Argonne NATIONAL LABORATORY

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

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On Behalf of the ANL Physics Division Linac Development Group

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U.S. DEPARTMENT OF ENERGY

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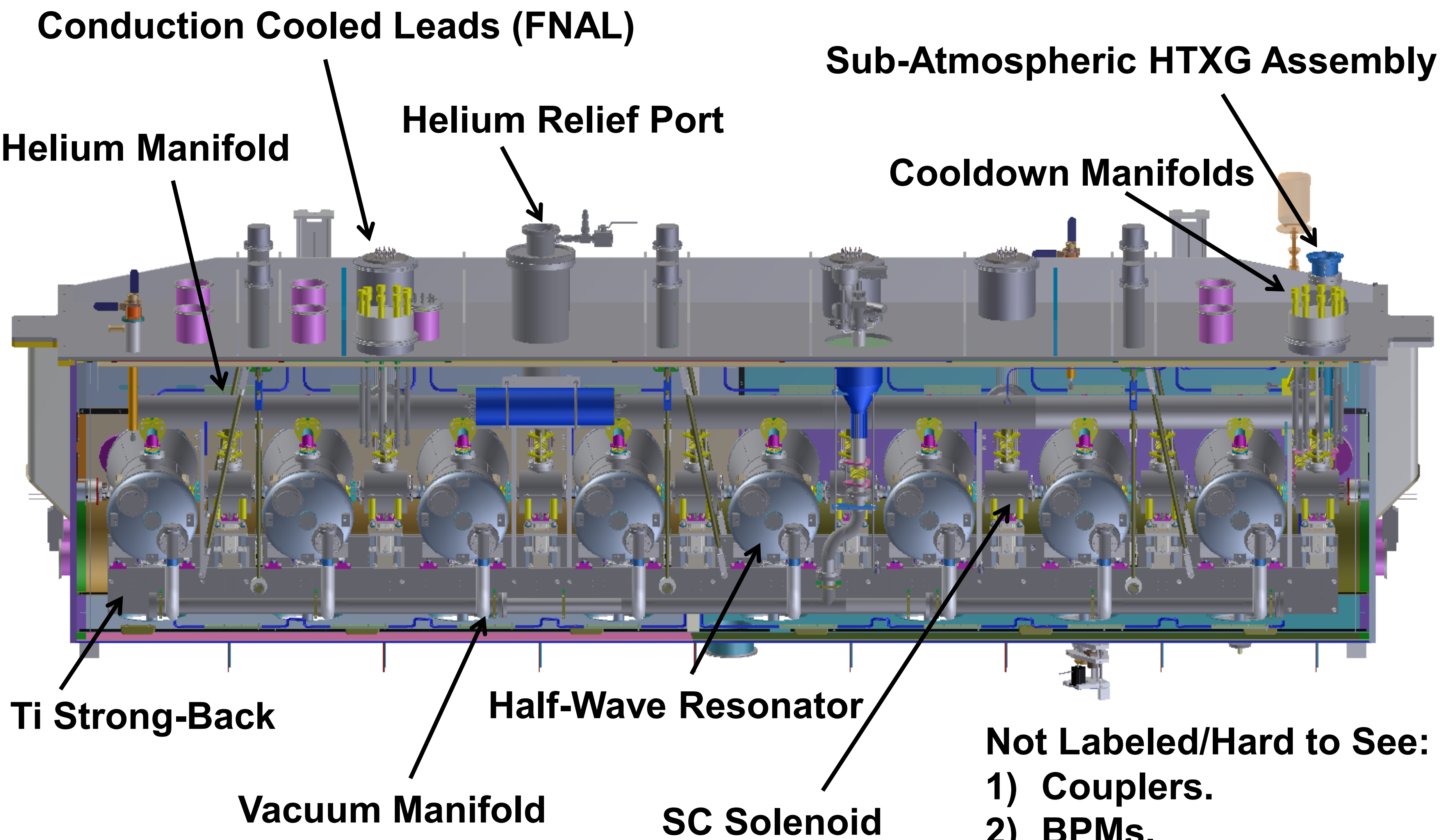
Introduction

- **We are building a cryogenic accelerator system which 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



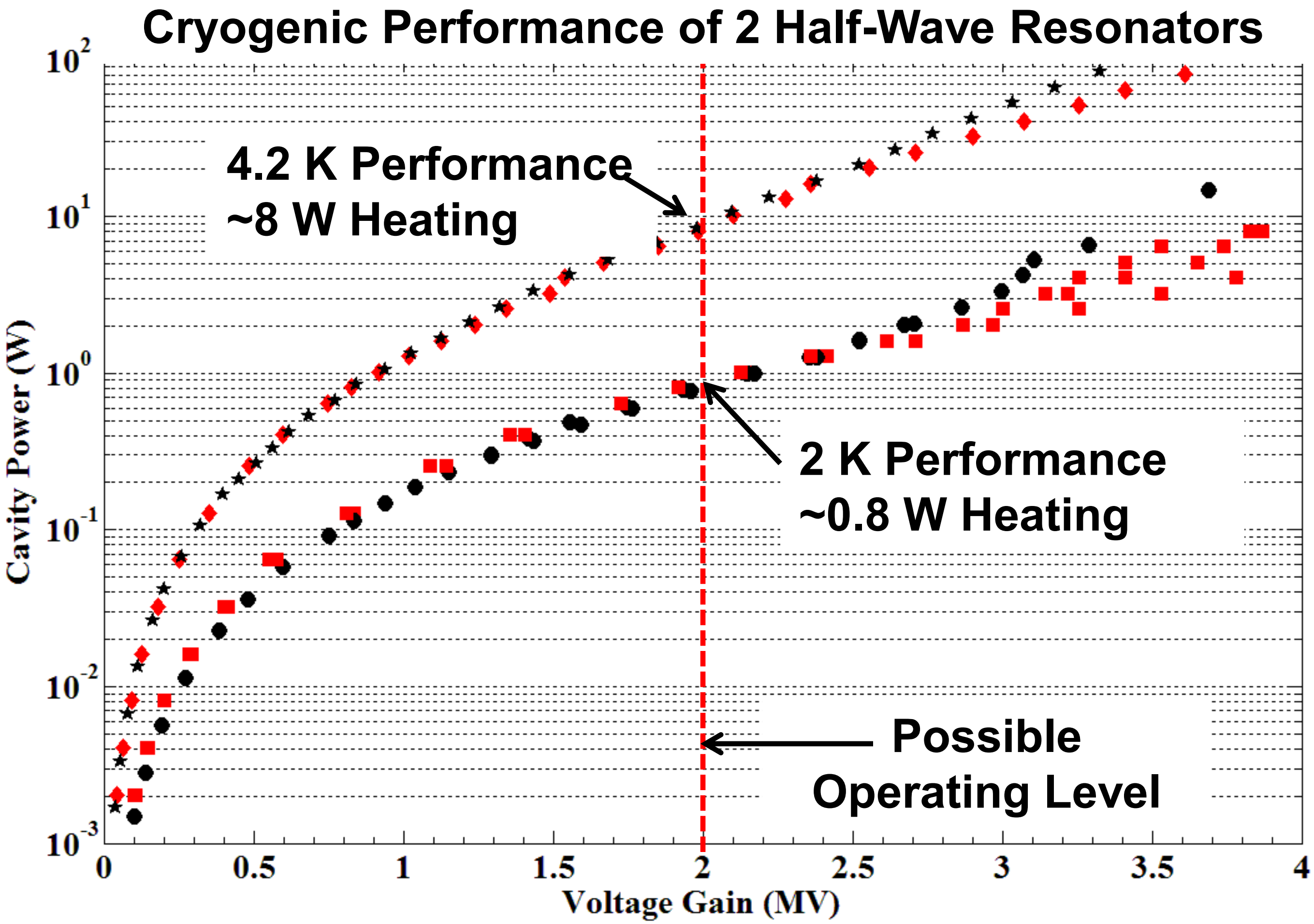
2.2 m X 2.2 m X 6.2 m

Not Labeled/Hard to See:

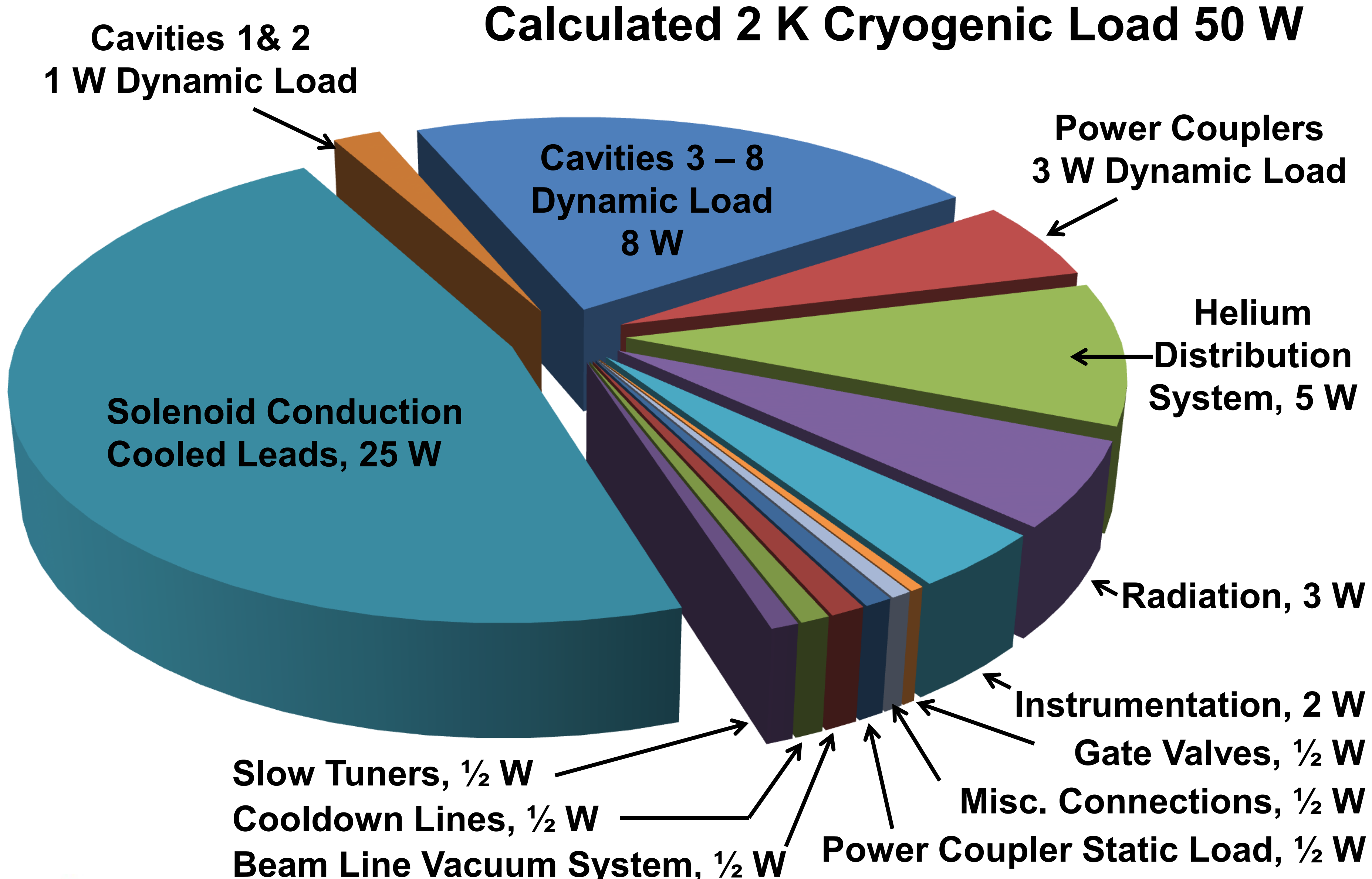
1) Couplers.
2) BPMs.
3) 70K HTXG.
4) Beam-line gate valves.

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.**

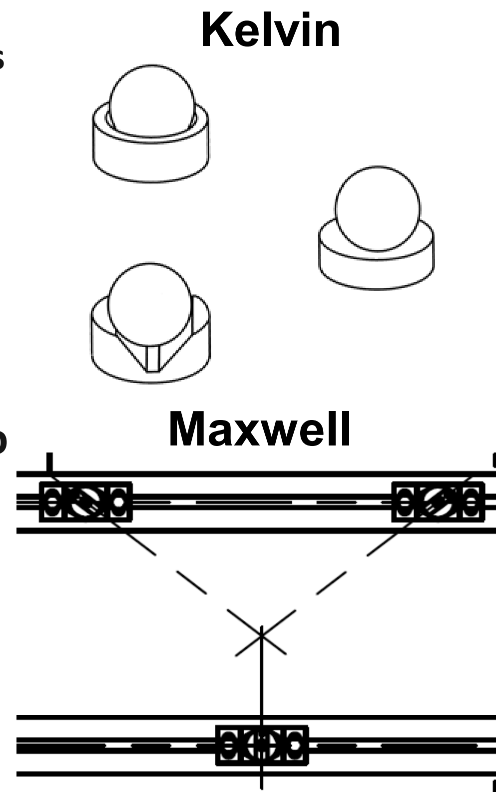


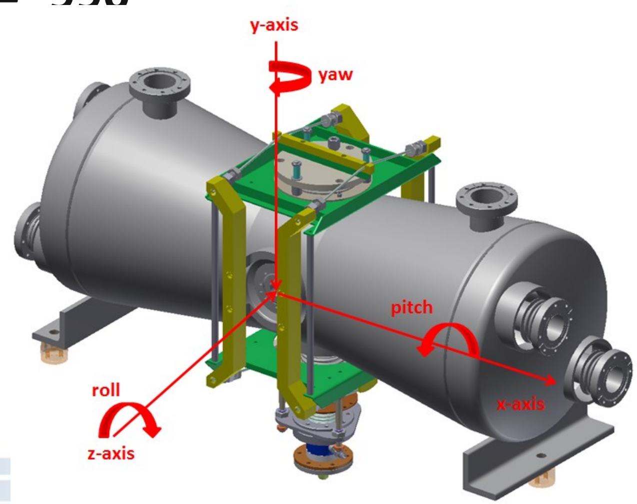
Cryomodule 2 K Design Thermal Loads

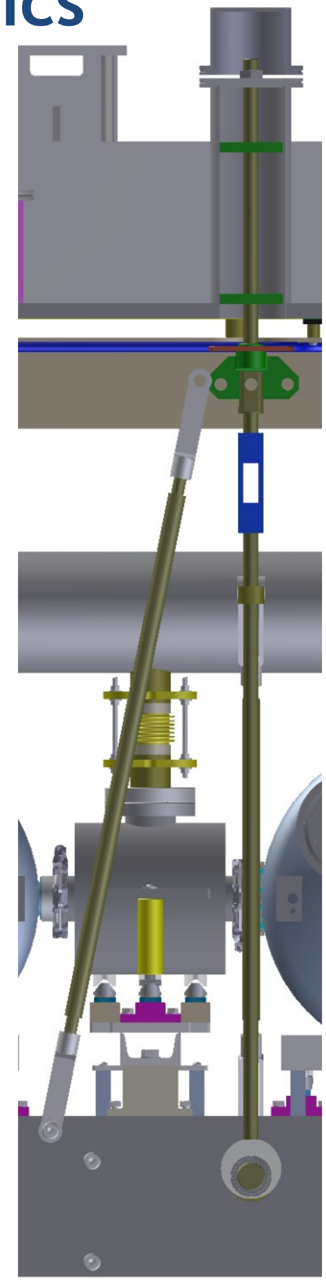


Alignment – 1: Thermal Contraction & Kinematics

- **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.**



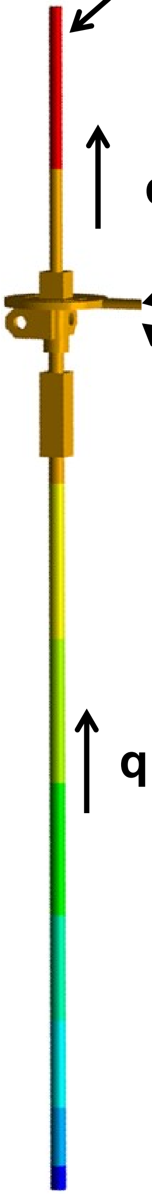




"Design of three-grove kinematic couplings," A.H. Slocum, Precision Engineering **14**, Pg. 67 (1992).
"Optimal design techniques for kinematic couplings," Precision Engineering **25**, Pg. 114 (2001).

Cold-Mass Hangers

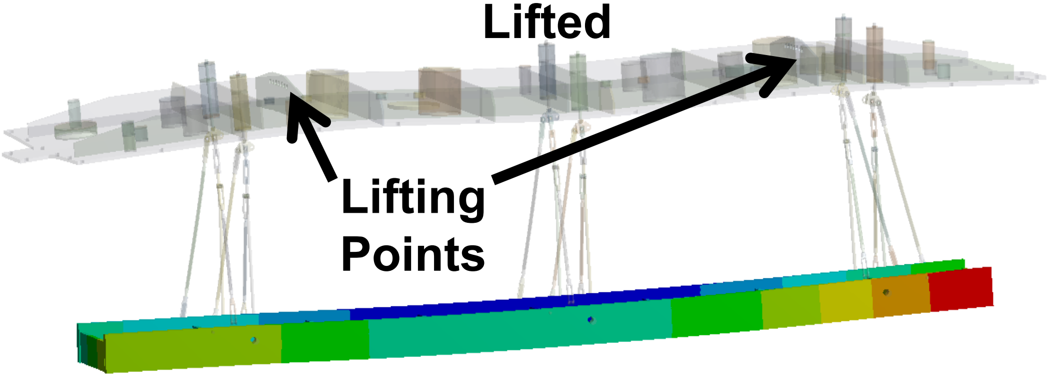
- Hangers have to:
  - Support the 4 ton cold-mass.
  - Allow for adjustment and alignment of the cold-mass.
  - Thermally isolate the ~2 K cold-mass from room temperature.
- We take advantage of:
  - Low thermal conductivity materials.
  - Relatively high thermal contact resistance for grease- and lubrication-free connections.



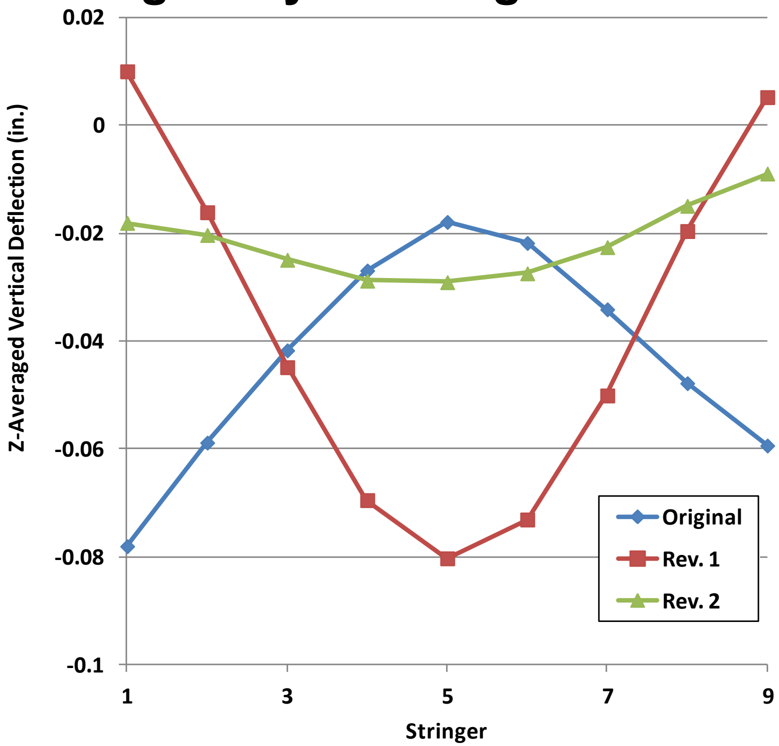
Alignment – 2: Ti Strong-Back

- 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



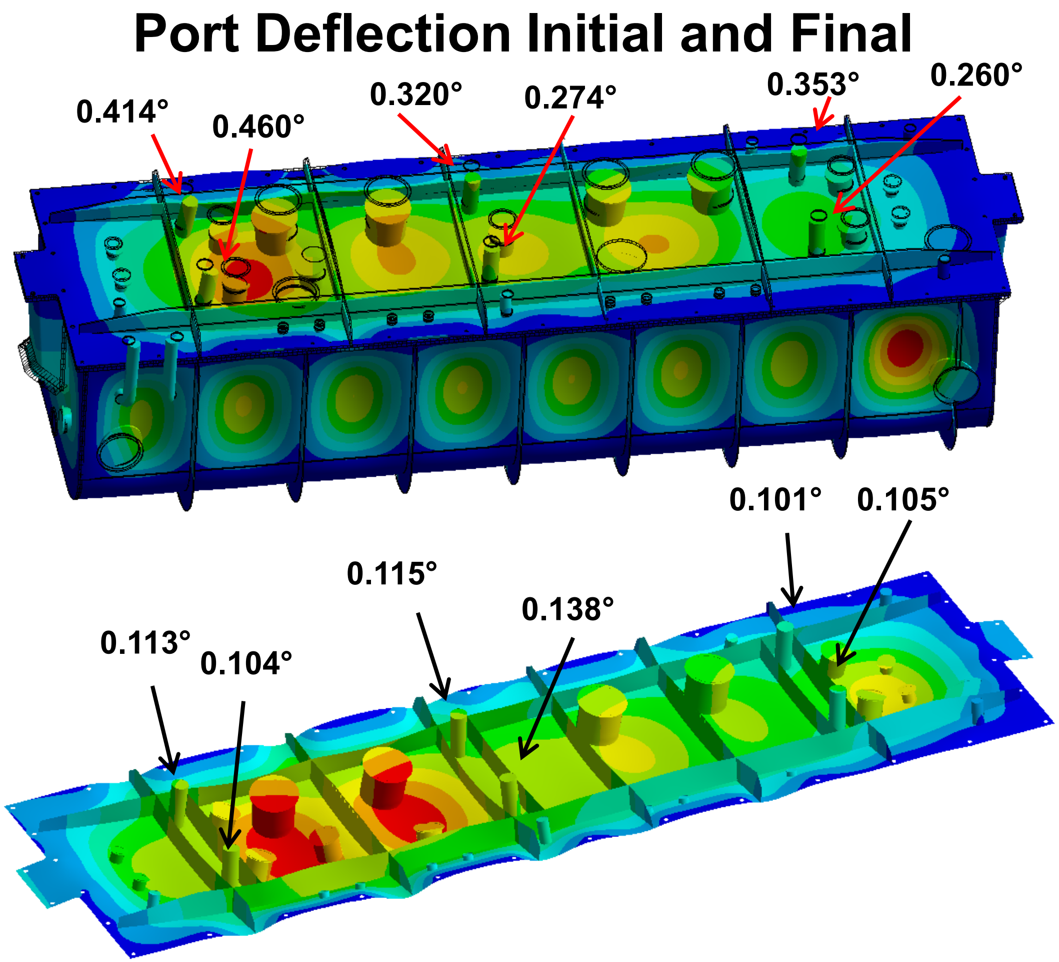
Lifting Analysis Design Evolution



Strong-Back

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.

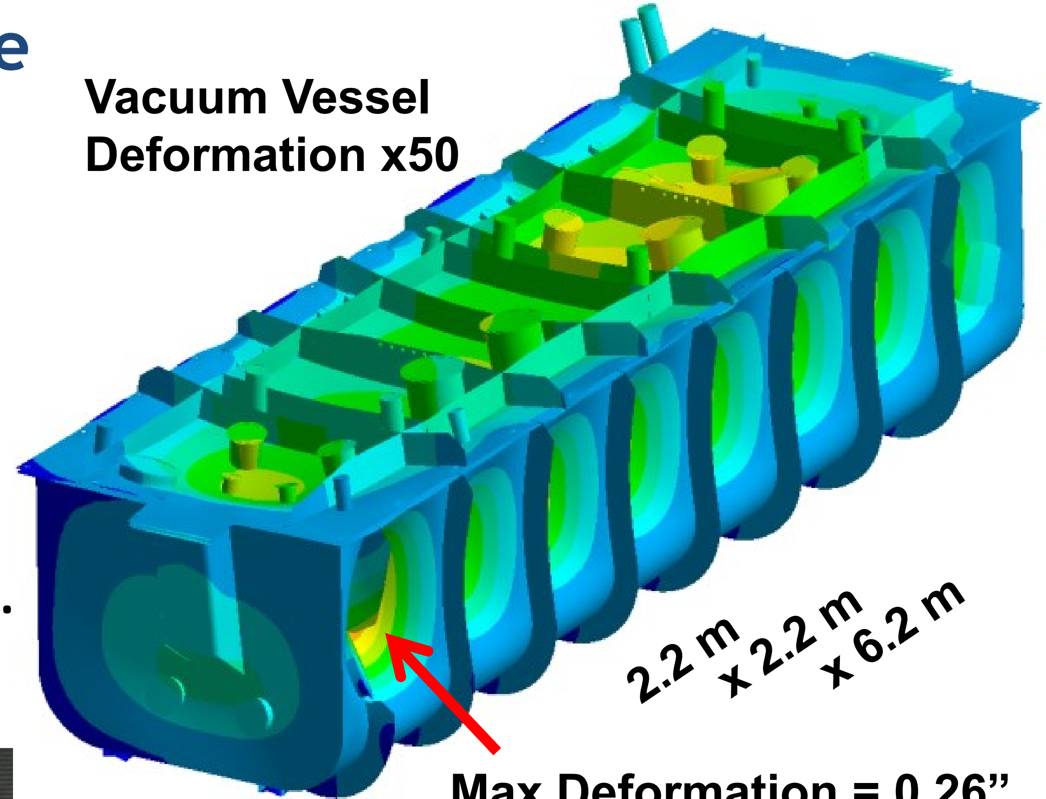


20^0C Material Properties

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

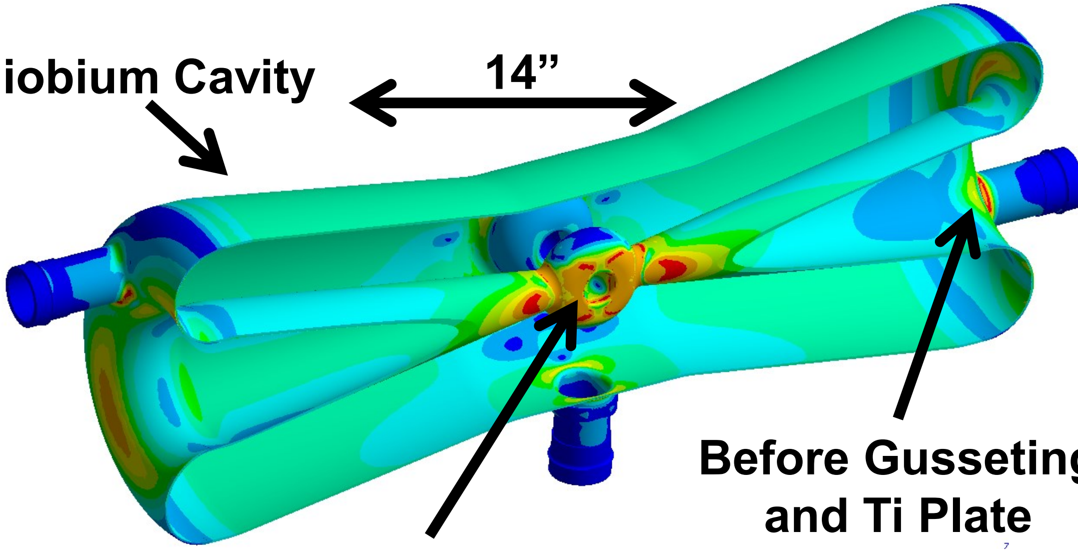
- **Vacuum Vessel @ 14.7 psiv.**
- **Used ASME BPVC code to demonstrate protect against:**
  - **Plastic Collapse (Limit-Load).**
  - **Local Failure.**
  - **Buckling.**
  - **Ratcheting and Cyclic Loading.**
- **Very safe vacuum vessel.**



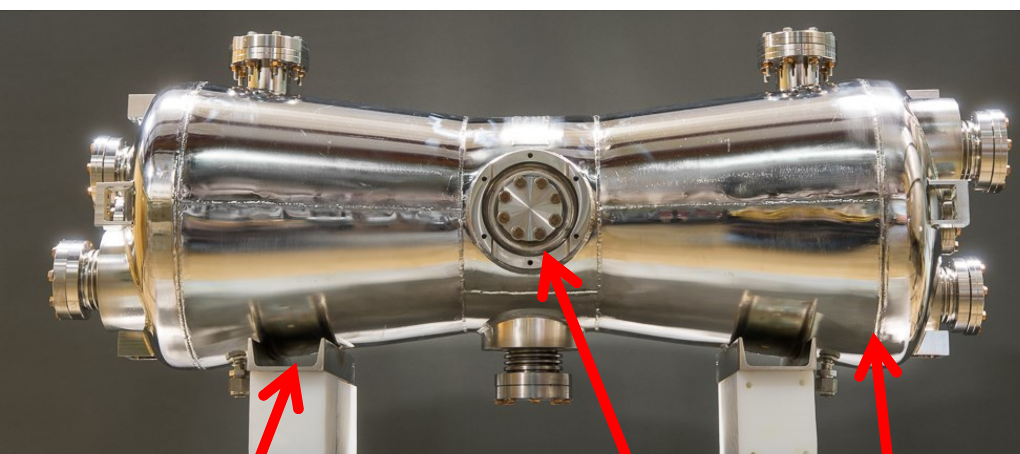
- **Magnetic shielding lines the inner surface of the vacuum vessel.**
- **70 K thermal shield inboard of magnetic shield.**
  - **32 layers MLI outside.**
  - **16 layers MLI inside.**

Vessel Design: Cavities

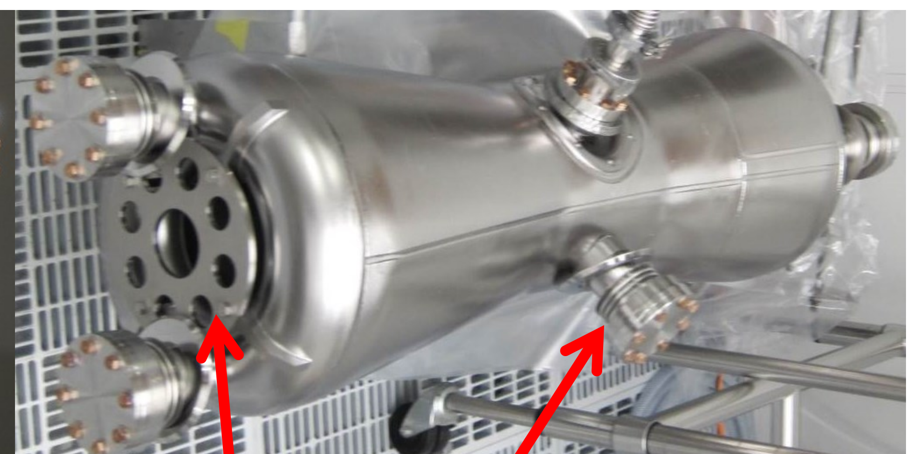
- Design Loads:
  - 2 bar @ R.T.
  - 4 bar @ 2 K.
- Used the rules in the ASME BPVC. No code stamp.
- Used material properties for Nb in compliance with FNAL safety guidelines.



Finished Cavity



Bare Niobium Cavity

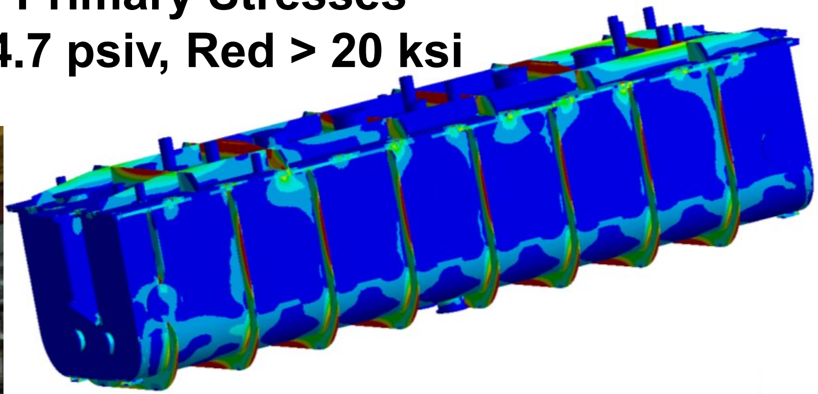


Summary

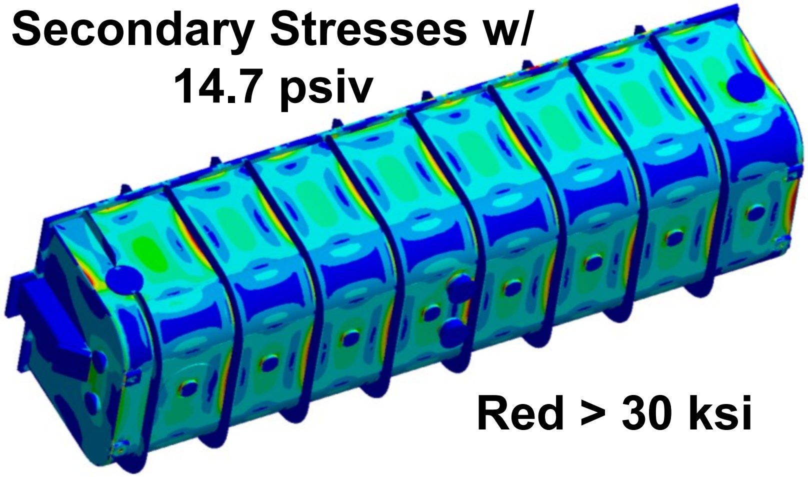
- At ANL we are developing a 2K superconducting accelerator cavity cryomodule.
- Cryomodule assembly is starting now.
- Hope to test the system without cavities or solenoids late this year.

Delivery of Cryomodule @ ANL

Primary Stresses
14.7 psiv, Red > 20 ksi



Secondary Stresses w/
14.7 psiv



Red > 30 ksi