AvailSim4: Open-Source Framework For Availability and Reliability Simulations

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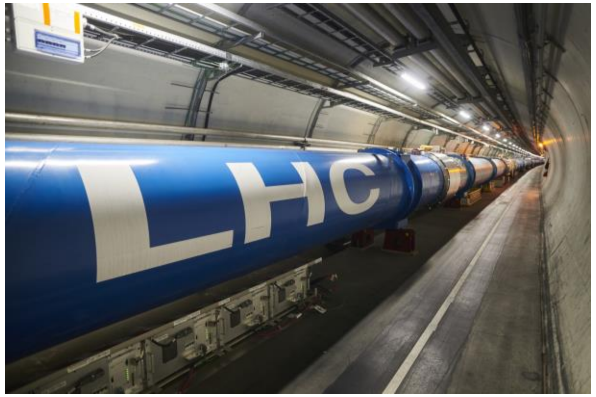
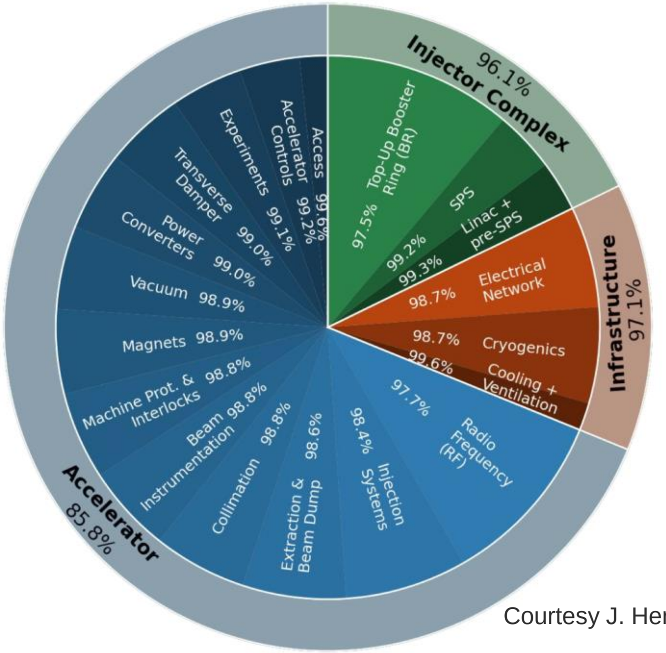
RAMS simulations & CERN



- **Stochastic simulations for RAMS studies**
  - A broad range of tools is available to **estimate** or **predict** those metrics quantitatively.
  - Stochastic simulations:
    - **unparalleled flexibility,**
    - **straightforward translation** of a conceptual description into a model,
    - **highly realistic** representation of studied systems.

E(LHC powering magnets) = E(ship at 27 kn)

- **At CERN**
  - **Availability** concerns are relevant as the machine is an expensive project and downtime disrupts its scientific goals.
  - **Reliability** matters due to presence of systems that deal with large energy stored in the beams and magnets.



Courtesy J. Heron

Overview
What is AvailSim4?

AvailSim4
Project ID: 131878

Clone from **https://gitlab.cern.ch/availsim4/**
or

```
> pip install availsim4
```

Monte Carlo simulation framework for availability and reliability studies of complex systems.

Main characteristics of the framework:

- ✓ **Customizable models** for systems composed of **many sub-systems.**
- ✓ **Open source**; features tabular input & output, for **easy integration with other tools**.
- ✓ Parallelization capacity and distributed computing support for **large-scale simulations.**

Difficult to find in commercially availabile tools

The 4th take on the tool

Previous versions have been developed at other particle accelerator facilities.

Current version:

- written in **Python,**
- designed with **long-term maintainability** in mind,
- in use at CERN **since 2020.**

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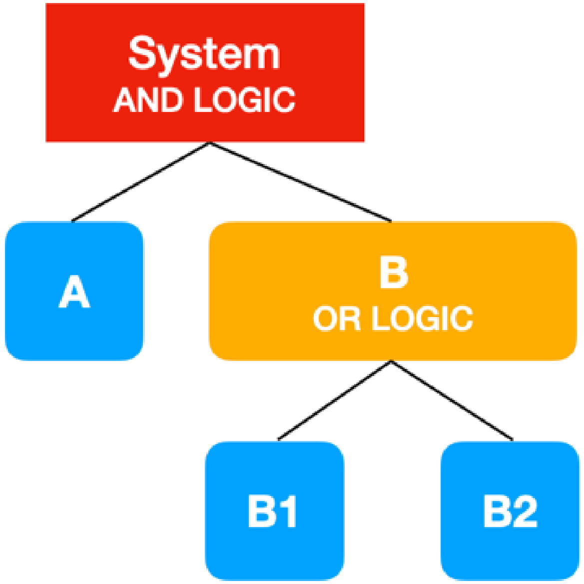
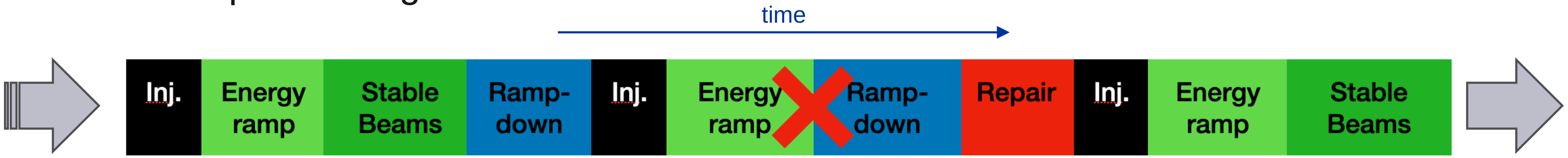
Model Description

- **Models are made of components:**
  - **Basic** – elements with a failure mode
  - **Compound** – elements aggregating other basic and compound components into more complex structures
- **Component dependencies with logic operators:**
  - X out of Y, AND, OR…
- **Additional parameters:**
  - Phase-dependent failure and repair behaviour
  - Inspection and repair strategies





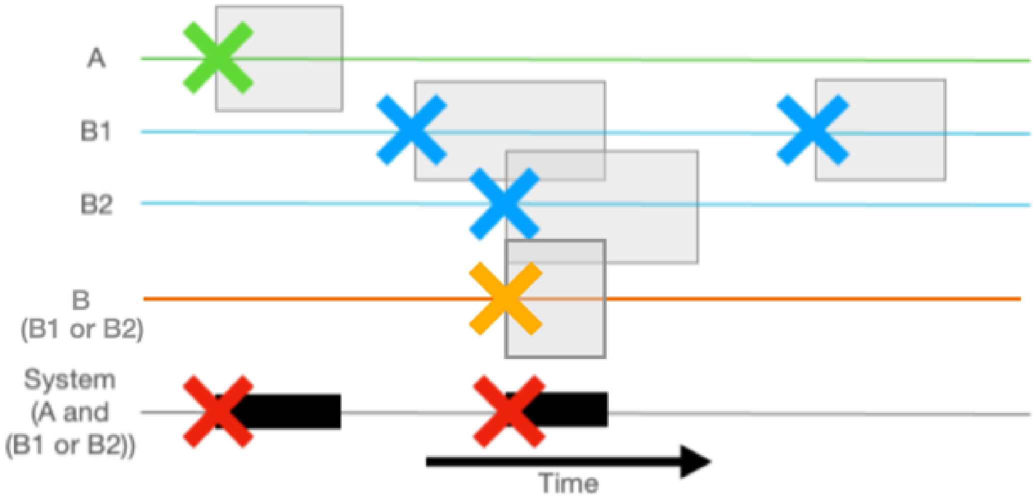
Algorithm & Implementation
Discrete Event Simulation & Monte Carlo

Discrete Event Simulation (DES):

- For driving the individual iterations.
- DES chosen to have maximum flexibility in modelling the system.

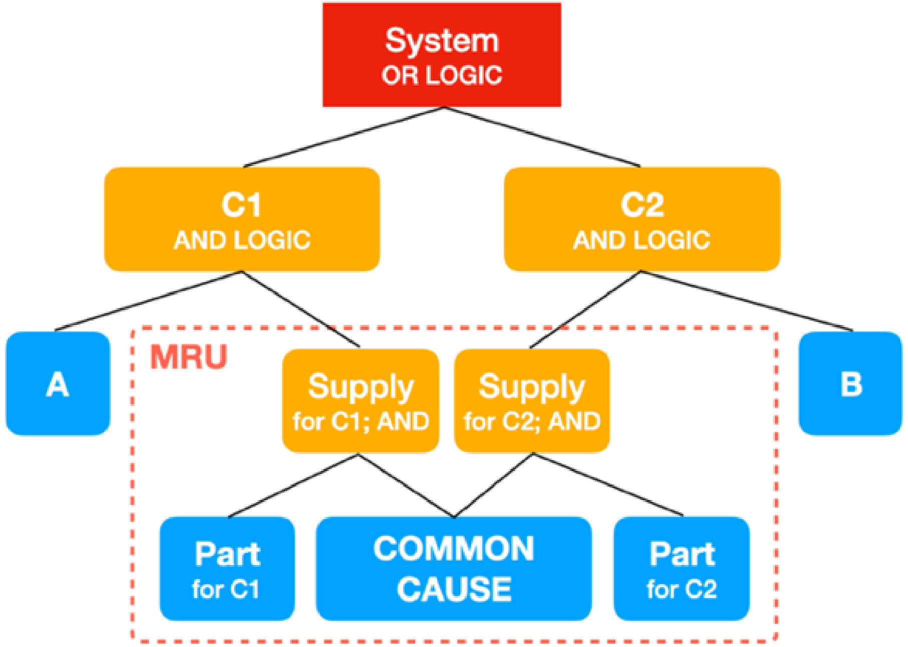
Monte Carlo (MC):

- DES performed repetitvely, each time sampling the desired probability distributions.
- The most flexible approach reflecting real-life events
  - Comes at the price of the slow convergence – for rare events, millions of iterations may be needed to obtain accurate results.



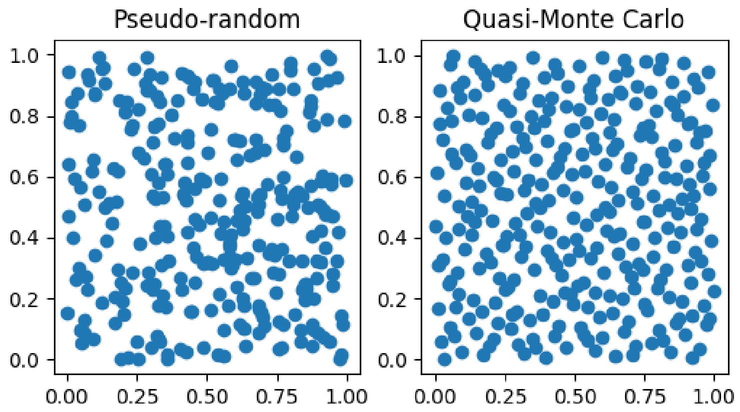
Selected built-in features
Support for complex models

- **Minimal Replaceable/Swappable Units**
  - Failures of certain components may trigger repairs/replacement of others.
- **Shared children**
  - Parent components can be dependent on the same children.
- **Custom children logic**
  - Possibility to define custom advanced children logic through Python classes where other properties than a number of failures play a role.



Performance optimizations
Omptimized sampling

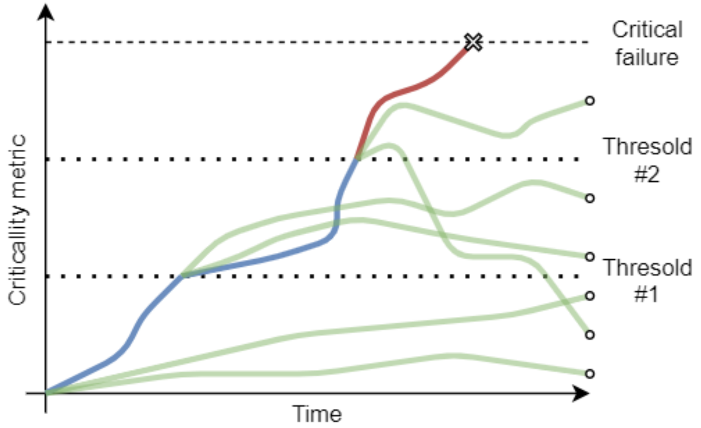
Quasi-Monte Carlo



- Improves convergence speed using **low-discrepancy sequences** (as opposed to pseudo-random in standard Monte Carlo).
- Reduces variance, increasing efficiency **"out-of-the-box"**.

Convergence of QMC closer to $O(1/N)$ instead of $O(1/N^2)$.

Importance Splitting
(RESTART and similar approaches)



- Focuses on rare, critical events, through **splitting simulations** at crucial points.

Increased efficiency by **orders of magnitude** in synthetic test cases but **feasibility varies** per use-case and depends strongly on additional user input.

Code quality and long-term maintainability
Project features

AvailSim4 @ CERN Gitlab

- **High code quality:**
  - written in Python 3, with dependencies on well known libraries only
  - 11,000 lines, >200 tests in the Continuous Integration pipeline, 95% lines coverage
- **Getting started and contributing aided by**
  - User and developer guides.
  - Examples
- **Releases so far:**
  - 1st release in 2021, 2nd in 2023.
- **Available through PyPI and CERN Gitlab instance.**
  - Released under the GPL-3.0 licence.

Status	Pipeline	Created by	Stages
Passed 00:11:12 1 year ago	#142 fixing errors after rebase #4528659 142-cython 81b8c0be latest		
Passed 00:10:46 1 year ago	Merge branch '135-type_checking-jobs-re... #4516037 master e9048e3b		
Passed 00:11:06 1 year ago	#135 implementing reviewer's comments #4514612 135-type_checking-jobs-reporting-type-issues 724038c5		
Passed 00:16:40 1 year ago	#135 implementing reviewer's comments #4511893 135-type_checking-jobs-reporting-type-issues 9dbb76b4		

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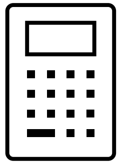
When to use AvailSim4?

Is modelling of **redundancy**, **demand**, **repair** required?

NO

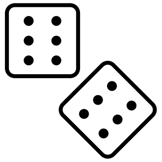
Analytical methods



- Limited by **complexity of the equations**, at a certain point computer aid is necessary
- May quickly result in **sets of convoluted formulas** difficult to comprehend
- **Fast** to compute

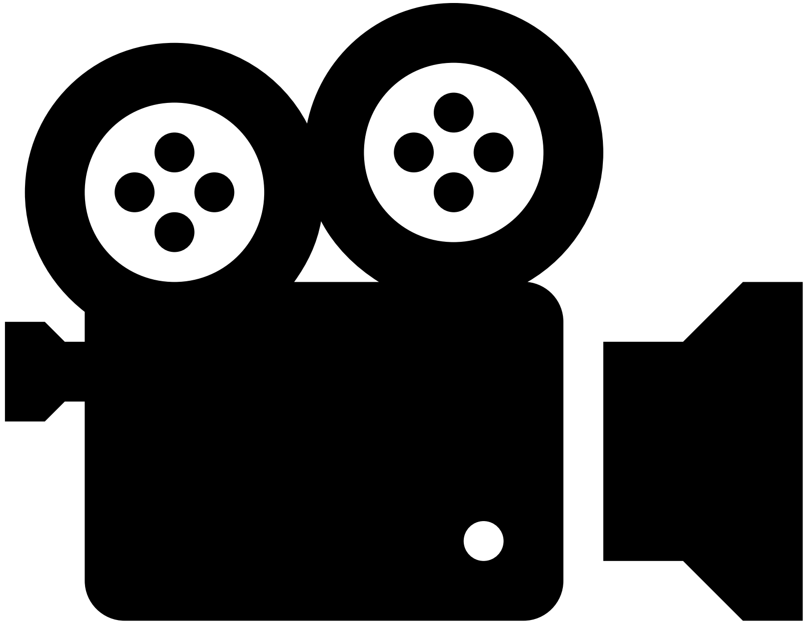
YES

Stochastic methods



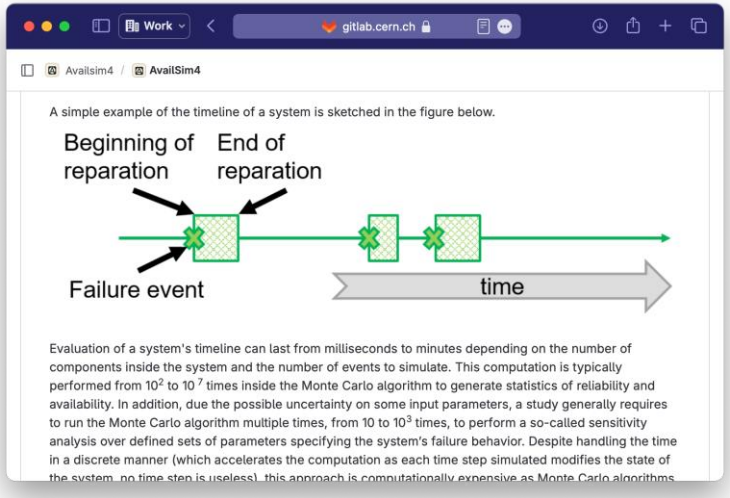
- **Very flexible**, potentially antyhing can be included in the simulation
- **Easy to understand** models
- Computationally **slow**

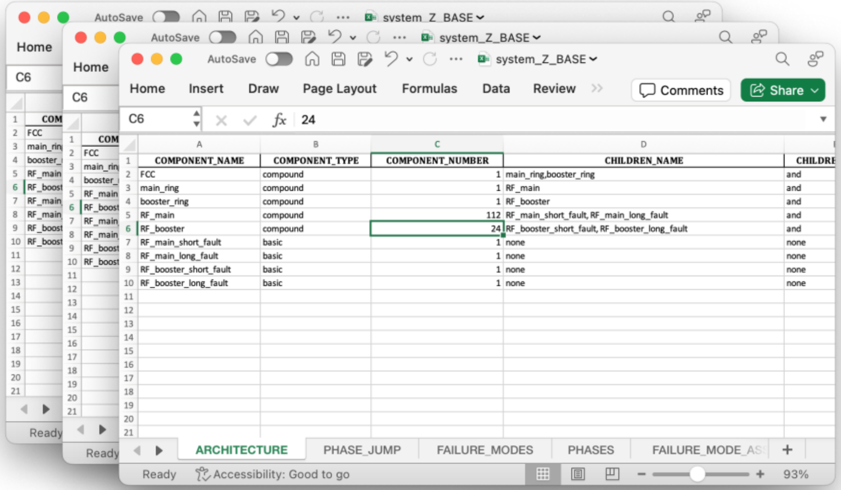
Demo



Getting started
Guides, examples, tools, etc.

- **User guide:** **CERN Gitlab - AvailSim4 User Guide**
- **Examples:** **CERN Gitlab - Simple Examples for AvailSim4 beginners**
- **FCC study:** **CERN Gitlab - FCC-ee Sensitivity Availability Study**
- **Custom children logic showcase:** **CERN Gitlab - Dynamic Compensation Study**
- **HTCondor Post Processing:** **CERN Gitlab - Scripts to facilitate running on HTCondor**





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Conclusions

- **Advanced simulation tools are indispensable in detailed availability and reliability studies.**
- **AvailSim4 delivers an open-source solution, which:**
  - works with complex models,
  - is easily interfaced with other tools,
  - supports large-scale simulations via multi-core and multi-node computing.
- **Has been used in availability (LHC, FCC-ee, MYRRHA, etc.) as well as reliability (LHC Energy Extraction, LHC's Safe Machine Parameter system, etc.) projects.**
- **Explore at: gitlab.cern.ch/availsim4 (open access)**

@ CERN Gitlab

home.cern

Case study: FCC-ee availability
Next generation of accelerators

Future Circular Collider (FCC)
a leading proposal for the next generation of energy-frontier particle accelerators.

91 km
circumference

2045
start of FCC-ee
(electron-positron accelerator)

Challenge in **building, operating and maintaining** the machine.

Many
sub-systems

Expected
80%
availability

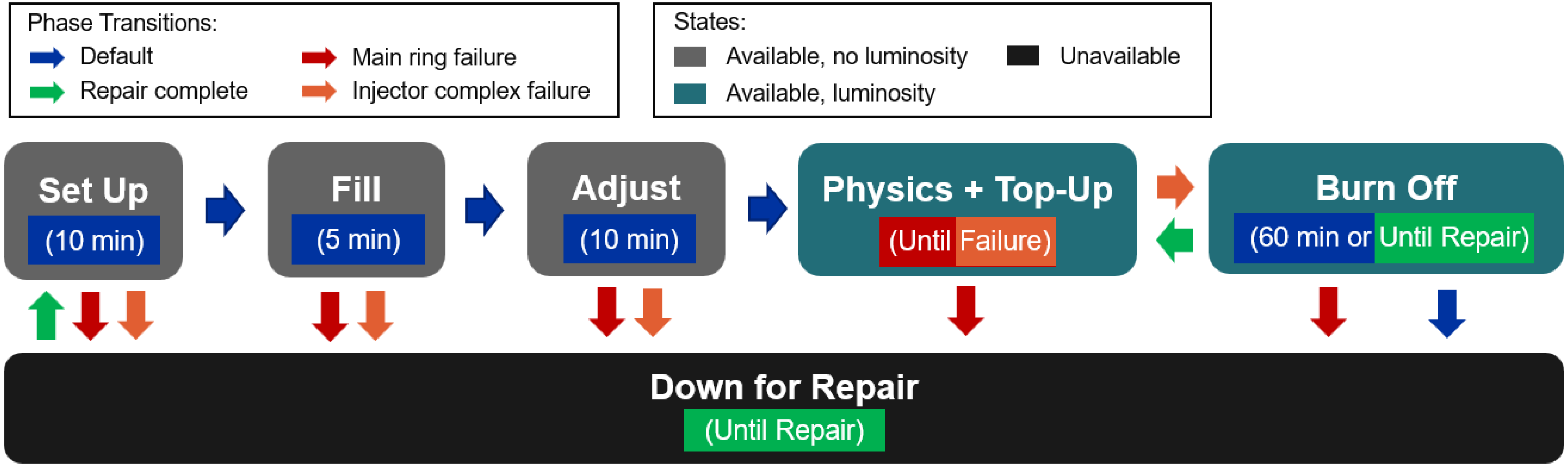
Radio Frequency (RF) system chosen as the subject of the study.

Redundancy

Z, W modes
0% - 10%

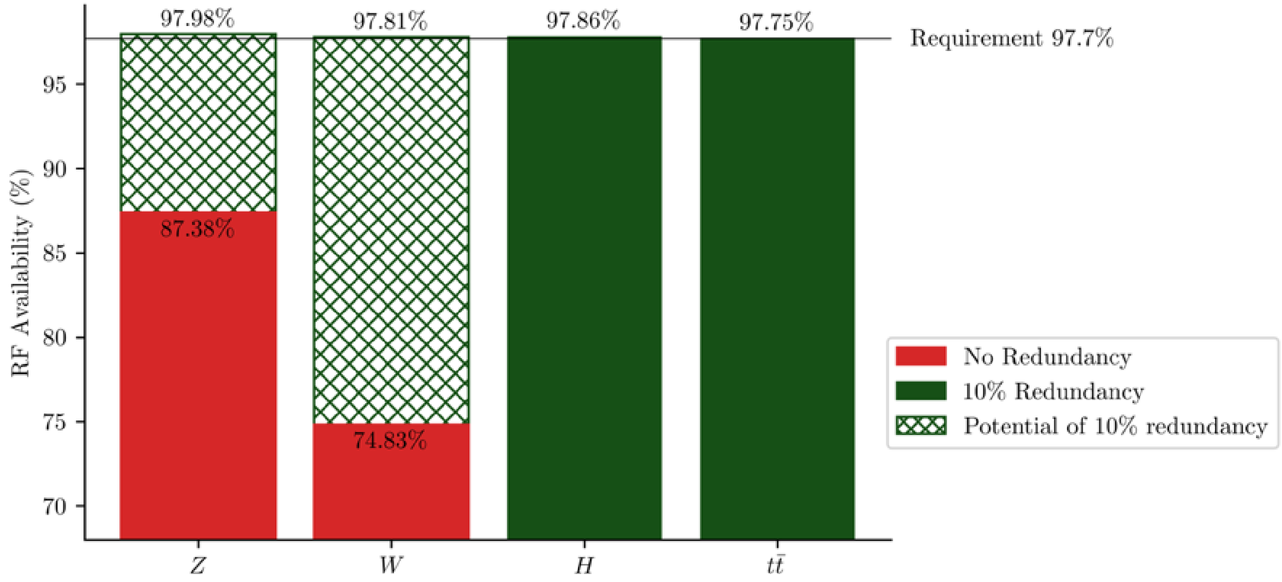
$H, t\bar{t}$ modes
10%

Case study: FCC-ee availability
Phase succession & parameters



Case study: FCC-ee availability
Simulation results

- **Availability findings:**
  - Two out of four energy modes (Z and W) show **inadequate availability** without redundancy.
  - Can be addressed by introducing 10% redundancy.



- **Outcomes & future directions:**
  - After iterations with equipment experts a solution was found to introduce redundancy
    → ferroelectric fast reactive tuning with a 4µs response time.

→ **AvailSim4 simulations can deliver crucial insights into availability of complex systems**