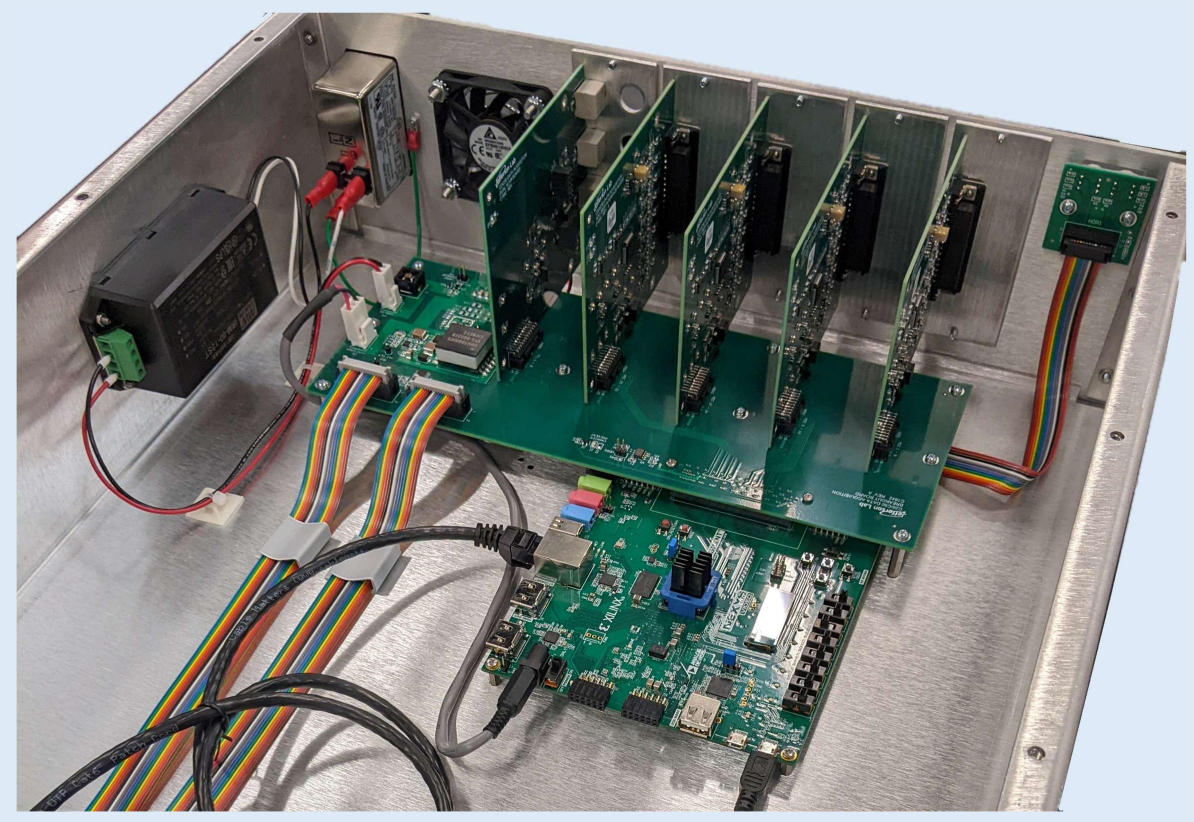
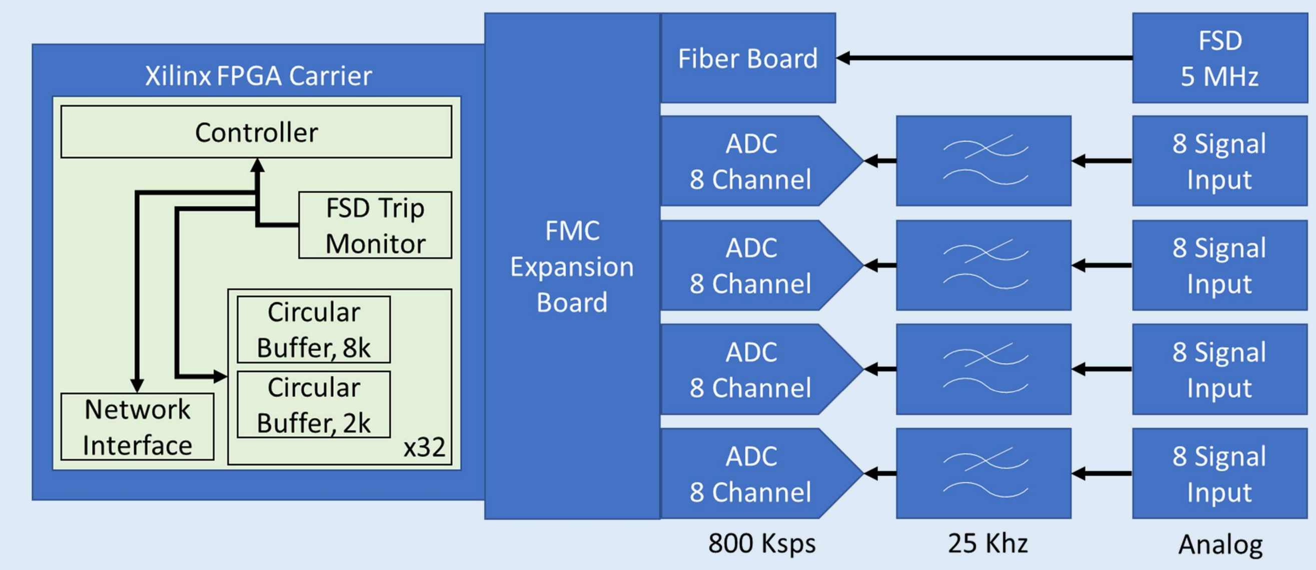
# Fast DAQ for Machine Learning

J. Latshaw, R. Bachimanchi, J. Tiskumara, D. Turner
Jefferson Lab, Newport News Virginia, USA

## Abstract

The Fast DAQ system was presented at LLRF conference in 2023 as a tool giving new life to CEBAF's legacy CAMAC RF Control system [1]. The legacy CAMAC system, though robust in its initial design, does not provide control signal information at a fast enough rate to be useful for debugging transients. The Fast DAQ system that CEBAF's LLRF team developed interfaces with control signals form the legacy CAMAC and makes them available to operators, engineers and technicians over the network. This poster will lightly review the functionality of the tool (see LLRF 2023 submission for full details) but will have its focus on how this new data has benefited CEBAF and generated several interesting spinoff projects.






## Overview of Deployment

The Fast data acquisition (DAQ) system for the legacy SRF cavities has been developed which samples and reports at an adjustable rate of 5 kHz to 20KHz. This allows for detection of transients in key RF control signals that the legacy zones were otherwise blind to. These chassis have been deployed through the North LINAC at CEBAF. Furthermore, an additional DAQ was deployed at the BSY to analyze beam position change just before a loss of beam. This can be distilled into an energy transient signature which is useful for classifying beam loss events [2]. This energy transient is used to empirically determine if the beam loss was due to a cavity or something else and has become a catalysis for maximizing the usefulness of these tools. This ability to capture data during a beam loss event for a wide range of cavities coupled with the ability to know if the beam loss was due to a cavity; has led to the ability diagnosis cavities that are causing beam loss events missed by the CAMAC control system. Without these tools CEBAF is otherwise blind to the source of these beam loss events.

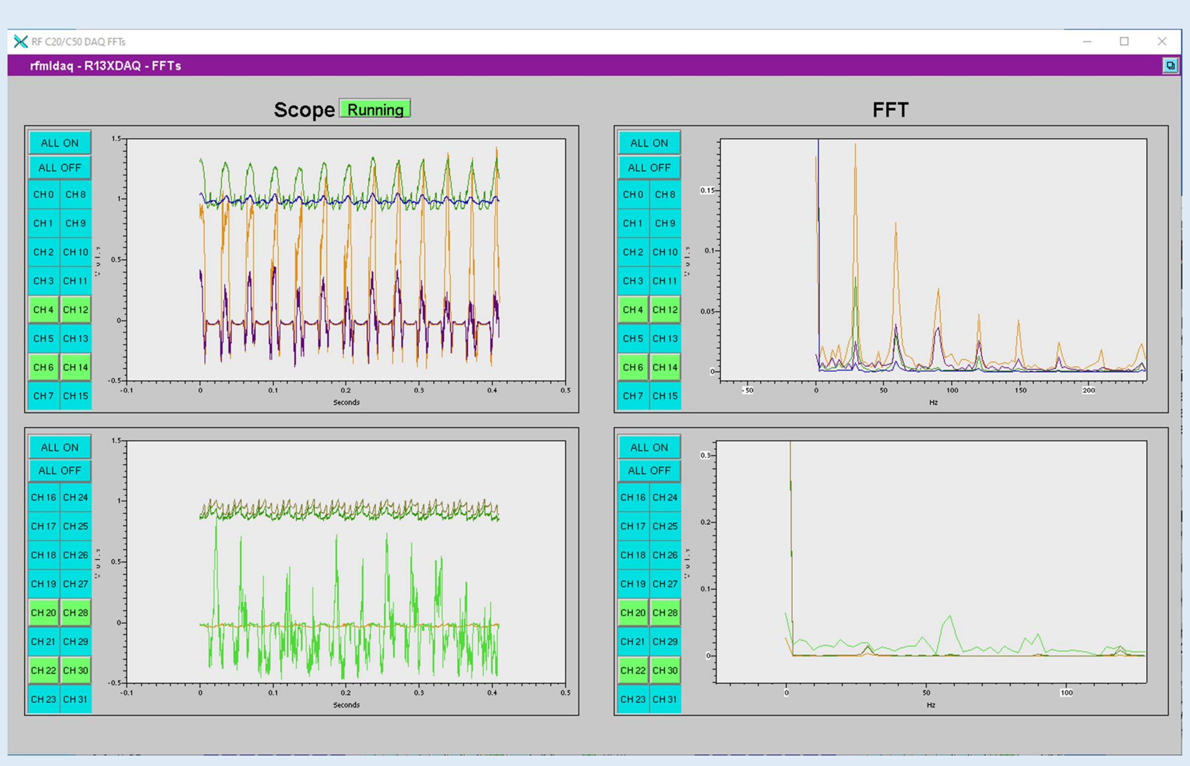
## DAQ Chassis

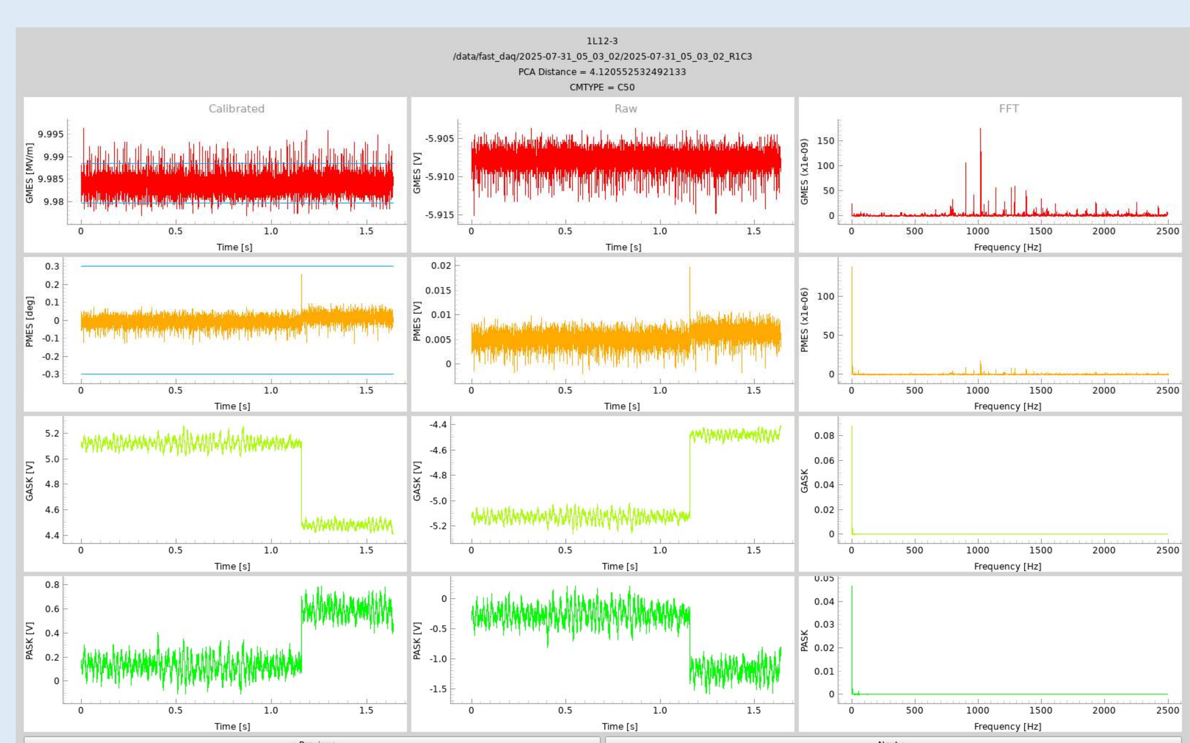
The Data Acquisition (DAQ) Chassis was developed to take in up to 32 channels of differential analog signals (+/- 12 VDC range) over 4 identical ADC boards. It was a design decision to choose board to board connections in place of ribbon cable connections. This increases the robustness of the design while making the design very compact. Additionally, there is one fiber trigger board which takes, as an input, a 5 MHz Fast Shutdown Signal (FSD). This FSD is held low when beam is lost, triggering a freeze in the data collection. This archived data is the raw form of the training data used for some of the machine learning projects at Jefferson Lab. The FPGA carrier for this is a Digilent Nexys Video board which has a Xilinx Artix 7 FPGA. This FPGA has more than enough internal BRAM to store all 32 of the 8k waveforms that are frozen when a trip occurs.

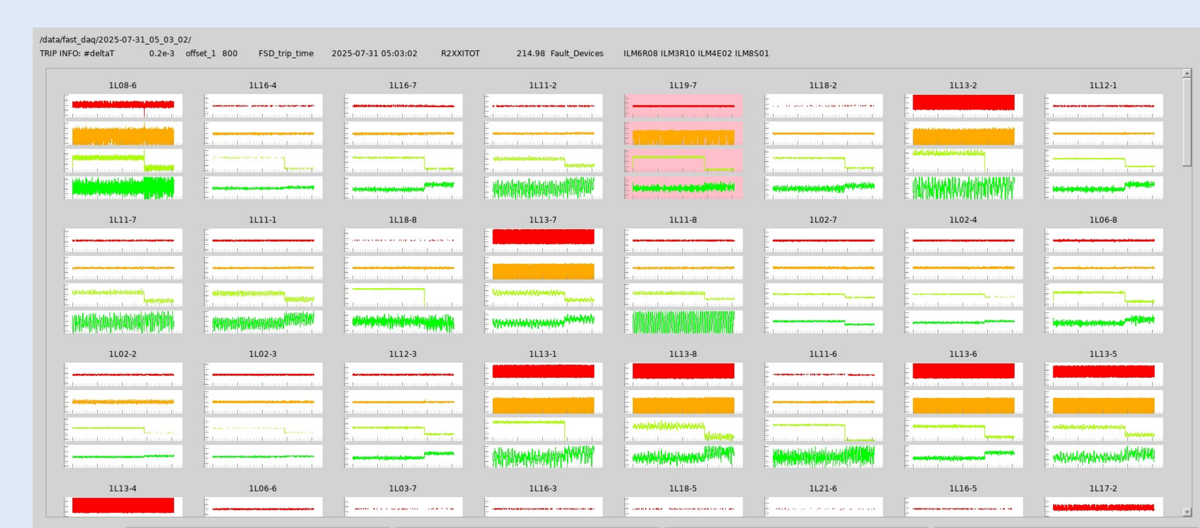
## System Level Block Diagram

The DAQ samples key control signals used to control the C20 which is an 8 cavity Cryomodule. There are 4 control signals looked at per cavity which pertain to the gradient and phase. All signals are continuously sampled and saved onto a circular buffer. Whenever beam is lost, the buffers are frozen which allows EPICS (a software based control system) to save all of the fault data on external hard drives. This is done for all zones which have the DAQ installed.

The fault data is used by RF experts to assess if a particular cavity may have caused the loss of beam and it is also given to machine learning tools which attempt to identify statistical variants from normal operation and flag them so that they can be looked at by an operator. Therse are several experimental models [3,4] but PCA is a popular one at CEBAF and has shown to be useful.







## Tuner Waveform Viewer

The DAQ allows for real time monitoring of cavity performance. The above shows a display of the waveform viewer. In addition to machine learning research, these tools are used to help debug cavities in real time.

The increased sample rate of the DAQ chassis has helped RF experts in identifying and detecting cavity instability in NL03 (shown above). Shown here is 30 Hz noise source (and its harmonics). These would have been invisible given the legacy cavity controls.

## Machine Learning Models

Other models using PCA (a pure statistics-based approach of machine learning) are also being actively investigated [3,4]. This tool monitors a cavity during beam loss events and highlights statistically unusual behavior. This has proven very useful in identifying cavities that cause the beam loss event but do not report it. The above image shows an example of this model in action, assigning a PCA score to the cavity. Other models which attempt to predict if a cavity is becoming unstable are being developed.

## Development of Tools

It is easy to get lost in all the data that can be available. Distilling this data into useful tools is of paramount importance. The above picture shows an example of such a tool. This tool filters through the PCA model and highlights the most deviant cavities which merit further investigation. This takes the overwhelming amount of data and helps a human identify which cavity needs to be looked at first.

Other tools which correlated [2] and [4] have shown to be extremely useful in finding cavities that have caused the beam loss event but did not report any faults.

## Future Work

CEBAF has two LINACs (North and South). Only the North LINAC has been outfitted with the fast DAQ system. The LLRF team is hoping to receive funding to outfit the south LINAC with this system. This is a $100k investment which will allow all the legacy CAMAC zones to be monitored.

## Summary

The Fast DAQs are being used for their intended purpose, to create tools to allow individuals to analyze key RF control signals and to use the data as a platform to build future tools to help with operations. We look forward to continuing to expand on this project and work with researches to refine and develop the toolset. This has been an exciting project and continues to gain interest as its usefulness to operations is made manifest.

I would like to thank J. Tiskumara for her work as this has been a catalyst for realizing the potential of the DAQ system [2]. I would also like to thank D. Turner and A. Carpenter for their hard work moving forward with a lot of the software tool development.

## References

[1] J. Latshaw, et al. "DAQ for JLAB Legacy Analog LLRF Systems"
[2] J. Tiskumara et al., "Proposal for Beam Trips and Energy Jitter Analysis with BPM"
[3] D. Turner et al., "SRF CAVITY INSTABILITY DETECTION WITH MACHINE LEARNING AT CEBAF" in Proceeding of 5th North American Particle Accel. Conf., Albuquerque, NM, USA, 2015.
[4] H. Ferguson. "CAVITY INSTABILITY DETECTION FOR THE CONTINUOUS ELECTRON BEAM ACCELERATOR FACILITY" Tech note, Jefferson Lab.
[5] Rama Bachimanchi, private communication and developer.
[6] Larry Doolittle, private communications regarding RGMII firmware.
[7] Clyde Mounts, private communications and expert suggestions.
[8] Adam Carpenter, private commutations and tool development.