ML and related studies at SPIRAL2

A Ghribi⚛ ; C Lassalle⚛ ; A Plaçais⚙ ; F Bouly⚙ ; G Normand⚛ ; A Orduz⚛; A Leduc⚛

⚛GANIL ; ⚙LPSC

M4CAST Annual meeting, Nov 6th 2024

Outline

Context

Virtual diagnostic : NN based heat load observer

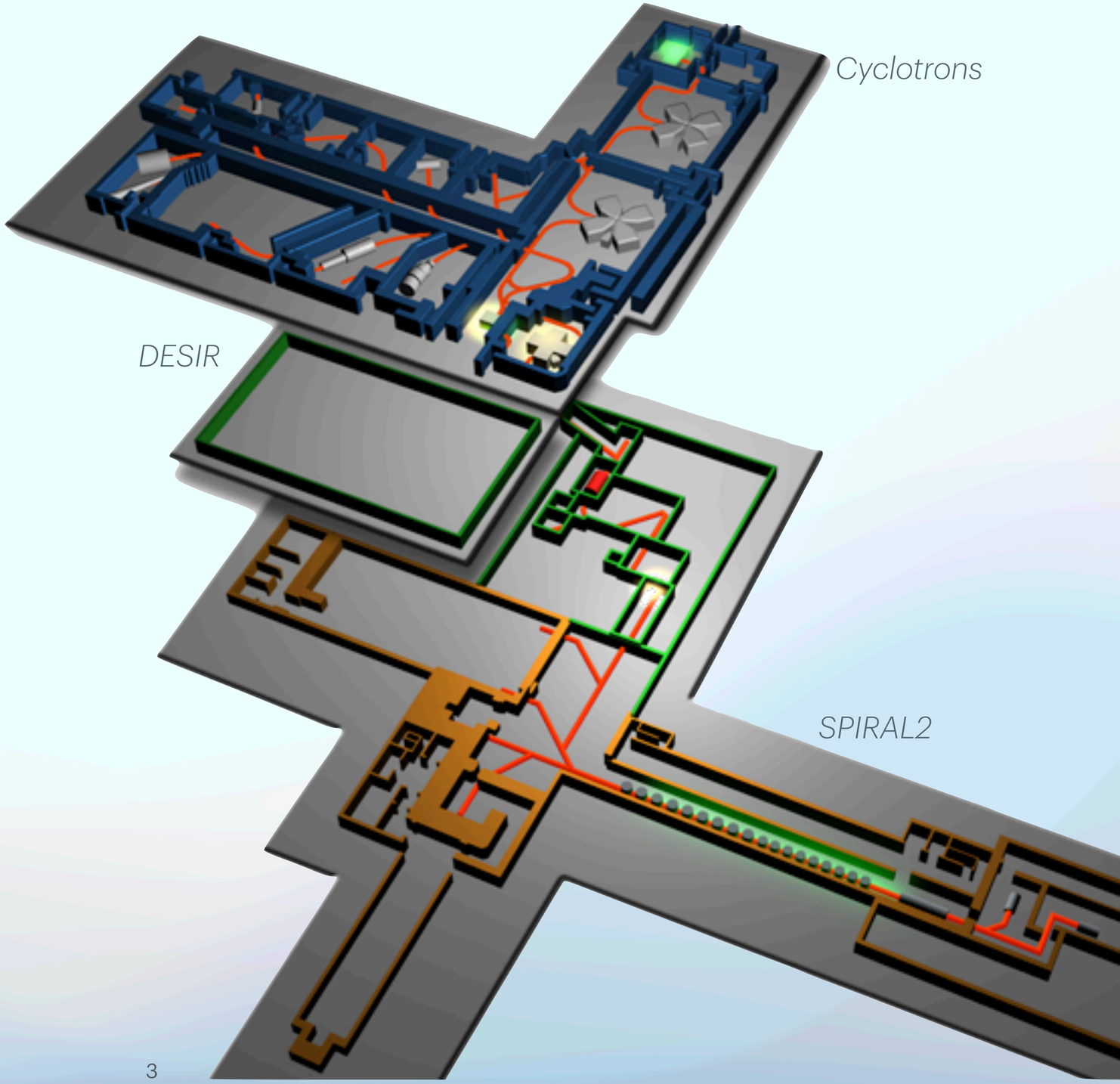
Optimized tuning : LigthWin

Coming up next

SPIRAL2

Context

- **GANIL**
- **The LINAC**
  Ions sources, MEBT, RFQ, SRF cavities, experimental areas, ...
- **The superconducting radio frequency (SRF) cavities**
  26 cavities, 19 cryomodules, two types



SPIRAL2

Context

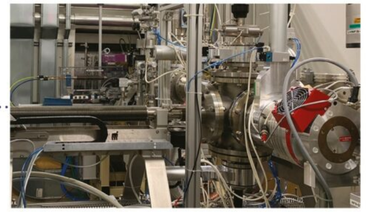
- **GANIL**
- **The LINAC**

  Ions sources, MEBT, RFQ, SRF cavities, experimental areas, ...
- **The superconducting radio frequency (SRF) cavities**

  26 cavities, 19 cryomodules, two types

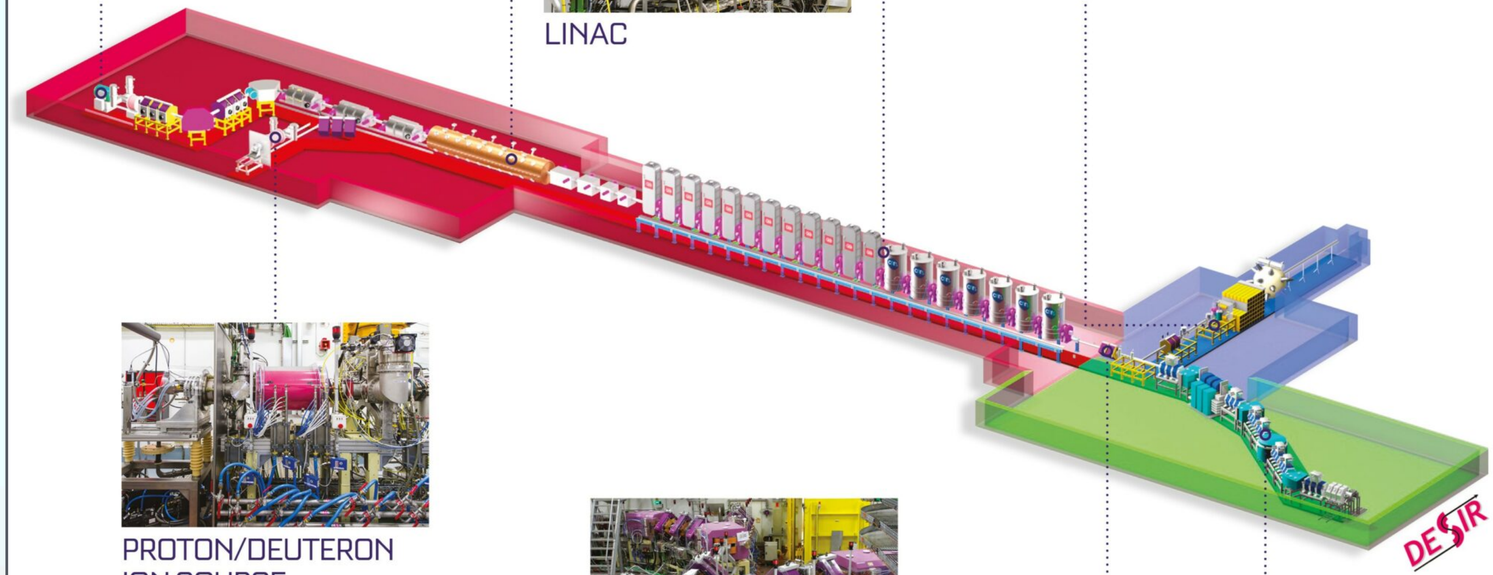
HEAVY ION SOURCE

RADIO **F**REQUENCY **Q**UADRUPOLE

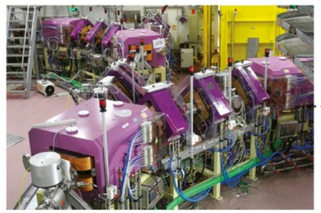


NEUTRONS **F**OR **S**CIENCE CONVERTOR HALL

LINAC



PROTON/DEUTERON ION SOURCE



HIGH ENERGY LINE

SUPER **S**EPARATOR **S**PECTROMETER

SPIRAL2

Context

- **GANIL**
- **The LINAC**

  Ions sources, MEBT, RFQ, SRF cavities, experimental areas, ...
- **The superconducting radio frequency (SRF) cavities**

  26 cavities, 19 cryomodules, two types.

SPIRAL2

Context

- For an infrastructure in operation, **reliability** is key !
  We try to have less down time by :
  - Detecting and preventing **anomalies**
  - Dynamically **compensating** failures in SRF cavities

SPIRAL2

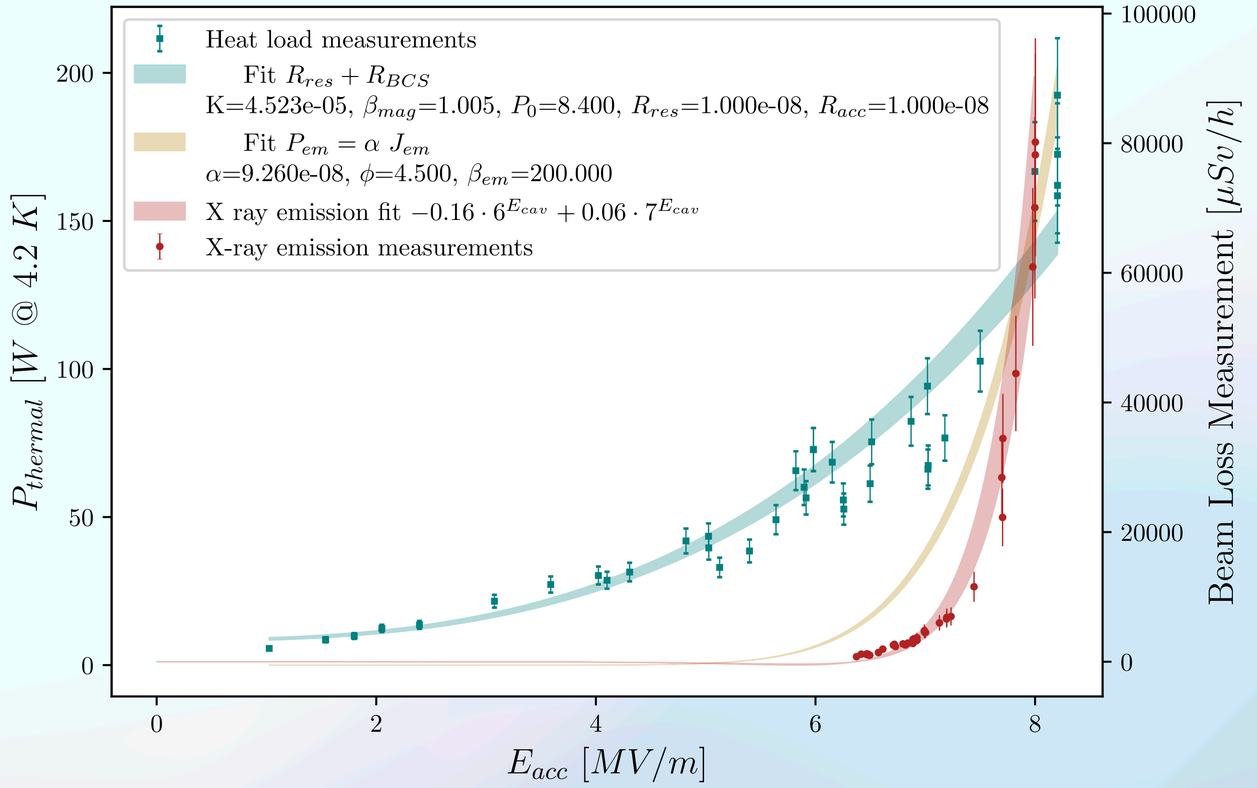
Issues

- **Cavities abnormal behaviors monitoring**

  ➡ A dedicated virtual heat load / Q_0 observer ;

- **Cavities fault-compensation strategies**

  ➡ A dedicated knowledge database for faults compensation.



CMA11 abnormal behavior : heat load and BLM measurements as a function of the accelerating field.

SPIRAL2

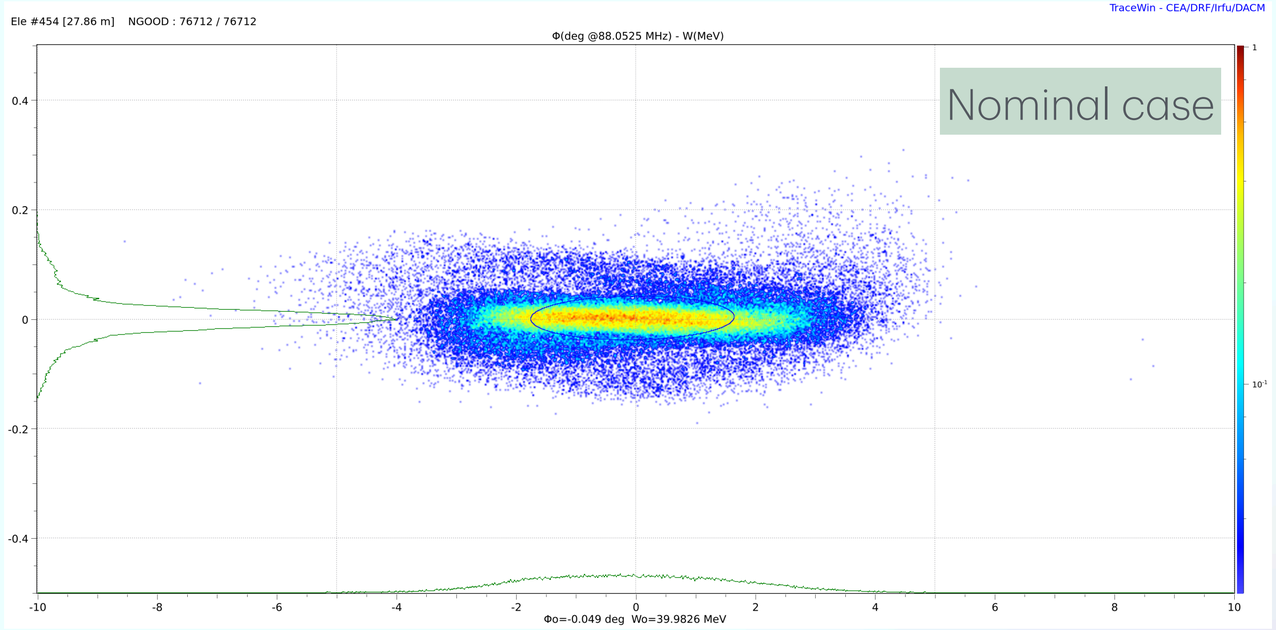
Issues

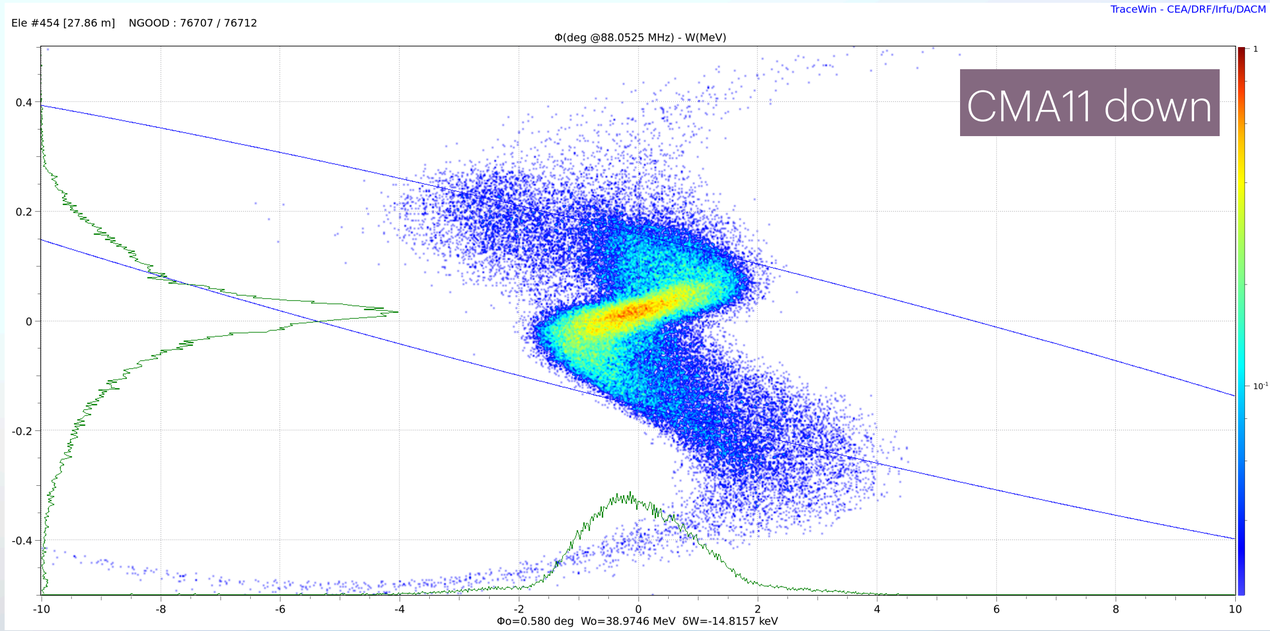
- **Cavities abnormal behaviors monitoring**

  ➡ A dedicated virtual heat load / Q_0 observer ;

- **Cavities fault-compensation strategies**

  ➡ LightWin : A dedicated tool for multi-variate optimization.



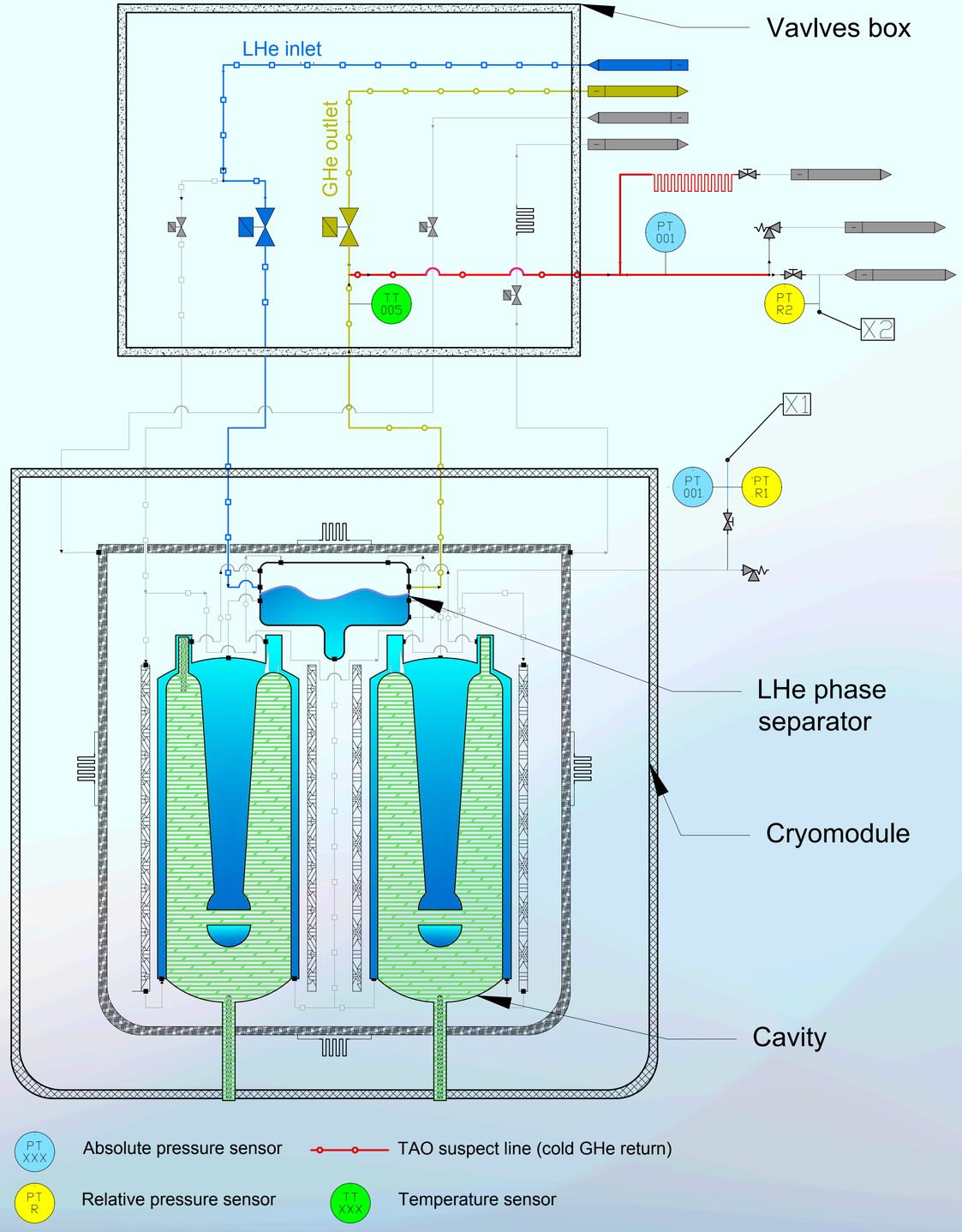


Emittance degradation before and after CMA11 failure

Virtual observer

Genesis

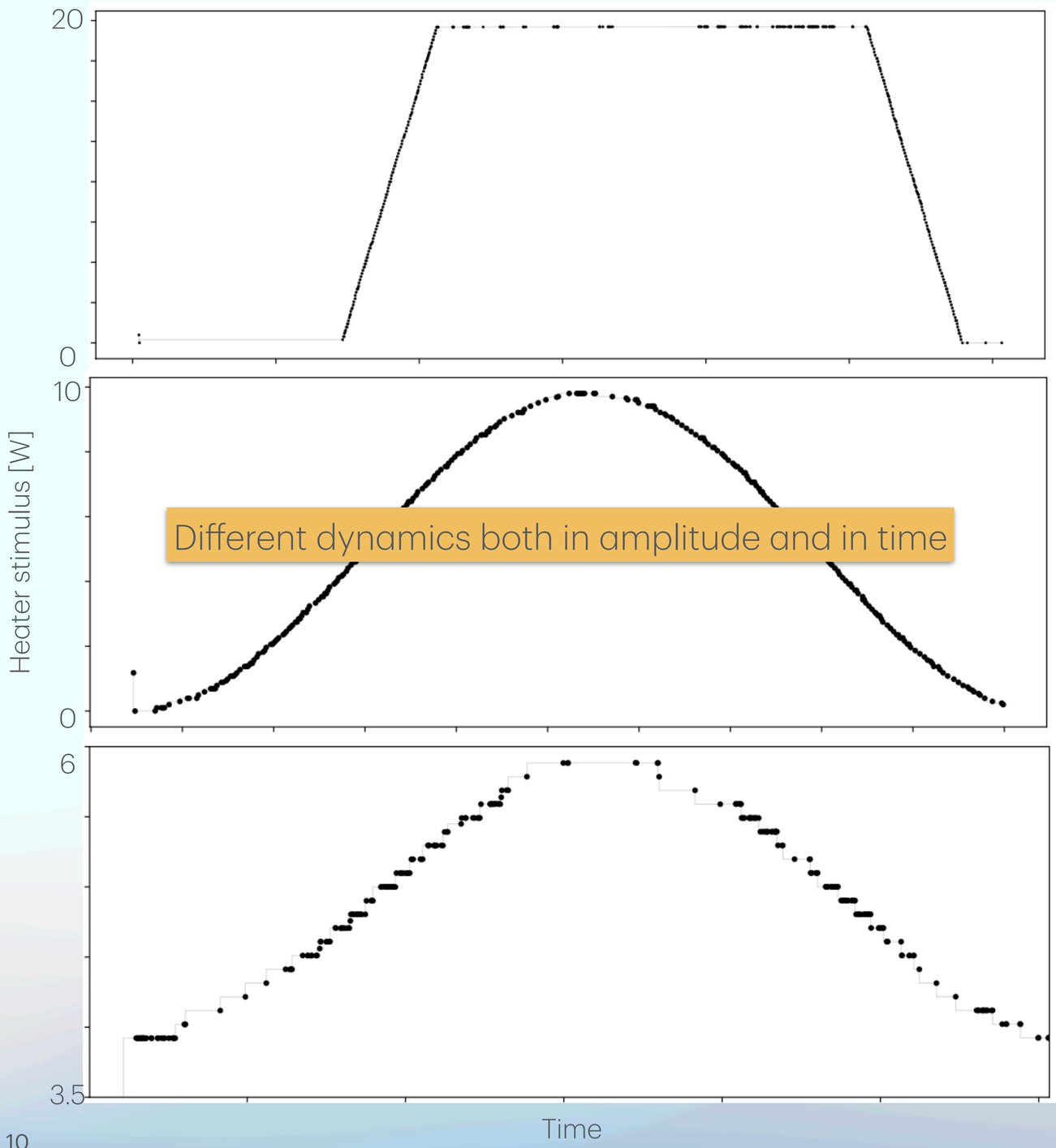
- **Inputs**
  - Multiple sensors and actuators for each cryomodule ;
- **Data**
  - Dedicated machine studies campaigns (3 campaigns) ;
- **Architectures**
  - DNN, CNN, LSTM, Stacked mixtures, Mixtures of experts.



Virtual observer

Genesis

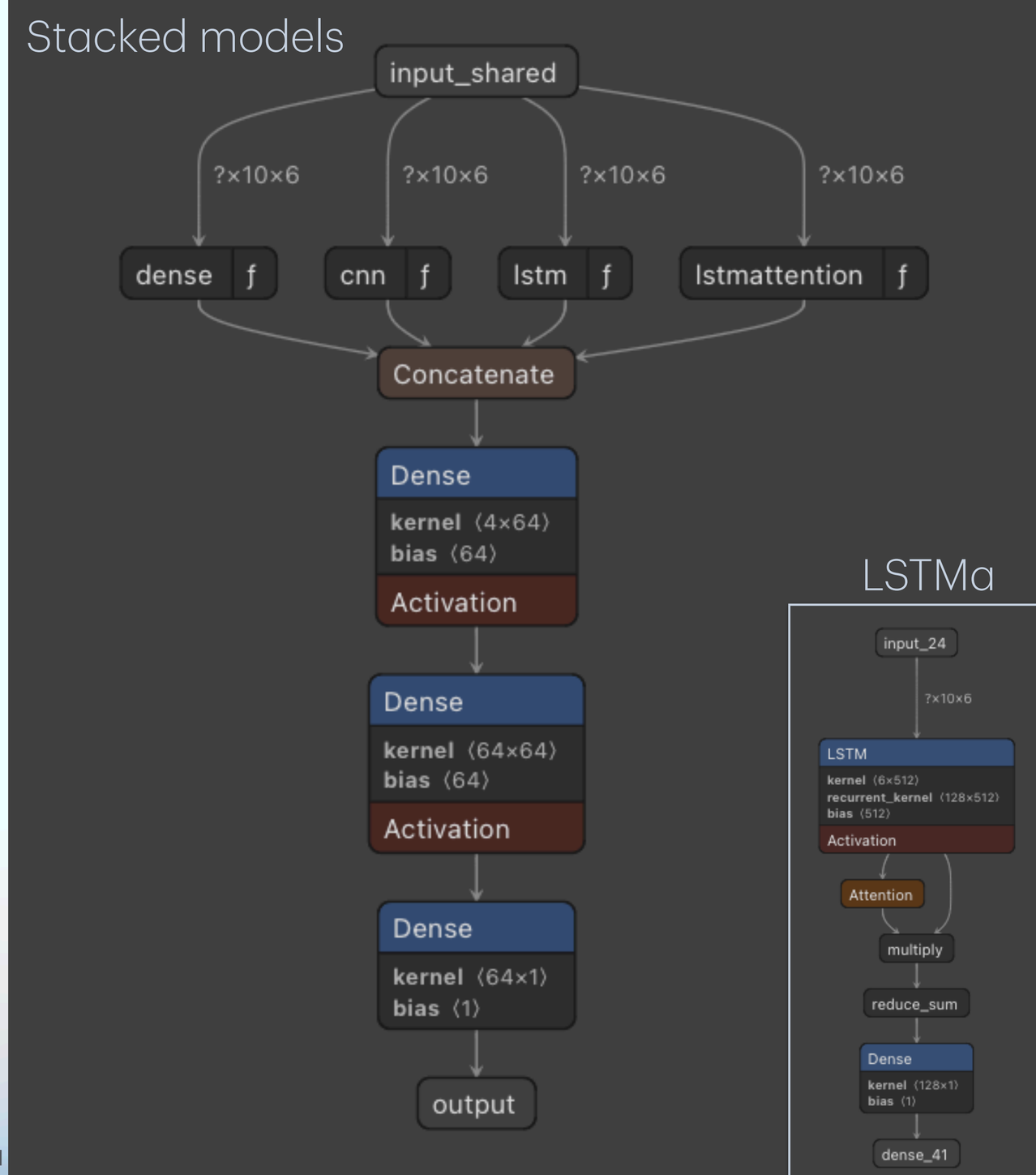
- **Inputs**
  - 5 sensors and two actuators for each cryomodule ;
- **Data**
  - Dedicated machine studies campaigns (3 campaigns) ;
- **Architectures**
  - DNN, CNN, LSTM, Stacked mixtures, Mixtures of experts.



Virtual observer

Genesis

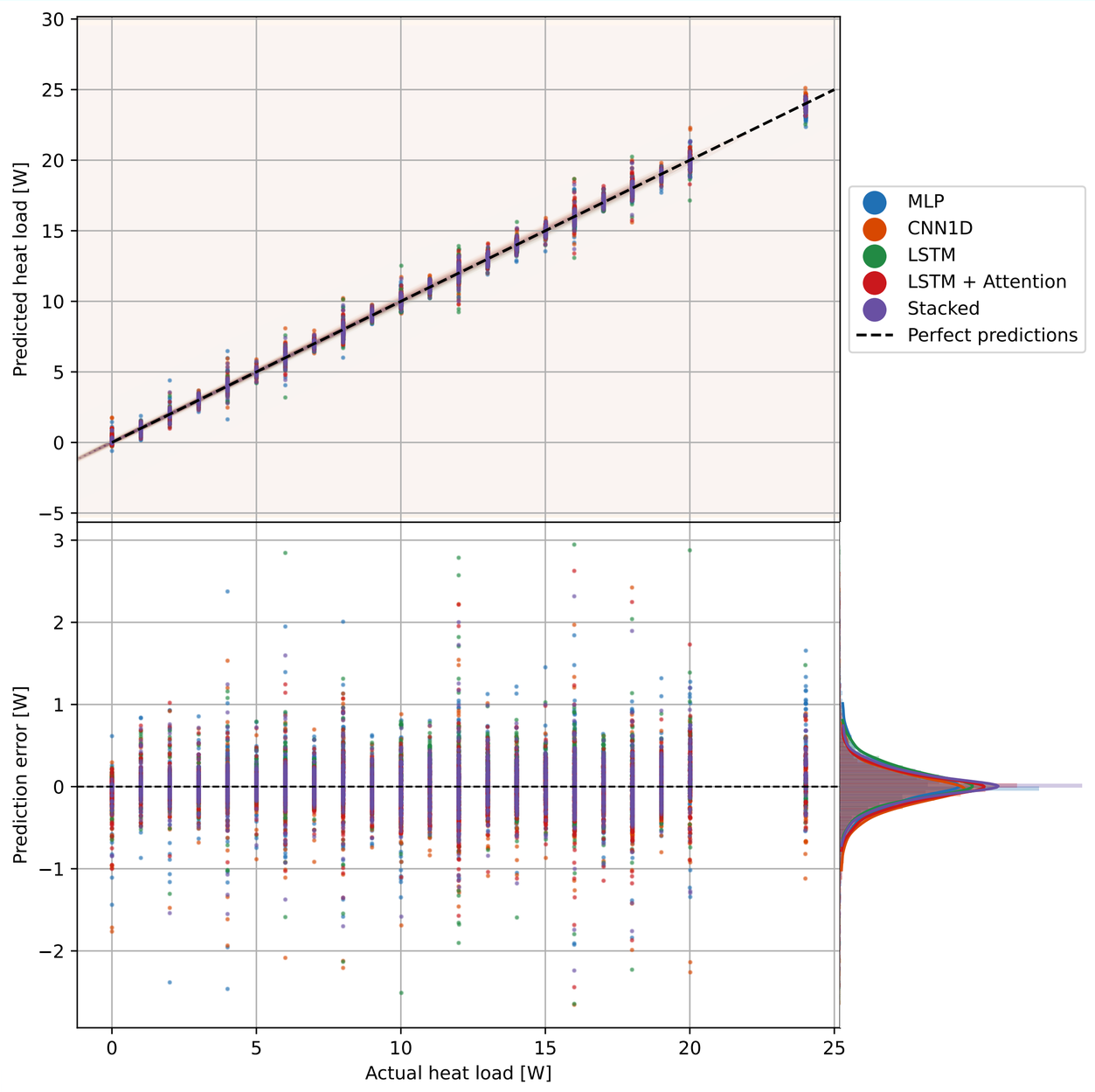
- **Inputs**
  - 5 sensors and two actuators for each cryomodule ;
- **Data**
  - Dedicated machine studies campaigns (3 campaigns) ;
- **Architectures**
  - DNN, CNN, LSTM, Stacked models, Mixtures of experts.



Virtual observer

Some results

- All trained models performances are within specifications ;
- Stacked models improve the predictions ;

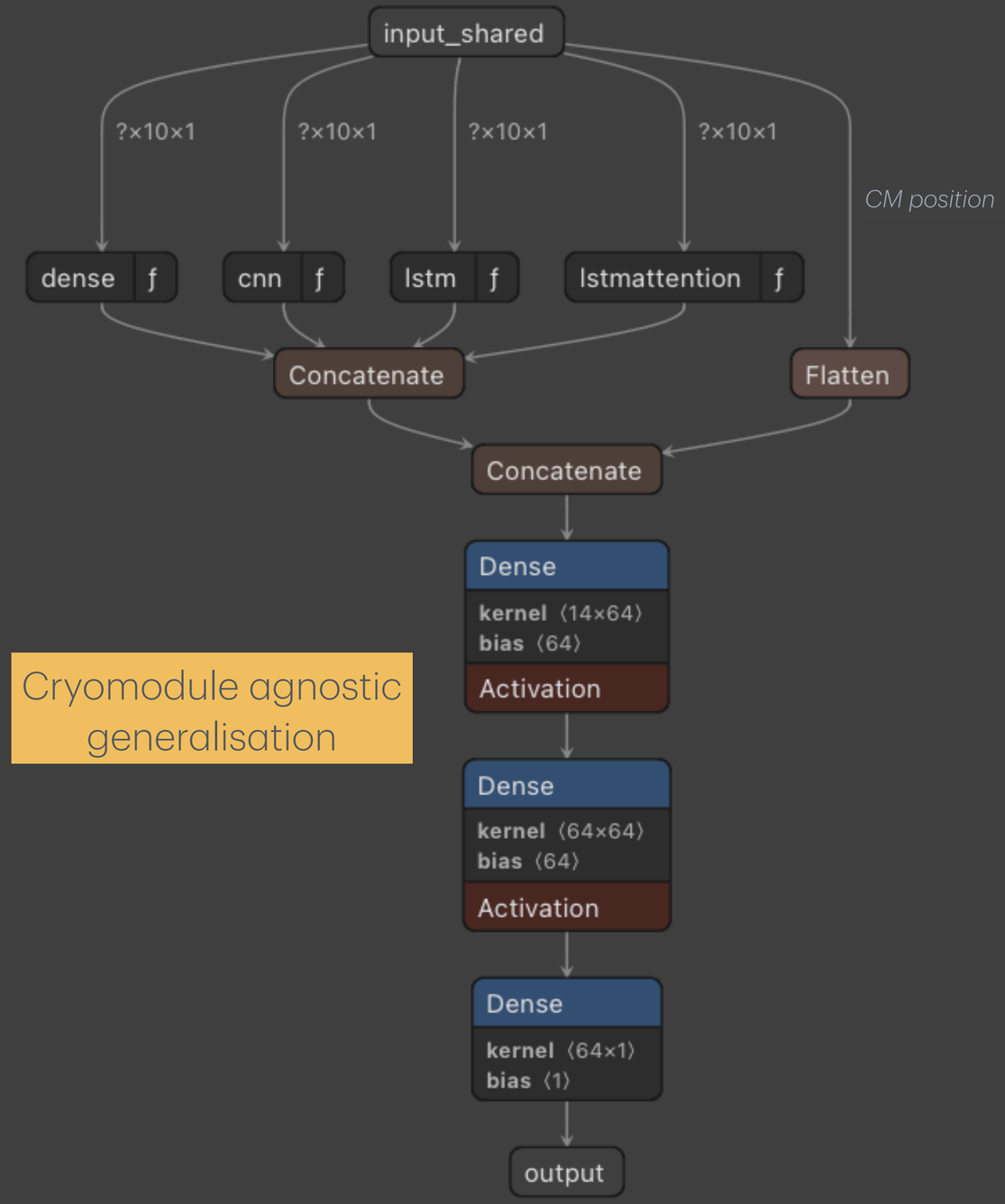


CMA12 inference results for different NN architectures trained on 2022 campaign data sets with all sensors.

Virtual observer

Challenges

- **Reproducible behavior**
  - The machine deviates from year to year ;
- **Generalized representation**
  - Different dynamics, different cryomodules and different operating conditions ;
- **Embedding compatible**
  - Compatible with pruning without performance degradation ;

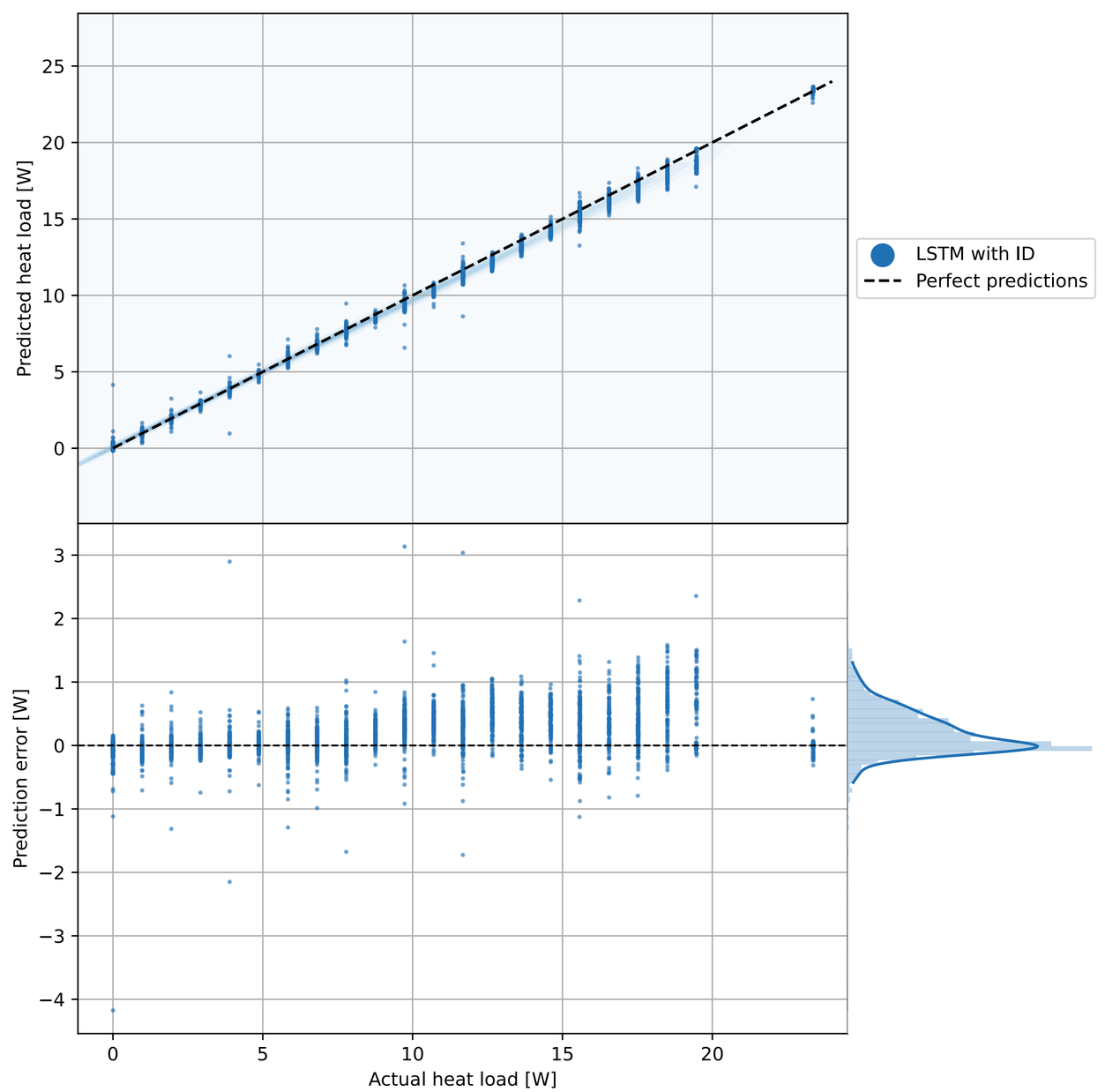


Cryomodule agnostic generalisation

Virtual observer

Challenges

- **Reproducible behavior**
  - The machine deviates from year to year ;
- **Generalized representation**
  - Different dynamics, different cryomodules and different operating conditions ;
- **Embedding compatible**
  - Compatible with pruning without performance degradation ;

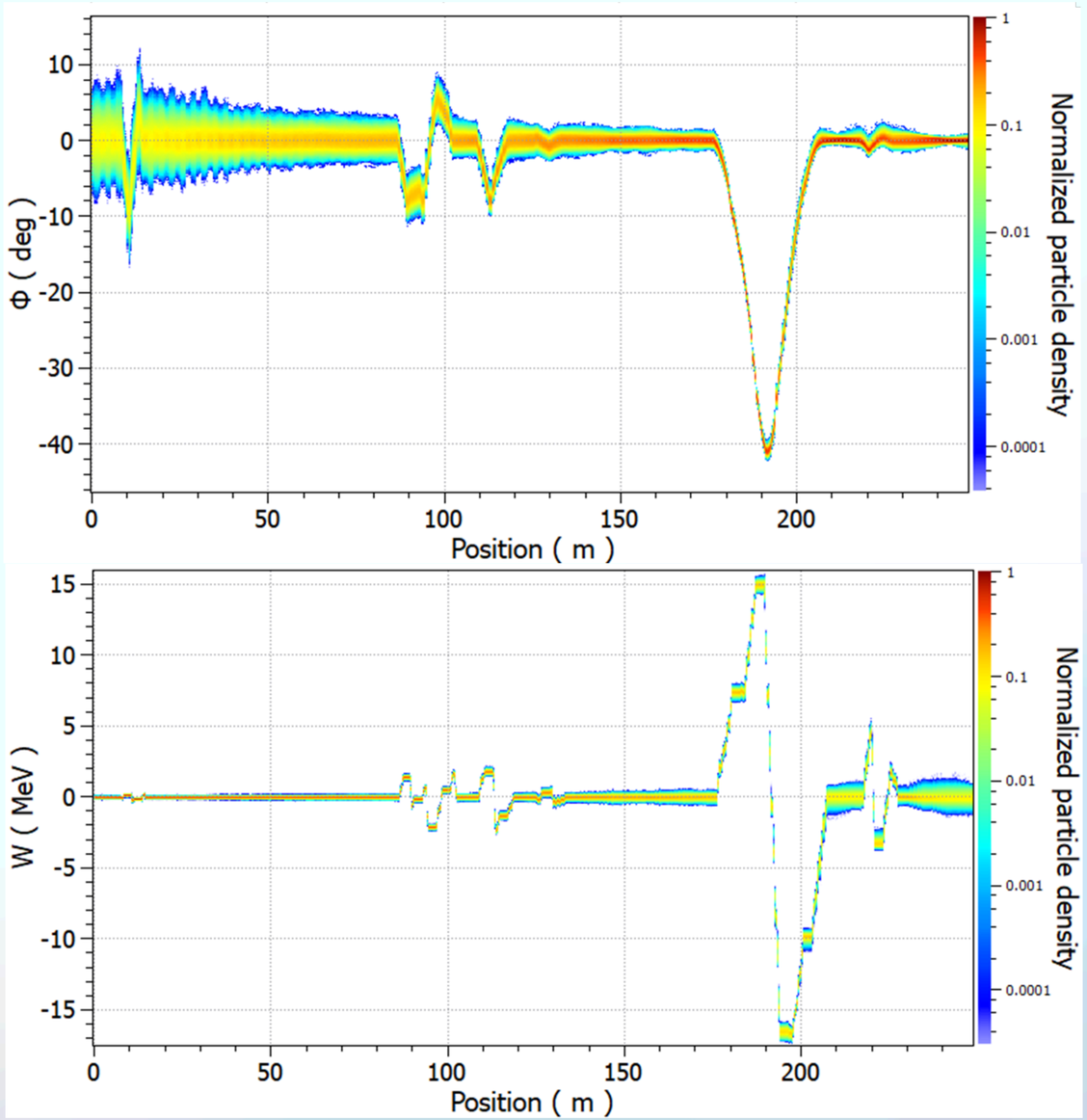


Generalised, cryomodule agnostic (type A) model based on a LSTM architecture trained on CMA02 to 12. Inference on CMA06.

LightWin

The tool

- A light, beam-dynamics optimization algorithm
- Used to find faults compensation settings in linear accelerators



Compensation of a multi failure scenario in the MYRRHA–ADS. Particle densities of the retuned linac, w.r.t. nominal linac. Courtesy of F. Bouly.

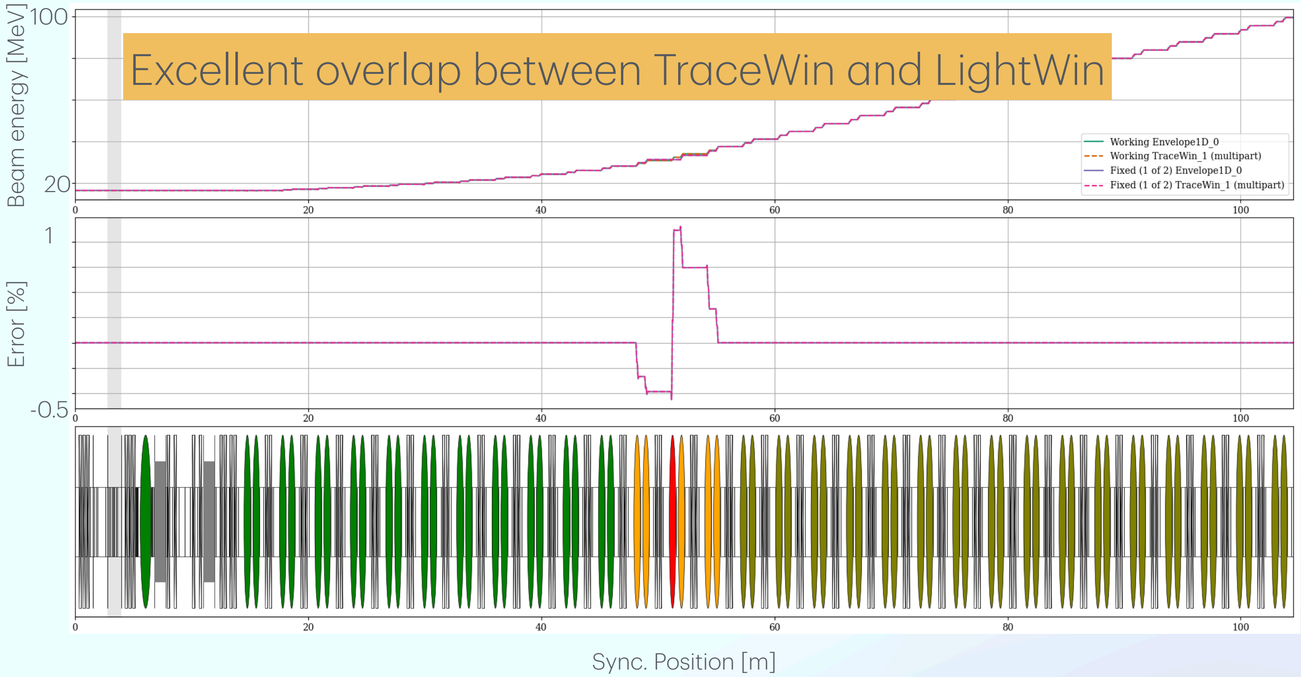
Plaçais et al. (2024), LightWin, https://github.com/AdrienPlacais/LightWin

LightWin

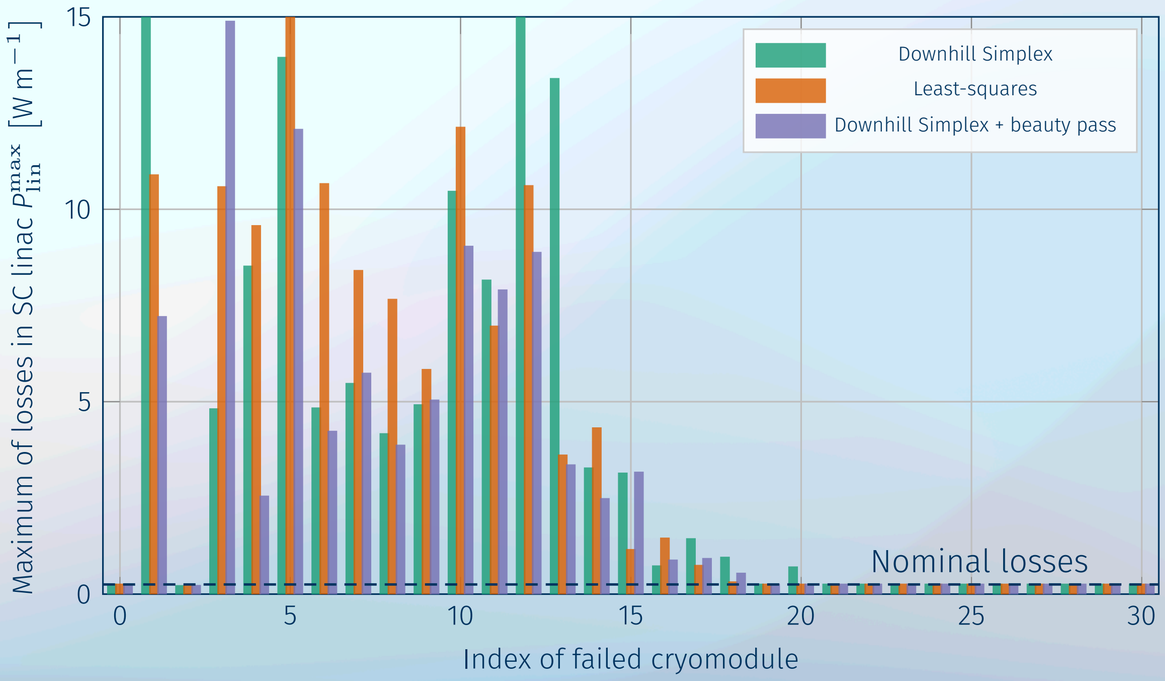
Under the hood

- **Beam dynamics**
  - Envelope calculation based longitudinal dynamics ;
- **Optimisation**
  - Downhill simplex ;
  - Least squares ;

LightWin vs TraceWin benchmark



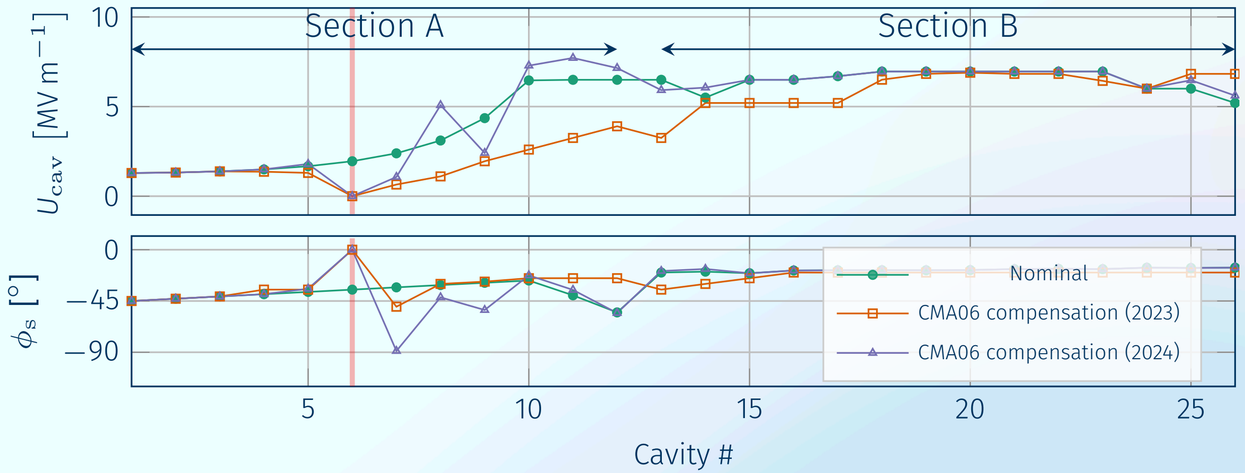
Miverva CM benchmarks



LightWin

@SPIRAL2

- **Challenges**
  - Reduced longitudinal acceptance (with respect to ADS links) ;
  - Reduced RF amplifiers power margin ;
- **Ongoing**
  - Need to account for space charge in longitudinal dynamics ;
  - New optimization algorithms :
    - Particle Swarm Optimisation (PSO) ;
    - Non-dominated Sorting Genetic Algorithm (NSGA).



CMA06 manual failure scenario compensation using TraceWin (~ 1 week)

Coming next

- **Anomalies**
  - LLRF postmortem faults classification
- **Optimisation**
  - SPIRAL2 as a use case for extended capabilities of LightWin

Thank you

Questions ?