Status of the Accelerator Complex

Matteo Solfaroli BE/OP

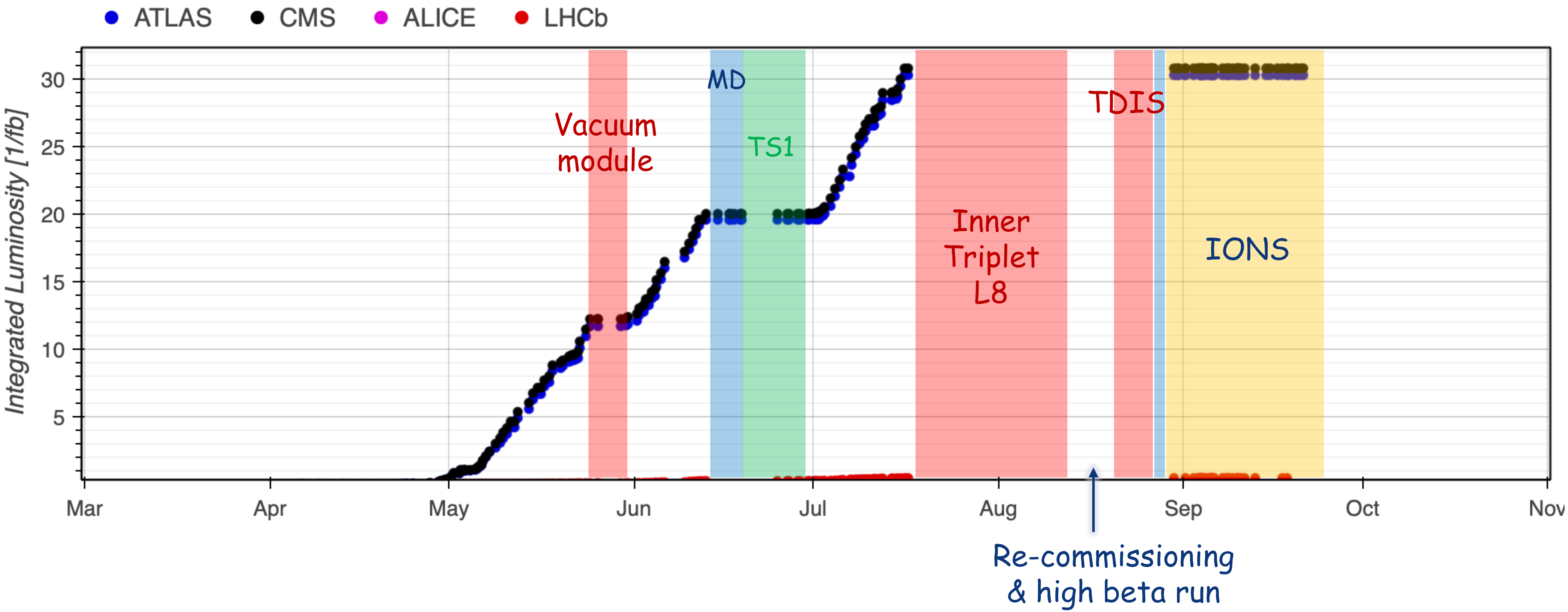
Plenary RRB 58th Meeting

April 22nd, 2024

Outline

- **Main issues from 2023: status and impact**
- 2024 beam commissioning status
- Outlook for rest of Run3

2023 luminosity production vs main faults



Vacuum module

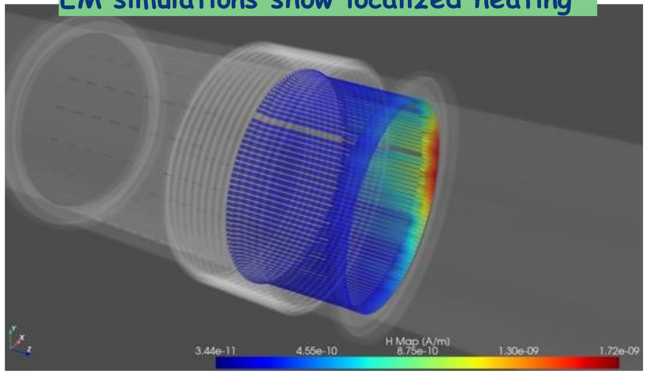
IMPACT in 2023

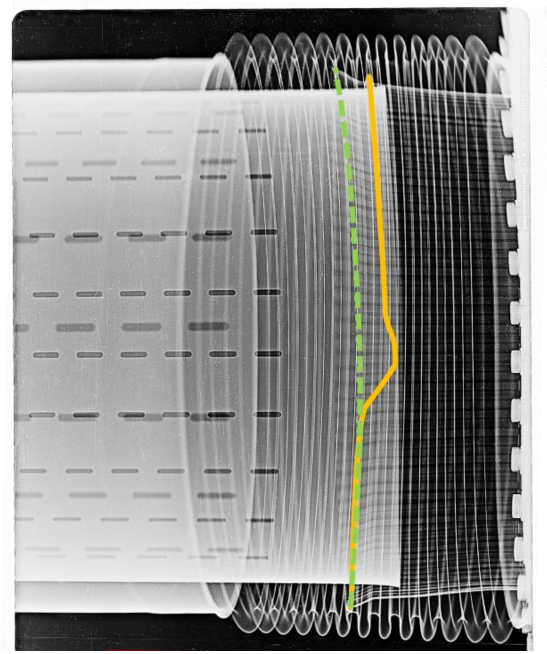
- ~5 days lost
- Bunch intensity limited to 1.6e[11] p/b

- Difficult to identify **intensity limitation** (strong dependence on contact quality)
- **2024 LHC operation** presently limited to 1.6e[11] p/b
- **Simulations ongoing** to assess impact of beam parameters on power deposition

VISUAL INSPECTION
annealed/plasticised spring on the 212 mm vacuum module due to localized temperature increase to more than 500°C

EM simulations show localized heating



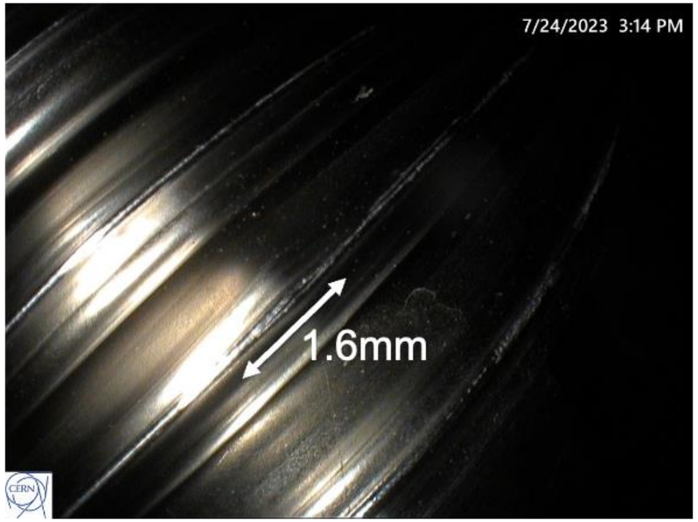


Consolidation plan:

- 47 replaced during 23/24 EYETS
- 24 foreseen in 24/25
  - No failure expected with ideal contact

IT.L8

- Electrical glitch triggered Inner Triplet (IT) **magnets protection**
- **Fast pressure rise** in the cold mass
- **Leak** in vacuum vessels ➔ atmospheric pressure in ~8h
- Fast repair thanks to **special cryo procedure**



Equivalent risk of failure on others ITs

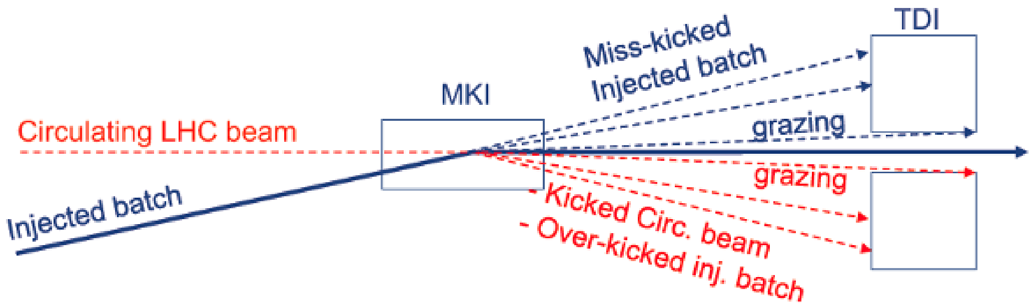
- Similar bellow extension
- Multiple pressurisations since their installation: NO fault

Mitigation measures

- **No intervention** planned (IT maintained at cold)
- **Consolidation planned** for LS3

Target Dump Injection Segmented (TDIS)

- **TDIS:** absorber meant to protect downstream equipment during injection phase
- **High-Luminosity compliant** devices were installed during LS2
- **2 vacuum leaks**, due to NON-conform bellows led to end of pp operation
- During EYETS 23/24 **both TDIS replaced** with spare (“non-compliant”)



NO limitation expected

- Mechanical stress reduced
- Conform spares expected by **September 2024**

Outline

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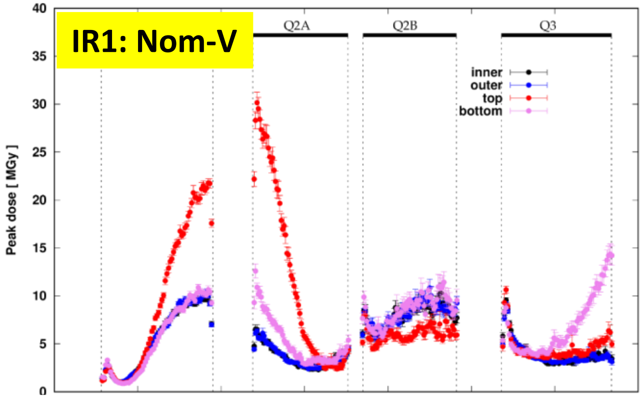
- **2024 beam commissioning status**
- Outlook for rest of Run3

Reversed Polarity (RP) optics

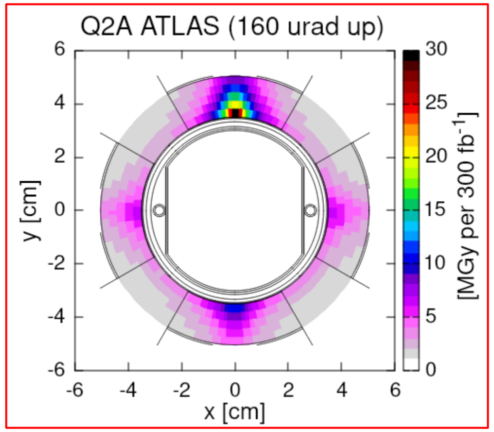


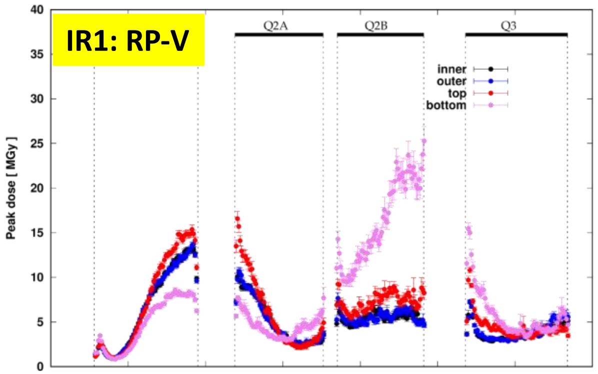
Excessive dose deposition on magnets of Inner Triplet region (close to interaction point) can lead to <u>damage and failure</u>

Solutions to **redistribute the radiation**, allowing for longer lifetime of the equipment:

- Local optics change (implemented in P1, as most critical)

Example for IP1



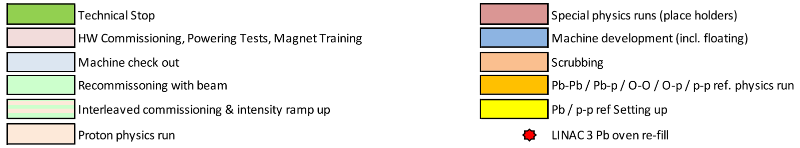


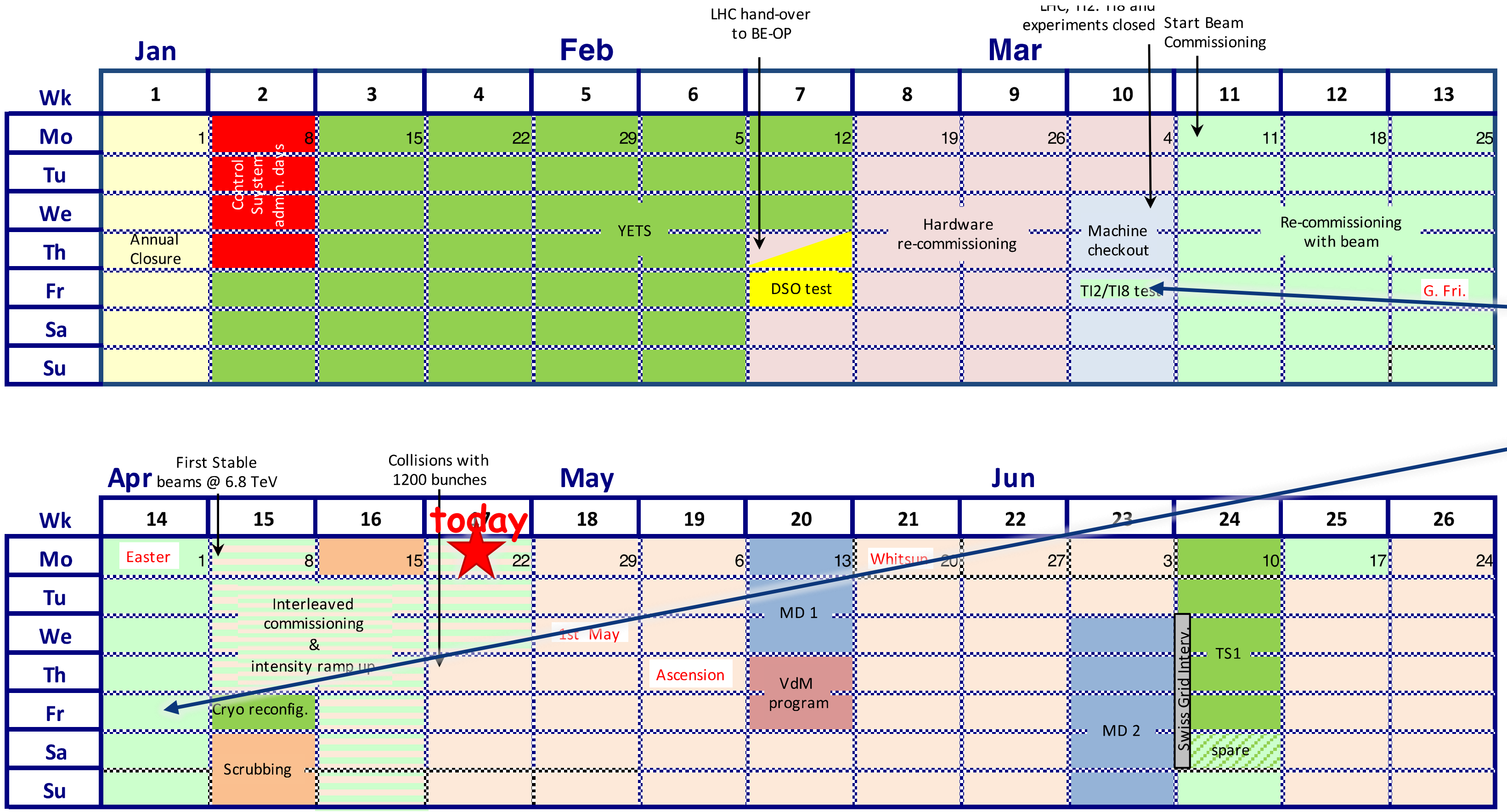
Configuration	Peak dose [MGy] at end of 2025 (430 fb^{-1})	
	IT	MBXA (D1)
NO change	26.5 (IR1) 26.5 (IR5)	**105** 70
2024 - **IP1-RP** 2025 - Full RP	20.5 (IR1) 22.5 (IR5)	70 60
2024 - **IP1-RP** 2025 – NO change	22 (IR1) 26.5 (IR5)	70 70

Estimated damage limit:

- 30 MGy for IT
- 90 MGy for D1

2024 LHC schedule ver. 2.0 + Q1+Q2

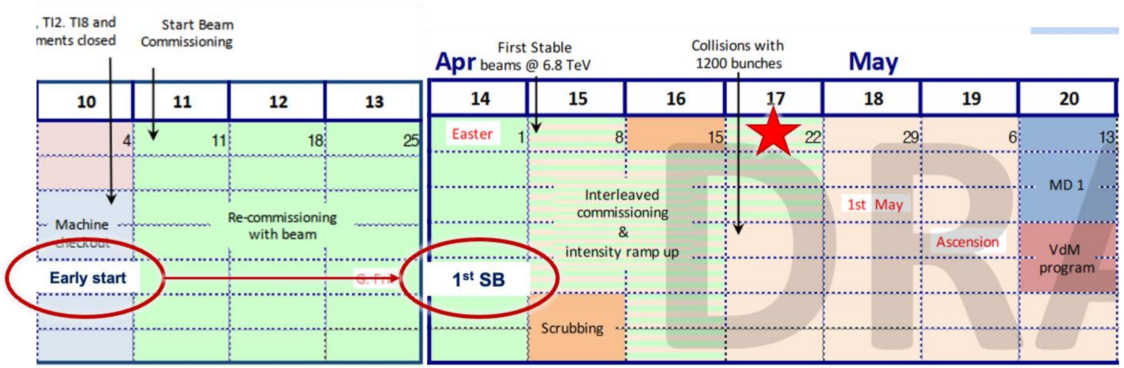




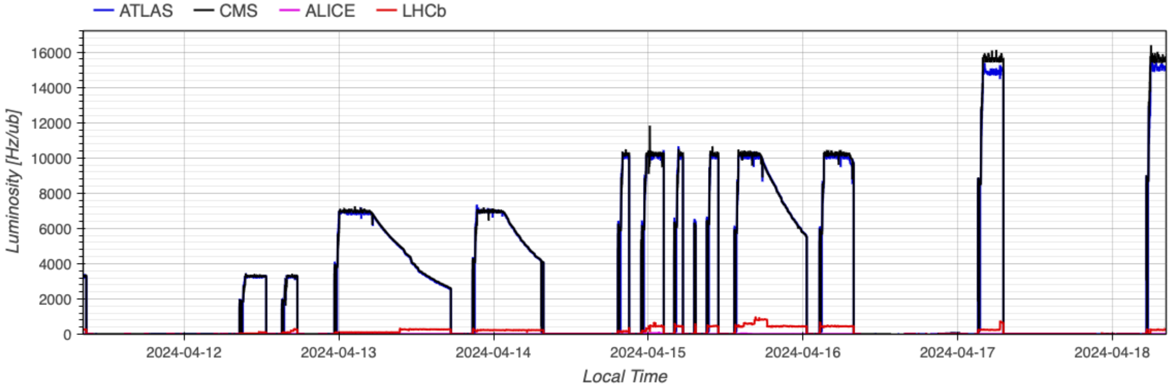
- **Hardware commissioning** completed in time
- **First injection** on 8th March (3 days ahead of schedule)
- **First STABLE BEAMS** at 6.8 TeV on 5th April (3 days ahead)
- **Scrubbing** succesful
- **Intensity ramp-up** ongoing (presently physics with 1983 bunches)

Establishing physics production

- **Beam commissioning** completed in the 4 weeks allocated:
  - Well established baseline, effective knowledge and control: **early start** (3 days) -> **early stable beams** (3 days)
  - Optics change accounted for ~1 week (as expected)
- Step-wise approach for **intensity ramp-up**:
  - Monitor behavior during >15h in stable beams
  - Validate progressively correct functionality of machine-protection system and operational tools
  - Bunch intensity ~1.55e^{11} p/b



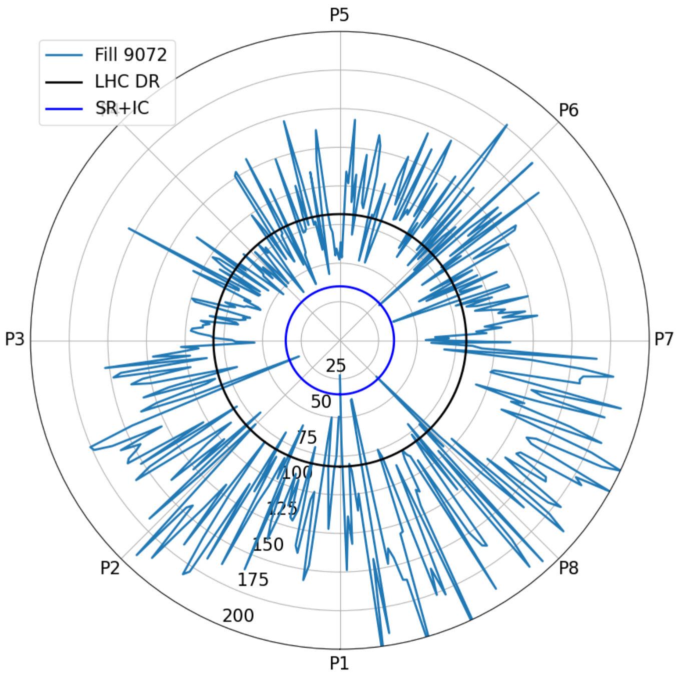
3/12 - 75 - 400 - 800 - 1200 - 1800 - 2400 - full machine*



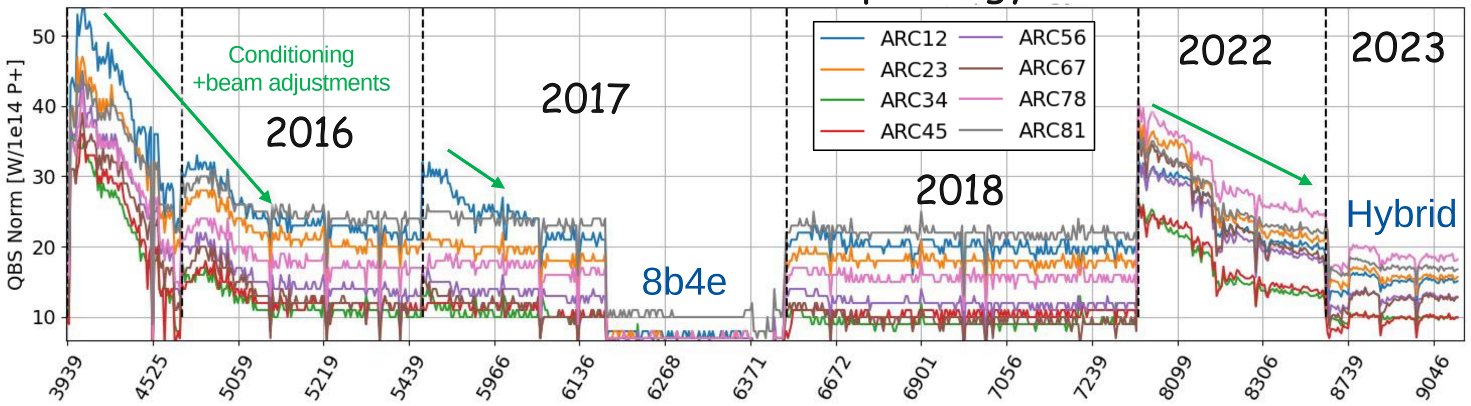
Heat load

- Heat load (HL) deposited by the beams **can become a limitation** when not enough cryo capacity (presently well beyond the Design Report value)
- **Gradual conditioning** helps to increase the beam intensity
- **Degradation observed** when sectors are vented to air (LS)
- **Non-homogeneous distribution** across the machine
  - Sector 78 is the highest sector in Run3

Geographical HL distribution



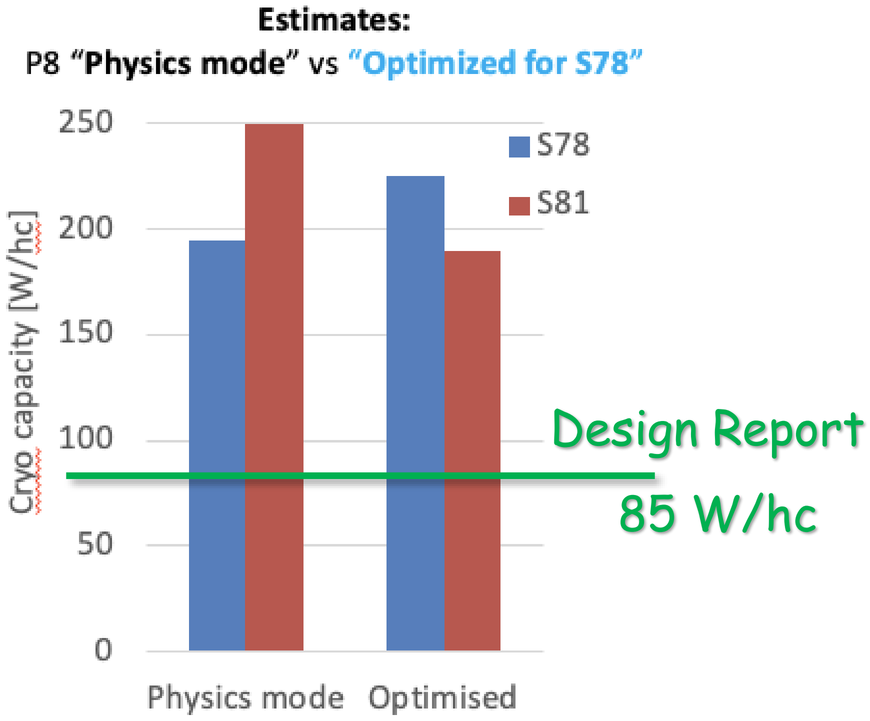
Normalised HL at top energy



Heat load in Run3

- **2023**: Kept under control thanks to **hybrid filling scheme** (8b4e and 36 bunch trains) – e-cloud suppressed but penalization on number of bunches

- **2024**: Modified cryogenic configuration (capacity rebalanced between S78 and S81) allows to operate LHC <u>without hybrid scheme</u> at 1.6e^{11} p/b:
    - **Larger number** of bunches
    - Better beam quality

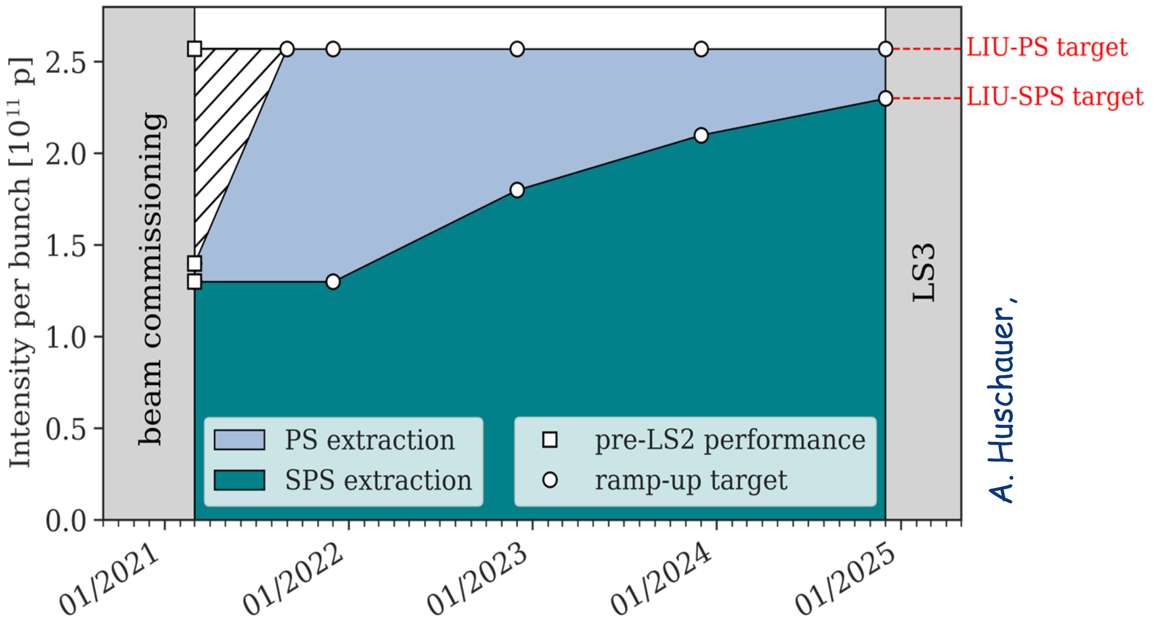


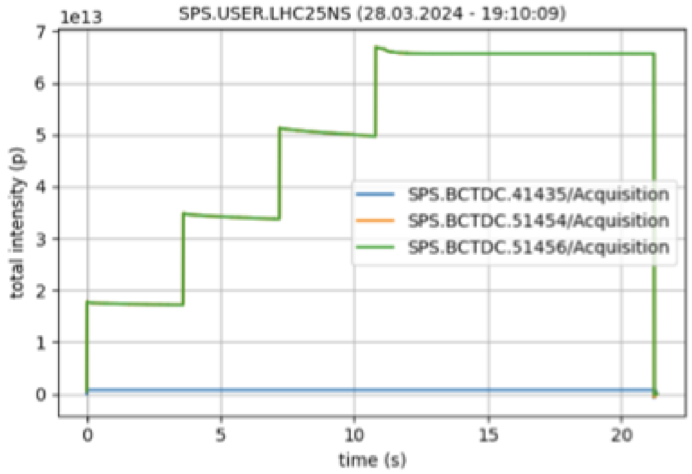
- **Dedicated scrubbing session** with long trains (72b) allowed to inject for the first time **2676 bunches** in each beam (at injection energy!)

LHC injectors performance

Year-by-year intensity goals of the ramp-up at SPS extraction

- **2021**: **1.3e^{11} p/b** – Recover Pre-LS2 beam parameters
- **2022**: **1.8e^{11} p/b** – Set base for LHC 2023 operation
- **2023**: **2.1e^{11} p/b** – Toward LIU targets (HL parameters)
- **2024: 2.3e^{11} p/b** – LIU target for HL-LHC operation





LIU intensity and bunch length at SPS extraction **achieved:**

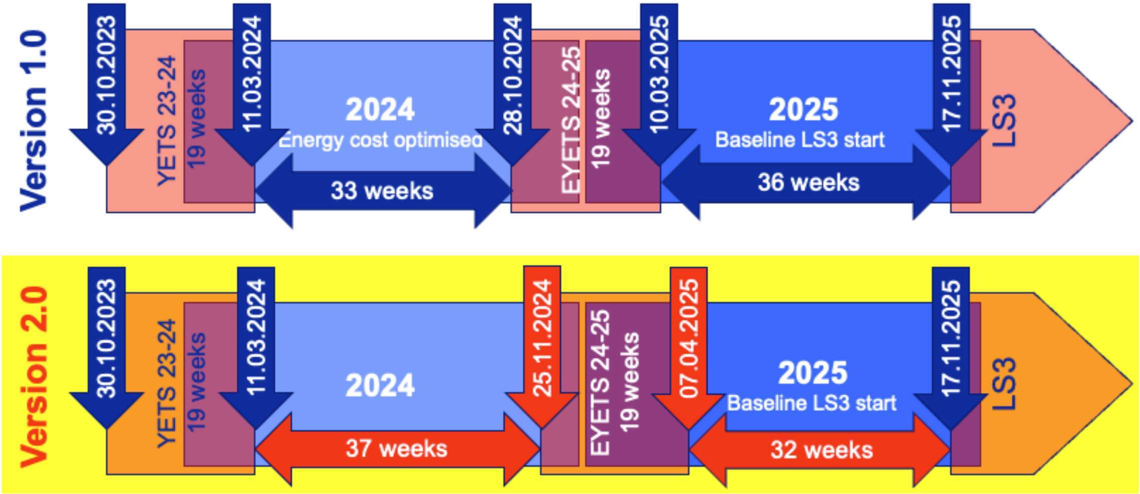
- 4x72 bunches at 2.3e^{11} p/b with bunch length of 1.65 ns
- Transverse emittances did not yet satisfy LIU specification (optimization will be done in the next high intensity sessions)

Outline

- Main issues from 2023: status and impact
- 2024 beam commissioning status
- **Outlook for rest of Run3**

LHC schedule - changes

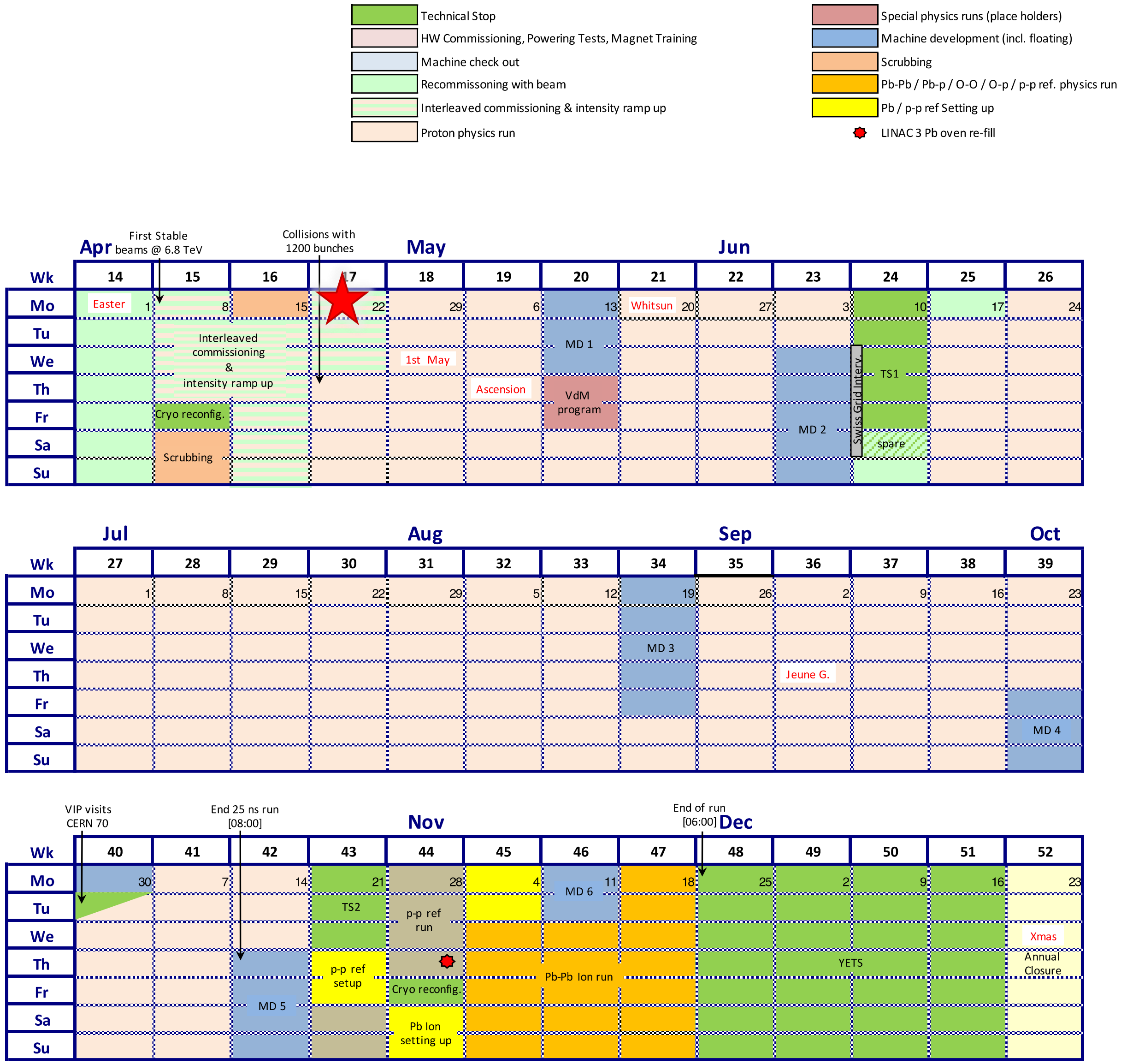
- **Injectors YETS** shifted by 5-weeks
  - 3-weeks reduction, more physics
- **LHC YETS** shifted by 4-weeks (Start date 28.10 -> 25.11)
  - 19 weeks length (beam-to-beam) maintained
  - Extended time used for proton physics
- **2025 run** shortened by 4 weeks -> one Technical Stop removed
- NO additional technical stop for **2024 run**



Activity	2024+2025 v1.0 [days]	2024+2025 v2.0 [days]	Diff [days]
Proton physics	269	274.5	**+5.5**
Ion physics & p-p ref. run (Oxygen included)	44.5	45	**+0.5**
Scheduled stops & recovery	28.5	22.5	**-6**

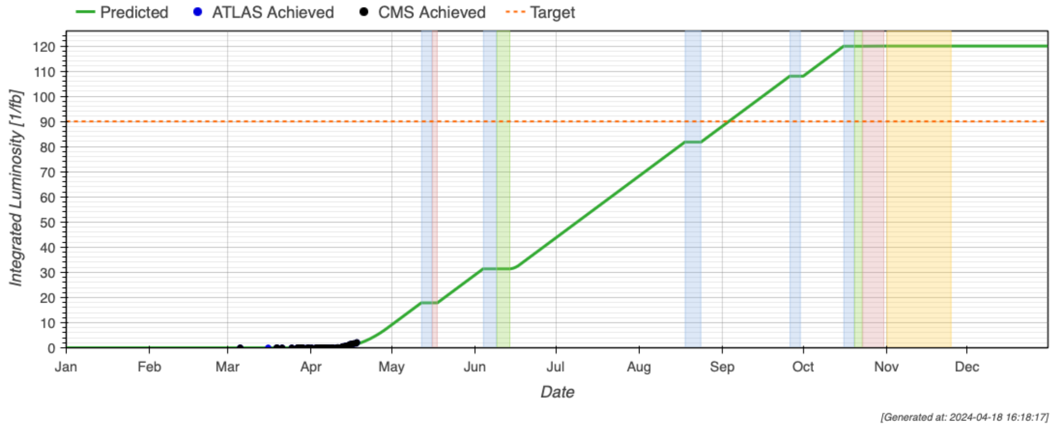
2024 LHC schedule

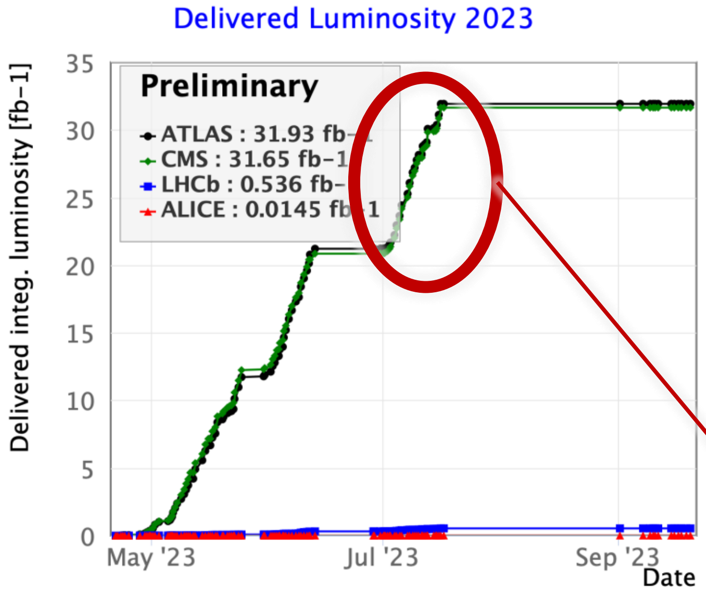
Activity	Duration [days]	Ratio [%]
Beam Commissioning & Intensity ramp-up	41	15.8
Scrubbing	3	1.2
25 ns physics (>1200 bunches)	**147.5**	**56.9**
Special physics runs (incl. setting-up)	**2**	**0.8**
Pb-Pb ions & p-p ref. setting-up	6	2.3
Pb-Pb ions physics & p-p ref. run	**23**	**8.9**
Technical stop	9	3.5
Technical stop recovery	2	0.8
Other scheduled stops	2.5	1.0
Machine Development	23	8.9
Total:	**259**	**100%**

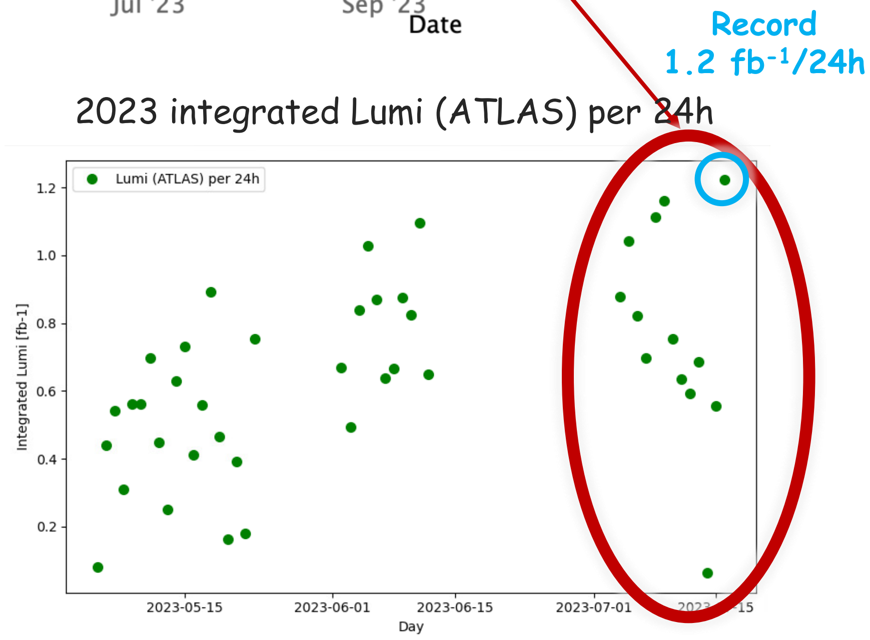


Performance

2023 production rate reached **~0.8 fb^{-1}/day** in stable periods (2 weeks only) with 1.6e^{11} p/b and ~50% time in SB





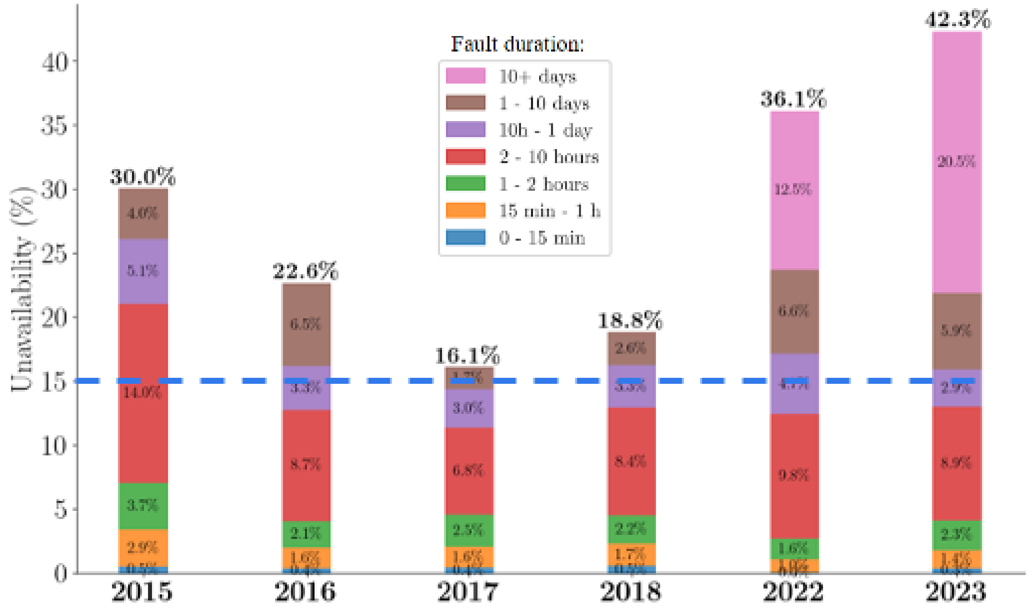


Availability

- Availability is THE key factor for accelerator performance
- Accelerator Fault Tracking (**AFT**) systems allows for analysis and cataloguing of down time
- **LHC availability factor** was constant through Run2 and Run3 for small (<24h) faults
- **“Long faults” have been so far** dominant for Run 3

Facility	Overall availability [%]			
	2021	**2022**	**2023**	**2024***
LINAC4	97.3	96.8	98	93.2
PSB	94.5	94.8	96.1	90.9
PS	88.1	89.6	92	88.6
SPS	73.4	74.1	86 (94.3 LHC)	85.1 (92.2 LHC)
LHC		76.3	43.7**	75.2

** Affected by Klystron replacement and extraction kicker repair in PSB*
*** Includes RF finger module exchange & Cold mass to insulation vacuum repair*



Conclusions

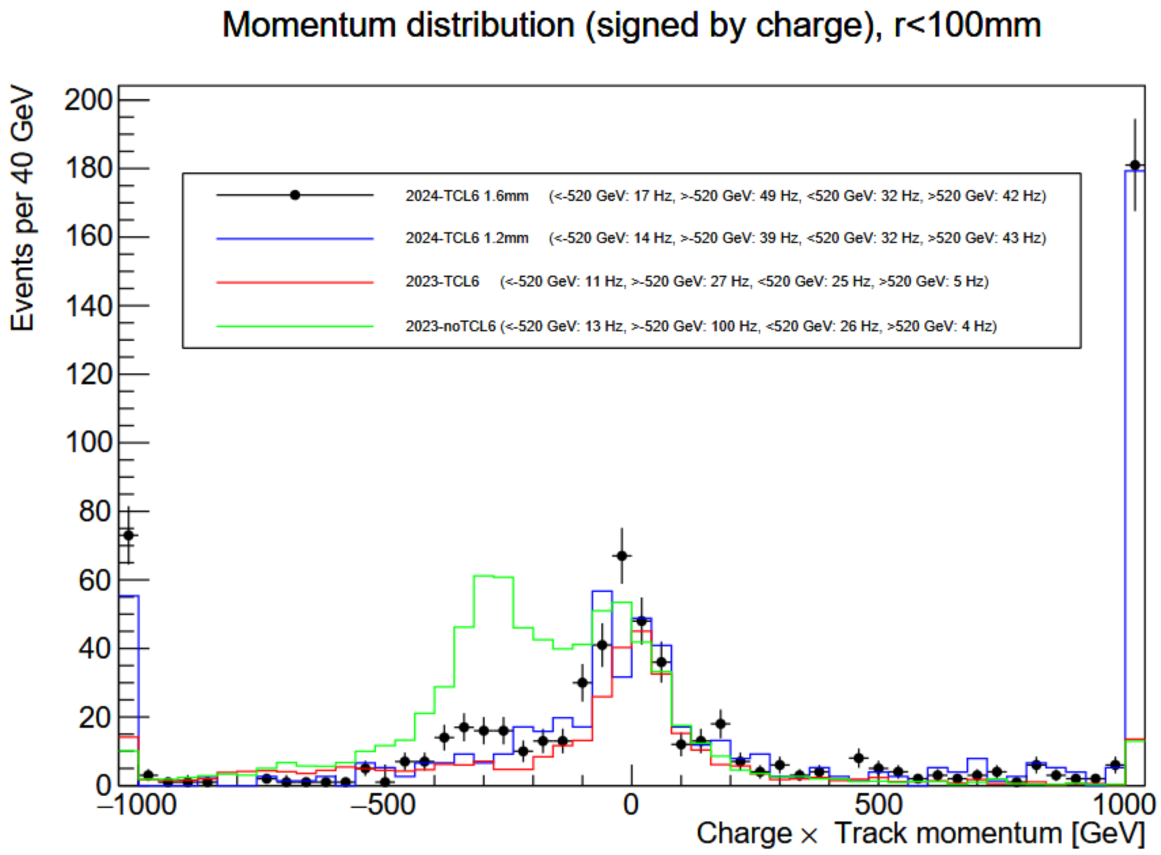
- **2024 Run** has started and NO limitation is identified
- **Bunch intensity** presently limited to $1.6e^{11}$ p/b for risk mitigation
  - Until **further understanding** of heat deposition dynamics
  - Pushing bunch intensity in Run3 is important to unveil any **potential limitations**, before LS3
- **Heat load** should be kept under control in 2024
- **YETS shift** (4 weeks forward) will result in a net gain of about 6 days (dedicated to pp physics)

Thanks for your attention

SPARE

FASER/SND background

- **FASER and SND background rates** are ~doubled wrt 2023 (non-RP optics)
  - Implies more frequent emulsion exchanges (if available!)
- Background tests for FASER demonstrated **little impact of collimation system** on background, as increase is driven by TeV-scale muons, originating from IP
  - Agreement with FLUKA simulations which indicate an origin before TCL4
  - More simulations ongoing



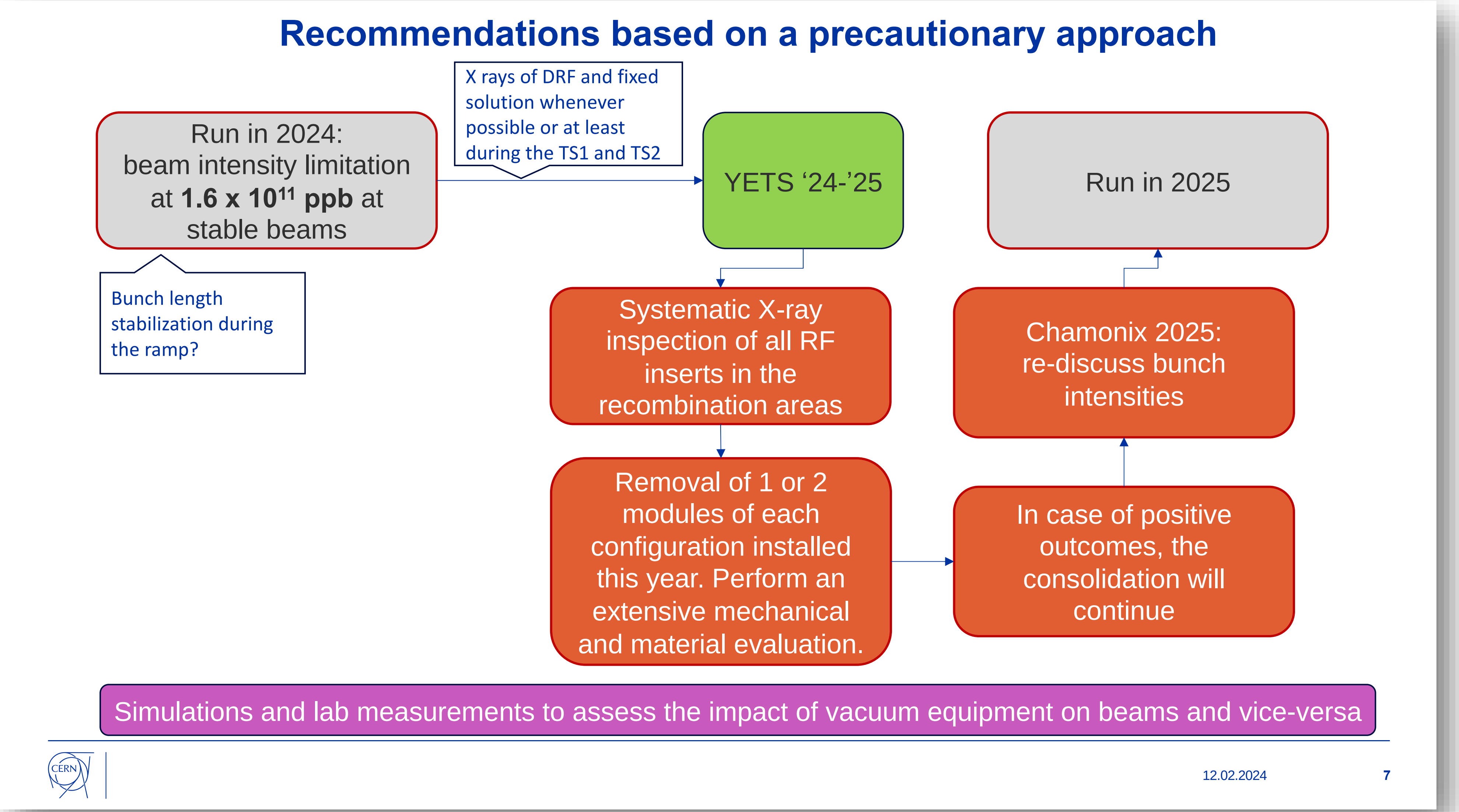
Courtesy of B. Petersen

2024 LHC schedule

	Version 2.0		Version 1.0		Gains & Losses
Activity	Duration [days]	Ratio [%]	Duration [days]	Ratio [%]	
Beam Commissioning & Intensity ramp-up	41	15.8	42	18.2	=
Scrubbing	3	1.2	3	1.3	=
25 ns physics (>1200 bunches)	**147.5**	**56.9**	**124**	**53.7**	**+ 23.5**
Special physics runs (incl. setting-up)	**2**	**0.8**	**2**	**0.9**	**=**
Pb-Pb ions & p-p ref. setting-up	6	2.3	6	2.6	=
Pb-Pb ions physics & p-p ref. run	**23**	**8.9**	**22.5**	**9.7**	**+ 0.5**
Technical stop	9	3.5	9	3.9	=
Technical stop recovery	2	0.8	2	0.9	=
Other scheduled stops	2.5	1.0	0.5	0.5	=
Machine Development blocks (incl. floating MDs)	23	8.9	20	8.7	+ 3
Total:	**259**	**100 %**	**231**	**100 %**	**+28**

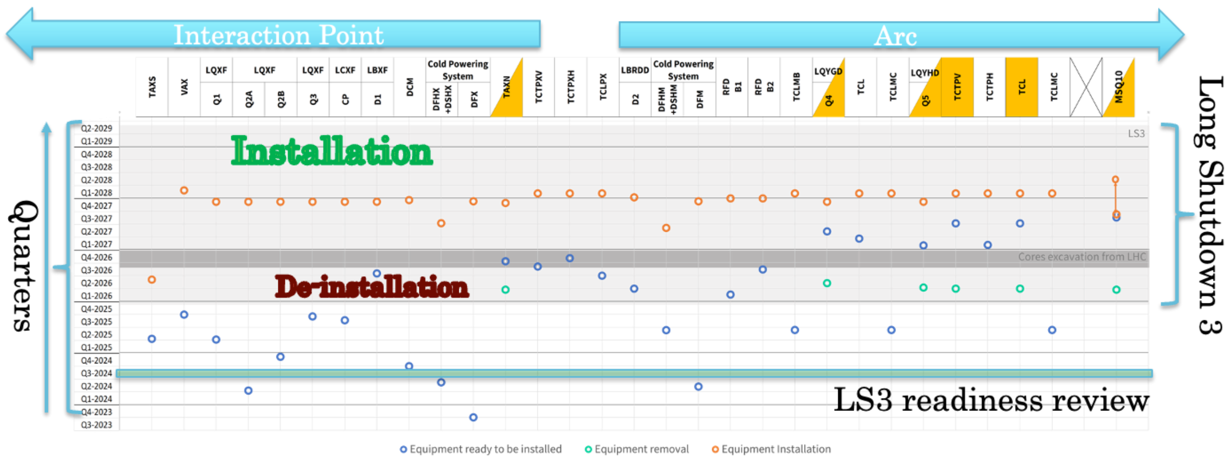
2025 LHC schedule

	Version 0.6		Version 0.4		Gains & Losses
Activity	Duration [days]	Ratio [%]	Duration [days]	Ratio [%]	
Beam Commissioning & Intensity ramp-up	36	16.1	37	14.7	=
Scrubbing	2	0.9	2	0.8	=
25 ns physics (>1200 bunches)	**123**	**54.9**	**141**	**56**	**-18**
Special physics runs (incl. setting-up)	**2**	**0.9**	**2**	**0.8**	**=**
Oxygen ion setting-up	4	1.8	4	1.6	=
Oxygen ion physics	**4**	**1.8**	**4**	**1.6**	**=**
Oxygen ion recovery	0.5	0.2	0.5	0.2	=
Pb-Pb ions & p-p ref. setting-up	6	2.7	6	2.4	=
Pb-Pb ions physics & p-p ref. run	**18**	**8.0**	**18**	**7.1**	**=**
Technical stop	8	3.6	13	5.2	- 5
Technical stop recovery	2	0.9	4	1.6	- 2
Other scheduled stops	1.5	0.7	0.5	0.2	+1
Machine Development blocks (incl. floating MDs)	17	7.6	20	7.9	- 3
Total:	**224**	**100%**	**252**	**100**	**- 28**

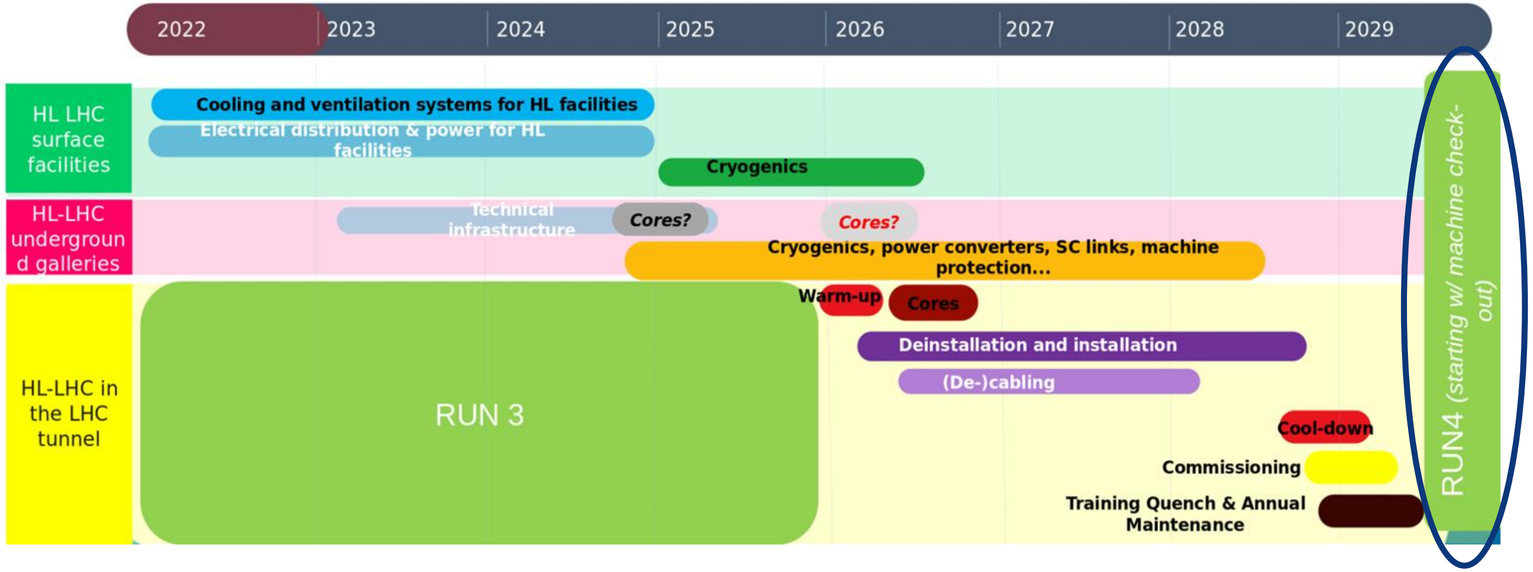


P. Chiggiato @ LMC #479

HL-LHC readiness



- LS3 installation schedule shows **~1 year float** for most equipment
- The overall critical paths appear **credible** and the associated schedule margins **adequate**
- The potential delays are **well covered**

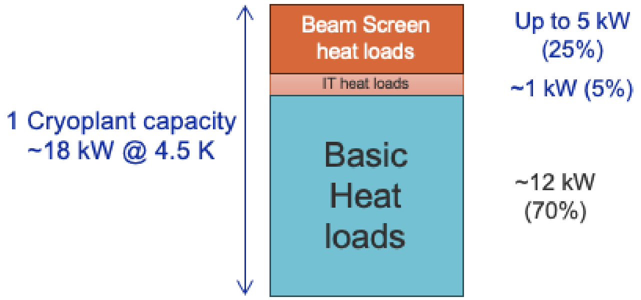


2023 HL-LHC Cost and Schedule review, CMAC report: “Although schedule risks remain in several areas, the CMAC is convinced that the project will be ready for implementation in LS3.”

Heat load expectations

Beam screen cryo capacities during HL-LHC era

- **LHC cryoplants are supplying many devices in parallel at different temperatures**
  - Thermal shields between 50 K and 75 K
  - Main superconducting magnets at 1.9 K (ARC dipoles/quadrupoles)
  - Stand Alone superconducting magnets at 4.5 K (D2, D3, Q4, Q5, Q6)
  - RF cavities at 4.5 K
  - DFB at 4.5 K with their current leads and superconducting links
  - Inner Triplet at 1.9 K around experiments (dynamic heat loads, depending on luminosity)
  - Beam Screens (BS) between 4.5 K and 20 K (dynamic heat loads, depending on beams)



- **All LHC cryoplants are slightly different and have different capacities & loads (RF, SAM, DFB, triplets, etc.)**

Expected changes in Run 4++	Helium massflow	Q @ 1.9 K [per sector]	BS Capa 4.5 K - 20 K [per ARC]	BS Capa 4.5 K - 20 K [per half-cell]	Concerned sectors
Removal of IT at P1 & P5 in LS3 (Run4)	-12 g/s	-280 W	+1.3 kW	+25 W/hc	S12, S81, S45, S56
Increase of Lumi at P8 with LHCb++ after LS4 ? (Run5)	+11 g/s	+260 W	-1.2 kW	-23 W/hc	S78, S81

➔ **The available beam screen cryogenic capacities will change from Run 4**

Beam screen treatment

Risks:

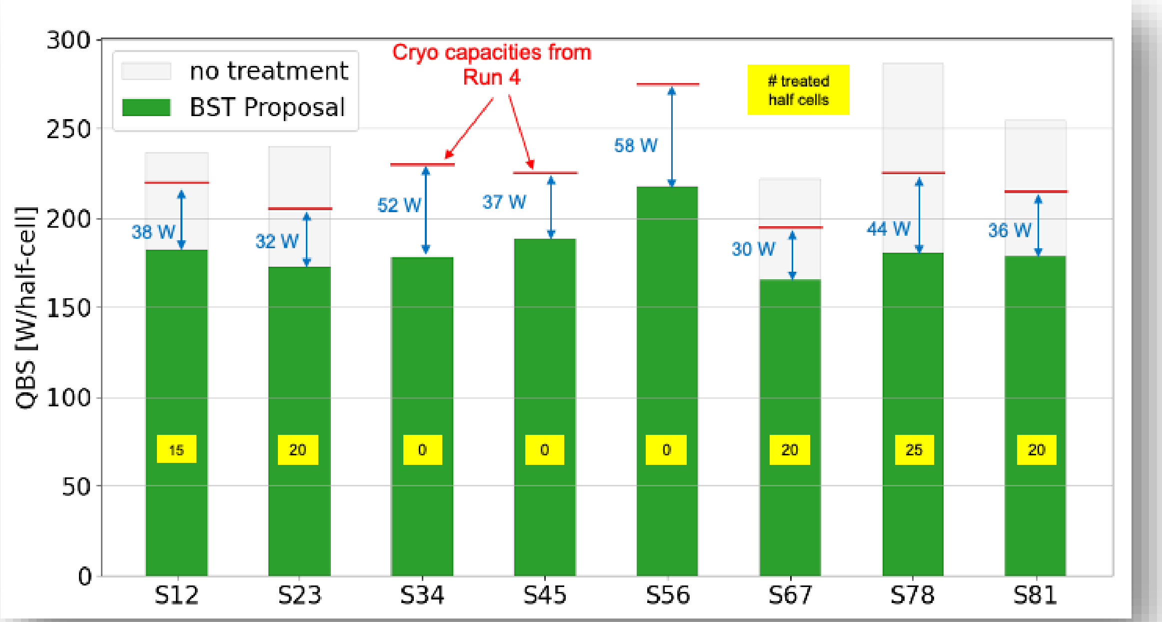
- **Degradation** of un-treated half-cells during future LS
    - Extremely difficult to quantity and impossible to localize
- **Higher than expecter heat loads** of treated half-cells
- **Low(er) number** of treated half-cells in LS3

Possible mitigations?

- Treat **larger number** of half-cells (more margins)
- Produce **less e-cloud**
    - Filling scheme (36b/48b (2022), hybrid (2023))
    - Continue the beam screen treatment in future LS

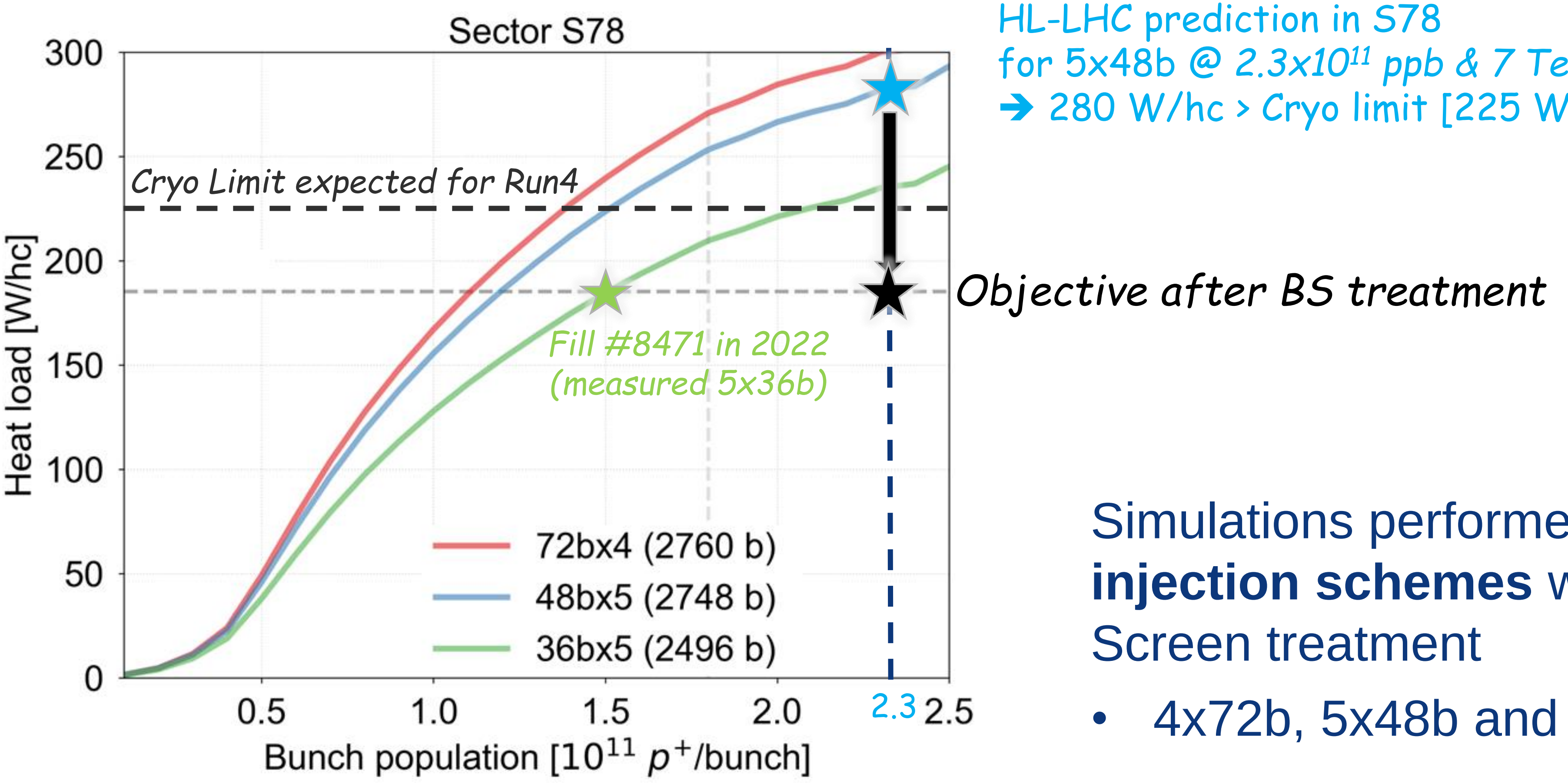
OBJECTIVES

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



A scenario treating **100 half-cells** looks realistic

Heat load expectations



HL-LHC prediction in S78
for 5x48b @ 2.3×10^{11} ppb & 7 TeV
➔ 280 W/hc > Cryo limit [225 W/hc]

Simulations performed for **main beam injection schemes** without any Beam Screen treatment

- 4x72b, 5x48b and 5x36b