Fault Tracking in 2024

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

05.12.2024

Introduction

Fault recording stopped last week for most machines

- More than 12,500 faults recorded and reviewed in 2024
- Many thanks to everyone involved!

This talk should give an overview of availability statistics for the past year

Sent out ‘templates’ last week, which were completed by OP – Thank you!

- Full sets of slides uploaded to Indico
- This presentation is a summary of all inputs received

Trigger thoughts and discussions to prepare for Montreux meeting

If any specific stats are needed, please get in touch: jack.heron@cern.ch

Presented statistics and findings are still preliminary and may change! To be used as discussion basis.

Structure

1. Proton injectors
2. Ion injectors
3. LHC
4. Experimental Areas
5. Preliminary Conclusions

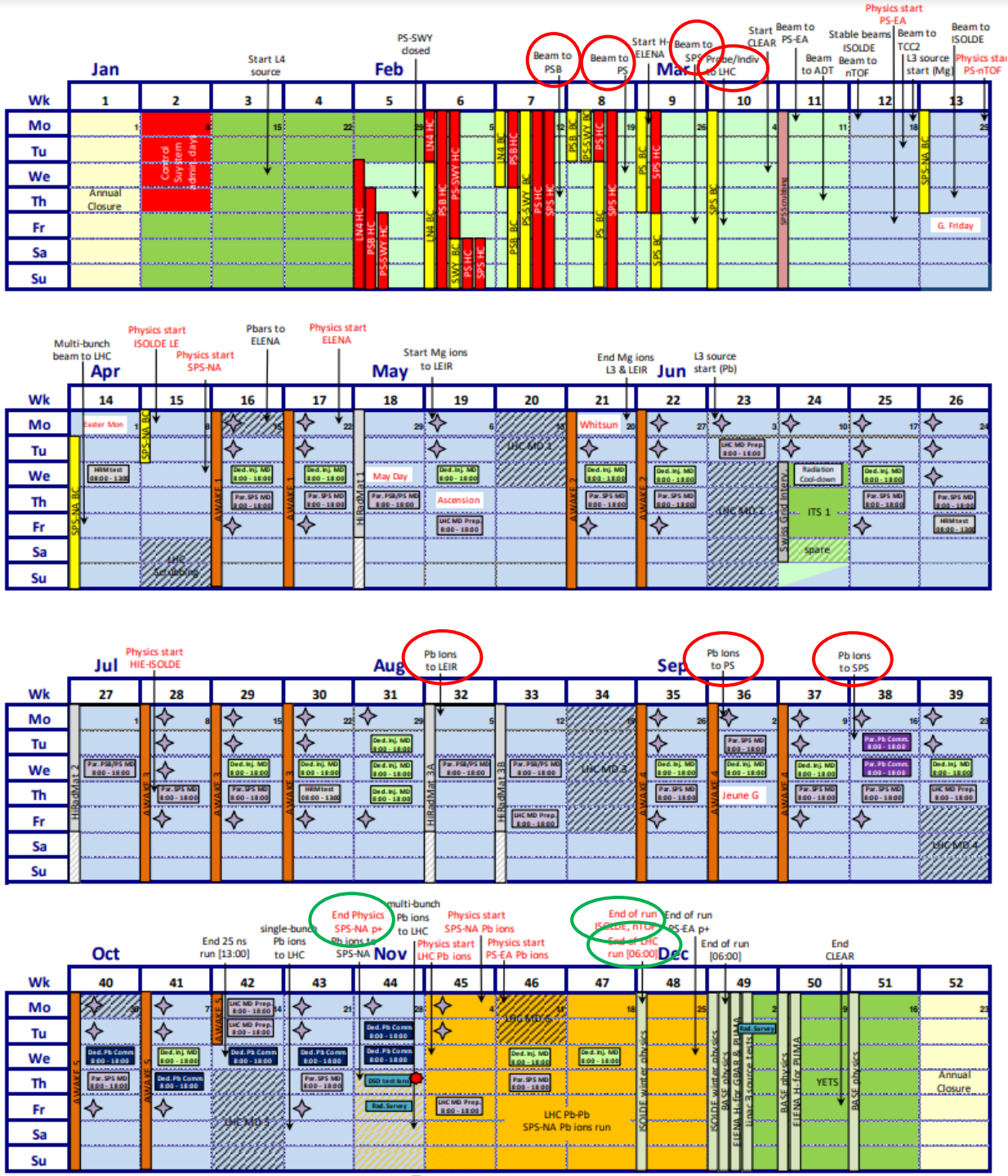
Injector Schedule

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



1. **Proton injectors**
2. Ion injectors
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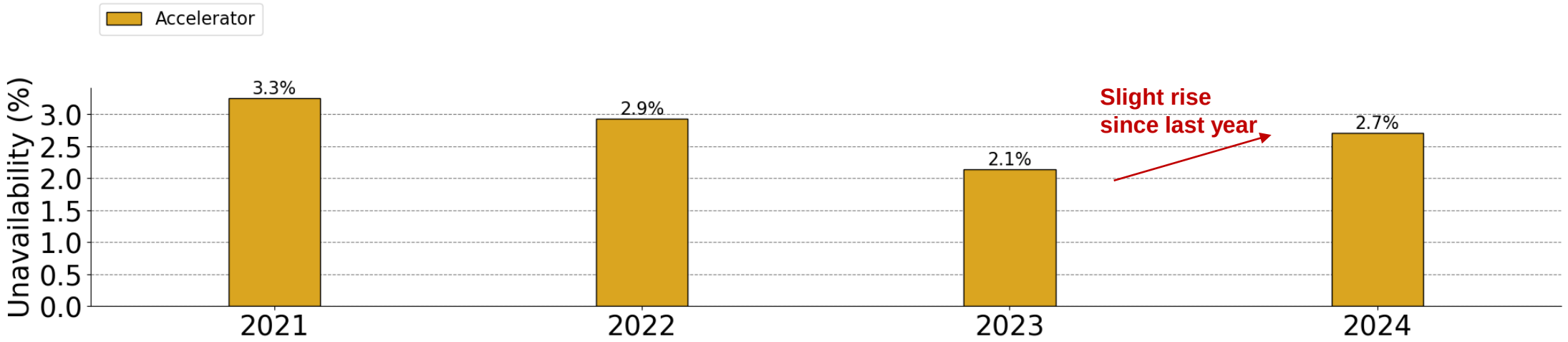
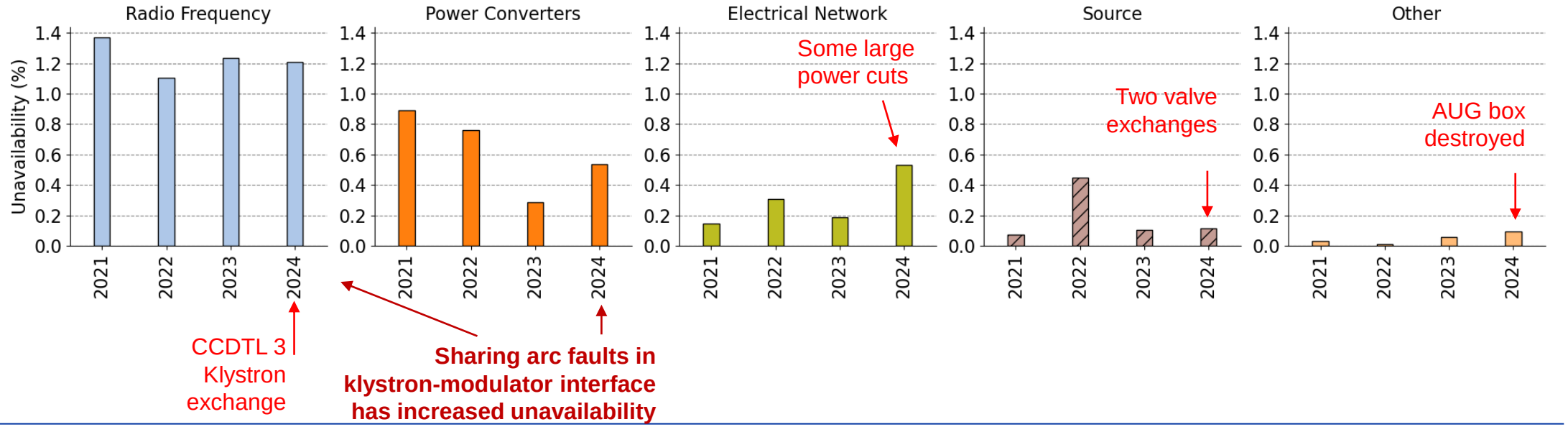
LINAC4

Acknowledgment: Gian Piero Di Giovanni

LINAC4



RF: Increased cavity protection and mis-pulse identification



(w/o injector complex)

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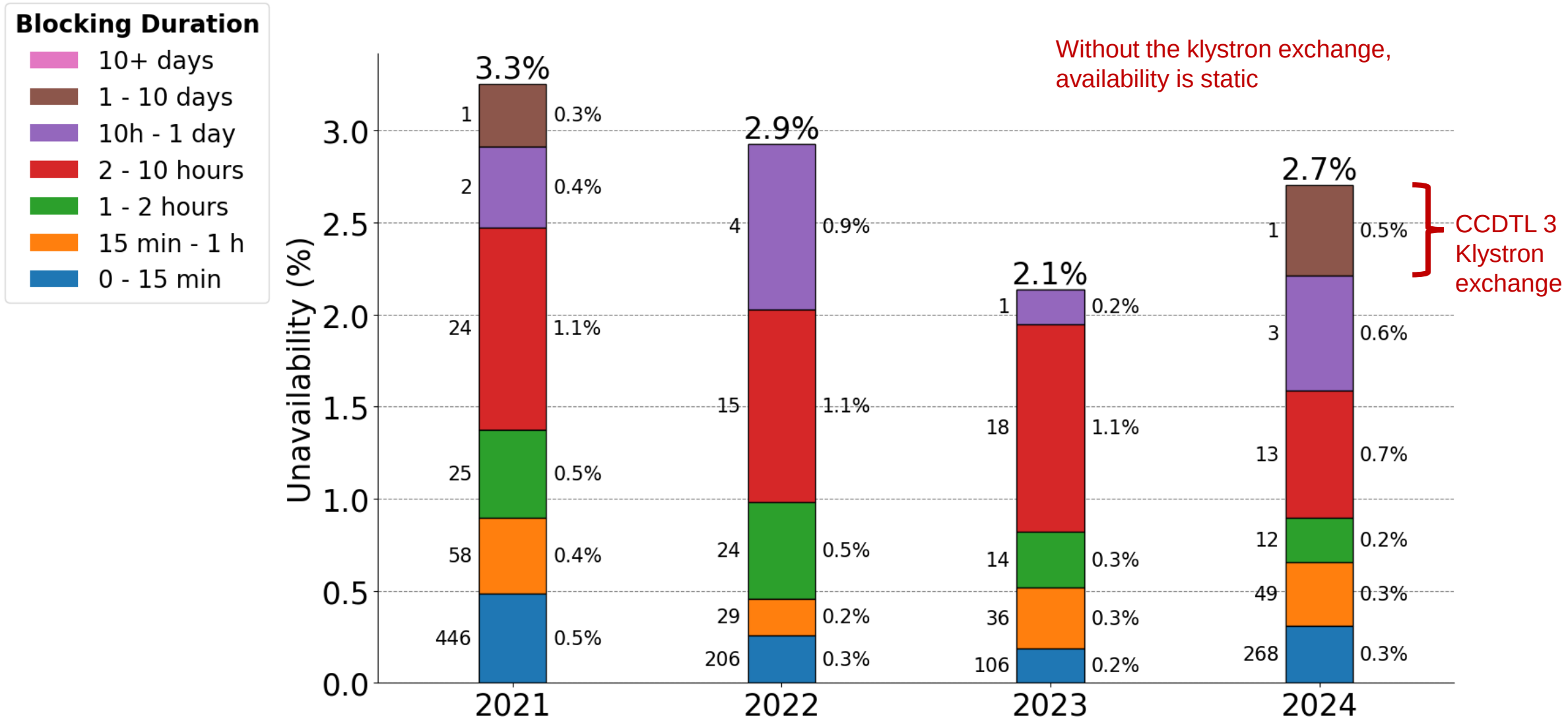
LINAC4



LINAC4 Conclusions

- **Availability stable (97.3 %)**
- **Variations are from single-event long-duration faults**
- **“LINAC4 has reached a steady state in availability performance”**
- **Outlook on RF and modulators in 2025 ?**

Comments LINAC4?

1. **Proton injectors**
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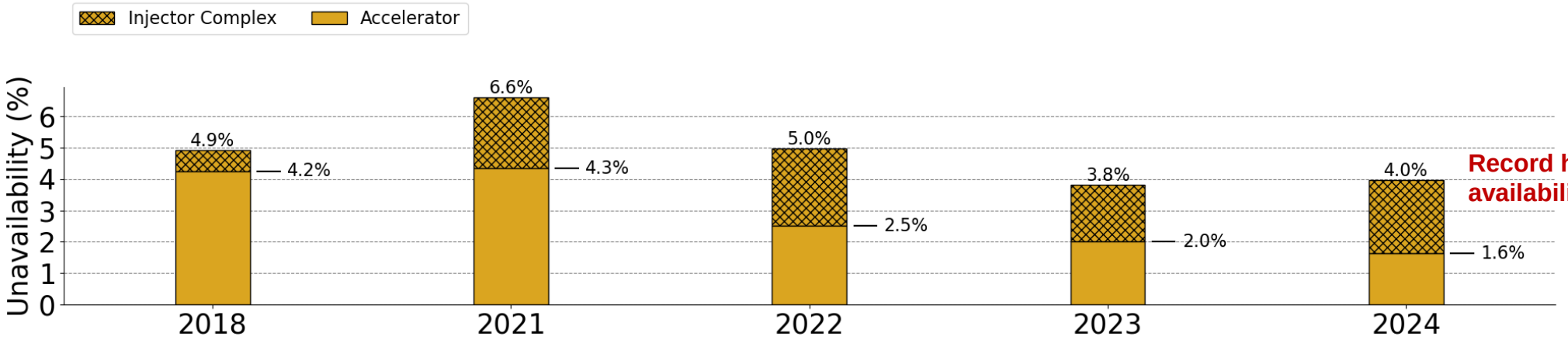
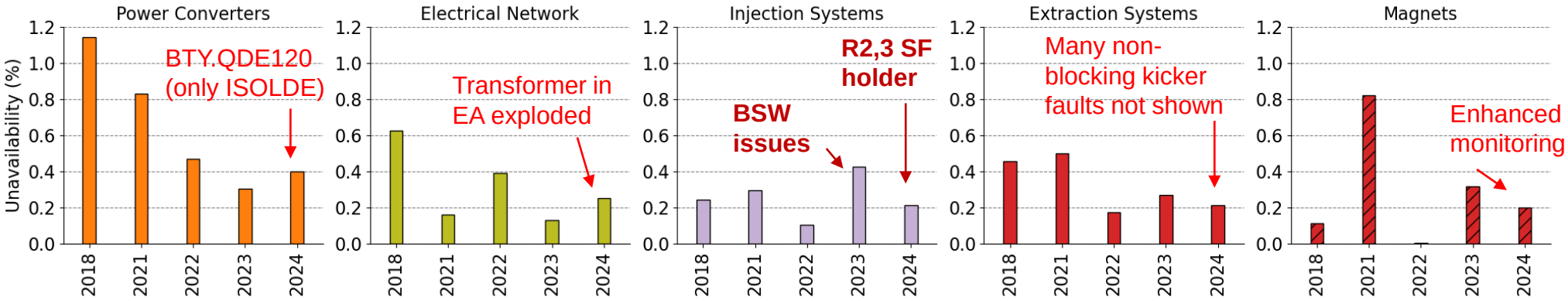
PSB

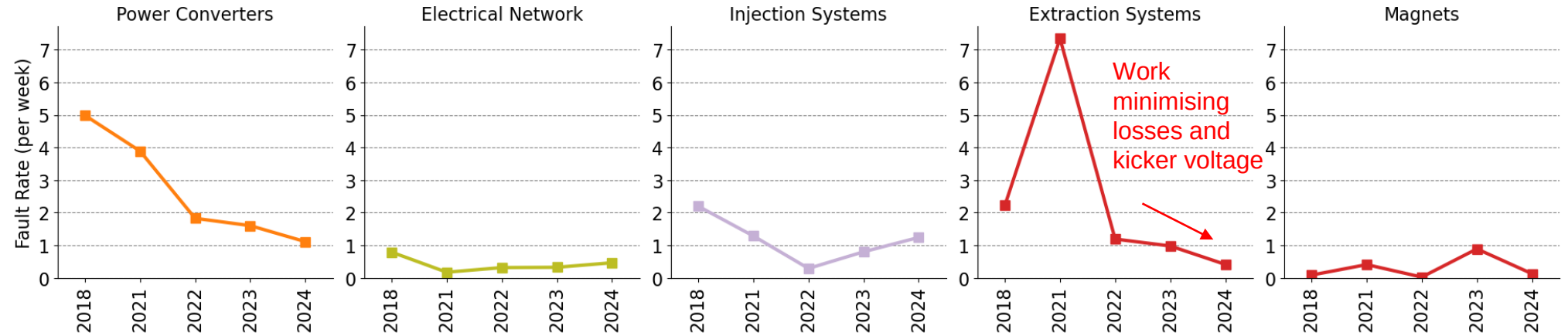
Acknowledgment: Gian Piero Di Giovanni

PSB

- PC: Longer repair times due to ageing BTY electronics
- 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







PSB Conclusions

- **Highest availability on record (98.4%)**
- **“PSB has reached its availability limit”**
- **PSB has availability advantage as full performance can often be gained with three of four rings. (Thanks to great work by the operations team)**
- **Power converters repair duration should improve post LS3 with ISOLDE 2 GeV upgrade**

Comments PSB?

1. **Proton injectors**
2. Ion injectors
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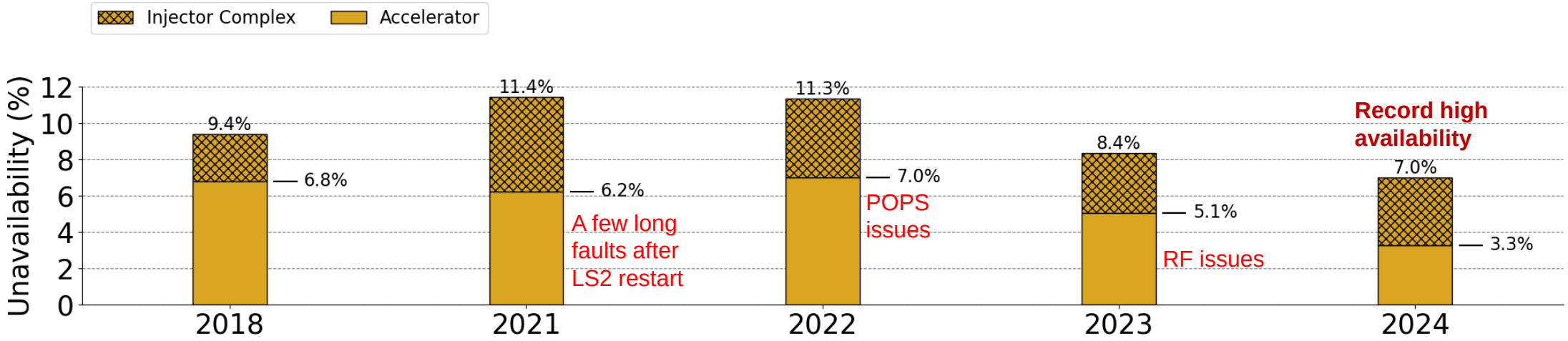
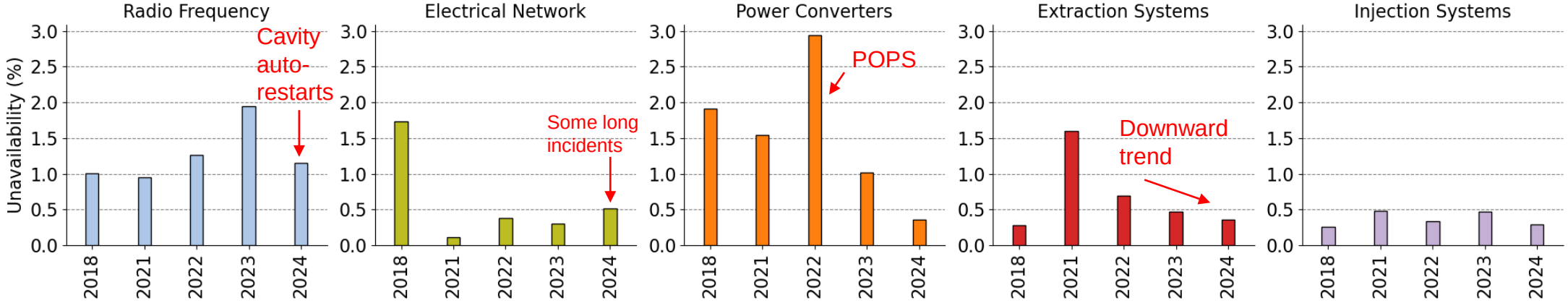
PS

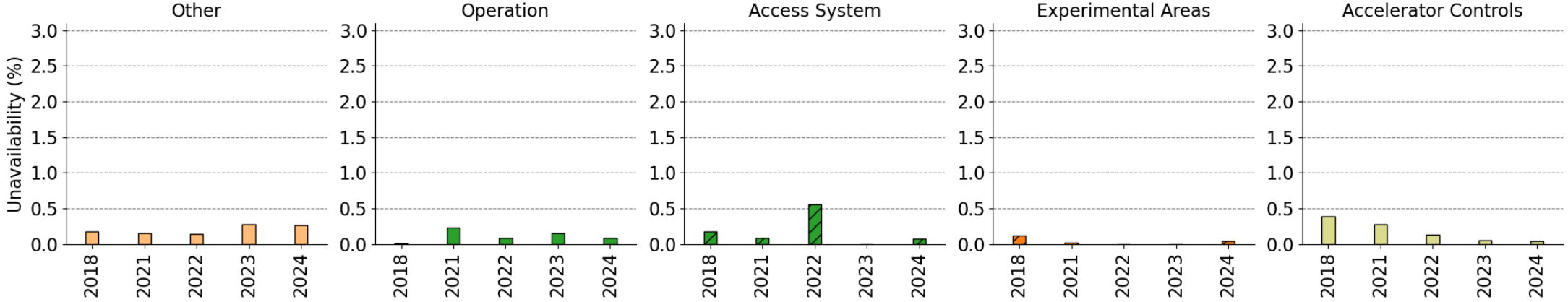
Acknowledgment: Bettina Mikulec

PS

- Continuous work and improvements from equipment experts and OP
- Resolution of certain fault types (POPS, RF, ABT)
- RF: Automatic restart of cavities







Radio Frequency

Manual reclassification of all 2024 RF faults by RF team ☑

Does 2024 match your expectations?

- ✓ Yes for standard operation
  - ✓ Downtime reduced wrt. 2023 outlier due to maintenance activities during YETS
  - ✓ Cavity auto-resets and auto-restarts implemented
- ○ No for SPS LIU MDs
  - ○ PS RF faults had impact.
  - ○ Not covered in AFT

Outlook:

- Frequent short duration faults since start of Run2 not well understood.
  - ➢ Lack of tools to address this; being developed
- Long lasting hardware issues to be addressed with LS3 upgrade/CONS
  - ➢ Downtime from signal quality on the LLRF, which will be replaced by digital system during LS3
  - ➢ Downtime from gap relays which are now obsolete (alternatives being investigated), and from amplifiers

(w/o injector complex)

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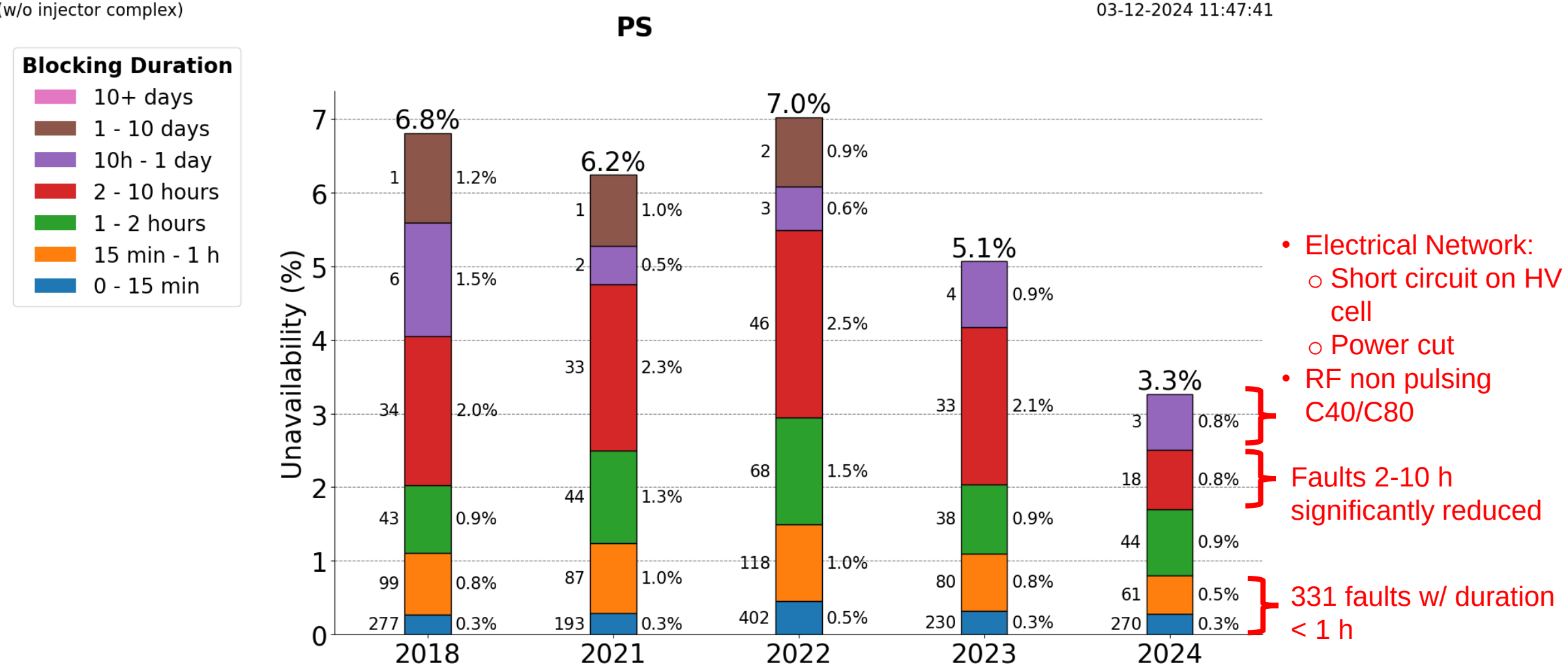

- Electrical Network:
  - Short circuit on HV cell
  - Power cut
- RF non pulsing C40/C80

Faults 2-10 h significantly reduced

331 faults w/ duration < 1 h

- **Faults 2-10 h are significantly reduced**

PS Conclusions

- **Highest availability on record (96.7%)**
- **RF: “expected comparable or worse”. No time for maintenance during YETS25/26**
  - Uncertainties due to upgrades and prototyping.
- **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.**

Comments PS?

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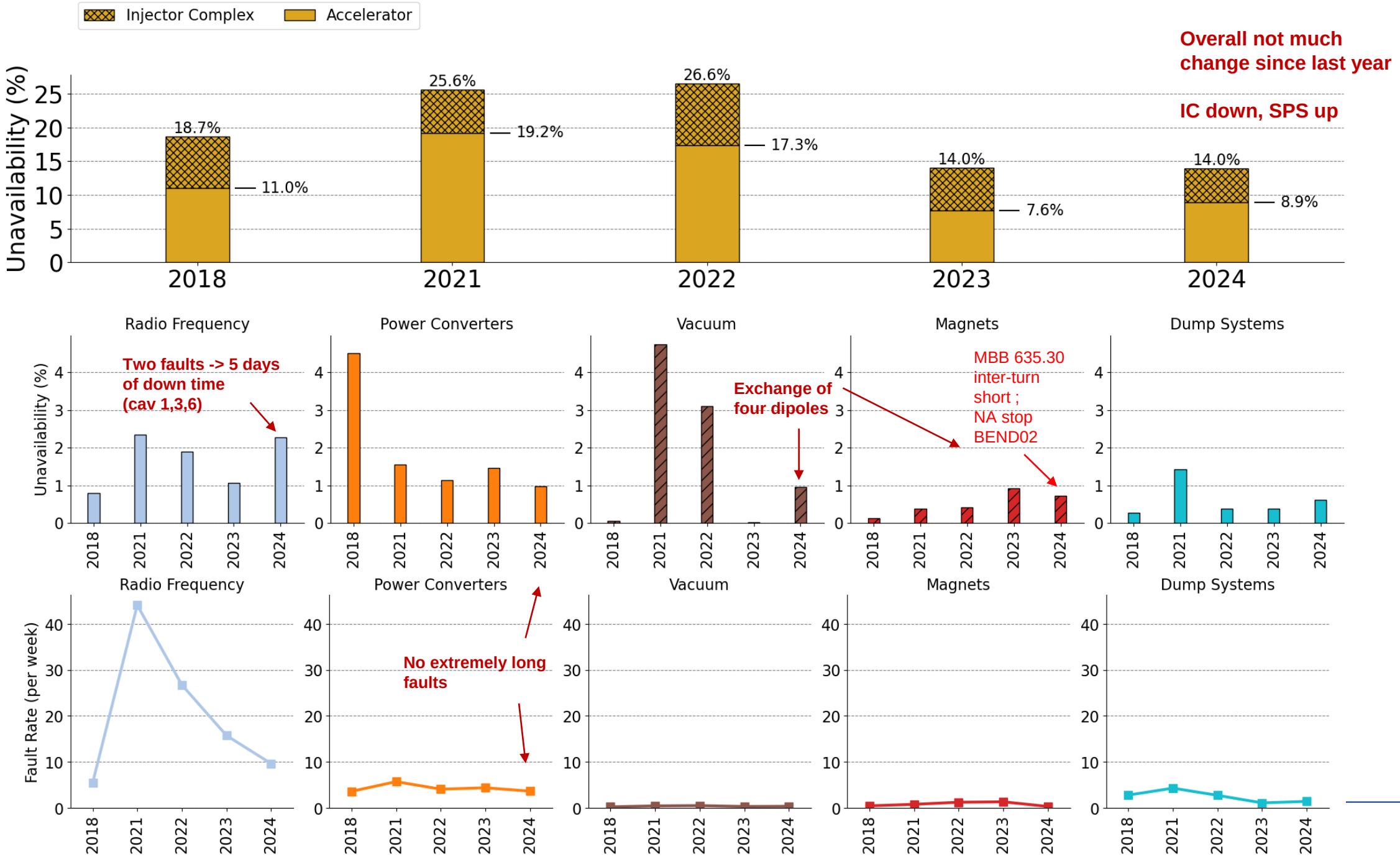
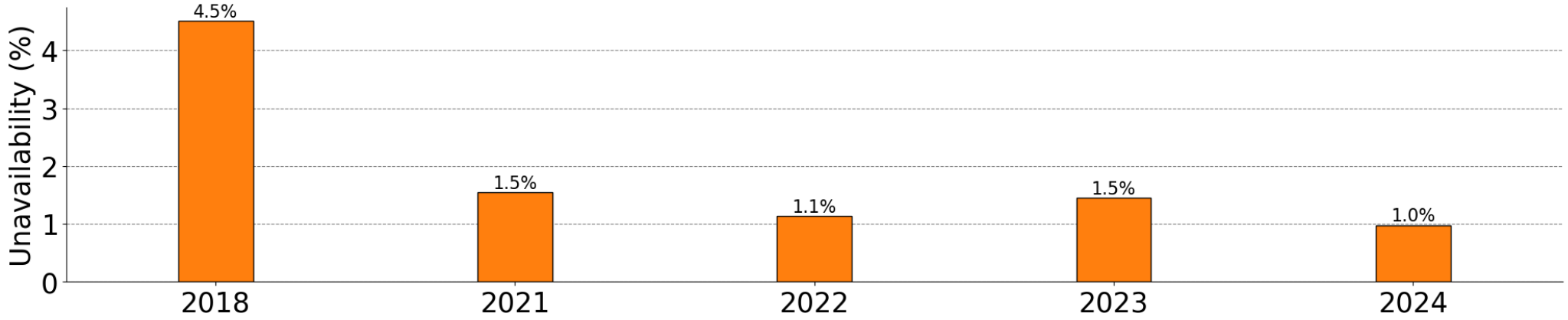
SPS

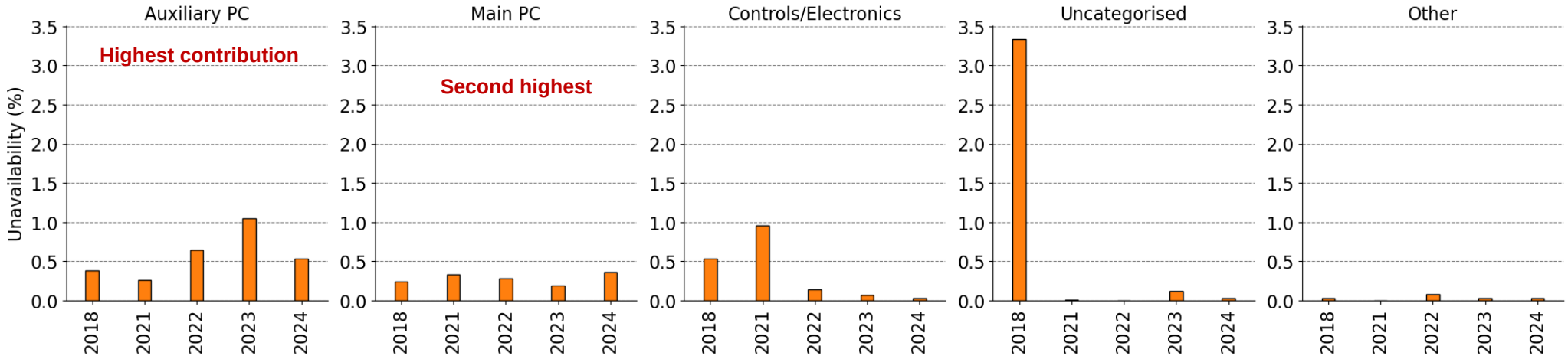
Acknowledgment: Kevin Li

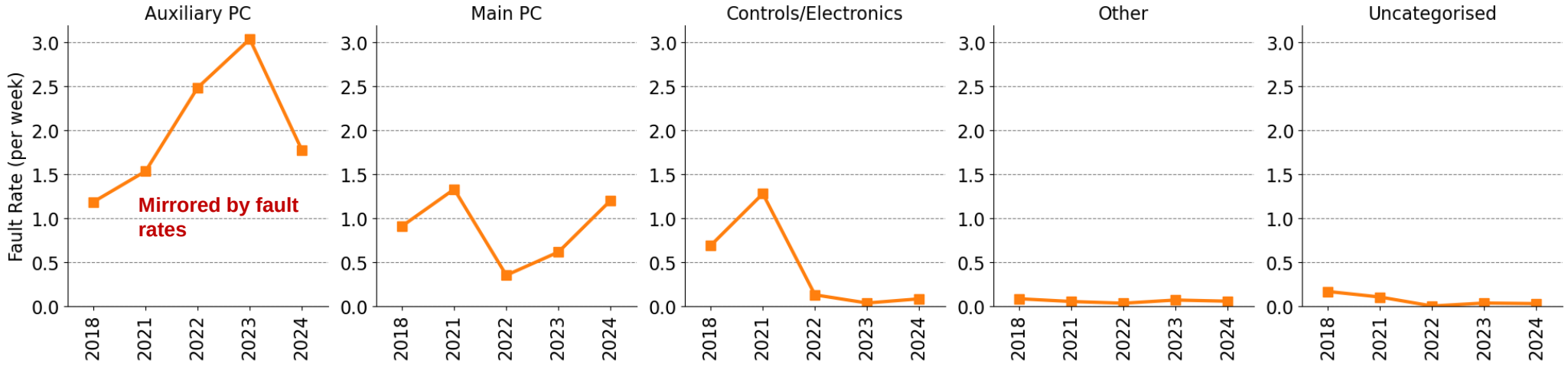
SPS


Injector Complex
Accelerator
Overall not much change since last year
IC down, SPS up
Unavailability (%)
18.7%
11.0%
25.6%
19.2%
26.6%
17.3%
14.0%
7.6%
14.0%
8.9%
2018
2021
2022
2023
2024
Radio Frequency
Two faults -> 5 days of down time (cav 1,3,6)
Power Converters
Vacuum
Exchange of four dipoles
Magnets
MBB 635.30 inter-turn short ; NA stop BEND02
Dump Systems
Fault Rate (per week)
No extremely long faults

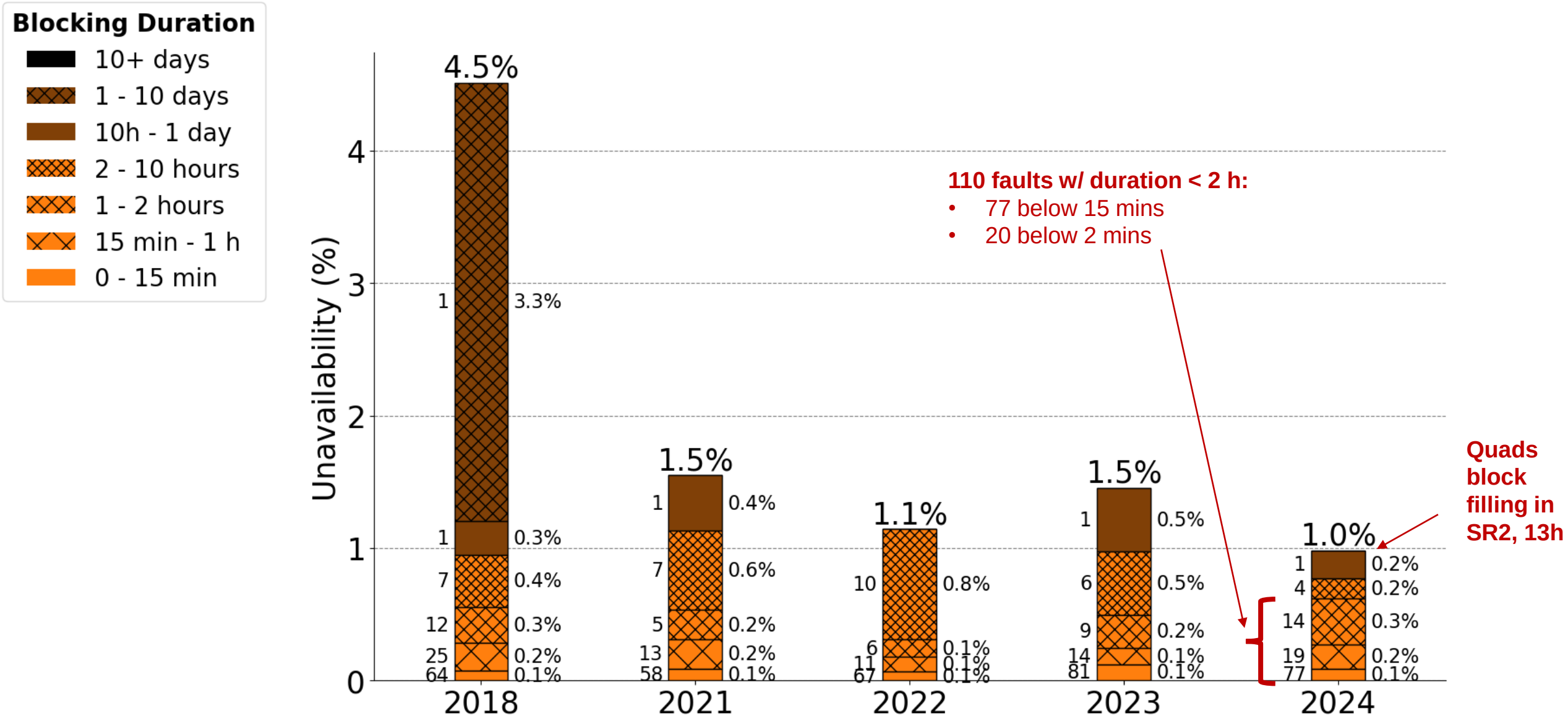
SPS - Power Converters







SPS - Power Converters



(w/o injector complex)

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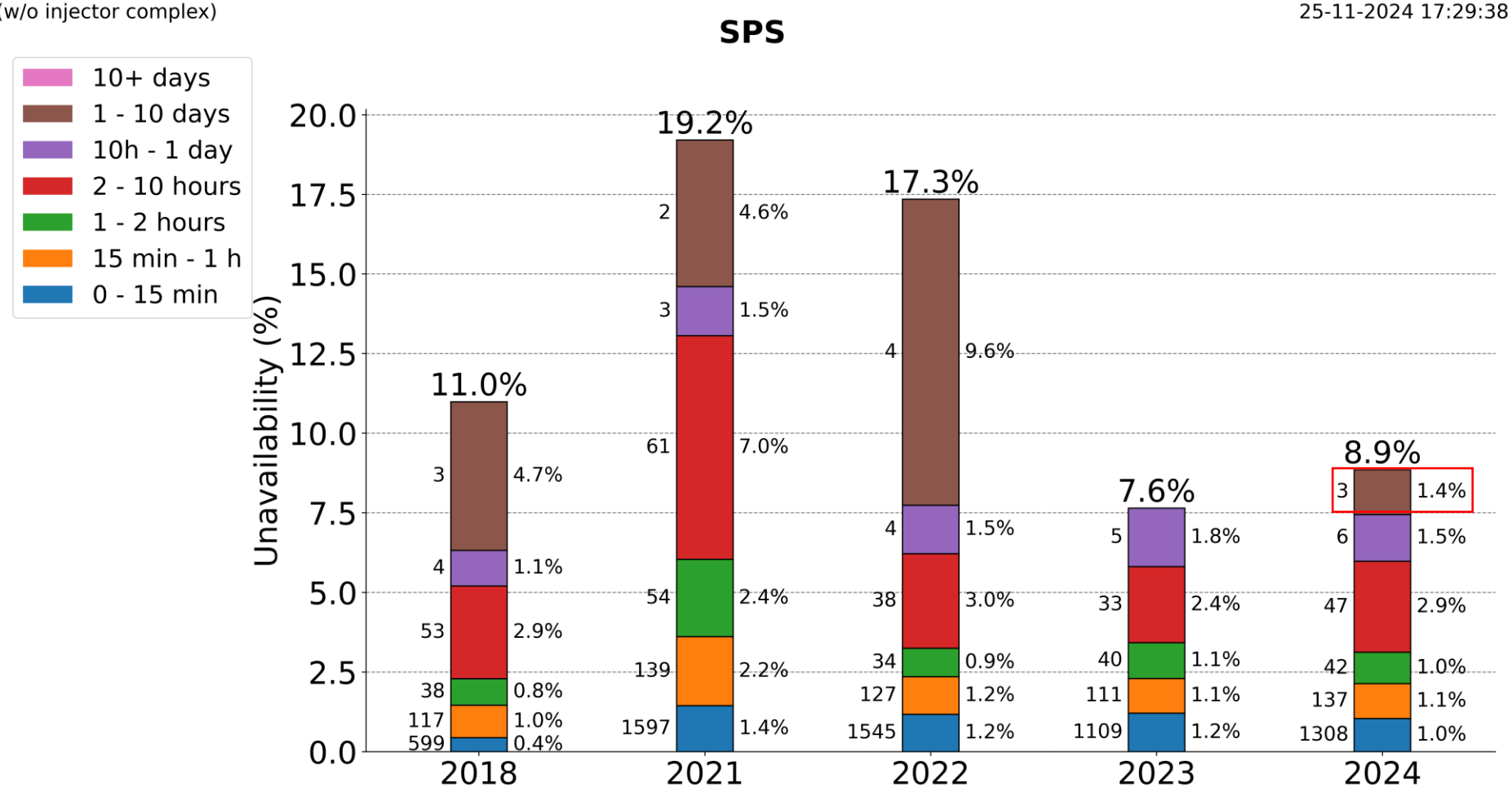


- Magnets: MBB 635.30 inter-turn short, 1d 9h, 10 Jun
- Vacuum: Exchange of magnet MBA.63450 with leaking vacuum chamber, 1d 3h, 30 May
- CV: Water circuit blocked, 1d 3h, 25 Jun

- **Mitigations are foreseen in RF and CV.**
- **Magnets expected to keep failing at the given rate.**
- **Hope to reduce the long down times next year in RF and CV**
- **And short faults?**

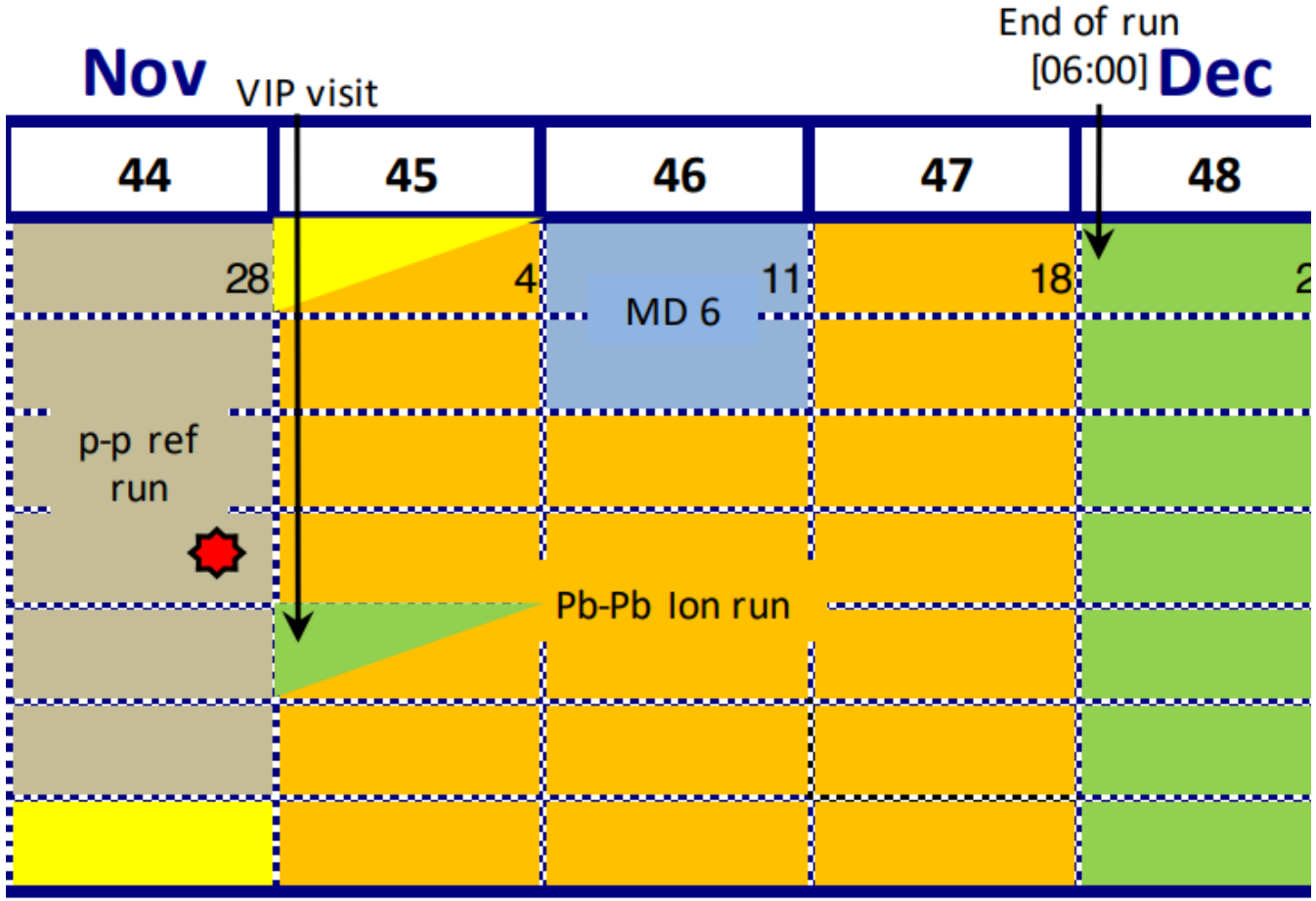
SPS Conclusions

- **Availability is stable (91.1 %)**
- **Mitigations foreseen for longer faults. Magnets will likely continue unchanged.**
- **Short faults (<2h) are a significant contributor to down time**

Comments SPS?

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?



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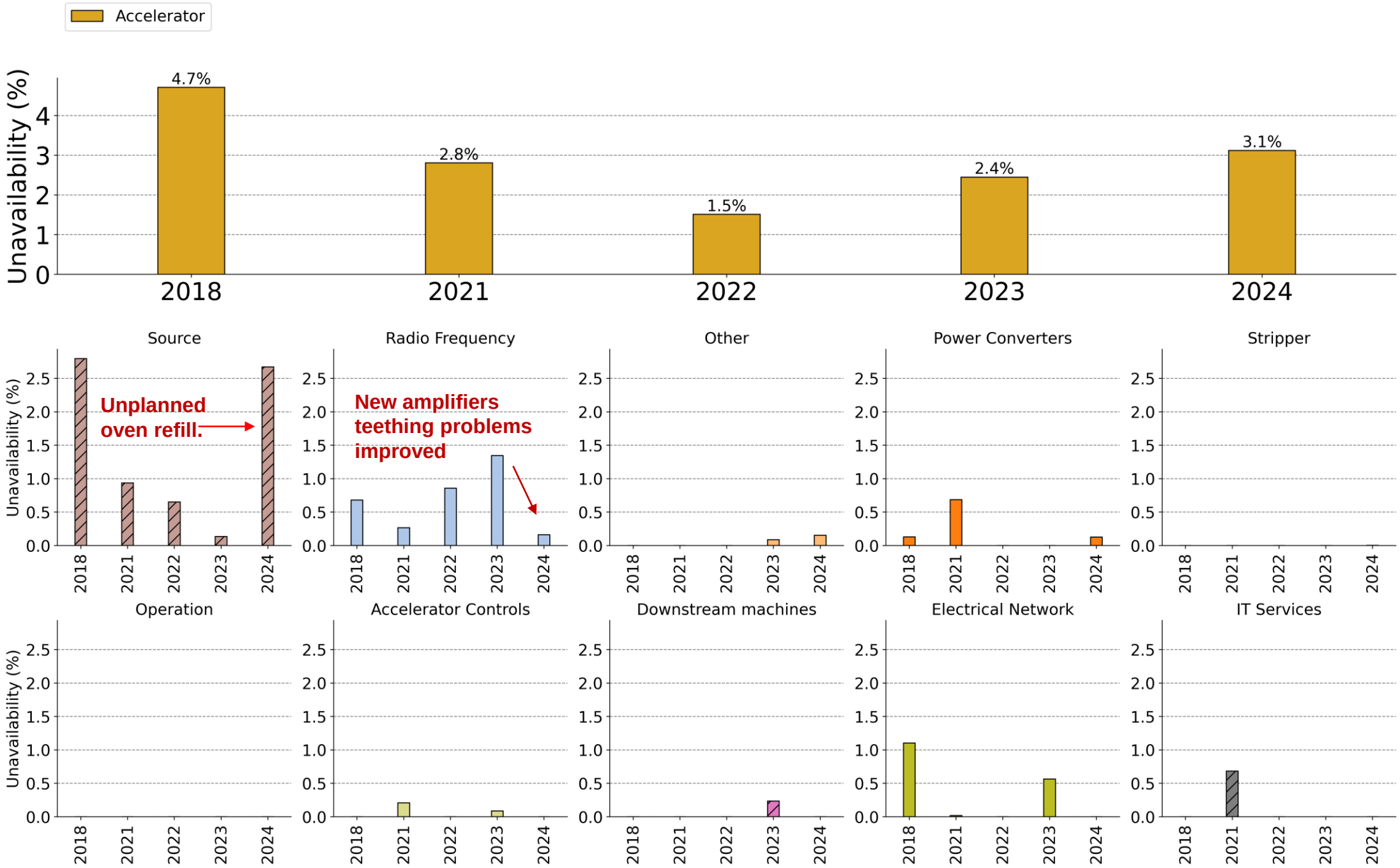
LINAC3

Acknowledgement: Richard Scrivens

LINAC3


Accelerator
Unavailability (%)
4.7%
2.8%
1.5%
2.4%
3.1%
2018
2021
2022
2023
2024
Source
Unplanned oven refill:
Radio Frequency
New amplifiers teething problems improved
Other
Power Converters
Stripper
Operation
Accelerator Controls
Downstream machines
Electrical Network
IT Services

(w/o injector complex)

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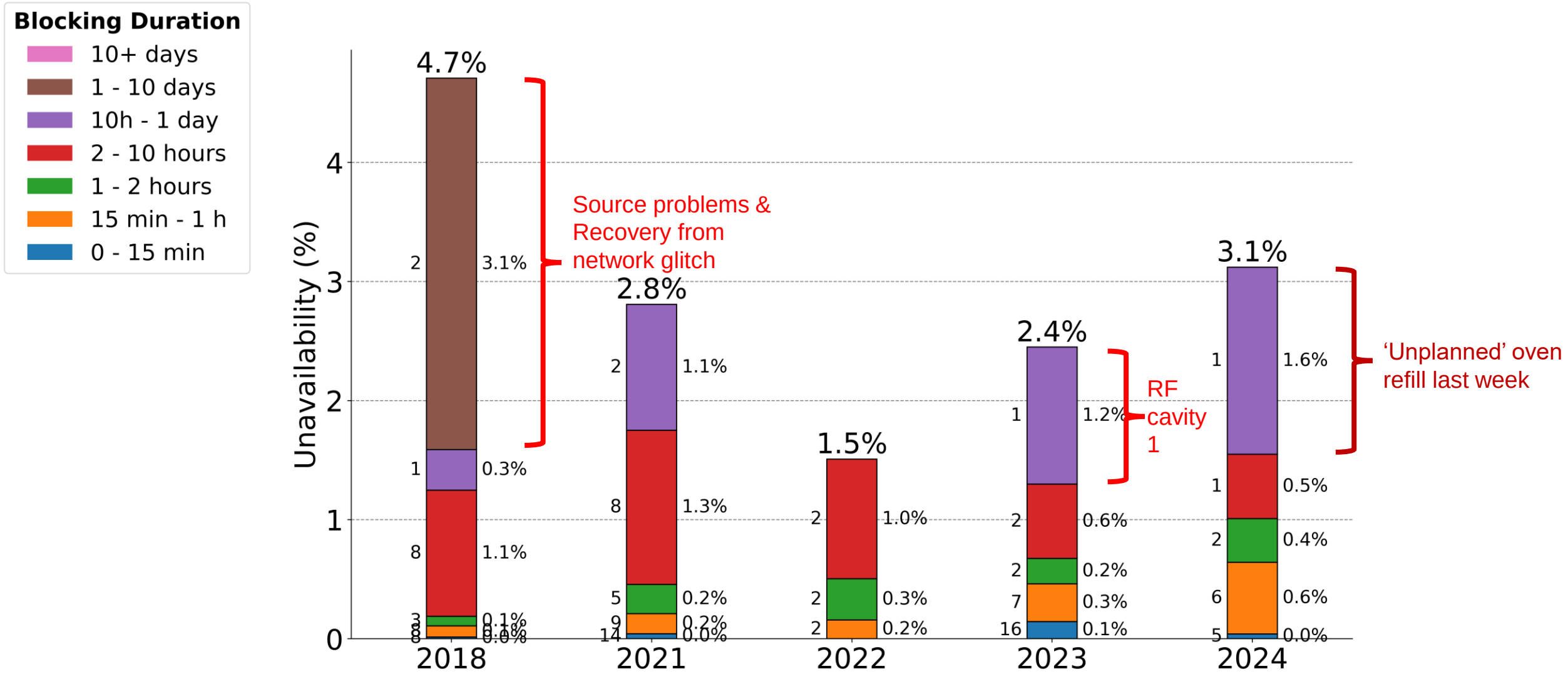
LINAC3



- **Up to last week it was an excellent year**
- **Short AFT periods lead to strong statistical variations across years.**

LINAC3 Conclusions

- **Overall strong performance this year (96.9%)**
  - 32 days scheduled without oven refill. Failure on the 28th day. Will be followed up.
  - Otherwise, no major faults (>4 hours)
- **Only 4 weeks accounted in 2024 → ‘weak’ statistics**

- **No major consolidation foreseen in YETS**
- **2025 has two physics runs (oxygen and lead).**
  - Source has been reliable but concerns over long lead time spares. **Lack of spares led to long downtimes during the ion start up**. A long-term strategy for the 14GHz generator must be arranged.

1. Proton injectors
2. **Ion injectors**
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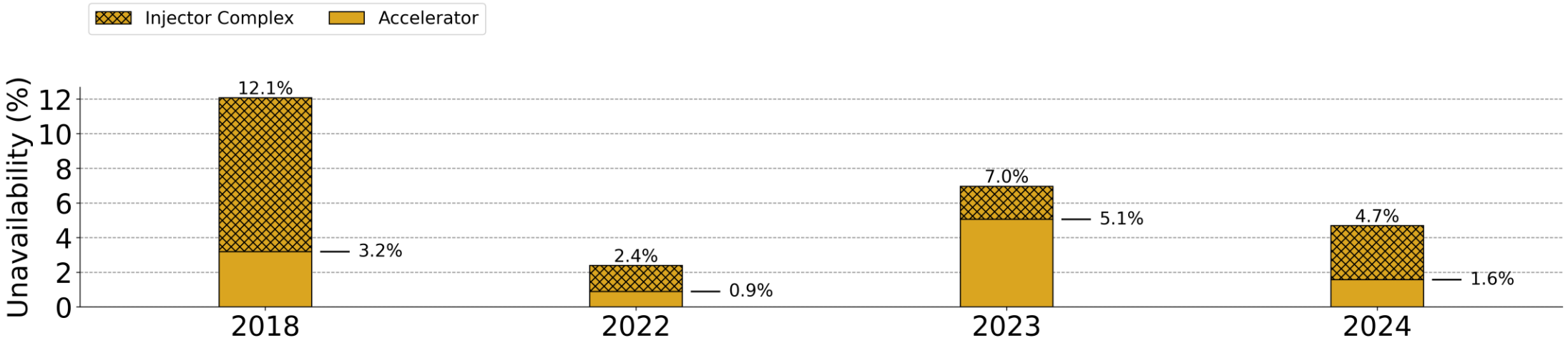
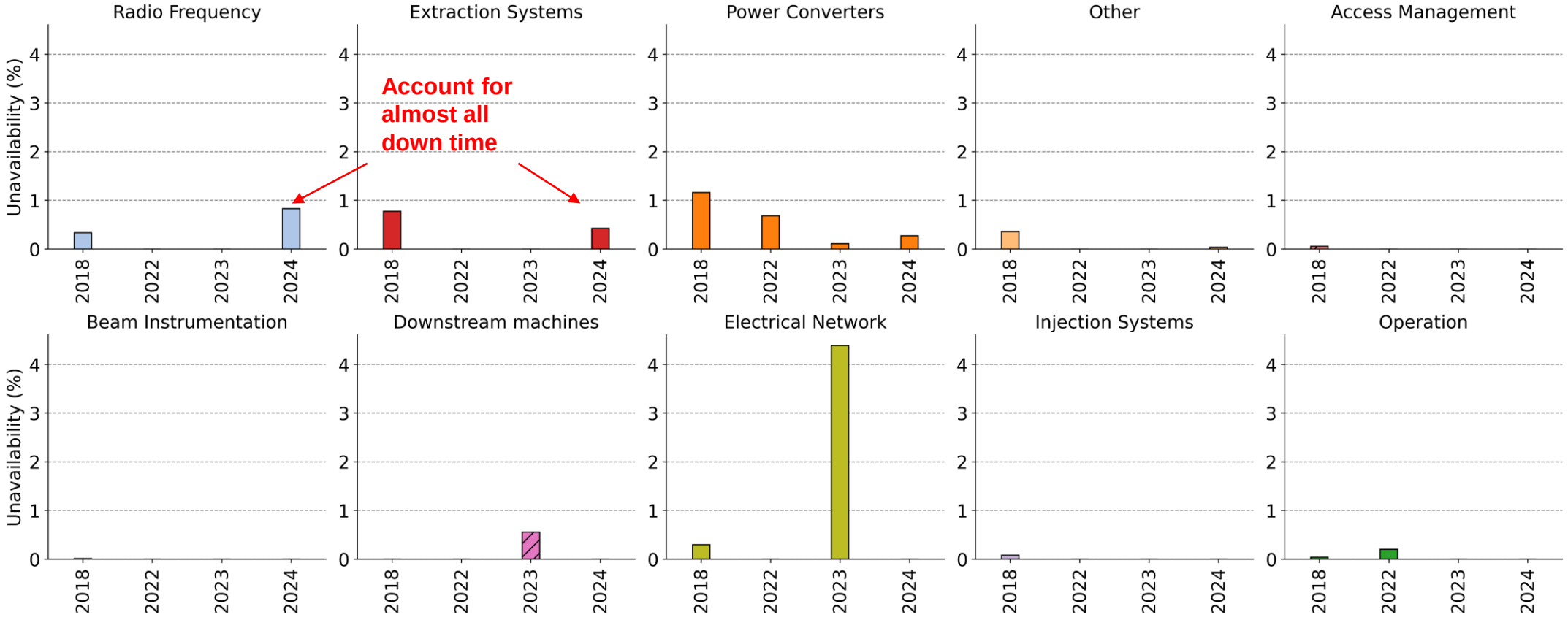
LEIR

Acknowledgement: Theodoros Argyropoulos, Oliver Hans

LEIR





Mitigations foreseen in YETS

LEIR Conclusions

- **LEIR has been operating reliably (98.4 %). This year no long faults.**

- **2025 expected to be similar to 2024.**
  - Reaction time from OP (reset magnets etc) could still be improved, but won't lead to a big change
- **RF cavities (PLC, PC, amplifiers) and Extraction Systems to be mitigated during YETS.**

- **Only 4 weeks accounted in 2024 → 'weak' statistics**

Comments LINAC3 / LEIR?

1. Proton injectors
2. Ion injectors
3. **LHC**
4. Experimental Areas
5. Preliminary Conclusions

LHC

Acknowledgement: Matteo Solfaroli Camillocci

LHC Schedules

V2.2 – Oct 14th 2024

LHC “All Operation”:

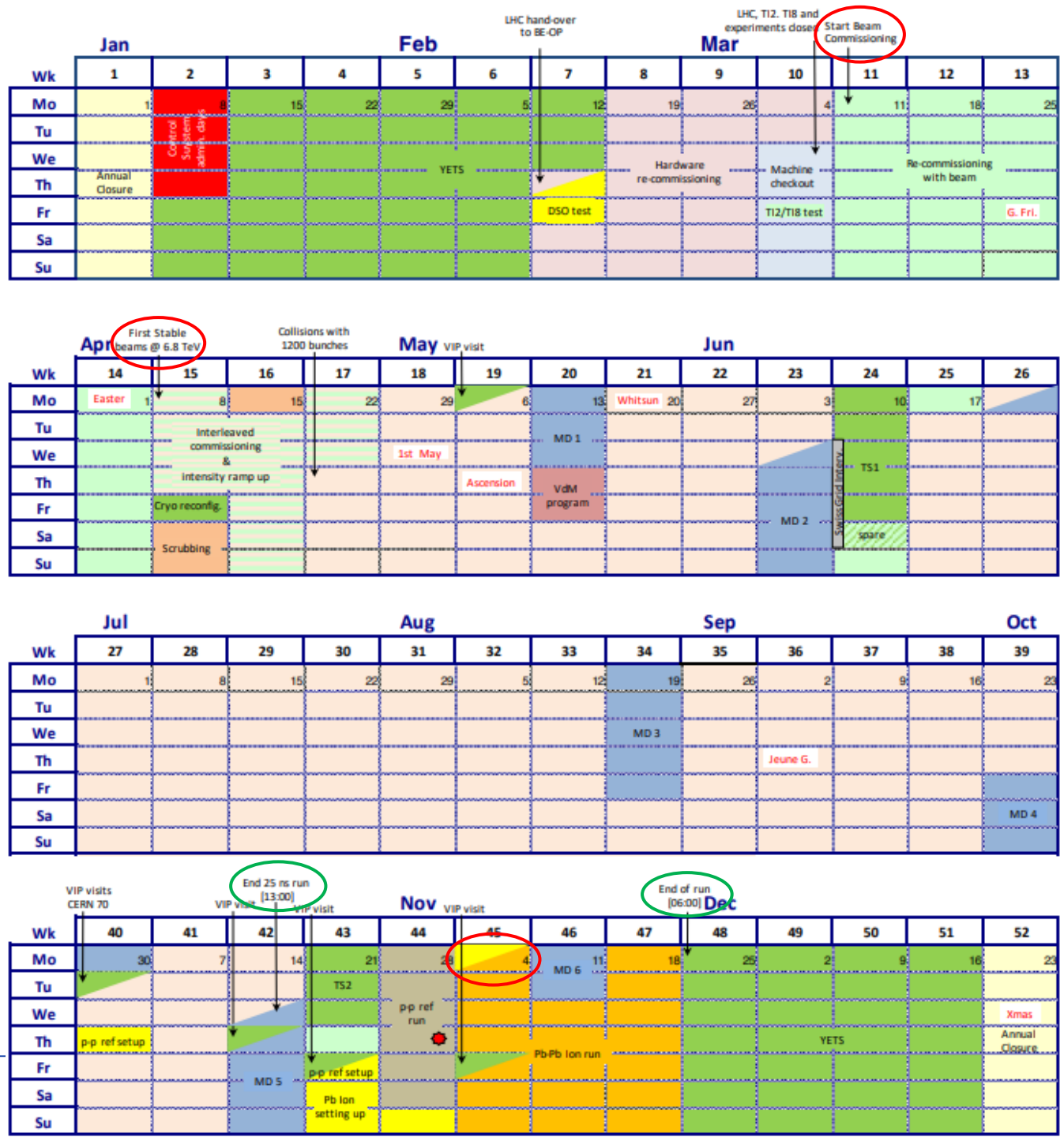
- From start of recommissioning with beam to start of annual shutdown
- Includes all TSs and MDs
- Permits tracking of all faults and delays

LHC Protons:

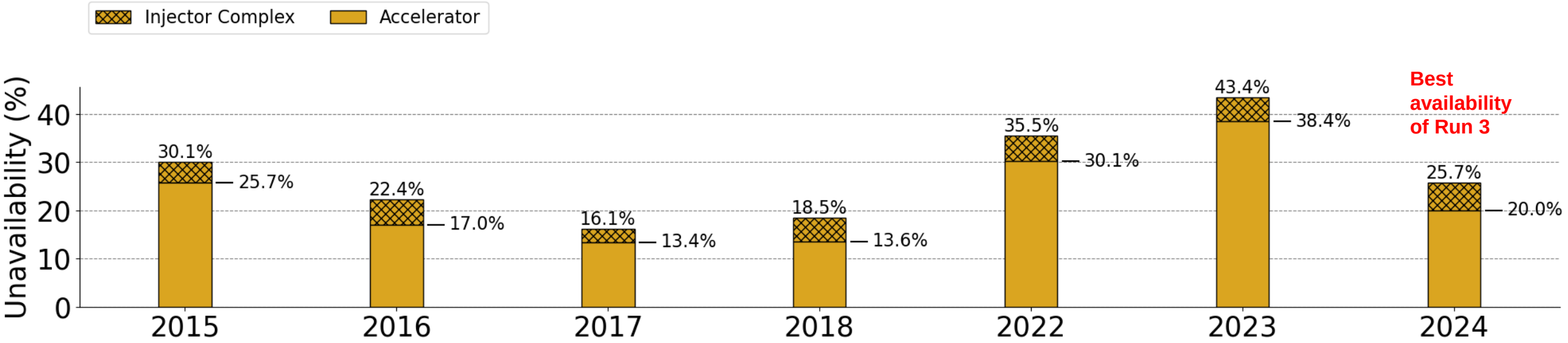
- From first stable beams declaration to end of 25ns run
- Dedicated MDs and TS are excluded from statistics

LHC Ions:

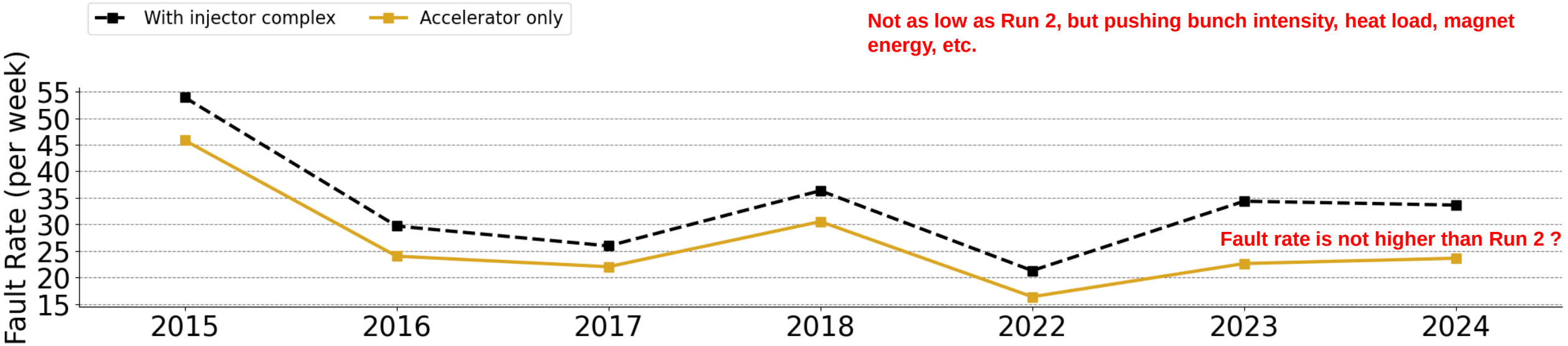
- From start to end of Pb-Pb Ion run
- Dedicated MDs and TS are excluded from statistics



LHC All Operation



Best availability of Run 3



Not as low as Run 2, but pushing bunch intensity, heat load, magnet energy, etc.

Fault rate is not higher than Run 2 ?

(w/o injector complex)

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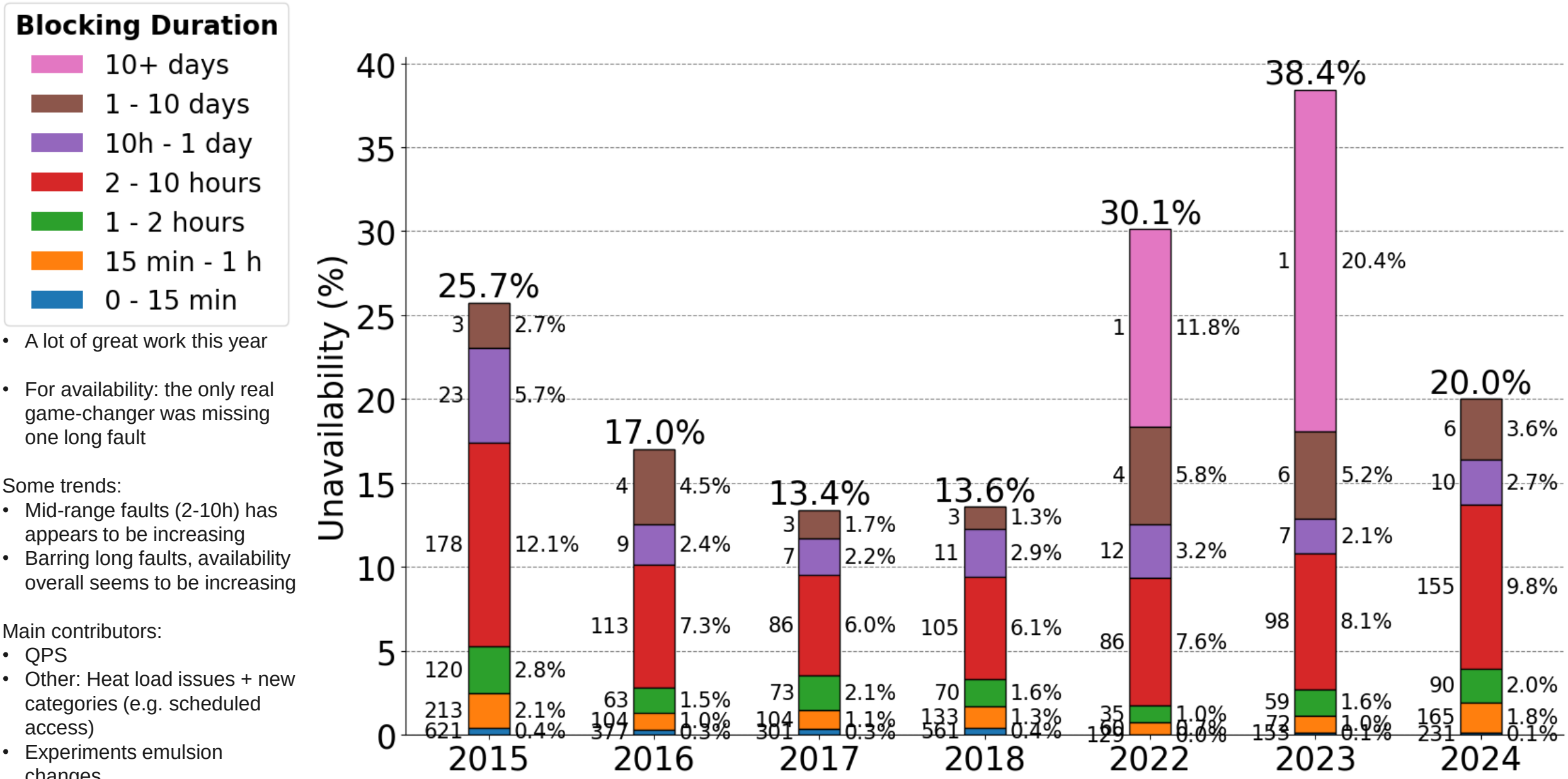
LHC All Operation

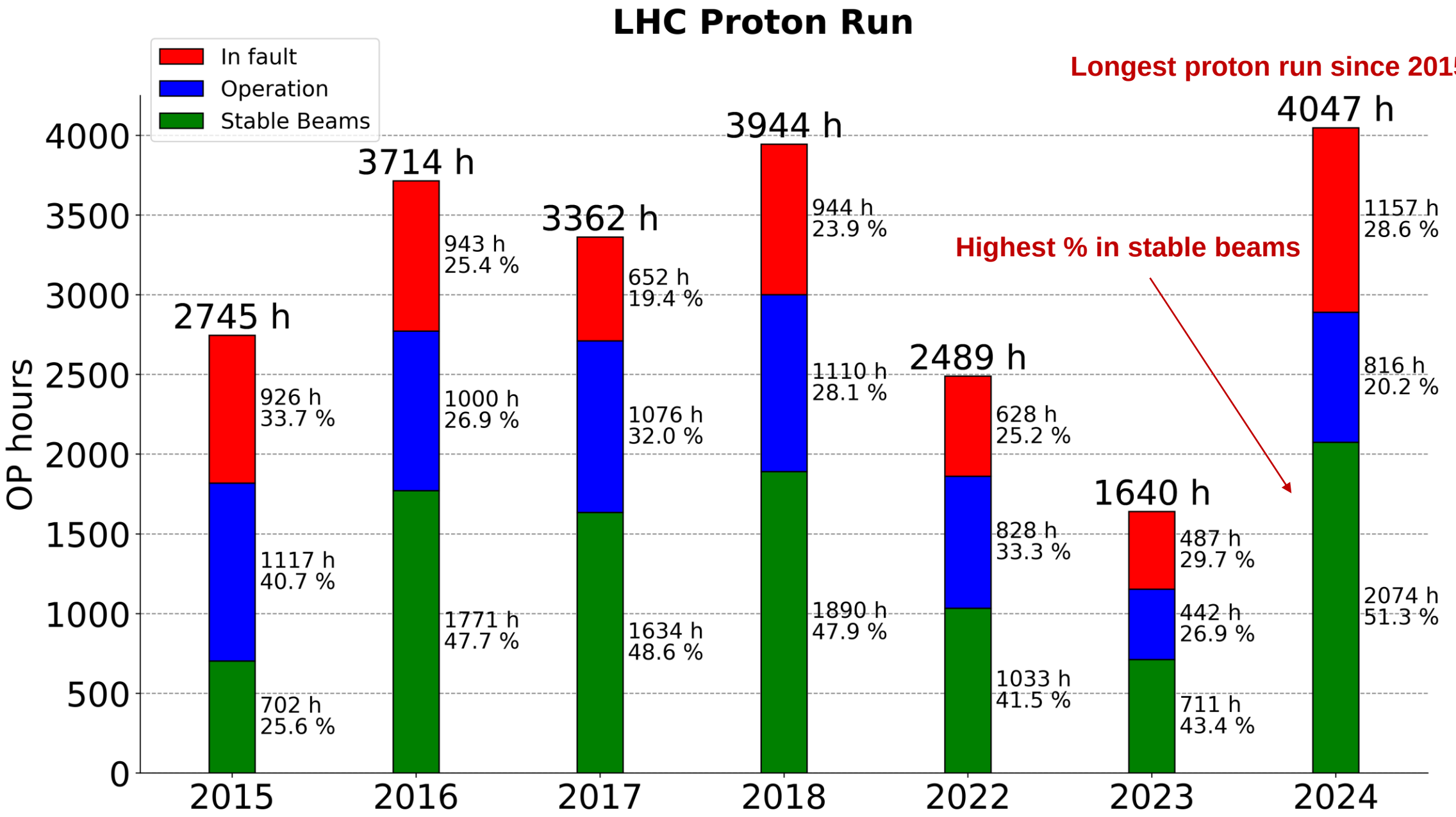


- A lot of great work this year

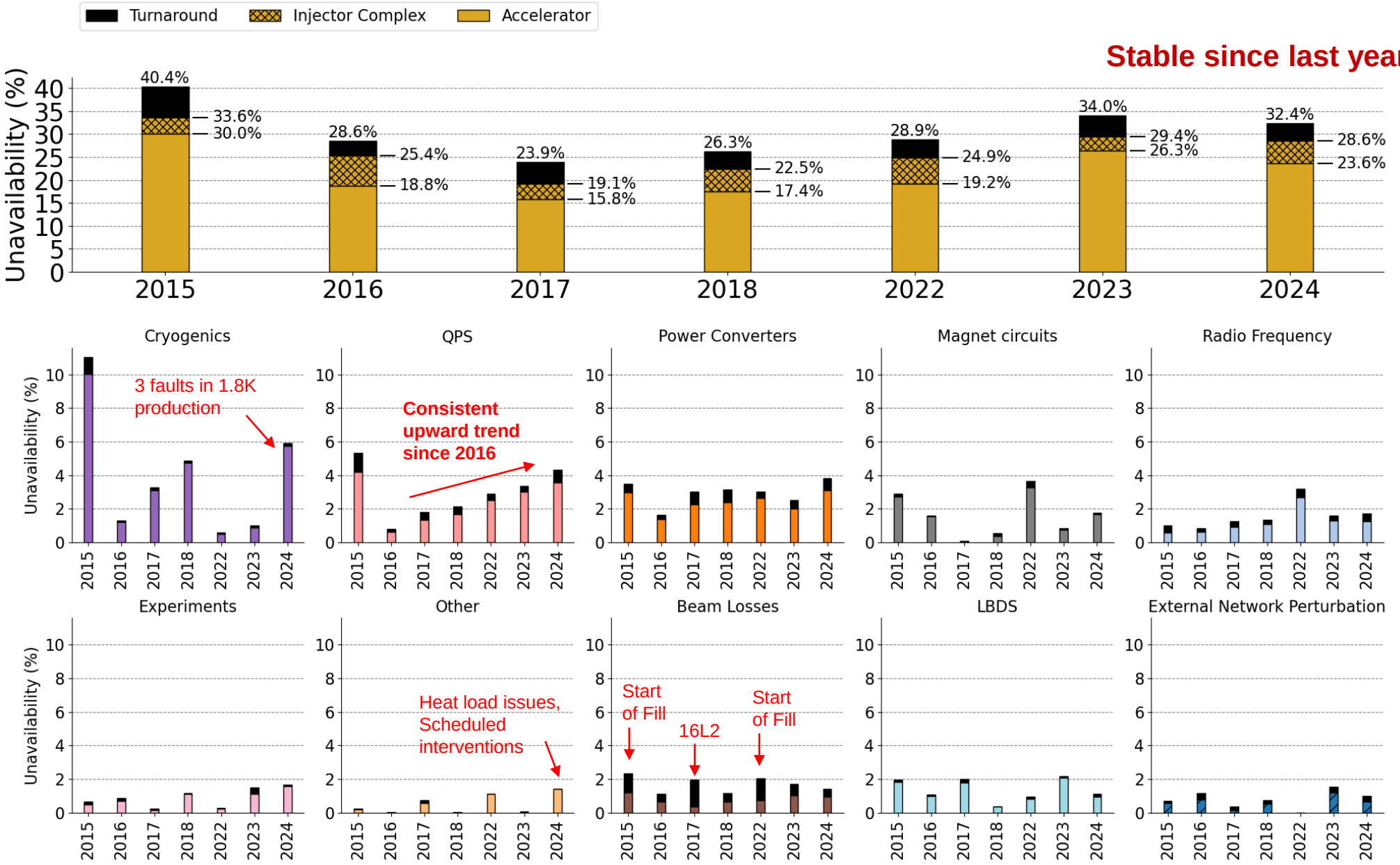
- For availability: the only real game-changer was missing one long fault

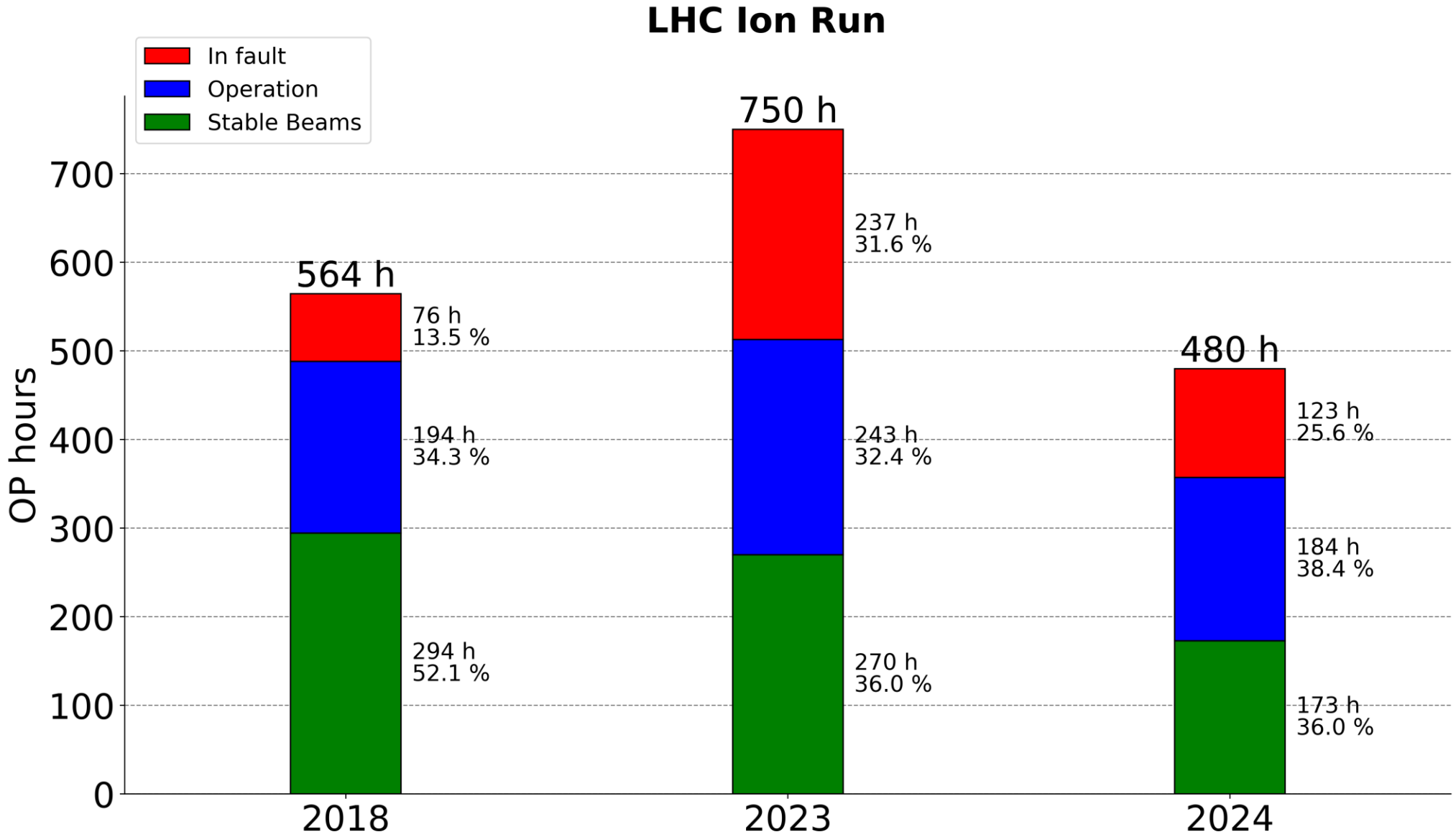
Some trends:
- Mid-range faults (2-10h) has appears to be increasing
- Barring long faults, availability overall seems to be increasing

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


LHC Proton Run
In fault
Operation
Stable Beams
Longest proton run since 2015
Highest % in stable beams
OP hours
0
500
1000
1500
2000
2500
3000
3500
4000
2015
2745 h
926 h
33.7 %
1117 h
40.7 %
702 h
25.6 %
2016
3714 h
943 h
25.4 %
1000 h
26.9 %
1771 h
47.7 %
2017
3362 h
652 h
19.4 %
1076 h
32.0 %
1634 h
48.6 %
2018
3944 h
944 h
23.9 %
1110 h
28.1 %
1890 h
47.9 %
2022
2489 h
628 h
25.2 %
828 h
33.3 %
1033 h
41.5 %
2023
1640 h
487 h
29.7 %
442 h
26.9 %
711 h
43.4 %
2024
4047 h
1157 h
28.6 %
816 h
20.2 %
2074 h
51.3 %

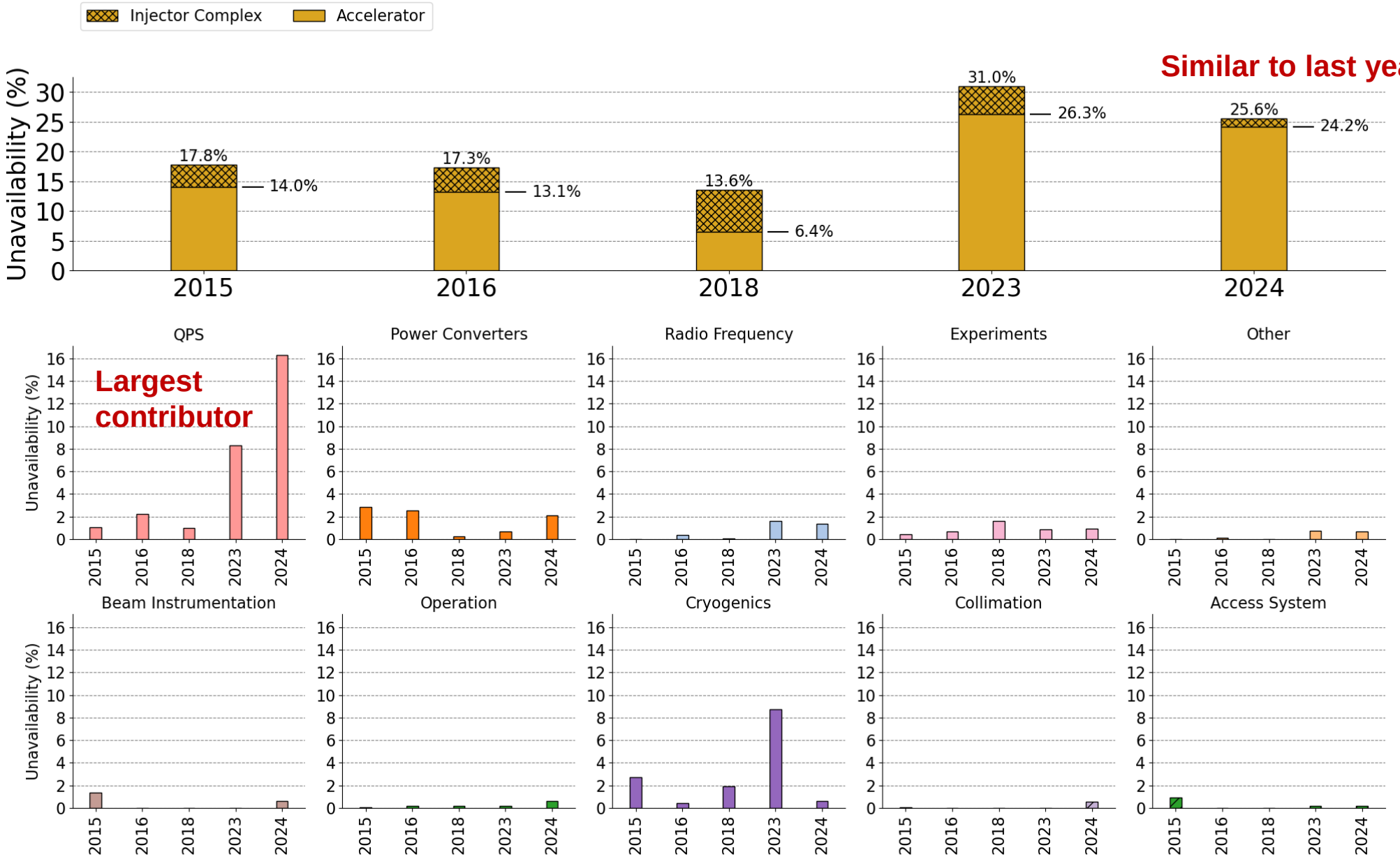
- **Cryogenics** bad year
  - 3 faults > 132 h
- **QPS** concerning trend





Same % in stable beams as last year

LHC Ion Run


Injector Complex
Accelerator
Unavailability (%)
17.8%
14.0%
17.3%
13.1%
13.6%
6.4%
31.0%
26.3%
25.6%
24.2%
2015
2016
2018
2023
2024
Similar to last year
QPS
Largest contributor
Power Converters
Radio Frequency
Experiments
Other
Beam Instrumentation
Operation
Cryogenics
Collimation
Access System

LHC Conclusion

- **Best availability in Run 3 (80 %). Longest proton run. Largest fraction in stable beams.**
- **No long faults**
- **Availability in physics is stable. Some trends worth following up (e.g. QPS)**

Outlook:

- **Cryogenics mitigation planned in YETS at IP8**
- **Possible bunch intensity increase in 2025 could have an impact on availability. Change of beam type (25 ns vs hybrid filling scheme) may also bring surprises**
- **QPS ion run problems are being mitigated**
  https://indico.cern.ch/event/1484357/contributions/6255477/attachments/2980053/5246981/LMC04122024_Quenches_during_Ion_Run_2024_v2.pdf

Comments LHC?

1. Proton injectors
2. Ion injectors
3. LHC
4. **Experimental Areas**
5. Preliminary Conclusions

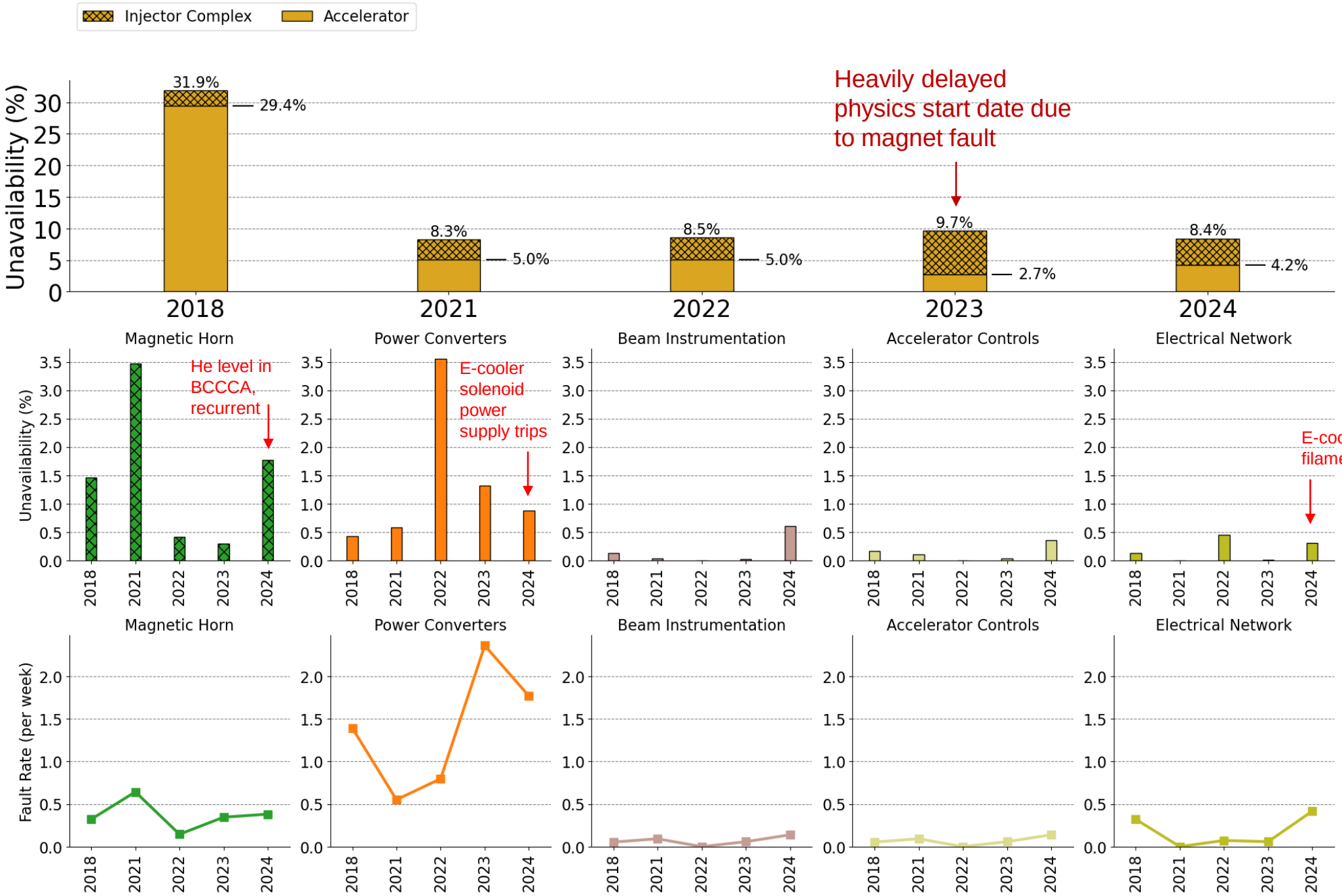
AD/ELENA

Acknowledgement: Laurette Ponce

AD

Significant issues not covered by AFT:

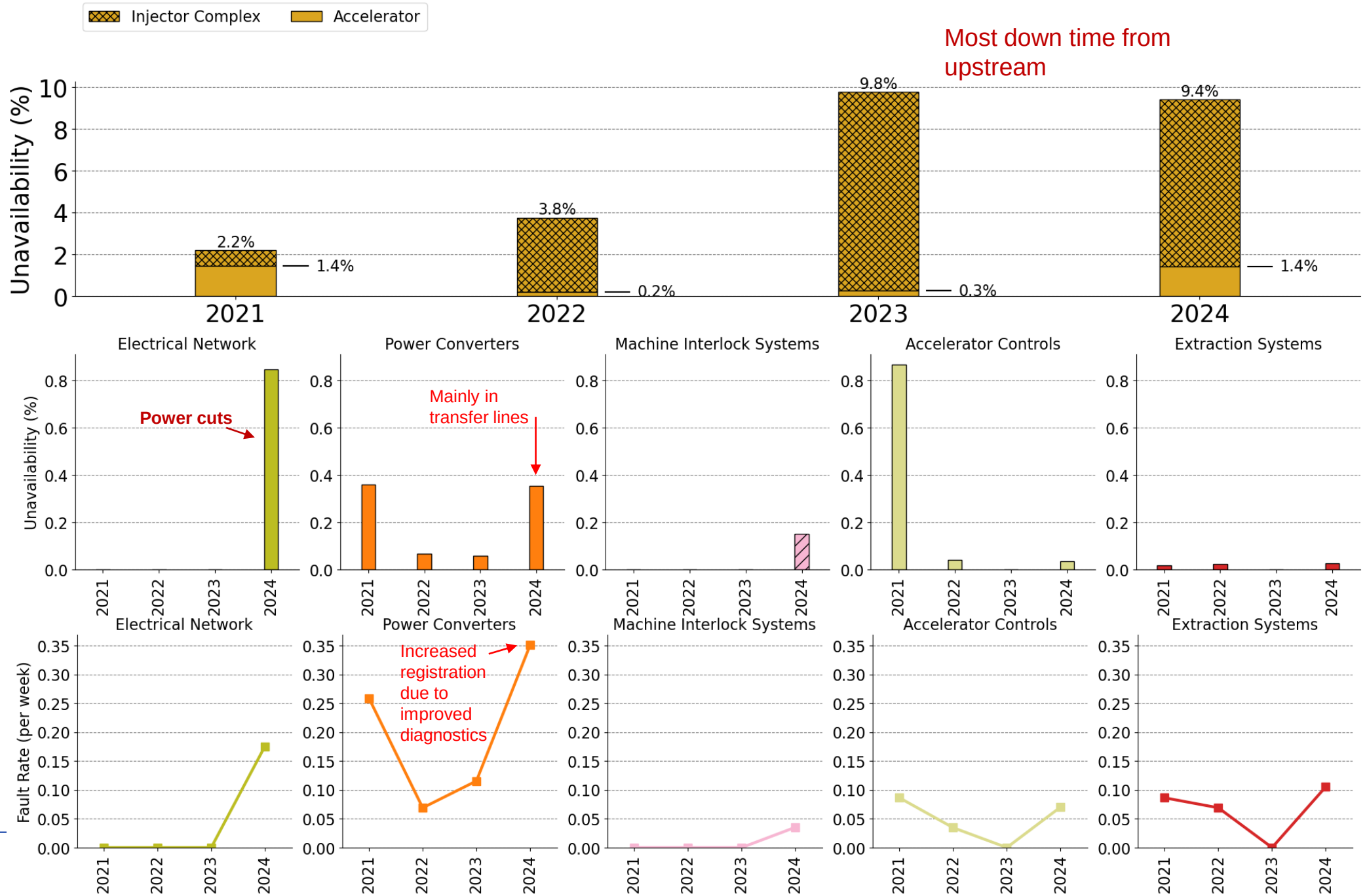
- Many systems in degraded mode: target, magnetic horn
- Non availability of instruments
- Non-blocking faults with stochastic cooling



<u>Magnetic Horn:</u>
Recurrent magnet fault in BCCCA He Level, access needed to refill

<u>PC & Elec. Net.:</u>
Trips of the e-cooler filament lead to ~8h beam set up

ELENA


Injector Complex
Accelerator
Most down time from upstream
Unavailability (%)
2.2%
1.4%
3.8%
0.2%
9.8%
0.3%
9.4%
1.4%
2021
2022
2023
2024
Electrical Network
Power Converters
Machine Interlock Systems
Accelerator Controls
Extraction Systems
Power cuts
Mainly in transfer lines
Fault Rate (per week)
Increased registration due to improved diagnostics

(w/o injector complex)

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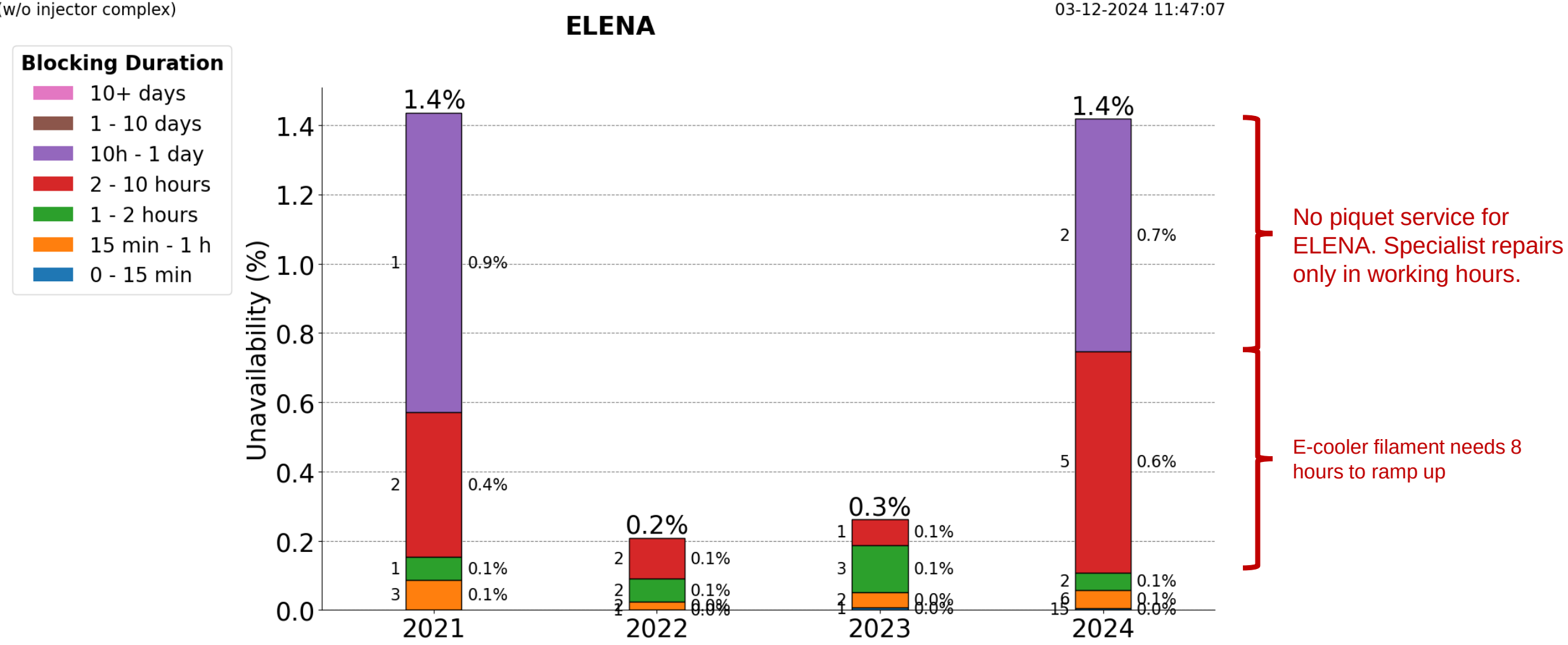


AD/ELENA Conclusions

- **Availability lower than last year, but still quite high (AD 95.8 %, ELENA 98.6 %)**
- **“No significant change in 2025”**
- **ELENA:**
  - Improved recovery of extraction system after power cuts due to controls configuration
  - FGC93 type power converter: Improved diagnostics means OP can anticipate and track

Comments AD/ELENA?

1. Proton injectors
2. Ion injectors
3. LHC
4. **Experimental Areas**
5. Preliminary Conclusions

ISOLDE

Acknowledgement: Emiliano Piselli

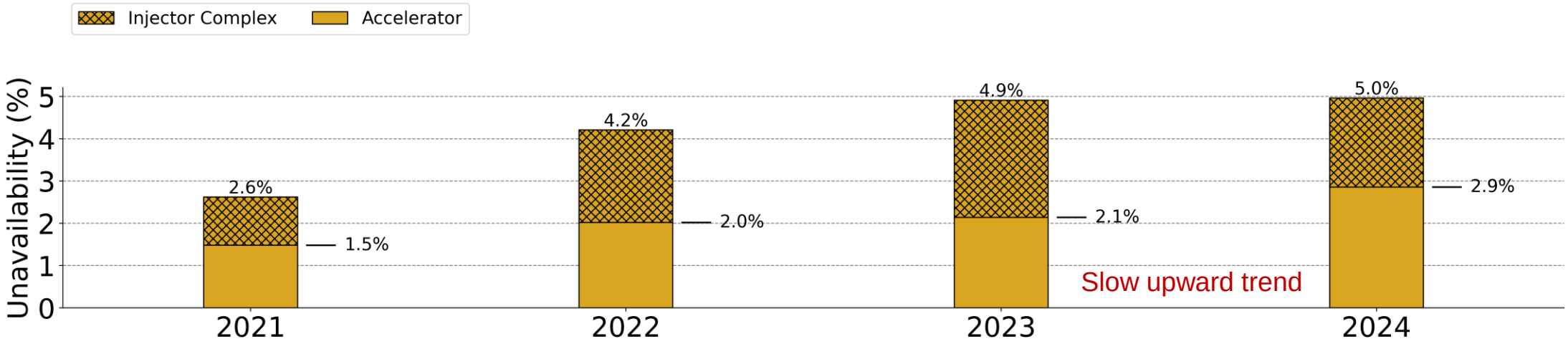
ISOLDE

ISOLDE	GPS: 95.5 %	HRS: 97.6 %	MS: Miguel Lozano → Erwin Siesling
Wk. 46	▪ **GPS:** Separator setup and start of physics on 14.11 (IS671: $^{34}Mg^{+}$ to MIRACLS). ▪ **HRS:** End of IS694 experiment (13.11). MD on low-energy optics model by ABP. ▪ **REX/HIE-ISOLDE:** Tests in SRF cavities by RF. Investigation by ABP on the source of REXTRAP discharges (13.11). Preparation for the YETS.		

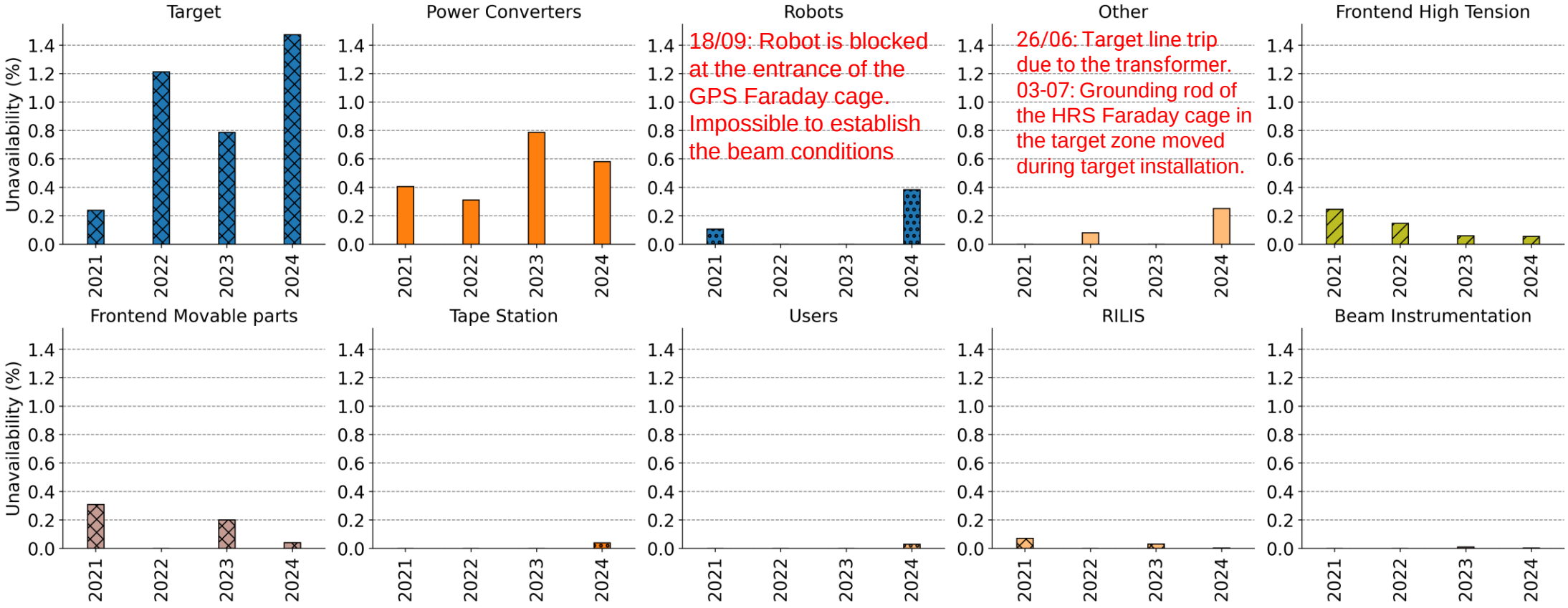
- **<u>Schedule Issues:</u> Operational periods of GPS, HRS & REX-HIE re-constructed from weekly FOM reports**
  - Granularity limited to weeks – to be improved for next year?

- **<u>Review Issues:</u> Several systems did not have AFT expert egroups**
  - E.g. **Target**, RILIS, EBIS, Frontend, Robots
  - → faults could not be reviewed by equipment groups
  - To be addressed for 2025

ISOLDE GPS

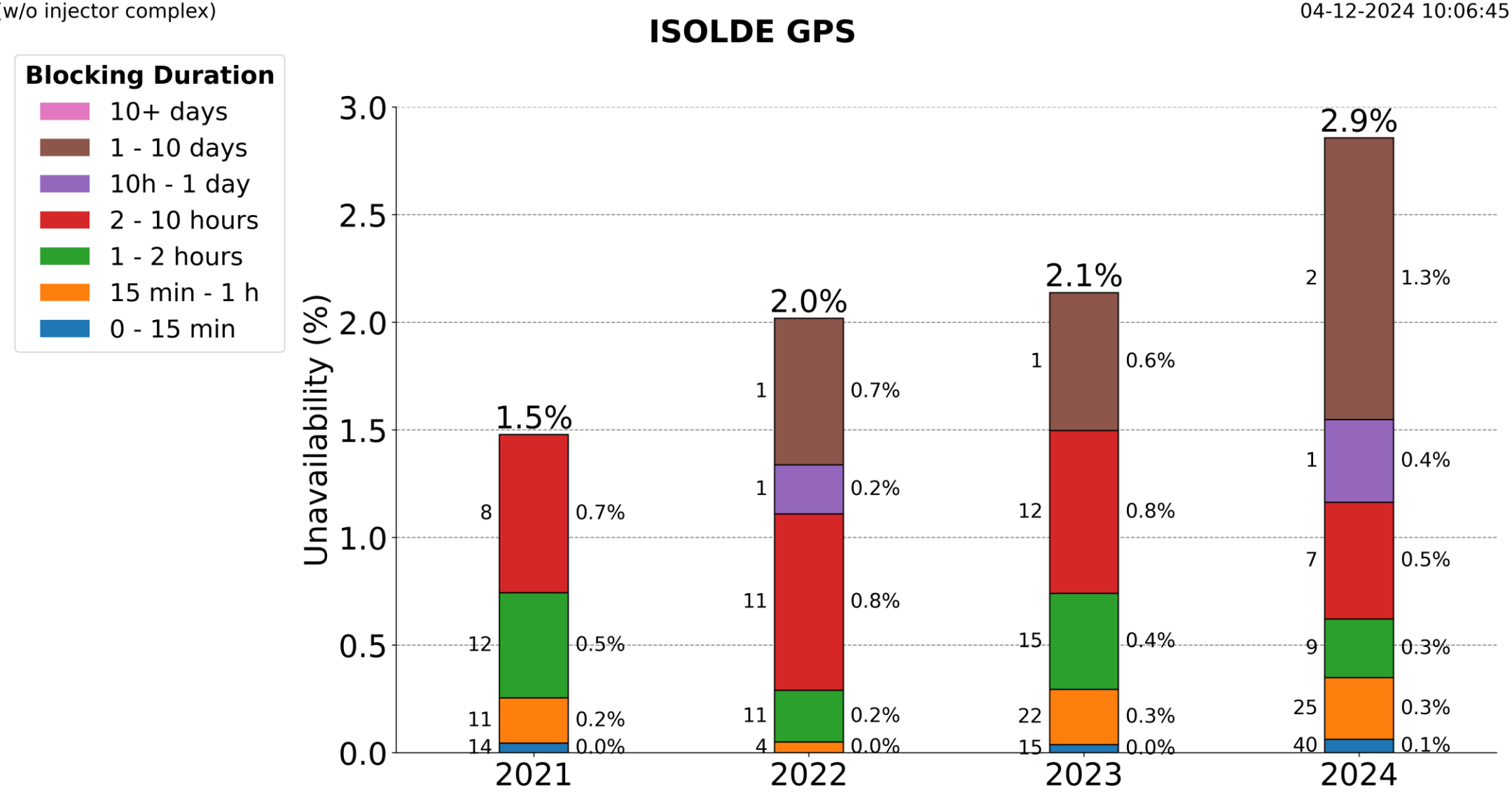


Target 2024:
18/07: Sulfur dispenser heater not working - No Miniball Physics.
21/09: Oven filament problem.



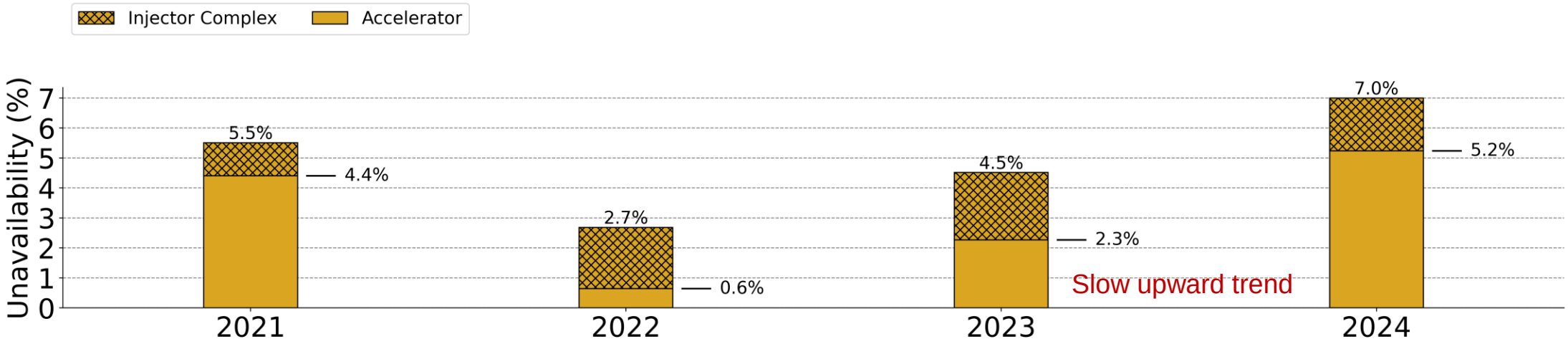
(w/o injector complex)

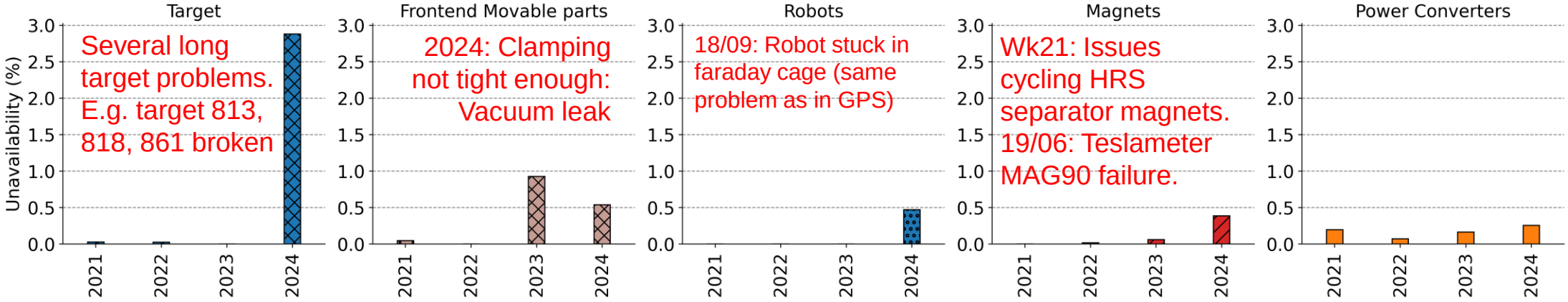
04-12-2024 10:06:45

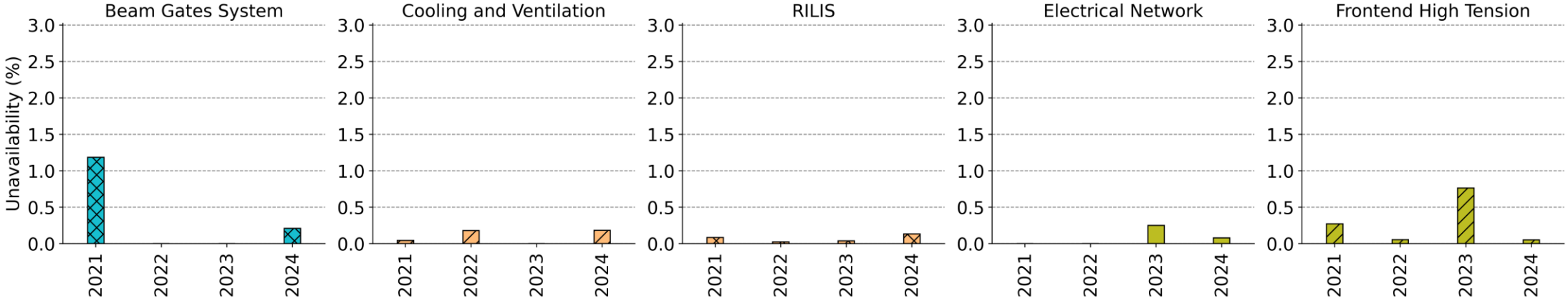


Long faults (> 1 days) on the rise (possibly statistical effect). Short faults stable.

ISOLDE HRS

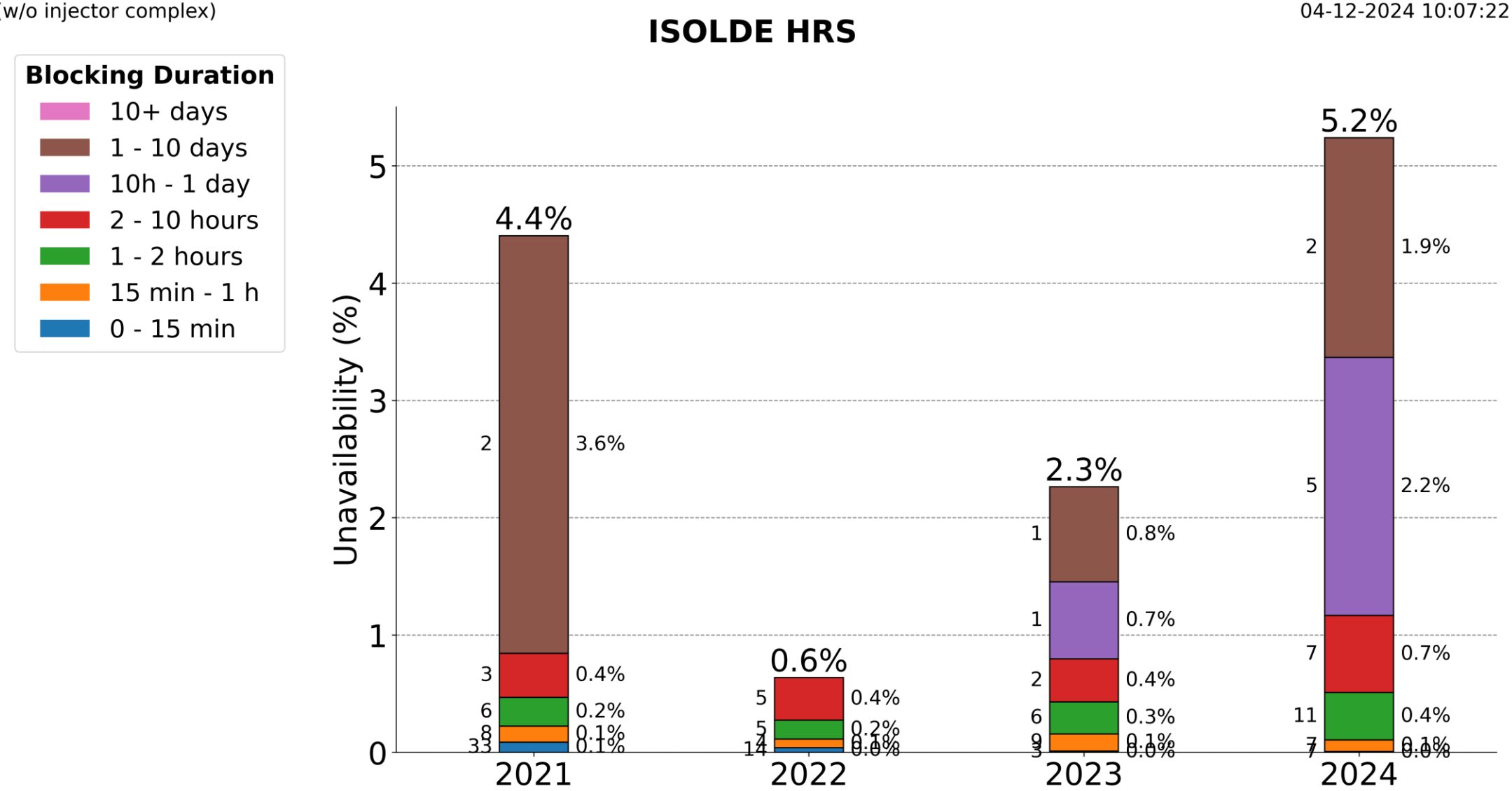

Injector Complex
Accelerator
Unavailability (%)
5.5%
4.4%
2.7%
0.6%
4.5%
2.3%
7.0%
5.2%
Slow upward trend
2021
2022
2023
2024


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

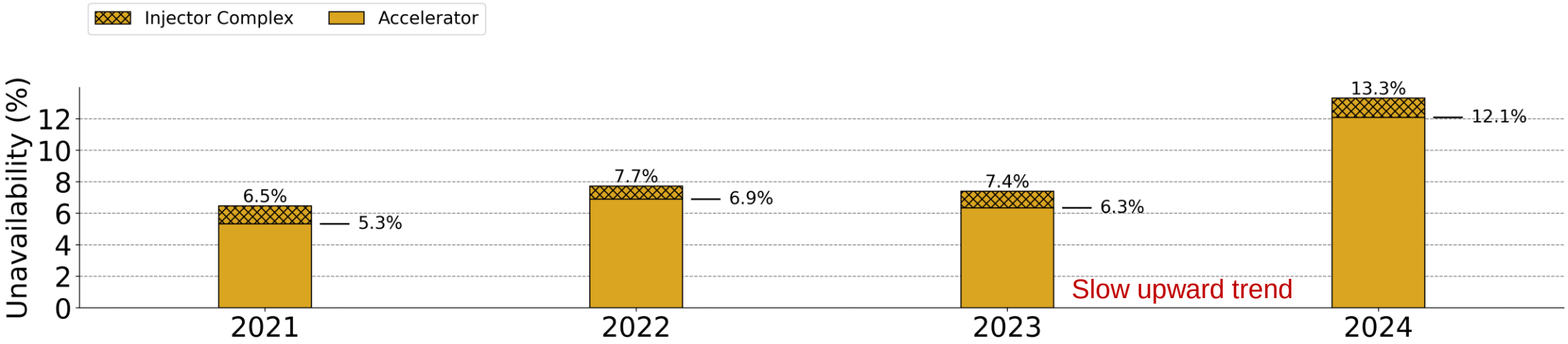
(w/o injector complex)

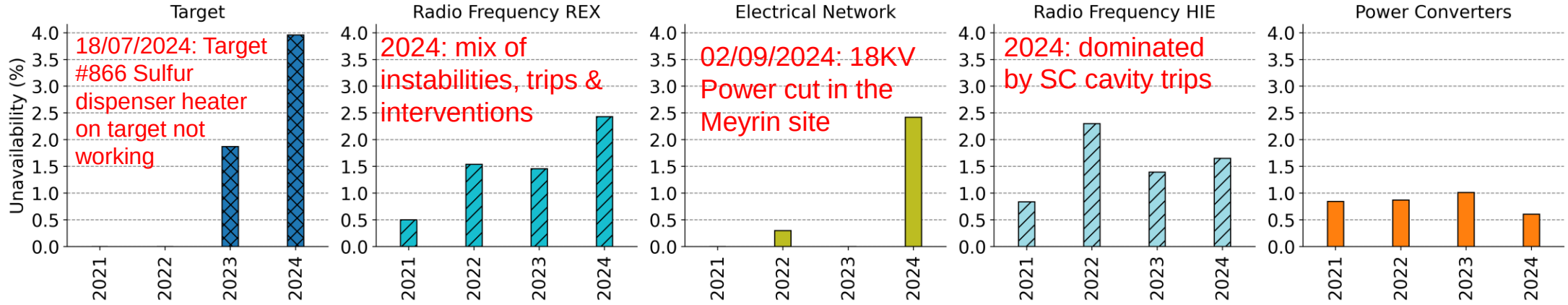
04-12-2024 10:07:22

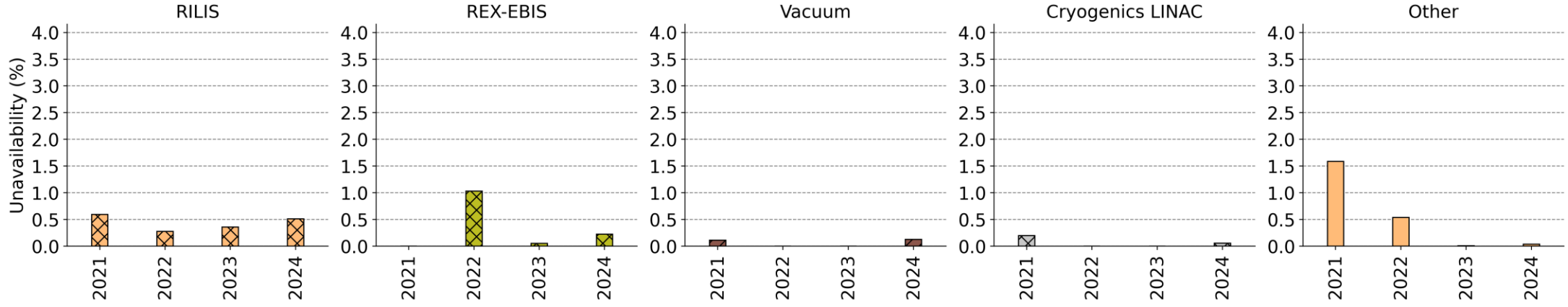


Volatility due to few long faults.

ISOLDE REX HIE







(w/o injector complex)

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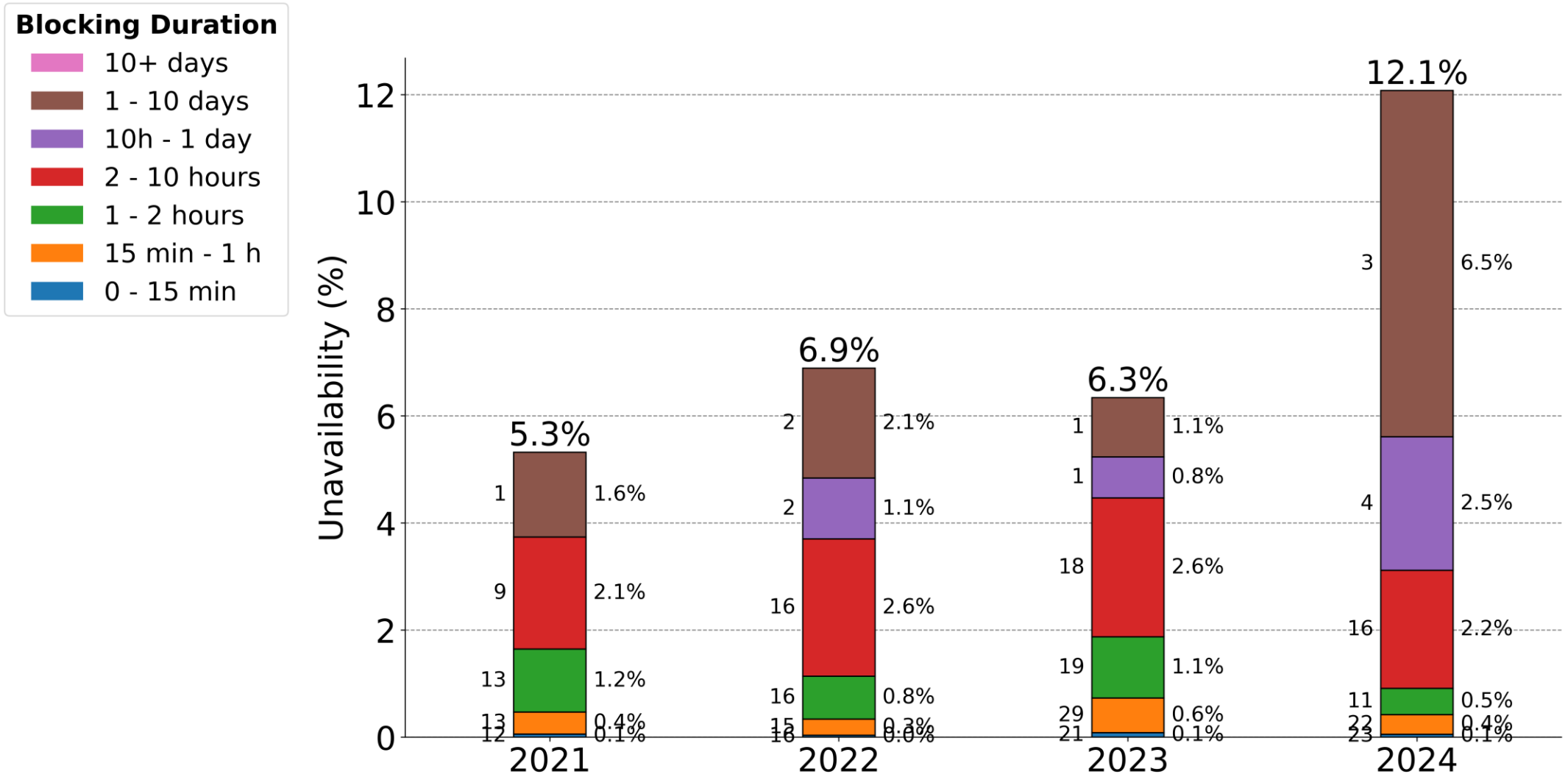
ISOLDE REX HIE



2024 main contribution is few long faults.

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

ISOLDE Conclusions

- **Most down time is from the target due to new users conducting R&D.**
- **Otherwise generally stable situation (97.1%, 94.8%, 87.9%)**
  - Downtime dominated by few long faults
  - Some trends visible, especially slow increase of RF unavailability REX-HIE

- **No mitigations foreseen for 2025, but maybe in LS3.**

Comments ISOLDE?

1. Proton injectors
2. Ion injectors
3. LHC
4. **Experimental Areas**
5. Preliminary Conclusions

EA / NA

Coming for JAPW

Conclusion Overall

- **A good year:**
  - Proton injectors improved or stayed high performing
  - LHC best availability of Run 3, highest percent in stable beams since 2015
  - Experiments are performing well, but some trends need to be tracked

- **Many thanks for great effort by all AFT contributors across the complex**

- **All plots and many more available at**

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

Comments Overall?

AFT Feature requests

Gian Piero di Giovanni:

- Make plots available in real time e.g. in AFT. And the processed data extractable as .pkl, .csv or .parquet files.
- Separate analysis by destination
- Display the data geographically from the layout DB. E.g. correlate with radiation data.

Bettina Mikulec:

- Dedicated evaluation for SPS LIU MD
- Extend fault propagation between PS complex and the SPS during YETS

Laurette Ponce:

- All faults affecting AD should be propagated by default to ELENA

Kevin Li:

- Problems with access system management – patrol broken due to careless manipulations is never recorded as it happens during stop periods. How can this be made more apparent?

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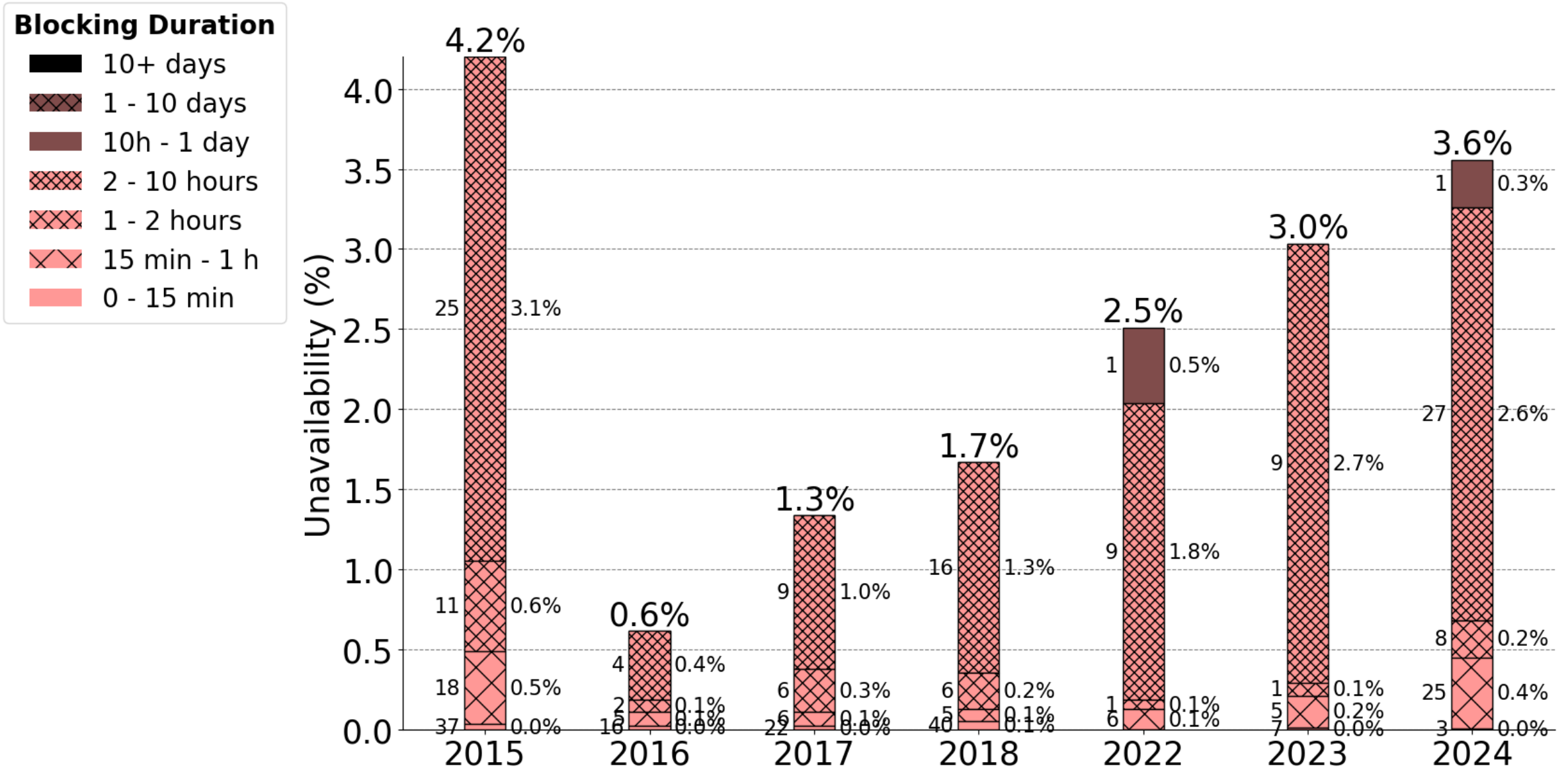
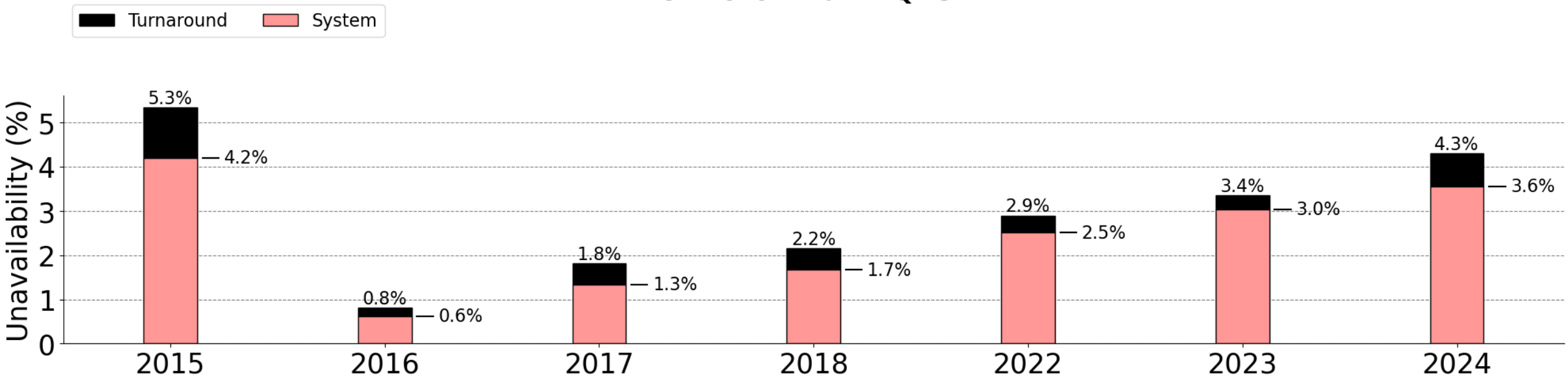
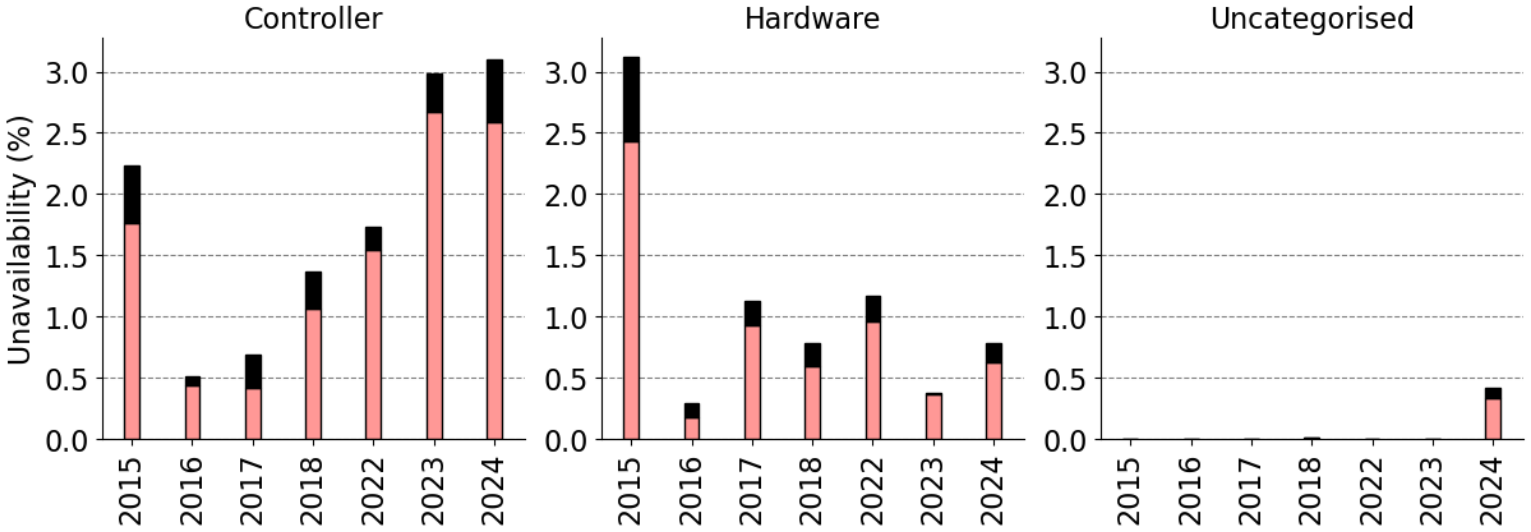
LHC Proton Run - QPS



LHC Proton Run - QPS





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