A New 2 K Superconducting Half-Wave Cavity Cryomodule for PIP-II

Zachary Conway

On Behalf of the ANL Physics Division Linac Development Group

June 29, 2015

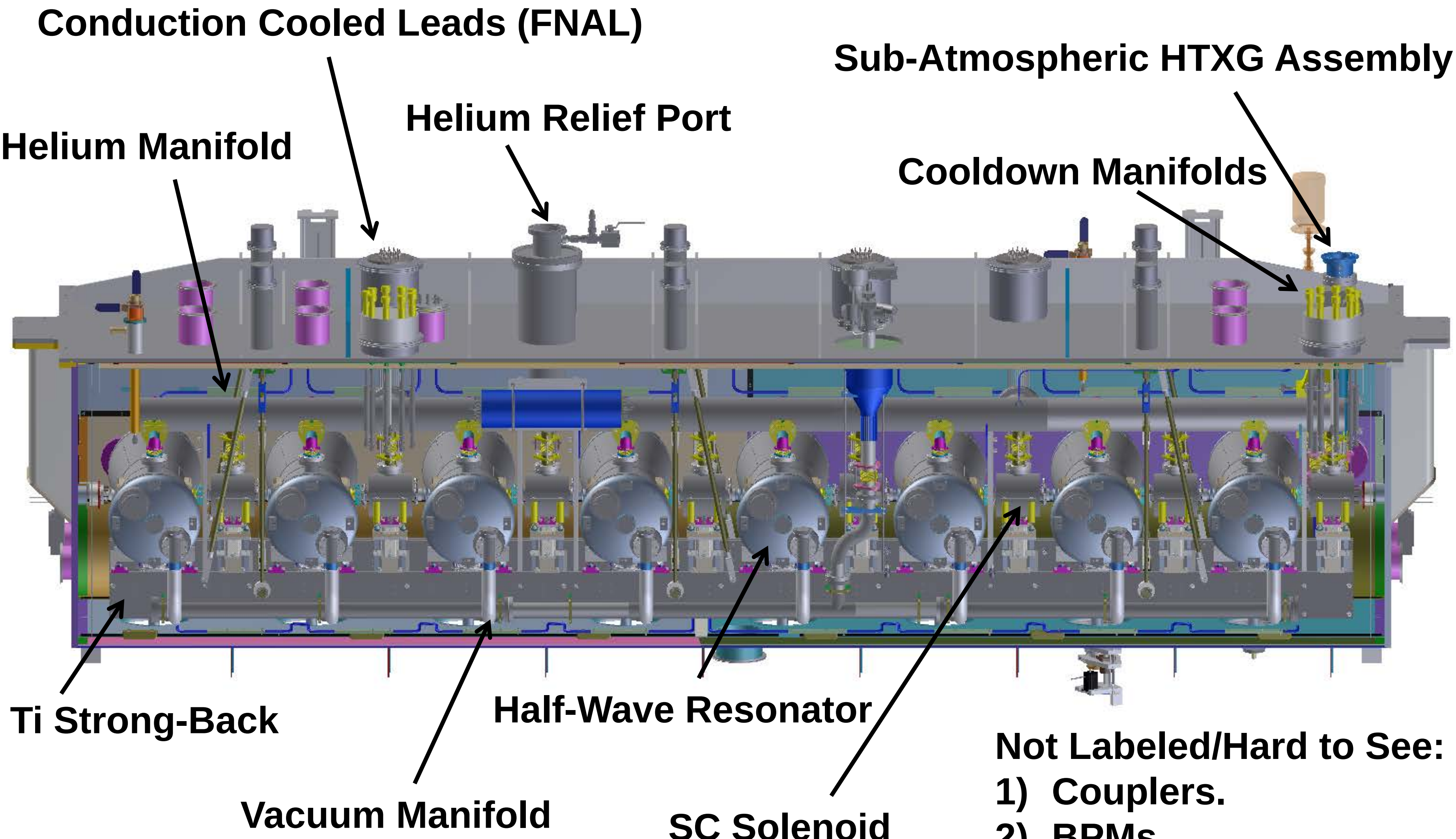
Acknowledgements

- People Working at ANL:
  - PHY: P. Ostroumov, M. Kelly, S. Gerbick, M. Kedzie, G. Zinkann, S. MacDonald, S.H. Kim and C. Hopper.
  - NE: R. Fischer, A. Barcikowski and G. Cherry.
  - HEP: T. Reid and B. Guilfolye.
  - APS: J. Fuerst and W. Jansma.
  - TechSource: K. Shepard.
  - Towson U.: N. Prins.
  - Elmhurst College: D. McWilliams.
- FNAL Cryogenics Group & Tech Division.
  - T. Nicol and M. White.
- Many Vendors:
  - Meyer Tool and Manufacturing, IL.
  - Advanced Energy Systems, NY.
  - Adron EDM, WI.
  - Ti Fab, PA.
  - Numerical Precision, IL.
  - M-1 Tool Works, IL.

Introduction

- Building a cryogenic system for the acceleration of H- ions from 2.1 to 10 MeV for PIP-II @ FNAL.
  - Will contain accelerator cavities and magnets operating at 2 K.
- Will be the first operational 2 K cryomodule for superconducting accelerator cavities with low-beta (beta = v/c < 0.5) structures.
  - Using many techniques developed by velocity-of-light (or close to) accelerators; e.g., elliptical cell cavities.
  - Others are in development too; e.g., IFMIF, MSU-FRIB.
- Design goals for the:
  - Operate at 2 K instead of 4 K.
  - Further reduce static cryogenic loads relative to previous low-velocity cavity cryomodules.
  - Comply with DOE, ANL and FNAL safety guidelines for cryogenic, vacuum and pressure vessels.
  - Enable faster more-accurate alignment.

Half-Wave Resonator Cryomodule



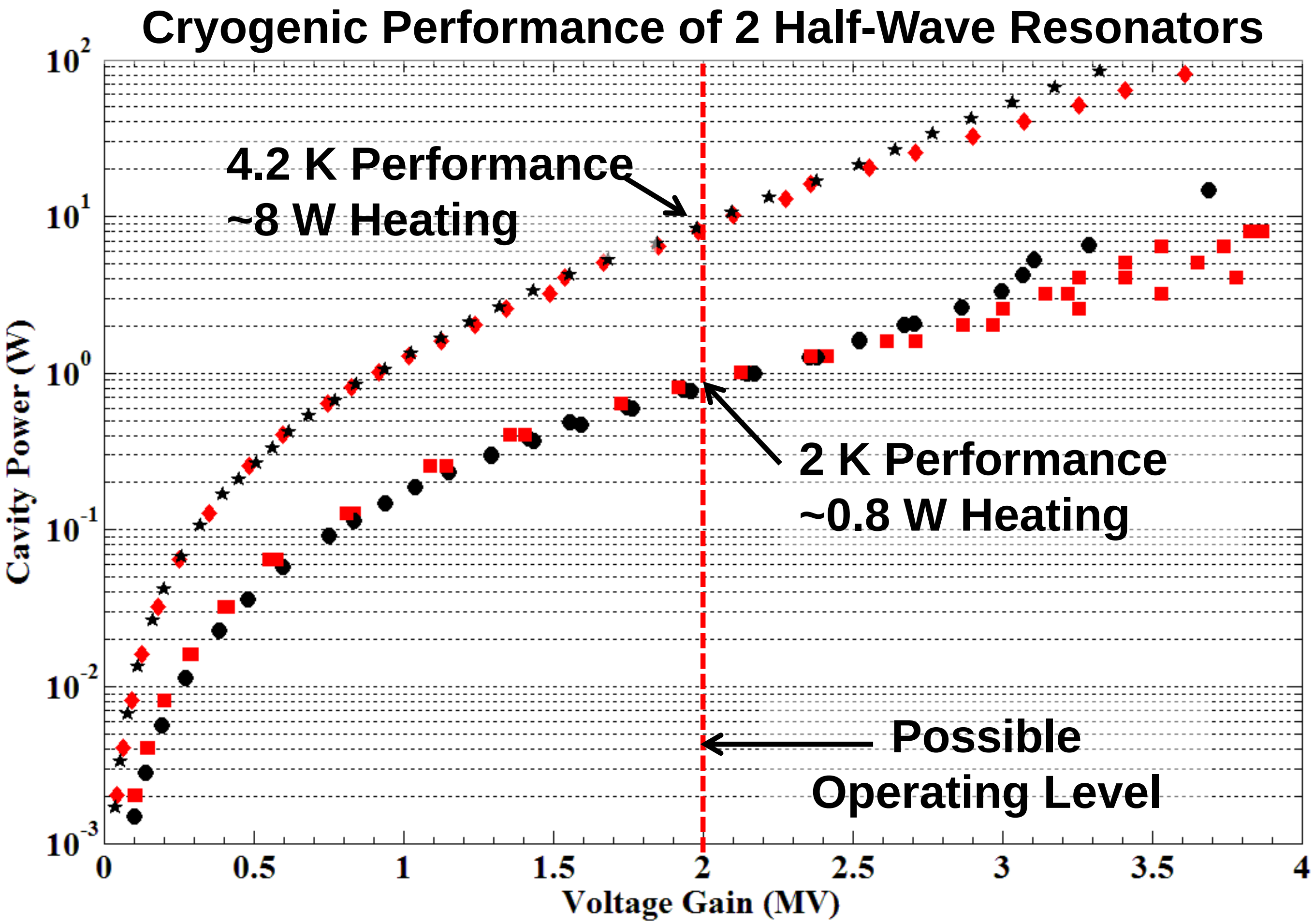
2.2 m X 2.2 m X 6.2 m

Not Labeled/Hard to See:

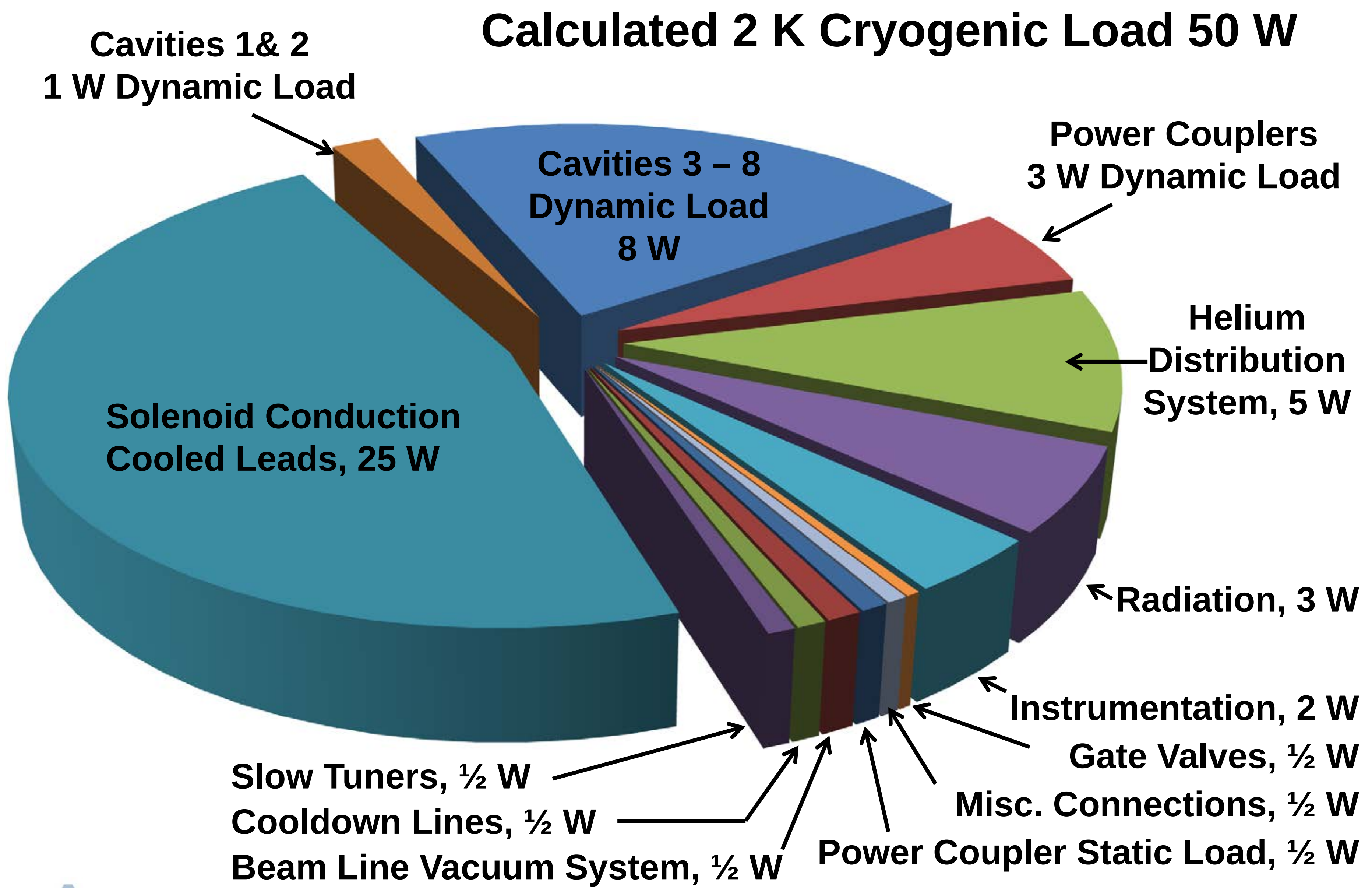
1) **Couplers.**
2) **BPMs.**
3) **70K HTXG.**
4) **Beam-line gate valves.**

2 K Low-Beta Cavity Cryomodules

- **Low-beta = low-frequency and losses scale as f^2. Low-beta cavities have traditionally operated at 4.2 K to save on refrigeration.**
- **Why operate at 2 K now?**
  - **The rest of the system is 2 K = Simplified Cryogenic Distribution.**
  - **The performance improvement justifies the extra cryogenic cost.**



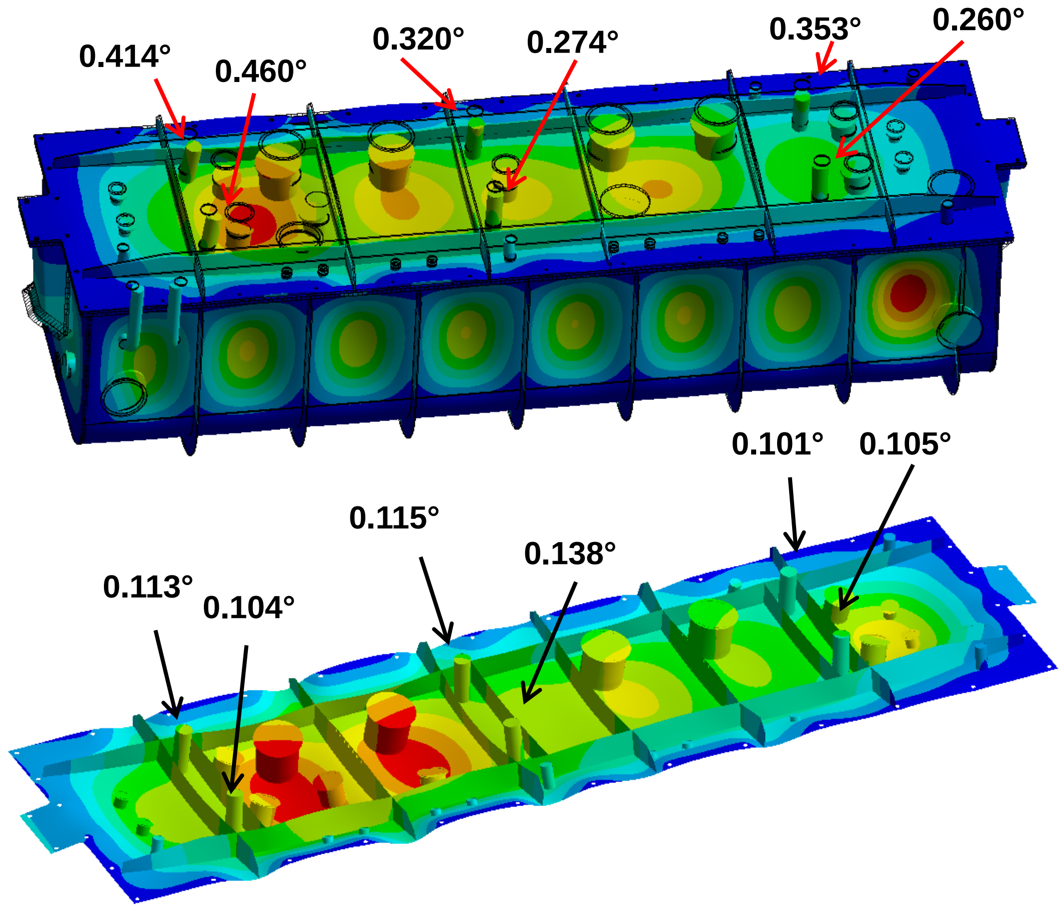
Cryomodule 2 K Design Thermal Loads



Design: Cavities and Cryomodules

- Design must protect against:
  - Plastic Collapse.
  - Local Failure.
  - Buckling.
  - Failure with Cyclic Loading.
- Design must also:
  - Maintain alignment.
  - Not break penetrations.
- Not discussing solenoids. They receive an ASME U-stamp.

Port Deflection Initial and Final

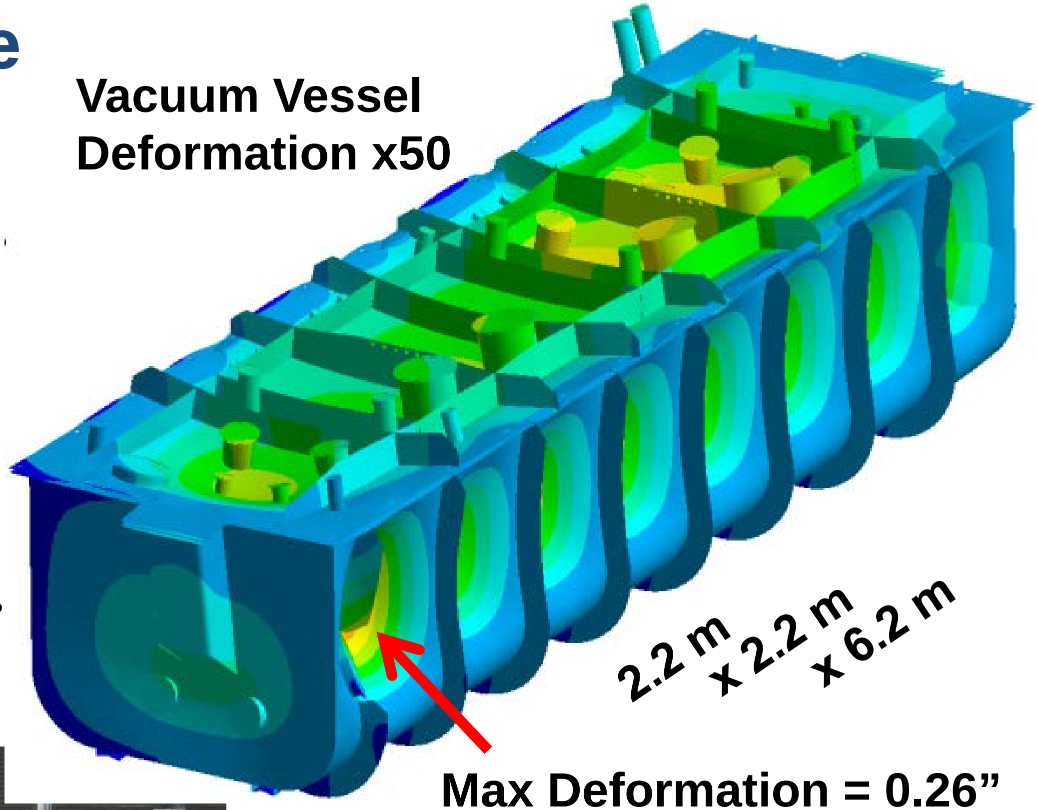


20^0C Material Properties

Material	Young's Modulus (ksi)	Poisson's Ratio	Density (lbs/in^3)	Maximum Allowable Stress (ksi)
304 Stainless Steel	29,000	0.270	0.286	20.0
Niobium	15,200	0.396	0.310	5.5

Vessel Design: Cryomodule

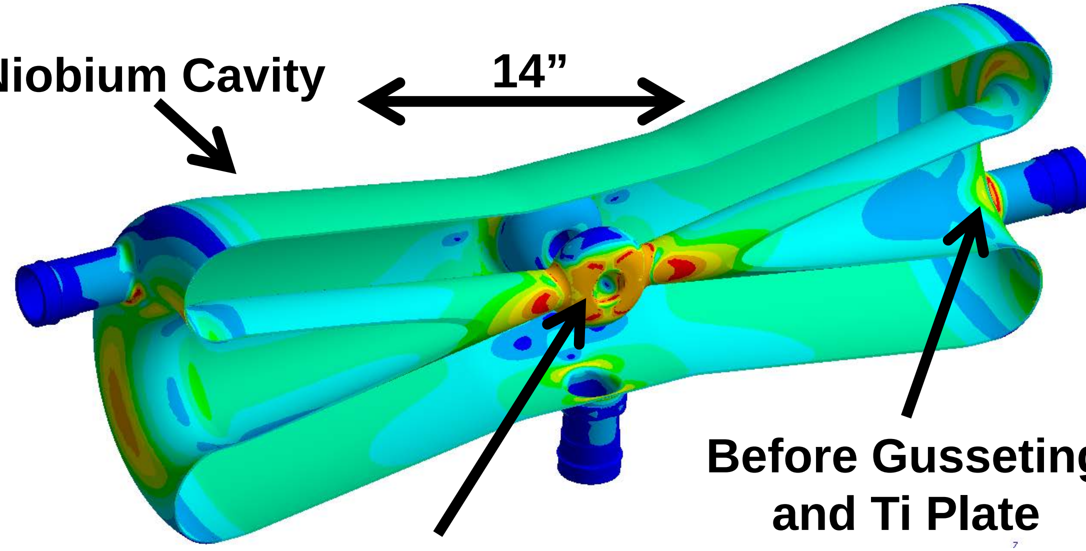
- Vacuum Vessel @ 14.7 psiv.
- Used ASME BPVC code to demonstrate protect against:
  - Plastic Collapse (Limit-Load).
  - Local Failure.
  - Buckling.
  - Ratcheting and Cyclic Loading.
- Very safe vacuum vessel.



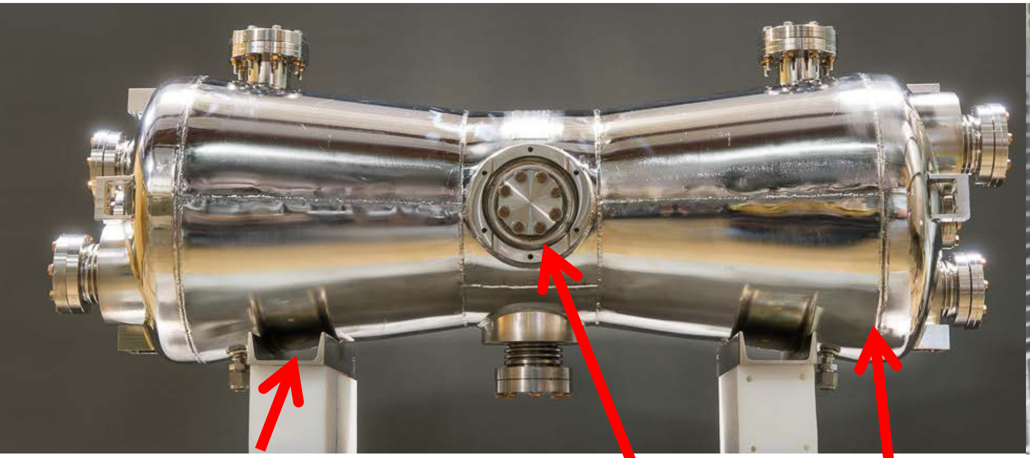
- Magnetic shielding lines the inner surface of the vacuum vessel.
- 70 K thermal shield inboard of magnetic shield.
  - 32 layers MLI outside.
  - 16 layers MLI inside.

Vessel Design: Cavities

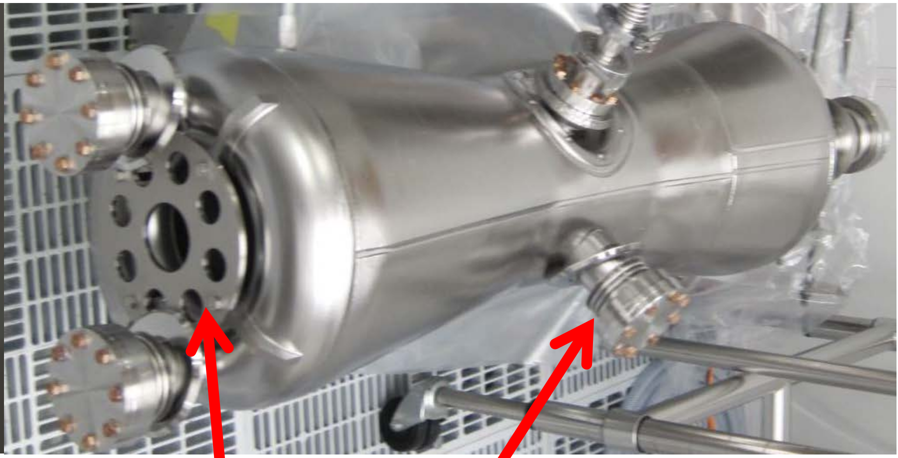
- Design Loads:
  - 2 bar @ R.T.
  - 4 bar @ 2 K.
- Used the rules in the ASME BPVC. No code stamp.
- Used material properties for Nb in compliance with FNAL safety guidelines.



Finished Cavity



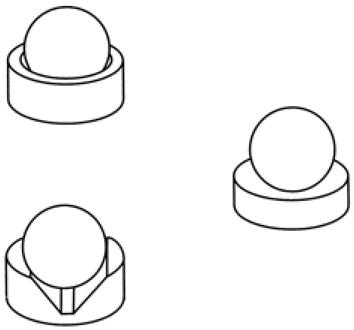
Bare Niobium Cavity



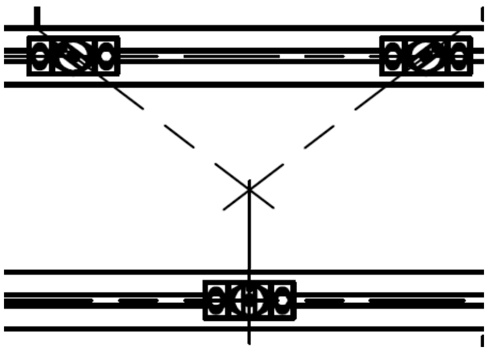
Alignment – 1: Thermal Contraction & Kinematics

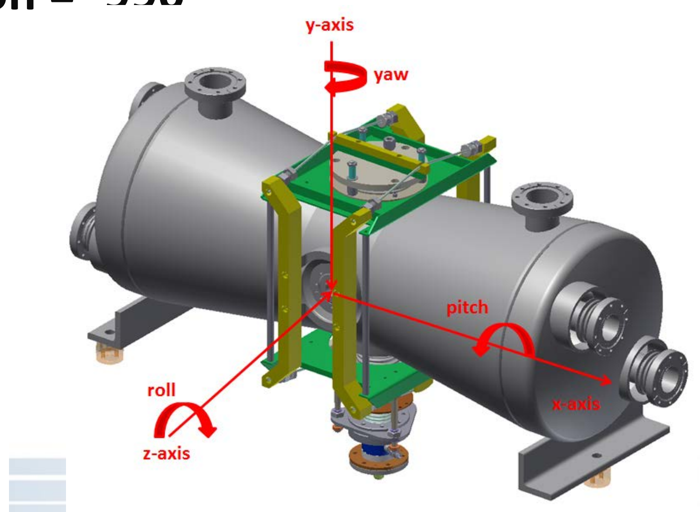
- **Need to align solenoids to ±250 μm_{rms} and ±0.1^0 in pitch, yaw and roll relative to the beam axis.**
- **Transverse shift ~ negligible.**
  - **We have changed from a Kelvin to a Maxwell planar kinematic coupling.**
    - **Maxwell geometry can be designed to be thermally invariant.**
    - **Kelvin geometry shifts toward fixed point.**
- **Vertical Shift = 650 μm up.**
  - **Hanger Contraction = + 1,640 μm up.**
  - **Alignment System contraction = -990 μm up.**
  - **Possible to zero.**

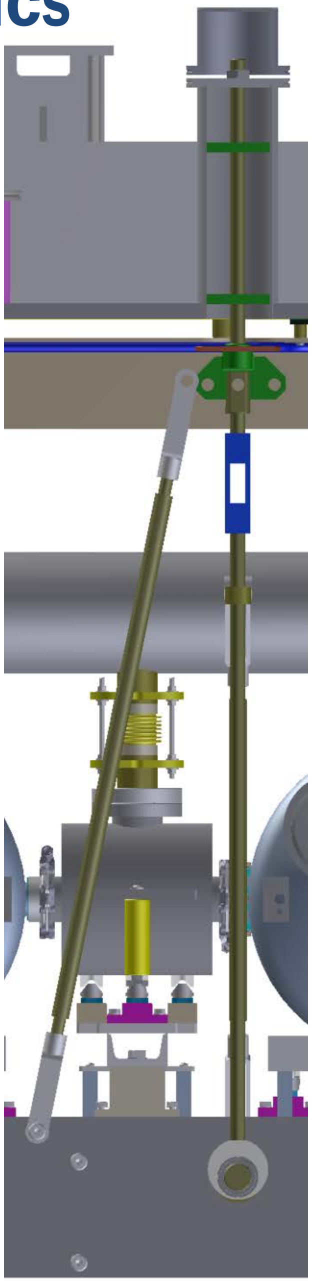
Kelvin



Maxwell





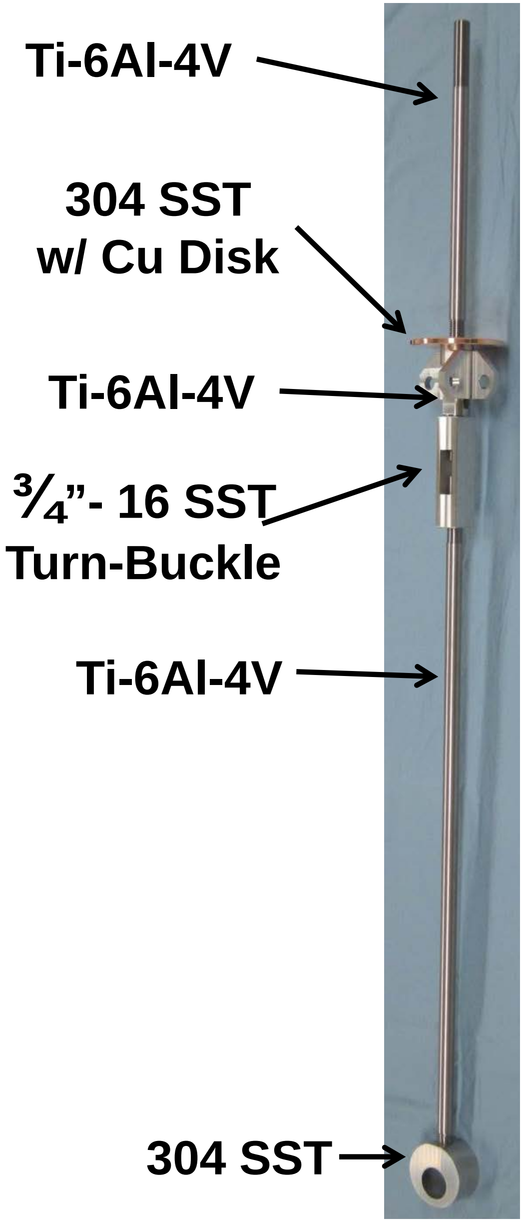


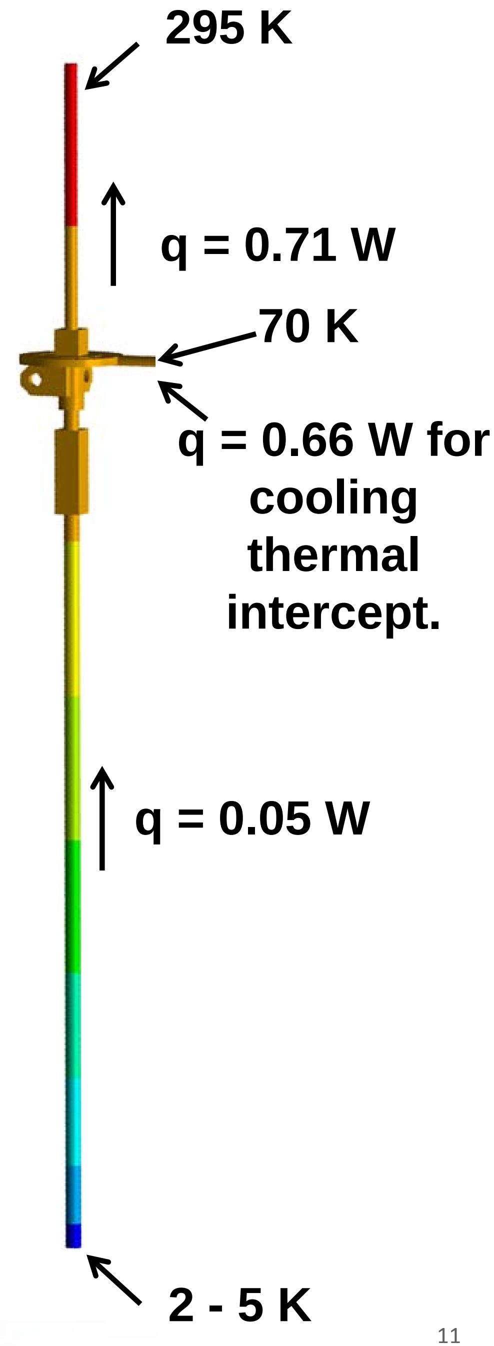
"Design of three-grove kinematic couplings," A.H. Slocum, Precision Engineering **14**, Pg. 67 (1992).
"Optimal design techniques for kinematic couplings," Precision Engineering **25**, Pg. 114 (2001).

Cold-Mass Hangers

- **Hangers have to:**
  - Support the 4 ton cold-mass.
  - Allow for adjustment and alignment of the cold-mass.
  - Thermally isolate the ~2 K cold-mass from room temperature.

- **We take advantage of:**
  - Low thermal conductivity materials.
  - Relatively high thermal contact resistance for grease- and lubrication-free connections.

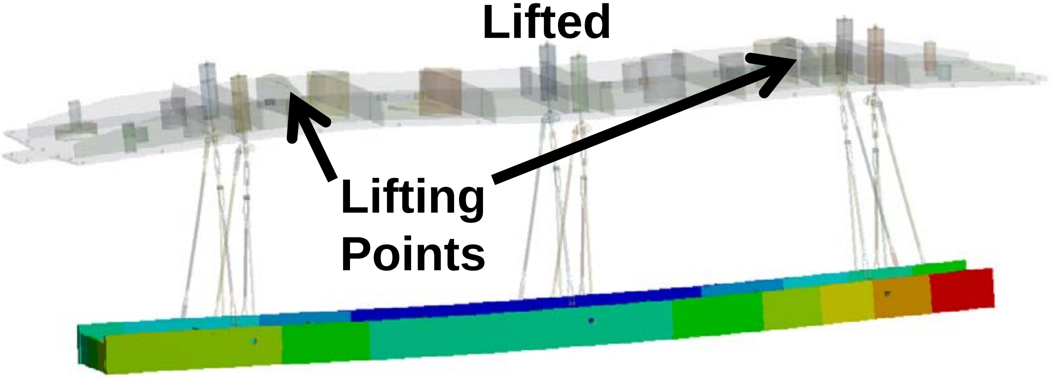




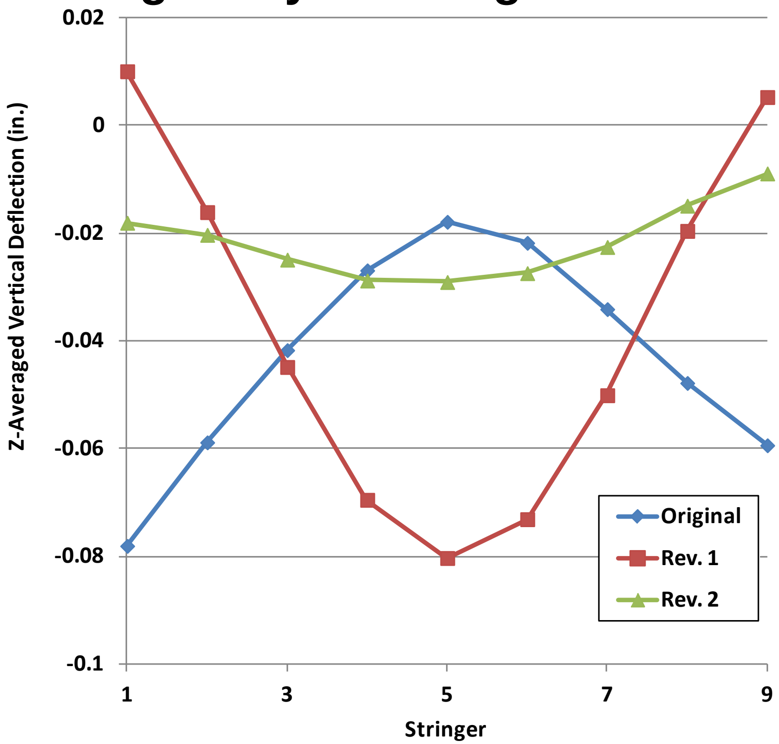
Alignment – 2: Ti Strong-Back

- When lid is on the box the loaded strong-back rails are flat and parallel within 0.005”.
- Lifting may perturb the alignment.
- Reduced lifting disturbance via design.

Model of Lid/Strong-Back being Lifted



Lifting Analysis Design Evolution



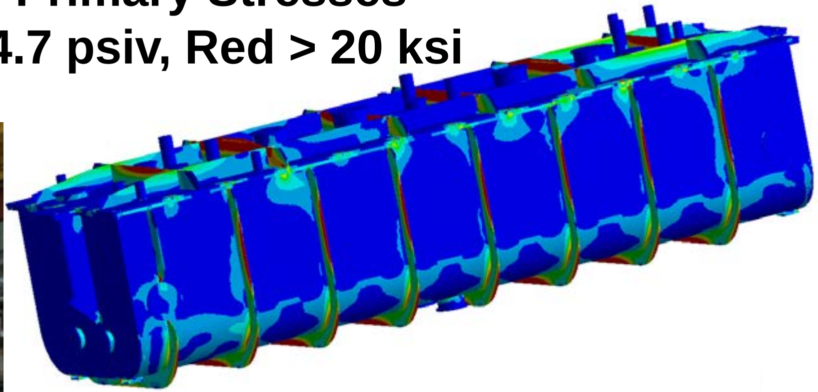
Strong-Back

Summary

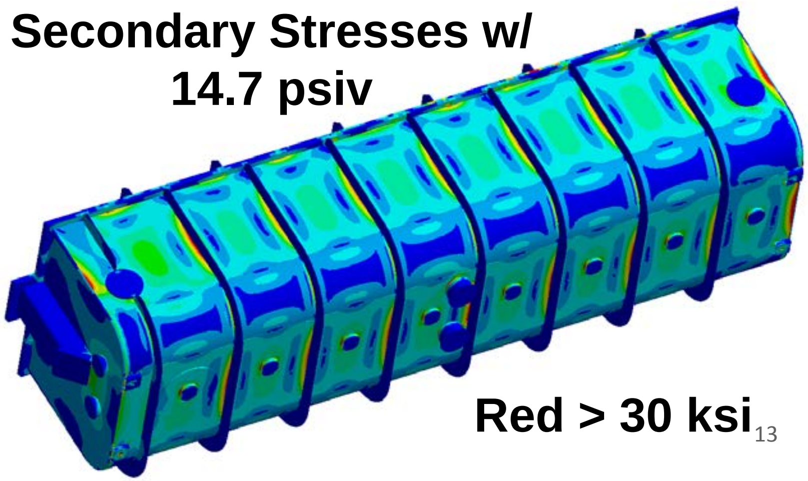
- At ANL we are developing a 2K superconducting accelerator cavity cryomodule.
- Cryomodule assembly is starting now.
- Hope to test the system without cavities or solenoids late this year.

Delivery of Cryomodule @ ANL

Primary Stresses
14.7 psiv, Red > 20 ksi



Secondary Stresses w/
14.7 psiv



Red > 30 ksi