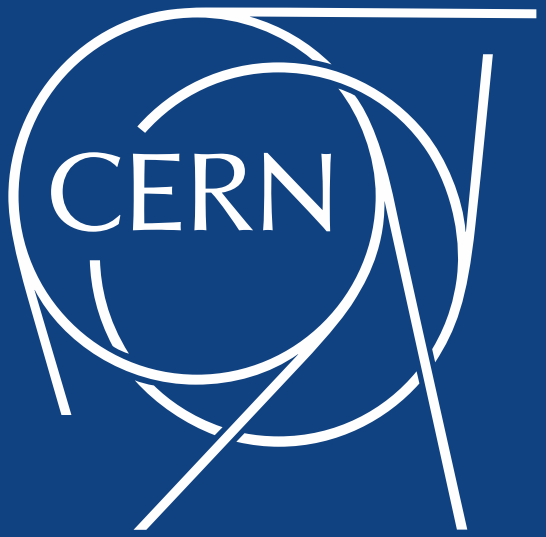
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FCC Availability Studies

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Motivation

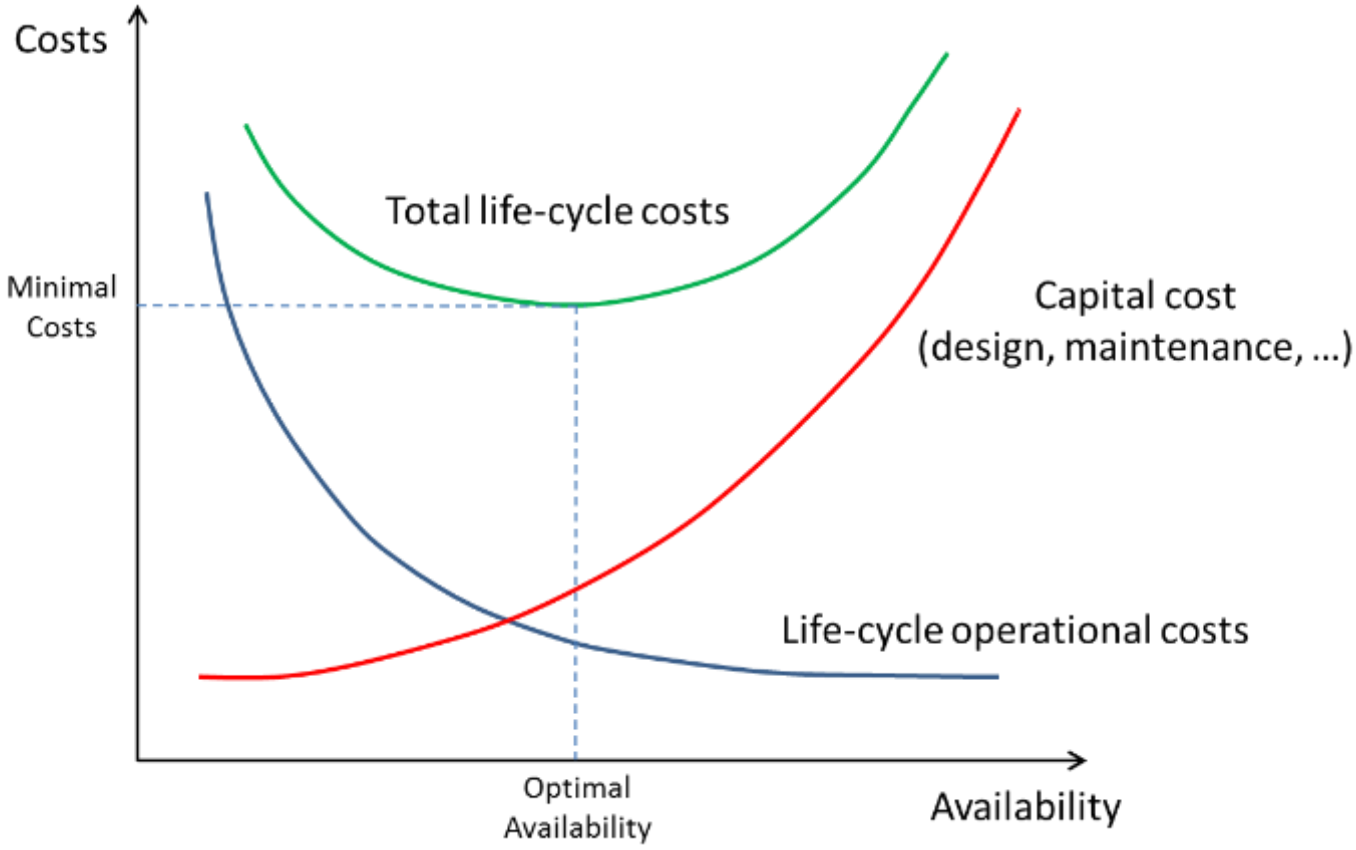
- **Technological and financial boundary conditions** set a limit for the peak beam performance for accelerators at the forefront of science

- Important to address **availability requirements** since early design stages and across entire **accelerator lifecycle** (starting with conceptual design)

Qualitative Definitions

- **Availability** is a measure of the **useful time** for user experiments during the accelerator run
- Key performance indicator **for colliders** is **integrated luminosity [fb^{-1}]**

Availability and Costs



- Given a target integrated luminosity, life-cycle operational costs decrease with increasing availability

Scope of the Study

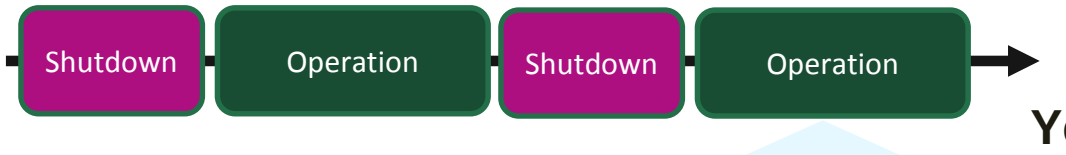
- Evaluate the suitability of **industrial reliability methods** in the domain of particle accelerators…
- …taking the **LHC as a case study**
- Identify and analyse possible **design and operational scenarios** for a h-h Future Circular Collider
- Identify **key impact factors** on availability and luminosity production
- RAMS study DOES NOT give guidelines for individual system design and optimization

FCC-hh – A New Machine

- **How should it be operated?**
  - What would the FCC-hh cycle look like?
  - What are the impacts of different injector designs/options?

- **How should it be maintained?**
  - What is the ideal number of scheduled shutdowns?
  - How can planned/predictive/corrective maintenance contribute to availability improvements?

Accelerator Schedule



Years

$$A1 = \frac{Operation}{Acc.\,Lifetime}$$

$$A2 = \frac{Lumi.\,Production}{Operation}$$

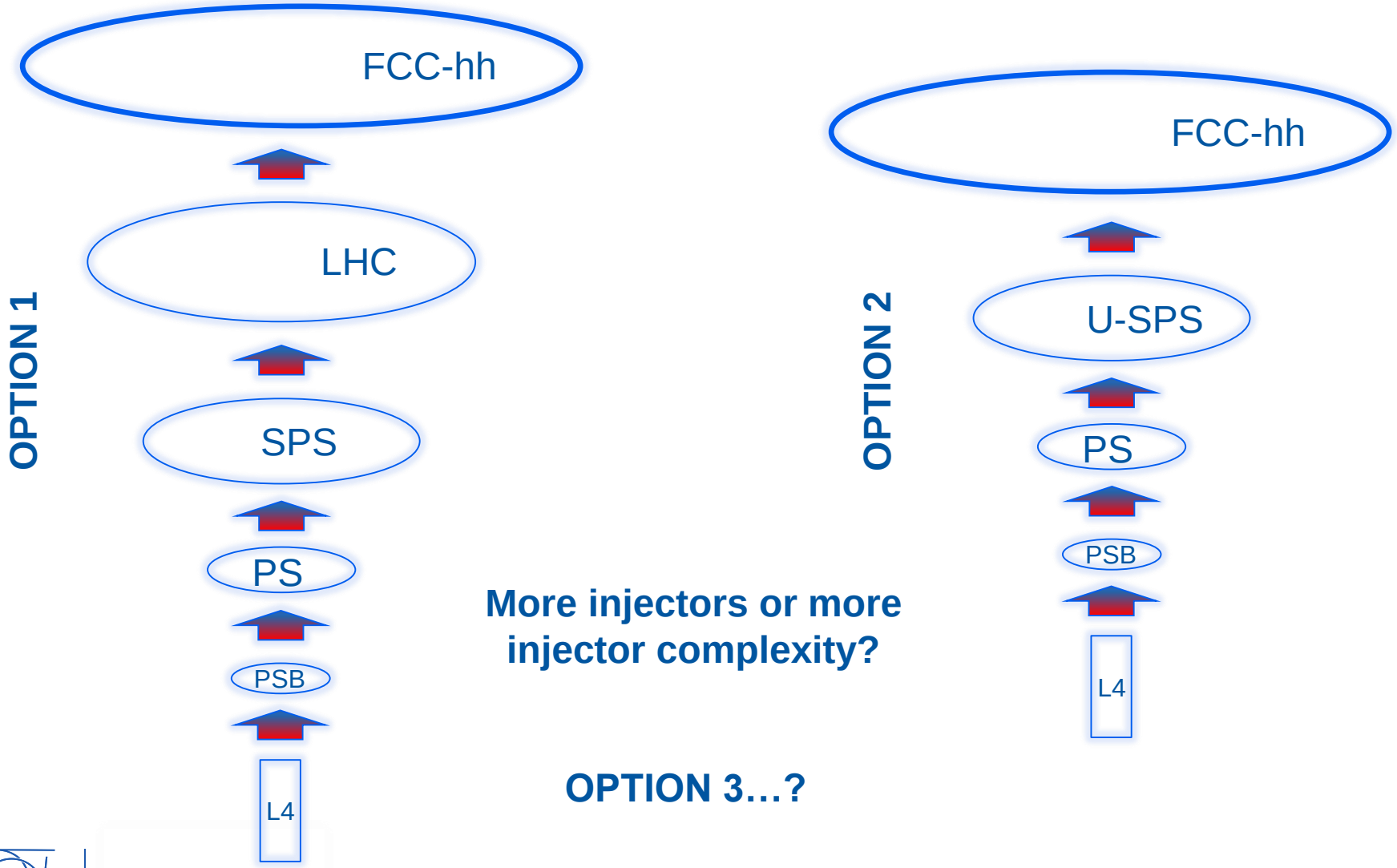
Weeks

$$A3 = \frac{Stable\ Beams}{Lumi.\,Production}$$

$$A\ for\ Physics = A1 * A2 * A3$$

Hours

FCC-hh – Injector Options

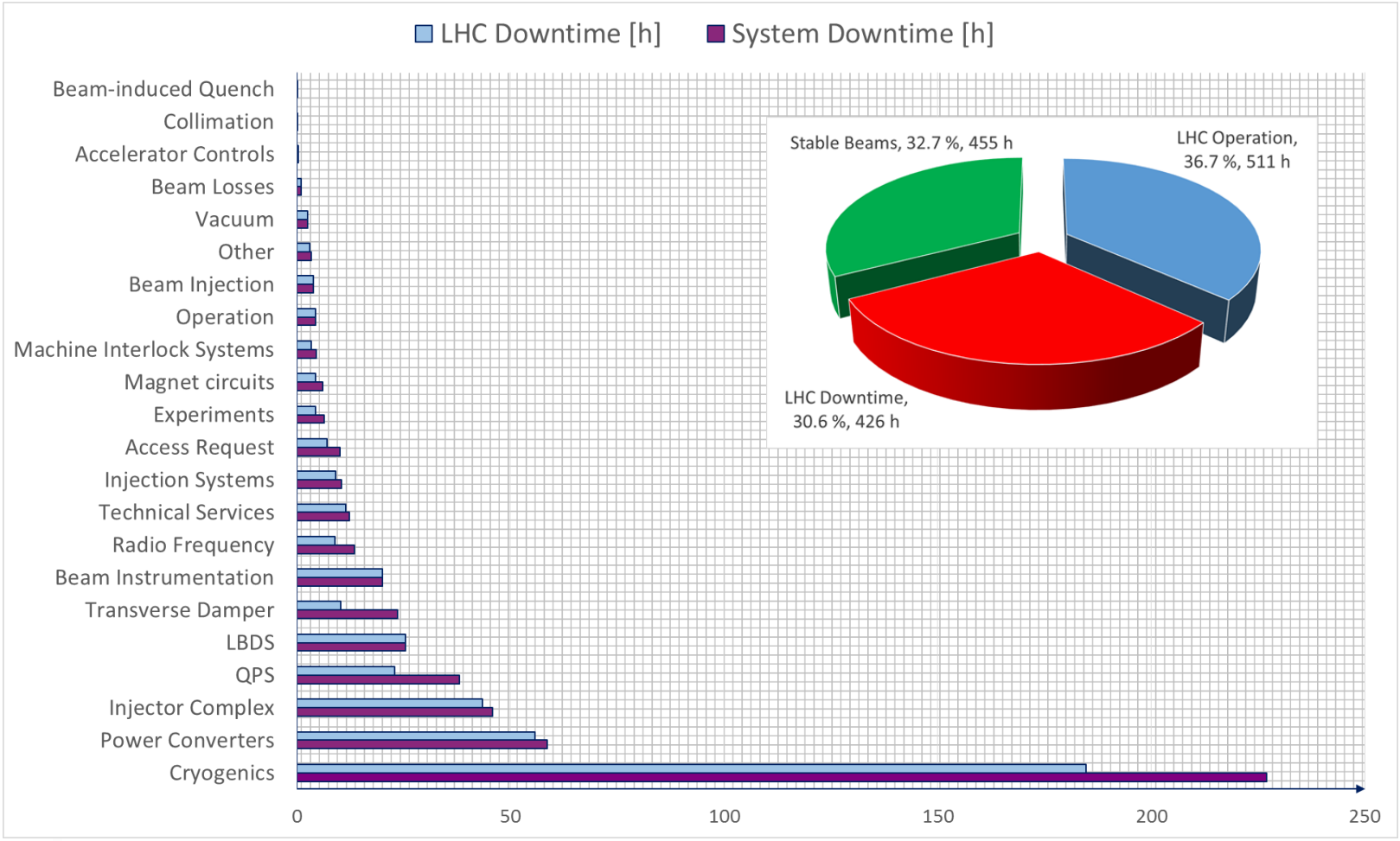


More injectors or more injector complexity?

OPTION 3…?

The LHC – Our Reference

- What do we know from the LHC? (25 ns Run in 2015)



FCC-hh – A Complex Machine (1/2)

- **4 times bigger machine = 4 times less availability?**

- LHC, today:
  - Average cycle time (not including stable beams) ~ 7 h
  - Availability ~ 70 %

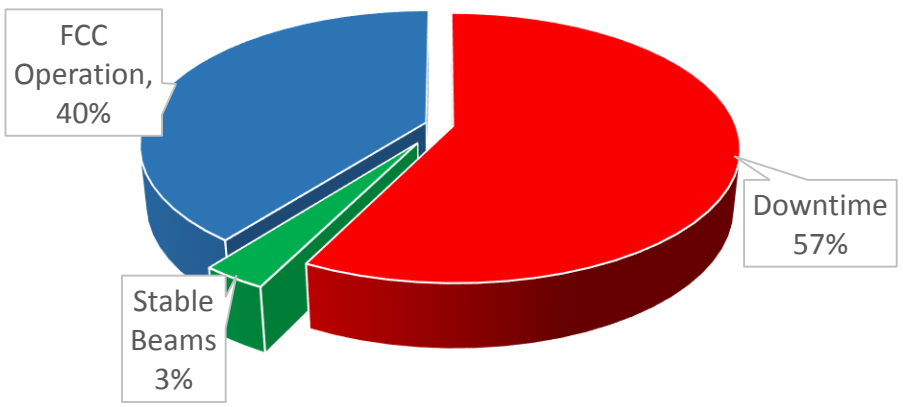
- Assumptions for FCC-hh:
  - Use LHC as an injector
  - Overall availability of the injector chain = 80%
    (90% LHC, 90 % SPS, 98 % PS complex)

	Cycle Duration	Failure Rates
Optimistic Cycle*	1.8 h	λ_{LHC} x 4 for distributed systems
Realistic Cycle	7 h	λ_{LHC} x 4 for distributed systems

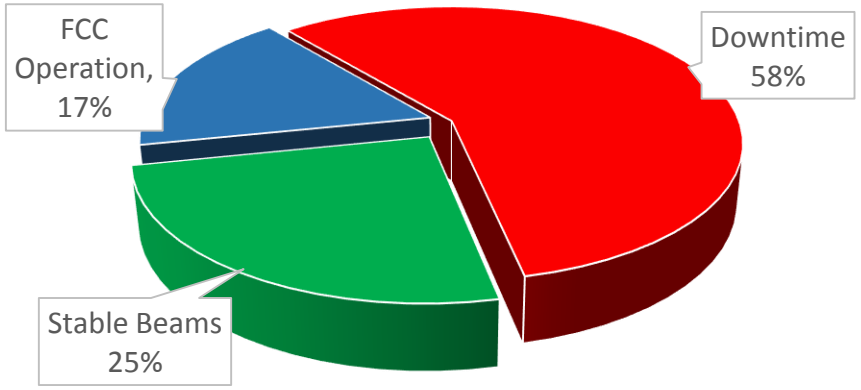
** See presentation on FCC Cycle by R. Alemany Fernandez*

FCC – A Complex Machine (2/2)

Realistic Cycle



Optimistic Cycle



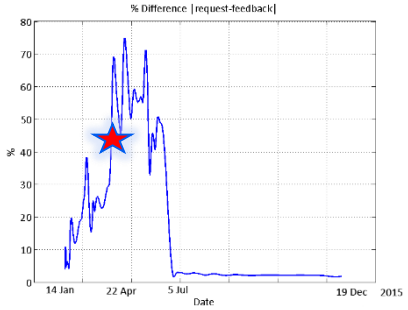
Requirements for luminosity production:

- ❑ Extremely high availability of the injector chain
- ❑ Extremely efficient cycling
- ❑ Significantly reduced downtime

Breakdown of System Downtime

System Downtime

Identification



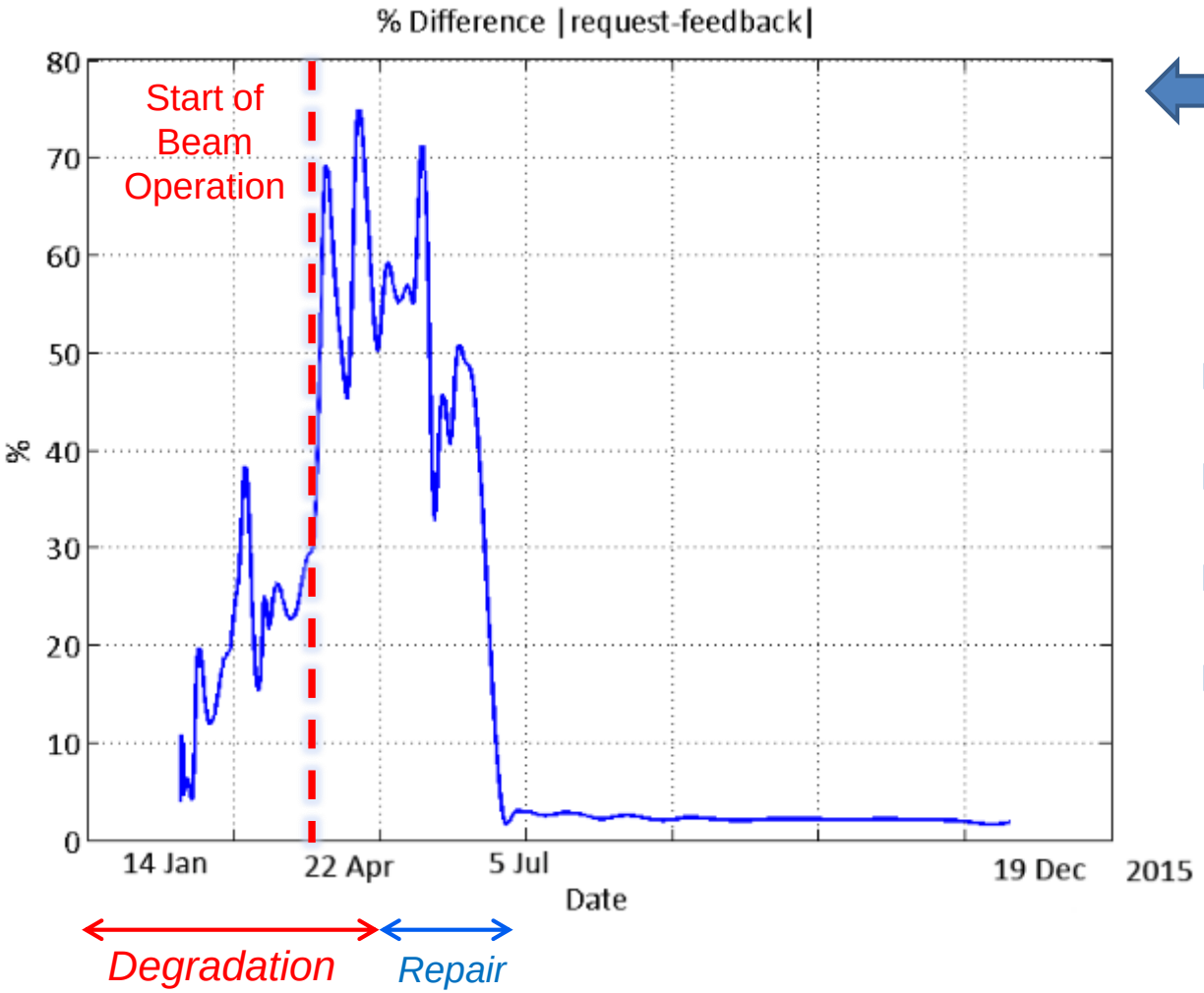
Diagnostics

Logistics

Repair

New strategies required!

Predictive Maintenance – Cryogenic Valves



Faulty cryogenic control valve (bellow):
mechanical failure of pneumatic actuator

- Degradation observed during 3 months (Jan-Apr)
- 22 Apr – failure recorded in the cryogenics logbook
- Online processing of data can predict failure
- Online processing of data can lead to failure rate functions:

$$\lambda(t) = 0.0178 \cdot t^{0.398} *$$

E. Rogova, TU Delft

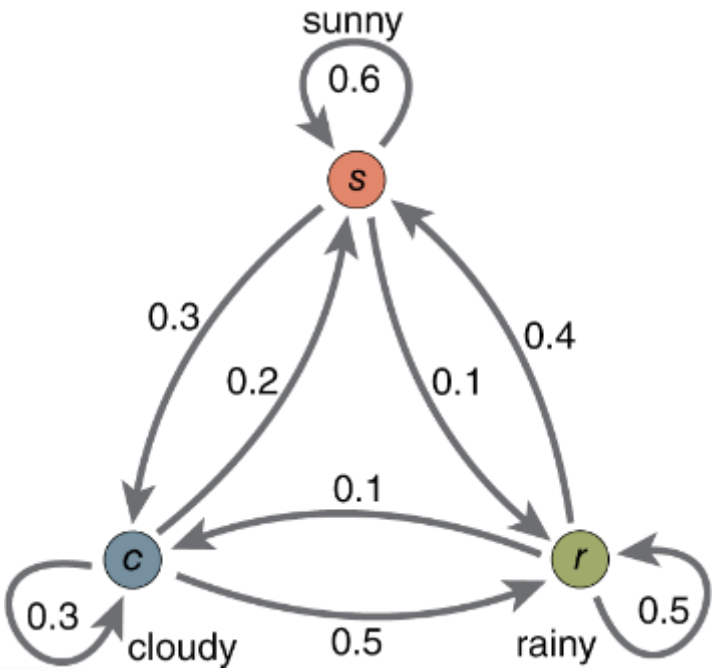
** - preliminary estimation - will be corrected in the final version of the slide based on operating hours of a valve*

LHC Availability Model

- Model **failures and consequences**
  - Failure probability
  - Downtime (identification, diagnostics, logistics, repair/recovery)
- Model **system/accelerator dependencies**
  - Infrastructure supplies
  - Injector complex
- Model **failure dependencies**
  - Operational modes (beam commissioning, user operation,…)
  - Beam parameters (intensity, energy)
  - Environmental effects
- Model **long term effects**
  - Experience
  - Conditioning/deconditioning
  - Ageing/maintenance effects

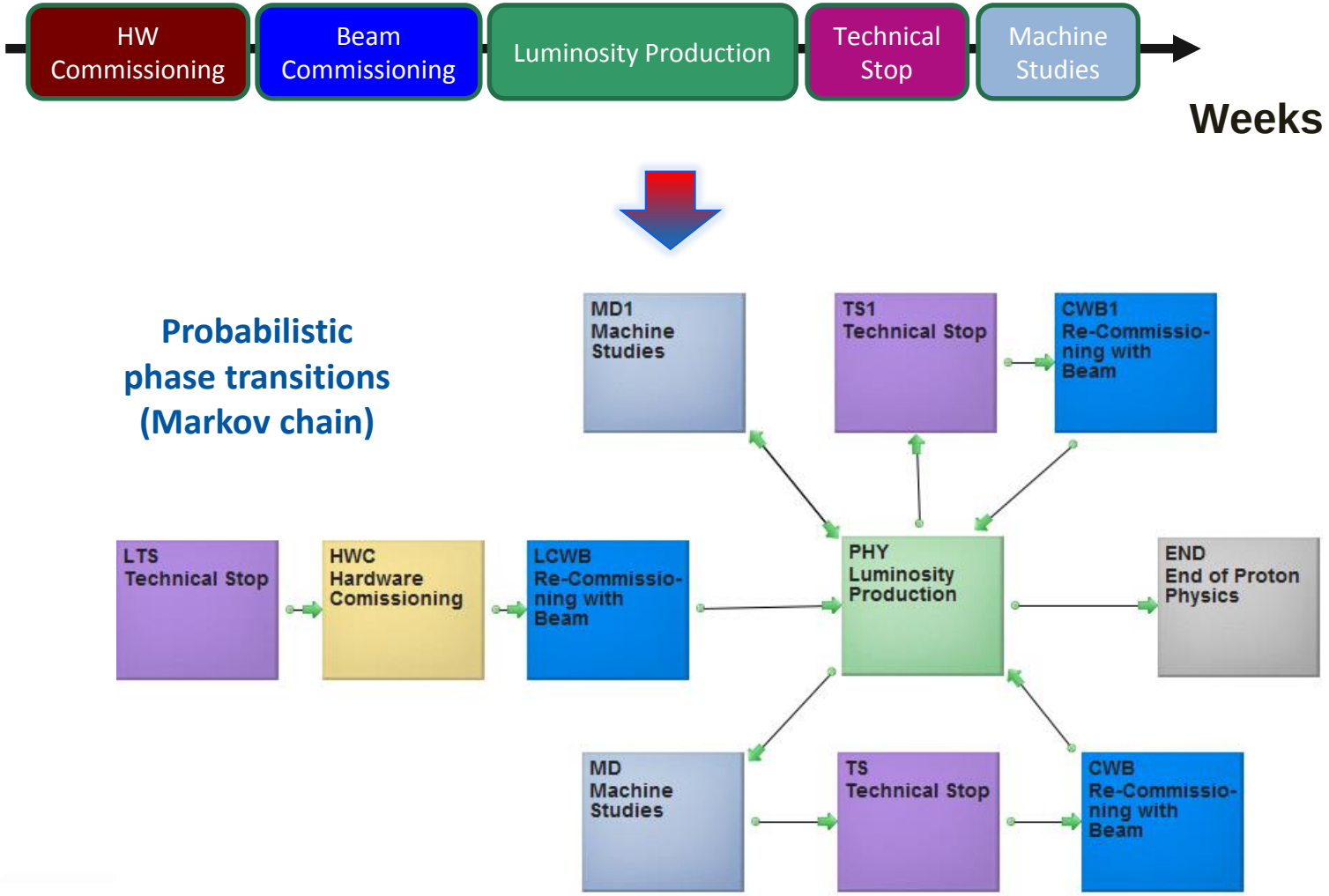
Model Implementation

- Development of a LHC availability model
- Collaboration with Tampere University of Technology and RAMENTOR
- Software ELMAS used as a platform for modelling (Monte Carlo based)
- Markov-chain models for state transitions

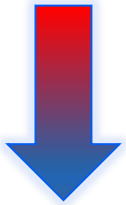


Probabilistic phase transitions (Markov chain)

Model Implementation



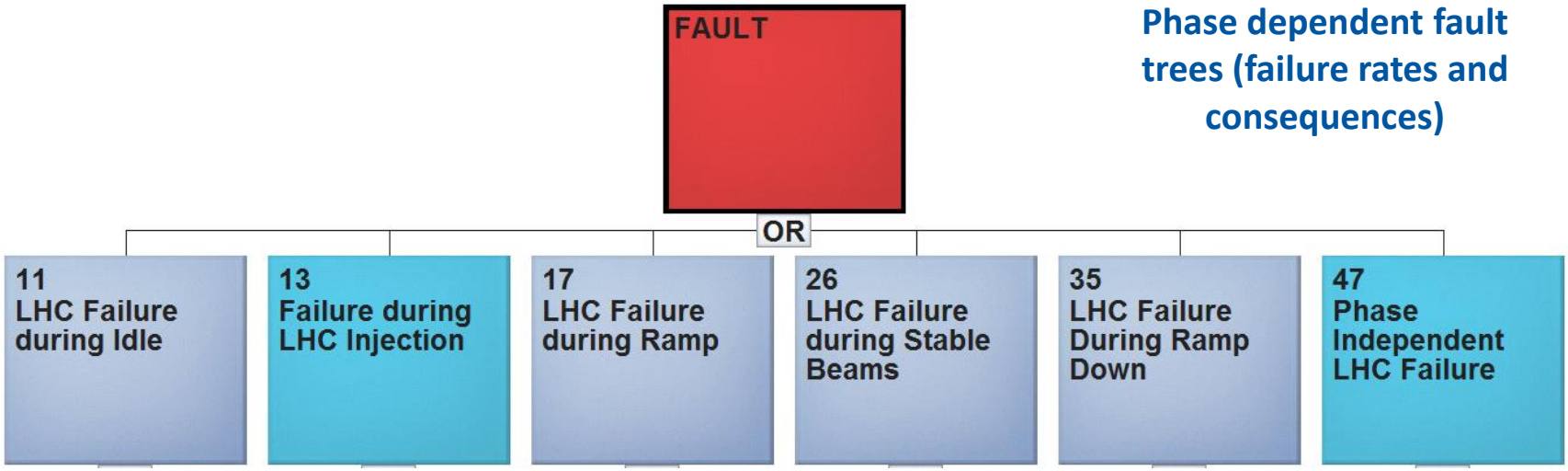
Model Implementation



Probabilistic phase transitions (Markov chain)

Randomly generated failures (base on calculated probability distributions)

Model Implementation



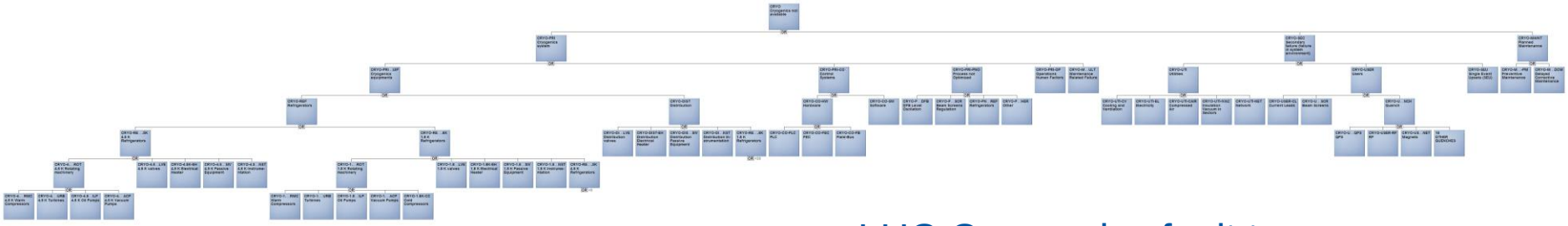
Phase dependent fault trees (failure rates and consequences)

Active nodes

- Example: Failures in Injectors only relevant at Injection from the LHC perspective

Example: Cryogenics Fault Tree

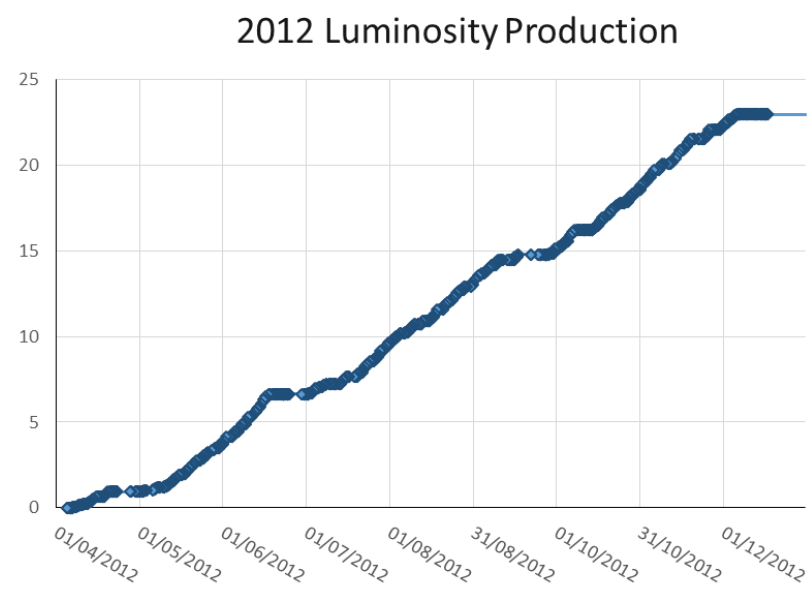
- **Model complexity** – impossible to model the entire accelerator to a sufficient level of detail within the FCC study
- Start from **top contributors to downtime**
- Collaboration with TU Delft for cryogenic system modelling and prognostic methods

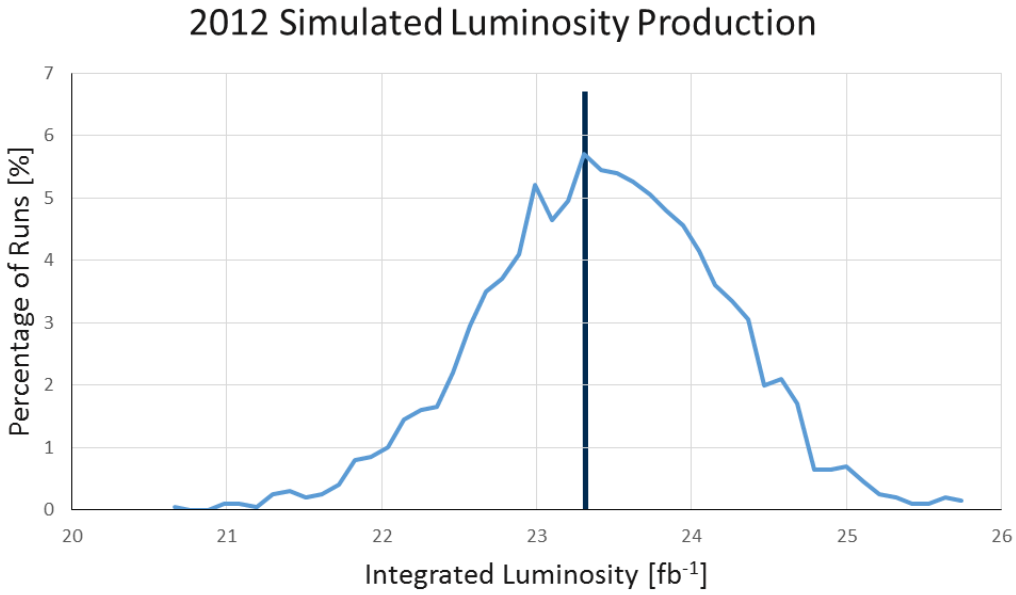


LHC Cryogenics fault tree

BONUS: the developed cryogenic fault tree will be used in 2016 for fault data capture by the cryo-operations team

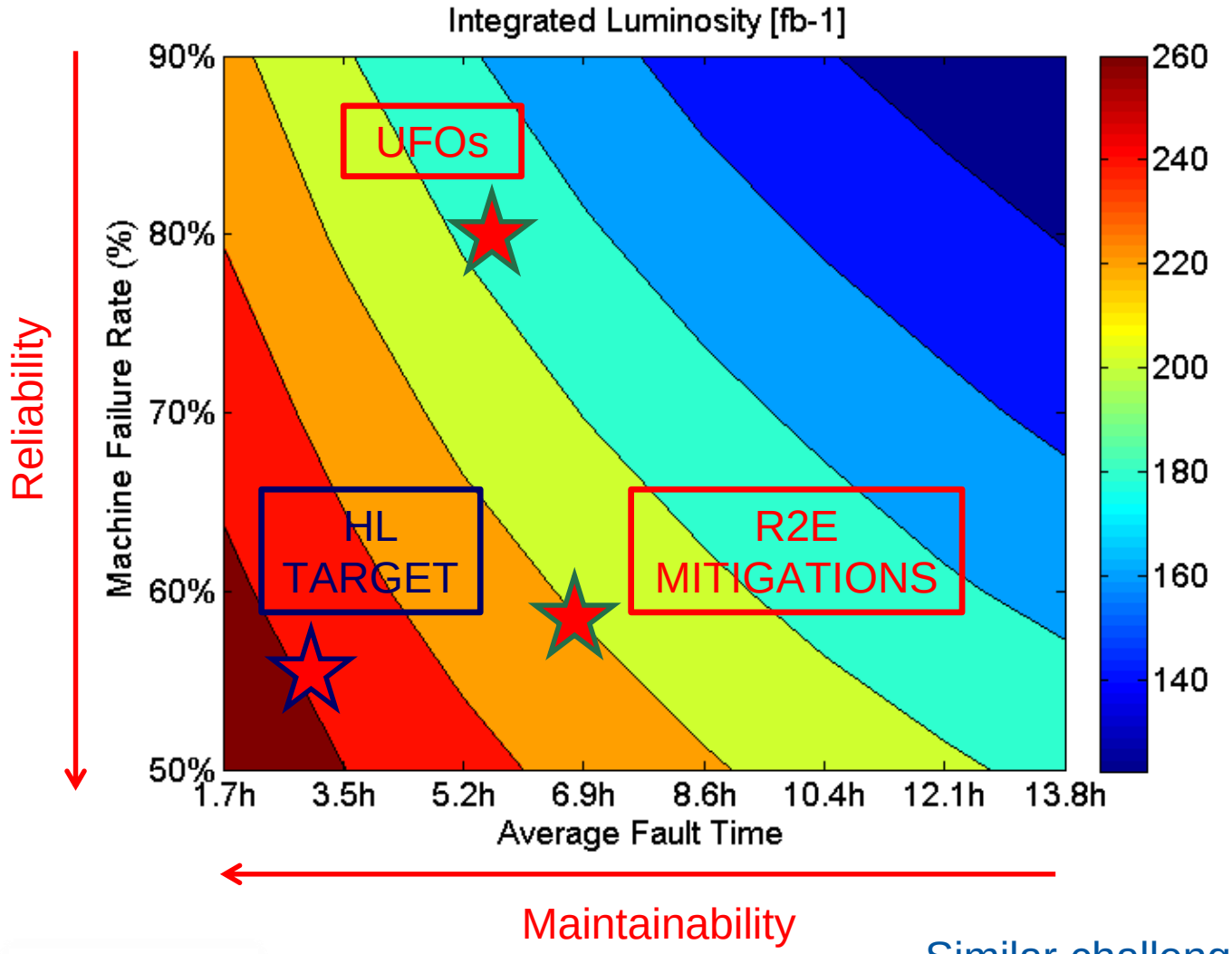
Model Validation: 2012 Luminosity Production





- Developed model allows reproducing 2012 LHC luminosity production (23.27 fb^{-1})
- Results from 1000 model iterations

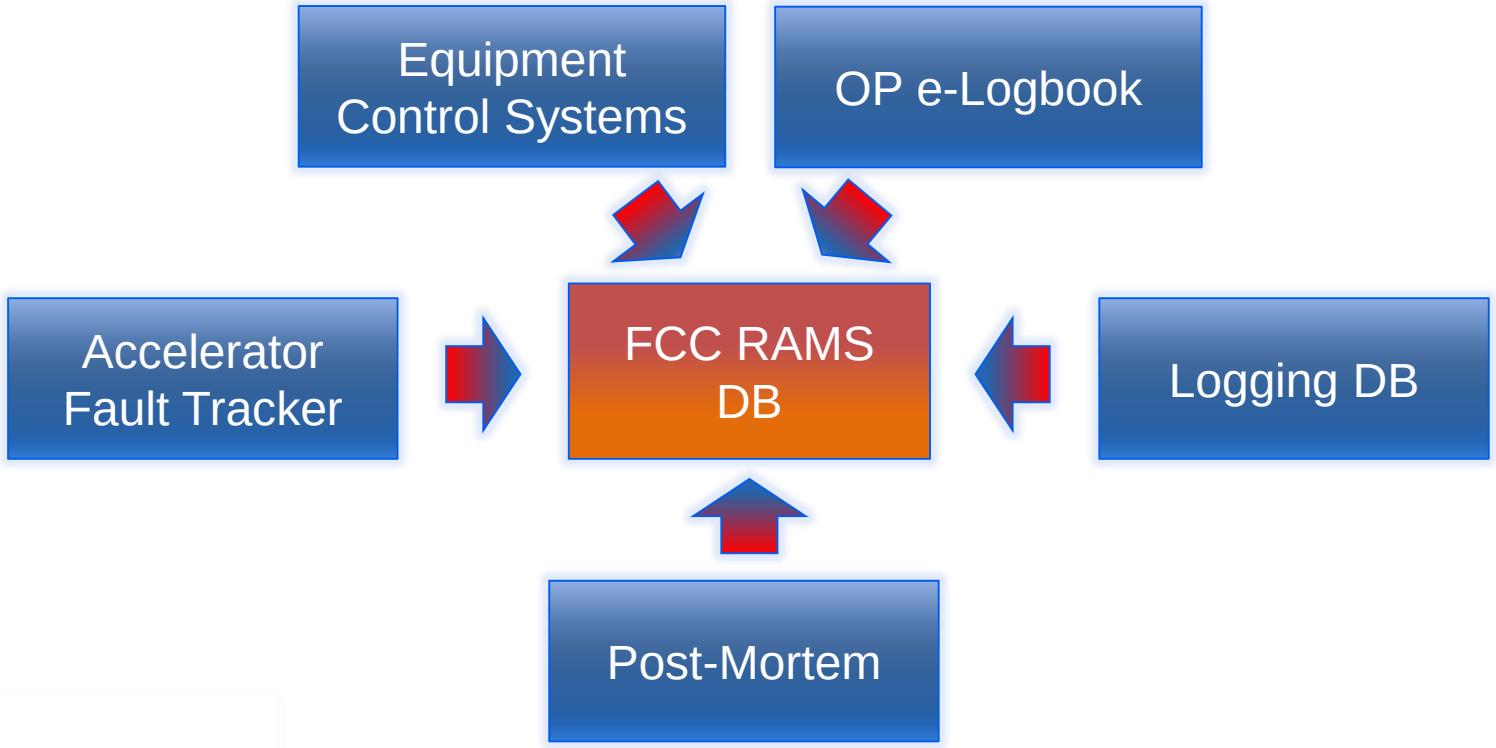
Sensitivity Analyses – HL-LHC Case



Similar challenges still apply for LHC and HL-LHC

Limits for Modelling

- **Data availability and data quality** – impossible to derive reliability figures without a dedicated effort
  - Consistent monitoring of signal trends necessary for predictive maintenance
- FCC RAMS database (collaboration with IT Department @CERN)



Conclusions & Outlook

- FCC-hh: big challenge from many different aspects, in particular from the availability point of view

- Future studies should focus on:
  - Definition of a fixed cycle duration
  - Analysis of different injector options (also influencing cycle duration)
  - Identify strategy for scaling number of components (e.g. number of power converters, redundancy in cryogenic system,…)

- Possibility: extend the study to the FCC-ee?
  - Requires expertise (and data) on lepton machines – not trivial

Thanks a lot for your attention!

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