ASTeC

Science and Technology Facilities Council

astec.stfc.ac.uk

# Machine Learning for RF Breakdown Detection at CLARA


A. E. Pollard (amelia.pollard@stfc.ac.uk), A. J. Gilfellon, D. J. Dunning

ASTeC, Cockcroft Institute, STFC Daresbury Laboratory, Warrington



## Abstract

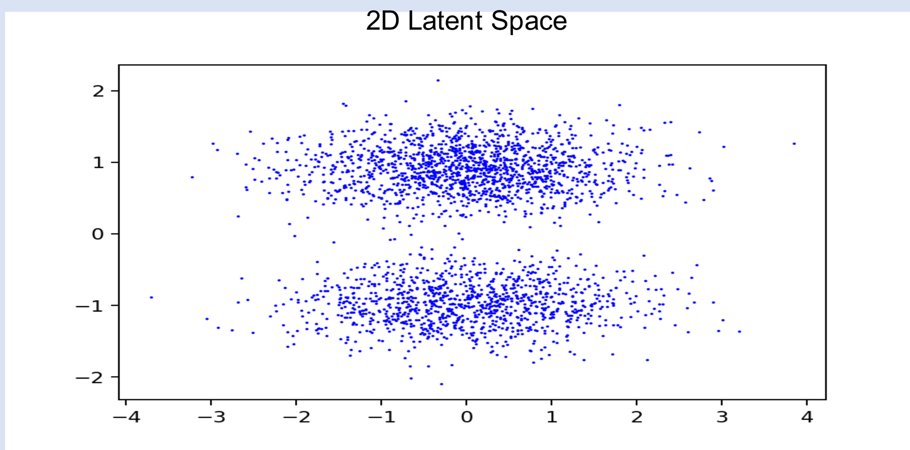
Maximising the accelerating gradient of RF structures is fundamental to improving accelerator facility performance and cost-effectiveness. Structures must be subjected to a conditioning process before operational use, in which the gradient is gradually increased up to the operating value. A limiting effect during this process is breakdown or vacuum arcing, which can cause damage that limits the ultimate operating gradient. Techniques to efficiently condition the cavities while minimising the number of breakdowns are therefore important. In this paper, machine learning techniques are applied to detect breakdown events in RF pulse traces by approaching the problem as anomaly detection, using a variational autoencoder. This process detects deviations from normal operation and classifies them with near perfect accuracy.

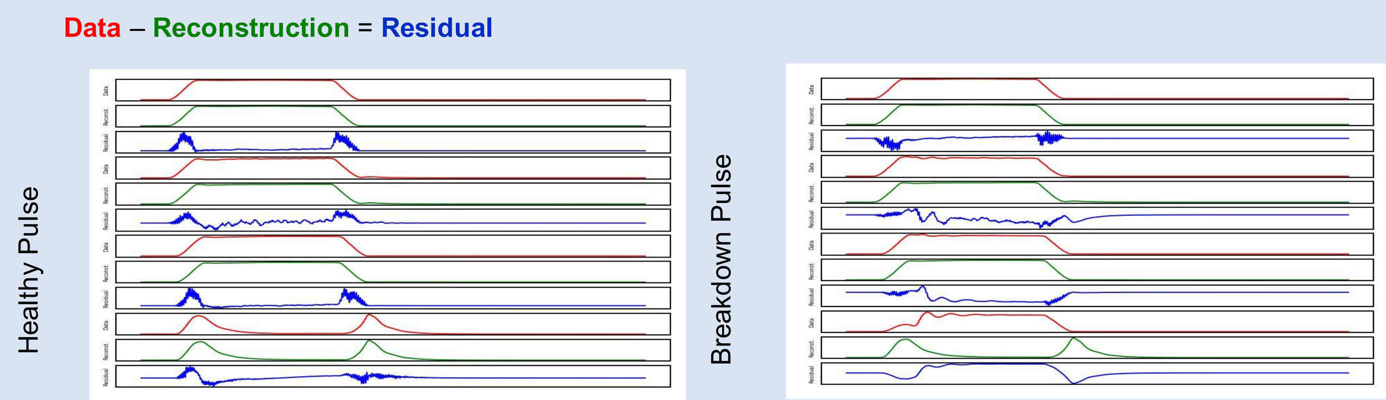
Offline data from various sources has been used to develop the techniques, which we aim to test at the CLARA facility at Daresbury Laboratory. Deployment of the machine learning system on the high repetition rate gun upgrade at CLARA has begun.


## Introduction

There are two main aims with this project. Firstly, we aim to assemble a machine learning based system that could be used to replace the current mask method of radio frequency breakdown detection which is standard in the automated code used in the RF conditioning of accelerating cavities at CLARA. Secondly, we aim to ensure that the mid-process features of the same mechanism could be used as inputs for an ML algorithm designed to predict whether or not the next RF pulse would lead to a breakdown.

## Results




CLARA Breakdown Detection

| | Positive | Negative |
|---|---|---|
| True | 95.8% | 98.0% |
| False | 4.2% | 2.0% |

XBOX-2 Breakdown Detection

| | Positive | Negative |
|---|---|---|
| True | 97.9% | 99.6% |
| False | 2.1% | 0.4% |

## Conclusion

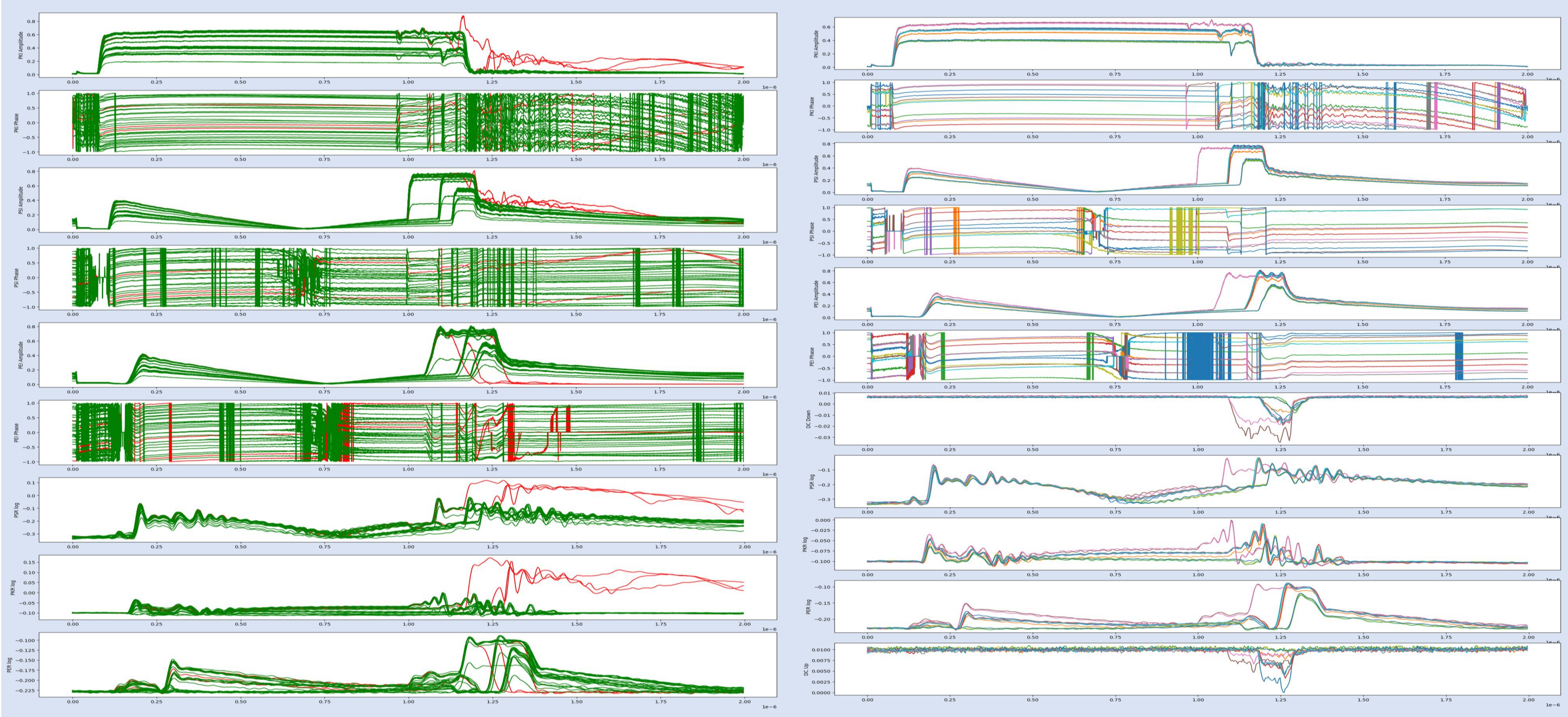
We find that the application of a variational autoencoder as an anomaly detector is extremely effective as a breakdown detector for RF cavities. A significant benefit of this approach is that it requires only healthy signals to train a strong detector, in contrast to supervised approaches which require careful balancing of positive and negative signals.

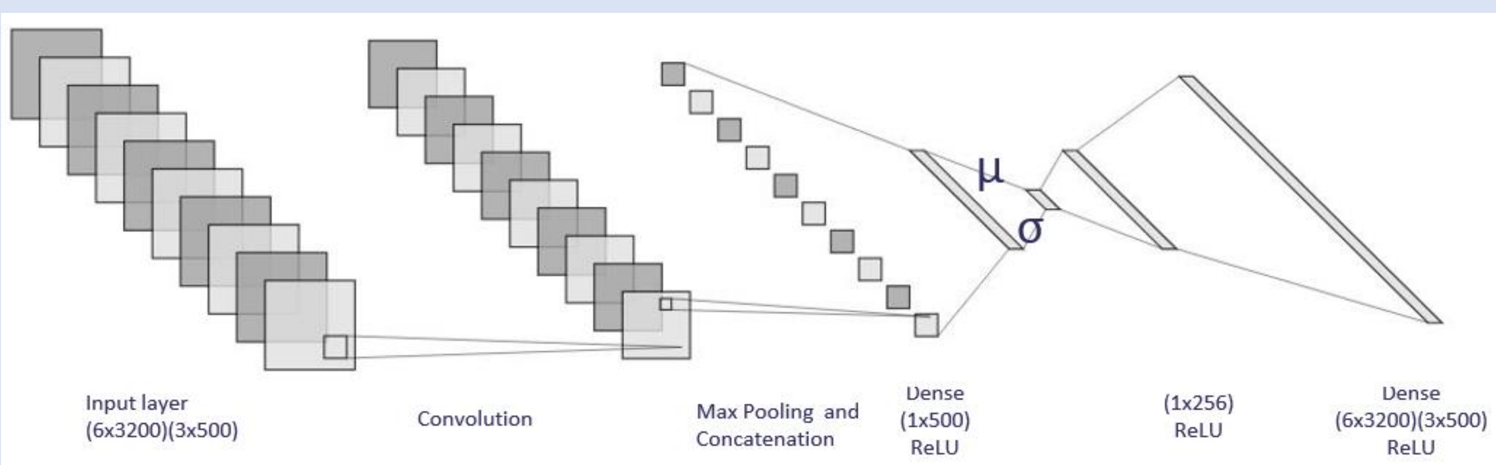
## Methodology

We constructed a beta convolutional variational autoencoder with RF conditioning data signal traces as inputs. We train the autoencoder to reconstruct healthy (non-breakdown) traces, with all breakdown traces held back. The per-channel reconstruction error and latent space vector of the autoencoder are then fed into a deep neural network-based classifier to detect breakdowns. By this approach, we ensure that the network can only reconstruct healthy signals well, allowing for strong detection of breakdown signals despite few examples of breakdowns – thus we avoid the need to mitigate class imblance.

Here we use data gathered during the RF conditioning of CLARA's 10Hz photoinjector, which includes both the RF pulse traces themselves and other non-RF, such as the temperature and pressure inside Gun-10.

In addition to the CLARA data, a larger dataset was provided by the CLIC team at CERN covering a cavity test which took place in CERN's XBOX-2 test stand. The structure tested in this dataset was a T24 high-gradient prototype X-band cavity produced at the Paul Scherrer Institute



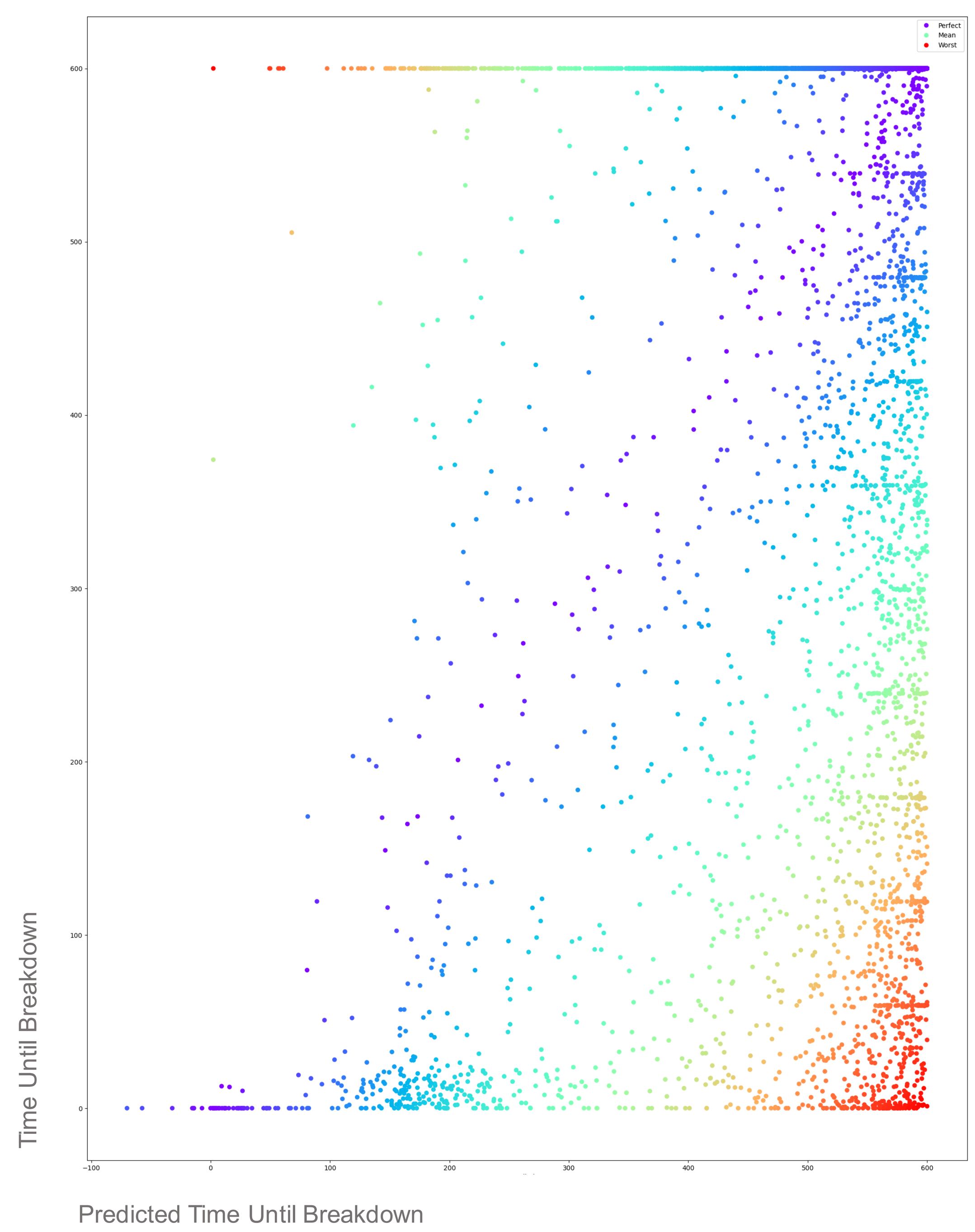



## Deployment & Future Development

### Breakdown Prediction

Training the network to instead predict time-until-breakdown resulted in overall poor accuracy, at 73% prediction of time until breakdown within a 30 second window.

We believe this poor prediction performance is due to the low sampling frequency of the shot capture, with only one shot per minute being captured.




### Next Steps

- Collection of 100% of shot data for a new dataset to train prediction.
- Refining the anomaly detection system to achieve perfect classification of breakdowns.
- Deploying this detection and prediction system to CLARA for online ML-based breakdown monitoring.


### Deployment

Work is now underway at the CLARA facility to deploy this machine learning system, operating at 400Hz, using a Xilinx Alveo U200 FPGA card. Additionally, in order to facilitate further work in prediction of RF breakdowns, a full duty cycle recording system is being developed in parallel to capture all RF traces at 400Hz. Following testing of this system against the mask method currently employed, integration into the safety interlocks is intended.