Linac4 Reliability Run

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MPE-PE Section meeting

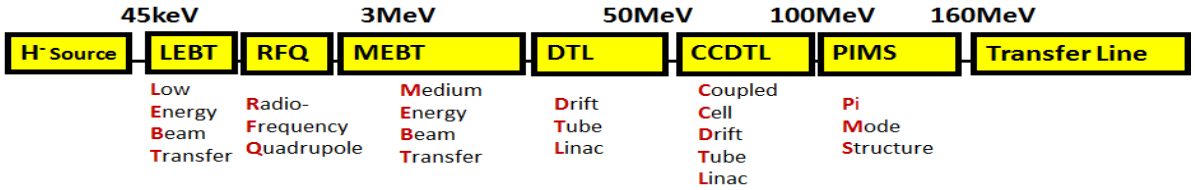
Acknowledgements: A. Apollonio, J. Uythoven, Linac4 team

Outline

- Linac4 at CERN
- Linac4 Reliability Run
  - Fault tracking
  - Performance
- Modelling vs Reliability Run
- Summary and Outlook

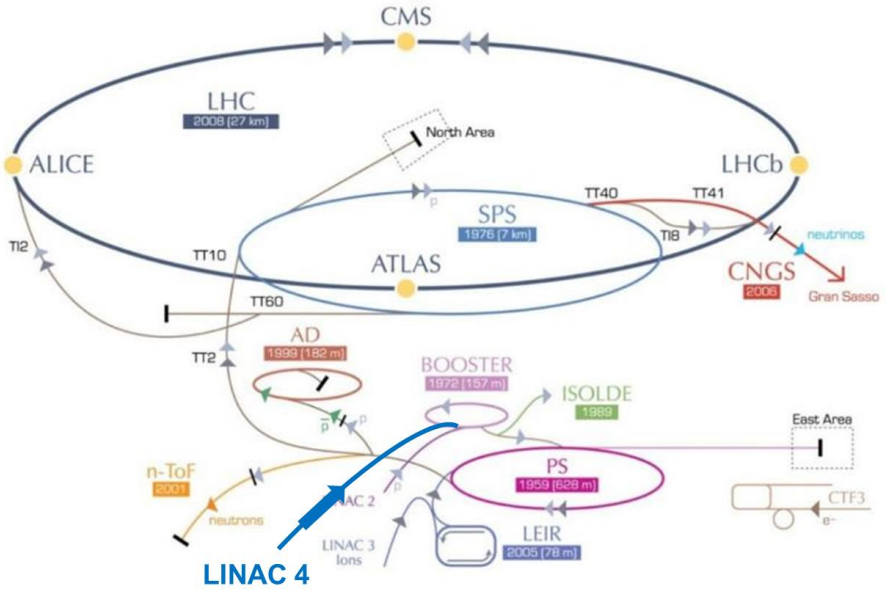
Linac4 at CERN

Linac4 at CERN



- Linac4 will replace Linac2 in the CERN Injector complex from 2020 (after LS2)
- **Availability-critical accelerator**: target > 95% availability
- Linac4 will provide beam for LHC and other accelerators
- Linac4 "pure" commissioning ended before the start of the Reliability Run
- Until now, **Linac4 running at half the nominal current**

LINAC 4 PARAMETERS	
Ion species	H-
Output energy	160 MeV
Bunch frequency	352.2 MHz
Max. rep.-rate	2 Hz
Beam pulse length	400 us
Source current	80mA
RFQ output current	70mA
Linac current	40mA
Beam power	5.1kW
Linac transverse emittance	0.4 pi mm*mrad



Linac4 Reliability Run

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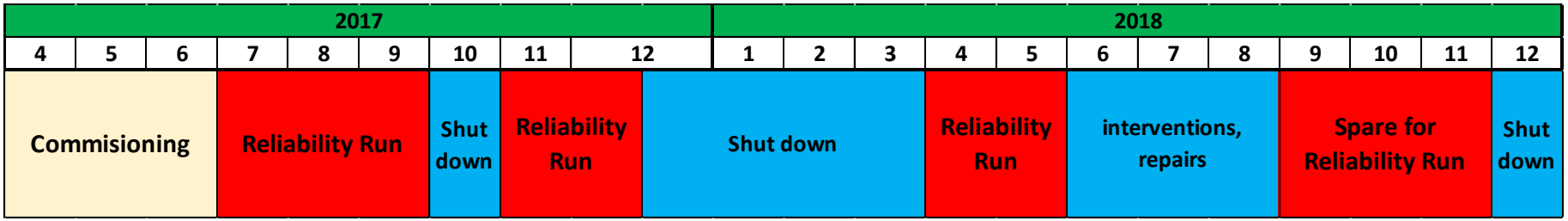
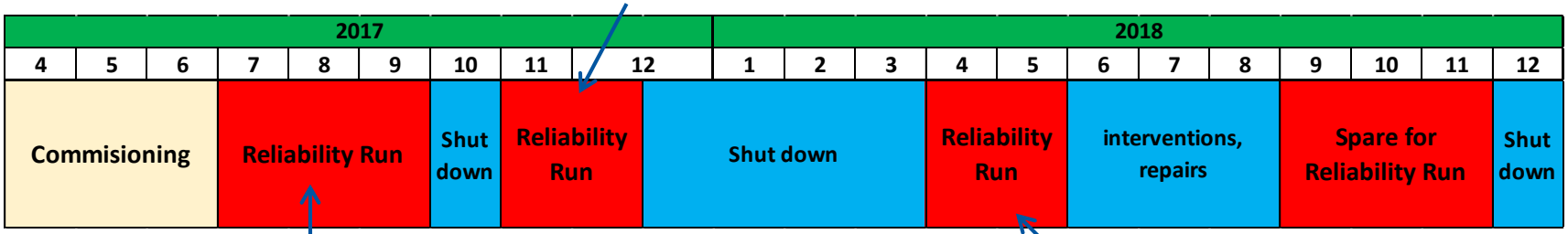


Goals

- Ensure a smooth transition from commissioning to operation
  - Train operators, necessary software development
- Find any weak point and improve them in time for final operation
- Achieve a **beam availability above 90%**
  - Importance of the Accelerator Fault Tracking system
  - Verify Linac4 availability modelling
- Derive lessons for the MYRTE project

Linac4 Reliability Run

Phase 2:
Long periods followed by repairs & optimization
Operation from the **Main control room** by operators 24/7



Phase 1:
Short periods followed by repairs & optimization
Operation from the **LINAC4 control room**

Phase 3:
Long periods followed by repairs & optimization
Operation from the **Main control room** by operators 24/7
Teething problems fixed permanently

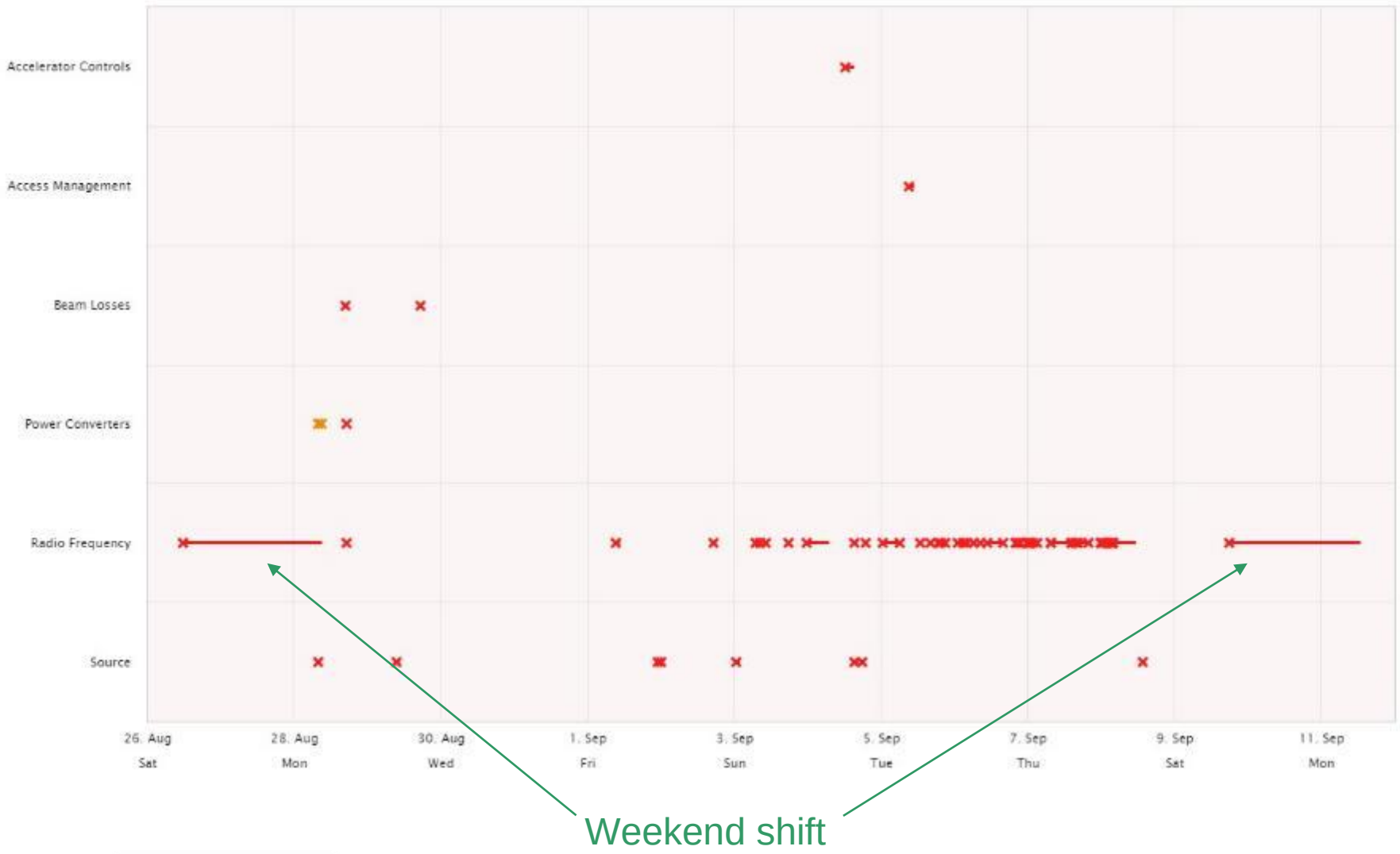
- Operational without major problems for over **15 weeks** in total *[17-07-2017, 15-05-2018]*
  - Achieved beam availability **> 91%** of the operating time (spec. 95%)
- Experts contact and intervention only during working hours
  - Night and weekend shifts not considered
- Registration of the faults with the ***Accelerator Fault Tracker*****
  - Working well, team motivated for tracking the faults
- Restart of the Reliability Run foreseen for mid-September 2018

Linac4 Fault Tracking

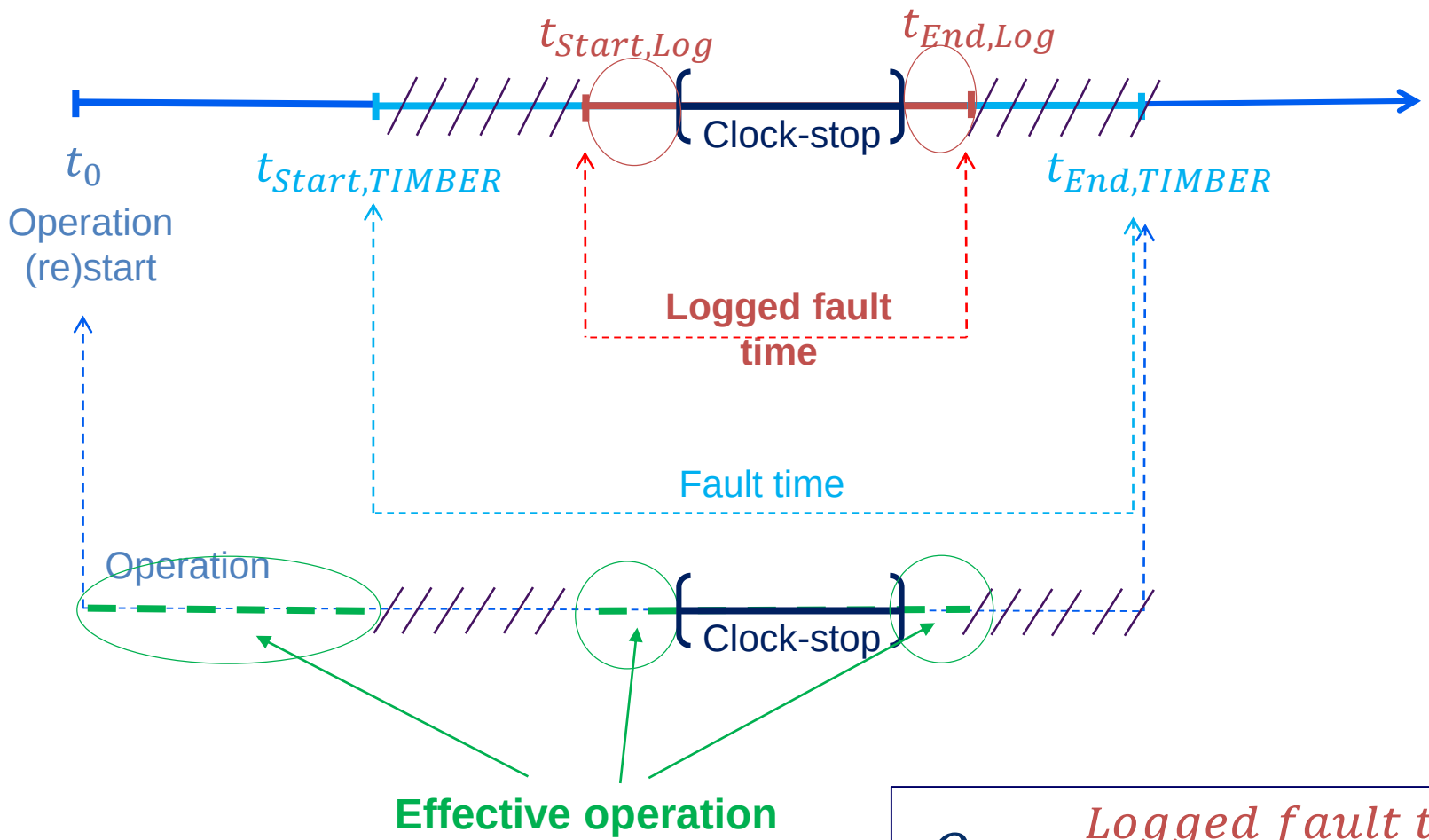
Linac4 Fault tracking

- Registration of the faults with the ***Accelerator Fault Tracker***
- Predefined **Fault Tree** to classify the faults
- Linac4 fault classification = Faults in the Linac4 availability model
- **Weekly follow-up** and analysis of the faults, logbook and alarm system verification
- Need to **exclude clock-off times** (weekend shifts, MD, etc.) → custom-made code for fault analysis
- From September, feature to exclude clock-off times implemented in AFT

Linac4 Fault tracking



Linac4 Fault tracking

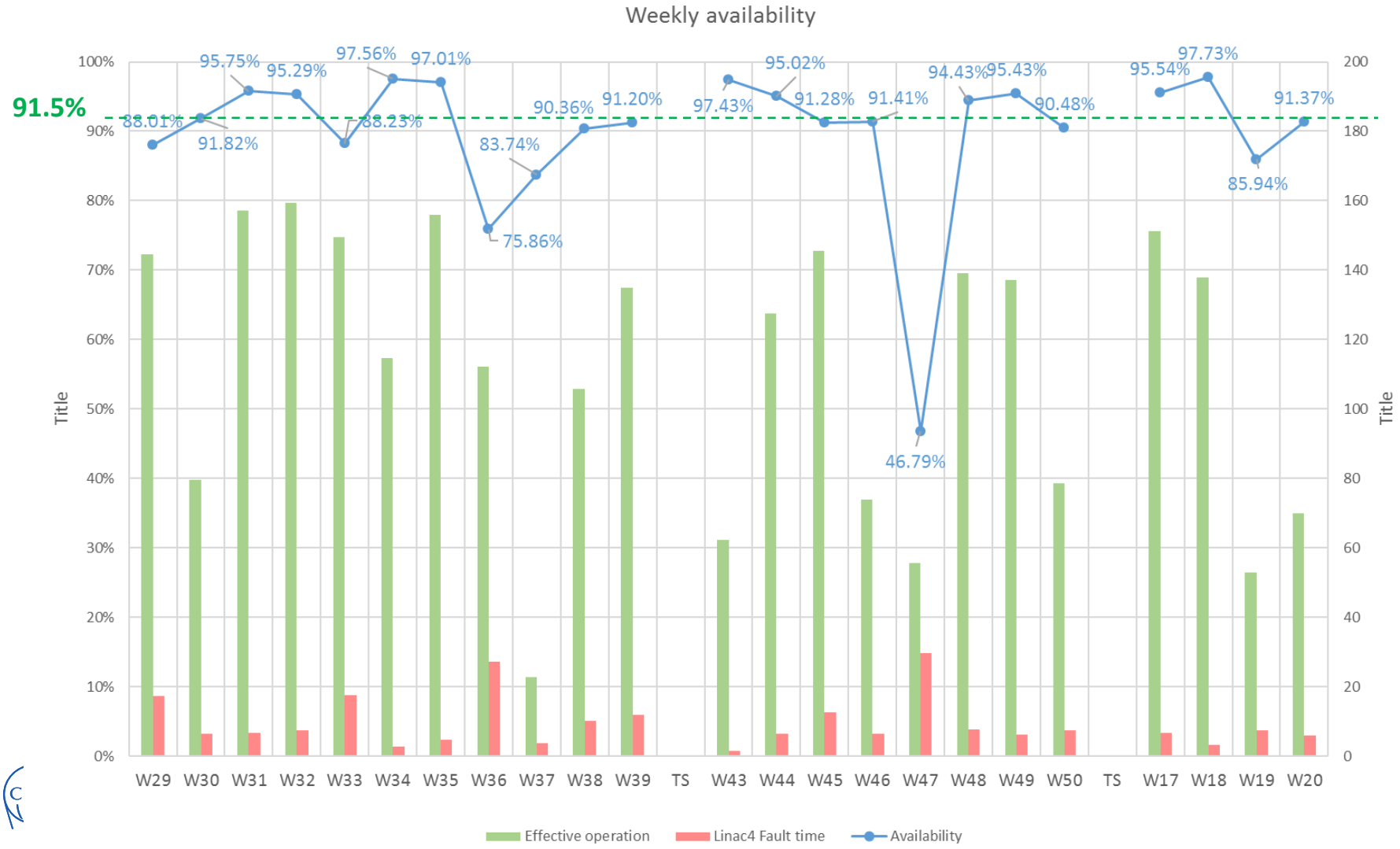


$$Q = \frac{Logged\ fault\ time}{Effective\ Operation}$$

Linac4 performance during the Reliability Run

Linac4 performance during the RR

Availability	Fault Count	Operation	Suspended OP	Effective Operation	Fault Mean Time to Repair
91.5%	**449**	23 weeks	~ 8 weeks	~15 weeks	~29 min



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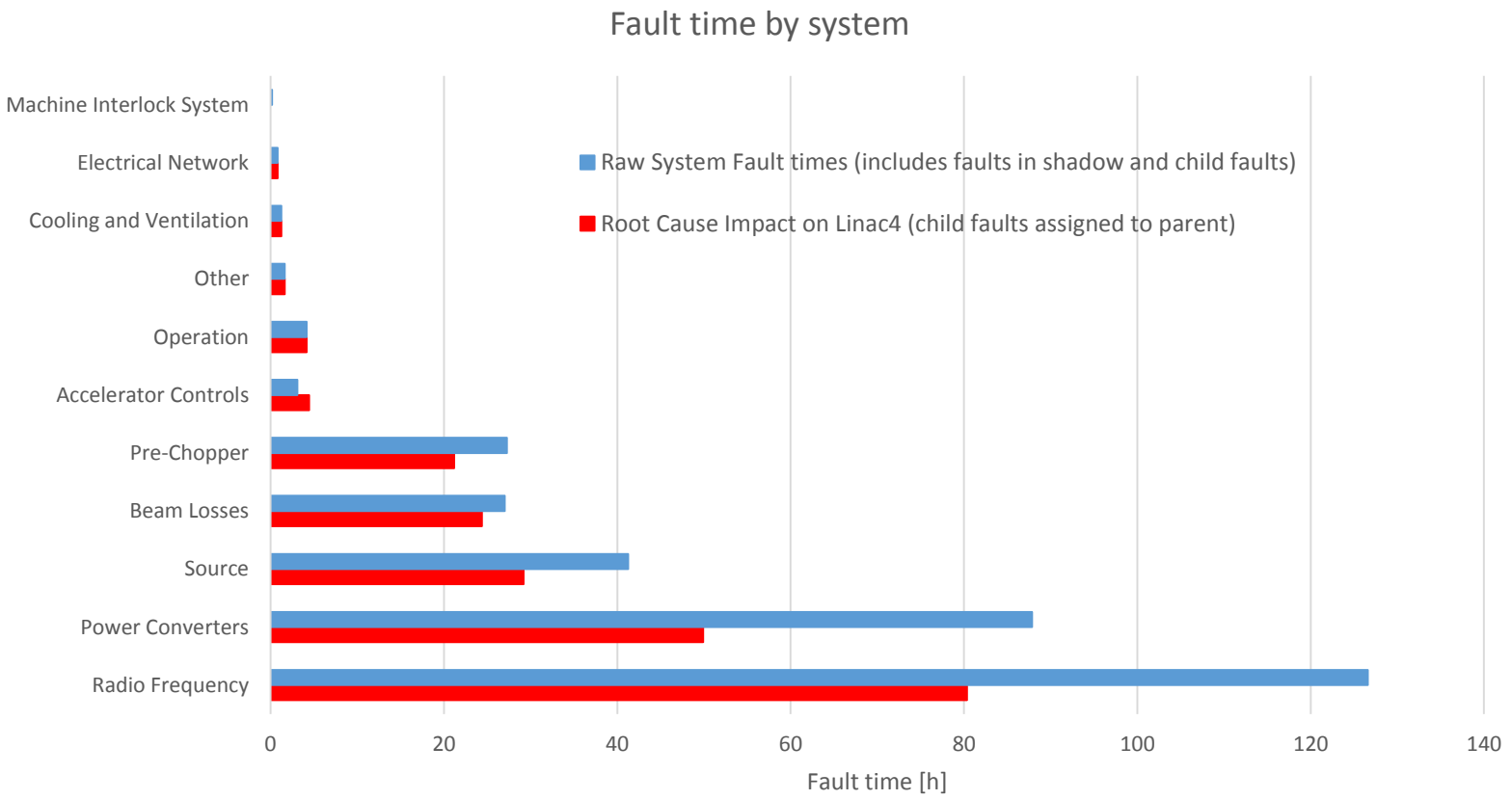

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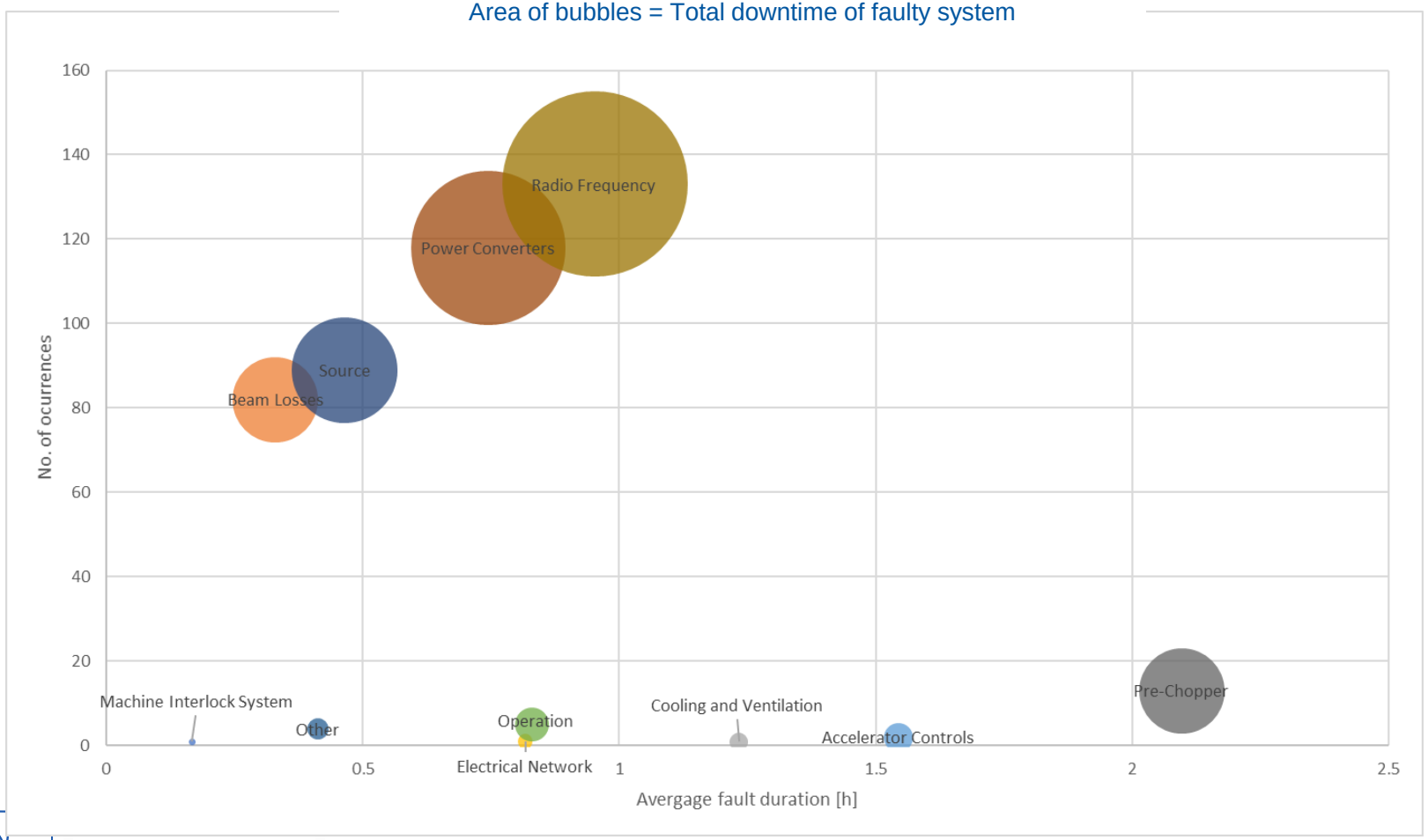
Fault frequency vs fault duration

Area of bubbles = Total downtime of faulty system



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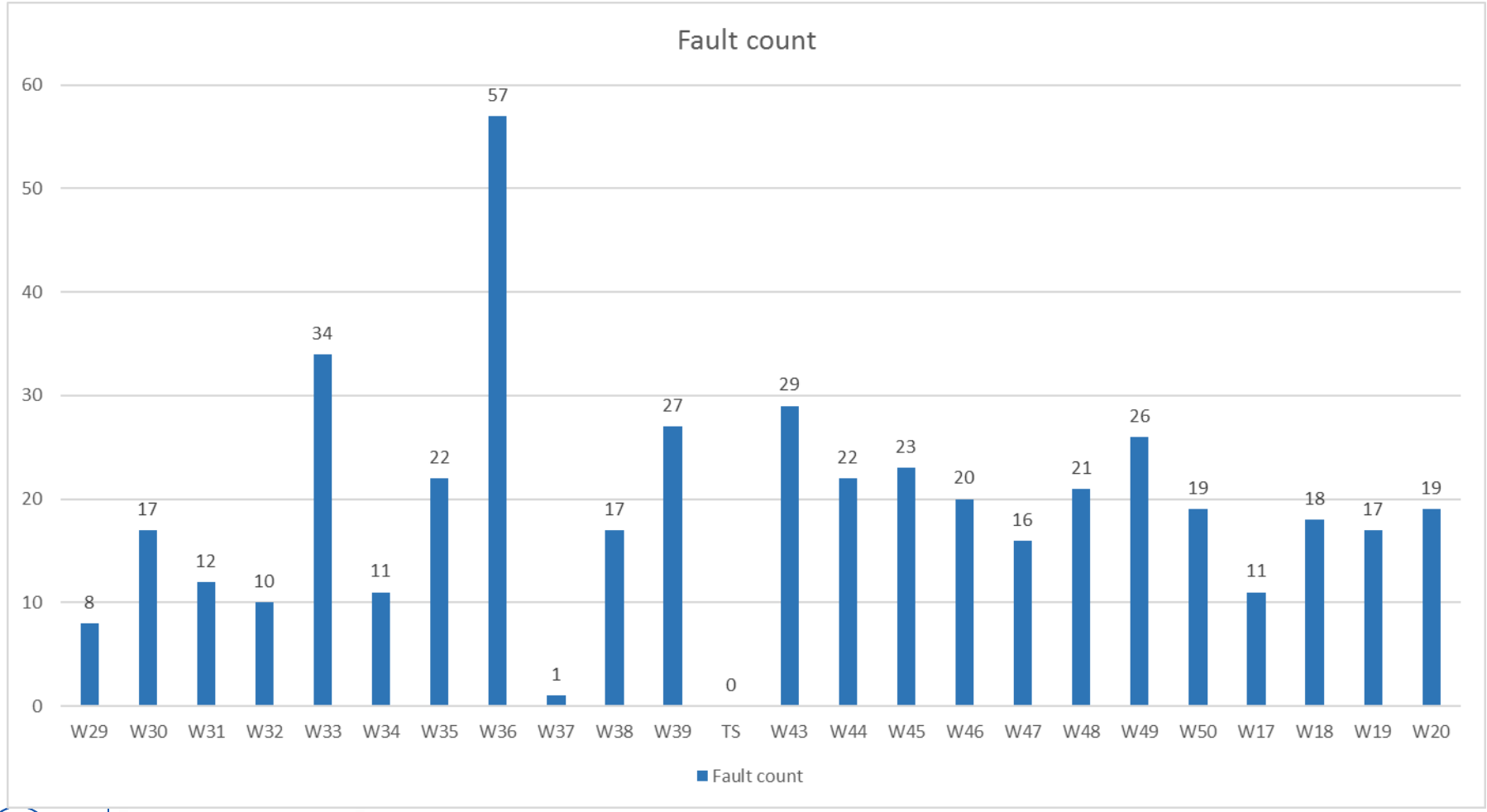

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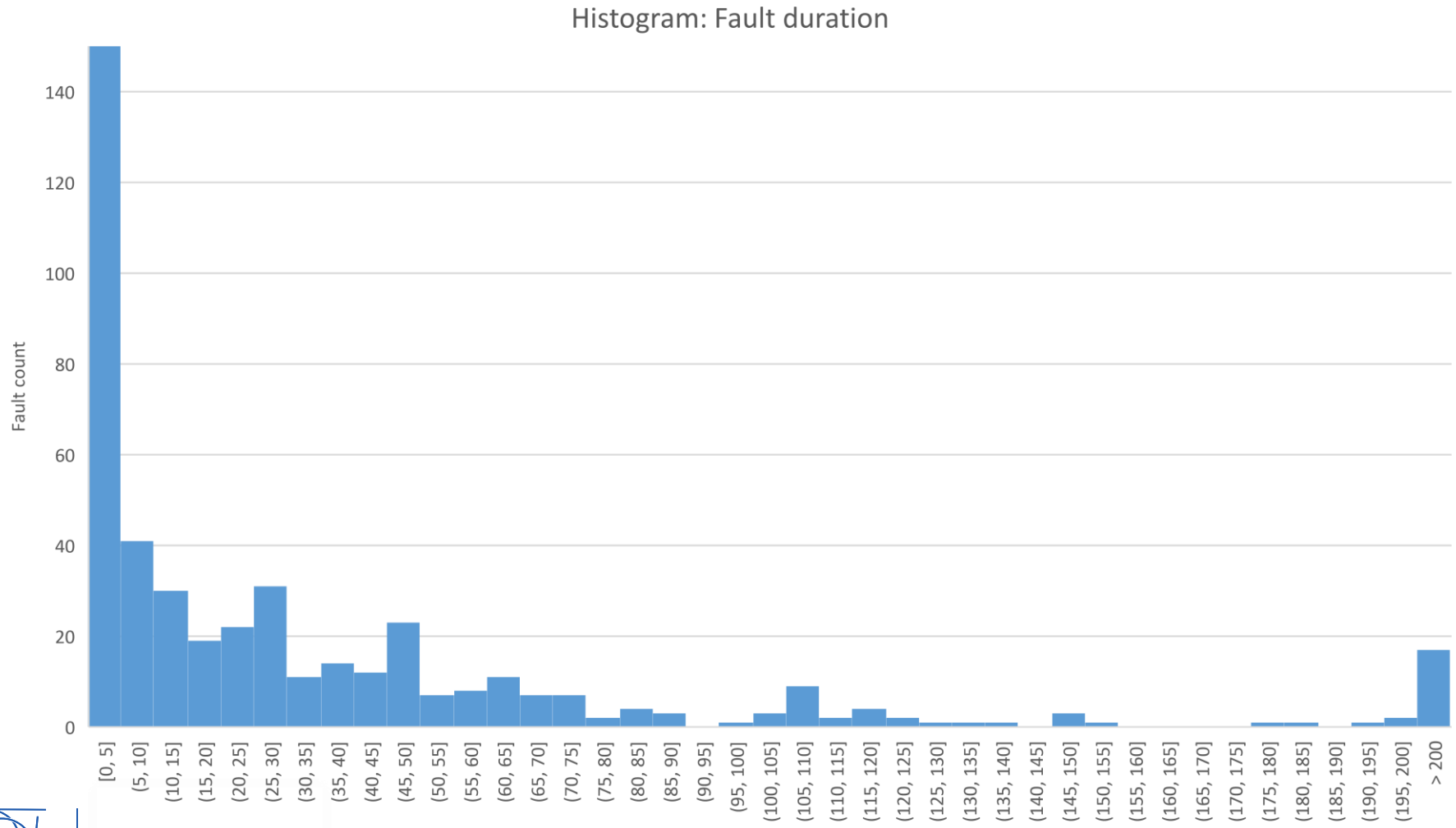

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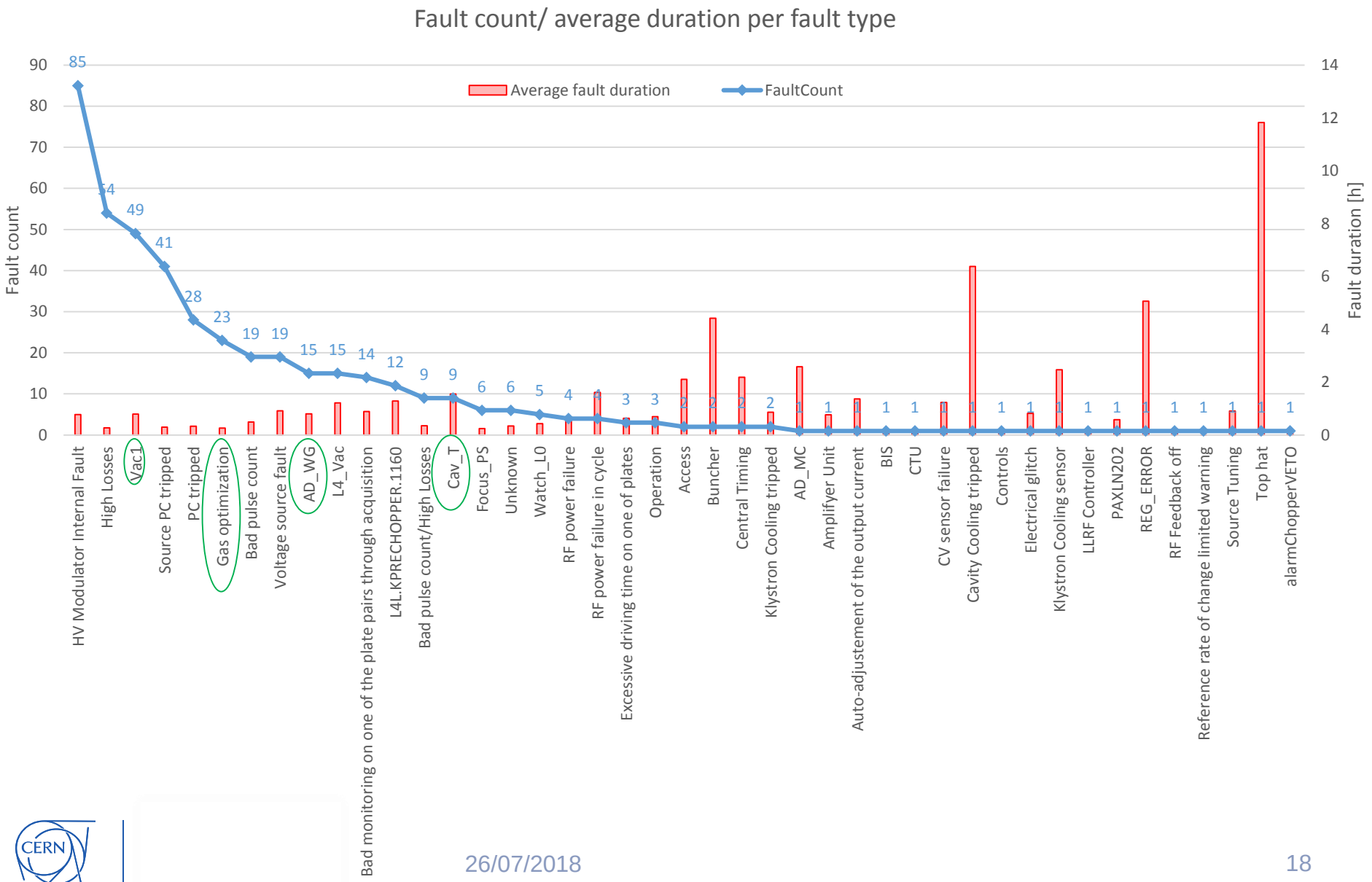


Linac4 performance during the RR

Observations

- Teething problems identified -> Strategies for mitigation implemented before Phase 3 (2018)

  Radio Frequency Systems:

  - Arc Detectors (AD_WG, to be fixed after the TS 2018)
  - Power supply of klystron vacuum pump in RF cavities (Vac1)
  - Defective flow meter of a CCDTL tank (Cav_T)

  Pre-Chopper: feedthrough to vacuum exchanged twice

- Recurrent and long faults: RF Modulators, Power Converters, Pre-Chopper, Source

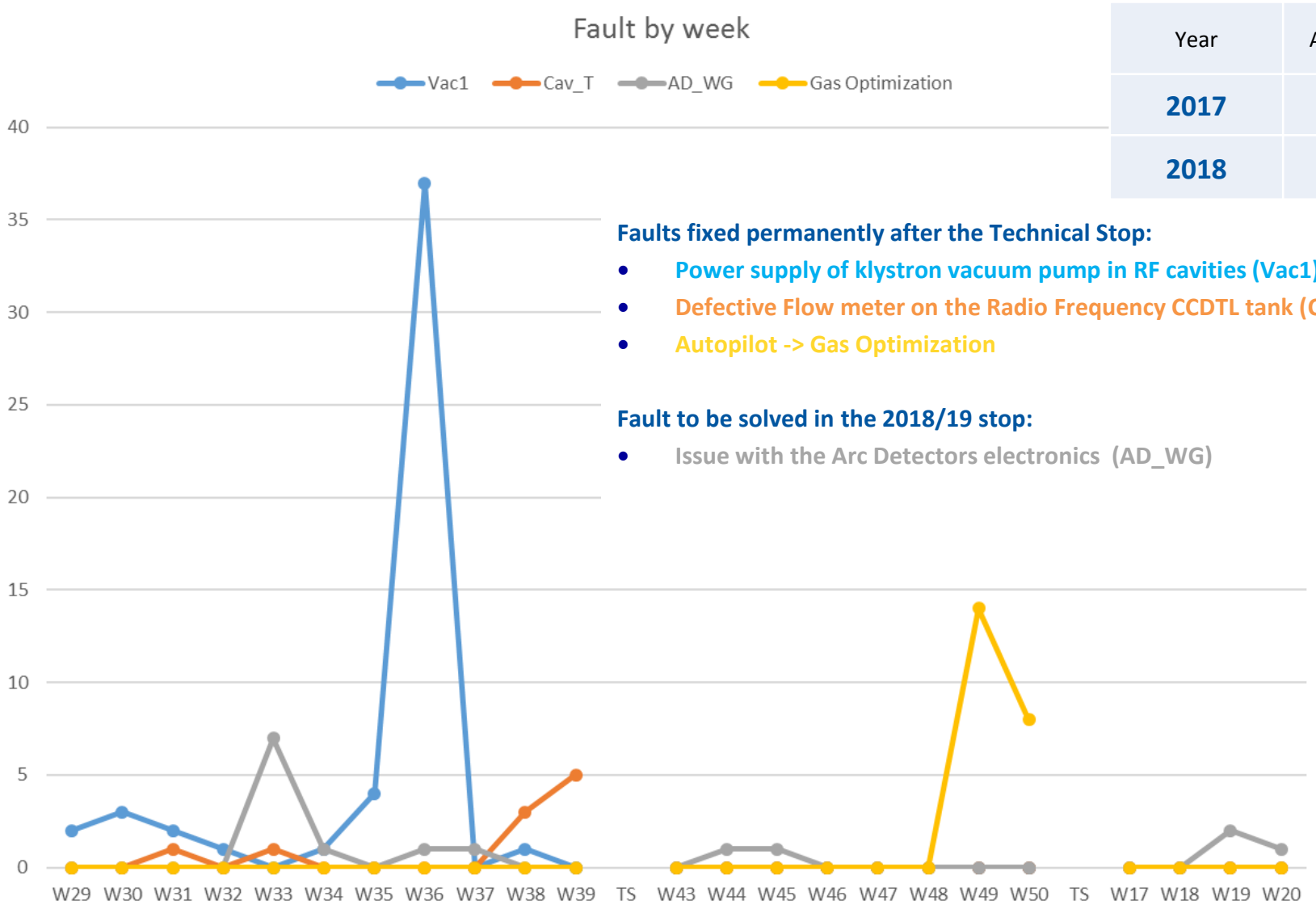
  Strategy: accept increased downtime in favour of understanding and finding the root cause

  - Power Converters: HV modulator Internal fault-> found aluminium chips in insulator oil for old LEP klystrons -> Systematic cleaning considered
  - Possible redesign of the Pre-Chopper feedthrough to vacuum

- Identification of areas that need strengthening
  - Clearer procedures for the Source
  - Autopilot (Gas optimization): Automatic regulation of the source parameters that can end up compromising the beam transmission in the LES

    For the coming RR, Autopilot will be OFF -> the faults should not appear. In the future, the application will be optimised

Linac4 performance during the RR



Year	Availability
2017	**91%**
2018	**94.3%**

Faults fixed permanently after the Technical Stop:

- **Power supply of klystron vacuum pump in RF cavities (Vac1)**
- **Defective Flow meter on the Radio Frequency CCDTL tank (Cav_T)**
- **Autopilot -> Gas Optimization**

Fault to be solved in the 2018/19 stop:

- **Issue with the Arc Detectors electronics (AD_WG)**

Linac4 RR vs Modelling

Linac4 RR vs modelling

Linac4 RR data → Model Input

	OP / Fault count	OP / Fault count* (without child faults)	Raw **DT**/Fault count	Root **DT**/Fault count
System	**MTTF data set 1 [h]**	**MTTF data set 2* [h]**	**MTTR data set 1[h]**	**MTTR data set 2** [h]**
Accelerator Controls	1289.61	1289.61	1.54	1.54
Access Management	859.74	859.74	3.62	3.62
Beam Losses	31.45	**34.39**	0.33	**0.30**
Cooling and Ventilation	2579.2	2579.21	1.23	1.23
Electrical Network	2579.21	2579.21	0.82	0.812
Machine Interlock System	2579.21	2579.21	0.17	0.17
Operation	515.84	515.84	0.83	0.83
Other	644.80	644.80	0.41	0.41
Power Converters	21.86	**31.84**	0.74	**0.43**
Pre-Chopper	198.40	198.40	2.1	**1.57**
Radio Frequency	19.39	19.84	0.95	**0.60**
Source	28.98	**32.24**	0.46	**0.32**

Linac4 RR vs modelling

Results – no parallel faults simulated

	Availability	Fault Count	Downtime [h]	Fault Mean Time to Repair
Linac4 RR	**91.2%**	**452 (396*)**	**226.7**	**~35 min**
Linac4 model [set 1-1]	88.6%	399	294.3	~ 45 min
Linac4 model [set 2-1]	89.7%	356	264.7	~ 45 min
Linac4 model (set 1-2)	91.9%	415	207.7	~30 min
Linac4 model (set 2-2)	92.7%	367	187.8	~30 min

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MTTF	OP / Fault count	OP / Fault count* (without child faults)
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Less failures simulated:
- No parallel faults -> Faults with lower MTTF ignored during off time
- No parent-child relation considered -> Lower MTTF considered

Less failures but higher repair, why?

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Summary and Outlook

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- LINAC4 Reliability Run

  Successful experience, identification of issues beyond the possibilities during commissioning

  Achieved beam availability >**91%** of the operating time (91% in 2017, 94.3% in 2018)

  Lessons learnt:

  - ✓ Accept increased downtime in favour of understanding and finding the root cause
  - ✓ Systematic cleaning considered of HV modulator
  - ✓ Possible redesign of the Pre-Chopper feedthrough to vacuum
  - ✓ Clearer procedures for the Source are needed

- The Accelerator Fault Tracking is working well (clock-off time to be tested)

  People motivated, weekly reviews of faults

  Clean inconsistencies between logbook and AFT

- Detailed availability modelling LINAC4 done

  Simulations showed realistic predictions

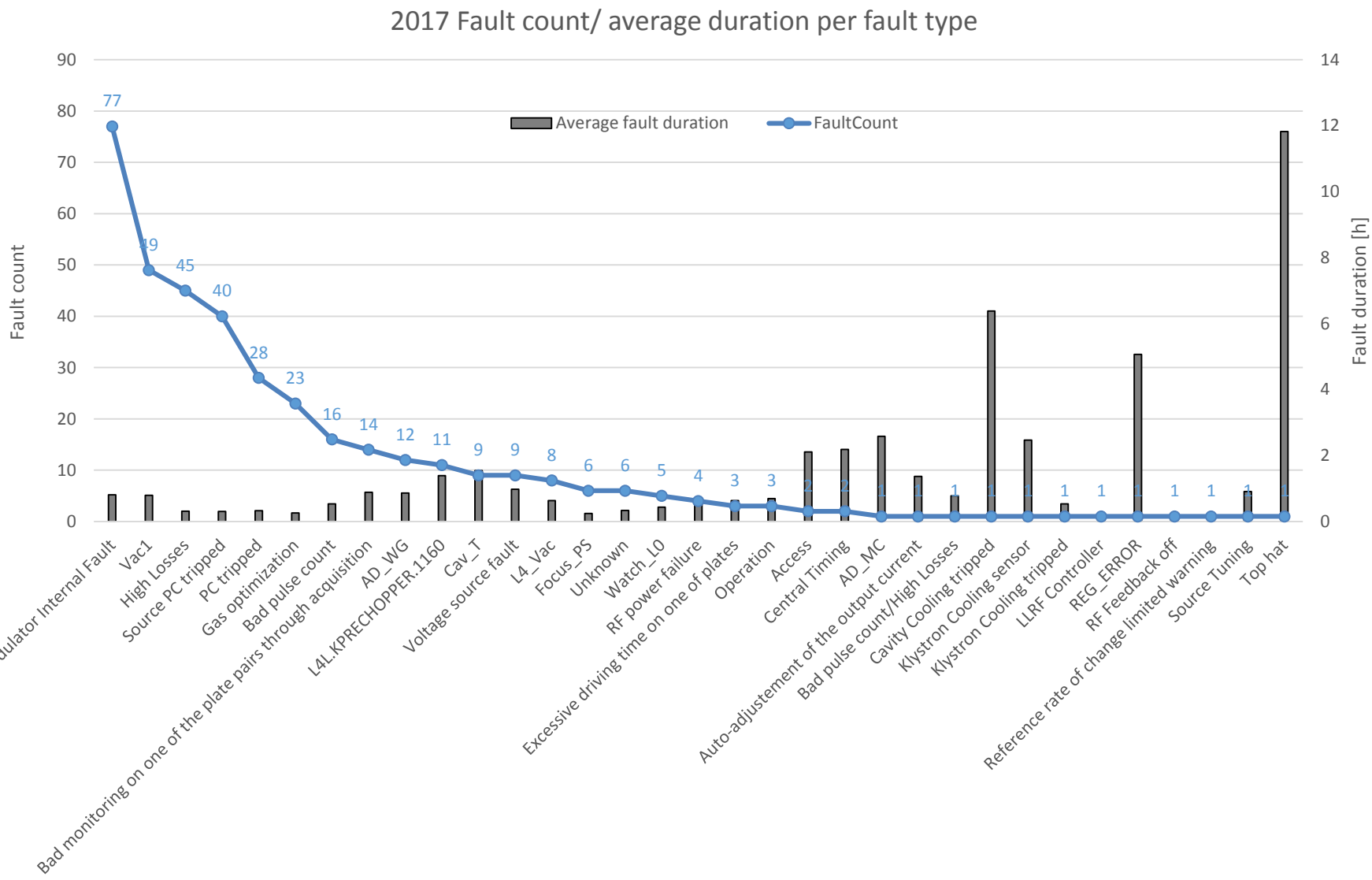
  Synchronisation of failure catalogue and Fault Tracking

Thanks for your attention!

Back-up slides

Linac4 Availability

Period: 13/07/2017 – 15/05/2018
Last update: 22/06/2018



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