



# **First efforts on availability studies for new HL-LHC systems**

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Acknowledgements: O. Rey Orozco, M. Motyka, A. Siemko, J. Uythoven, D. Wollmann, M. Zerlauth.



8<sup>th</sup> HL-LHC Collaboration Meeting, CERN

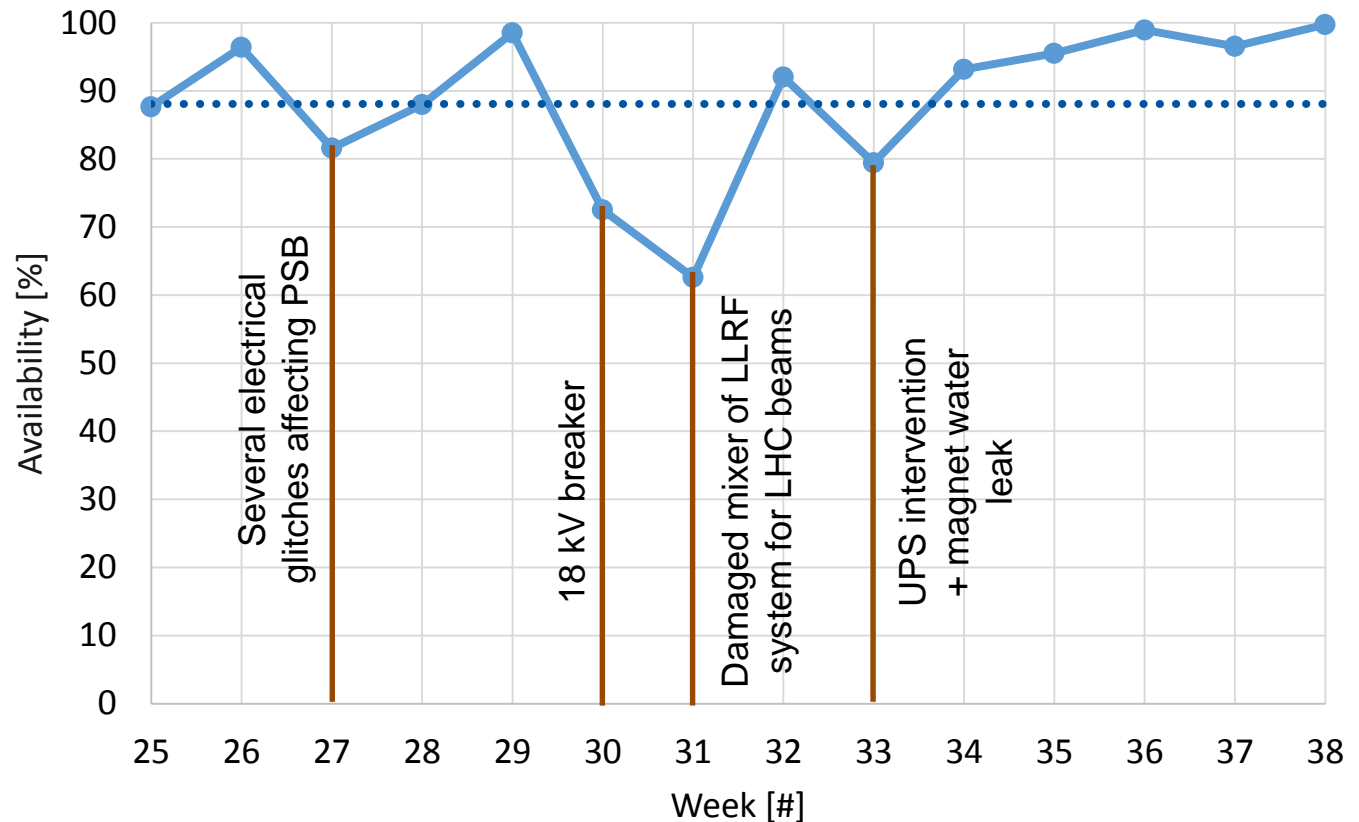
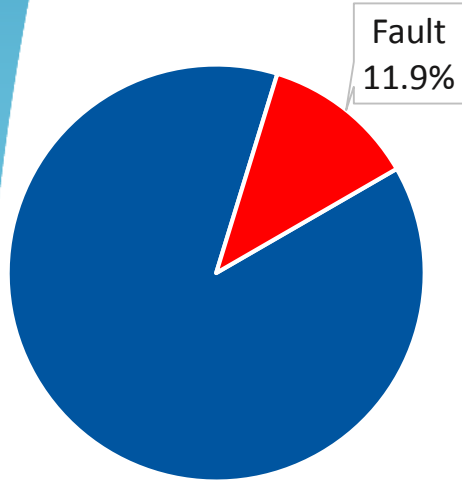
# Ongoing Availability/Reliability Activities in WP7

- Availability modelling and performance predictions for HL-LHC
  - Fault tracking and performance extrapolation to HL-LHC (Accelerator Fault Tracker)
  - Development of tools for availability simulations (AvailSim 3.0)
  - Modelling of HL-LHC availability
- Risk assessment and performance impact of HL-LHC systems
  - Machine protection, see [presentation](#) by M. Blumenschein on IT and [presentation](#) by D. Sollich on 11T magnet
  - Dedicated risk assessment for HL activities (e.g. [STRING](#))

# Fault Tracking at CERN

- Since 2015: fault tracking in LHC managed via the Accelerator Fault Tracker ([AFT](#))
- Following recommendations from the CMAC in Chamonix 2016: since 2017 AFT extended to entire accelerator complex, including Linac4
- Fundamental: data stored in AFT is the reference for developed availability models
  - Failure modes, failure rates and repair times
  - Failure dependencies on accelerator modes and parameters

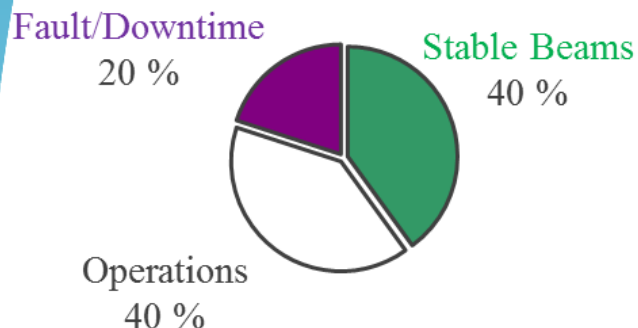
# Example: 2018 PS availability TS1-TS2



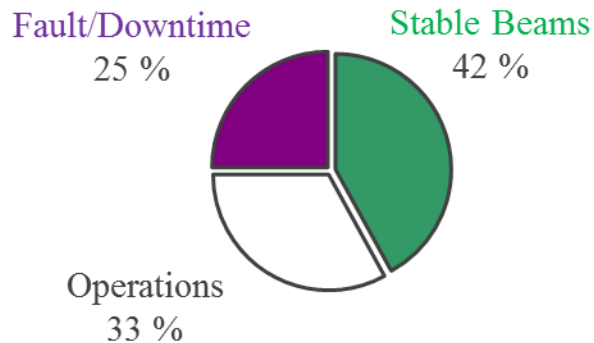
- Excellent granularity reached in failure analysis of injector complex (destination-dependent failures), see recent [IEFC presentation](#)
- Ready for **fault tracking in the LIU era**, which will allow for more accurate extrapolation for HL-LHC

# LHC Availability 2017-2018

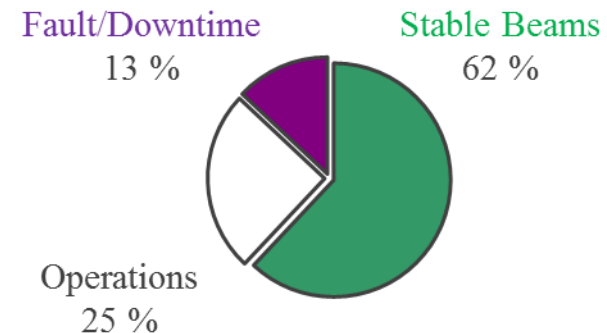
## Restart-TS1 2017



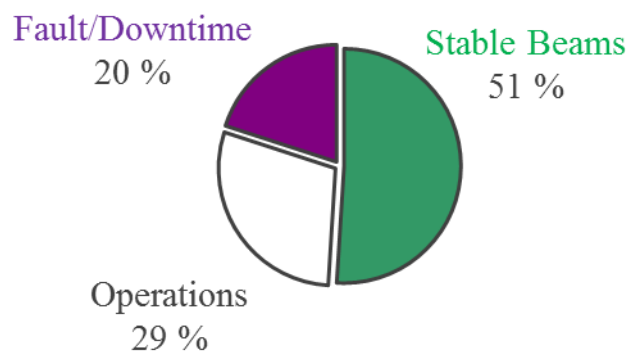
## TS1-TS2 2017



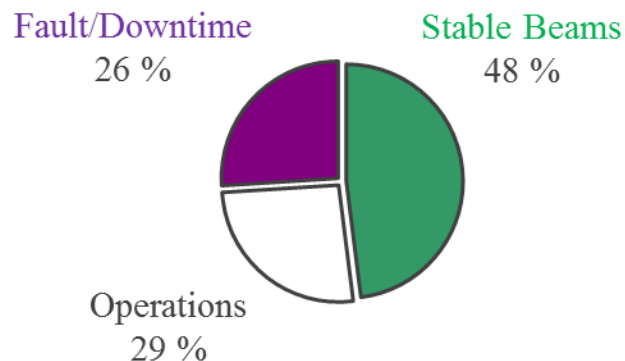
## TS2-TS3 2017



## Restart-TS1 2018



## TS1-TS2 2018

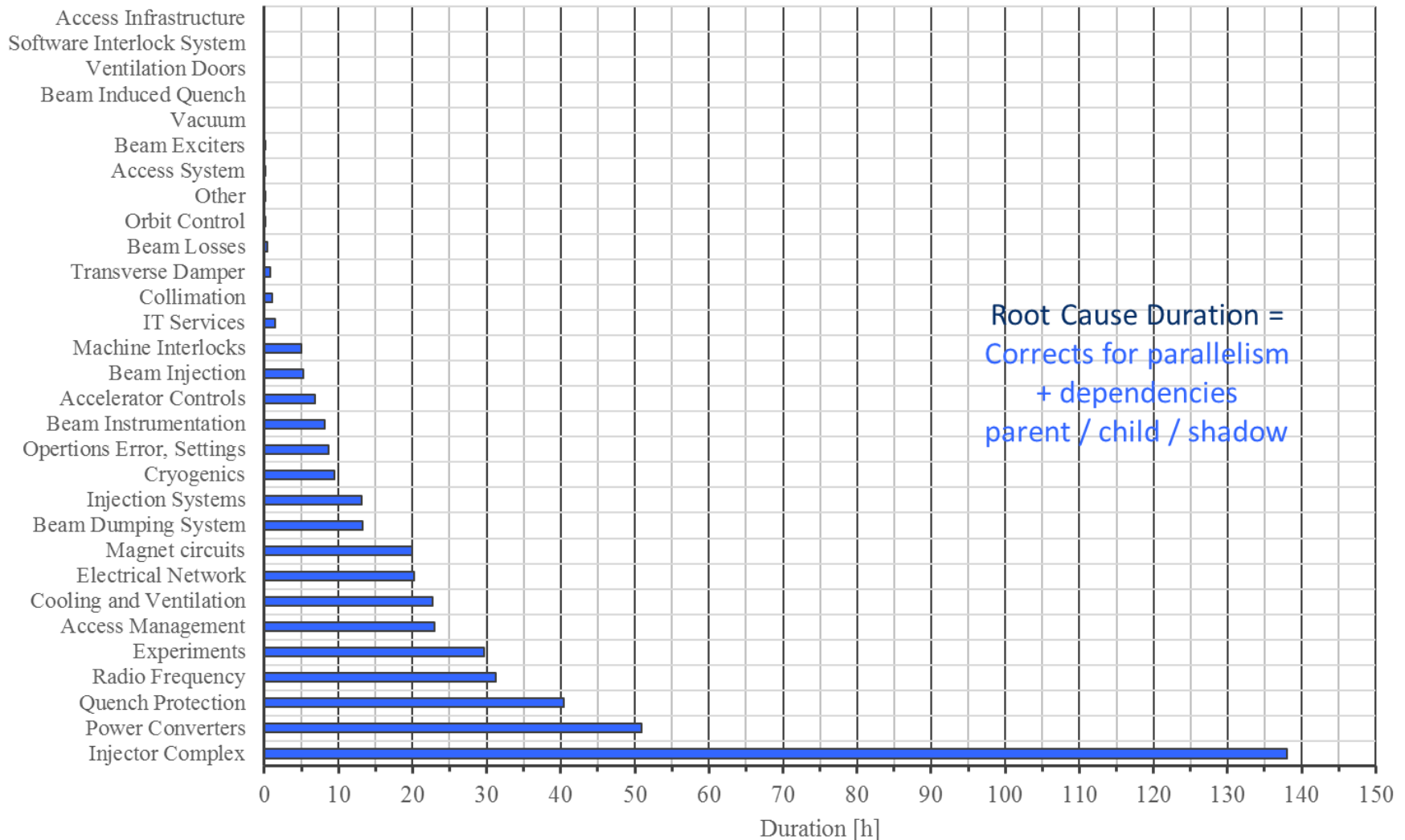


## TS2-TS3 2018



# 2018 LHC Downtime Distributions (TS1-TS2)

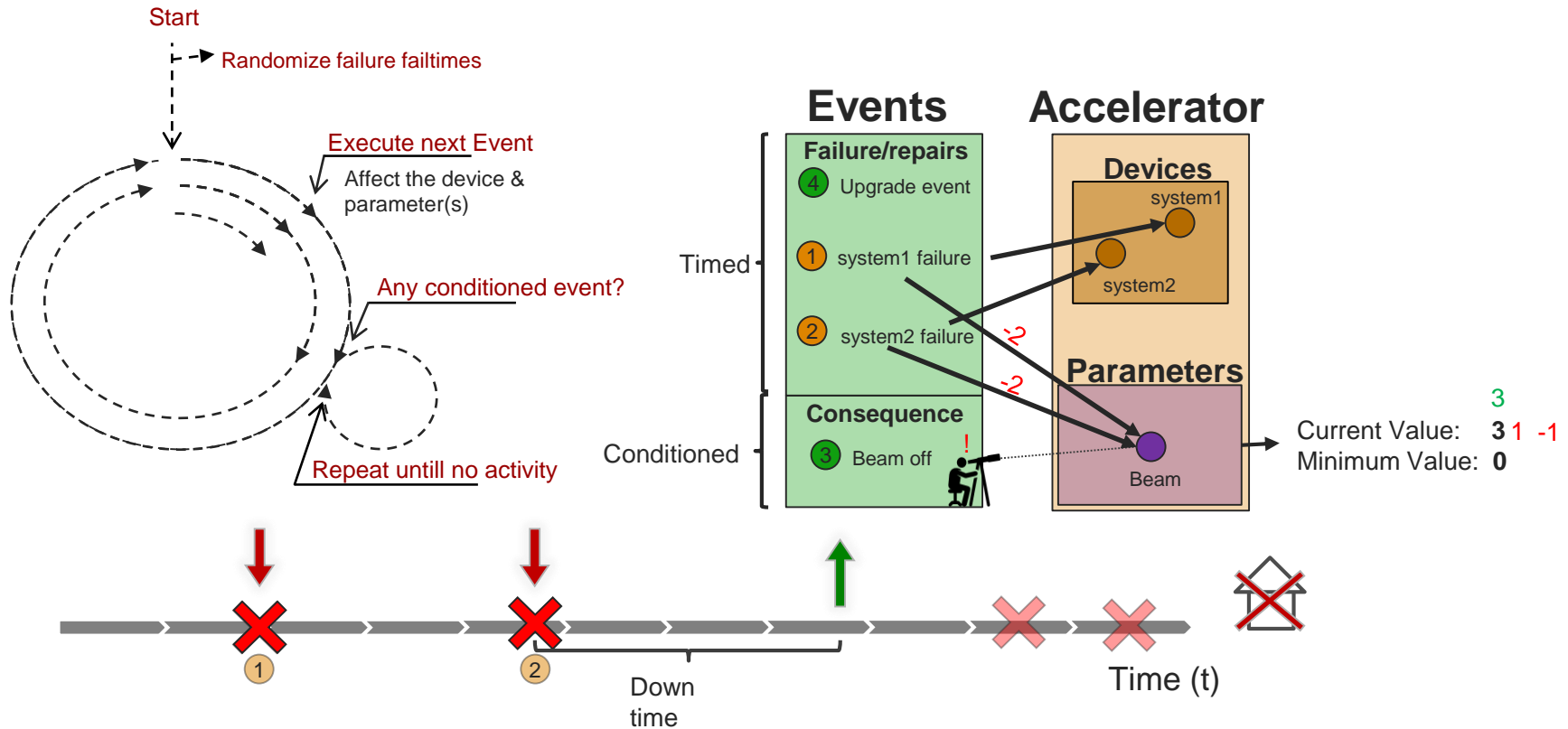
Stacked Pareto - Fault Duration and Root Cause Duration vs System



# Simulation Tool: AvailSim 3.0

- AvailSim 1.0 originally developed at SLAC
- AvailSim 2.0 tailored for IFMIF modelling
- AvailSim 3.0 developed from scratch in Python3 (2017/18, in collaboration with ESS)
- Object oriented
- Open sourced
- A simulation in discrete time that uses a so called "three-phased" approach (Pidd, 1998)
- Monte Carlo Discrete Event Simulation (DES)
- Tailored to particle accelerator domain (both linear and circular machines)

# AvailSim 3.0: Basic Concepts



# AvailSim 3.0: HL-LHC Model

From AFT (2017-18): phase  
dependent Mean Time To Fail (MTTF)  
and Mean Time To Repair (MTTR)

Failure Mode Name	Distribution	MTTF [h]
Accelerator Controls Failure Cycle	exponential	192
Accelerator Controls Failure Stable Beams	exponential	192
Access Management Scheduled	exponential	48
Access System Failure Cycle	exponential	48
Access System Failure Stable Beams	exponential	467
Beam Dumping System Failure	exponential	74
Beam Exciters Failure Cycle	exponential	3266
Beam Exciters Failure Stable Beams	exponential	3266
Beam Instrumentation Failure Cycle	exponential	142
Beam Instrumentation Failure Stable Beams	exponential	142
Collimation Failure Cycle	exponential	344
Collimation Failure Stable Beams	exponential	344
Cooling & Ventilation Failure Cycle	exponential	653
Cooling & Ventilation Failure Stable Beams	exponential	653
Cryogenics Failure	exponential	43

[...All other LHC systems...]

11T Dipole Quench	exponential	?	?
Crab Cavities Failure	exponential	?	?
SC link quench	exponential	?	?

- Many uncertainties for extrapolation to HL + new systems

# AvailSim 3.0: HL-LHC Model

11T Dipole Quench	exponential	?	?
Crab Cavities Failure	exponential	?	?
SC link quench	exponential	?	?

- 11 T dipole quenches:
  - Reference scenario: same quench rate as NbTi magnets, see [presentation](#) by L. Bottura
  - Pessimistic scenario: MTTF = 30 h while in stable beams (similar to complex LHC systems), MTTR = 10 h
- Crab cavity failures:
  - Reference scenario: same MTTF and MTTR as LHC RF system (comparable hardware complexity)
  - Pessimistic scenario: MTTF = 30 h while in stable beams (similar to complex LHC systems), MTTR = 10 h, i.e. quenches caused by crab cavity failures
- SC link quenches:
  - Reference scenario: no quenches of SC link, as from design, see [presentation](#) by A. Ballarino
  - Pessimistic scenario: MTTF = 30 h while in stable beams (similar to complex LHC systems), MTTR = 6 h, i.e. quench of triplet
- In addition:
  - Cryogenics: failure rate scaled in both scenarios accounting for new HL cryoplants
  - Beam Dumping System: failure rate doubled in conservative scenario due to operation at 7 TeV

# HL-LHC Model: Results (1/2)

Time

Phase	Duration_Without_DT [h]	Downtime [h]	Phase_Changed_By
Cycle	1.06	[1.67]	Injector Complex Failure
Cycle	1.83	[]	Default
Stable Beams	0.97	[0.10]	Error, Settings Operation Stable Beams
Ramp-down	0.83	[]	Default
Cycle	0.90	[1.67]	Injector Complex Failure
Cycle	1.83	[]	Default
Stable Beams	3.91	[0.10]	Radio Frequency Failure
Ramp-down	0.83	[]	Default
Cycle	1.27	[1.20]	Injection Systems Failure
Cycle	1.83	[]	Default
Stable Beams	0.62	[0.10]	Crab Cavities Failure
Ramp-down	0.83	[]	Default
Cycle	0.19	[1.67]	Injector Complex Failure
Cycle	0.58	[1.67]	Injector Complex Failure
Cycle	0.47	[1.20]	Injection Systems Failure
Cycle	0.05	[1.20]	Injection Systems Failure
Cycle	1.83	[]	Default
Stable Beams	3.19	[0.10]	Losses Occurrence
Ramp-down	0.83	[]	Default
Cycle	0.38	[1.67]	Injector Complex Failure
Cycle	1.83	[]	Default
Stable Beams	8.00	[]	Default
Ramp-down	0.83	[]	Default
Cycle	1.83	[]	Default
Stable Beams	6.74	[0.10]	Losses Occurrence

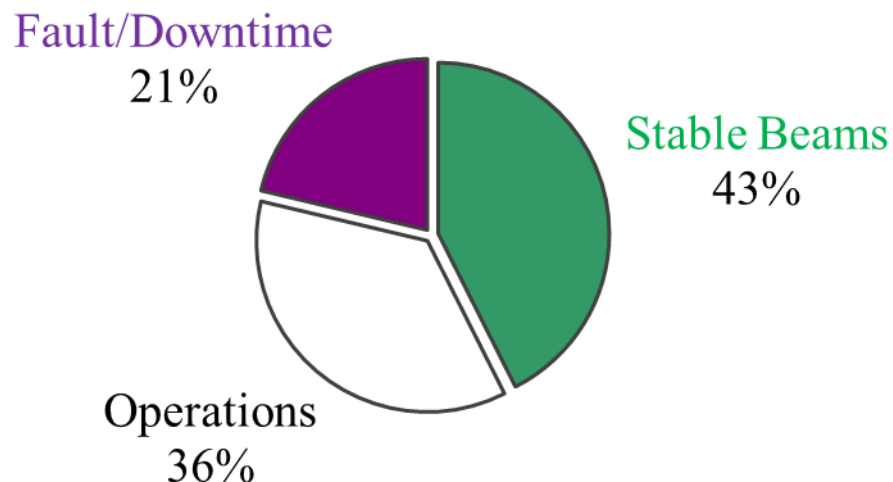
X 100 times

[...until 160 days of operation are reached...]

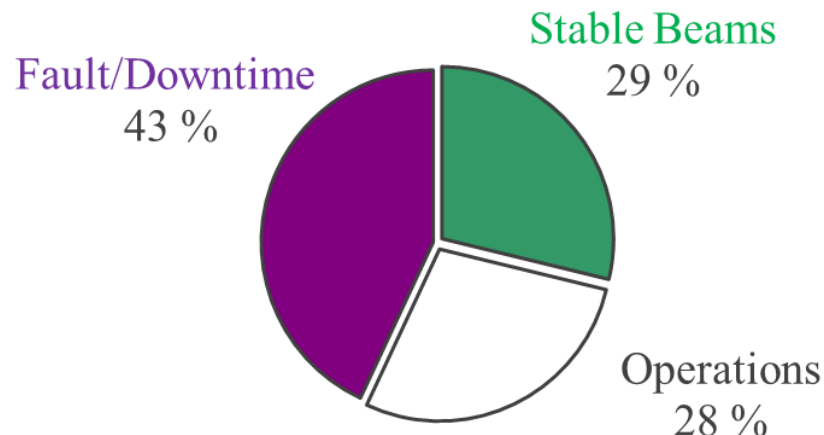
- LHC cycle closely reproduced

# HL-LHC Model: Results (2/2)

Reference Scenario



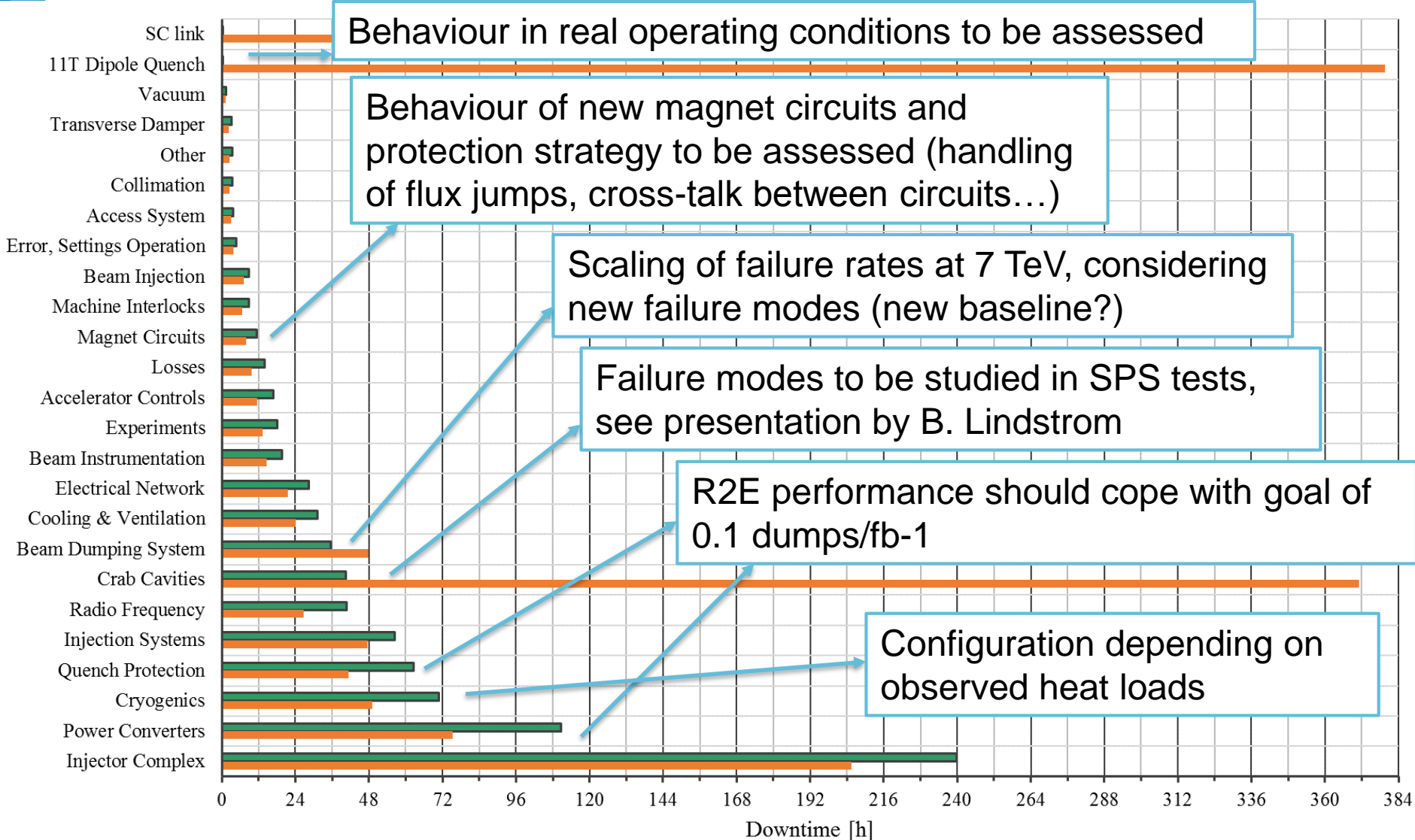
Pessimistic Scenario



- Luminosity levelling will lead to a reduction of the optimal fill length
- → more time spent in 'operations' compared to LHC
- → higher sensitivity to turnaround duration and injectors performance

- LHC MTTF and MTTR + assumptions in slide 10
- ~20 % availability loss
- ~15 % physics efficiency loss

# Simulated HL Downtime Distribution



# Conclusions and Outlook

- Well established fault tracking at CERN
  - Estimates available for failure rates and recovery times for all systems in the accelerator complex
  - Outlook (short term): refine models based on Run 2 experience, analysing system failure modes and their evolution over time
  - Outlook (longer term): refine models based on LIU experience
- New tool for availability models - AvailSim 3.0 - allows for realistic simulation of (HL) LHC operation
- Individual HL system availability models to be created in collaboration with system experts
- Ready to discuss reliability modelling of any system with HL WPs

**Thank you for your attention!**