From LHC statistics to AvailSim modelling
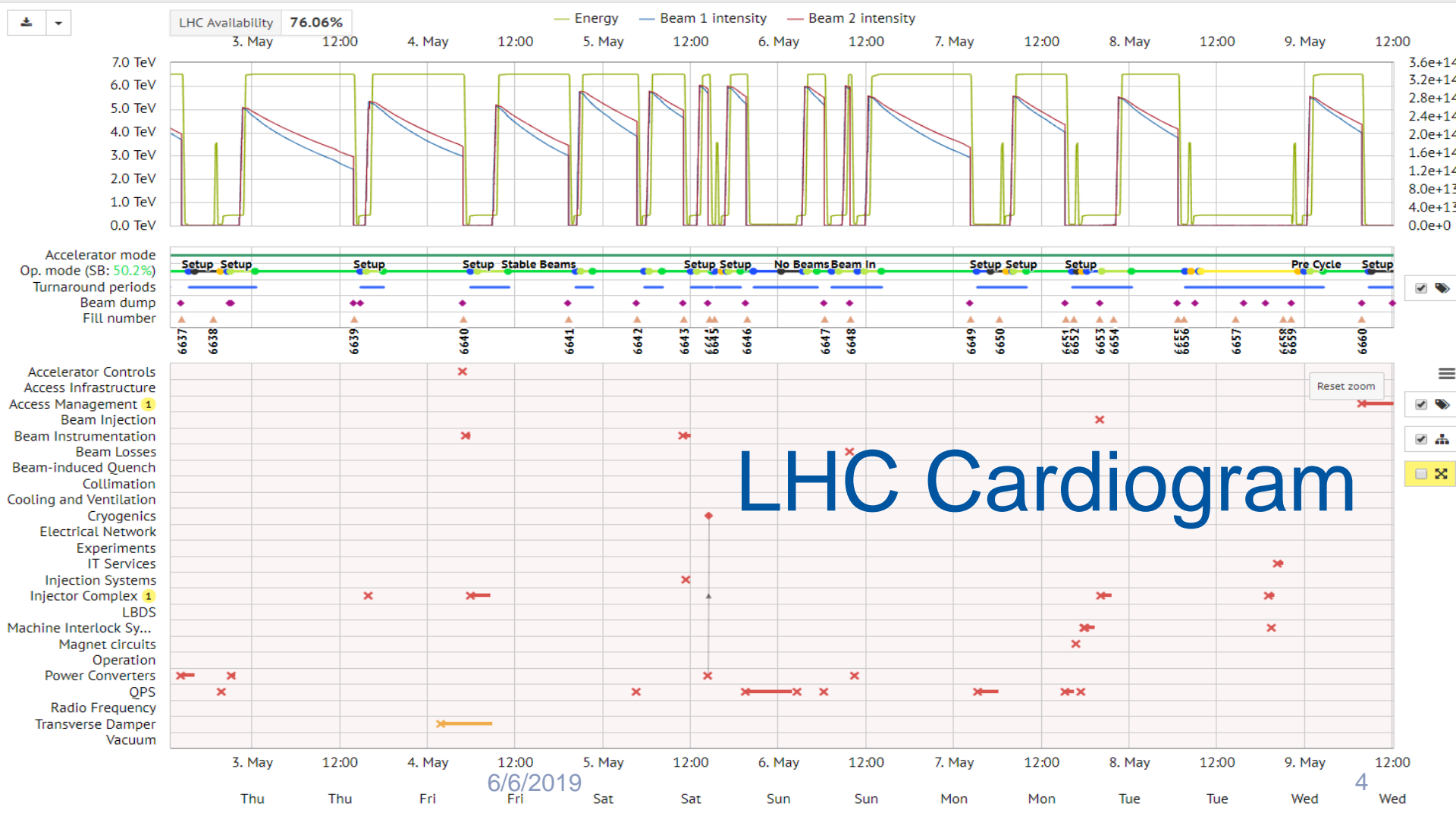
M.Vekaria, A.Apollonio, T.Cartier-Michaud

6/06/2019

Introduction
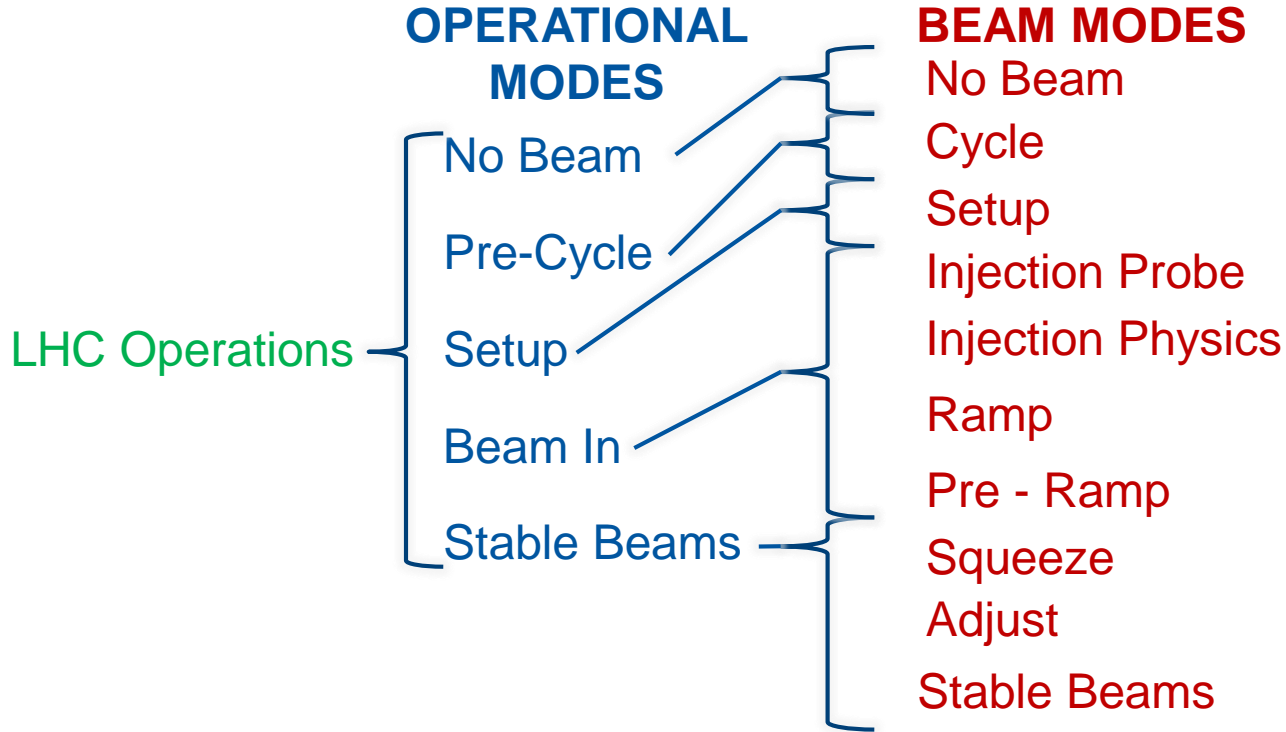
- Data sources
- Introduction to LHC Operations
  - Fault statistics in BModes
- Injection Investigation
  - Physics and Probe
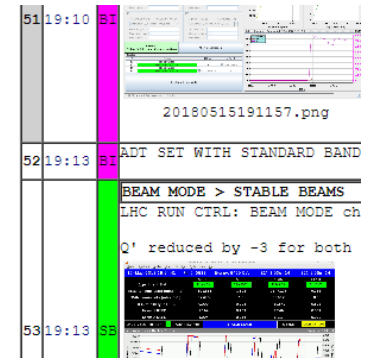- AvailSim inputs

LHC Cardiogram

Availsim

- Monte-Carlo simulation tool
  - Simulate the operation of accelerators eg. LHC
- Inputs based on observed performance
  - Works using different reliability measures (Mean Time To Repair, Mean Time To Fail) from faults
  - These change depending on the beam mode they occur in.
- Also requires Beam Mode durations as an input

LHC Operation Breakdown

Aim is to calculate Beam Mode durations and calculate failure rates and repair times based on beam mode

OPERATIONAL MODES

LHC Operations
- No Beam
- Pre-Cycle
- Setup
- Beam In
- Stable Beams

BEAM MODES
- No Beam
- Cycle
- Setup
- Injection Probe
- Injection Physics
- Ramp
- Pre - Ramp
- Squeeze
- Adjust
- Stable Beams

51 | 19:10 | BI

20180515191157.png

52 | 19:13 | BI

ADT SET WITH STANDARD BAND

BEAM MODE > STABLE BEAMS
LHC RUN CTRL: BEAM MODE ch

Q' reduced by -3 for both
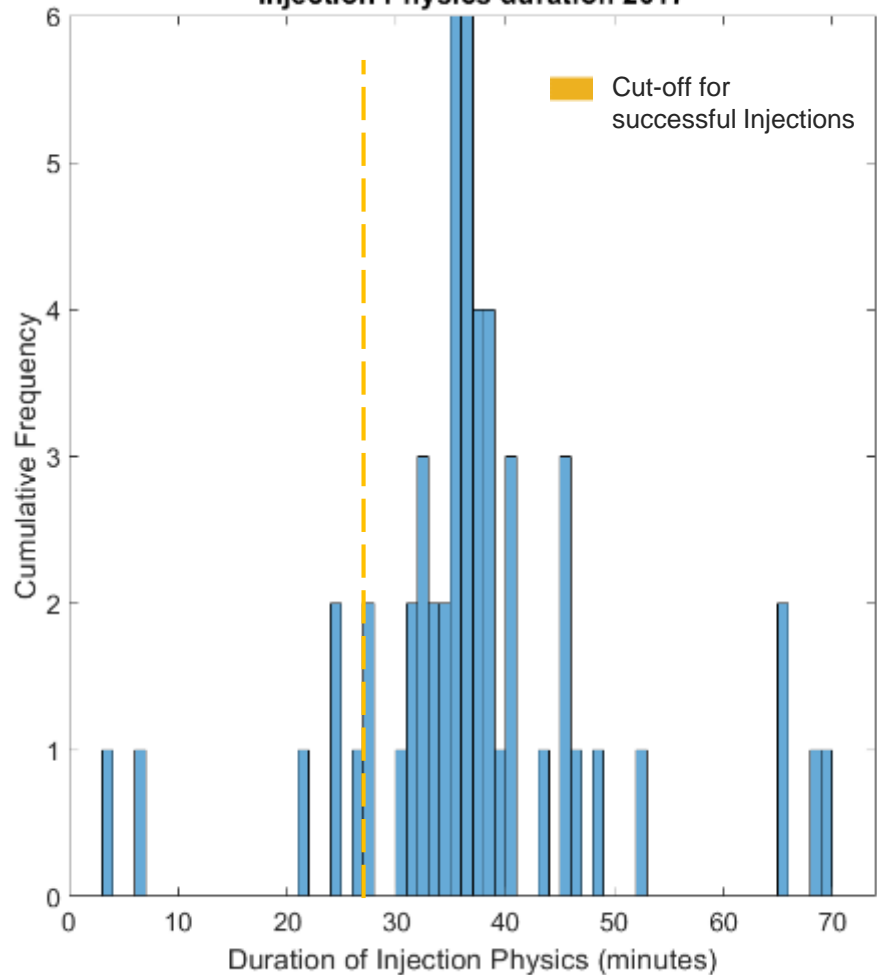
53 | 19:13 | SB

E-Logbook

Data Sources

- Timber
  - Fill number timings
  - Beam modes
  - Beam Intensity
- AFT
  - Fault data
- Post Mortem
  - Injection scheme

Injection Statistics

- Tasked with looking into Injection inefficiencies.

  - Looked at "injection physics" and "injection probe" for year 17-18 for AvailSim

  - One of the least reproducible modes in LHC operation

    - Why isn't theoretical minima (28mins) reached?

      - $42*20*2/60 = 28$

      - Variety of discrepancies between injections that cannot be explained by faults

  - Failures should be expected to correlate to beam intensity

    - Looked at 25ns spaced 2556b

Injection Physics duration 2017
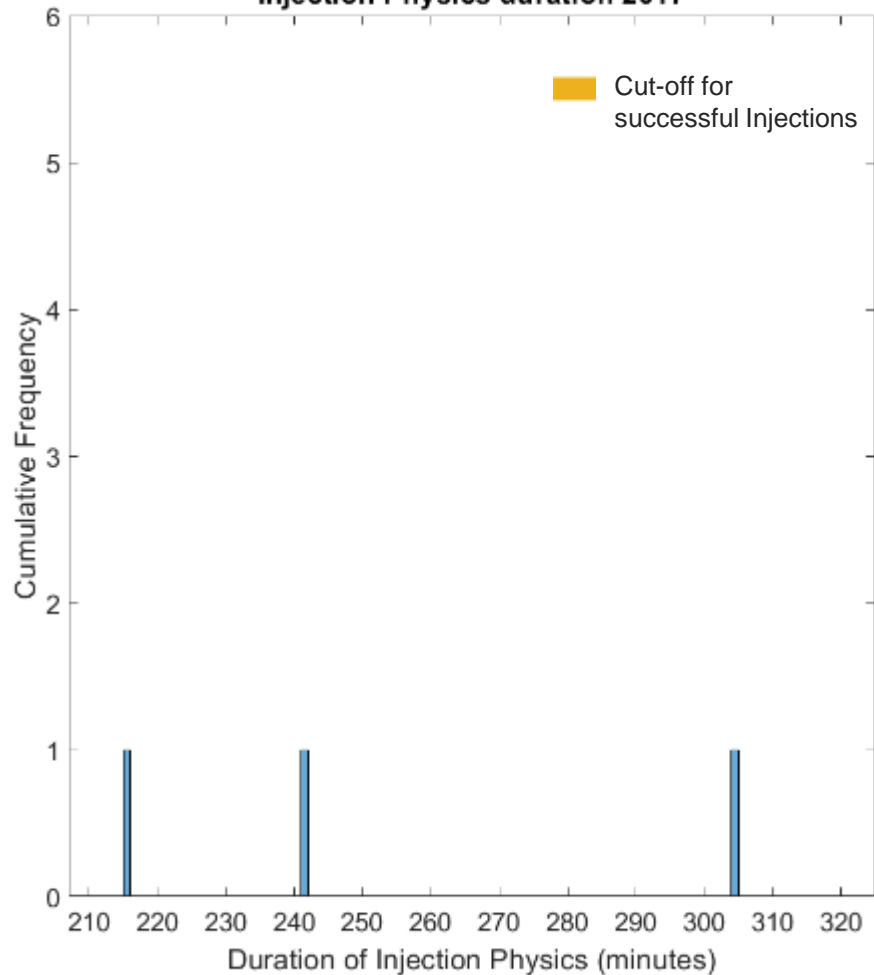
Why Categorise?

- When looking through E-Logbook, these are the most common
- What is "no explanation"?
  - There is no clear explanation in the logbook
- All of this takes into account registered blocking faults, unregistered are noted as "minor hardware error" e.g.. Faulty QPS circuit board
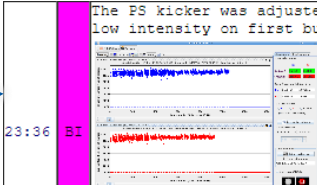
(ﾉ °□°）ﾉ ︵ ┻━┻

fill#	injphy start	injph end	nominal dur	net dur	reason
6643	05/05/2018 10:15	05/05/2018 11:13	00:57:15	00:57:15	ATLAS restart
6645	05/05/2018 14:33	05/05/2018 15:04	00:30:23	00:30:23	no explanation
6646	06/05/2018 01:04	06/05/2018 01:35	00:31:12	00:31:12	no explanation
6647	06/05/2018 06:13	06/05/2018 07:11	00:58:33	00:58:33	no explanation
6648	06/05/2018 09:44	06/05/2018 10:23	00:38:48	00:38:48	minor hardware error
6650	07/05/2018 05:32	07/05/2018 06:07	00:35:10	00:35:10	no explanation
6654	07/05/2018 20:04	07/05/2018 20:33	00:29:22	00:29:22	no explanation
6659	08/05/2018 22:09	08/05/2018 22:42	00:32:40	00:32:40	no explanation
6662	09/05/2018 19:31	09/05/2018 20:01	00:29:53	00:29:53	losses
6663	10/05/2018 11:25	10/05/2018 11:58	00:33:23	00:33:23	minor hardware error
6666	10/05/2018 19:39	10/05/2018 20:25	00:45:26	00:45:26	injection tuning
6671	11/05/2018 14:37	11/05/2018 15:28	00:51:02	00:51:02	measurements
6672	11/05/2018 15:36	11/05/2018 16:07	00:30:27	00:30:27	no explanation
6674	12/05/2018 01:41	12/05/2018 02:12	00:30:45	00:30:45	losses
6677	13/05/2018 10:46	13/05/2018 11:16	00:29:46	00:29:46	losses, scraping
6680	14/05/2018 03:46	14/05/2018 04:16	00:29:24	00:29:24	injection tuning
6681	14/05/2018 04:21	14/05/2018 04:54	00:32:20	00:32:20	losses
6684	15/05/2018 03:58	15/05/2018 04:38	00:40:10	00:40:10	PS cavity pulse
6685	15/05/2018 06:04	15/05/2018 07:10	01:06:09	01:06:09	injection tuning
6685	15/05/2018 07:16	15/05/2018 08:35	01:18:39	01:18:39	losses, orbit correction
6687	15/05/2018 13:37	15/05/2018 14:35	00:58:06	00:58:05	losses
6696	17/05/2018 23:01	17/05/2018 23:35	00:33:40	00:33:40	BSRT reset
6700	19/05/2018 00:52	19/05/2018 01:28	00:35:20	00:35:20	correction
6702	19/05/2018 19:40	19/05/2018 20:12	00:32:01	00:32:01	no explanation
6703	20/05/2018 01:31	20/05/2018 02:00	00:29:08	00:29:08	BSRT blocked
6705	20/05/2018 04:56	20/05/2018 05:25	00:29:43	00:29:43	no explanation
6709	20/05/2018 18:46	20/05/2018 19:18	00:32:04	00:32:04	no explanation
6710	21/05/2018 10:20	21/05/2018 10:52	00:32:21	00:32:21	SPS BQM
6711	21/05/2018 23:23	22/05/2018 00:27	01:03:54	00:45:09	SPS BQM
6712	22/05/2018 15:21	22/05/2018 15:52	00:30:21	00:30:21	no explanation
6724	25/05/2018 15:33	25/05/2018 16:41	01:07:28	01:07:28	no explanation
6729	26/05/2018 13:07	26/05/2018 13:38	00:30:54	00:30:54	losses

Some examples

- <u>Upstream</u>
- <u>No explanation</u>
- <u>Losses</u>
- <u>Hardware</u>
- <u>Intervention</u>

The PS kicker was adjusted for a longer pulse width which resulted in less BQM rejected bunches due to low intensity on first bunch and overall smaller spread of bunch intensity.
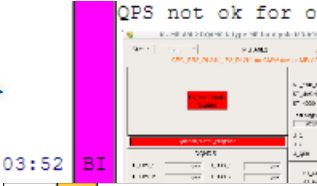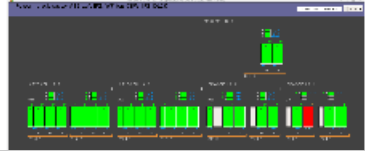
23:36 BI

Beam dump. Losses:

16:27:44 - Alarm on: BLMTI.04L6.B1E10_TCDSA.4L6.B1, integration time: 82 ms, losses = 1.278255E-01,
16:27:44 - Alarm on: BLMTI.06R7.B2I10_TCP.B6R7.B2, integration time: 80 us, losses = 9.354351E00, t
16:27:44 - Alarm on: BLMTI.06R7.B2I10_TCP.B6R7.B2, integration time: 40 us, losses = 9.498337E00, t
16:27:44 - Alarm on: BLMTI.04L6.B1E10_TCDSA.4L6.B1, integration time: 10 ms, losses = 5.333119E-01,
16:27:44 - Alarm on: BLMTI.04R6.B2I10_TCDSA.4R6.B2, integration time: 10 ms, losses = 5.578611E-01

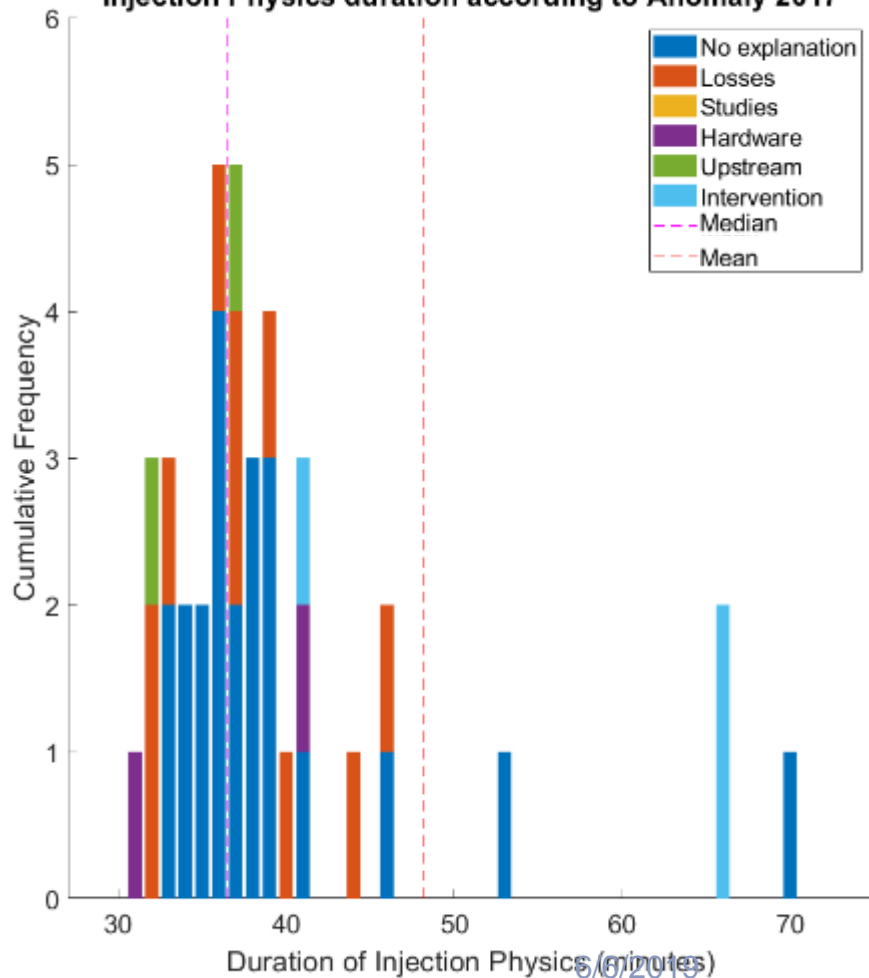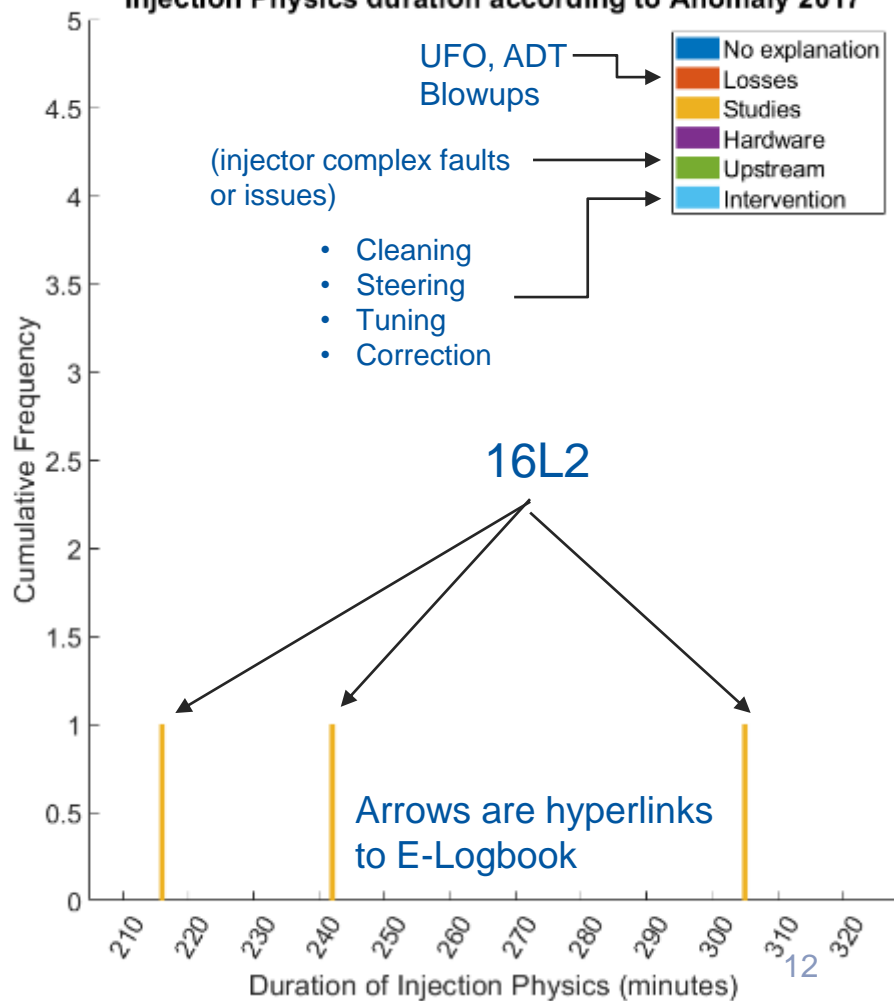QPS not ok for one board (MB.A9L2). We mask it and wait until it recovers.

03:52 BI

08:17 INJ During the access on the 10/05, the solenoids were switched off and then switched back on again to 55A.
the 16L2 issues

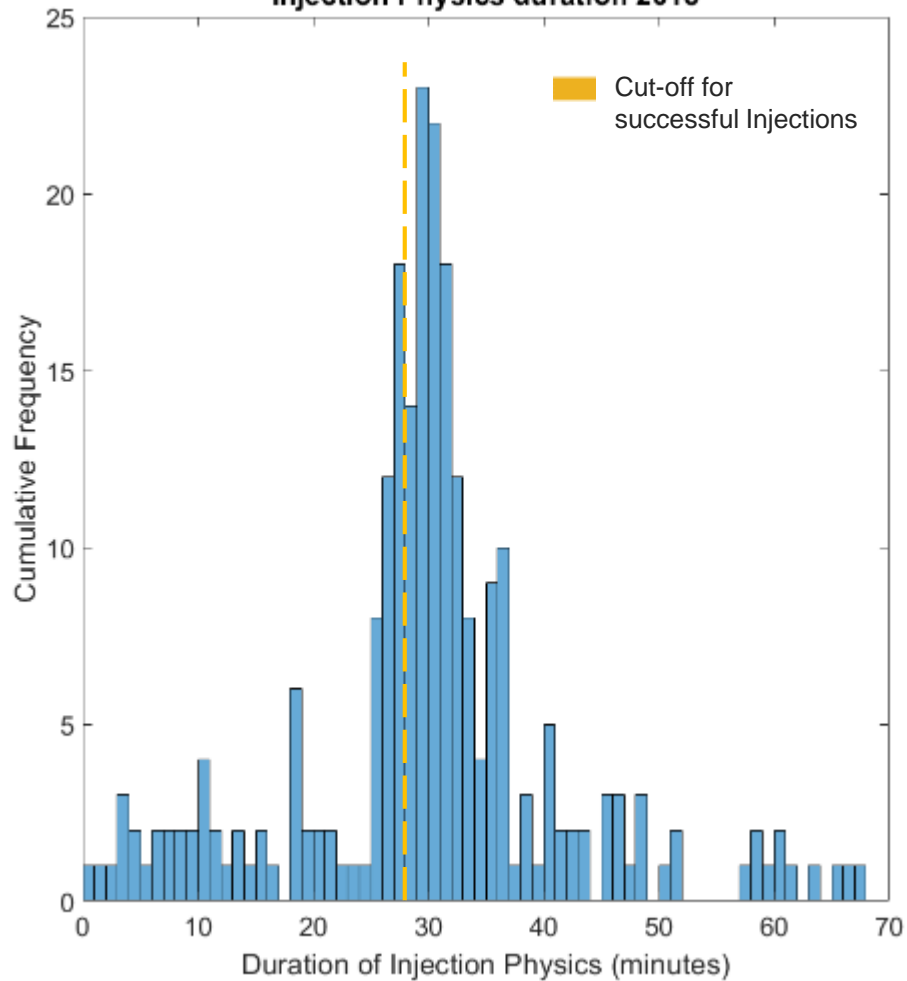Injection Physics duration according to Anomaly 2017

UFO, ADT Blowups

(injector complex faults or issues)

- Cleaning
- Steering
- Tuning
- Correction

16L2

Arrows are hyperlinks to E-Logbook

Injection Probe Time 2017
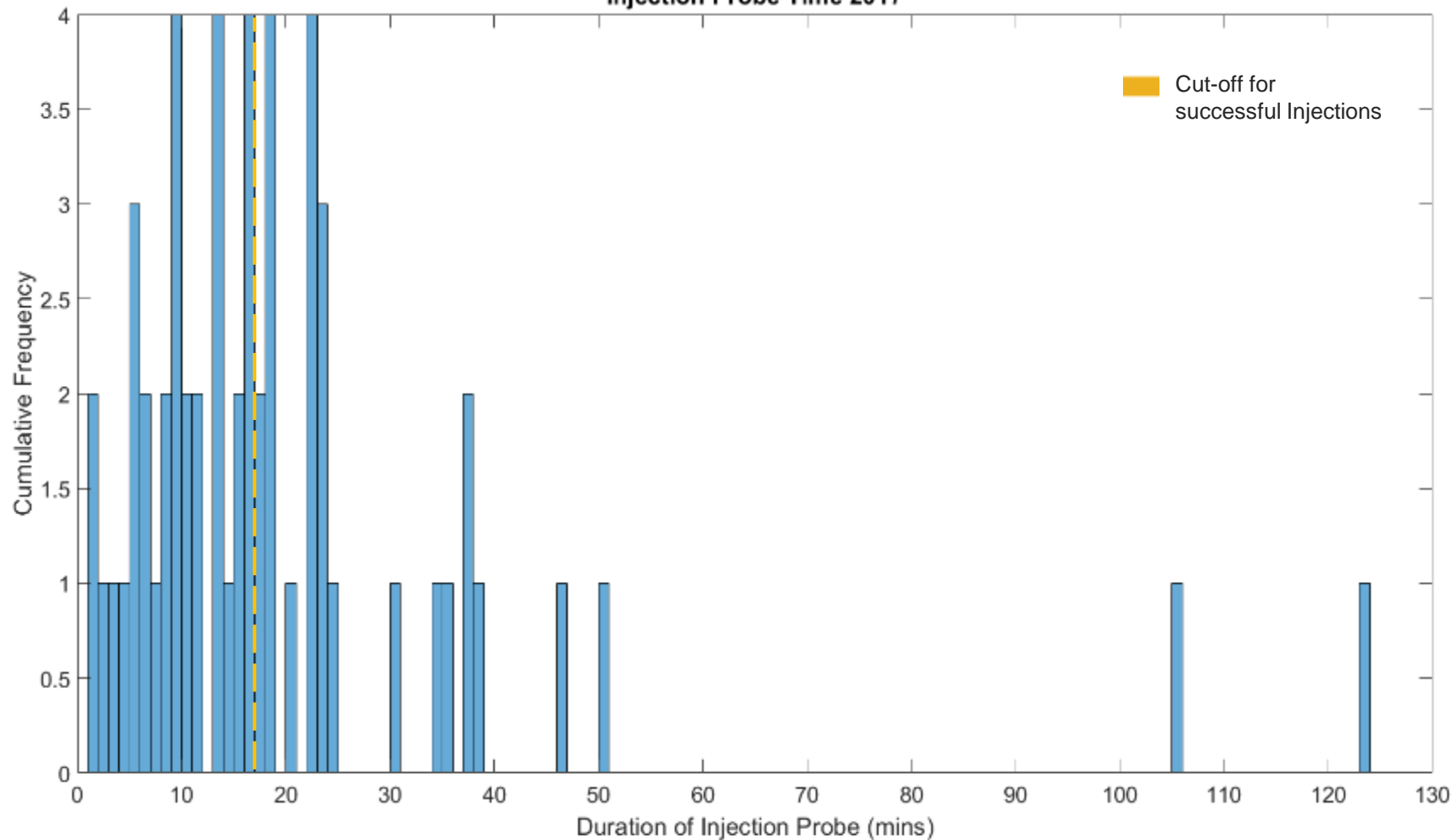
Injection Probe duration according to Anomaly 17
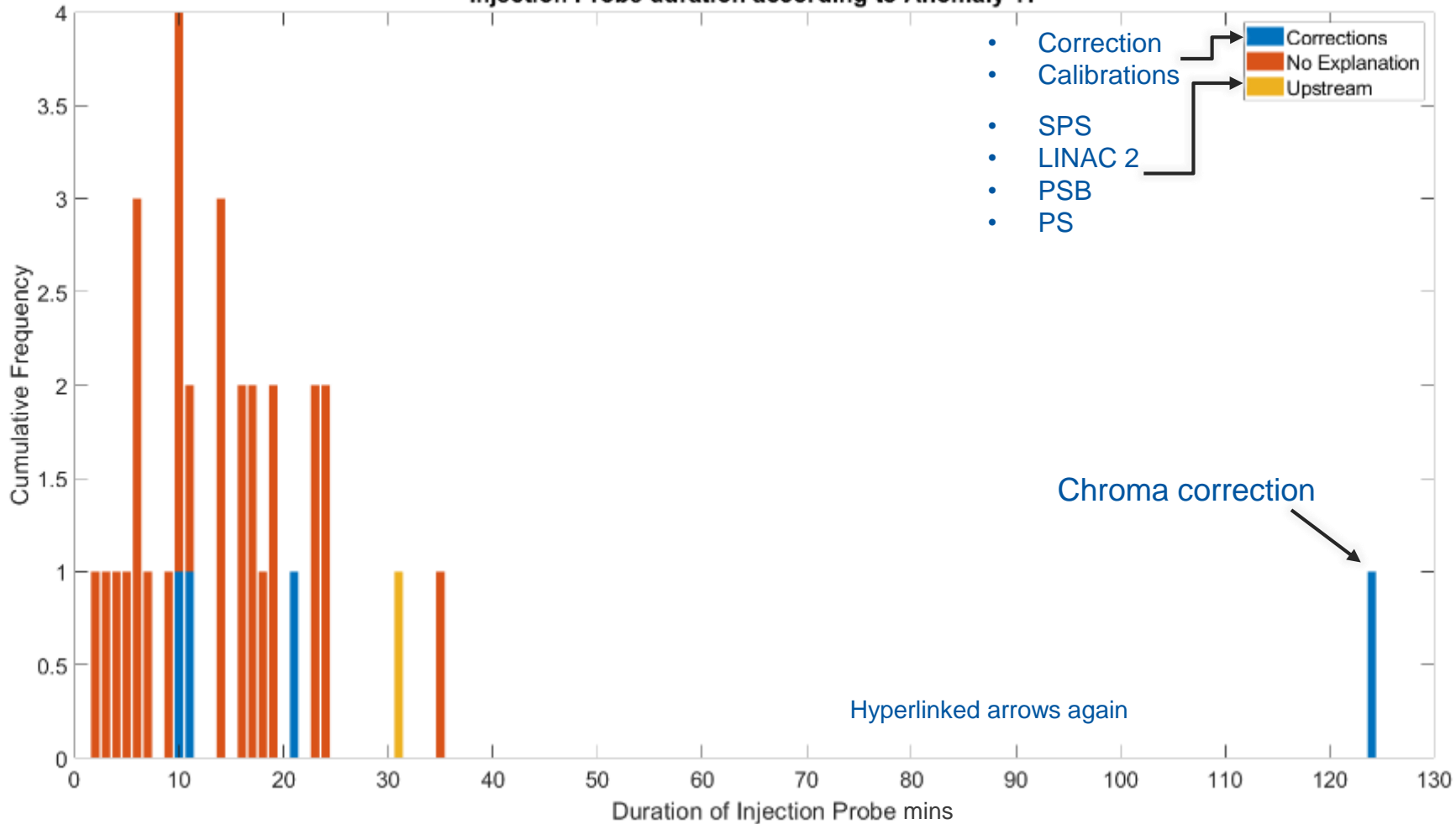
Injection Probe duration 2018
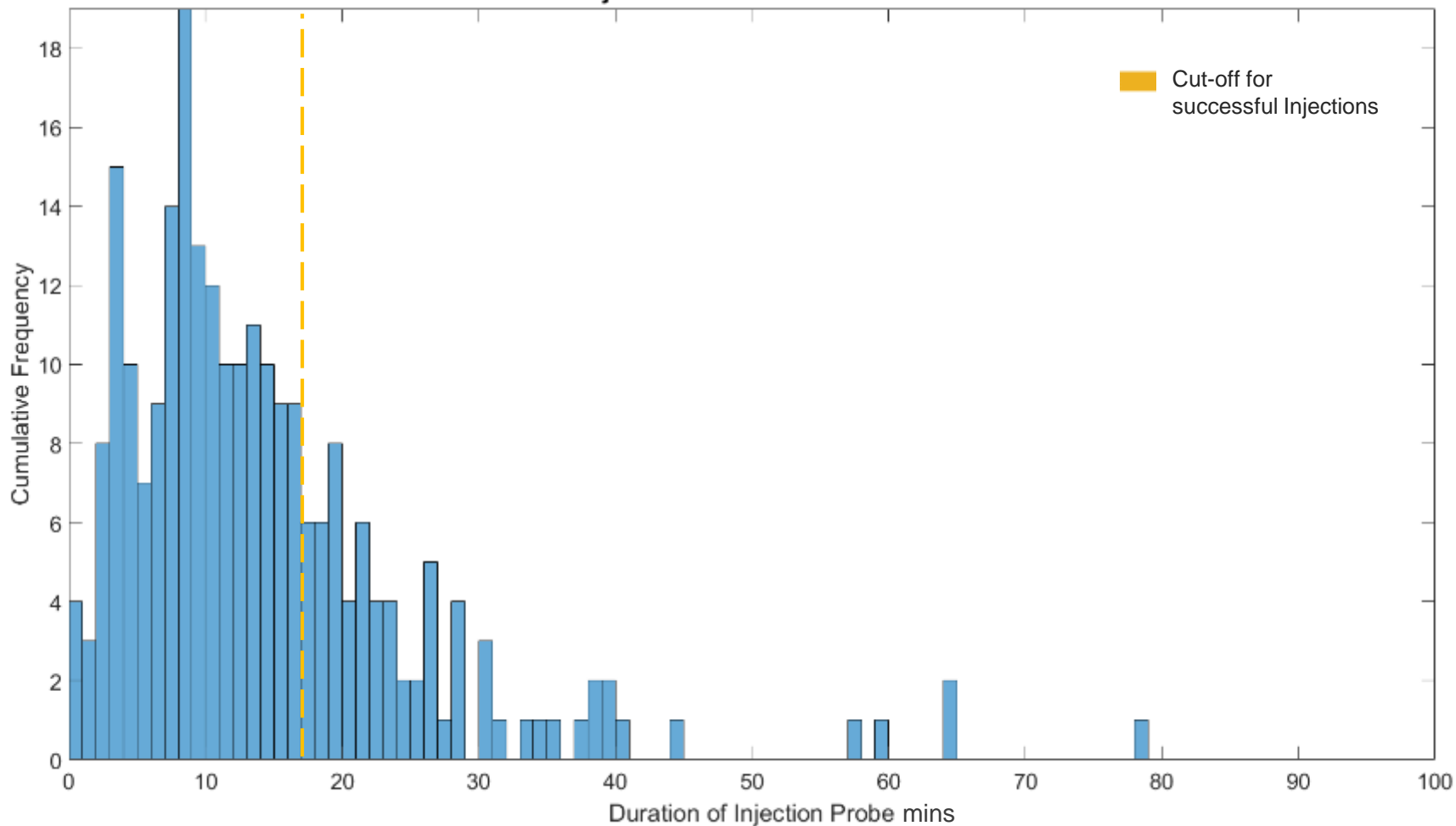
Injection Probe duration according to Anomaly 18
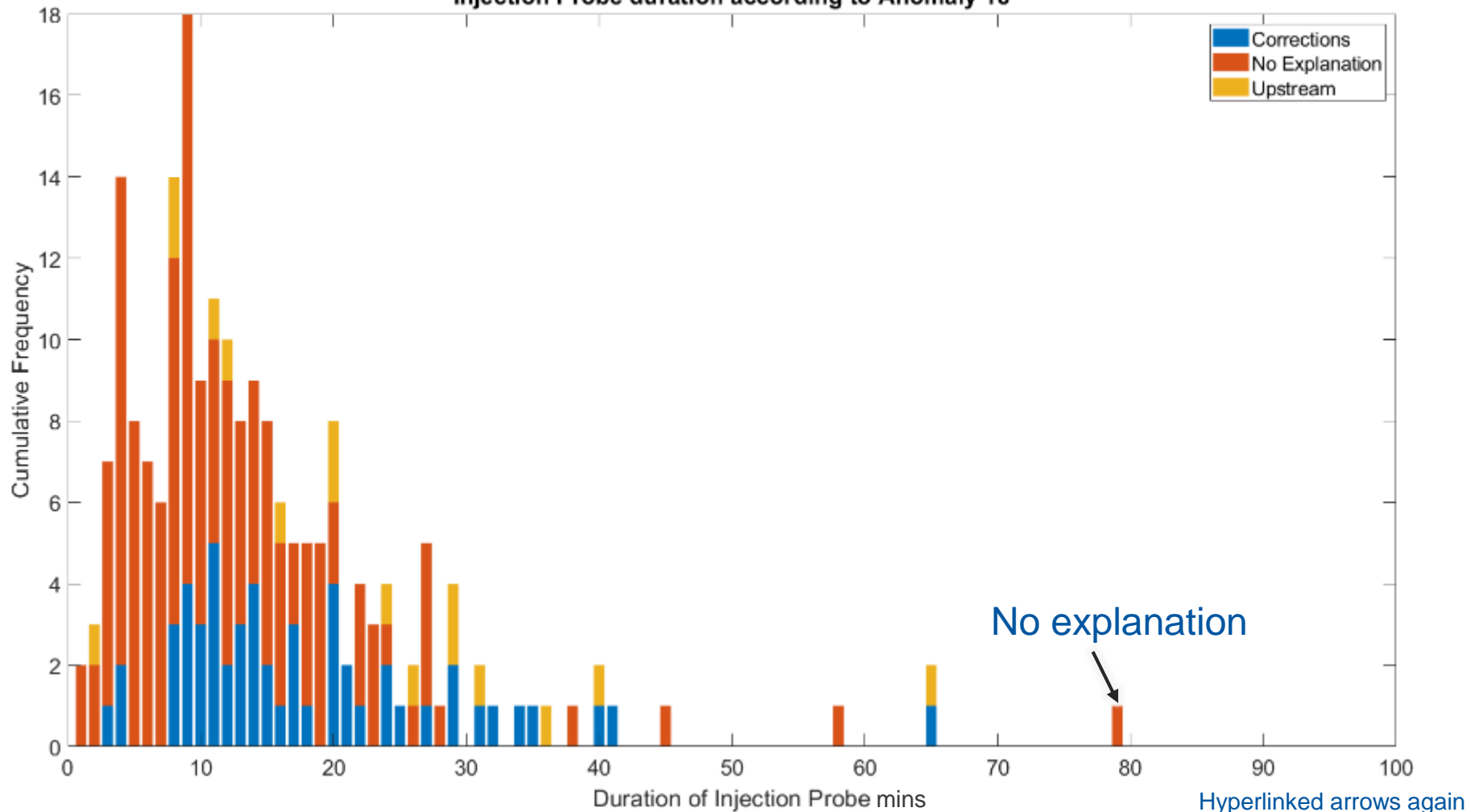
Review

- There's a lot of "no explanation"

  - This isn't necessarily a bad thing!

  - This introduced a new task that would follow up from this (recommended by Bartosik and Rumolo), which is the first 12 bunch train.

  - Expect largest variance because of the required synchronisations and corrections between injectors and LHC

- Could not apply filter to such a large dataset, but 12b injection should be consistent across beam parameters.

First 12 Bunches 2017

Beam 1
Beam 2

str Name	Mean	Median	StDev	Skew
"Beam 1"	8.8386	2.7000	33.2361	10.4226
"Beam 2"	9.8453	2.7000	34.3954	9.8919

Cumulative frequency

Duration in minutes   06/06/2019

First 12 Bunches 2018

Beam 1
Beam 2

str Name	Mean	Median	StDev	Skew
"Beam 1"	8.6776	2.4500	41.7971	12.0328
"Beam 2"	8.6086	2.4500	40.5282	12.7119

Cumulative frequency

Duration in minutes

This doesn't show the variance we expected to see, next steps would be to plot the variance of the whole of the injection process
More analysis to come
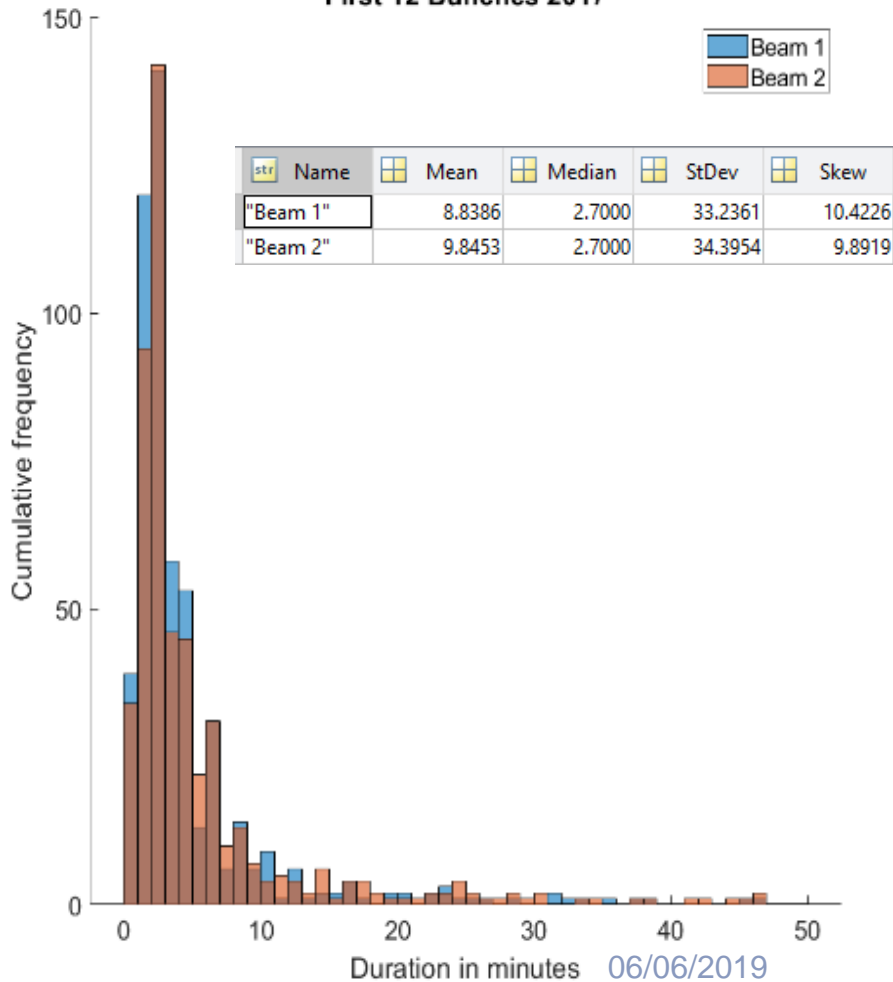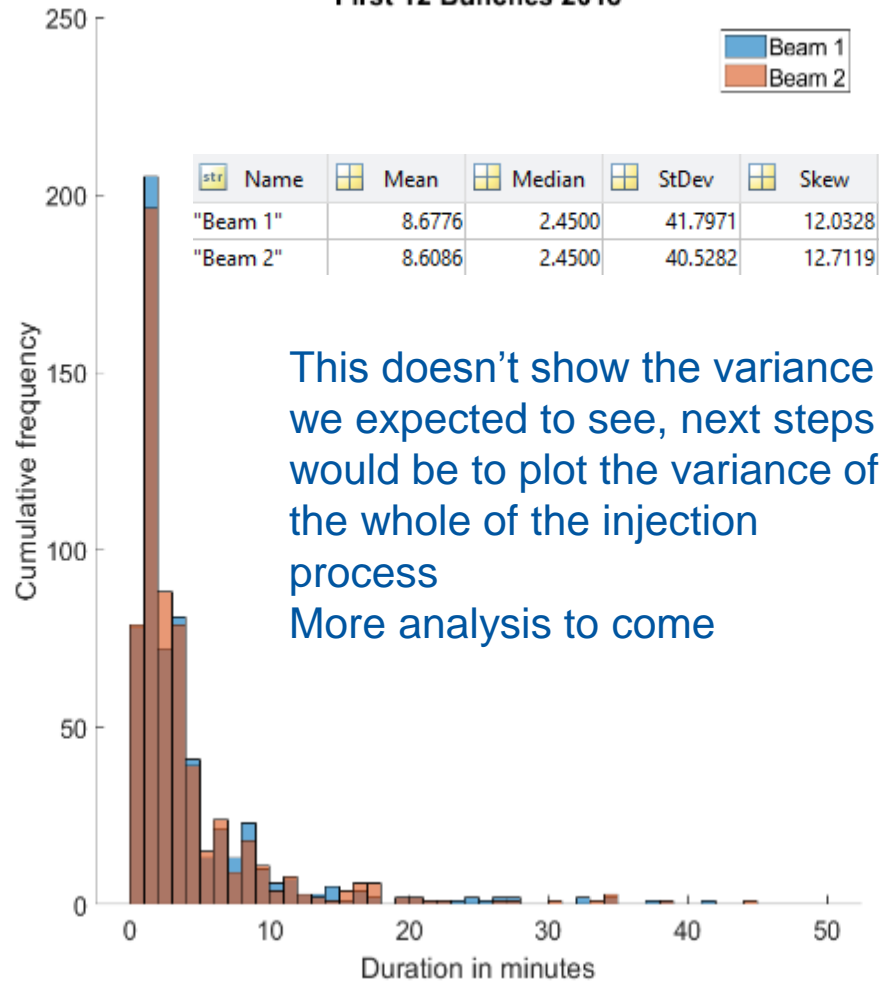
AvailSim

- Fault and beam mode statistics calculated and output into the 'common input format'.

━━ System Fault

| Beam Mode B | Beam Mode A | Beam Mode B | Beam Mode A |
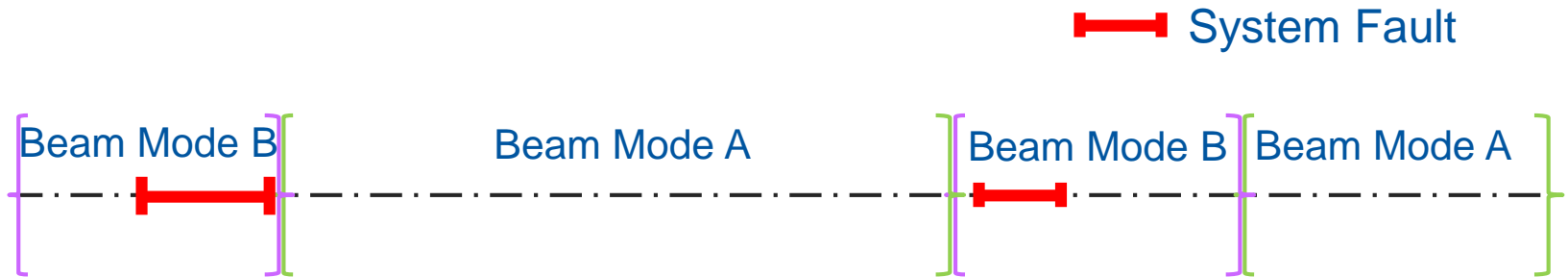
Beam mode B experiences 2 faults, while A experiences 0.
MTTF given by Mode duration, ergo: MTTF in A ≡ ∑A/0 = inf   MTTR
MTTF in B ≡ ∑B/2 = val

Process

AFT   Timber (LDB)

Beam Mode | Index

'LHC'	'Magnetcirc...	'03/04/2015...	'03/04/2015...
'LHC'	'Cryogenics...	'03/04/2015...	'04/04/2015...
'LHC'	'Cryogenics...	'03/04/2015...	'04/04/2015...
'LHC'	'Cryogenics...	'04/04/2015...	'04/04/2015...
'LHC'	'Experiment...	'05/04/2015...	'05/04/2015...
'LHC'	'InjectorCo...	'06/04/2015...	'06/04/2015...
'LHC'	'VacuumHa...	'06/04/2015...	'07/04/2015...
'LHC'	'PowerCon...	'07/04/2015...	'07/04/2015...
'LHC'	'PowerCon...	'07/04/2015...	'07/04/2015...
'LHC'	'PowerCon...	'07/04/2015...	'07/04/2015...

- Attribute beam mode and Index location of beam mode using data from AFT and Timber

'2012-02-07 13:40:52.304'	0
'2012-02-07 17:31:27.254'	0
'2012-02-09 13:36:06.550'	21
'2012-02-09 13:36:11.300'	1
'2012-02-27 15:37:33.857'	0
'2012-03-02 07:53:33.566'	2
'2012-03-02 07:53:59.670'	21

Mode durations must discount fault time for MTTF

	Name	Count	MTTF tavg	Failure Rate	STDev	Skewness	MTTR	STDev
1	Name							
2	Operation	3	894.4952	0.0011179	5798.049	0.68852	0.059907	0.034635
3	Orbit	0	1E+12	0	0	0	0	0
4	Other	5	536.6971	0.0018632	1586.985	1.2655	0.25622	0.22556
5	PowerConverters	62	43.282	0.023104	643.2234	4.9242	1.8513	2.8988
7	QPS	49	54.765	0.01826	778.3988	4.0663	1.659	1.8931
8	RadioFrequency	14	191.6775	0.0052171	1354.057	1.3064	1.4619	1.3999
9	SIS	1	2683.4855	0.00037265	0	0	0.023611	0
10	TransverseDamper	1	2683.4855	0.00037265	0	0	0.023056	0

◄ ► ... **Stable** | Unstable | Beam Dump | ... ⊕

Output

PowerConverters Inj Dump	exponential	3.4511
PowerConverters Inj Physics	exponential	0.76964
PowerConverters Inj Probe	exponential	0.44701
PowerConverters No Beam	exponential	1.5052
PowerConverters Pre Ramp	exponential	0.01
PowerConverters Ramp	exponential	0.85618
PowerConverters Setup	exponential	0.63669
PowerConverters Squeeze	exponential	1.8548
PowerConverters Stable	exponential	1.8513

Moving Statistics

Stable
Failure Rate for All systems
Systems unaffected by beam in dashed

QPS CRISIS

16L2

Legend:
- AcceleratorControls
- AccessInfrastructure
- AccessManagement
- AccessSystems
- BeamExciters
- BeamInjection
- BeamInstrumentation
- BeamLosses
- Beam-inducedQuench
- Collimators
- CoolingandVentilation
- Cryogenics
- ElectricalNetwork
- Experiments
- ITServices
- InjectionSystems
- InjectorComplex
- LBDS
- MachineInterlockSystems
- MagnetCircuits
- Operation
- Orbit
- Other
- PowerConverters
- QPS
- RadioFrequency
- SIS
- TransverseDamper
- Vacuum
- VentilationDoors

	Failure Mode Name	Distribution	Parameters	Ref.	Description	StandbyState	Failure effects ParamAffected	AffectType	Degradation	Corrective Maintenance	Ref.	ManpowerType	No.Of Manpower	On-Off Site maintenance	RepairStrategy	Reference System	Si re
326	Orbit Pre Ramp	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
327	Orbit Ramp	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
328	Orbit Setup	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
329	Orbit Squeeze	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
330	Orbit Stable	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
331	Orbit Unstable	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
332	Other Adjust	exponential	514.6972	1		COLD				0.0025	1			on	repairable	1	y
333	Other Beam Dump	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
334	Other Cycling	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
335	Other Down	exponential	118.8893	1		COLD				0.38021	1			on	repairable	1	y
336	Other Flat Top	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
337	Other Inj Dump	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
338	Other Inj Physics	exponential	299.6204	1		COLD				0.088519	1			on	repairable	1	y
339	Other Inj Probe	exponential	196.4782	1		COLD				0.32535	1			on	repairable	1	y
340	Other No Beam	exponential	1175.4804	1		COLD				5.3553	1			on	repairable	1	y
341	Other Pre Ramp	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
342	Other Ramp	exponential	55.3966	1		COLD				0.062944	1			on	repairable	1	y
343	Other Setup	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
344	Other Squeeze	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
345	Other Stable	exponential	536.6971	1		COLD				0.25622	1			on	repairable	1	y
346	Other Unstable	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
347	PowerConverters Adjust	exponential	85.7829	1		COLD				0.84315	1			on	repairable	1	y
348	PowerConverters Beam Dump	exponential	7.6455	1		COLD				0.91231	1			on	repairable	1	y
349	PowerConverters Cycling	exponential	3.2301	1		COLD				0.83491	1			on	repairable	1	y
350	PowerConverters Down	exponential	11.3228	1		COLD				0.19735	1			on	repairable	1	y
351	PowerConverters Flat Top	exponential	155.7925	1		COLD				0.10292	1			on	repairable	1	y
352	PowerConverters Inj Dump	exponential	30.3978	1		COLD				3.4511	1			on	repairable	1	y
353	PowerConverters Inj Physics	exponential	64.2044	1		COLD				0.76964	1			on	repairable	1	y
354	PowerConverters Inj Probe	exponential	98.2391	1		COLD				0.44701	1			on	repairable	1	y
355	PowerConverters No Beam	exponential	130.6089	1		COLD				1.5052	1			on	repairable	1	y
356	PowerConverters Pre Ramp	exponential	80.9561	1		COLD				0.01	1			on	repairable	1	y
357	PowerConverters Ramp	exponential	34.6229	1		COLD				0.85618	1			on	repairable	1	y
358	PowerConverters Setup	exponential	17.3766	1		COLD				0.63669	1			on	repairable	1	y
359	PowerConverters Squeeze	exponential	33.2263	1		COLD				1.8548	1			on	repairable	1	y
360	PowerConverters Stable	exponential	43.282	1		COLD				1.8513	1			on	repairable	1	y
361	PowerConverters Unstable	exponential	1E+12	1		COLD				0	1			on	repairable	1	y
362	QPS Adjust	exponential	257.3486	1		COLD				2.1014	1			on	repairable	1	y
363	QPS Beam Dump	exponential	5.7341	1		COLD				2.0264	1			on	repairable	1	y
364	QPS Cycling	exponential	71.0623	1		COLD				2.5847	1			on	repairable	1	y

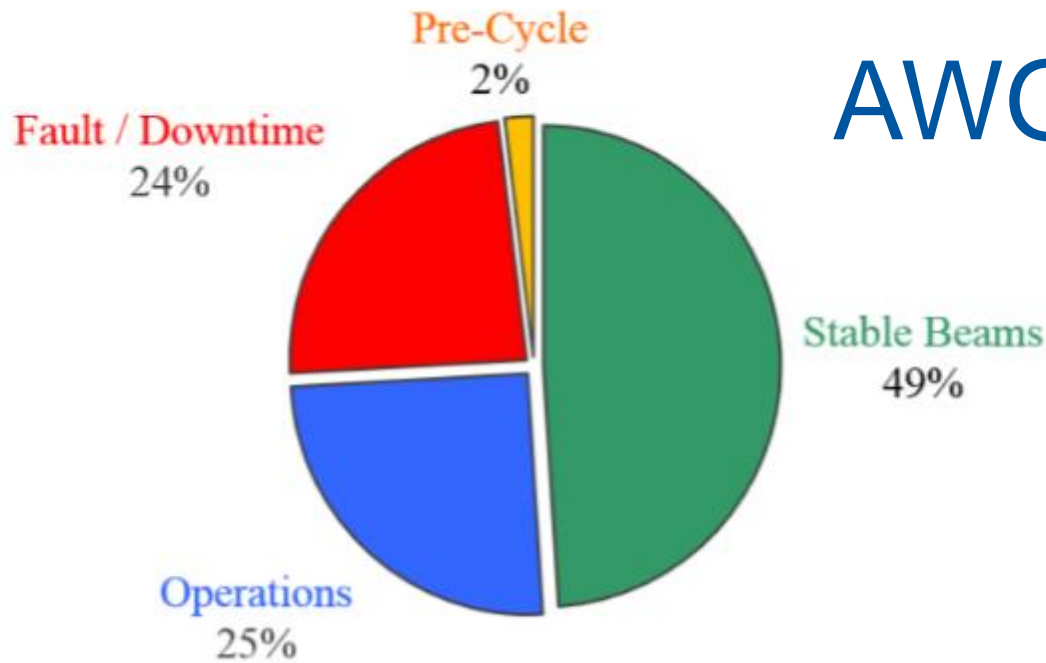|	Facility	Phase	Duration	Phase Type	Phase Group	Parent OP Phase	Next Default phase	DownRepairPolicy	Can run parallel to donwtime?	Description
2	LHC	Operation	4956	Operation				1		
3	LHC	Setup	0.24723	CycleStart		Operation	Injection Probe	1	n	
4	LHC	Injection Probe	0.24625	Cycle		Operation	Injection Physics	1	n	
5	LHC	Injection Physics	0.50865	Cycle		Operation	Pre-Ramp	1	n	
6	LHC	Pre-Ramp	0.063956	Cycle		Operation	Ramp	1	n	
7	LHC	Ramp	0.33951	Cycle		Operation	Flat Top	1	n	
8	LHC	Flat Top	0.068008	Cycle		Operation	Squeeze	1	n	
9	LHC	Squeeze	0.18184	Cycle		Operation	Adjust	1	n	
10	LHC	Adjust	0.05	Cycle		Operation	Stable	1	n	
11	LHC	Stable	10.7314	Cycle		Operation	Beam Dump	1	n	
12	LHC	Beam Dump	0.0081066	Cycle		Operation	Down	1	n	
13	LHC	Down	0.56228	Cycle		Operation	Setup	1	y	
14	LHC	No Beam	1.4931	Cycle		Operation	Setup	1	n	

Figure 4 : Machine Mode Breakdown during Physics

- *Operations* encompasses all regular machine phases carried out between fills, including planned access. This is *all* phases when the machine is not in stable beams, not in fault, and not pre-cycle.
- All *pre-cycles* were approximated as having a fixed length of 45 minutes.
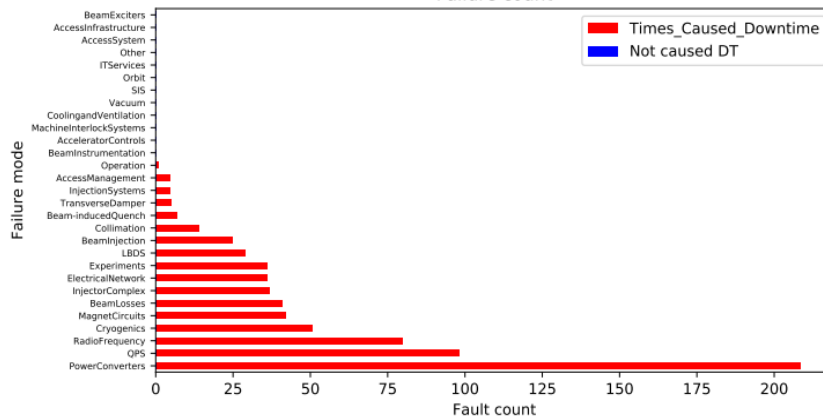
Results
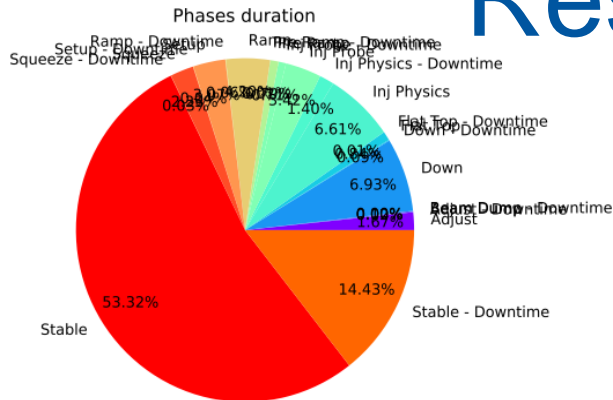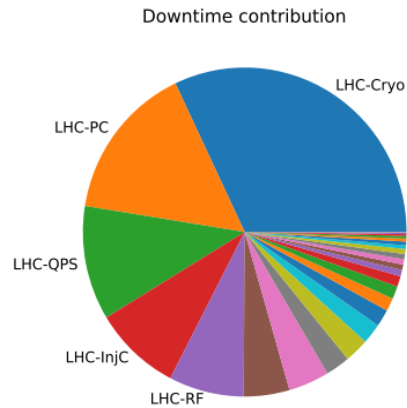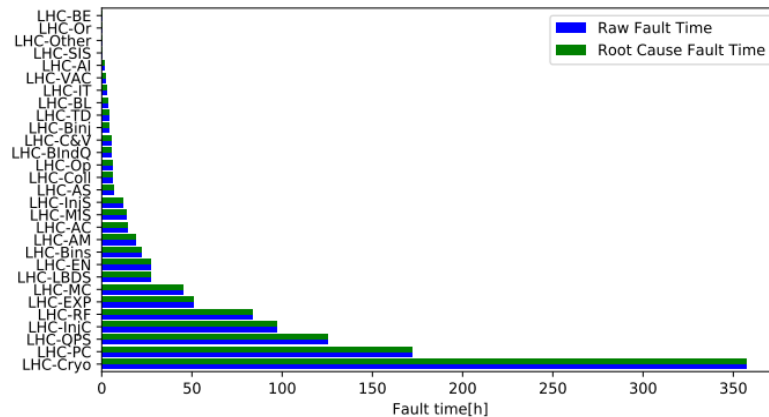
Conclusion

- Continued work on data for AvailSim
  - Currently refining both Fault and Beam Mode statistics
  - Ideally matching AWG reports
  - Extend to other Accelerators (statistics started)
  - Predictive tool for unknown scenarios (HiLumi)
  - GAN Network as a pose to regular Neural Network
  - Translate for SWAN package?

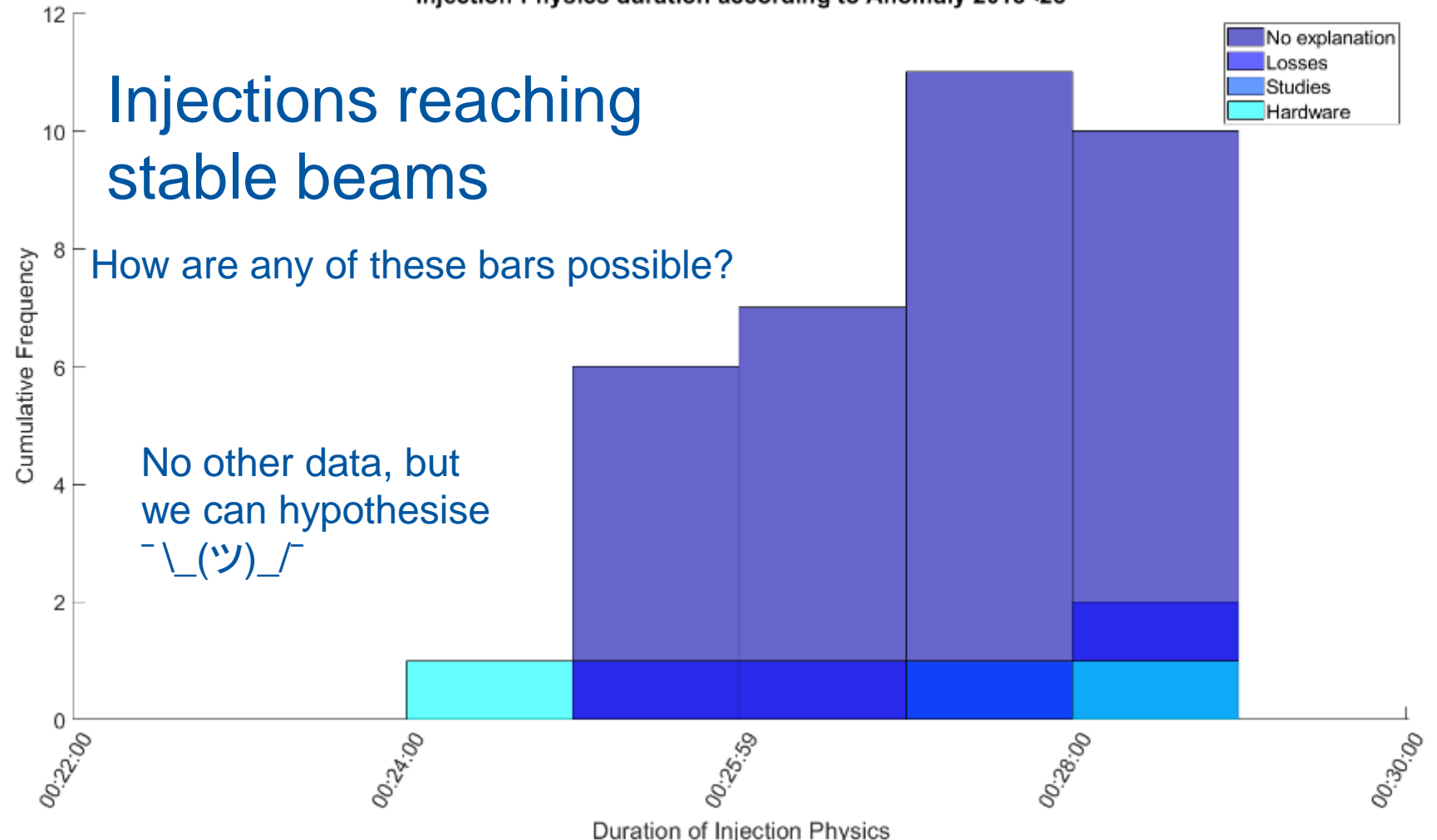Goal - Complete model of CERN accelerator complex
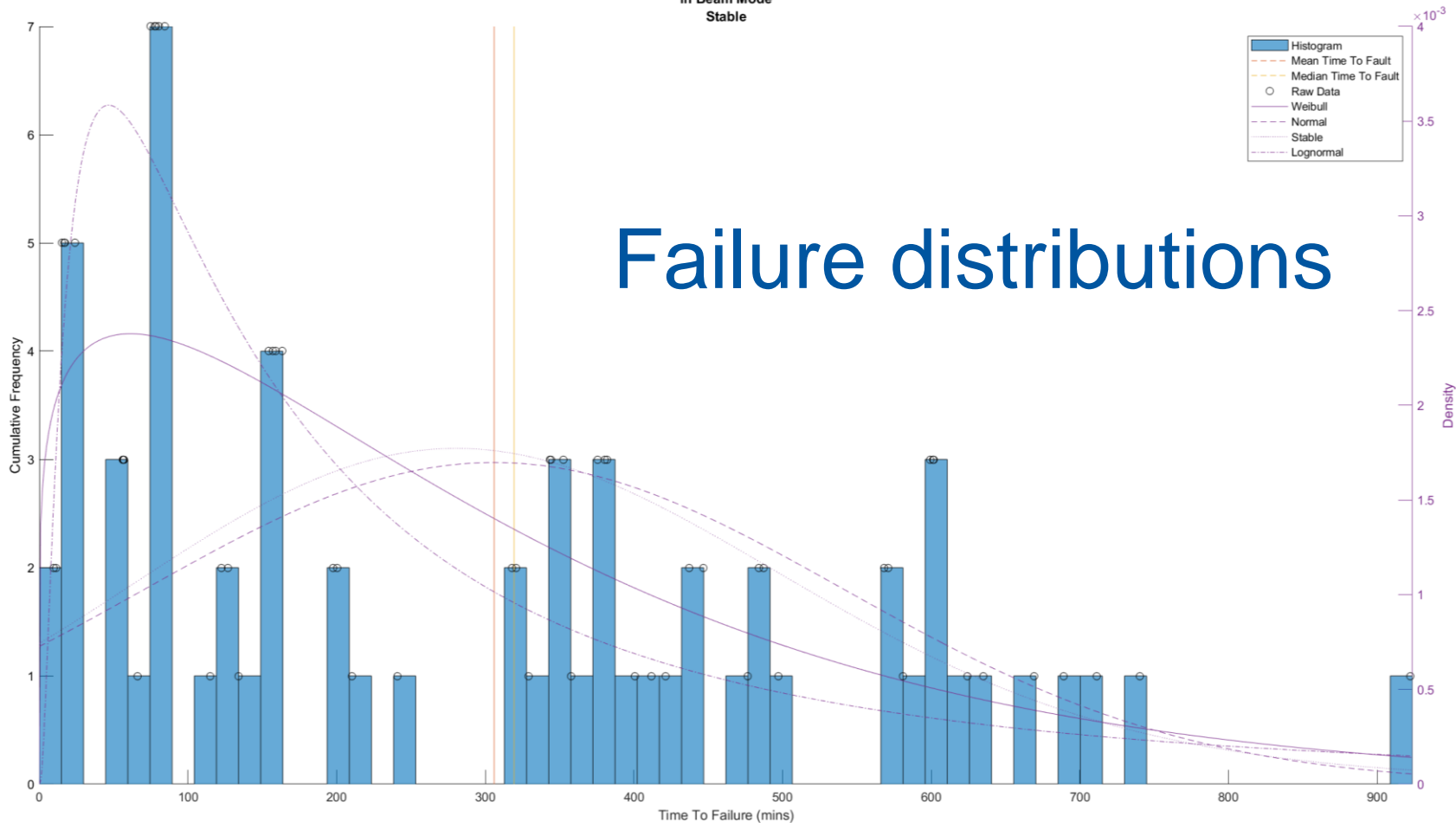
Extra Slides

Injection Physics duration according to Anomaly 2018<28

Injections reaching
stable beams

How are any of these bars possible?

No other data, but
we can hypothesise
¯_(ツ)_/¯

Legend:
- No explanation
- Losses
- Studies
- Hardware

Y-axis: Cumulative Frequency (0, 2, 4, 6, 8, 10, 12)

X-axis: Duration of Injection Physics (00:22:00, 00:24:00, 00:25:59, 00:28:00, 00:30:00)

Failure distributions