ADVANCED RF AND CRYOGENICS CONTROL AND FAULT DETECTION FOR SUPERCONDUCTING ACCELERATORS EXPLOITING MACHINE LEARNING ALGORITHMS

Adnan Ghribi[1,2] ; Daniel Berkowitz Zamora[5] ; Pierre-Emmanuel Bernaudin[1,3] ; Patrick Bonnay[3] ; Julien Branlard[4] ; Marco Di Giacomo[1,3] ; Frederic Doucet[5] ; Patxi Duthil[2] ; Annika Eichler[4] ; Robin Ferdinand[1,3] ; Mário Grosso Xavier[5] ; Christophe Haquin[1,3] ; Victor Martinez Illamola[5] ; François Millet[3] ; Franck Pompon[5] ;Jean-Pierre Thermeau[2] ; Dirk Vandeplassche[5]

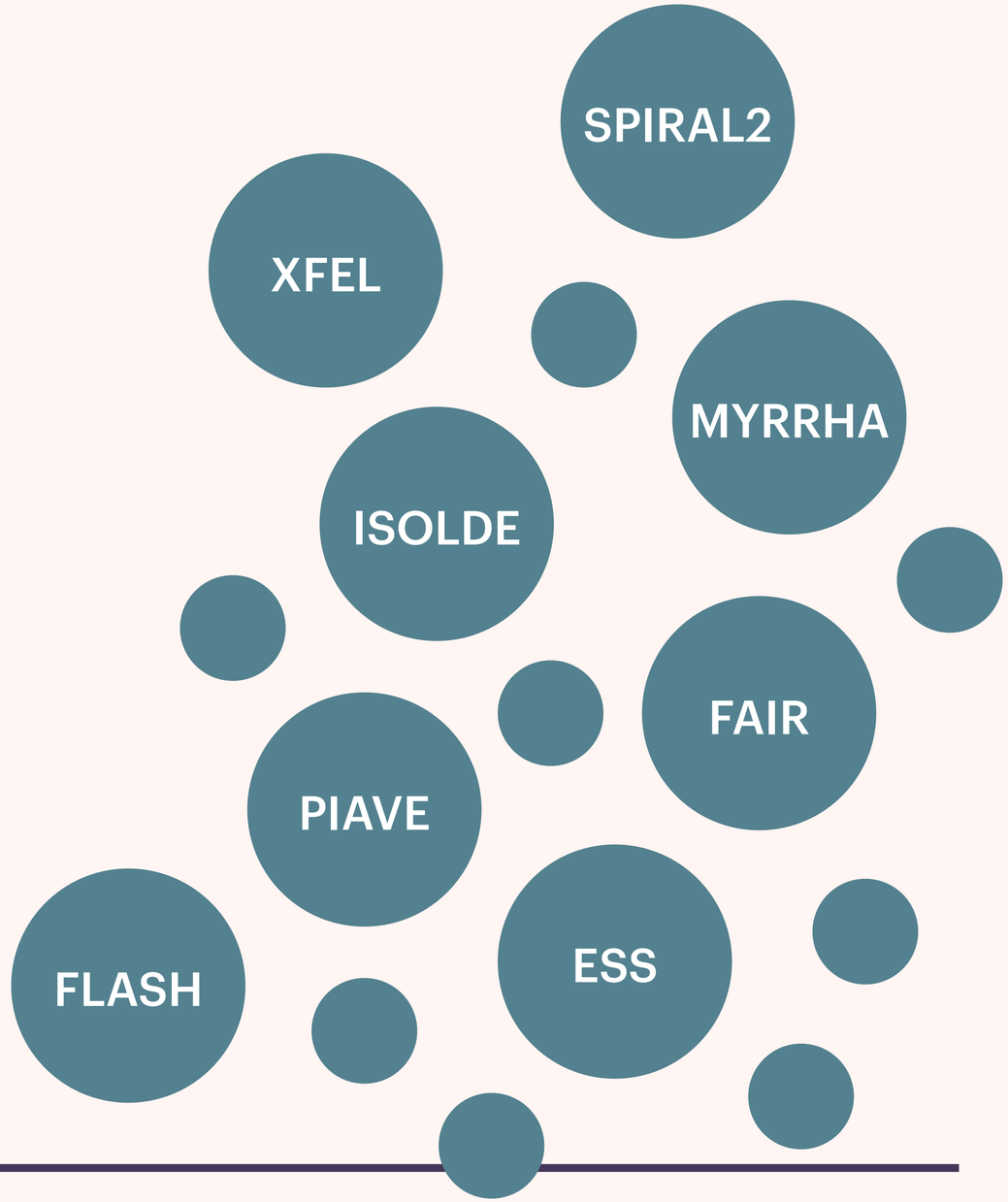
EUROLABS MEETING

[1]GANIL, [2]CNRS, [3]CEA, [4]DESY, [5]SCK

2021/04/26

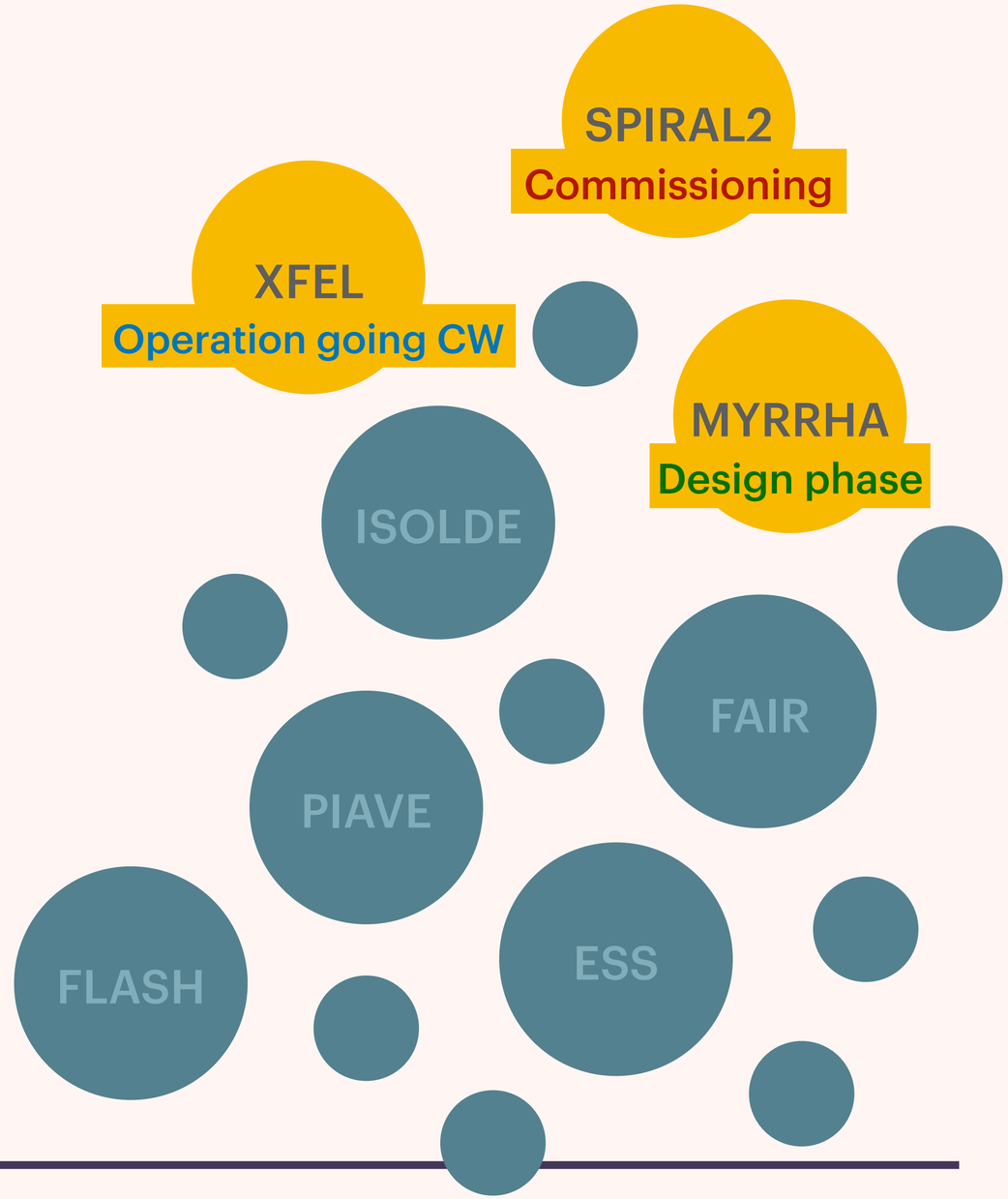
WHY

- **Superconducting accelerators face specific challenges**
  - **Tackled during design phase, commission phase or operation**
  - **Focusing on building solid partnership around specific issues**



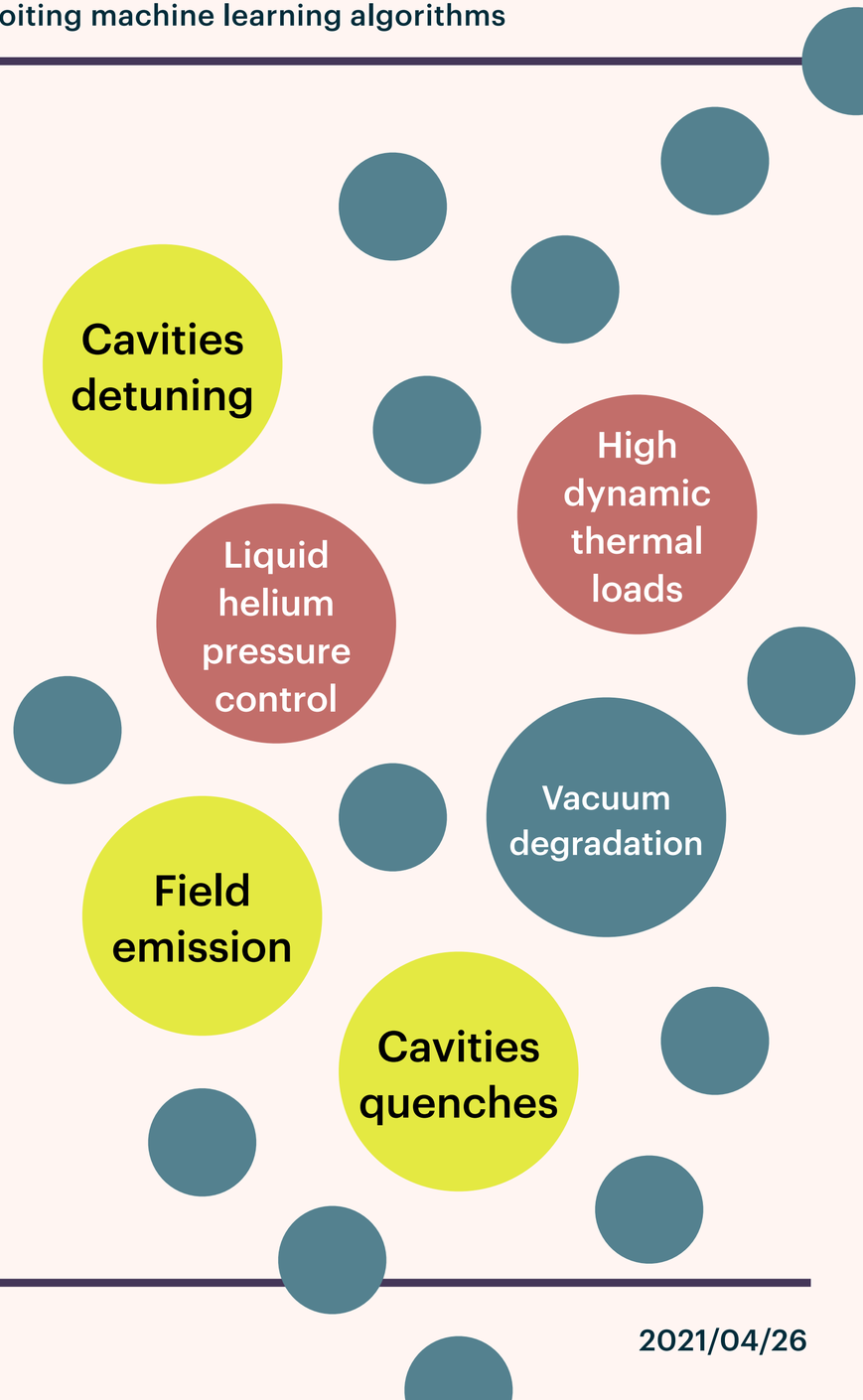
WHY

- **Superconducting accelerators face specific challenges**
  - **Tackled during design phase, commission phase or operation**
  - **Focusing on building solid partnership around specific issues and common methods**



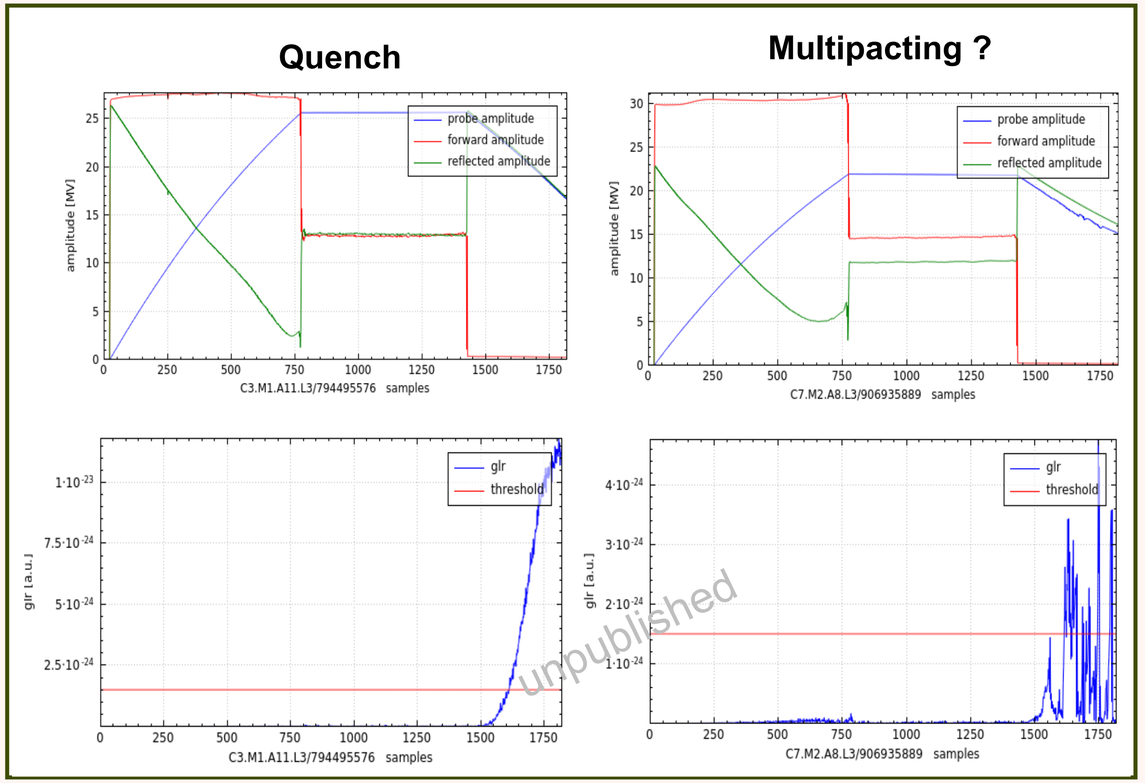
APPROACH

- Different effects occurring in different sub-systems might seem uncorrelated
- Cross or self correlation features are hidden in the data
- Physics informed models can allow to extract these features
  - ➡ Smart fault Detection
  - ➡ Optimized intelligent control
  - ➡ Increased reliability and beam availability



BUILDING ON EXISTING GROUND

- **XFEL : differentiating different RF trips signatures with general likelihood ratios : first step towards expert fault classifiers**
- **SPIRAL2 + CEA/DSBT: Successful setup of physics informed control of cryogenic system, smart dynamic heat load observer, towards ML fault detection**
- **MYRRHA / IJCLab : Extending thermodynamic cryogenic models to RF models for single cryomodules. Preparing the future challenges of MYRRHA.**

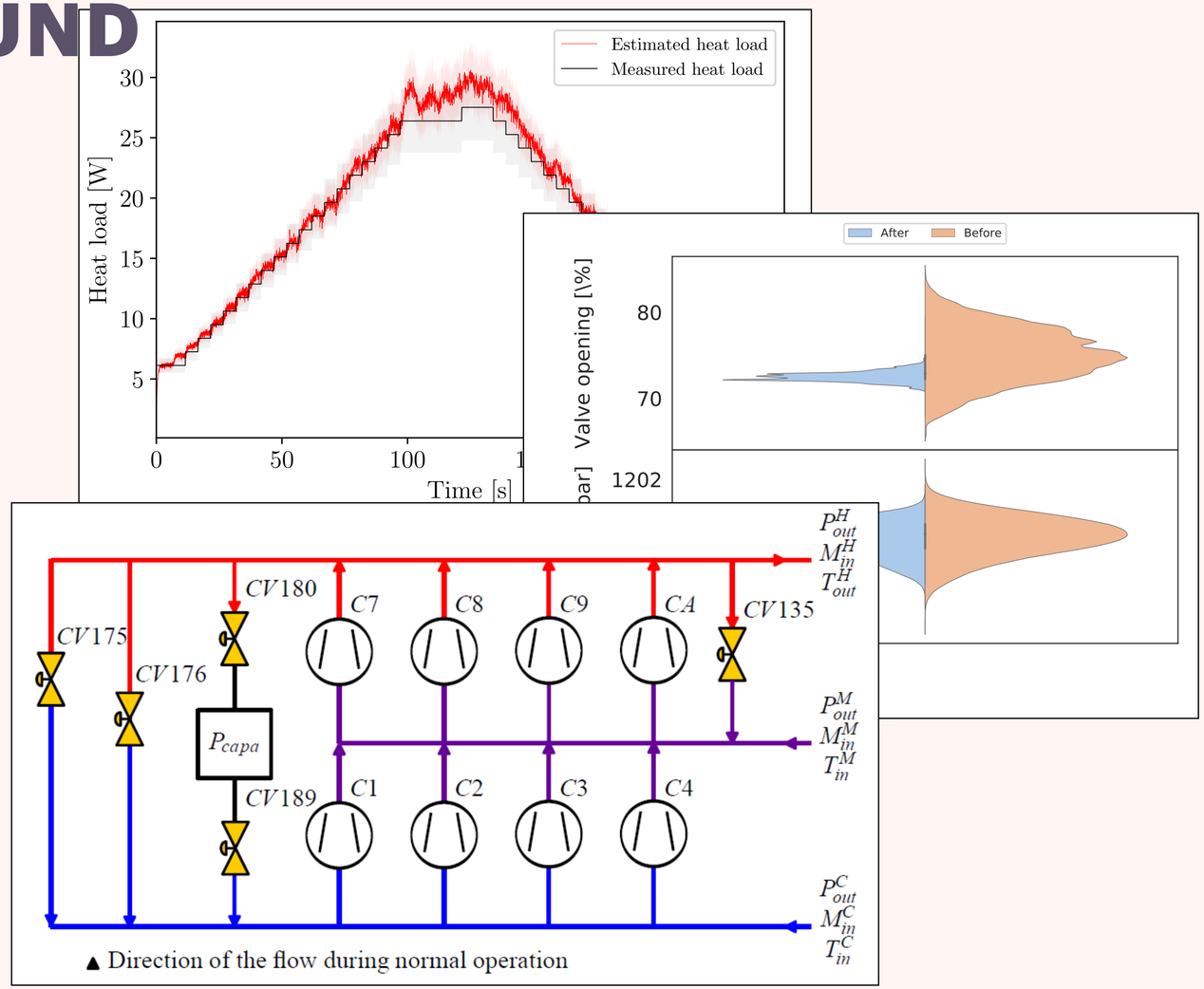


A.S.Nawaz et al.,"ProbabilisticModel-BasedFault Diagnosis for the Cavities of the European XFEL," at — Automatisierungstechnik, 2021.

A.Bellandi et al.,"Integral resonance control in continuous wave superconducting particle accelerators," in Proceedings of the 21st IFAC World Congress, 2020.

BUILDING ON EXISTING GROUND

- XFEL : differentiating different RF trips signatures with general likelihood ratios : first step towards expert fault classifiers
- **SPIRAL2 + CEA/DSBT: Successful setup of physics informed control of cryogenic system, smart dynamic heat load observer, towards ML fault detection**
- MYRRHA / IJCLab : Extending thermodynamic cryogenic models to RF models for single cryomodules. Preparing the future challenges of MYRRHA.



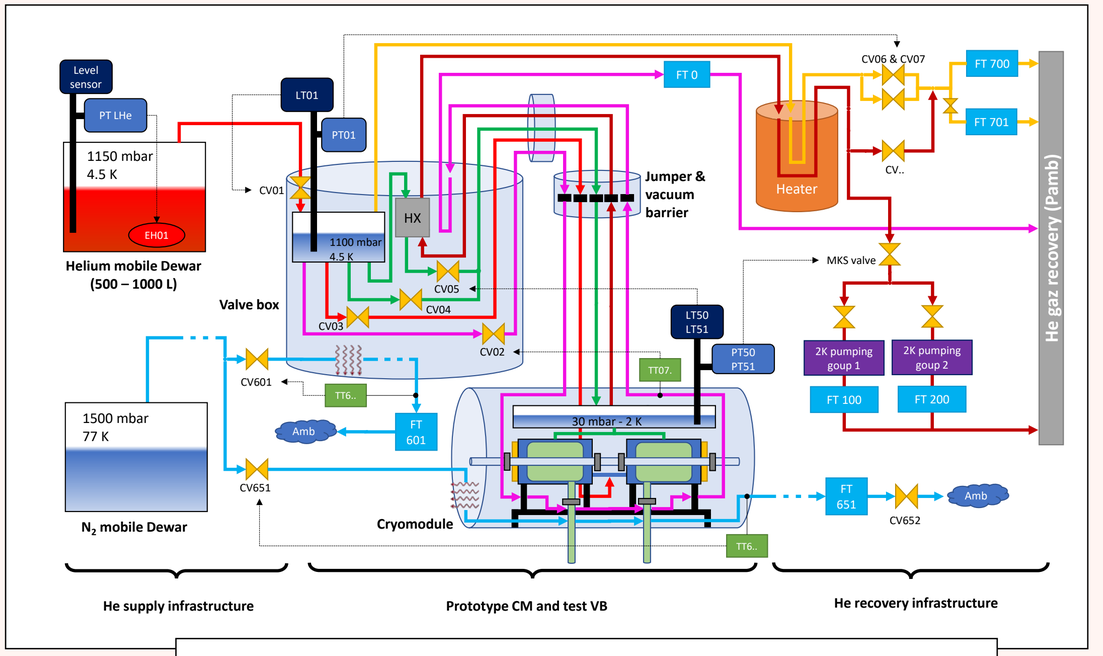
A Vassal et al., “SPIRAL2 Cryomodules Models: a Gateway to Process Control and Machine Learning”, arXiv:2103.10299 [physics.acc-ph], 2021.

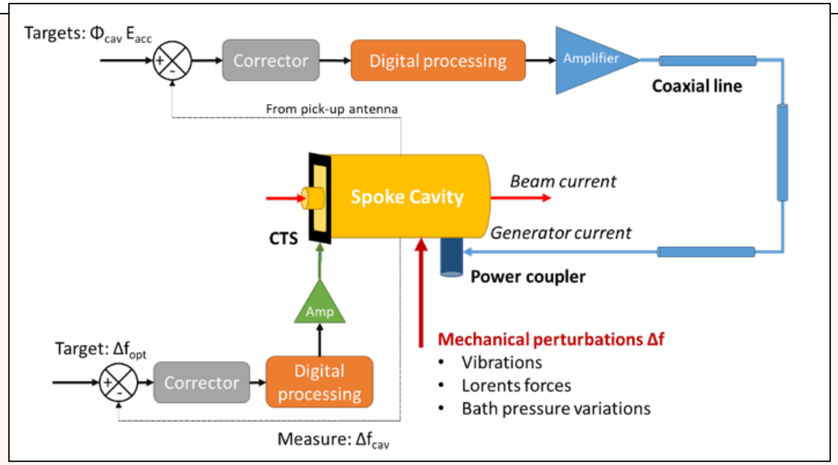
A Vassal et al., "SPIRAL2 cryogenic system thermodynamic behavior prediction through dynamic modeling". In : Proc. 29th Linear Accelerator Conference (LINAC’18), 2018.

Bonne F., Model based multivariable controller for large scale compression stations. Design and experimental validation on the LHC 18KW cryorefrigerator, AIP Conference Proceedings (2014)

BUILDING ON EXISTING GROUND

- XFEL : differentiating different RF trips signatures with general likelihood ratios : first step towards expert fault classifiers
- SPIRAL2 + CEA/DSBT: Successful setup of physics informed control of cryogenic system, smart dynamic heat load observer, towards ML fault detection
- **MYRRHA / IJCLab : Extending thermodynamic cryogenic models to RF models for single cryomodules. Preparing the future challenges of MYRRHA.**





BOULY,Frédéric. The MYRRHA Superconducting linac-Fault-tolerant design and developments. In:Technology and Components of Accelerator-Driven Systems (TCADS-4). 2019.

CHALLENGES

- **Adapting the same models to different constraints. Going more and more multiphyiscs yet keeping it simple enough for command/control and heavy ML optimisation algorithms (CC-IN2P3 computing center use for offline calculations)**
- **Preparing the required data framework, adapting independant acquisition systems (LLRF FPGA postmortem, clock synchronisation, ...)**
- **Working on the present (XFEL, SPIRAL2) while preparing the more stringent and challenging future requirements (MYRRHA)**

BACK UP

SPIRAL2

- A superconducting LINAC with 26 bulk Nb cavities
- Successful first commissioning stage
- Successful use of physics informed control for cryogenics.
- Currently ramping up the current !

XFEL

- **Operating the longest superconducting LINAC in the world with extended experience in RF fault identification**
- **New group created for data driven identification methods**
- **New challenge : going CW**

CEA/DSBT

- **More than 10 years experience in developing and deploying physics informed command and control strategies (JT60, SPIRAL2)**
- **Simcryogenics library achieved maturity for superconducting accelerators applications with the SPIRAL2 commissioning (GRAAL Collaboration)**
- **Going multi-physics with new partnerships (IJCLab)**

IJC LAB

- Extended experience in designing, fabricating and deploying RF and cryogenics subsystems for superconducting accelerators (SPIRAL2, ESS)
- LLRF and CTS modelling
- Currently working on RF/Cryo modeling of a single cryomodule in the frame of MINERVA/MYRRHA (ongoing PhD with Accelerators and Cryogenic System using the SimCryogenics library)
- Prototype Spoke cavity cryomodule will be tested in the IJCLab test stand

MYRRHA

1. **The MYRRHA project**
   - **MYRRHA ADS à SC linac 600 MeV, 4 mA in CW delivery**
   - **MYRRHA phase 1: MINERVA linac 100 MeV, 4 mA**
   - **injector 0 – 17 MeV is NC (CH-cavities)**
   - **SC linac 17 – 100 MeV, 30 cryomodules with 2 single spoke SC cavities each**
2. **The MYRRHA challenge**
   - **Realizing a beam-MTBF of 250 hours need for fault tolerance**
   - **2 injectors (parallel redundancy)**
   - **Serial redundancy in SC linac by fault compensation (up to entire cryomodule)**
   - **Complete fault recovery in < 3 seconds**