



# LHC Availability 2016 Proton Run

7<sup>th</sup> Evian Workshop, 13/12/2016

A. Apollonio

On behalf of AWG-core team (L. Ponce, B. Todd)

Acknowledgements: Availability Working Group, AFT Team

AWG Core Team	B. Todd (TE/EPC) L. Ponce (BE/OP) A. Apollonio (TE/MPE)
---------------	---

AFT Team	C. Roderick (BE/CO)
----------	---------------------

Controls	M. Gourber Pace (BE/CO) C. Roderick (BE/CO)
Access System	S. Di Luca (BE/ICS) T. Ladzinski (BE/ICS)
Access Management	L. Ponce (BE/OP)
Beam Exciters	R. Barlow (TE/ABT) N. Magnin (TE/ABT)
Beam Induced Quenches	A. Verweij (TE/MPE)
Injection	L. Ponce (BE/OP)
Instrumentation	E. Bravin (BE/BI)
Beam Losses	L. Ponce (BE/OP)
Collimation	S. Redaelli (BE/ABP) A. Masi (EN/STI)
Cryogenics	L. Delprat (TE/CRG) G. Ferlin (TE/CRG)
Experiments	B. Gorini (EP/ADO)
Injection Systems	R. Barlow (TE/ABT) A. Masi (EN/STI)
Injector Complex	J.-F. Comblin (BE/OP) D. Cotte (BE/OP) J. Dalla-Costa (BE/OP) V. Kain (BE/OP) B. Mikulec (BE/OP) R. Steerenberg (BE/OP)

IT Services	E. Dafonte (IT/DB)
Beam Dumping System	N. Magnin (TE/ABT)
Machine Protection	J. Uythoven (TE/MPE) D. Wollmann (TE/MPE) M. Zerlauth (TE/MPE)
Magnet Circuits	Z. Charifoulline (TE/MPE)
Operation	L. Ponce (BE/OP)
Orbit	J. Wenninger (BE/OP)
Power Converters	M. Bastos (TE/EPC) V. Montabonnet (TE/EPC) C. Mugnier (TE/EPC) H. Thiesen (TE/EPC)
Quench Protection	R. Denz (TE/MPE)
Radio Frequency	O. Brunner (BE/RF) A. Butterworth (BE/RF) N. Schwerg (BE/RF)
Software Interlocks	J. Wenninger (BE/OP)
Technical Services	J. Nielsen (BE/IO) R. Ledru (BE/IO)
Transverse Damper	W. Hofle (BE/RF) E. Montesinos (BE/RF) D. Valuch (BE/RF)
Vacuum	G. Bregliozzi (TE/VSC) J. Sestak (TE/VSC)

## 2016 LHC Availability Reports (B. Todd, L. Ponce, A. Apollonio)

Restart – TS1: <https://cds.cern.ch/record/2195706?ln=en>

TS1 – TS2: <https://cds.cern.ch/record/2235082?ln=en>

TS2 – TS3: <https://cds.cern.ch/record/2235079?ln=en>

Proton Run: <https://cds.cern.ch/record/2237325?ln=en>

	Jan			Feb				Mar					
Wk	1	2	3	4	5	6	7	8	9	10	11	12	13
Mo	4	11	18	25	1	8	15	22	29	7	14	21	Easter Mon 28
Tu													
We													
Th				Year end technical stop						Powering tests			
Fr								OSO test				Machine checkout	6. Friday
Sa													
Su													

25<sup>th</sup> March

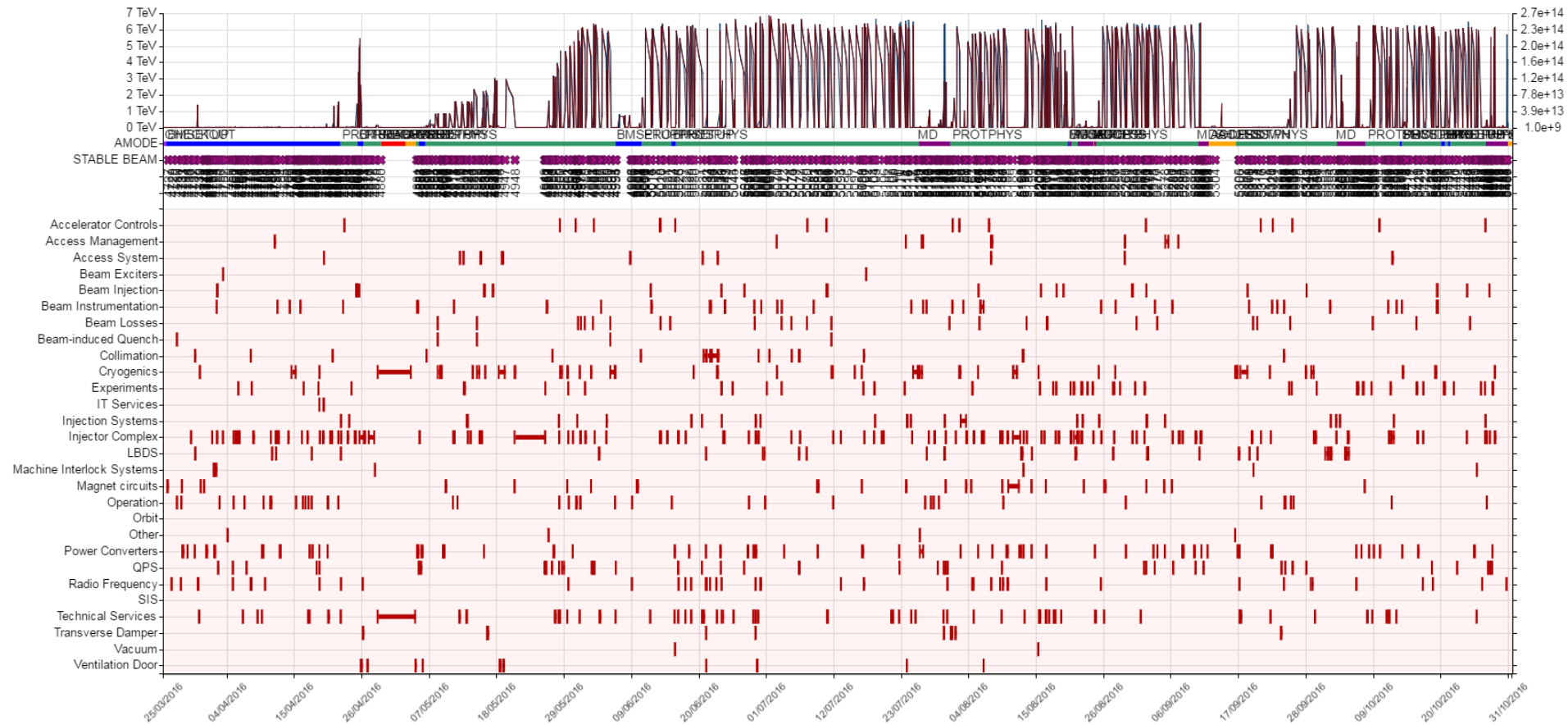
	Apr			May				June					
Wk	14	15	16	17	18	19	20	21	22	23	24	25	26
Mo	4	11	18	25	2	9	White 16	23	30	6	13	20	27
Tu							VdM			TS1			
We		injector TS (6 hours)									beta* 2.5 km dev.		
Th					Ascension								
Fr					May Day comp			VdM					
Sa	Recommissioning with beam												
Su				1st May									

	July			Aug				Sep					
Wk	27	28	29	30	31	32	33	34	35	36	37	38	39
Mo	4	11	18	25	1	8	15	22	29	5	12	19	26
Tu								MD 2					
We											TS2	beta* = 2.5 km data taking	
Th				MD 1						Jeune G			
Fr								beta* 2.5 km dev.					
Sa										MD 3			
Su				beta* 2.5 km dev.									

	Oct			Nov				Dec					
Wk	40	41	42	43	44	45	46	47	48	49	50	51	52
Mo	3	10	17	24	31	7	14	21	28	5	12	19	26
Tu	MD 4					Ions setup				Extended year end technical stop			
We					TS3								
Th		Ions setup						Ion run (p-Pb)				Lab closed	
Fr				MD 5									
Sa													
Su								Pb MD				Xmas	New Year

31<sup>st</sup> October





25<sup>th</sup> March

31<sup>st</sup> October

782 Faults registered and analyzed (manually!)  
65 Parent/child relationships identified  
New categories: Access Management, Ventilation Doors

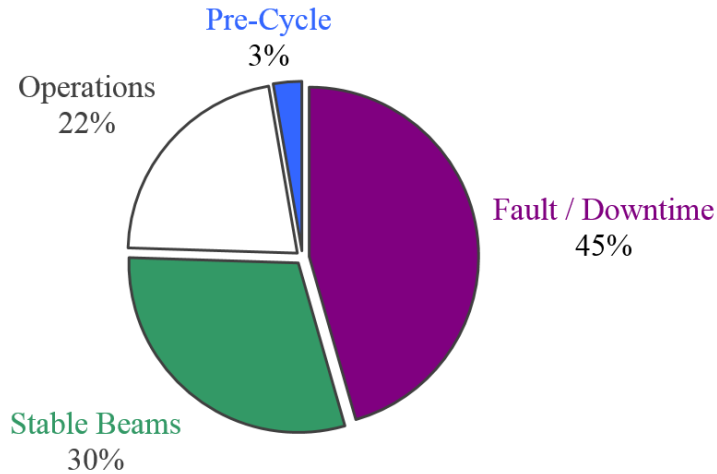
	Restart – TS1	TS1 – TS2	TS2 – TS3	
Beam Commissioning	29	1 ½	2 ½	33
Ion Cycle Setup	0	0	2	2
Special Physics Commissioning	0	3	0	3
Scrubbing	2	0	0	2
Machine Development	0	11	9	20
Special Physics	3	0	4	7
Physics	40	79	27	146

= 213 days

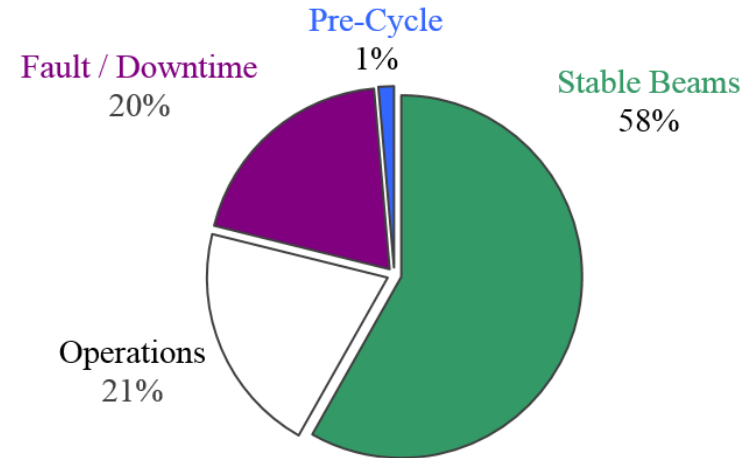
	Restart – TS1	TS1 – TS2	TS2 – TS3	
Beam Commissioning	29	1 ½	2 ½	33
Ion Cycle Setup	0	0	2	2
Special Physics Commissioning	0	3	0	3
Scrubbing	2	0	0	2
Machine Development	0	11	9	20
<b>Special Physics</b>	3	0	4	<b>7</b>
<b>Physics</b>	40	79	27	<b>146</b>
		= 213 days		= 153 days



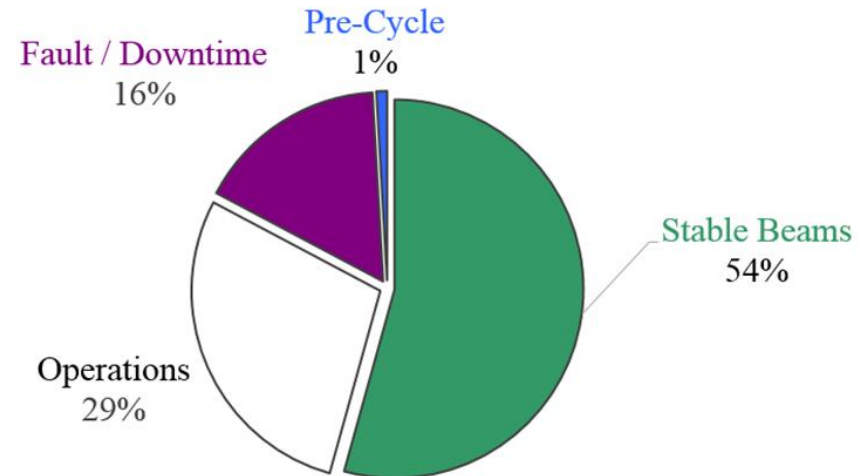
## Restart – TS1



## TS1 – TS2



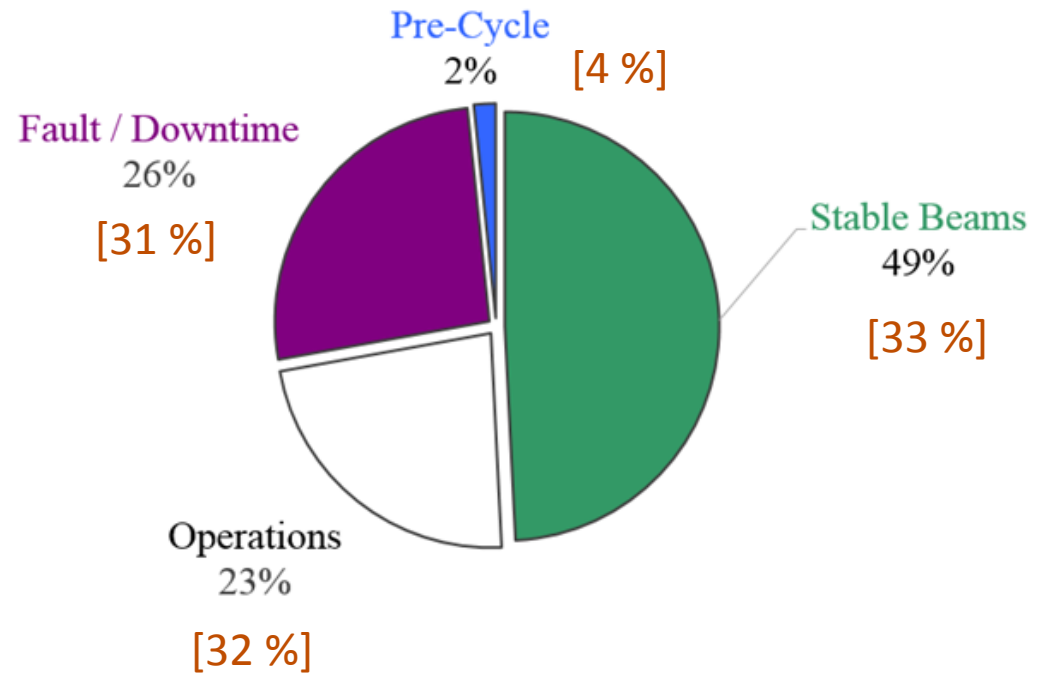
## TS2 – TS3



Operations contains nominal cycle + extra measurements (116h) + injection setting-up (23h) + some loss maps (35h) + planned accesses

153 days physics  $\approx$  3738.7 hours

	Duration [h]
Stable Beams	1839.5
Fault / Downtime	980.0
Operations	857.9
Pre-Cycle	61.3
	= 3738.7

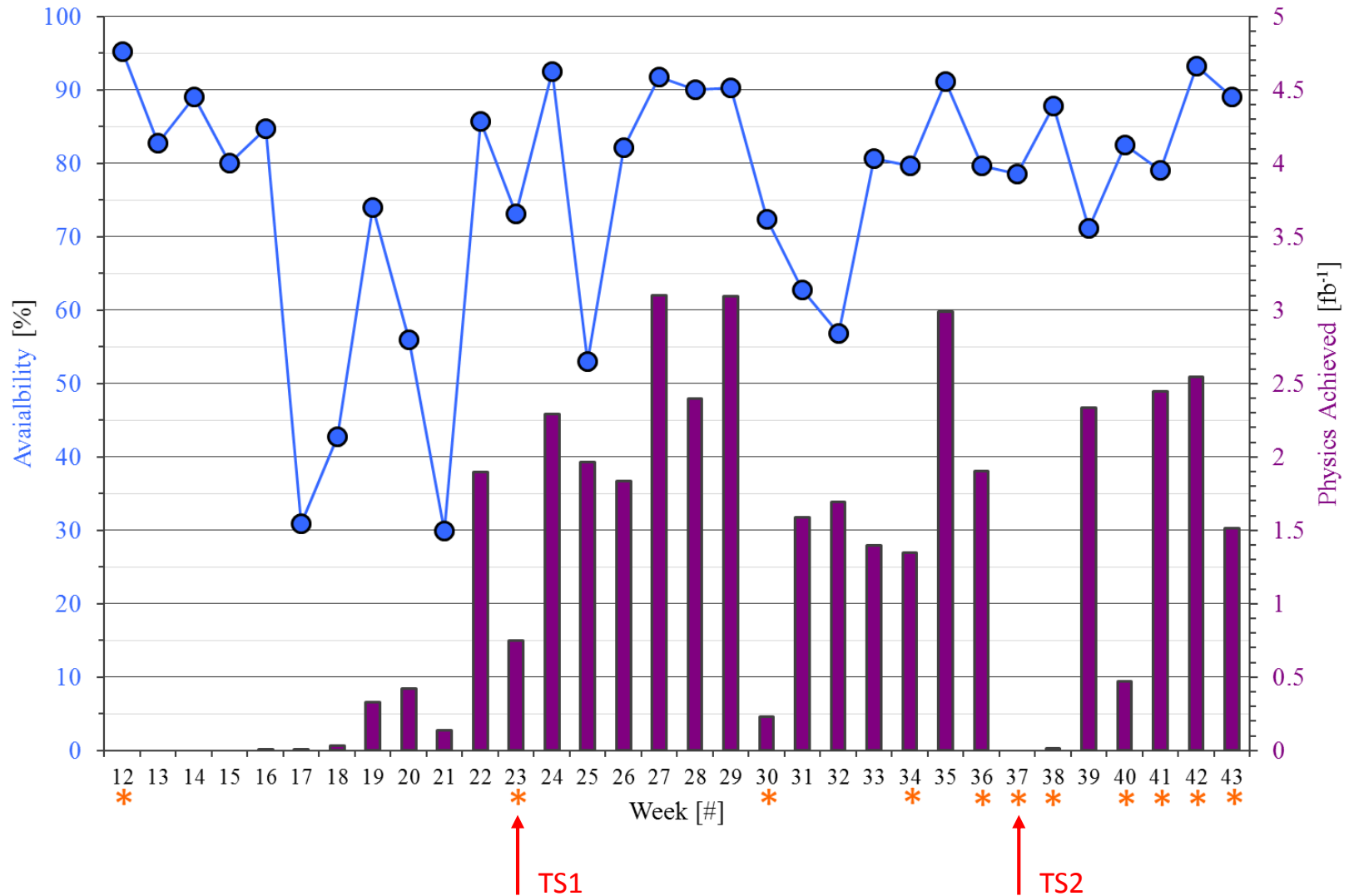


Operations contains nominal cycle + extra measurements (116h) + injection setting-up (23h) + some loss maps (35h) + planned accesses

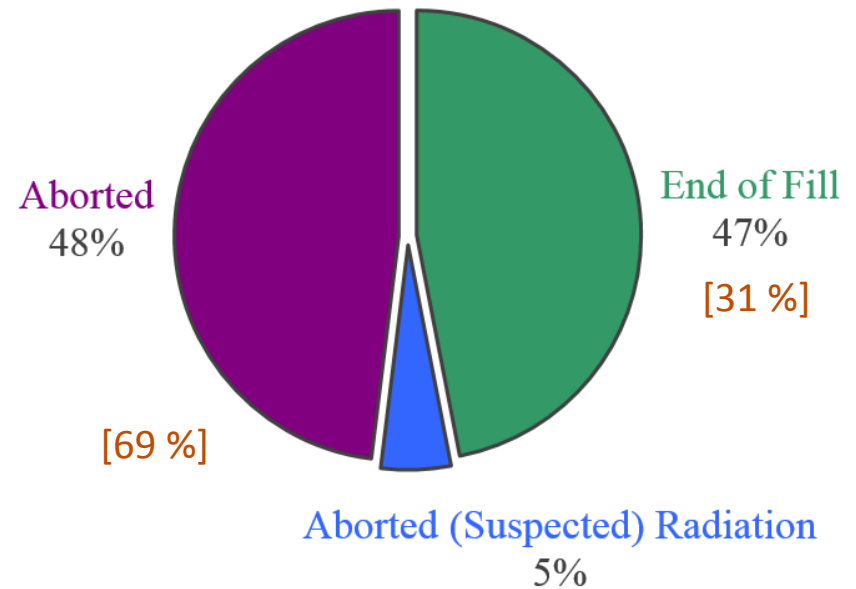
[25 ns Run in 2015]

\* = incomplete weeks

Availability and Physics Achieved by Week



	[#]
Total Fills	762
Fills with Stable Beams	175
Fills with Physics in Adjust	4
→ End of Fill	84
→ Aborted	86
→ Aborted (suspected) R2E	9



Premature Beam Aborts:

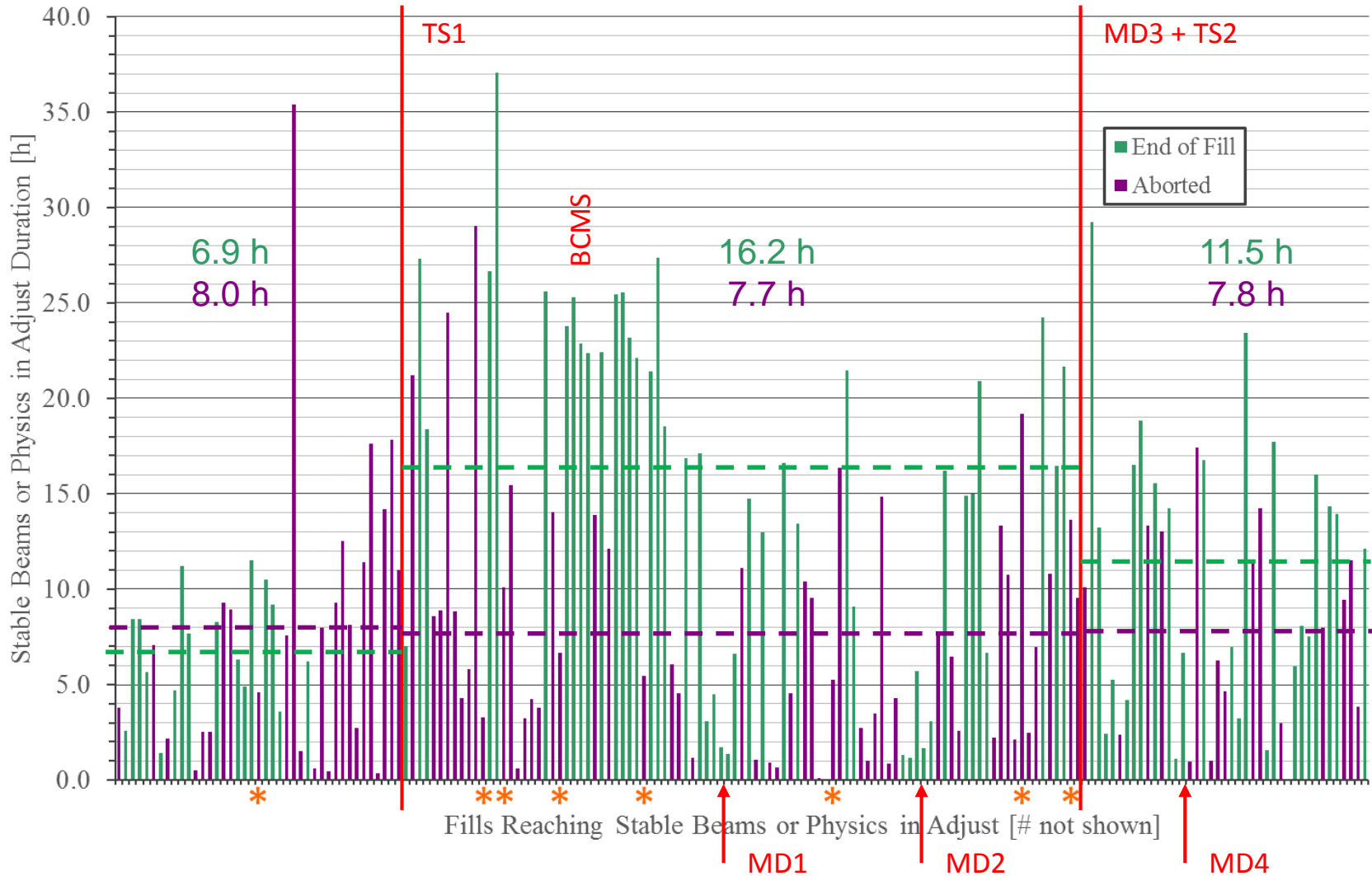
- Main categories [M. Zerlauth, S2]
  - Mains Disturbances (being addressed EYETS) [J. Nielsen, S2]
  - Unidentified Falling Objects (manageable) [A. Lechner, S7]

[25 ns Run in 2015]

## 175 + 4 fills with stable beams

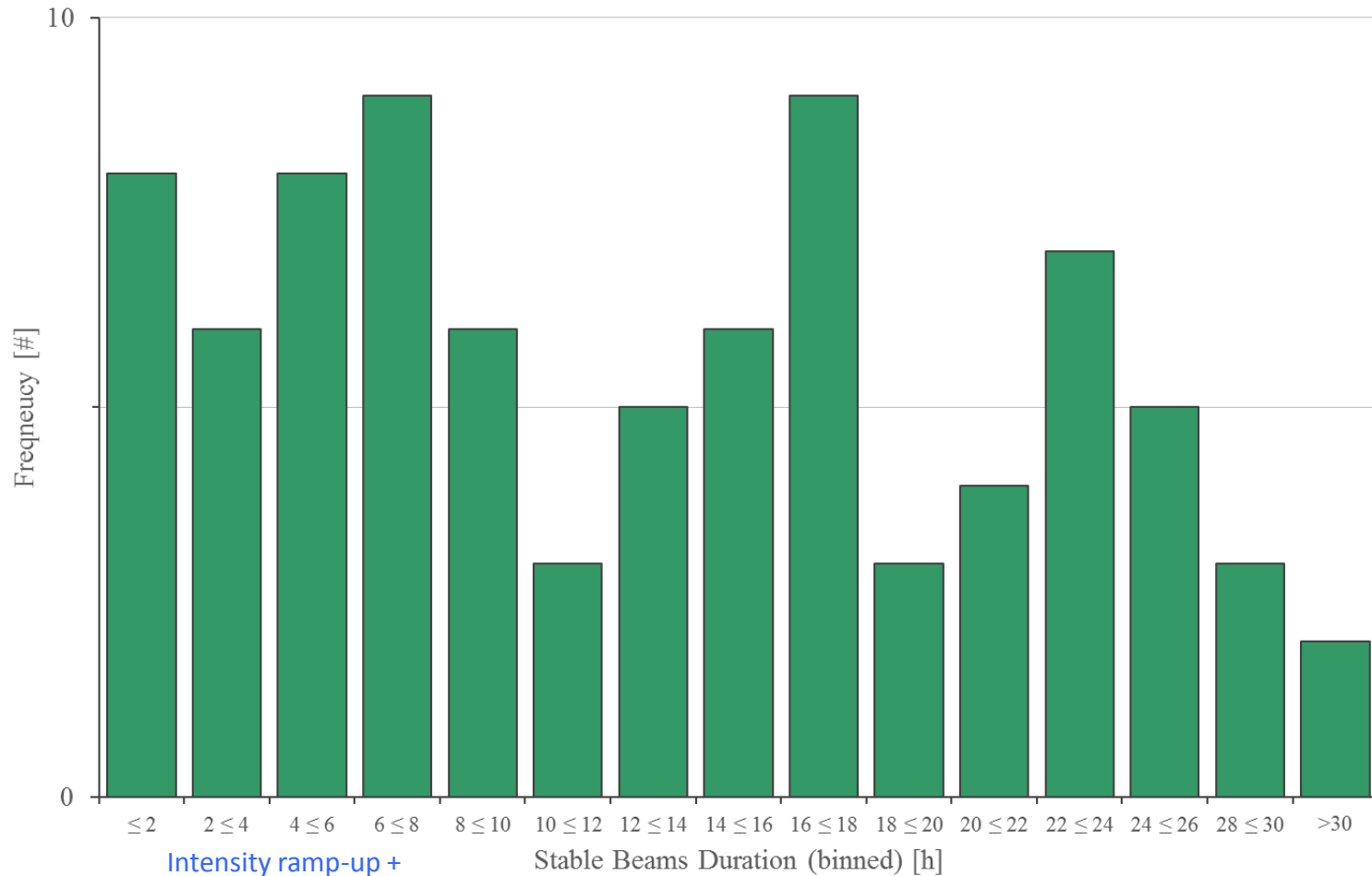
Fill Number vs Stable Beams Duration

\* = (suspected) radiation effect



## 84 fills reaching End Of Fill

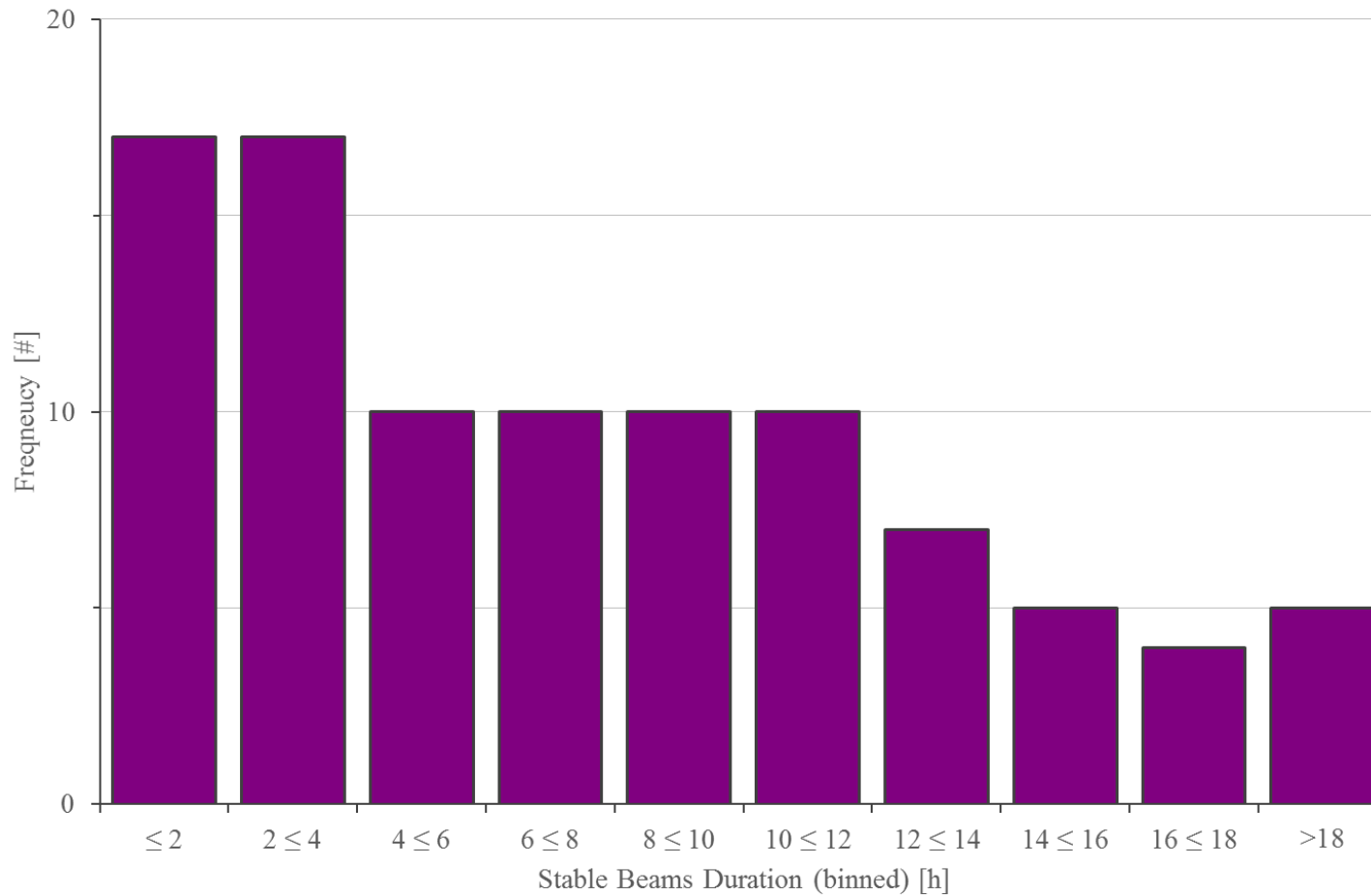
End of Fill Stable Beams Duration Histogram



Intensity ramp-up +  
 Access requests +  
 Anticipate loss of cryo conditions +  
 Measurements (e.g. e-cloud reference)

86 + 9 fills prematurely Aborted

Aborted Fills Stable Beams Duration Histogram



Full period = 779 faults & 77 pre-cycles due to faults

Root Cause Class	Root Cause System	Faults [#]
Equipment	Injector Complex	138
	Technical Services	67
	Power Converters	66
	Experiments	52
	Quench Protection	45
	Cryogenics	42
	Beam Instrumentation	40
	Radio Frequency	40
	Beam Dumping System	30
	Injection Systems	30
	Magnet circuits	27
	Collimation	23
	Accelerator Controls	19
	Access System	12
	Transverse Damper	10
	Ventilation Door	10
	Machine Interlocks	8
	IT Services	2
	Other	2
	Vacuum	2
Beam Exciters	1	
Orbit Control	0	
Beam	Injection	29
	Losses	27
	Induced Quench	5
Operations	Error, Settings	44
	Access Management	8
	$\Sigma$	779



Full period = 779 faults & 77 pre-cycles due to faults

Root Cause Class	Root Cause System	Faults [#]	Fault Duration [h]
Equipment	Injector Complex	138	360.38
	Technical Services	67	221.68
	Power Converters	66	106.62
	Experiments	52	59.86
	Quench Protection	45	36.97
	Cryogenics	42	361.08
	Beam Instrumentation	40	47.08
	Radio Frequency	40	40.20
	Beam Dumping System	30	70.20
	Injection Systems	30	46.27
	Magnet circuits	27	74.50
	Collimation	23	73.42
	Accelerator Controls	19	9.63
	Access System	12	24.50
	Transverse Damper	10	13.84
	Ventilation Door	10	21.12
	Machine Interlocks	8	5.96
	IT Services	2	2.52
	Other	2	0.13
	Vacuum	2	1.37
Beam Exciters	1	0.04	
Orbit Control	0	0.00	
Beam	Injection	29	9.18
	Losses	27	0.75
	Induced Quench	5	0.34
Operations	Error, Settings	44	11.36
	Access Management	8	21.48
	$\Sigma$	<b>779</b>	<b>1620.5</b>

Full period = 779 faults & 77 pre-cycles due to faults

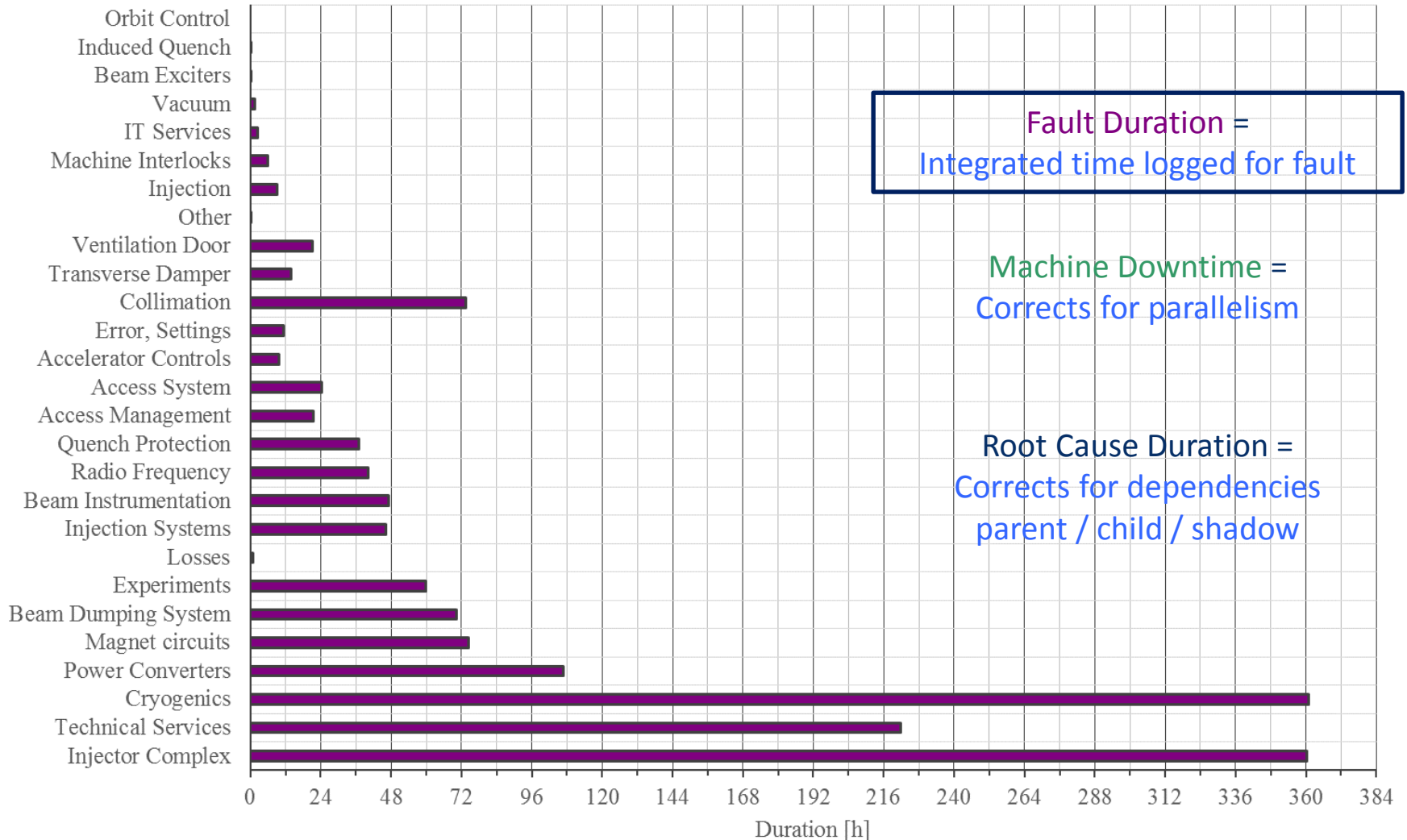
Root Cause Class	Root Cause System	Faults [#]	Fault Duration [h]
Equipment	Injector Complex	138	360.38
	Technical Services	67	221.68
	Power Converters	66	106.62
	Experiments	52	59.86
	Quench Protection	45	36.97
	Cryogenics	42	361.08
	Beam Instrumentation	40	47.08
	Radio Frequency	40	40.20
	Beam Dumping System	30	70.20
	Injection Systems	30	46.27
	Magnet circuits	27	74.50
	Collimation	23	73.42
	Accelerator Controls	19	9.63
	Access System	12	24.50
	Transverse Damper	10	13.84
	Ventilation Door	10	21.12
	Machine Interlocks	8	5.96
	IT Services	2	2.52
	Other	2	0.13
	Vacuum	2	1.37
Beam Exciters	1	0.04	
Orbit Control	0	0.00	
Beam	Injection	29	9.18
	Losses	27	0.75
	Induced Quench	5	0.34
Operations	Error, Settings	44	11.36
	Access Management	8	21.48
$\Sigma$		<b>779</b>	<b>1620.5</b>

Fault Duration =  
Integrated time logged for fault

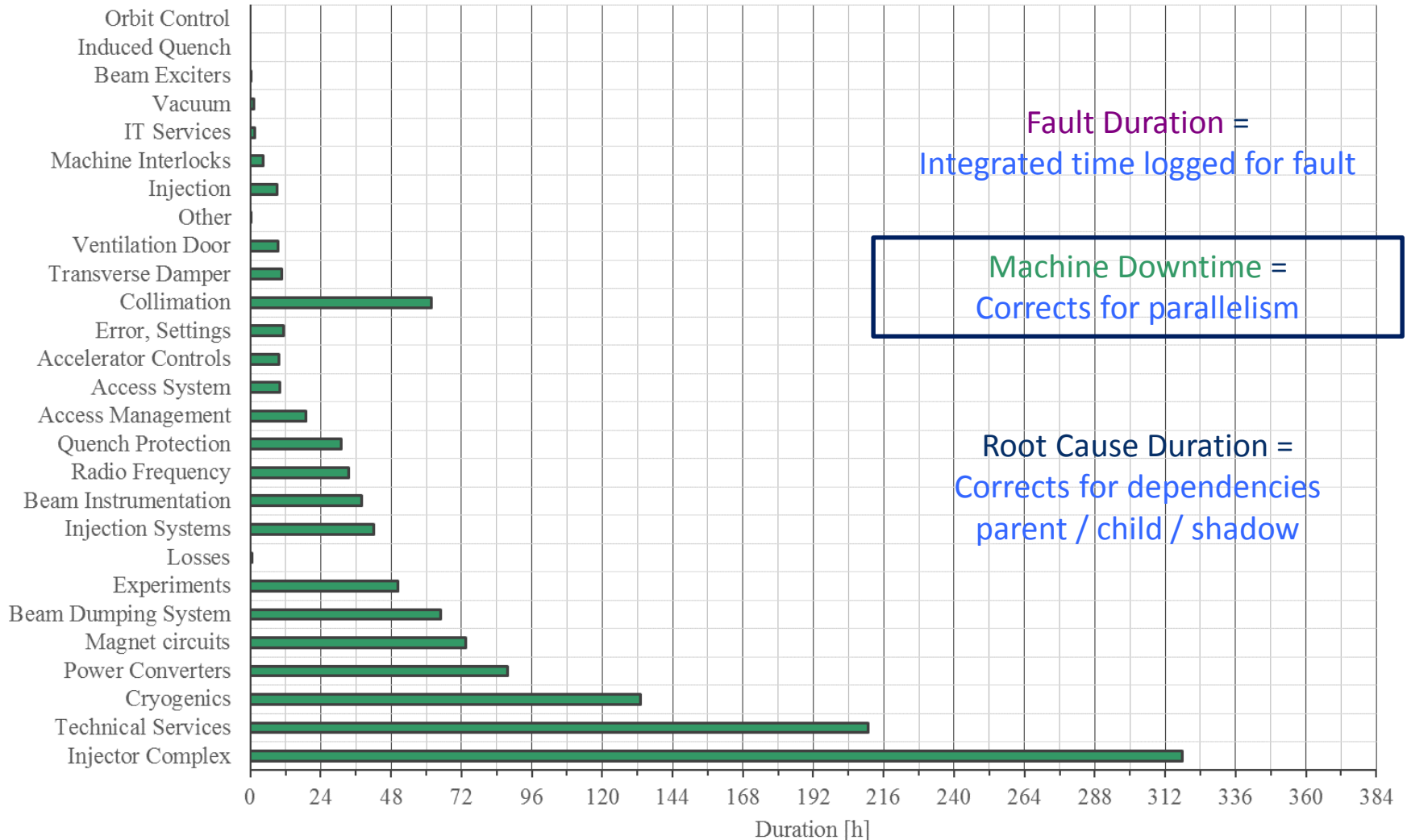
Machine Downtime =  
Corrects for parallelism

Root Cause Duration =  
Corrects for dependencies  
parent / child / shadow

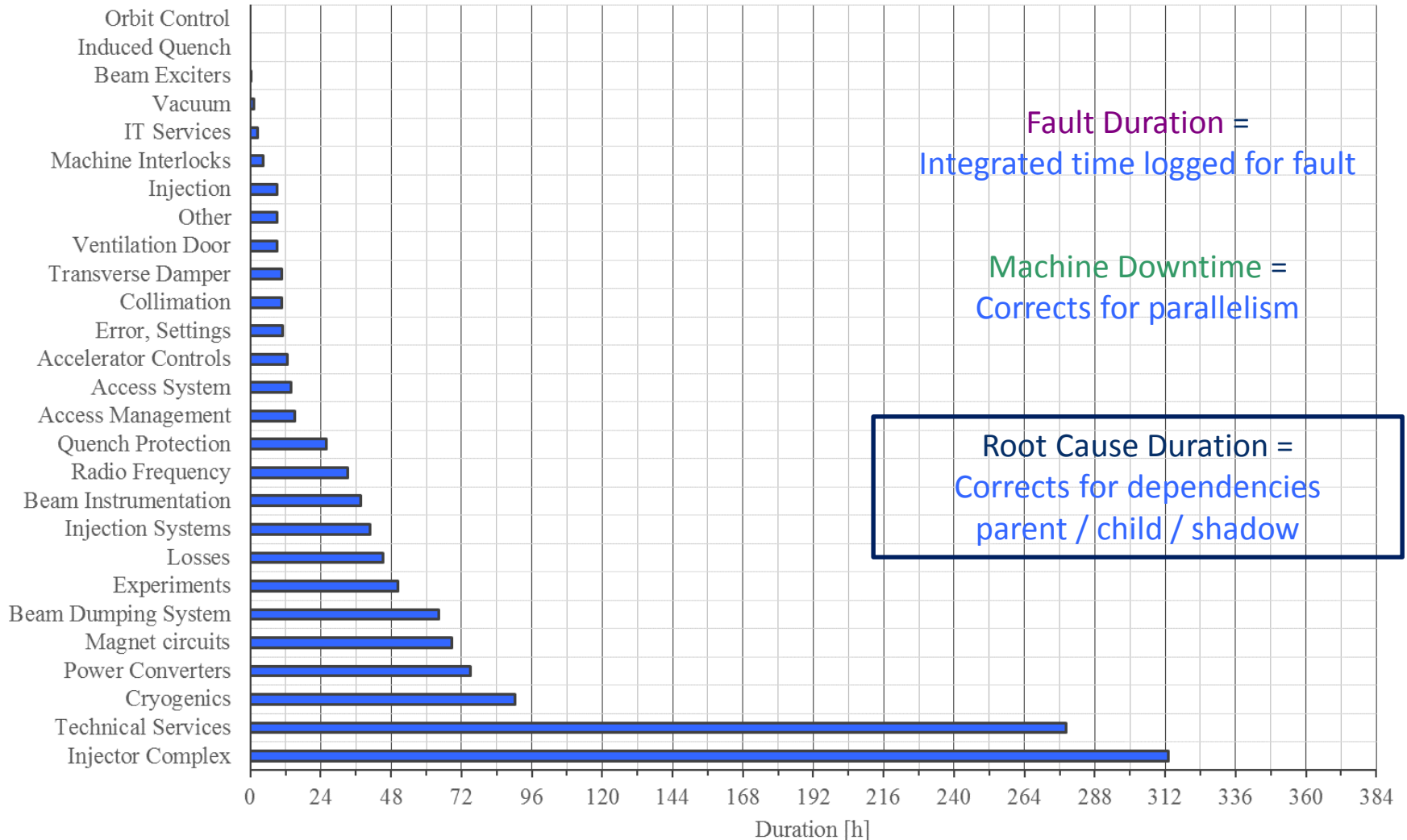
Stacked Pareto - Fault Duration, Machine Downtime and Root Cause Duration vs Root Cause System



Stacked Pareto - Fault Duration, Machine Downtime and Root Cause Duration vs Root Cause System



Stacked Pareto - Fault Duration, Machine Downtime and Root Cause Duration vs Root Cause System



5 systems ≈67%

Root Cause System	Root Cause Duration [h]	% of Total Duration
Injector Complex	313.21	25.4
Technical Services	278.35	22.6
Cryogenics	90.32	7.3
Power Converters	75.05	6.1
Magnet Circuits	68.75	5.6

= 825.7 hours

= 67.0%

- Dominated by high-impact faults:
  - Injector Complex: PS main power supply, PS vacuum leak.
  - Technical Services: 66kV transformer issue, flooding in point 3.
  - Cryogenics: PLC, cold compressor failures.
  - Magnet Circuits: Investigation of suspected inter-turn short in RB.A12.
  - In addition, LBDS: 3x MKBH erratic triggering (1 during ion run).

[B. Mikulec, S2]

[J. Nielsen, S2]

[K. Brodzinski, S2]

[D. Wollmann, S7]

[E. Carlier, S7]

- Quench Protection System [J. Steckert, S7]
  - Almost invisible to OP (except trips during ramp-down & pre-cycle)
  
- Radiation Effects to Electronics [S. Danzeca, S6]
  - Significantly fewer events than predicted
  
- Cryogenic System [K. Brodzinski, S2]
  - Impact of e-cloud under control
  - Solved recurring sources of faults

## Availability:

- Excellent
  - Several weeks  $> 90\%$  ,  $> 3 \text{ fb}^{-1}$
  - Key: very reproducible operating conditions

## Un-Availability:

- Typically due to long-isolated issues
  - 66kV transformer issue, flooding in point 3, ...
- Premature beam aborts
  - Mains Disturbances (being addressed EYETS)
  - Unidentified Falling Objects (manageable)

## 2017 Outlook:

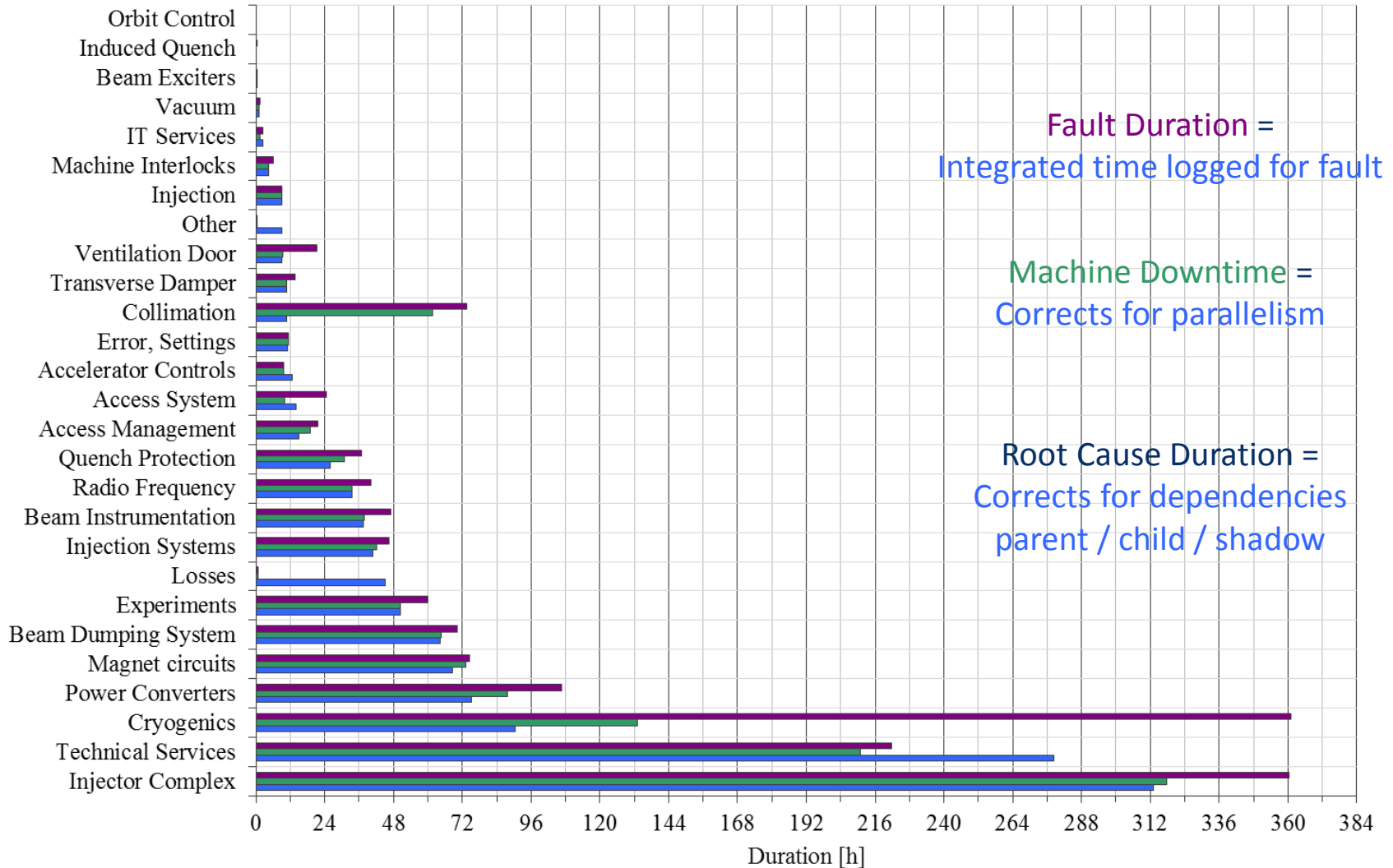
- No reason to expect worse availability than 2016 with same operating conditions
  - Possibly learning required if 288 b/ injection
  - Deconditioning of S12 following magnet replacement (e-cloud and UFOs)

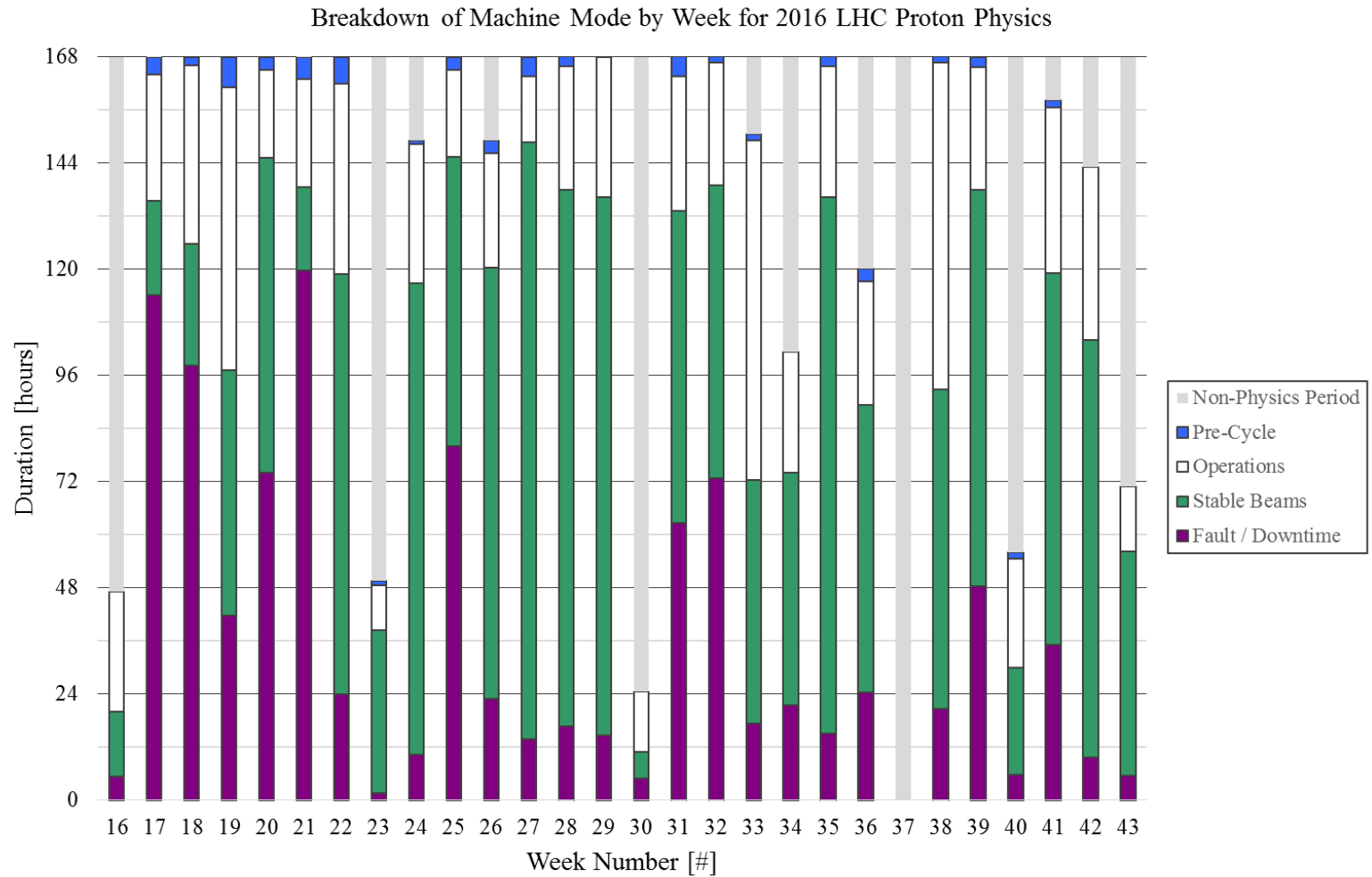


Thank you!

Questions?

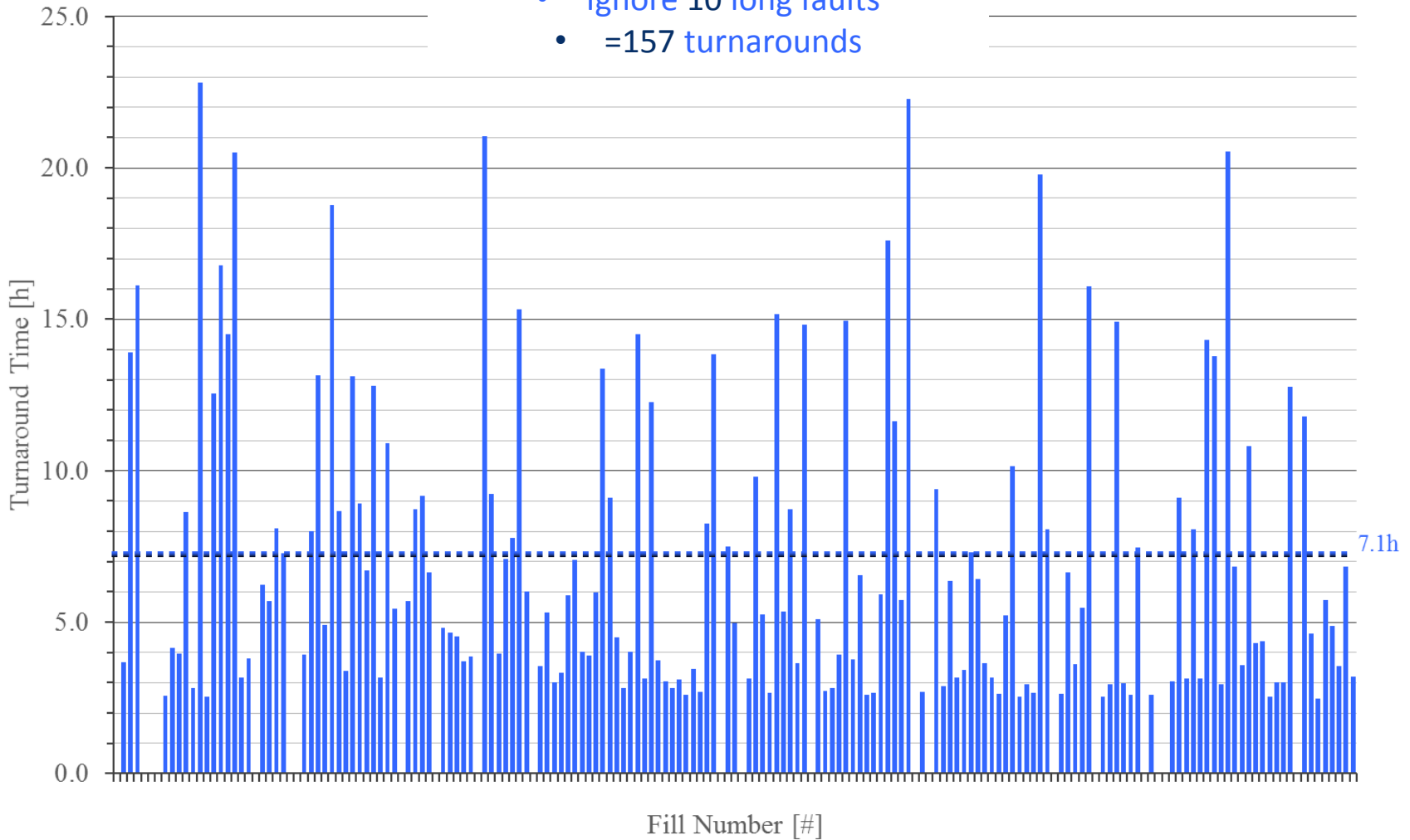
Clustered Pareto - **Fault Duration**, **Machine Downtime** and **Root Cause** Duration vs Root Cause System





175 + 4 fills with stable beams, time to get to fill # from previous fill

- Ignore 12 mode changes
- Ignore 10 long faults
- =157 turnarounds



175 + 4 fills with stable beams, time to get to fill # from previous fill

- Ignore 12 mode changes
- Ignore 10 long faults
- =157 turnarounds

