Helium Mass Flow Project

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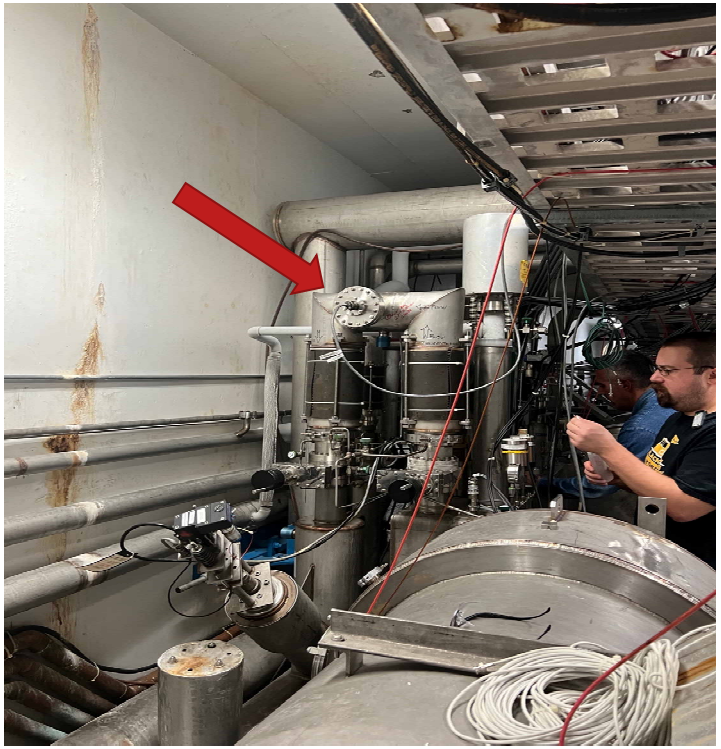


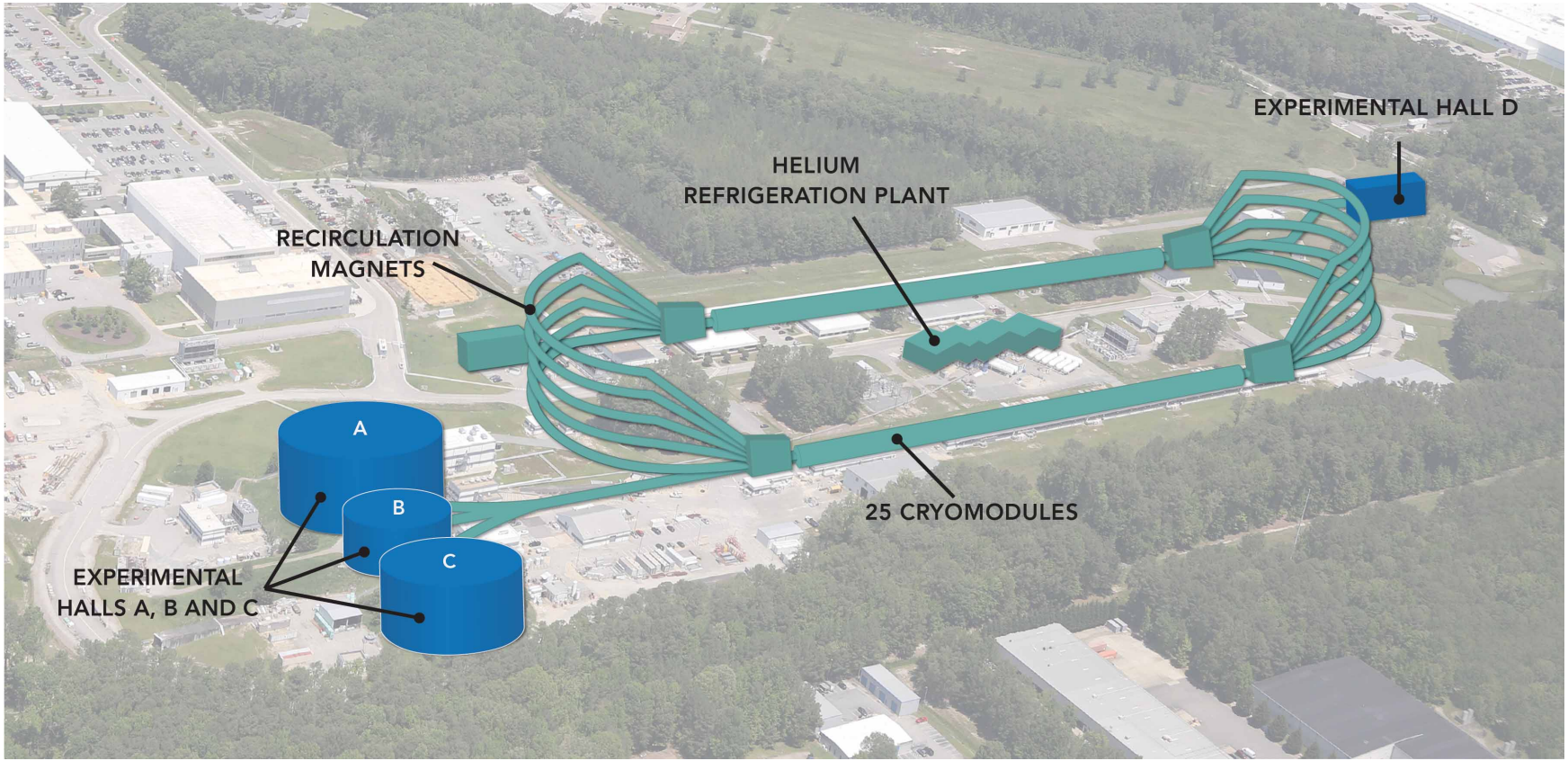
Outline

- Introduction to Jefferson Lab
- Need for Helium Mass Flow Sensor system
- Evolution of the system; HEFLOW Sensor
- U-Tube modification
- Hardware description
- Summary

Introduction to Jefferson Lab

- Jefferson Lab is a U.S. DOE Office of Science national laboratory
- Electrons are accelerated in a recirculating linac to 12GeV using Superconducting Radio Frequency (SRF) cavities
- These SRF cavities operate at 2 K, cooled by liquid helium *under vacuum*
- There are 53 Cryo-modules (CM) that each contain 8 SRF cavities, these are connected to the Central Helium Liquefier (CHL) via “U-Tubes”
- There has never been an on-line cryogenic “power meter” for the cryomodules
- The helium mass flow sensors are located in the return U-Tube

CEBAF – Continuous Electron Beam Accelerator Facility

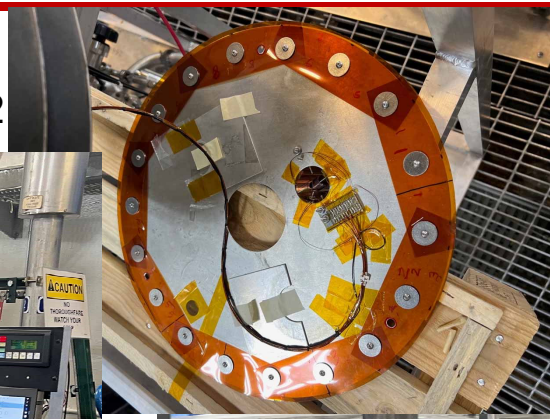


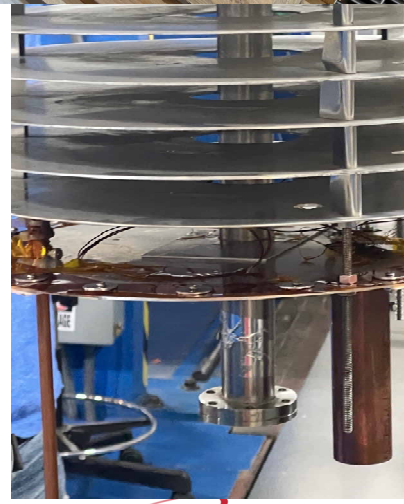
Helium Mass Flow Sensor – The Need

- There was no good way to non-invasively determine the heat load of a CM
- For 30 years the Bomb Calorimetry method was used
  - Shut off accelerator, go into the tunnel to lock return valve closed
  - Exit accelerator, secure for RF operations, monitor rate of rise of pressure
  - Rate of pressure rise is proportionate power dissipated in a given cavity – Q_0
- The SBIR topic was suggested, posted, and awarded to Hyperboloid LLC
  - A phase II was also awarded in April 2023
- The helium mass flow system does not require accelerator access & can be used parasitically
- During CEBAF operations the system can monitor the *health* of a CM
  - By scanning through the installed sensors it can determine is the losses increase in a give CM – ie field emitter turning on or insulating vacuum deteriorating
  - If the beam is off then Q_0 of individual cavities can be determined

Helium Mass Flow Sensor – Evolution from Testing to Deployed System

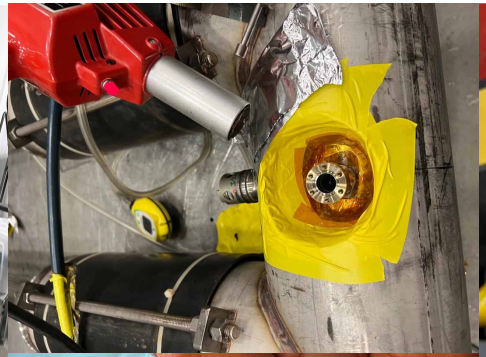
- Initial testing was done in the Vertical Test Area (VTA)
  - Using commercial instruments & LabView, then Raspberry Pi – 6/2022
- Final version is with LabJack T7 to EPICS

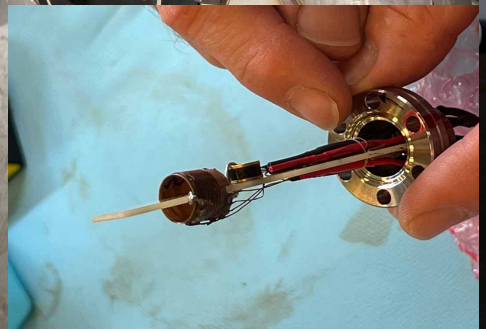


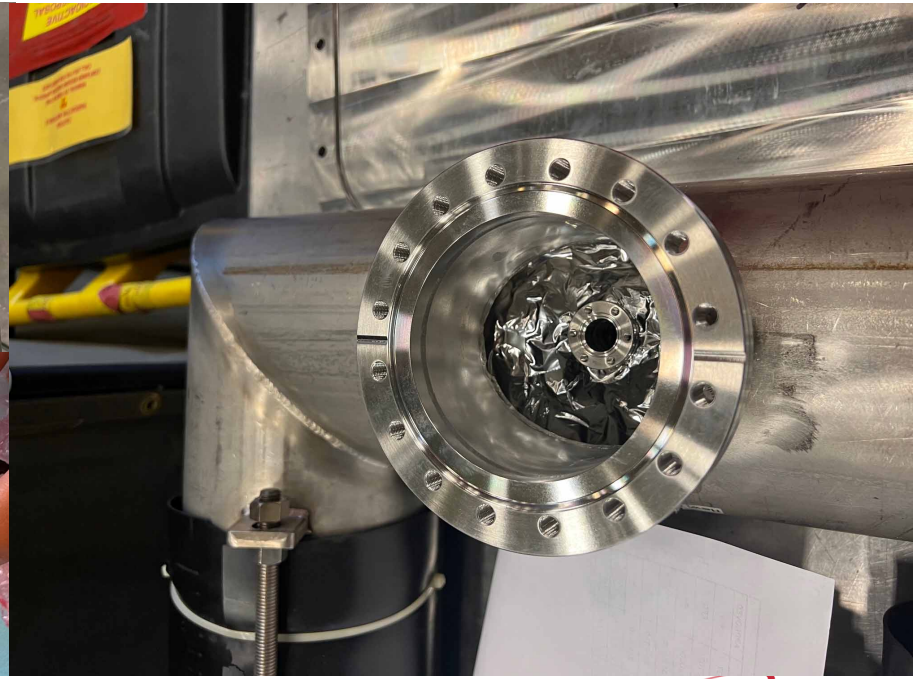


U-Tubes – Connection between Cryo-module (CM) & Helium Transfer-line

- There are 53 CMs in CEBAF to accelerate electrons to 12 GeV
- Some CMs have last been warmed up during Hurricane Isabel in 2003
- Every time a U-Tube is pulled it gets modified with mass flow sensor



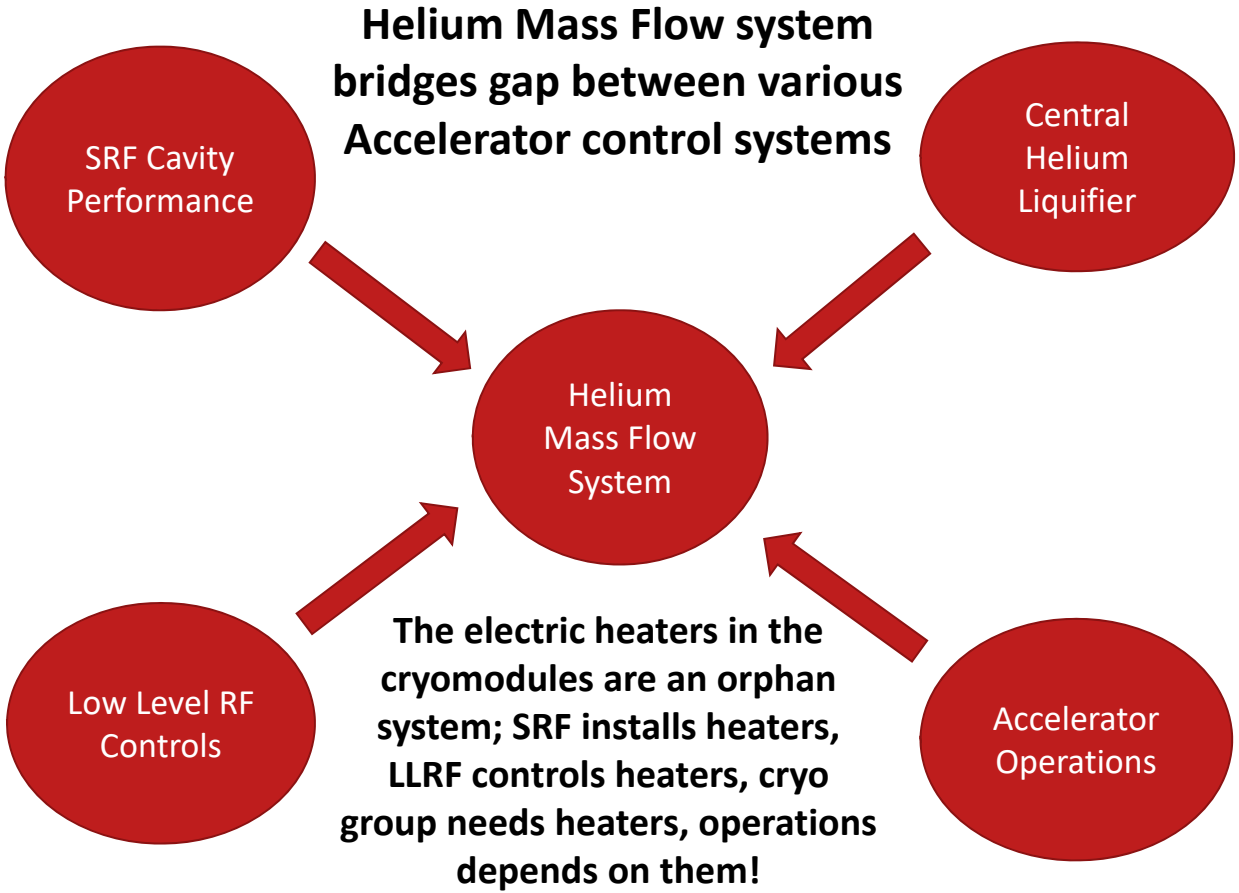




Helium Mass Flow Sensor

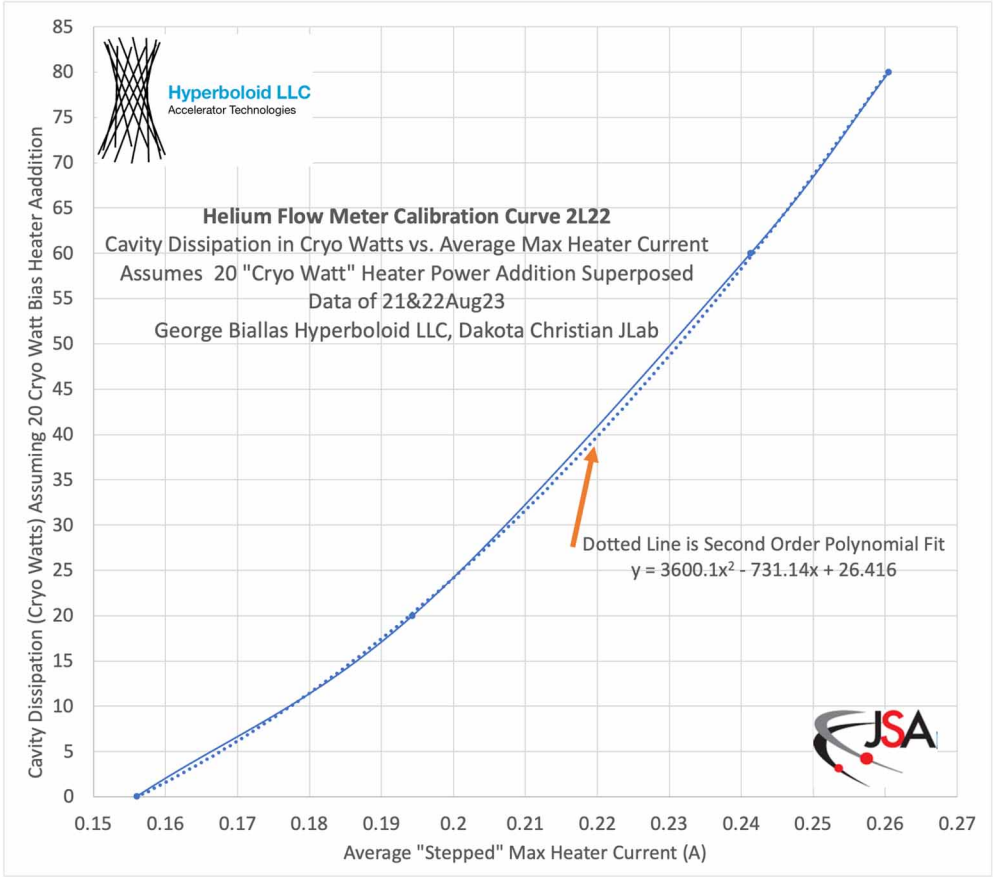
- How the Instrument Head works
  - The *cooling* from **helium flow** is bucked against the *heat* from a **rising current** in a **heater wire**
  - Heater is strongly coupled to a superconductor that yields a large resistance signal when it quenches (T_c ~ 9 K) to go “normal” conducting
  - Digital electronics tracks the maximum heater current at a flow, compares it to a calibration curve and expresses the flow rate - resolutions to 0.1 g/s in a 3 in pipe (~1 watt)
- The current in the heater is directly proportionate to the helium mass flow
  - Power dissipated by individual cryomodule/cavities
- A temperature sensor is included in the package
- Fully integrated into the EPICS control system
- Calibration is done using electric heaters in each cryomodule
  - Each location has individual calibration curve – eliminate minor installation variations

Helium Mass Flow Sensor – It Ties Together Various Systems



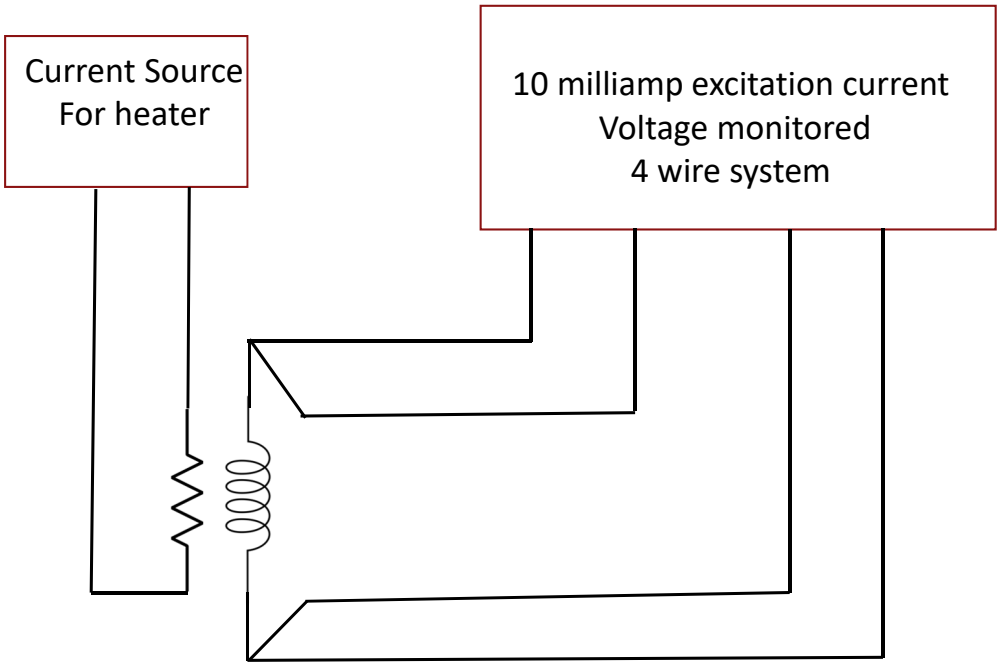
Helium Mass Flow Sensor – Calibration

- Each Cryo-Module (CM) has electric heaters that are turned on when the RF power is shut off (or trips off) to maintain a constant load to the CHL
  - If the load changes by even a few percent the CHL plant could trip off
  - Recovery is 2 to 4 hours to pump back down to 2 K, (0.031 ATM)
- The sensors are calibrated in place by turning on the electric heat in the CM
- Challenge is helium supply & return
  - Joule-Thompson valve controls liquid level; need to lock or close during calibration
  - Return header pressure also varies
  - System can see variations ~1millibar!



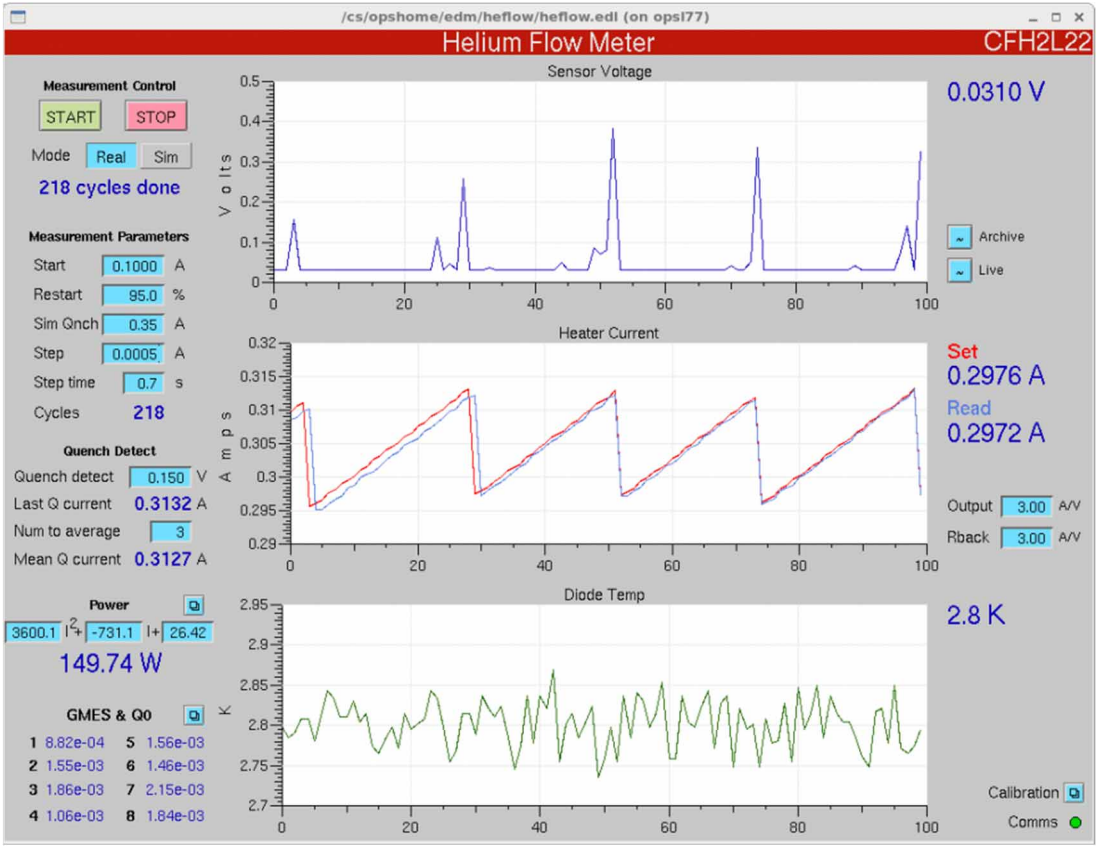
Block Diagram

- Lab Jack T7 interface to EPICS
- Chassis is two channel, 2U x 14” deep
- All cabling is twisted pair
- Temperature diode included
- Maximum current is 500 milliamps
  - Adds ~1watt to cryogenic load when operating; scan each sensor ~ 1 hour
- Current is ramped up at 1 mA/sec
  - Variable set in EPICS
- Quench detection voltage ~50 mV
  - Variable set in EPICS



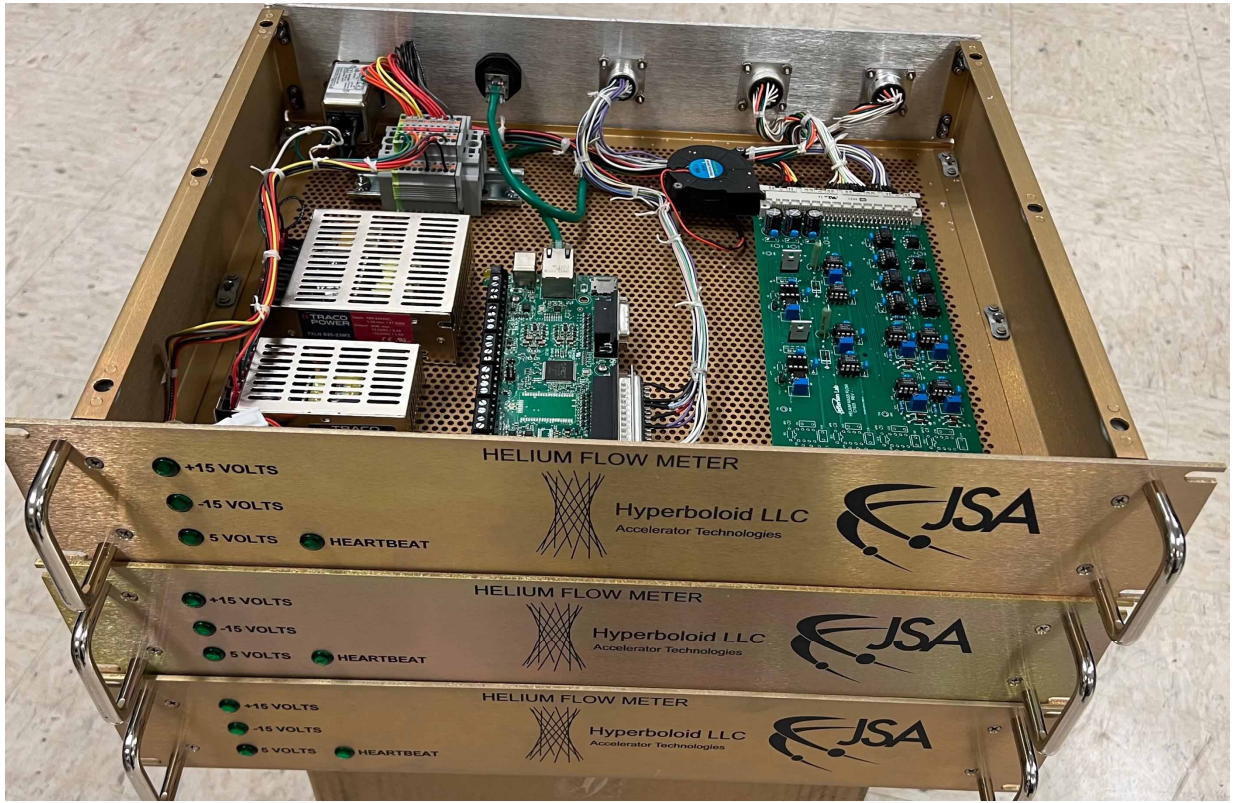
Operation

- Ramp sensor heater current until sensor quench voltage detected
  - Scaling is 3mV/1 milliamp
- Restart at ~ 95% of quench value
  - Quench recovery is prompt
- Software does rolling average of last 5 quench heater currents
- Dissipated CM power displayed based on calibration curve
- There are high power (full CM) calibration curves & curves for Q_0 of individual cavities



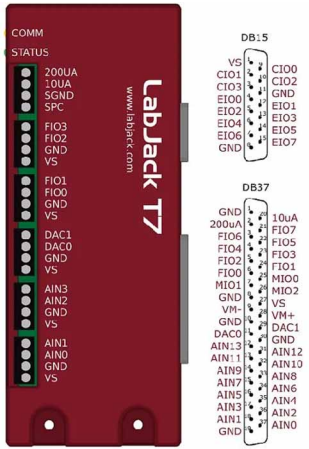
Interface Chassis

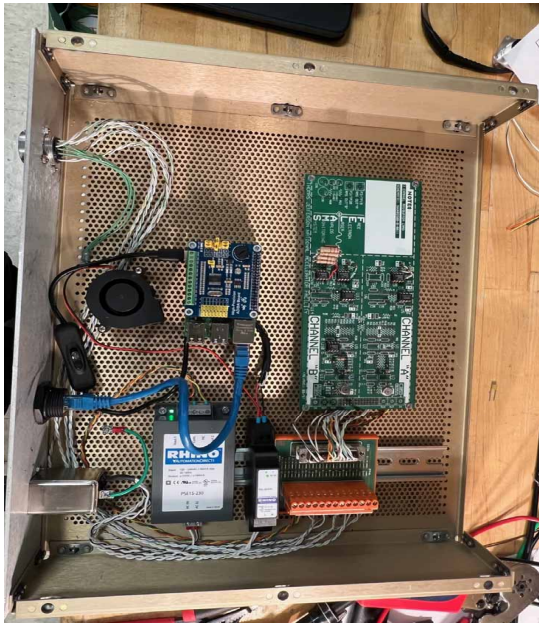
- Custom PCB interfacing to sensors
- Two connectors for sensors
- Diagnostics port with all signals
  - Break-out box is used instead of breaking out signals on front panel
- All cabling is twisted pair
  - Instrumentation amp front end >90dB CMMR
- 1.5 years from 1st funding to fully deployed operational system!



Control Platform

- Initial EPICS development on Raspberry Pi
- Production deployment uses LabJack T7
  - 14 16-bit Analog Inputs
  - 2 12-bit Analog Outputs
  - 23 Digital I/O
  - Each LabJack supports two flow meters
- Soft IOC
- RHEL 9
- Modbus TCP via Ethernet
- Custom PCB interfacing to sensors

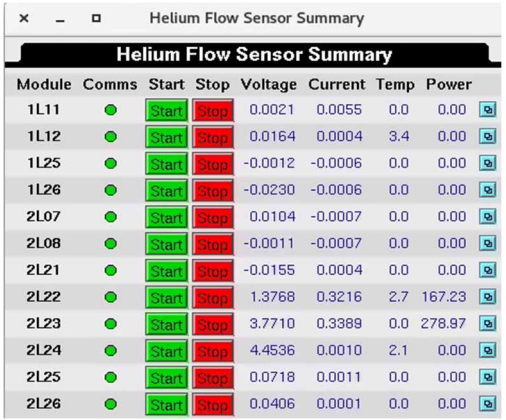


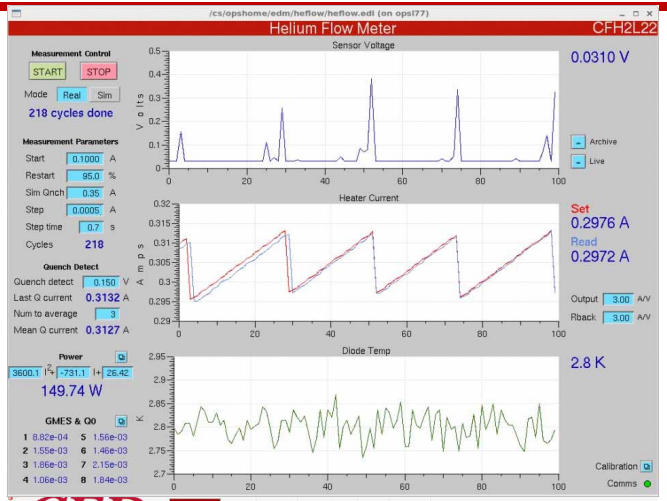


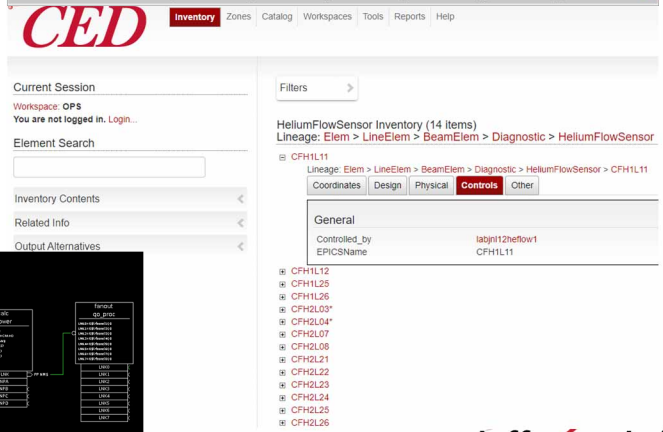
- Experience with LabJack led to development of networked EPICS DAQ system
- Streams 100 ksps over Ethernet to EPICS waveform records

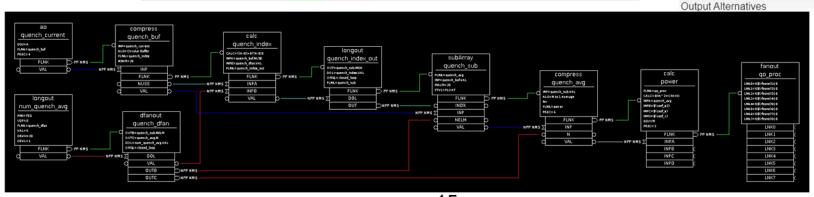
Application Design

- EPICS 3.15.9
- Asyn & Modbus modules
- SNL sequencer, 100 lines of code
- 10 record database
- EDM GUIs (OTF)
- Configuration via CED
  - Screen generation
  - Boot script generation
  - Auto archiving









Summary

- 11 sensors were installed in U-Tubes during Scheduled Accelerator Down
- 12 two channel chassis are being built by outside vendor (24 channels)
  - The first 4 chassis are complete and are deployed in the accelerator
- Testing & calibration are being done now with machine at 2 K
- Challenge is getting calibration curve better than 1% ($\leq$ 1 watt) resolution
  - Variations in helium supply & return pressures affect calibration
  - Correlate these pressure variations to improve resolution