WEPV025

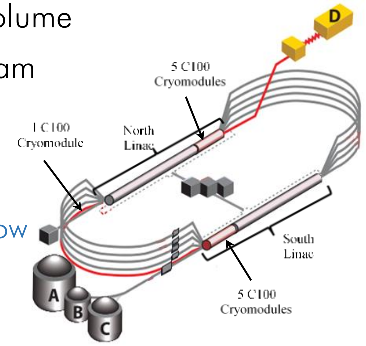
INITIAL STUDIES OF CAVITY FAULT PREDICTION AT JEFFERSON LABORATORY

L. Vidyaratne†, A. Carpenter, R. Suleiman, C. Tennant, D. Turner, Jefferson Laboratory, New-port News, VA, USA
K. Iftekharuddin, Md. Monibor Rahman, Old Dominion University, Norfolk, VA, USA

Motivation

- CEBAF experiences frequent downtime trips due to RF fault volume
- Automated prediction of RF faults is beneficial to expedite beam recovery and to apply fault prevention measures
- Preliminary study conducted in two stages
  - Prediction of impending fault as a binary classification task
  - Analyzed RF fault *type prediction* with respect to forecast window

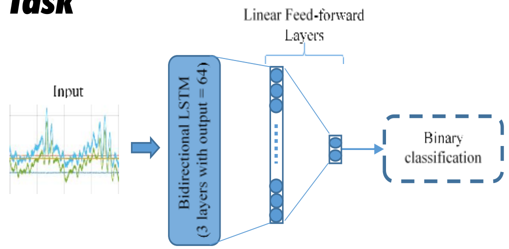
RF waveforms used for analysis



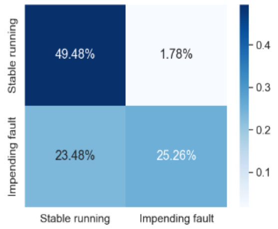
CEBAF schematic with locations of C100 cryomodules

Binary Classification Task

- Classification of impending RF fault versus stable running conditions in a C100 cavity
- 100 ms waveforms for impending fault extracted from data 105 to 5 ms before fault onset
- High false negatives denote difficulty in identifying impending fault conditions for certain fault types



Deep learning model architecture used for the analysis



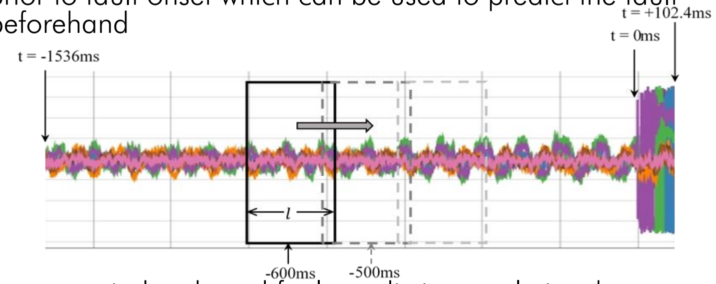
Confusion matrix

Binary classification performance

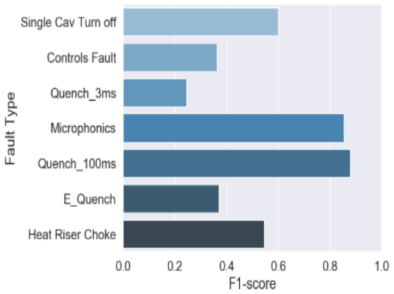
Class	Precision	Recall	F1-score
Stable running	67.8%	96.5%	79.6%
Impending fault	93.4%	51.8%	66.7%

Fault Type Prediction

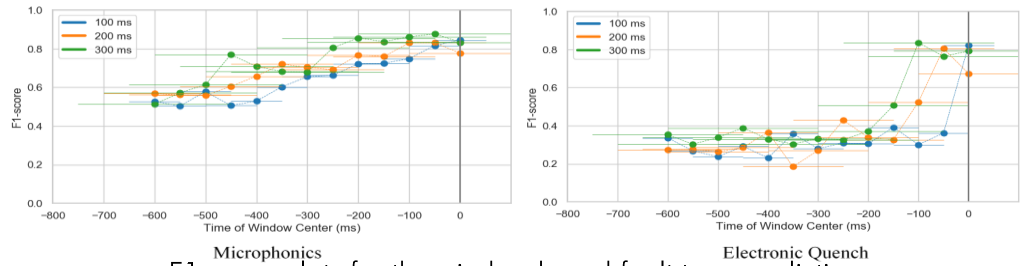
- Analyzing the possibility of identifying the RF fault type before fault onset
- Window based analysis with each fault type: waveforms extracted from 600 ms up to 0 ms (onset of fault)
- Several faults (example: "Microphonics") show precursors prior to fault onset which can be used to predict the fault beforehand



window-based fault prediction analysis scheme



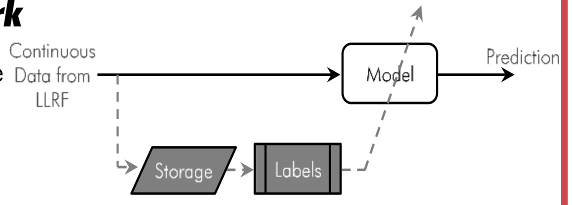
Prediction performance for 300 ms data window centered at -200 ms



F1-score plots for the window based fault type prediction

Future Work

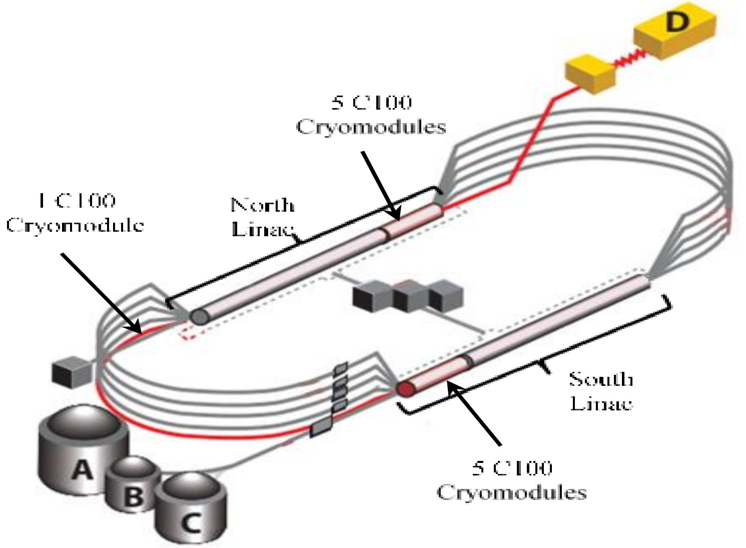
- Fault prediction with adequate lead time is feasible
- The DAQ systems planned for data streaming
- A framework is proposed to apply ML models to streaming data for fault prediction



Framework for using ML with streaming data

Motivation

- CEBAF experiences frequent short downtime trips due to RF system faults
- Faults are prominent in newly installed C100 cryomodules (100 MV gain)
- Faults, and offending SRF cavities are typically identified by experts post factum by manually analyzing recorded RF waveforms
- Artificial intelligence (AI) systems have been investigated to automate this task, aid experts, and speed up the diagnosis



CEBAF schematic with locations of C100 cryomodules used for this study

ML and DL models for automated cavity fault classification

	Cavity Identification	Fault Classification
ML Model (%)	88.0	86.9
DL Model (%)	87.8	81.3

- This work investigates the feasibility of predicting faults ahead of time
  - Identifying an imminent RF failure from stable running
  - Identifying the type of RF fault w.r.t. lead time before beam trip
- Successful fault prediction with sufficient lead time will aid in significantly reducing certain faults from occurring
- The RF data acquisition system is being upgraded for continuous data streaming for compatibility with predictive models

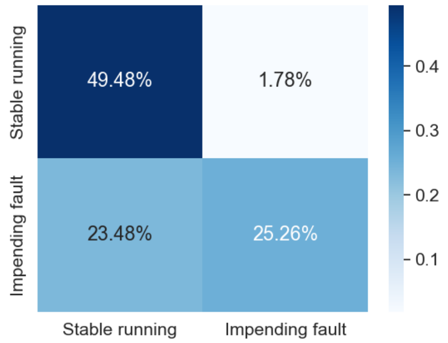
Binary Classification Task

- Classification of impending fault from stable running
  - Dataset: Examples extracted from recorded fault waveform data
  - Model: Deep LSTM for binary classification
- Results show high false negatives
  - Certain impending fault segments closely resemble stable running conditions

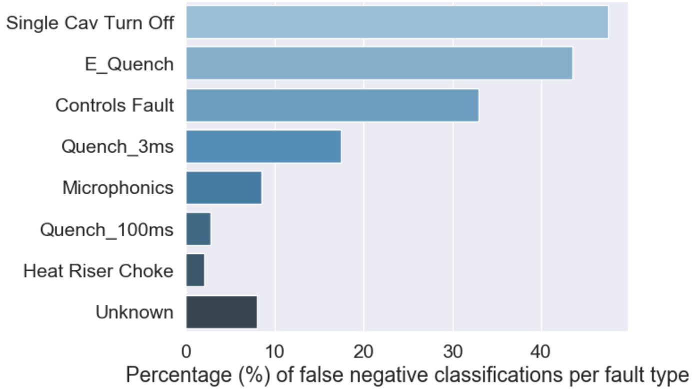
Results

Binary classification performance

Class	Precision	Recall	F1-score
Stable running	67.8%	96.5%	79.6%
Impending fault	93.4%	51.8%	66.7%

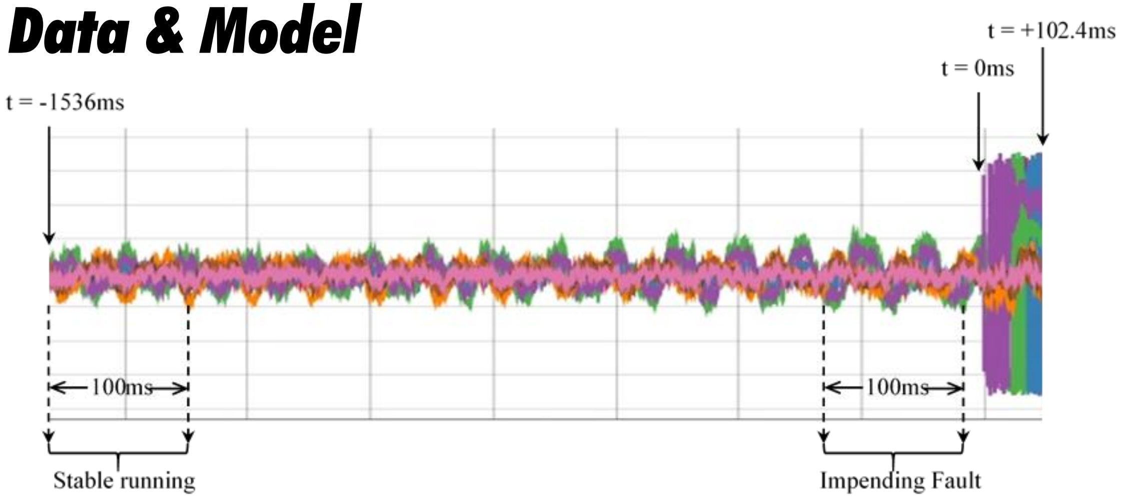


Confusion matrix for classification of stable running versus impending fault

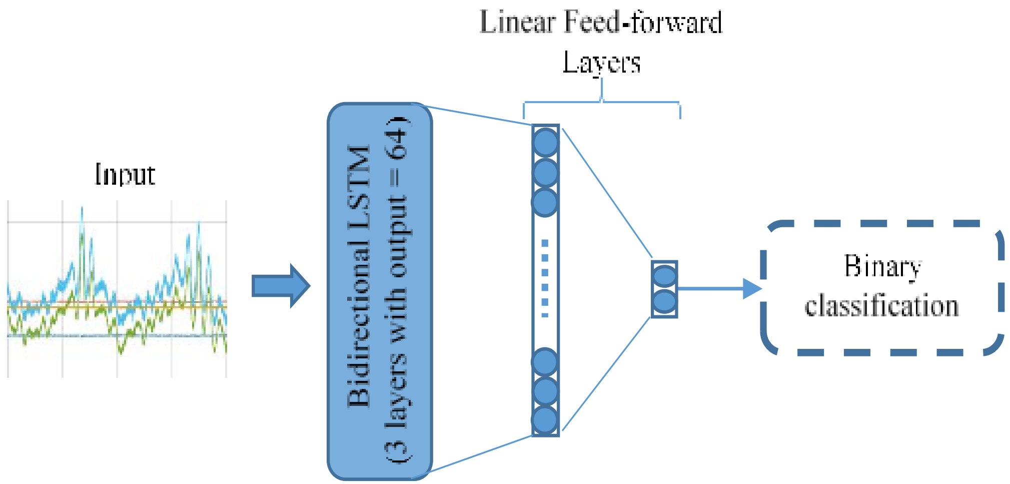


Distribution of false negative events according to fault type

Data & Model



RF waveform extraction to represent impending fault and stable running

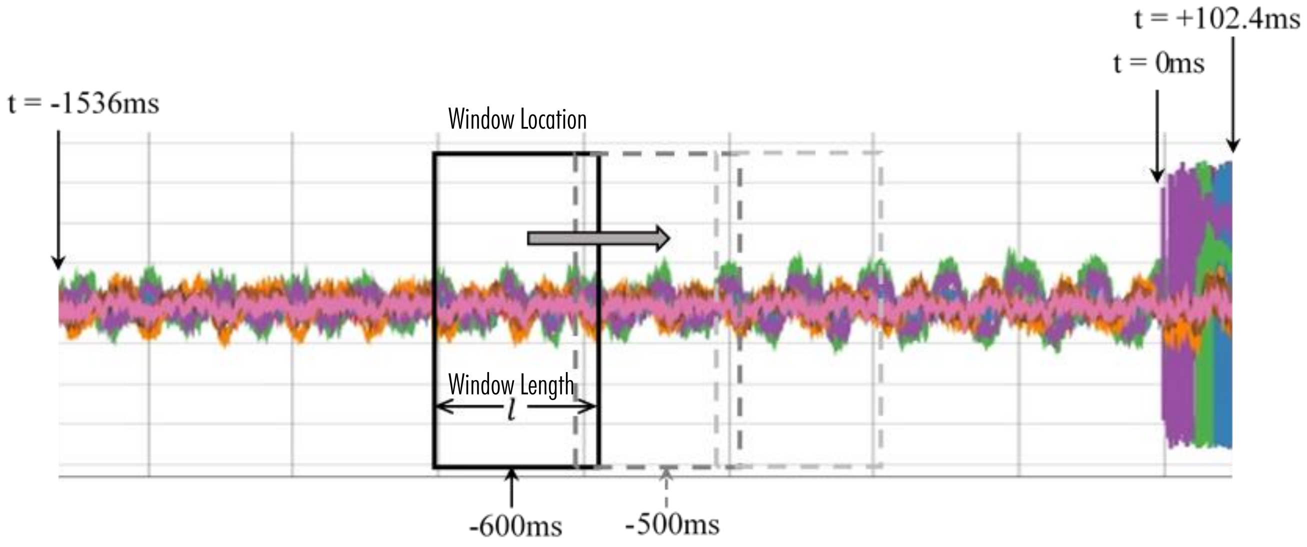


Deep LSTM for binary classification of pre-fault data

Fault Type Prediction Task

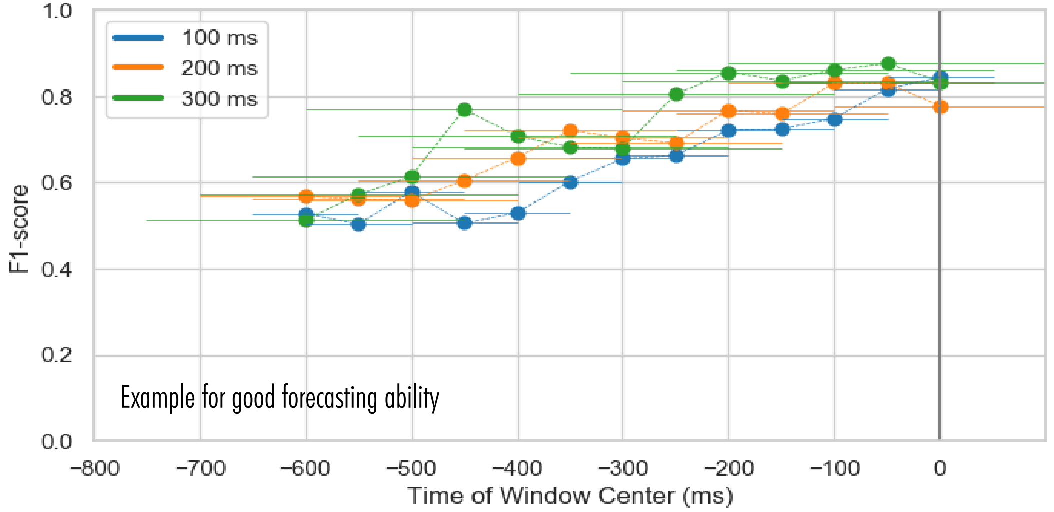
- Predict the fault type before the onset of RF fault
- Window-based analysis on recorded data to analyze fault type prediction performance
  - Window length (l) (100 ms, 200 ms, 300 ms)
  - Window location (from -600 ms to 0 ms in 50 ms intervals)
- Results show certain fault types exhibit precursors ahead of onset to use for prediction.
  - Some fault types do not exhibit precursors

Data

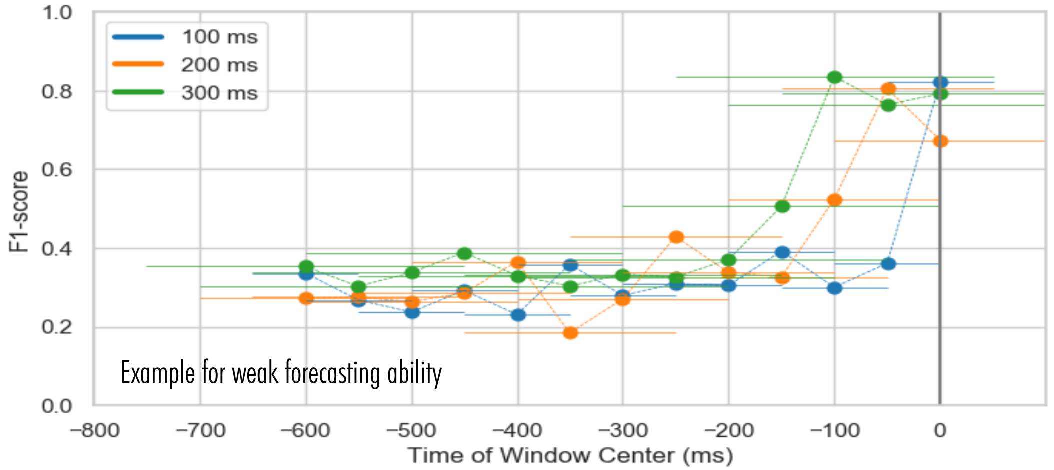


Window based fault prediction analysis scheme

Results



F1-score plot for the window based fault type prediction of microphonics

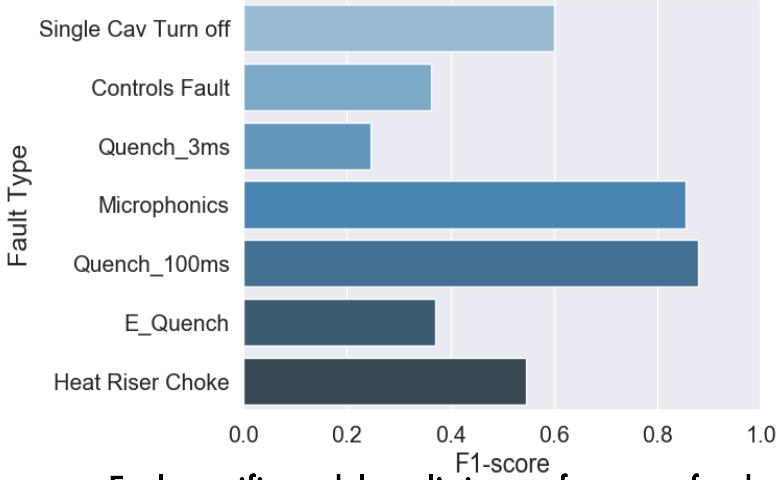


F1-score plot for the window based fault type prediction of Electronic Quench

Discussion and Future Work

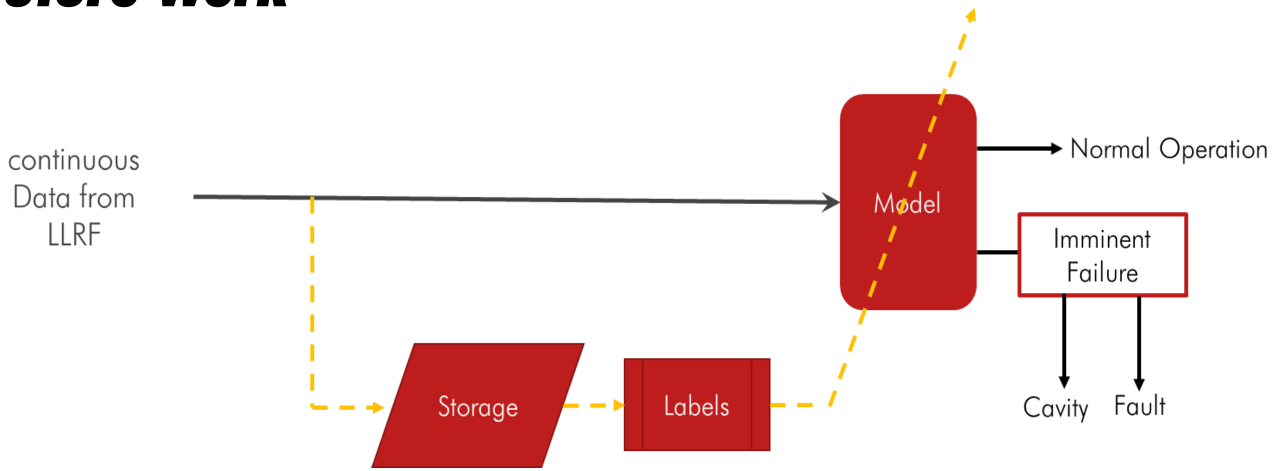
Discussion

- Preliminary analysis show successful RF fault prediction for certain fault types
  - Binary classification task with selected fault types show high performance
  - Fault type prediction task identifies some faults that are easier to predict using the waveforms considered for this study
- Plan to expand the study incorporating available ancillary data to capture fault types that are not well represented in current waveforms



Fault specific model prediction performance for the case of 300 ms data window centered at -200 ms

Future Work



Preliminary framework for using machine learning models with continuously streaming data

- ML models in the study are trained using static datasets
- Alternatively, treat data as a continuous stream
  - The ability to process each example as it becomes available (inspect once, predict, and discard)
  - Routinely update models as it is exposed to new data
- Upgrades to LLRF underway for data streaming