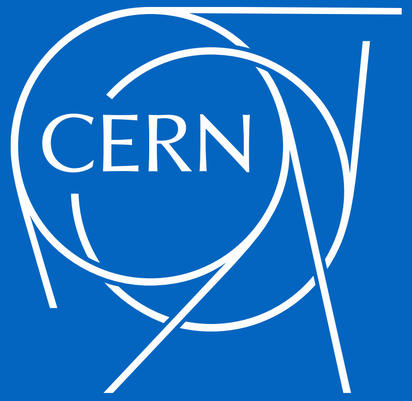
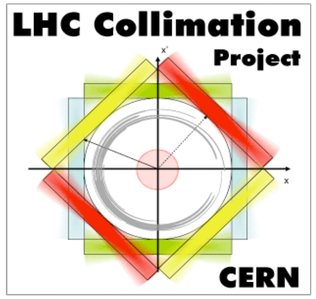


www.cern.ch



HL-LHC collimation status

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

Inputs: R. Bruce, F. Carra, M. Di Castro, A. Perillo Marcone, F.-X. Nuiry, A. Rossi

Acknowledgements: O. Brüning, Y. Papaphilippou, M. Zerlauth

13th HL-LHC Collaboration Meeting
25-28 September, 2023
Simon Fraser University, Vancouver, Canada

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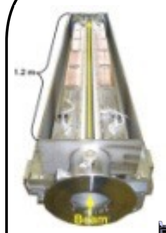
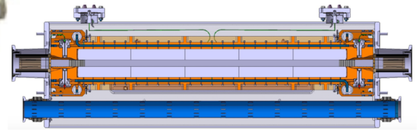
Introduction: WP5 upgrade items

LS3

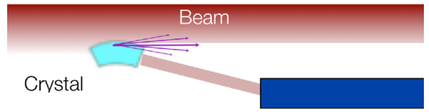


IR collimation: Completely new layouts and collimator designs: IR1+IR5: incoming and outgoing. Full remote alignment system (FRAS)



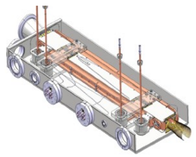
LS2+YETS

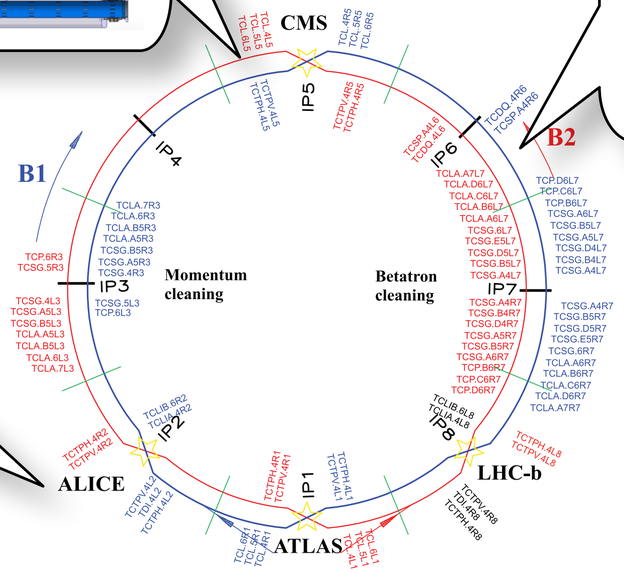
Crystal-assisted collimation (Pb ions)
4-8 bent crystals, 50 μrad bending
IP7 (betatron cleaning)



LS2

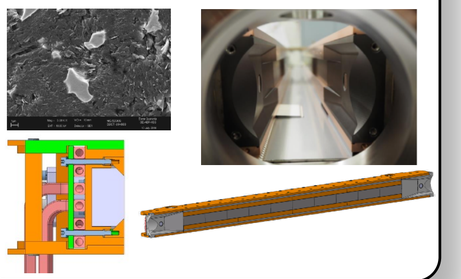
Dispersion suppressor collimation: Secondary beams from ion physics





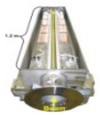
LS2+LS3

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



LS2+LS3

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



Crucial upgrades took place in LS2: LHC Run 3 operation already profiting!
See WP5@12th Annual Meeting

WP5 devices to be installed:
LS2: 14 movable collimators
LS3: 20 collim. + 12 masks (IR1/5) + 10 collimators (IR7)

Final WP5 upgrade baseline

- **No hollow electron lenses for Run 4**
  - *Driven by lack of in-kind support from Russia;*
  - *Even stronger effort on halo studies to understand limitations;*
  - *Continue supporting the R&D program to prepare a later deployment, if needed.*
- **No TCLD collimators around IR7, following the de-scoping of 11T dipoles**
  - *ECR under approval for 11T dipoles;*
  - *Supported by the quench tests in 2022 indicating that the performance with protons is ok;*
  - *Crystal collimation for Pb ion beams; new IR7 optics if further mitigation were needed.*
- **New baseline material for the low-impedance secondary collimator (TCSPM)**
  - *Very successful deployment of Mo-coated MoGr in LS2, but expensive.*
  - *For the second-phase upgrade, we now plan to use Cu-coated isostatic graphite*
    Showed better behaviour for very extreme injection failure scenarios → see backup
- **Tertiary collimators in Inermet180, like the previous generation collimators**
  - *CuCD: 15-20x more robust, but enough margin in present baseline; production challenging;*
  - *Needed for pushing non-baseline optics (162nd TCC). Gain of <5% considered not justified.*

Recent WP5 milestones and updates

- **Completed the installation of crystal primary collimators (TCPCs)**
  - *Last two of 4 units installed in IR7 during the YETS2022-23*
  - *Hiccup with a TCPC that had to be replaced*
  - *Full system deployed for operations and being commissioned with Pb ions*
- **Closed vacuum vessels of two "X" collimator prototypes: new two-in-one tertiary (TCTPXH) and physics-debris (TCPLX) collimators**
  - *Last validation tests ongoing, mounted in the collimation X-string*
- **Huge effort in preparing the procurement for LS3 collimator production**
  - *See talk by Hector. François-Xavier around — feel free to ask him details if interested!*
- **New beam dynamics studies for the final WP5 baseline**
  - *Report to IPAC2023 on the effect from new materials.*
- **Support LHC operations through the setup of the new HL-LHC collimators**
  - *Crystal collimation, quench tests, studies for halos and new IR7*
- **Excellent progress on the electron beam test stand for HEL hardware**
  - *Beam gas curtain tests, assessment of hollow gun performance*

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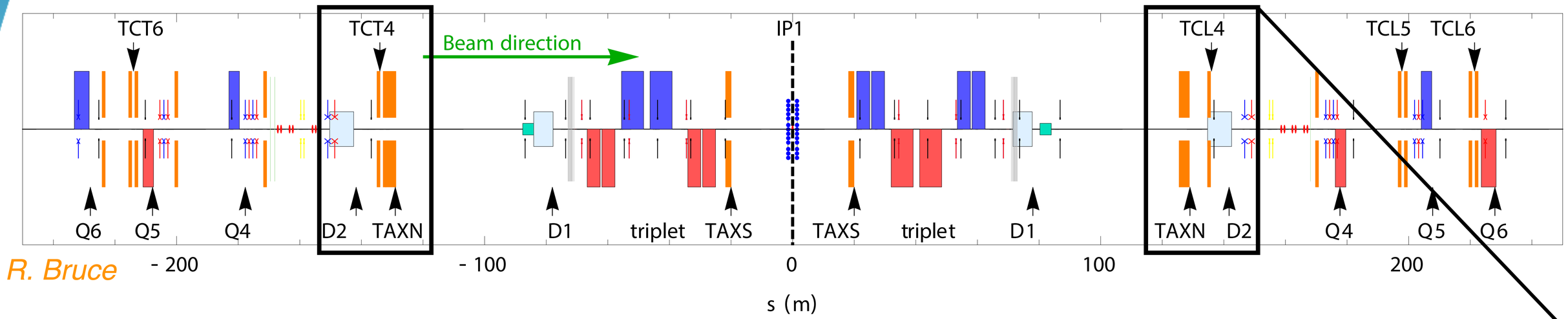
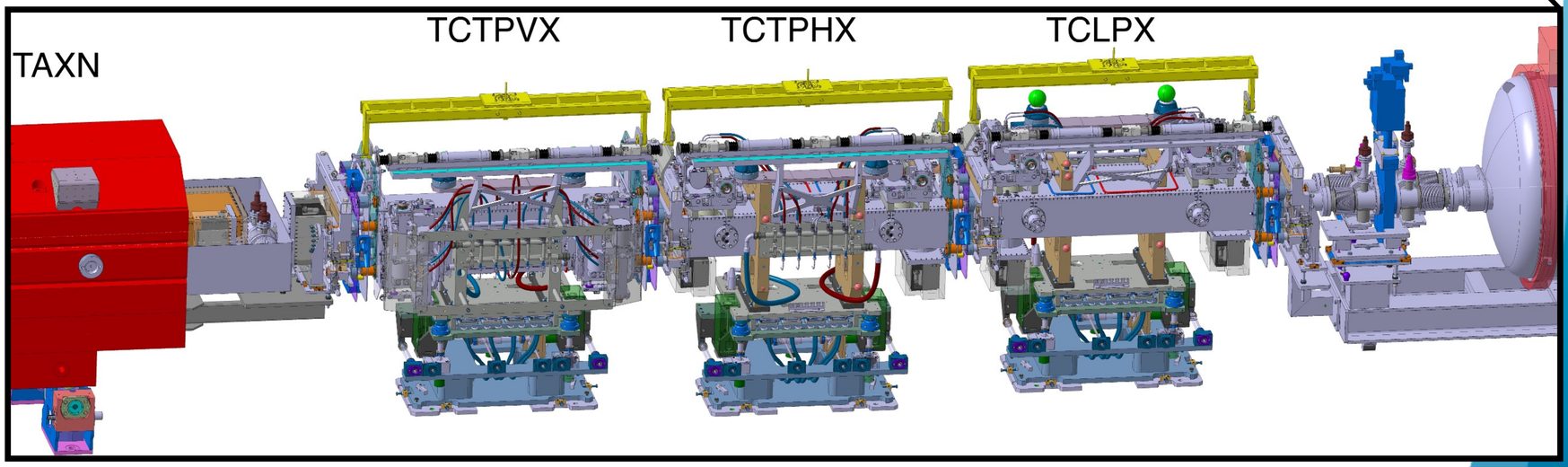
IR collimation systems for LS3

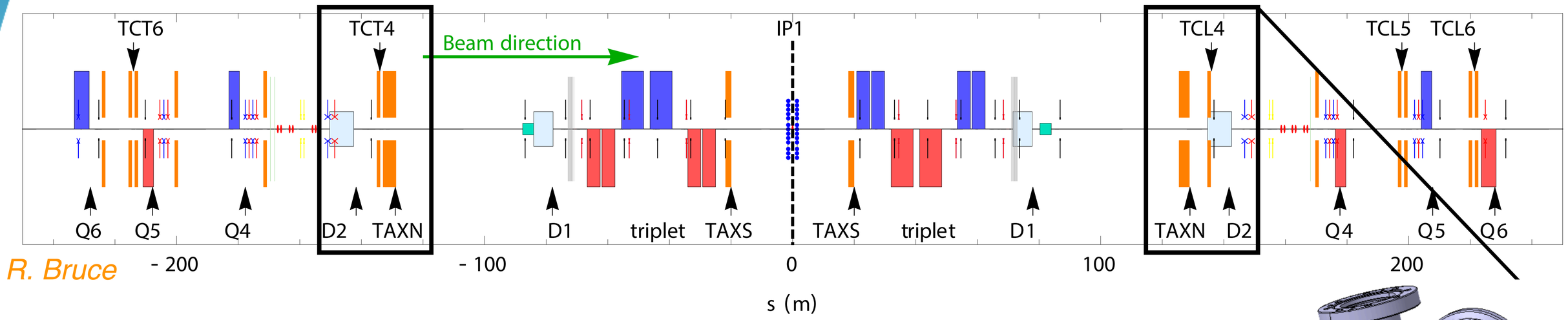


R. Bruce

- **Tertiary collimators** to protect against incoming beam losses + **physics debris collimators**
- **Two-in-one design** for H collimators to fit the tight space at the re-combination region between TAXN and D2.
- Other collimators in cell 5 and cell 6 use the more-conventional single-beam design



IR collimation systems for LS3



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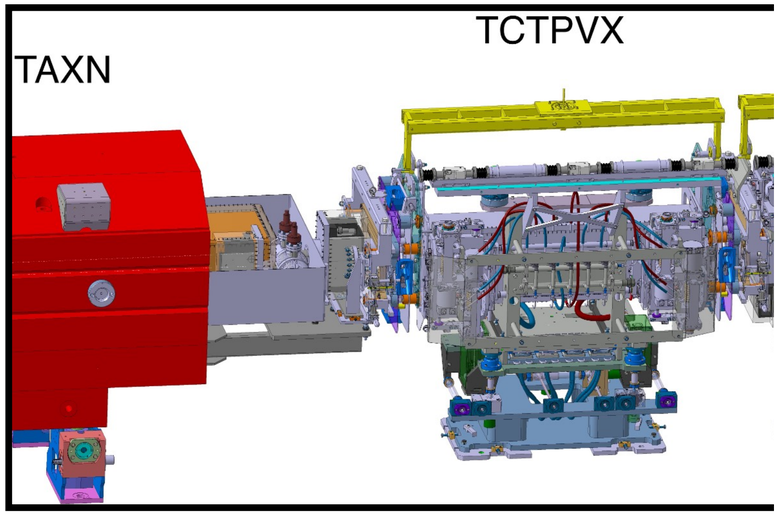
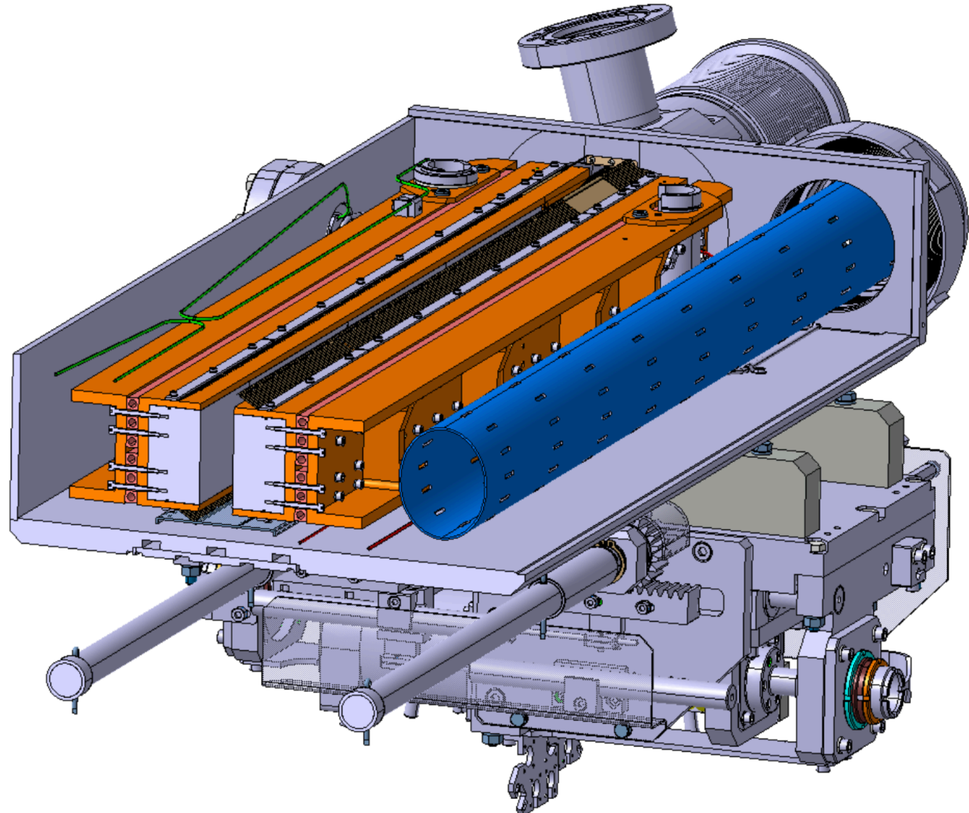
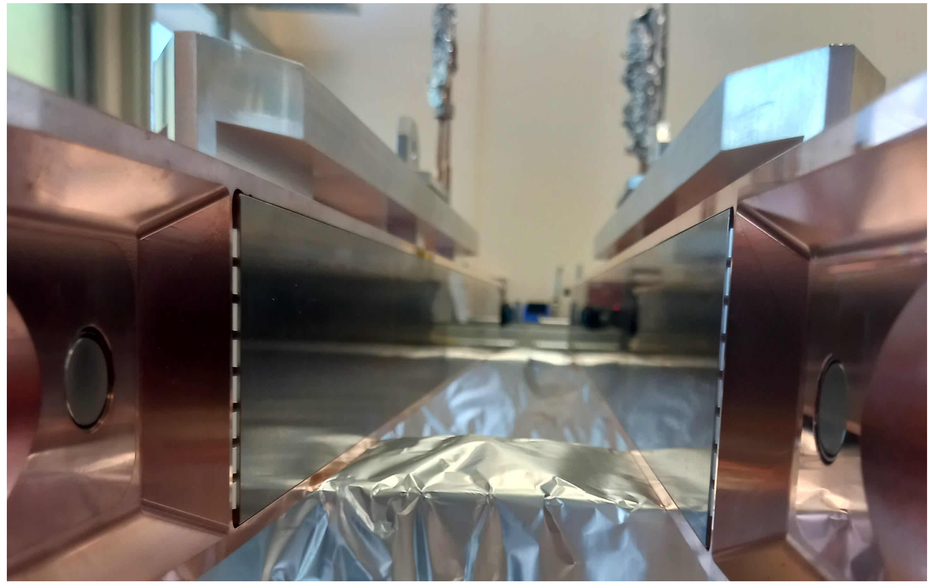




Update on “X” collimator prototypes: the jaws — i

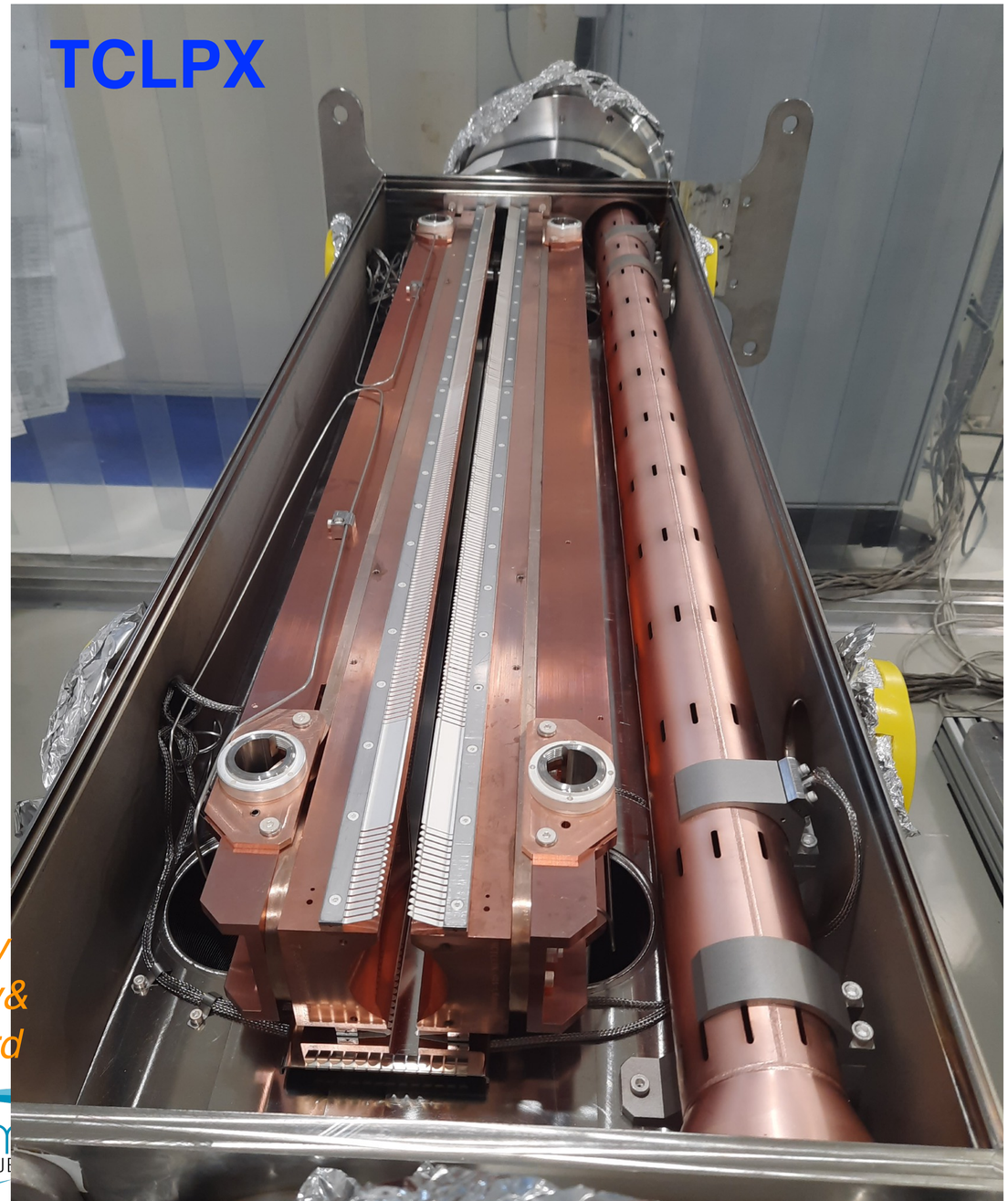
TCLPX jaw (thicker)

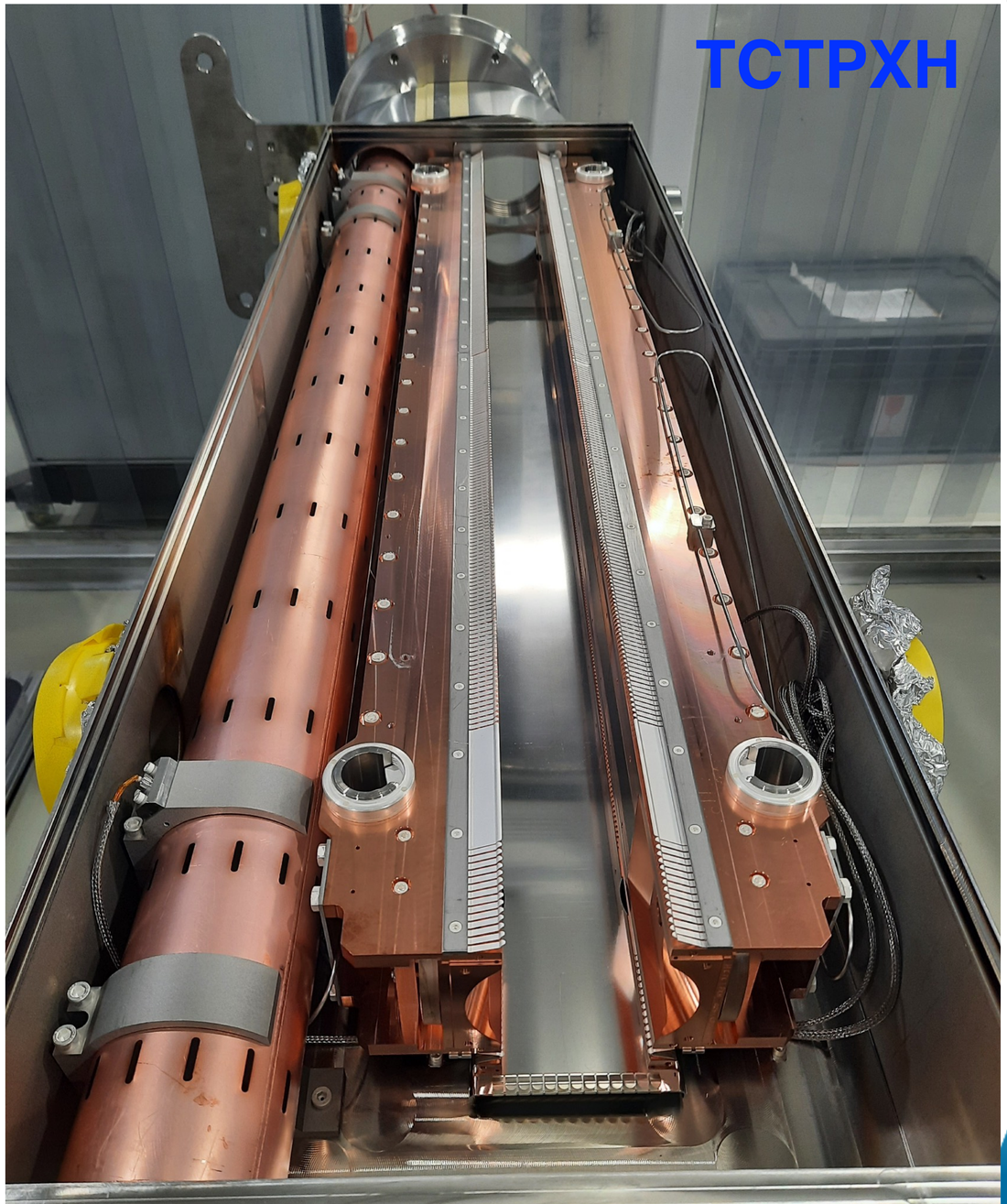


- Jaw prototypes are fully compliant (straightness and UHV cleanliness confirmed);
- TCLPX and TCTPXH prototypes assembled and vessel is leak tight;
- Final UHV test (RGA + total outgassing, including bake-out) ongoing;
- New supports with integrated UAP assembled, tested and technically compliant.

Courtesy F.X. Nuiry & D. Baillard

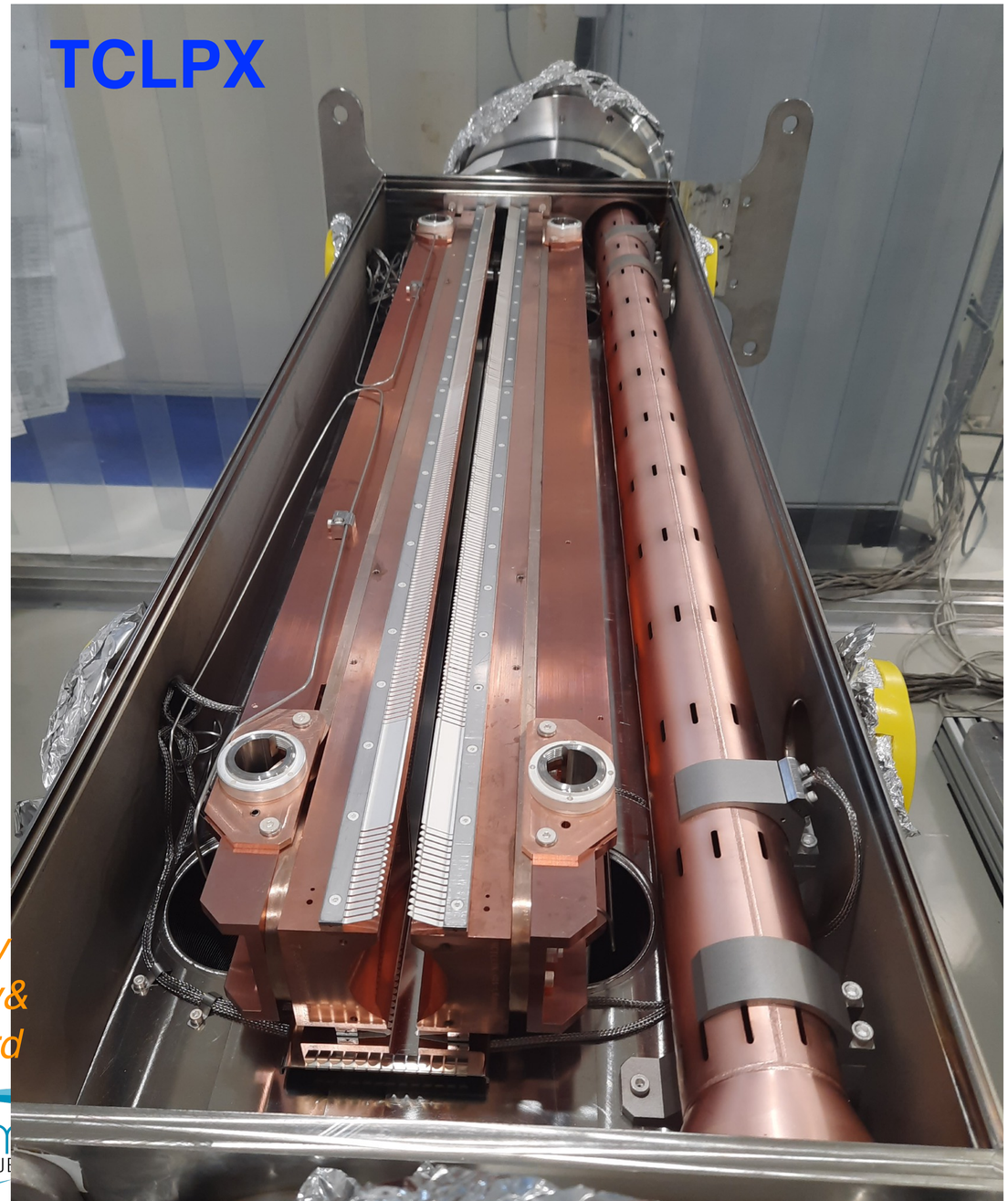
“X” collimator prototypes, open tanks — ii



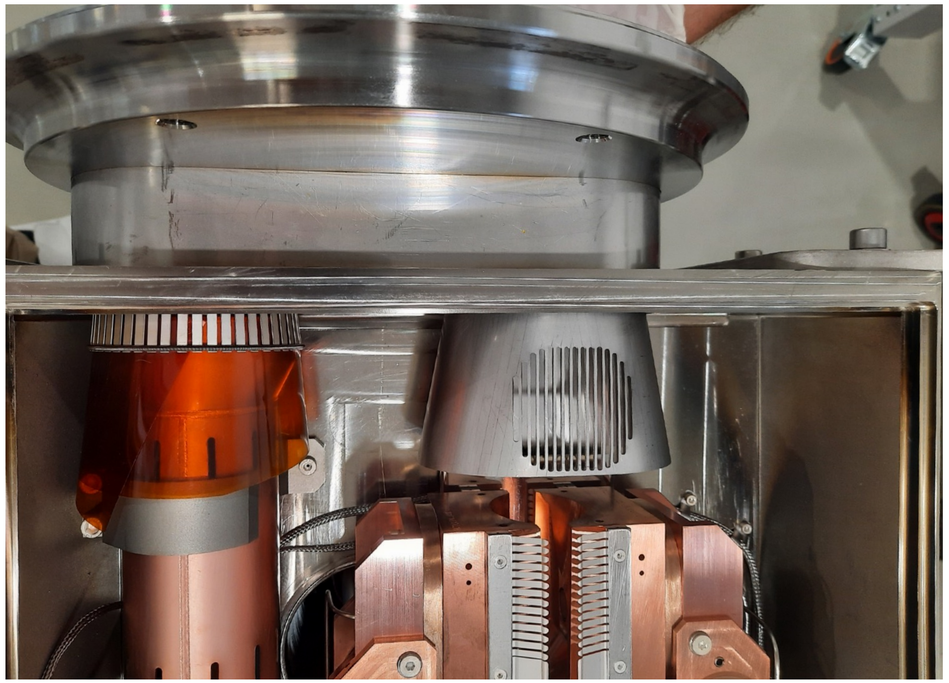


Courtesy F.X. Nuiry& D. Baillard

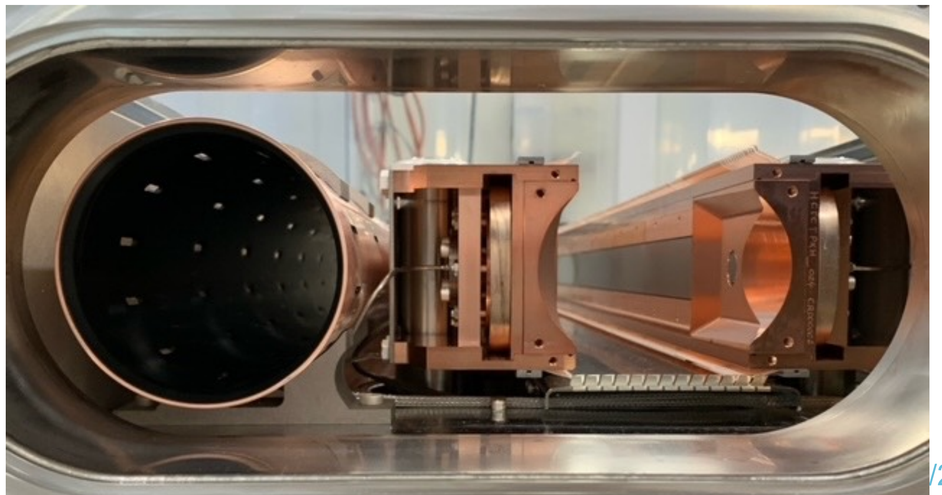
“X” collimator prototypes, open tanks — ii



TCLPX extremity, top view



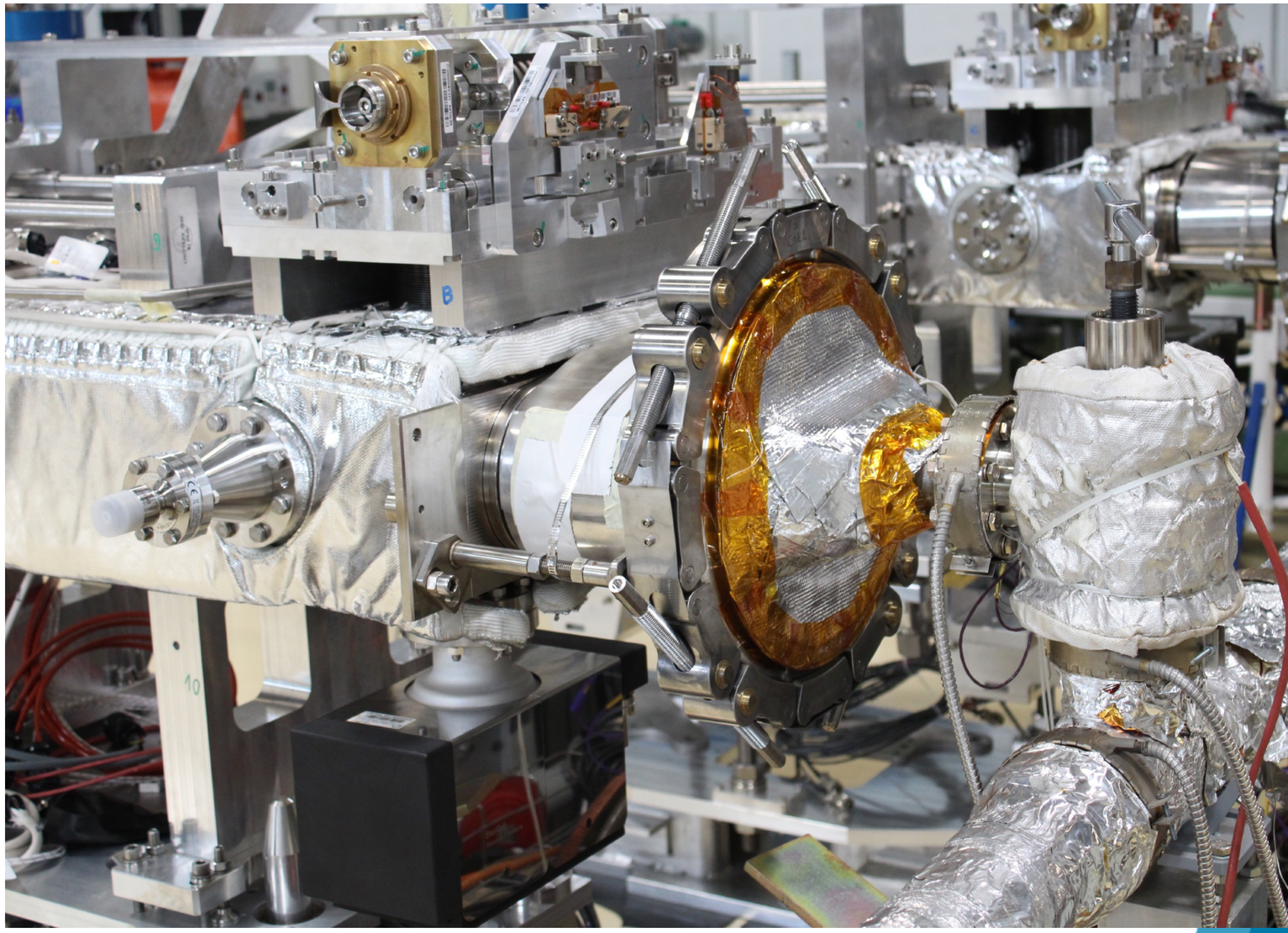
Front views of a TCTPXH



Courtesy F.X. Nuiry& D. Baillard

Closed vessels & “X-collimation string” — iii

Installation of collimator on marble for flange flatness measurements.



Collimators connected to the UHV test bench: preparation for bake out at 250˚C.

Courtesy F.X. Nuiry& D. Baillard

Closed vessels & “X-collimation string” — iii

Installation of collima
flatness measureme

HL-LHC collimators’ prototypes installation on the surface mock-up stand

05 September, 2023

https://hilumilhc.web.cern.ch/article/hl-lhc-collimators-prototypes-installation-surface-mock-stand

Collimator's prototypes together on the mock-up stand mock-up stand in building 927 (Image: Regis Seidenbinder)

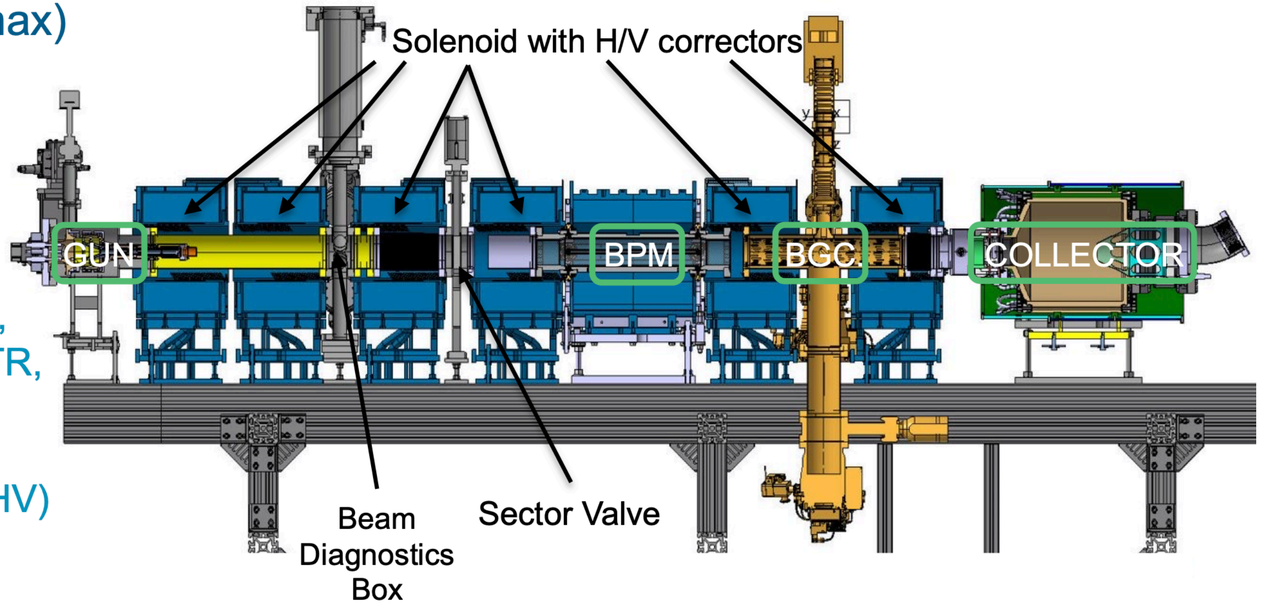
The WP5.2 achieved a new important milestone last August, with the closing of the two HL-LHC collimators’ prototypes vessels and their installation on the surface mock-up stand in building 927. This achievement has been possible thanks to the commitment of all WP5.2 team members, gathering CERN collaborators

Collimators connected to the UHV test bench: preparation for bake out at 250˚C.

Courtesy F.X. Nuiry& D. Baillard

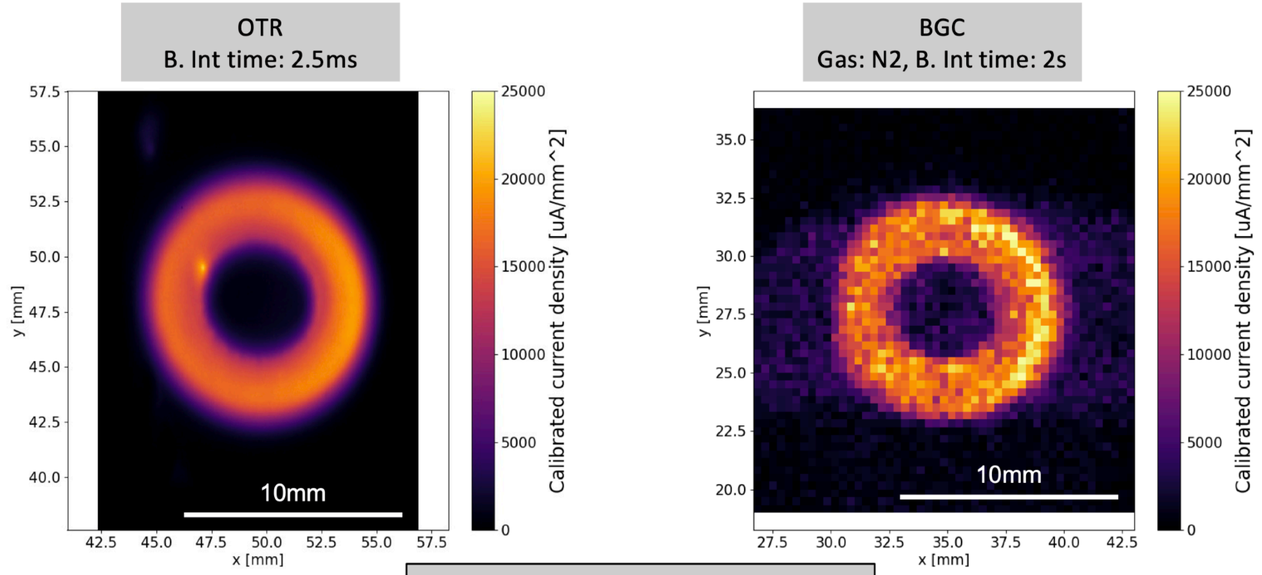
Update on electron beam test stand

- Resistive magnets (0.4T max)
- H/V correctors
- Modular installation
- Capability of testing:
  - Electron Gun
  - Collector
  - Beam Diagnostics: BPM, BGC, Screens (YAG, OTR, Chromox, etc.)
  - Modulator
  - Power convertors (incl. HV)
  - Controls and interlocks



Drawing: A. Kolehmainen

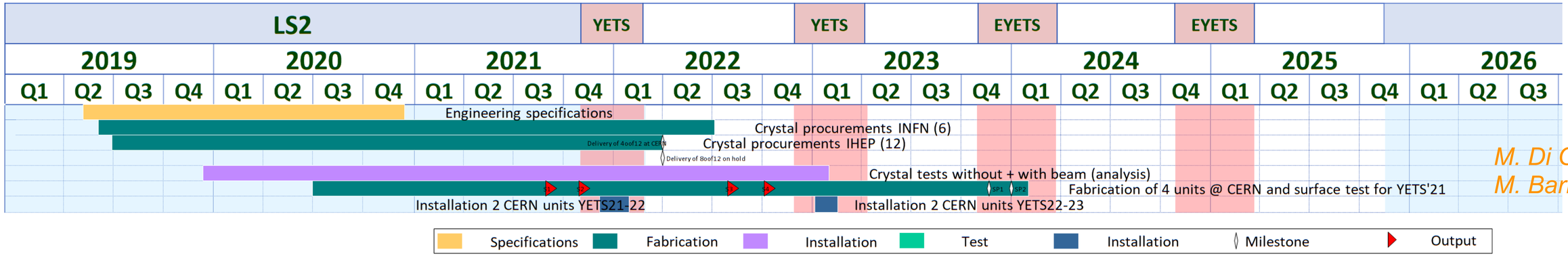
- Upcoming: test of new BPMs and, later, collector.



Beam: 1.1 A
B_Gun: 0.055 T
B_BGC: 0.115 T, with correctors

Courtesy A. Rossi & M. Sameed

Crystal collimation hardware



M. Di Castro, M. Barberan

- Installations of 2 units in Q1-2023 proceeded as planned.
- However the B1-H units developed a mechanical issue during HW commissioning.
  - Replaced with a drift chamber before starting operation, re-installed in TS1 (see back-up)
  - Many thanks for the support from STI/CEM/VSC + planning team + OP
- Small delays on the preparation of spare units, now moved to Q4 2023
- Fully upgraded system (4 devices) operational and being used at the LHC
  - Complete commissioning of new crystals with protons
  - Successful usage for the special run “high-β*” for background reduction
  - Being commissioned for ion beam operation.

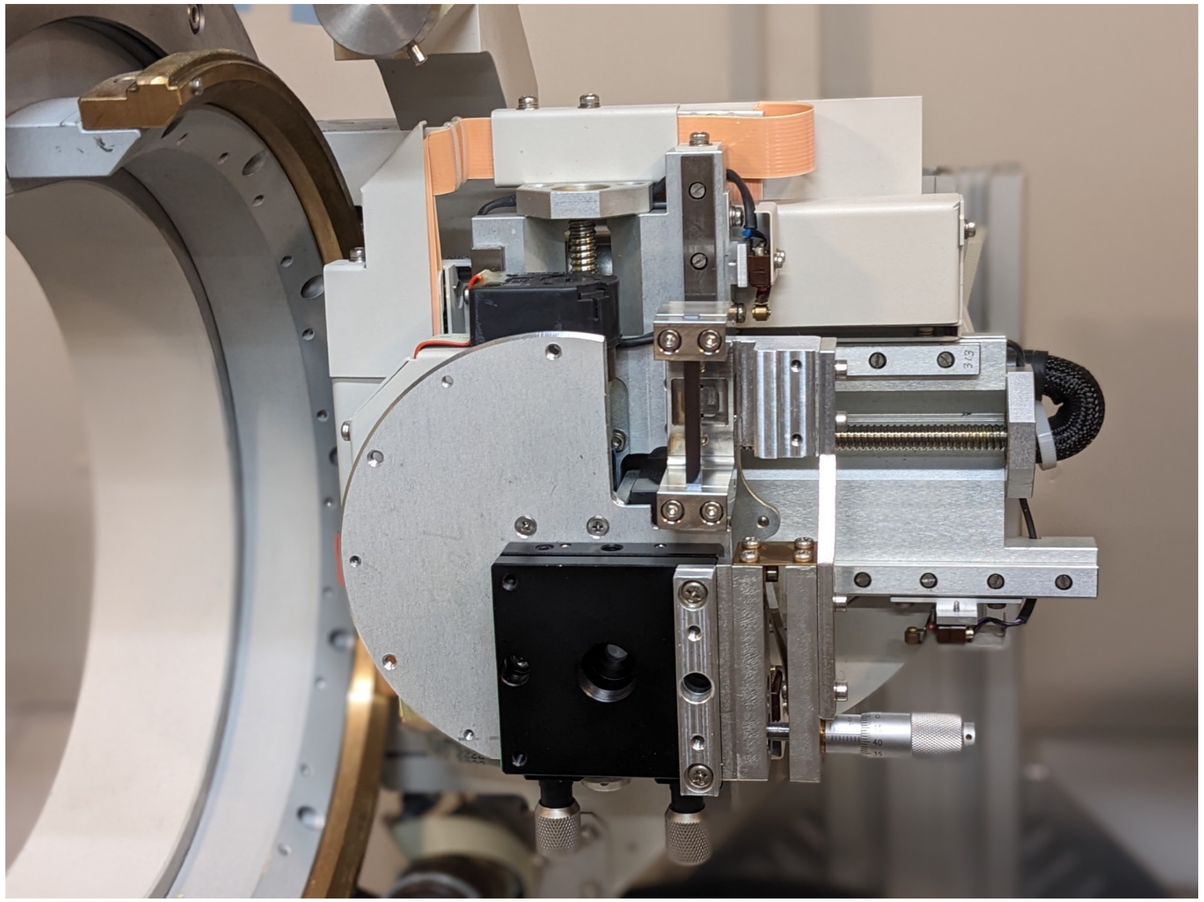
Crystal collimation hardware

Di Castro, Barberan

- Installations of 2 units in Q
- However the B1-H units de ng.
  - Replaced with a drift chan up)
  - Many thanks for the suppo
- Small delays on the prepar
- Fully upgraded system (4 d
  - Complete commissioning c
  - Successful usage for the s
  - Being commissioned for io

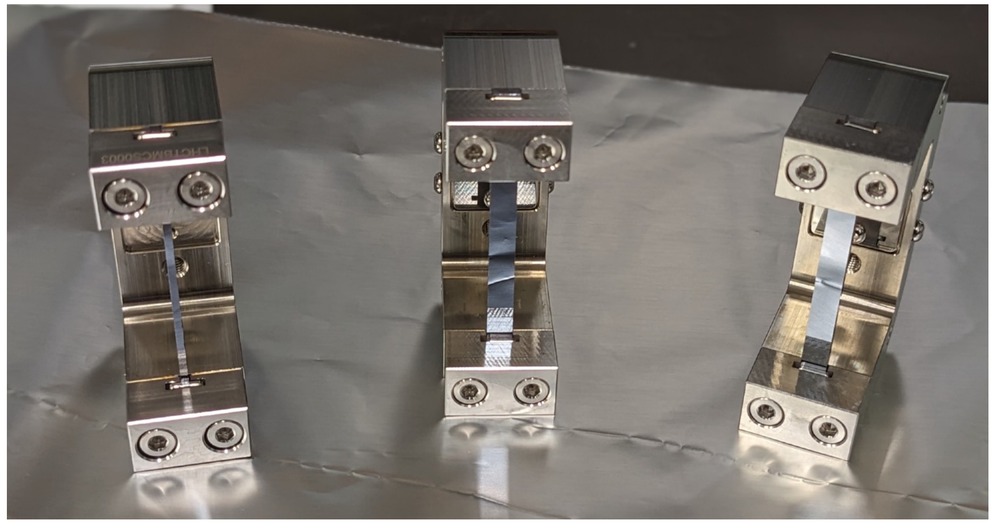
Courtesy R. Seidenbinder

Xray machine for crystal characterisation



Facility in BE/CEM funded by WP5 & PNPI enables detailed measurements of mechanical properties of bent crystals: Geometric properties and their stability vs thermal cycles; the crystal miscut.

Being finalised, will be used also for other crystal project at CERN.
All WP5 crystal tested as part of the acceptance.



Courtesy M. Di Castro, E. Matheson

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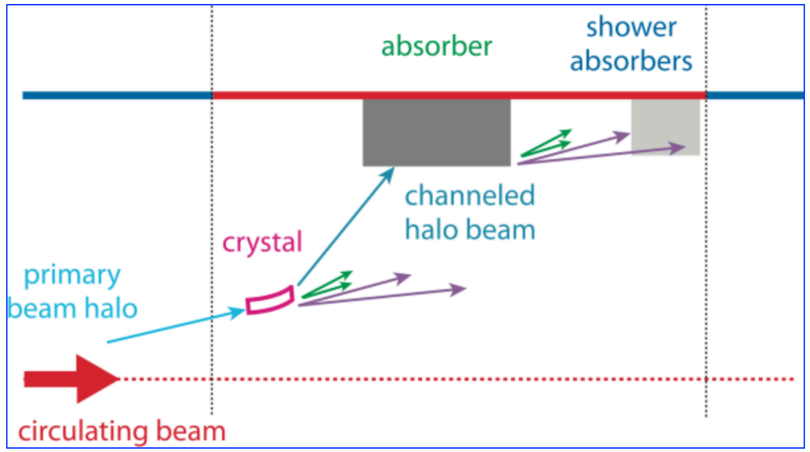
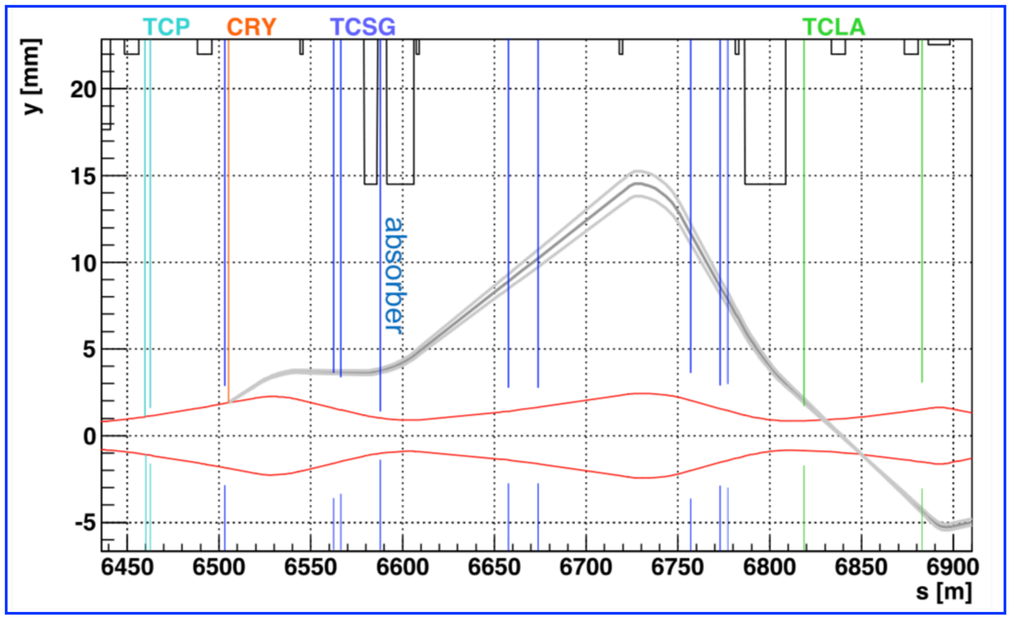
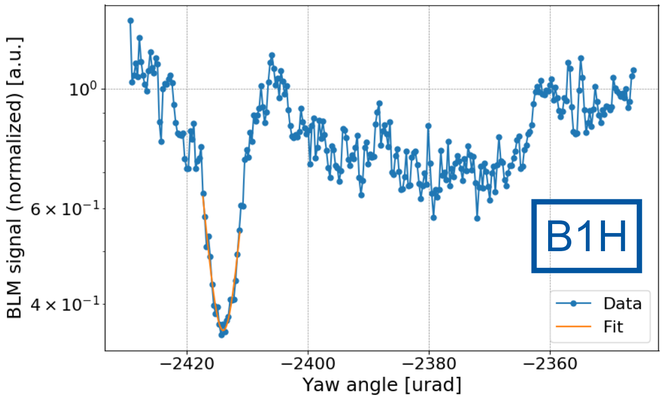
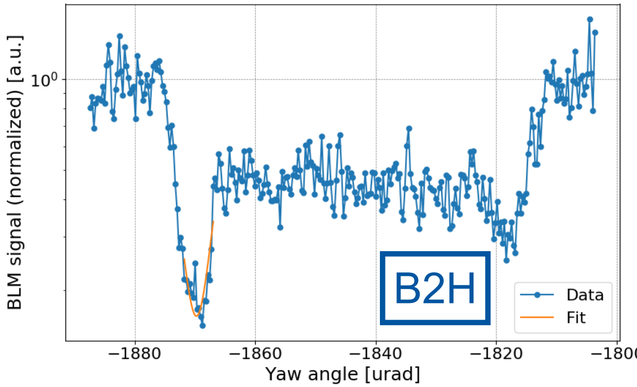
New HL-LHC crystal validation at the LHC

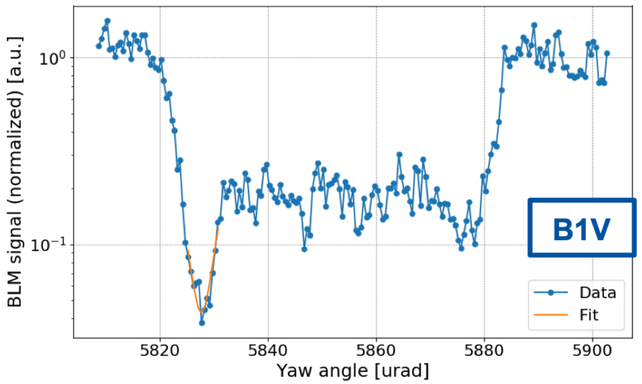


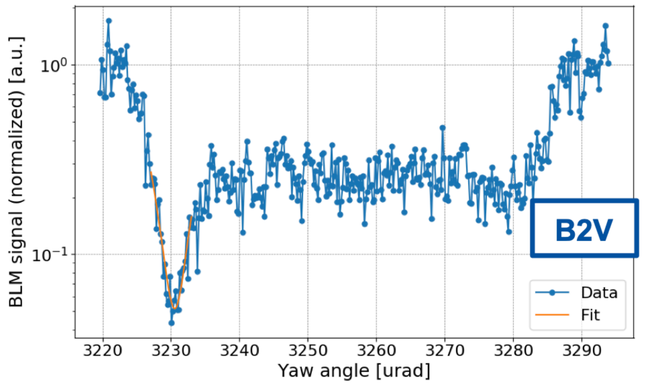


TCP = primary collimator
TCSG = secondary collimator
TCLA = shower absorber







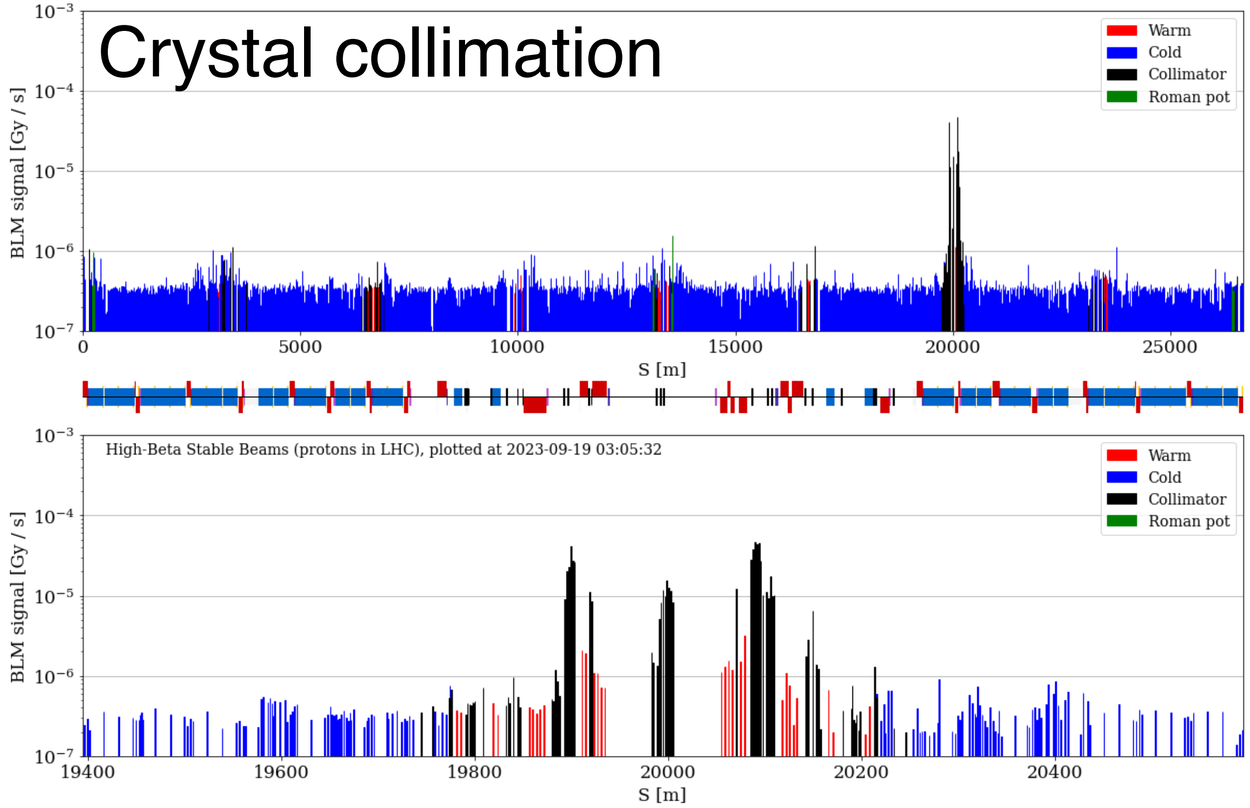


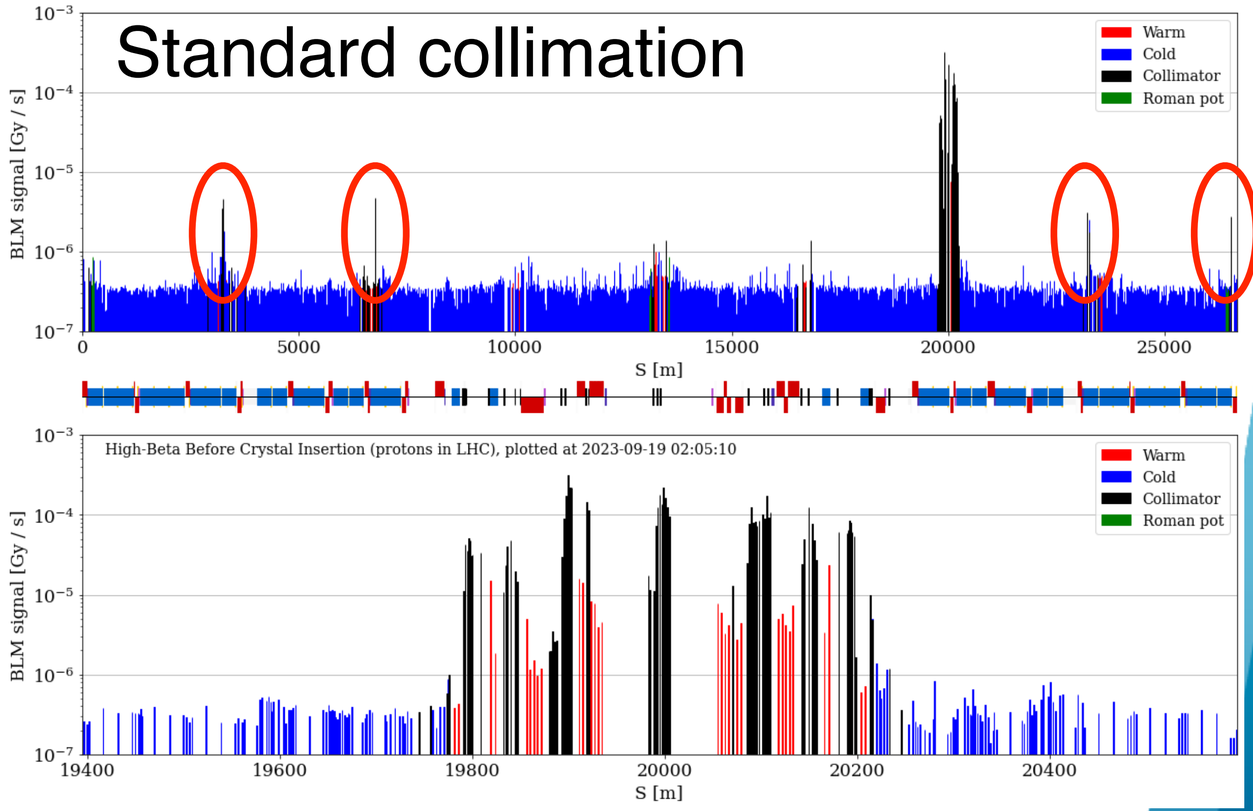
- All the 4 new crystals are well in spec.
- Excellent quality, with miscut <2μrad for 3 crystals an ~ 6 μrad for one.
- Goniometer controls working as expected

Courtesy M. D'Andrea

High-β* run 2023

- Crystal collimation used to suppress backgrounds in the Roman pots in ATLAS-ALFA and TOTEM during a recent high-β* run at 6.8 TeV
  - Special optics with 3km/6km, Roman pots operating down to 3 beam sigmas.
- Low burn-off → long fills up to 9h-10h. Crystal used reliably over ~2 weeks

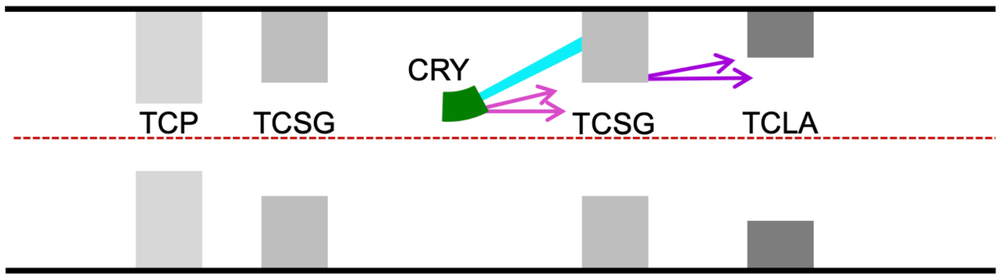




Courtesy M. D'Andrea

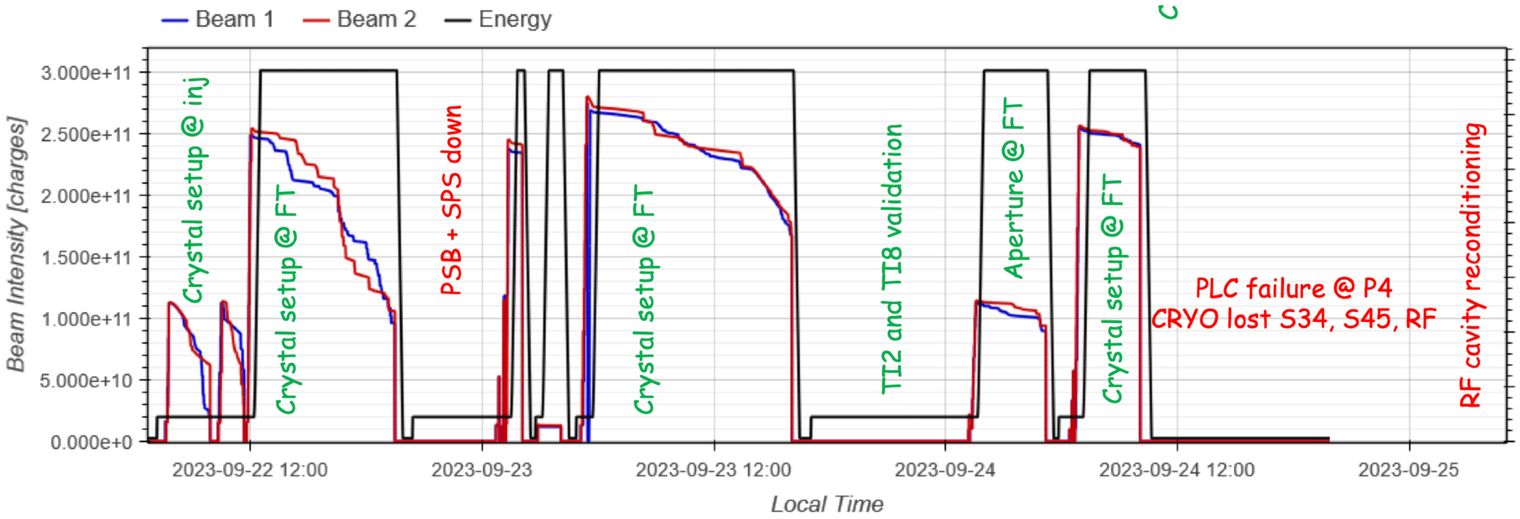
(Ongoing) commissioning for Pb ion run

Crystal scheme — “adiabatic” insertion in to the betatron system



Tested at the end of Run 3 and already in 2022 with 2/4 new crystals.

Fresh news, as commissioning carried out over last weekend



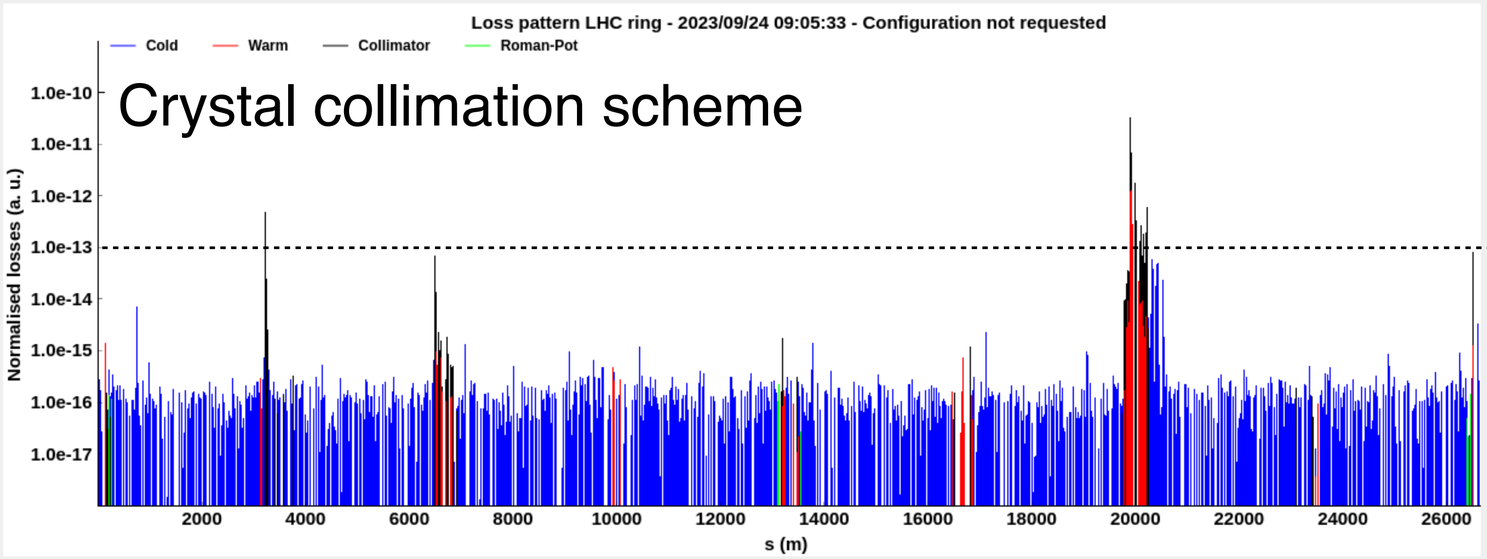
2023 commissioning just completed, validation ongoing. Last loss maps performed until yesterday night. Crystals are part of the intensity ramp up.

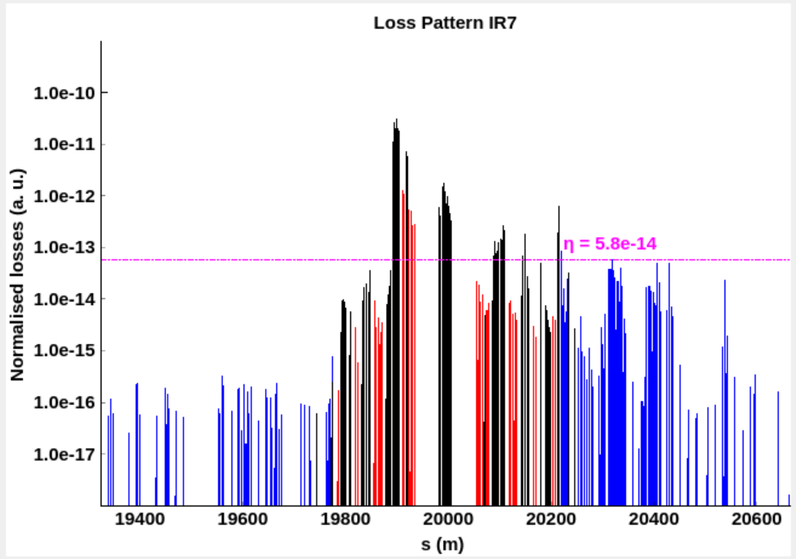
Beam/Plane	Inefficiency Standard [Gy/charge]	Inefficiency Crystal [Gy/charge]	Gain Factor
B1H	6.80E-13	2.90E-14	23.45
B1V	8.00E-13	6.60E-14	12.12
B2H	2.60E-13	5.60E-14	4.64
B2V	3.50E-13	9.10E-14	3.85

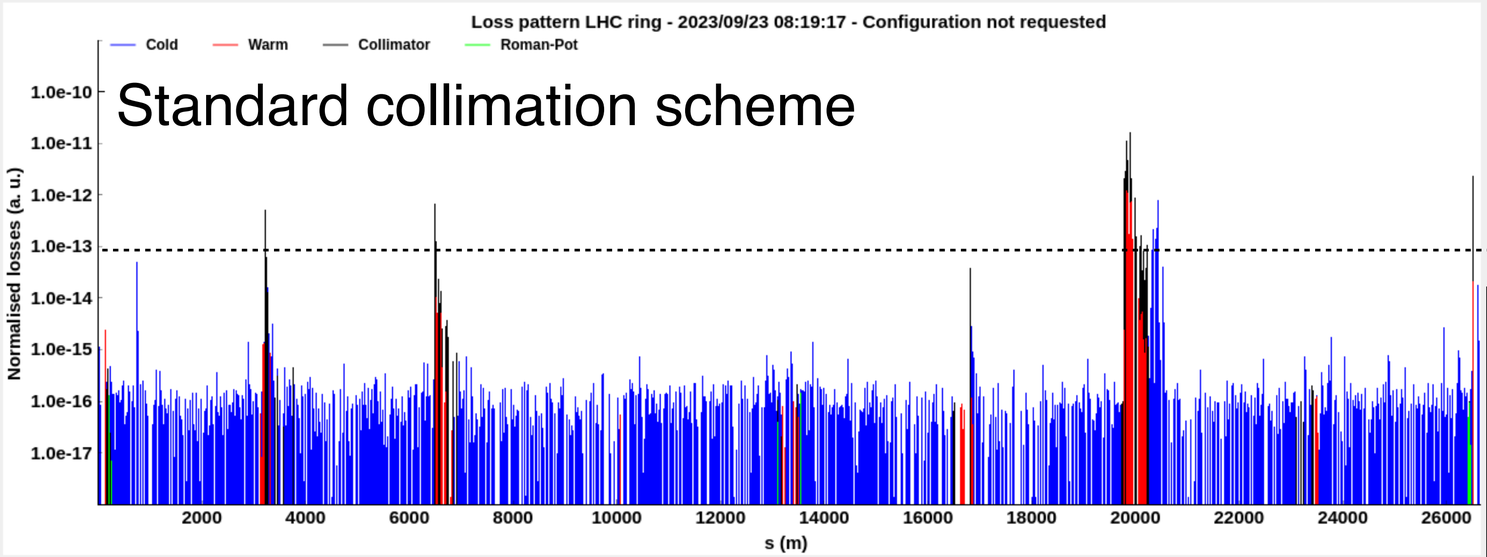
PRELIMINARY

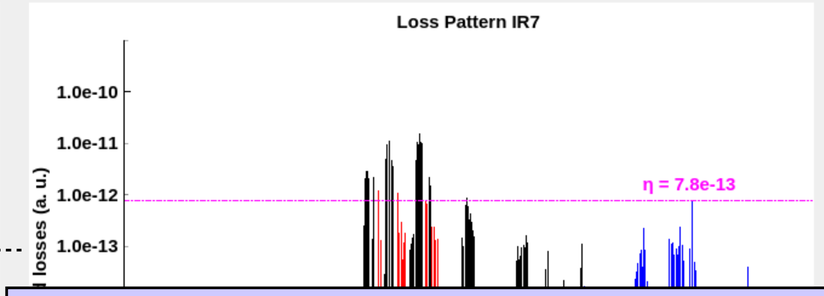
BIG effort in the last week! Many thanks in particular to D. Mirarchi (OP) & M. D’Andrea, R. Bruce and R. Cai (ABP).

Preliminary crystal collimation cleaning









Very promising, although some challenges found in commissioning. **Fill-to-fill stability** over a long run to be established.

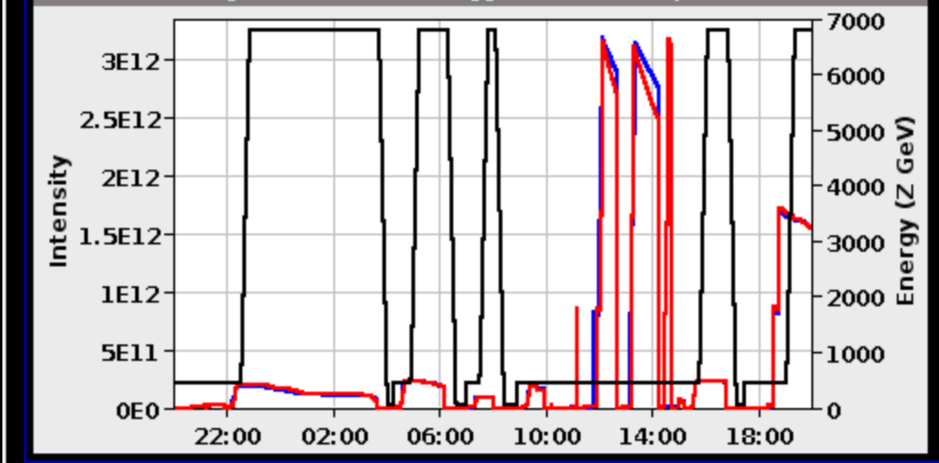
LHC Page1 | Fill: 9192 | E: 6799 Z GeV | t(SB): 00:11:12 | 26-09-23 19:58:10

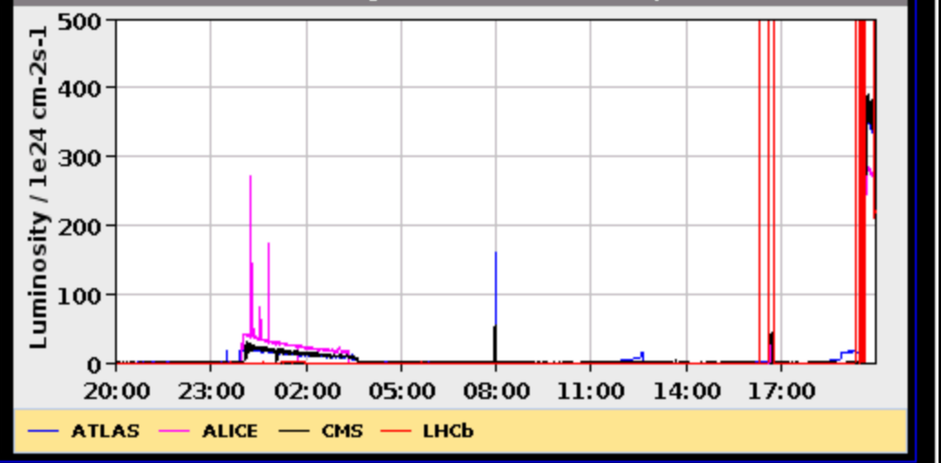
ION PHYSICS: STABLE BEAMS

Energy:	6799 GeV	I B1:	1.63e+12	I B2:	1.60e+12

Beta* IP1:	0.50 m	Beta* IP2:	0.50 m	Beta* IP5:	0.50 m	Beta* IP8:	1.50 m

Inst. Lumi [(b.s)^-1] IP1: 328.44 IP2: 263.77 IP5: 332.39 IP8: 221.13





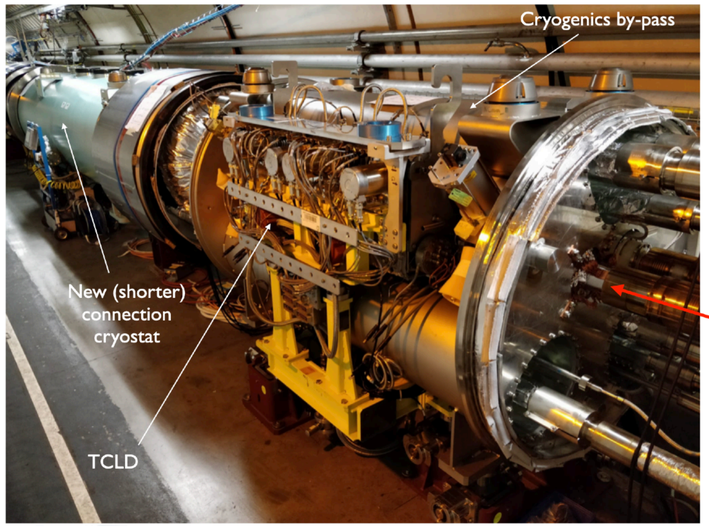
Comments (26-Sep-2023 19:57:58)

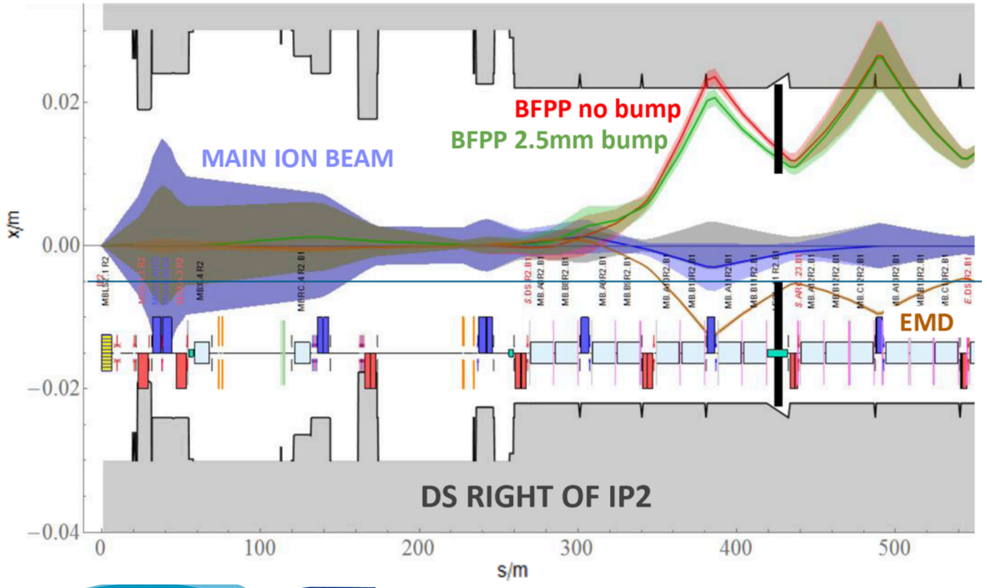
First STABLE BEAMS with heavy ion beams
in Run 3 with crystal collimation!

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	true	true
Global Beam Permit	true	true
Setup Beam	false	false
Beam Presence	true	true
Moveable Devices Allowed In	true	true
Stable Beams	true	true

AFS: 50ns_119b_58_51_58_56bpi_9inj_3INDIV_4NC_PbPb PM Status B1 ENABLED PM Status B2 ENABLED

TCLD collimation in action for ALICE luminosity upgrade

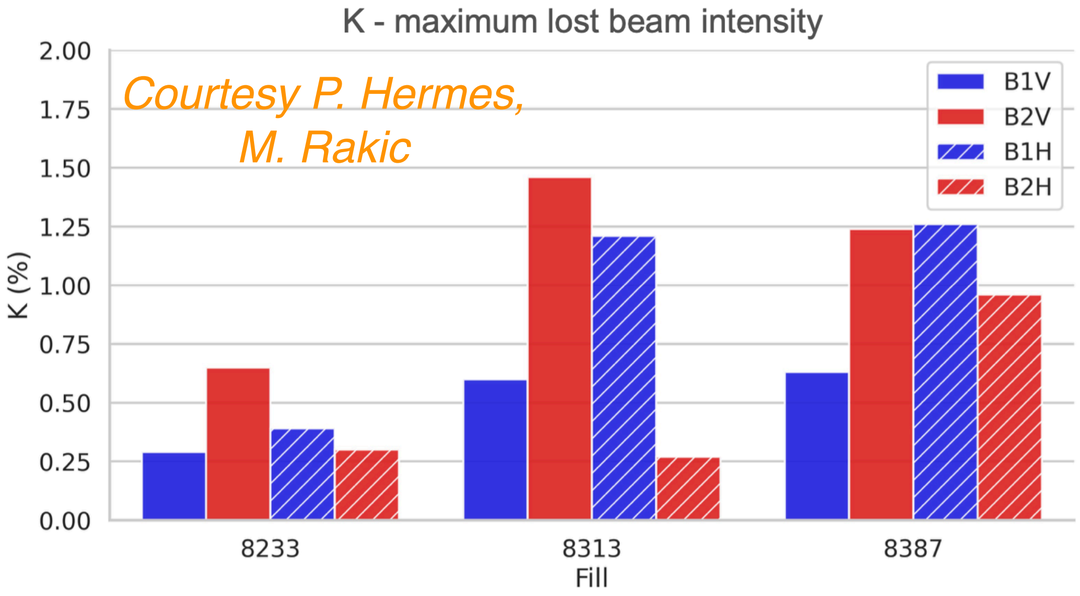


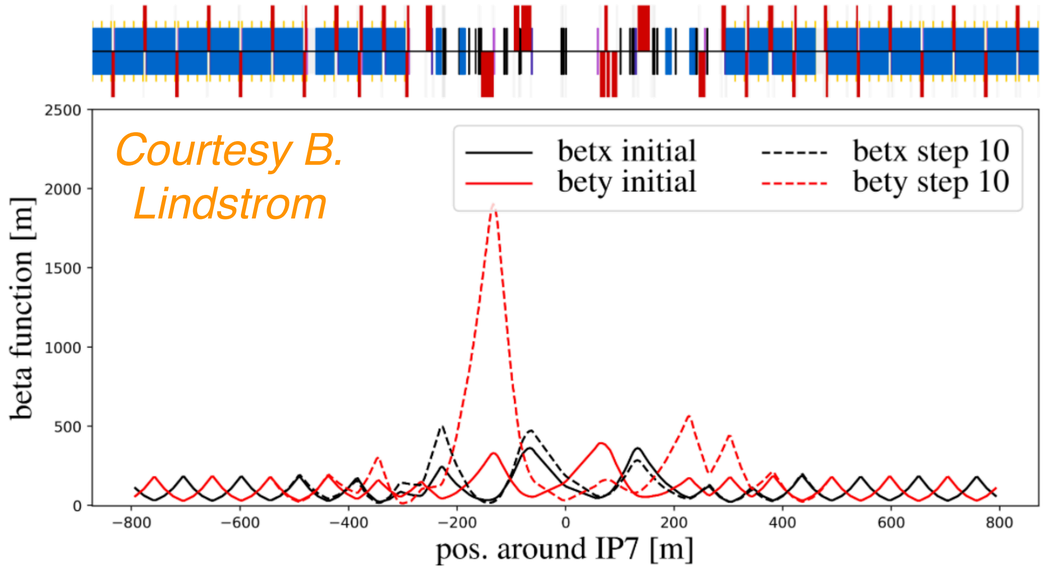


Courtesy R. Bruce et al.

Operational news not covered today

- Several WP5 studies cancelled in 2023 due to lack of high-intensity MDs
  - Very important to **maintain priority high** until the end of Run 3
- Collimation quench tests of B1 → *postponed;* Impedance: only partially done.
- Detailed halo studies → *postponed*
  - Only a few tests. Promising results: lower tail populations with the small-emittance LIU beams
- Lifetime analysis 2023: worsening with respect to 2023 in ADJUST.
  - 6 dump while going in coll. (recently presented to the 167th ColUSM)
- New collimation optics IR7 (improved cleaning and impedance) — still scheduled!





Conclusions

- Reported the key WP5 activities in the last year
  - Worked on consolidating the updated baseline, focus in studies/beam measurements to support mitigation strategies for the “missing” hardware
- Important progress on the hardware preparation for the LS3 productions
  - Successful production of the “X” collimator prototype, so far conform for machine installation
  - Big effort on the preparation of the production contract (not reported here)
- Support to the LHC Run 3 operation continued, profiting from the new HW
  - New collimators for low impedance and TCLD around ALICE fully operational
  - Performance is as expected — key asset to push the Run 3 performance with LIU beams
- Very promising results from crystal collimation
  - Recent high-β* fully relied on this technique for low-background
  - Very encouraging results from ion beam tests — looking forward to seeing intensity ramp up
- Various very important studies in MD delayed because of LHC availability
  - Important to keep the pressure high to preform them in 2024.

Reserve slides

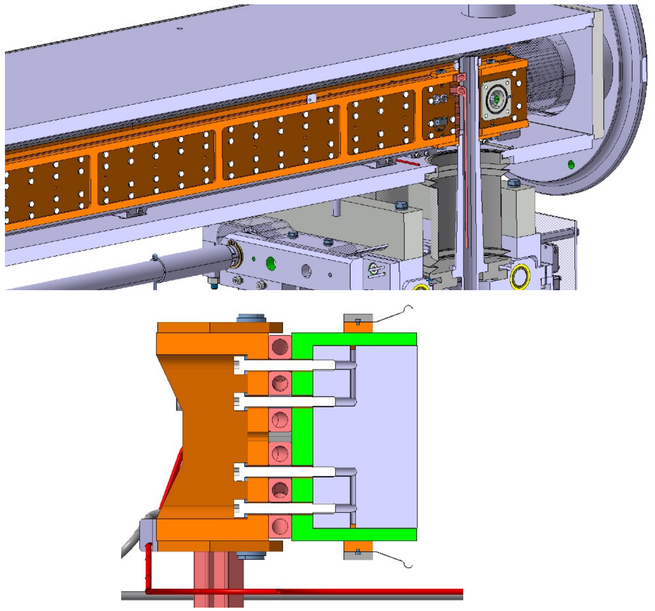
More on production plans for LS3

- 20 × TCTP contract (+ TCTW)
- 16 × TCDIL contract: **25 months**
  - Started on 11/04/2017
  - Ended on 14/05/2019
- 20 × TCSPM/TCPPM/TCLD contract: **26 months**
  - Started on 1/02/2018
  - Ended on 30/03/2020

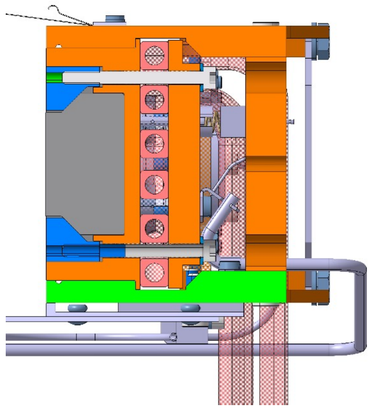
- Coming CERN need:
  - 36 × TCLPX/TCTPXH/TCTPXV/ TCTPM/TCSPM
  - **~2.5 years contract**

Courtesy F.X. Nuiry

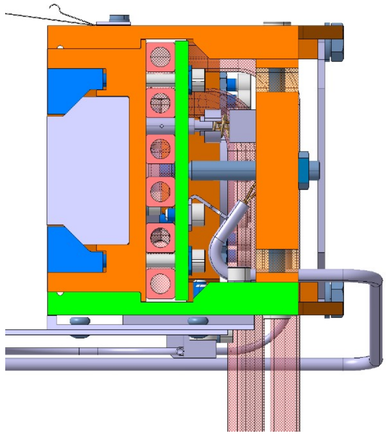
TCLPX



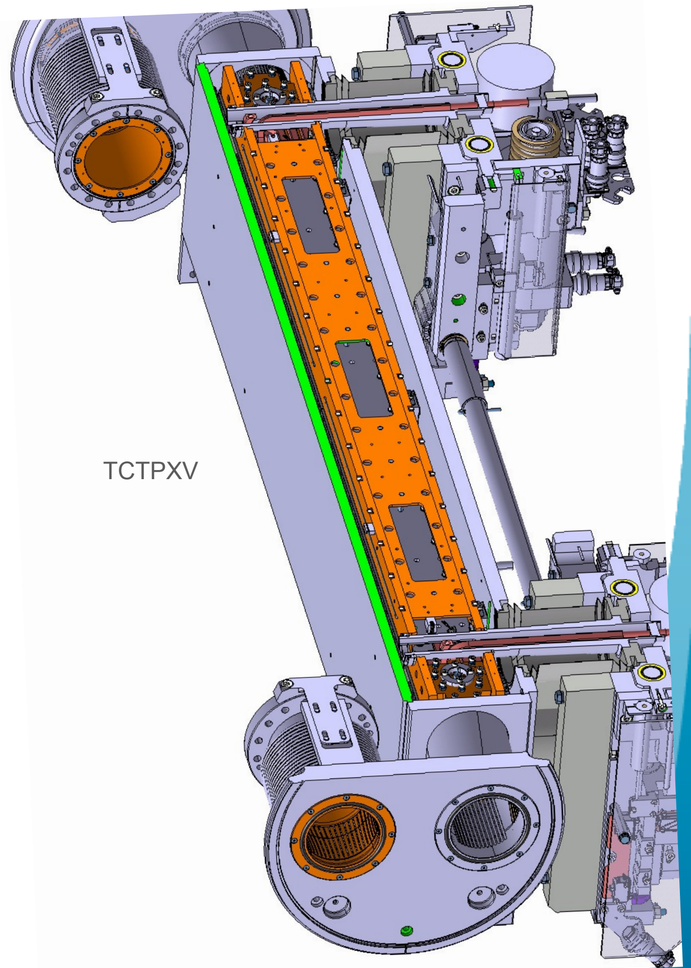
TCSPM



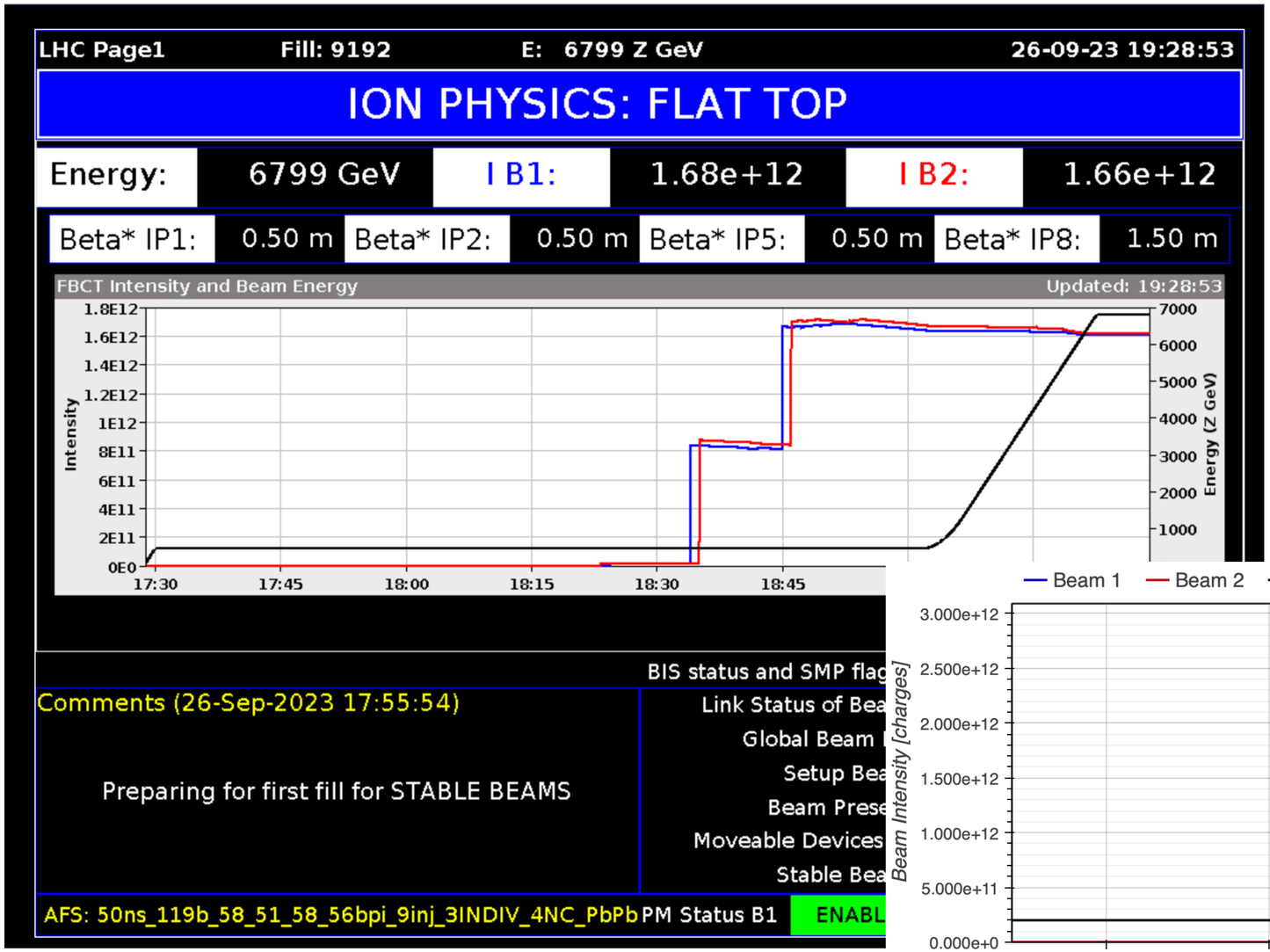
TCTPM & TCLP
TCTPXH & TCTPXV

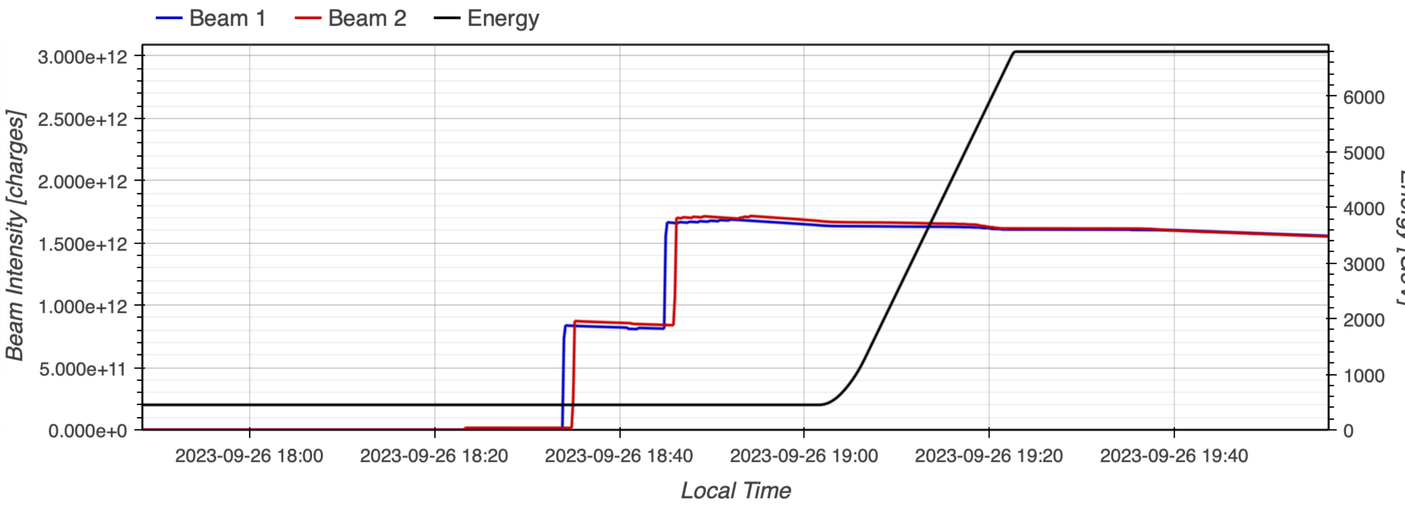


TCTPXV



First ramp with ion trains and crystal collimation

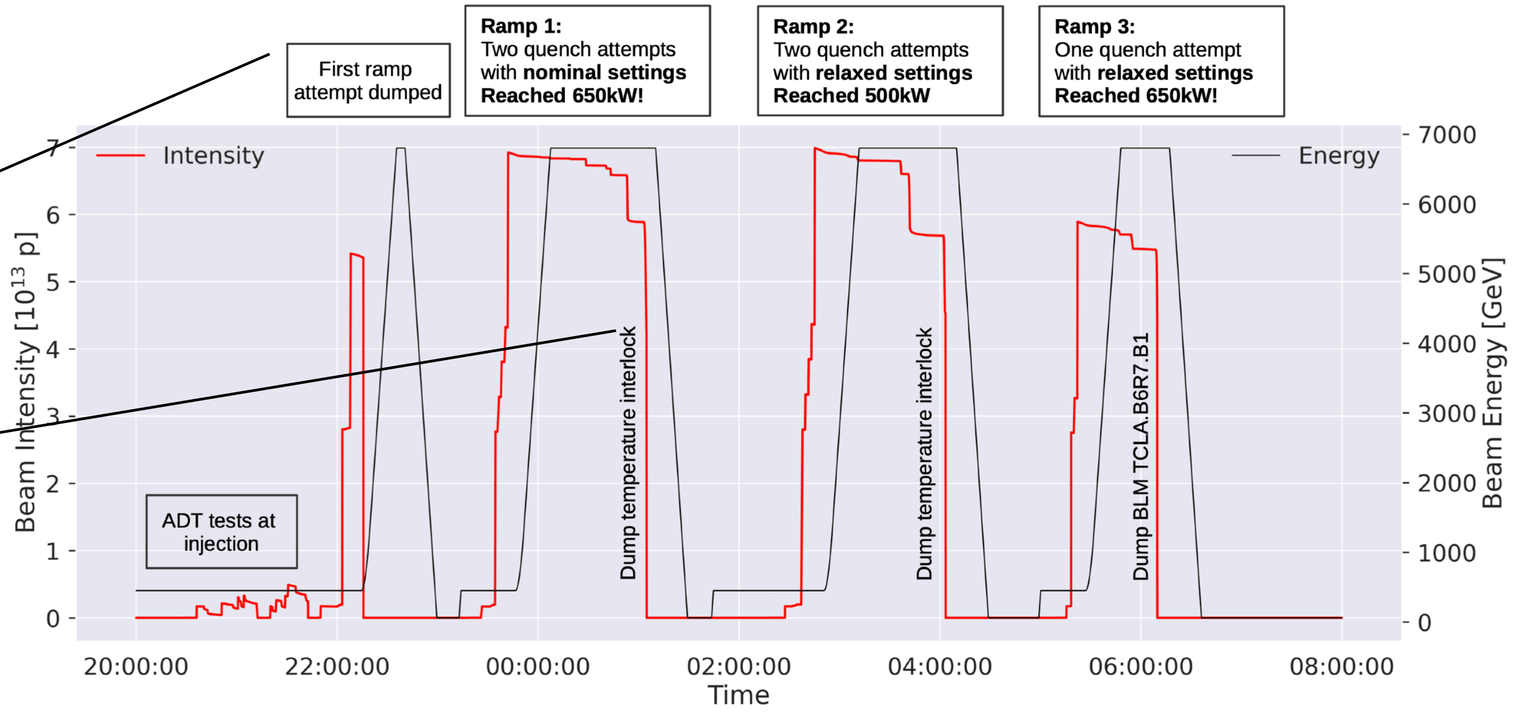




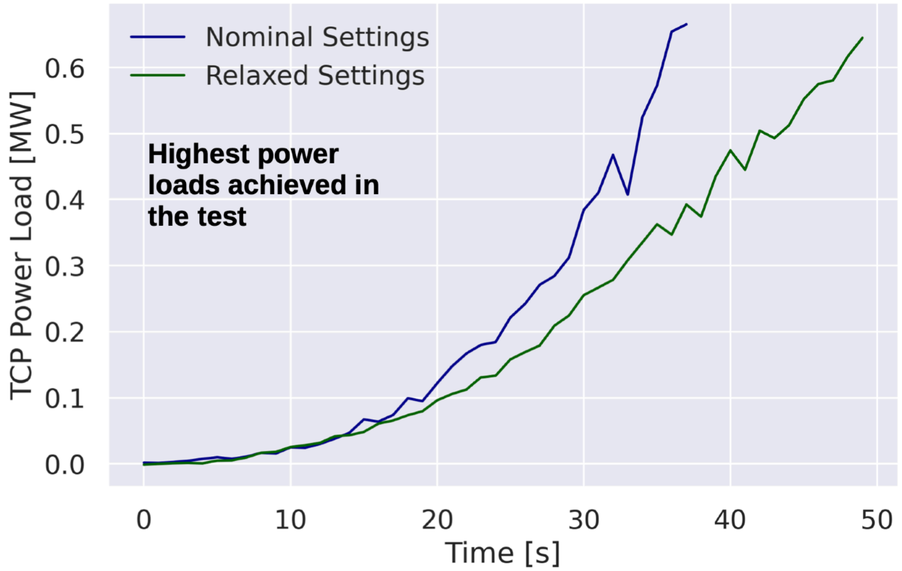
Proton quench test in 2022

Spurious interlock, not related to quench test setup

Collimator jaw temperature: interlock limit at 50 deg



Courtesy P. Hermes



No quench achieved with estimated peak loss:

15.8-17.0 mW/cm³ (6.8 TeV)

(7 TeV HL-LHC design for 0.2h = 15 mW/cm³)

Proton quench test in 2022

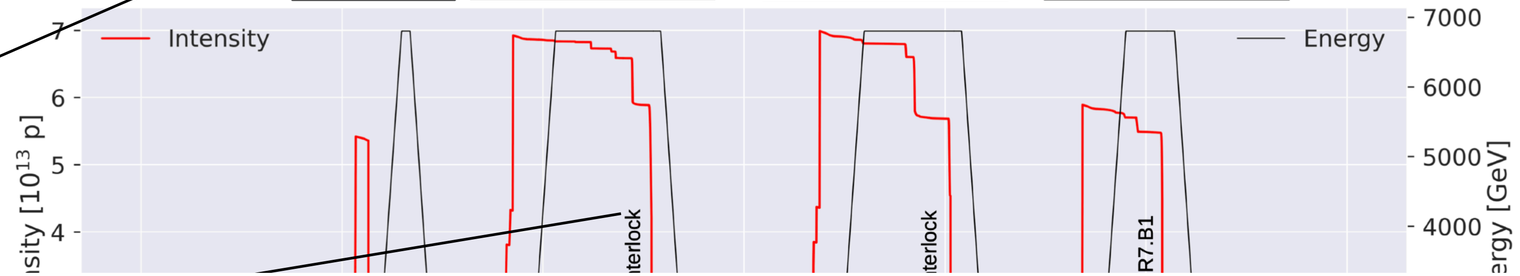
Spurious interlock, not related to quench test setup

First ramp attempt dumped

Ramp 1:
Two quench attempts with **nominal settings**
Reached 650kW!

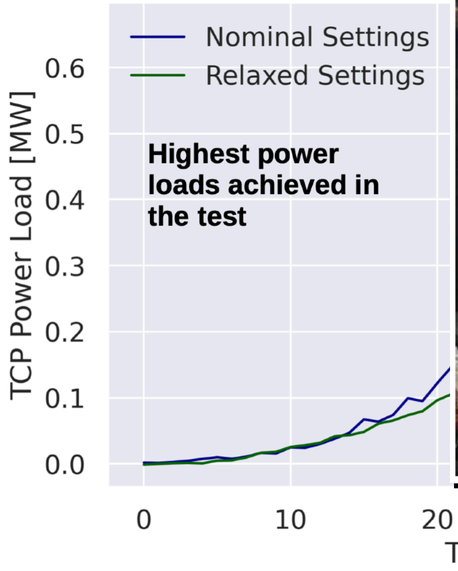
Ramp 2:
Two quench attempts with **relaxed settings**
Reached 500kW

Ramp 3:
One quench attempt with **relaxed settings**
Reached 650kW!



Collimator temperature: in limit at 50

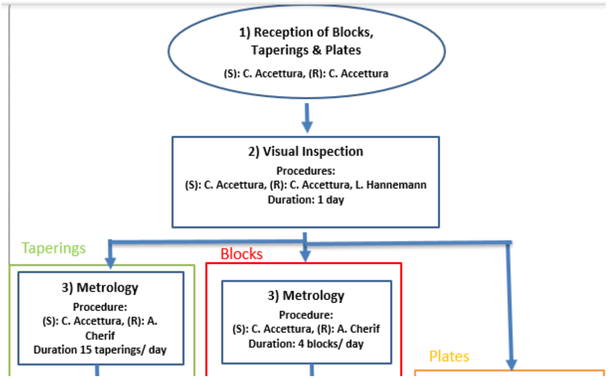
Courtesy P. Hermes

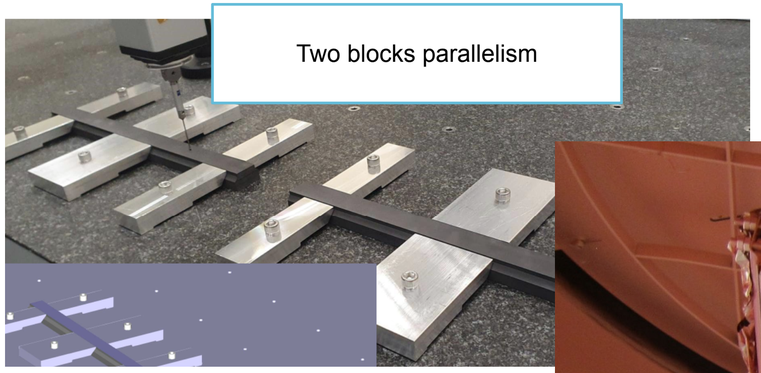


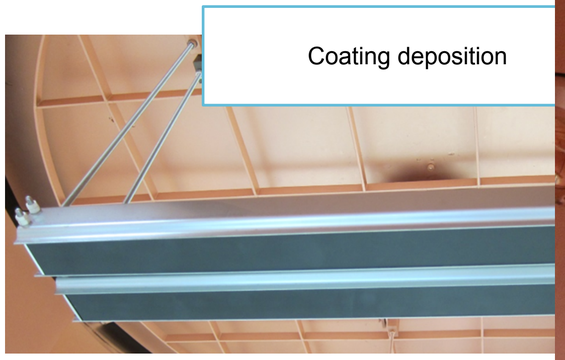
Teams/groups involved: ABP, MME, MPE, RF, STI, BI, OP, …

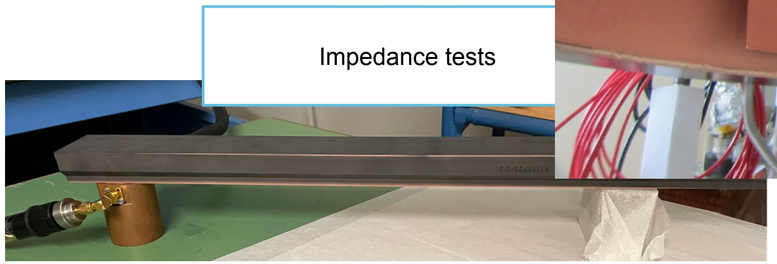
Status of Cu coating on Gr

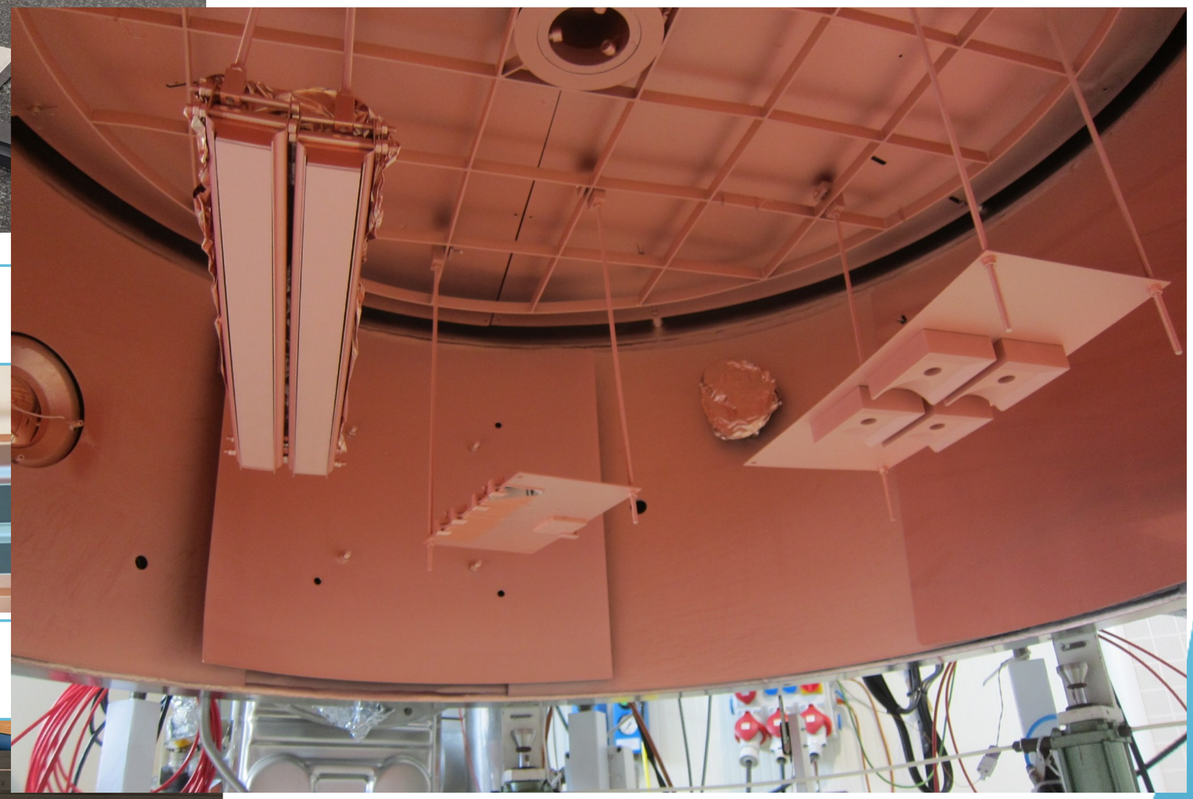
- Small pre-production:
  - Dimensional **tolerances** ☑
  - UHV **compatibility** ☑
  - **Optimized** the copper-coating deposition ☑
  - Electrical conductivity **> 30MS/m** ☑
- Procurement for the series production ongoing (10+2 TCSPM):
  - DAI launched
  - 60 blocks+60 taperings expected by the end of the year
  - Planning for the coating and for the validation at CERN updated
  - Procedures and flowchart ongoing











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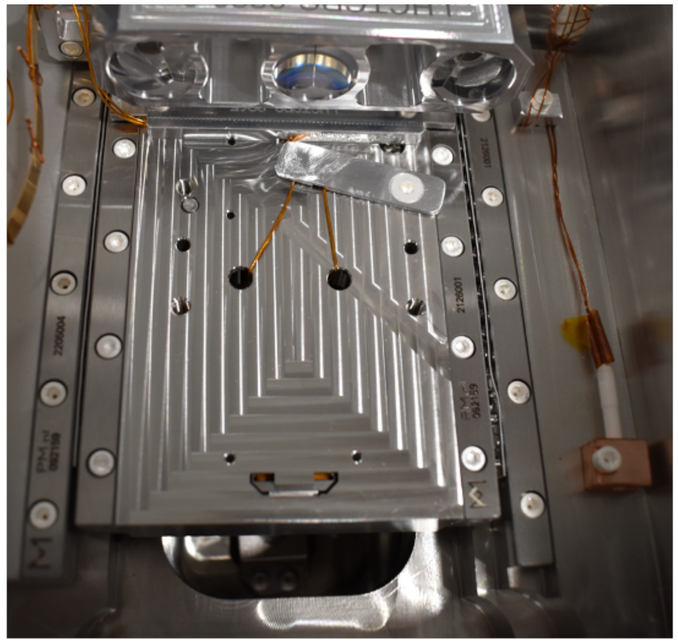
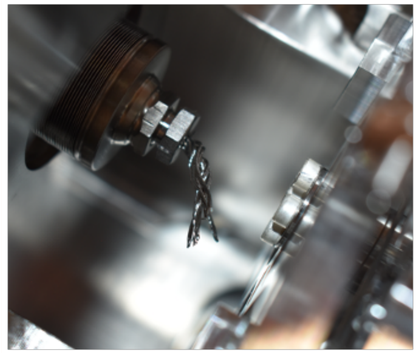
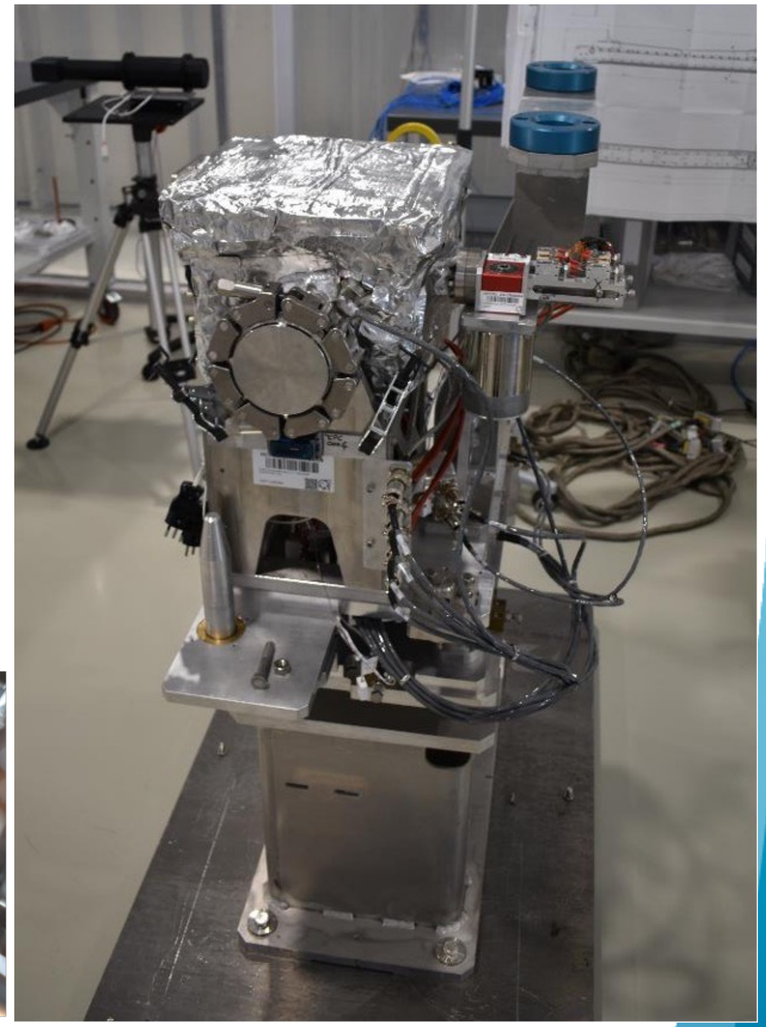
Courtesy Q. Demassieux, 178th TCC (June 2023)

Crystal collimation hardware — issue and re-furbishment

- **TCPC was open in B867 clean room. The following observations were made:**
  - The linear stage was stuck in its motion, with visible damage on the linear bearings on the tank side
  - Crimped cable separated from the stage, with visible strands torn apart
  - Removal of the bearing cage showed that one of the rollers broke out of the cage and jammed into the rails, causing local scrapping of the rail
- **Based on theses observation, most likely failure scenario was :**
  - Assembly procedure caused a local defect in the bearing cage
  - The defect trickled an accelerated fatigue of the bearing cage until a roller broke out
  - The roller jammed the linear guiding system, freezing the motion of the stage
  - The motor continued pushing and caused extreme compression of the cable, forcing the strands apart
  - On following pull, individual cable strands slipped out of the crimping and separated the stage from the motor assembly



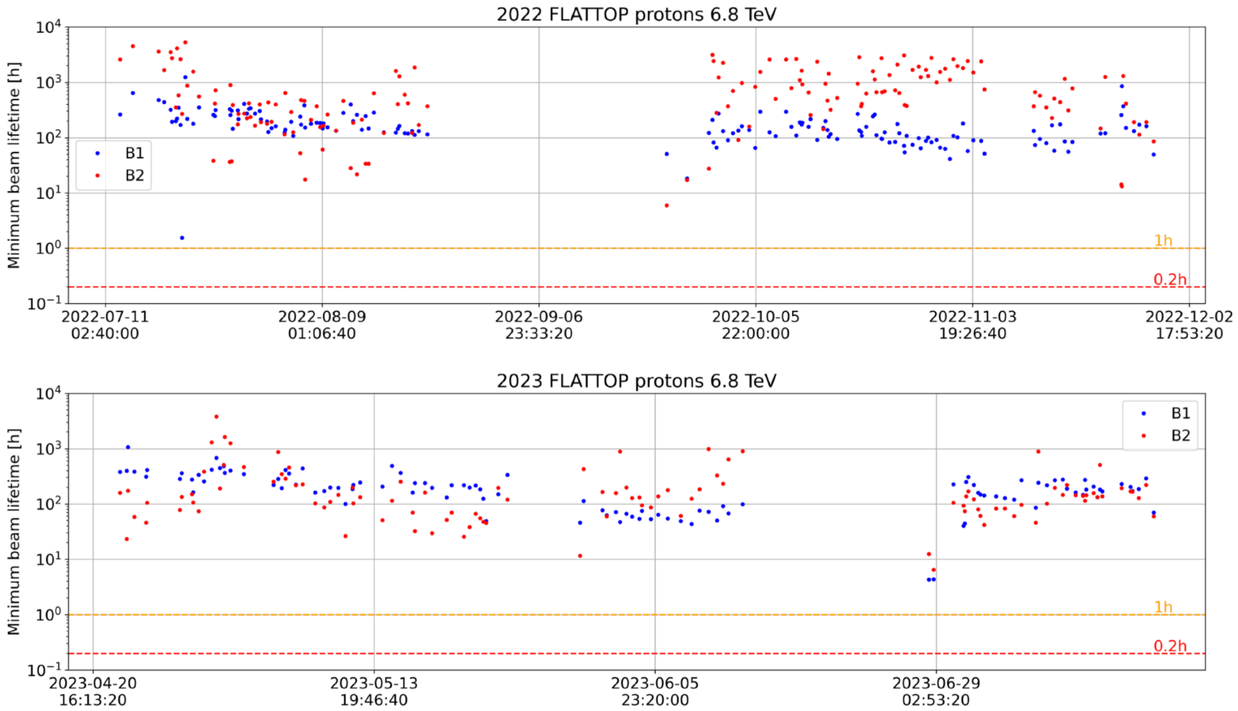




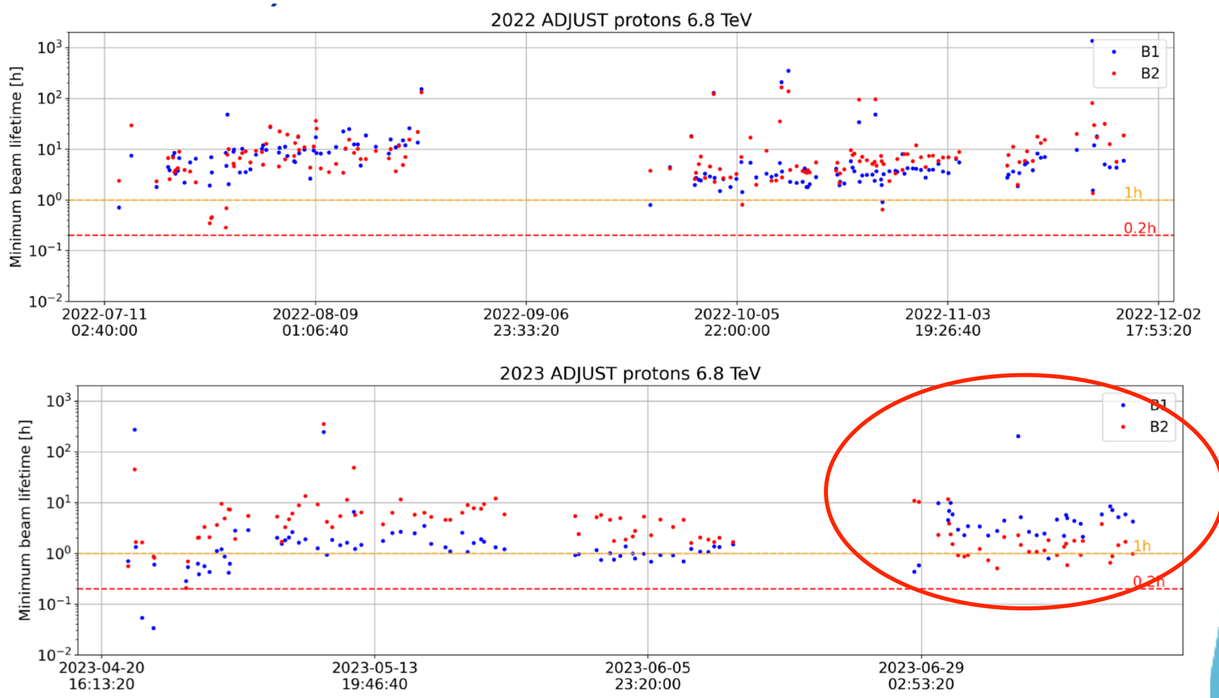
Courtesy Q. Demassieux, 178th TCC (June 2023)

Crystal collimation hardware — issue and re-furbishment

Flat top



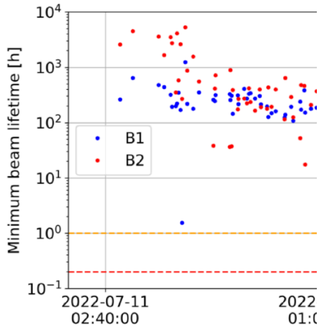
Adjust (setup of collisions)

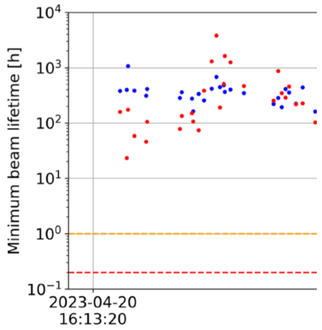


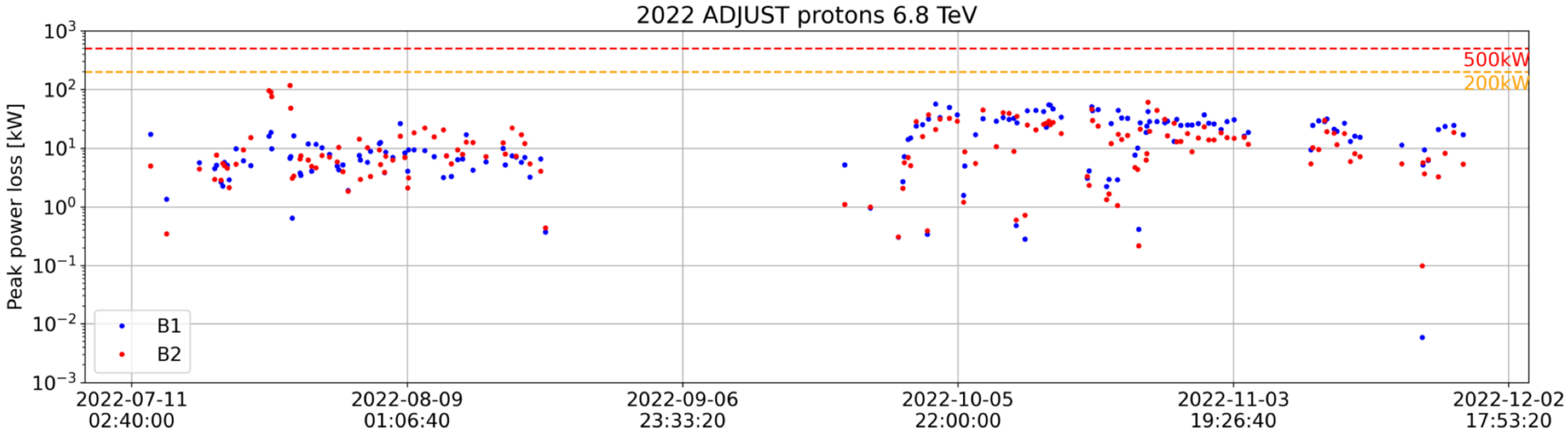
6 dump because of losses recorded in 2023!

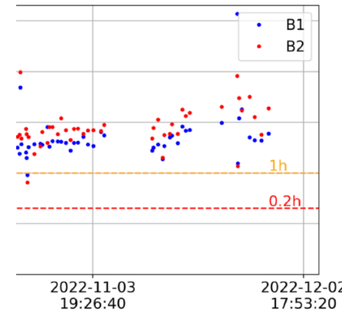
Courtesy S. Morales, B. Salvachua

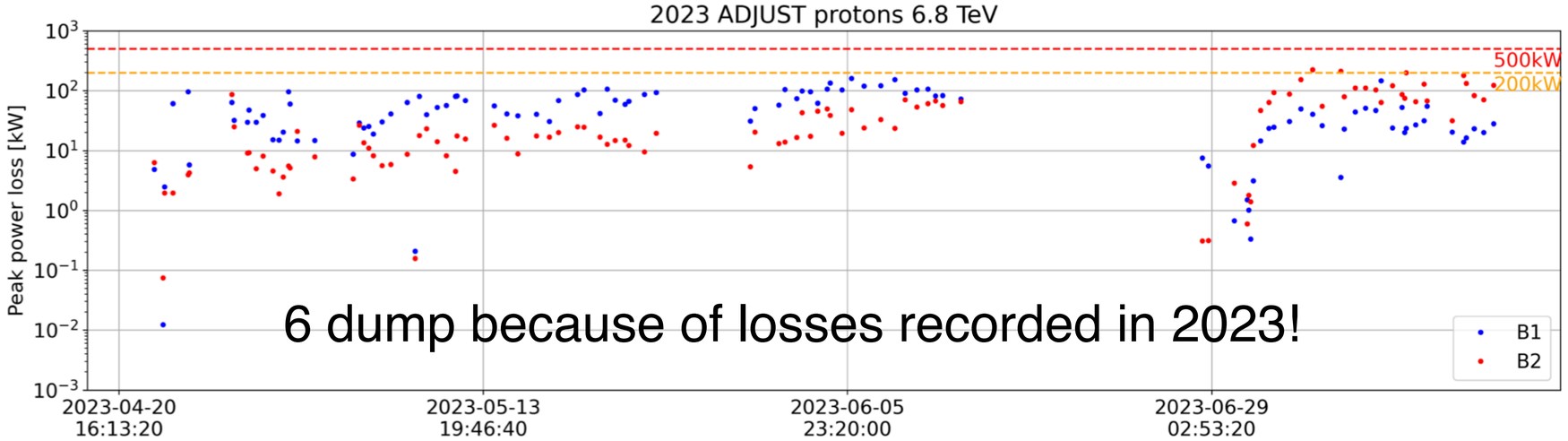
Crystal collimation hardware — issue and re-furbishment

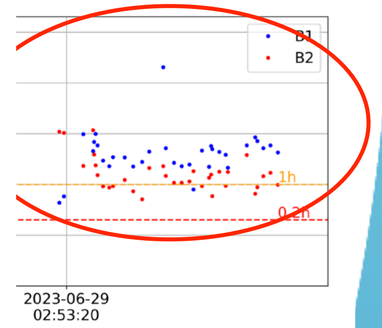












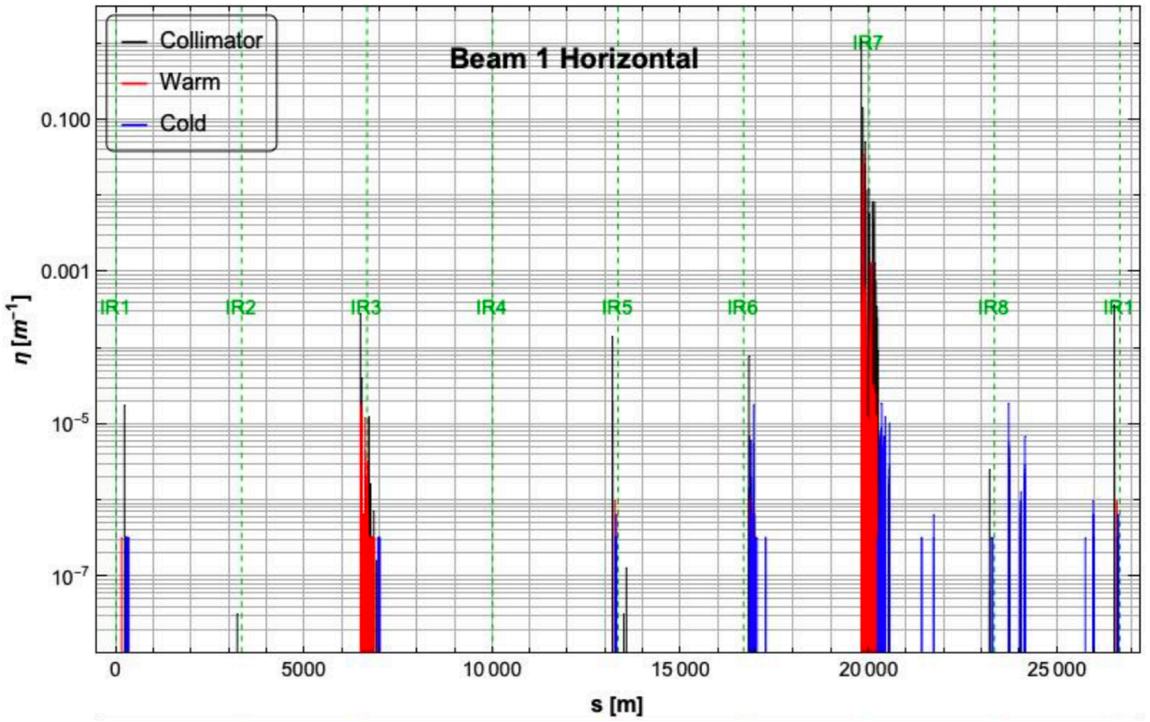
6 dump because of losses recorded in 2023!

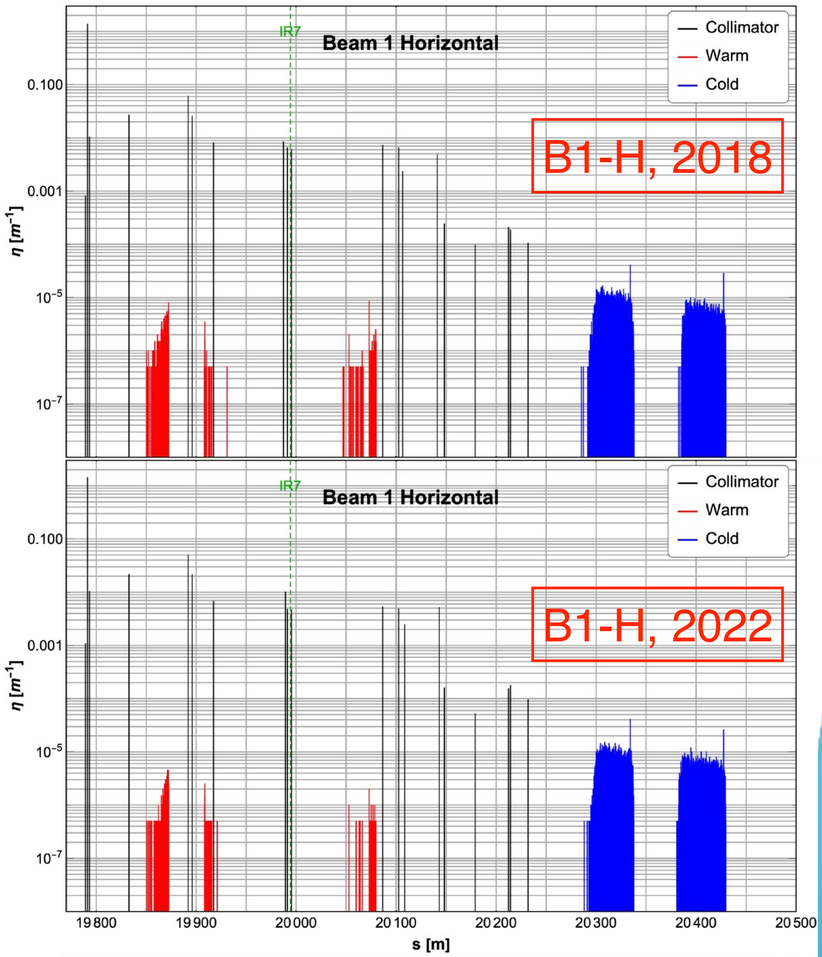
Courtesy S. Morales, B. Salvachua

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





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).

Courtesy: F. Van Der Veken BE/ABP