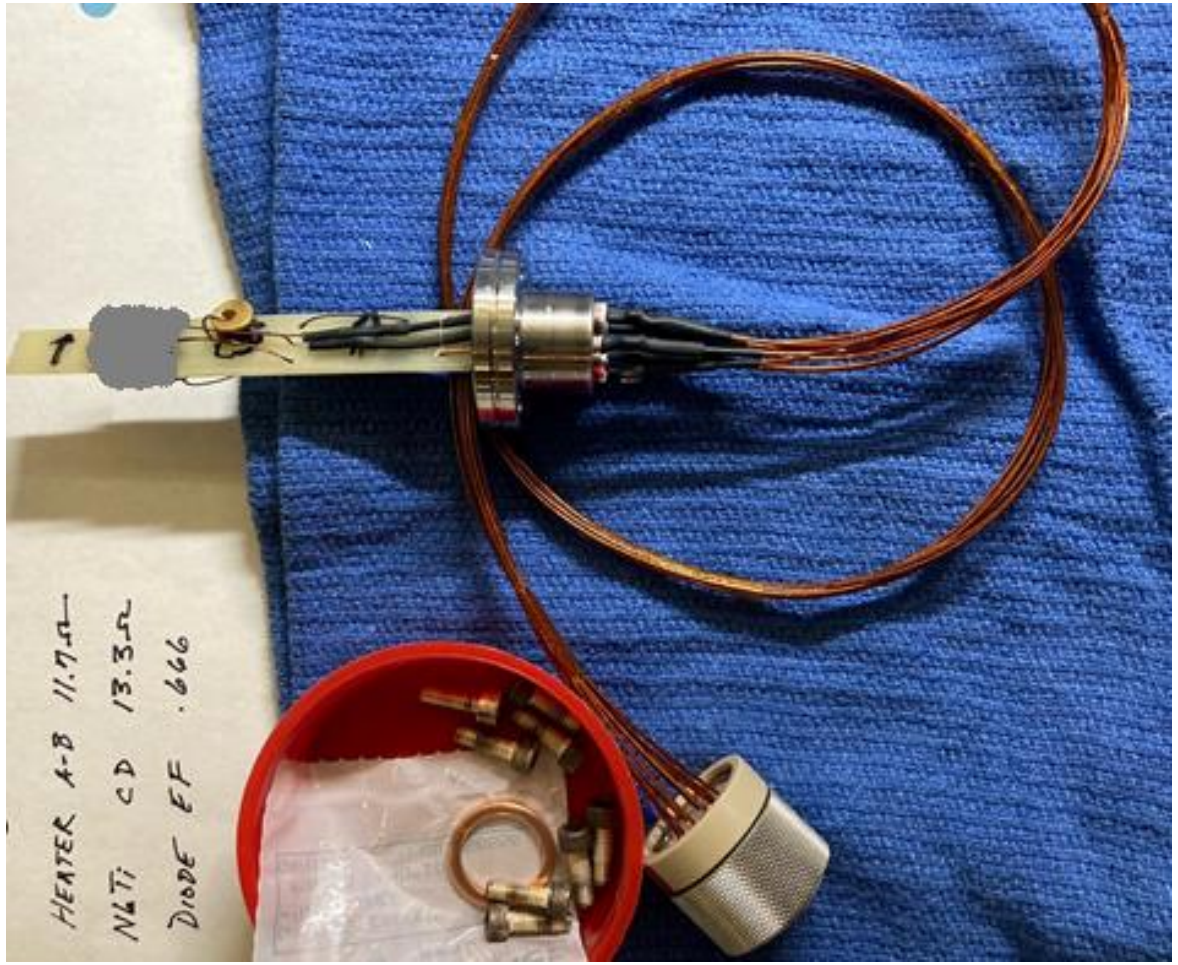
Helium Flow Meter

- 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.**

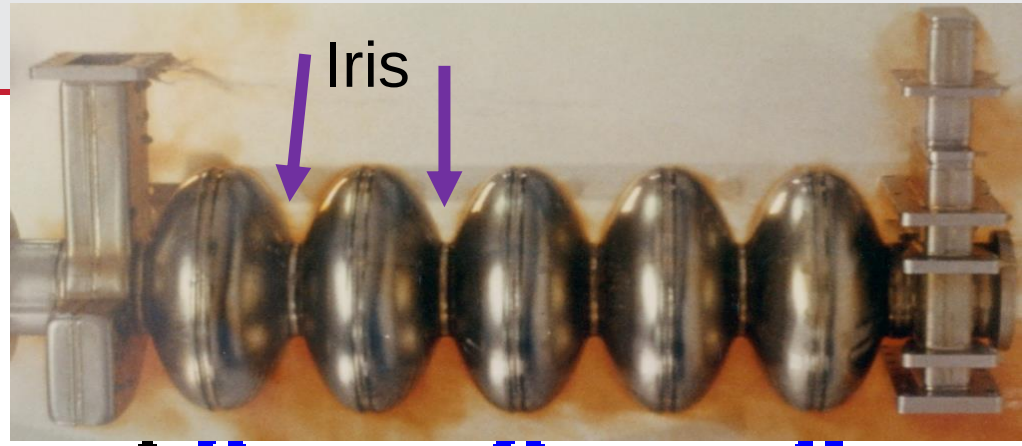
Meet Hyperboloid LLC

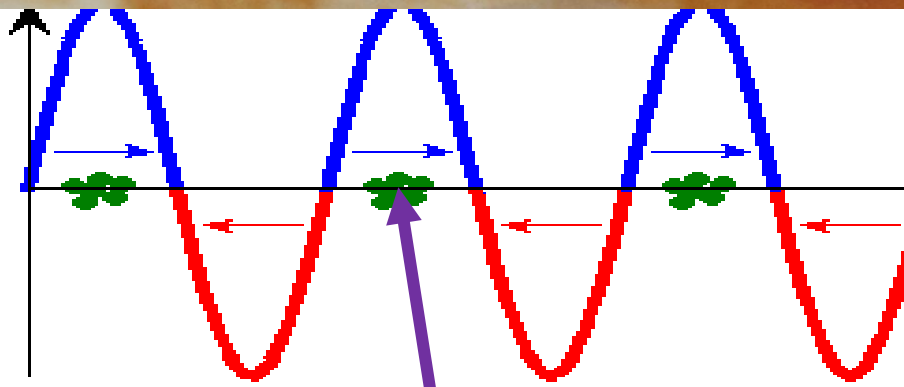
- **I had additional Jlab collaboration experience**!
  - I was the engineer for BNNT LLC for their Phase II and IIA SBIR, in collaboration with Jlab, that uses Boron Nitride Nano Tubes to increase accelerator reliability.

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

Tutorial - SRF Cavities and Q_0

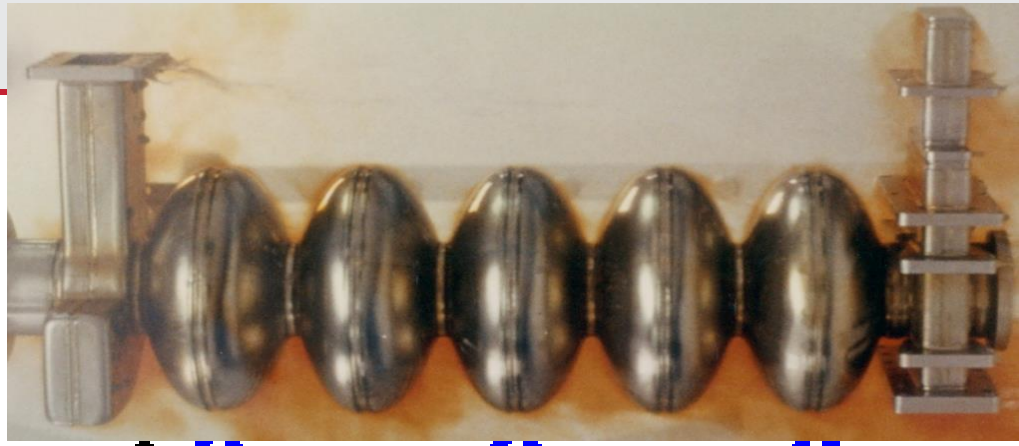
- Radio Frequency Cavities are used to accelerate charged particles in a Linear Accelerators – used since 1945.
- Radio Frequency (RF) –microwave- Power is piped into the cavity and the dimensions of the cavity are resonant at 1.5 GHz (at Jlab) – like the hot nodes in your microwave oven.
- Huge currents 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**.





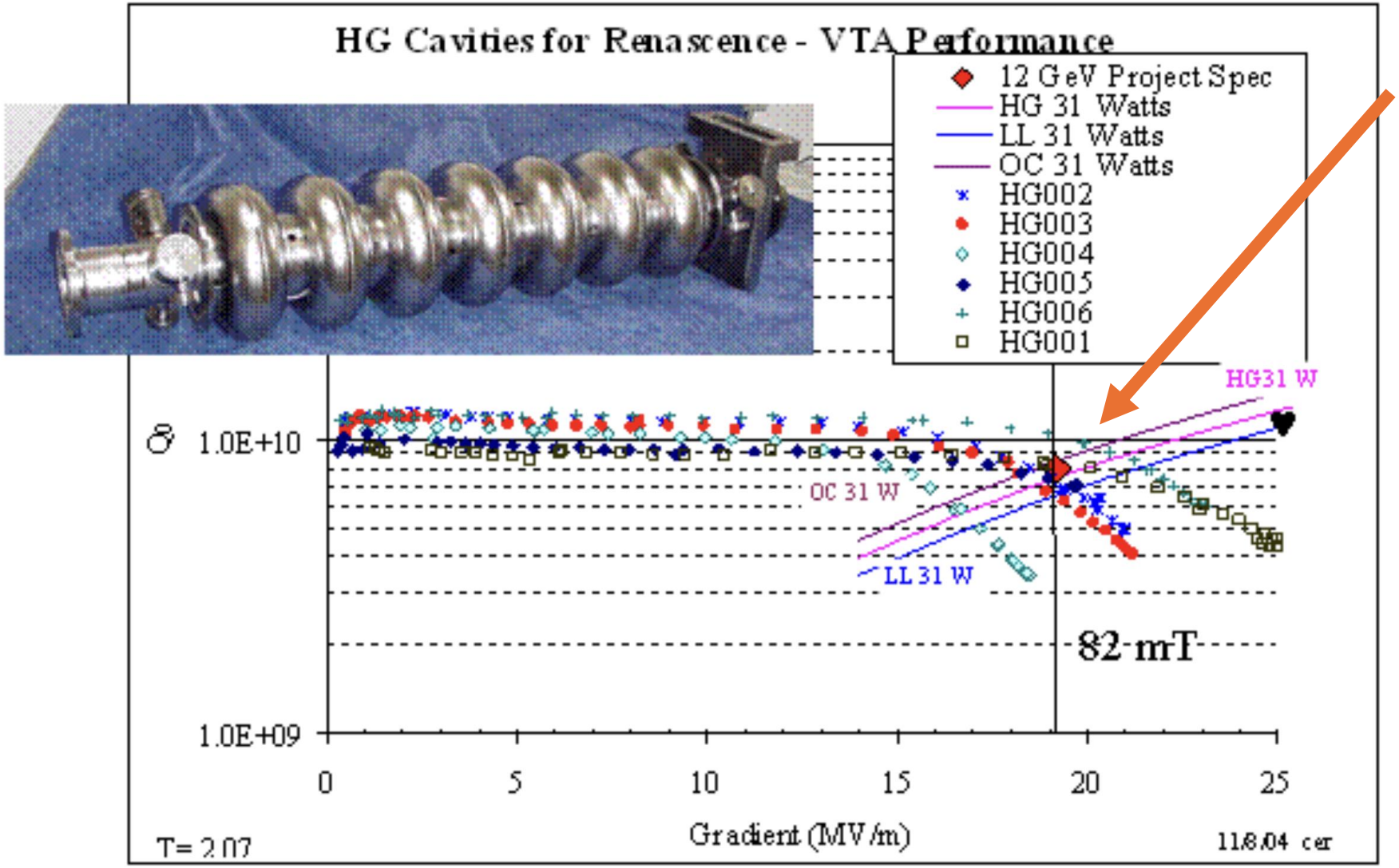
Green particles accelerated by the blue phase of the voltage

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 - 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

- Once installed in a Cryomodule, there **was** no **good** way to non-invasively determine how much power dissipation from a cavity 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 the answer?

- **Evaporated helium gas FLOW could provide cavity dissipation information.**
  - **1 g/s = 22 watts**
- **Jlab tried to measure the evaporated helium gas flow from a cryomodule** several times with home-made as well as commercially available flow meters – 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.*

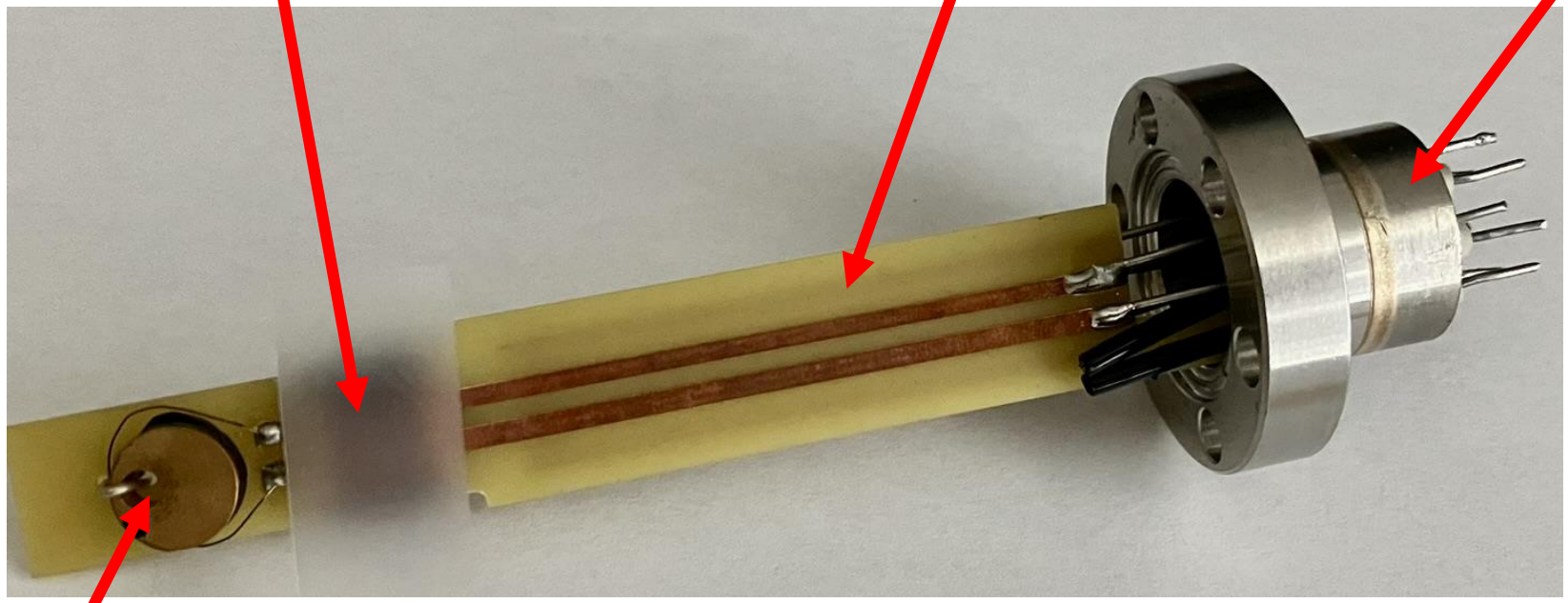
I was sucked into the Project

- Kevin Jordan and Michael Tiefenback of Jlab informed me of the Topic.
- They sent me a paper showing that H. Okubo et. al. in Japan, in 2000, made a superconducting “hot wire” anemometer with a usable signal - using **superconducting or not superconducting!**
  - Very fragile, very low signal, limited temperature range - **but better than what was available.**
- I bet that I could make a **more robust and larger signal version**.
- I applied for, and was awarded the Phase I SBIR.

Making it Simple worked

- I was confident that I could do it in collaboration with my PI at Jefferson Lab
  - Kevin Jordan - a man who is a force of nature in making anything – worked with him for over 45 years.
- I believe in thinking "***how would an old-fart-farmer solve a problem***".
- **Make it simple** – the **1st Try WORKED**.
- I used some available materials.

The Flow Meter Instrument Head Assembly

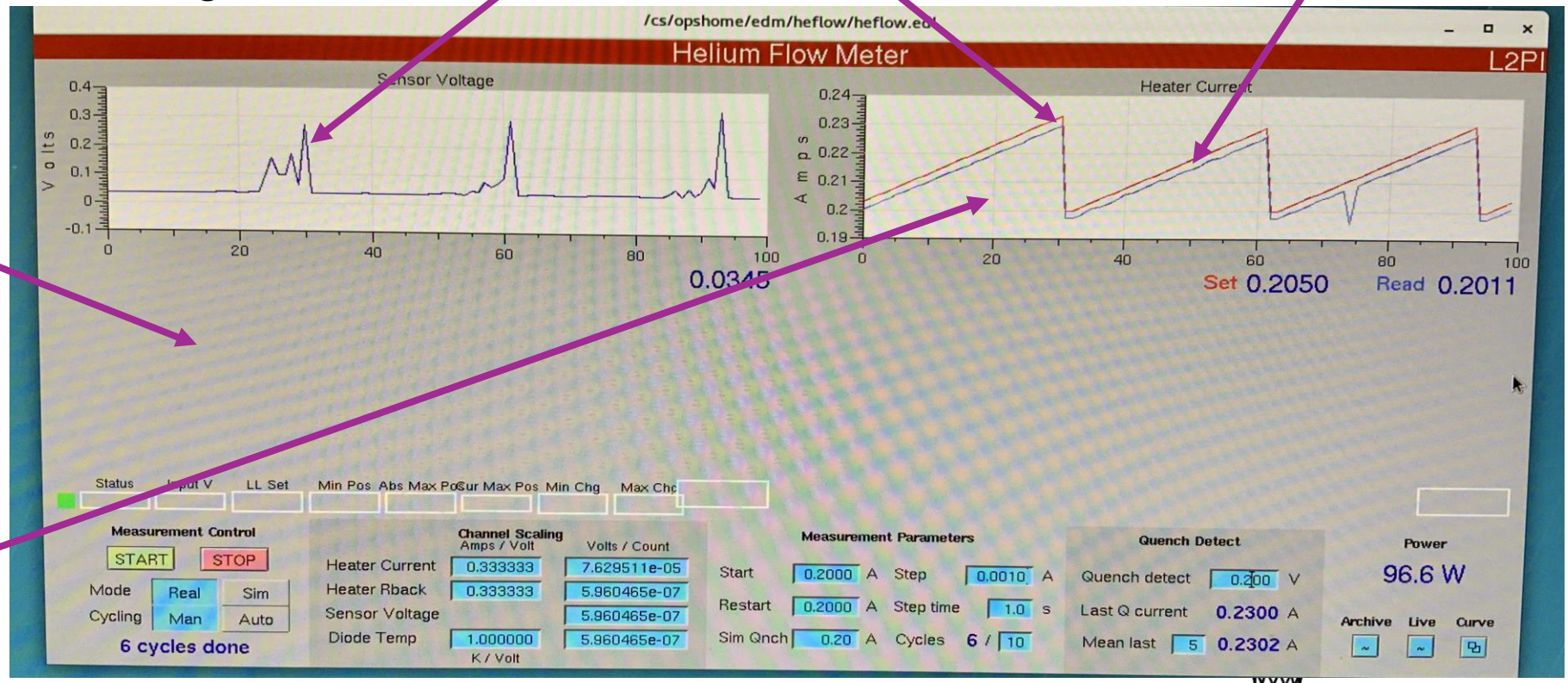


How the Instrument Head Works

- The ***cooling*** from **helium flow** is bucked against the ***heat*** from a sawtooth pattern of **rising current** in the **resister wire –** current drops when superconducting state is detected.
- The superconductor element yields a large resistance 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.**

EPICS Screen

Sawtooth heater current pattern

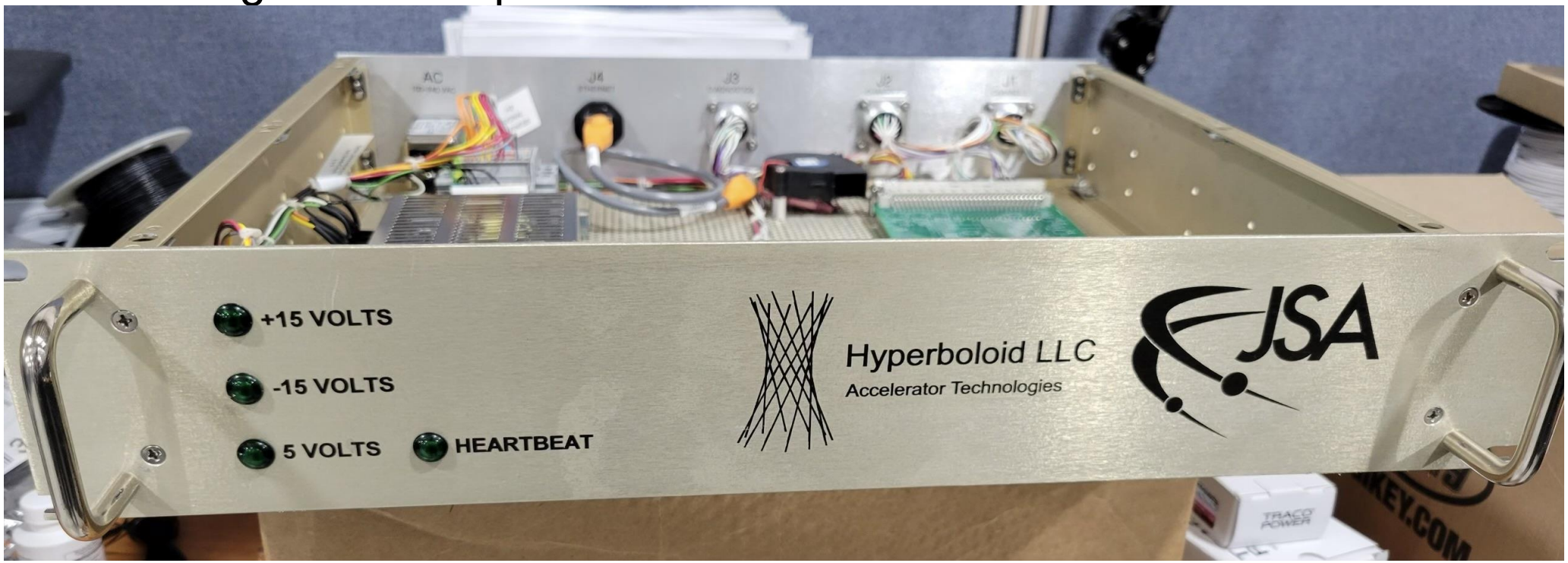


How the Instrument Head Works

- The **Cavity Dissipation in Watts** is found by turning off the **cavity** and finding what power generated in a Cryomodule's resister, in the bath, **matches the Cavity's Maximum Heater Current**.
- Fortunately, the Cryomodule's resistors in the bath can be used for this contemporary calibration!
- The Flow Meter 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 JJab.
- An 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



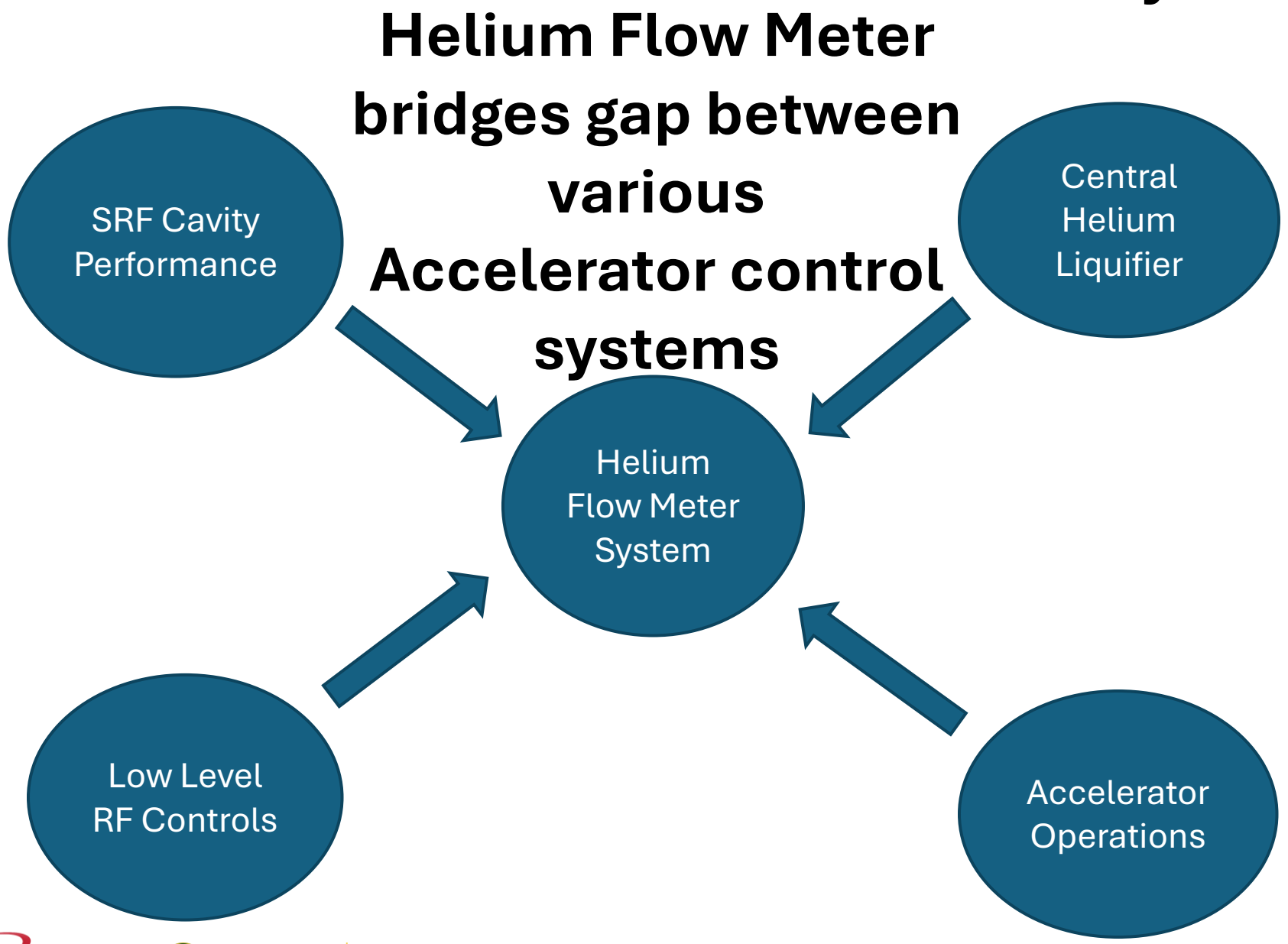
Phase II Plan

- 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 11 in ’23 and will support 14 installations this year (**out of the 53 cryomodule positions).

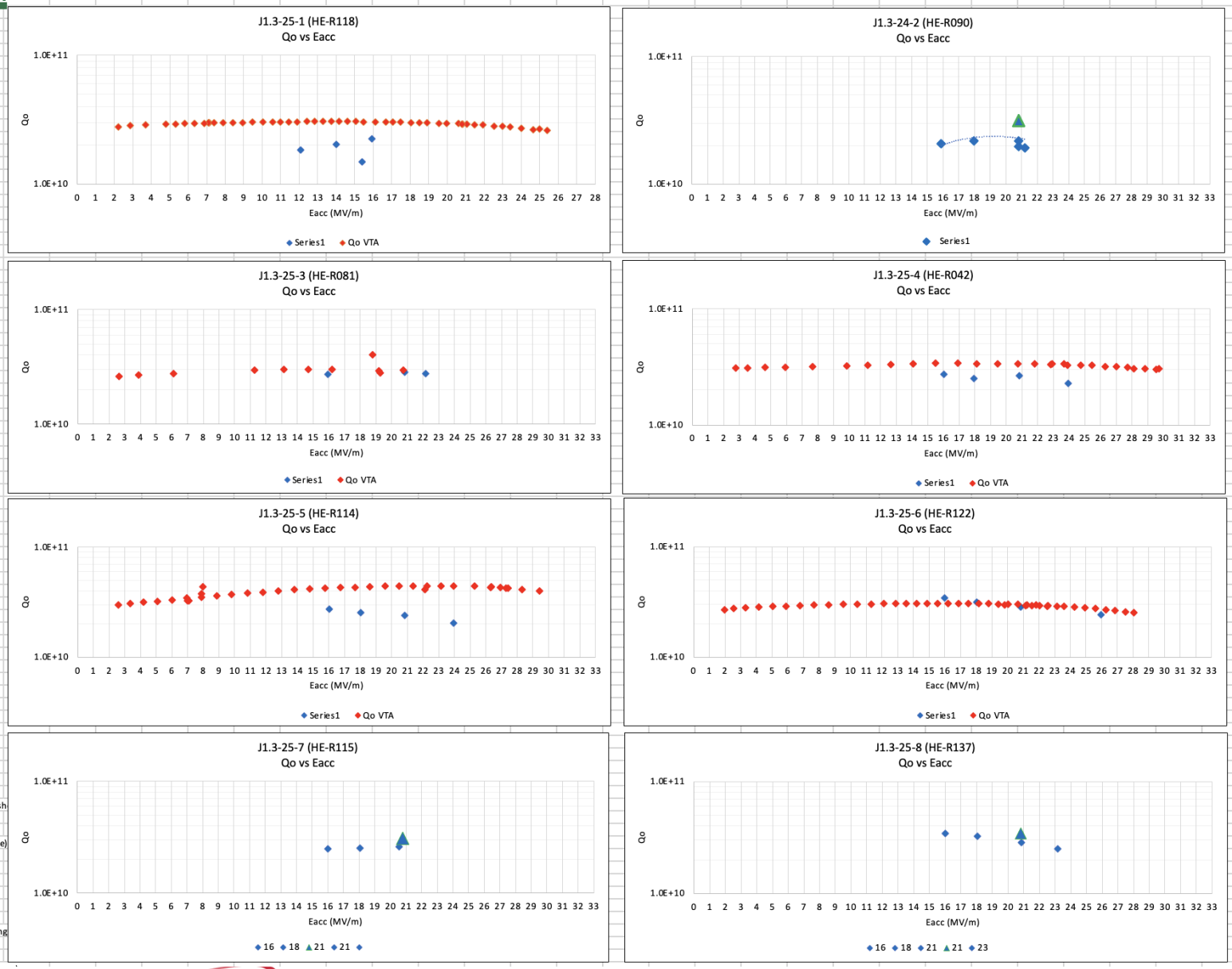
Phase II Plan

- Remaining Task - **Perfect the software and procedures** to use the Flow Meter.
  - **Michael Tiefenback**, a senior researcher in CASA (Center for Advanced Study of Accelerators) – a 28-year advocate for the meter - and **Dakota Christian**, an accelerator operator **are developing the procedures** for using the meter and incorporating the knowledge gained into **accelerator operation**.
  - **Gary Croke** of the Software Group is implementing **the EPICS Control System and its screens**.

Phase II Plan and Relevance to Nuclear Physics



Phase II Plan and Relevance to Nuclear Physics – 1st USE



Used during qualification tests for a Cryomodule for the LCLS-II-HE

- The graphs show the Cavity **Vertical Test's Q_0** (Red points and Green Triangles) vs. the **Q_0 results from the Flow Meter** (Blue points).
- The Blue Q_0 Points **coincide with the Vertical Test points for Cavities 3 & 6** . This coincidence **proves the accuracy of the Flow Meter.** Blue Points on all other graphs fall below the JLab or Fermilab Vertical Test Points.
- **Lower Q_0 is probably an indication of cavity degradation as a result of the assembly process.**

Phase II Plan and Relevance to Nuclear Physics

- **Commercialize** the Flow Meter to other SRF Labs
  - Hyperboloid **Sold 2 Flow Meters** to the the SNS Project at Oak Ridge National Lab in May – ½ way through Phase II – **They said they "needed" it**.
  - Contacts with the EIC Project at Brookhaven say that **they want one unit** for their prototype, and if it works, **they want 80!**
  - The LCLS-II-HE Project at SLAC & FRIB at Michigan State are interested.
  - The European Spallation Source (ESS) expressed interest at a Control's Conference.
  - After Phase II, sell Flow Meters to JLab to complete their System - 28 more positions to fill.

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**

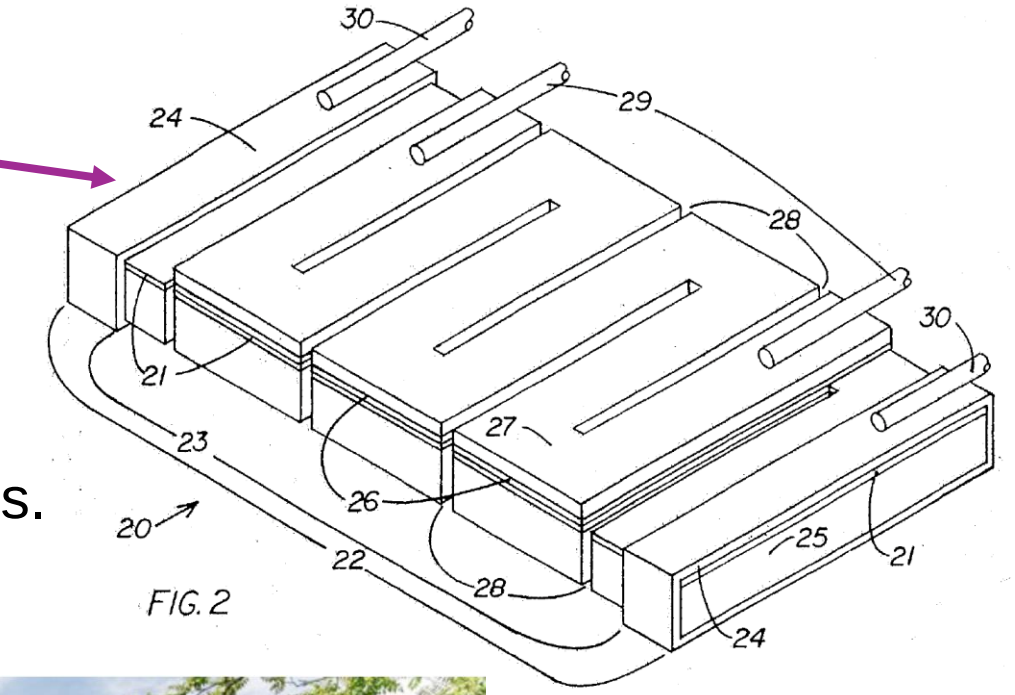
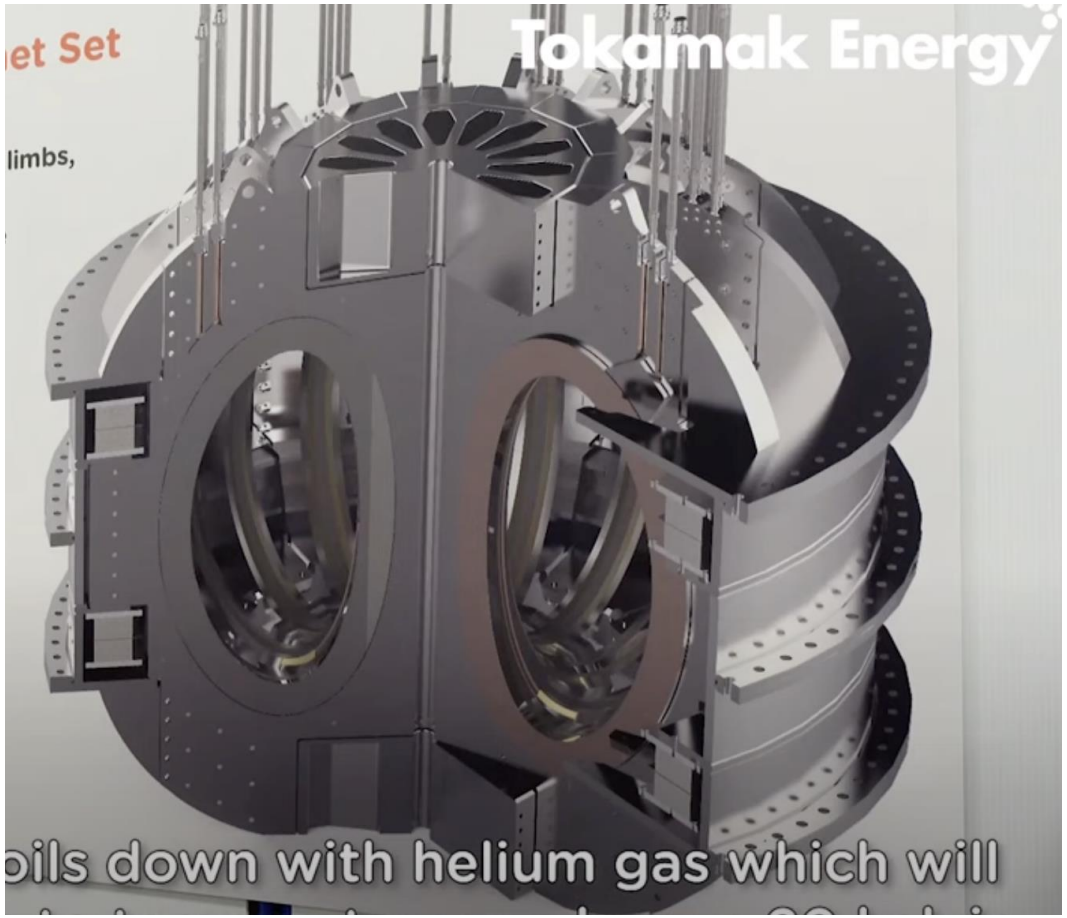


FIG. 2

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.

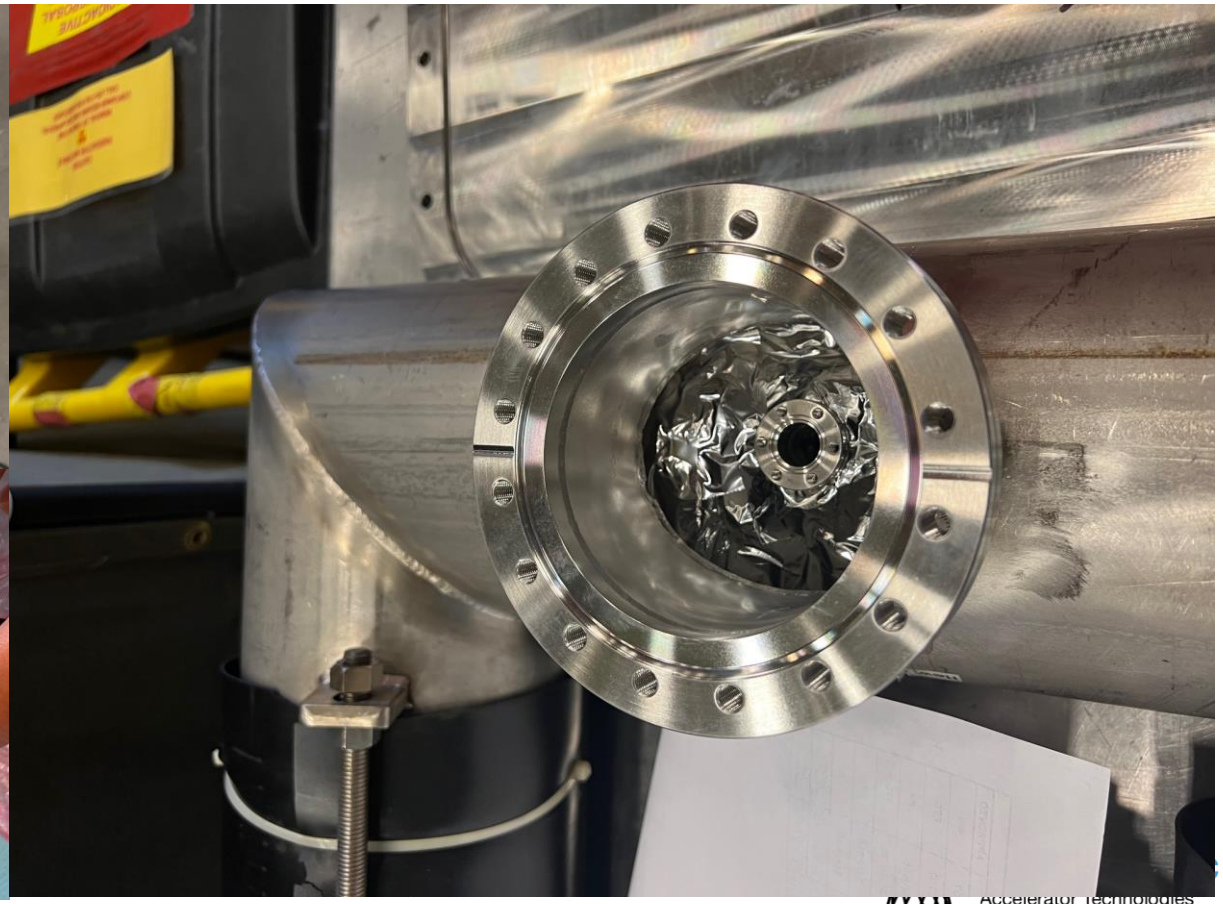


Concluding Remarks - Convert to Selling Mode

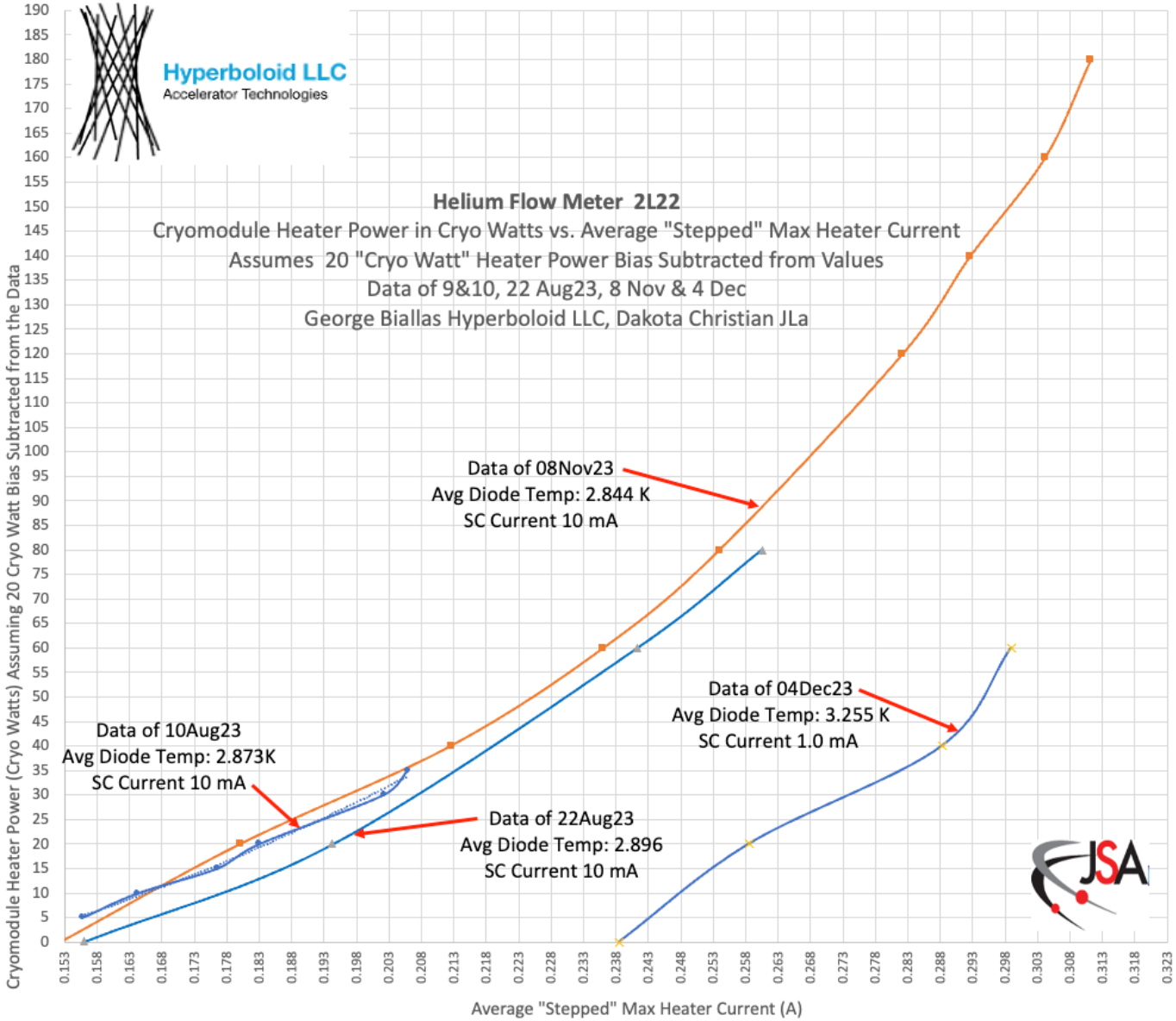
- A **Patent** for the Flow Meter and its future upgrades **is applied for** in both Hyperboloid's name and Jlab as co-inventors.
- This is a **Sustainable Business for a Retiree**
  - I can personally make the Instrument Heads for the small quantities of this niche market, < 200 over several years.
  - 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,
  - License to an Instrument Company asap.
- Pricing: Price the Meter as if the Instrument Company is already making and selling it.

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



Back-up #2 Helium Flow Meter – 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.

Calibration Curves show:

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