Achieving High Peak Fields and Low Residual Resistance in Half-Wave Cavities

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On Behalf of The Physics Division-Linac Development Group

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Acknowledgements

- **Argonne National Laboratory Personnel:**
  - **P. Ostroumov, M. Kelly, Z. Conway, S. Gerbick, B. Guilfolye, C. Hopper, M. Kedzie, S.H. Kim and T. Reid.**

- **Many Vendors:**
  - **Advanced Energy Systems, NY.**
  - **Adron EDM, WI.**
  - **Numerical Precision, IL.**
  - **Meyer Tool and Manufacturing, IL.**

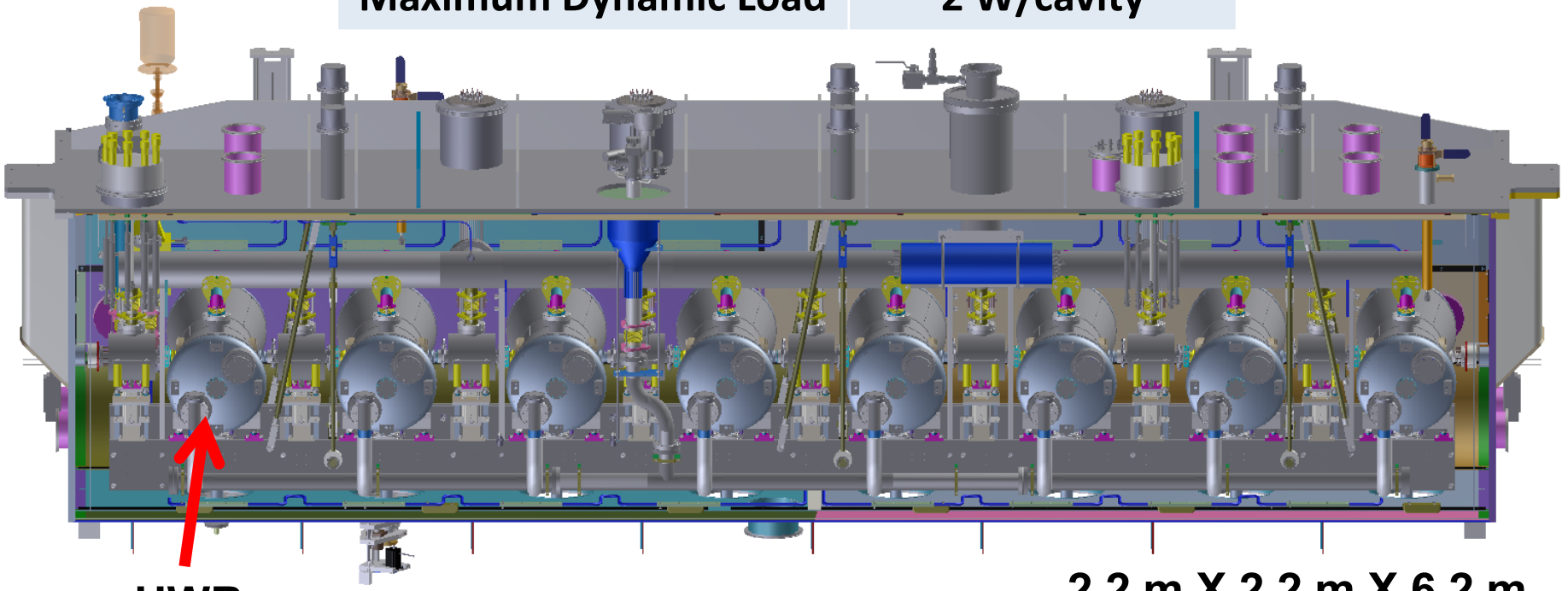
162.5 MHz β = 0.11 Half-Wave Resonator (HWR)

48” (122cm)

HWR Cryomodule for PIP-II

A new half-wave resonator (HWR) cryomodule for FNAL's PIP-II project.

Half-Wave Resonator	Requirement
Operating Voltage	2 MV/cavity
Operating Temperature	2.0 K
Maximum Dynamic Load	2 W/cavity



2.2 m X 2.2 m X 6.2 m

V. Yakovlev, TUAA05

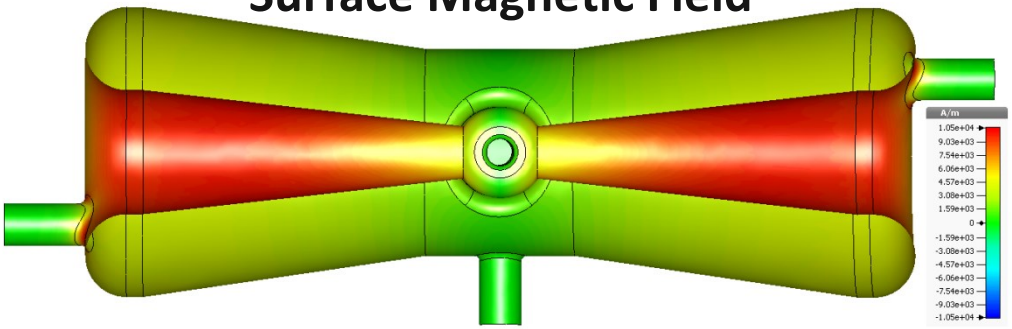
What goes into a half-wave cavity?

- The complex cavity system:
  - Beam physics design.
  - RF Performance.
  - Fabrication.
  - Polishing.
  - Cleaning.
  - Assembly.
  - Safety standards.

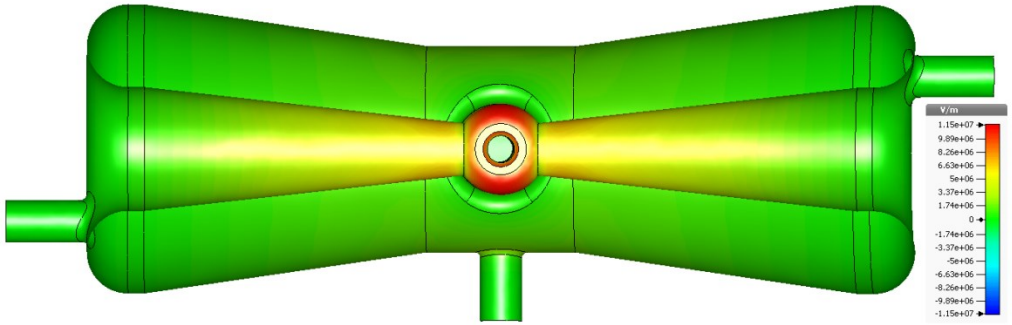
- RF Performance:
  - Maximize voltage gain.
  - Low cryogenic load.
  - Low peak surface fields.
  - Design supports fabrication, processing and cleaning.

Cavity Type	HWR
Freq. (MHz)	162.5
β	0.112
l_{eff} (cm, $\beta\lambda$)	20.68
E_{pk}/E_{acc}	4.7
B_{pk}/E_{acc} (mT/(MV/m))	5.0
QR_s (Ω)	48.1
R_{sh}/Q (Ω)	272

Surface Magnetic Field



Surface Electric Field



Fabrication

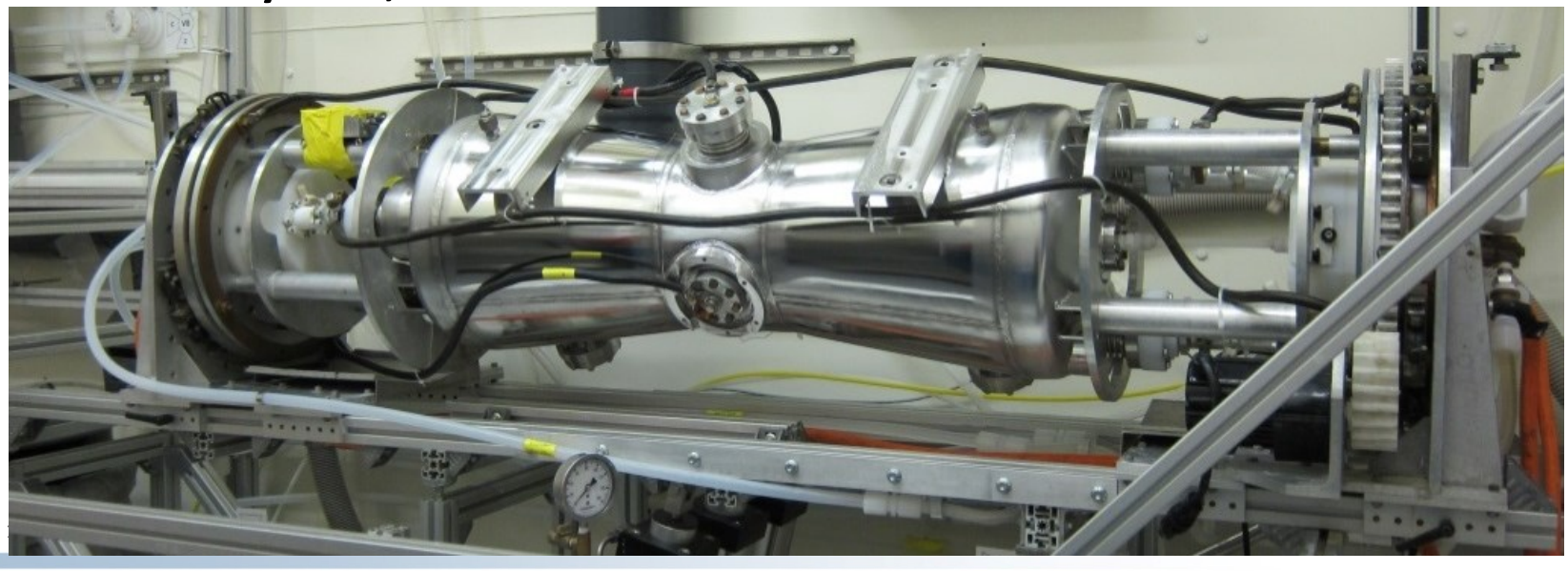
- Cavities are built largely in house with critical vendors.
- ANL does intermediate QA.
- EDM.
- Keyhole EB welding in all high-field regions.
- Significant hand polishing.

Electrostatic Discharge Machining

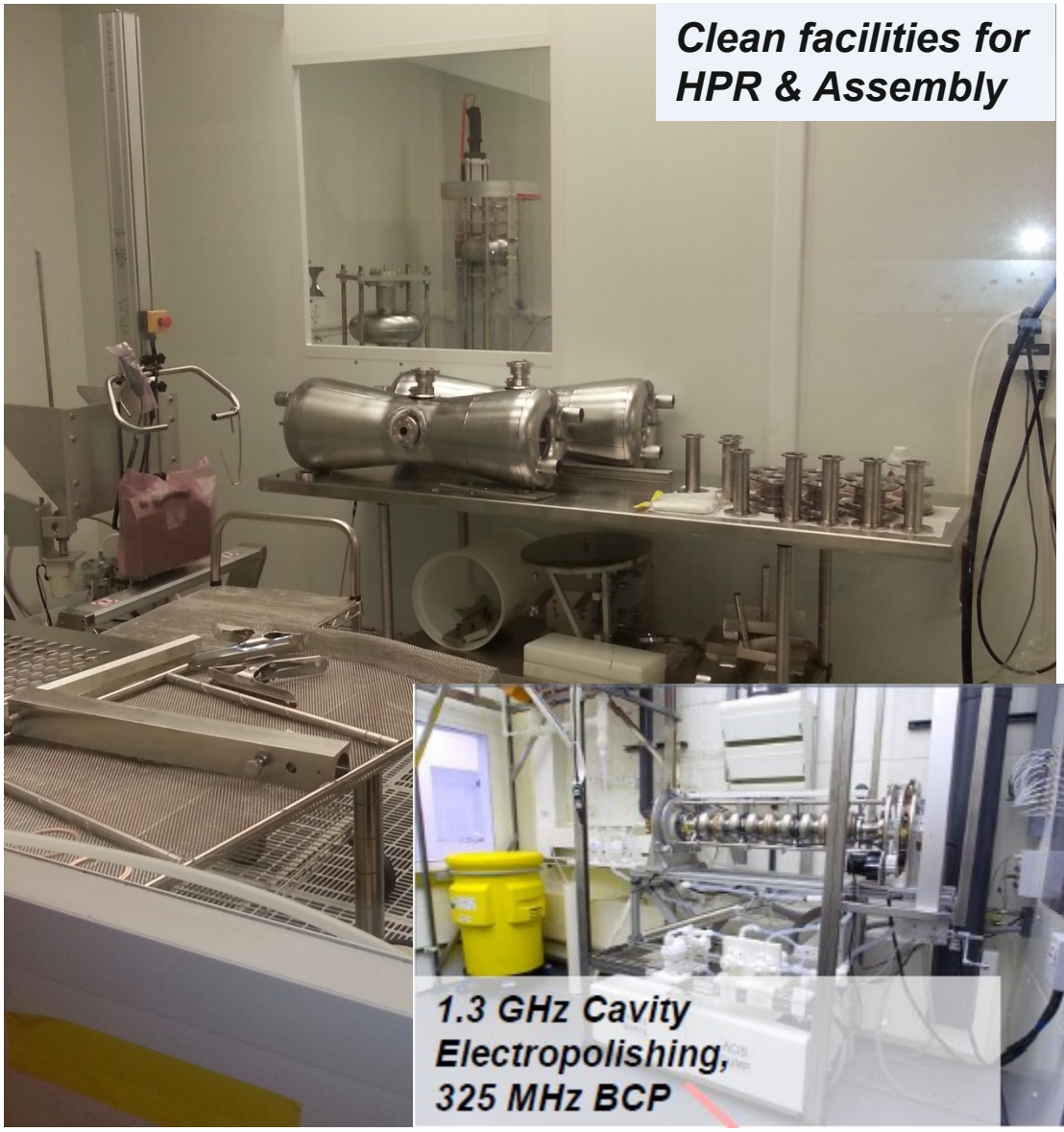
Keyhole Electron Beam Welding in High Field Regions

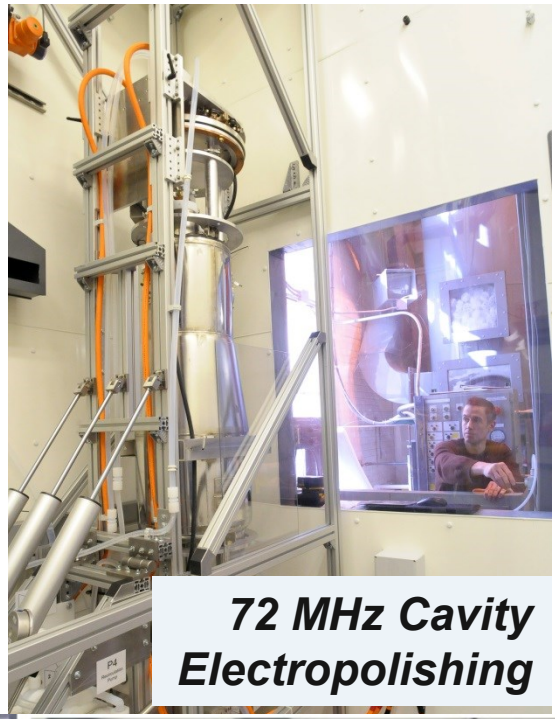
Cavity Polishing and Processing

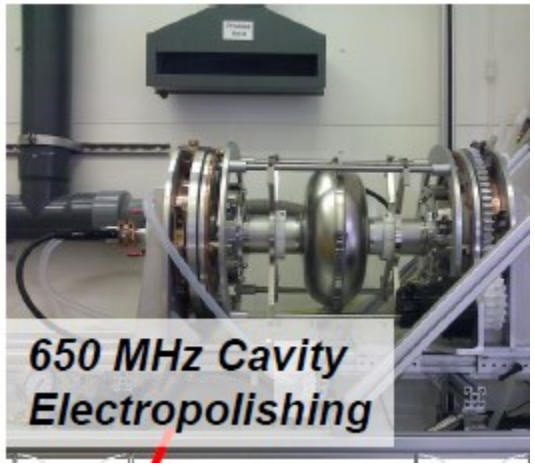
- All polishing is done after fabrication is finished.
- Cooling water flow through space between helium jacket and Nb cavity.
- Unique Argonne Low-Beta Cavity EP Tool.
  - S.M. Gerbick et al, SRF'11.
  - M.P. Kelly et al, SRF'11.
- Successful many times with QWRs:
  - M.P. Kelly et al, SRF'13.



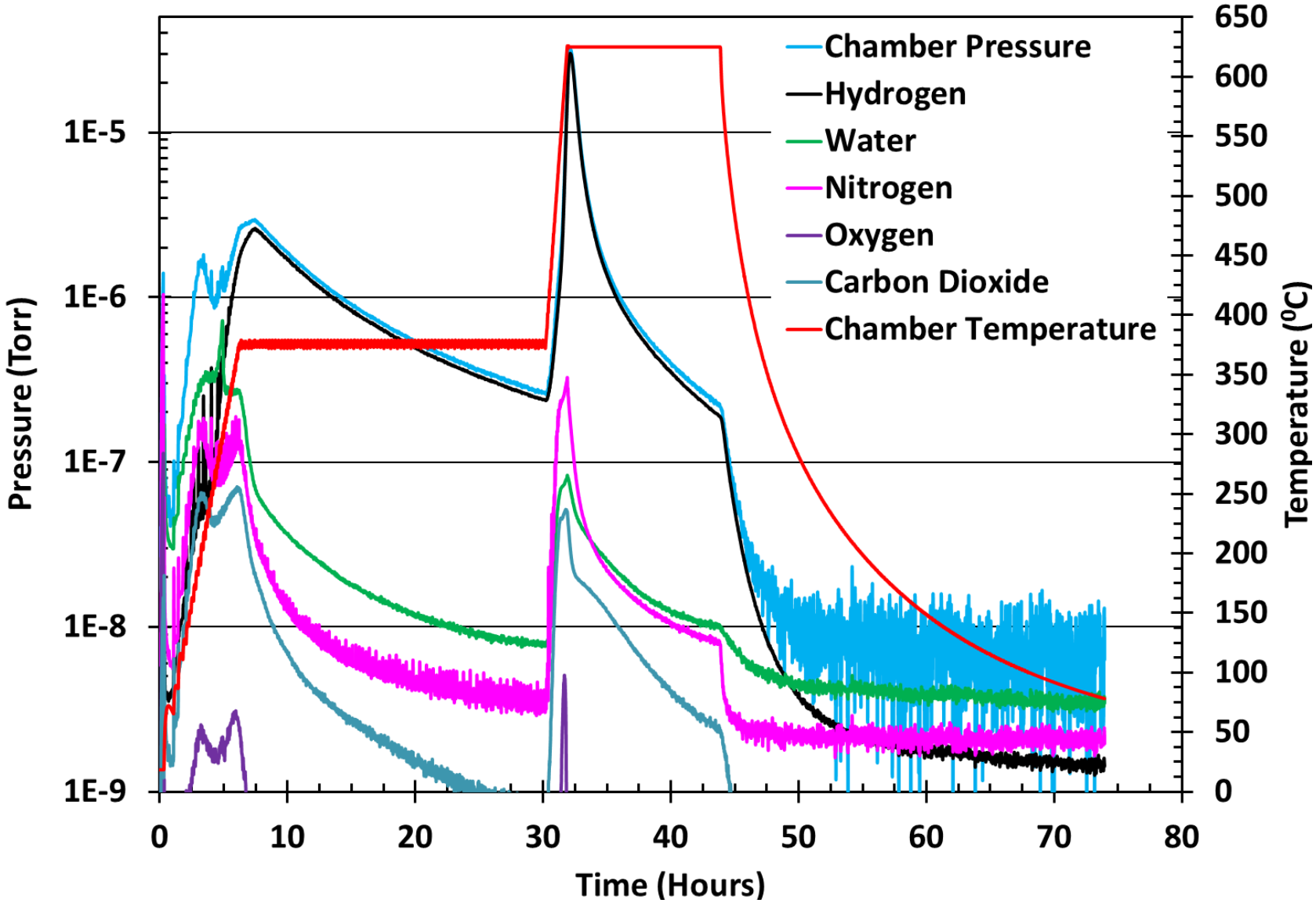
ANL-FNAL Collaboration on SRF







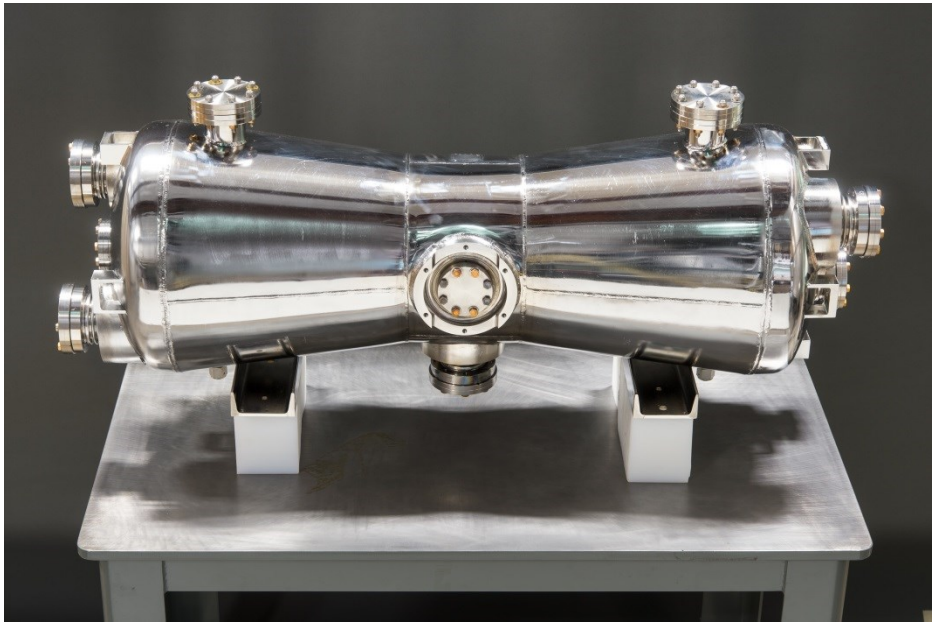
Hydrogen Degassing @ FNAL

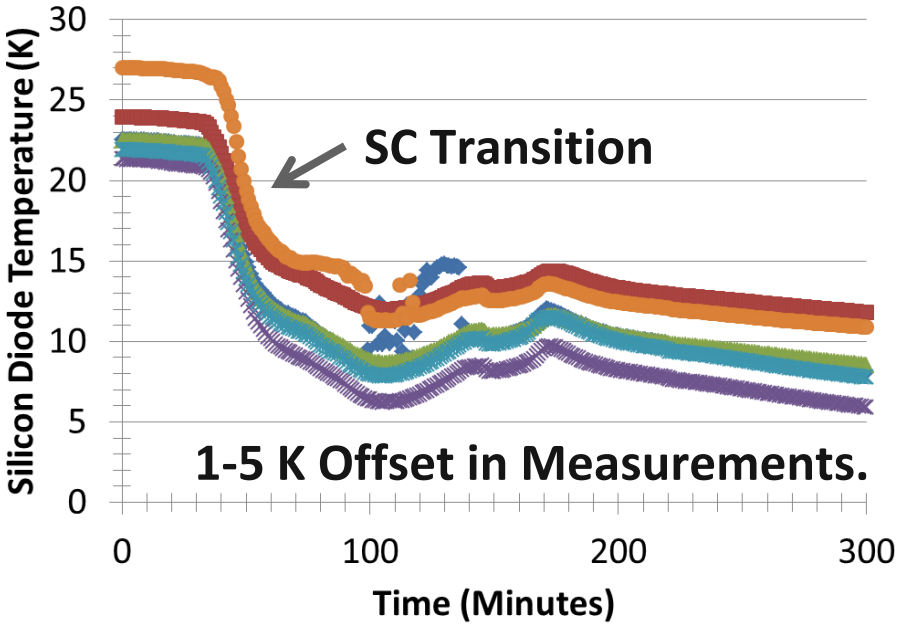


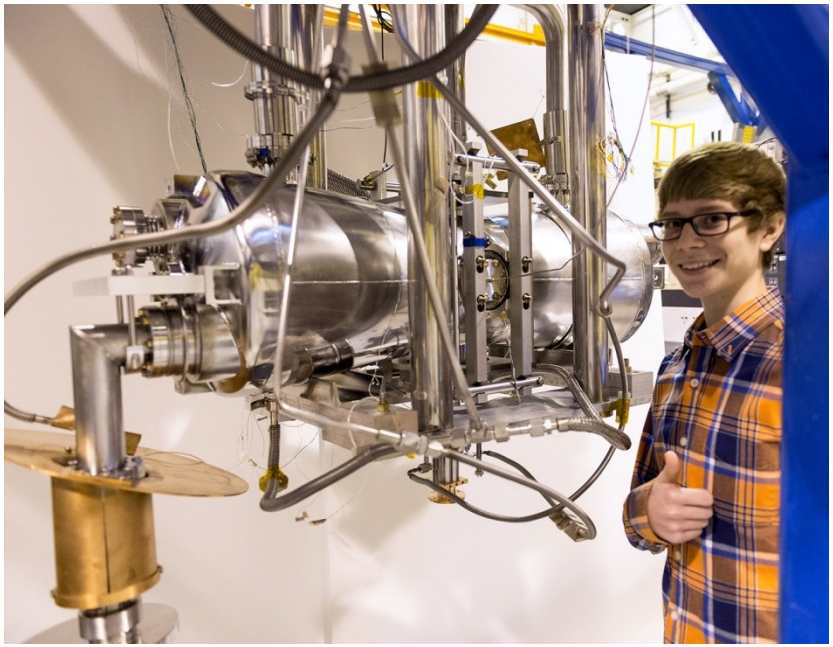
625°C High-Vacuum Bake thanks to M. Merio and A. Rowe (FNAL).

Cold Test & Cooldown

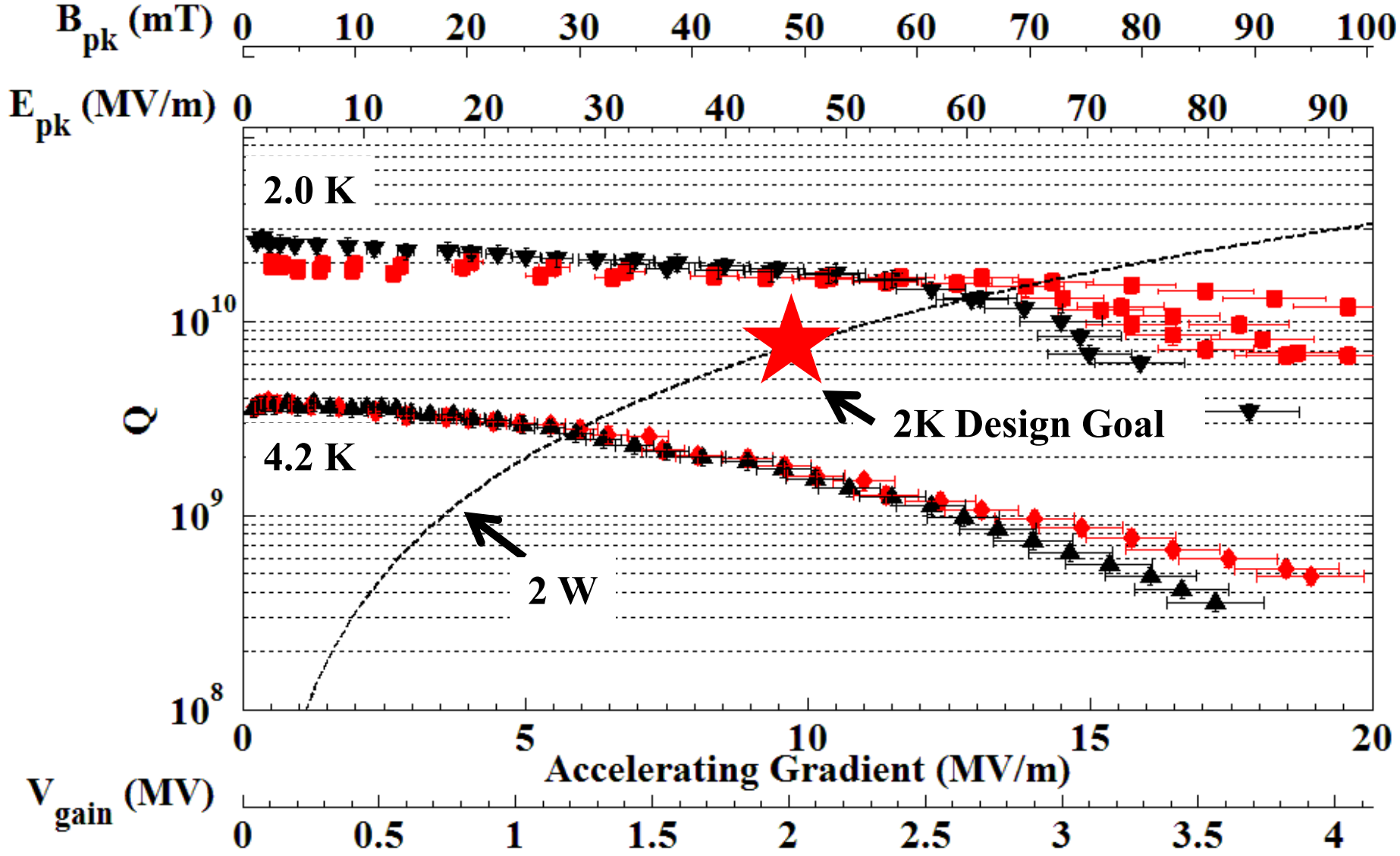
- Cavity hung beneath a large helium reservoir.
- Silicon diodes are used for temperature measurement.
- Cavity cooled to 4 K with dewars.
  - Rapid cooling 165 – 50 K.
- Entire bath pumped to 2.0 K.



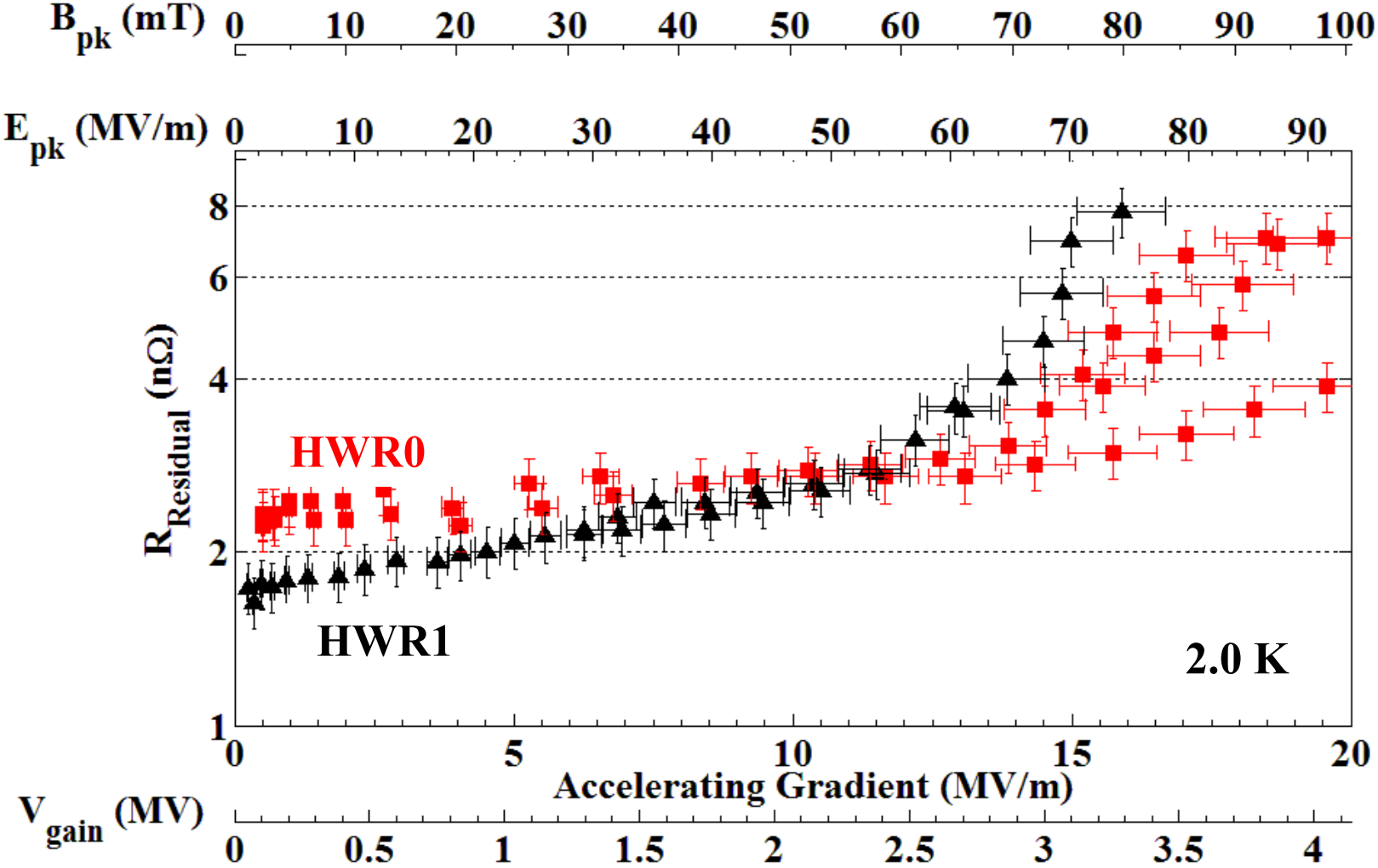




162.5 MHz HWR Q Curves



162.5 MHz Residual Resistance



- Based on weakly coupled energy decay time.
- Ambient magnetic field 0-40 mG mostly aligned with the axis of the cavity. Fluxgate magnetometers used for this measurement.

Concluding Remarks

- **Highly optimized cavities.**
  - **RF Performance improved by increase volume over which the magnetic energy is distributed.**
  - **Including fabrication and processing.**
- **Constantly working to improve cavity fabrication and processing.**
- **High peak fields achieved.**
  - **Peak Electric > 70 MV/m.**
  - **Peak Magnetic Field no fundamental limit observed.**
- **Low residual resistance:**
  - **Low field 1.7 - 2.3 nΩ.**
  - **Full range 1.7 – 8 nΩ.**
  - **@ operating voltage of 2 MV/cavity 2.3 – 2.7 nΩ.**
    - **< 1 W into helium bath for E_{pk} = 45 MV/m and B_{pk} = 48 mT.**