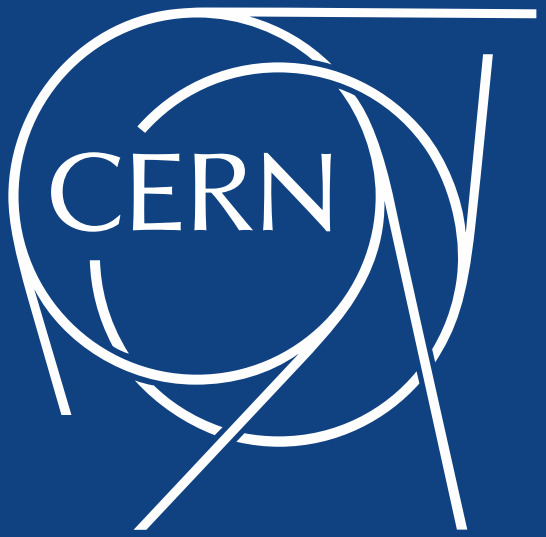

CERN

FCC Availability Studies

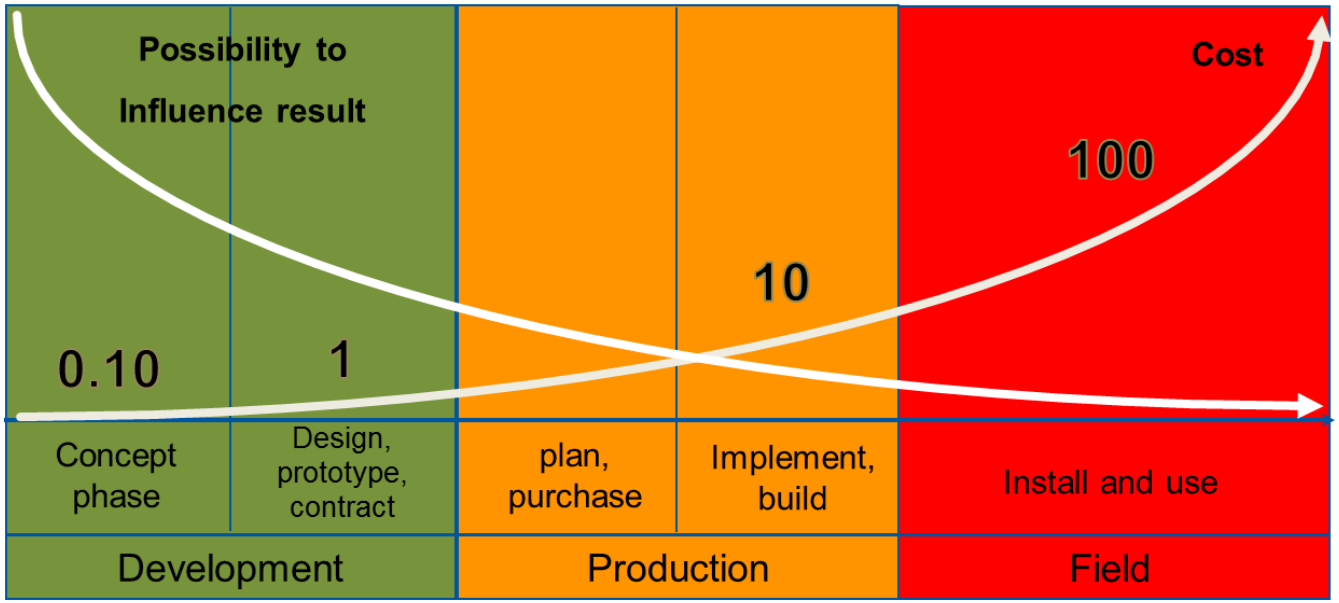
Andrea Apollonio on behalf of FCC RAMS Working Group

FCC Week 2016, 14/04/2016

Acknowledgements: R. Alemany Fernandez, M. Benedikt, V. Begy, J. Gutleber, A. Niemi, E. Rogova, A. Romero Marin, J.-P. Penttinen, R. Schmidt, P. Sollander

Motivation

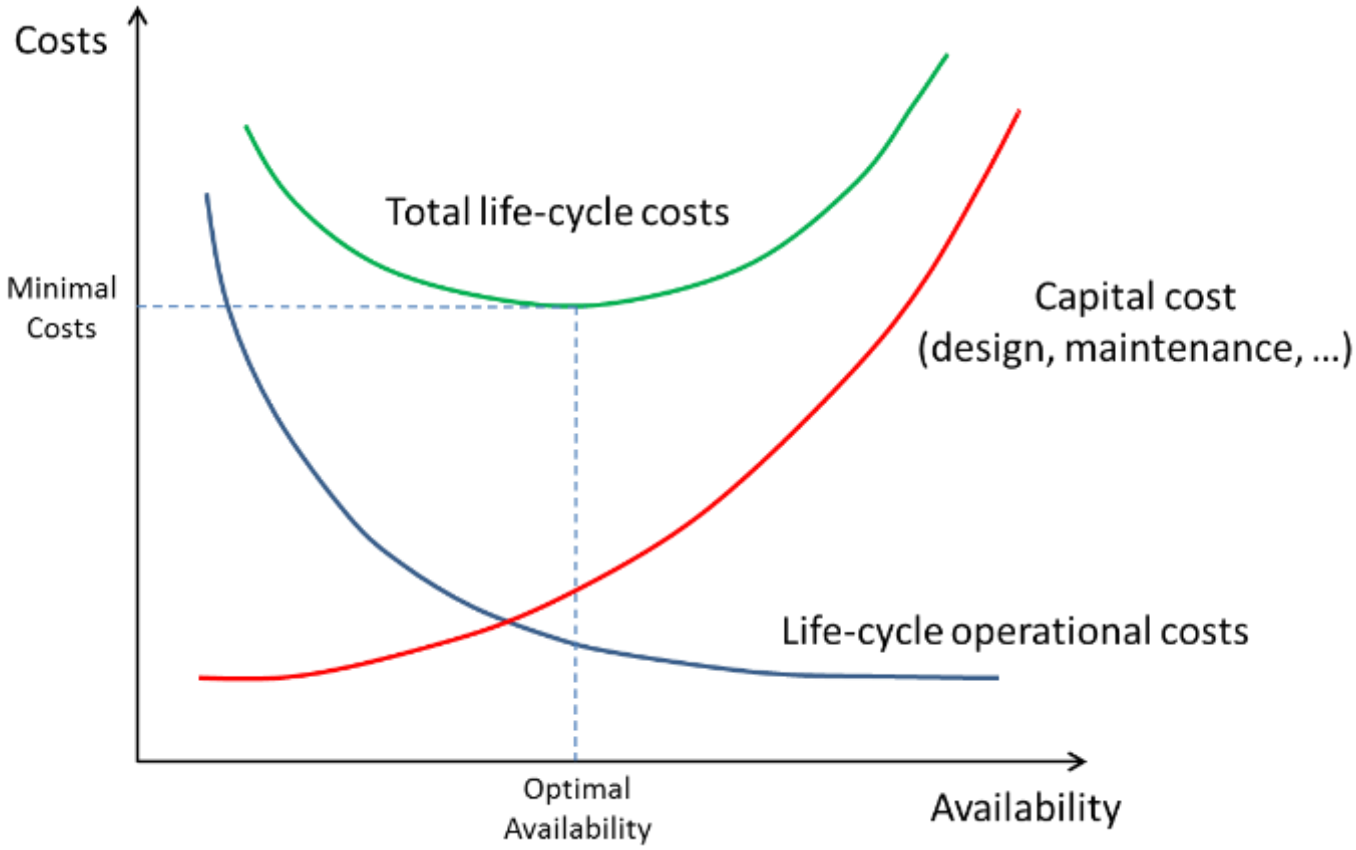
- **Technological and financial boundary conditions** set a limit for the peak beam performance for accelerators at the forefront of science
- Important to address **availability requirements** from conceptual design and across the entire **accelerator lifecycle**



Qualitative Definitions

- **Availability** is a measure of the **useful time** of beam delivered to physics experiments
- **Integrated luminosity [fb^{-1}]** is the key performance indicator for particle colliders

Availability and Costs



- For a set target integrated luminosity, operation costs decrease with increasing availability
- The cost to achieve higher availability requires higher capital expenses

Scope of the Study

- Evaluate the suitability of **industrial reliability methods** for 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
- Assess potential of methods for HL-LHC
- Identify **key impact factors** on availability and luminosity production
- <u>This reliability & availability study DOES NOT intend to give specific guidelines for individual system design and optimization</u>

Collaboration Contributions

CERN
Coordination, modelling simulation, analytics, data management, use-case definition, technical infrastructure

Ramentor Oy
Modelling and simulation Software, training

Tech. Uni. Delft
Analytics, cryogenics system modelling

Tampere U. of Tech.
Method and tool consultancy

Uni. Stuttgart:
Method and tool consultancy, training

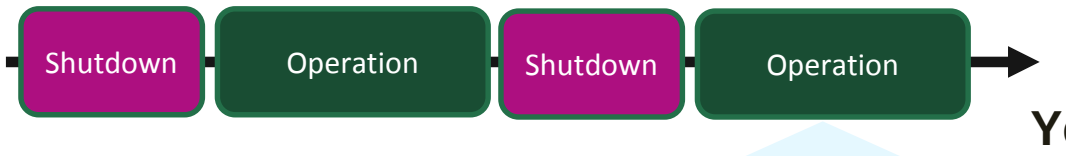
Uni. Wien
Data analytics platform development

FCC-hh – A New Machine

- **How should it be operated?**
  - What would the FCC-hh cycle look like? (see talk by R. Alemany Fernandez on Wednesday)
  - 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/condition-based/corrective maintenance contribute to availability improvements?

Accelerator Schedule



Years

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

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

Weeks

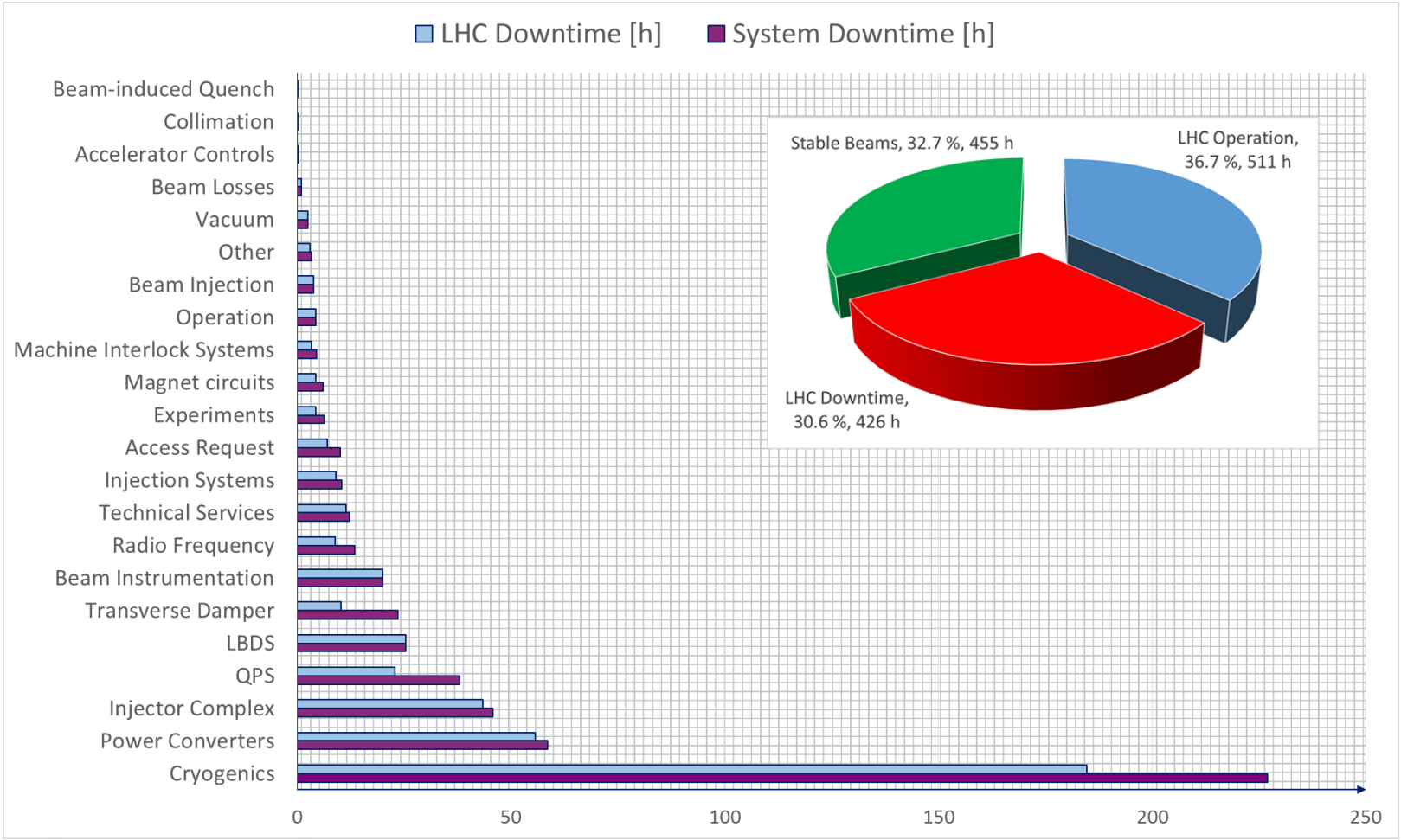
$$A3 = \frac{Stable\ Beams}{Lumi.\,Production}$$

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

Hours

LHC – Our Reference

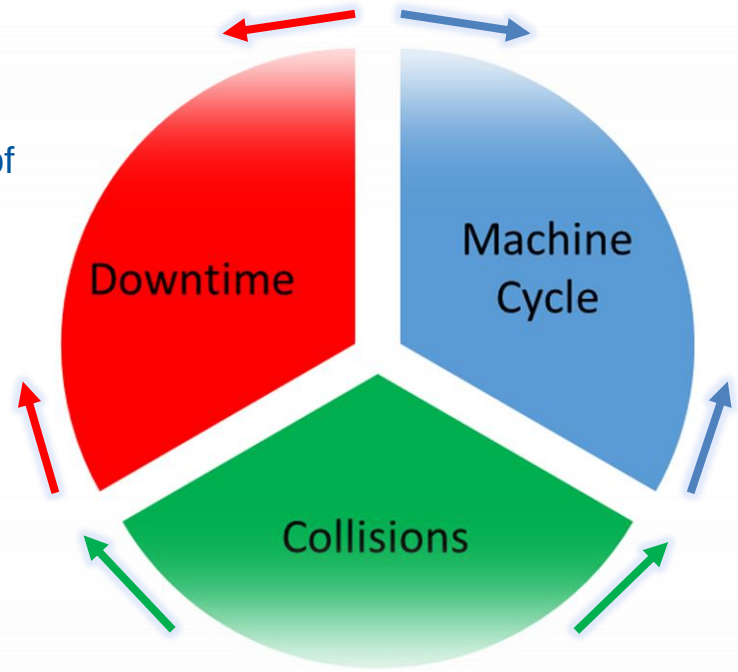
- What do we know from the LHC? (25 ns Run in 2015)



FCC-hh – A Complex Machine

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

- Improved reliability for high-impact systems (redundancy)
- Explore the potential of condition-based maintenance



- High availability of the injector chain
- Extremely efficient cycling

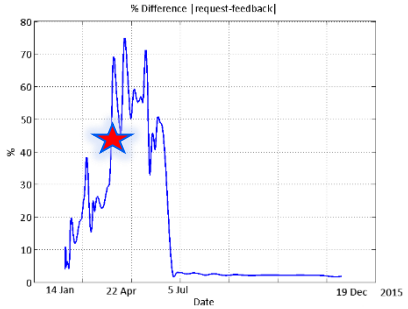
Sensitivity analyses of key contributors for luminosity production

- Optimization of machine protection settings
- Reduced fraction of premature dumps

Breakdown of Failure Duration

Failure Duration

Identification



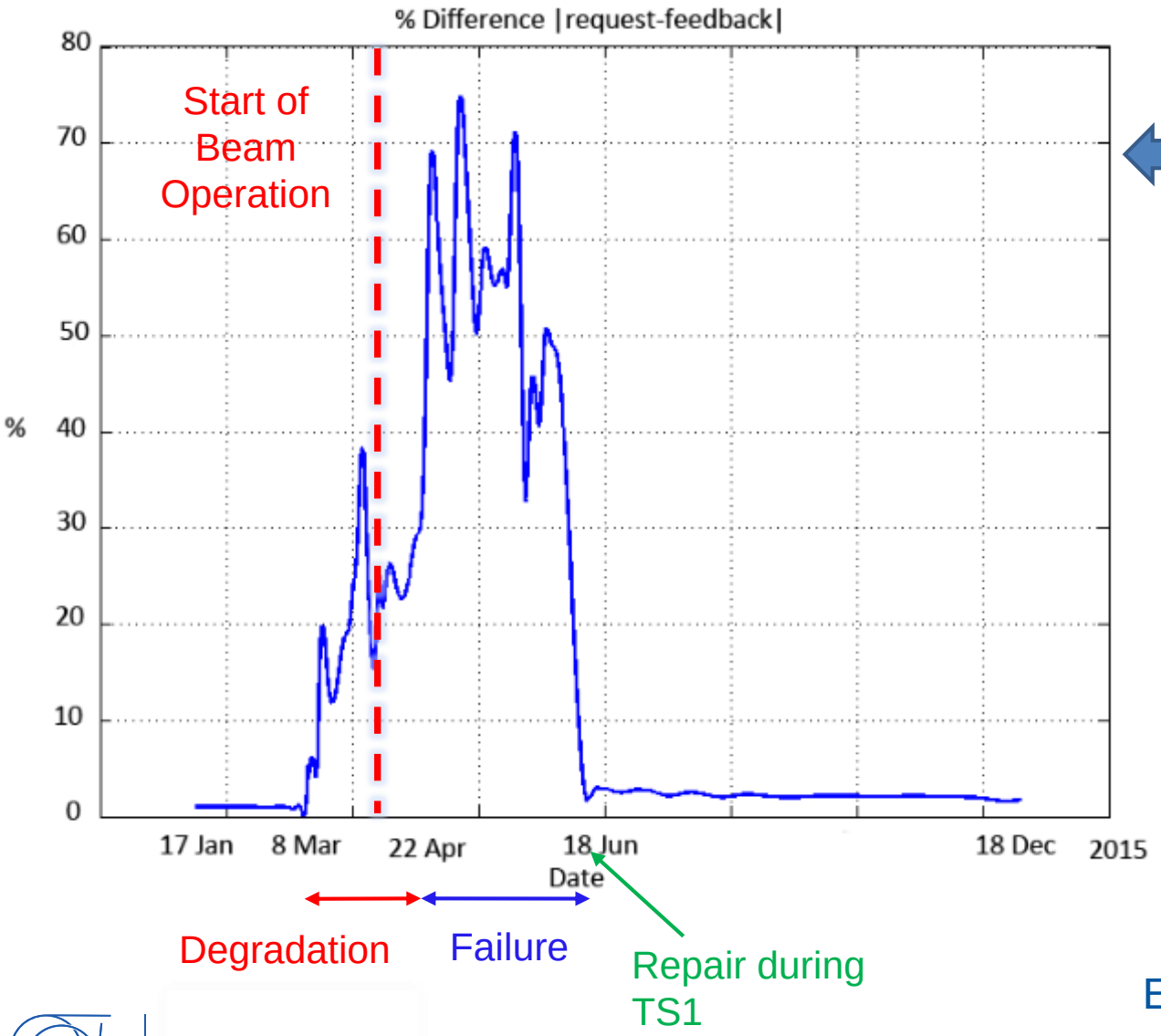
Diagnostics

Logistics

Restore

New strategies required!

Potential of Condition-Based Maintenance



Faulty cryogenic slide valve (CV120 - hydraulic)

- Degradation and failure observed during 3 months (9 Mar-17 Jun)
- 22 Apr – failure recorded in the cryogenics logbook
- 5 Apr – Start of Beam operation

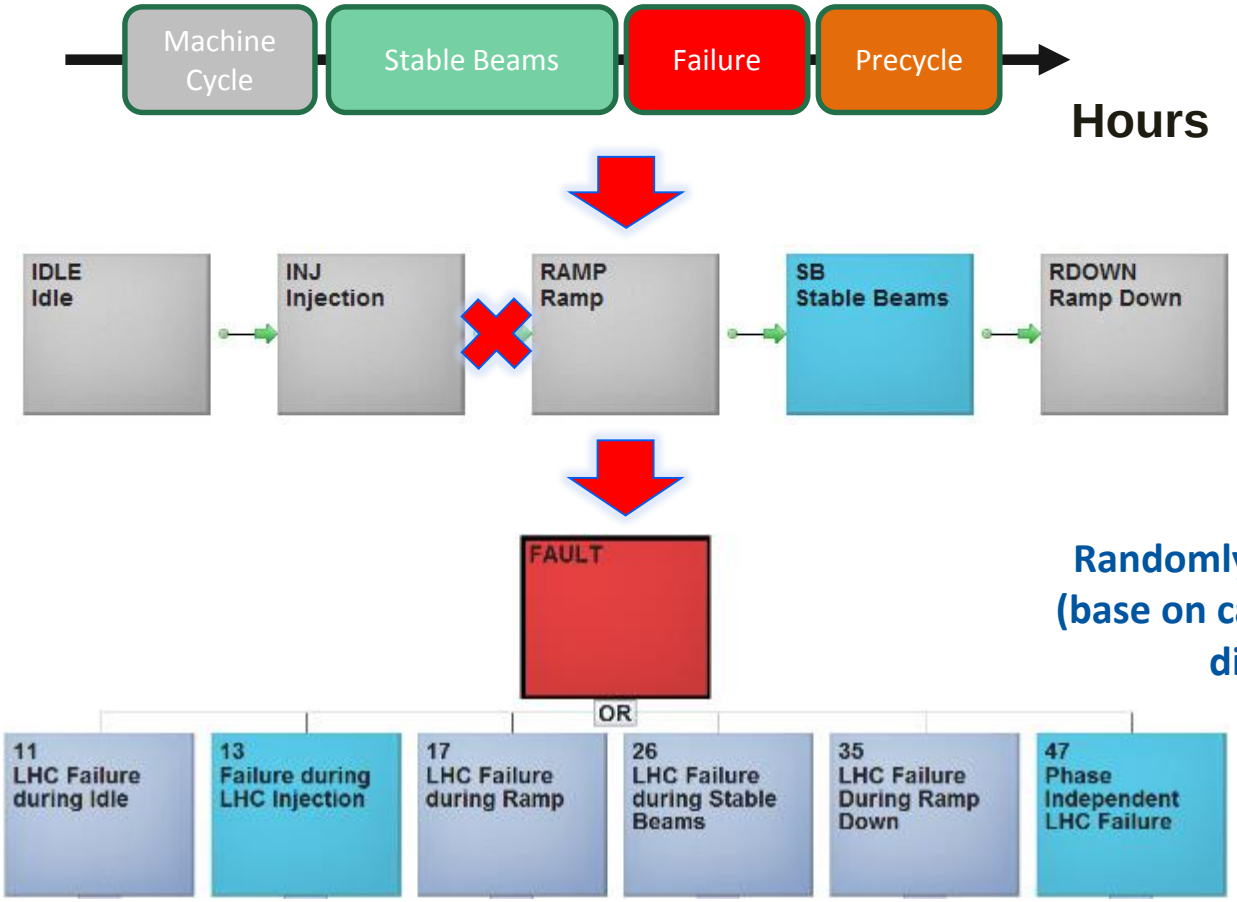
- **Online processing of data can predict failures!**

E. Rogova, TU Delft

LHC Availability Model Elements

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

Model Implementation



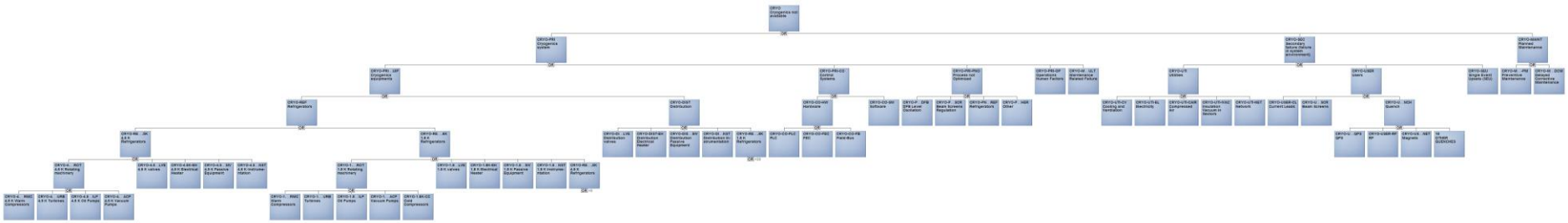
Probabilistic phase transitions (Monte Carlo approach)

Randomly generated failures (base on calculated probability distributions)

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

Example: Cryogenics Fault Tree

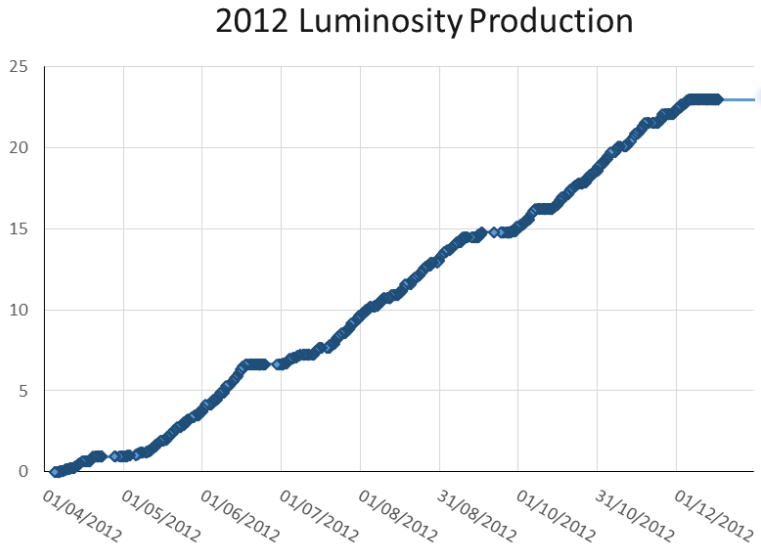
- **Model complexity** – impractical to model the entire accelerator to a sufficient level of detail within the FCC study
- Start from **top contributors to downtime**

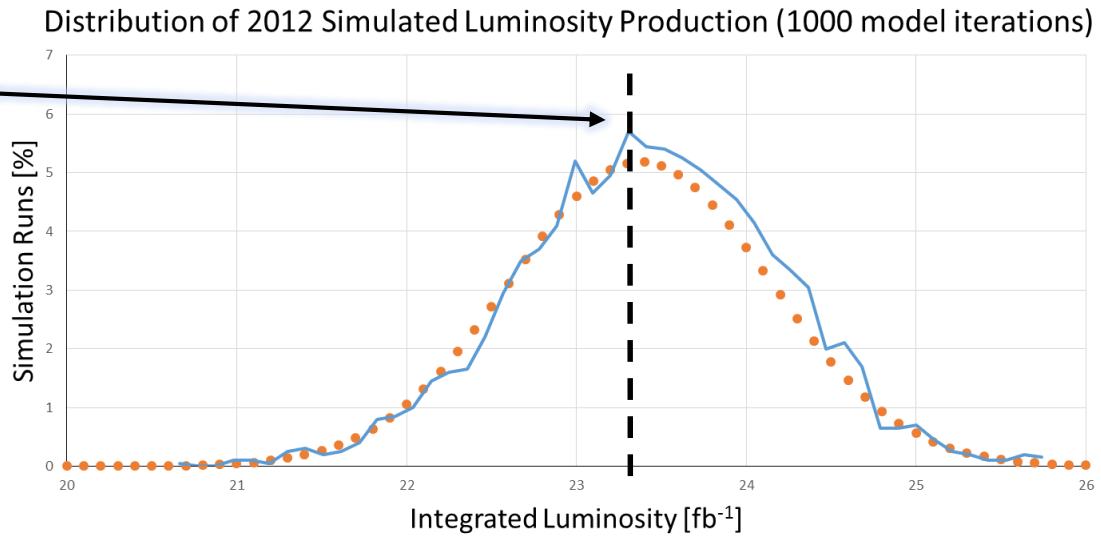


LHC Cryogenics fault tree

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

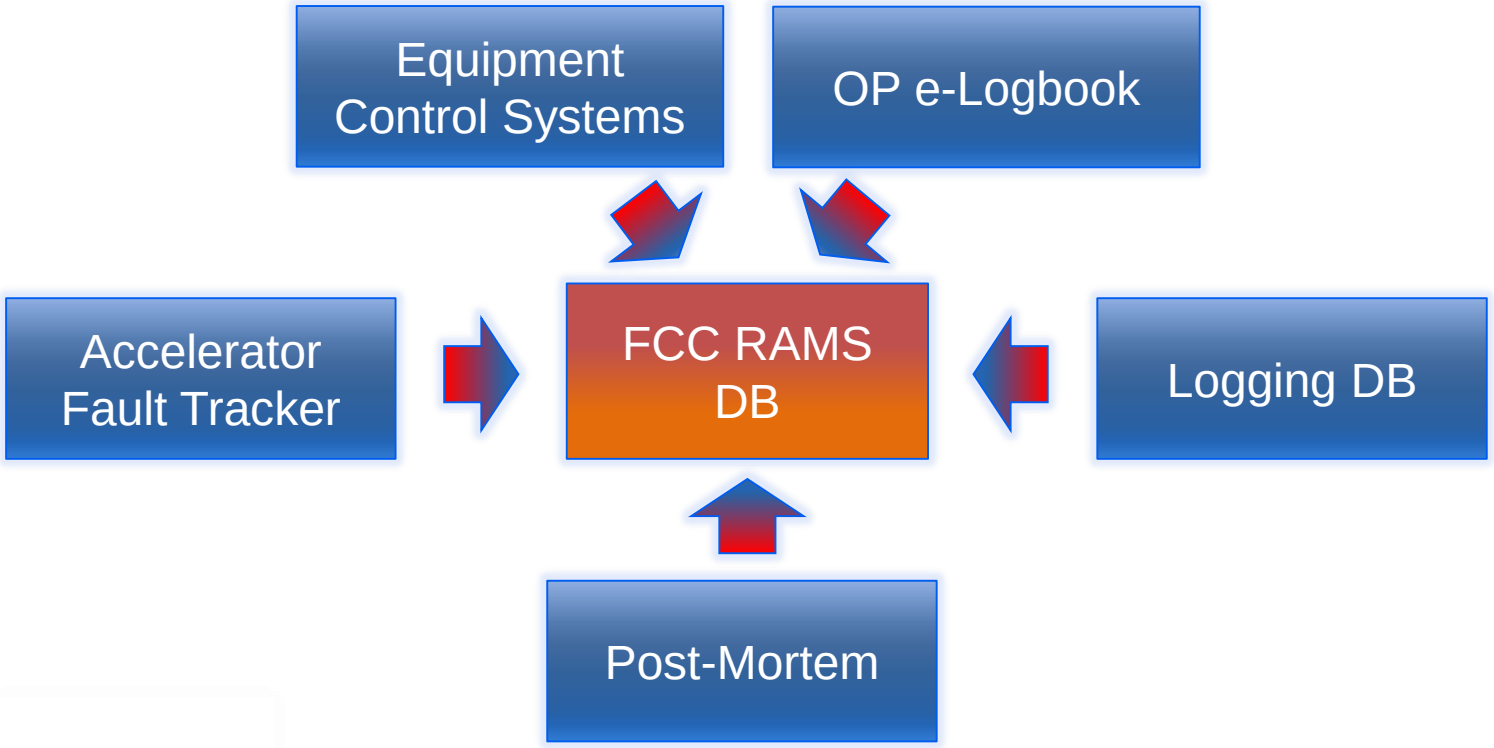




- 2012 LHC Luminosity production 23.27 fb^{-1}
- Developed model allows predicting 2012 LHC luminosity production with better than 1 % accuracy
- Results from 1000 model iterations (~10 min)

Enabling Technologies for Modelling

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



Conclusions & Outlook

- Estimates of the **achievable availability** of the FCC-hh will be one of the main factors for the assessment of its **feasibility**
- LHC Availability model implemented (better than 1 % acc.), ready for extrapolation to FCC
- Future studies should focus on:
  - Definition of a FCC **cycle duration** (also influencing system design)
  - 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,…)
  - **Data quality** management (RAMS Database)
- Possibility: extend the study to the FCC-ee?
  - Requires expertise (and data) on lepton machines

Thanks a lot for your attention!

www.cern.ch

Join us in the FCC RAMS study!
FCC-RAMS@cern.ch