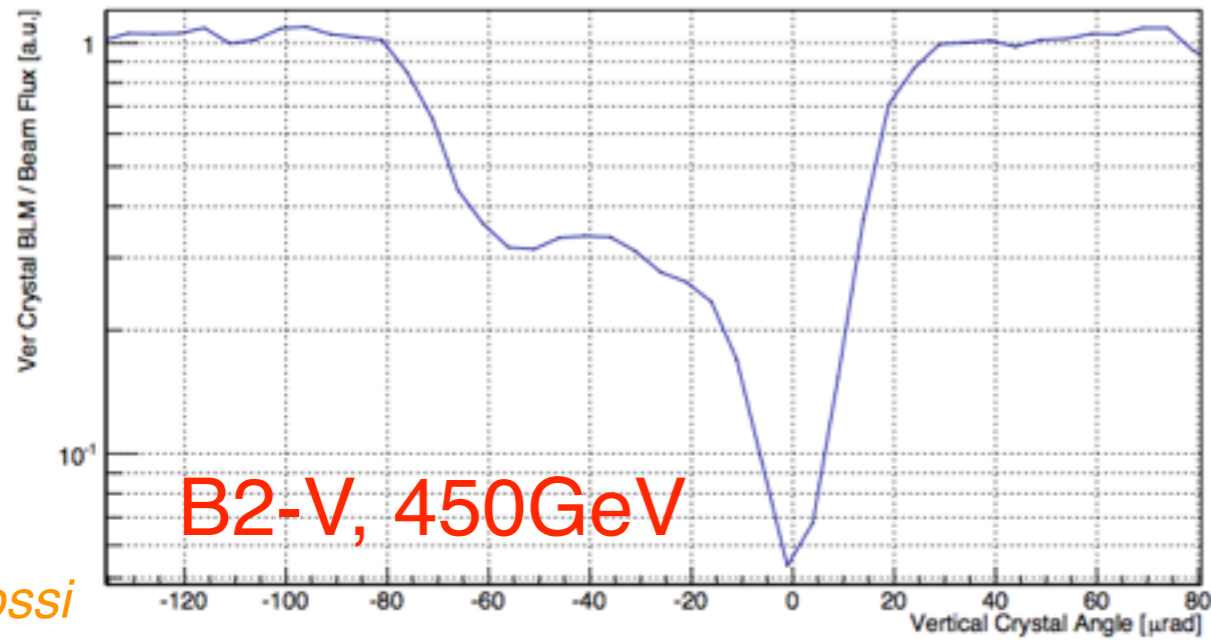
*Key measurements: “angular” and “linear” scans are used to demonstrate the channeling conditions.*



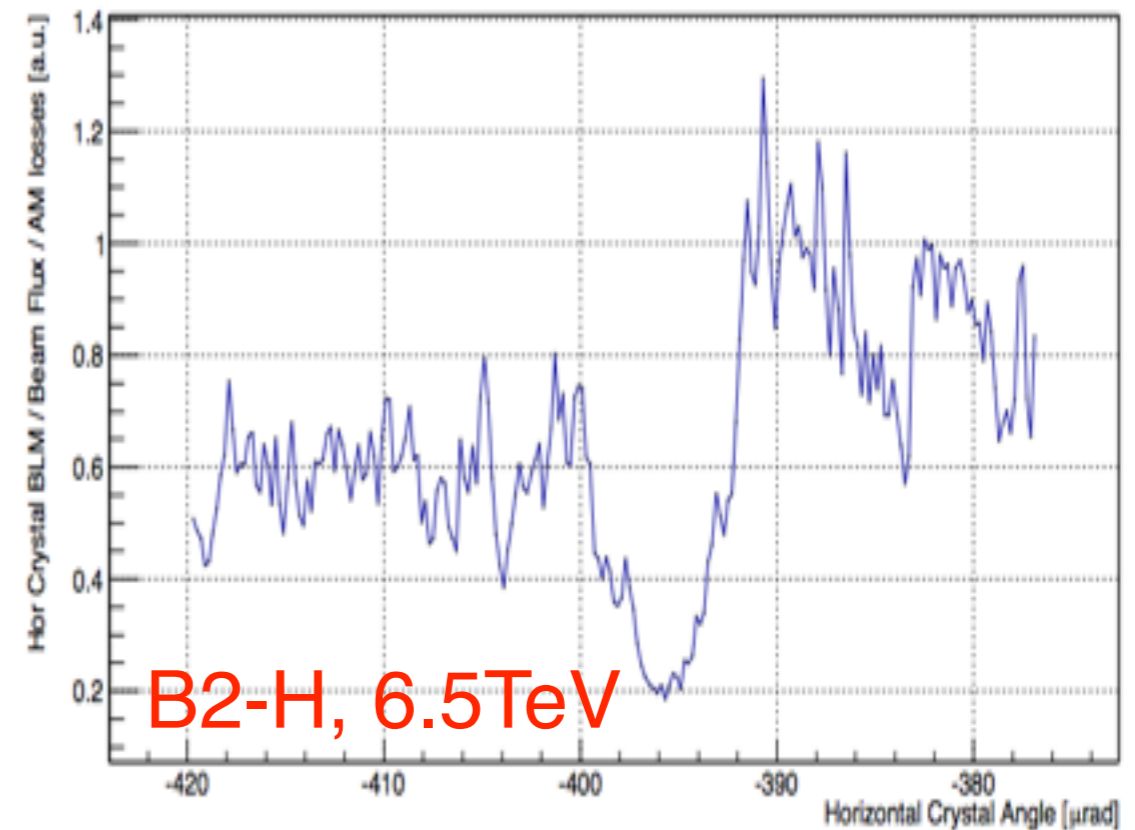
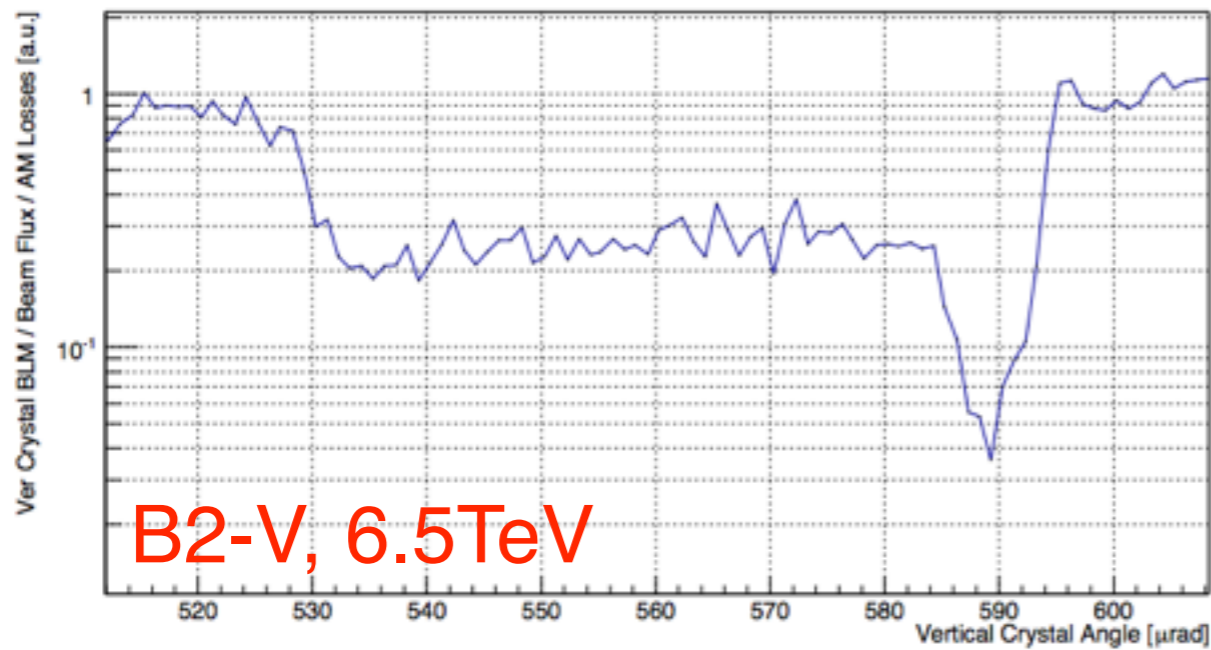
Example: injection measurement, B1-H  
 Crystal aligned at  $5.7 \sigma$   
 Best channeling angle @  $2066.6 \mu\text{rad}$   
 Reduction factor ( $L_{AM}/L_{CH}$ ) = 12.5  
 Bending angle about  $65 \mu\text{rad}$

## Vertical crystal

## Horizontal crystal

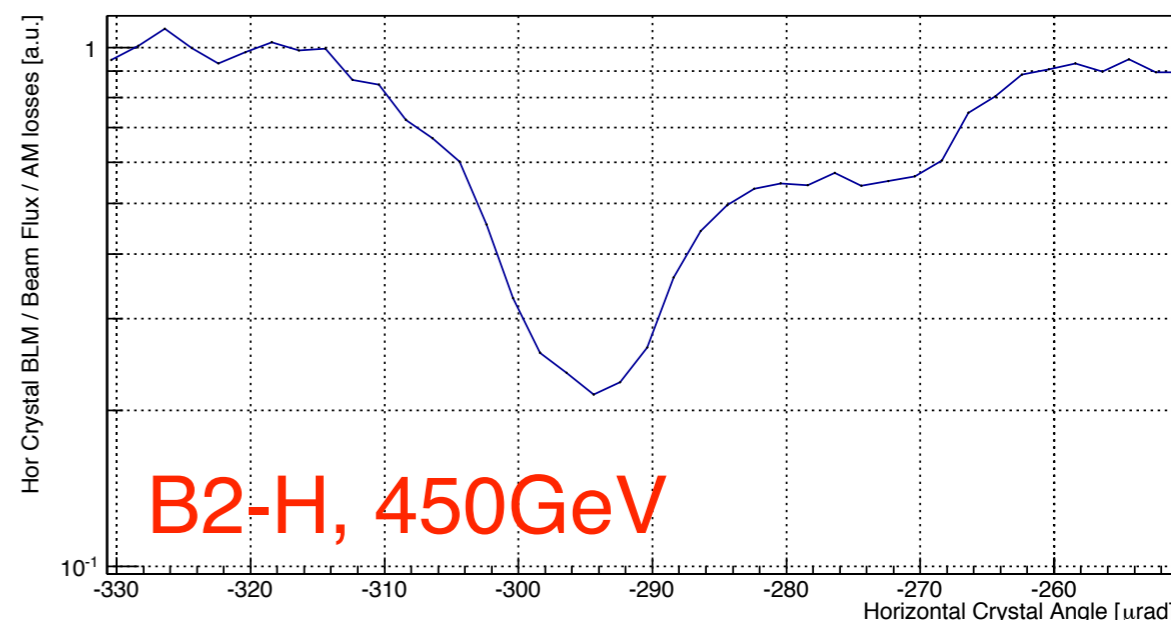
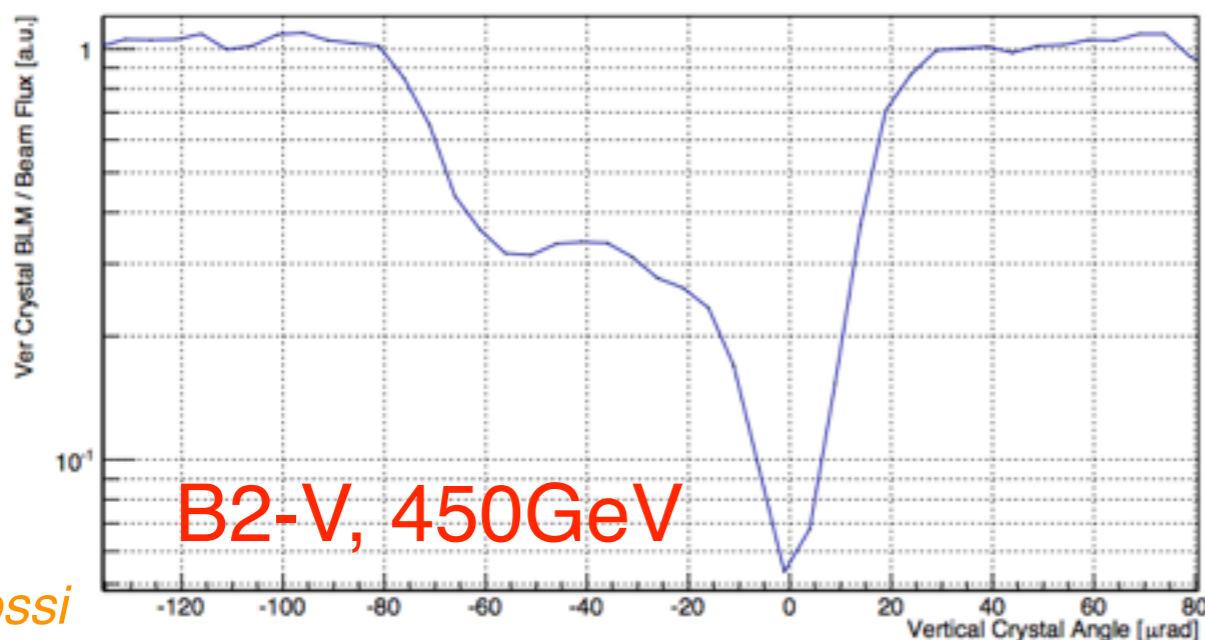


R. Rossi

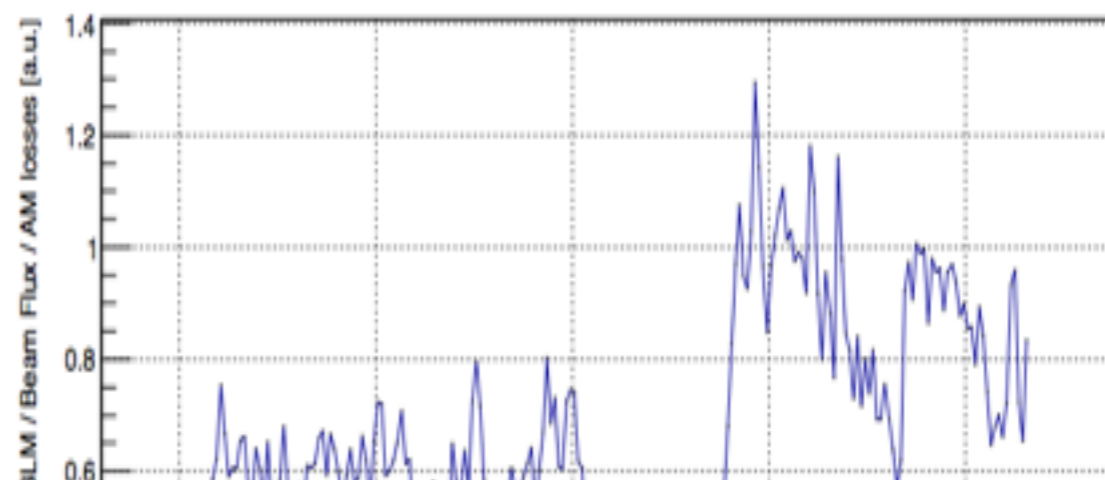
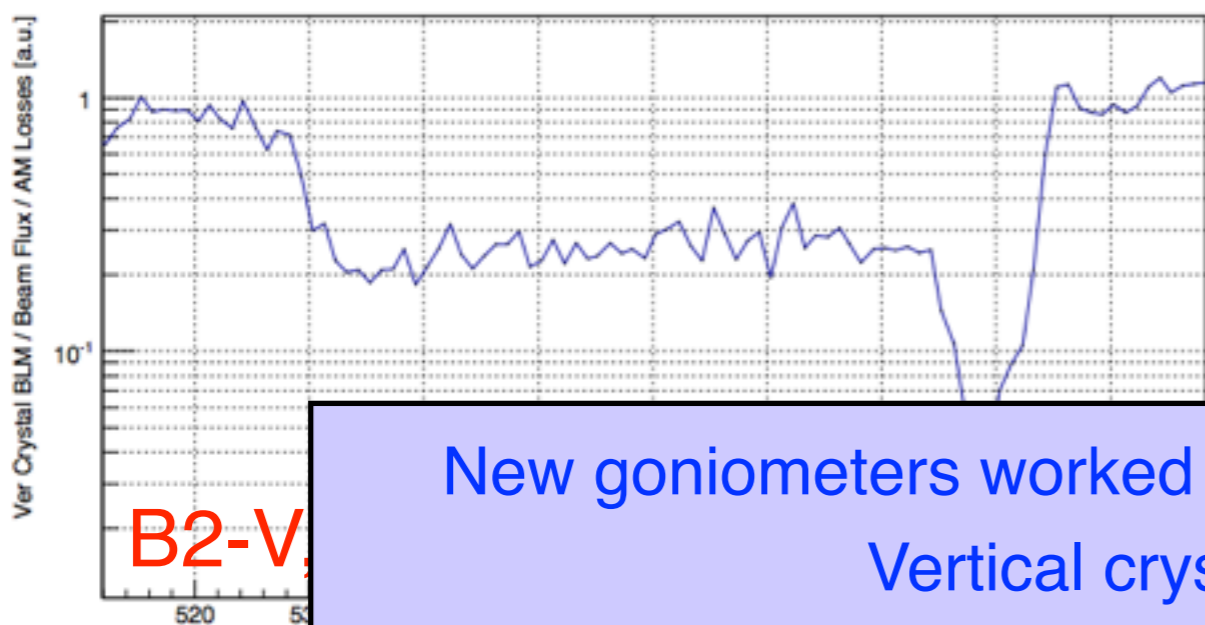


## Vertical crystal

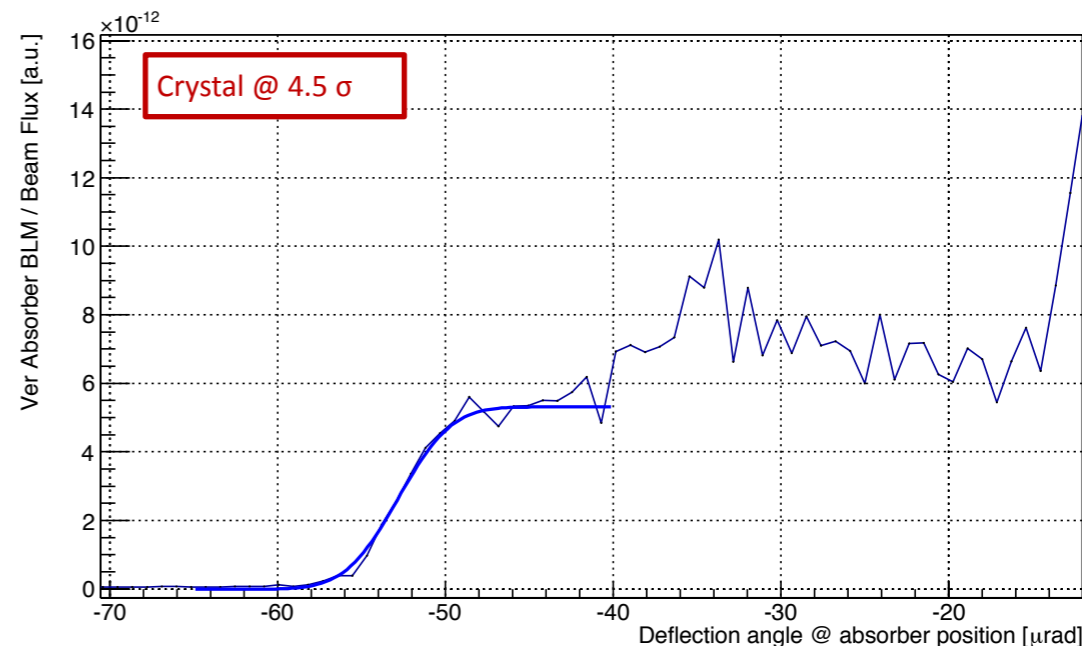
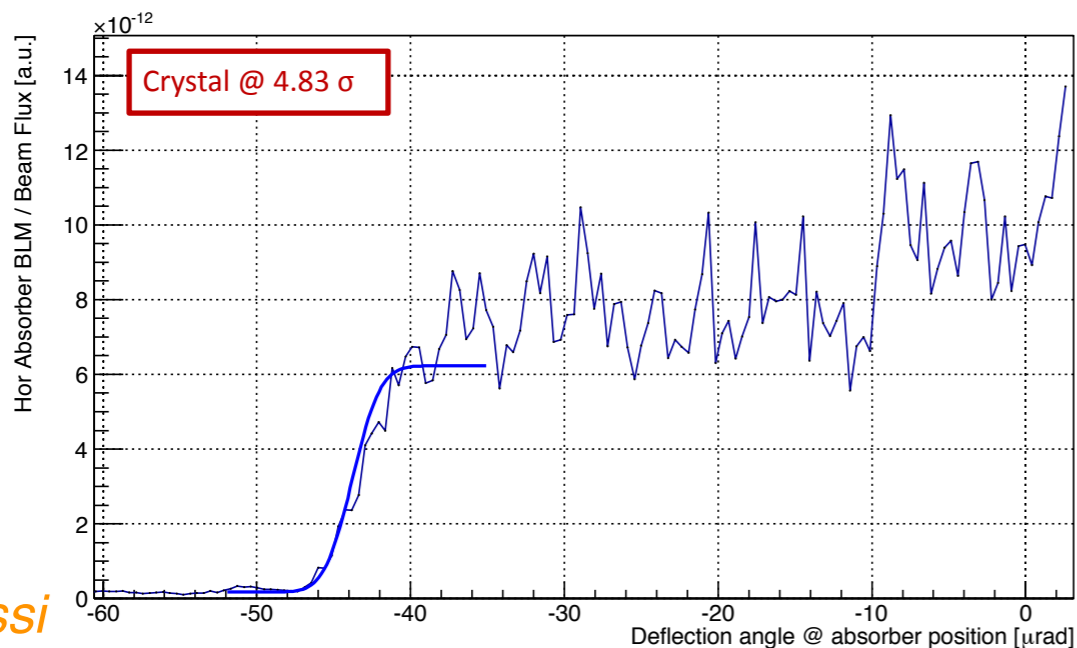
## Horizontal crystal



R. Rossi



New goniometers worked well! Old goniometers well reproducible.  
 Vertical crystal behaved as expected.  
 Horizontal crystal: features not understood: poor reduction factor at injection, perhaps from bad data quality at top energy. To be repeated.



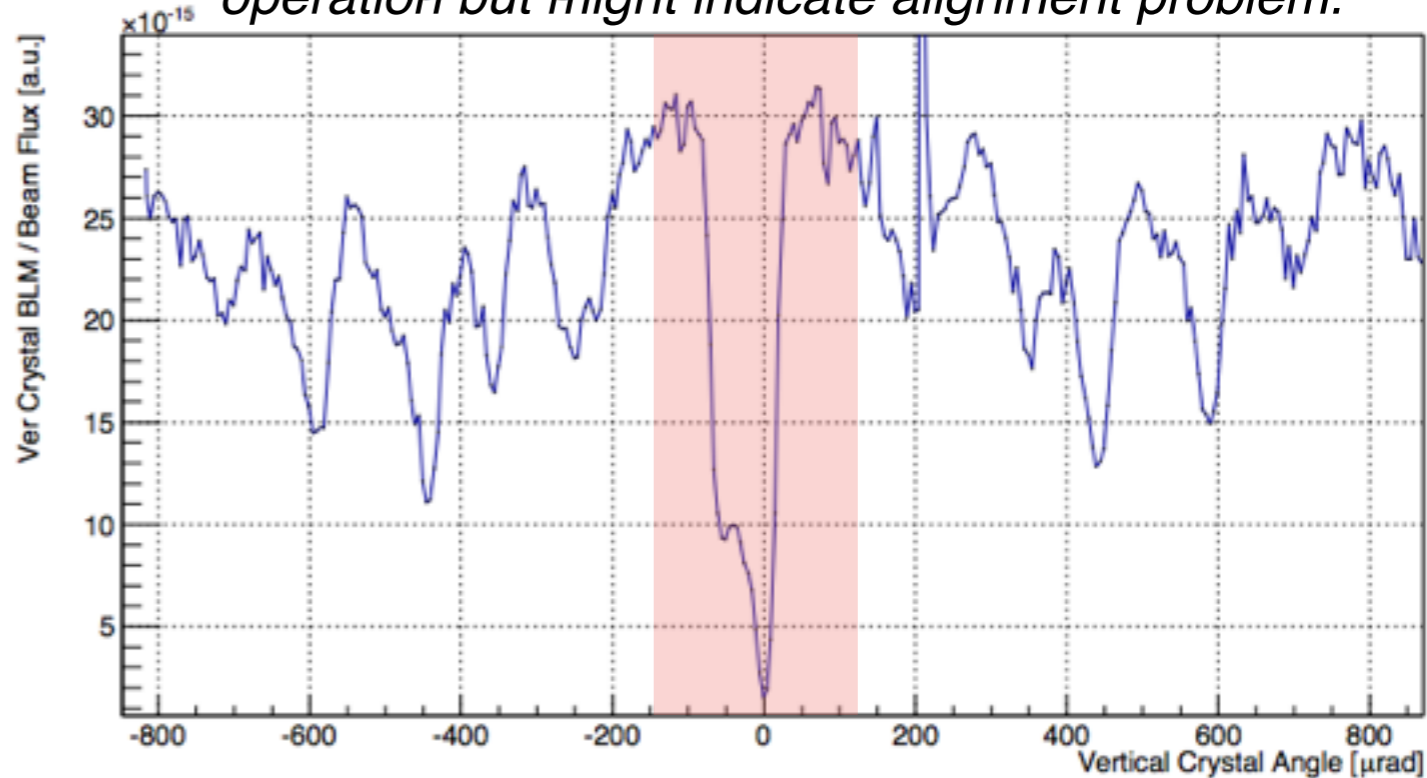
R. Rossi

## Summary at 6.5TeV

Crystal	2017, 6.5TeV [ $\mu$ rad]
B2 – H [QM]	43.8
B2 – V [QM]	52.8

Design : 55  $\mu$ rad

*Vertical: parasitic channeling planes, no concern for operation but might indicate alignment problem.*



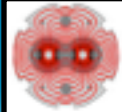




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## The LARP Rotatable Collimator Prototype Candidate for a Phase II Secondary Collimator

LARP

Two jaw collimator made of Glidcop

- Rotate jaw after 1MJoule beam abort failure accident occurs

Each jaw is a cylinder with an embedded brazed cooling coil

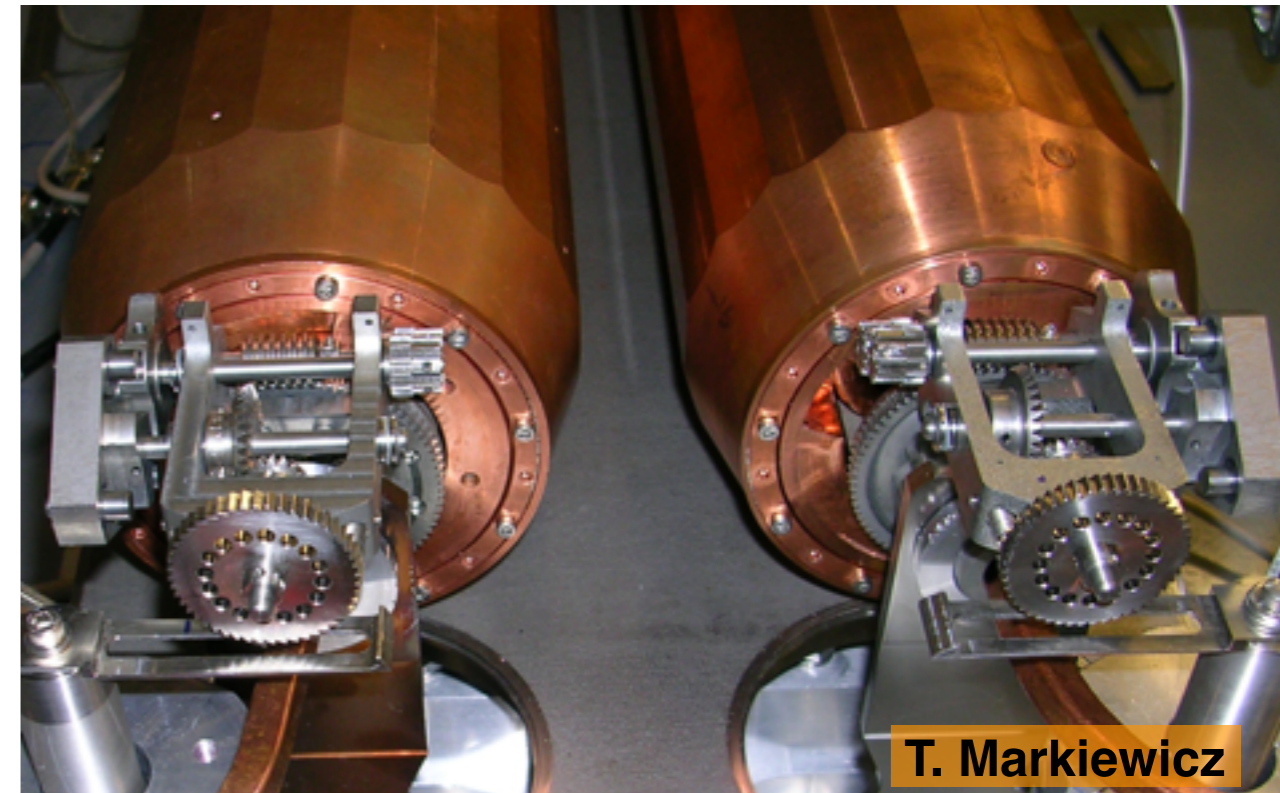
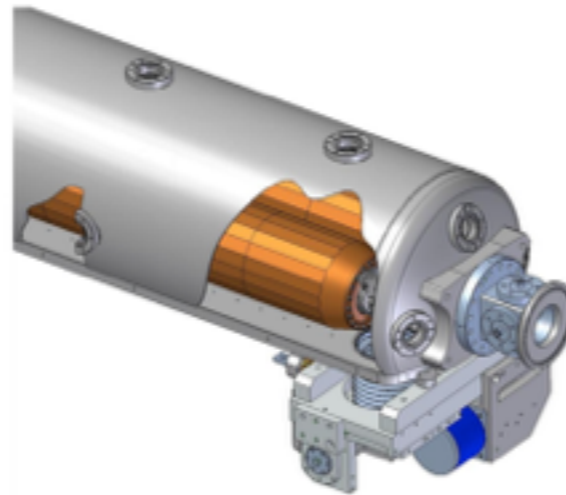
- No vacuum-water braze; 12kW/jaw cooling; minimal thermal distortion
- Maximum radius cylinder possible given beam pipe separation
- BPMs integrated on ends of tank

Advantages:

- Not exotic material
- High Z for better collimation efficiency & more debris absorption
- Low resistance for better impedance
- Elemental for high radiation resistance

Disadvantages:

- Glidcop **WILL** be damaged in asynchronous beam abort



T. Markiewicz

- Nice concept. Might be reconsider it in light of the recent material tests and updated safe limits?
- Cannot be considered as candidate until fully validated by beam tests (HRM, SPS?)
- Shipped to CERN in 2014.

- Initial plan: destructive tests at HiRadMat to verify rotation mechanics (experiment HRMT-21).
- Extensive tests done in 2014 showed:
  - Movement system ok;
  - Vacuum ok for SPS (and LHC!);
  - Impedance ok for SPS in 2015;
  - Rotation ok bef/aft bake out.
- Circulating beam tests at SPS (2015)



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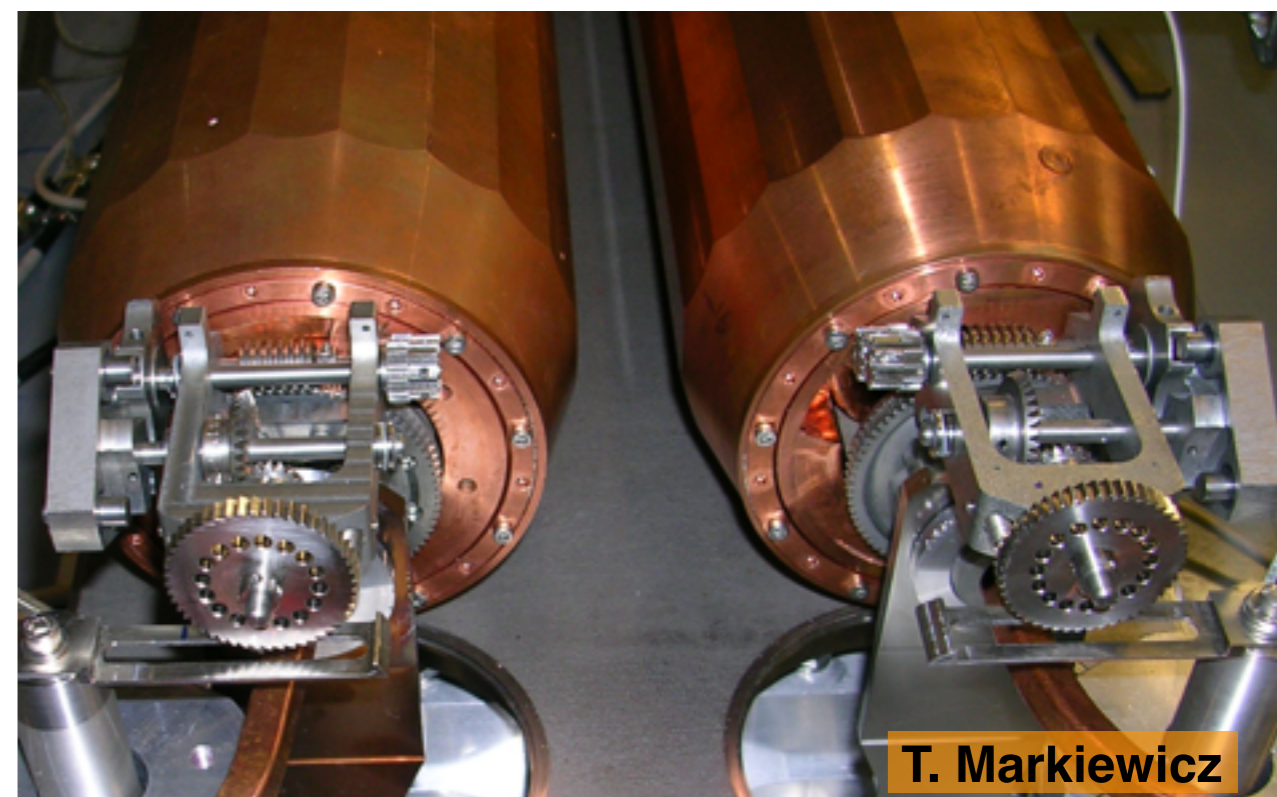
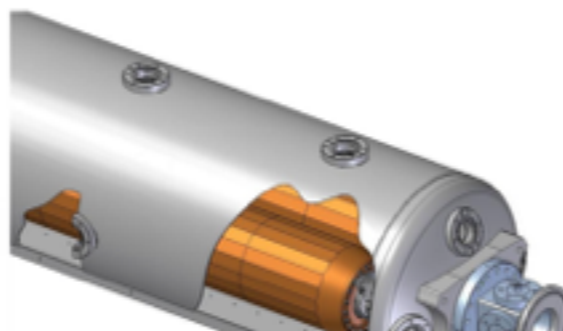
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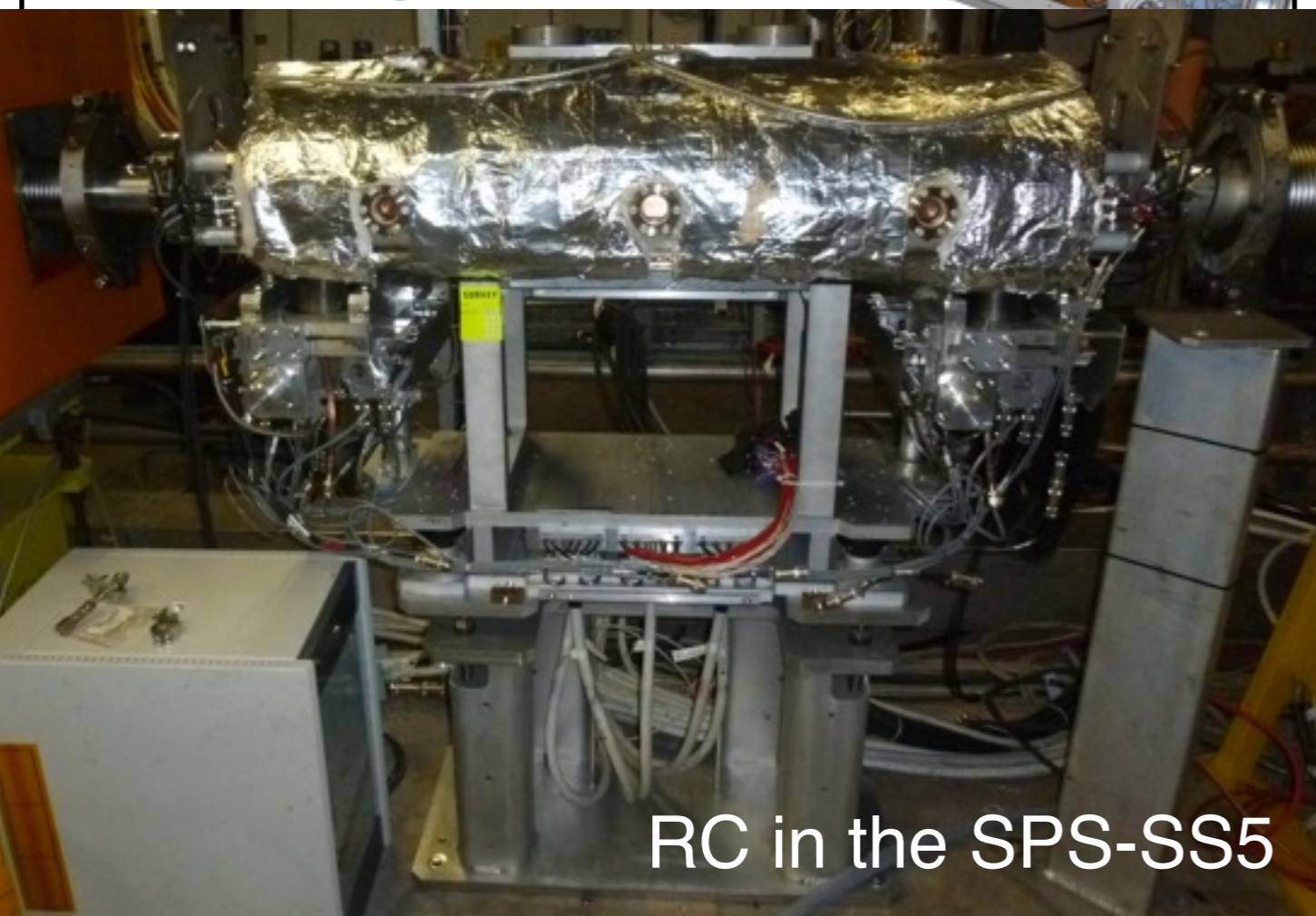
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T. Markiewicz



RC in the SPS-SS5

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  - Movement system ok;
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  - Impedance ok for SPS in 2015;
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- Circulating beam tests at SPS (2015)

## Measurements performed

- Demonstrate design case of 8b at 7TeV (primary goal)  
HRM equivalent  $\sim 144b$  at 440GeV
- Things proceeded very well so we went beyond this
- Repeated alignment of each facet.

step	Reference pulse	Jaw	Facet	Goal	 Extraction Date	 Extraction Time	Bunch spacing [ns]	 # Bunches	 Total Intensity	 Nominal sx [mm]	 Nominal sy [mm]
1	none	left	4	Onset of plasticity	7/18/2017	9:21:00 PM	2025	4	4.326E+11	0.39	0.30
2	none	left	5	Onset of plasticity	7/19/2017	12:45:00 AM	25	12	1.270E+12	0.34	0.31
3	none	left	6	BLM alignment	7/19/2017	11:43:00 PM	25	24	2.670E+12	0.34	0.31
4	none	left	7	BLM alignment	7/20/2017	3:53:00 PM	25	48	5.200E+12	0.36	0.34
5	none	left	8	BLM alignment	7/20/2017	9:55:00 PM	25	72	7.650E+12	0.40	0.32
6	none	left	13	BLM alignment	7/21/2017	7:40:00 PM	25	144	1.456E+13	0.35	0.32
7	none	right	11	BLM alignment	7/22/2017	7:36:00 AM	25	288	3.200E+13	0.39	0.36
8	none	left	18	BLM alignment	7/25/2017	12:43:00 PM	25	288	3.245E+13	0.27	0.21

People involved (recently) in these tests:

EN/STI: O. Aberle, I. Lamas Garcia, P. Gander, M. Butcher, M. Donze, **L. Lacny**, J. Lendaro

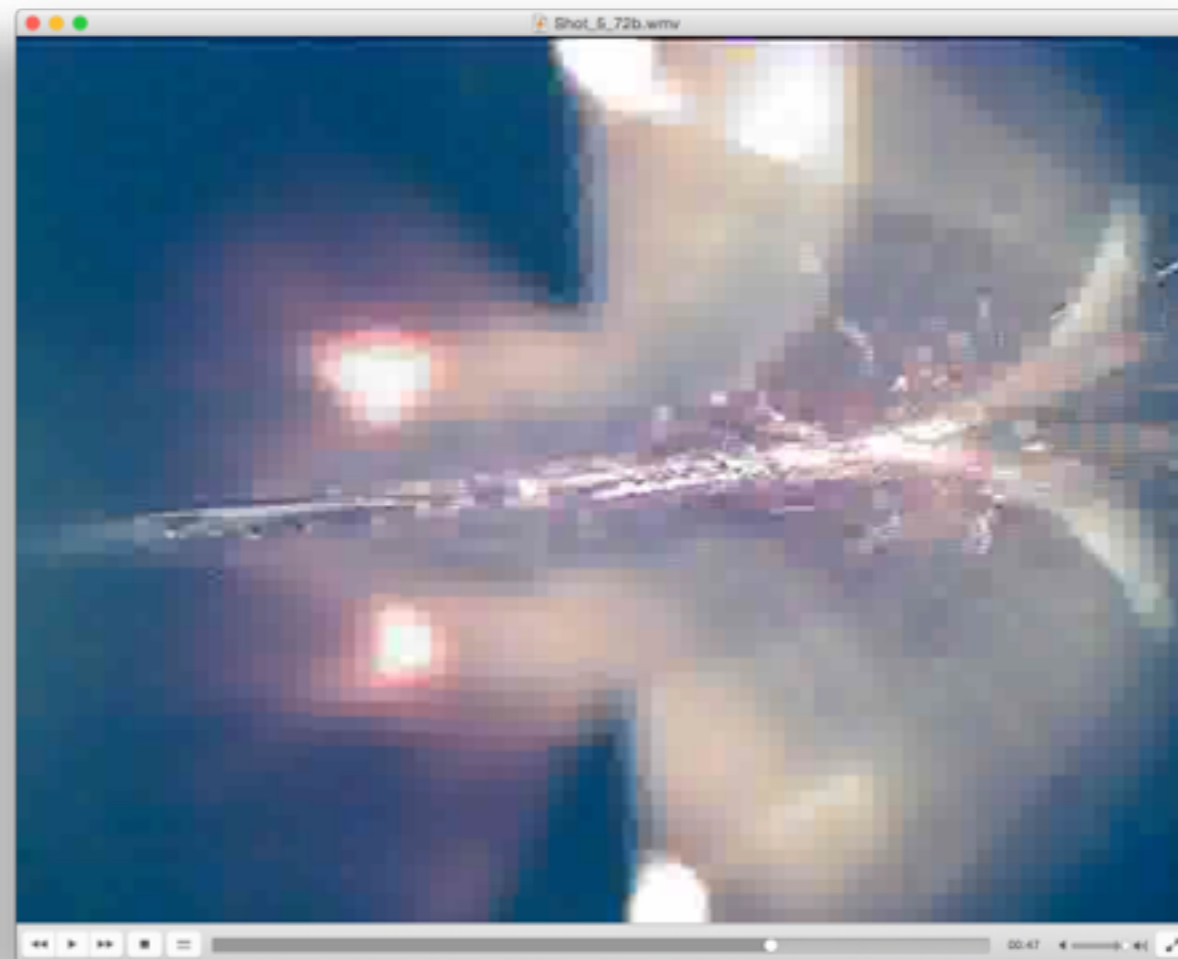
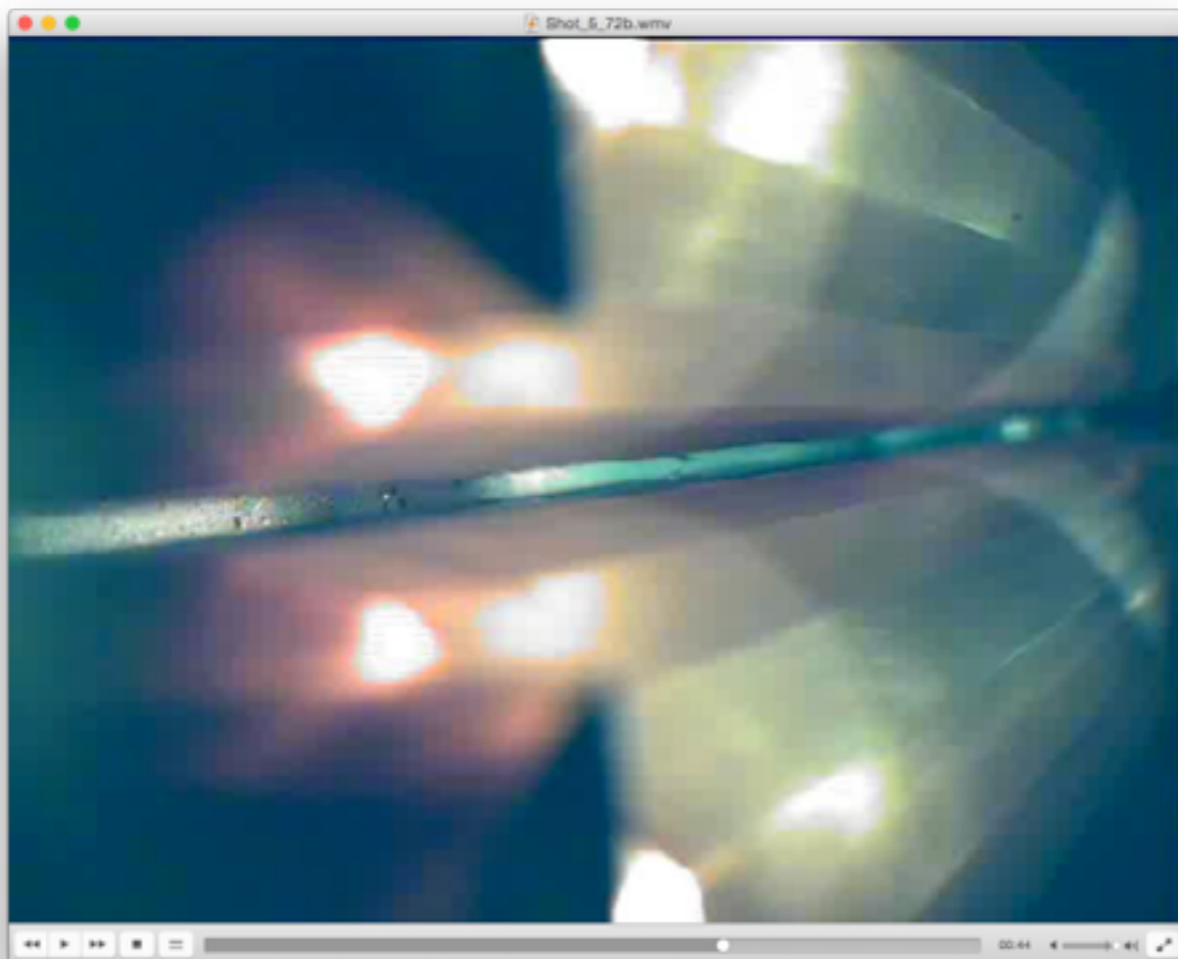
EN/MME: A. Bertarelli, **F. Carra**, M. Pasquali, M. Guinchard, E. Berthome

EN/EA: A. Fabich, F. Harden, A. Bouvard

BE/ABP: S. Redaelli

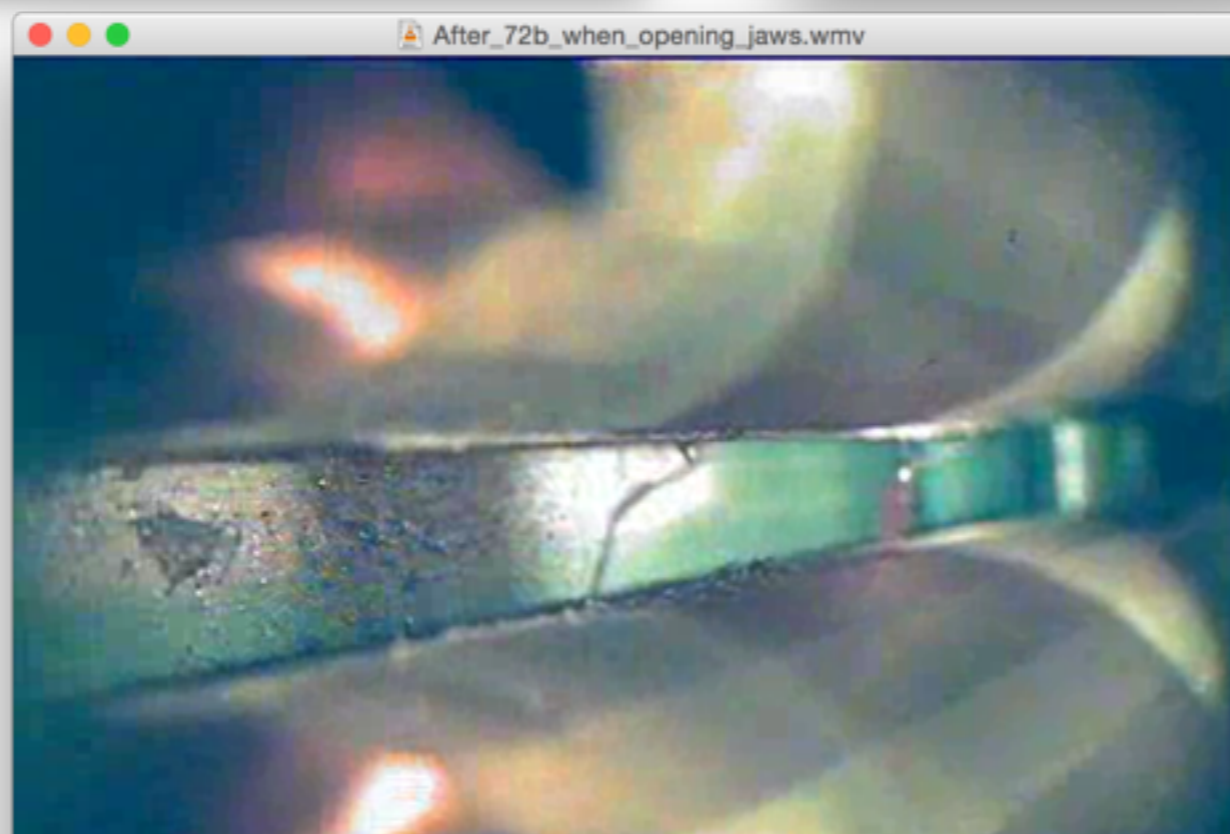
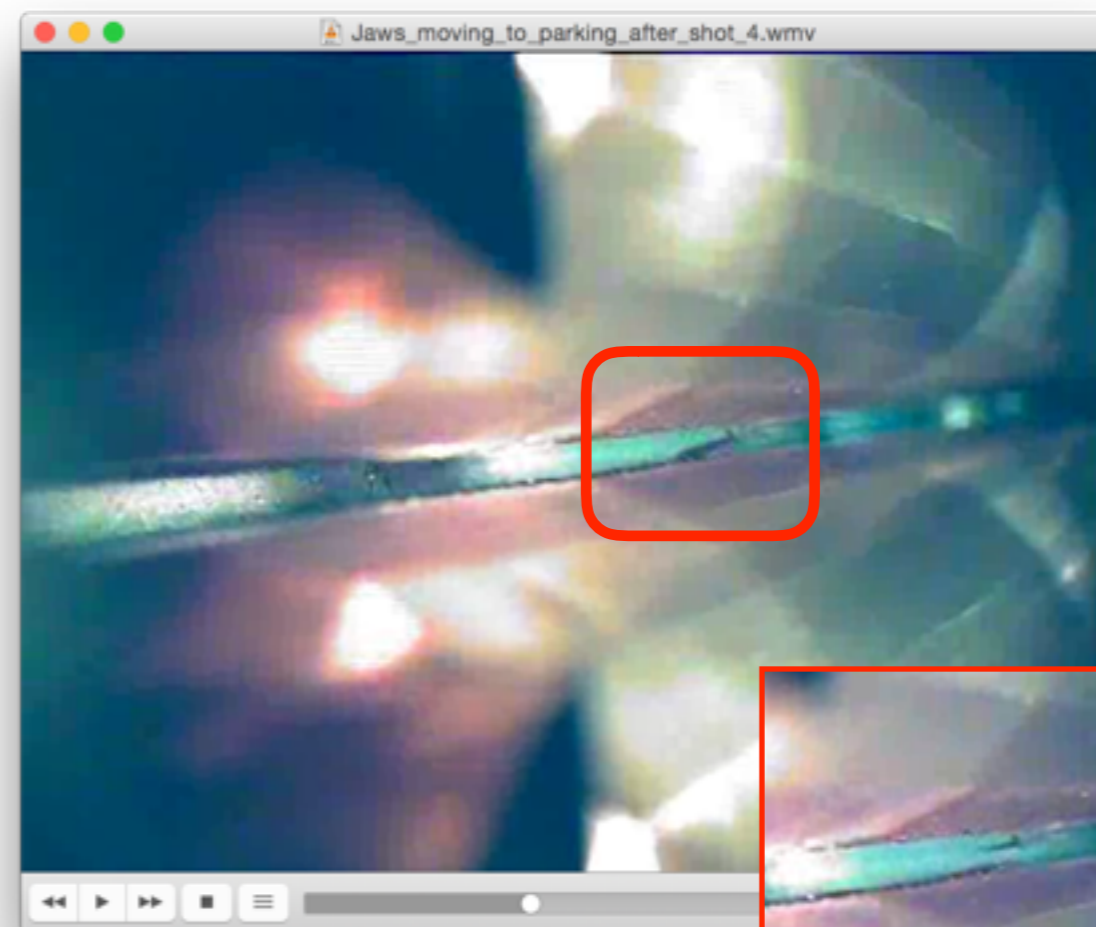
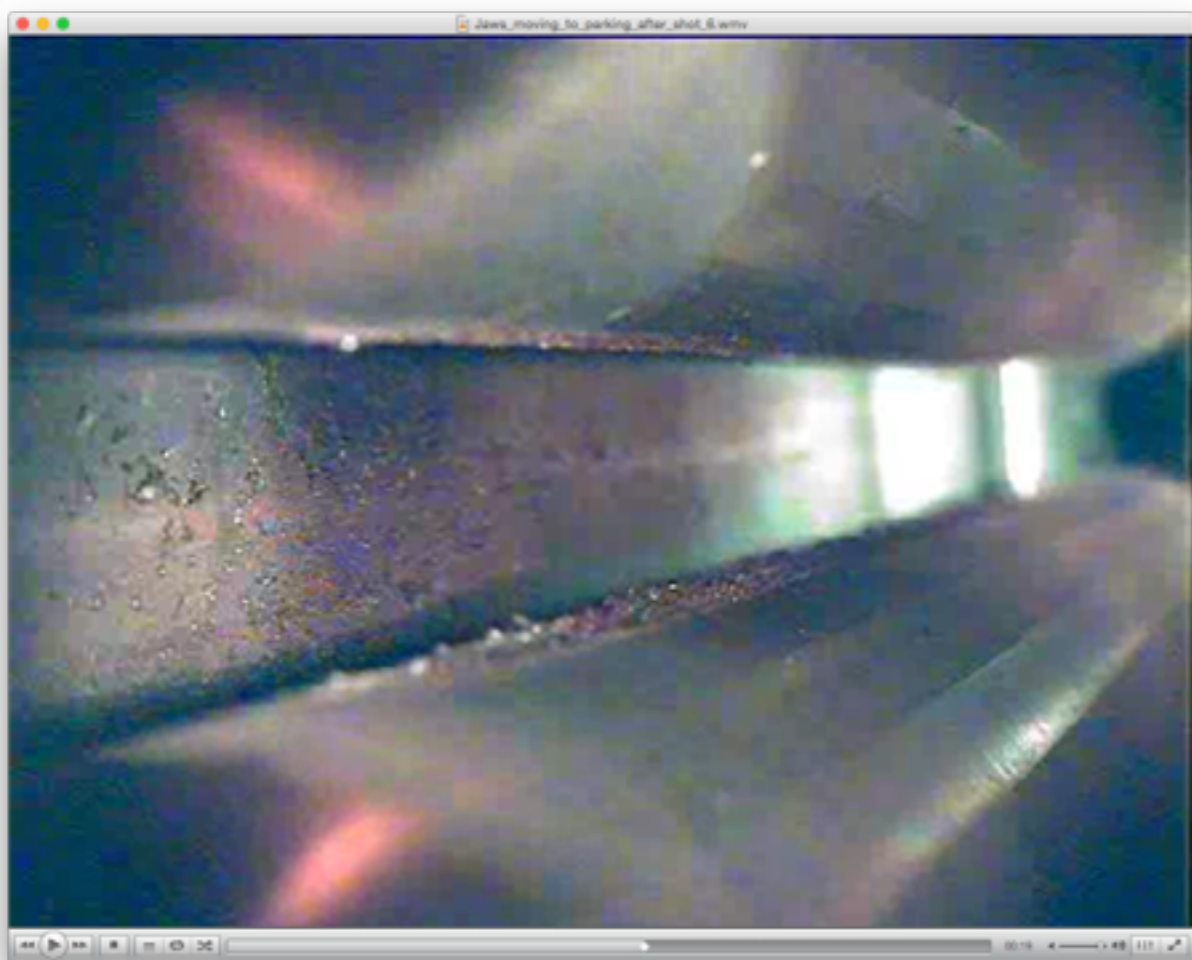
external collaborators: **T. Markiewicz**, **G. Valentino**

# Example: 72b shot



Visible sign of damage and debris visible after 288b shot.  
Successfully recovered "clean" surface after jaw rotation.

# Collateral damage



- The HiRadMat test was a **success**: we achieved all the design impact scenarios and even went beyond the design failure case!
- **Remote instrumentation** and (by now) usual procedures for the setup worked smoothly.

*Issue with water pressure measurements, not working.*

- The **rotation mechanisms** worked for both jaws. We managed to perform a full rotation for both jaws, after different impact conditions.
- Remote inspection revealed a set of possible collateral damage cases that need to be studied in detail.

Could the jaw be operated

- **Post-irradiation analysis** will be focused on quantifying the extent of damage of the facets that were directly hit, and the overall deformation of the jaws.
- Plan to write a **joint comprehensive report** with SLAC, covering qualification tests at CERN, results with circulating beams at the SPS (alignments, BPMs, impedance...) and HiRadMat test.



# Outline



- Introduction
- Recap. of new collimators
- Performance with beam and MD results
- HiRadMat results with SLAC “RC”
- **Conclusions**



- ☑ **Reviewed performance of the new HL-LHC collimators**  
*Several devices tested with beam.*
- ☑ **The operational performance during beam tests was excellent**  
*Complex new designs worked well and already at MD1 could perform a comprehensive set of measurements*
- ☑ **Collected preliminary results but detailed analysis ongoing**  
*Crystals and goniometer on B2 worked, but puzzling results on h plane.  
Very nice set of impedance measurements with different surfaces, being analysis  
Preliminarily confirmed models used HL-LHC.  
Analysis still ongoing on various fronts.*
- ☑ **We still need more support for MD time!**  
*More impedance measurements, probing different beam parameters  
Need to understand features of B2-H crystal and complete measurement plans  
(cleaning, rump functions with new goniometers, possibly Xe ions)*
- ☑ **Completed the beam tests planned with the SLAC RC**  
*Successful tests at HiRdMat, demonstrated the rotation mechanisms after beam impacts well beyond the RC design  
Post-mortem checks needed to confirm the possibility to use operationally.*