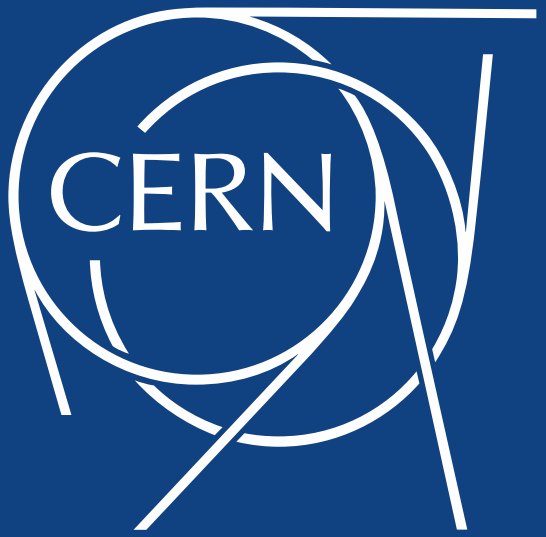

CERN

LHC Availability – Status and Prospects

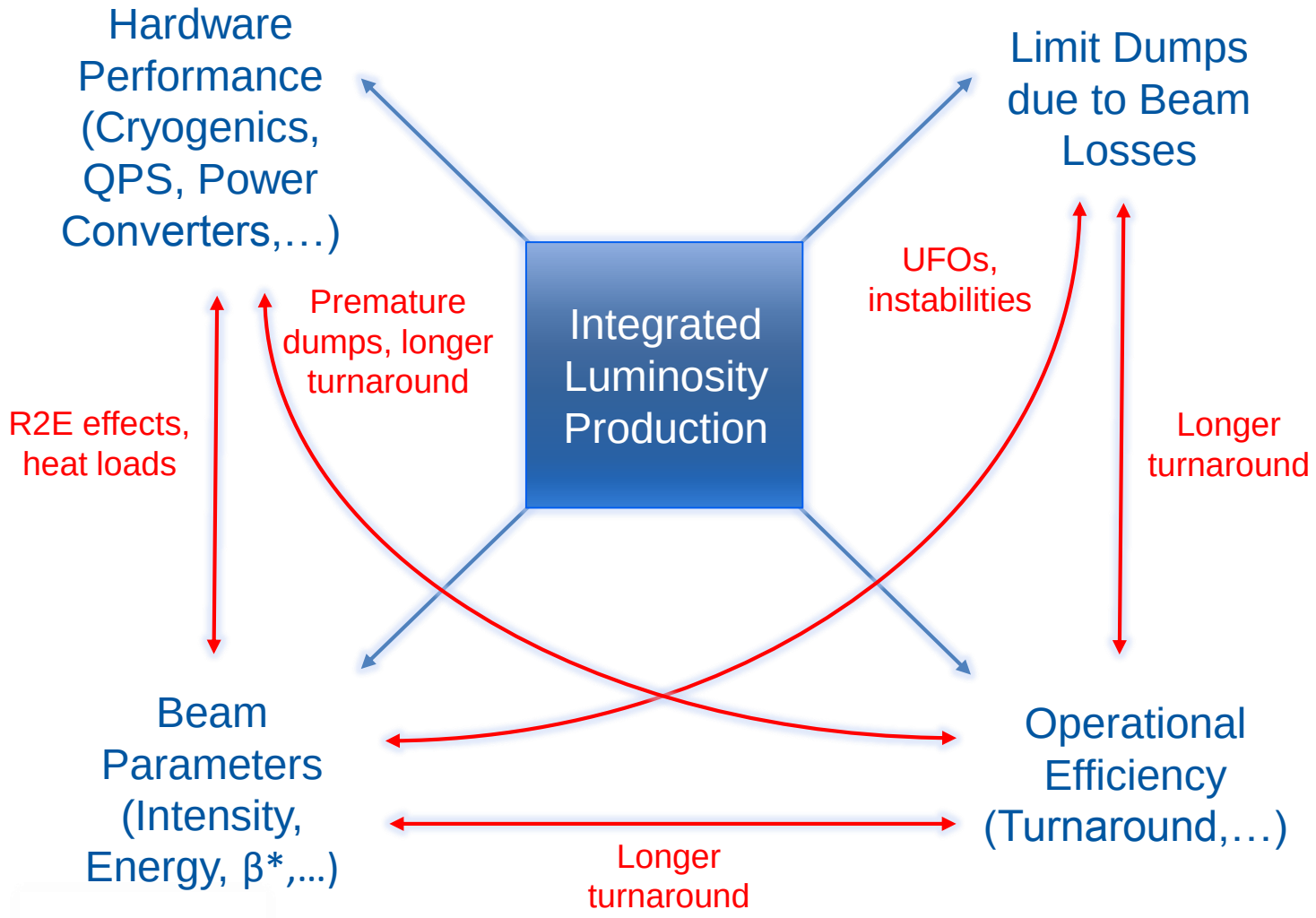
Andrea Apollonio, TE-MPE-PE

On behalf of the Availability Working Group (AWG) - L. Ponce, B. Todd

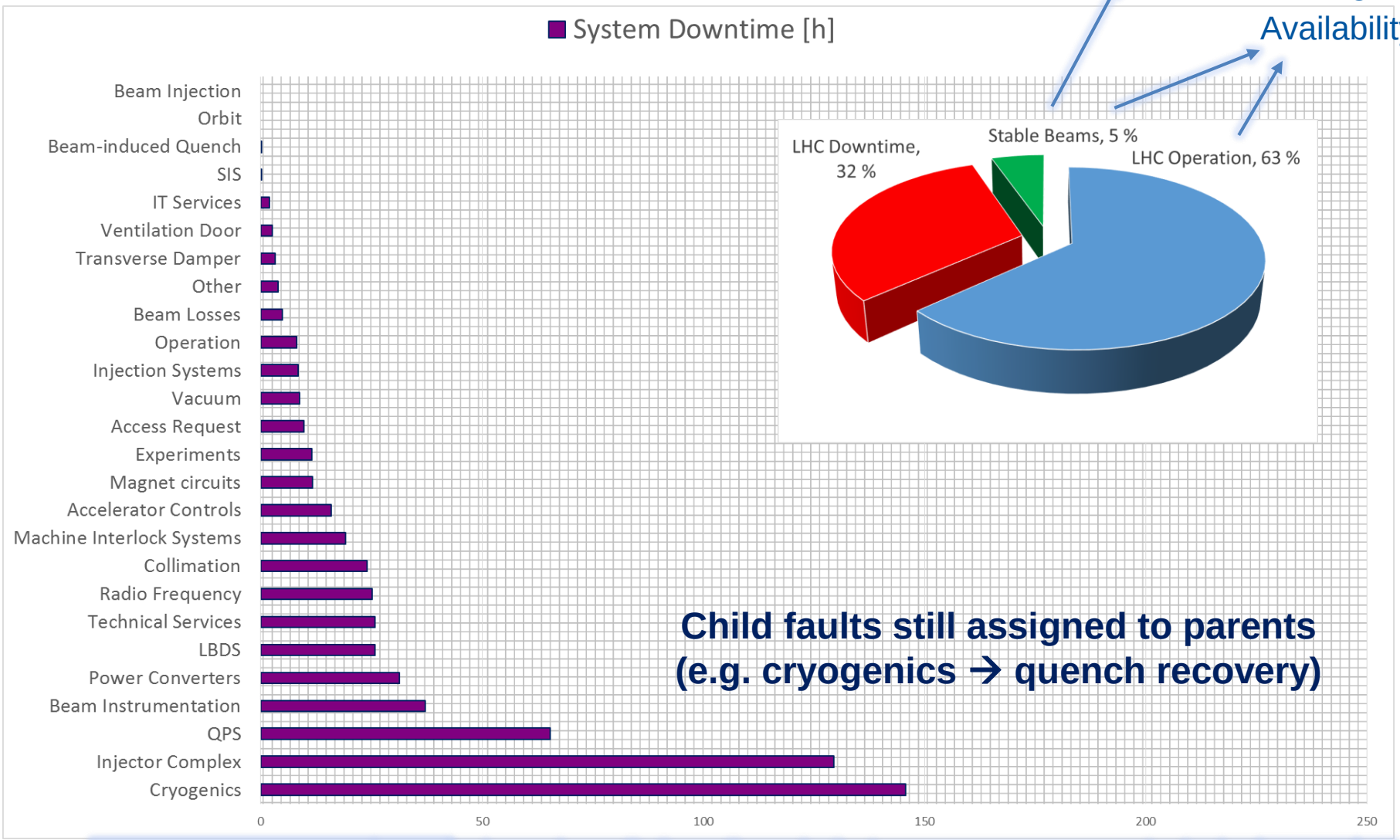
LHC Performance Workshop - Chamonix, 26/01/2016

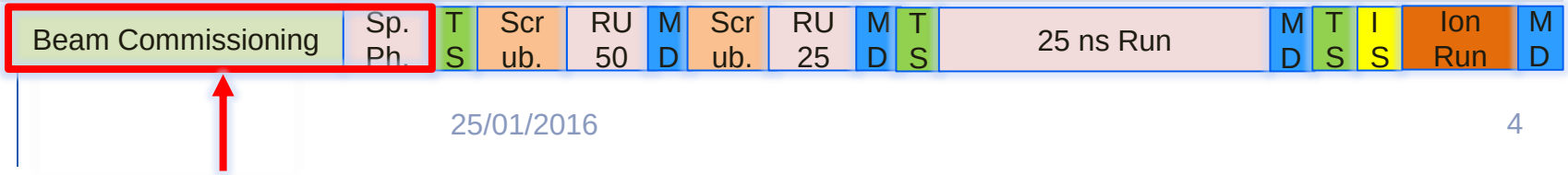
Acknowledgements: C. Roderick & AFT team, R. Schmidt, D. Wollmann, M. Zerlauth, A. Niemi, A. Siemko, B. Auchmann, R. Denz, A. Verweij, F. Rodriguez Mateos, V. Montabonnet, G. Ferlin, L. Delprat, J. Uythoven, N. Magnin, C. Bracco, M. Solfaroli, M. Pojer, J. Wenninger, Y. Papaphilippou, AWG-members.

Integrated Luminosity Production / Outline

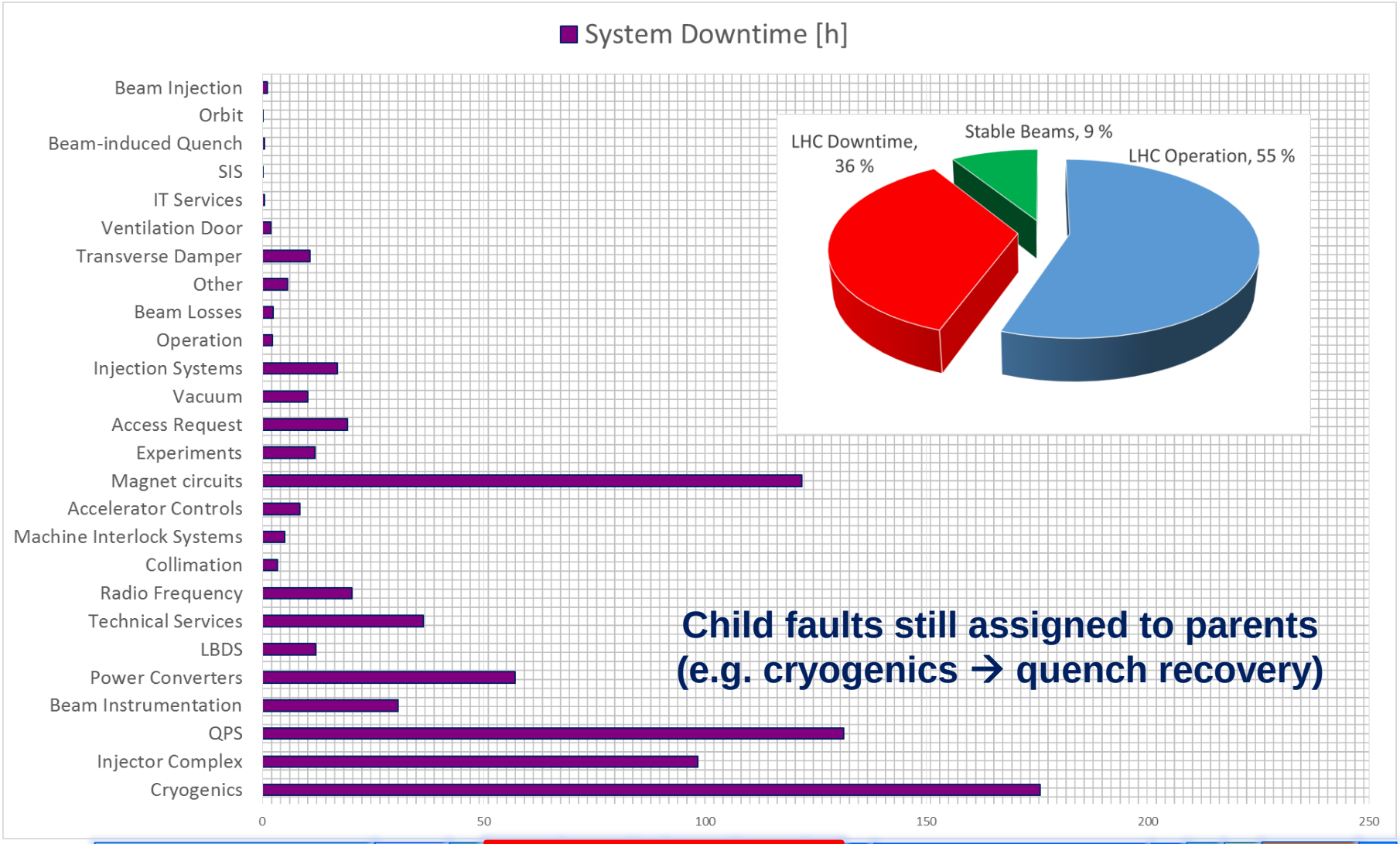


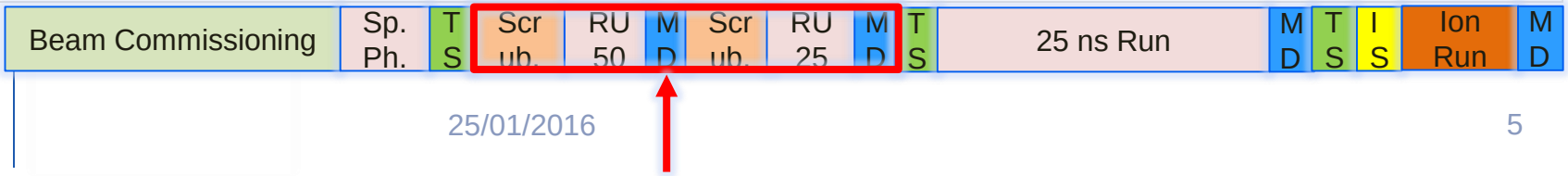
2015 Availability – before TS1



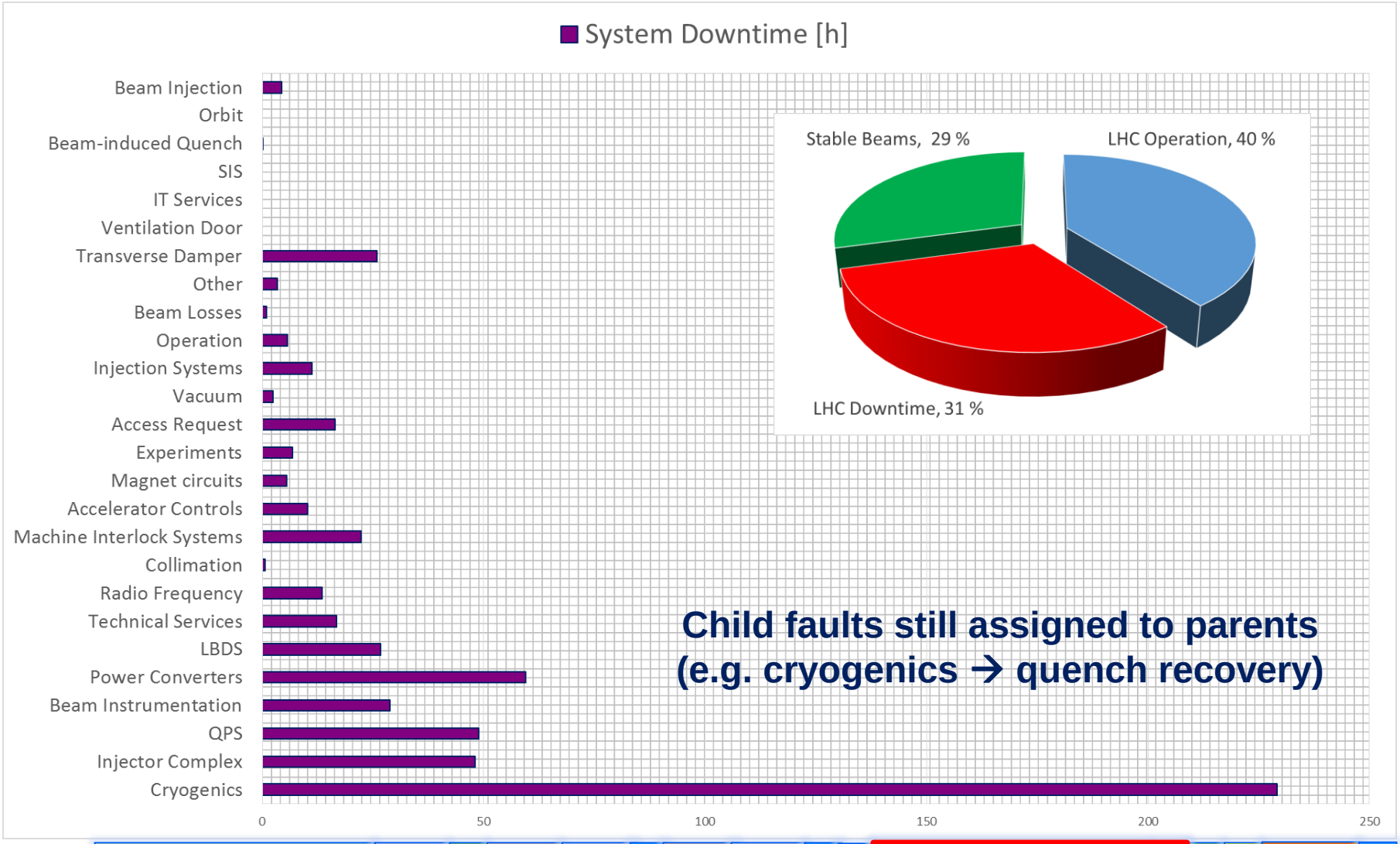


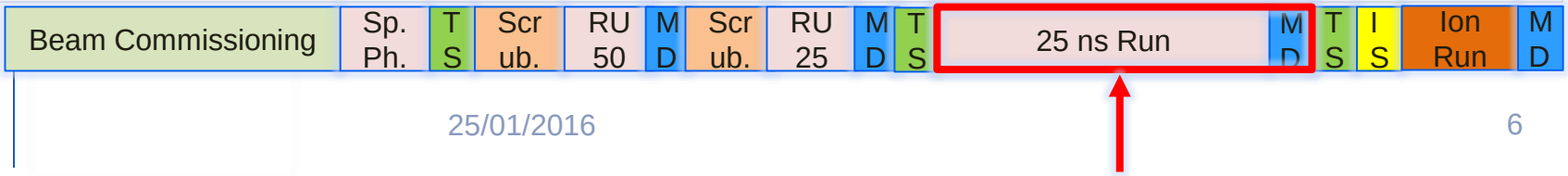
2015 Availability – TS1 to TS2



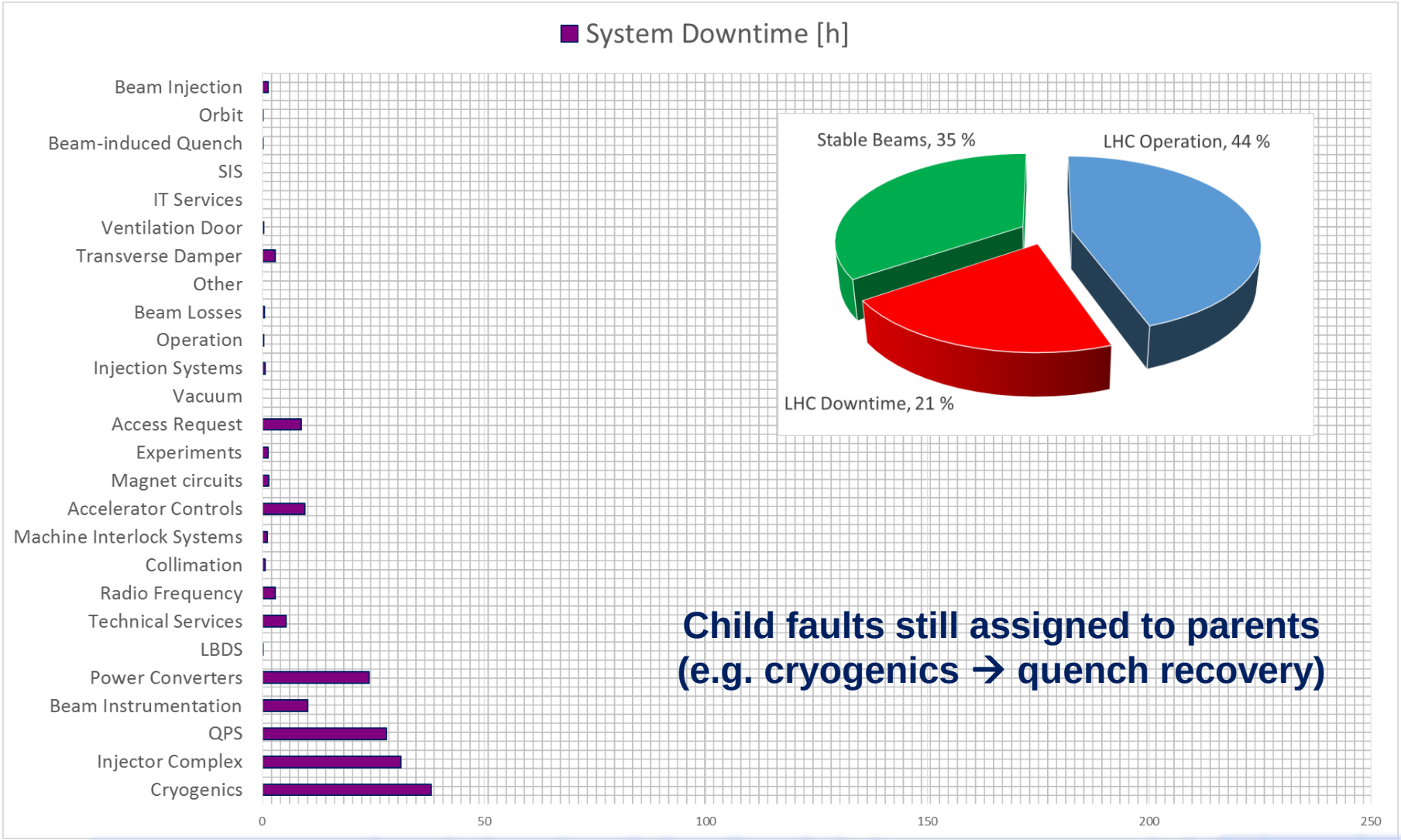


2015 Availability – TS2 to TS3

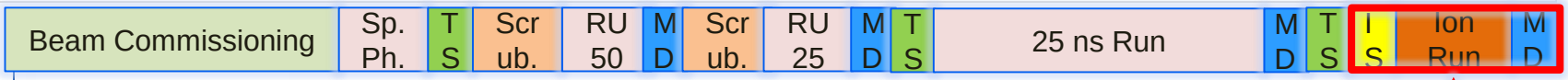




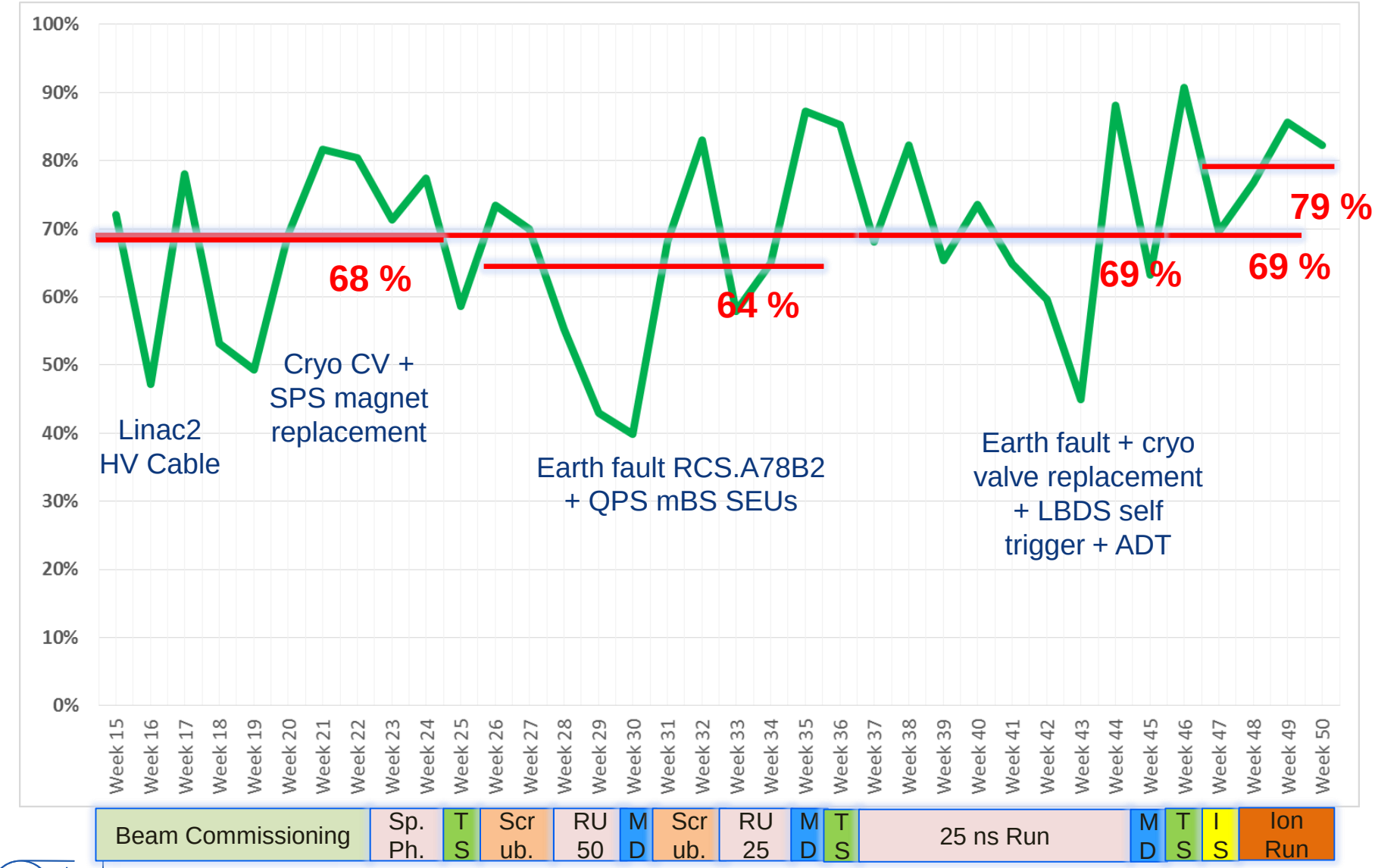
2015 Availability – after TS3



Child faults still assigned to parents (e.g. cryogenics → quench recovery)

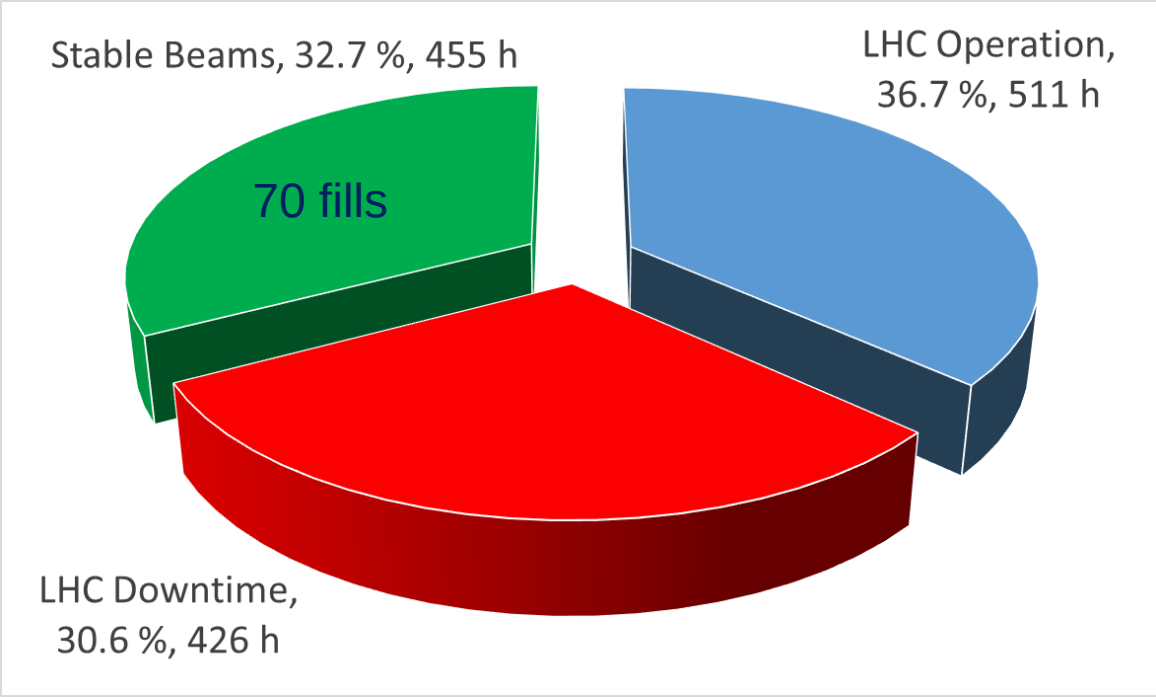


2015 Availability

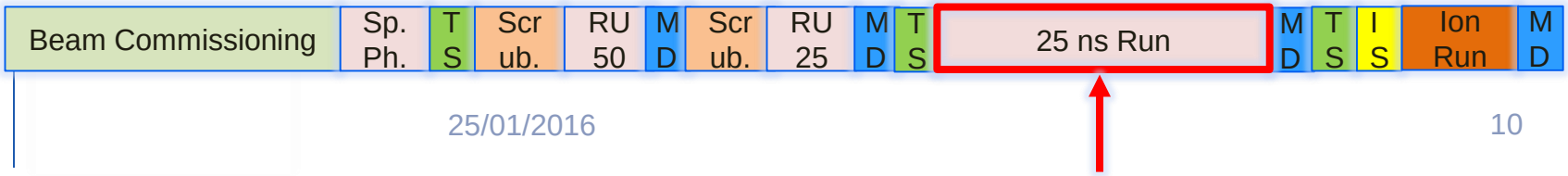


FOCUS: 25 ns Run (7/9/2015 to 3/11/2015)

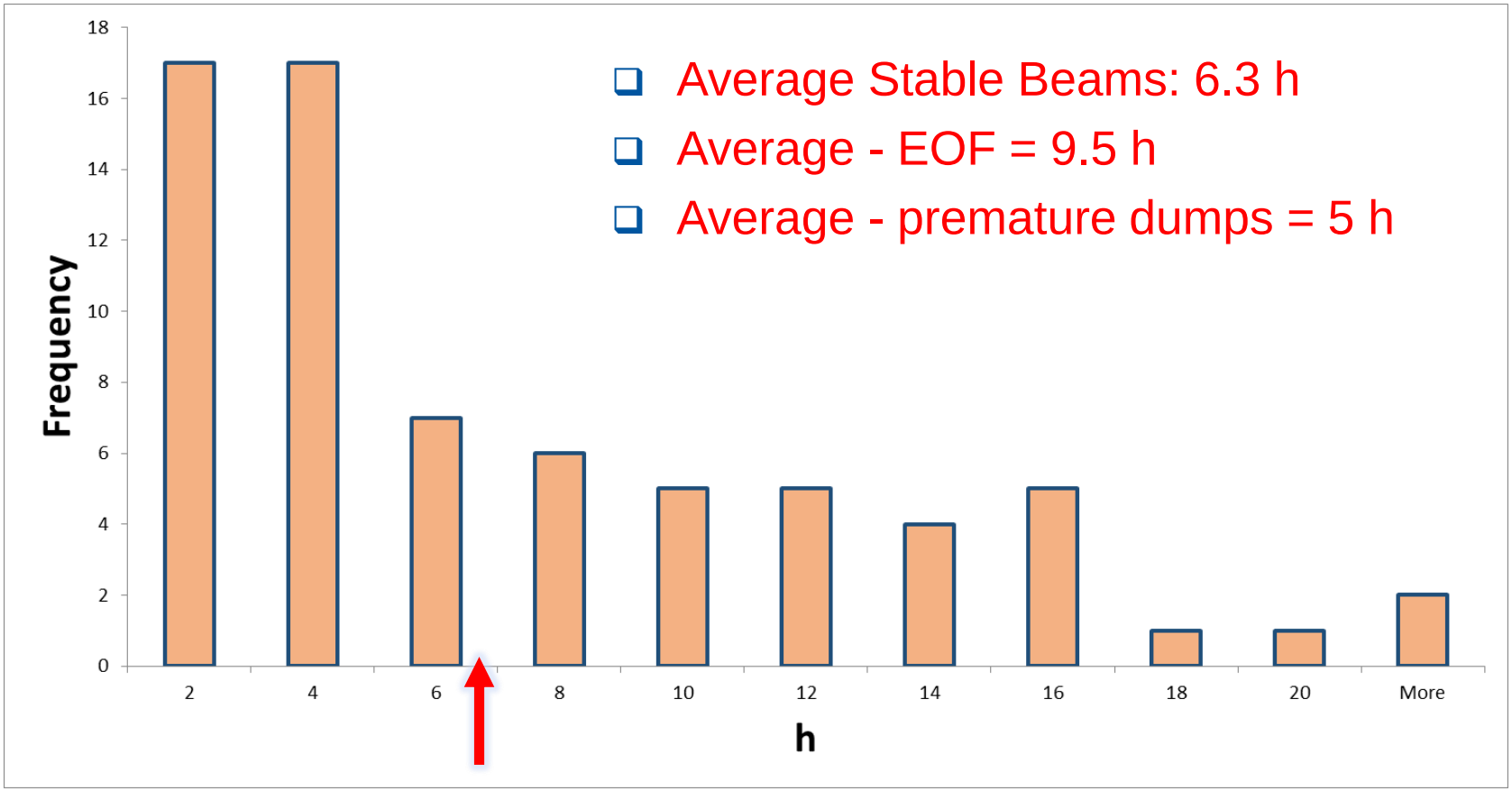
Availability for Physics – 25 ns Run



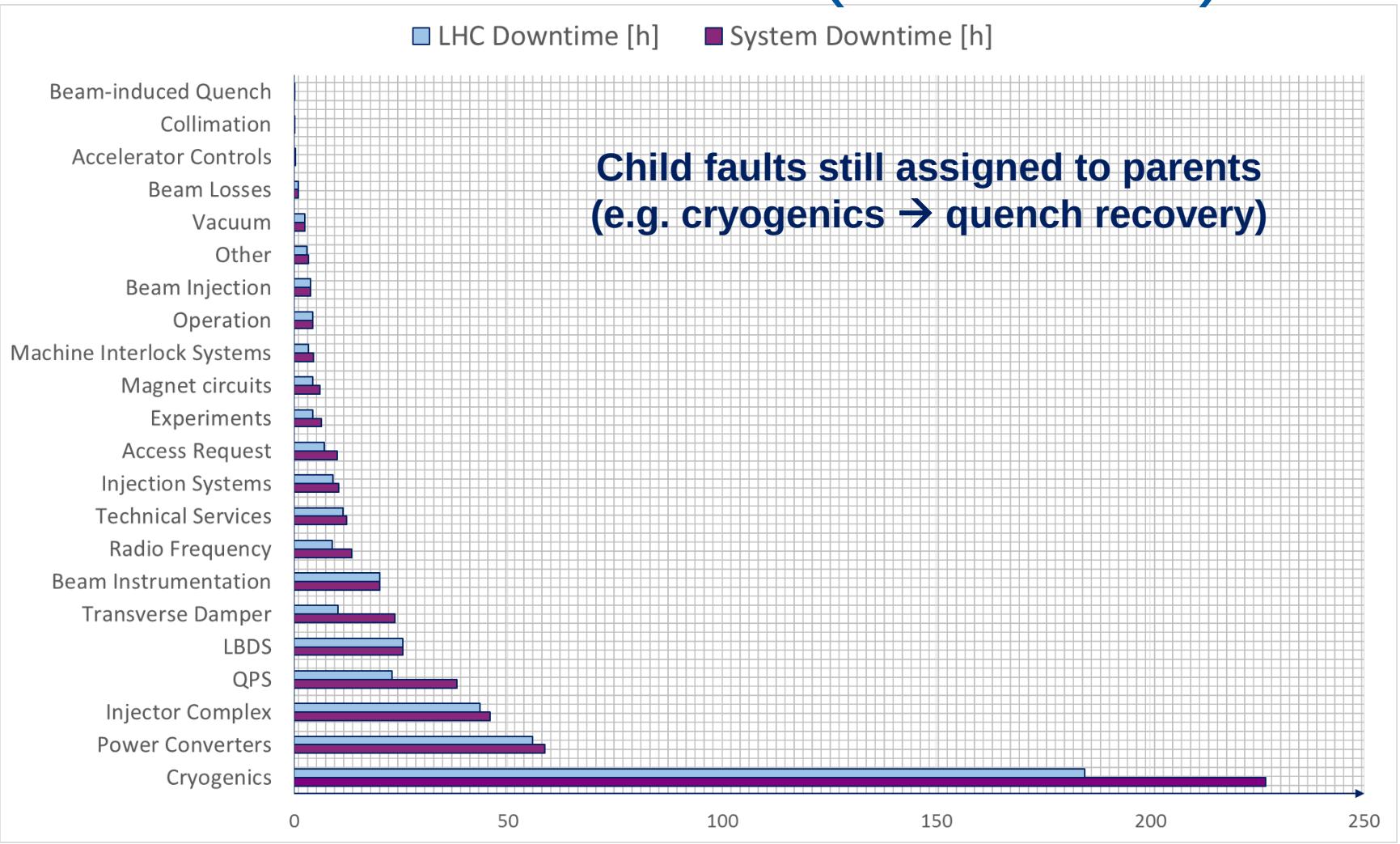
- 22 End-Of-Fill, 48 dumped due to faults
- Fraction of premature dumps: 48/70 = 68.6 %
- Average operational turnaround (per SB) = 511/70 = 7.3 h
- Average Fault time (per SB) = 426/70 = 6 h



Stable Beams Distribution – 25 ns Run

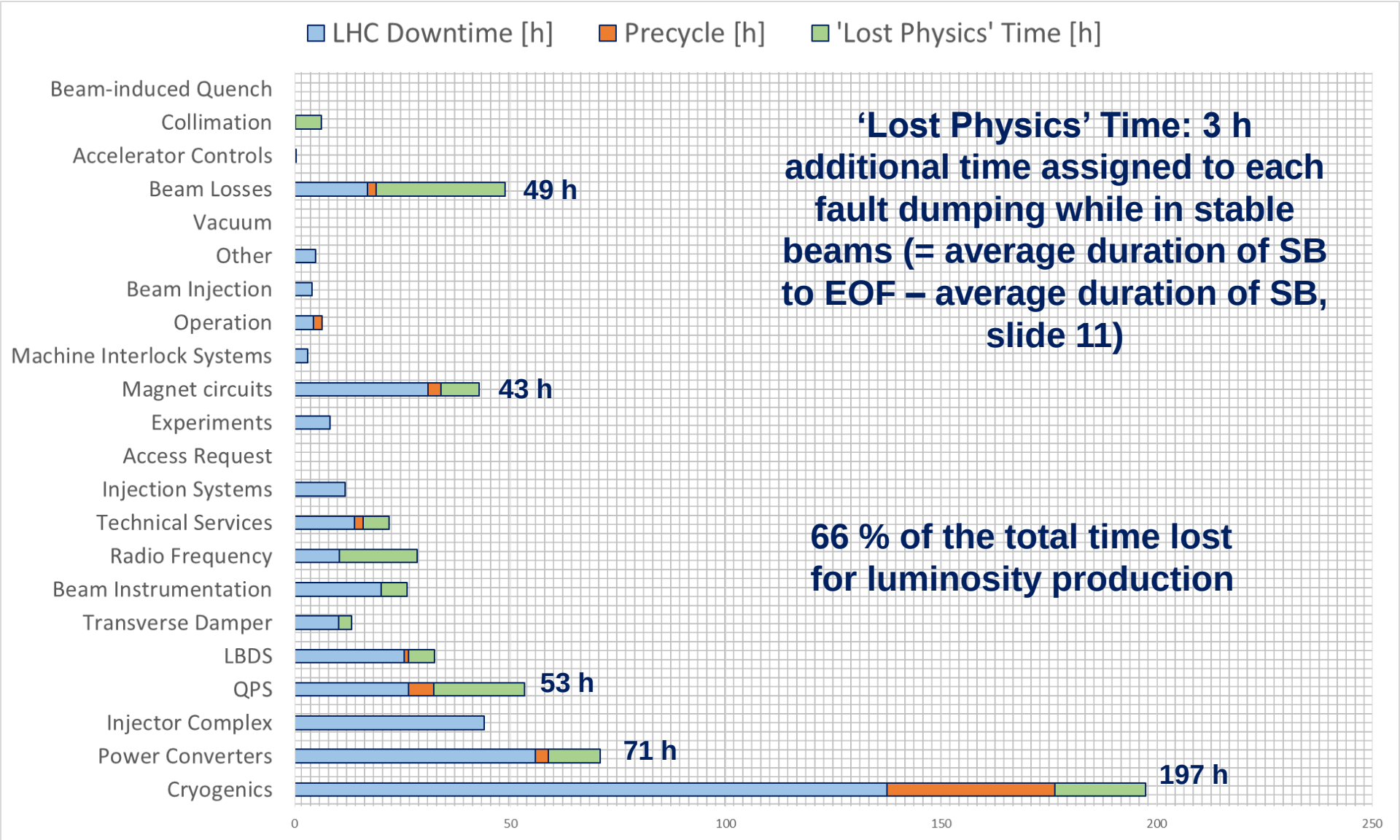


Downtime Distribution (25 ns Run)



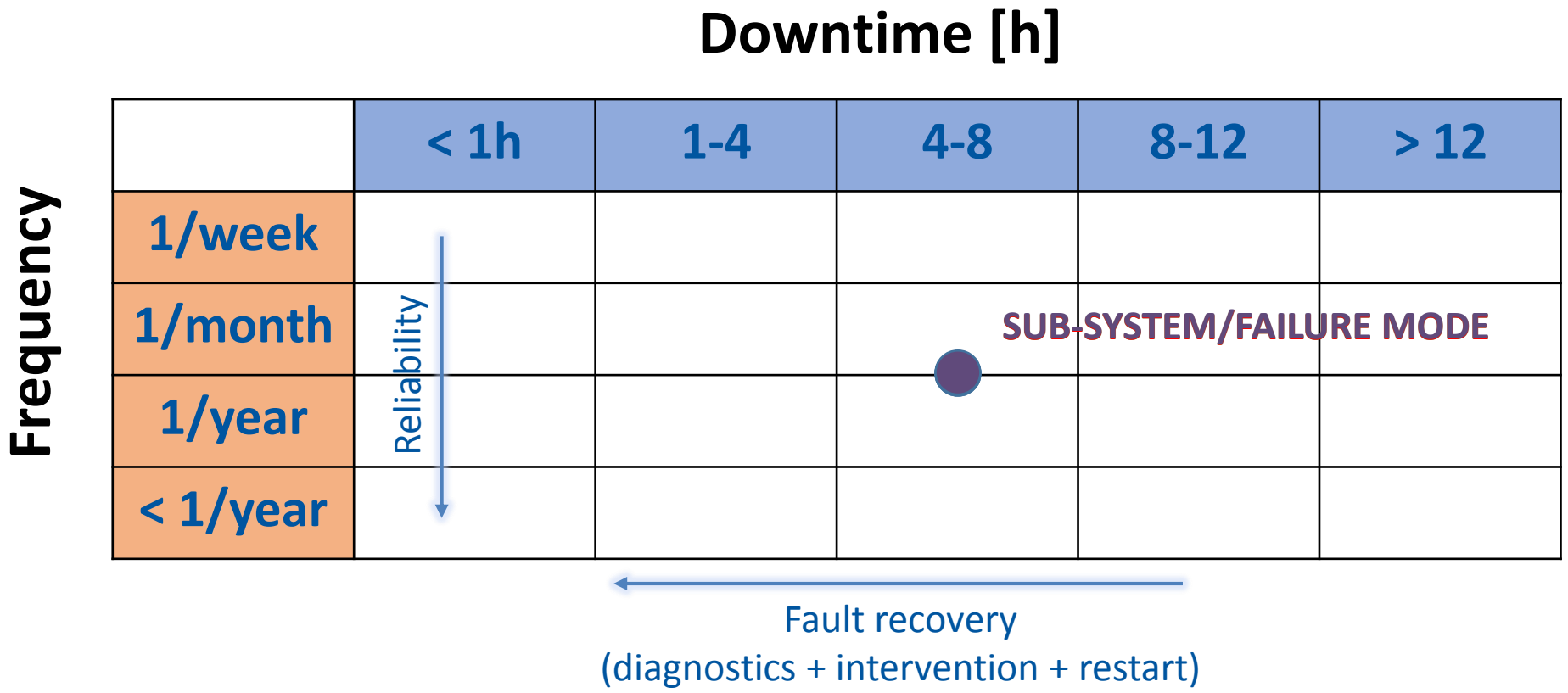
- **LHC Fault Time**: filtering faults occurred in the shadow of others
- **System Fault Time**: NOT filtering faults occurred in the shadow of others

…Impact on LHC Operation (25 ns Run)



Hardware Performance: 2015 and Outlook

Availability Matrix



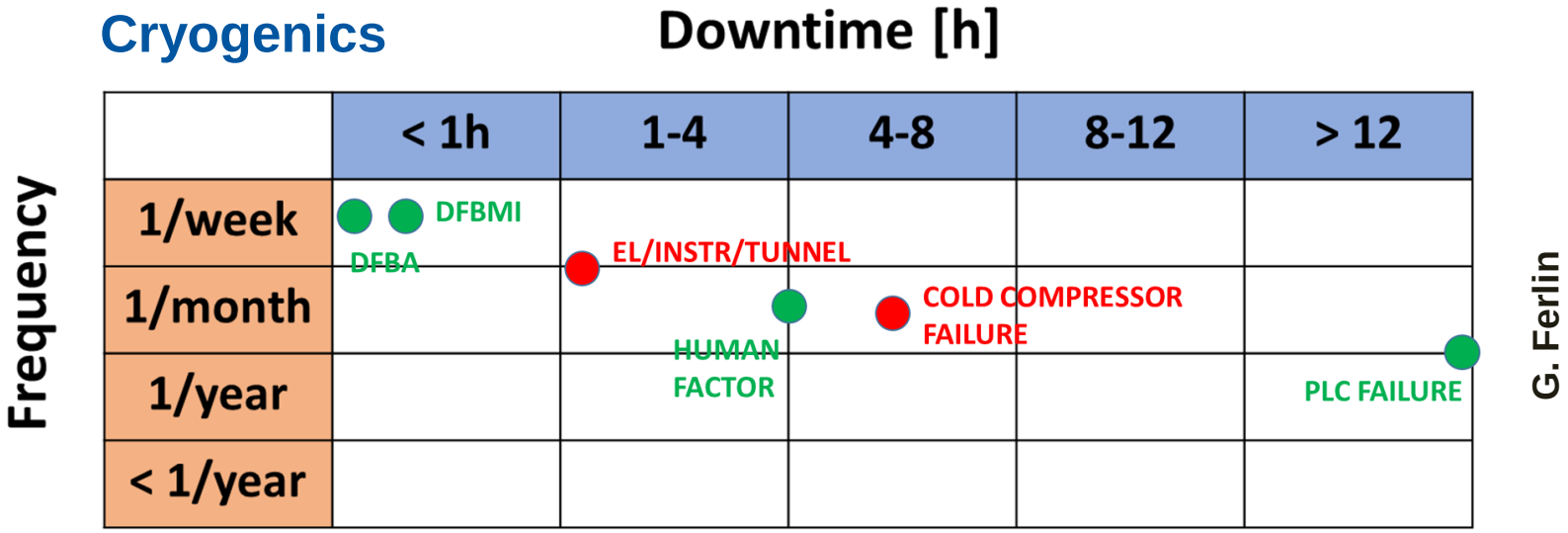
Mitigated/not expected to re-appear

Not yet mitigated/mitigation not justified

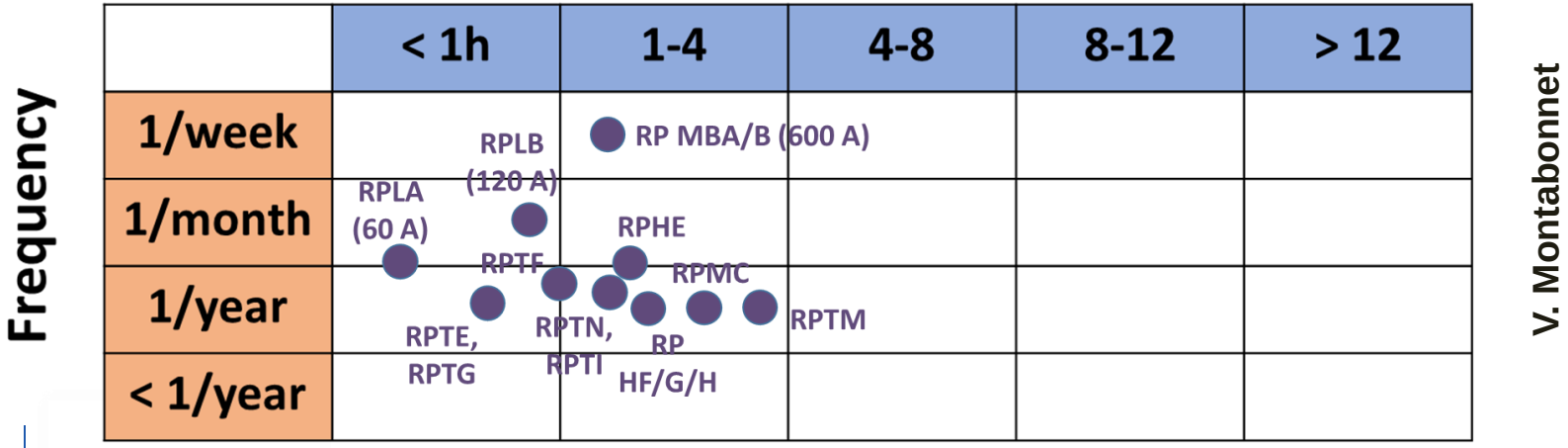
Partially mitigated

Hardware Systems – Availability Matrices (1/2)

Cryogenics

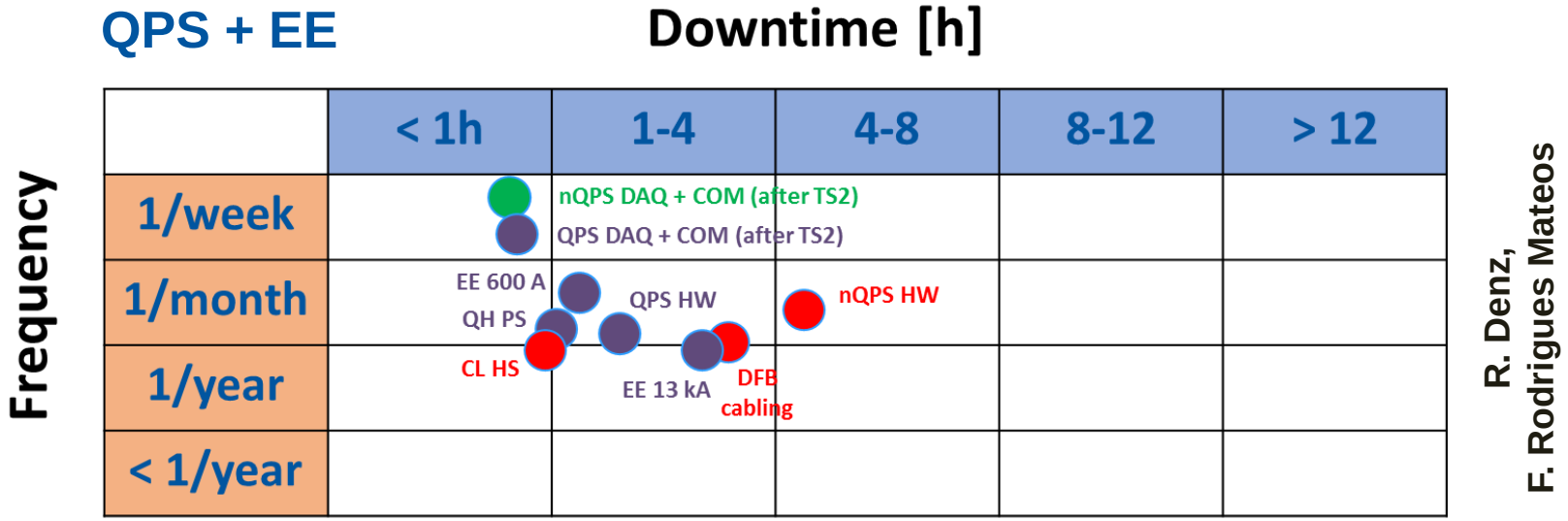


Power Converters

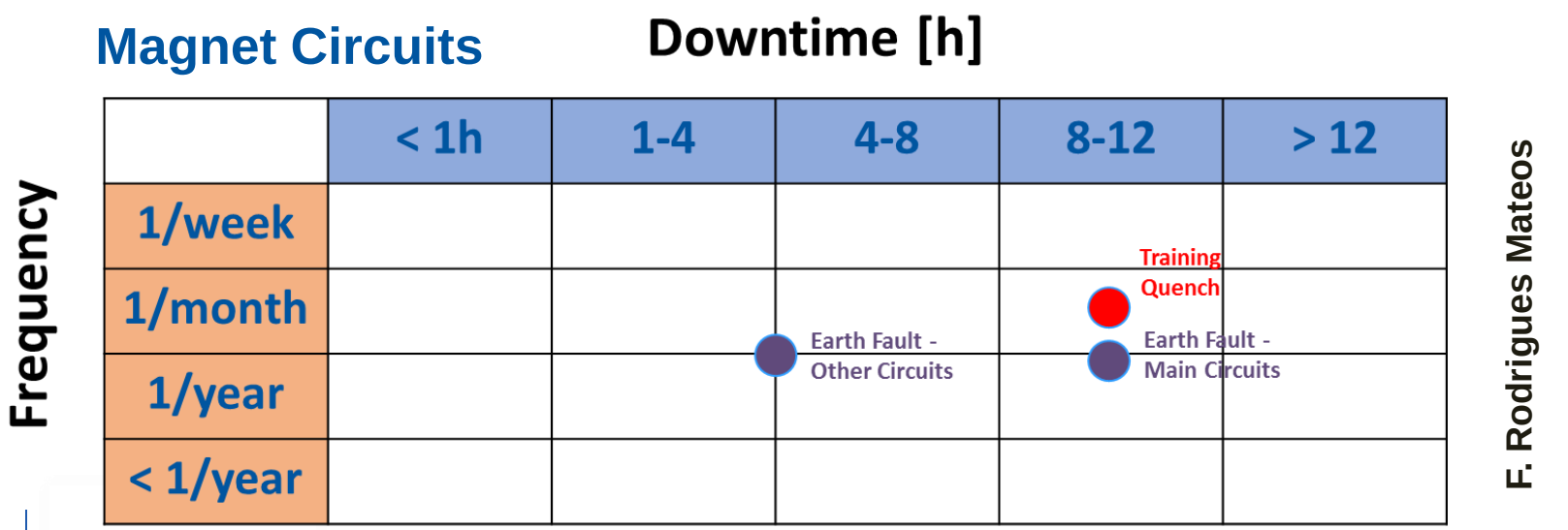


Hardware Systems – Availability Matrices (2/2)

QPS + EE

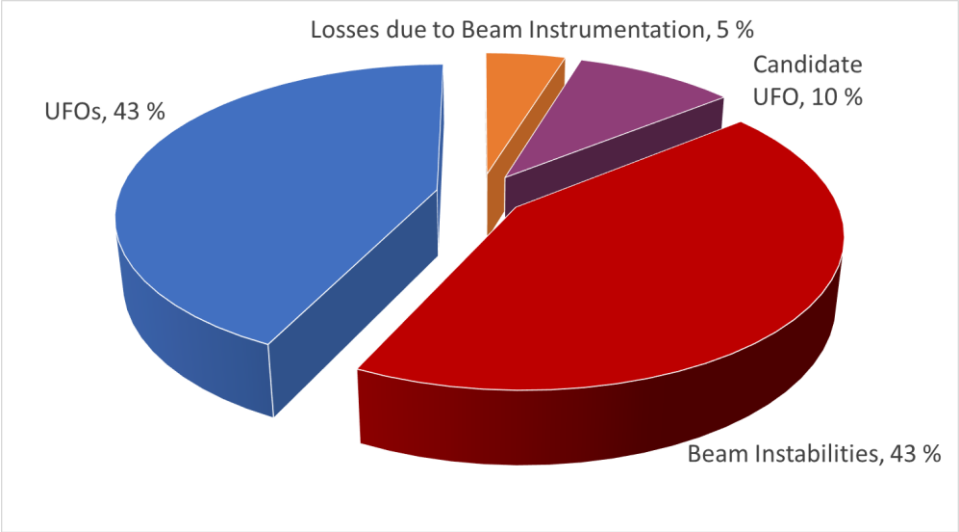


Magnet Circuits



Dumps due to Beam Losses

Comparison of Dump Causes – Stable Beams

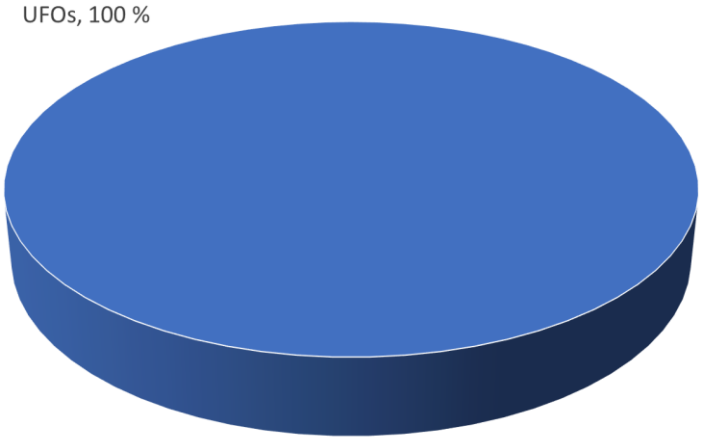


2012 (200 days - 50 ns):

- 9 UFOs
- 2 Fast losses @ RP (UFO?)
- 9 Beam Instabilities (detection: 4 BLMs, 5 BPM IR6)
- 1 Loss due to beam instrumentation (wire scans)

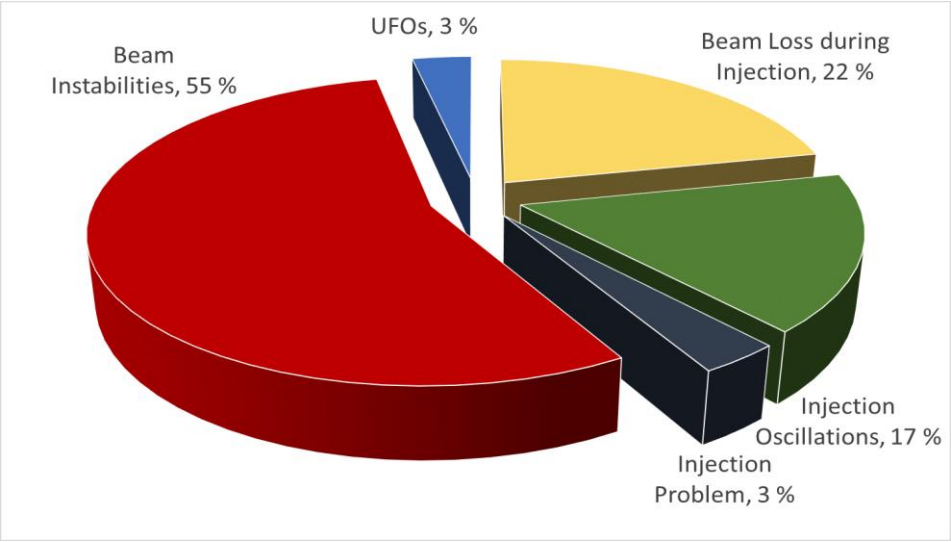
2015 (58 days - 25 ns):

- 10 UFOs, 1 Quench (3 for all 2015)
  - Purely statistical* linear extrapolation for 200 days -> ~ 35 UFOs, 3 quenches



*Linear scaling may be highly inaccurate following the increase of BLM thresholds

Comparison of Dump Causes- Injection

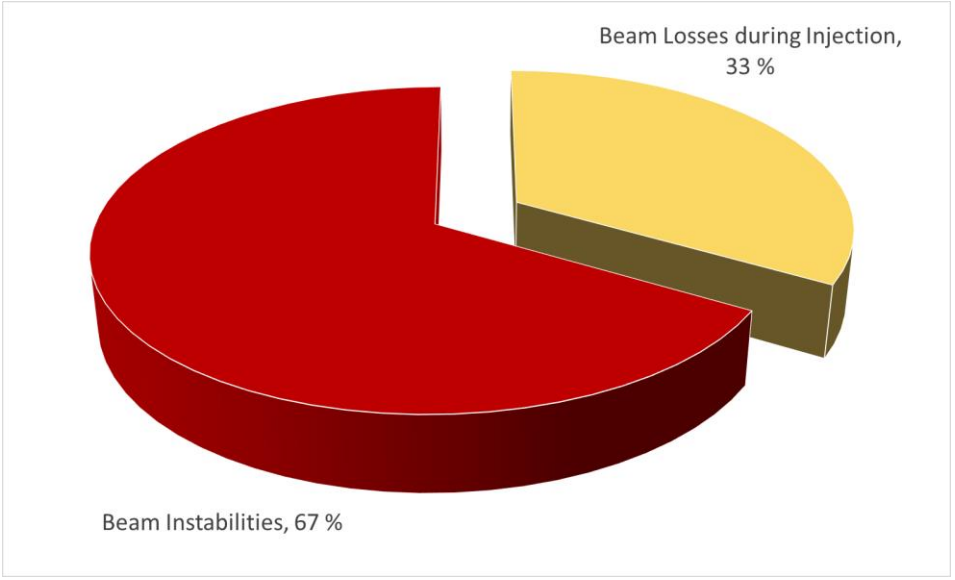


2012 (200 days - 50 ns):

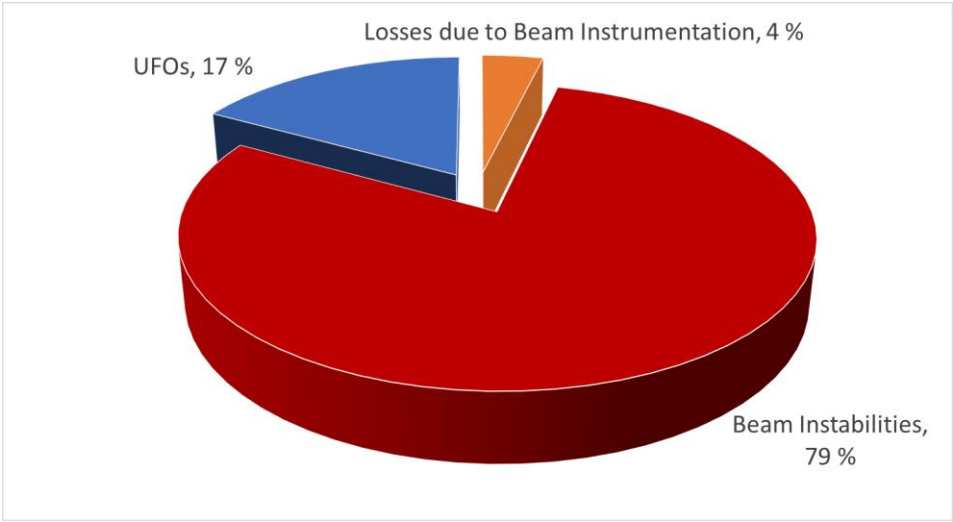
- 13 Beam Losses during Injection (BLMs Pt.2&8)
- 33 Beam Instabilities (32 BPM IR6, 1 LHCb BCM)
- 10 Injection Oscillations
- 2 Injection Problem (timing SPS)
- 2 UFOs

2015 (58 days - 25 ns):

- 3 Beam Losses during Injection (extr. -> ~10)
- 6 Beam Instabilities (5 BLM, 1 BPM IR6) (extr. -> ~21)



Comparison of Dump Causes – Cycle

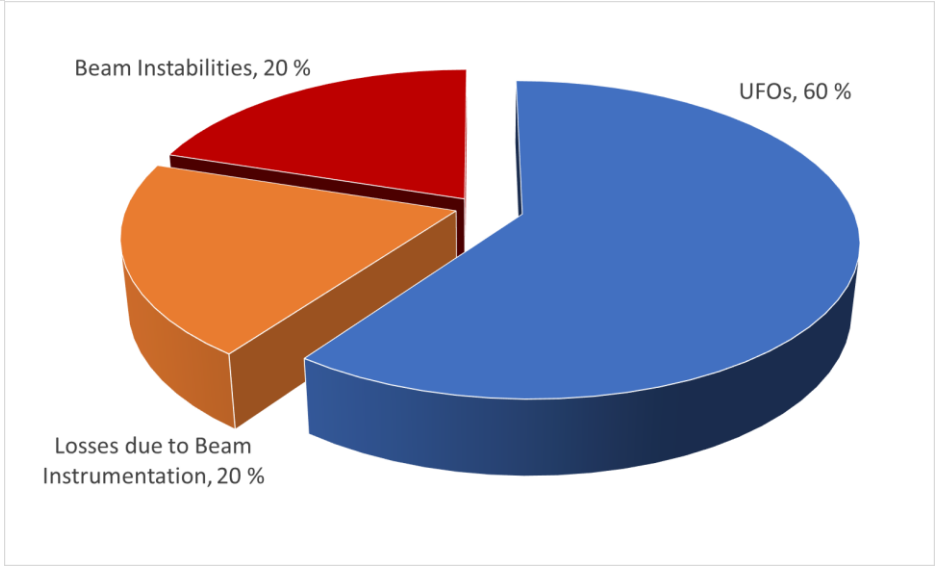


2012 (200 days - 50 ns):

- 42 Beam Instabilities
- 9 UFOs
- 2 Losses due to instrumentation (Tune feedback)

2015 (58 days - 25 ns Run):

- 1 Beam Instabilities (extr. -> ~3)
- 3 UFOs (extr. -> ~10)
- 1 Loss due to instrumentation (Tune feedback) (extr. -> ~3)



Outlook – Beam Losses

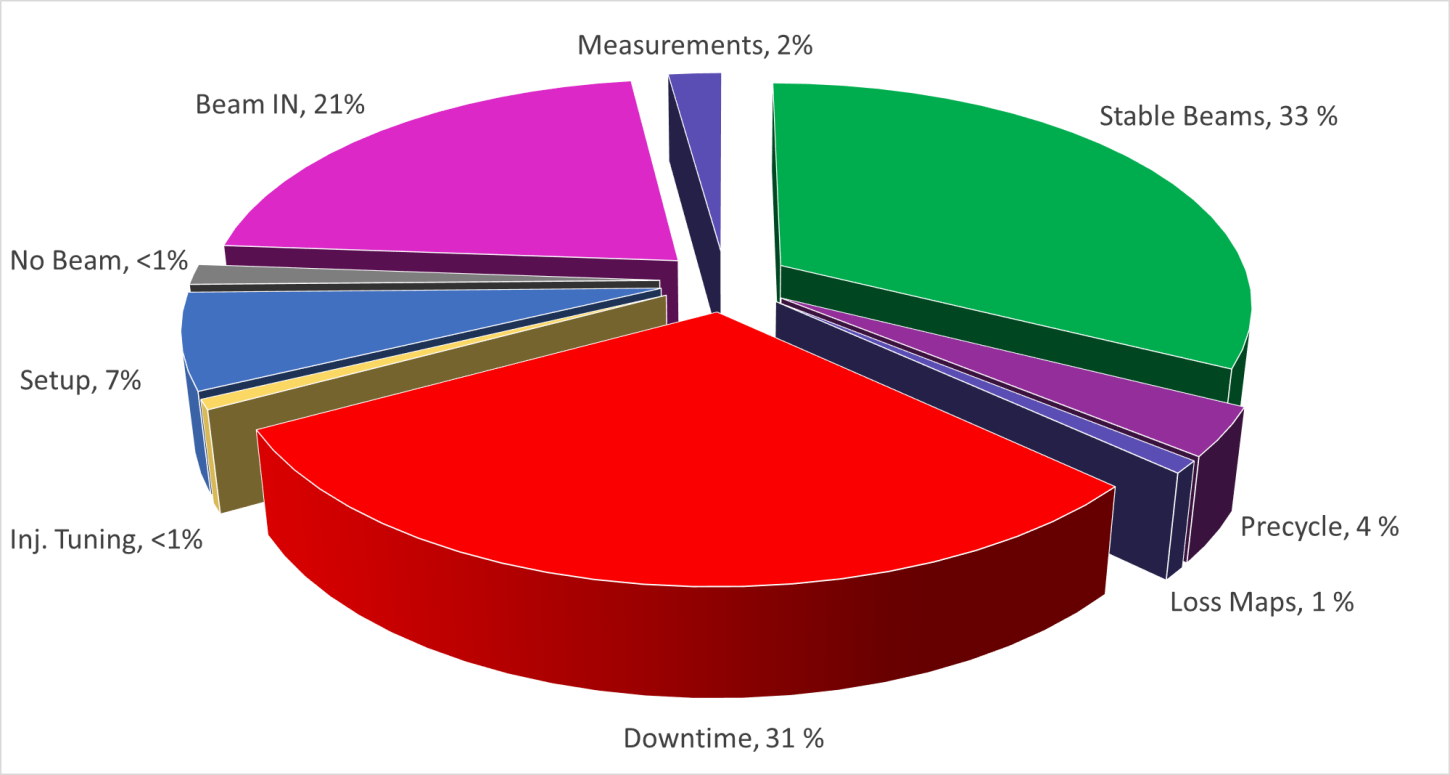
Downtime [h]

Frequency	< 1h	1-4	4-8	8-12	> 12
1/week	UFOs, Transv. Instabilities				
1/month	BL during injection			UFOs + quench (?)	
1/year					
< 1/year					

- No significant improvement of the turnaround time despite less beam losses through the all cycle → main driver for the turnaround - excluding faults - is the injection process

LHC Operation

Breakdown of Operational Mode (25 ns Run)



3 main areas for improvement:

- Reduction of downtime
- Reduction of the precycle time (~ 50%, see also M. Solfaroli)
- Cycle optimization (see also M. Solfaroli):
  - Optimization of injection process
  - Combined ramp and squeeze
  - Optimization of time in adjust

Luminosity Predictions

Availability Scenarios

- **2015-like availability** (from 25 ns Run):
  - LHC Availability: ~ 69 %
  - Stable Beams Efficiency: 33 %
  - Average Downtime per SB = 6 h
  - Average Turnaround = 7.3 h
  - Fraction of premature dumps: 70 %

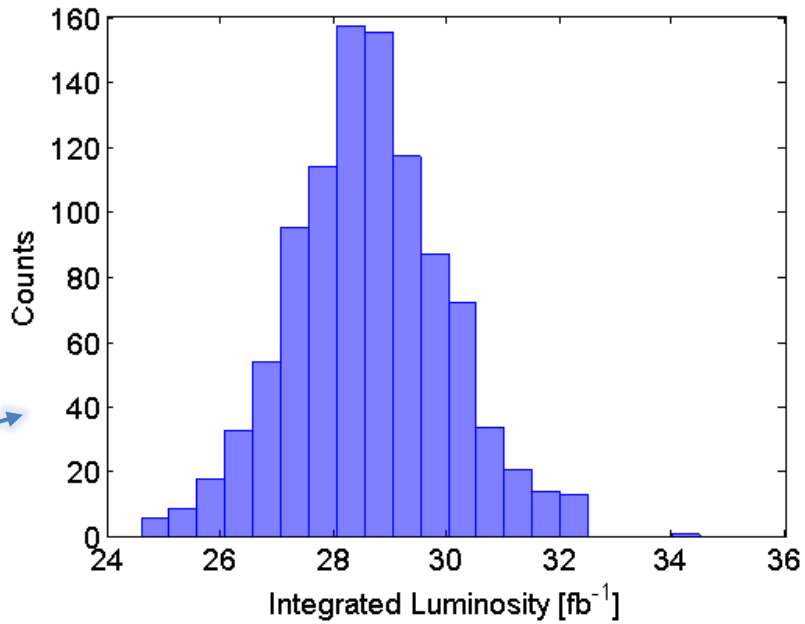
- **Long Term Target towards HL-LHC**
  - LHC Availability: ~ 90 %
  - Stable Beams Efficiency: >= 50 %
  - ~25 % Reduction of Average Downtime
  - ~30 % Reduction of Average Turnaround
  - Fraction of premature dumps: 20 %
  - Optimized Fill lengths

Experience:
- Limited Beam Losses
- Optimized MPS settings
- Reduced Downtime (HW)
- Faster Turnaround
- …

Hardware Performance:
- New Systems -> New Failure Modes?
- Ageing
- R2E
- …

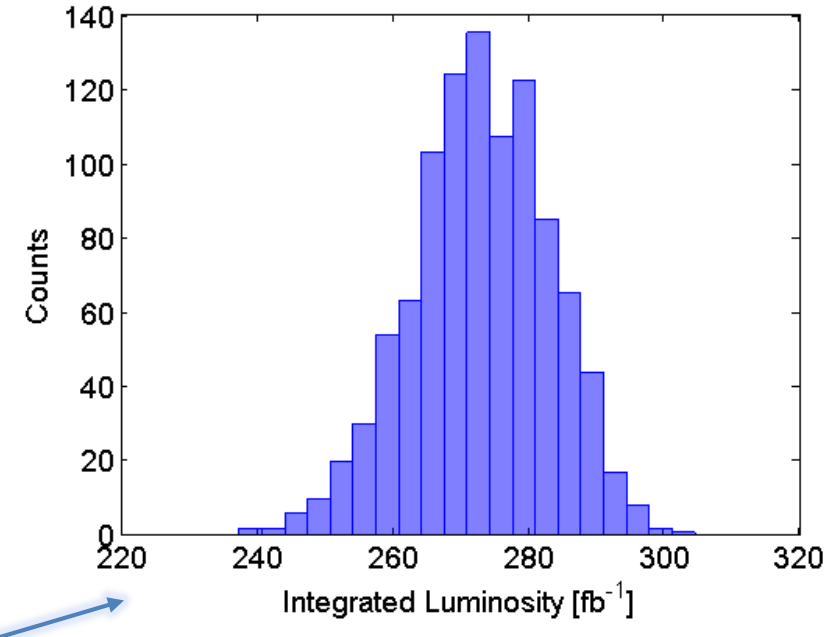
2016: Integrated Luminosity

- Assumptions:
  - Same intensity ramp-up as 2012
  - 160 days of physics production
  - Average Peak Luminosity: $1*10^{34}\ cm^{-2}s^{-1}$
  - Luminosity lifetime: 15 h
    - Pessimistic given 2015 performance (?)
- 2015-like availability: $28.6\ fb^{-1}$
- (If long term target would be met: $45.6\ fb^{-1}$)



HL-LHC: Integrated Luminosity

- Assumptions:
  - Same intensity ramp-up as 2012
  - 160 days of physics production
  - Levelled Luminosity: $5*10^{34}$ $cm^{-2}s^{-1}$
  - Virtual Peak Luminosity: $1.9*10^{35}$ $cm^{-2}s^{-1}$
  - Levelling Time: 8.3 h
- 2015-like availability: 183 fb^{-1}
  - ~220 fb^{-1} for 200 days of operation
- If long term target is met: 273 fb^{-1}
  - ~328 fb^{-1} for 200 days of operation



Conclusions

- Average LHC availability in 2015: 69 %
- 25 ns Run: large fraction of LHC downtime due to cryogenic stops (regulation problems, time to stabilize, quench recoveries, etc.) – significant improvement during the ion run thanks to reduced heat loads
- Beam instabilities well under control in 2015
- Difficult to predict impact of UFOs on future operation
- Possibilities to improve operational efficiency (precycle strategy, combined ramp and squeeze, …)
- Improving availability is one of the main challenges to increase integrated luminosity towards HL-LHC !

Thanks a lot for your attention!

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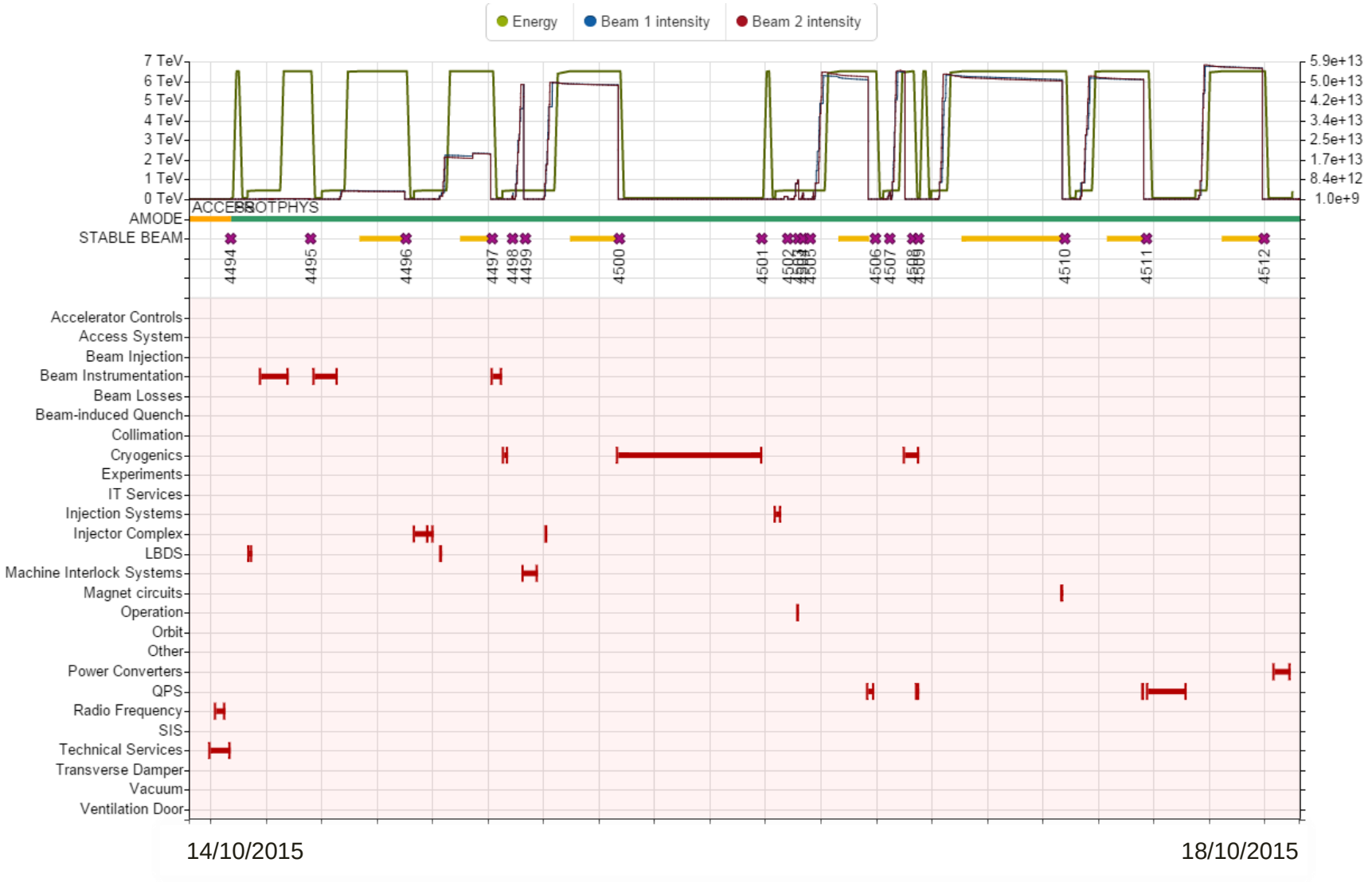
Standardized Availability Summary

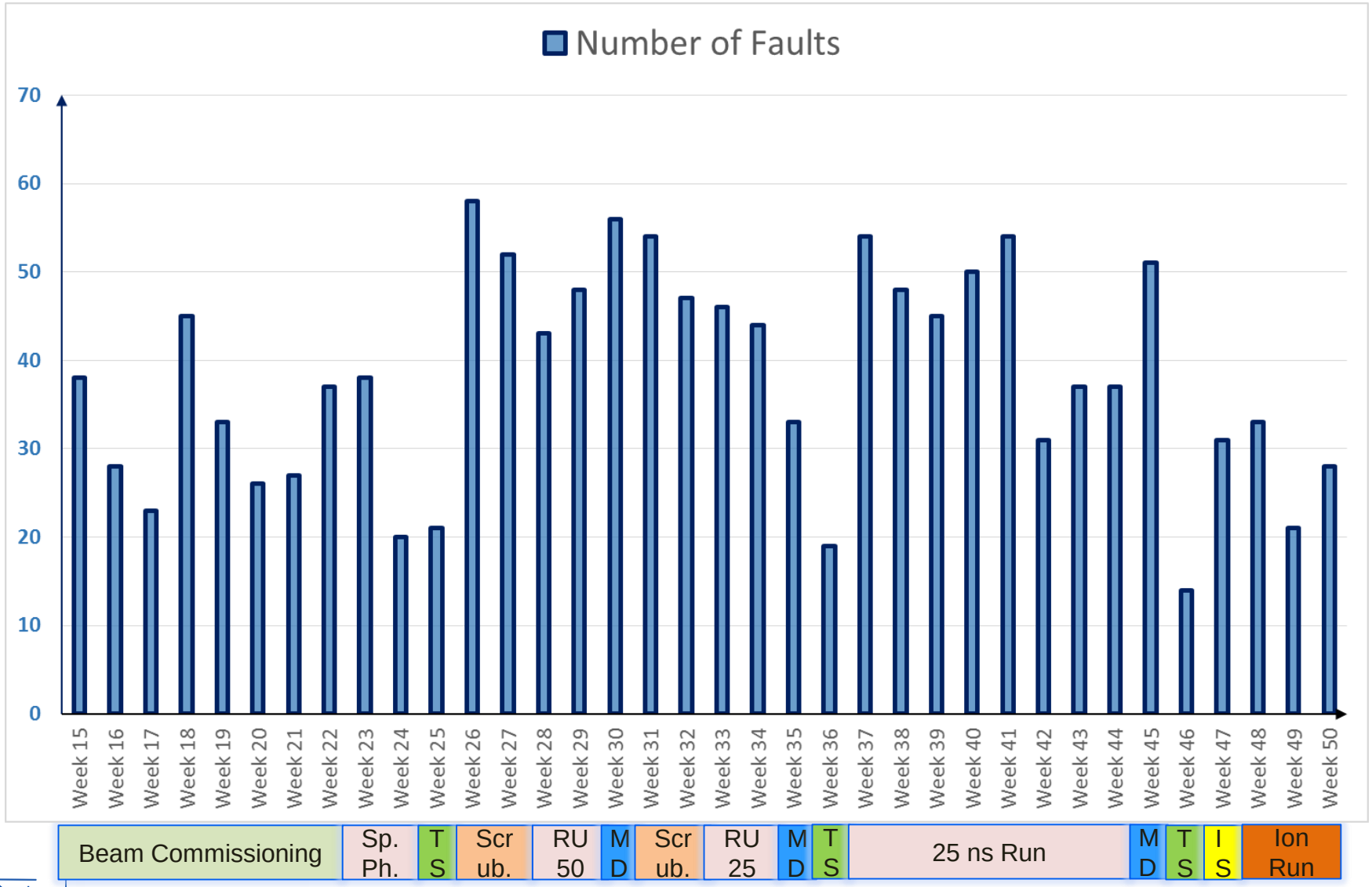


"Cardiogram" of LHC operation

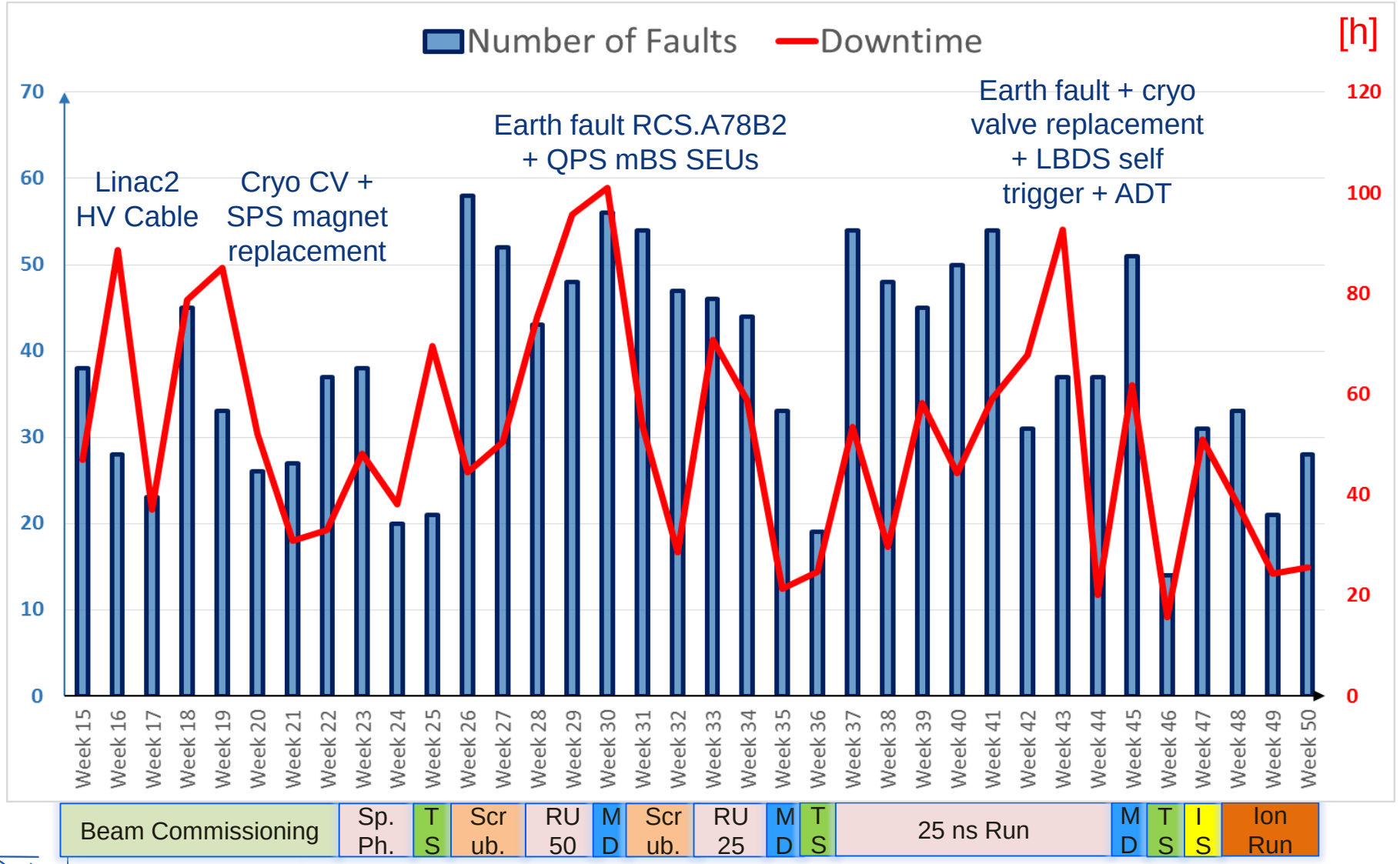
Some Statistics on Fault Review…

- Reference period: 6/4/2015 to 13/12/2015 (weeks 15 to 50)
- **1375 faults** recorded and analysed (761 in 2012)
- ~ 90 relevant **parent/child relationships** identified
- ~ 20 modifications in the eLogbook required per week
- ~ 5 h, 2 people per week for fault review + collaboration on tool development
- Consistent picture of **‘operational modes’** (loss maps, measurements, MDs, etc.)

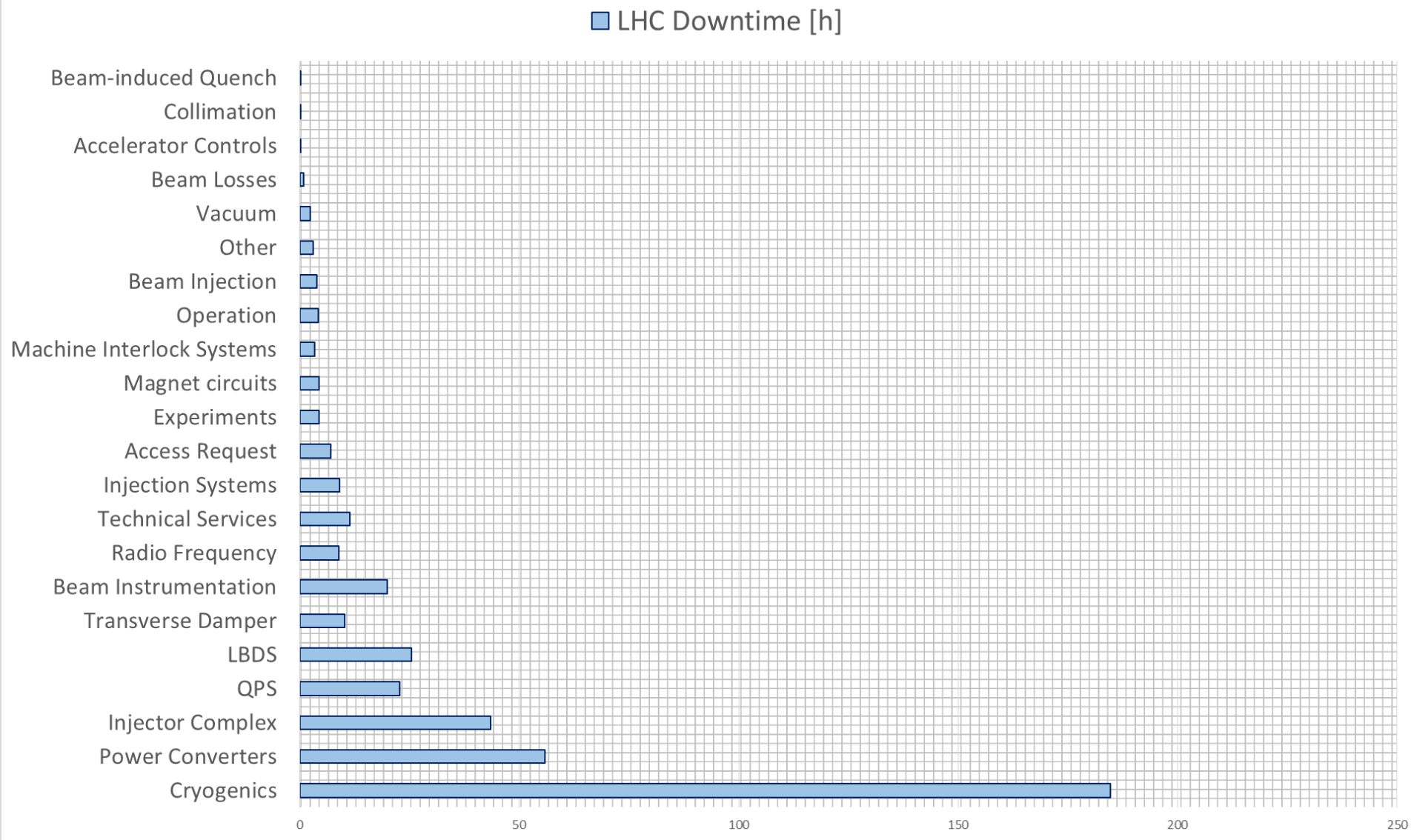
2015 Fault Overview



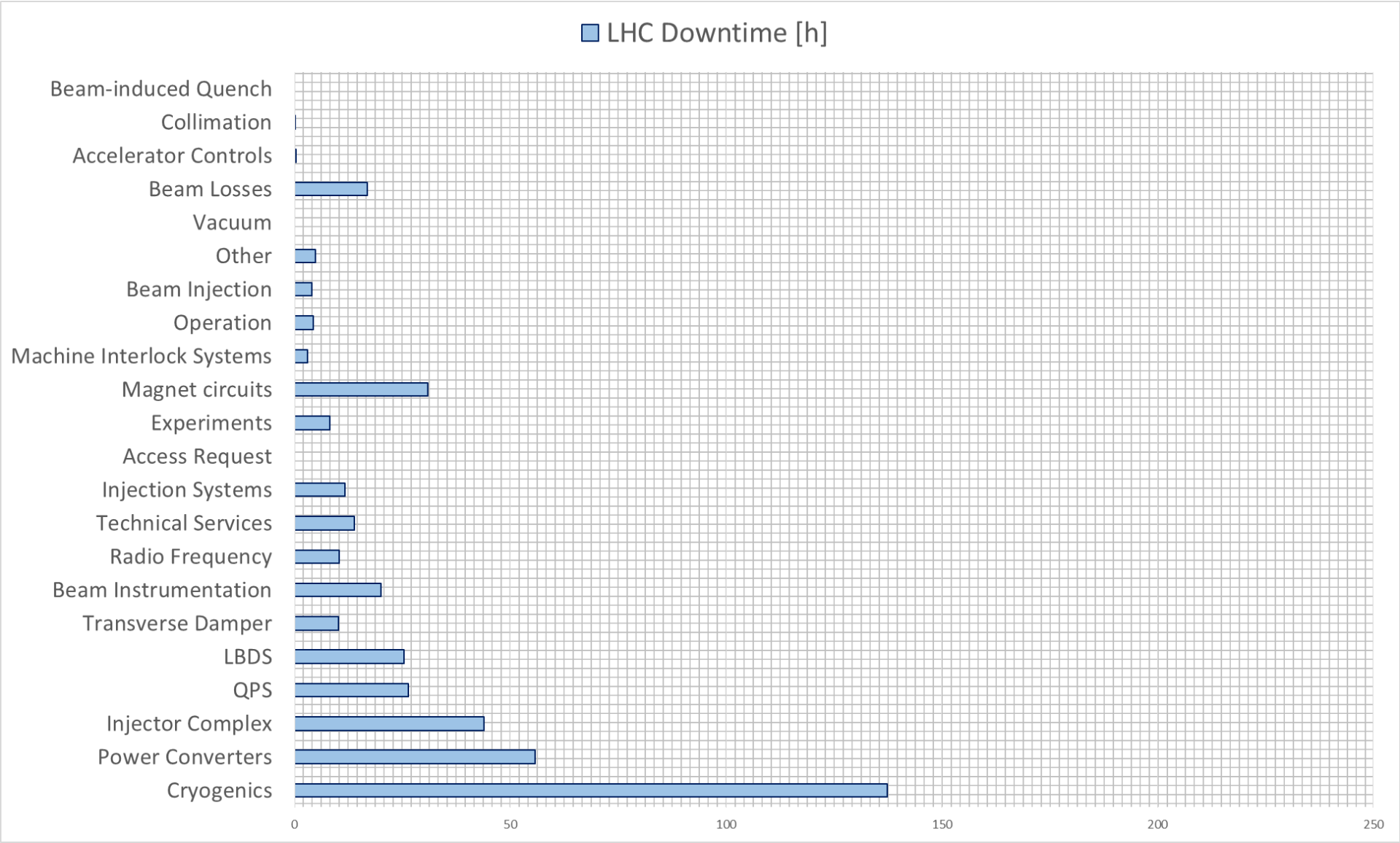
2015 Fault + Downtime Overview



Consider Only LHC Downtime…

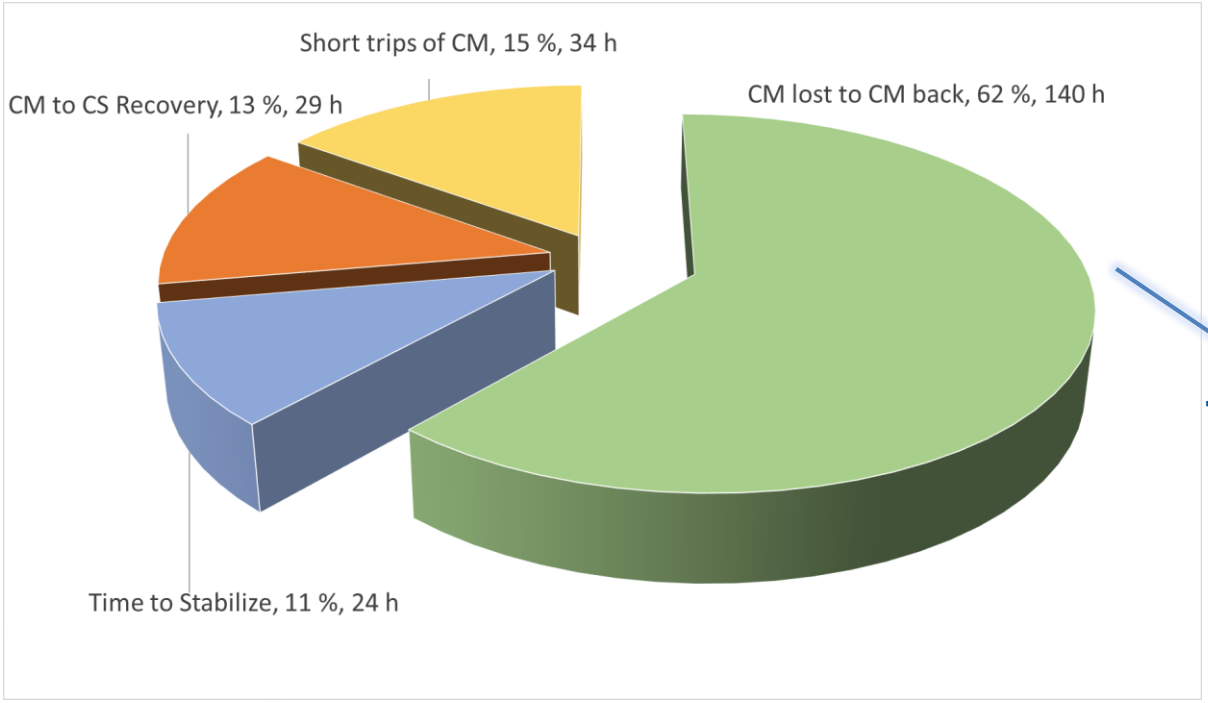


…Accounting for Parent/Child Relationships



Cryogenic System (25 ns Run)

- Total system downtime: 227 h
- Total LHC downtime: 185 h
- Total time as ‘child’: 52 h
- Total time as ‘parent’: 4.4 h
- Number of dumps in stable beams: 7
- Number of precycles required: 39



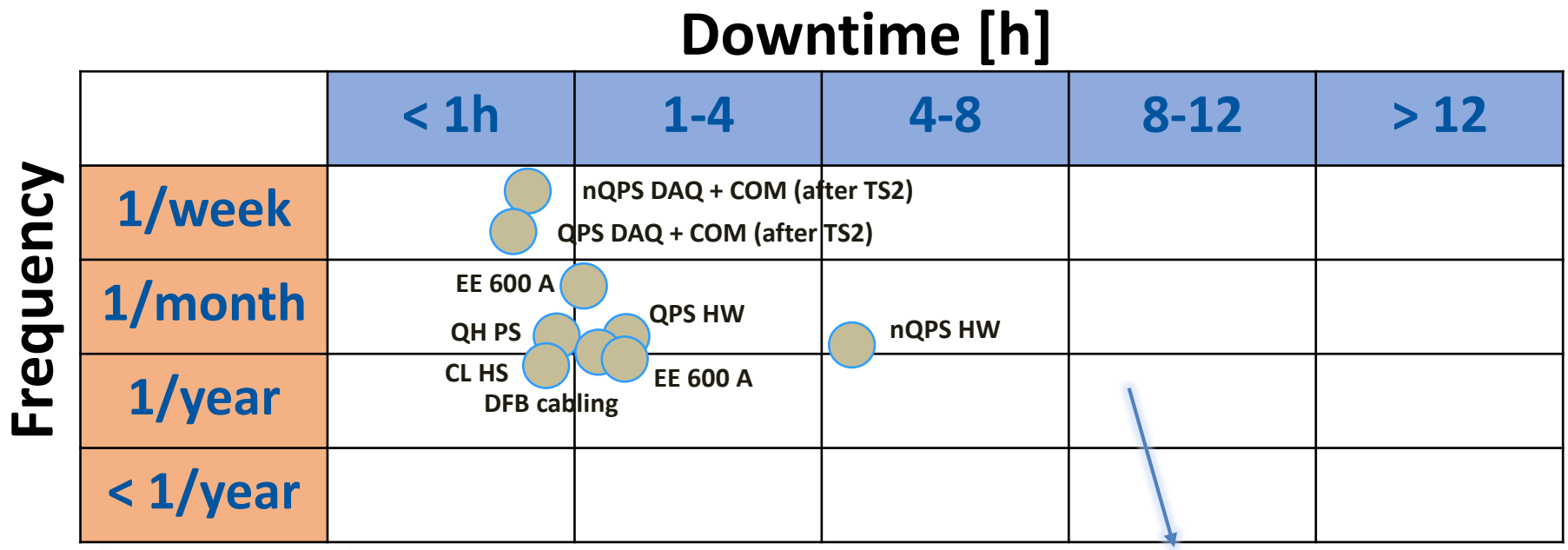
Talk by K. Brodzinski in Evian 2015

Power Converters (25 ns Run)

- Total system downtime: 53.5 h
- Total LHC downtime: 50.5 h
- Total time as ‘child’: 0 h
- Total time as ‘parent’: 0 h
- Number of dumps in stable beams: 4
- Number of precycles required: 3

Quench Protection System (25 ns Run)

- Total system downtime: 38 h
- Total LHC downtime: 23 h
- Total time as ‘child’: 5.5 h
- Total time as ‘parent’: 9 h
- Number of dumps in stable beams: 7
- Number of precycles required: 6



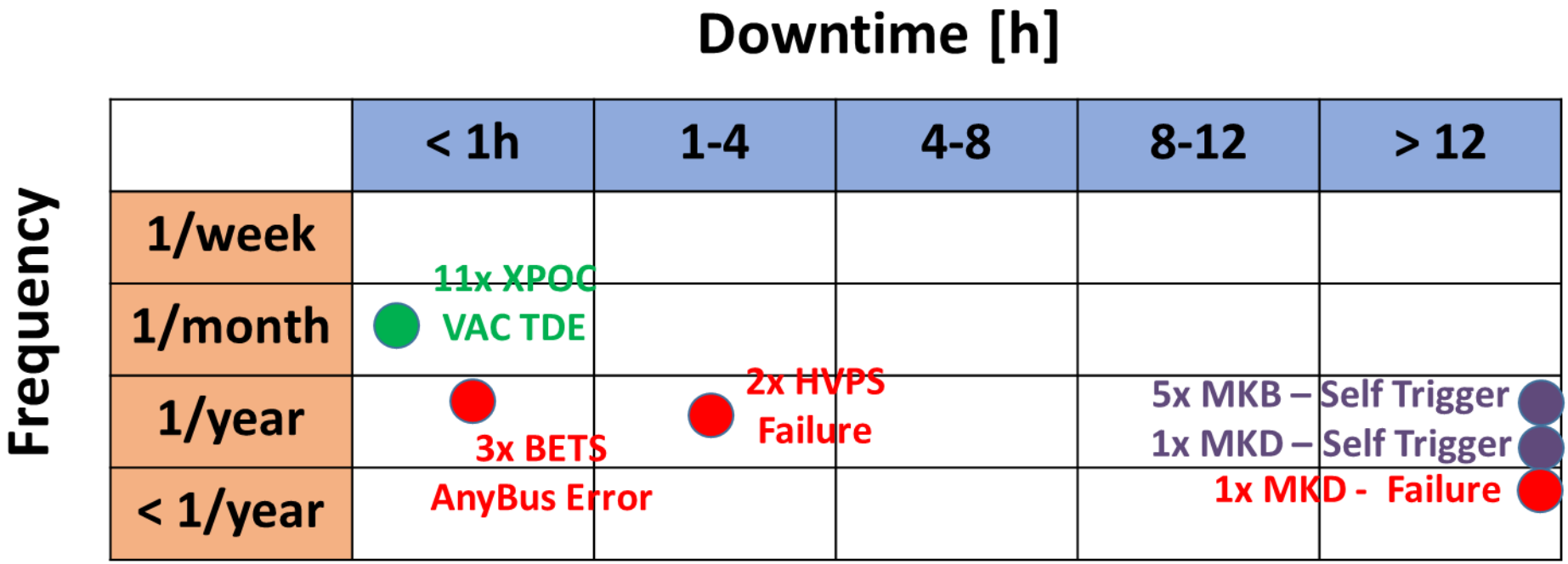
Talk by M. Pojer in Evian 2015

Quench Protection System (25 ns Run)

Responsible	Subsystem	Faults	Average intervention time [h]	Power aborts	Remote	Access	Foreseen mitigation	Remark
EP	nQPS hardware (after TS#2)	2	4.1	2	1	1	No	1 x SEU during ion run @ hot spot
EP	nQPS DAQ + COM (after TS#2)	25	0.8	0	25	0	Full during YETS	
EP	QPS DAQ + COM	30	0.9	0	19	11	Partially	Including EE DAQ problems
EP	QPS hardware	3	2.1	3	0	1	R2E cases yes	2 x SEU 600 A QDS
EE	Energy extraction 600 A	10	1.5	3	2	8		
EE	Quench heater power supplies	5	1.0	0	0	5		
EE	DFB cabling	3	3.2	0	0	3		
EE	Energy extraction 13 kA	3	3.0	0	1	2		
EE	Current lead heating system	4	1.0	0	0	4		
		85		8	48	35		

Courtesy R. Denz

LBDS



Green: mitigated/not expected to re-appear

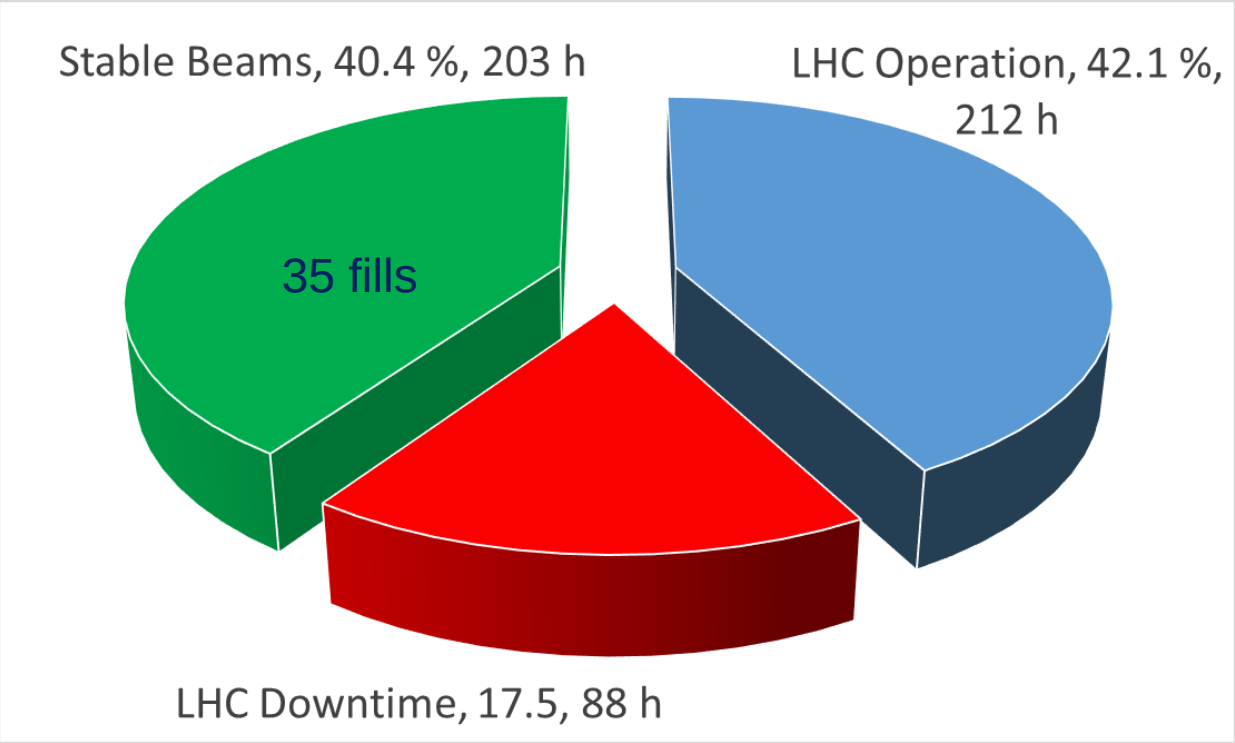
Red: not yet mitigated/mitigation not justified

Violet: partially mitigated

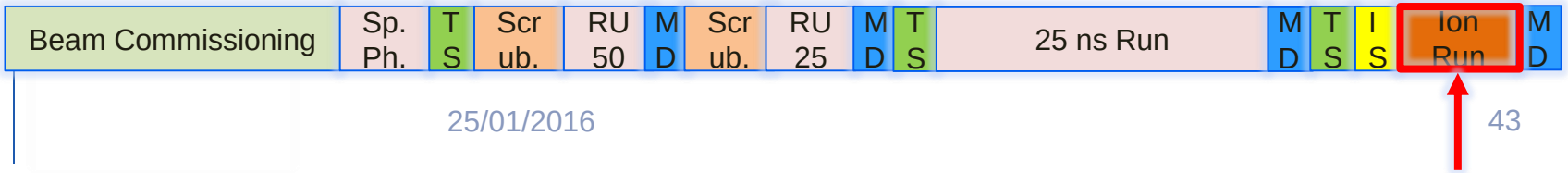
N. Magnin

FOCUS: Ion Run (23/11/2015 to 13/12/2015)

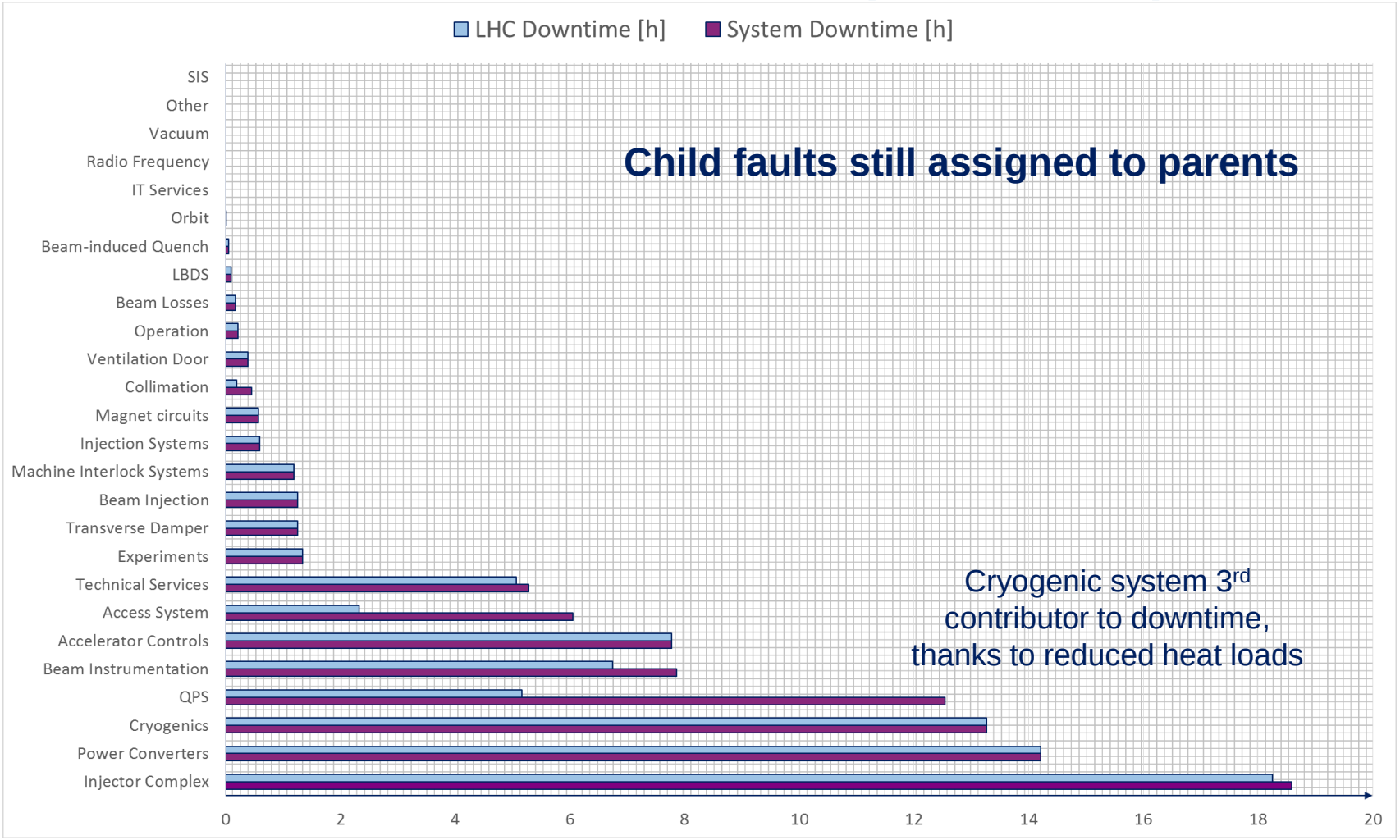
Availability for Physics – Ion Run



- 30 End Of Fill, 5 dumped due to faults
- Fraction of premature dumps: 5/35 = 14.3 %
- Average turnaround (per SB) = 204/35 = 5.8 h
- Average Fault time (per SB) = 88/35 = 2.5 h



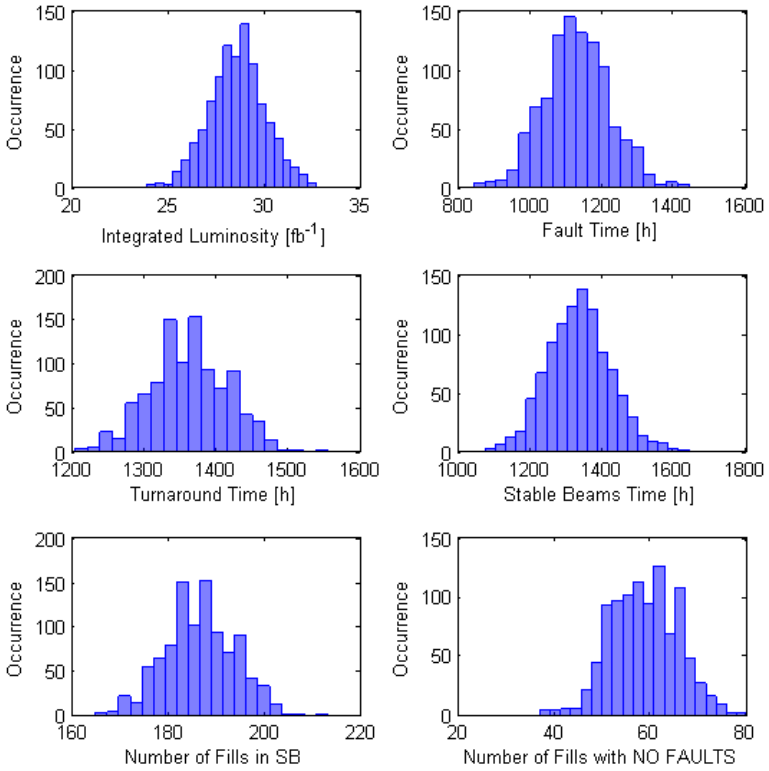
Downtime Distribution (Ion Run)



- **LHC Fault Time**: filtering faults occurred in the shadow of others
- **System Fault Time**: NOT filtering faults occurred in the shadow of others

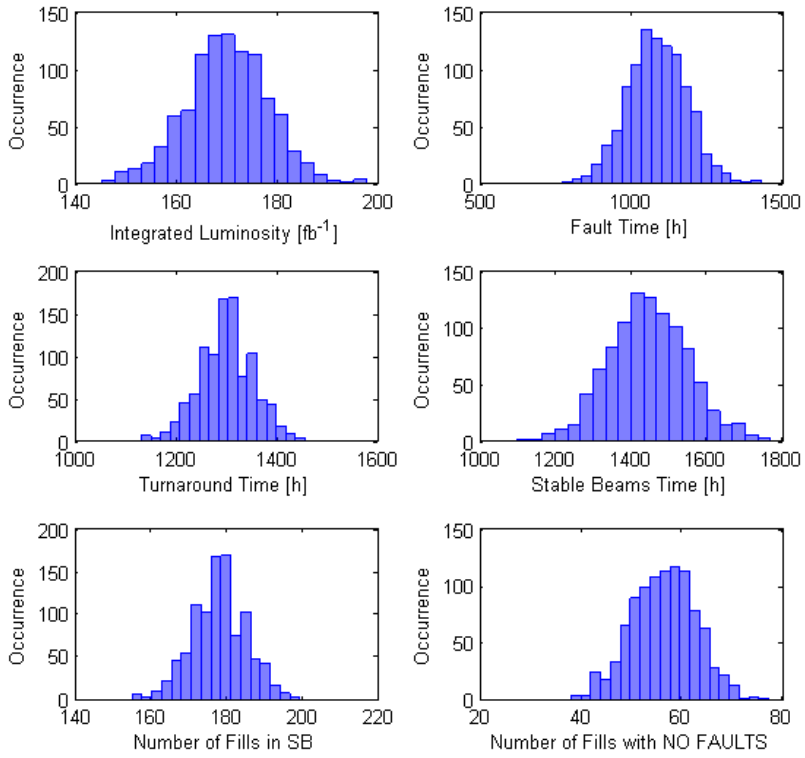
2016: Integrated Luminosity

- Assumptions:
  - Same intensity ramp-up as 2012
  - 160 days of physics production
  - Average Peak Luminosity: $1*10^{34}\ cm^{-2}s^{-1}$
  - Luminosity lifetime: 15 h
    - Pessimistic given 2015 performance
- 2015-like availability: $28.6\ fb^{-1}$
- (If long term target would be met: $45.6\ fb^{-1}$)

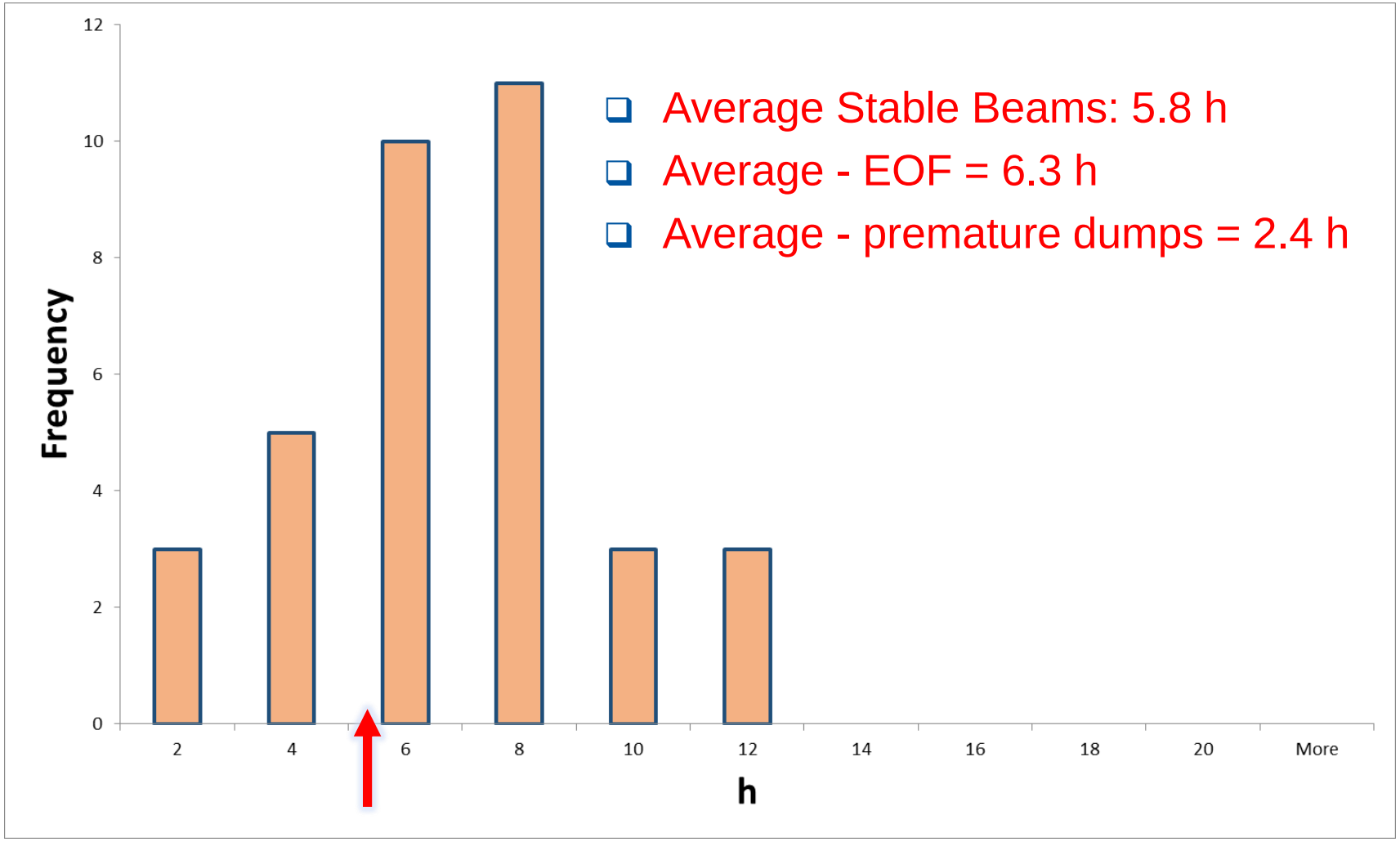


HL-LHC: Integrated Luminosity

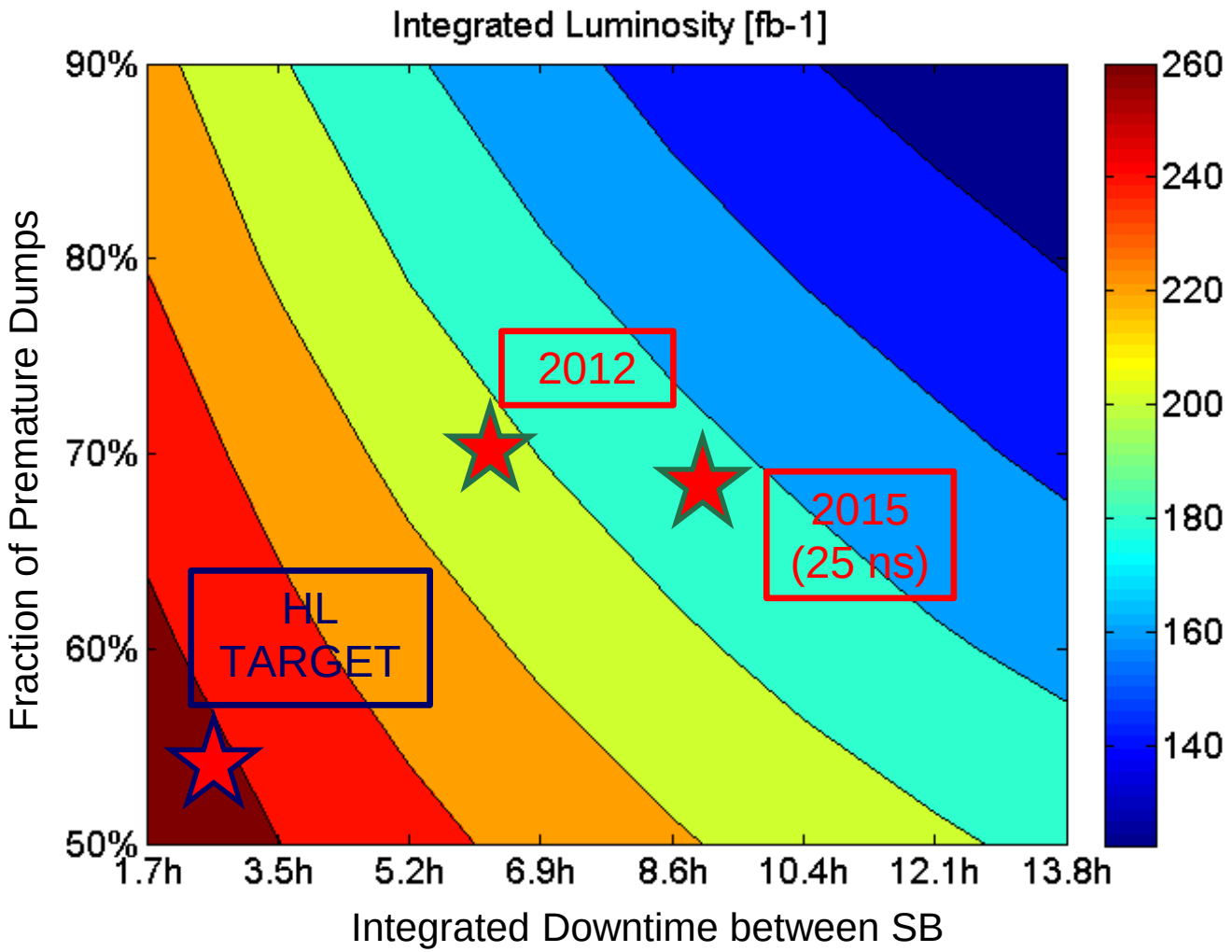
- Assumptions:
  - Same intensity ramp-up as 2012
  - 160 days of physics production
  - Levelled Luminosity: $5*10^{34}$ $cm^{-2}s^{-1}$
  - Virtual Peak Luminosity: $1.9*10^{35}$ $cm^{-2}s^{-1}$
  - Levelling Time: 8.3 h
- 2015-like availability: 183 fb^{-1}
  - ~220 fb^{-1} for 200 days of operation
- If long term target is met: 273 fb^{-1}
  - ~328 fb^{-1} for 200 days of operation



Stable Beams Distribution – Ion Run



HL-LHC: Sensitivity Analysis



Additional Considerations (all 2015)

- Impact of **UFOs** (21 UFO dumps), talk by B. Auchmann
  - Significant effort to optimize BLM thresholds in terms of MPS and availability
  - Number of quenches: 3
- 7 **Training quenches**
- Unidentified Lying Object (**ULO**)
  - 14 dumps
  - Number of quenches: 3
- **Single Event Upsets (SEUs)**
  - QPS: 2 confirmed SEUs - on top of mBS SEUs, solved during TS2
  - Power Converters: 6 candidate SEUs
  - RF: 4 candidate SEUs