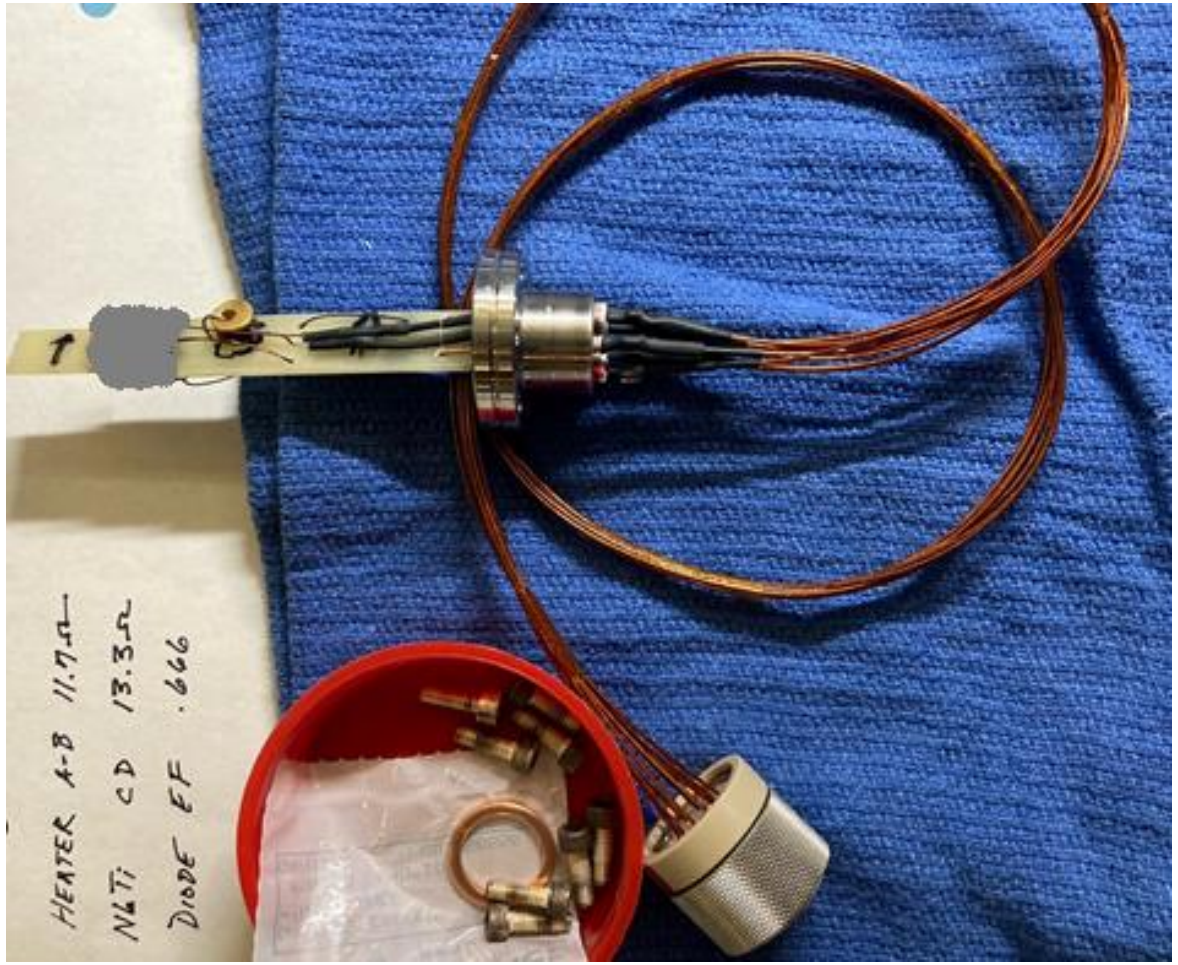
Helium Flow Meter – **A WATT METER**

- George Biallas PE
- **Hyperboloid LLC**
- Yorktown, VA

- Kevin Jordan PE
- **Jefferson Lab**
- Newport News, VA



Meet Hyperboloid LLC

- Hyperboloid LLC is a 1-person entity
- I am a retired engineer from Thomas Jefferson National Accelerator Facility (Jlab).
- I have cryogenic, superconducting magnet and **lots of experience making Physics apparatus.**
- **I did an SBIR before – I knew how to do it**. It was an unrelated, successful Phase I Project using **collaboration with Jlab.**

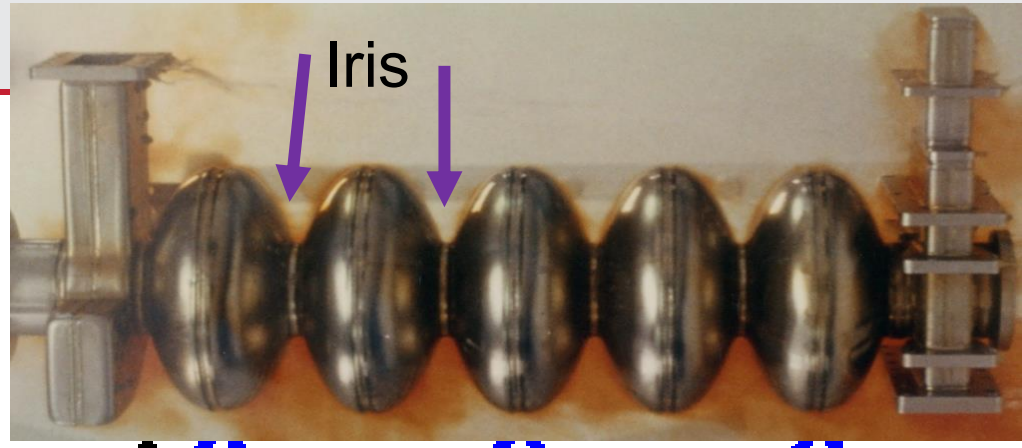
Meet Hyperboloid LLC

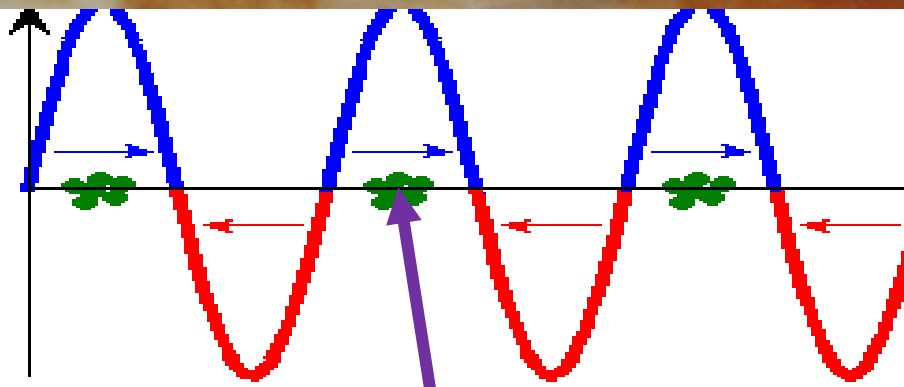
- **I had additional Jlab collaboration experience**!
  - I was the engineer for BNNT LLC for their Phase II and IIA SBIR, in collaboration with Jlab, that uses Boron Nitride Nano Tubes to increase accelerator reliability.

- **I don't need much room -** I make the Flow Meter Instrument Head in my air-conditioned garage.

Tutorial - SRF Cavities and Q_0

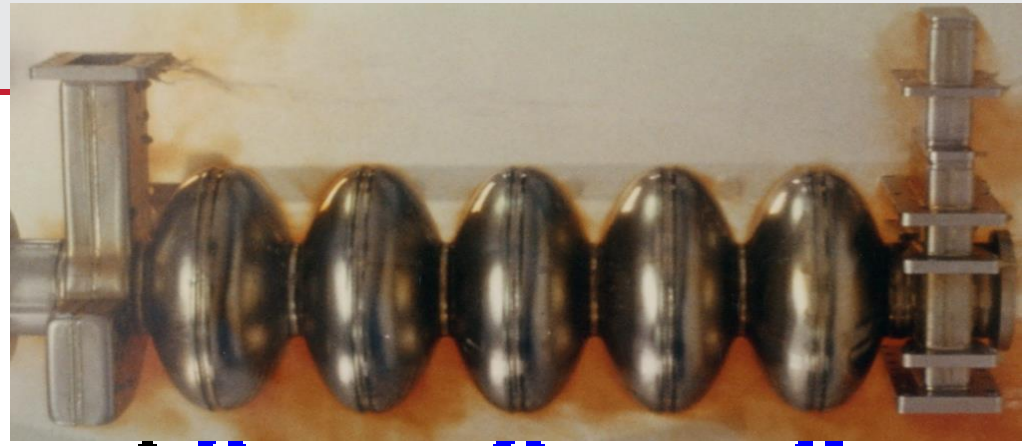
- Radio Frequency Cavities are used to accelerate charged particles in a Linear Accelerators – used since 1945.
- Radio Frequency (RF) –microwave- Power is piped into the cavity and the dimensions of the cavity are resonant at 1.5 GHz (at Jlab) – like the hot nodes in your microwave oven.
- Huge currents slosh back and forth, **charging the irises alternately** to give an **electrostatic** kick to the particles – if a cavity is made of copper, **most of the power goes to I^2R heating**.





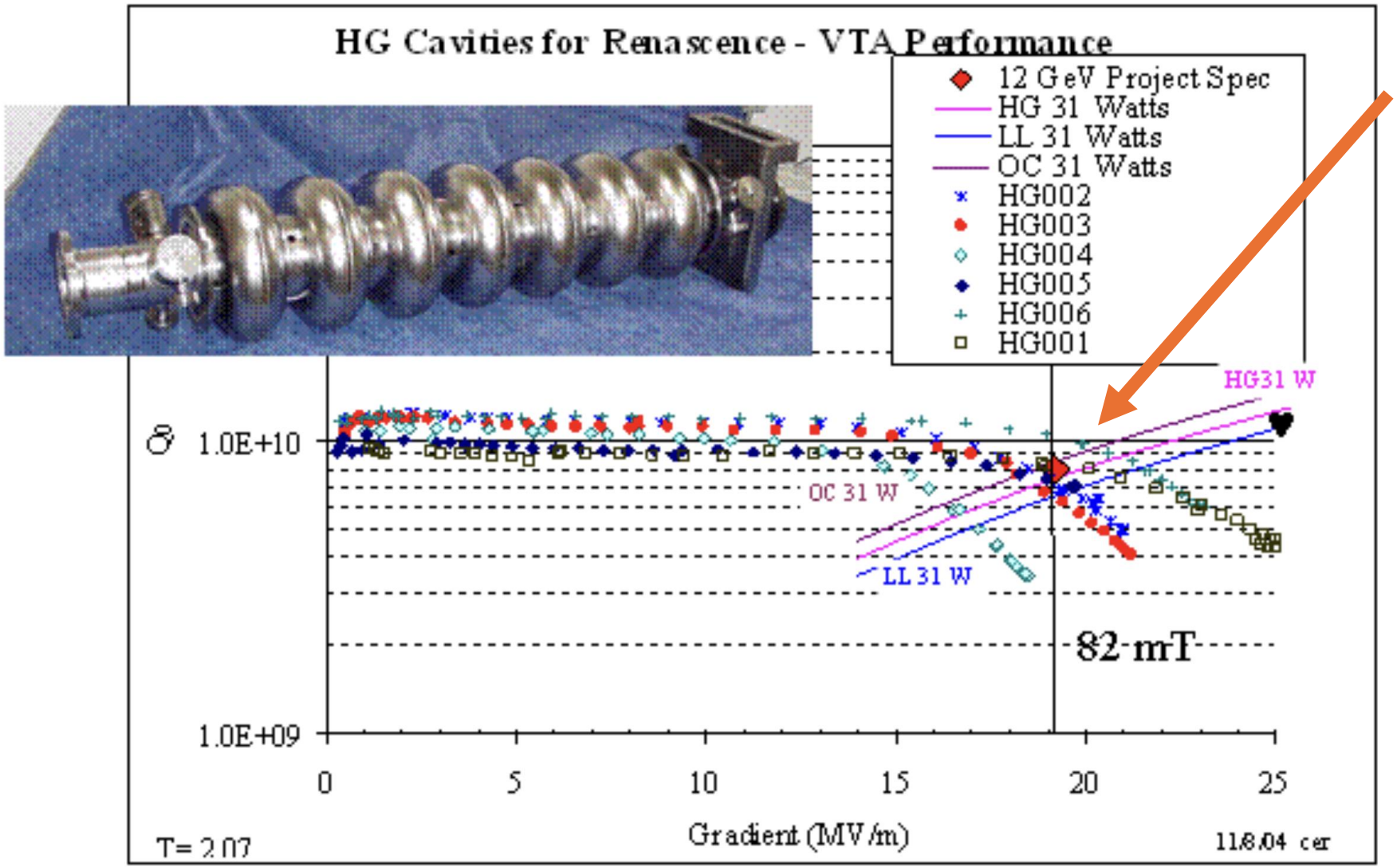
Green particles accelerated by the blue phase of the voltage

Tutorial - SRF Cavities and Q_0



- **Superconducting Radio Frequency (SRF) Cavities** offload virtually all their power to the particles! ALL EXCEPT FOR SMALL LOSSES AT THE 10^{-10} LEVEL.
- The ratio of acceleration power to small loss is called **Q_0**.

SRF Cavity Q_0 vs. Gradient – inverse of power lost to the Liquid Helium Bath



Q_0 starts **decreasing at higher Gradients** as field emitted electrons from contamination and other processes dump power (at the 10 to 30 W Level) into the niobium. This evaporates helium from the 2 K helium bath they are immersed in.

Helium Flow Meter – Cryomodule and what Operators Need

- SRF Cavities are housed in longitudinal Dewars Called **CRYOMODULES**

Usually 8 Cavities per Cryomodule

- There **was** no **good** way to non-invasively determine how much power dissipation is going to the 2 K Helium Bath (How contaminated one of the cavities is!).
- Accelerator operators need this knowledge.
  - Which cavities require **lower Gradients**.
  - To keep the **Cryo System** from **CRASHING**, how much **heat to substitute** in a cryomodule when you turn a cavity off – **cryomodules have heaters for this purpose.**

Operators NEEDS – Flow measurement is the answer!

- **Evaporated helium gas FLOW provides cavity dissipation information.**
  - **1 g/s = 22 watts**
- **Jlab tried to measure the evaporated helium gas flow – all failed - not enough signal.**
- JLab suggested the SBIR topic:
- **FY 2022 PHASE I RELEASE 1**
  - *Topic 34,*
  - *b. Design and Operation of Radio Frequency Beam Acceleration Systems,*
  - *3) devices and methods for accurate in-situ measurement of SRF cavity Q_0s.*

I was sucked into the Project

- Kevin Jordan and Michael Tiefenback of Jlab informed me of the Topic.
- Idea from a 2000 Japanese paper that used **superconducting** **vs.** **not superconducting** **as the detectable signal!**
- I made a **more robust and larger signal version at a higher superconducting temperature.**
- I was awarded the Phase I SBIR.

Making it Simple worked

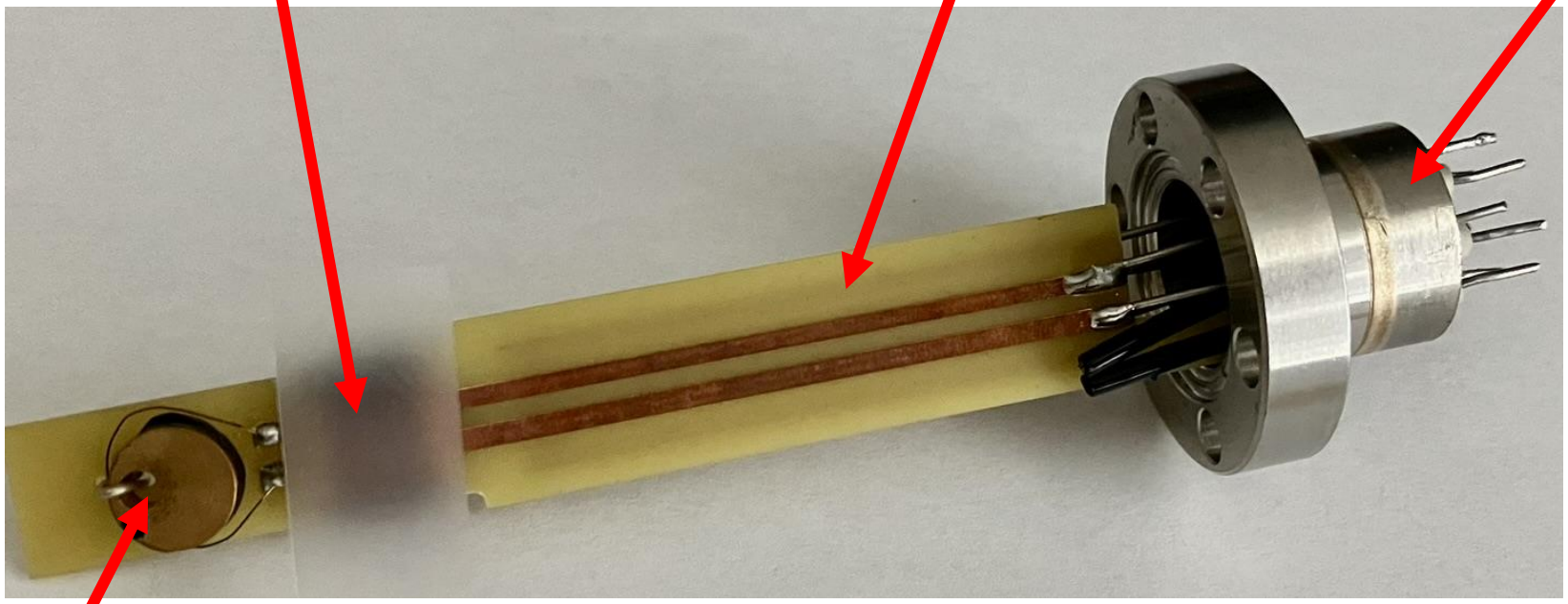
- I collaborated with Kevin Jordan (colleagues for 46 years) at Jefferson Lab via a CRADA.
- I believe in thinking "***how would an old-fart-farmer solve a problem***".
- I used some available materials.
- **Make it simple** – the **1st Try WORKED**.

The Flow Meter Instrument Head Assembly

Instrument Head (Blanked for proprietary reasons)

Custom PC Board

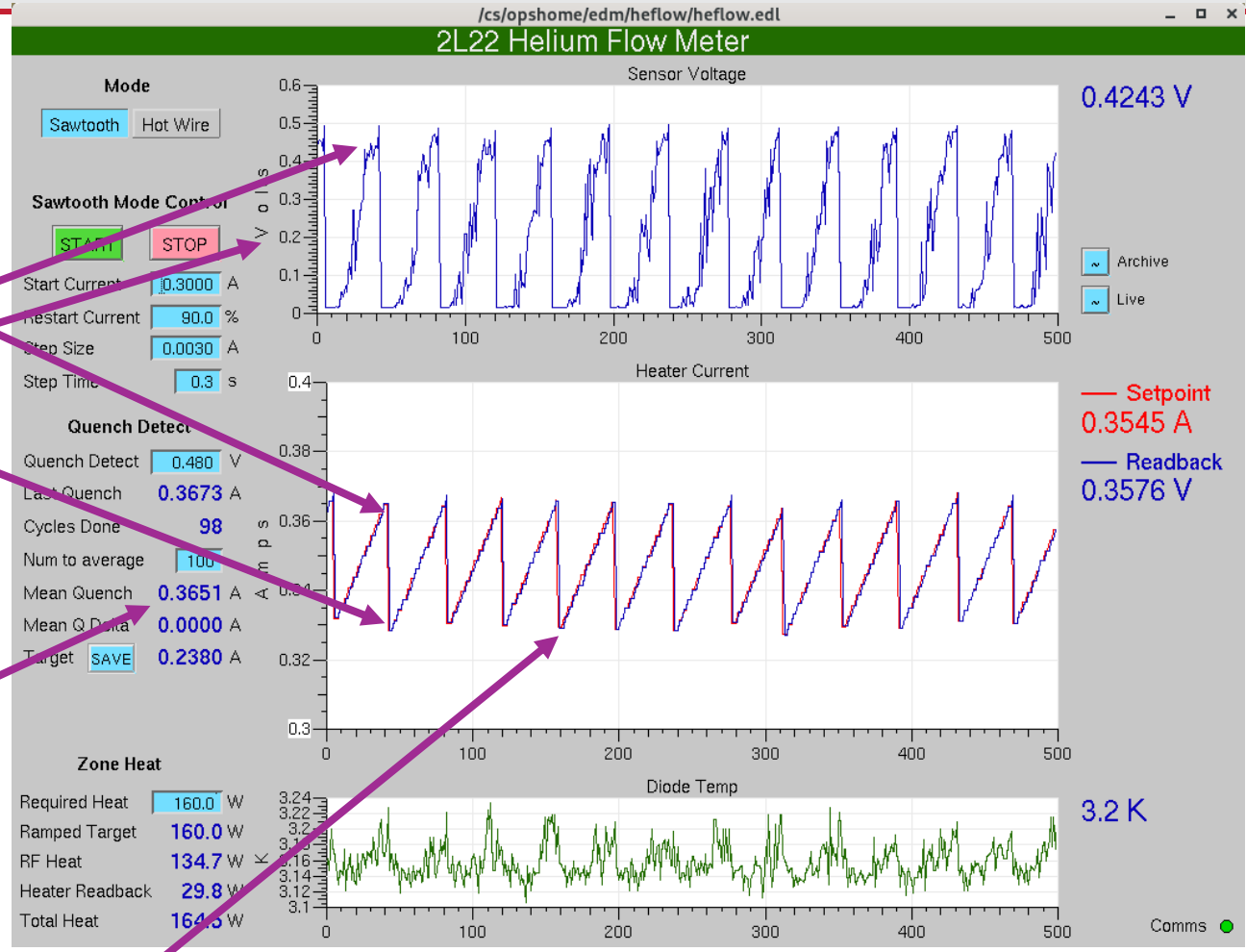
Mini CF, Cryo-Rated Feedthrough



Temperature Diode

How the Instrument Head Works

- The ***cooling*** from **helium flow** is bucked against the ***heat*** from a sawtooth pattern of **rising current** in a **resister wire**
- Software drops the current when non-superconducting state is detected in an adjacent superconducting wire.
- The superconductor element yields a large voltage signal when its temperature is high enough to go “normal” conducting.
- Digital electronics averages readings of the **Maximum Heater Current** at a **flow, while a cavity is at a gradient.**



Sawtooth heater current pattern

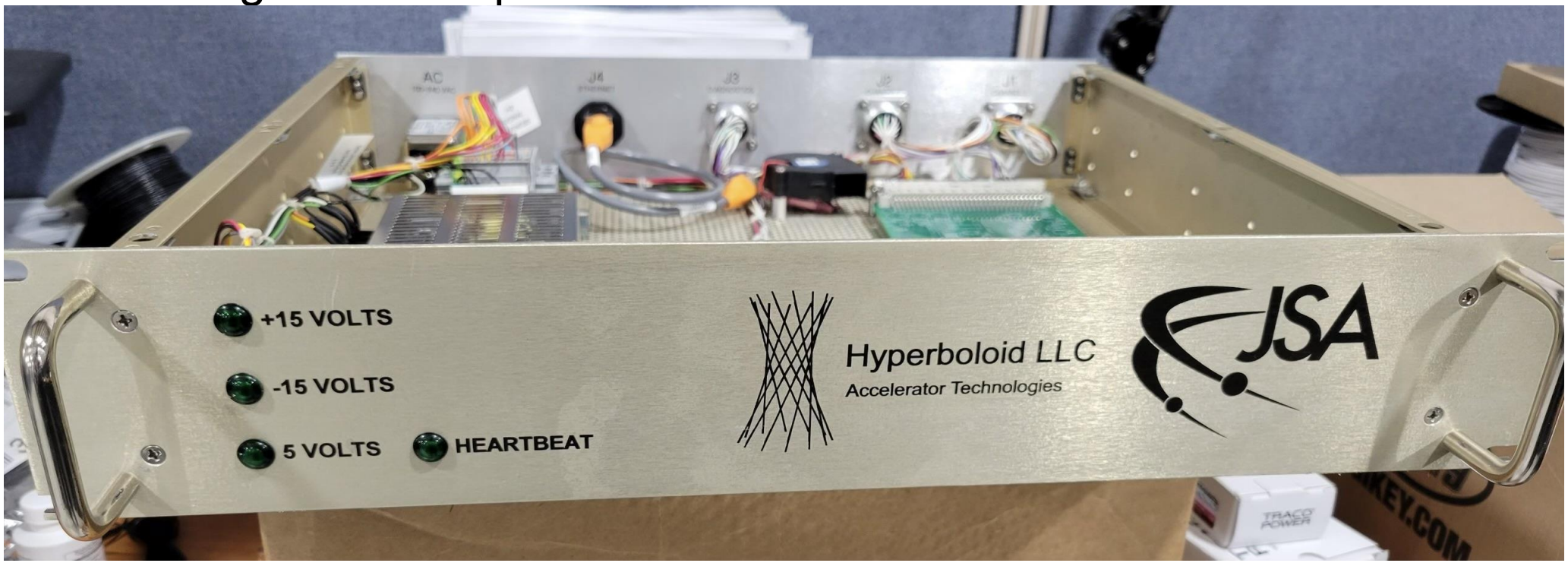
EPICS Screen

How the Instrument Head Works

- The **Cavity Dissipation in Watts** is found by turning off the **cavity** and hunting for what **power** from the Cryomodule's resister, in the bath, **matches the Cavity's Maximum Heater Current**. THAT IS THE READING!
- The Flowmeter is **contemporaneously calibrated** for every reading!
- The Flowmeter resolves **one Watt.**
- The Software Group fully integrated the Chassis signals into the EPICS, JLab's control system.

Electronics Chassis – built by local industry

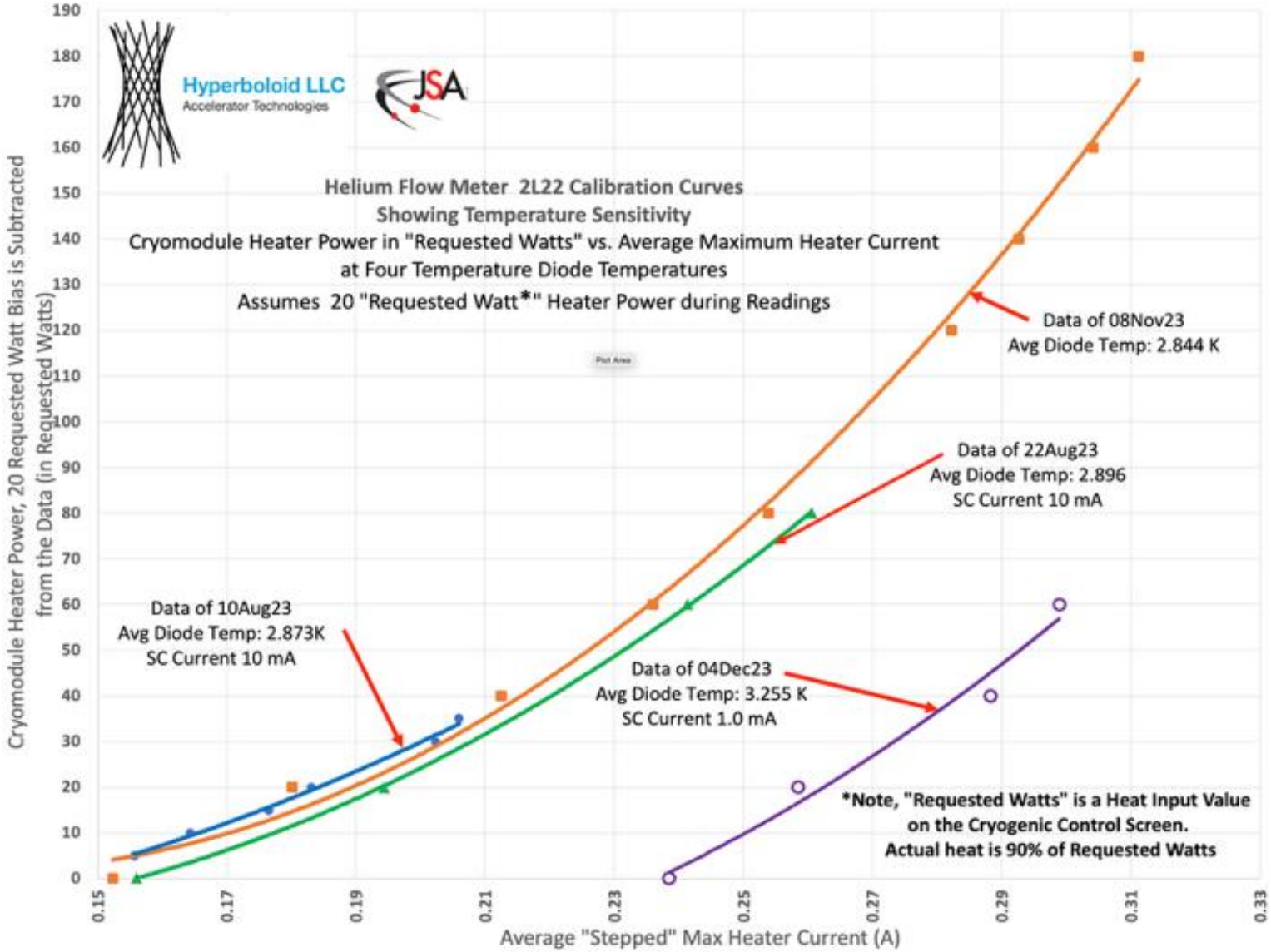
- Designed and prototyped by Kevin Jordan of JLab.
- A LabJack a-to-d, d-to-a unit interface to EPICS
- Custom PCB interfaces to the Instrument Head
- Chassis services 2 Instrument Heads
- All cabling is twisted pair



Hyperboloid received a Phase II on the initial success

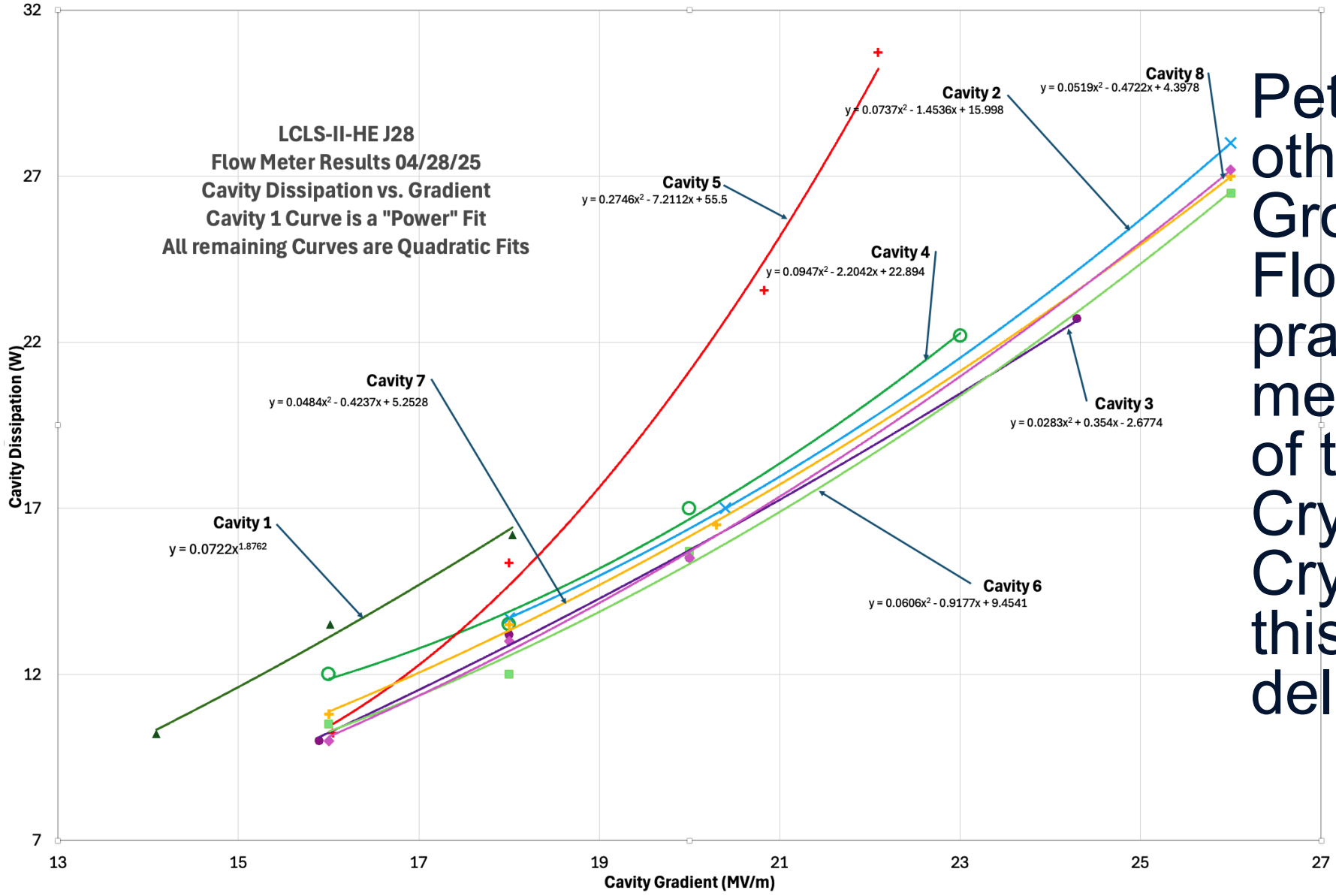
- Phase II plan was to install into CEBAF, **3** Flow Meters during the ‘23 Down Period and **2** during the ‘24 Down Period.
- **Instead,** because of ***less cost than estimated***, **we installed 1 in Phase 1 in ‘22! Then 11 in ’23 and 8 installations in ‘24 (**out of the 53 cryomodule positions).

Success in Phase II



Dakota Christian and Jerone Sameri, accelerator operators, Perfected **the software and procedures** to use the Flow Meter in CEBAF.

Success in Phase II – We fulfilled the TOPIC!

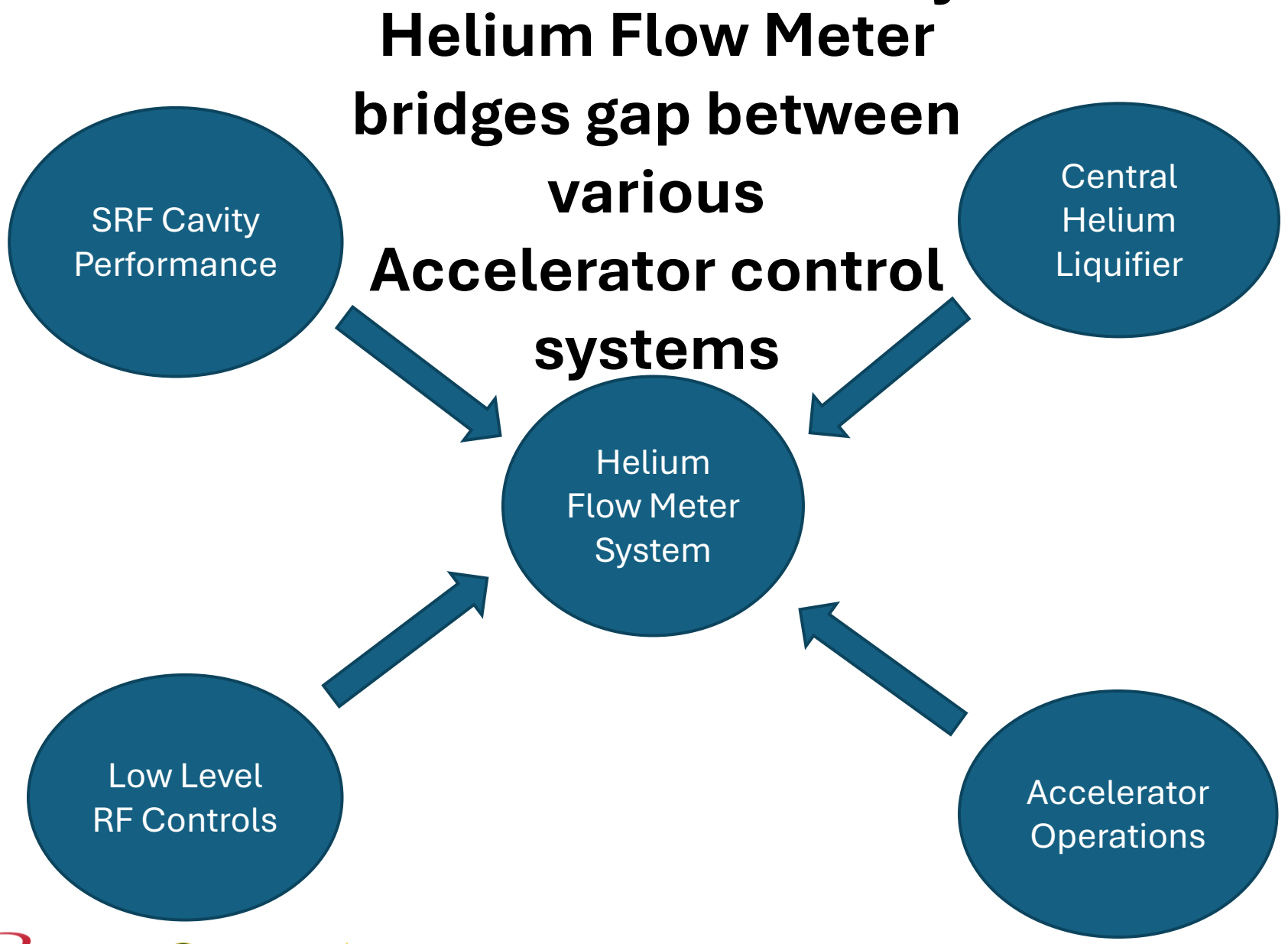


Peter Owen and others of the SRF Group used the Flowmeter as the only practical way to measure Q0s for tests of the LCLS-II-HE Cryomodules. 5 Cryomodules tested this way and delivered.

Problem in Phase II

- The “Supposed Superconductor” in Six Flowmeters installed in CEBAF indicated NOT SUPERCONDUCTING!
- Appears to be a short length in the middle of the first reel of material from the manufacturer
- A “Good” Instrument Head was substituted in one position and is now working.
- All remaining stock of Superconductor was Dewar tested at 4.2 K – it tested SUPERCONDUCTING.
- The extracted “bad” length tested as non-superconducting and was sent to the manufacturer for analysis – no feedback so far.
- Hyperboloid will provide substitute Instrument Heads to JLab as Warranty goods, 4 to be substituted in the next Down Period

Flowmeter Relevance to Nuclear Physics Accelerator



Follow-on to Success

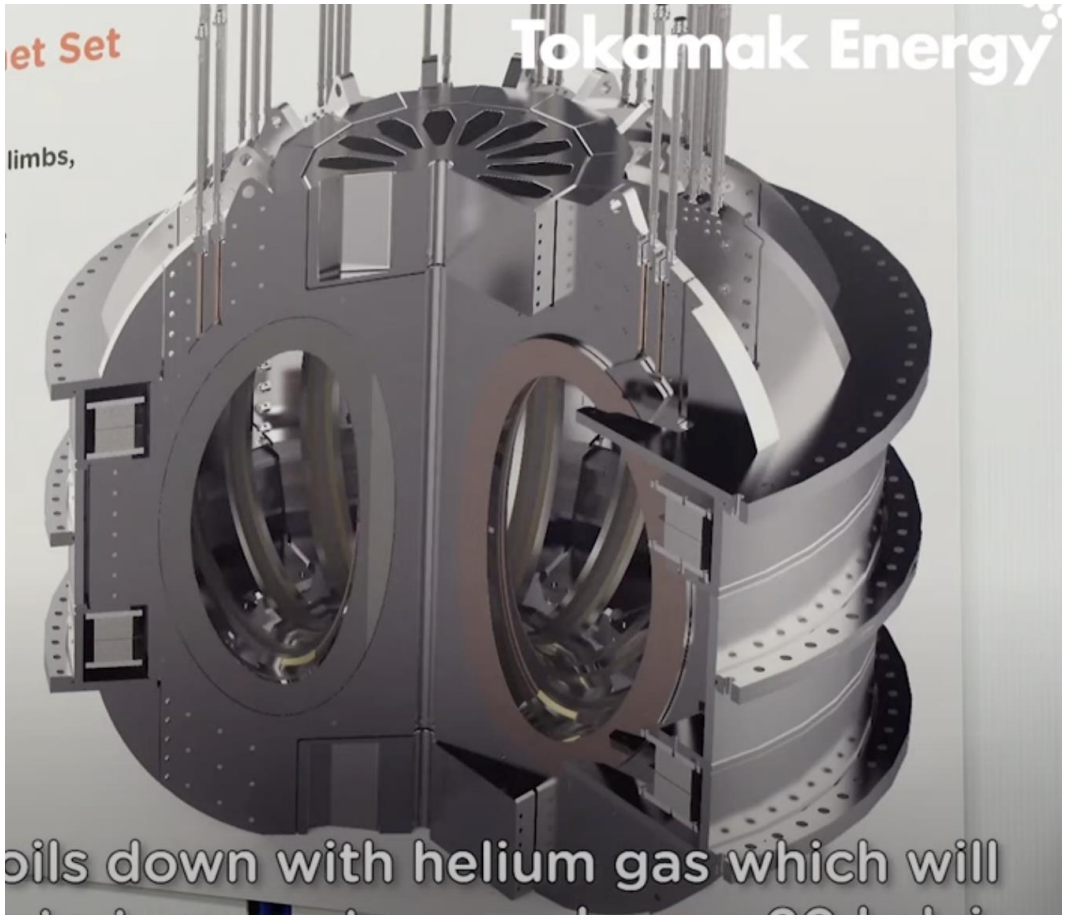
- Hyperboloid Sold 2 Flow Meters to the the SNS Project at Oak Ridge National Lab in May of ‘24. It works , but no results because of Software Folk are a scarce resource.
- **Hyperboloid LLC received a 9 month, no cost extension to Phase II**
- Jlab installed one Flowmeter in the Jlab UITF where a pair of Nb_3Sn SRF Cavities are being tested at 4.7 K – results are imminent.
  - **EPICS Screen shows that it works in this higher temperature He Bath.**
- **Jlab is asking for a ballpark price for filling the remaining, 30 cryomodule positions**
- Working to establish a CRADA with Fermilab to install one Flowmeter in their PIP-II Cryomodule Test Facility – **They asked for ballpark pricing for 21 units.**

Follow-on to Success

- Contacts with the EIC Project at Brookhaven say that they want one unit for their prototype (now delayed). **They will need 80 units if it works**.
- We are working on the LCLS-II-HE Project at SLAC & FRIB at Michigan State
- The European Spallation Source (ESS) expressed interest at a Control's Conference.
- xLight, a start-up company to make UV FELs for chip-making, wants a Flowmeter for the many cryomodules in their installations.

The Future – Develop the Flow Meter as a Quench Detector

- With a resolution of **1 Watt**, Helium Gas Flow Meter could be a **Quench Detector** for new Fusion Magnets that use High Temperature Superconductor.
- Prevents BURN OUT when a segment of the wire goes normal.
- DOE spent millions of dollars with no viable candidate validated.
- We are working on contacts with the National High Magnetic Field Lab



The Future – Develop the Cryogenic Hydrogen Gas Flow Meter

- Modify a small segment of HTS (High Temperature Superconductor) Tape
- Not in SBIR scope
- Development requires:
  - Material **deposition facilities**
  - **Testing facility** (Hydrogen Hub)
  - **Collaboration** with professionals in these disciplines.
  - **Funding**

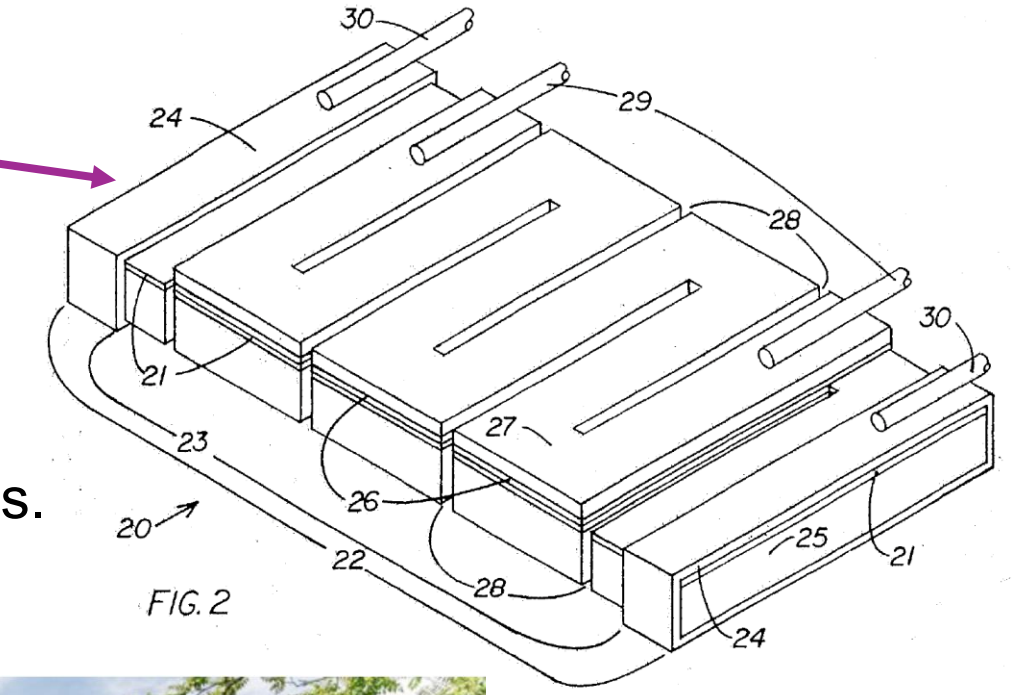
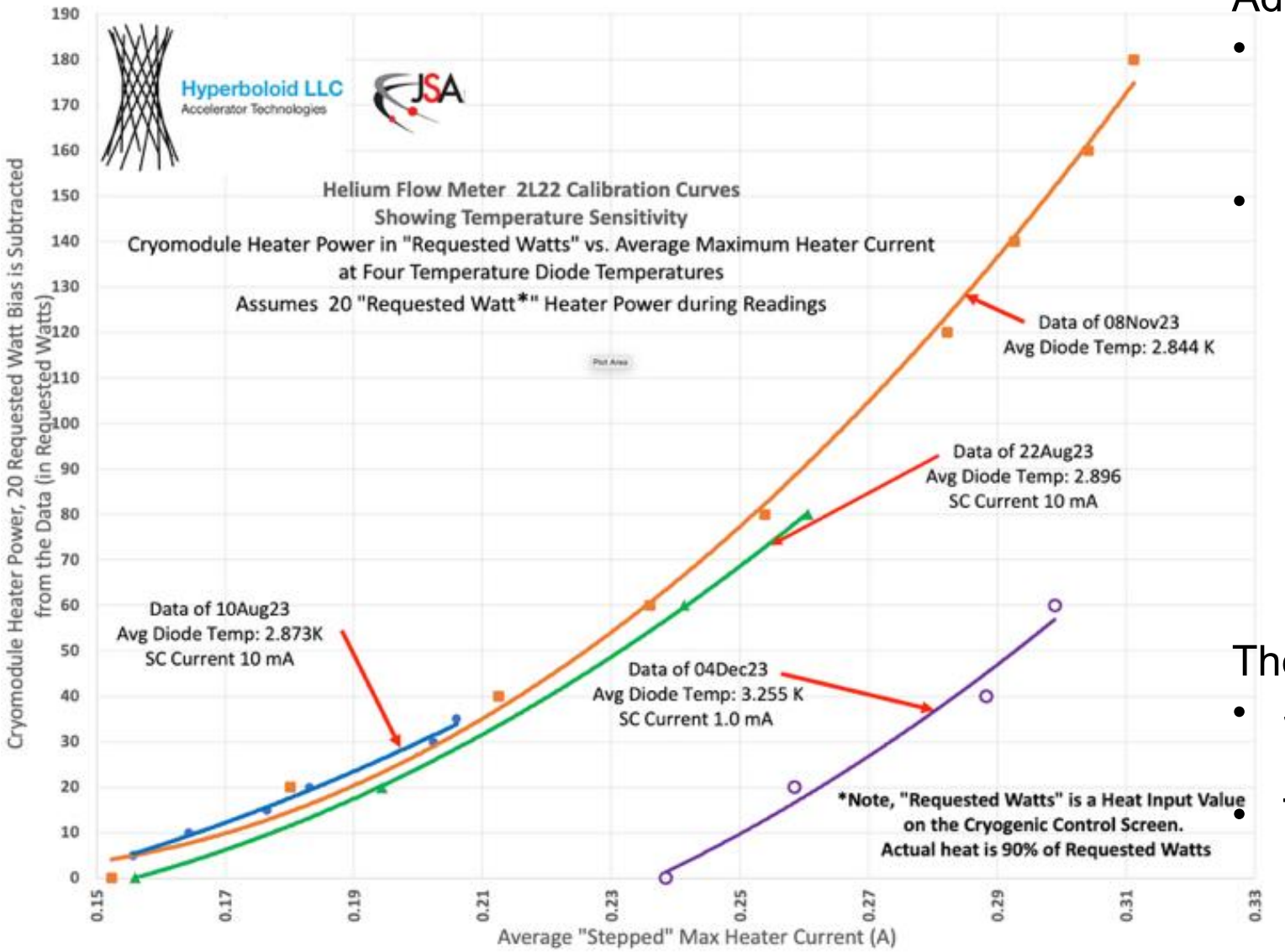


FIG. 2

Concluding Remarks - Converting to Selling Mode

- A **Patent** for the Flow Meter and its future upgrades **is applied for** in both Hyperboloid's name and Jlab as co-inventors.
- This is a **Sustainable Business for a Retiree**
  - I can personally make the Instrument Heads for the small quantities of this niche market, < 200 over several years.
  - Electronics manufacturing is off-loaded.
  - Software adaptation is the customer's responsibility.
- **BUT** – Succession is important for the Physics Community. I have to make **availability** sustainable:
  - 1st, off-load the winding of the Instrument Head, I have a price from one coil winder
  - License to an Instrument Company.
- Pricing: Price the Meter as if the Instrument Company is already making and selling it.

Helium Flowmeter – Additional Advantages, Range and Temperature Sensitivity



Advantages:

- The helium flow system does not require accelerator access & can be used parasitically.
- During CEBAF operations the system can monitor the *health* of a cryomodule
  - By scanning the installed sensors the system can determine if the losses increase in a give CM – ie field emitter turning on or insulating vacuum deteriorating.
  - When the beam is off, the Q_0 of individual cavities can be determined.

These Calibration Curves show:

- Sensitivity Range of the Flow Meter:
  - 5 W to 200 W.
- Temperature Sensitivity of the Flow Meter:
  - 180W/K

Back-up #1 U-Tubes – Connection between Cryo-module (CM) & Helium Transfer-line

- There are 53 Cryomodules (CM) 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