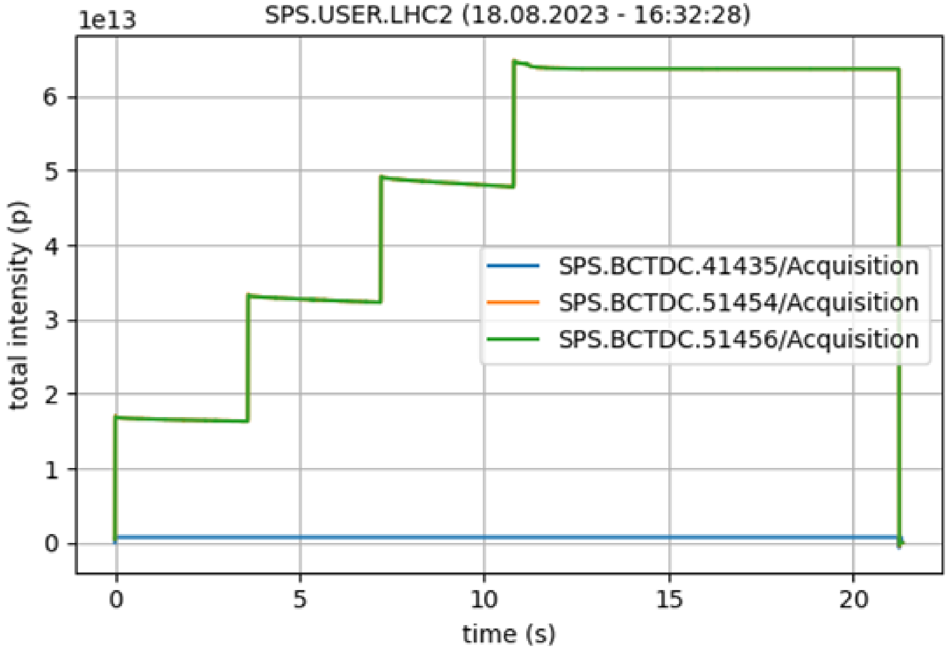
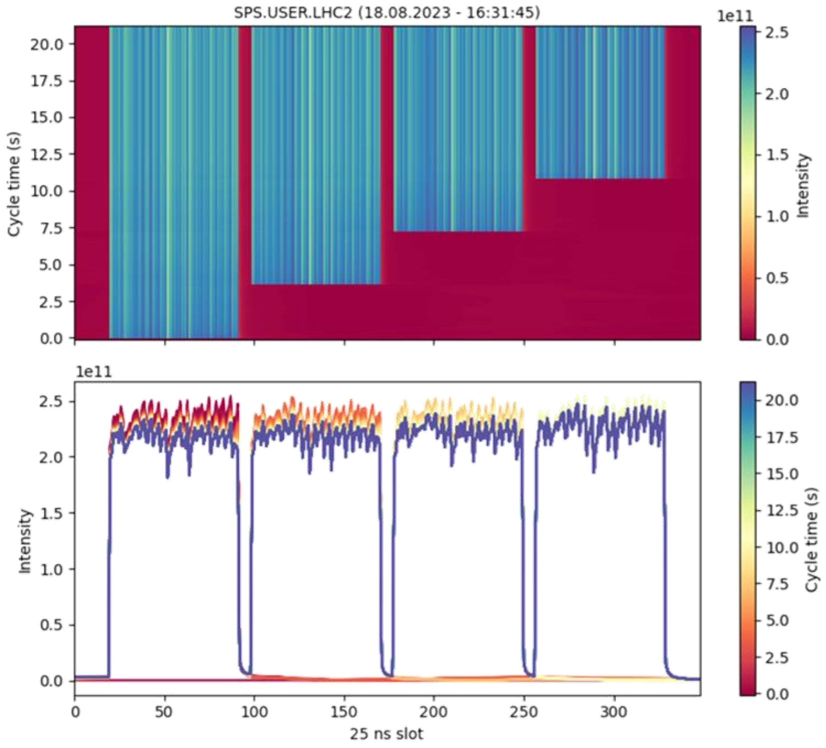
LHC Run 3 – Status and Outlook

Achieved SPS LIU intensity target

Intensity reach demonstrated on 13.06.23, 18.08.23:
<u>4x72 with 2.2e11 p/b at flat top</u>

- Excellent transmission (~95% without scraping)





LMC, "LIU beam parameters in the injectors", G. Rumolo et al.

LIU beams - Summary & outlook

year	Intensity at SPS FT [p/b]	# of bunches	Batch spacing [ns]	Transverse emittance (mm)	Bunch length [ns]	Beam type
2023	2.2e11	4 x 72	200	1.9	1.6	Standard
2023	2.15e11	4 x 56	200	2.05	1.6	8b4e
2023	1.8e11	56 + 5 x 36	200	1.6	1.6	hybrid

Demonstrate reproducibly LIU target intensity (2.3e11 p/b) at SPS flat top

- Prove and/or improve robustness of new WS design

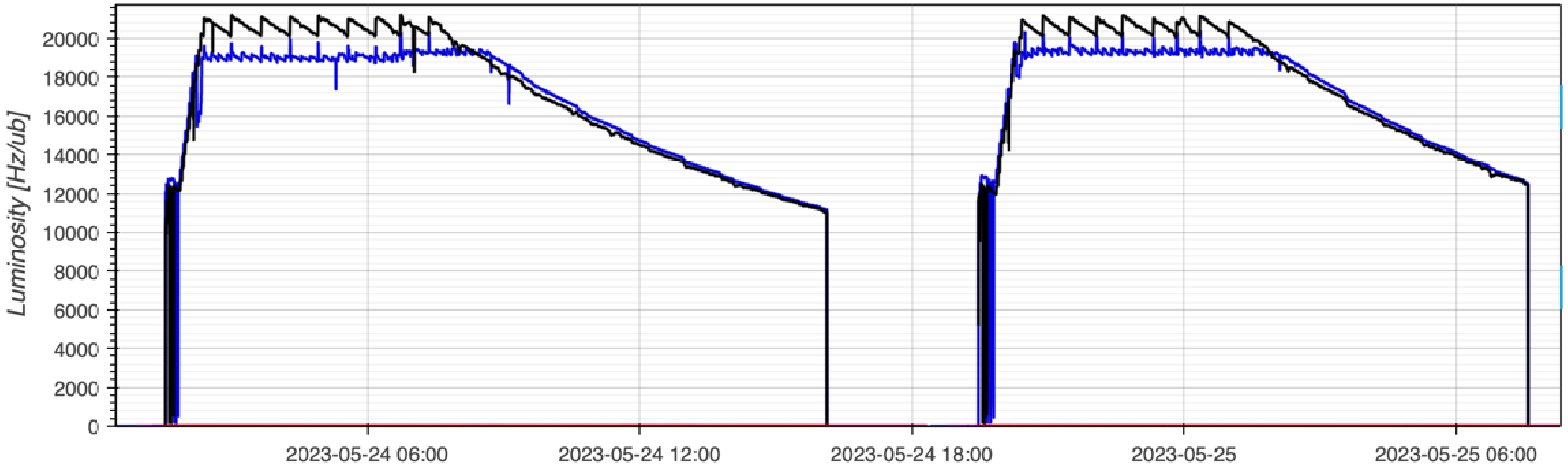
Improve 8b4e brightness and explore reach beyond 2.3e11 p/b, while continuing BCMS characterization

Beam quality: Study in detail and minimize tails in transverse beam profiles across chain

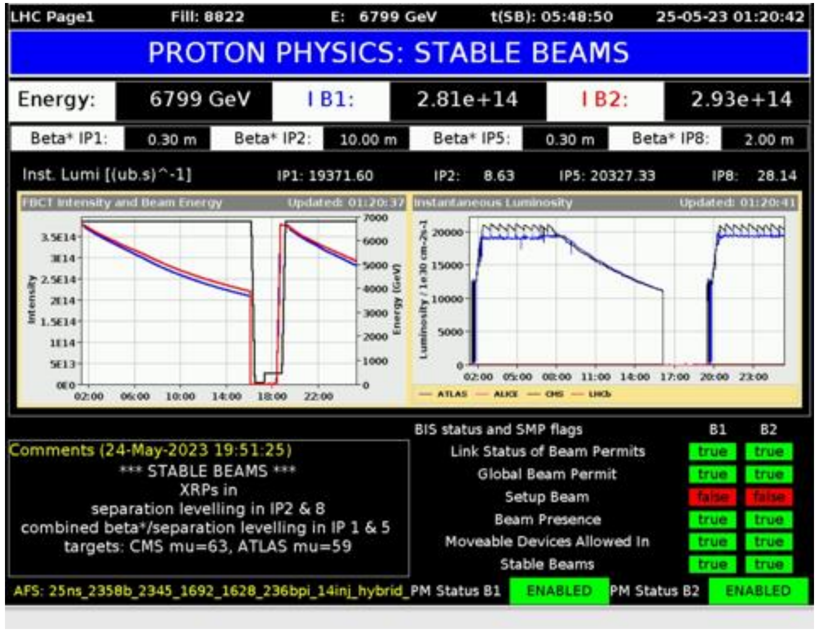
Some excellent physics performance

- **New record: Integrated luminosity of 1.2 fb^{-1} in 24h!**
- **Peak levelling just above 2.0 x 10^{34} $cm^{-2}s^{-1}$**
- **Pileup targets ATLAS/CMS = 63 / 59**
  - Thanks to combined separation β* levelling and separation levelling we can deliver different pile up to ATLAS and CMS

Max energy per beam at start of stable beams: **409 MJ**
1.59 x 10^{11} p/b (Injected: 1.61)

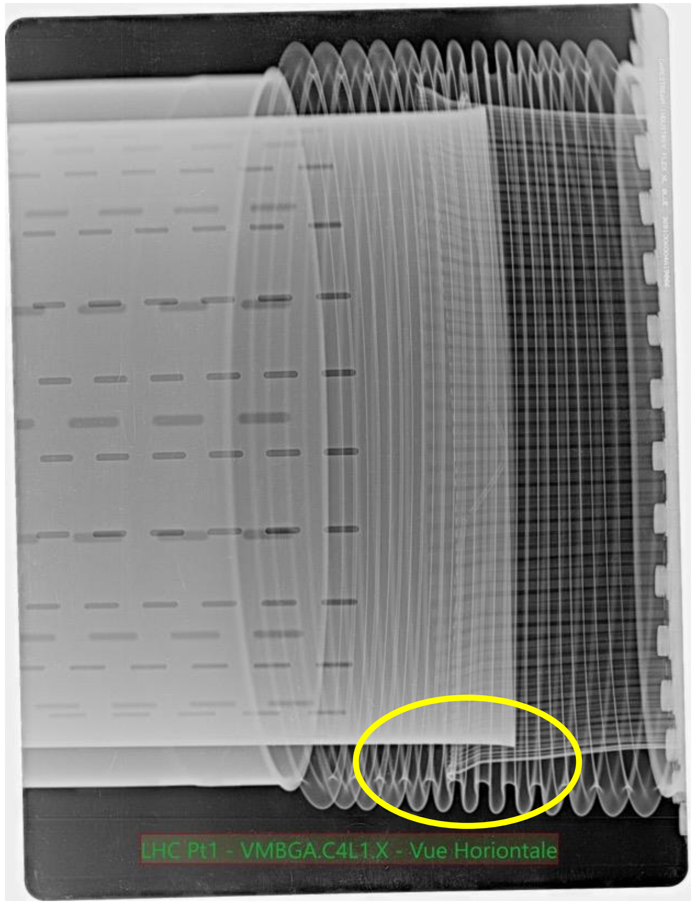


24th to 25th of May 2023

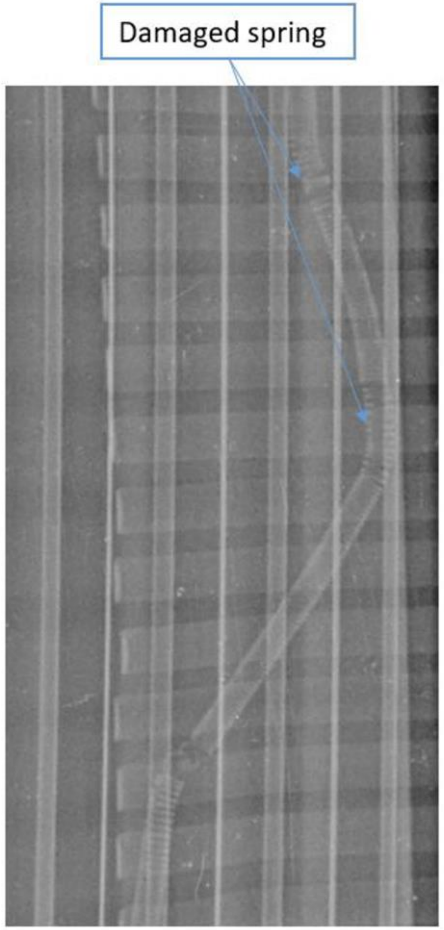


Vacuum Module R1 – May – 5 days lost

How it should look



Spring disengaged with RF fingers not touching

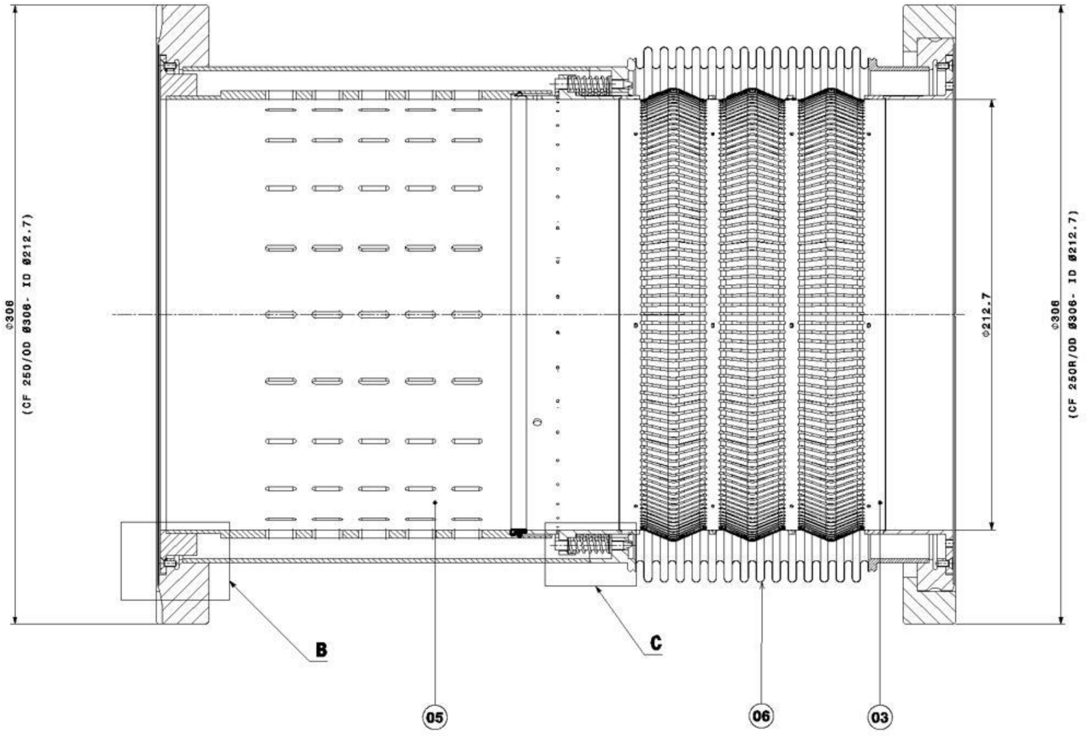


Clear sign of the spring heating

Possibly intensity driven hold at 1.6e11 ppb

Warm module exchange foreseen

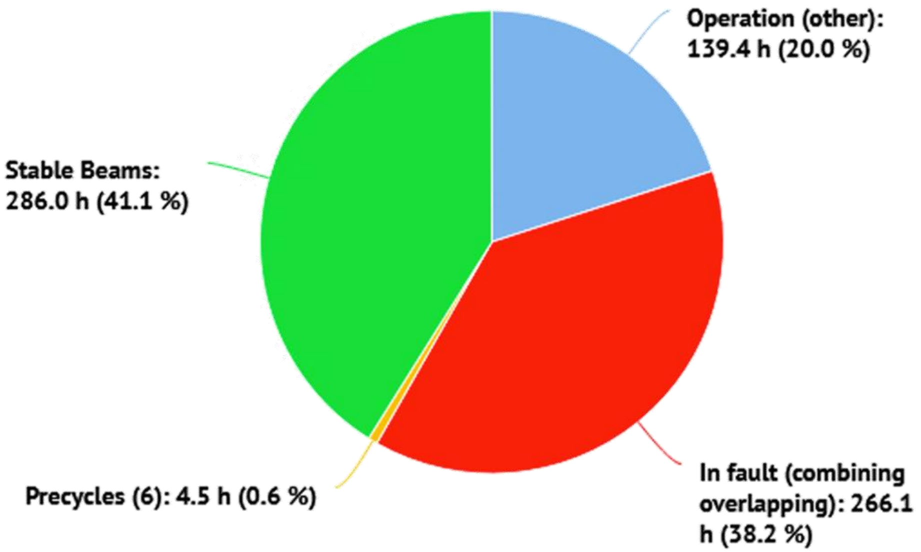
The new DRF warm module design does not contain any sliding RF fingers or a spring to guarantee electrical continuity.

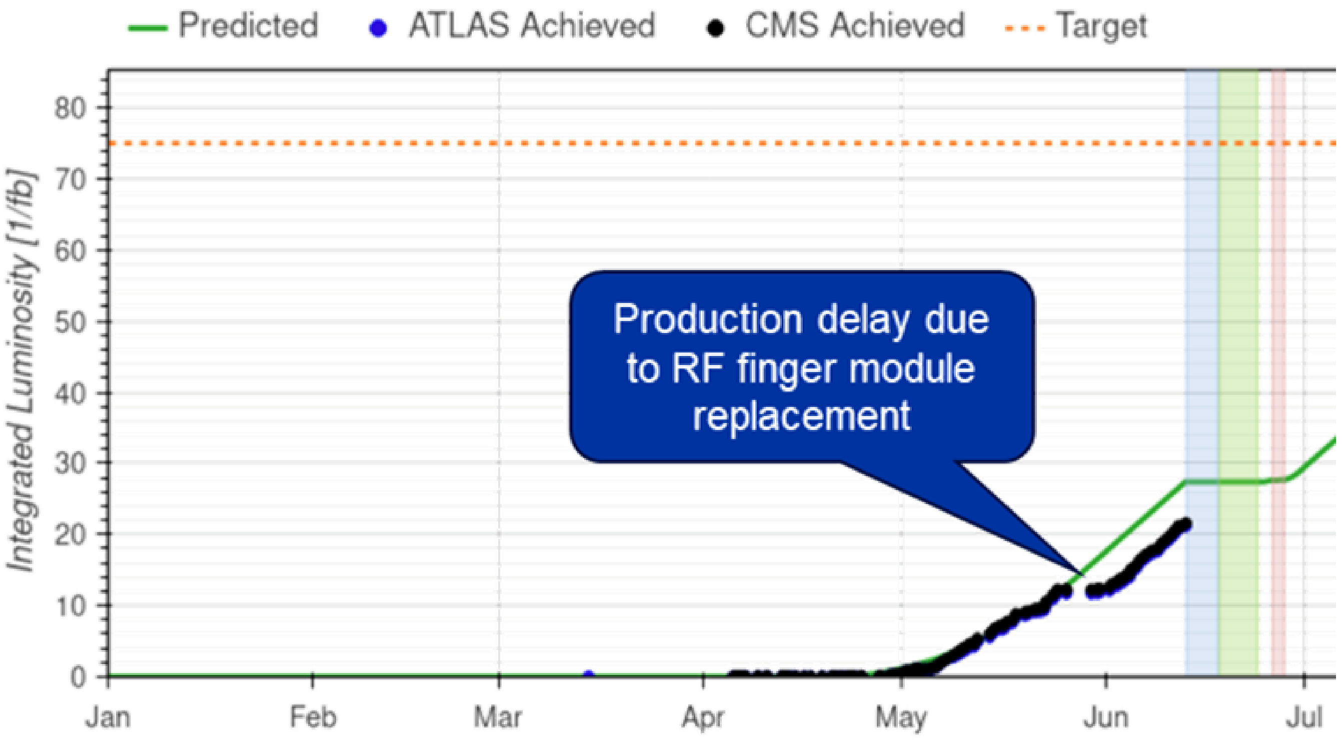


65 warm modules of ID212.7 with two beams circulating inside are installed in the LHC.
Replacement program foreseen – 28 modules in YETS 23/24, the rest in YETS 24/25.

Overall LHC Performance…

May 2023

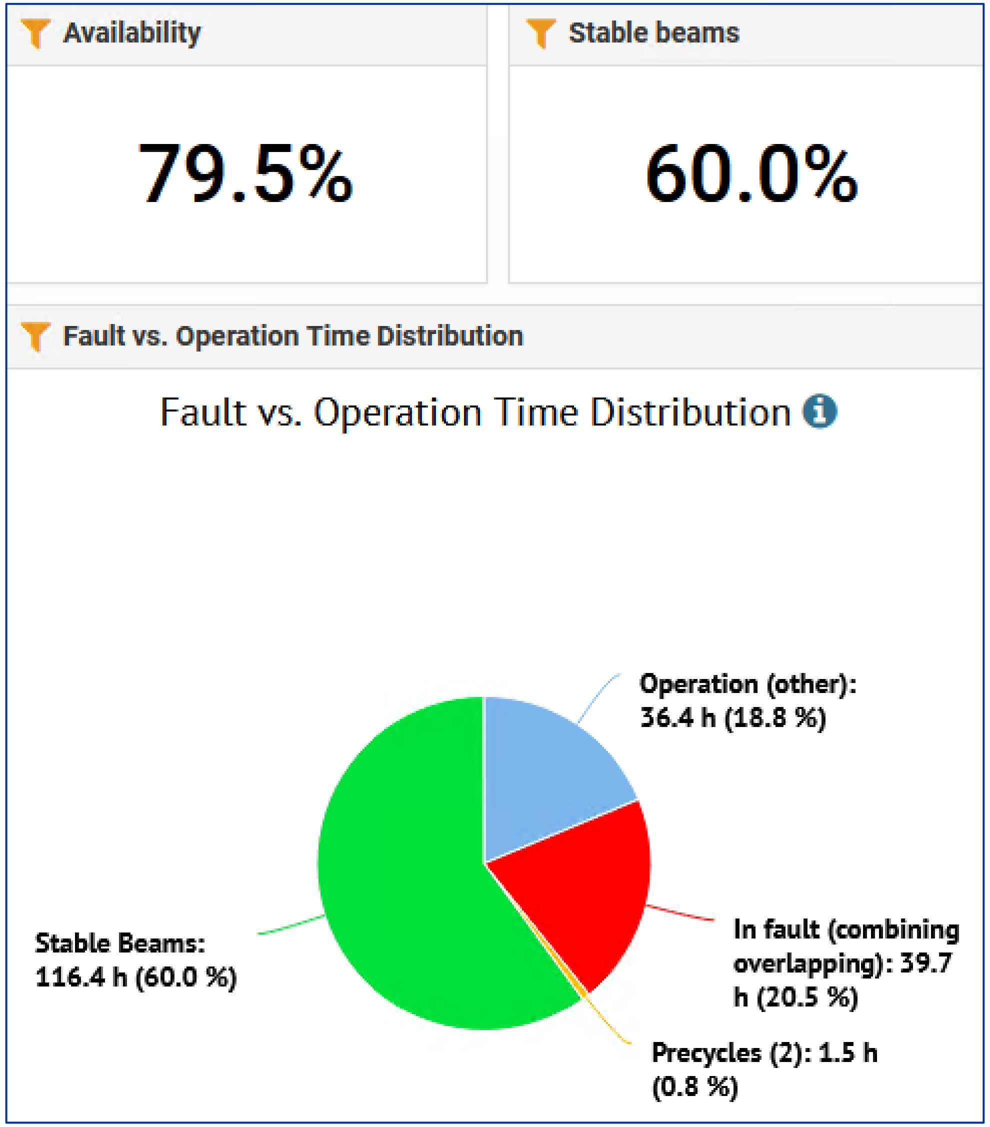




In June 2023

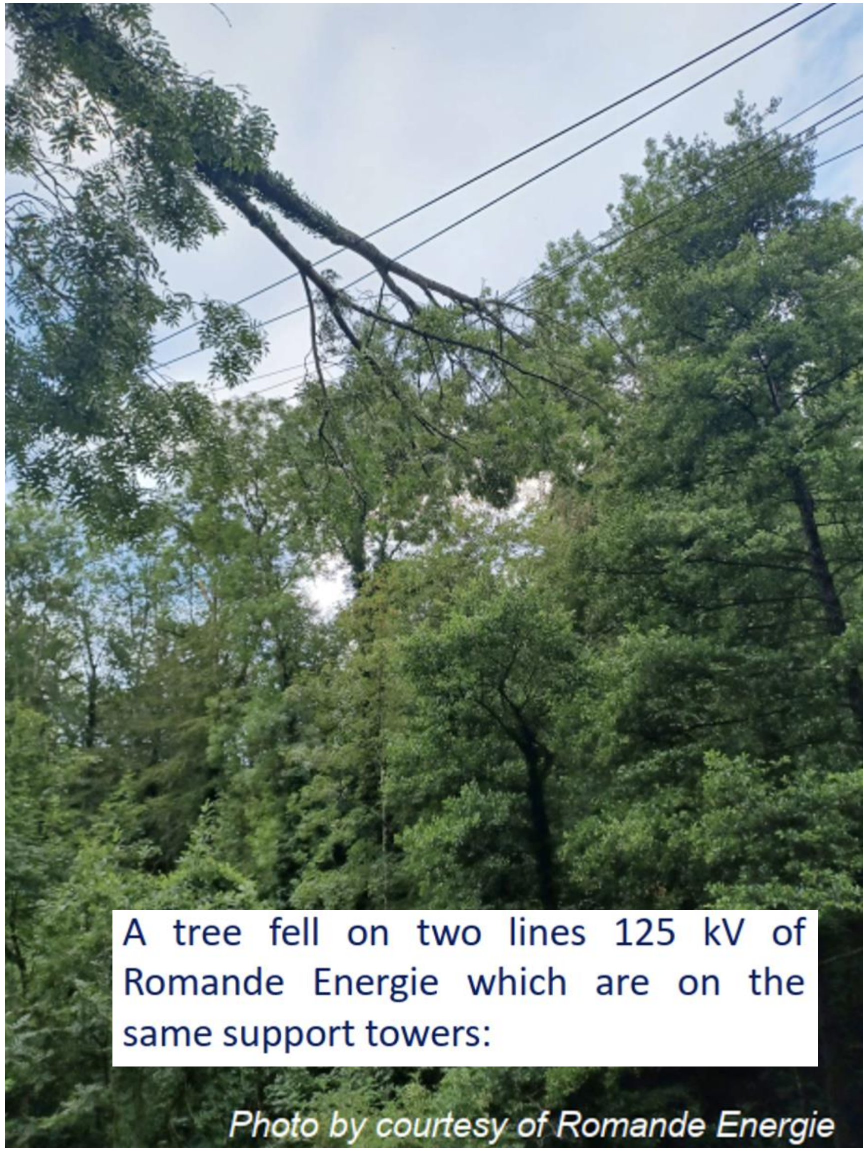
Machine Availability	LHC Stable Beam
71.5%	52.6%

… up to July



However…

17th July 2023 01:00:17



- Beams dumped at 01:00:17 by **RF fault**
- 370 ms later **several magnets quenched**:
  - RQ7/9/10.R4
  - RQ10.R8
  - **RQX.L8**
- The heat wave generated by RQX.L8 quench tripped the **IP8 cold compressor**

Electrical glitch and consequence

30 s after the quench, a significant leak appeared in the vacuum vessels of IT.L8 assembly.

8 hours after the quench, the pressure in the vacuum vessels is at 1 bar and the average temperature of the cold masses is 150 K

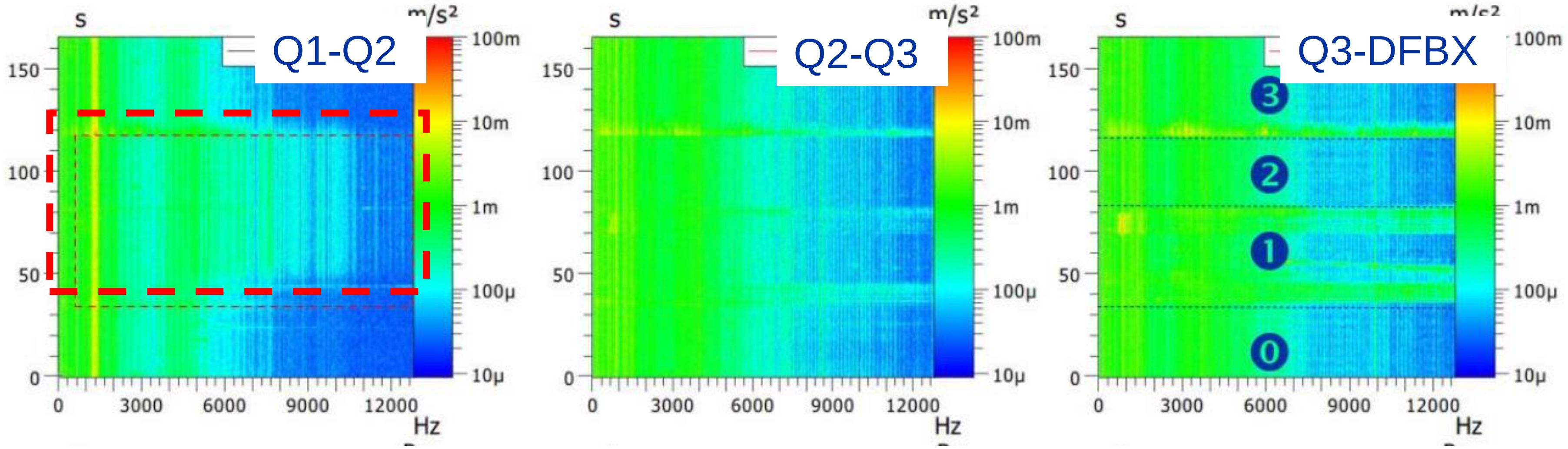
Leak location

Courtesy EN-MME

Confirmed to be in the cold masses volume, the helium leak had to be localised over the 40m of the triplet assembly.

Microphones and accelerometers were installed below the interconnection bellows.

With the pressurisation of the cold masses, accelerometers in Q1-Q2 interconnection measured significant vibration, indicating a possible position of the leak

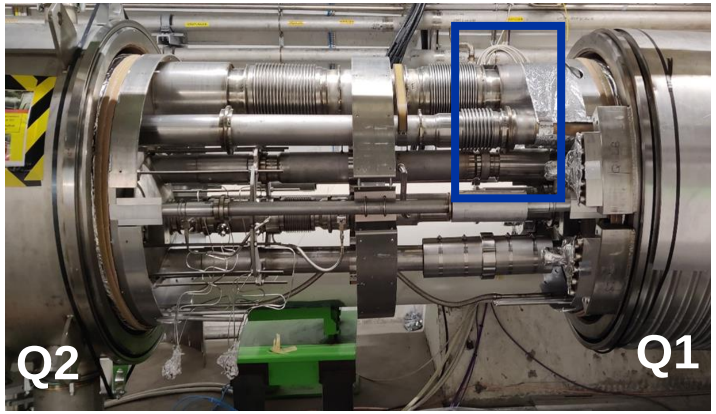


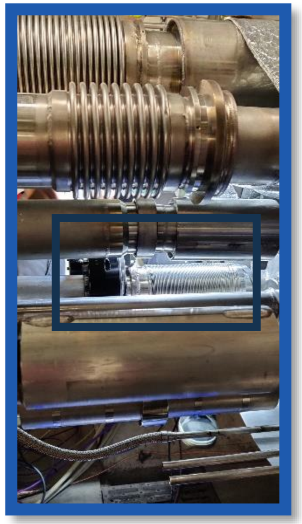
24th July, start of countdown

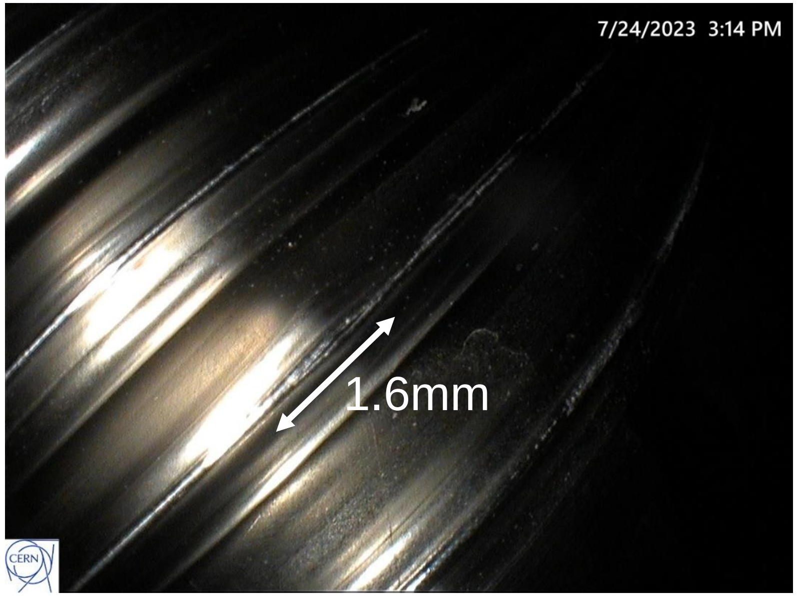
Cryogenics gives 10 day window for intervention - longer will mean warming up sector 78

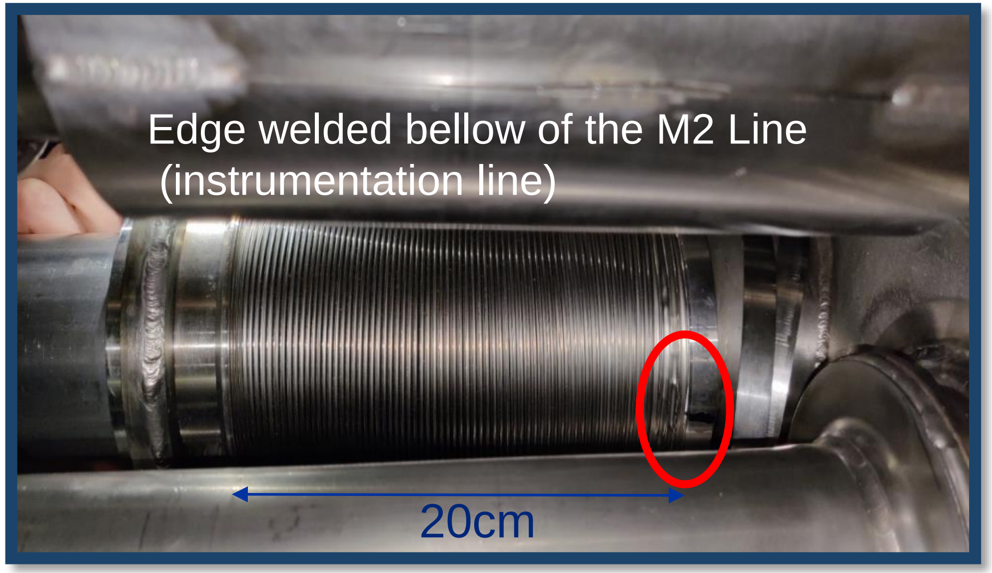
- Complete warm-up of the IT magnets
- Electrical lock out
- Depressurisation of all cryogenics lines
- Injection of dry air in the interconnections

→ Green light to open the IC







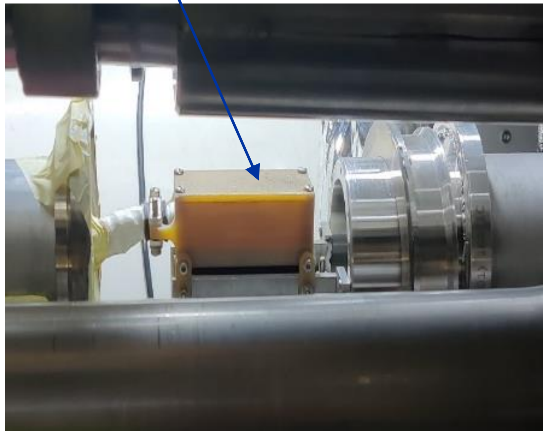


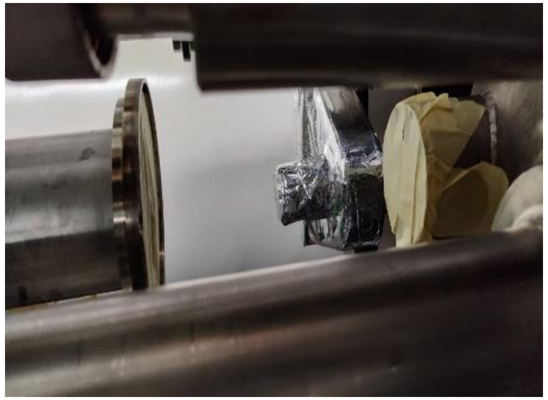
Bellow removal

Tuesday 25th

In IT.L8, the M2 bellow is removed.

Instrumentation onnection box

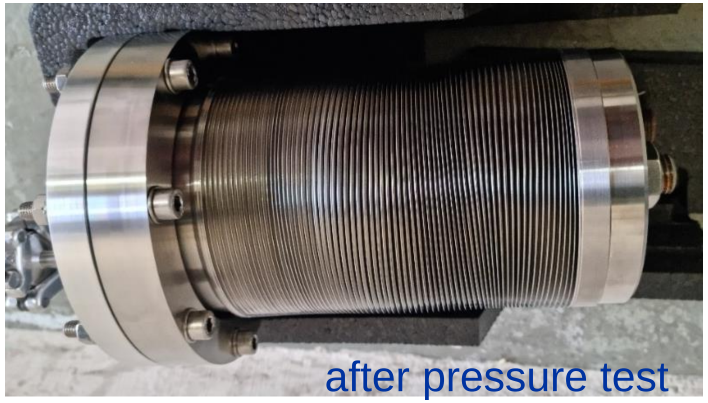




In the lab, 2 spare bellows are pressure tested.

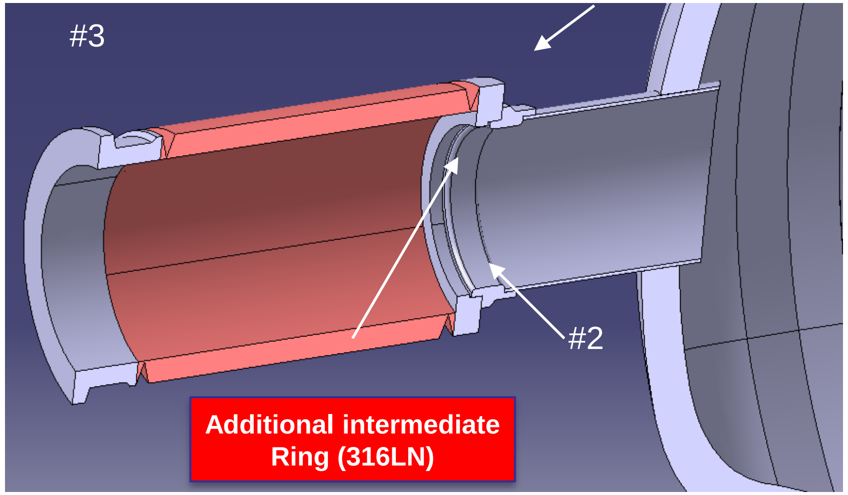
Leak test ⇨ pressure cycle to 20 barg ⇨ leak test

before pressure test



after pressure test

Spare bellows welding



Wednesday 26th & Thursday 27th

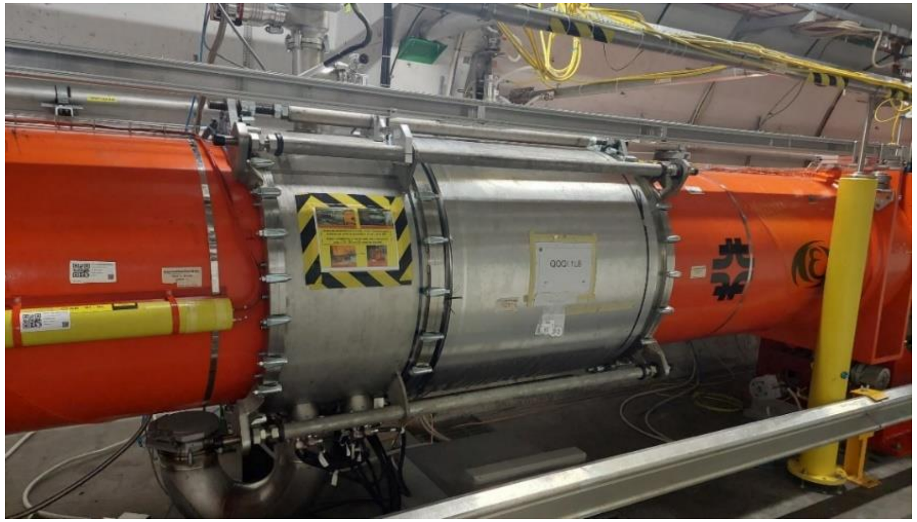
The M2 bellows is an integral component of the as-delivered Q1 cold mass. In-situ replacement of the bellows requires a new strategy of welding at the interconnection.

End of countdown

On Friday 28th, the Q1-Q2 interconnection is closed

→ **Start of Insulation vacuum pumping & tightness checks**

→ **Start of cold mass purging**



B	IT cold mass interconnect bellows	< 10 days *(ARC cooldown before 20 days)*	ARC @ 20 K ➔ 60 K QRL @ 20 K ➔ 250 K ➔ Reconditioning of the IT + D1 needed (without QRL)	+ QRL mechanical damage during unexpected transients (bellows) ✓

In total :

- IT magnet warm-up : 1 week
- Leak repair : 1 week
- Cool-down and reconditioning : 3.5 weeks
- ElQA and Powering : 0.5 weeks

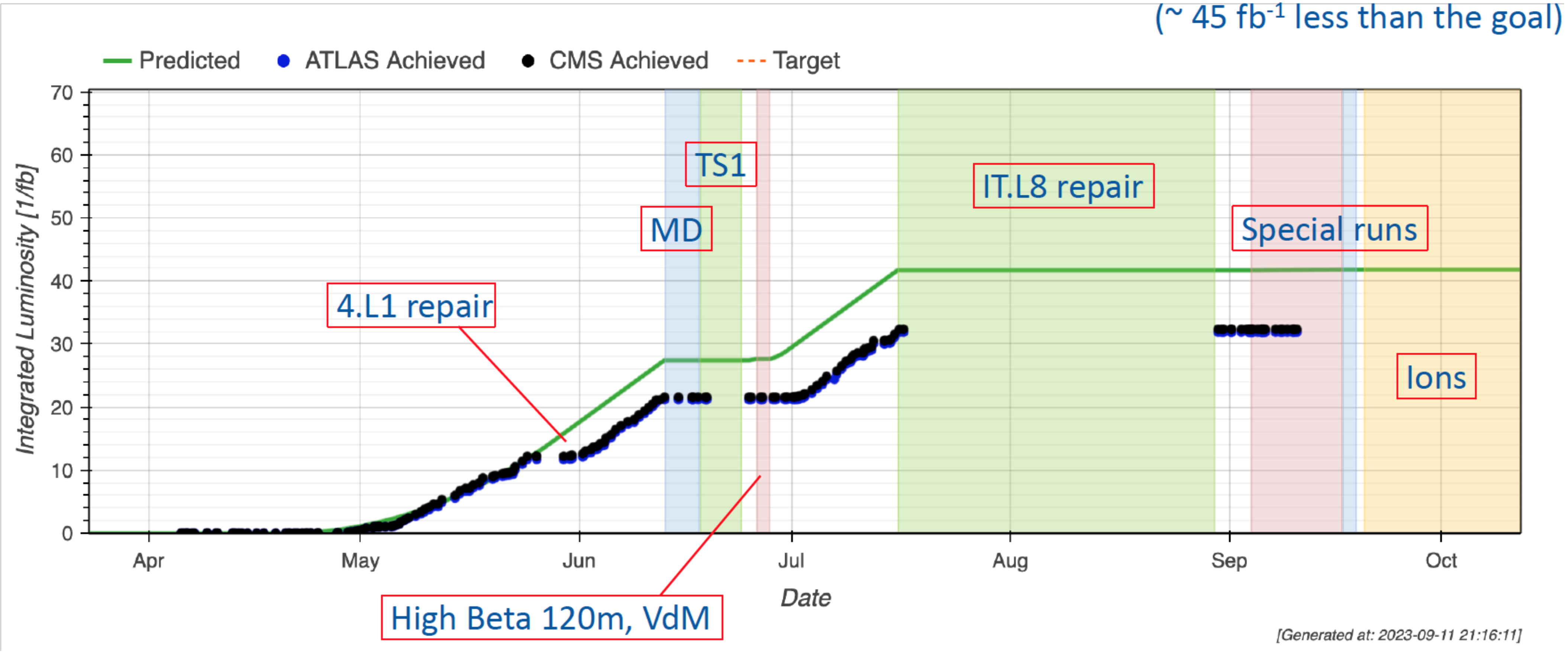
1½ months without beam in the LHC

Proton luminosity 2023

Original goal for 2023: 75 fb^{-1}

After the IT.L8 repair: no more high intensity proton operation in 2023 → total proton dataset for 2023 is 32 fb^{-1}

(~ 45 fb^{-1} less than the goal)

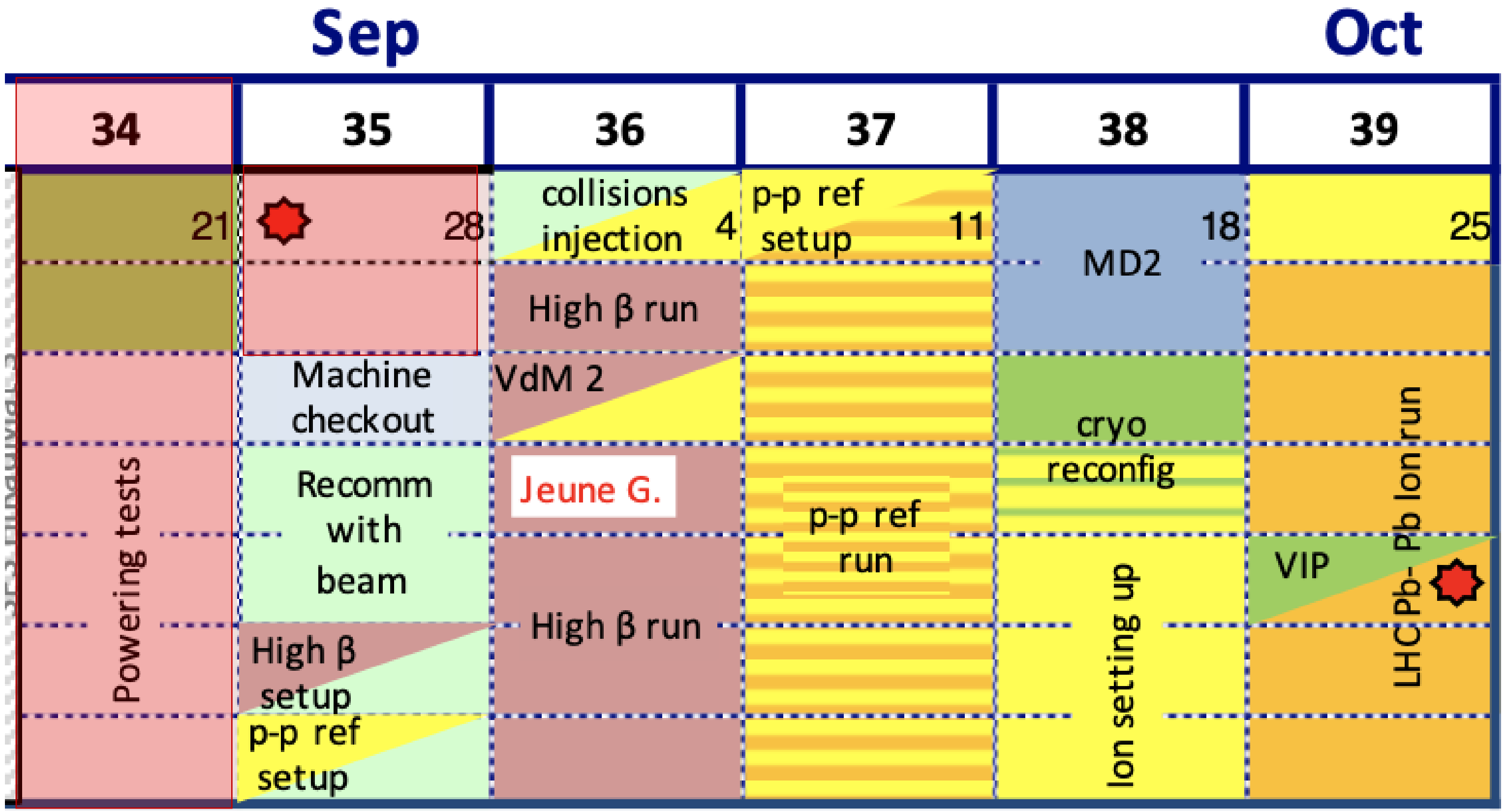


After 4.L1 incident, slope limited by intensity < 1.6×10^{11} ppb


CERN

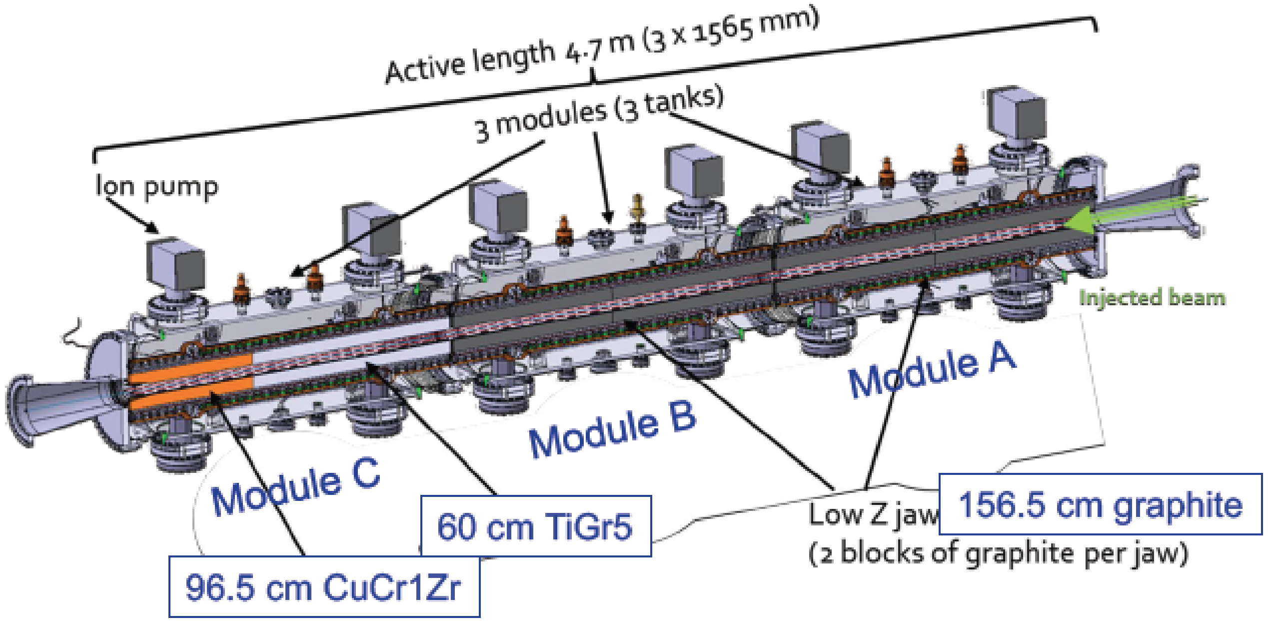
Change of plan

Decided to focus on special runs and ions in the remaining time



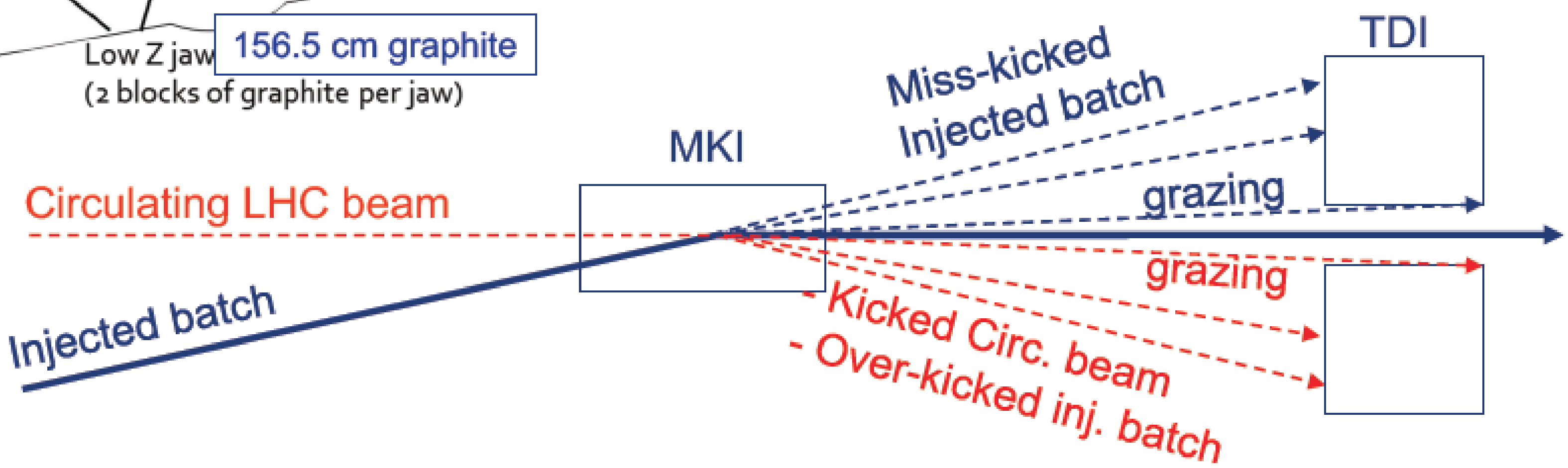
However…

TDIS – Injection Projection Devices



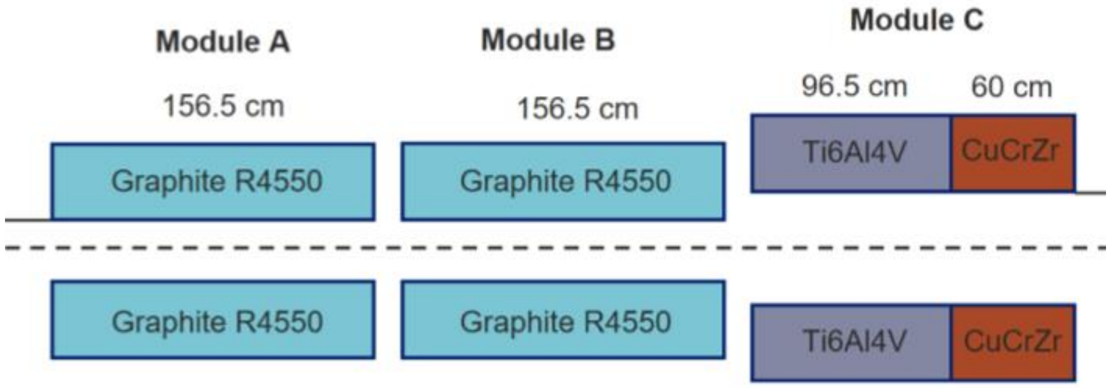
TDIS is an aborber intended to protect downstream LHC equipment during injection phase

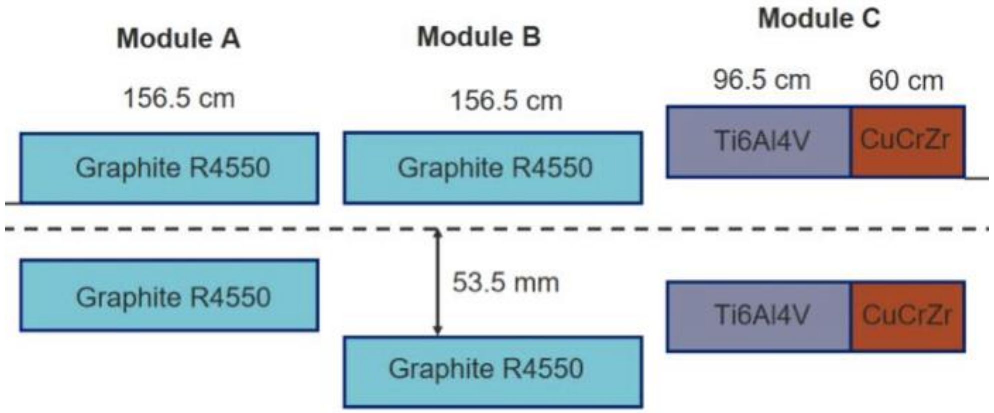
This is an HL compliant device, installed during LS2 in P2 and P8



TDIS-IP8

- A **vacuum leak** developed on IP8-TDIS, starting on 1st September
- **Leak** at the level of module B, bottom jaw, downstream bellow
- Leak varnished and jaw blocked in open position: **degraded injection** setup:
  - ➔ **slightly reduced** number of bunches for **ppref run** (impact on filing scheme)
  - ➔ **NO intensity limitation** for **ION run**

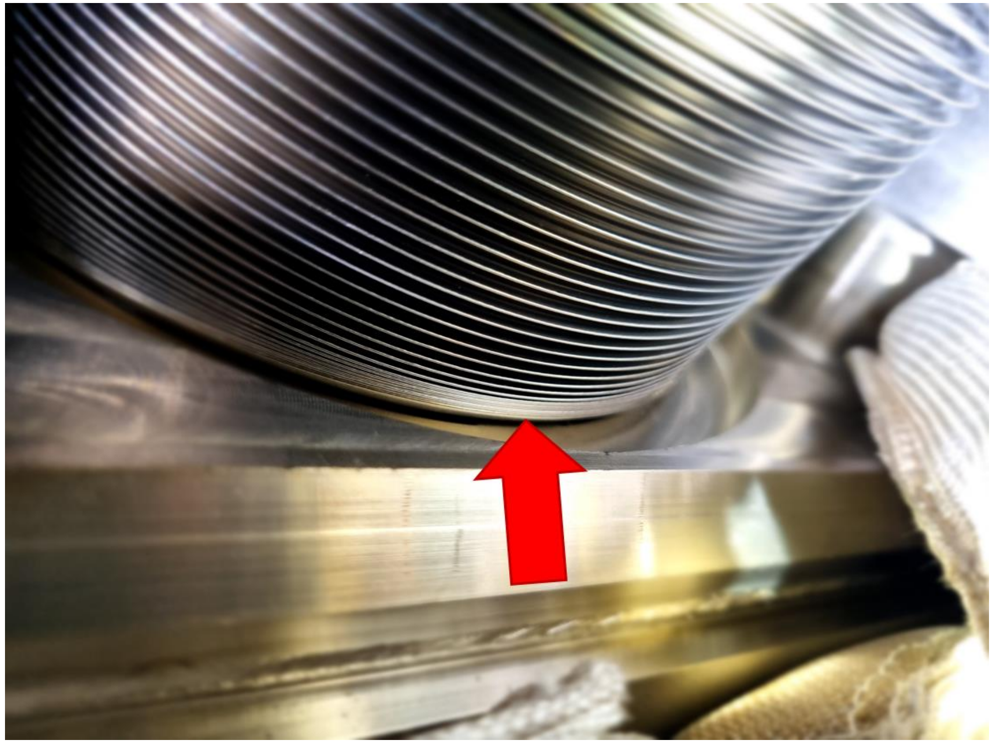


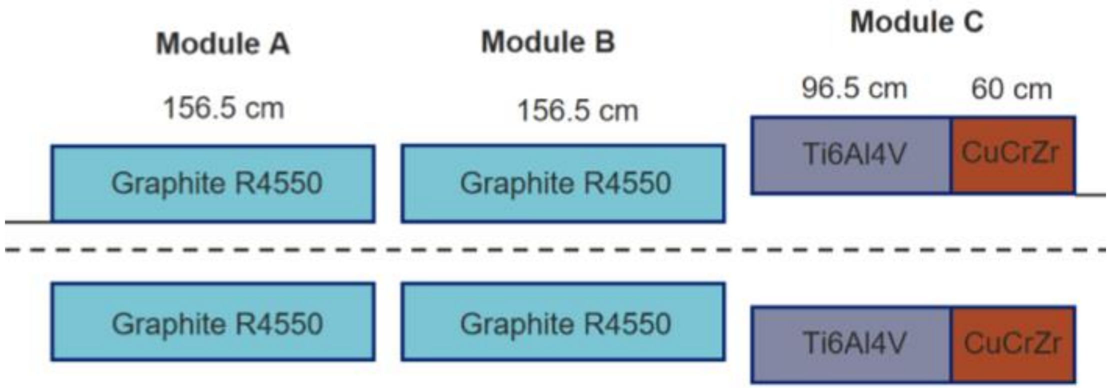


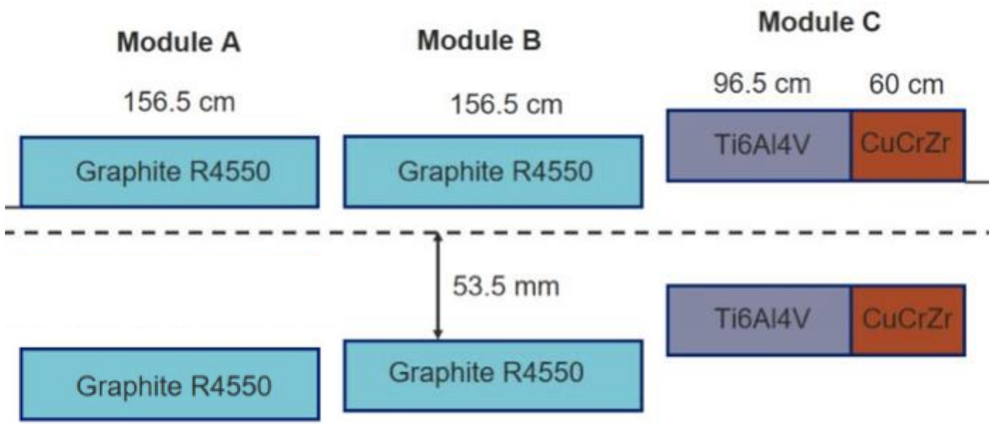
However…

TDIS-IP8

- An **additional leak** developed on the IP8-TDIS, starting on 8th September
- Investigation revealed a **leak** at the level of module A, bottom jaw, upstream bellow
- Leak was **varnished** and jaw **blocked** in open position

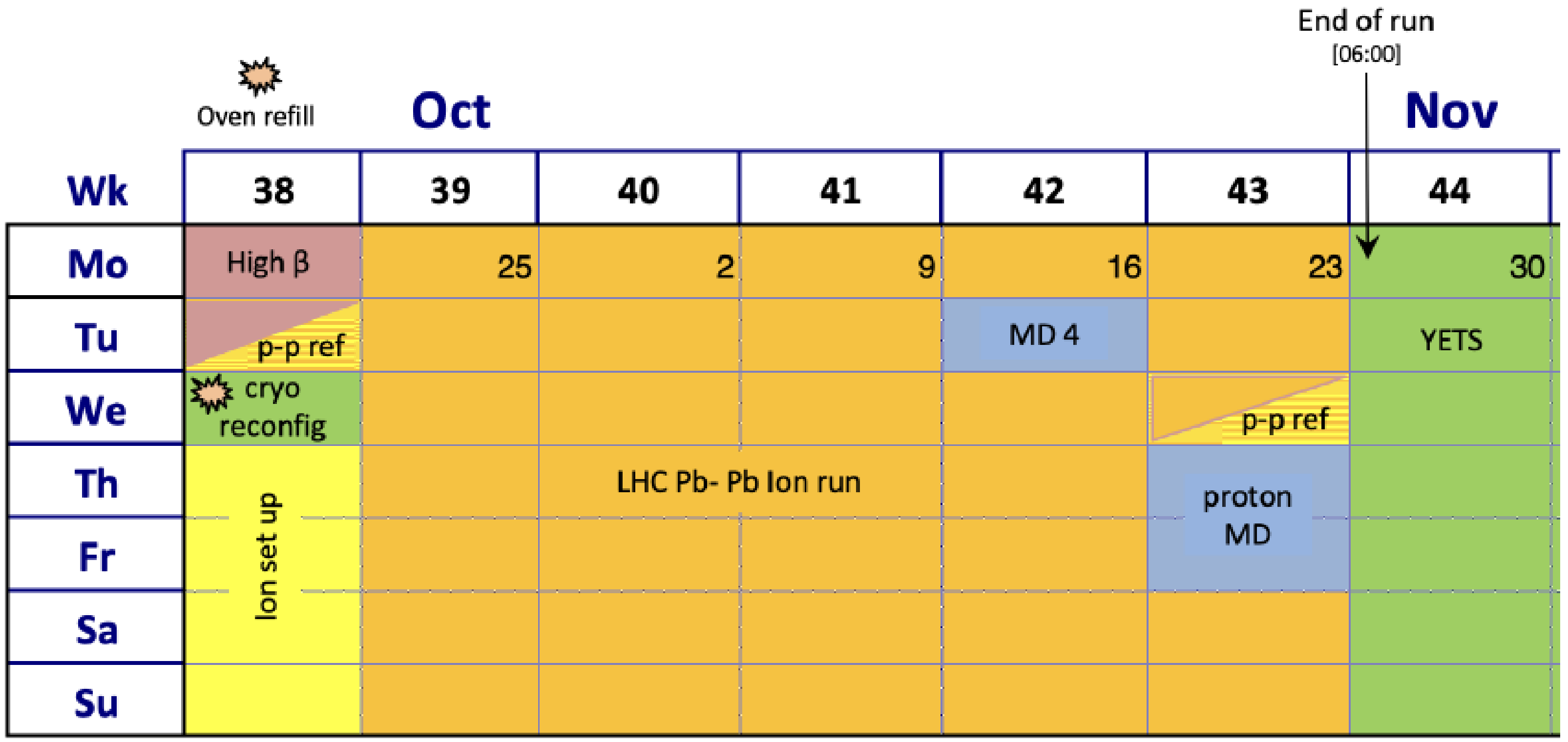






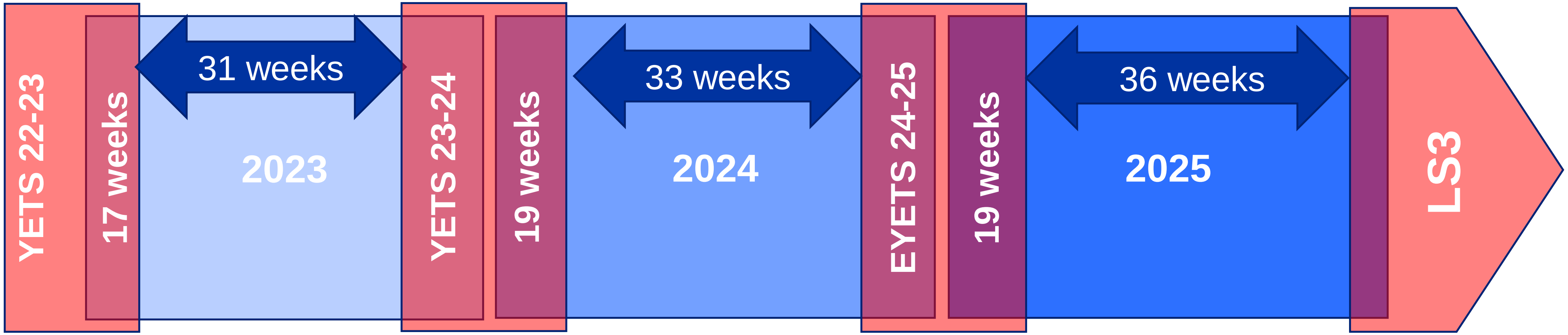
Another schedule update…

With 2 jaws blocked out, TDIS-IP8 OK for ion runs but not for full pp reference run



Run 3 Schedule

- **Reduced operation in 2023 but total for 2024/2025 remains unchanged**
- **Optimised the running time to adapt to energy costs to bring significant savings without impacting overall physics time beyond that introduced with 2022 & 2023 measures**

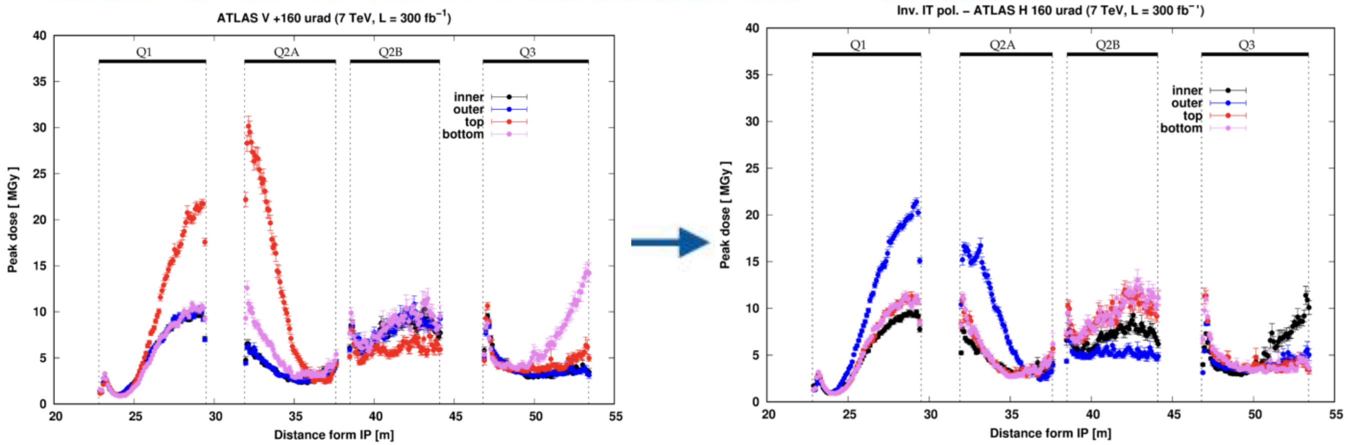


Baseline start of LS3 is 17 November 2025

Total pp goal for Run 3 was 300 fb-1, revised to ~260 fb-1

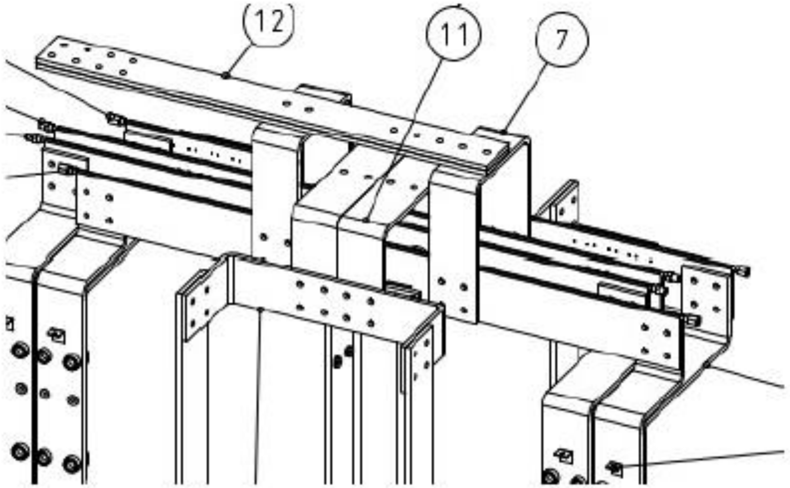
Triplet polarity inversion

Possibility to mitigate radiation dose to the triplets by inverting the polarity and changing the H/V crossing plane. Potential to extend the lifetime of the triplets by 25% (i.e. extra 125 fb^{-1}).



Task force investigated technical challenges of reverting the polarity.Proposed solution: polarity inversion on the power supply

After the end of 2023 run (first week of November) there will be powering test. No delay of YETS start.



Triplet Polarity Inversion (latest)

Assumption of 100 fb^{-1}/y for 2024 & 2025

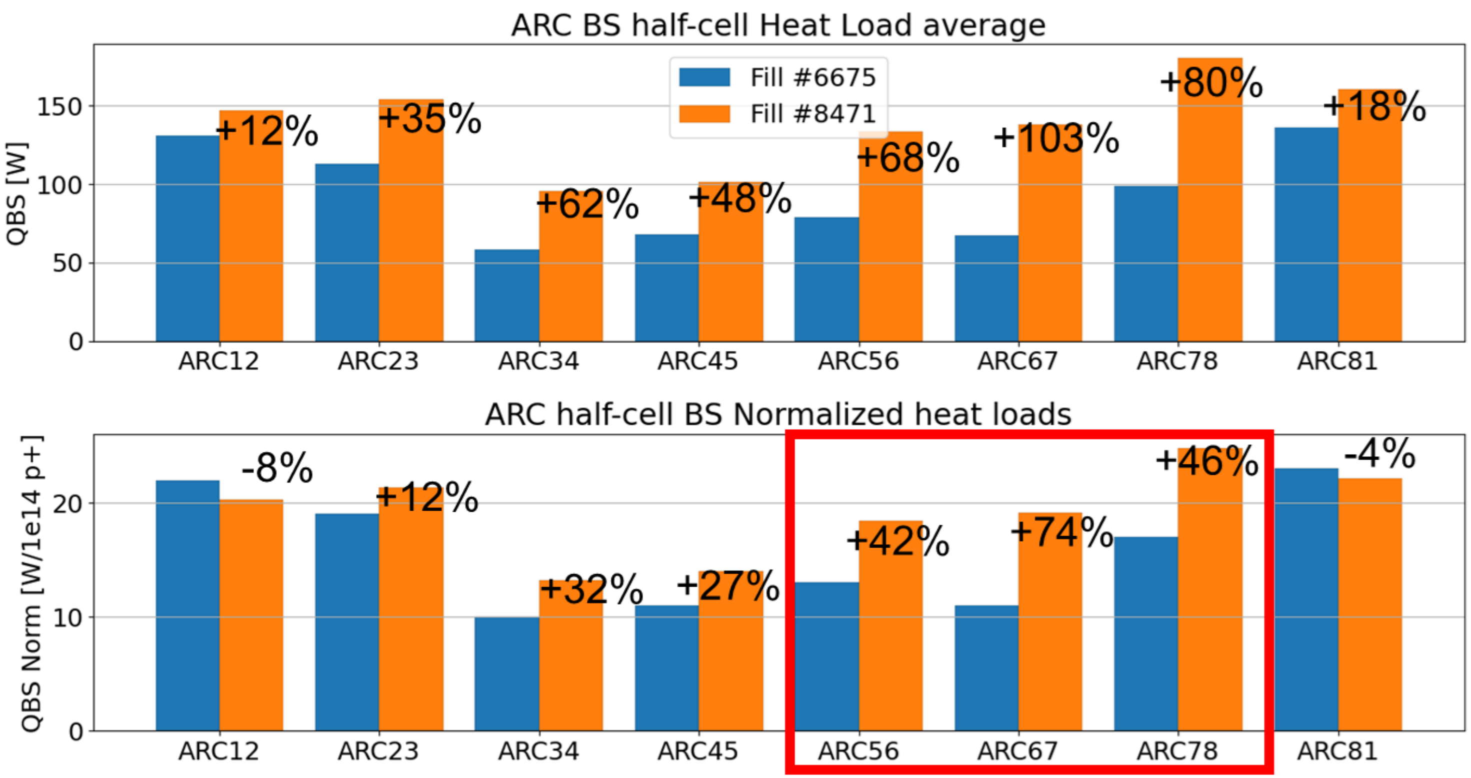
Optics	IP1 Xing	Max value (Q2A IP1)
Standard in 2024/2025	UP (2024) DOWN (2025)	28 MGy
	DOWN (2024) UP (2025)	28 MGy
Standard in 2024, RP in 2025	UP (2024) H (2025)	25.1 MGy
	DOWN (2024) H (2025)	27 MGy
RP in 2024/2025	H	21.3 MGy (*)

F. Cerutti

(*) but now Q2 in IP5 becomes the most irradiated, with ~22 .5 MGy

Electron Cloud Heat Load

Sector 7-8 emerged degraded from LS2, determining the heat load limitation of the LHC



LS1

- Provoked significant degradation of heat loads in S12 & S23 & S78 & S81

LS2

- Provoked significant degradation of heat loads in S56 & S67 & S78

Thanks to the **hybrid filling scheme** (mixture of 8b4e and 36 bunch trains),
the heat load is under control for Run 3

Beam screen heat load – longer term

Problem

- Non-uniform heat load along the LHC arcs
- Important scatter within arcs, cells, magnets.
- Degradation during Long Shutdowns

Origins*

- Presence of CuO layer – Max SEY > e- cloud threshold
- Low carbon concentration – limited surface graphitization (required for scrubbing)

Objectives

- Remove CuO and/or increase surface carbon concentration on selected Beam Screen (BS)
- BS surface passivation (robustness against re-oxidation)

*Cf. Valentine Petit's PhD thesis: https://cds.cern.ch/record/2721533

Beam-Screen Treatment Project phases

Proposal for a New Project aiming to reduce the LHC's heat load by in-situ Beam-Screen Treatment (BST) presented at last week's LMC

Phase 1 – Process selection / optimization (2 technological choices) (up to Q2-2024)

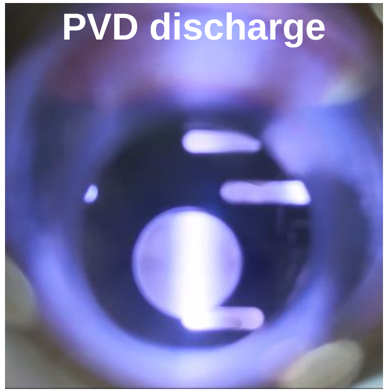
Phase 2 – Mock-up demonstration / Personnel training (Q2-2024 → Q1-2026)

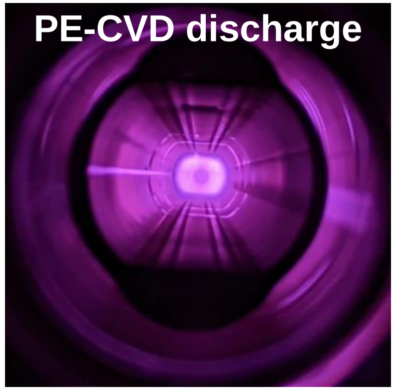
Phase 3 – Implementation in the machine (Q2-2026 → Q2-2028) – LS3

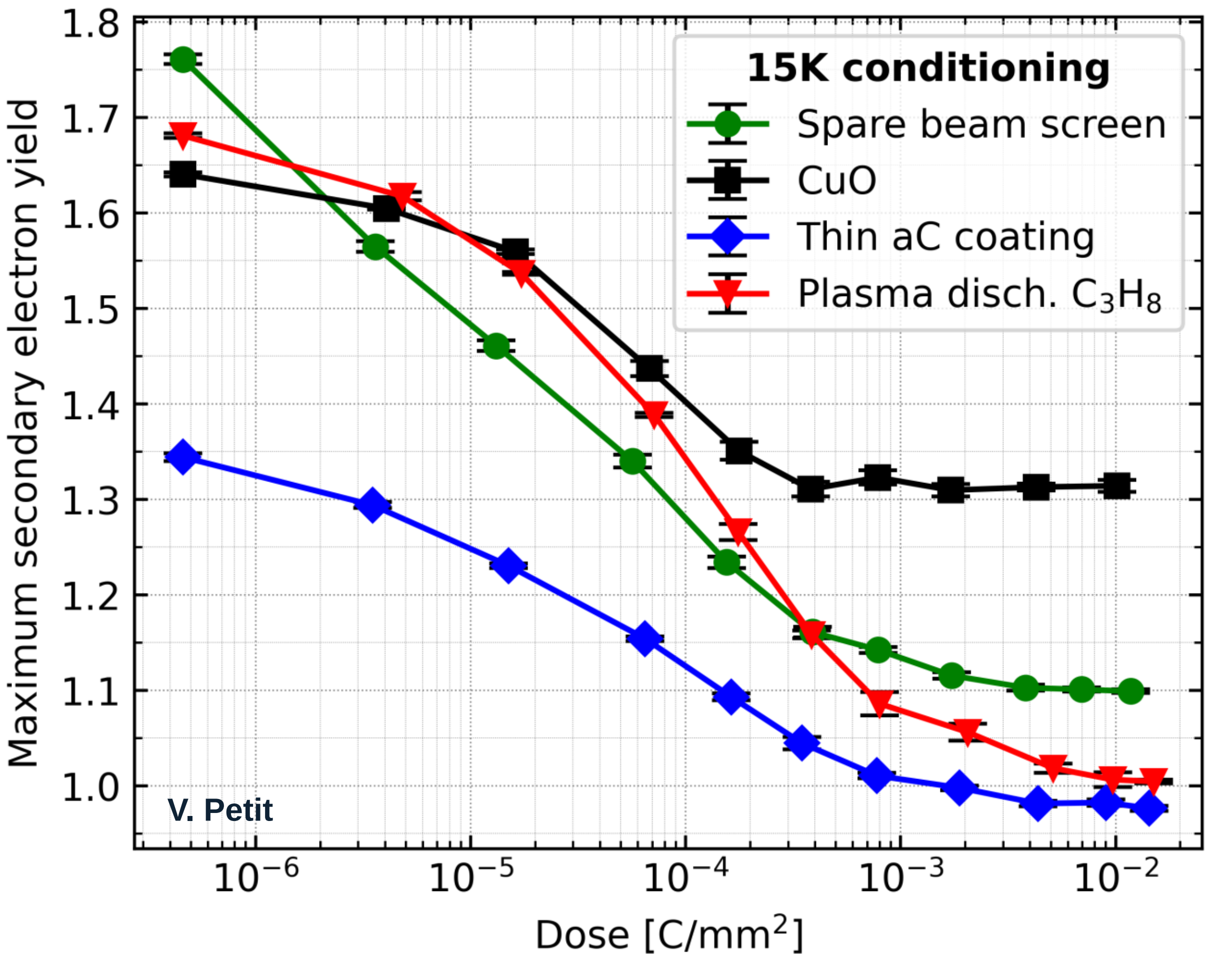
	2023				2024				2025				2026				2027				2028			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Phase-1																								
Phase-2																								
Phase-3																								

Phase 1 - Activities

- **Thin a-C coating vs Plasma discharge in C_xH_y**
- **Samples qualification**
  - SEY quantification on samples
  - **P**hoto-**E**lectron **Y**ield quantification on samples
  - Ageing (multiple 15K conditioning + Air exposure cycles)
  - Adhesion
  - **E**lectron **S**timulated **D**esorption







Summary remarks

LIU targets achieved in injectors!

LHC in Run 3 has demonstrated

- Excellent luminosity performance – both peak and integrated
- Good availability over sustained periods of time
- Impressive flexibility and sophisticated operational and system level control

However, 2023 has been a difficult year with poor availability

- Pushing performance in an aging machine? Non-conformities? Might worry that it’s systematic…

Reactivity has been fantastic as always, IT.L8 widely seen as a remarkable collaborative recovery

Triplet longevity and electron cloud remain key issues going forward…

THANKS!