

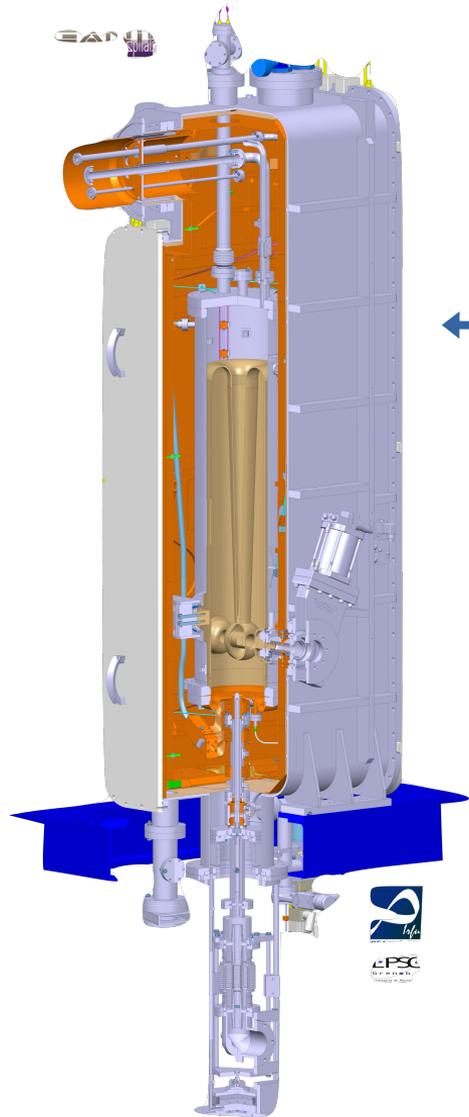
# **Korea–France Collaboration Meeting on LLRF Noise Reduction using FPGA and Machine Learning**

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The logo for GANIL, consisting of the letters G, A, N, I, L in a bold, dark blue, sans-serif font. The letters are closely spaced and have a slightly stylized appearance.

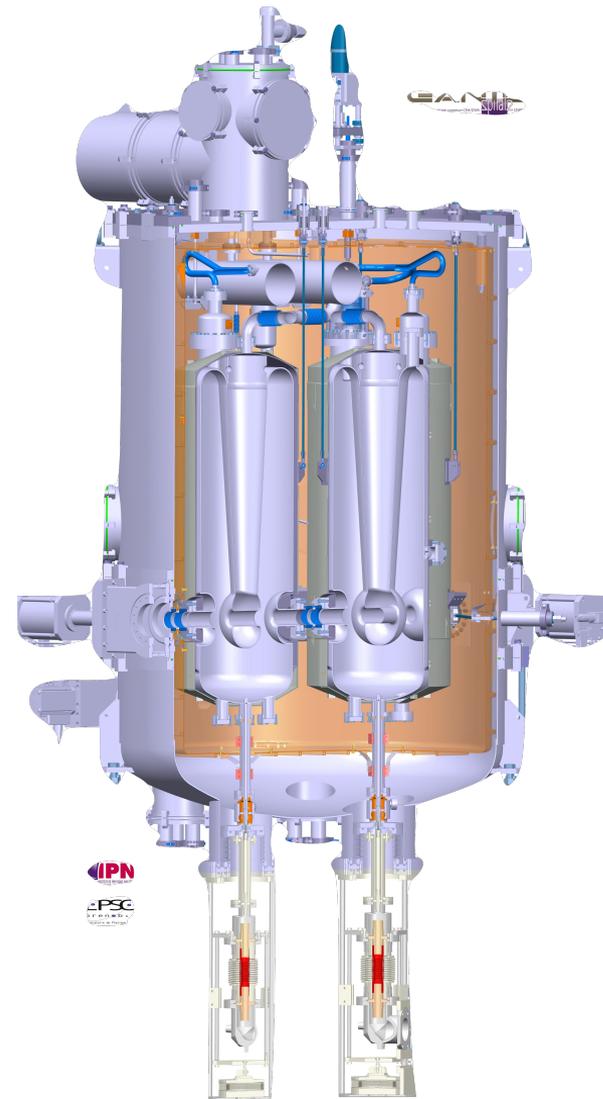
# SPIRAL2 @ GANIL

- Linac with 26 SRF cavities @ 4.2K
- 12 type A cryomodules (1 cavity each),  $Q_0 \approx 5 \cdot 10^5$
- 7 type B cryomodules (2 cavities each),  $Q_0 \approx 1 \cdot 10^6$
- 1 valve box per cryomodule
- CW operation, 88 MHz, no piezo tuner
- 1 digital LLRF + solid-state amplifier per cavity
- 2.5, 5, 10 and 20 kW amplifiers



← Type A

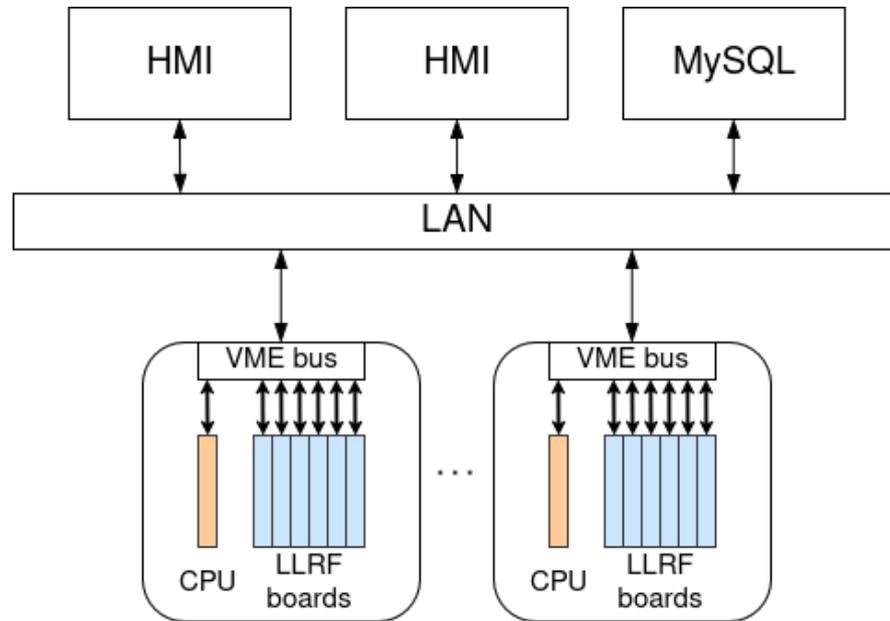
Type B →



# LLRF post-mortem data

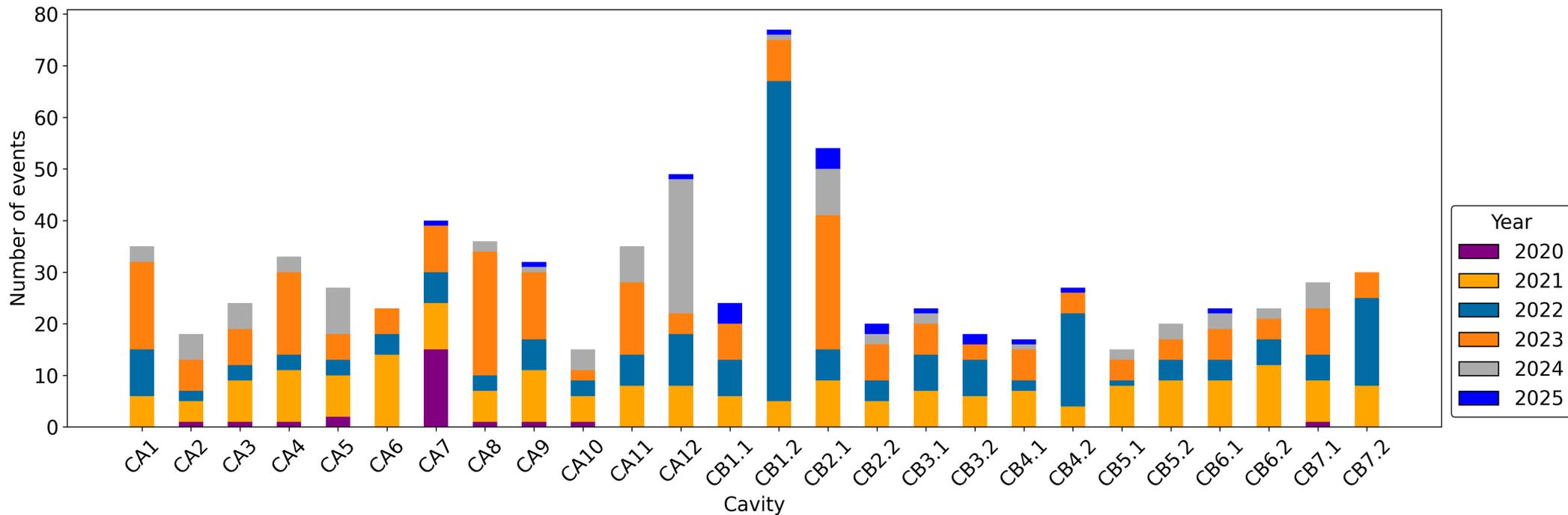
- Signals recorded
  - Amplifier input (amplitude) and output (amplitude + phase) powers
  - Cavity voltage (amplitude + phase)
  - Reflected power (amplitude), with lower sampling frequency
  - Cavity input-output phase difference
  - I/Q modulator drive signals
  - Coupler vacuum pressure
  - Electron pick-up current (near the alumina window)
- Sampling
  - ~11  $\mu\text{s}$
- Quantity
  - 766 faulty events
- Format
  - Binary

- Events recorded according to pre-defined conditions

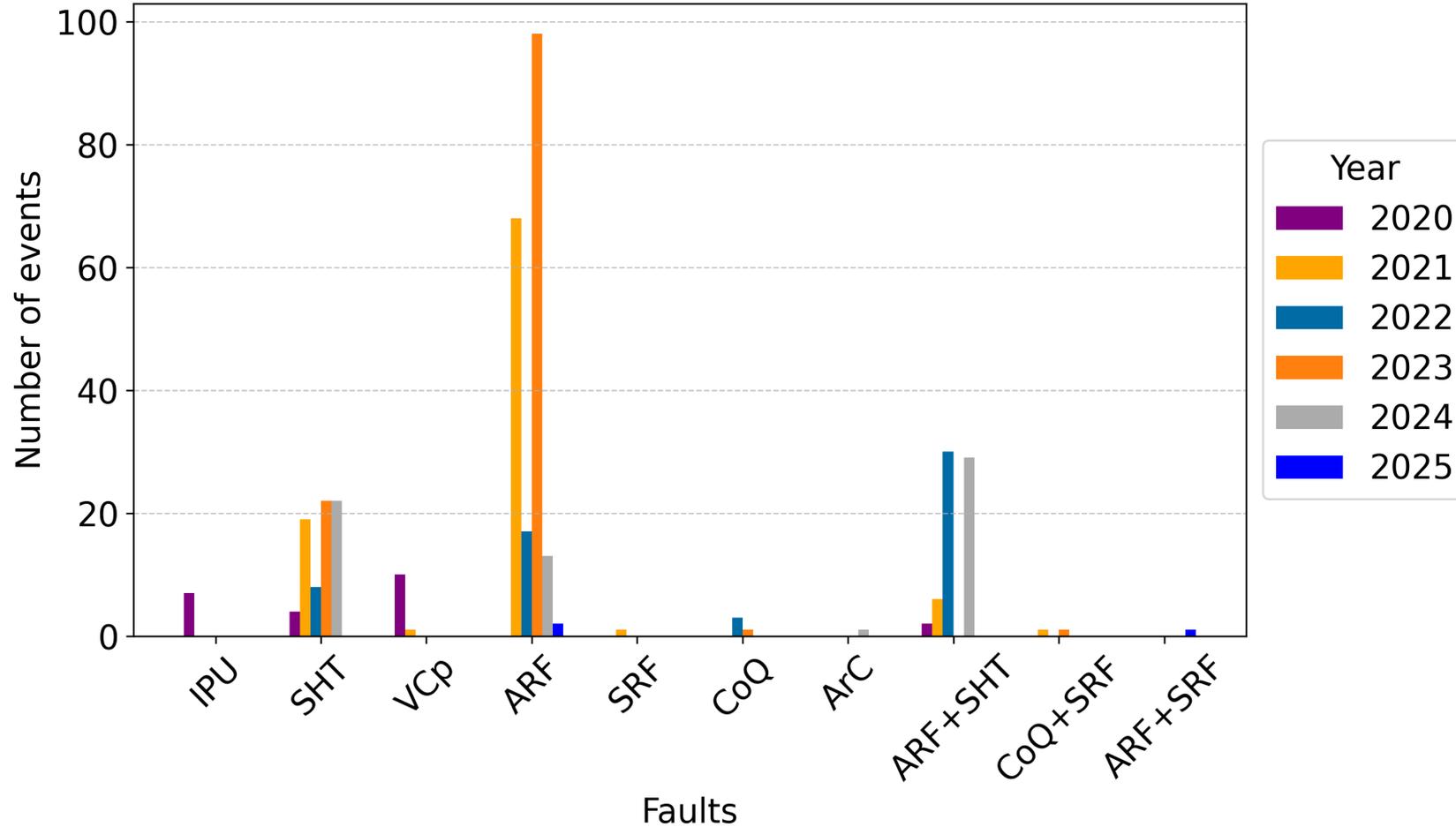


<b>Faults</b>	<b>Triggering conditions</b>
Electron pick-up	Pickup current less than threshold
Fast interlock	Arc detected by photodiode in circulator
No RF permission	No PLC permission
Vacuum threshold	Power coupler pressure greater than threshold
Cavity breakdown or quench	Amplitude of cavity field drops by 50% in less than 2 $\mu$ s
RF protection threshold	Amplitude of reflected power or cavity field more than threshold
RF signal out of tolerance	Cavity field undergoes variations greater than 10% in amplitude or 1° in phase (depending on the set points).

# Statistics



### Type A cavities



IPU : electron pick-up

ArC : fast interlock

ARF: no RF permission

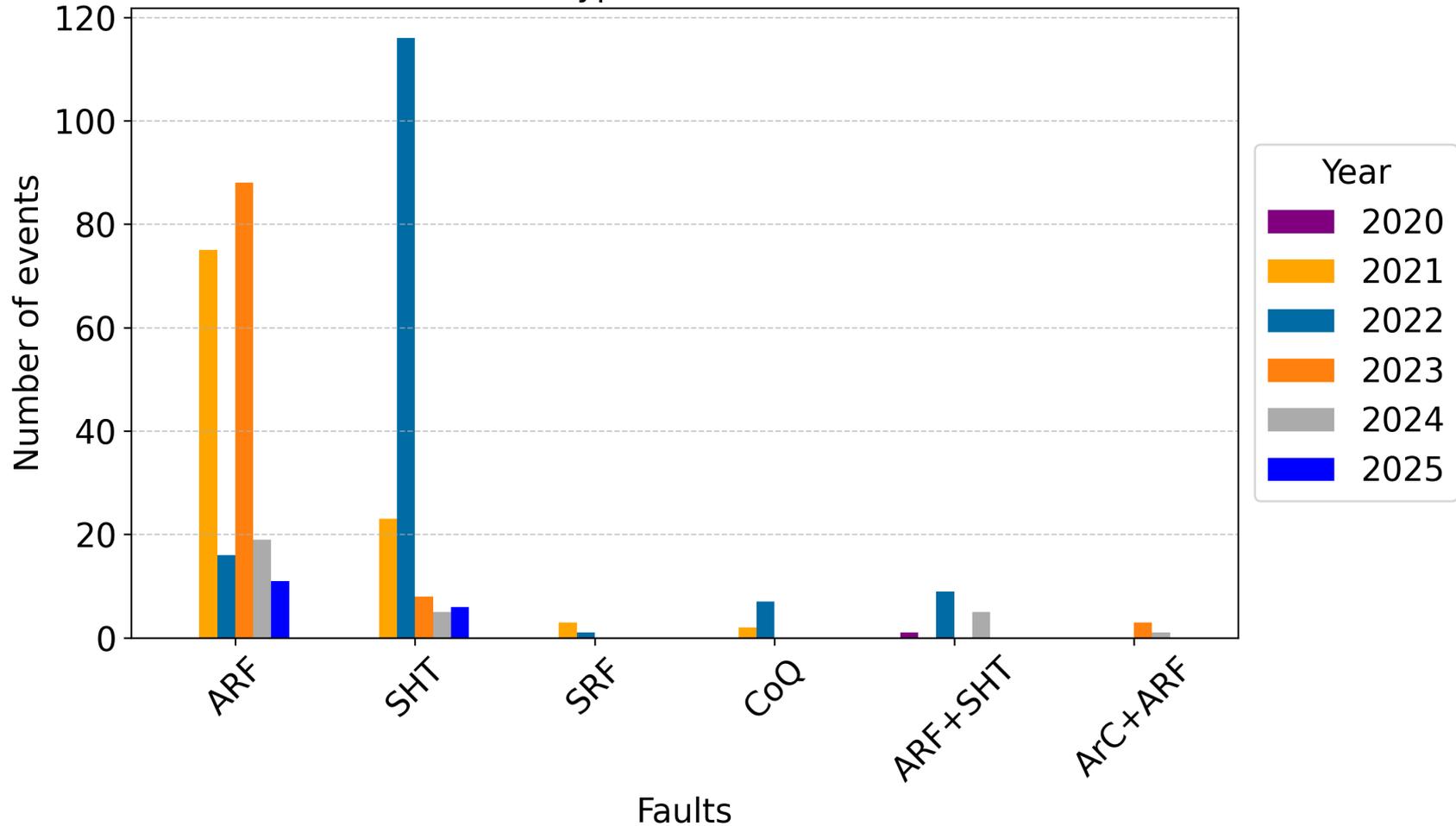
Vcp : vacuum threshold

CoQ : cavity breakdown or quench

SRF : RF protection threshold

SHT : RF signal out of tolerance

## Type B cavities



IPU : electron pick-up

ArC : fast interlock

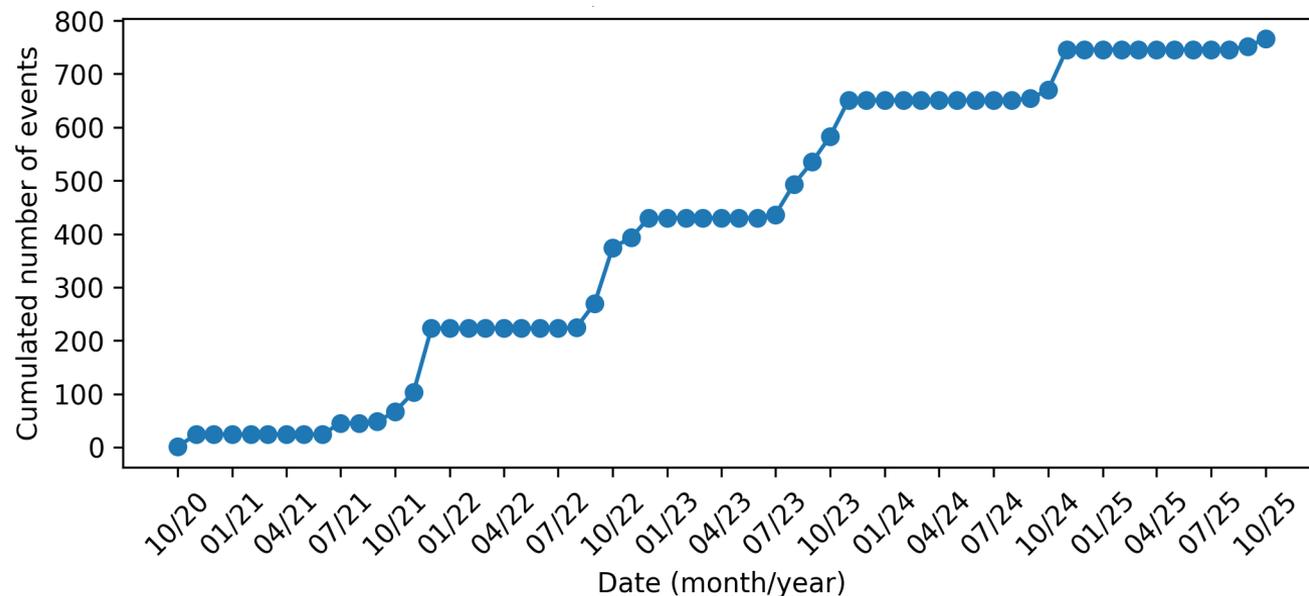
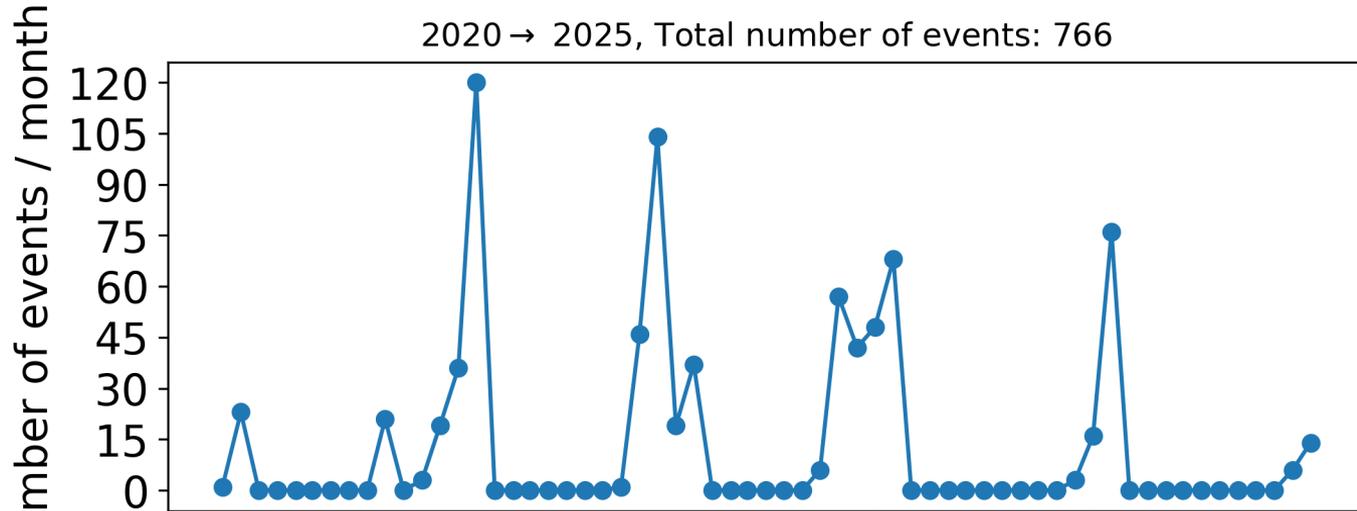
ARF: no RF permission

Vcp : vacuum threshold

CoQ : cavity breakdown or quench

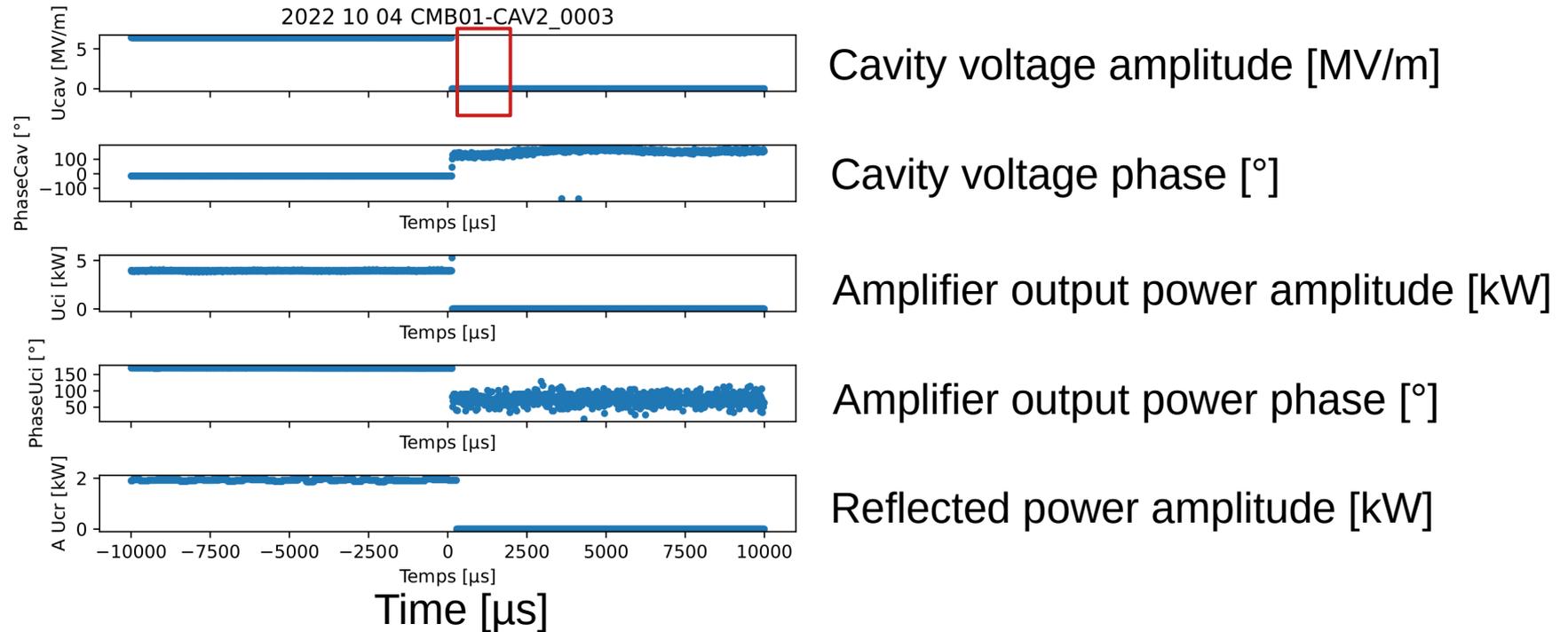
SRF : RF protection threshold

SHT : RF signal out of tolerance



# Electronic quench

- Sudden loss of energy ( $U_{cav}$ )



Cavity voltage amplitude [MV/m]

Cavity voltage phase [ $^{\circ}$ ]

Amplifier output power amplitude [kW]

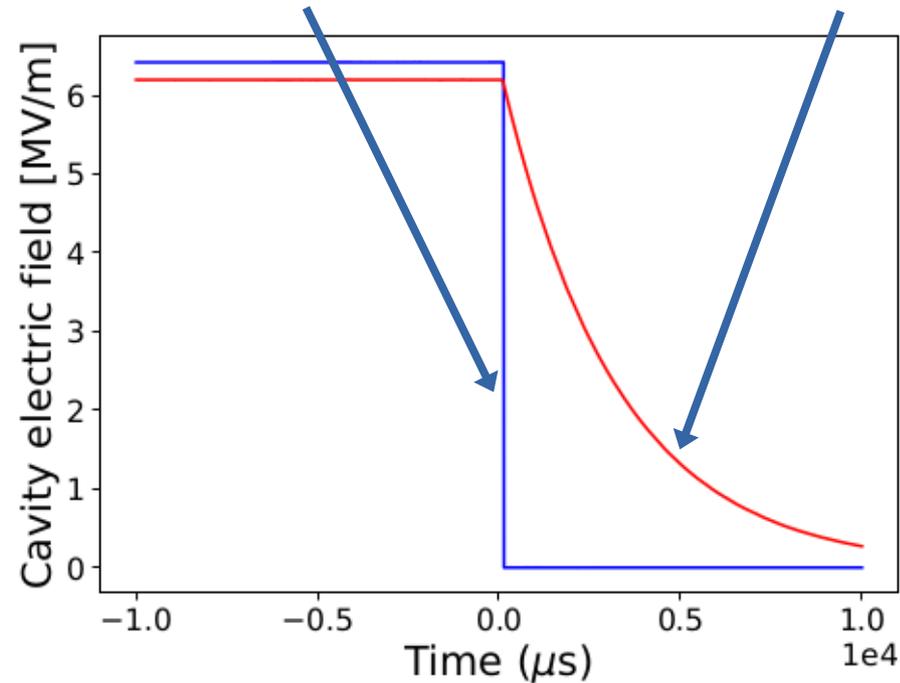
Amplifier output power phase [ $^{\circ}$ ]

Reflected power amplitude [kW]

# Binary classification

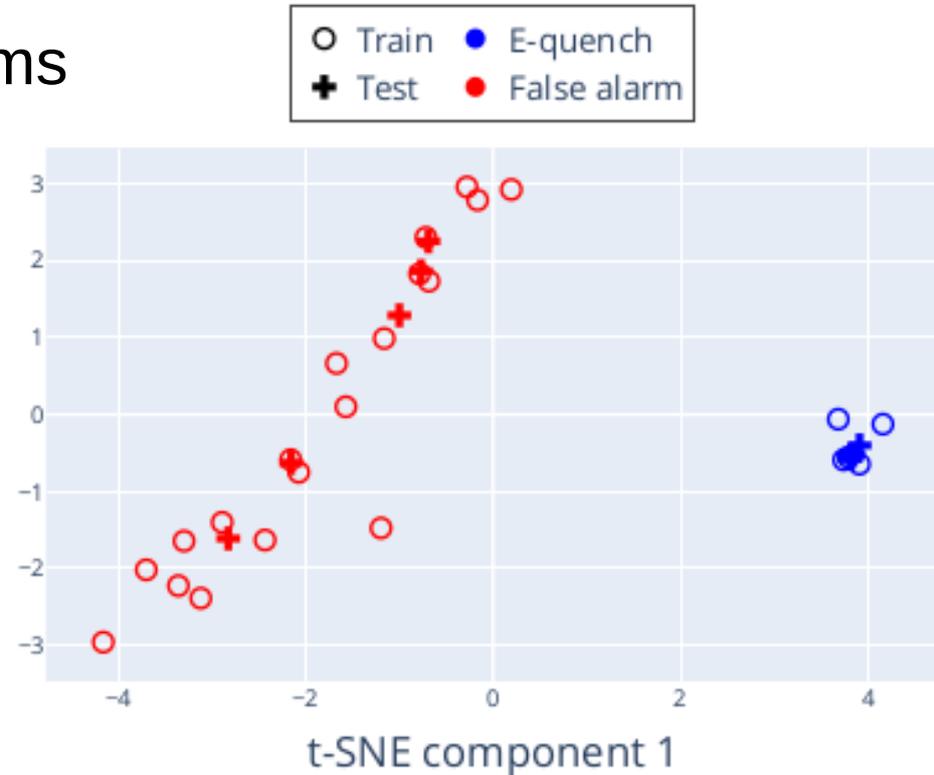
2 type of Ucav profiles :  
Electronic quenches

False alarms



t-SNE on  
tsfresh  
features

t-SNE component 2



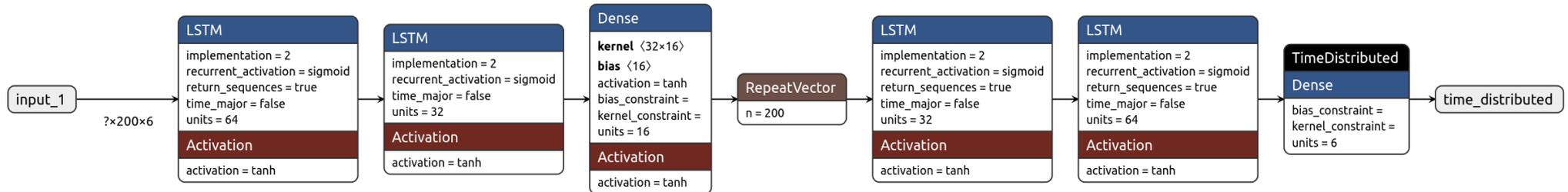
# Binary classification - results

<b>True labels</b>	E-quench	6	0
	False alarm	0	5
		<b>E-quench</b>	<b>False alarm</b>
		<b>Predicted labels</b>	

Successful classification BUT very small number of test events !

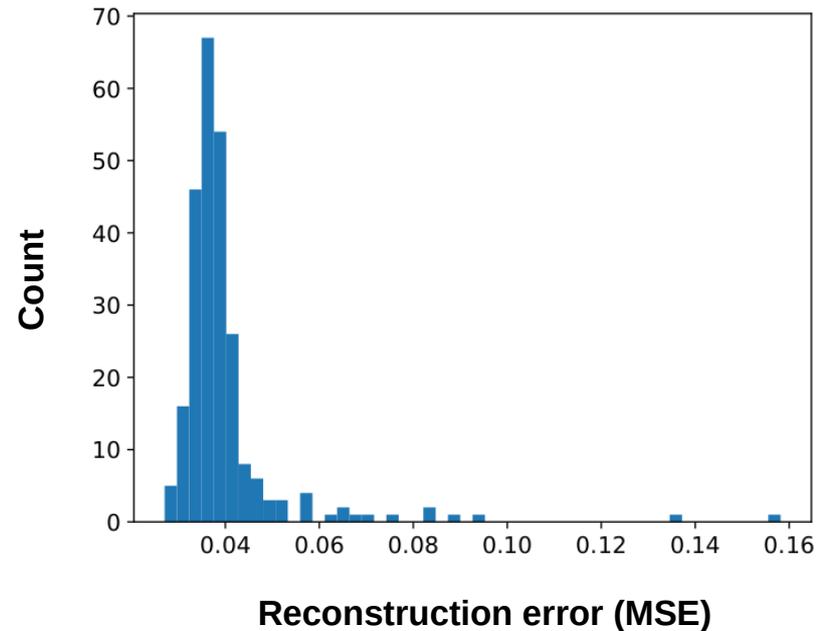
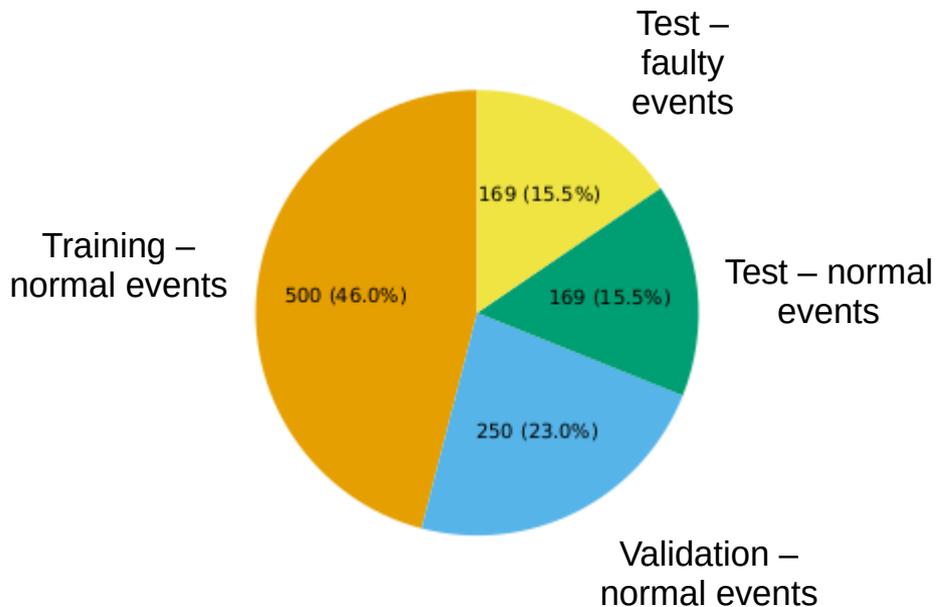
# Autoencoder

- Unsupervised classification
- LSTM layers
- Use directly time series as inputs
- Loss function : Mean Square Error



# Autoencoder

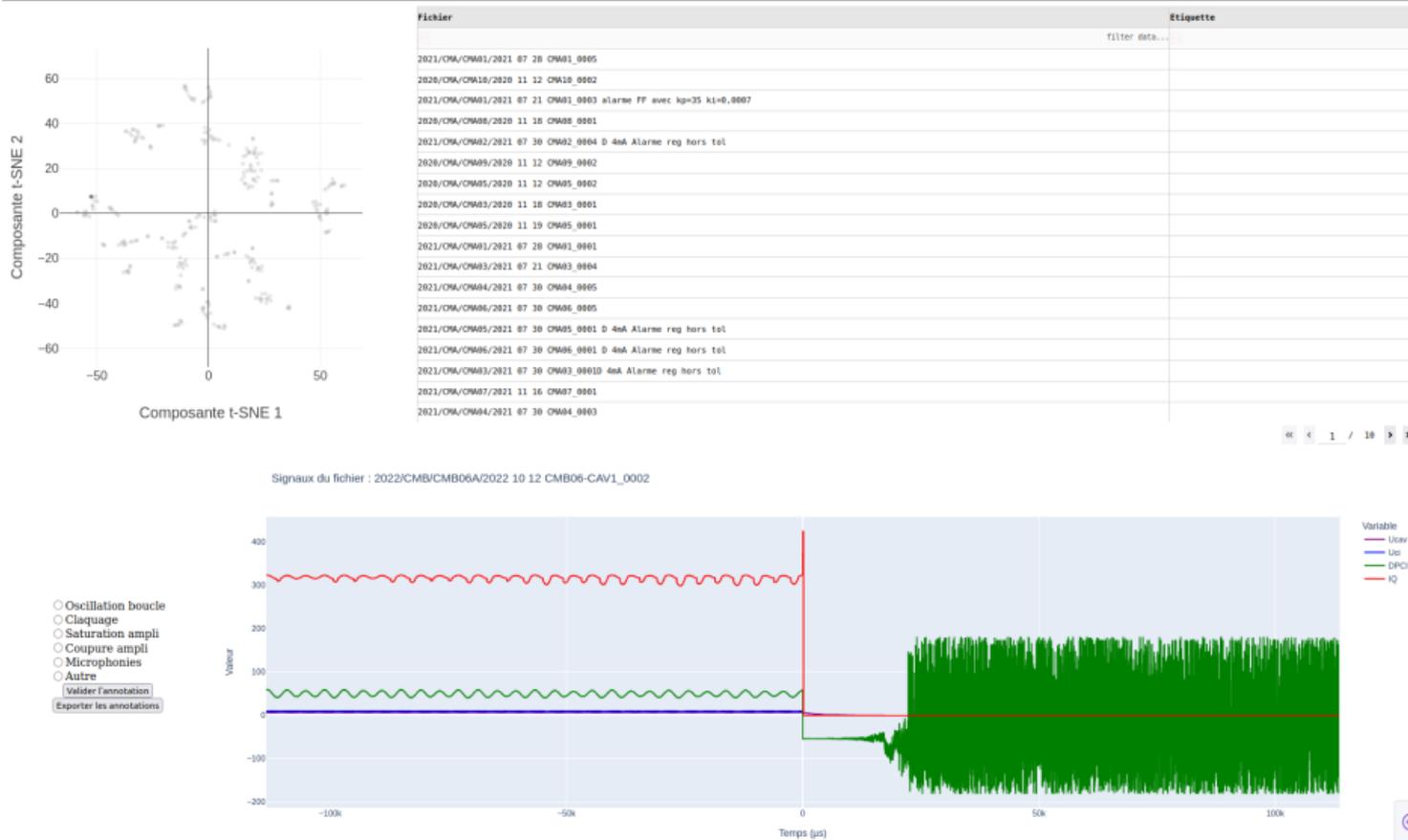
- Use reconstruction error as criterion
- Reconstruction error threshold defined from distribution on validation set



# Autoencoder – test results

Threshold (percentile)	True Positive	True Negative	False Positive	False Negative	Precision	Recall	F1 score
0.058 (95%)	162	162	7	7	0.959	0.959	0.959
0.069 (97%)	162	167	2	7	0.988	0.959	0.973
0.092 (99%)	153	168	1	16	0.994	0.905	0.947

# Labeling tool



- App for events labeling
- Deployment :
  - Locally
  - National computing centre

Why ? → supervised methods