HIGH LUMINOSITY LHC

12th HL-LHC Collaboration Meeting
UPPSALA - Sweden
19 - 22 September 2022

The 12th HL-LHC Collaboration Meeting will take place in Uppsala, Sweden, from 19th to 22nd September 2022, as an in-person meeting.

Based on the traditional programme with plenary and work package parallel sessions, this meeting will serve as a technical update forum for the 6th Cost and Schedule Review, planned at CERN in November 2022, and provides the framework for additional collaborative meetings between the project partners.

This year, the main objectives will be to update all HiLumi collaborators on the results of key HL-LHC prototypes tests, to highlight the progress made in the transition from prototype validation to series production, and to update all collaborators on the latest schedule changes.

CERN - Organizing Committee		Uppsala - Organizing Committee		For more details and registration
Oliver Brüning	Project Leader	Tord Ekelöf	Chairperson	cecile.noels@cern.ch
Markus Zerlauth	Deputy Project Leader	Richard Brenner	Head of Physics Department	www.hilumilhc.web.cern.ch
Cécile Noels	Project Office	Maja Olvegård	Head of FREIA Department	
Irene Garcia Obrero	Project Office	Rocio Santiago Kern	Technical Leader (DHF project)	

Collimation upgrade: transition from LS2 to Run 3 operation

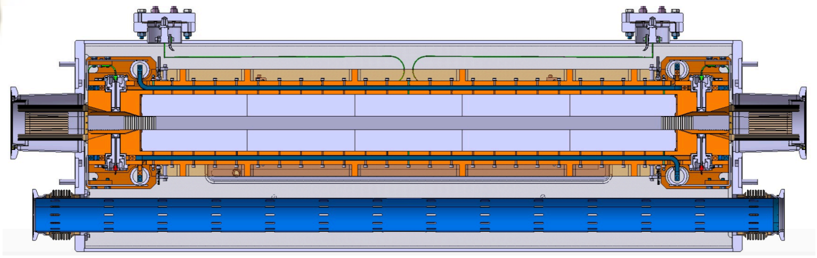
Stefano Redaelli, BE-ABP, on behalf of WP5 & LHC Collimation team

12th HL-LHC Collaboration Meeting
19-22 September, 2022
Uppsala Universitet, Uppsala, Sweden

Table of contents

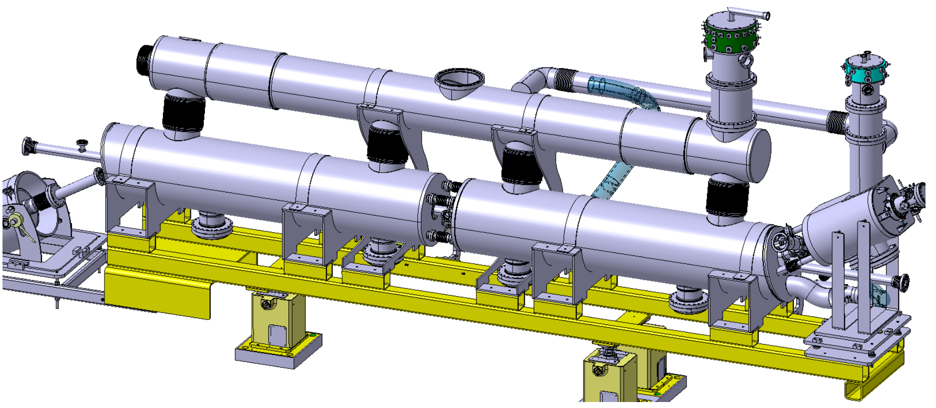
Introduction: WP5 upgrade items

LS3

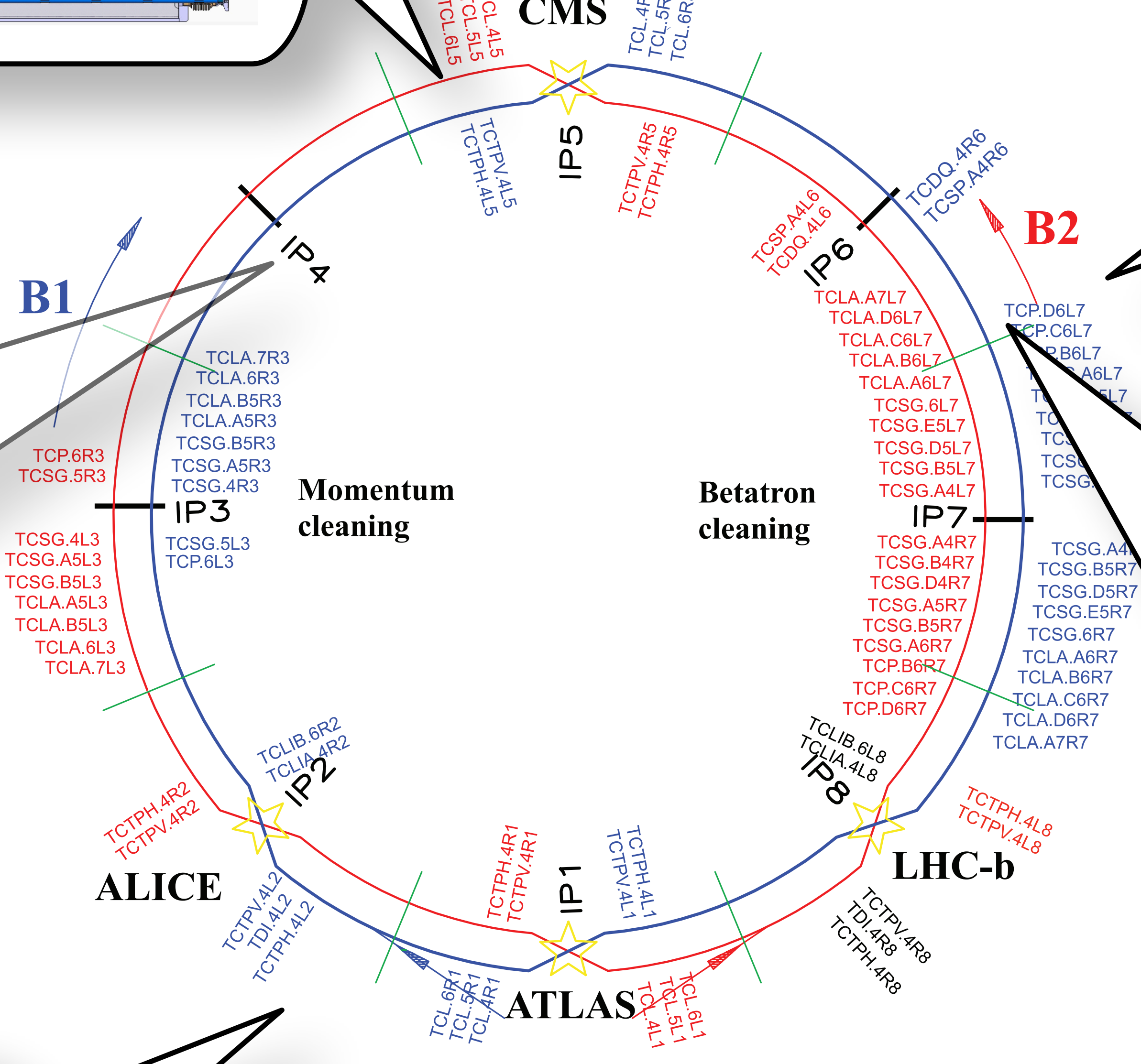



IR collimation: Completely new layouts and collimator designs: IR1+IR5: incoming and outgoing. Full remote alignment system (FRAS)

Descoped from LS3

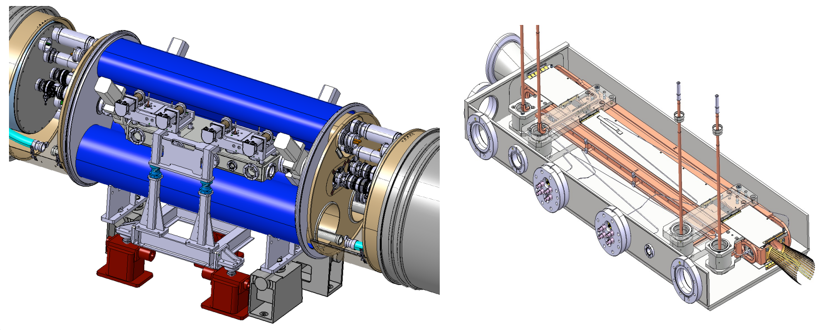


Hollow electron beam: 2 lenses
I_e = 5 A; l = 3 m; En = 10-15KeV; **IP4**



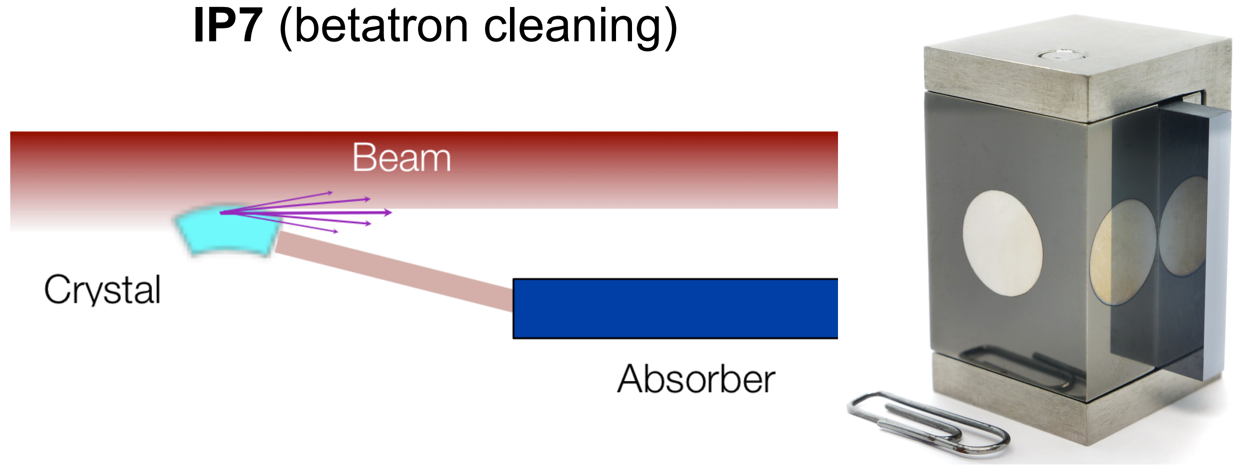
Deferred

Dispersion suppressor collimations: betatron halo cleaning, DS collimators between 11T dipoles



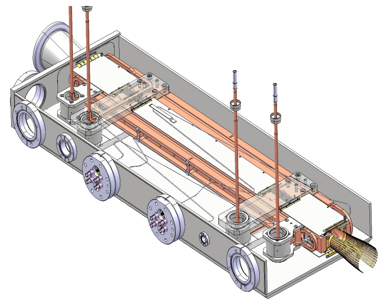
LS2+YETS

Crystal-assisted collimation (Pb ions)
4-8 bent crystals, 50 µrad bending
IP7 (betatron cleaning)



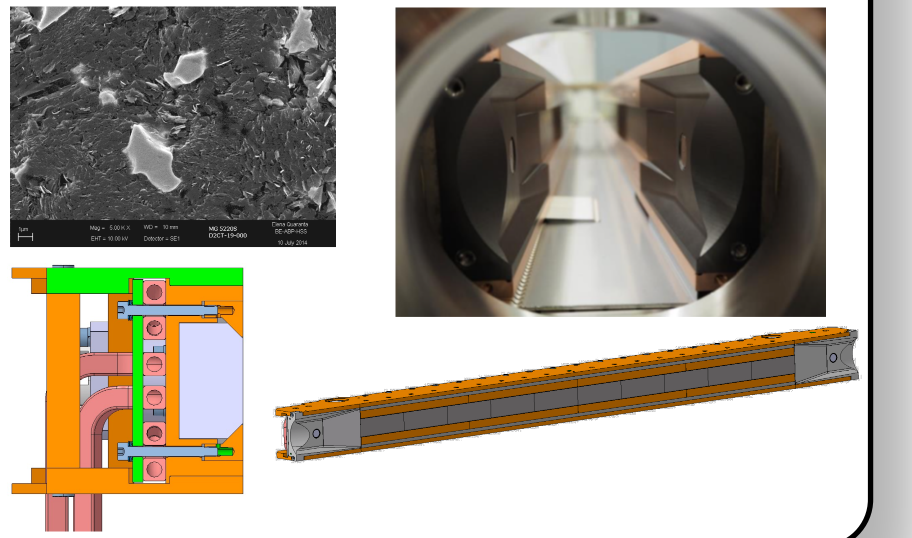
LS2

Dispersion suppressor collimation: Secondary beams from ion physics



LS2+LS3

Impedance reduction: low-impedance, high robustness secondary collimators: coated MoGr
Un-coated MoGr primary collimators.



LS2

Consolidation (not HL): low-impedance primaries (material from WP5), renew controls, maintain / replace rest of system

Collimation upgrade scope: LS2 and LS3

The LS2 upgrade provides an improved collimation performance for Run 3!

- **Upgrades in the second long shutdown (LS2)**
  - **Dispersion suppressor collimation:**
    - 2 **TCLD** collimators around IR2 for ALICE luminosity upgrade
  - **First phase of the low-impedance upgrade of the system**
    - 8 new secondary collimators make of Mo-coated MoGr (**TCSPM**) IR7
    - MoGr (uncoated) material for 4 new primary collimators (**TCPPM**) in IR7
  - **Upgraded betatron cleaning for heavy-ion beams**
    - 4 crystal primary collimators (**TCPC**) in IR7 (two installations: YETS2021-22 and YETS2022-23)
  - [CONS] New passive absorbers (**TCAPM**) for improved warm-quadrupole lifetime
  - Including spares, 22 new collimators built in LS2
- **Upgrades in the third long shutdown (LS3)**
  - Second phase of the low-impedance upgrade: 10 **TCSPM** in IR7
  - New collimation layouts in IR1/5: 20 movable collimators; 12 fixed masks (**TCT***, **TCL*, TCLM)**

Backup slides: more details on new designs

LS2 activities — completed

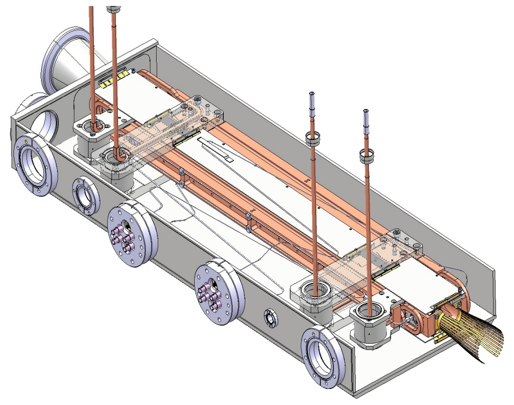
Important steps for the HL-LHC collimation upgrade carried out in LS2

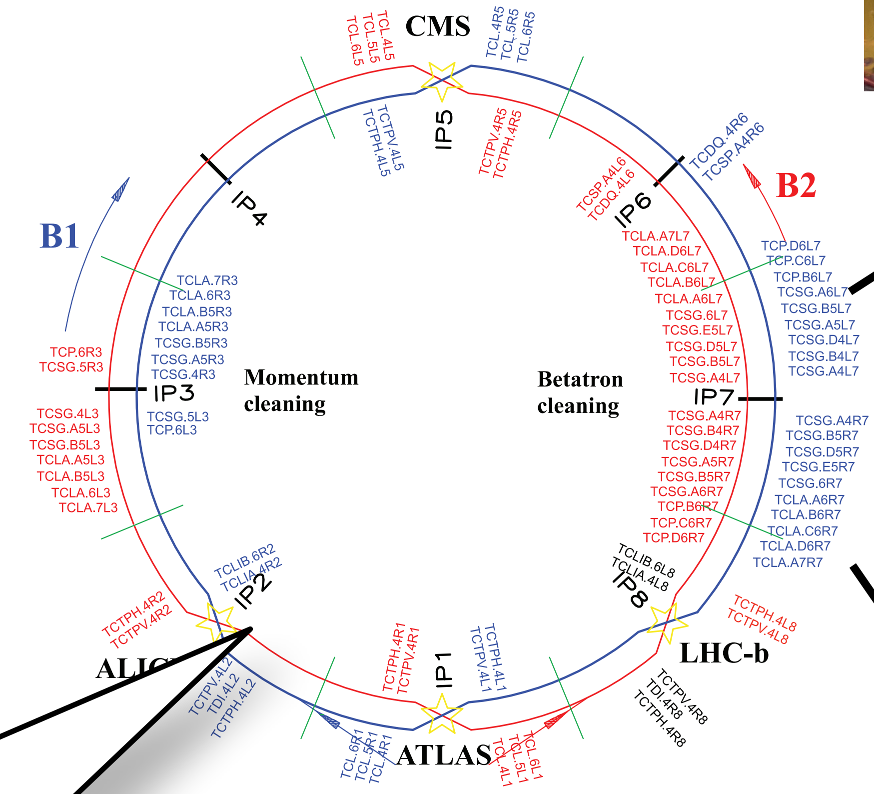
- Dispersion suppressor collimators, IR2
- Low-impedance secondaries (coated), IR7
- Low-impedance primaries, IR7
  (consolidation items; new material from HL-LHC)
- Passive absorbers for IR7

22 collimators built, 18 for installation (4 spares)

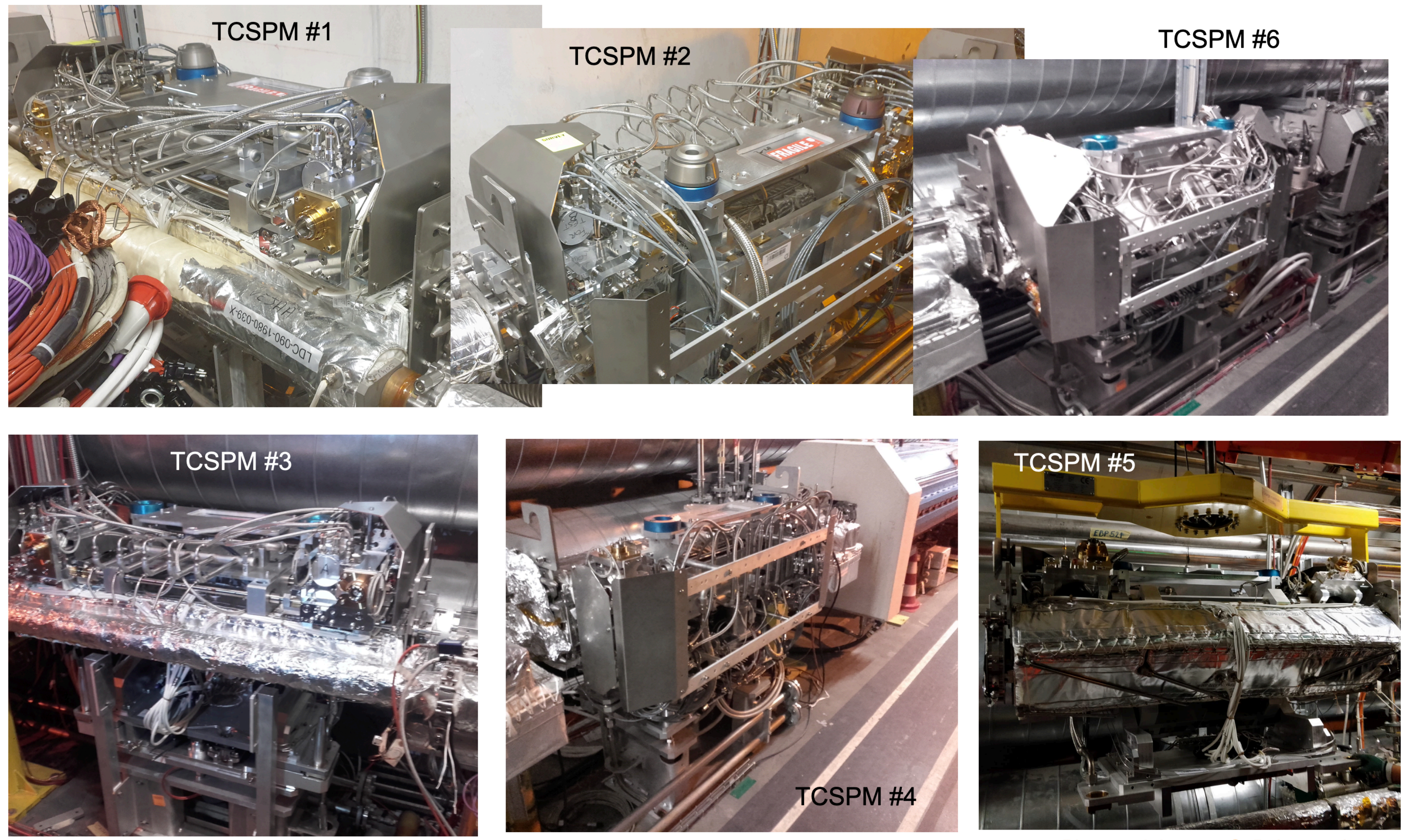
Very successful collaboration across several groups in the ATS sector! Particular thanks: SY/STI.

Dispersion suppressor collimation: Secondary beams from ion physics



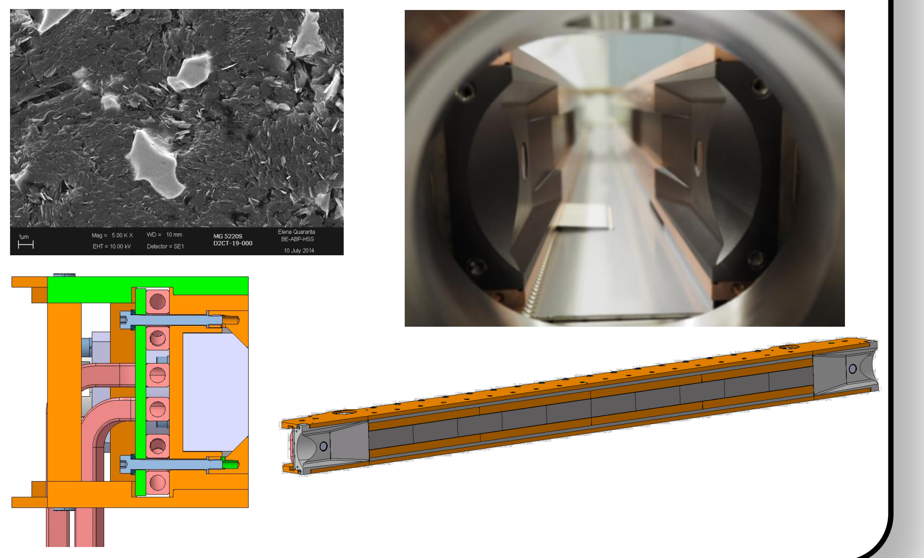


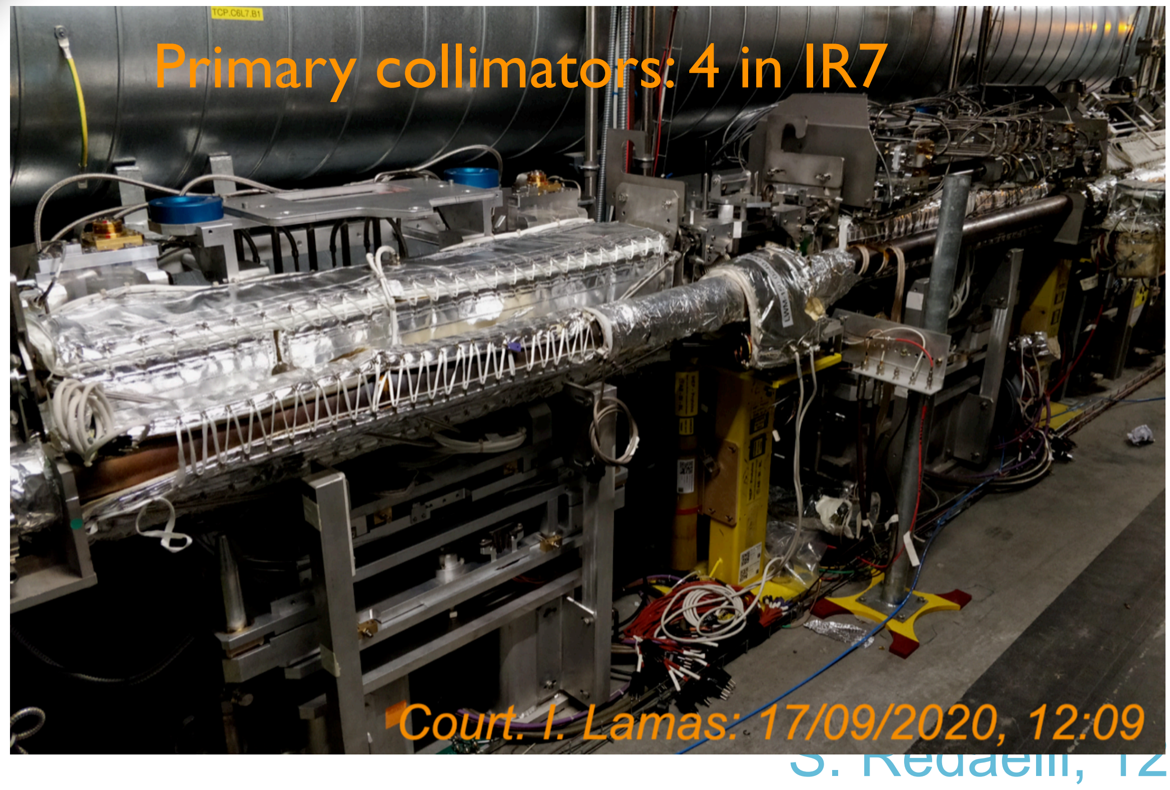
Coated secondary collimators: 8 installed IR7



Pictures: I. Lamas, C. Bahamonde

Impedance reduction: low-impedance, high robustness secondary collimators: coated MoGr
Un-coated MoGr primary collimators.





Primary collimators: 4 in IR7

Court. I. Lamas: 17/09/2020, 12:09

$$\mathcal{L} = \frac{N_1 N_2 k_b f \gamma}{4\pi \epsilon_n \beta^*} F$$

LS2 activities — completed

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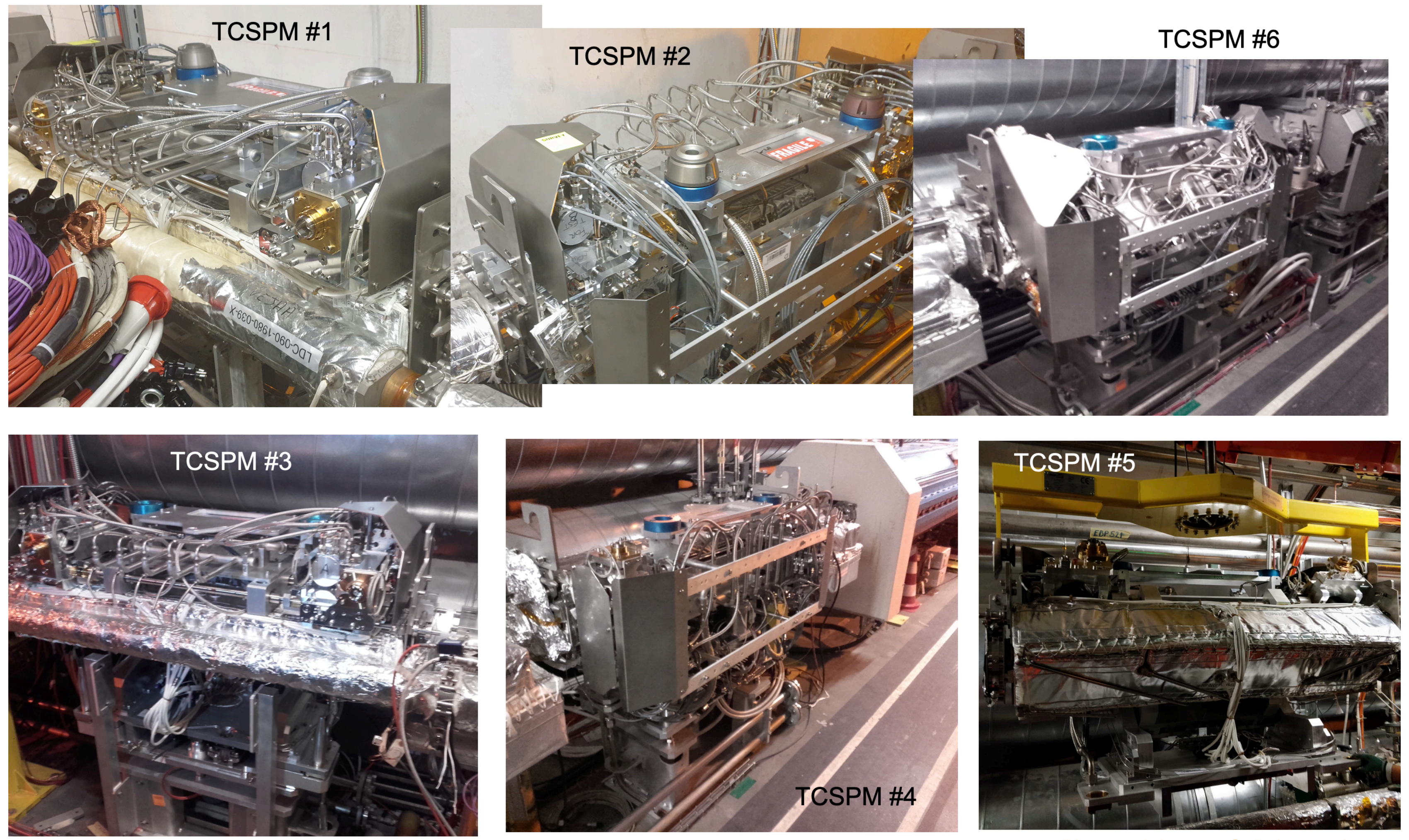

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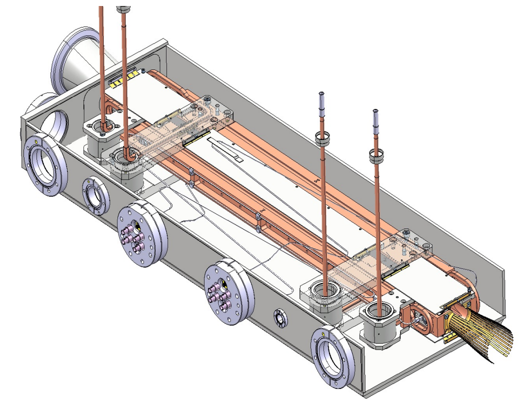
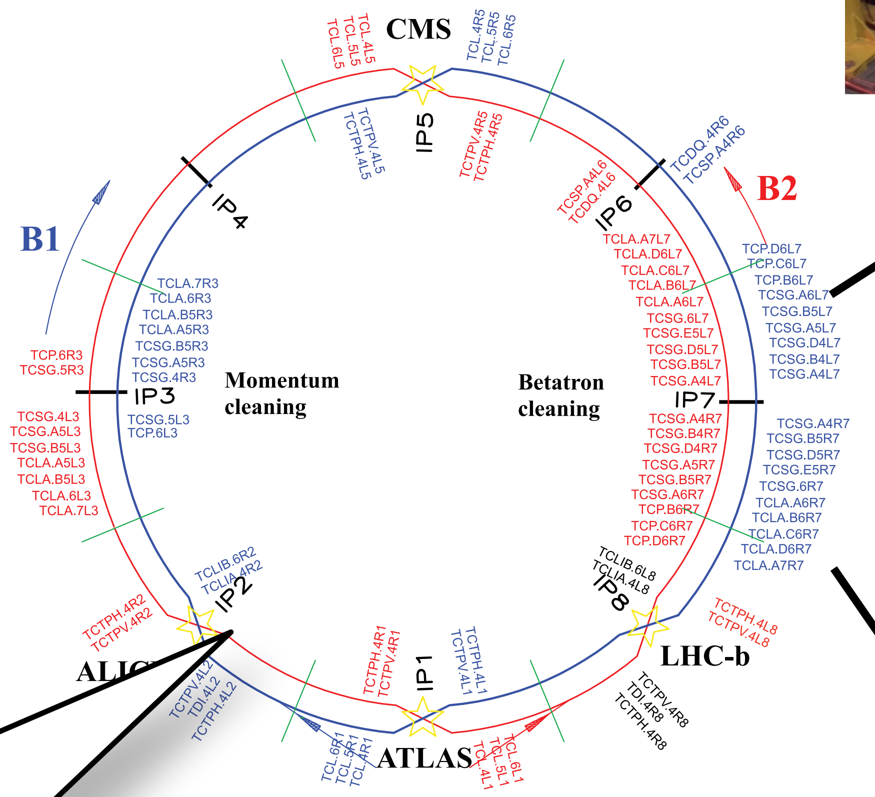
Dispersion suppressor collimation: Secondary beams from ion physics





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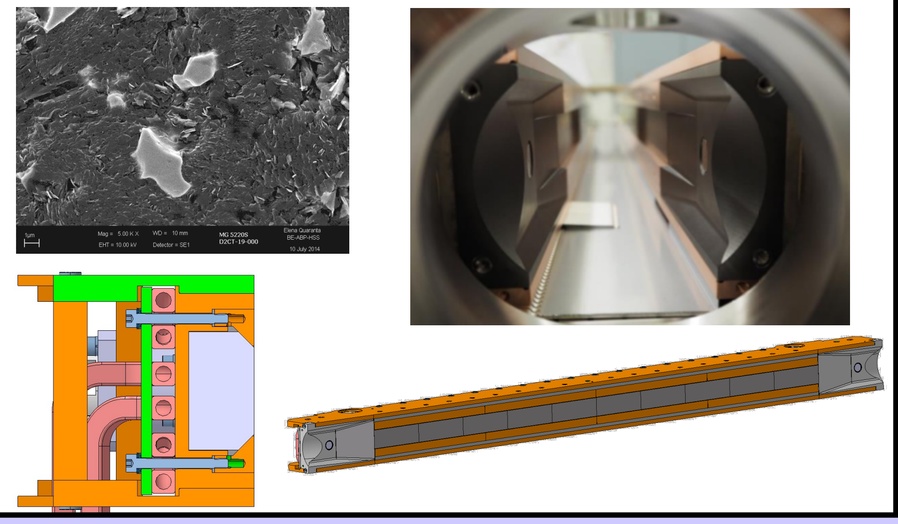
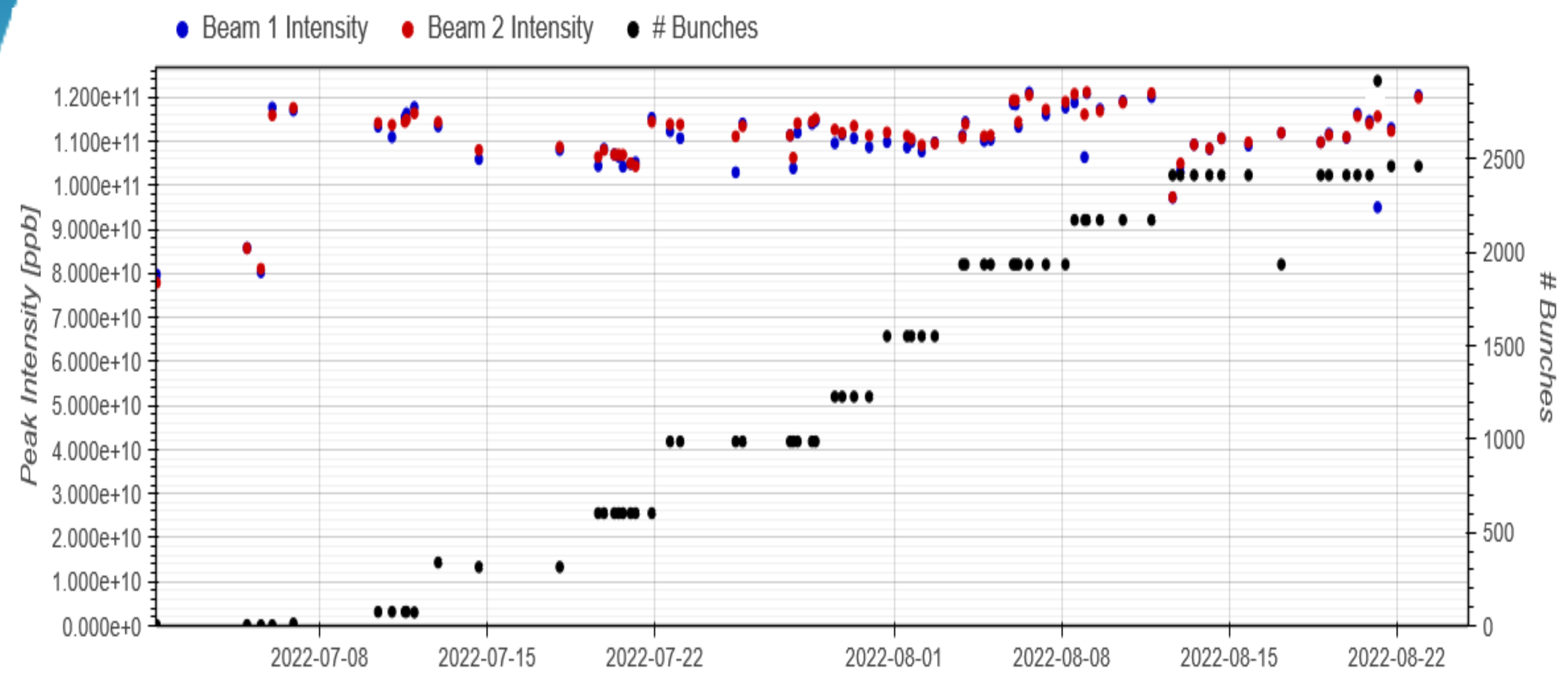
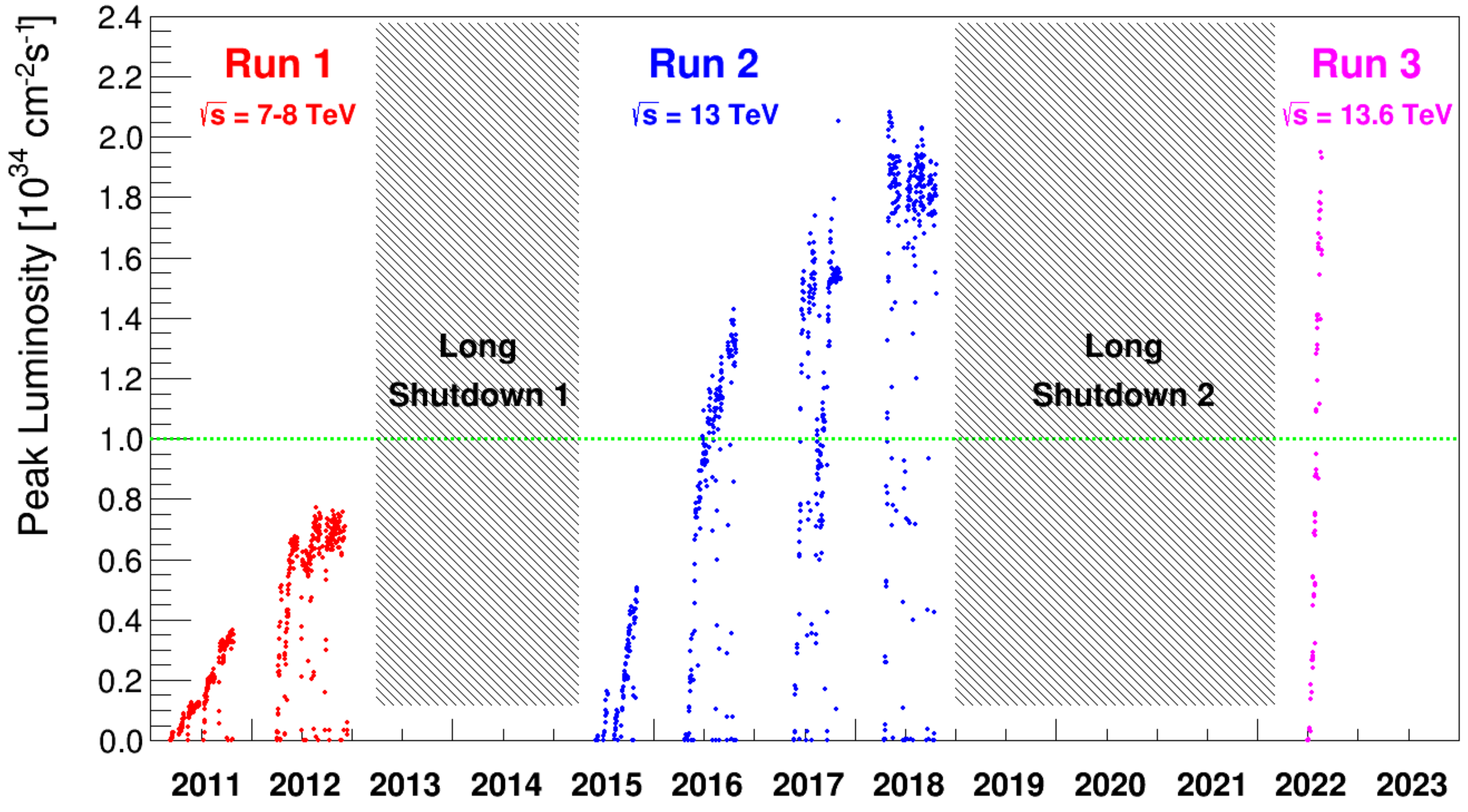


In addition: 2 crystal primary collimators (TCPCs) installed in Nov. 2021; 2 will be installed in the YETS2022-23 (+2 spares built)

Table of contents

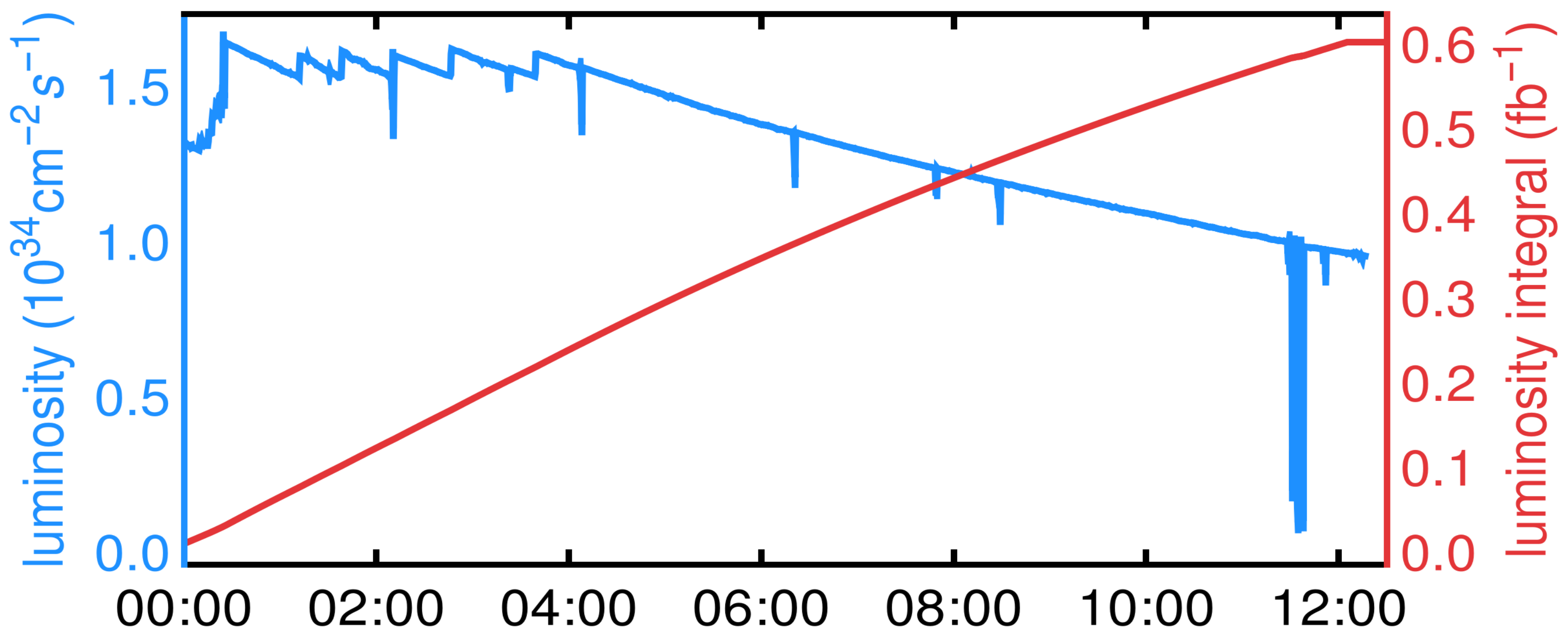
LHC status in a nutshell





Various operational aspects in 2022 are already particularly relevant for beam collimation:

- **330 MJ of beam stored energy at 6.8TeV**
  - No quench from circulating-beam losses
- **Peak bunch current ~ 1.25 x 10^{11} p**
- **Peak luminosity close to 2 x 10^{34}cm^{-2}s^{-1}**
- **Luminosity levelling schemes**



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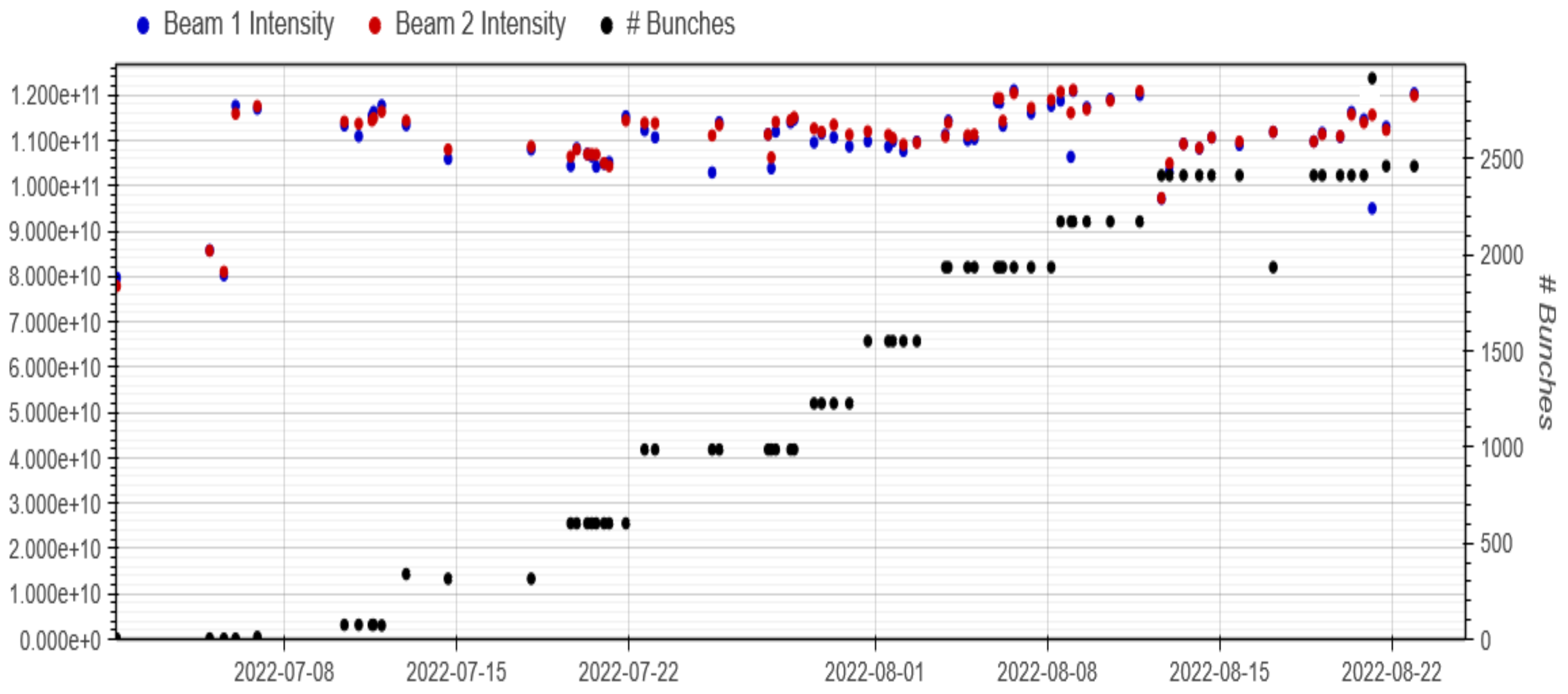

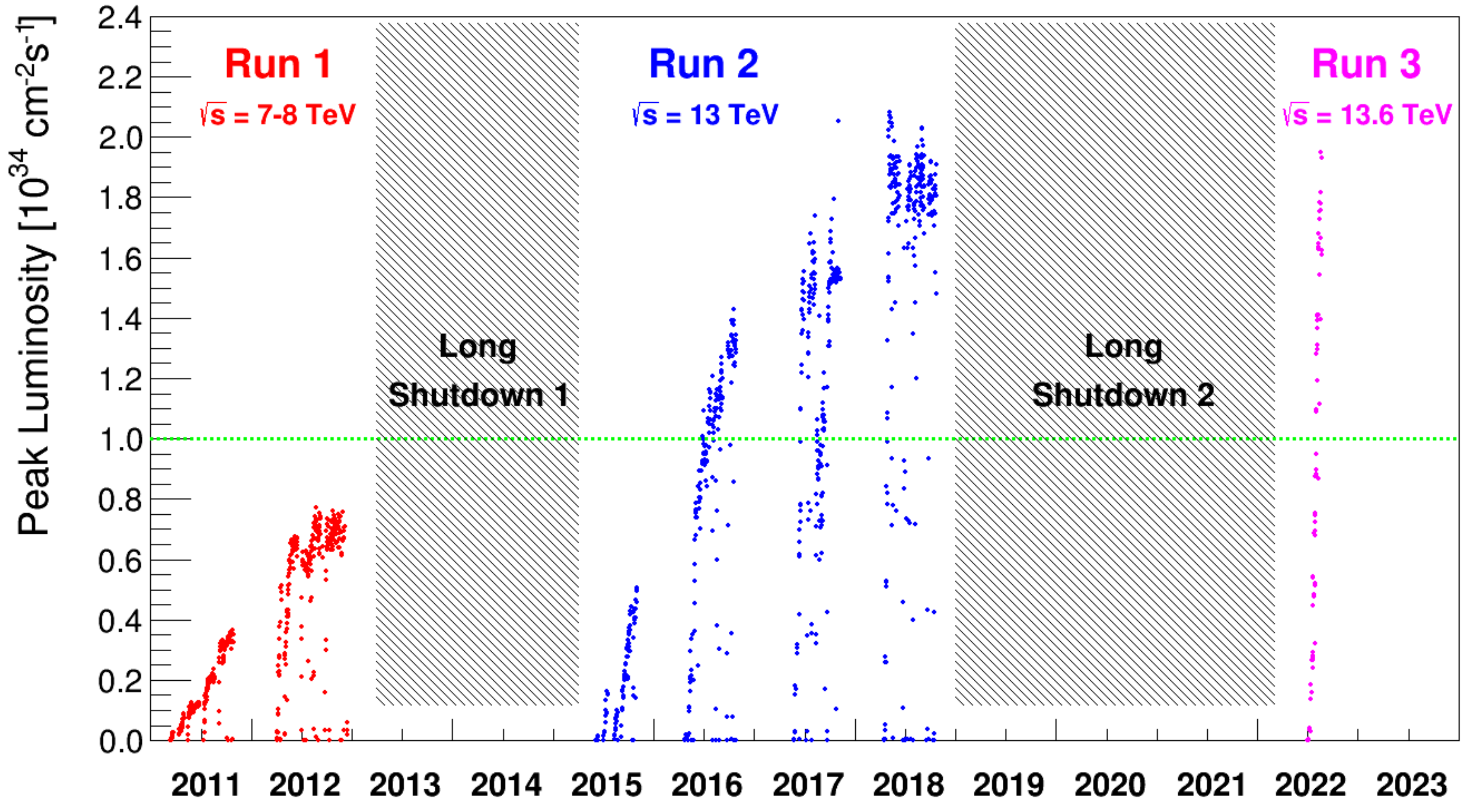

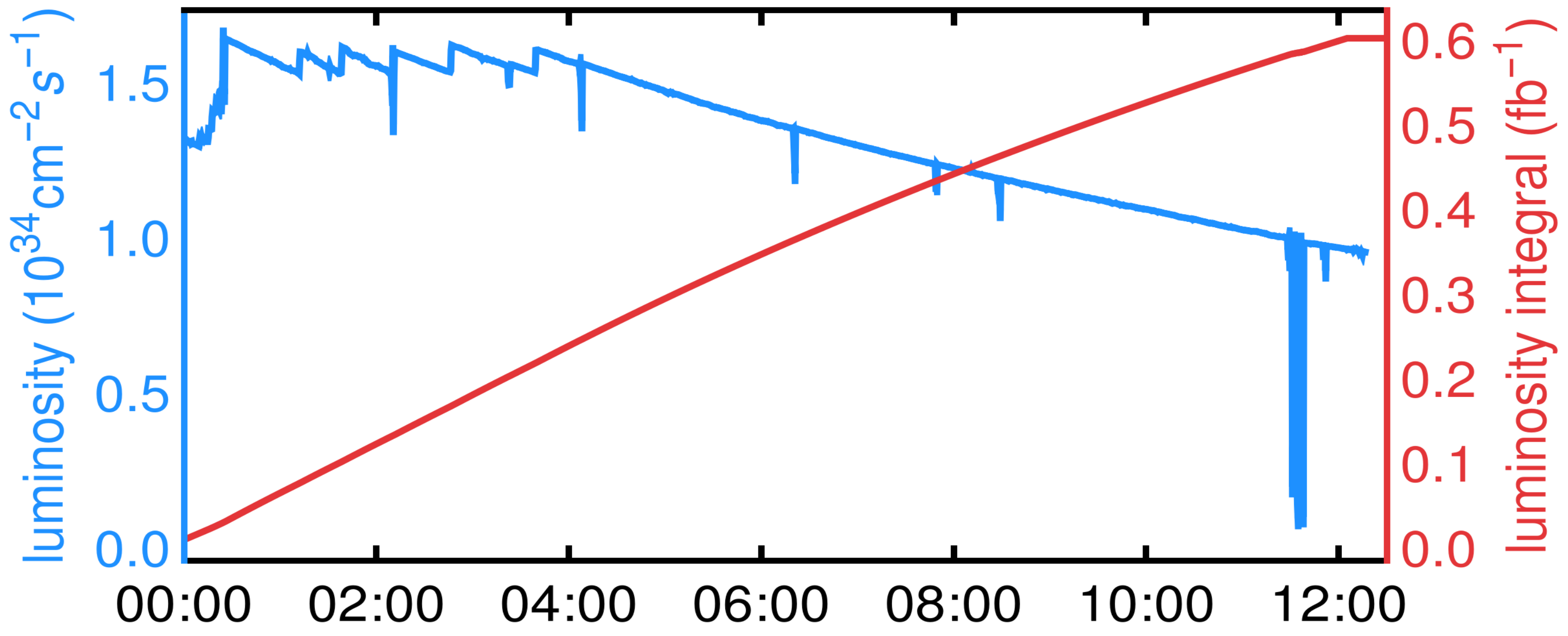

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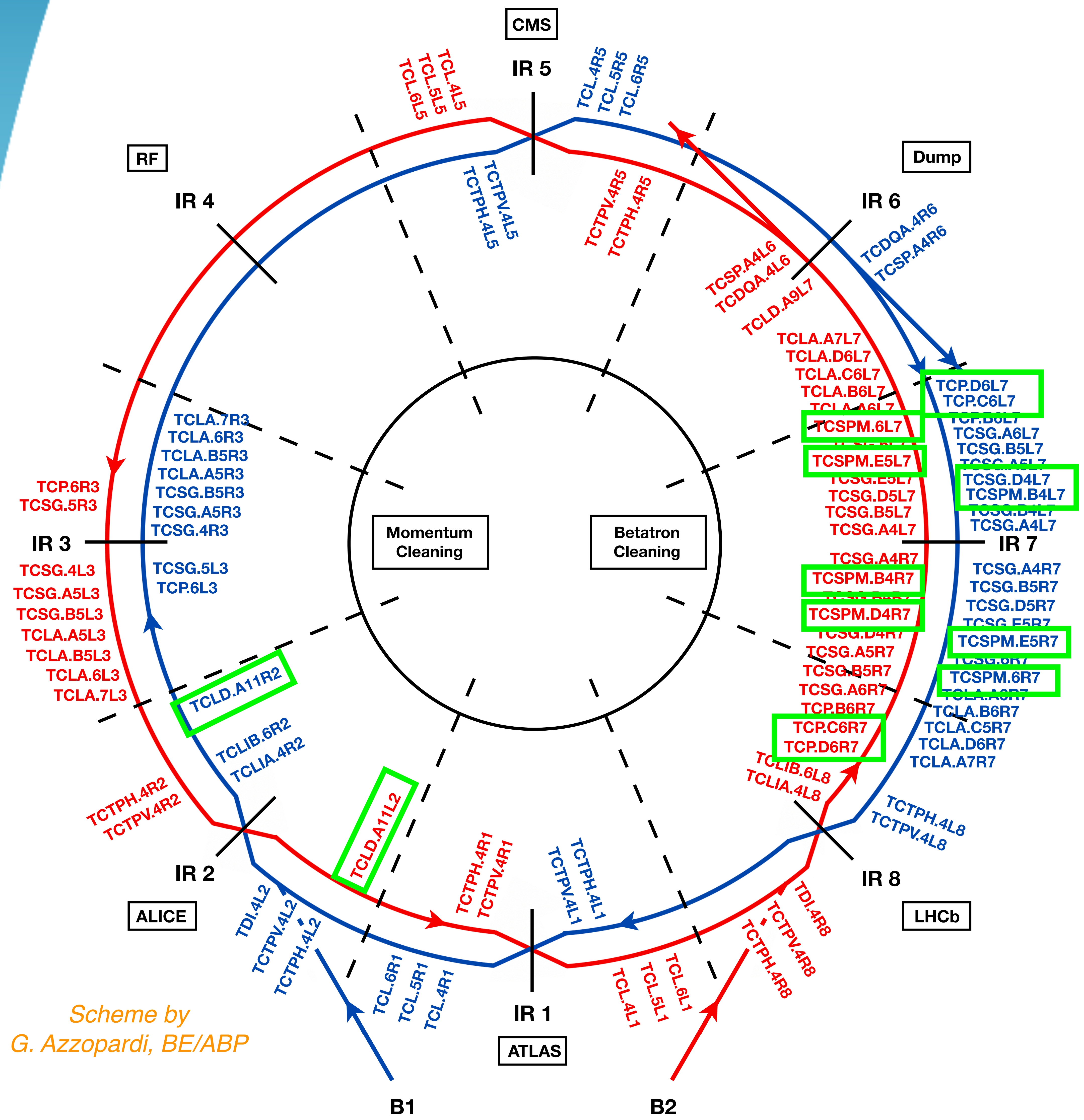
- **Luminosity levelling schemes**

WP5 LS2 upgrades:

- Improve performance in view of the progressive deployment of LIU beams (in particular for ion beams)
- Reduce workload from LS3
- Validate some key upgrade choices

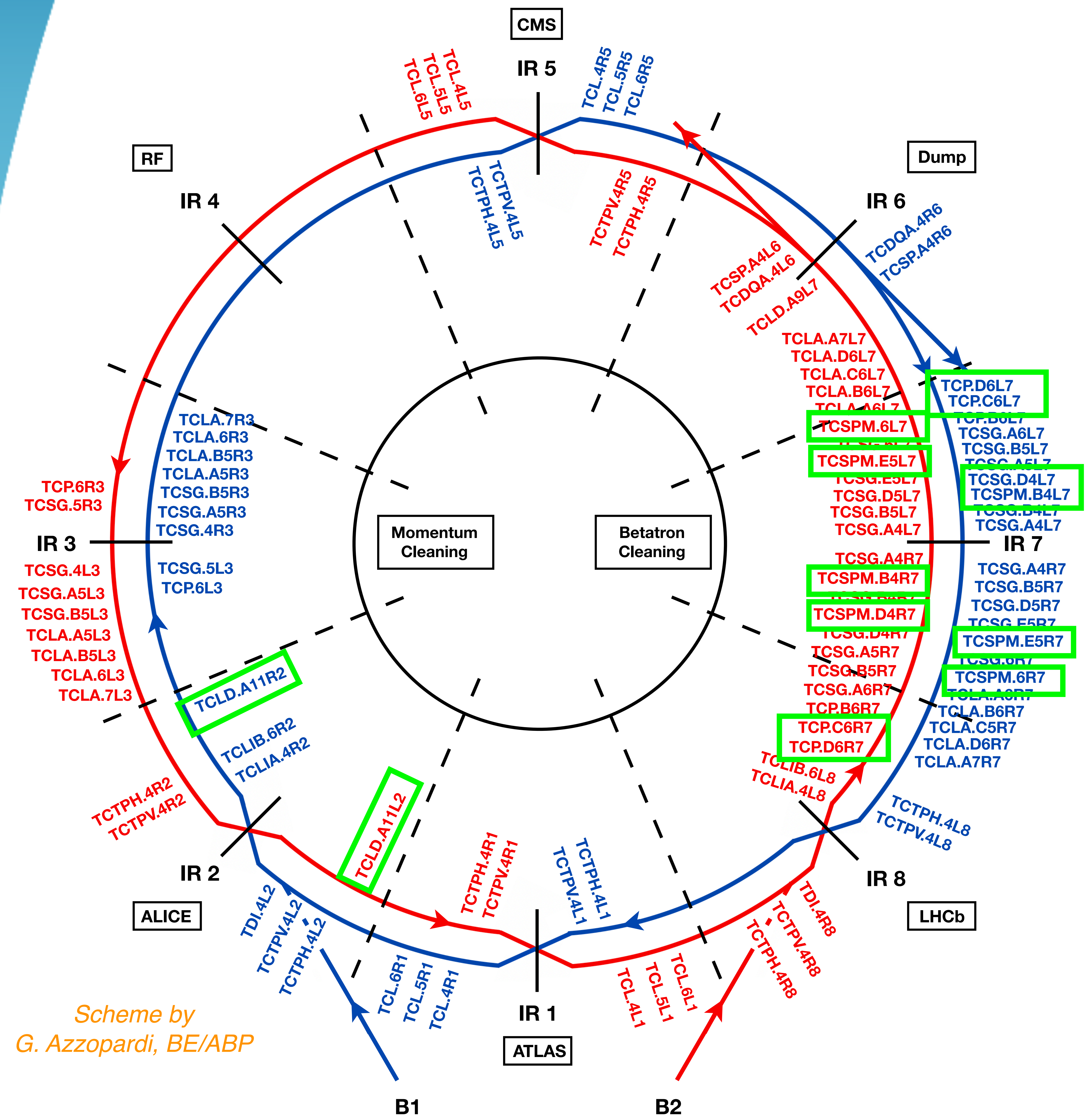
New devices available and the Run 3 performance can profit from them!

The upgraded collimation system for Run 3



Scheme by G. Azzopardi, BE/ABP

The upgraded collimation system for Run 3



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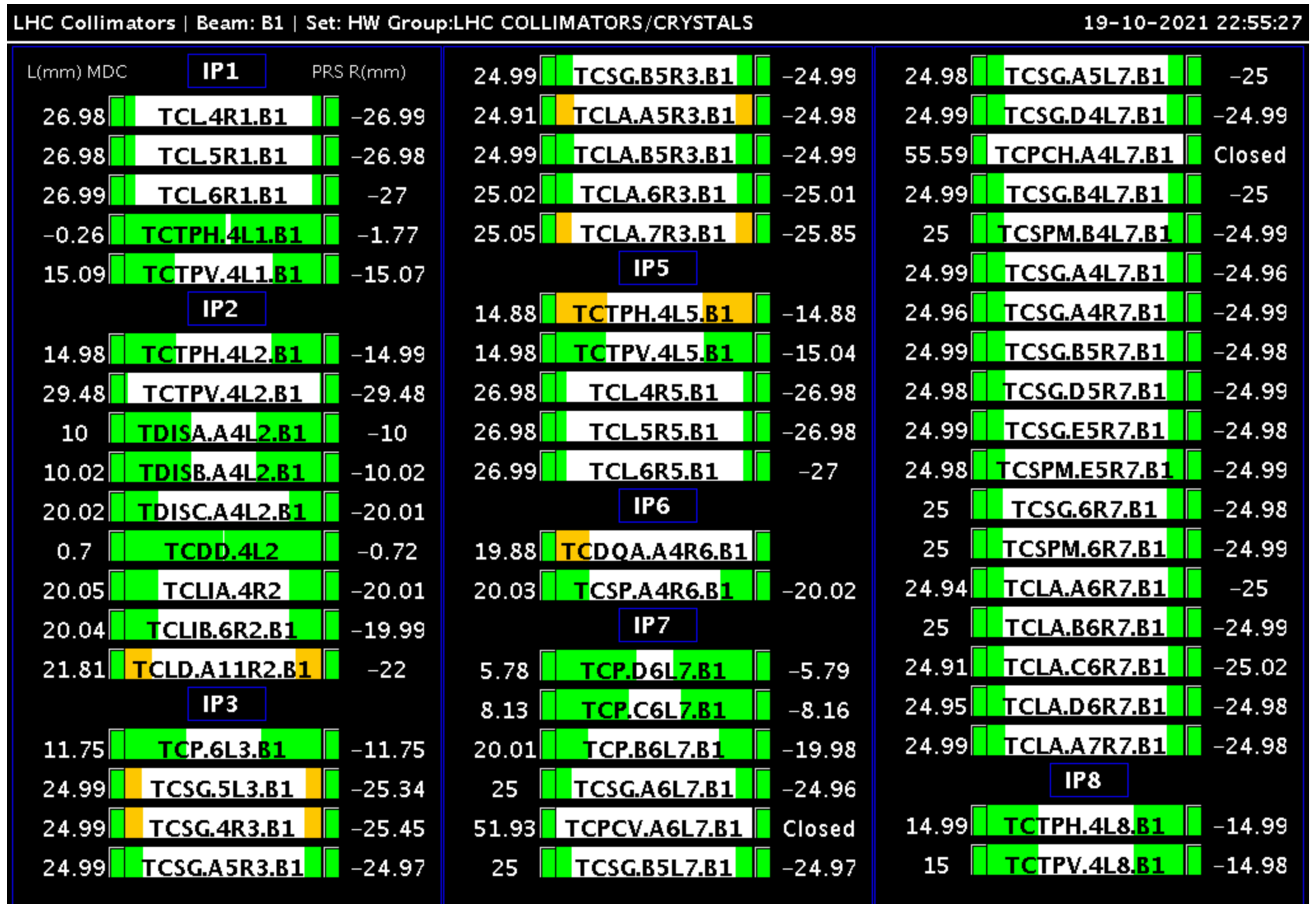

LHC Collimators | Beam: B1 | Set: HW Group:LHC COLLIMATORS/CRYSTALS 19-10-2021 22:55:27

L(mm) MDC		PRS R(mm)
	IP1	
26.98	TCL.4R1.B1	-26.99
26.98	TCL.5R1.B1	-26.98
26.99	TCL.6R1.B1	-27
-0.26	TCTPH.4L1.B1	-1.77
15.09	TCTPV.4L1.B1	-15.07
	IP2	
14.98	TCTPH.4L2.B1	-14.99
29.48	TCTPV.4L2.B1	-29.48
10	TDISA.A4L2.B1	-10
10.02	TDISB.A4L2.B1	-10.02
20.02	TDISC.A4L2.B1	-20.01
0.7	TCDD.4L2	-0.72
20.05	TCLIA.4R2	-20.01
20.04	TCLIB.6R2.B1	-19.99
21.81	TCLD.A11R2.B1	-22
	IP3	
11.75	TCP.6L3.B1	-11.75
24.99	TCSG.5L3.B1	-25.34
24.99	TCSG.4R3.B1	-25.45
24.99	TCSG.A5R3.B1	-24.97
24.99	TCSG.B5R3.B1	-24.99
24.91	TCLA.A5R3.B1	-24.98
24.99	TCLA.B5R3.B1	-24.99
25.02	TCLA.6R3.B1	-25.01
25.05	TCLA.7R3.B1	-25.85
	IP5	
14.88	TCTPH.4L5.B1	-14.88
14.98	TCTPV.4L5.B1	-15.04
26.98	TCL.4R5.B1	-26.98
26.98	TCL.5R5.B1	-26.98
26.99	TCL.6R5.B1	-27
	IP6	
19.88	TCDQA.A4R6.B1	
20.03	TCSP.A4R6.B1	-20.02
	IP7	
5.78	TCP.D6L7.B1	-5.79
8.13	TCP.C6L7.B1	-8.16
20.01	TCP.B6L7.B1	-19.98
25	TCSG.A6L7.B1	-24.96
51.93	TCPCV.A6L7.B1	Closed
25	TCSG.B5L7.B1	-24.97
24.98	TCSG.A5L7.B1	-25
24.99	TCSG.D4L7.B1	-24.99
55.59	TCPCH.A4L7.B1	Closed
24.99	TCSG.B4L7.B1	-25
25	TCSPM.B4L7.B1	-24.99
24.99	TCSG.A4L7.B1	-24.96
24.96	TCSG.A4R7.B1	-24.99
24.99	TCSG.B5R7.B1	-24.98
24.98	TCSG.D5R7.B1	-24.99
24.99	TCSG.E5R7.B1	-24.98
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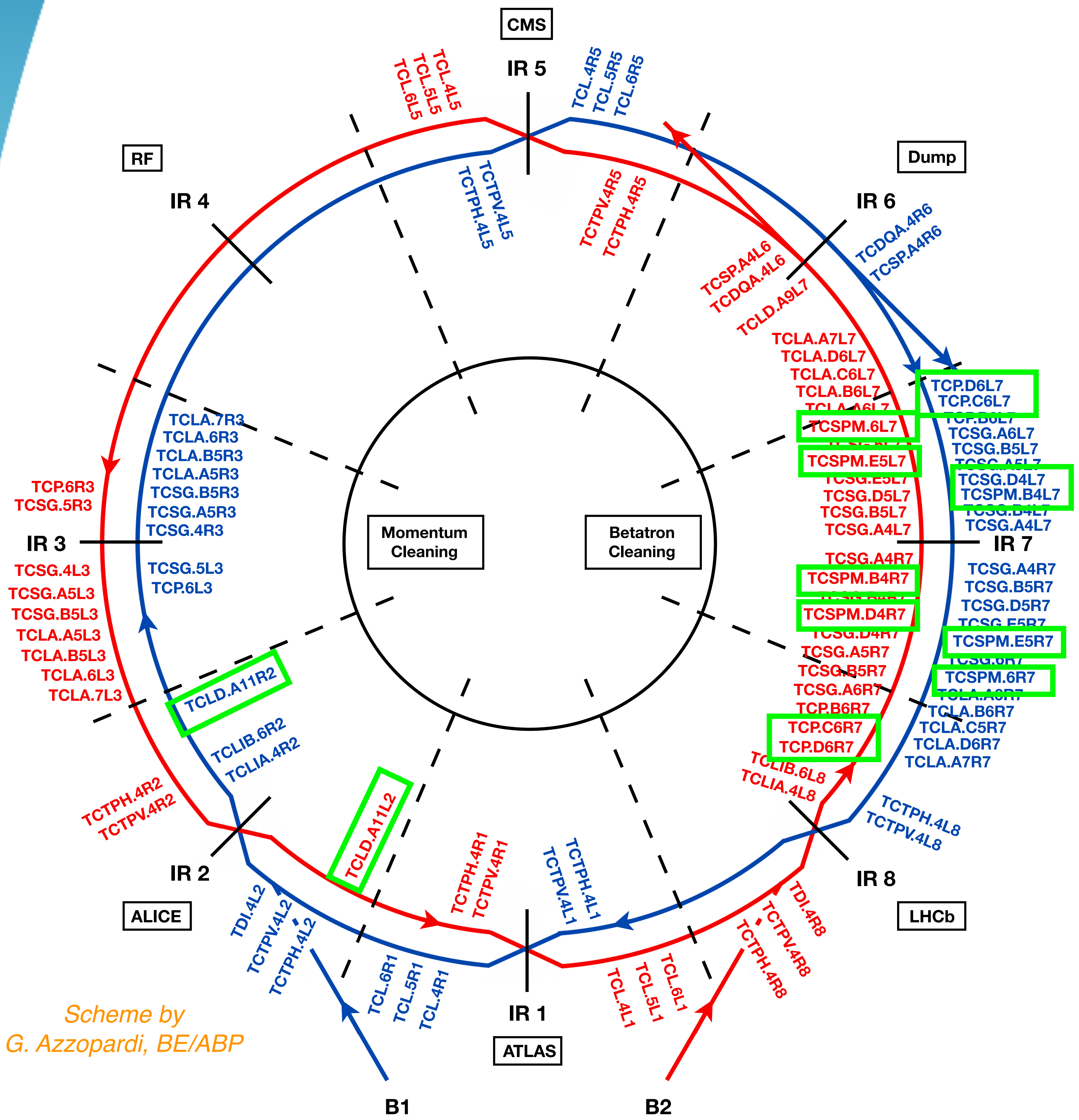
25	TCSG.6R7.B1	-24.98
25	TCSPM.6R7.B1	-24.99
24.94	TCLA.A6R7.B1	-25
25	TCLA.B6R7.B1	-24.99
24.91	TCLA.C6R7.B1	-25.02
24.95	TCLA.D6R7.B1	-24.98
24.99	TCLA.A7R7.B1	-24.98
	IP8	
14.99	TCTPH.4L8.B1	-14.99
15	TCTPV.4L8.B1	-14.98

The upgraded collimation system for Run 3



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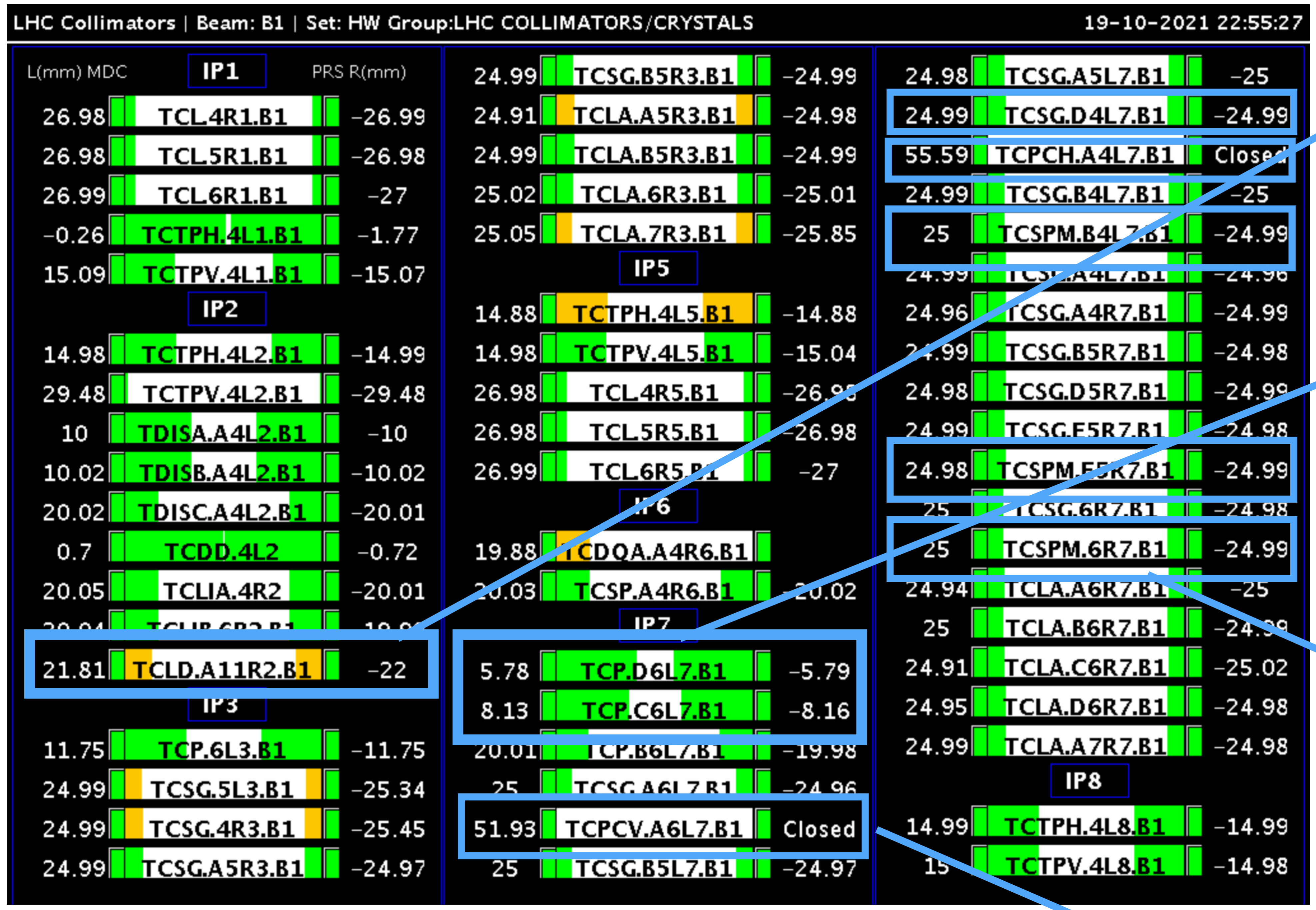

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14.88	TCTPH.4L5.B1	-14.88
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26.98	TCL.4R5.B1	-26.98
26.98	TCL.5R5.B1	-26.98
26.99	TCL.6R5.B1	-27
	IP6	
19.88	TCDQA.A4R6.B1	
20.03	TCSP.A4R6.B1	-20.02
	IP7	
5.78	TCP.D6L7.B1	-5.79
8.13	TCP.C6L7.B1	-8.16
20.01	TCP.B6L7.B1	-19.98
25	TCSG.A6L7.B1	-24.96
51.93	TCPCV.A6L7.B1	Closed
25	TCSG.B5L7.B1	-24.97
24.98	TCSG.A5L7.B1	-25
24.99	TCSG.D4L7.B1	-24.99
55.59	TCPCH.A4L7.B1	Closed
24.99	TCSG.B4L7.B1	-25
25	TCSPM.B4L7.B1	-24.99
24.99	TCSG.A4L7.B1	-24.96
24.96	TCSG.A4R7.B1	-24.99
24.99	TCSG.B5R7.B1	-24.98
24.98	TCSG.D5R7.B1	-24.99
24.99	TCSG.E5R7.B1	-24.98
24.98	TCSPM.E5R7.B1	-24.99
25	TCSG.6R7.B1	-24.98
25	TCSPM.6R7.B1	-24.99
24.94	TCLA.A6R7.B1	-25
25	TCLA.B6R7.B1	-24.99
24.91	TCLA.C6R7.B1	-25.02
24.95	TCLA.D6R7.B1	-24.98
24.99	TCLA.A7R7.B1	-24.98
	IP8	
14.99	TCTPH.4L8.B1	-14.99
15	TCTPV.4L8.B1	-14.98

TCLD: dispersion suppressor IP2

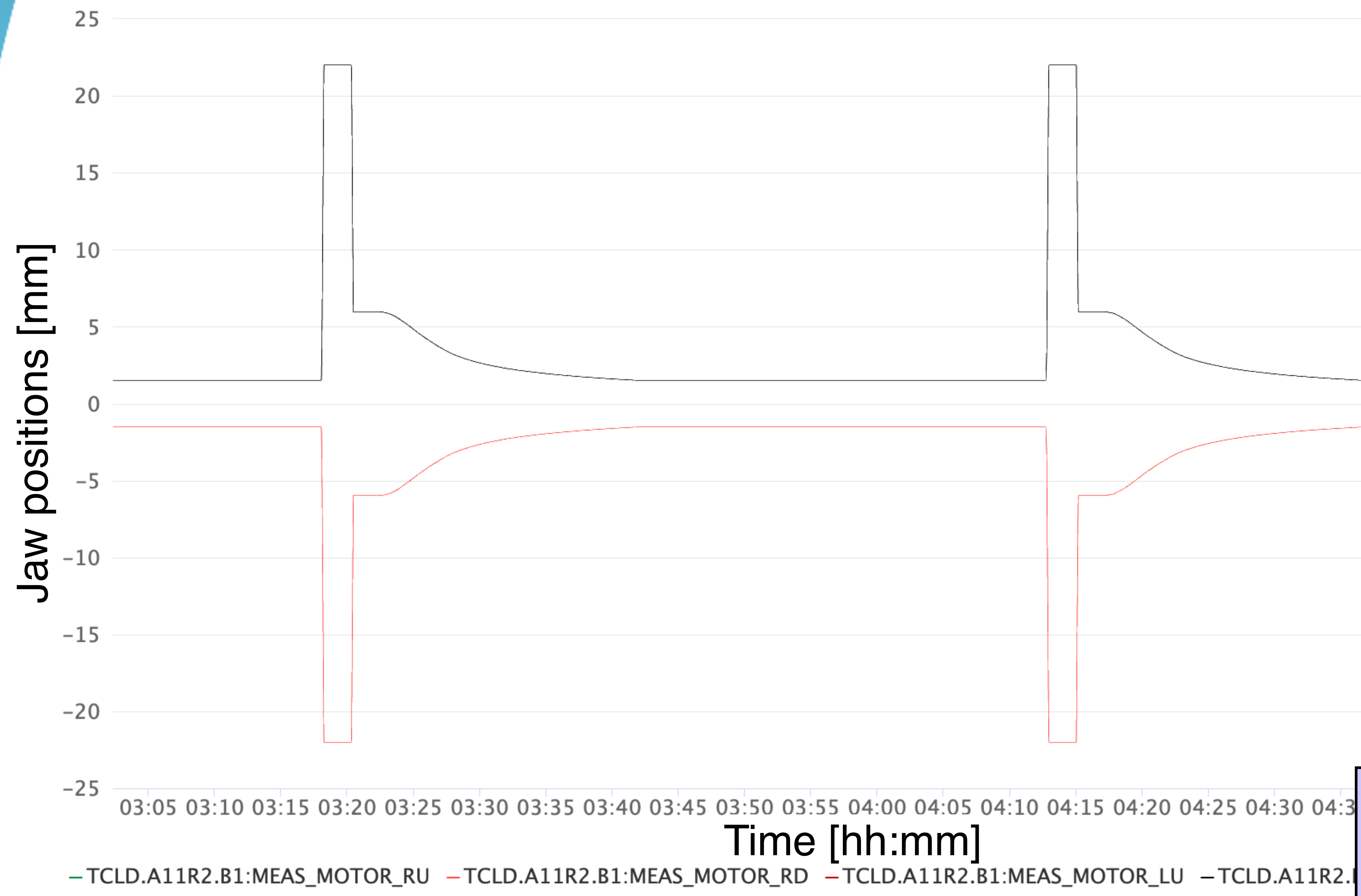
TCPPMs: New primaries

TCSPMs: New secondaries

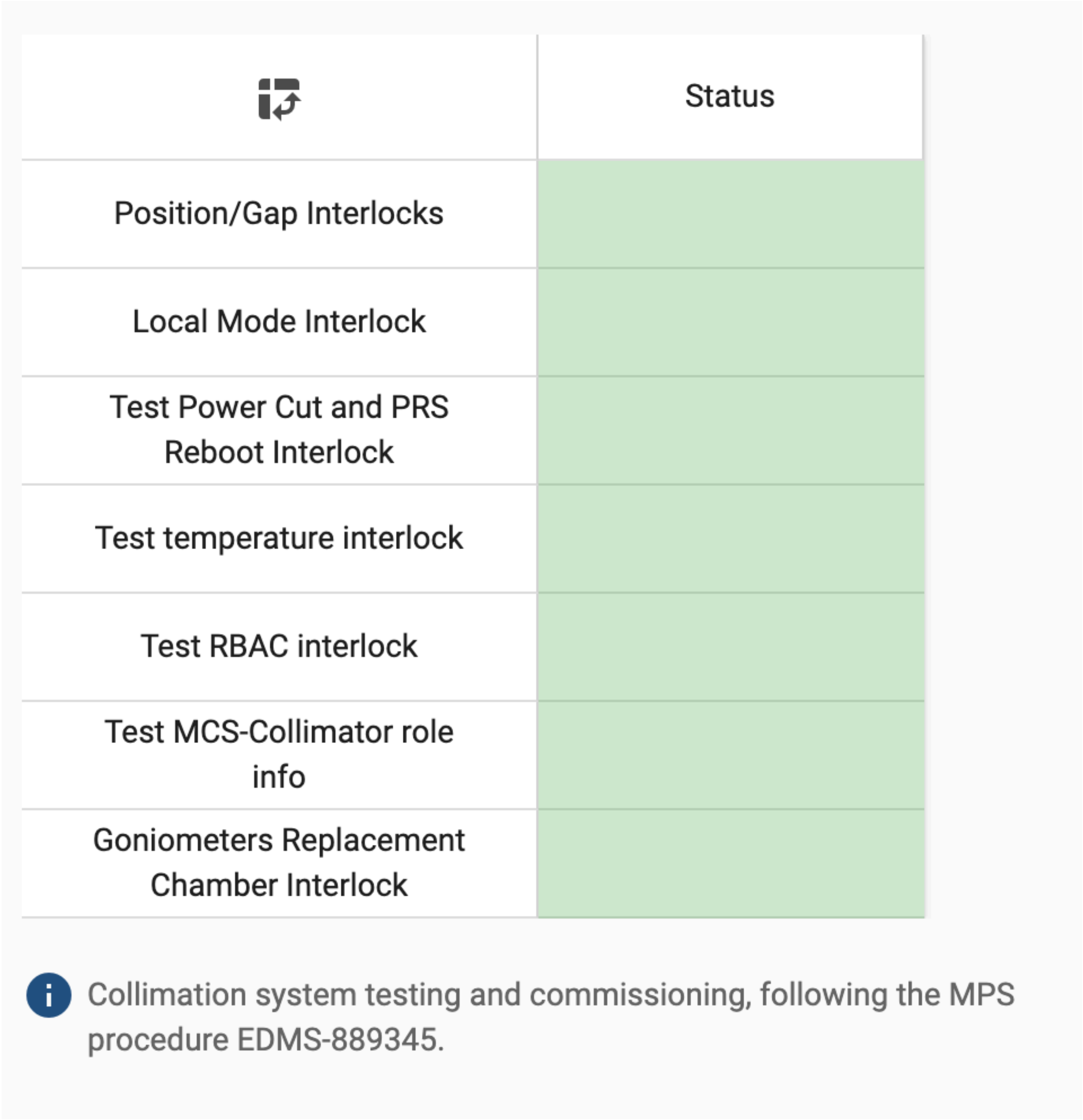
TCPCs: New & old crystals

2021-22 hardware commissioning → OK!

"Stress tests": order of hundred full-cycle functions executed by all collimators



Machine protection tests: verification of all interlocks



	Status
Position/Gap Interlocks	🟩
Local Mode Interlock	🟩
Test Power Cut and PRS Reboot Interlock	🟩
Test temperature interlock	🟩
Test RBAC interlock	🟩
Test MCS-Collimator role info	🟩
Goniometers Replacement Chamber Interlock	🟩

ⓘ Collimation system testing and commissioning, following the MPS procedure EDMS-889345.

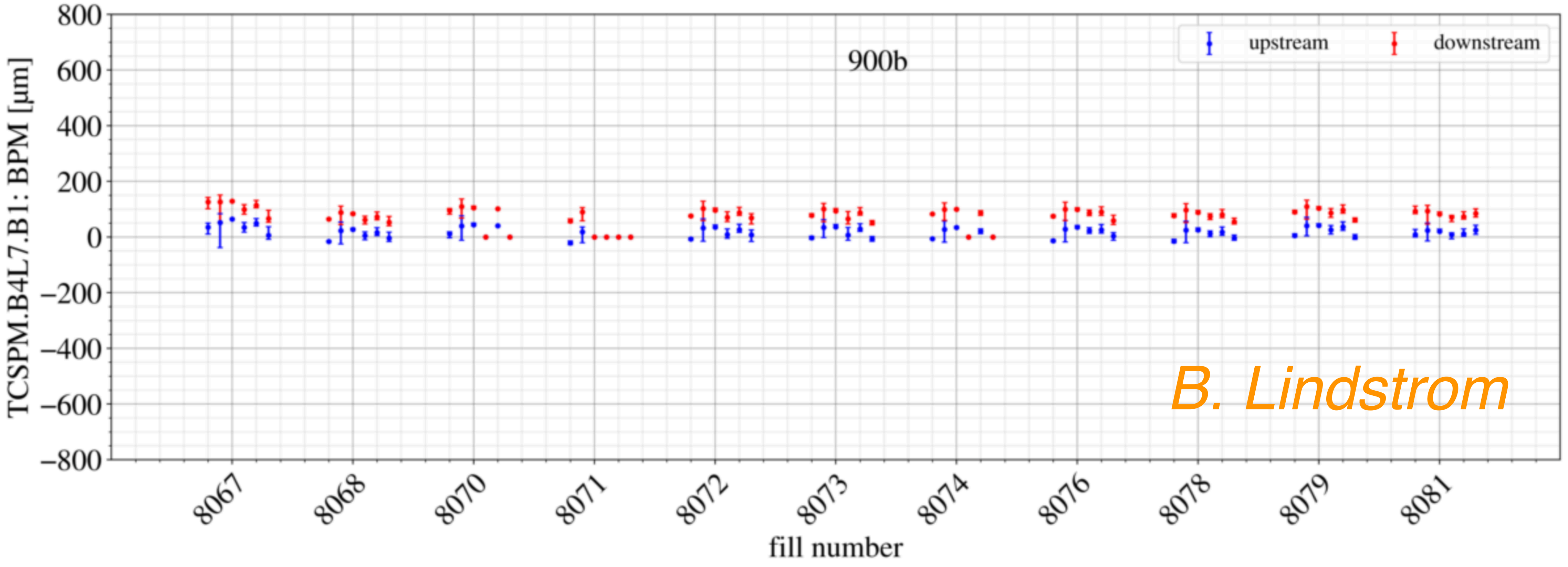
New HL-LHC hardware was part of the commissioning without and with beam from the beginning (2021 pilot run & 2022 operation)

Details: Collimation Working Group, #265 (talk by D. Mirarchi, BE/OP)

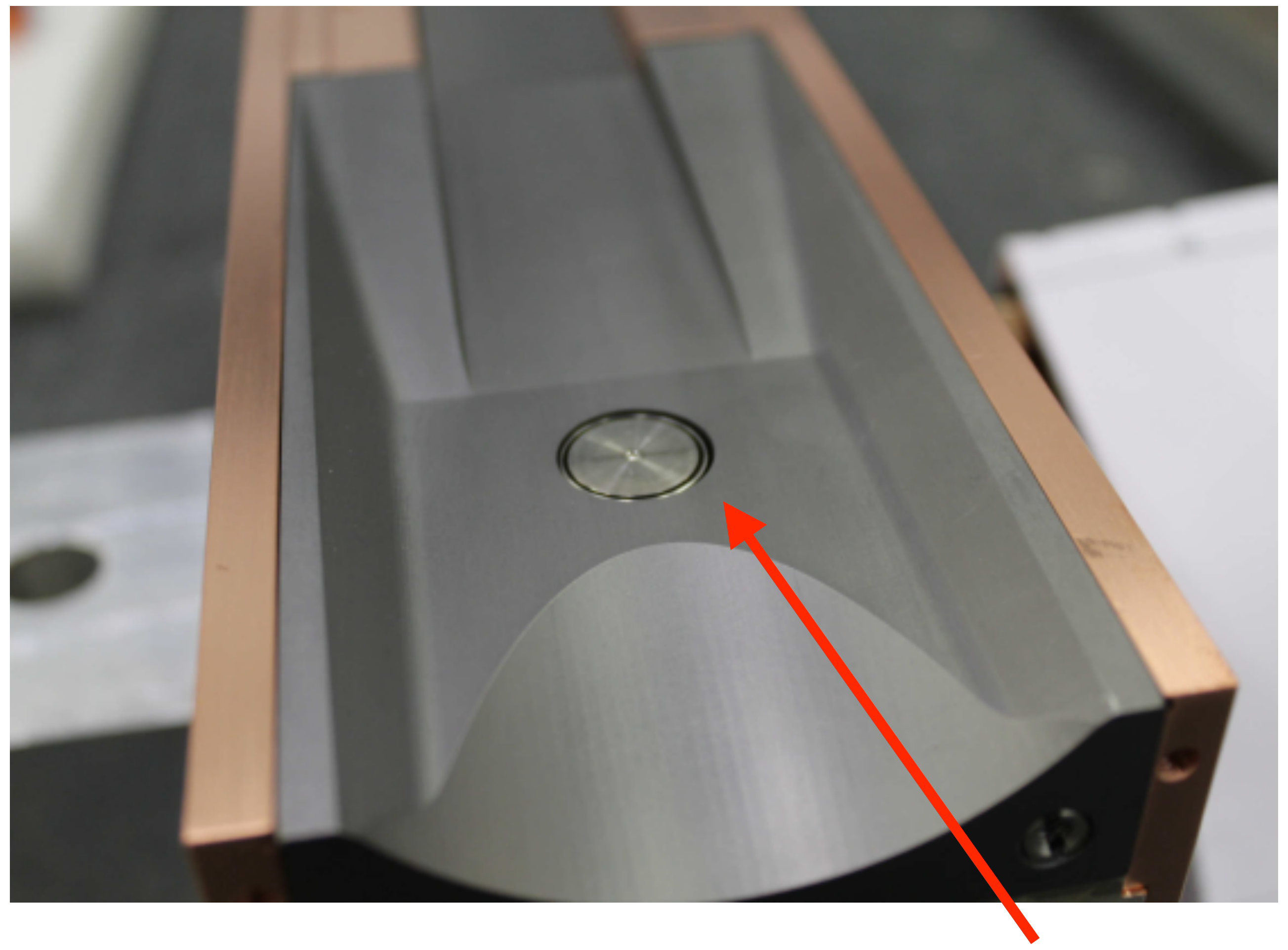
New BPM collimators in operation

- BPMs are the collimation "eyes" that allow faster alignment, continuous orbit measurements and beam interlocks
  - Now 12 IR7 collimators with BPM (before only around experiments and in dump region)
- Enable verification of collimator tilt → identified a few collimators that were re-aligned
- Adds operational flexibility: critical asset for levelling at HL-LHC

Thanks to the SY/BI team.



B. Lindstrom



BPM Pick-up Button

F. Carra

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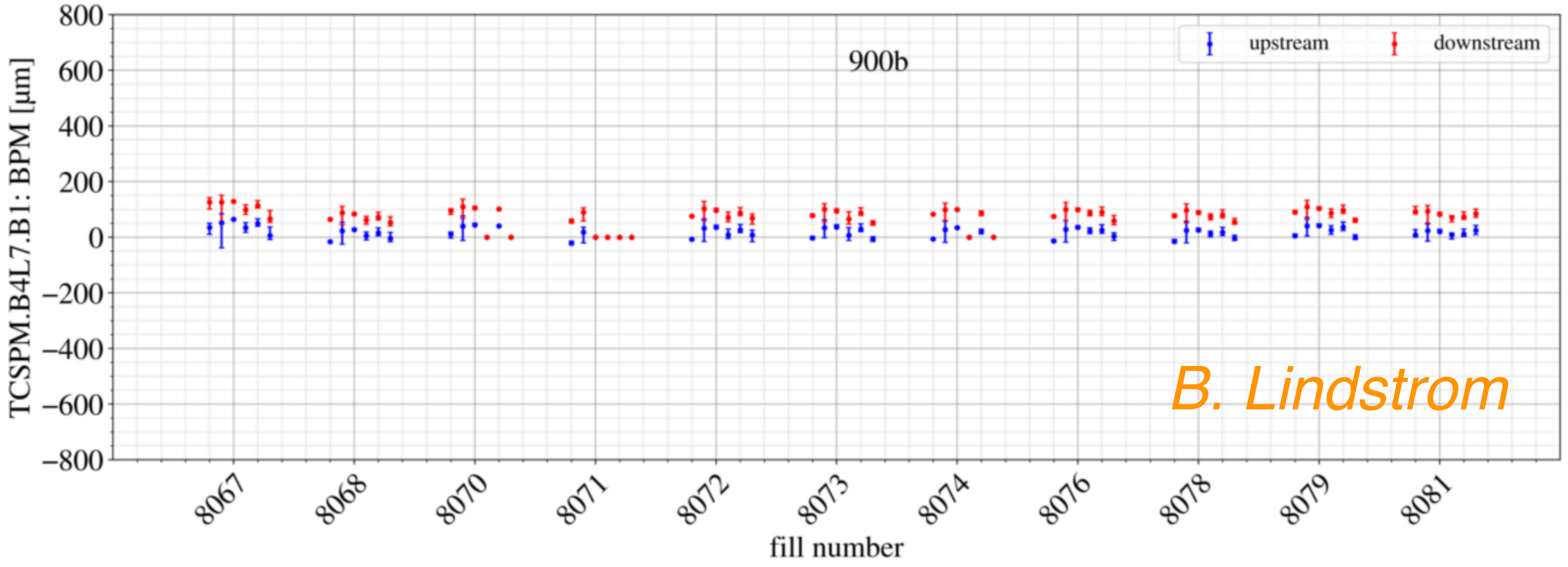
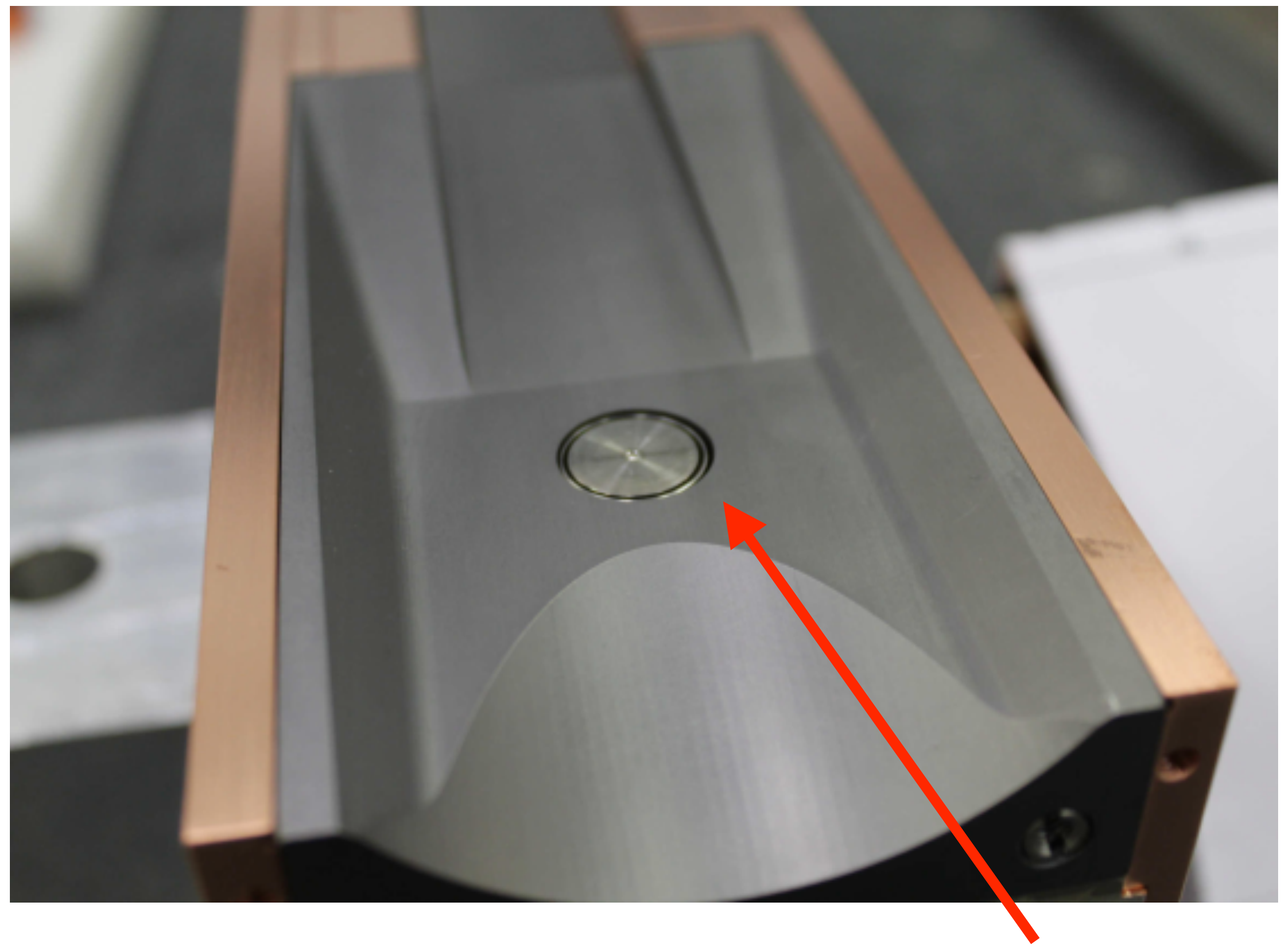
  - Now 12 IR7 collimators with BPM (before only around experiments and in dump region)
- Enable verification of collimator tilt → identified a few collimators that were re-aligned
- Adds operational flexibility: critical asset for levelling at HL-LHC

Thanks to the SY/BI team.

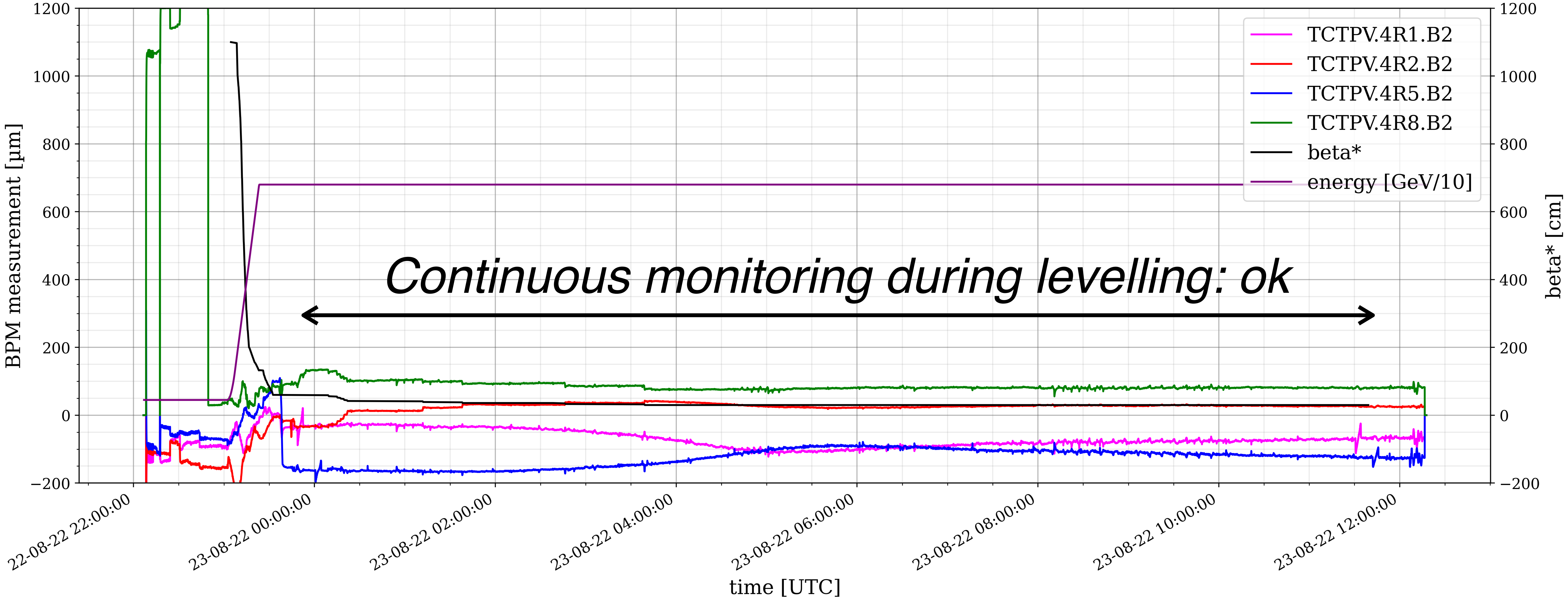


B. Lindstrom



F. Carra

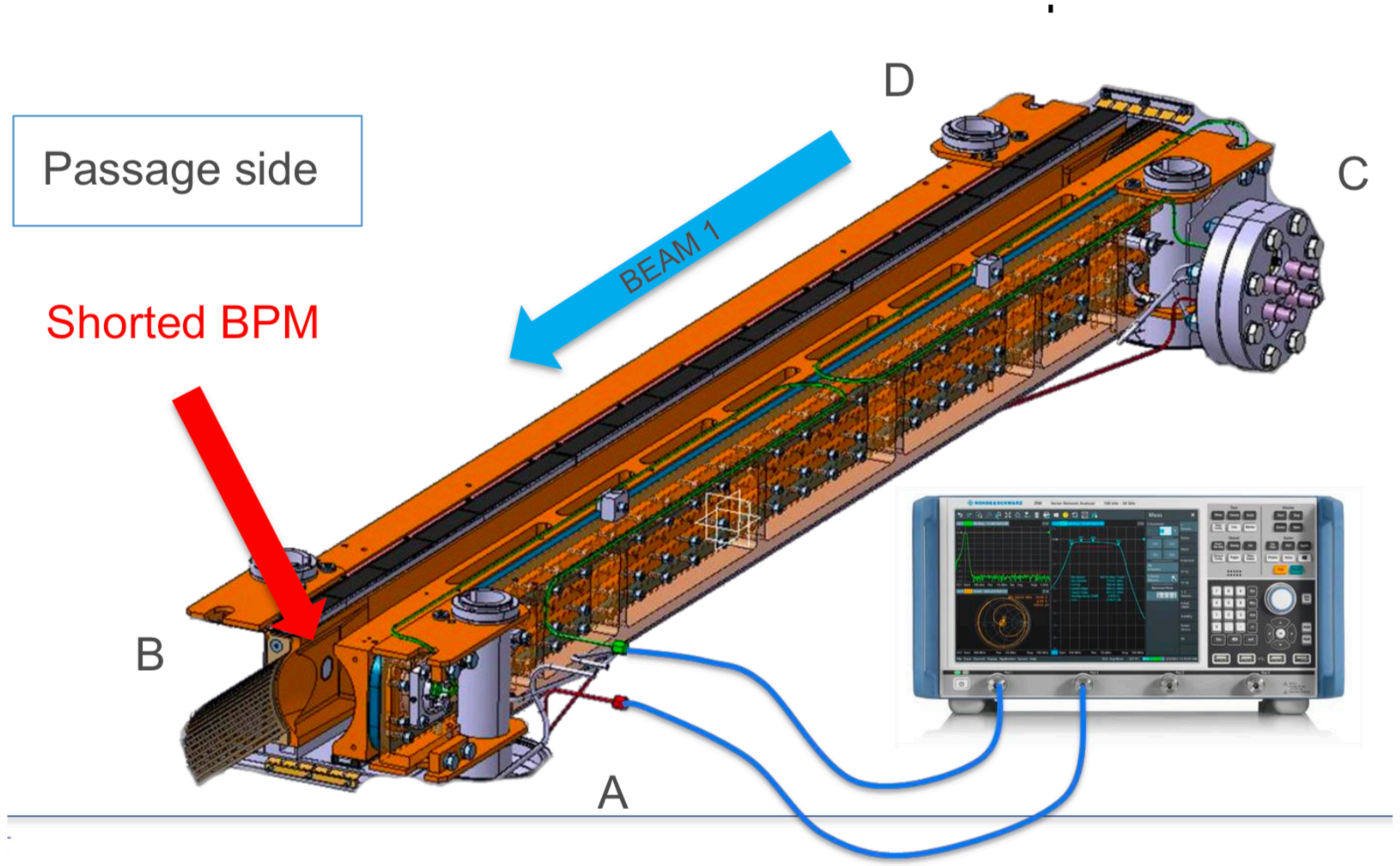
BPM Pick-up Button



Continuous monitoring during levelling: ok

Issue of short in a collimator BPM — fixed!

- ✓ The HCTCSPM001-CZ000004 was installed in the slot TCSPM.6R7.B1 during LS2.
- ✓ The BPM acquisition chain was successfully tested and validated after the installation.
- ✓ The BPM acquisition chain + DOROS were verified with beam on 23/10/2021.
- After checking the logged data we found that the LHC.BPTDH.6R7.B1 was not sending the expected signal to DOROS.
- On the 12th of May during the access period, a short circuit of ~1.5 Ohms was detected on the LHC.BPTDH.6R7.B1 channel.



By checking the logged data it was possible to trace back the error to 25/10/2021.

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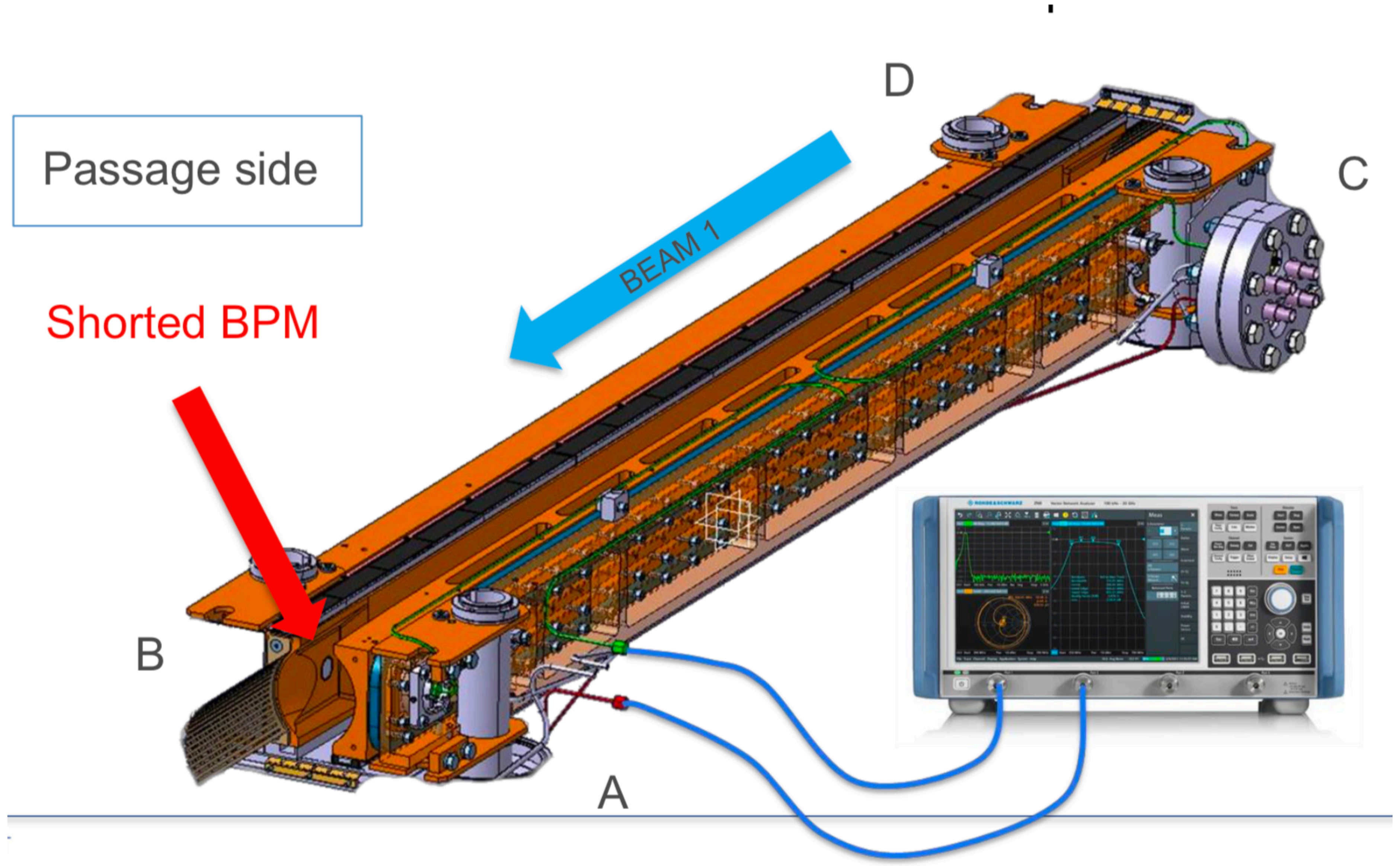

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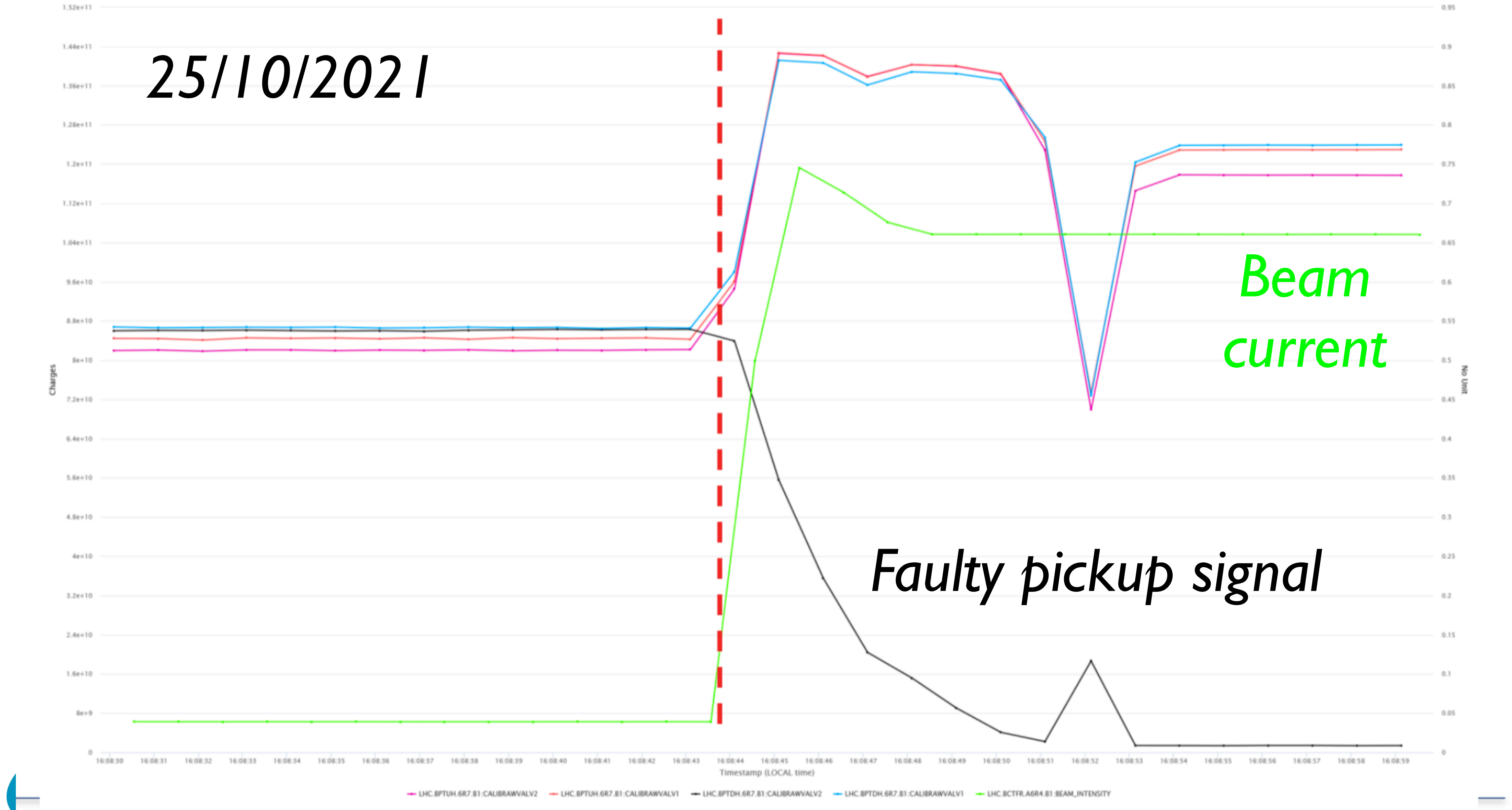
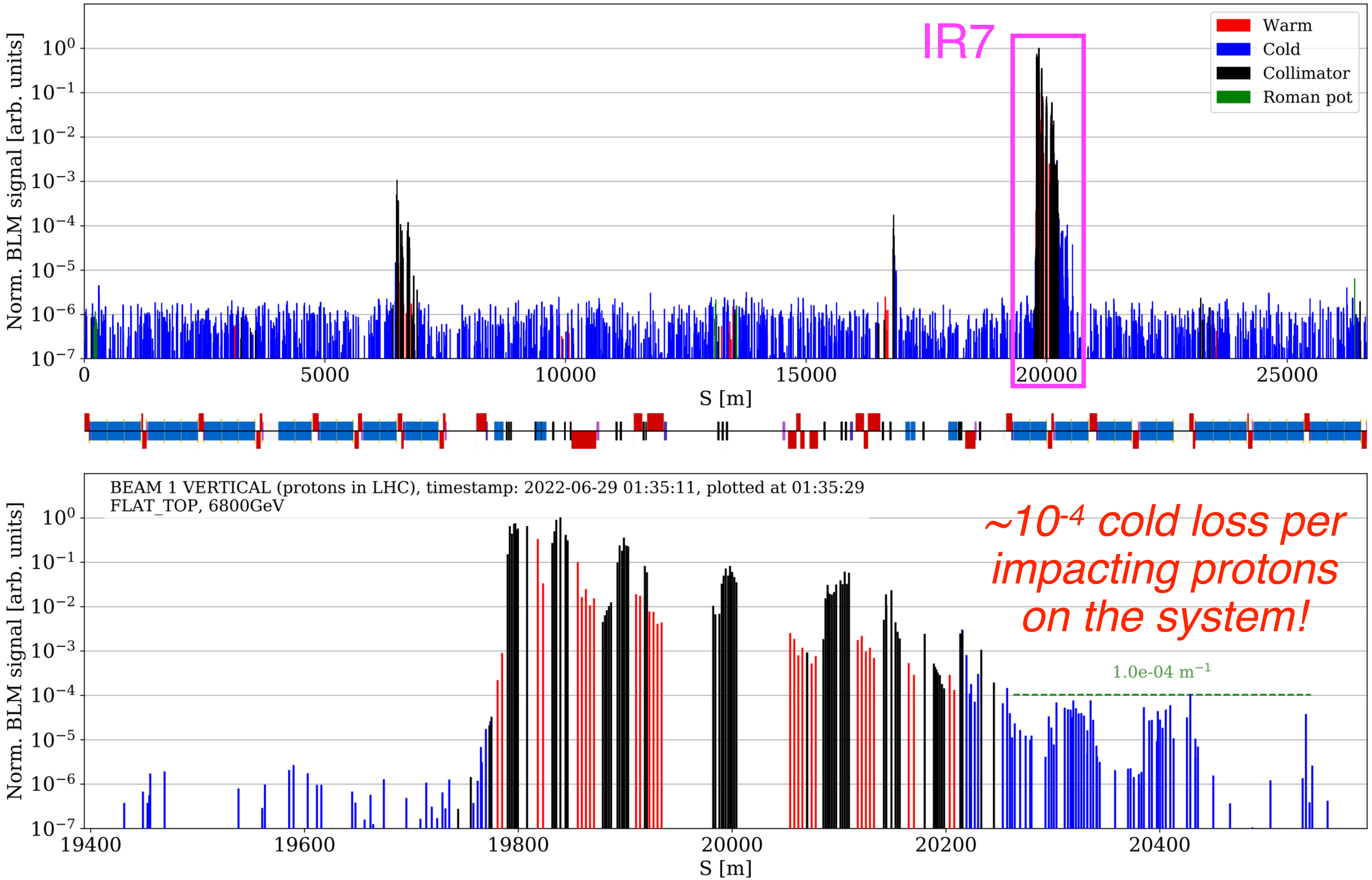


On May 17th, the SY-BI team intervened in IR7. After a detail diagnostic to **localise the short**, it was "burned away" by applying a small current <200mA

- Orbit measurements at this collimator fully back in operation and operational since then

Collimation cleaning performance

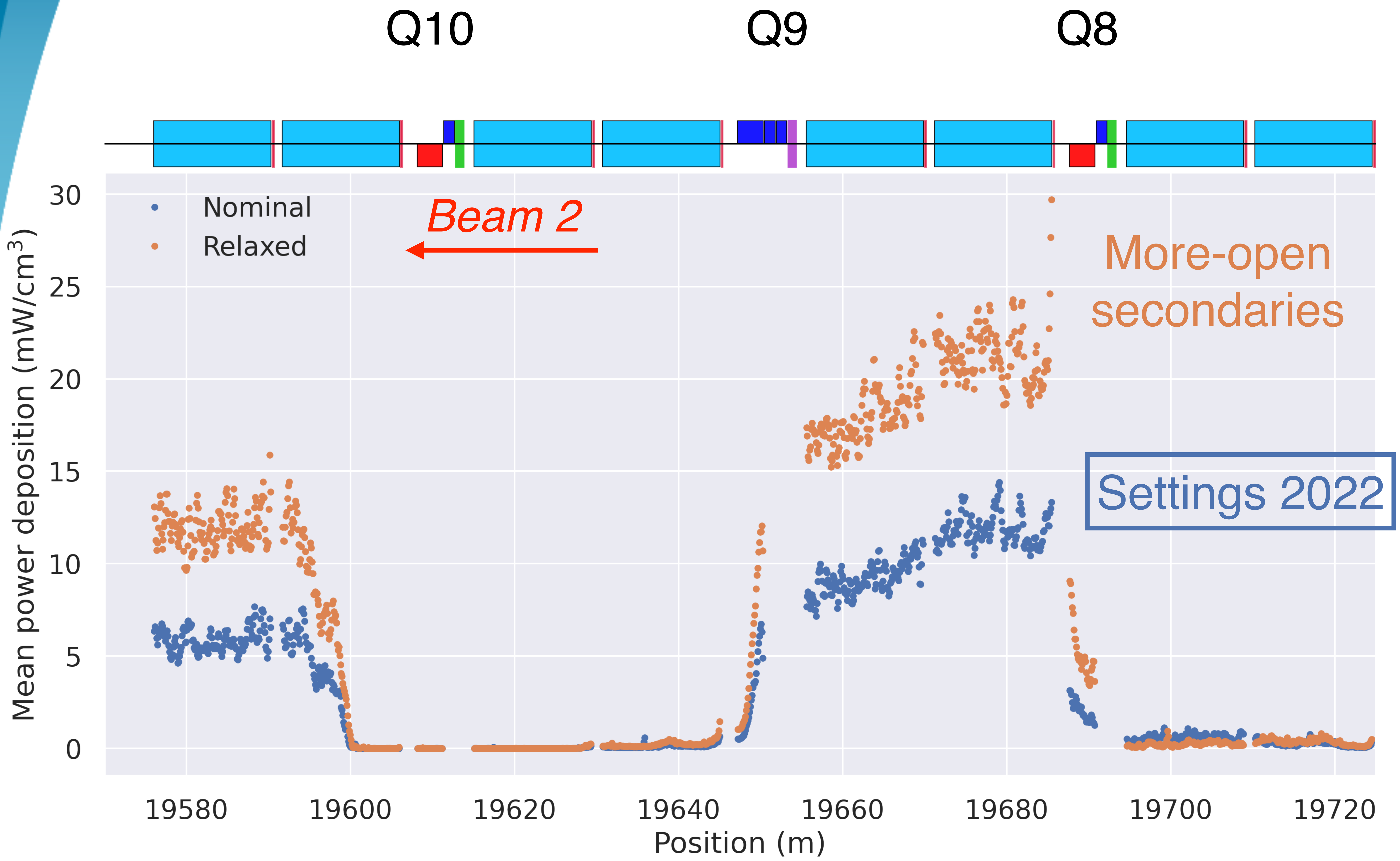


~10^{-4} cold loss per impacting protons on the system!

F. Van der Veken

- The system setup in 2022 worked smoothly and profited from the new BPM collimators
- Similar settings as in 2018 used: cleaning performance at the level of 10^{-4} achieved
  - *No quench so far from circulating-beam losses!*
- New material of primary collimators provides an improved cleaning performance

Expected energy deposition in cold magnets

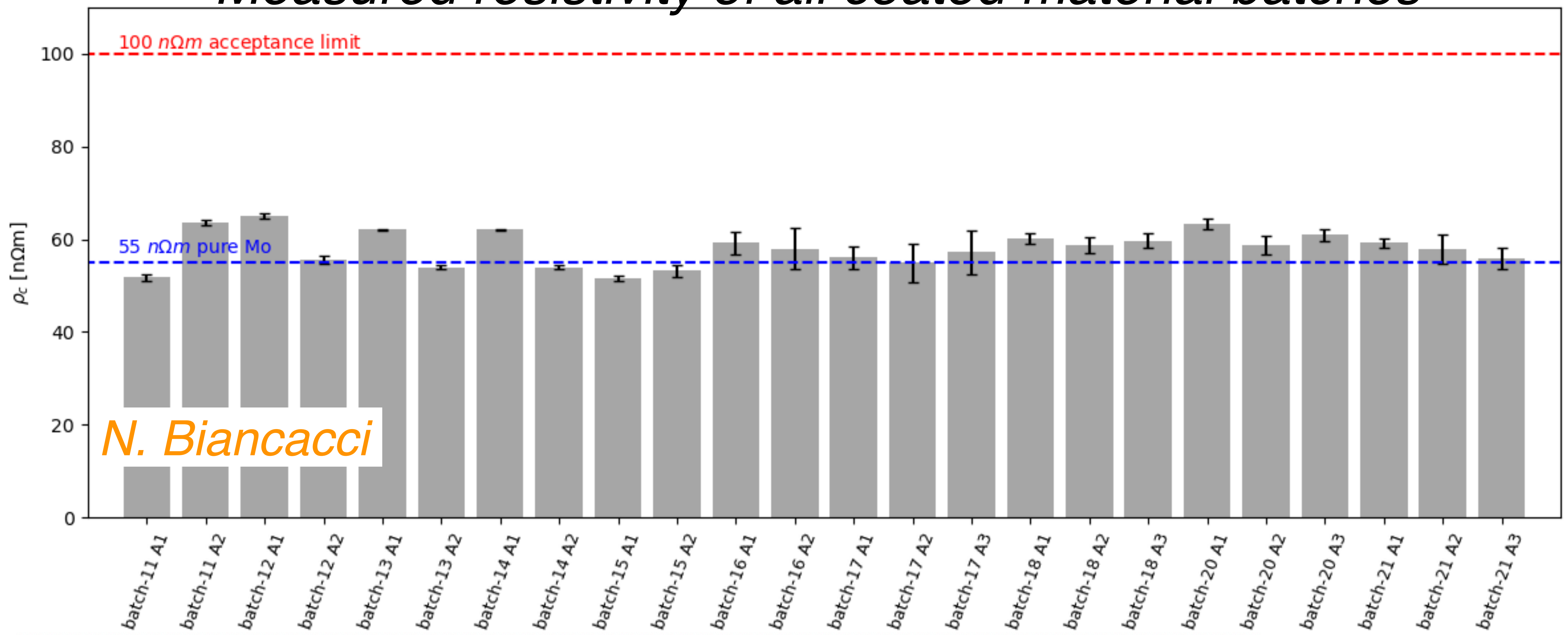


- Peak losses for 0.2h lifetime (scaled to HL-LHC parameters) produce ~15mW/cm^3 in the DS dipoles
- New TCPs improve cleaning by 15-20%
- *"More-open settings" conceived to perform quench tests in 2022, providing +50% in peak losses.*

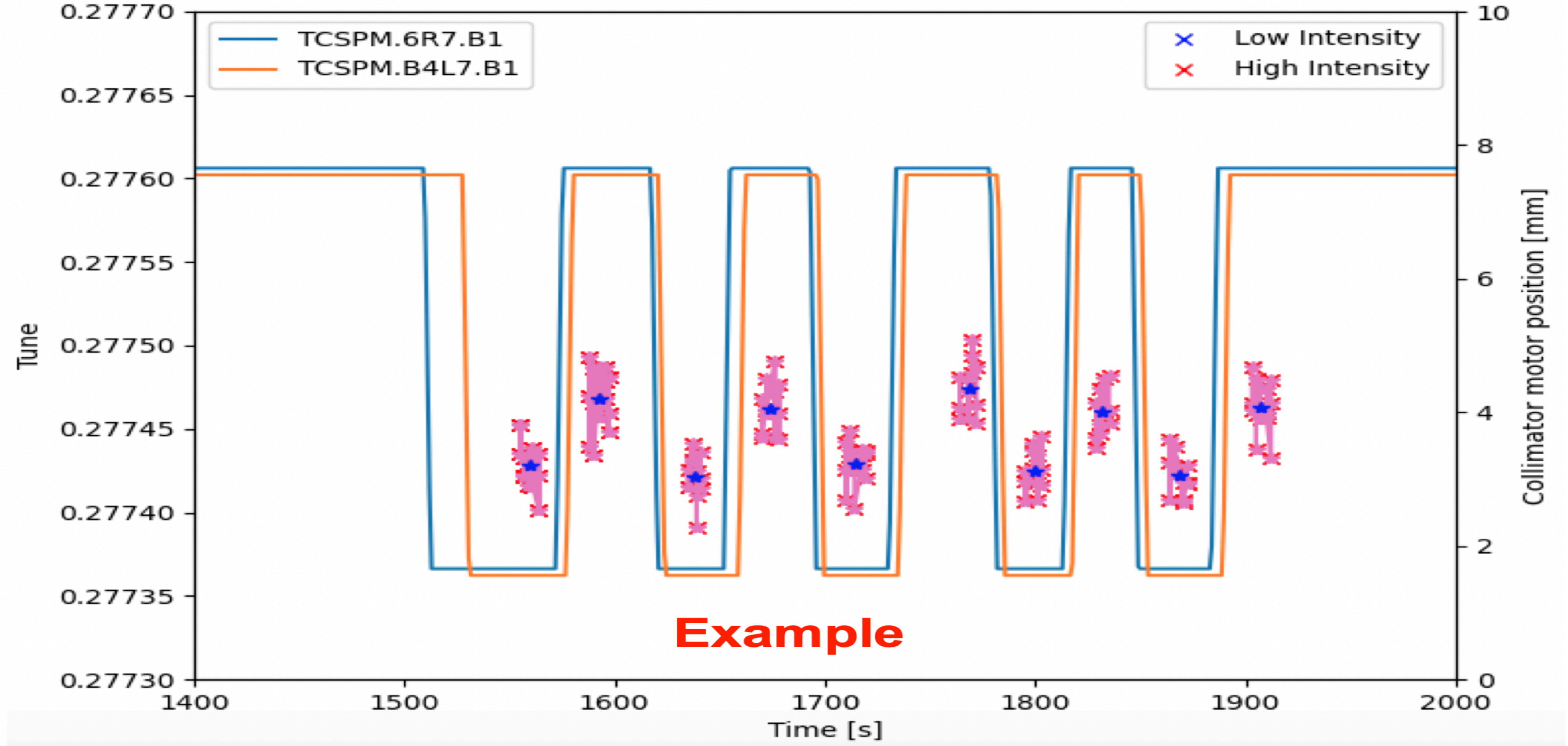
P. Hermes, V. Rodin

First look at collimator impedance

Measured resistivity of all coated material batches



N. Biancacci



A. Kurtulus

First look at collimator impedance

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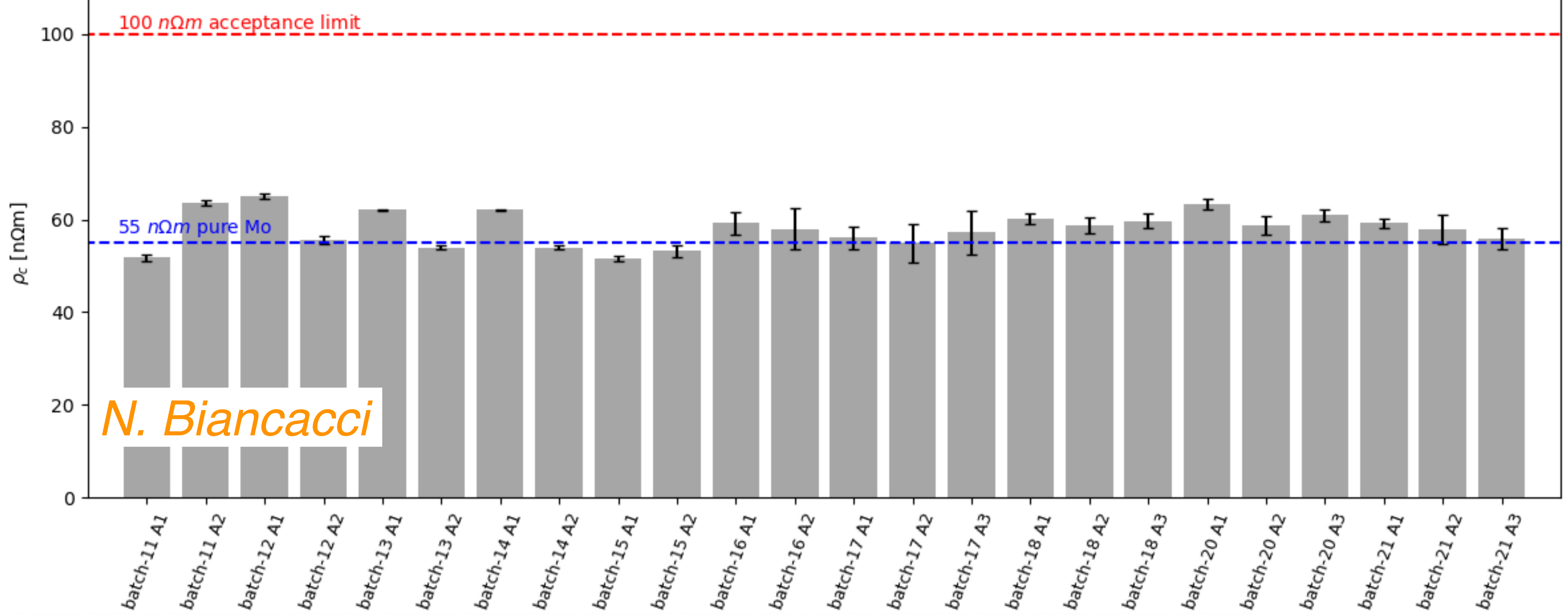

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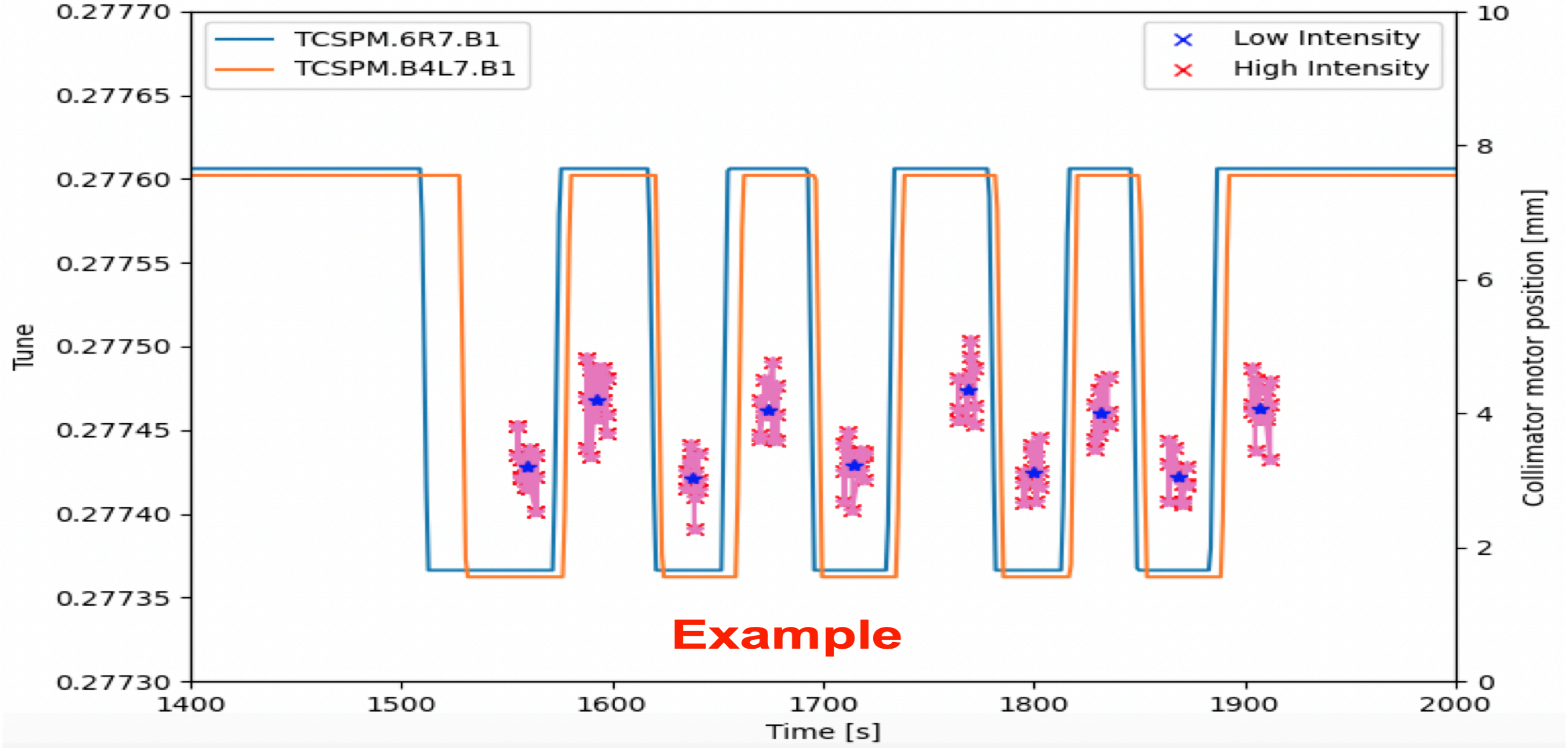
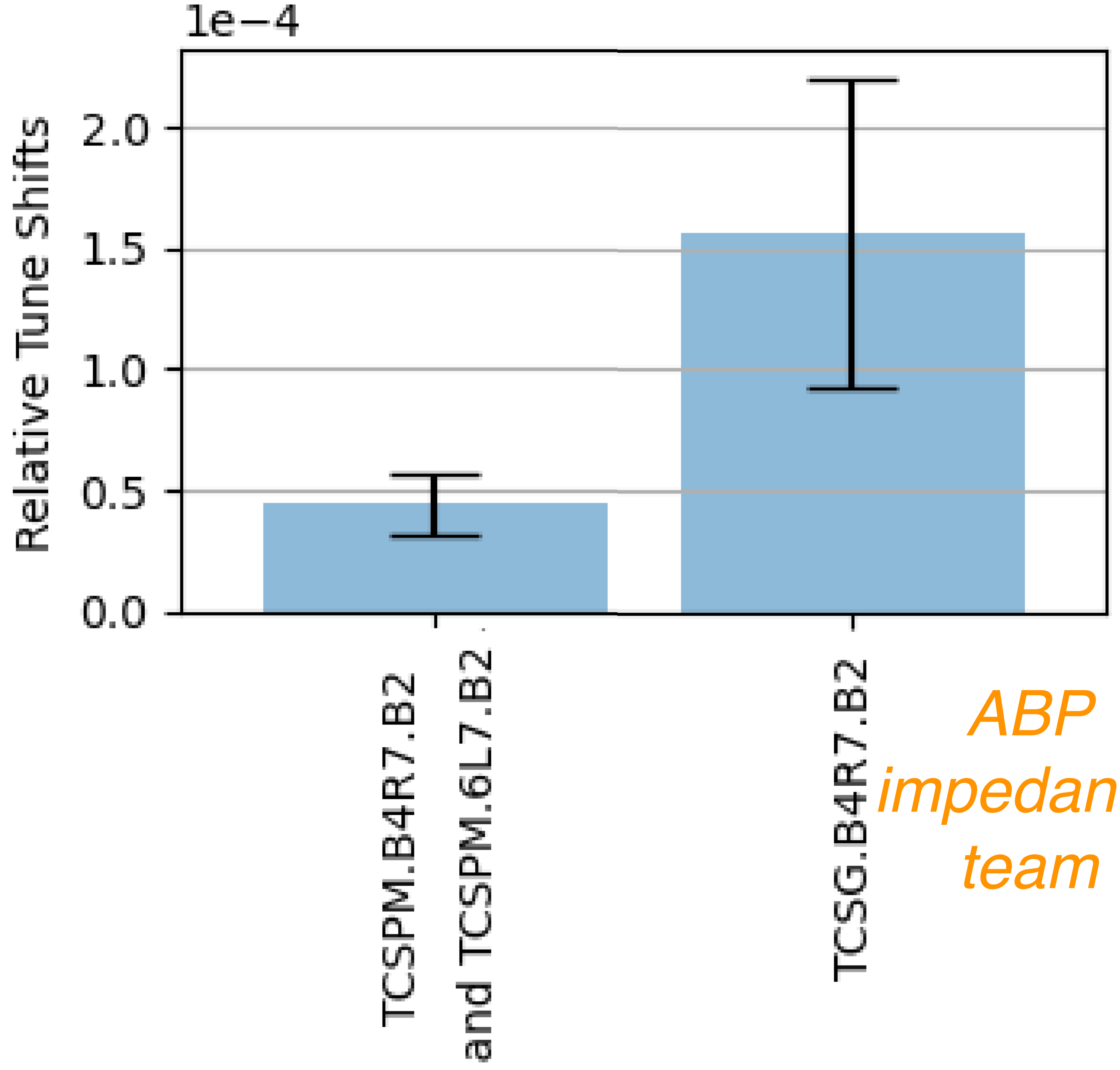


Example

A. Kurtulus

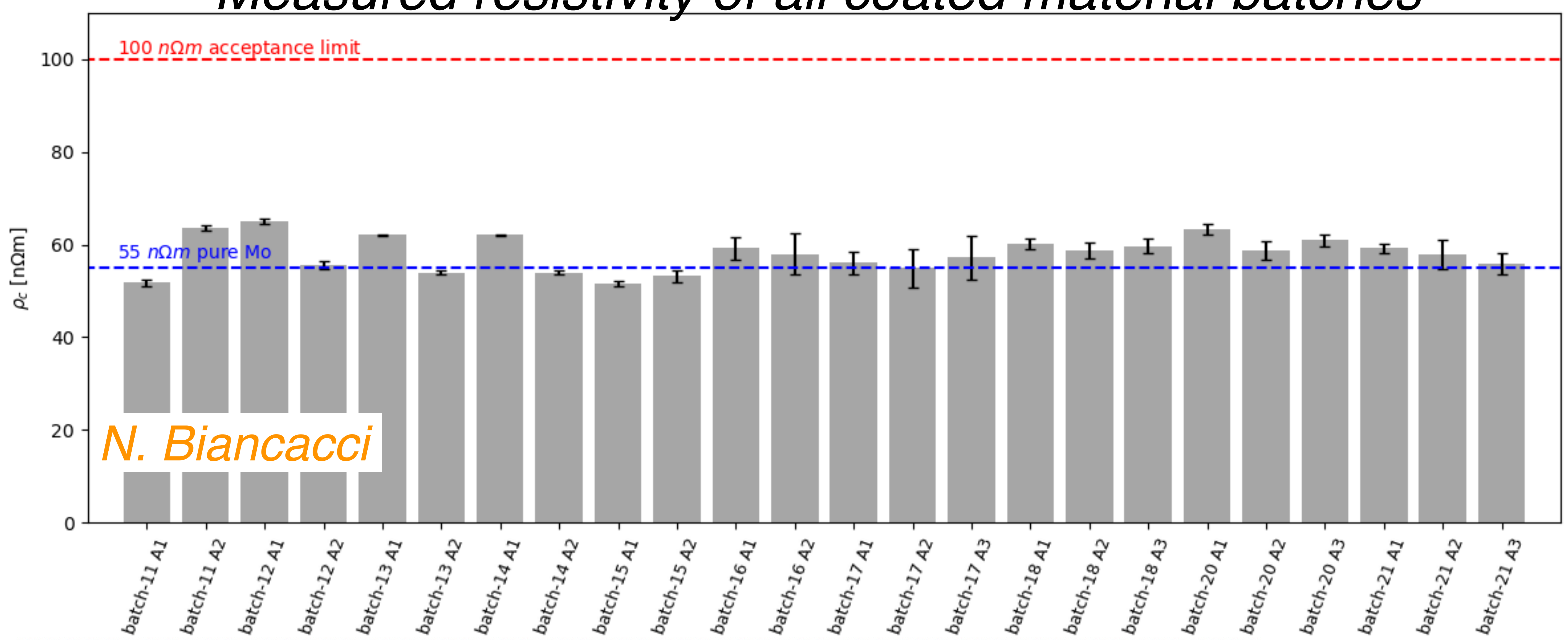
MoGr+Mo **CFC**



ABP impedance team

First look at collimator impedance

Measured resistivity of all coated material batches



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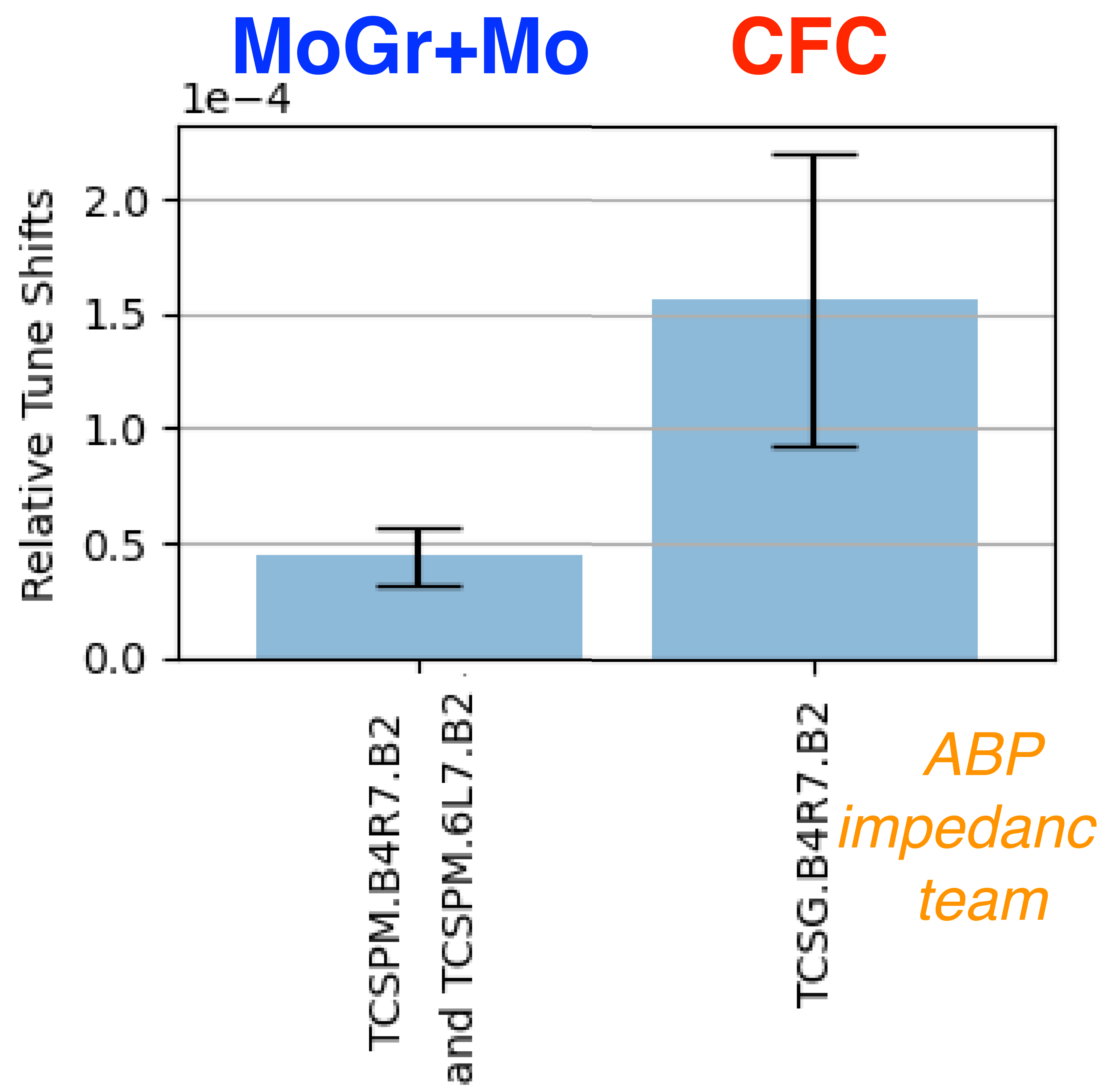
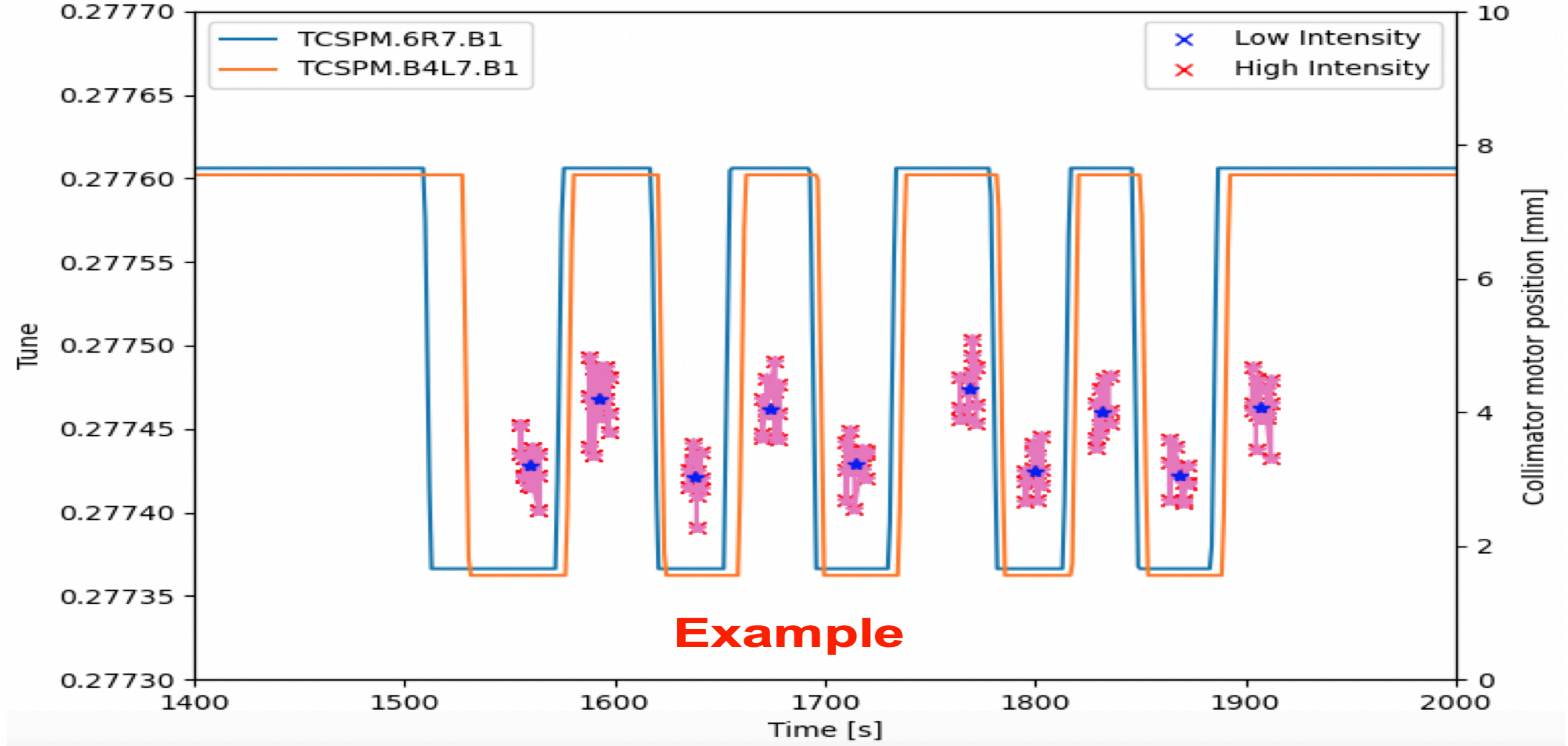


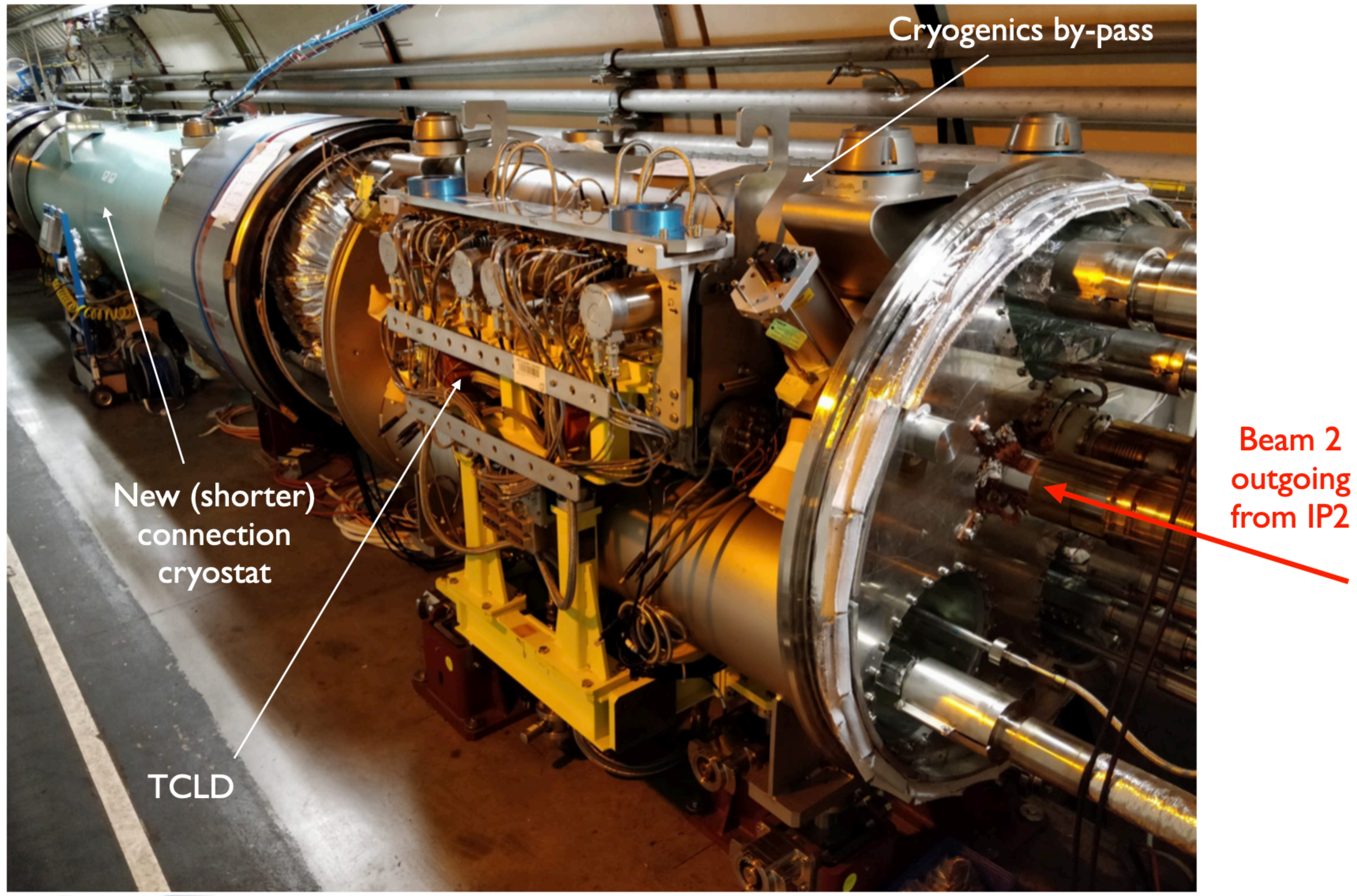
ABP impedance team



A. Kurtulus

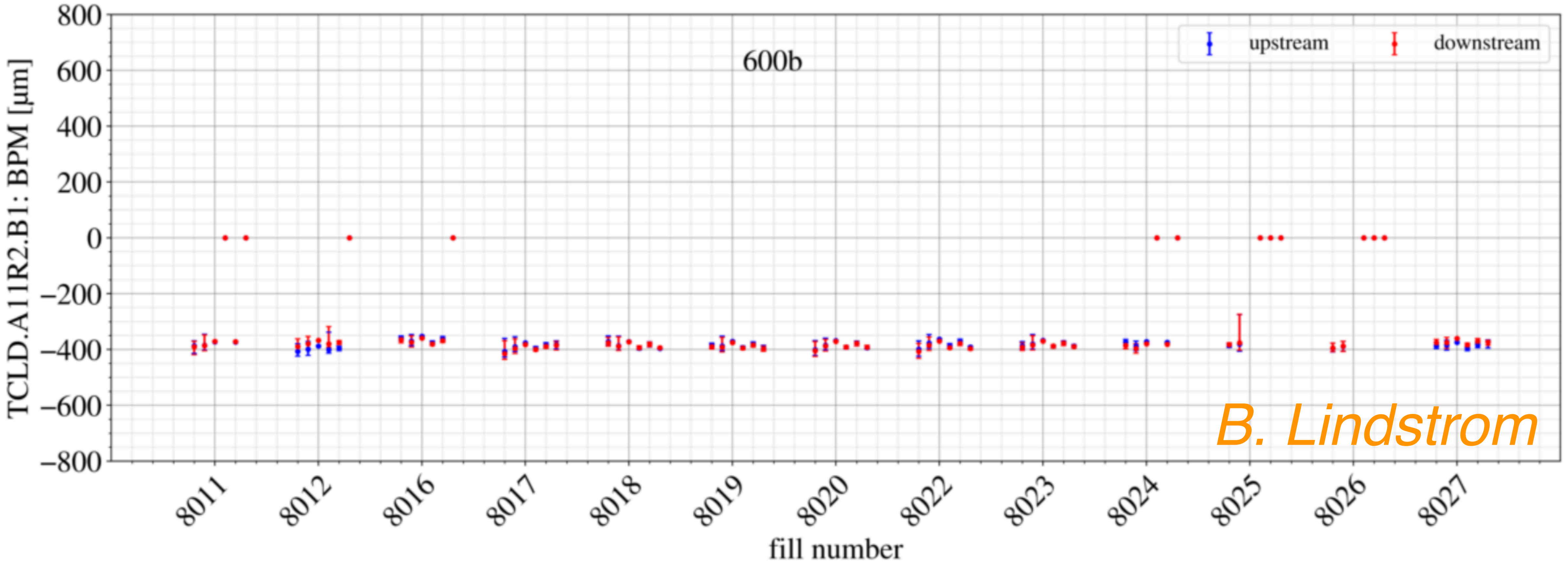
- Comparison ongoing with models to assess with beam the surface resistivity and the overall impact on stability models
- Measurements need to continue with higher bunch current.

TCLDs: waiting for Pb ion collisions



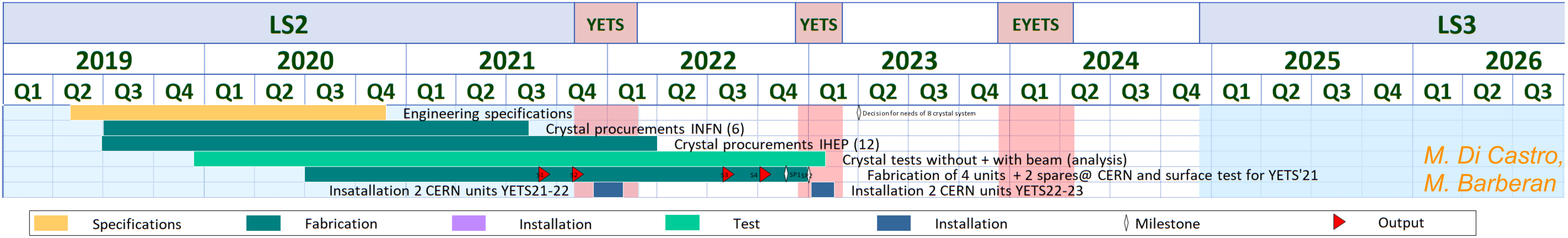
For the ALICE upgrade: TCLD at the connection cryostat will catch secondary beams from ion collisions. 1 TCLD per side.

- Part of the HW and beam commissioning
- Kept open during proton operation
  - Checked at every fill to confirm the operational state and controls and interlocks
- BPM checked — TCLDs are very well aligned



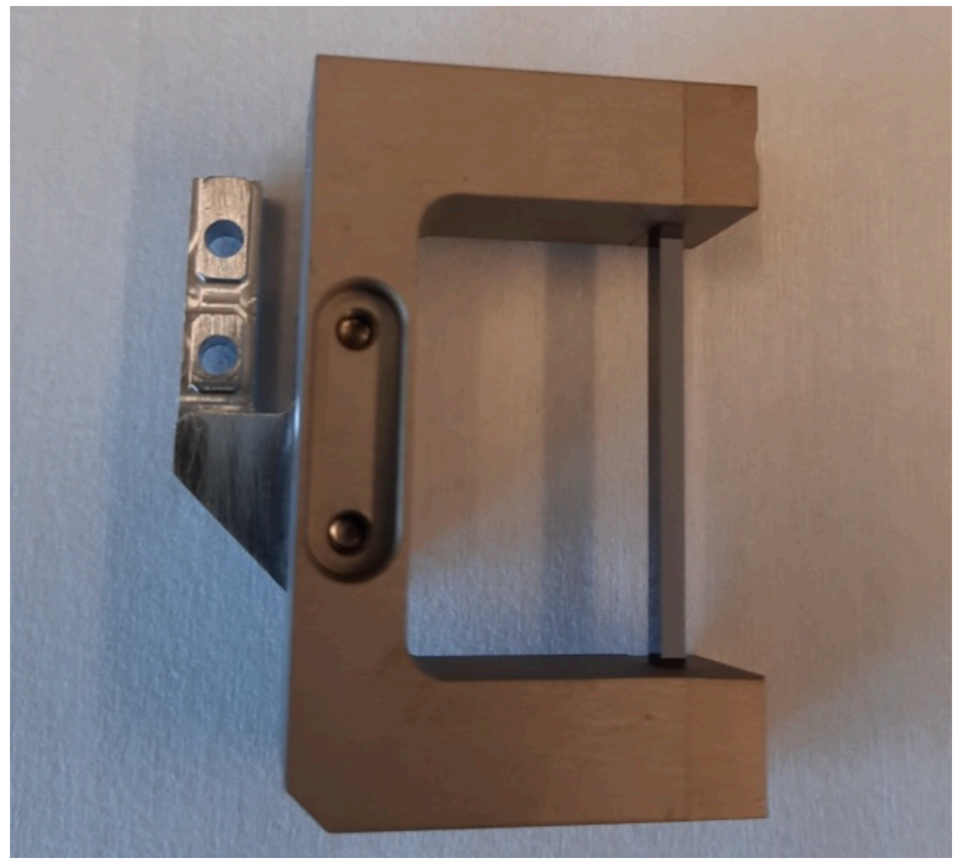
B. Lindstrom

Crystal collimation update — a crash effort



M. Di Castro, M. Barberan

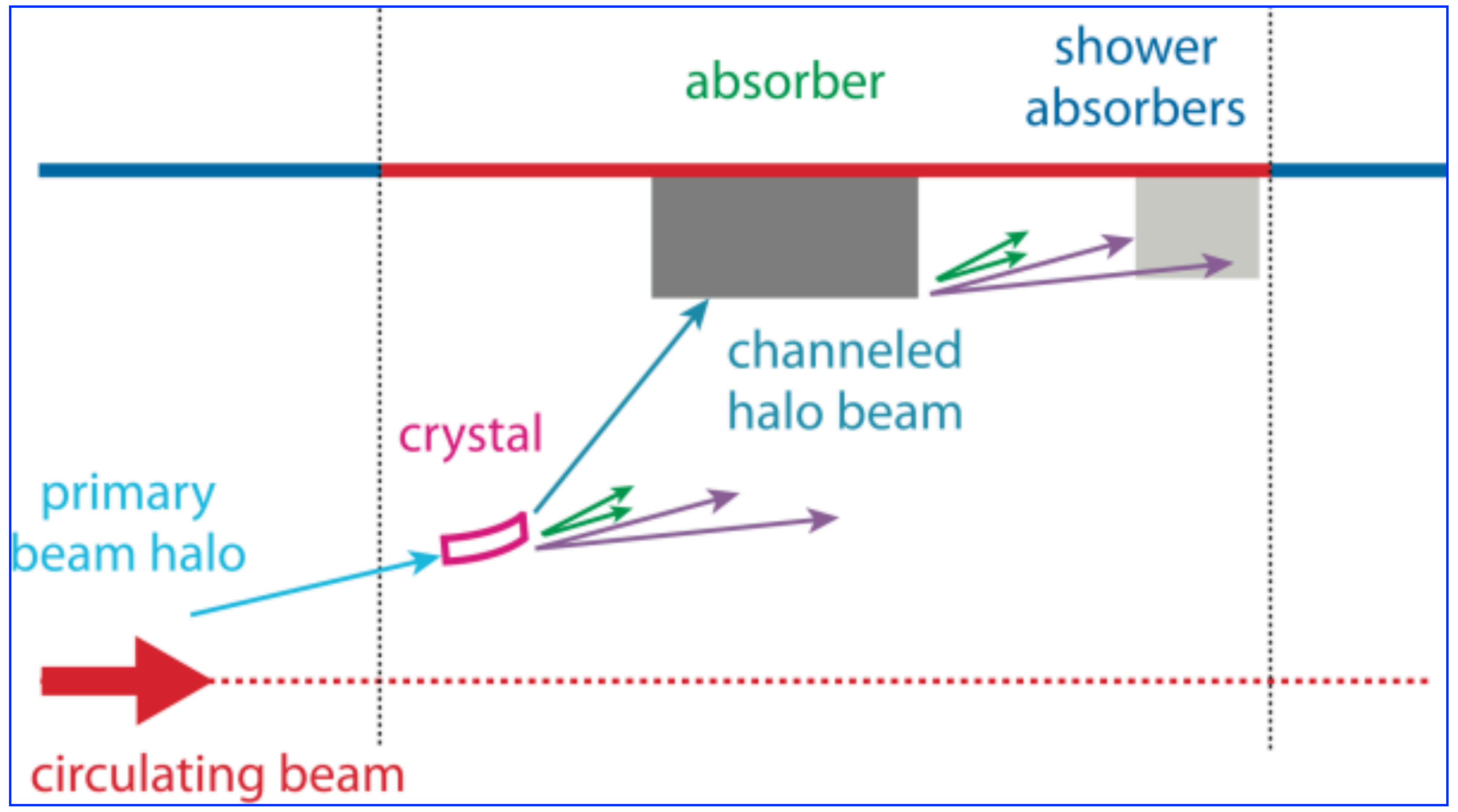
- Schedule established after Russian in-kind delays: full internalisation at CERN (6 units)
  - Two installation campaigns in YETS2022 & YETS2023
- TCPC assembly production at CERN fully on track for the remaining 4 devices
- Bent-crystal productions had some delays, but we received in 2021 enough crystals for the installation goals (INFN-Fe delivered by now all crystals; PNPI delivery on hold in 2022).

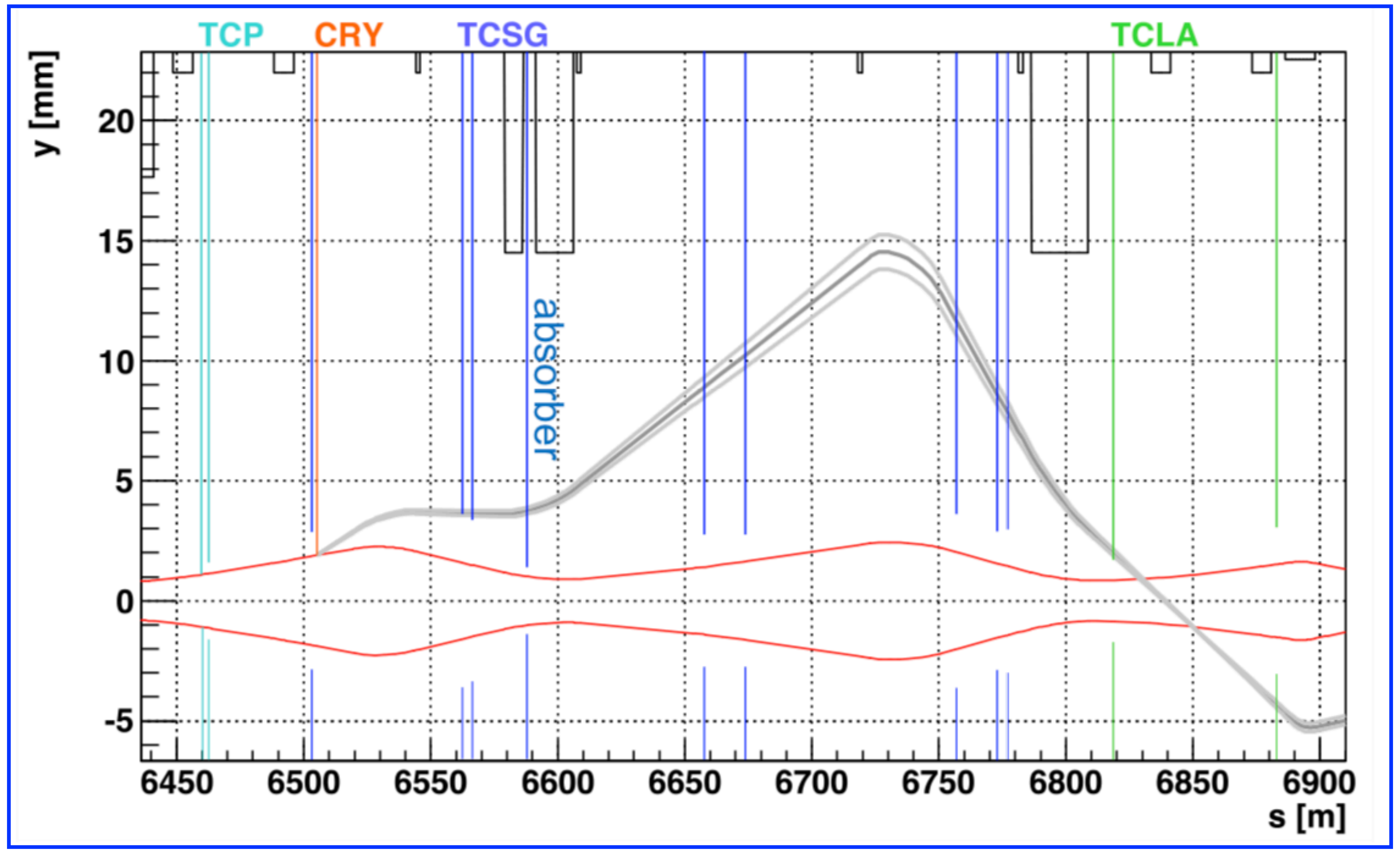


M. Di Castro

Courtesy Y. Gavrikov

Angular scans at 6.8 TeV (protons)



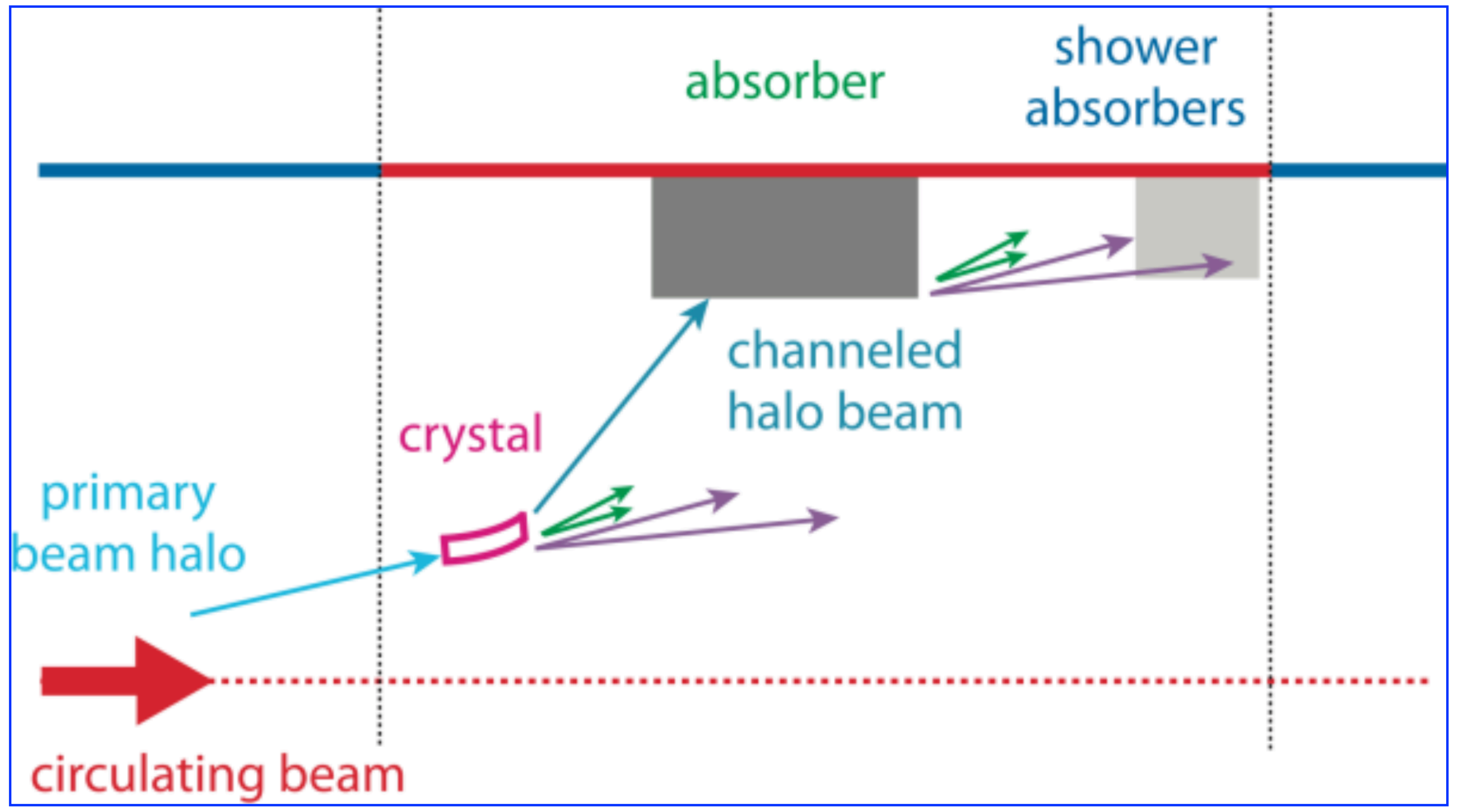


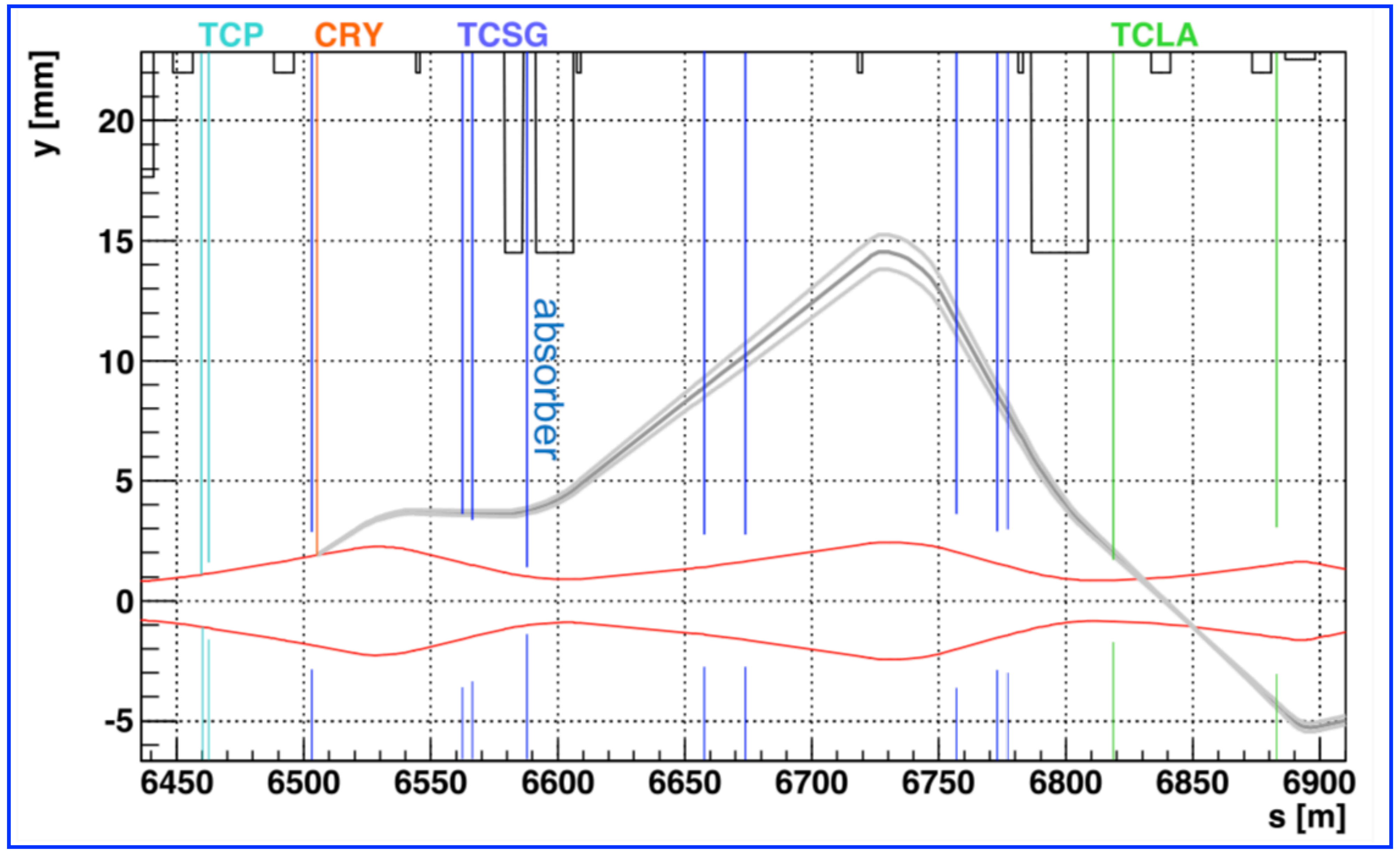
TCP = primary collimator
TCSG = secondary collimator
TCLA = shower absorber

M. D'Andrea

- All 4 crystal devices operational: good performance observed with protons
- Plan to use them already in the 2022 Pb ion run

Angular scans at 6.8 TeV (protons)





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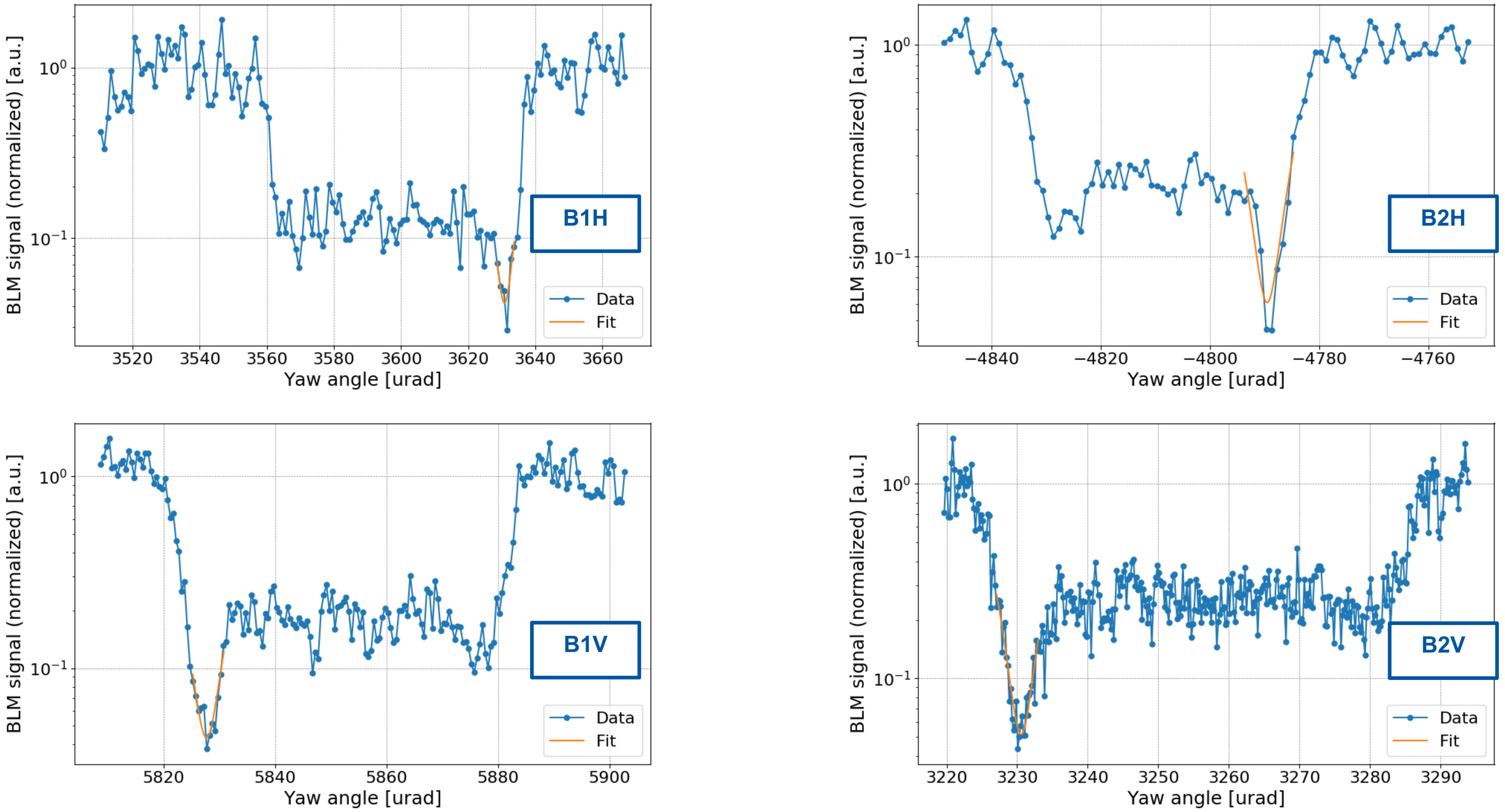


M. D'Andrea

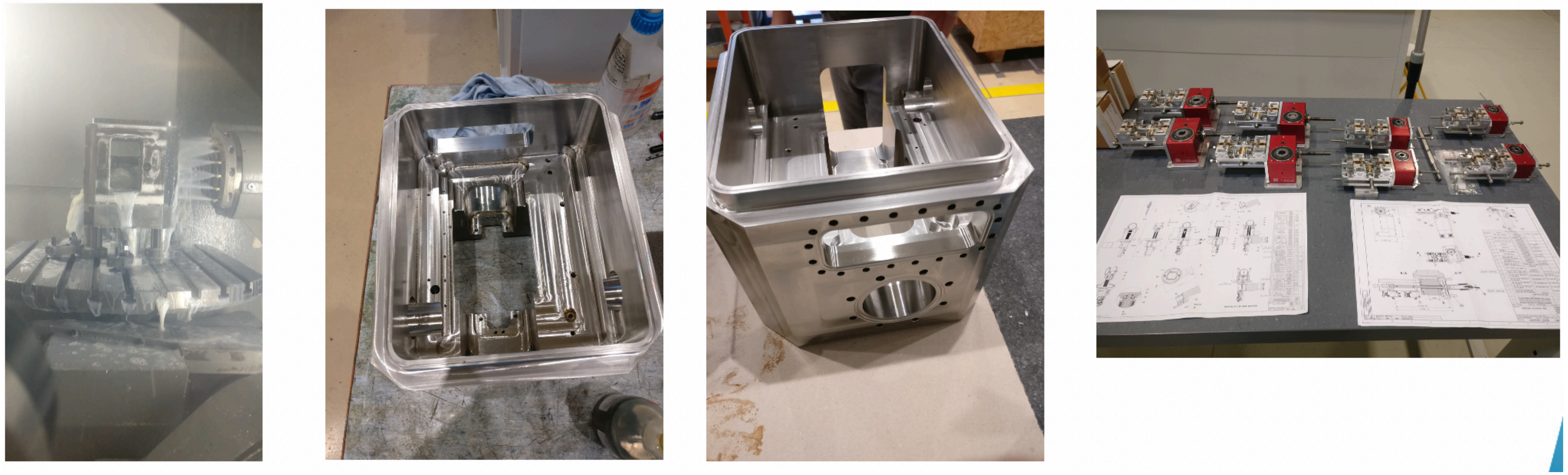
- All 4 crystal devices operational: good performance observed with protons
- Plan to use them already in the 2022 Pb ion run

Table of contents

LHC installation milestone

- Installation of 2 TCPCs planned in the YETS2022-23
  - Replace the two horizontal crystals from Run 2
- ECR in circulation, after presentation to the TCC (25/09/2022)
- Identified the best crystals in the pool of 6 available from INFN and PNPI (14/09/2022)
  - Following a complete validation of crystals, including X-rays (BE/CEM) and SPS beam (UA9 collaboration) tests — many thanks to the teams involved

TCPC tanks components under production and linear stages assembled (courtesy of SY-STI)



Next steps in Run 3

The issues with Russian in-kind and recent baseline changes affected strongly WP5:

- **11T dipoles** → LS2 installation deferred
- **Crystal collimation** of ion beams → fully internalised
- **HELs** → No more compatible with LS3, so de-scoped
- **LS3 collimator production** → fully internalised

The progressive availability in the LHC of the LIU beams gives the opportunity to re-assess the needs of deferred items and in general to understand future limitations for HL-LHC.

Various important priorities identified for WP5, both for MDs and for standard operation:

- Study the need for dispersion suppressor upgrades in IR7 for proton beams
  → **Quench tests** with beam
- Study **beam lifetime** as well as effects from beam-tail losses
- Characterise beam tail population and diffusion for different beam paramet
  configuration and collimator settings
- Assess the **collimation impedance** with the upgraded Run
- Advanced scenarios: New IR7 optics for reduced impedan leaning

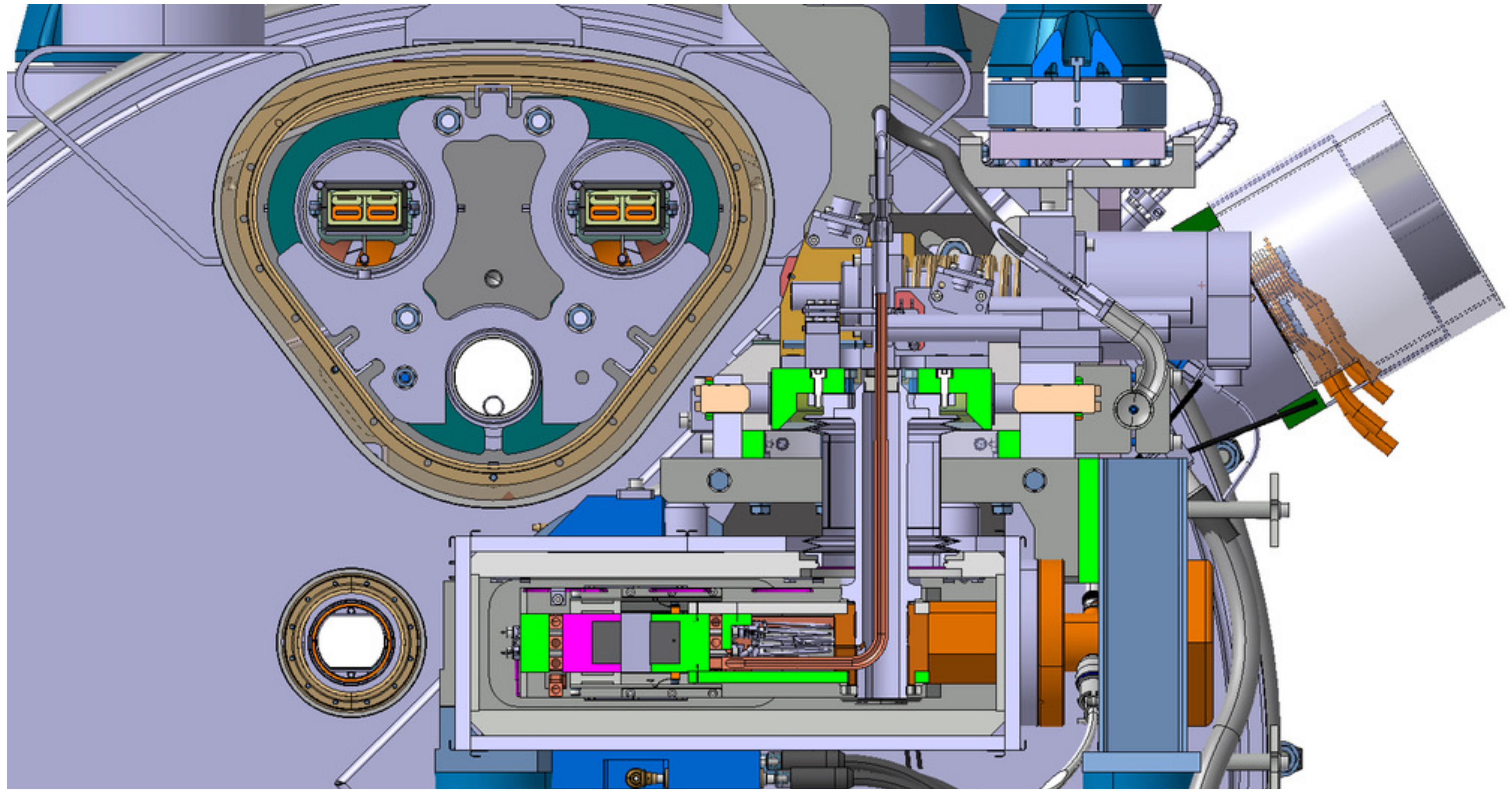
Dedicated LHC MD discussions in the parallel sessions.

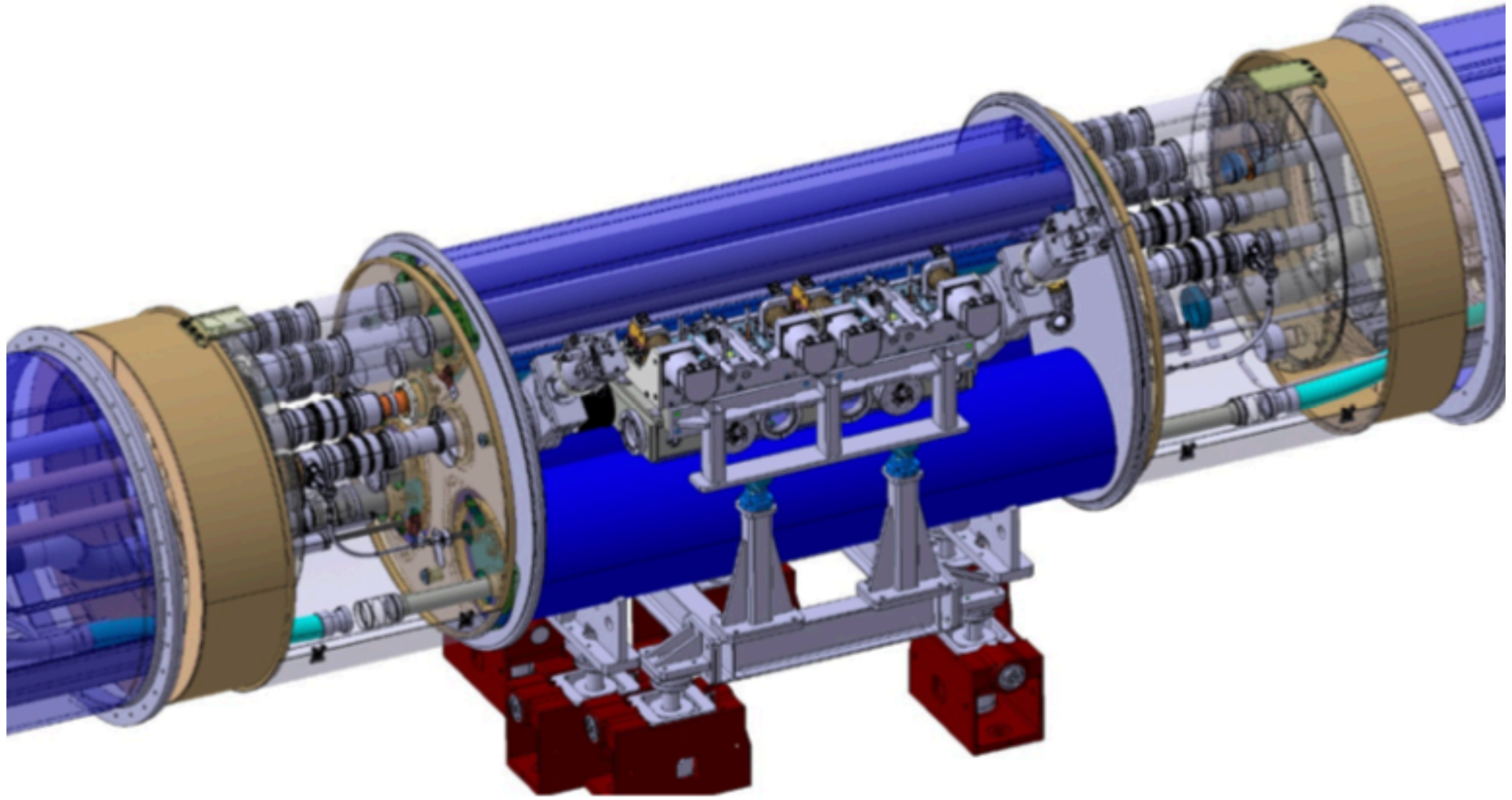
Conclusions

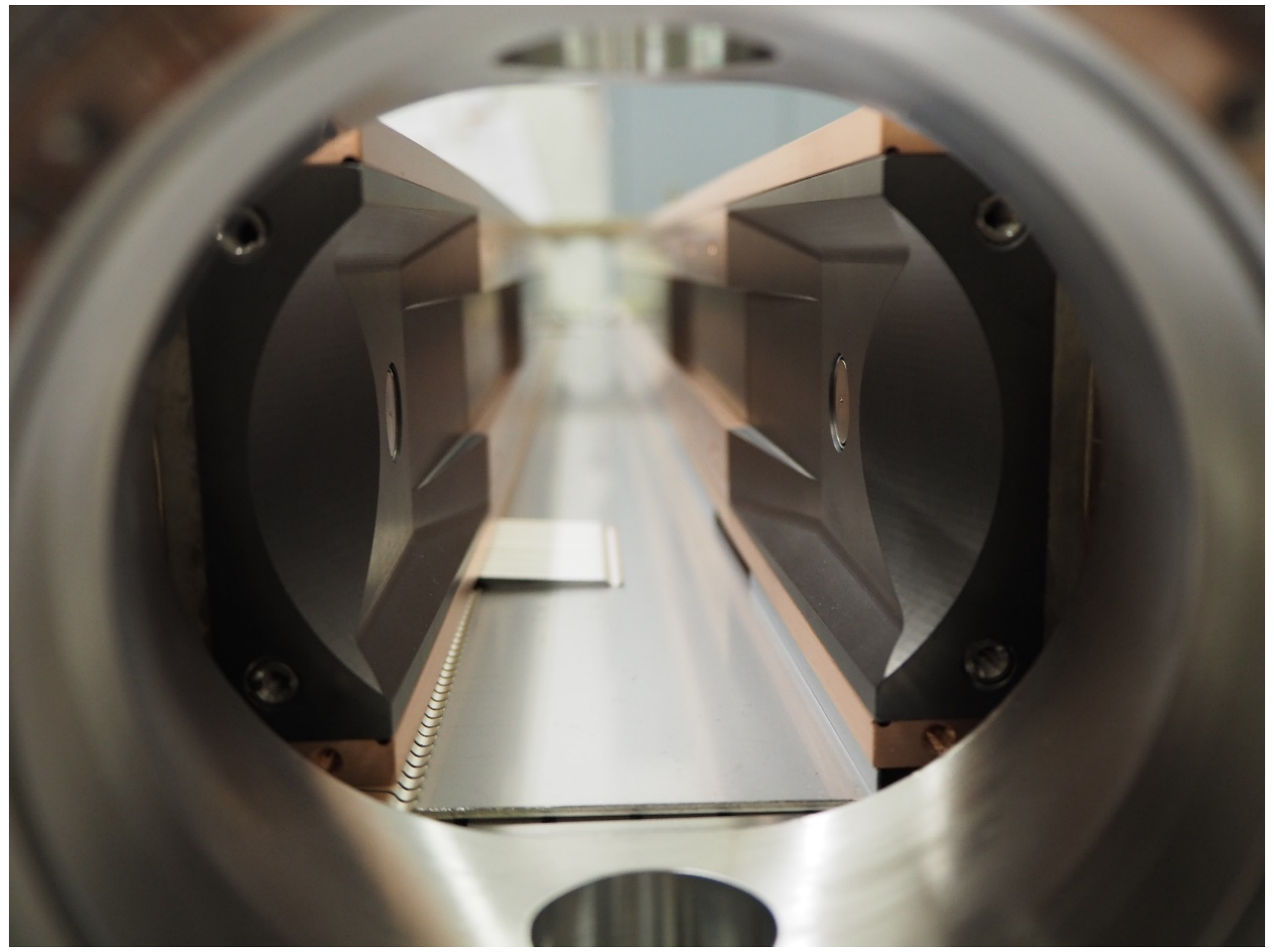
- The new collimators installed in the LHC are fully operational for Run 3
  - The LS2 & YETS2022 WP5 upgrades were completed successfully.
- The HL-LHC collimators were successfully commissioned and are now relied upon operationally at the LHC
  - Although the LHC is still far from the performance target for Run 3, important feedback already gained on operational aspects relevant for the HL-LHC. More to come!
- The new crystal collimators were tested extensively with proton beams and are planned to be used for the Pb ion run at the end of the year.
  - New and old hardware behaves as expected
  - Two more units are being prepared for installation in the YETS2023 to complete the upgrade
- Outstanding beam tests are planned to consolidate upgrade plans
  - Still hopefully in 2022: quench tests to assess needs for 11T dipoles
  - Lifetime assessment, halo measurements and new optics in IR7 to be scheduled

Reserve slides

Recap.: LS2 upgraded collimation designs







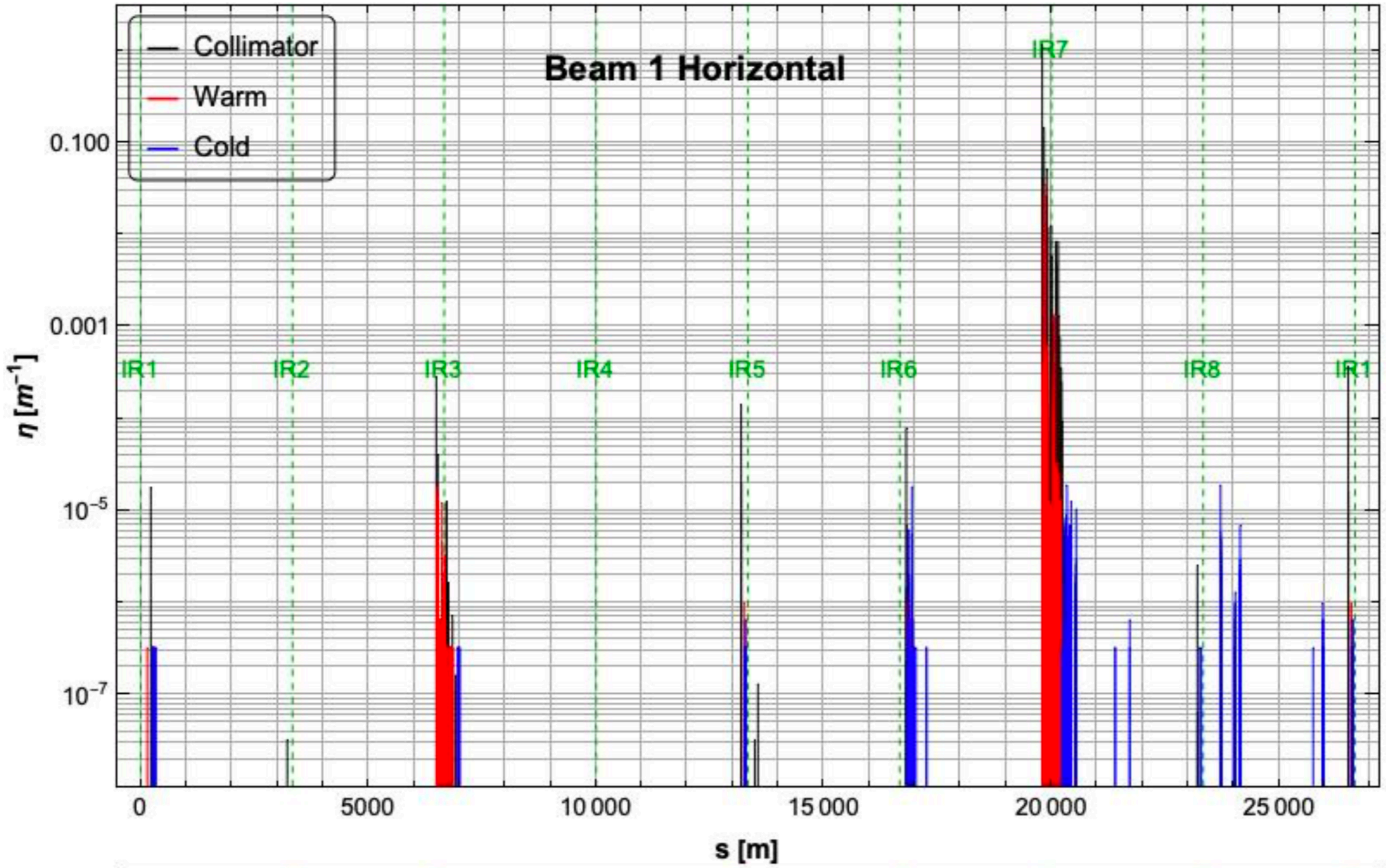
Several important technological demonstrations

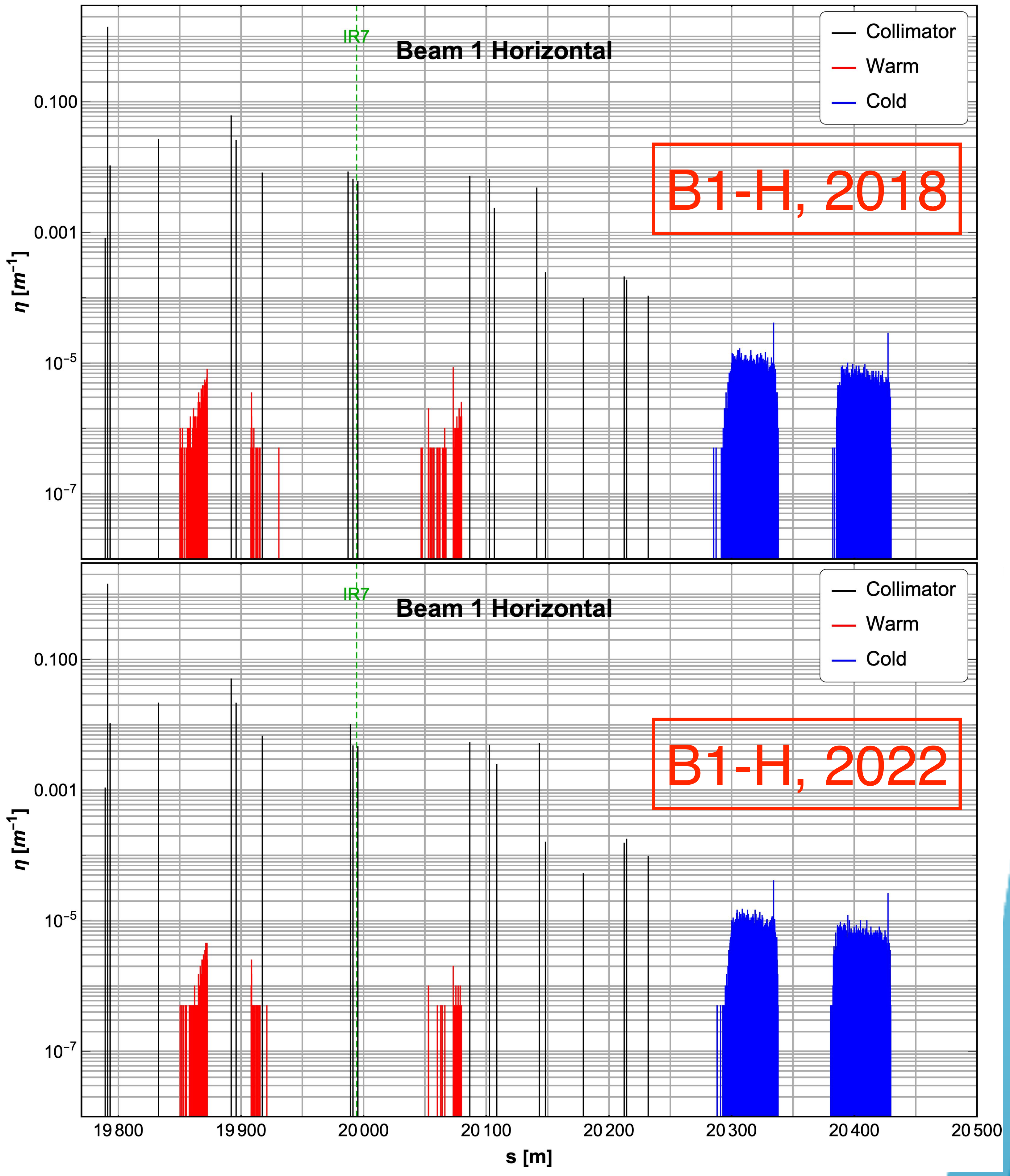
- Novel, compact design of the TCLDs in the cold region
- Industrial production of MoGr composite
- New coating technique for Mo on MoGr
  - HiPims, also applicable for Cu on Gr
- BPM integrated in all new jaws; 3rd BPM

Performance of the Run 3 system

Machine configuration 2023, β* = 30cm

collimator	$n\ [\sigma]$
TCP3	15
TCSG3	18
TCLA3	20
TCP7	5
TCSG7	6.5
TCLA7	10
TCDQ	7.3
TCSP	7.3
TCL4	17
TCL5	42
TCL6	20
TCT15	8.5
TCT2	37
TCT8	15





Courtesy: F. Van Der Veken BE/ABP

Performance of Run 3 assessed in detail in simulations

- Layouts updated with the “as-built” lattice
- Good performance with the new designs/materials
- Dispersion suppressor losses without TCLD, gain from new primary collimator material estimated at 20-25% level (A. Weats, ColUSM 137).