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Summary of LHC operation: issues and prospects for Run 3

M. Solfaroli

On behalf of the LHC team
In particular to: R.Bruce, A.Lechner, S.Redaelli, R.Steerenberg for the material

Outline

- 2023 operation recall of main events
- 2023 operation in numbers
- Outlook for 2024

The following topics are **NOT** part of this presentation:

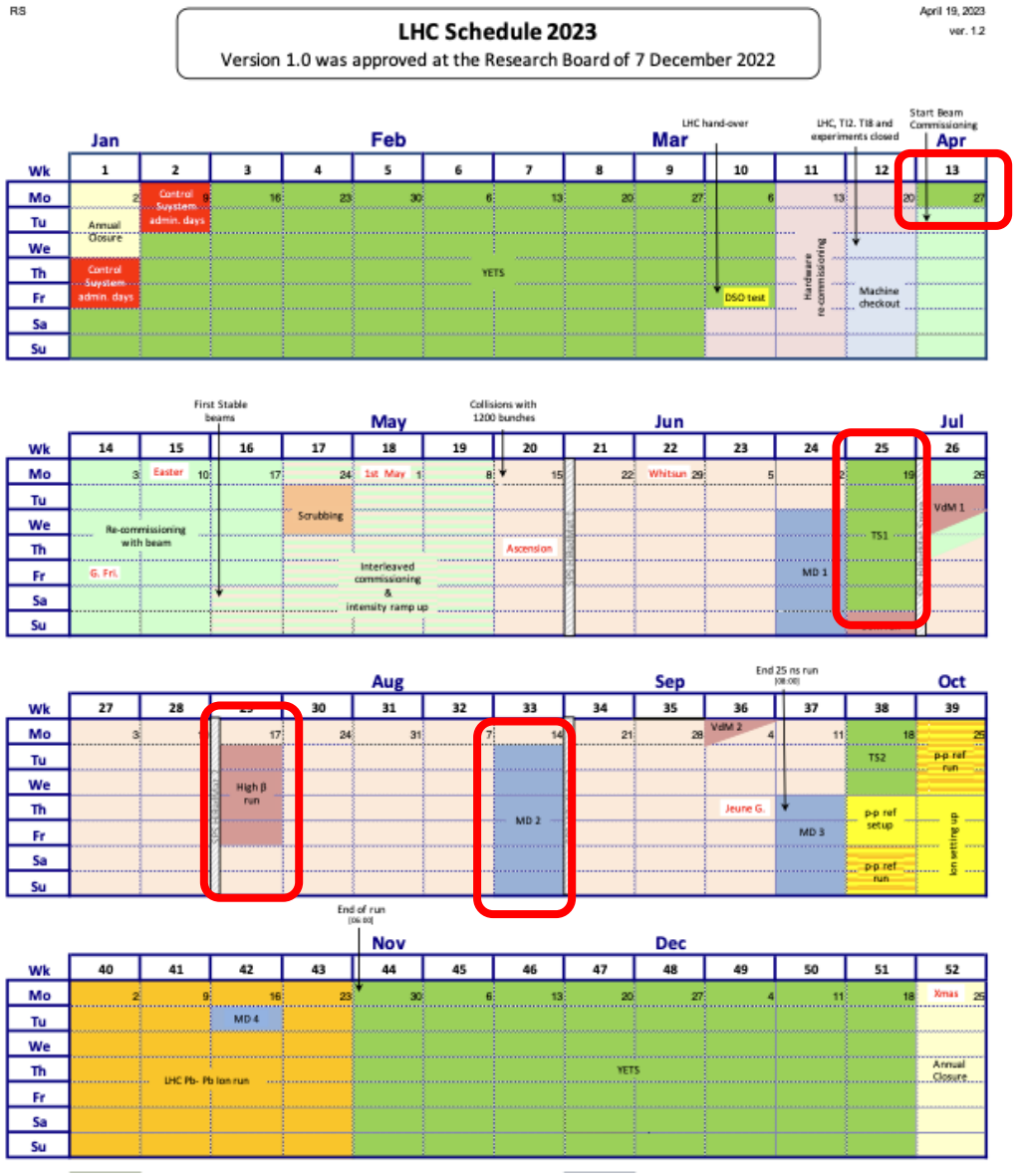
- **Technical details** of the faults (ONLY impact on operation) - see talks by Sandrine, Chiara, Calum,…
- **Machine configuration** – see Tobias' & Filip's talks
- **Heat Load** – see tomorrow morning session (in particular Kostantinos' talk)
- **Injection losses** – see Yann's talk
- **Commissioning & special runs** – see David's & Tobias' talks
- **10 Hz** – see Tobias' & Maria's talks
- **QPS-SEU during ION run** – see Jens' talk

18.03.2023
Crystal collimator
Non-Conformity
appeared during testing

p run

IONS run

March | April | May | June | July | August | September | October



V1.0 vs V1.2

- +1 day to YETS – broken crystal removal
- +1 day more to TS#1 - crystal re-installation
- 1 wk advancement for scrubbing
- Definition of the special physics runs
- MD#2 postponed by ~2wks

Activity	V1.2	V1.0
Beam Commissioning & Intensity ramp-up	**46**	**47**
Scrubbing	2	2
25 ns physics (>1200 bunches)	**96**	**97**
Special physics runs (incl. setting-up)	7	7
Pb-Pb ions & p-p ref. setting-up	6	6
Pb-Pb ions physics & p-p ref. run	32	32
Technical stop	8	8
Technical stop recovery	2	2
Other stops	2	0
Machine Development blocks (incl. floating MDs)	16	16
Total:	217	217

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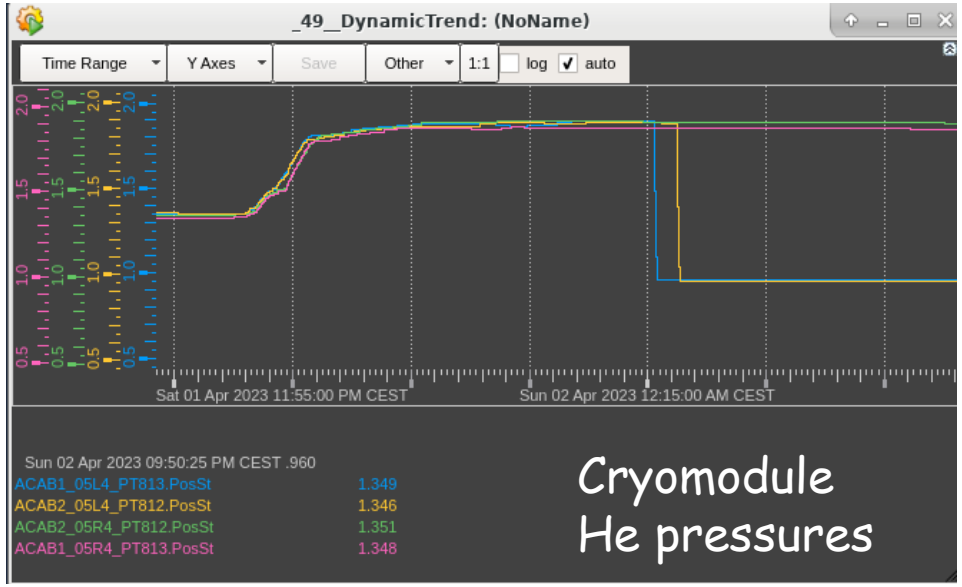
02.04.2023
RF Rupture discs
following IP4 SVC trip

RF burnt disk

Outcome of RF taskforce (LMC #454)

- **New** safety valve **configuration** (opening at 1.7 bar)
- Successful **commissioning of WRL** ➔ in case of power cut, we still rely on passive protection
- **New rupture disk** ➔ installed in the YETS
- **Review** of disk **replacement procedure** to limit exposure time



The event

- Sat (01.04) 23:57:
  - Loss of IP4-SVC -> He **pressure** in RF cavities **increased** -> release valves opened @1.7 bar
  - **Pressure stabilized** at around 1.9 bar, as expected
- Sun 00:15, 00:16:
  - Two rupture **discs burst** ➔ replaced in **within 3h**

Recovery

- Monday morning:
  - **Cryo conditions** re-established
  - **RF conditioning** to check performance
  - No significant degradation observed, full conditioning completed in 24h
- **Tue @9am: Ready for beam** (~2 days)

Mitigation (ECR): Installation of a fast-depressurising valve on the ACS cryomodules

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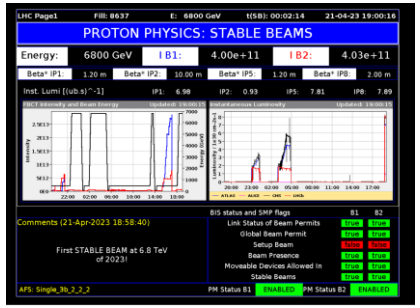
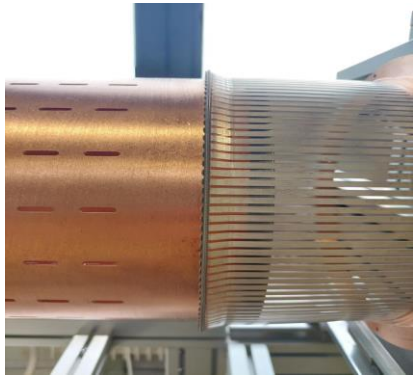
1st stable beam (3bx3b)





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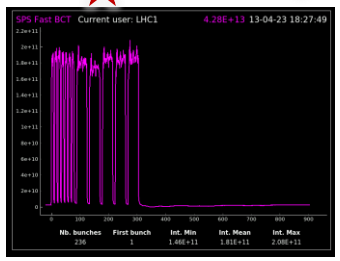
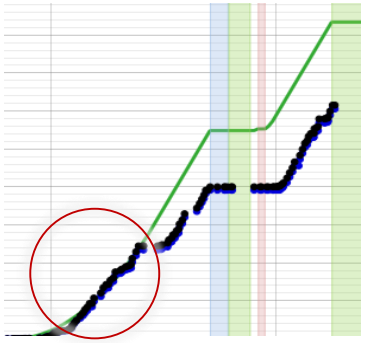
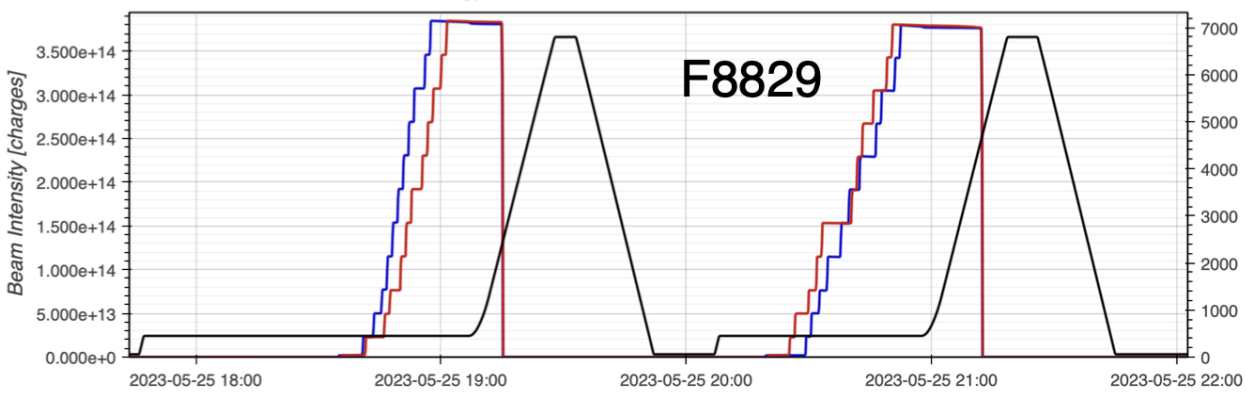


12.05.2023
1st collisions with 2374 b (mixed scheme to minimize HL)

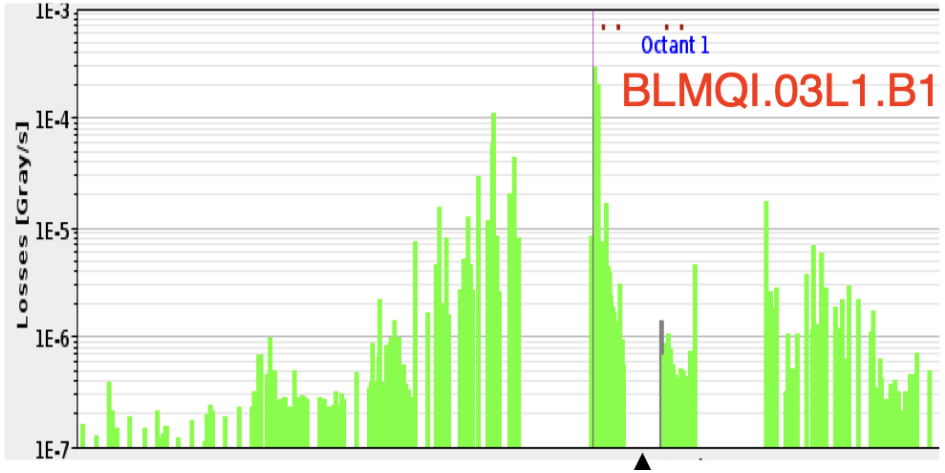
12 fb^{-1} in ~1month



RF Finger - observation



- **Dumps** at beginning of the ramp by **slow losses** left of IP1 (peak in Q3L1)
- Losses **not synchronised** with IP7 losses
- Indication that losses are from **both beams**
- Sign of **degraded situation** while injecting
- Measurements indicate that vacuum activity is trigger **primarily by B2**



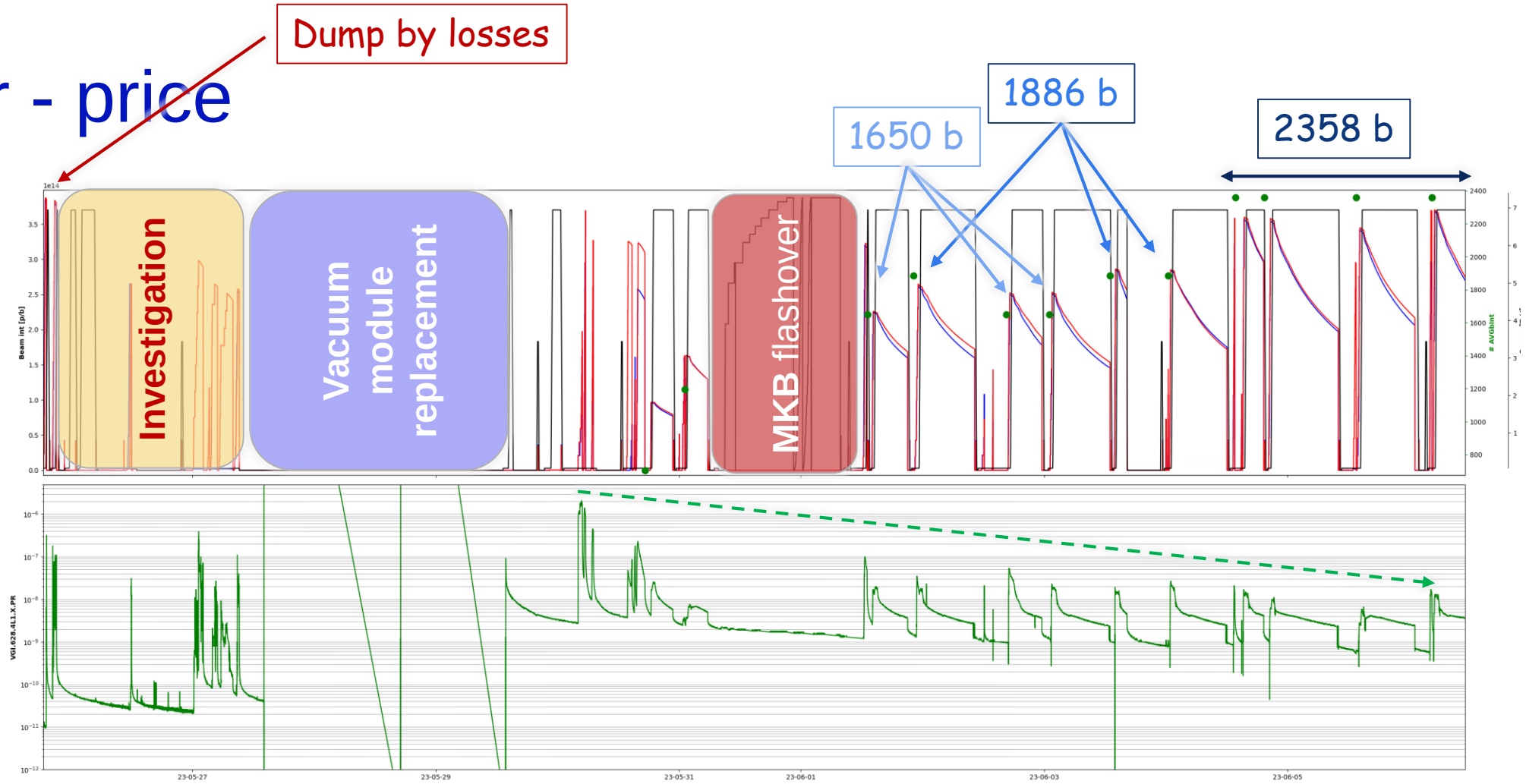
Investigation

- **Losses maps** and aperture check
- **X-rays**
- Installation of **BatMon**
- **New BLM** layout – 3 new BLM per side
- **Replacement of vacuum** module
- **ONLY partial** bake-out

See C. Antuono for technical details

RF finger - price

- **4.5** (physics) **days lost** for investigation and intervention
- **Quick intensity ramp-up**, start-up with “no major event”
- About **5 days of conditioning** needed



LIMITATION: Max bunch intensity = 1.6×10^{11} p/b

The issue will be (partially) addressed during YETS 23-24

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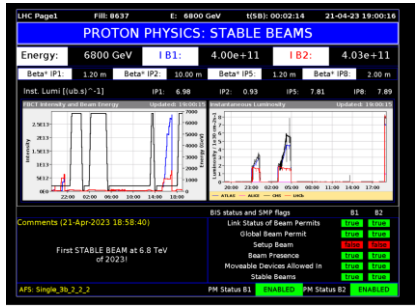

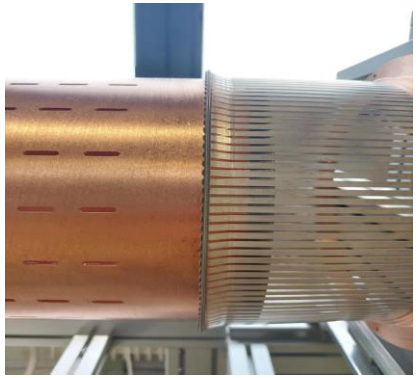

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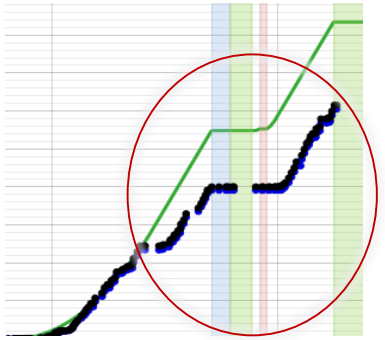

p run

IONS run

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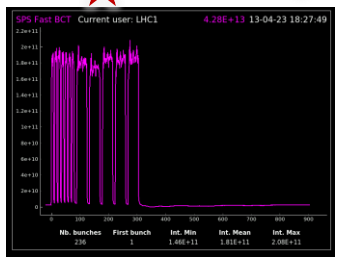

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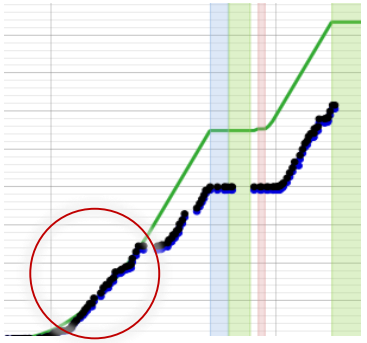
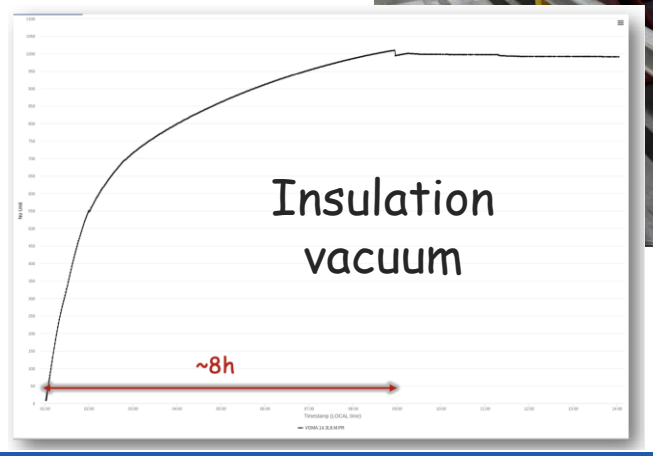


17.07.2023
Power glitch, magnet quench, and leaking bellow in IT.L8

V. 1.4

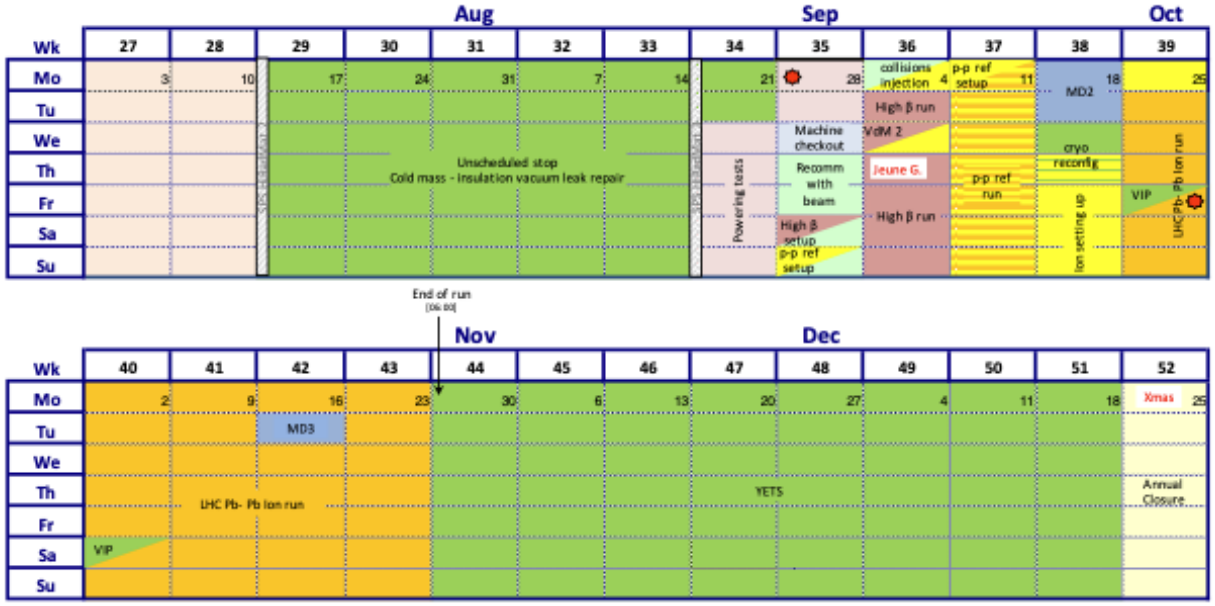
Beams dumped at 01:00:17 on July 17th by RF trip, 370 ms later **several magnets quenched**:

- RQ7/9/10.R4
- RQ10.R8
- RQX.L8



V1.4 IT triplet incident

- **Unscheduled stop** wk 29 - wk 34
- Powering **tests** & beam **re-commissioning**
- **Anticipation** of p-p reference and Pb ion runs
- **Reduced** MD block
- Plus other minor changes



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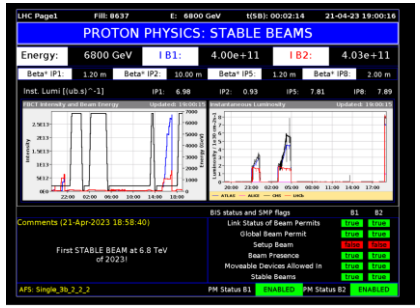

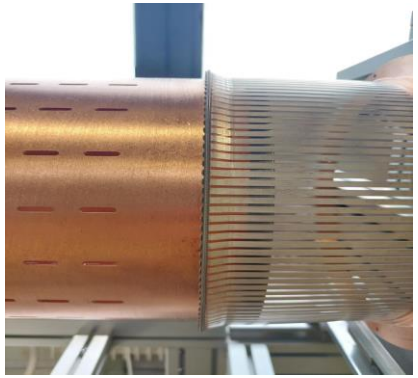

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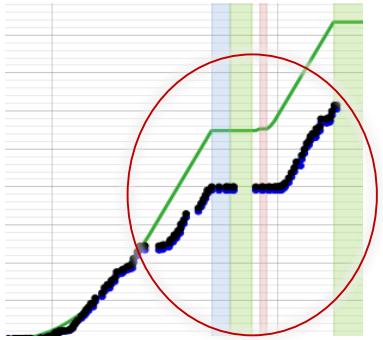
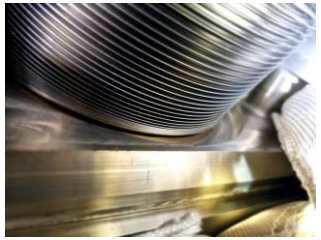
08.09.2023 (A)
2 vacuum leaks on IP8-TDIS
Preventing p operation, but Pb ion possible

20 fb^{-1} in ~1.5month





p run

IT.L8 fault

High Beta + recommissioning

IONS run

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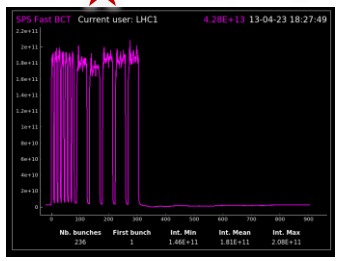

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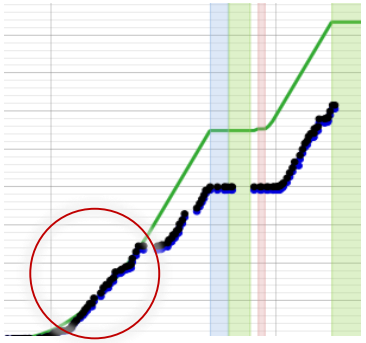
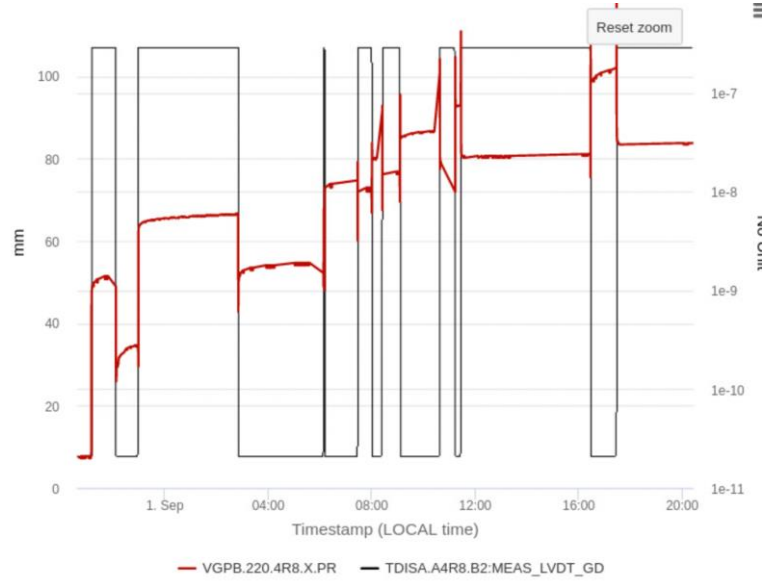
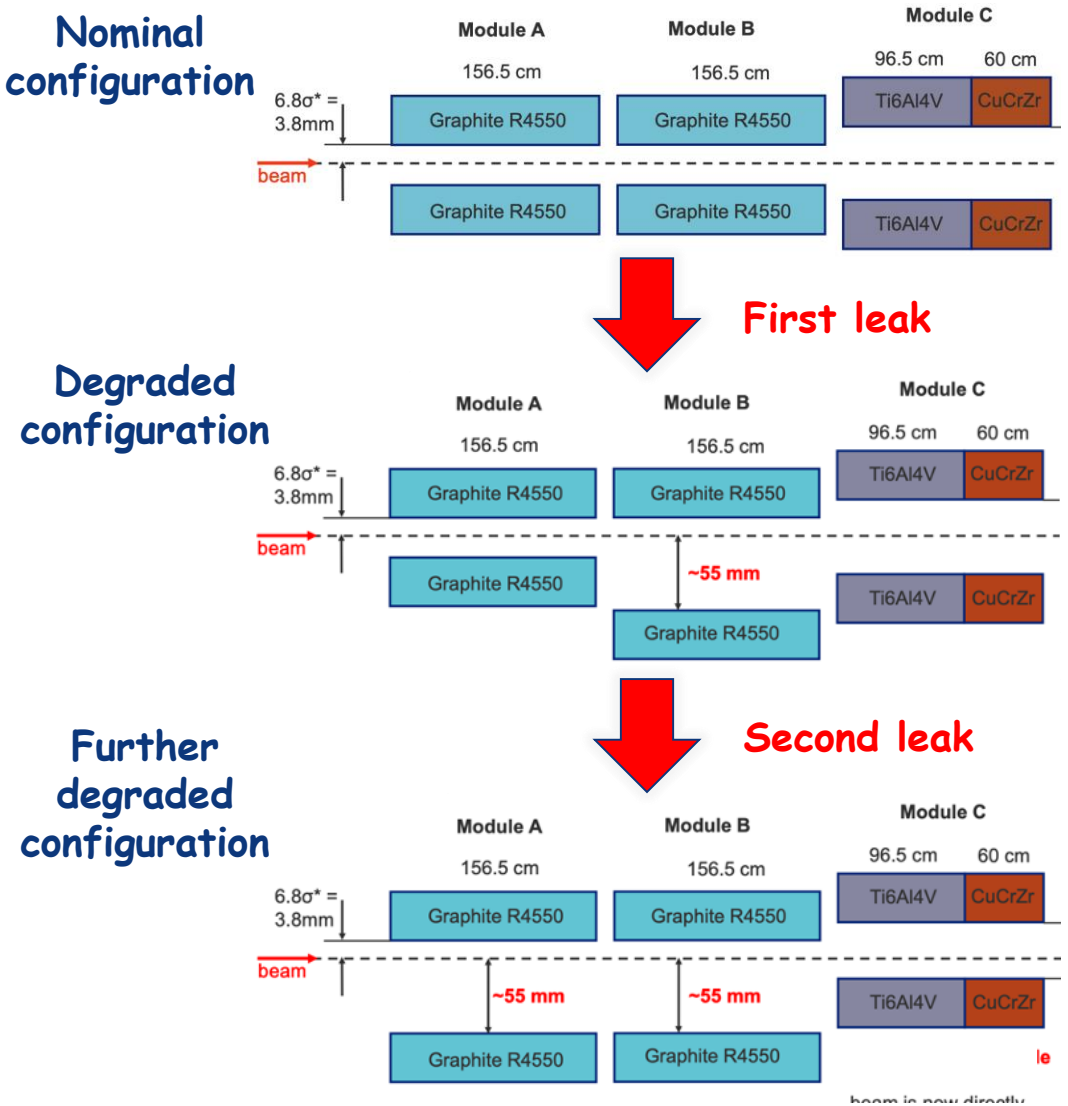


17.07.2023
Power glitch, magnet quench,
and leaking bellow in IT.L8

TDIS implications

- On Sep 1st beams dumped when opening TDI, as **vacuum reached interlock threshold** (vacuum valves closed)
- A **vacuum leak** had developed on IP8-TDIs, starting on **Aug 31st** - slowly but continuously degrading at every cycle
- An **additional leak** on another bellow appeared on **Sep 9th**
- The areas were varnished, and the **TDI configuration modified** to limit mechanical stress





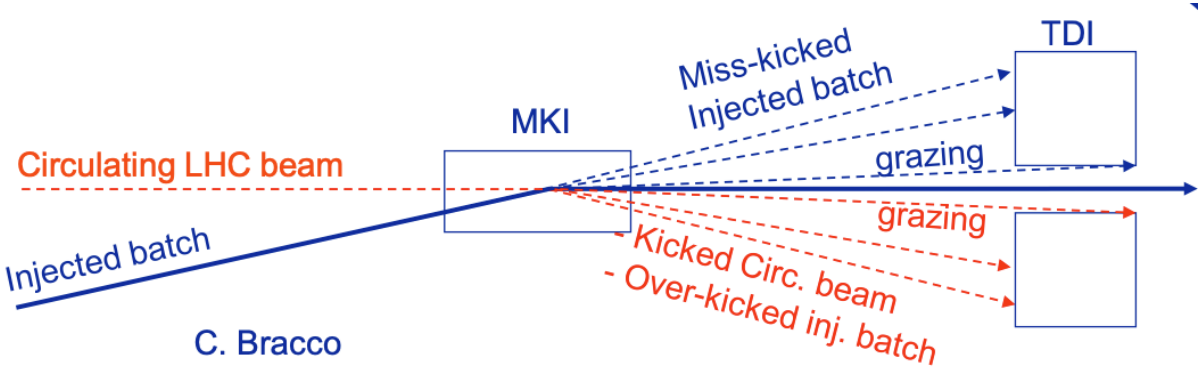
See C. Sharp for technical details

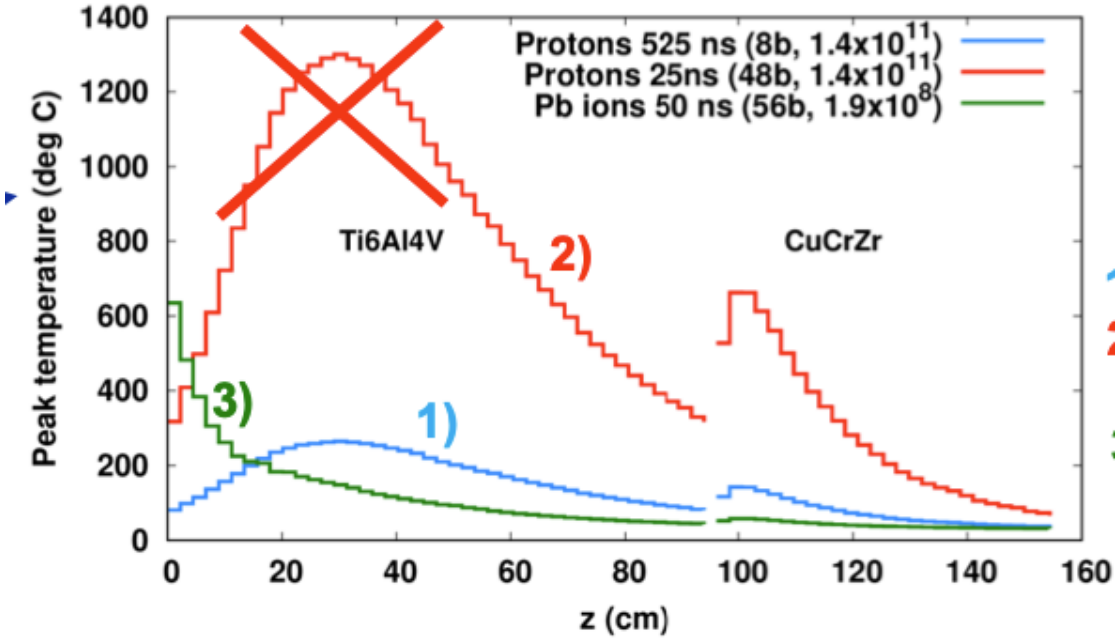
TDIS implications

Exhaustive studies (LMC#472) were done to evaluate the risks of running with TDIS in degraded configuration:

- **protons**: recommended **not to exceed 8 bunches** (1.4×10^{11} pb) per injection and not more than 8 bunches within ~4μsec window (limitation to ~100 bunches)
- **IONS**: **nominal Pb** (1.9×10^{8} Pb/bunch) are **acceptable** -> localized damage possible

➔ **Cancel** (postpone) the pp reference run





- Both TDIS **replaced** by present spares during YETS 23-24
- However, the spare TDIS are equipped with **same non-conform bellows**
  - Limit mechanical stress under discussion
  - **Possible limitation** in case of failure (NO additional spare until mid 2024)

See C. Sharp for technical details

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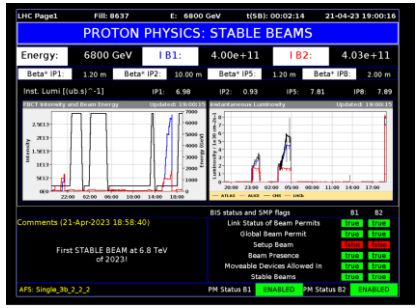

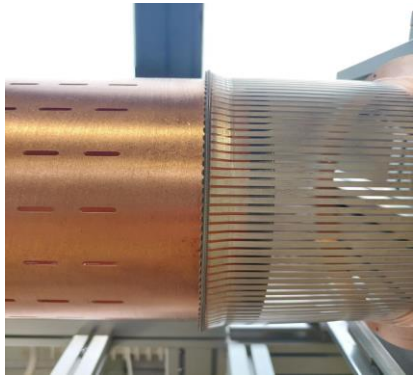

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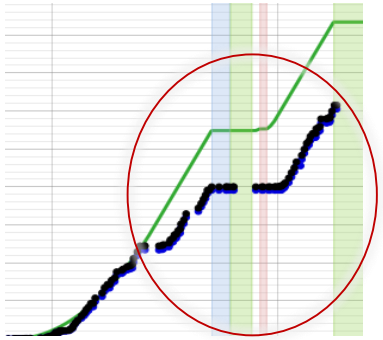

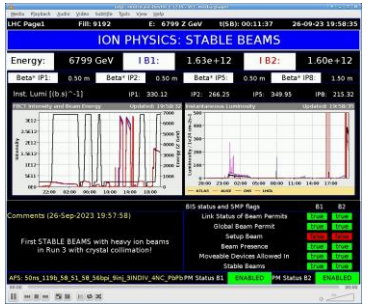

26.09.2023: 1st stable Pb ion beam of 2023

p run | **IT.L8 fault** | High Beta + recommissioning | **IONS run**

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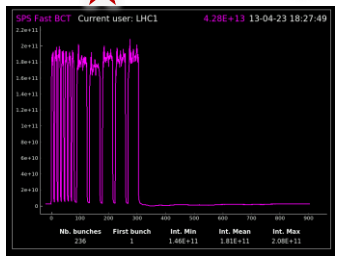

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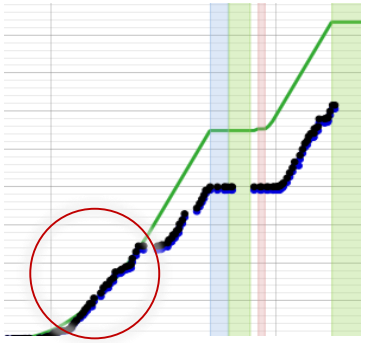

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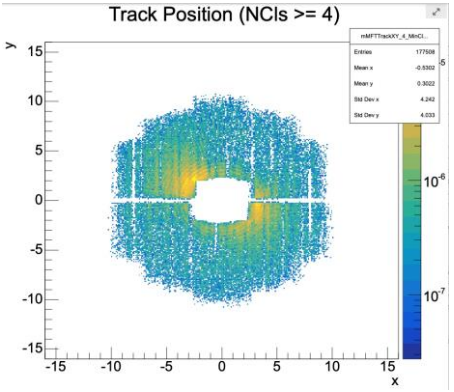
Power glitch, magnet quench, and leaking bellow in IT.L8

2.16 nb^{-1} to ALICE



2023 operation in numbers

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Pb-Pb ions & p-p ref. setting-up	**7.5**	**6**
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Technical stop	**7**	**8**
Technical stop recovery	**13.5**	**2**
Other stops	**42**	**0**
Machine Development	**7**	**16**
Total:	**217**	**217**

Major change in beam time:

- **Beam commissioning** & intensity ramp-up achieved in about **10 days less** than planned
- **Proton physics** time **only 49%** of initially scheduled - integrated lumi: 32 fb^{-1} instead of 75 fb^{-1}
- **Increased time** to complete the **high beta run** – **goal achieved!**
- **Increased time** for **Pb-Pb run**, due to cancellation of pp ref run - ~60% of the Pb ion luminosity goal
- **Stop for IT.L8** bellow repair: 37 days + 11.5 days to restart

2023 in numbers

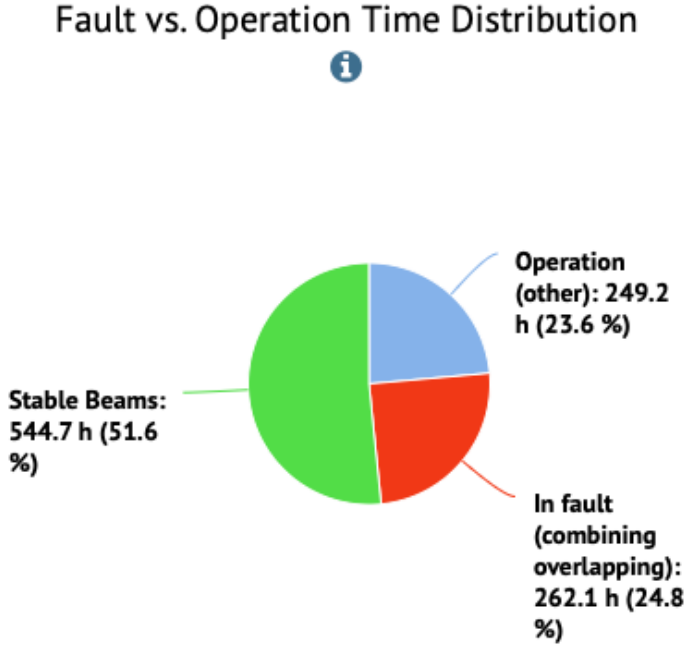
RF finger vacuum fault (and consequent intensity ramp-up) removed

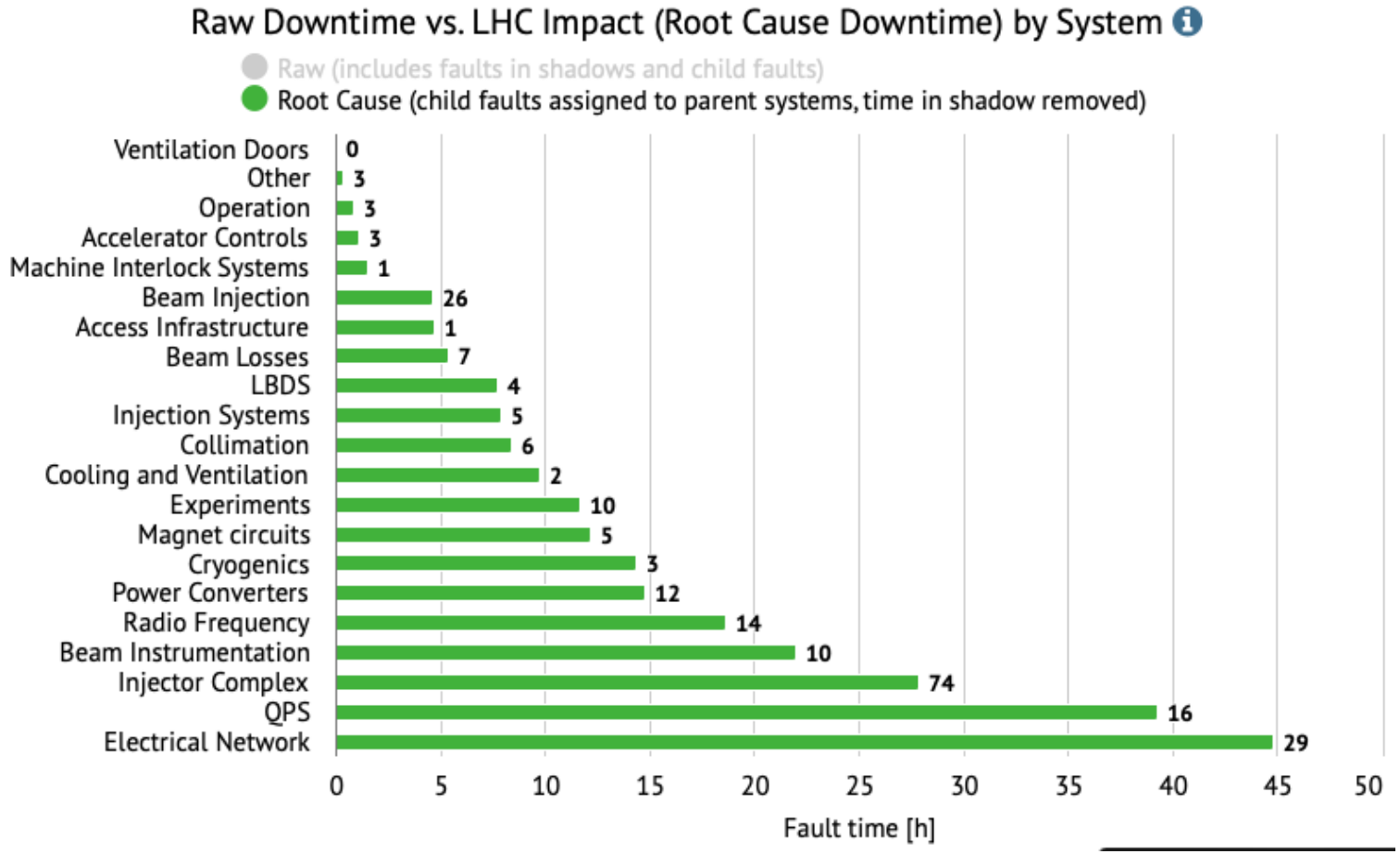
Time period: 05-05-2023 00:00:00 – 17-07-2023 00:00:00

Excluded time periods – Clear all: 24-05-2023 00:00:00 – 02-06-2023 00:00:00; 13-06-2023 00:00:00 – 03-07-2023 00:00:00

Availability	Stable beams (SB)
75.9%	51.6%

Fault vs. Operation Time Distribution





See L. Felsberger for details

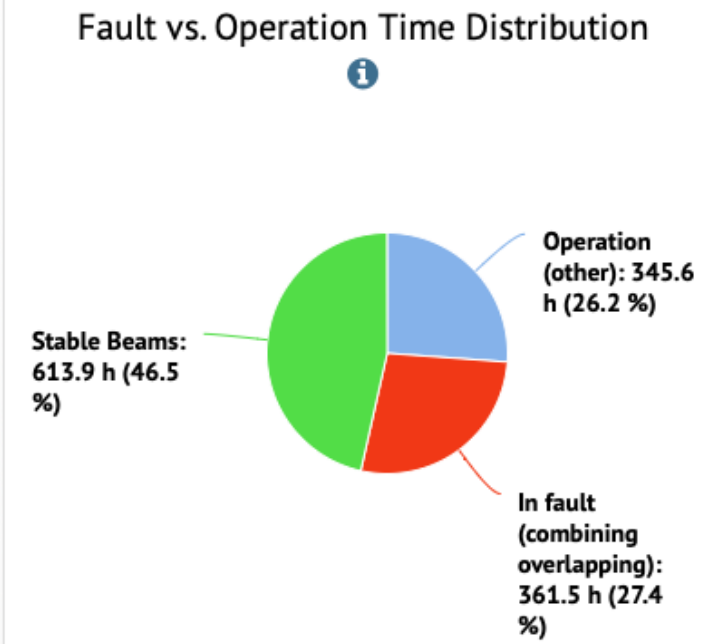
2022

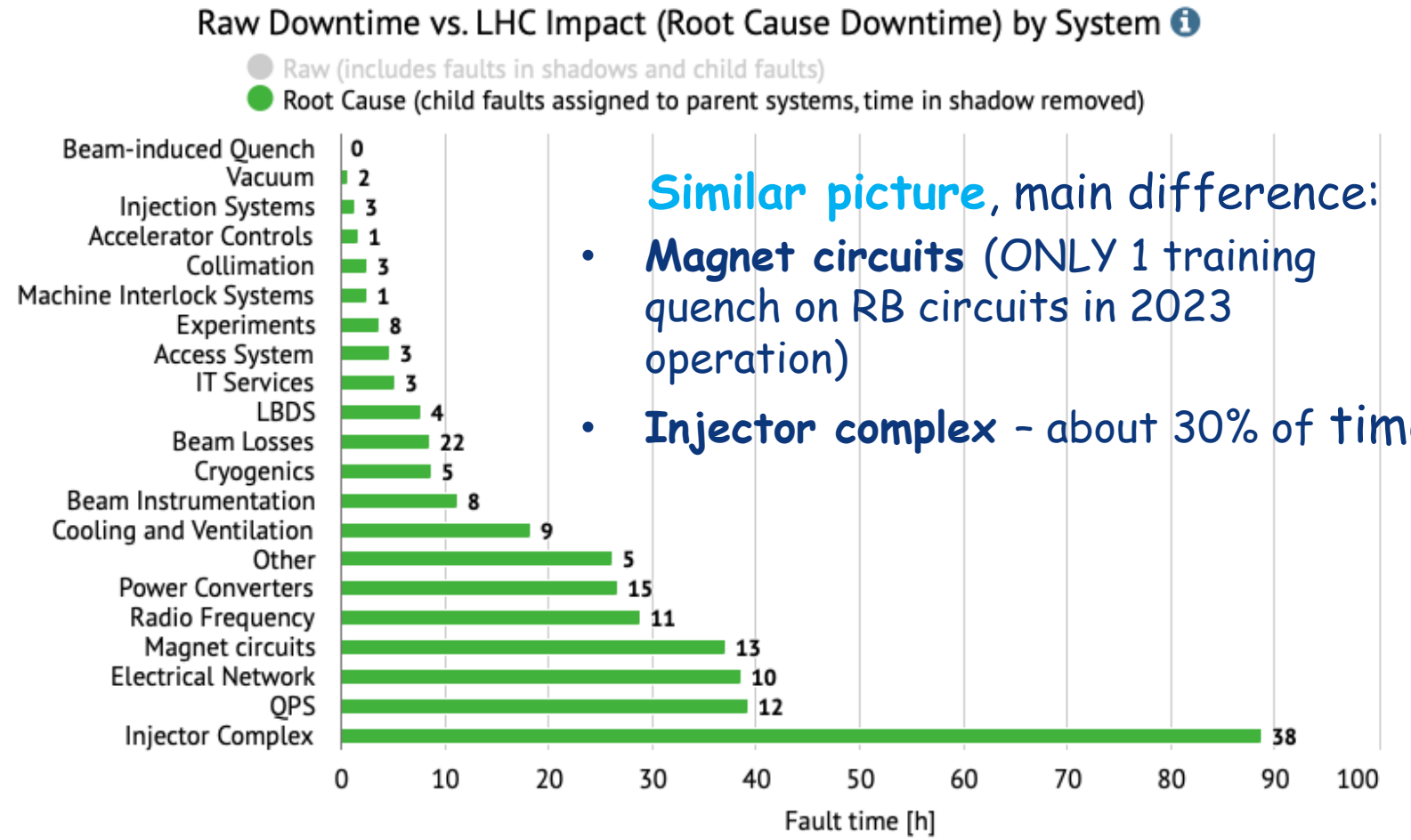
Time period: 04-08-2022 00:00:00 – 05-11-2022 00:00:00

Excluded time periods – Clear all: 23-08-2022 00:00:00 – 30-09-2022 00:00:00

Availability	Stable beams (SB)
72.9%	46.5%

Fault vs. Operation Time Distribution

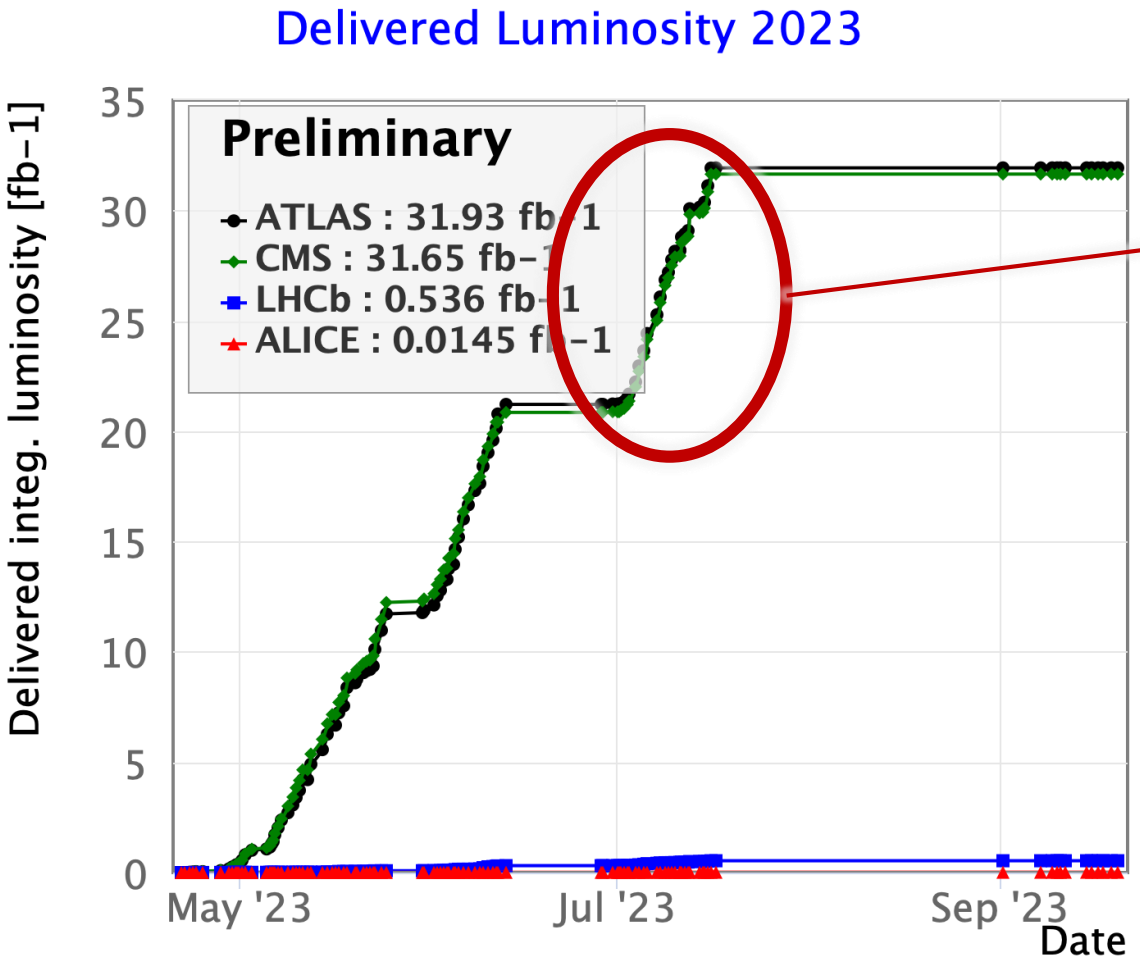


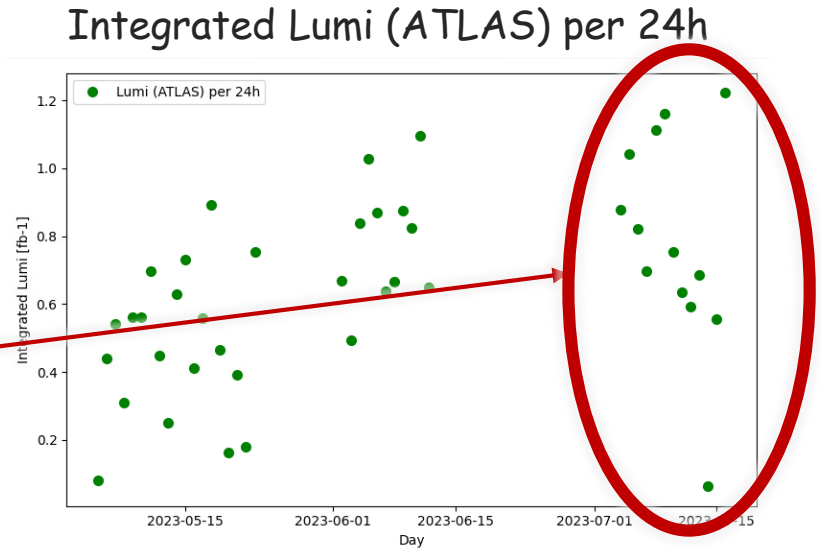


Similar picture, main difference:

- **Magnet circuits** (ONLY 1 training quench on RB circuits in 2023 operation)
- **Injector complex** – about 30% of time

Best operational period 2023





Best production period (4th - 17th July)

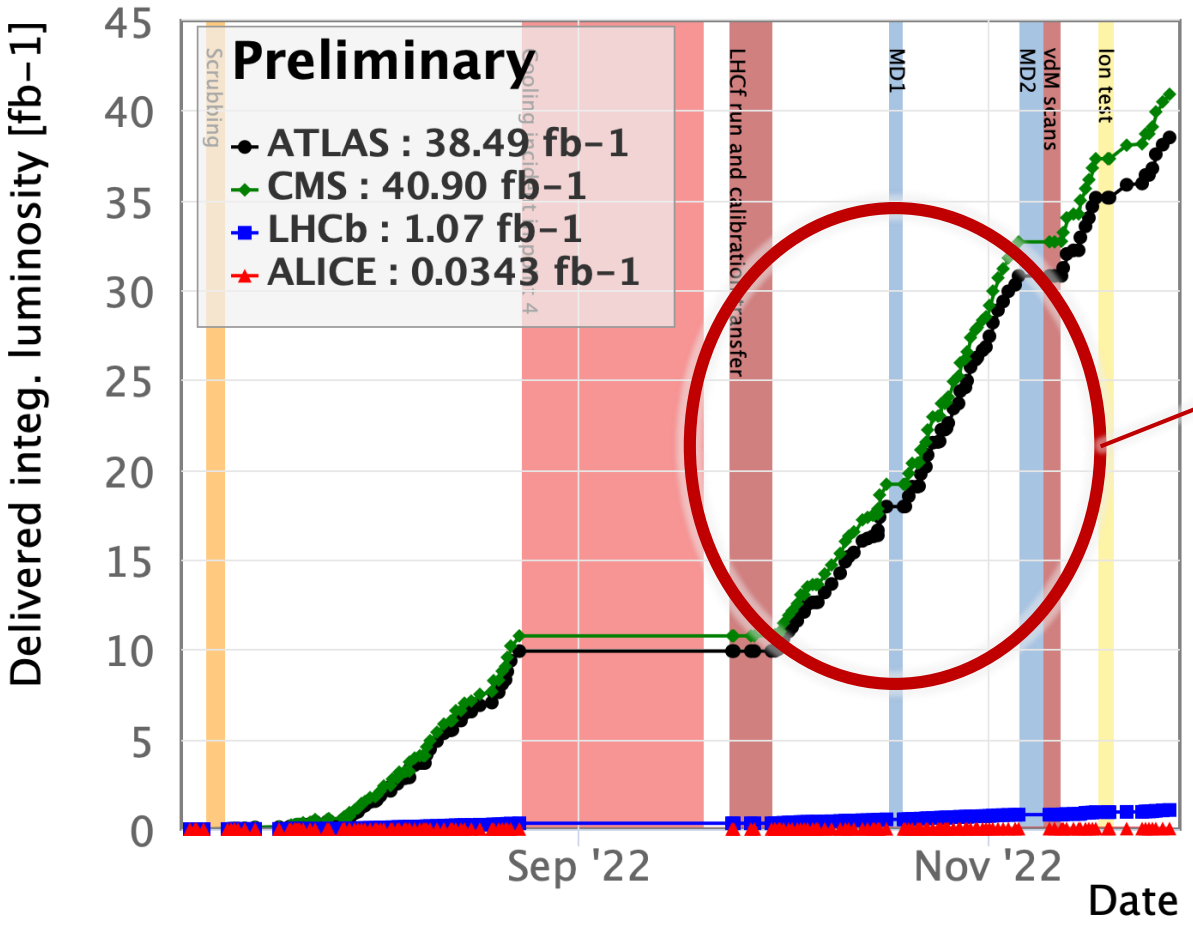
- AVG production = **0.79 fb^{-1}/24h**
- 790 h in SB in 47.5 days (69% time)
- Avg fill length = 7.4 h

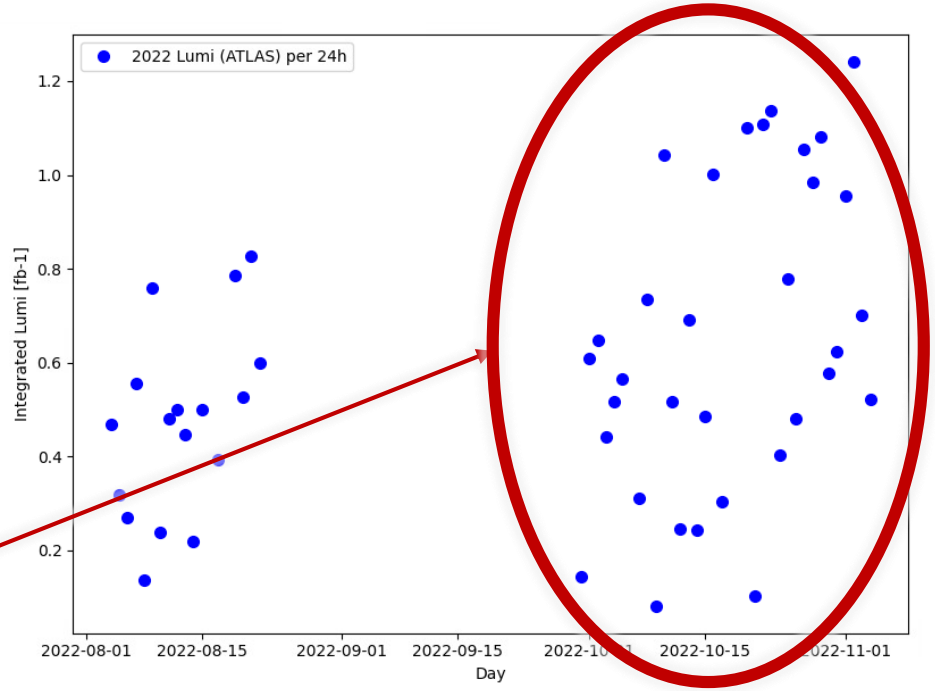
(96 - 47.5) * 0.79 + 32 = 70.3 fb^{-1}

Missed days — AVG production — integrated — **ESTIMATED**

Best operational period 2022

Delivered Luminosity 2022





Best production period

(30th Sep - 05th Nov)

- AVG production = **0.64 fb^{-1}/24h**
- 1171 h in SB in 70 days (68% time)
- Avg fill length = 6.8 h

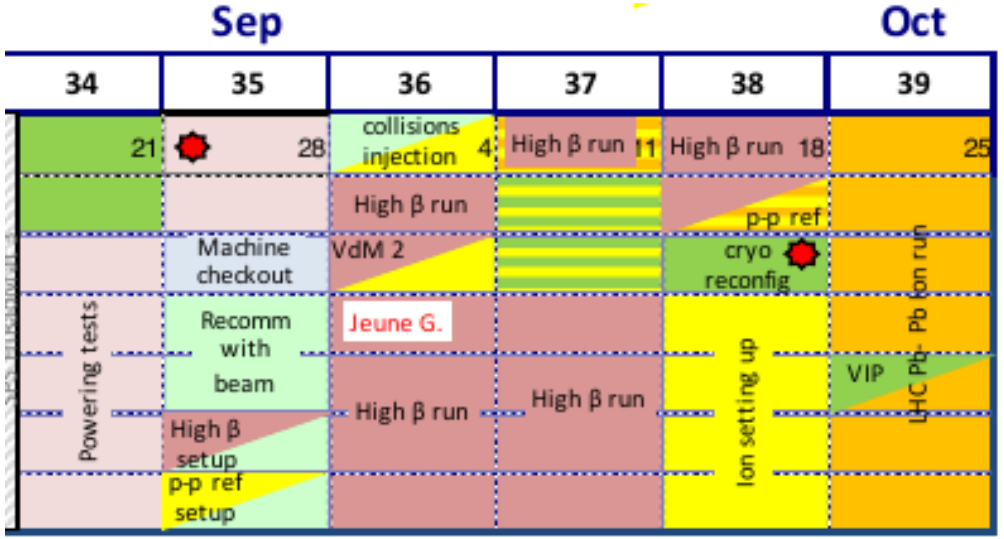
IONS

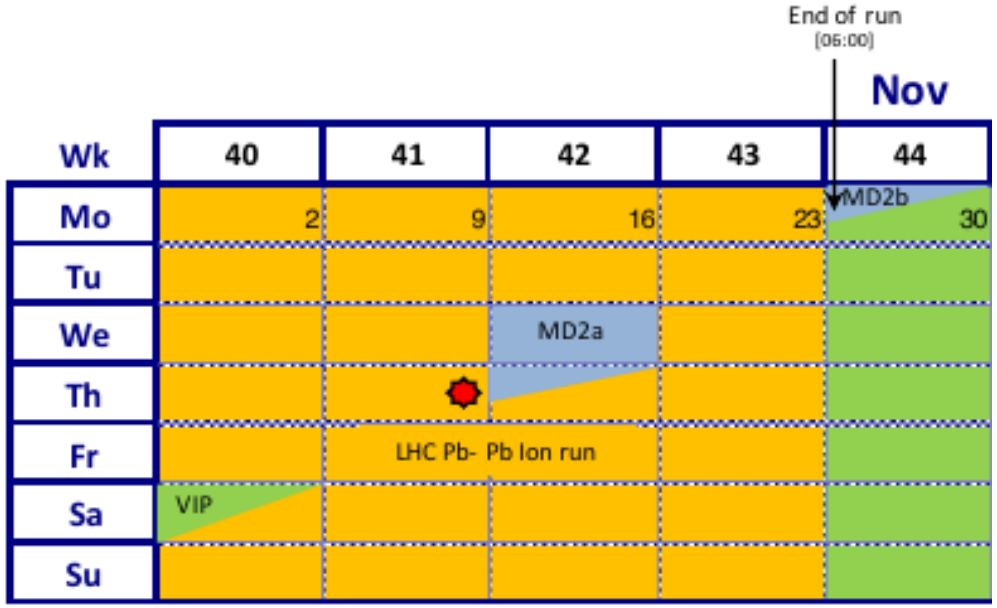
First Pb-Pb physics run @**6.8 Z TeV**

- 4 days **commissioning**
- 32 days **physics**
- **Breaks** for VIP visits, MDs, VdM

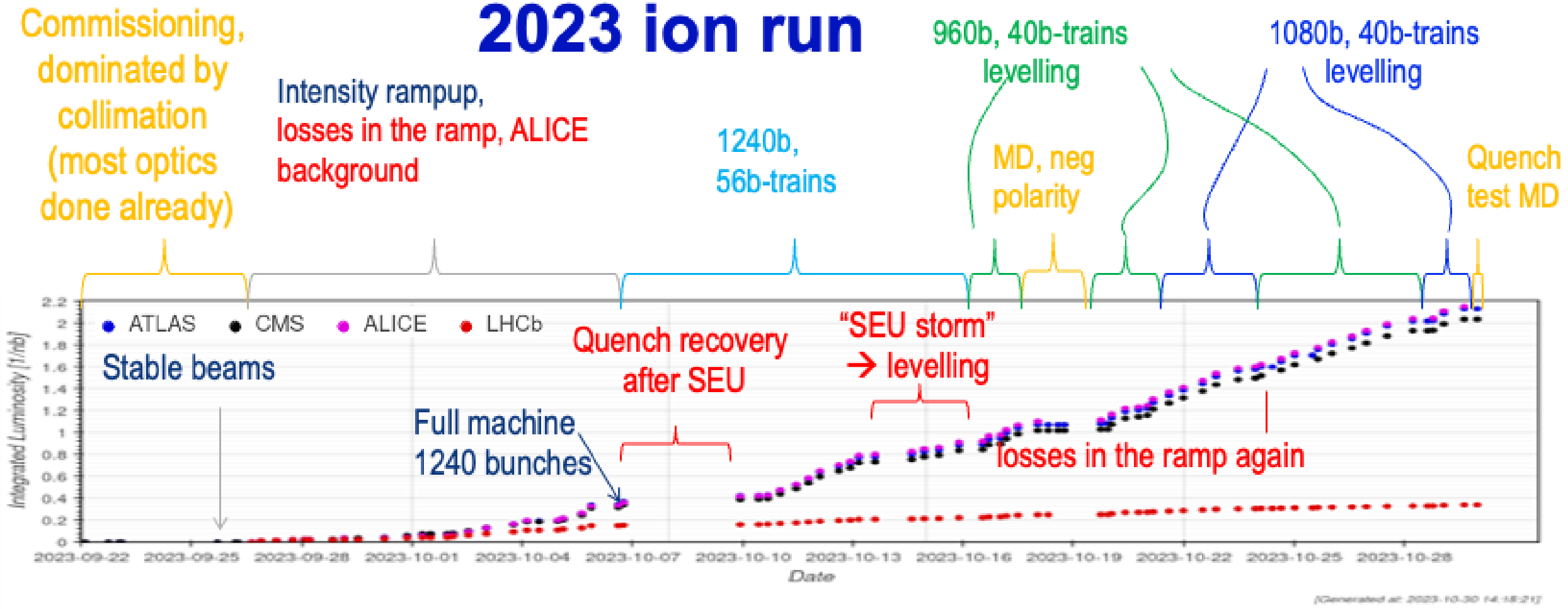
Several news with respect to past IONS runs:

- **Slip-stacking** for 50 ns beams
- **Crystals**
- **TCLD** collimators
- **BFPP orbit bump** in IR2 and IR8
- **Full squeeze** in ramp





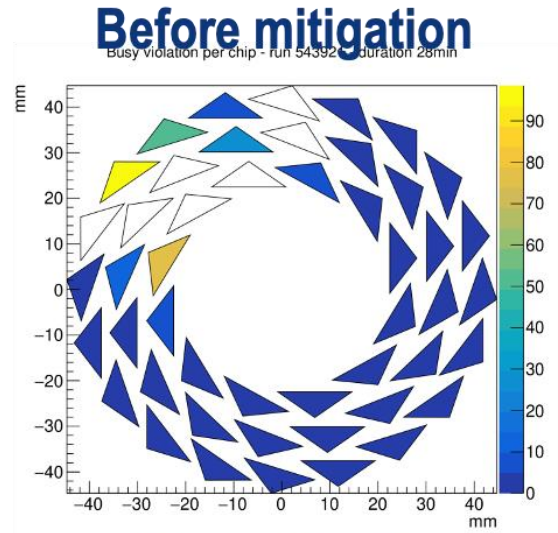
2023 ion run

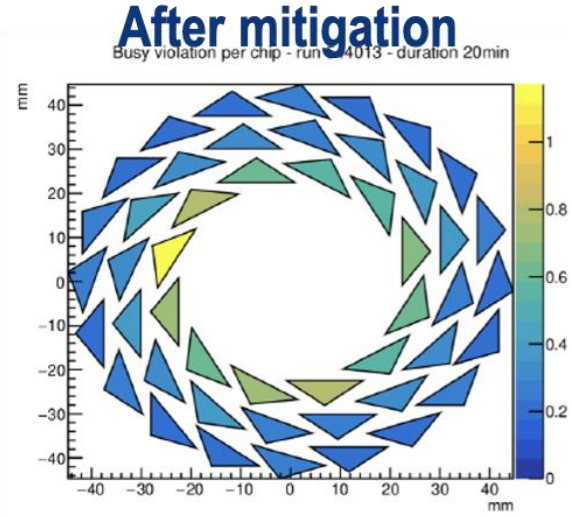


Courtesy R. Bruce

Main challenges encountered

- **13 Quench Protection System**, radiation-induced SEU => **beam dumps & magnet quench** (spurious heaters firing)
  - Mitigation (2023): level lumi in IP1/2/5 & cryo reconfiguration
- **10 Hz** Horizontal orbit oscillations => sudden **losses and beam dumps** (7 fills dumped +1 unclear), already seen in 2018!
  - **NO** real mitigation (2023) found
- **Transverse losses** during the ramp (≥ 5.5 Z TeV) => **Beams dump**, significant slowdown of intensity ramp-up
  - Mitigation (2023): orbit correction FFW + BLM thresholds increase
- **HW goniometer instability**
  - Mitigation (2023): “autopilot” for optimal channelling at top energy
- **Strong background** in ALICE => 5 fills of studies + simulation
  - Mitigation (2023): Orbit bump that modifies vertical dispersion

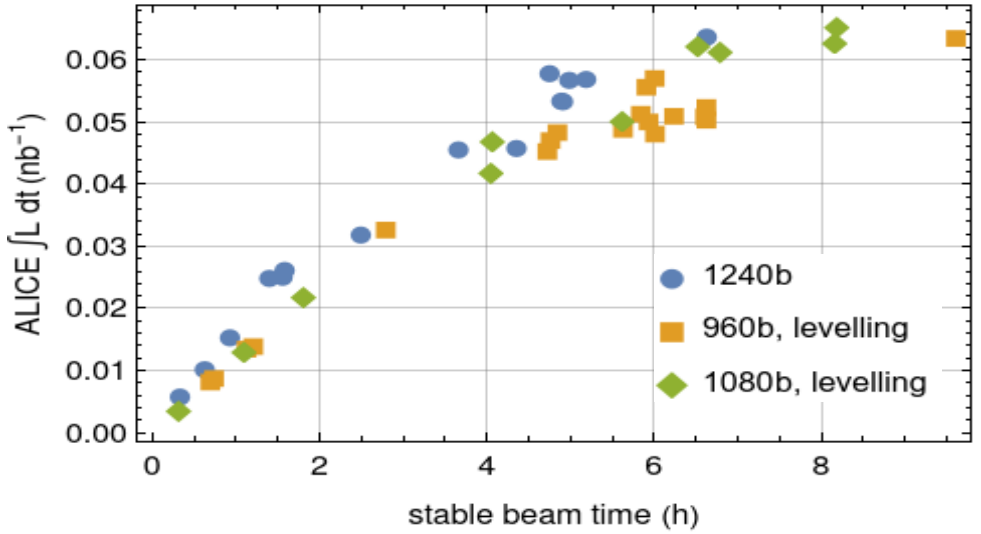


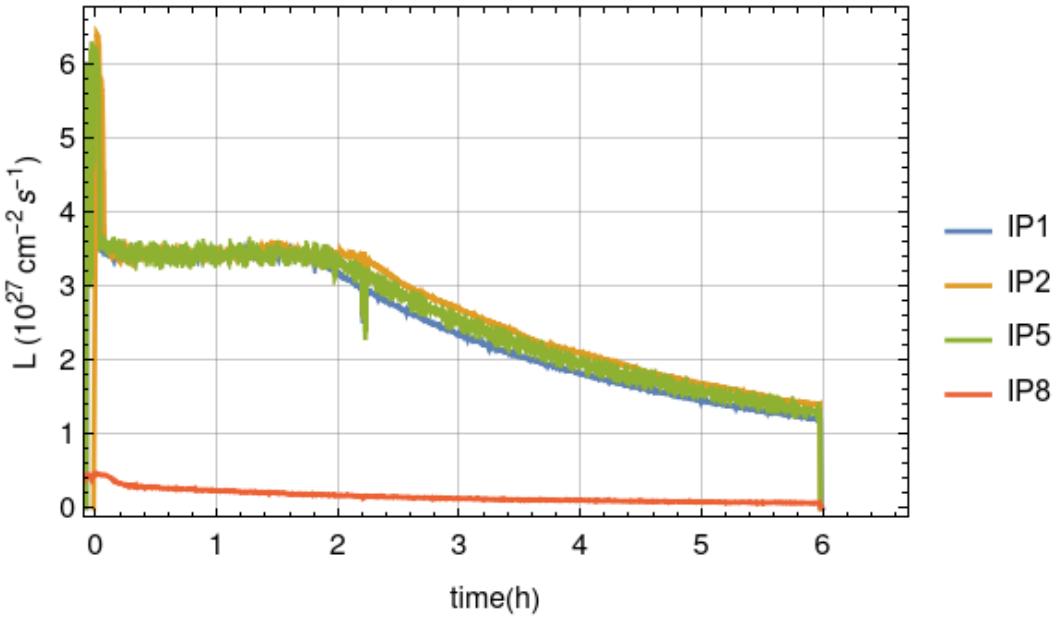


See R. Cai, S. Morales, J. Steckert for details

Luminosity production

- **Daily production: 100 μb^{-1}**
  - Reached 150 μb^{-1} on two occasions
- **Record peak luminosity** at ALICE:
  - Reached 6.4×10^{27} $cm^{-2}s^{-1}$ with only 961 bunches (average 1.8×10^{8} Pb/bunch at start of SB)
- **Integrated luminosity** **below initial targets**, but, delivered more data to all experiments than in 2018
  - ALICE got more data (2.16 nb^{-1}) than in Run 1 & Run 2 combined





Schedule constraints/comments for 2024

2024&2025 LHC **schedule had to be re-considered**, in the light of the challenges & possible limitations encountered during 2023:

- **Lost** LHC physics **time** will be **distributed** to proton physics, Pb ion physics and MDs
- **5.5 weeks remaining** for LHC Pb ion physics
  - => can be distributed over the 2 years or concentrated (Research Board)
- Impact on the **injectors schedules**

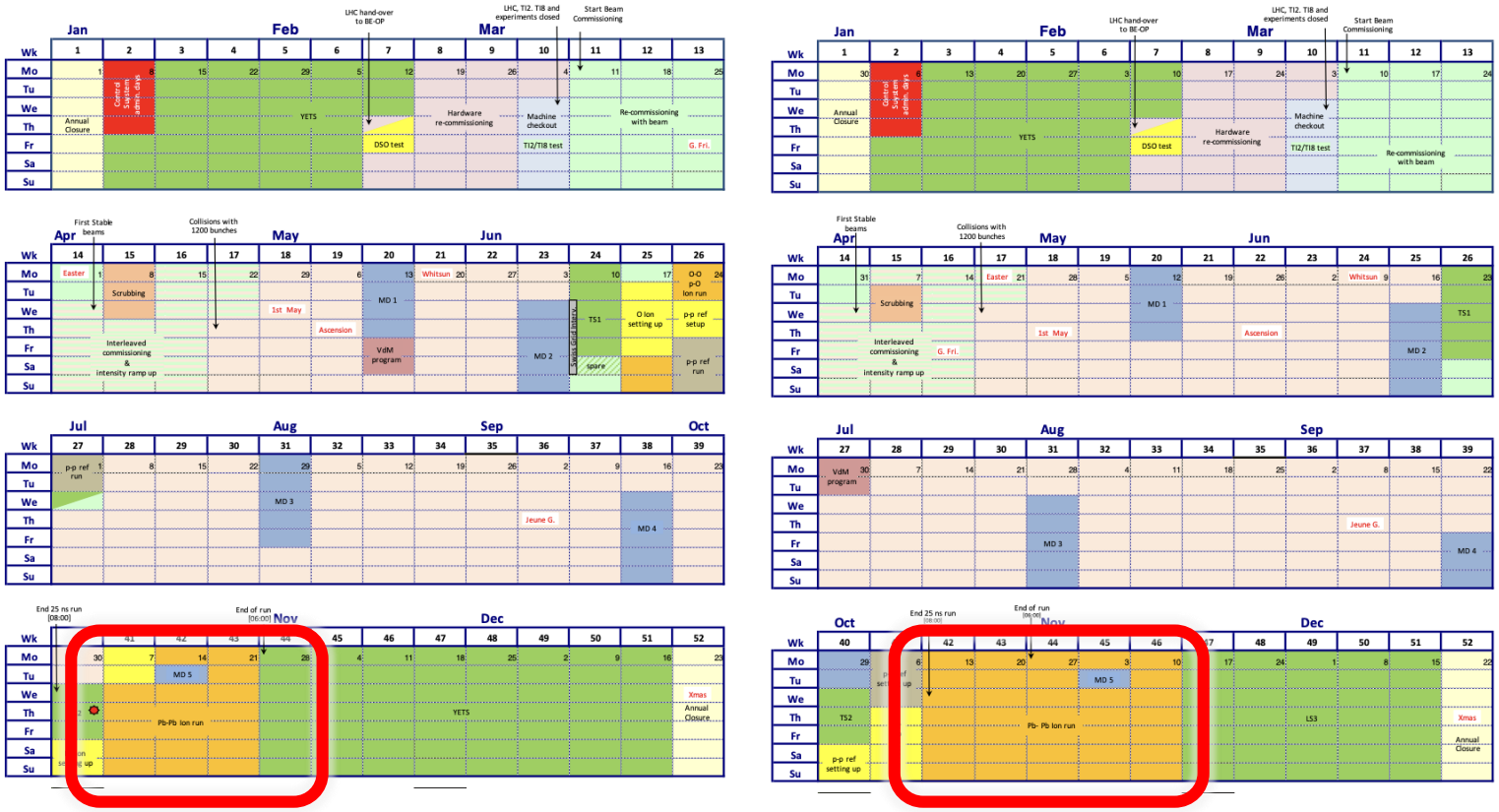
Two schedule **options**:

- **Baseline** with Pb ions in 2024
- **Alternative** with NO Pb ions in 2024, but all in 2025 (Oxygen in 2024)

In **both cases**:

- **3.5 weeks of commissioning** (see David's presentation)
- First beam in the LHC scheduled for **March 11th**

2024-2025 - option #1

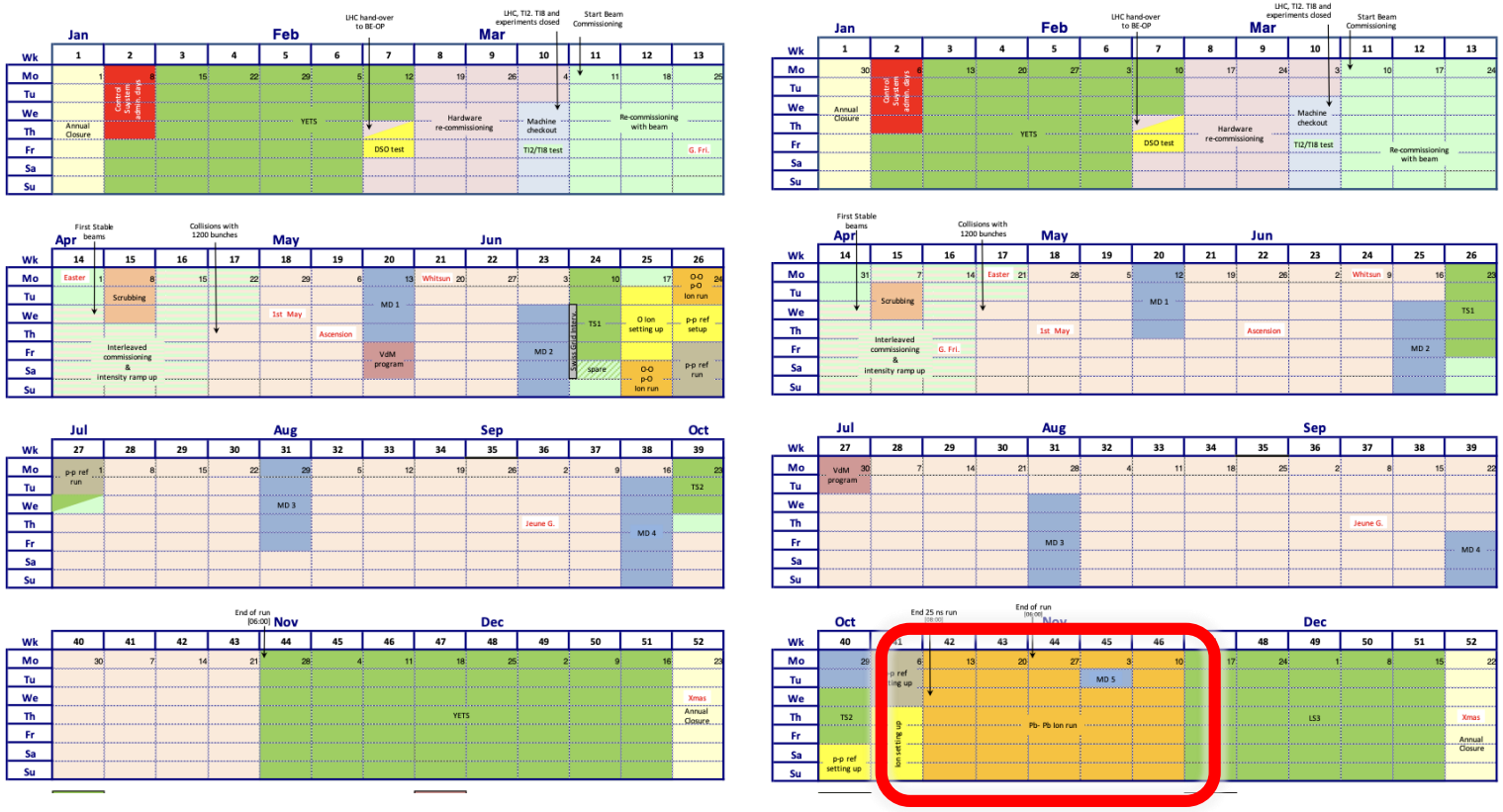


R. Steerenberg

- **Short PbPb run** (2.5-3 weeks) at end of **both** 2024 and 2025
- Less efficient, but **risk distributed**
- **Oxygen** run after TS#1 in 2024, NO special run in 2025
- **pp reference run** tentatively in 2024, after TS#1

	2024	2025
pp physics	115	145
OO + pO	4	
PbPb + ref	23	20
MD	20	20

2024-2025 - option #2



R. Steerenberg

- **Long PbPb run** (5.5 weeks) at the end of 2025
- **More efficient + Maximal radiation cooldown** before LS3
- **Oxygen** run after TS#1 in 2024, NO special run in 2025
- **pp reference run** tentatively in 2024, after TS#1

	2024	2025
pp physics	135	132
OO + pO	4	
PbPb + ref	5	39
MD	20	21

Conclusions

- **Rough year**, but despite of the limited availability we performed **well**
  - Proton run was almost on track to reach the target, despite the bunch intensity limitation
  - Ion run despite of the many challenges faced, good results (and records) achieved
- **No limitation** foreseen for the rest of Run3
  - Few critical points to watch closely (TDIS, RF finger,…)
- 2023 performance were **higher** than 2022 (expected)

Back-up slides

2023 in numbers

Time period: 05-05-2023 00:00:00 – 17-07-2023 00:00:00

Excluded time periods – Clear all: 13-06-2023 00:00:00 – 03-07-2023 00:00:00

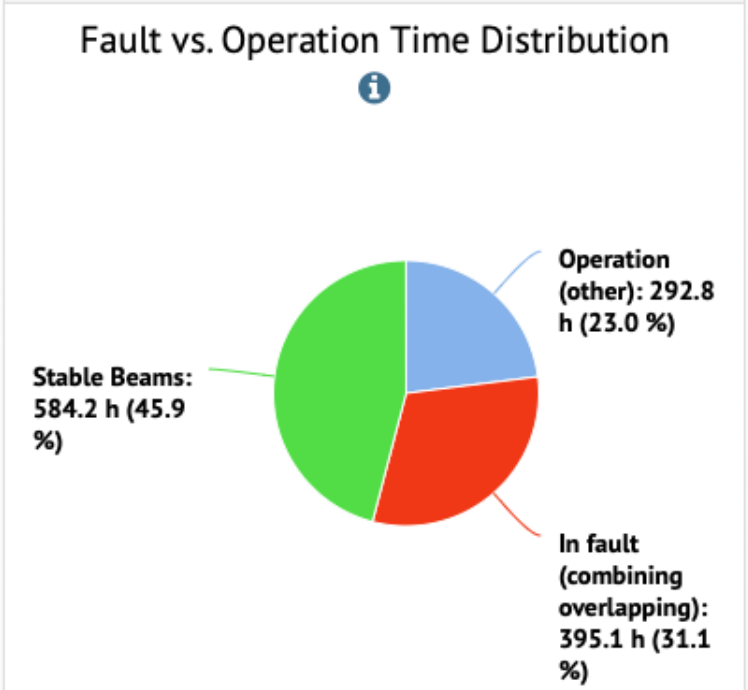
Availability

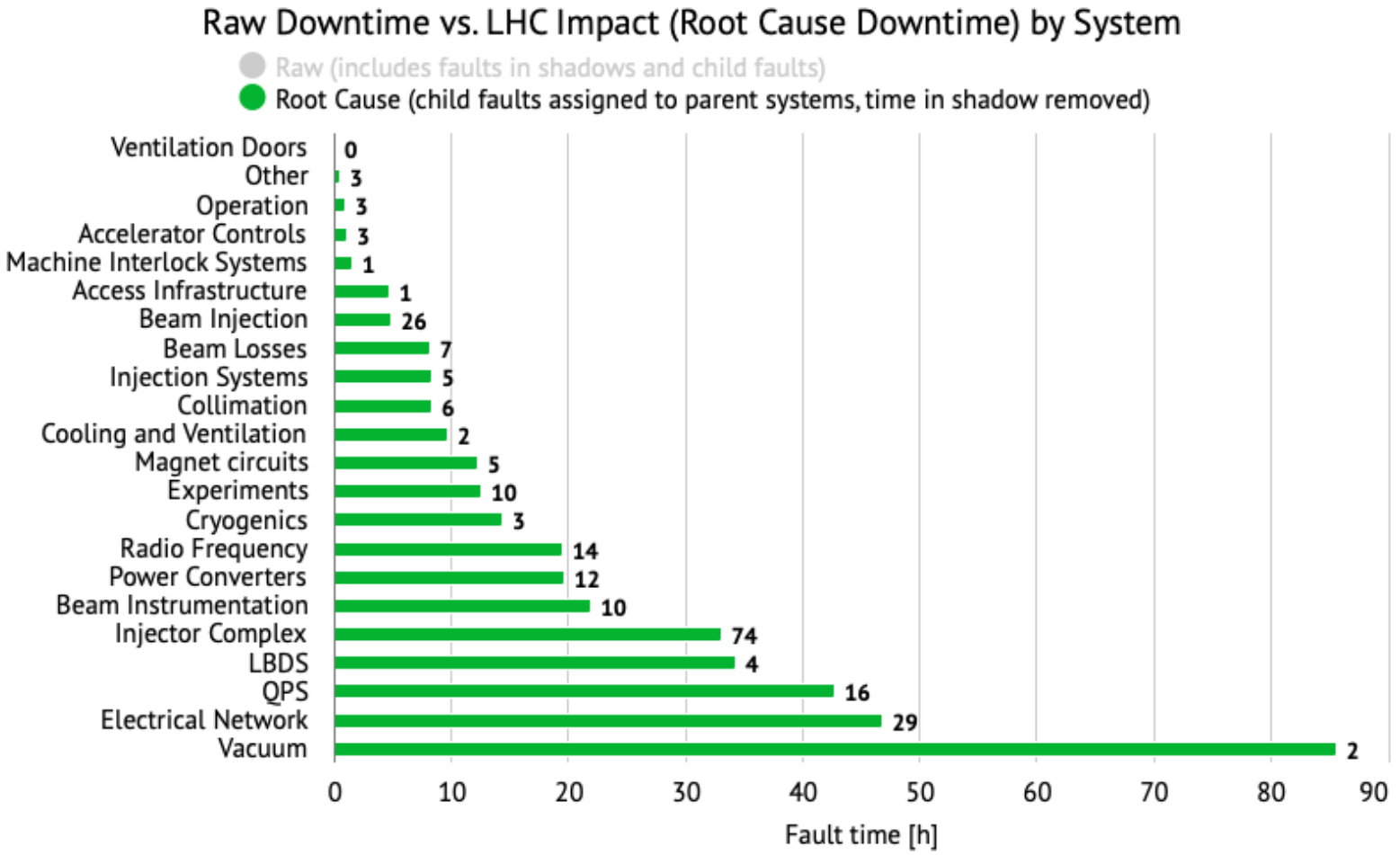
69.5%

Stable beams (SB)

45.9%

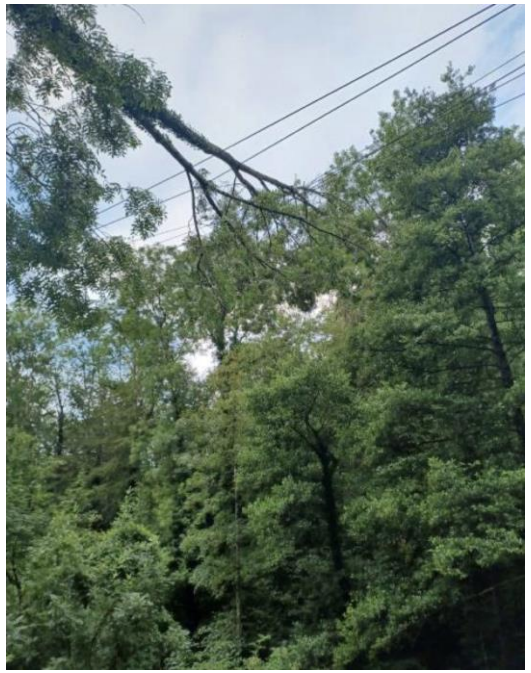
Fault vs. Operation Time Distribution





See L. Felsberger for details

2023 operation in numbers



A tree fell on two lines 125 kV of Romande Energie which are on the same support tower

Electrical glitches:

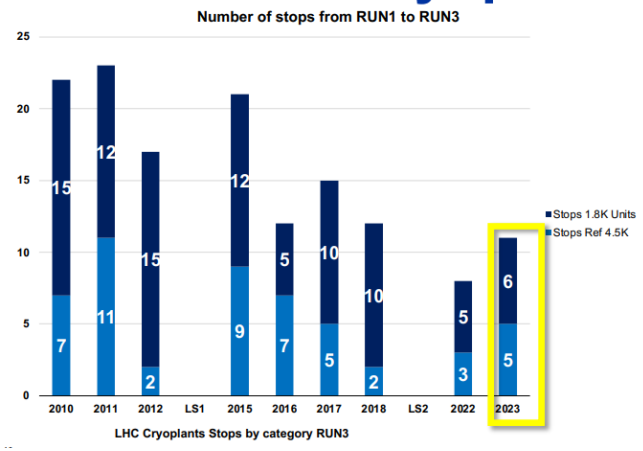
6 electrical glitches during 2023 production period:

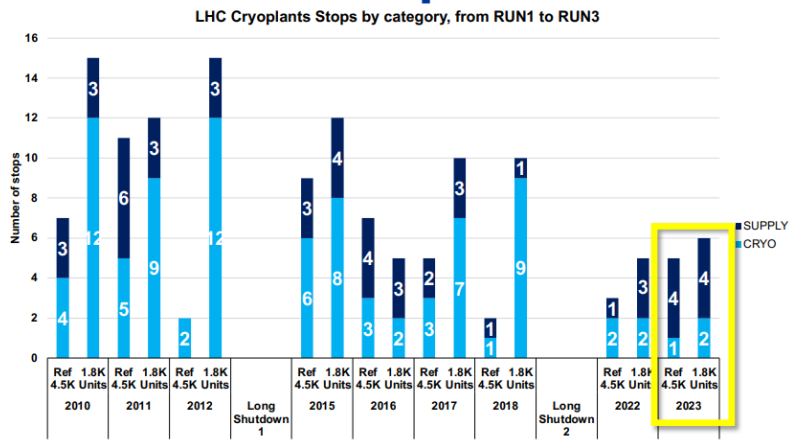
- 3 with minor consequence (just beam dump)
- 2 led to quenches of IPQs/Its (few hours)
- 1 led to IT.L8 stop (several days)

Cryo compressor stops:

- 3 stops

Cryoplants issues follow-up





2023 operation in numbers

	pp run	Special runs	Pb ion run	Total physics	MD time	Comment
2016	139	10	10	159	21	
2017	127	18	10	145	18	
2018	130	14	24	168	24	MD time increased in view of LS2
2022	70.5	7	2	77.5	9.5	Post-LS commissioning
2023	47.5	12.5	32	92	7	Mostly IT.L8