Fault Tracking in 2024

Jack Heron, Lukas Felsberger, Daniel Wollmann, Jan Uythoven, Bettina Mikulec, Anti Asko

Many thanks to inputs from OP colleagues, Machine Coordinators & System Experts

10.12.2024

Accelerator Fault Tracking (AFT)

More than 12,500 faults recorded and reviewed in 2024. Almost the whole CERN complex.

Many thanks to a tremendous effort from all contributors!

Numerous additional graphs and statistics (not in this presentation) can be found at:
https://gitlab.cern.ch/mpe-reliability-tools/aft_processing/-/tree/v2/output?ref_type=heads

Or please ask for specifics! - jack.heron@cern.ch

Structure

1. **Statistics:**
    a) Proton injectors
    b) Ion injectors
    c) LHC
    d) AD/ELENA
    e) ISOLDE
    f) EA/NA
2. **What is AFT “actually” offering the community?**
3. **Addressing Feedback from the Community**

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Proton Injectors

Acknowledgment: Gian Piero Di Giovanni, Bettina Mikulec, Kevin Li

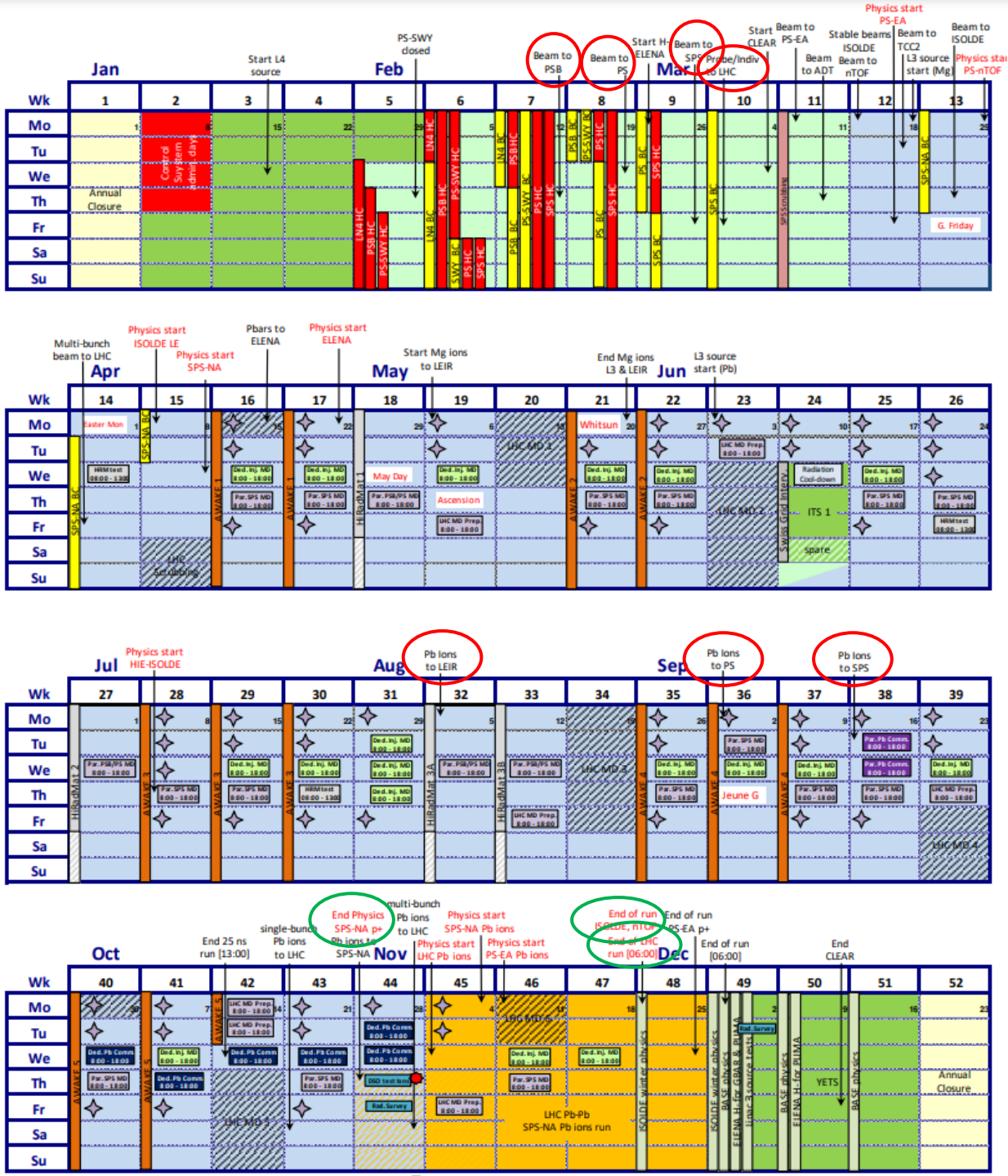
Injector Schedule

V2.2 – Oct 16th 2024

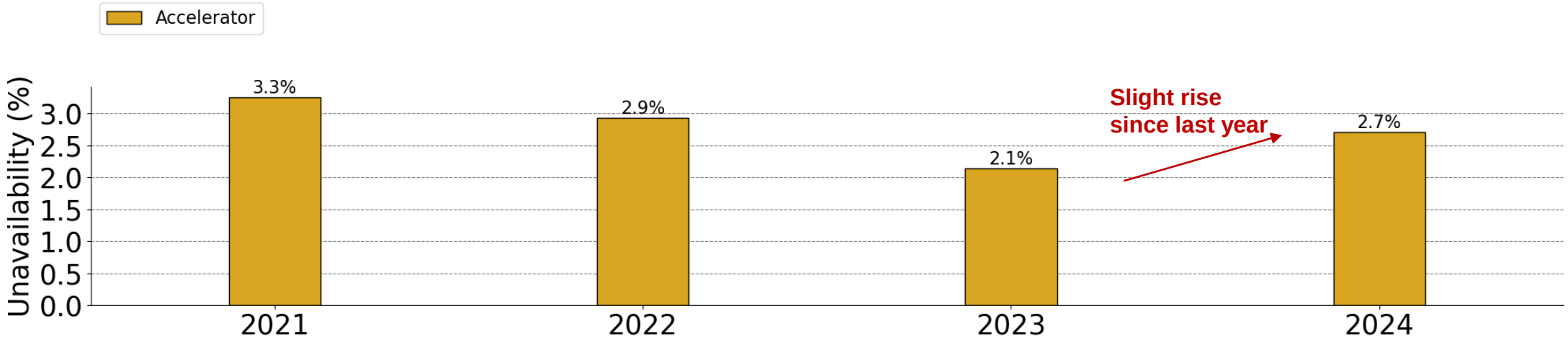
AFT fault recording starts once beam is required for a downstream machine (e.g. L4 AFT starts once PSB starts beam commissioning – Feb 15th 2024)

Dedicated MDs and TS are excluded from statistics (unless they cause delays of the physics periods)

Generally showing root-cause statistics: downtime attributed to system causing the downtime



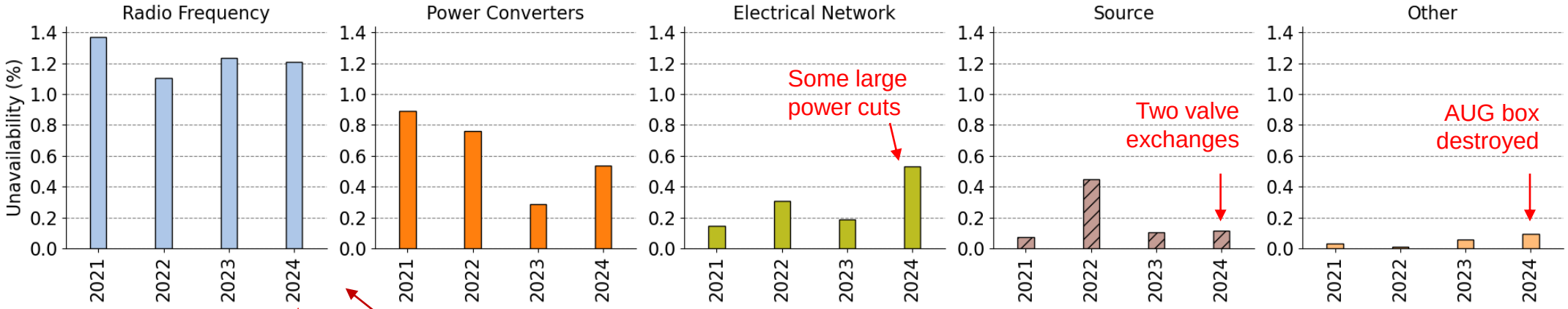
LINAC4

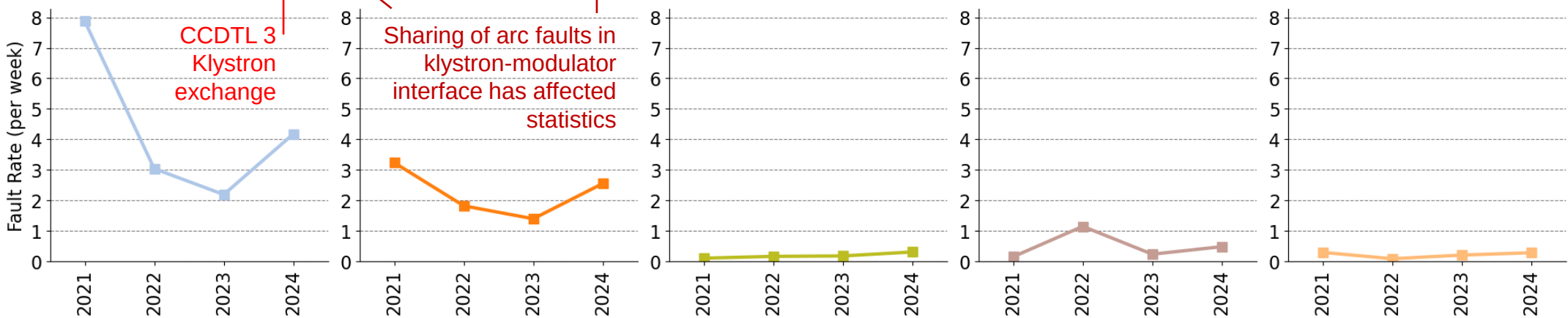


RF: Increased cavity protection and mis-pulse identification

A second klystron was exchanged during TS. Possible sign of LEP klystron ageing. Root cause unclear.

Without the CCDTL3 klystron exchange, unavailability is the same as last year (see appendix)

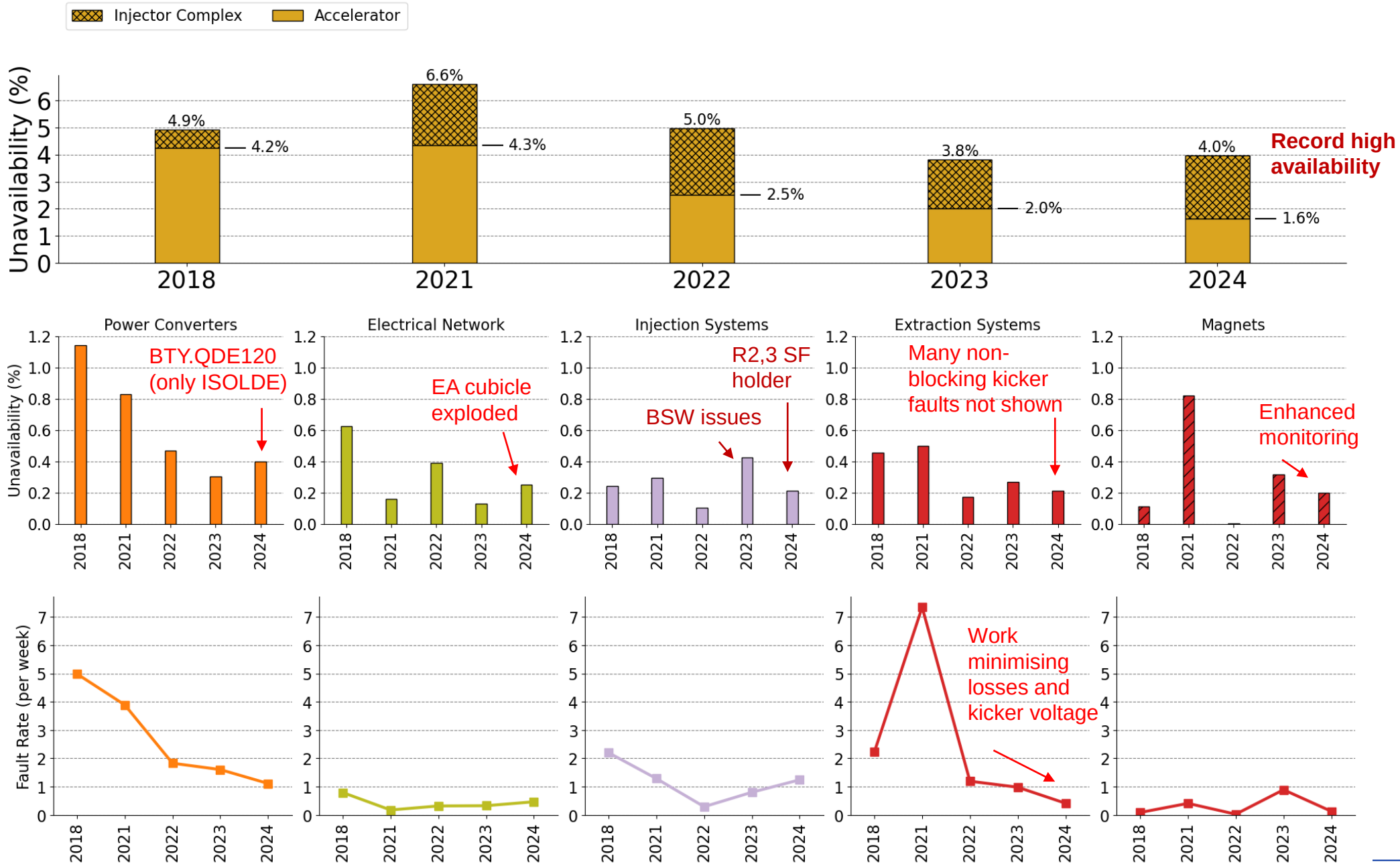




PSB

- **PC:** Longer repair times due to ageing BTY electronics. One delayed repair as team stuck in SPS. Should improve post LS3 with ISOLDE 2 GeV upgrade
- **Injection:** Improvement due to lack of BSW issues
- **Extraction:** Got lucky as longest faults were during commissioning
- **Magnets:** Enhanced monitoring minimised access for water leak. Magnets ageing concern has not manifested.

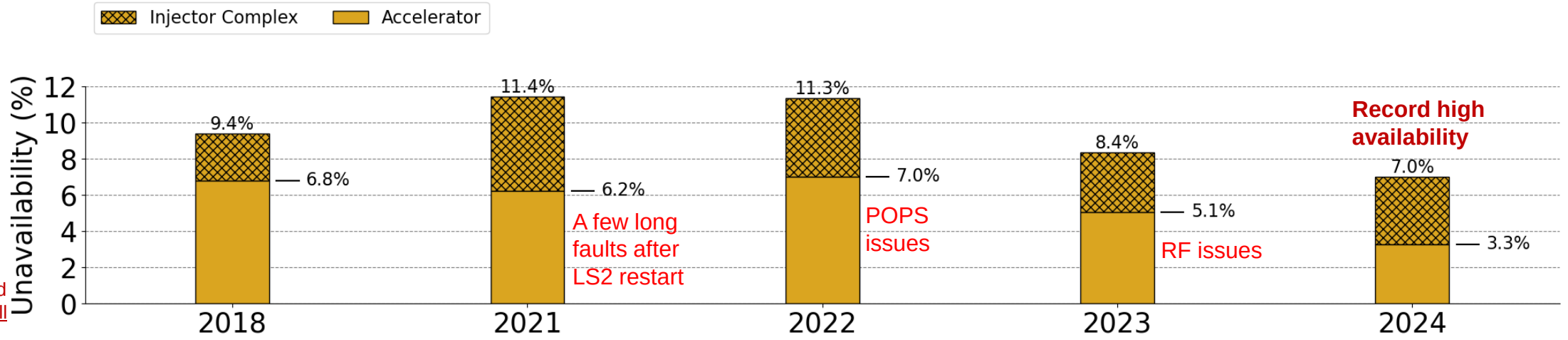
PSB has an availability advantage as full performance can often be gained with three of four rings. This is thanks to great work by the operations team!

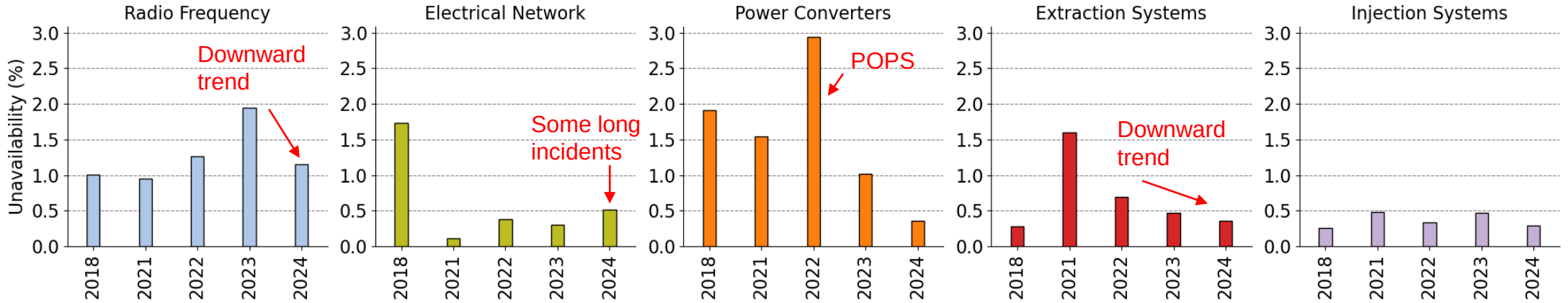


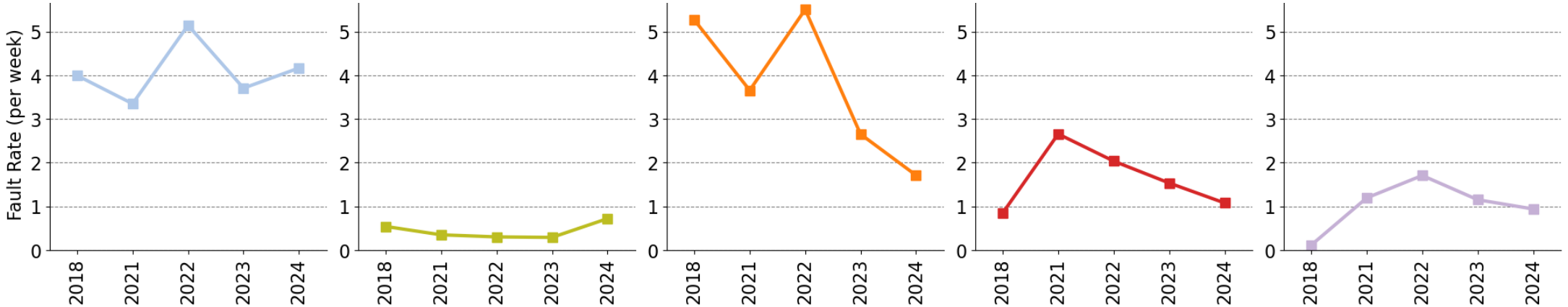
PS

- Continuous work and improvements from equipment experts and OP
- Resolution of certain fault types (POPS, RF, ABT)
- **RF:** Automatic reset and restart of cavities as well has hard work from RF team. This success has led to consideration for implementation in SPS.
- Long faults (LLRF signal, gap relays) to be mitigated in LS3
- **Power Converters:** accumulation of water-cooling faults for certain circuits will be followed up during YETS
- **Injection/Extraction:** Mitigations planned during YETS. Contribution expected to continue decreasing.

Huge reduction in medium down time faults since 2022 (see appendix)

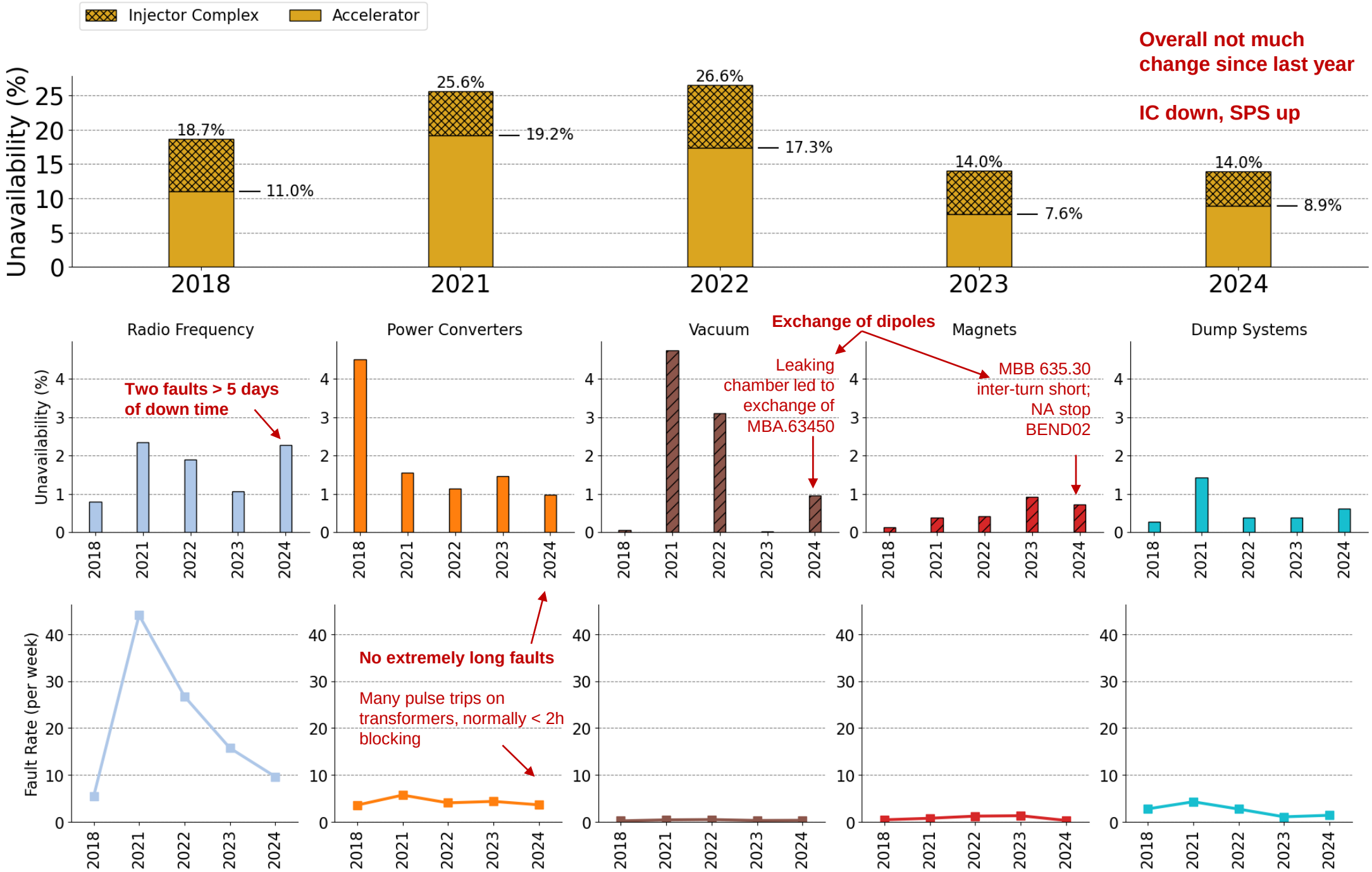






SPS

- **RF and CV:** Mitigations for long down time faults in YETS
- Short faults (<2h) remain a significant contributor to down time (see Appendix)
- Long MBB faults likely to continue



Proton Injectors - Conclusions

- **PSB and PS:** Record high availability! (98.4 %, 96.7 %)
- **LINAC4 and SPS:** Availability stable and high (97.3 %, 91.1 %)
- **Variations are mainly from single-event long-duration faults (see appendix)**
- **Warm magnet consolidation effort is underway. Long down times may persist.**
  - See 360th IEFC meeting 13 Dec 2024 https://indico.cern.ch/event/1485823/

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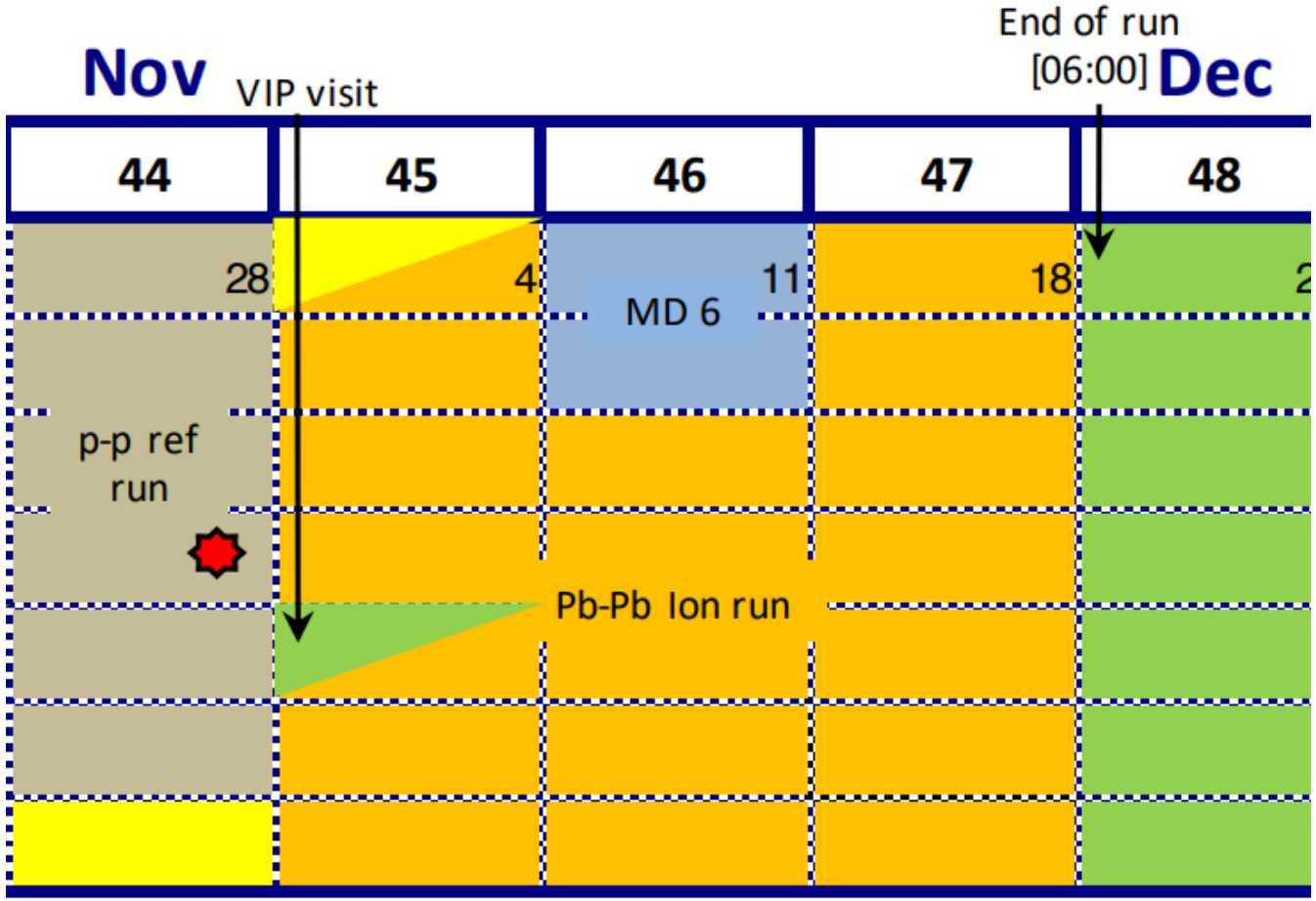
Ion Injectors

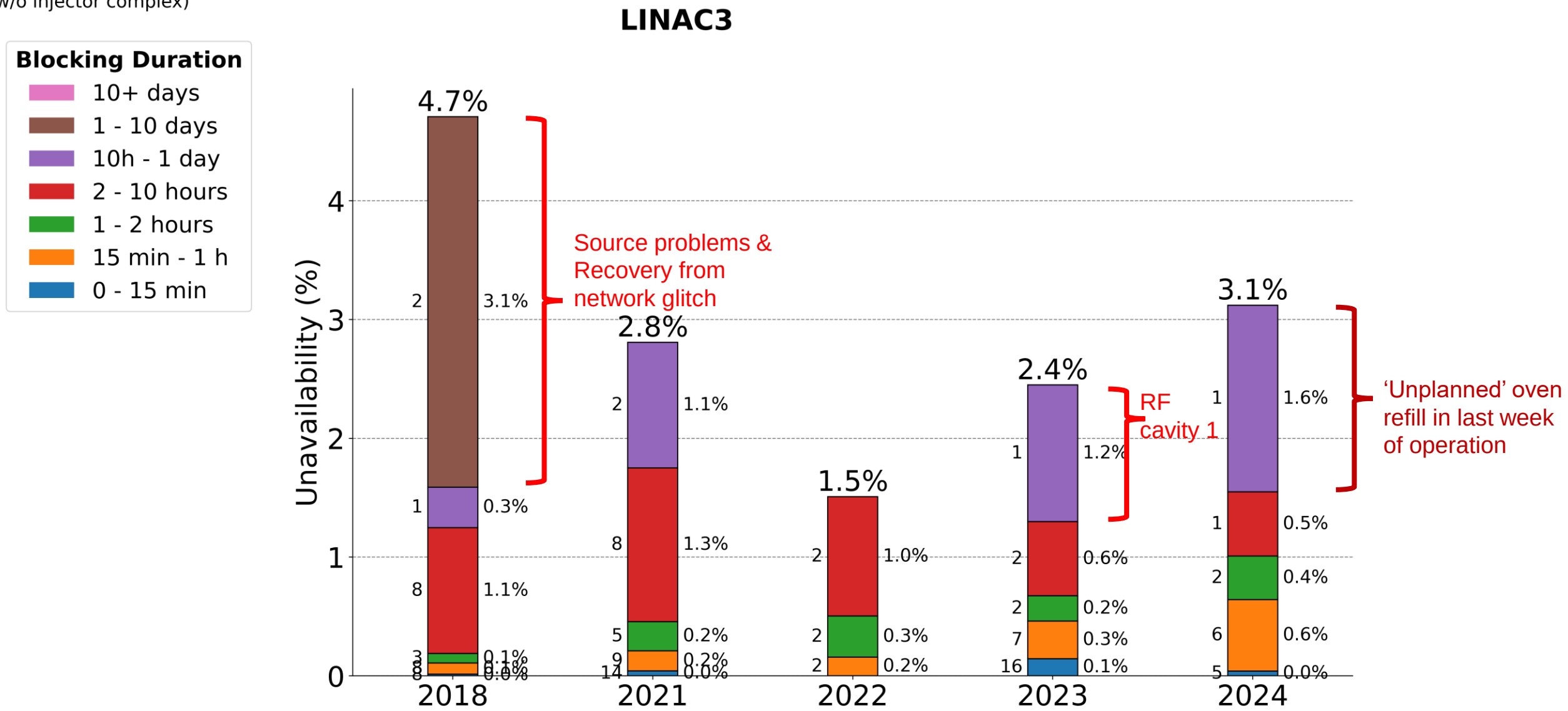
Acknowledgment: Richard Scrivens, Richard Scrivens, Theodoros Argyropoulos, Oliver Hans

Ion Injectors – LINAC3 & LEIR

- **When LHC, North Area and East Area get ions**
  - only 4 weeks in 2024 → ‘weak’ statistics. Graphs are not to be overinterpreted.
  - Review AFT periods for next year?

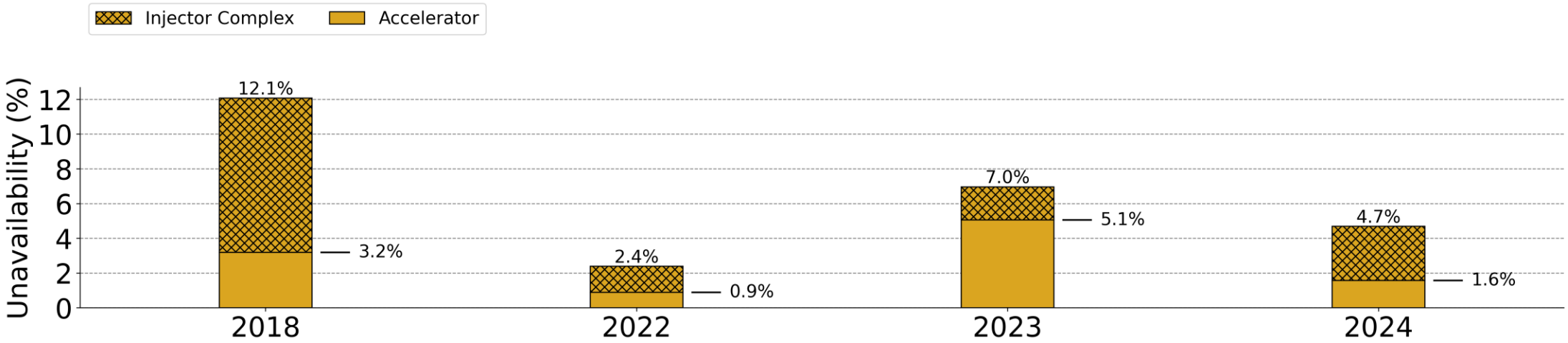


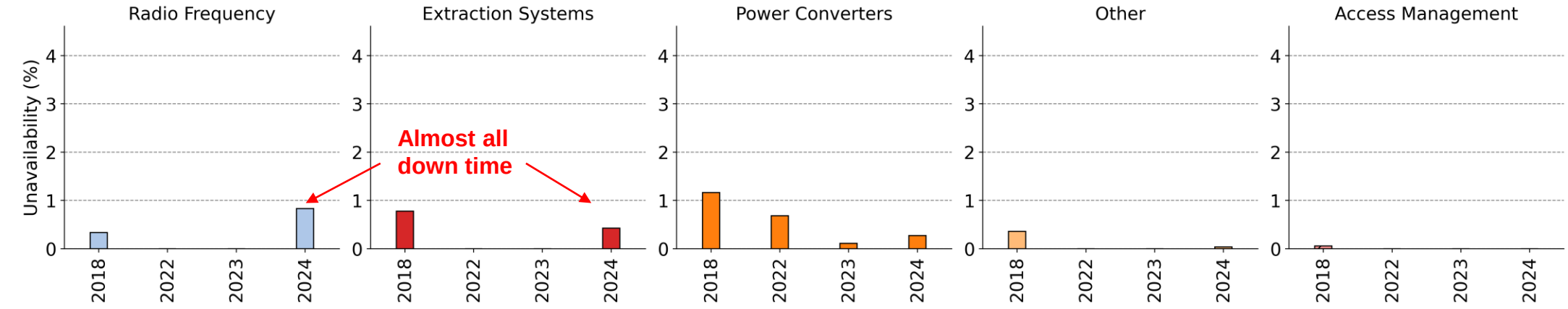
(w/o injector complex)

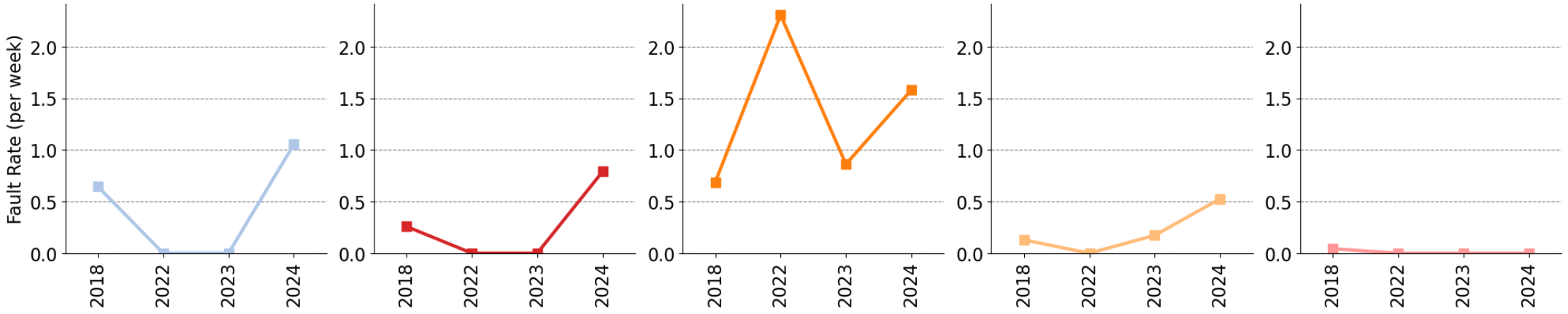


- **Up to last week it was an excellent year**
- **Long term strategy needed for long lead time spares in ion source**

LEIR







Mitigations foreseen in YETS

LINAC3, LEIR Conclusions

- **Overall strong performance (96.9 %, 98.4 %)**

- **Only 4 weeks accounted in 2024 → statistics shouldn’t be over-scrutinised**

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LHC

Acknowledgement: Matteo Solfaroli Camillocci

LHC Schedule

V2.2 – Oct 14th 2024

LHC "All Operation":

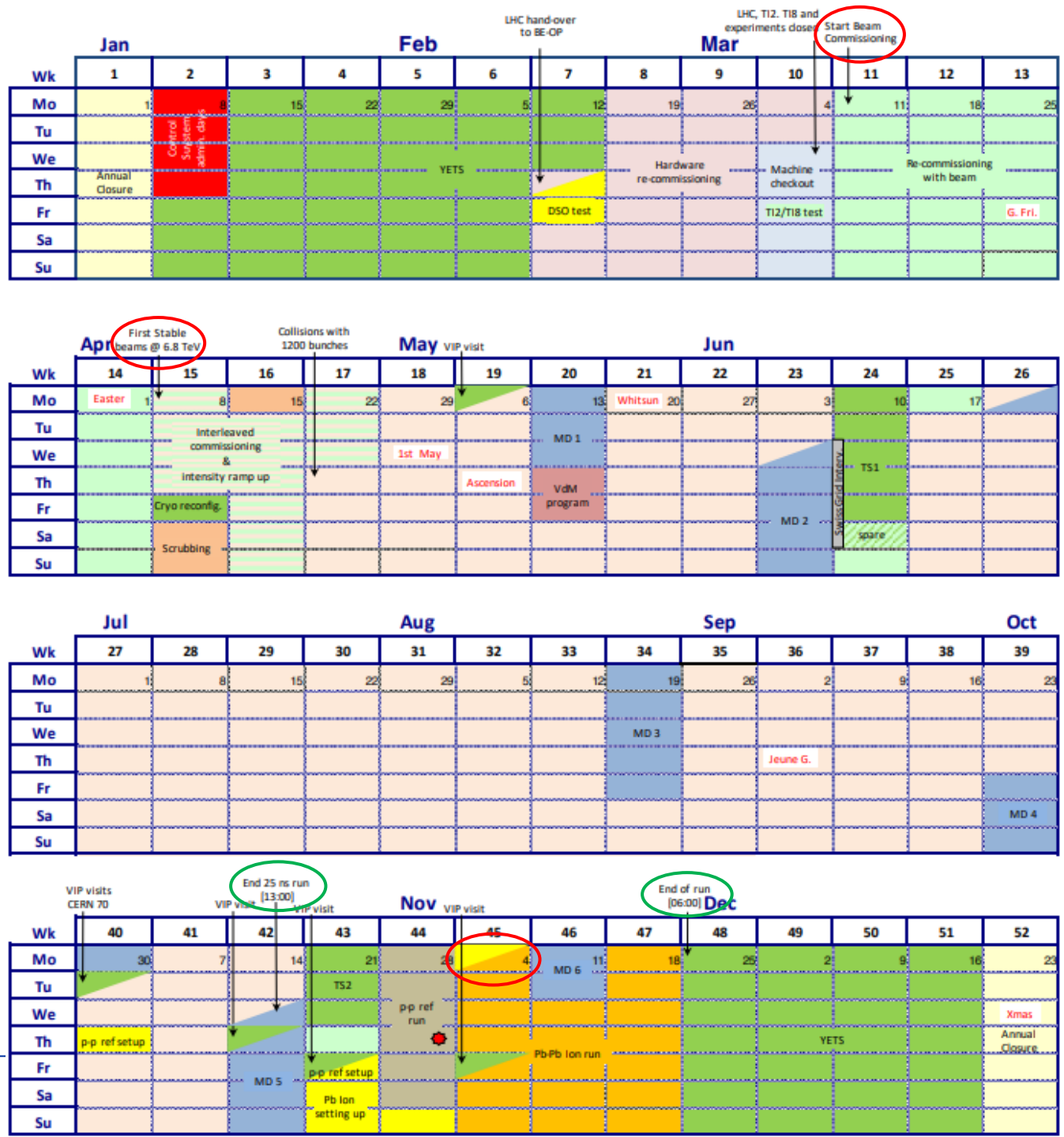
- From start of recommissioning with beam to start of annual shutdown
- Includes MDs, excludes TSs
- Permits tracking of all faults and delays

LHC Protons:

- From first stable beams declaration to end of 25ns run
- Dedicated MDs, set up periods, special physics, VIP visits and TS are excluded from statistics

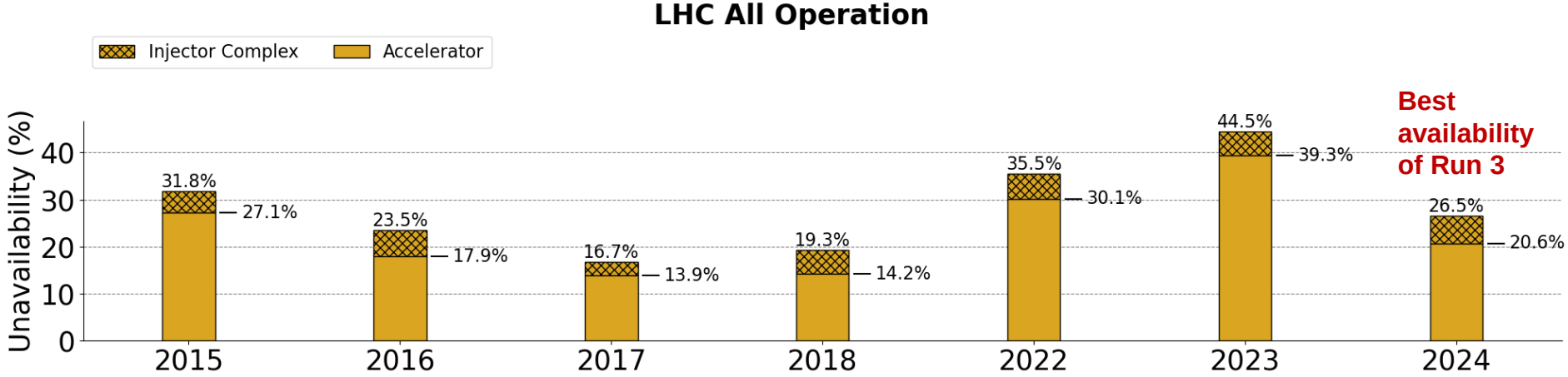
LHC Ions:

- From start to end of Pb-Pb Ion run
- Dedicated MDs, set up periods, special physics, VIP visits and TS are excluded from statistics



2024 had the best availability of Run 3

Not as strong as the best of Run 2, but we're also pushing bunch intensity, heat load, beam energy, etc.

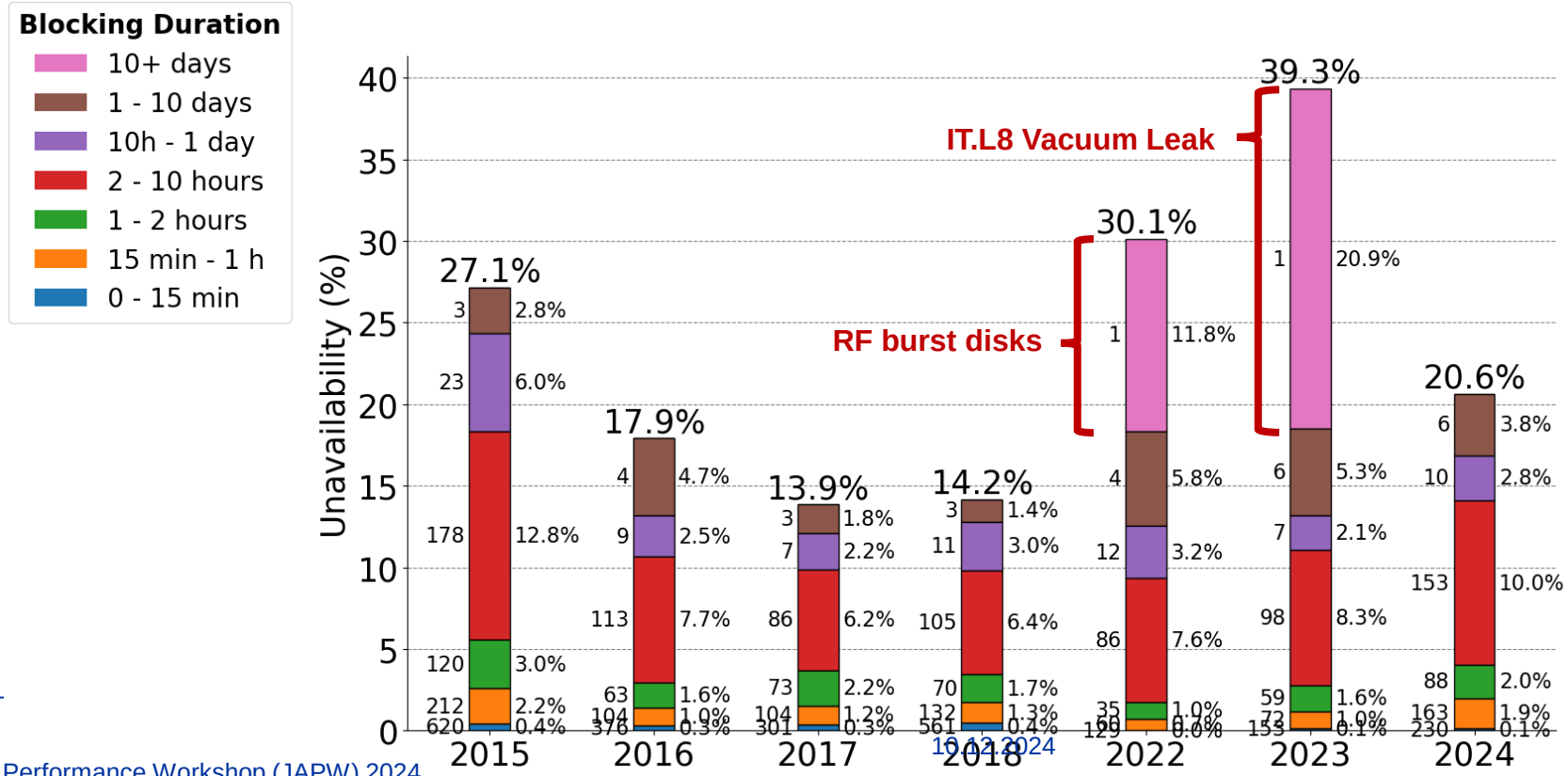


A lot of great work this year.

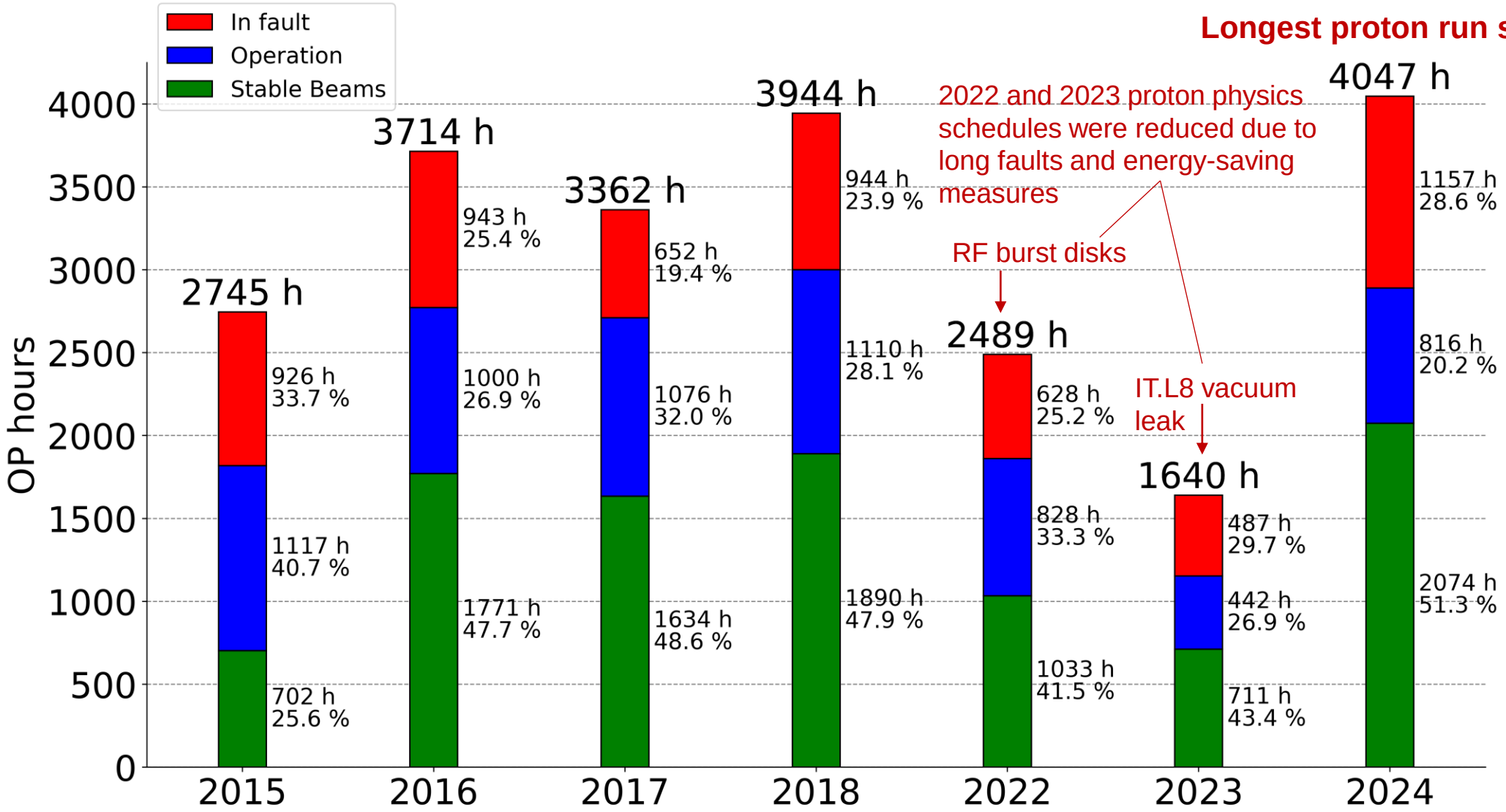
But for availability, the only real game-changer was missing one long fault.

Some trends:
- Mid-range faults (2-10h) increasing
- Overall faults <24h increasing

Explained by:
- QPS
- Other: Heat load issues + new categories (e.g. scheduled access)
- Experiments emulsion changes



LHC Proton Run



Longest proton run since 2015

2022 and 2023 proton physics schedules were reduced due to long faults and energy-saving measures

RF burst disks

IT.L8 vacuum leak

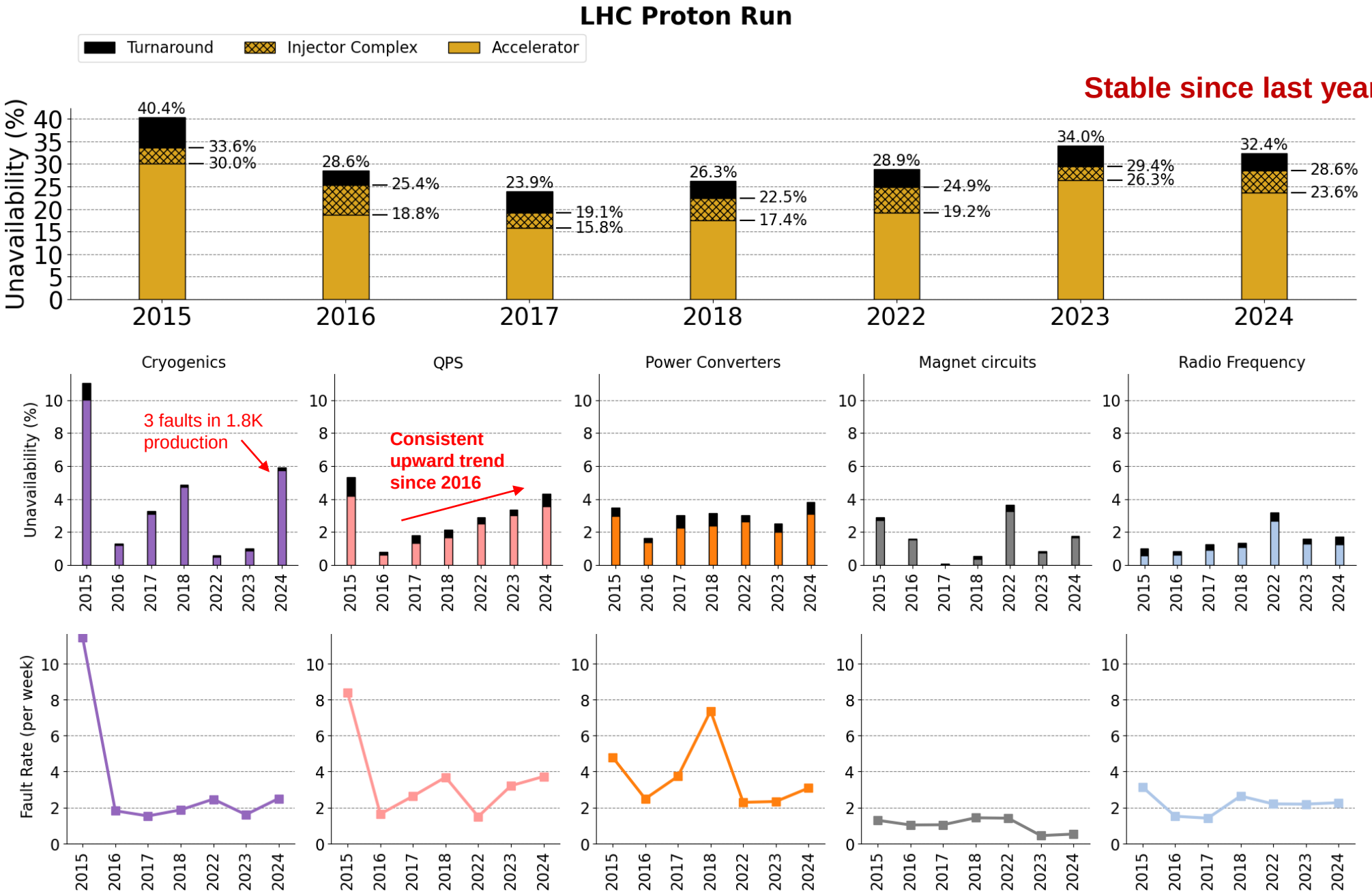
Highest % in stable beams

Cryogenics bad year
- 3 faults > 132 h
- Mitigations at IP8 planned during YETS

QPS concerning trend

Further bunch intensity increase could impact availability in 2025.

Change of beam type (25ns vs hybrid filling scheme) may also bring surprises.

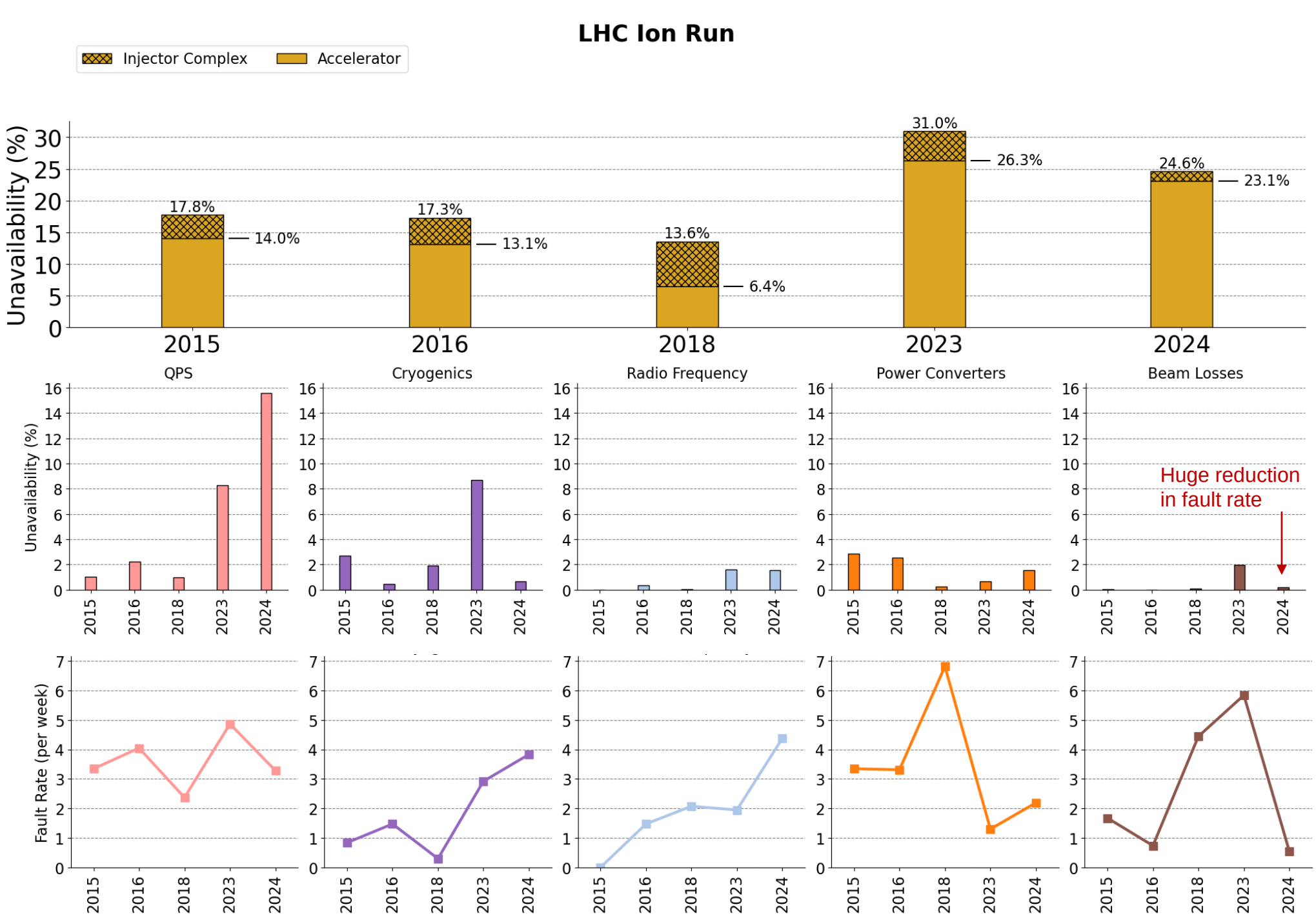


QPS: ion run problems
https://indico.cern.ch/event/1484357/contributions/6255477/attachments/2980053/5246981/LMC04122024_Quenches_during_Ion_Run_2024_v2.pdf

Not running in cryogenics eco mode has paid off

Excellent luminosity production because of higher bunch intensities.

Turnaround penalty not yet included for Ion statistics.



LHC Conclusion

- Best overall availability in Run 3 (80 %).
- Largest % of time in stable beams.
- No long faults
- Availability in physics is stable. Some trends are being following up.

AD/ELENA
ISOLDE
EA/NA

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Acknowledgement: Laurette Ponce, Emiliano Piselli, Bastien Rae, Nikolaos Charitonidis, Paraskevi Alexaki

AD:

Issues not shown in statistics:

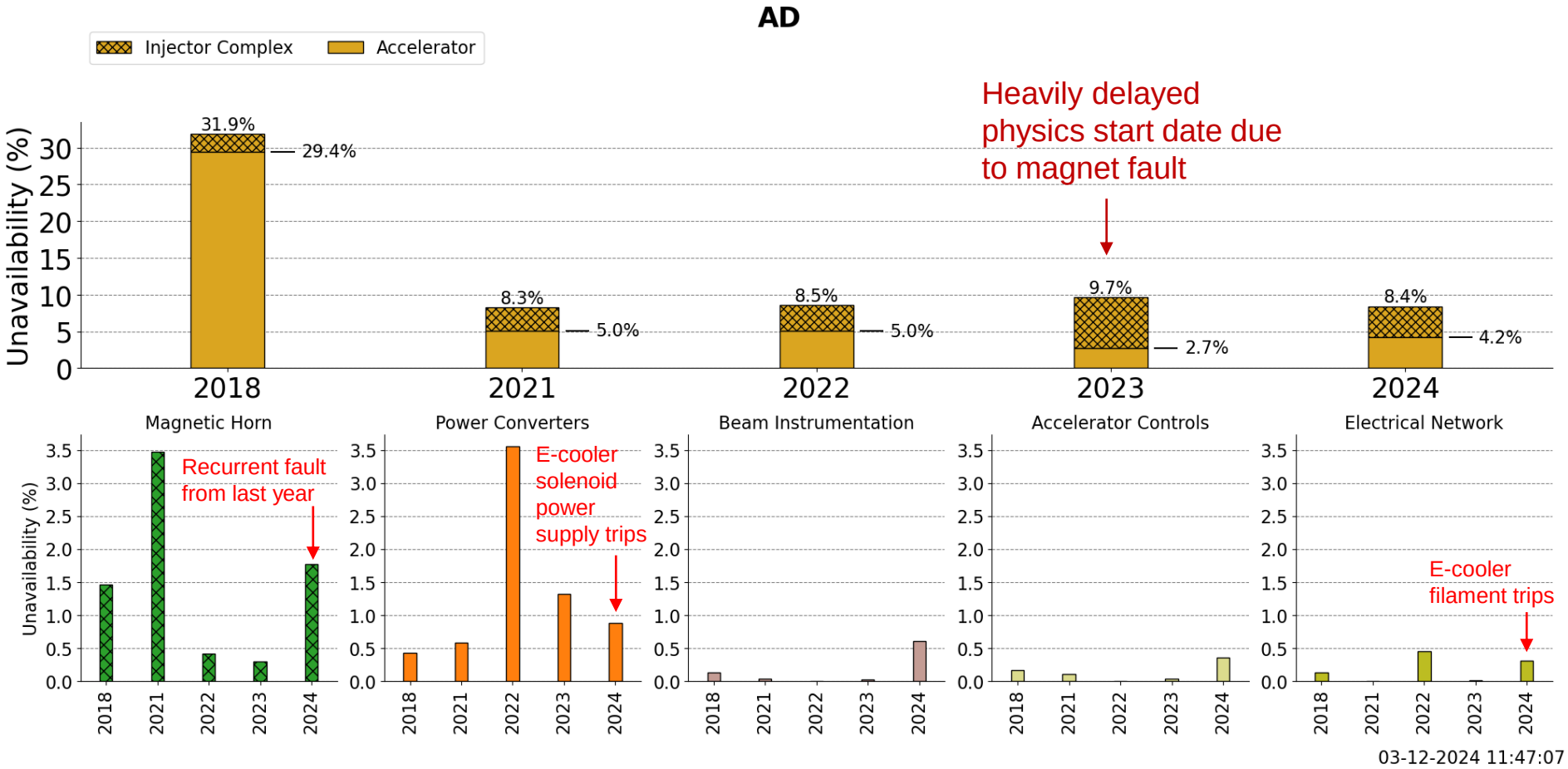
- Many systems in degraded mode: target, magnetic horn
- Non-blocking faults with stochastic cooling, instrumentation

<u>Recurrent issues from last year:</u>

- Spark in Magnetic horn,
- Cooling of the BCCCA (beam current monitor), 4h access needed to refill

<u>PC & Elec. Net.:</u>

- Increasing number of trips of e-cooler solenoid PC
- Increased number of power cut inducing filament trips → long recovery time
- Still many trips of the main QUAD, but quick recovery compared to last year

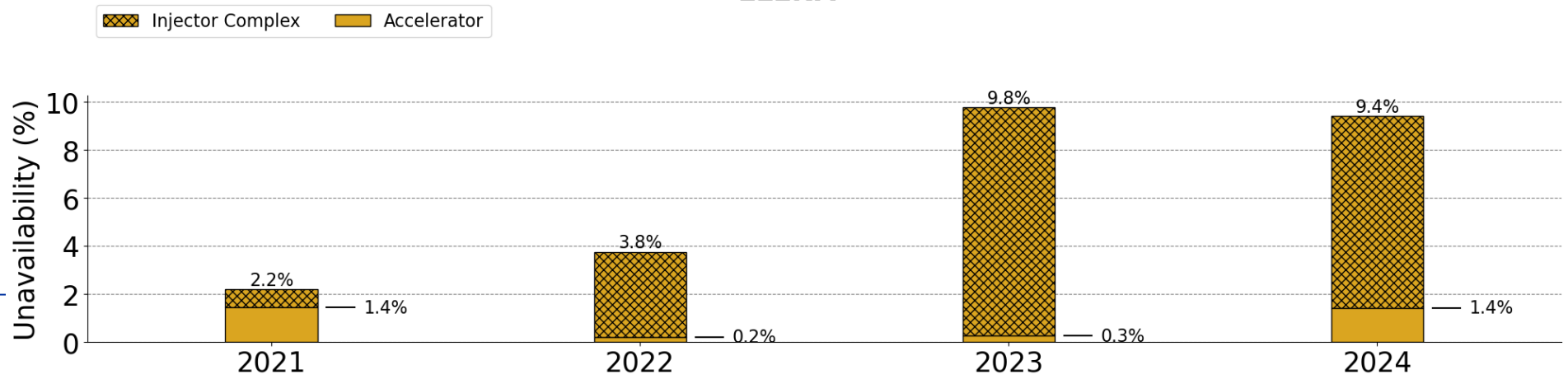


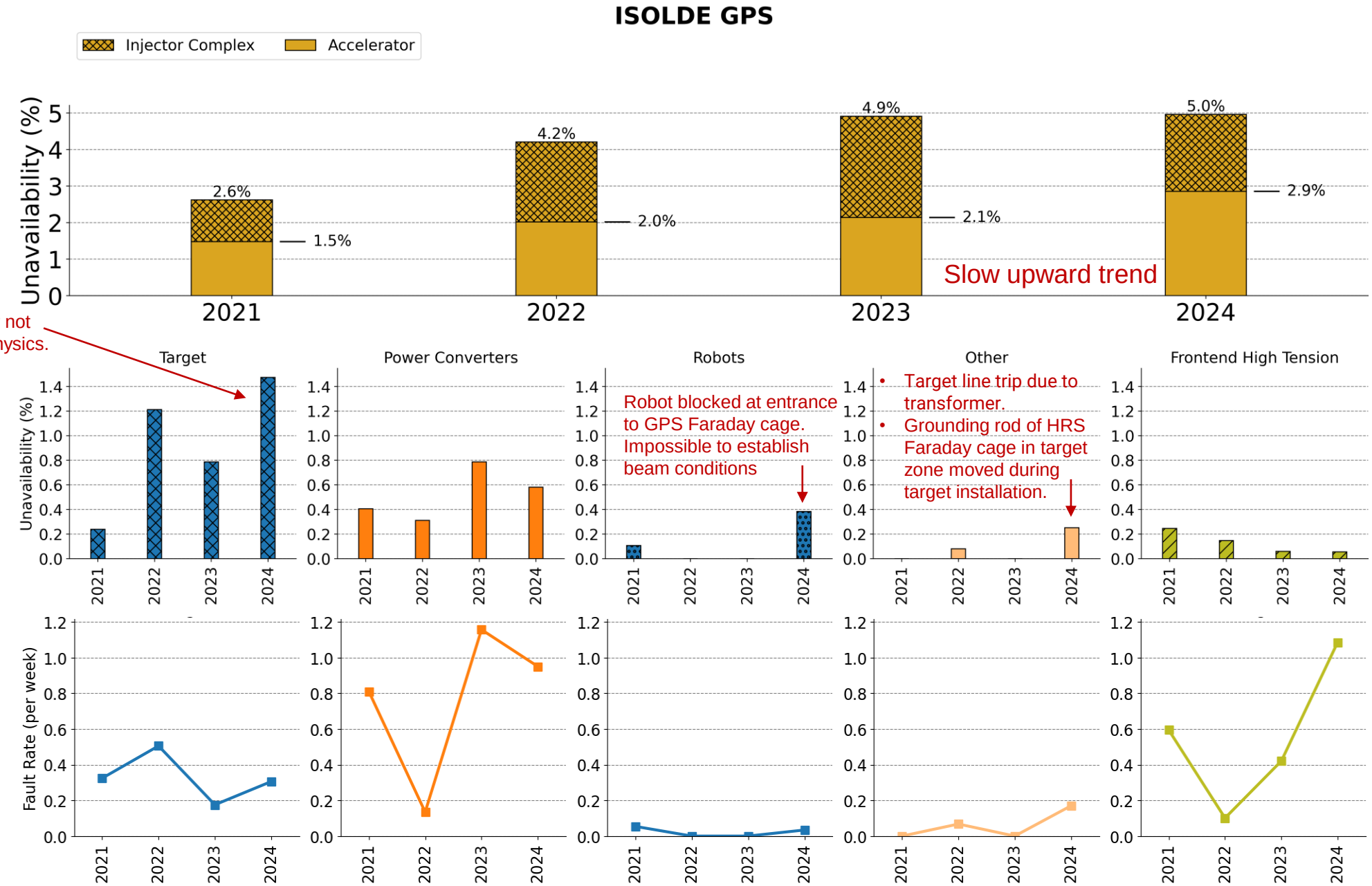
ELENA:

Most down time from upstream

Most down time is destination dependent

No piquet service – specialist repair only in work hours





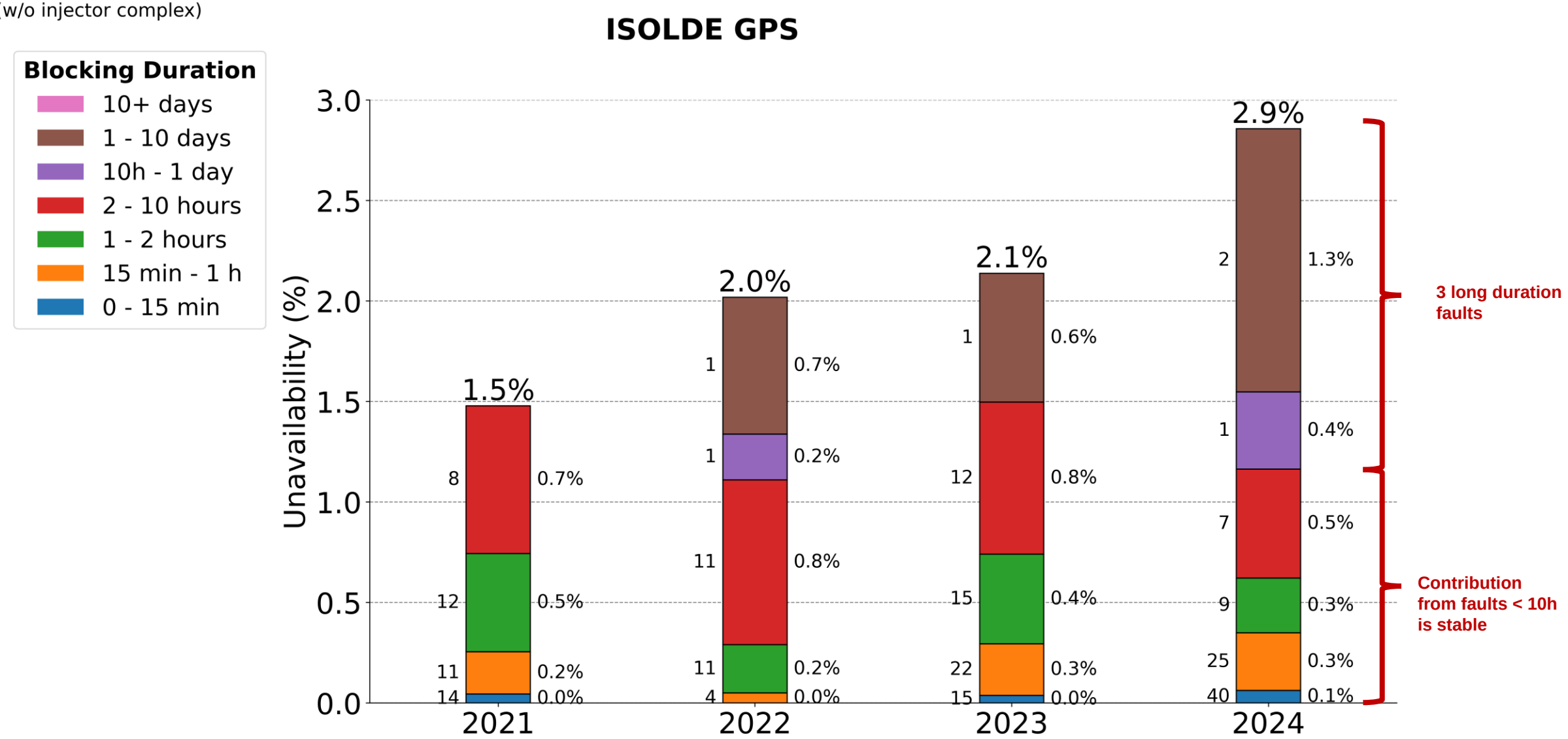
- Sulfur dispenser heater not working - no miniball physics.
- Oven filament problem.

ISOLDE:
Most of the down time due to target.
New users conducting R&D.

Slow upward trend is accountable to a small number of long duration faults (see appendix).

Contribution from faults w/ blocking duration <10h is stable.

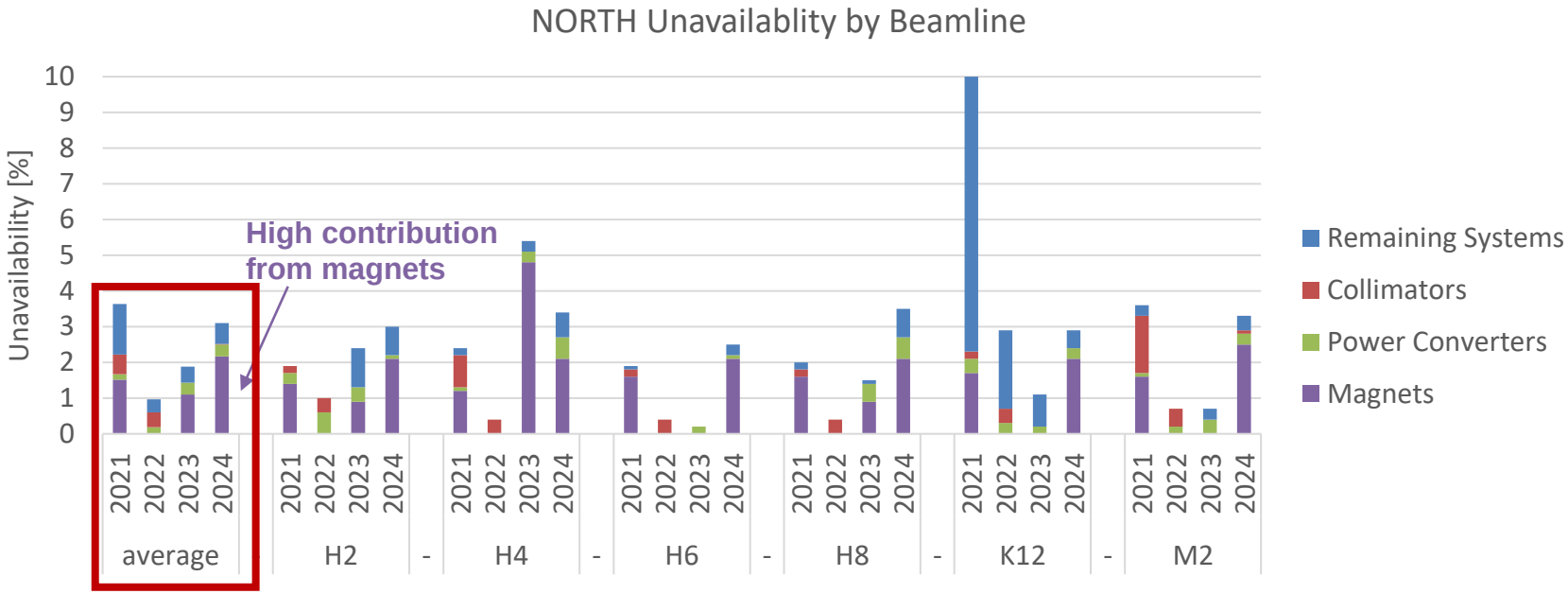
(w/o injector complex)



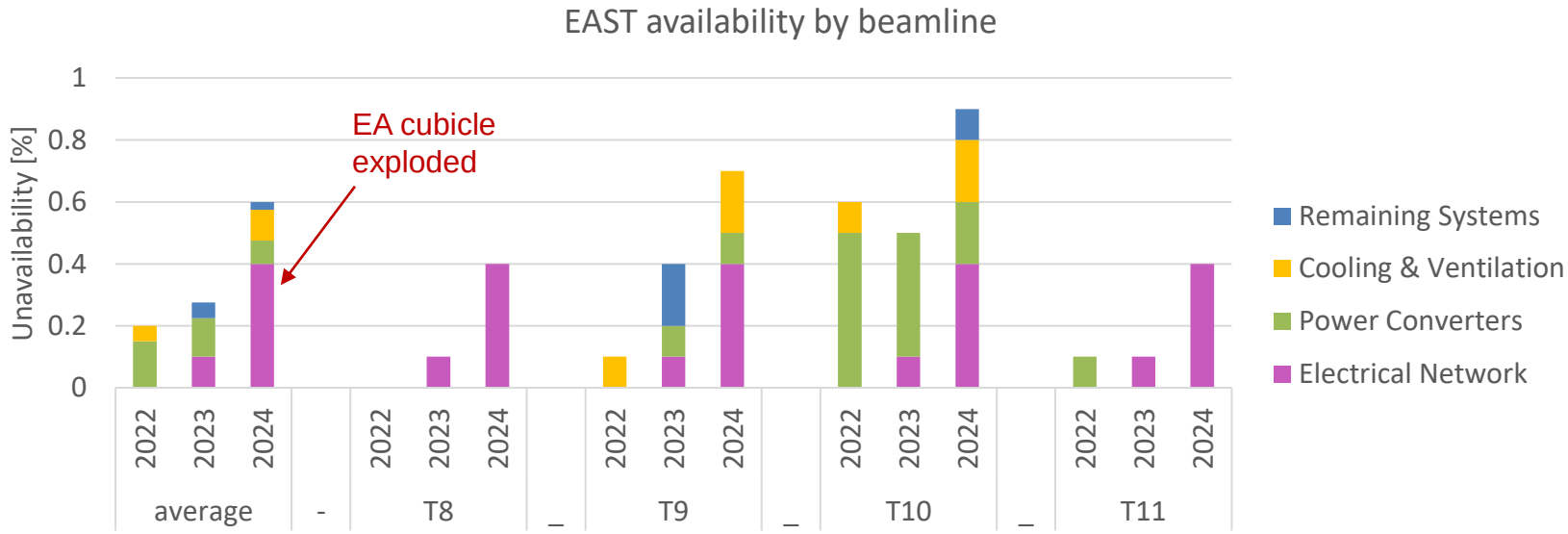
Long faults (> 1 days) on the rise (possibly statistical effect). Short faults stable.

North Area:

Magnet issues (see e.g. IEFC 27 October 2023, 25 May 2021), mitigation strategies are foreseen
https://indico.cern.ch/event/1339773/



East Area:

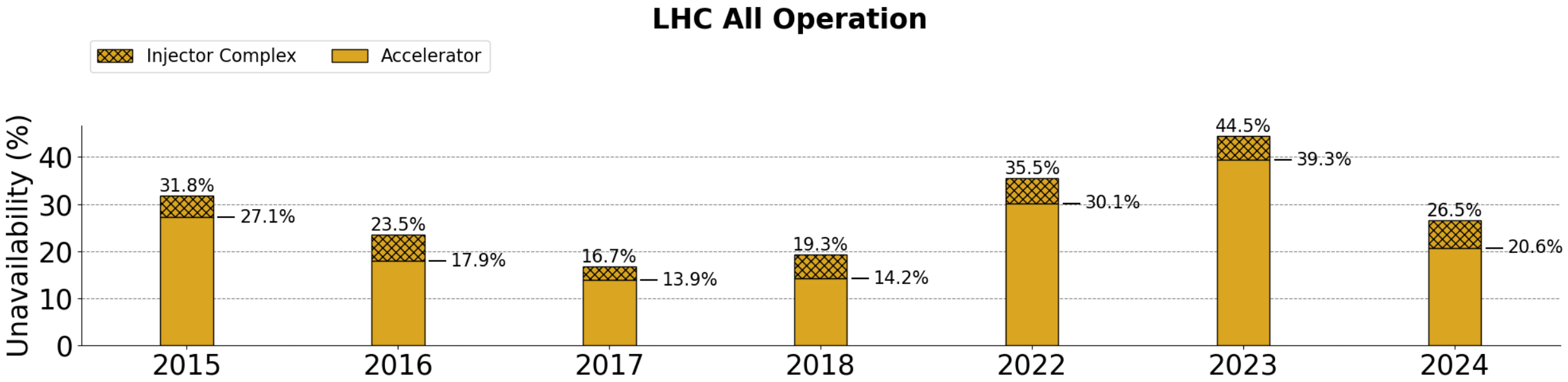


Many thanks to Paraskevi Alexaki for data extraction!

Conclusions AD/ELENA, ISOLDE, EA, NA

- **Availability good and stable:**
  - AD 95.8 %, ELENA 98.6 %,
  - ISOLDE GPS 97.1%, HRS 94.8%, REX-HIE 87.9%
  - EA >99%, NA 96-98%

What is AFT “actually” offering the community?



- **JAPW 2023: “Is the LHC falling apart?” – answer “no”**

“What is measured is improved”

This year we know:

- PSB and PS had record high availability
- LHC had best availability in Run 3
- We know why
- We agree on why

Input for:

- Performance benchmarking
- Consolidation priorities
- Availability modelling of future accelerators

Check out plots for your own system at:

https://gitlab.cern.ch/mpe-reliability-tools/aft_processing/-/tree/v2/output?ref_type=heads

Addressing Feedback from the Community

- **Convenience and ease-of-use for operators & equipment groups**
  - Road map for AFT 2.0 is prepared
  - Goal to launch for injector restart post-LS3

- **Integration w/ EAM asset management**
  - Prototype for EAM and AFT integration released, Nov 2024

- **Fault Tracking Automation**
  - “Automatic fault analysis and prognostics” – Anti Asko, Thursday 11:55

- **See for reference:** https://indico.cern.ch/event/1466640/

Conclusion Overall

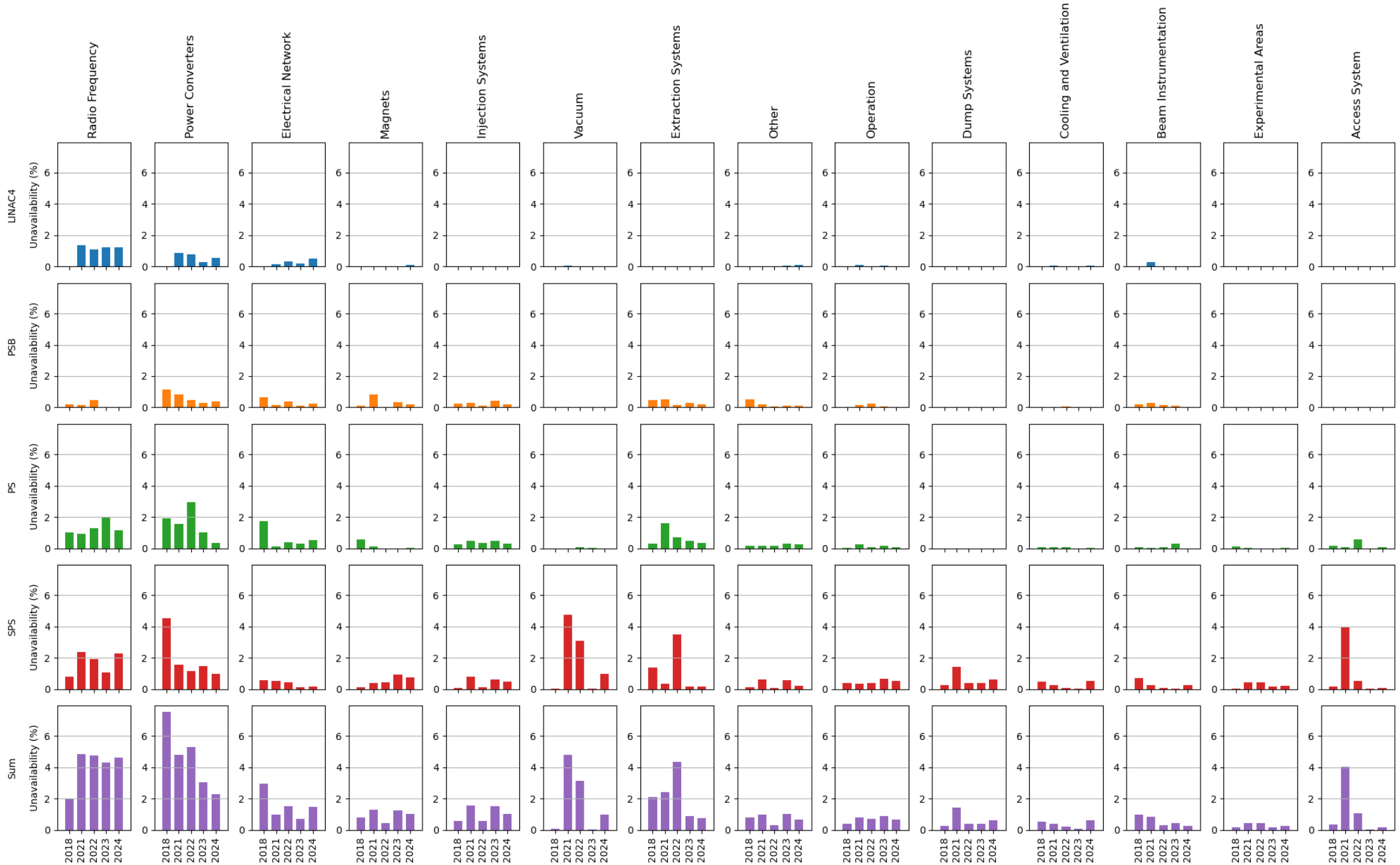
- **A good year:**
  - Proton and ion injectors are high performing
  - LHC best availability of Run 3, highest percent in stable beams
  - Experiments are performing well, no alarm bells
  - This shows consolidation strategy is paying off well.

- **AFT data gives us valuable insight on equipment performance across the complex**
  - No small amount of effort - many thanks to all AFT contributors!

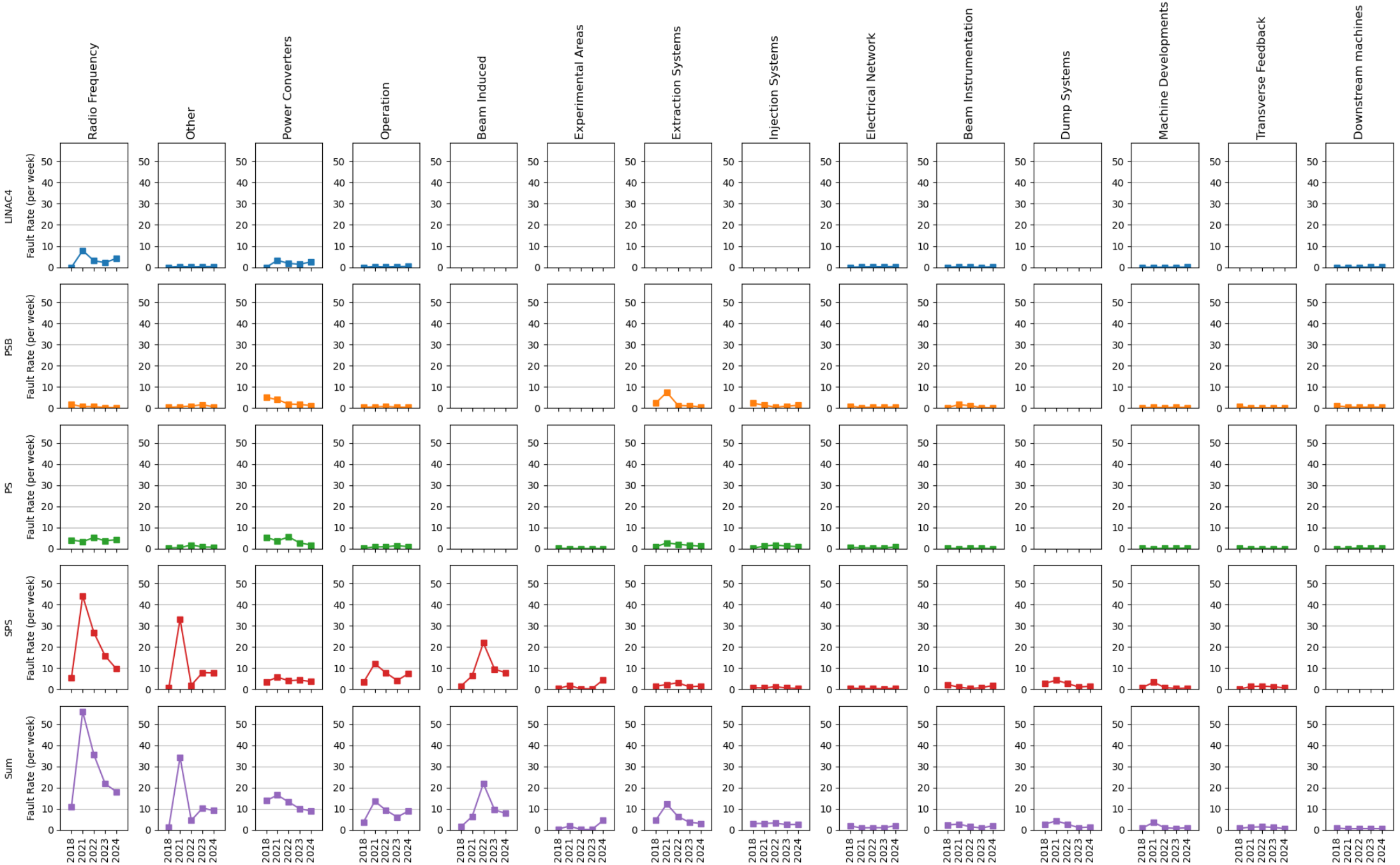
- **AFT is improving**
  - Feedback has been collected across the full spectrum of users
  - Aiming for significant leaps post-LS3!

home.cern

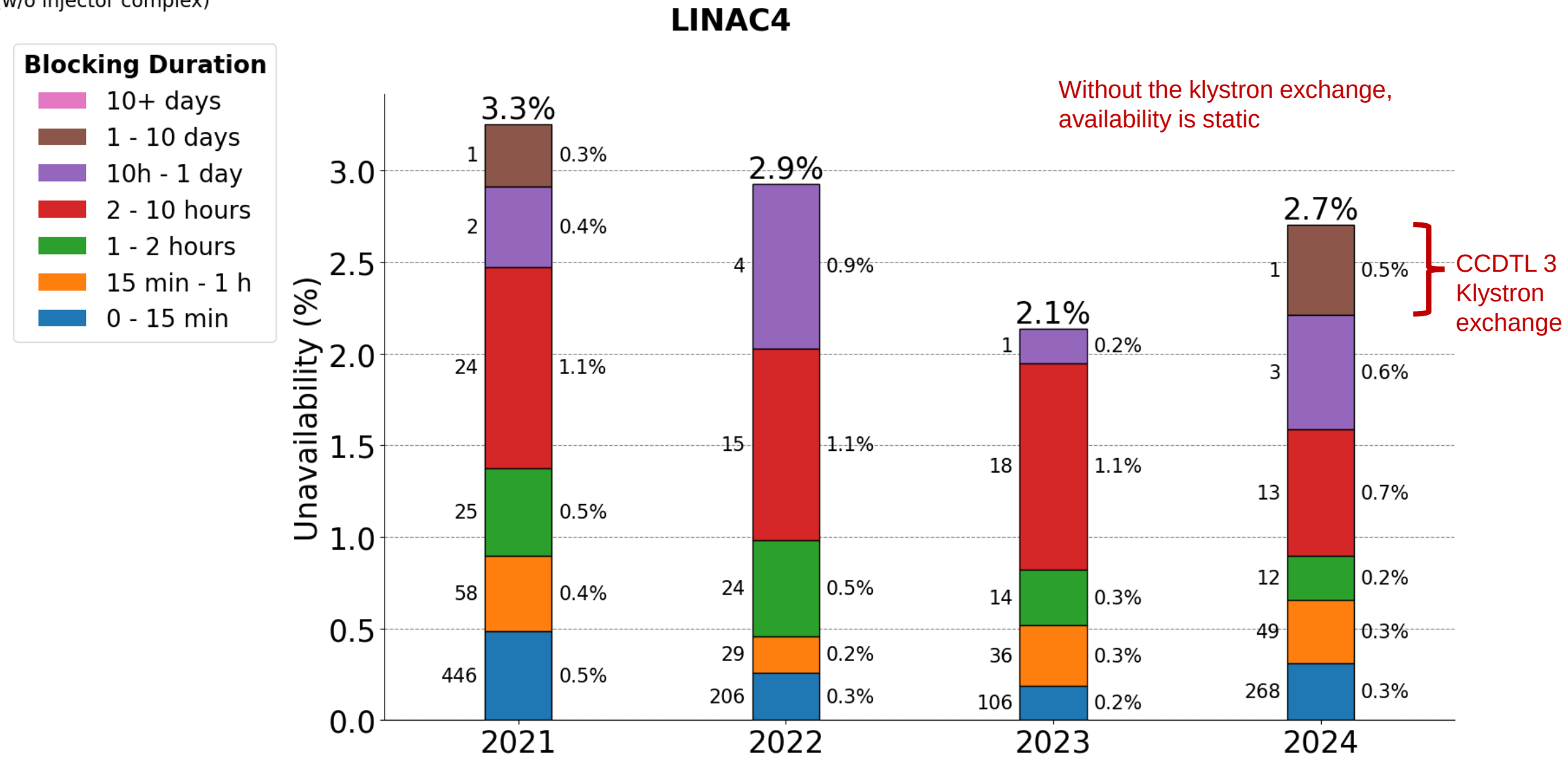
Injectors Overview: Unavailability



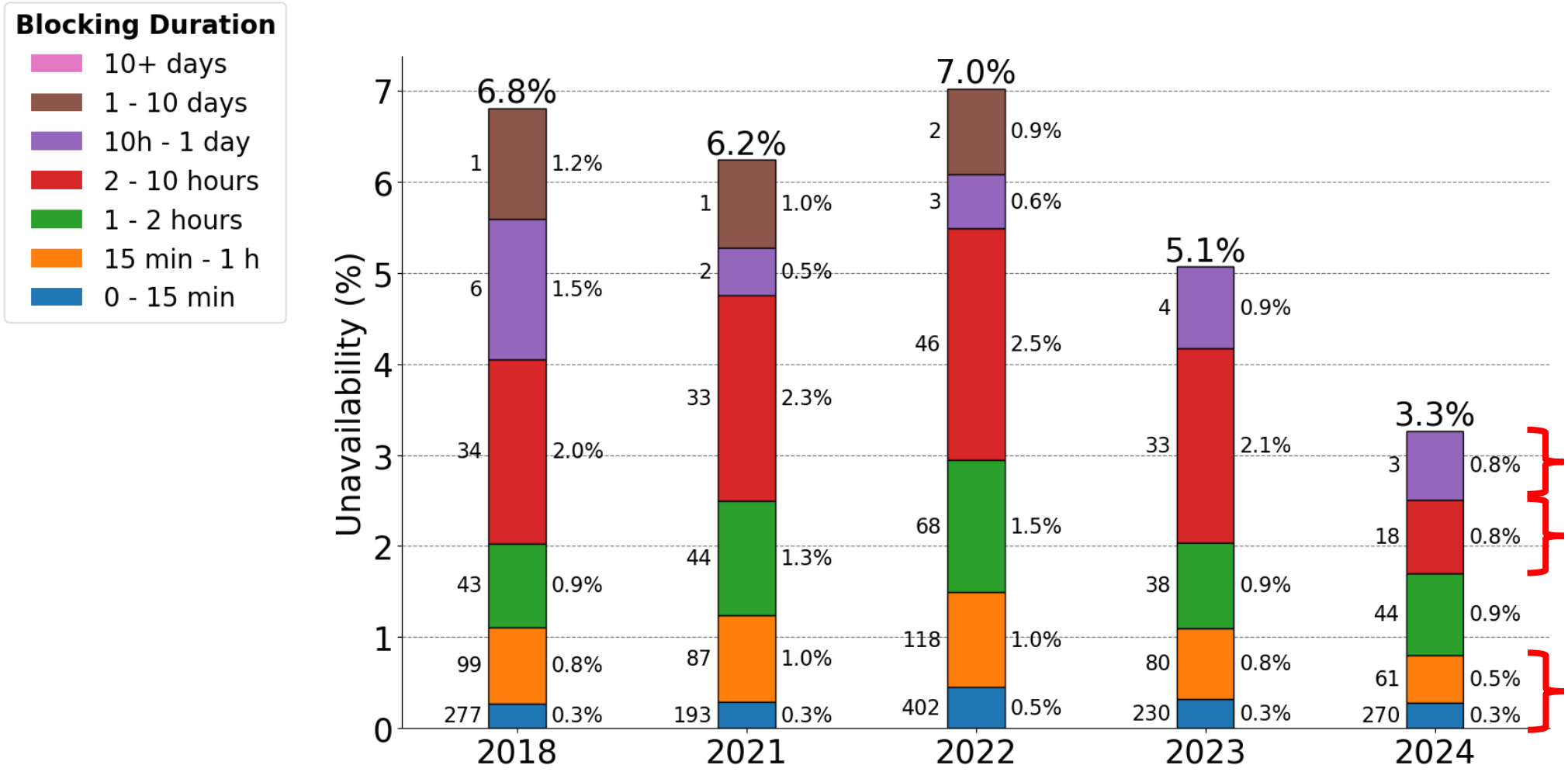
Injectors Overview: Fault Rate



(w/o injector complex)



PS

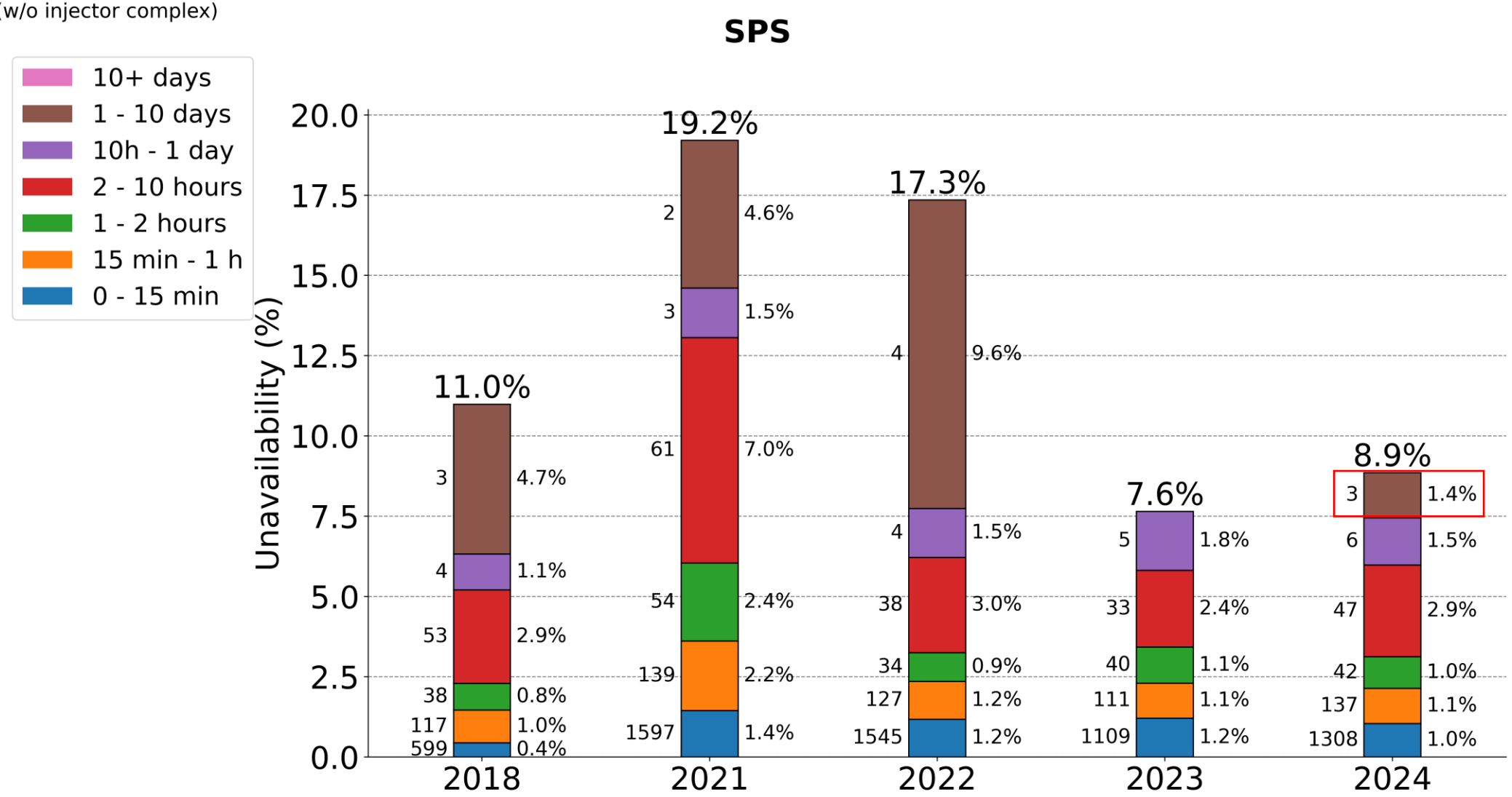


- Electrical Network:
  - Short circuit on HV cell
  - Power cut
- RF non pulsing C40/C80

Faults 2-10 h significantly reduced

331 faults w/ duration < 1 h
(Many from RF)

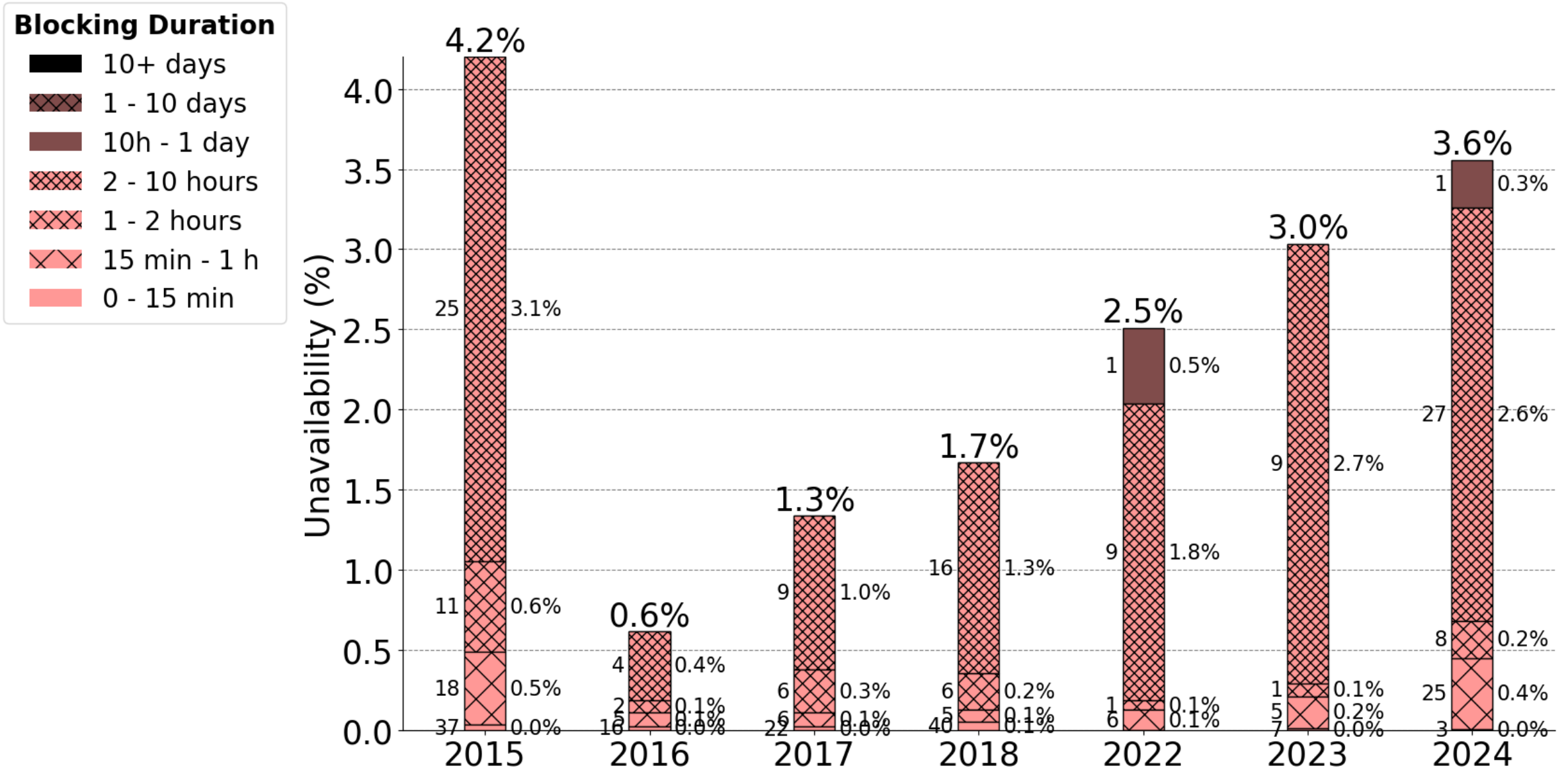
(w/o injector complex)



- Magnets: MBB 635.30 inter-turn short
- Vacuum: Exchange of magnet MBA.63450 with leaking vacuum chamber
- CV: Water circuit blocked

- **Mitigations are foreseen in RF and CV.**
- **Short faults (<2h) remain a significant contributor to down time.**

LHC Proton Run - QPS



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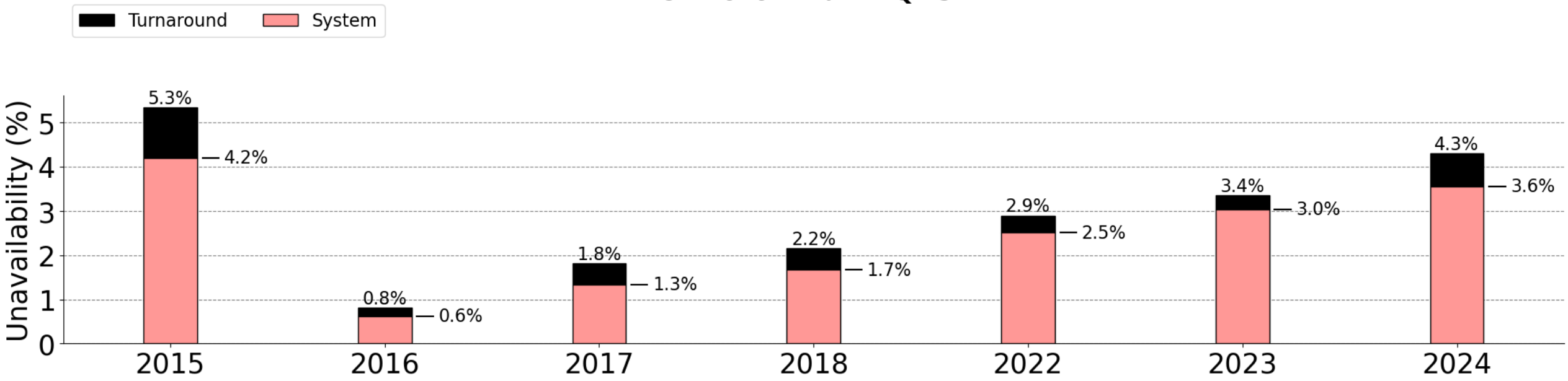
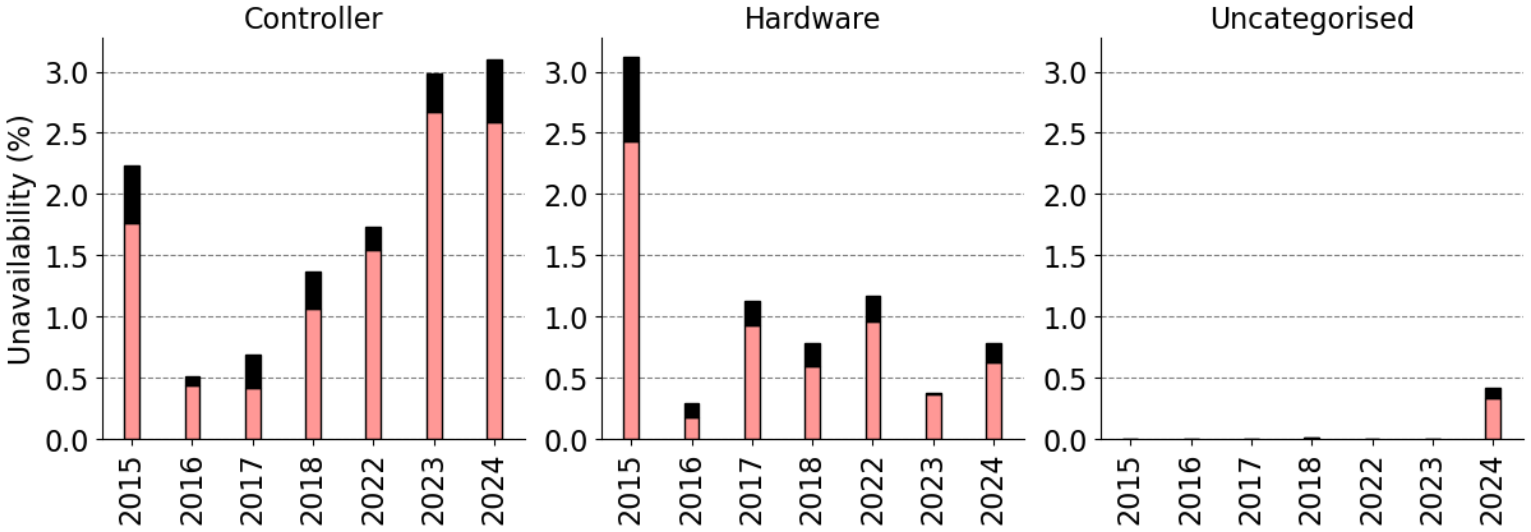
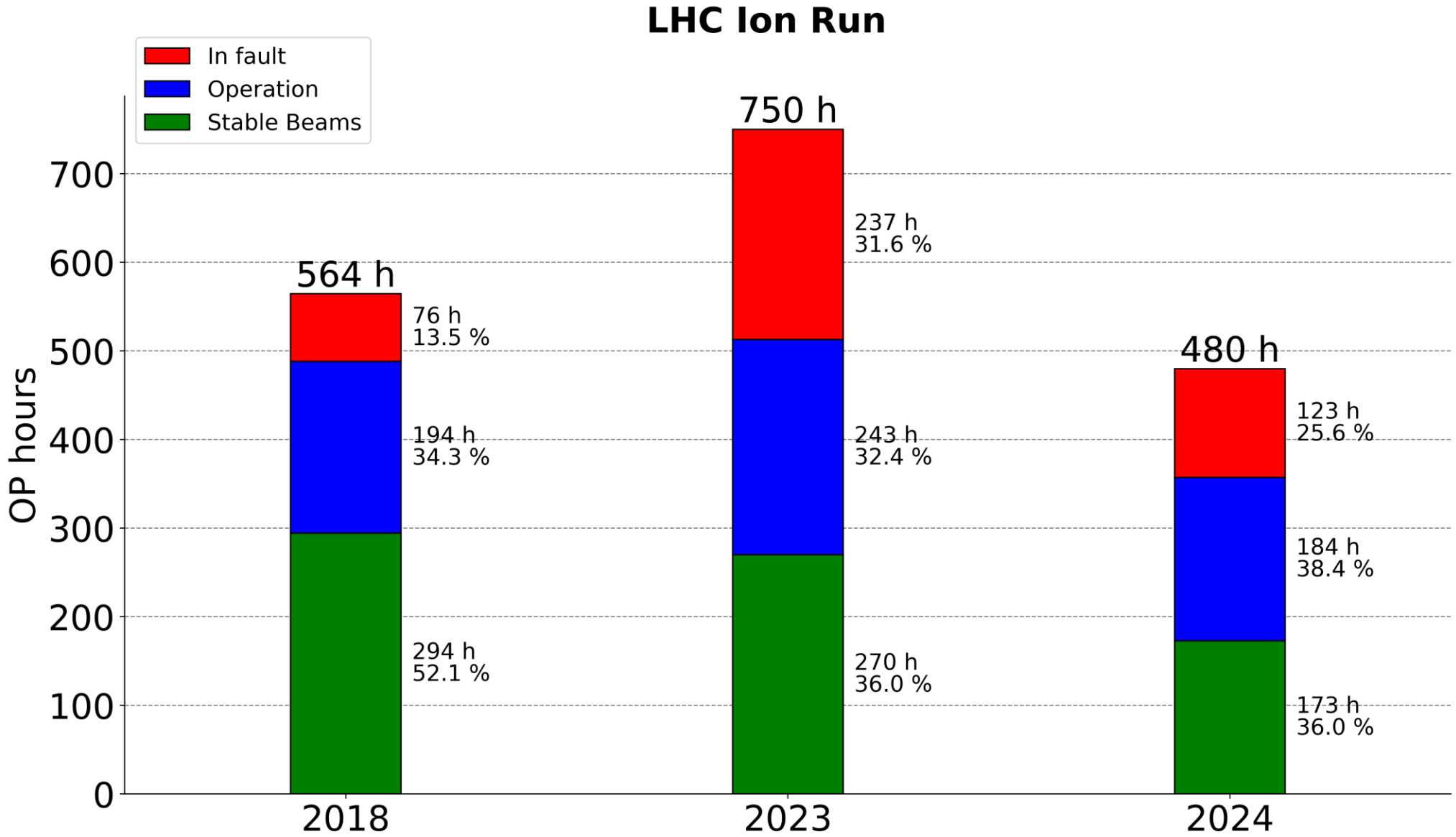


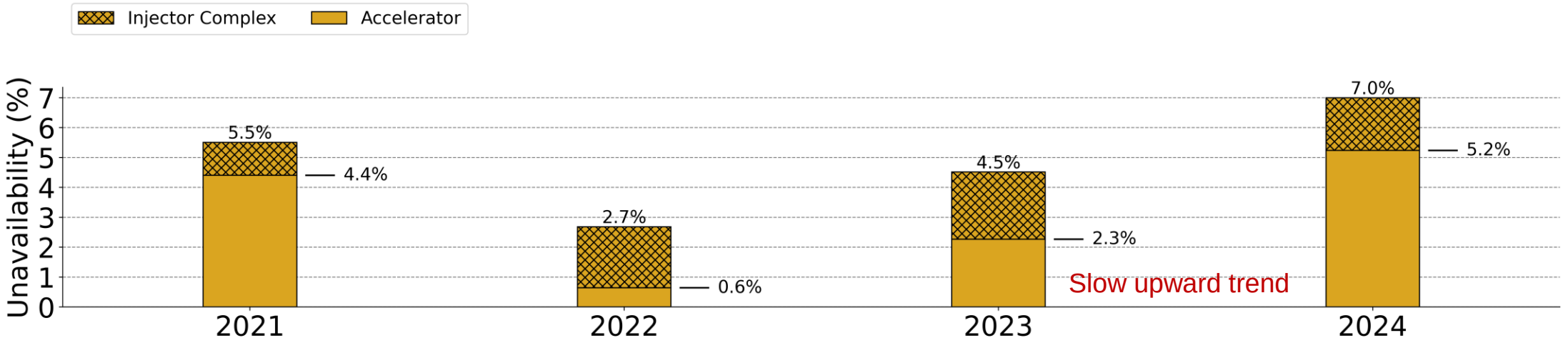


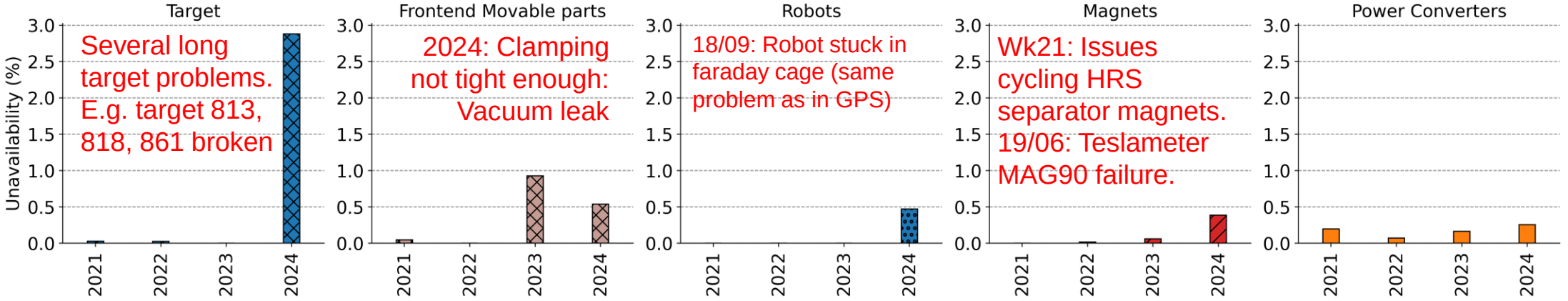
1. QPS board 11R2
2. RB23 issue with QPS board for B23R2
3. MB.B8L5 nQPS board 9L5 in fault, probably R2E, needed to be replaced.
4. Heaters fired on 4 IPQs (9L8, 10L8, 9R6, 10R6)
5. QPS fault on RQT13.R5B1
6. spurious quench heater firing
7. RB 56, board on 32.L6
8. QPS circuit breaker in UA43 (UA43.UNIT.B) tripped.
9. RQF fast abort triggered by QDS B16R5 in stable beams (possible SEU)
10. QPS RB78, C9L8
11. Suspected spurious QPS trigger still under investigation by MP3
12. Trip of RQ9.L8 leading to loss of S78 and Cryo conditions
13. QPS made RQT13.R5B1/2 trip
14. RQD.A23 QPS trip at 6.2 TeV - wrong configuration in nQPS 11R2
15. RCBXH1L8 trip
16. nQPS issue 23R2
17. Heater firing Q9.L8
18. suspect QPS board failure due to R2E (B9L8)
19. QPS tripped & fired heaters for RQ5.R5
20. Trigger of nQPS in sector12.
21. QPS resets after S23 quench recovery
22. R2E suspect communication issue on MB.B9R1
23. Lost communication with MB.C17L5
24. possible circuit breaker fault on RQ5.R4
25. bit flip (suspected R2E) in nQPS board 28R8
26. Blocked communication board type DQAMG, most likely by R2E

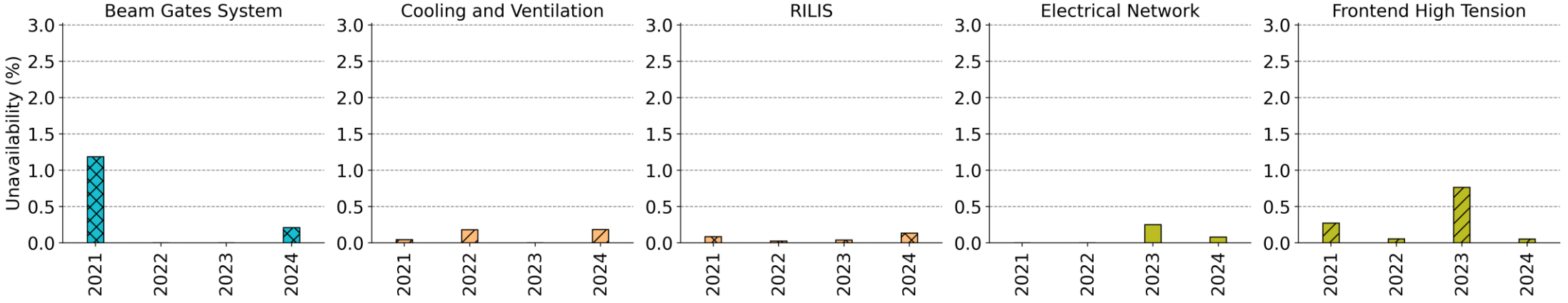


Same % in stable beams as last year

ISOLDE HRS

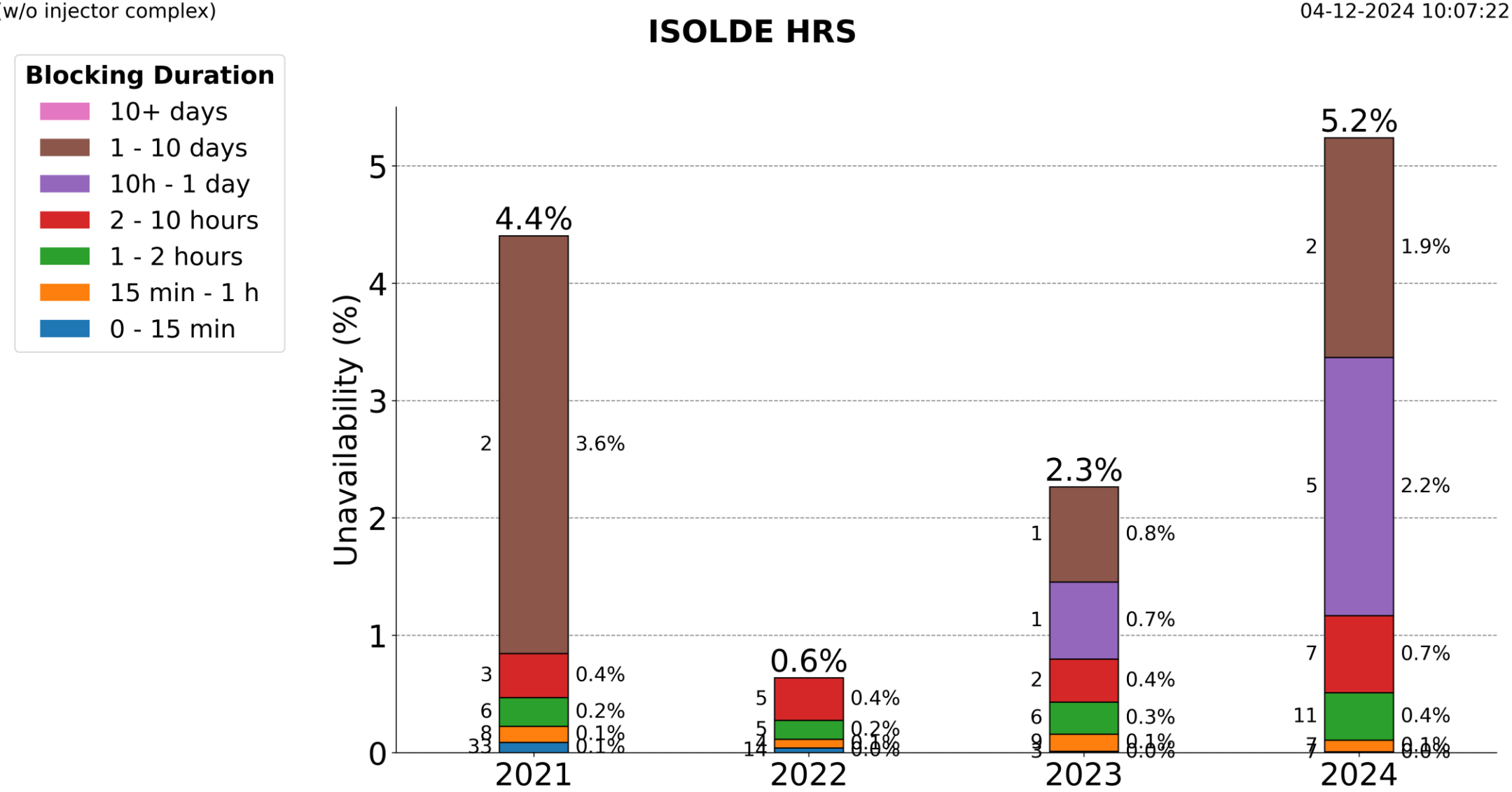

Injector Complex
Accelerator
Unavailability (%)
5.5%
4.4%
2.7%
0.6%
4.5%
2.3%
7.0%
5.2%
Slow upward trend
2021
2022
2023
2024


Target
Several long target problems. E.g. target 813, 818, 861 broken
Frontend Movable parts
2024: Clamping not tight enough: Vacuum leak
Robots
18/09: Robot stuck in faraday cage (same problem as in GPS)
Magnets
Wk21: Issues cycling HRS separator magnets. 19/06: Teslameter MAG90 failure.
Power Converters
Unavailability (%)
2021
2022
2023
2024


Beam Gates System
Cooling and Ventilation
RILIS
Electrical Network
Frontend High Tension
Unavailability (%)
2021
2022
2023
2024

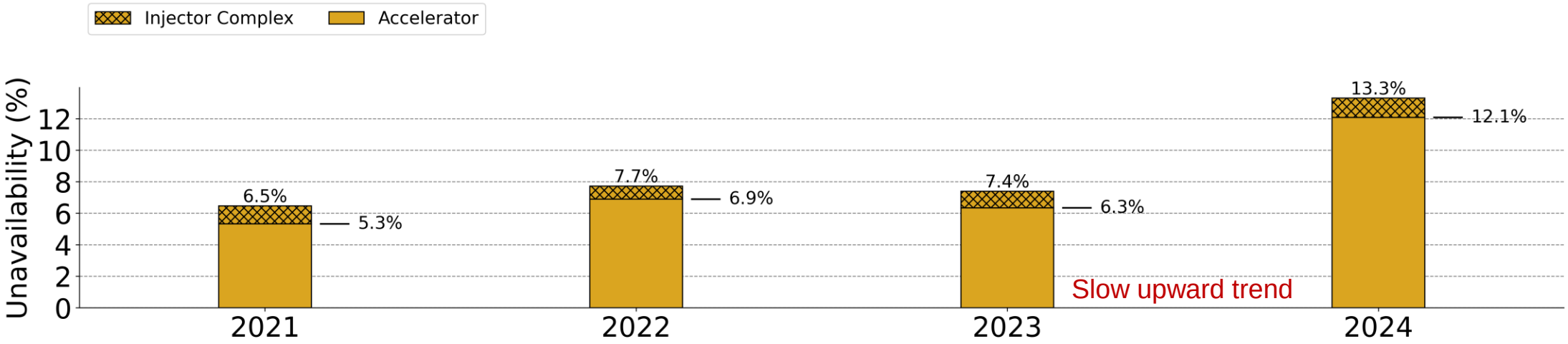
(w/o injector complex)

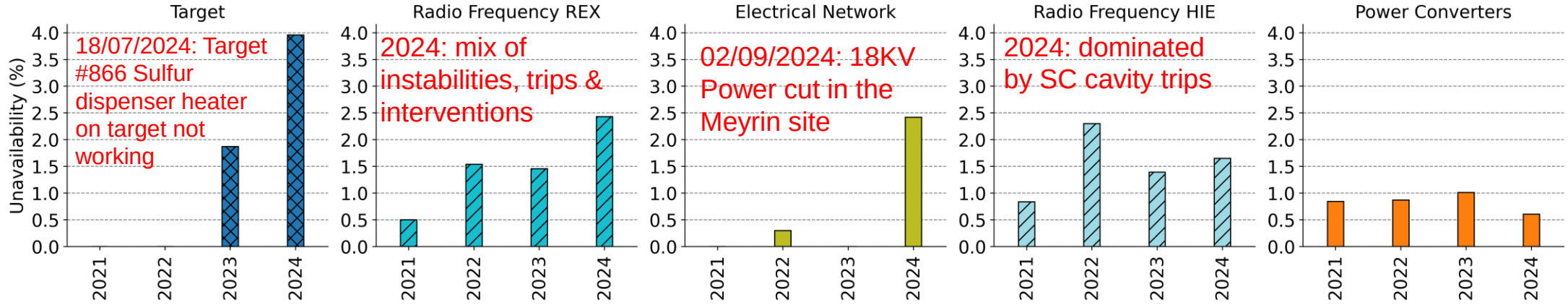
04-12-2024 10:07:22

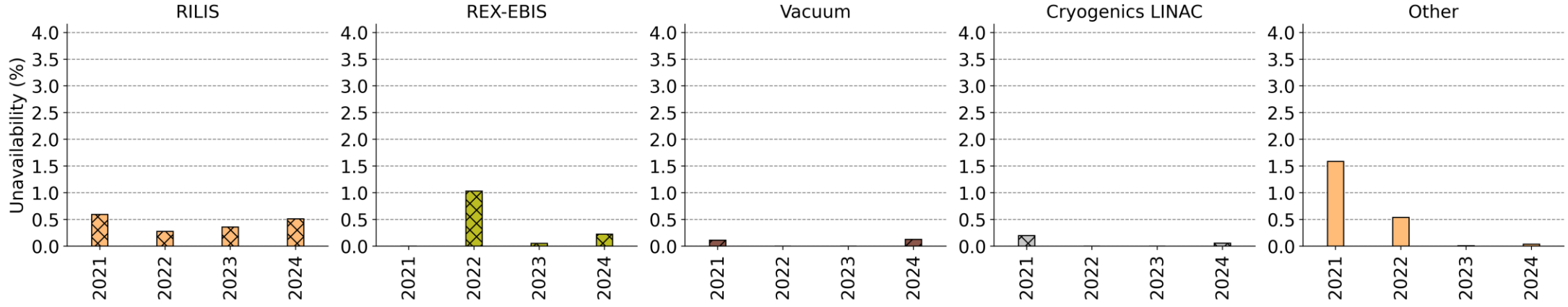


Volatility due to few long faults.

ISOLDE REX HIE







(w/o injector complex)

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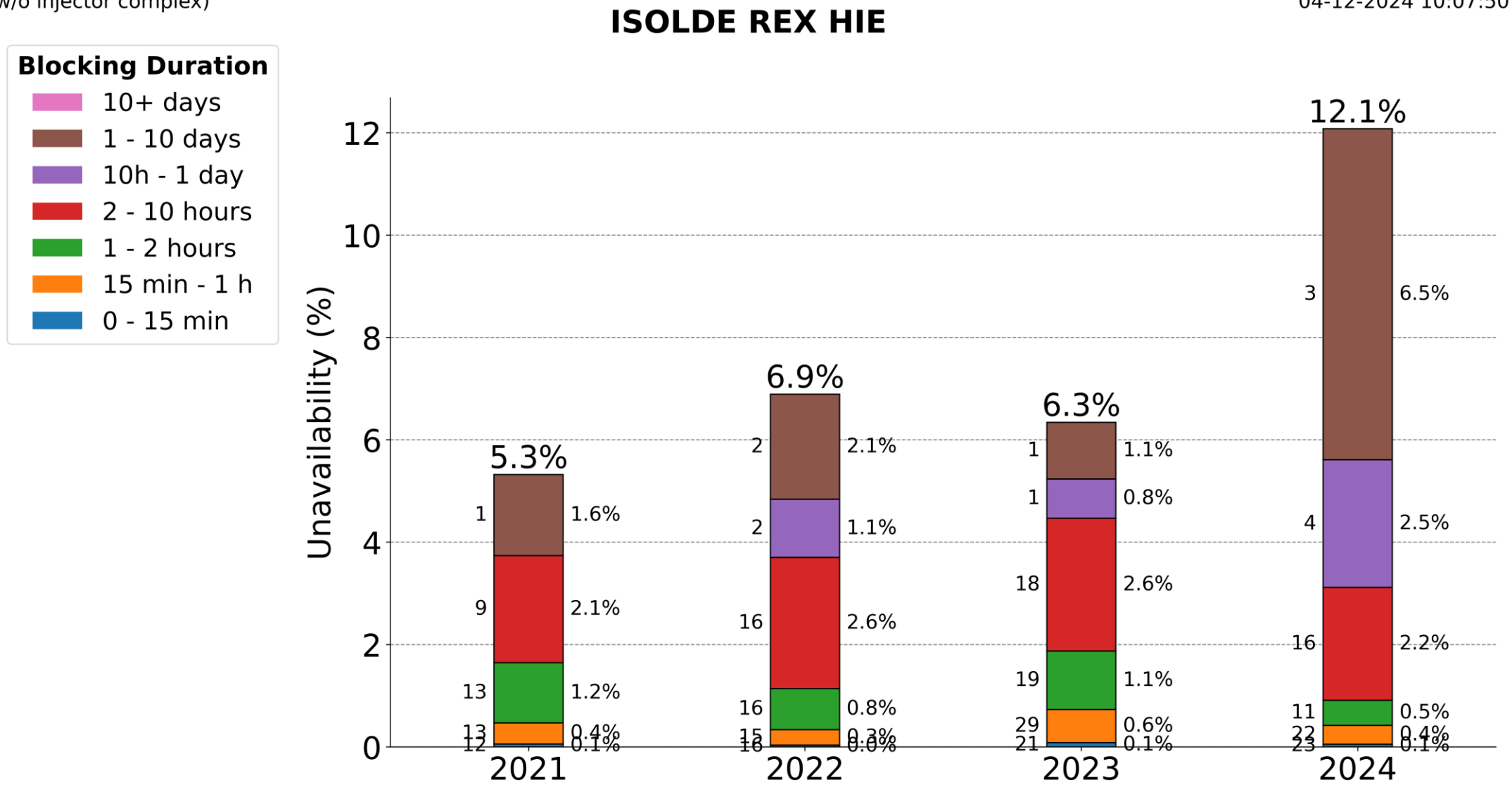

2024 main contribution is few long faults.

(SC cavity trips not recorded one by one, but by placeholder faults reflecting weekly downtime)