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Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Simulation of Conduction Cooled SRF Cavity

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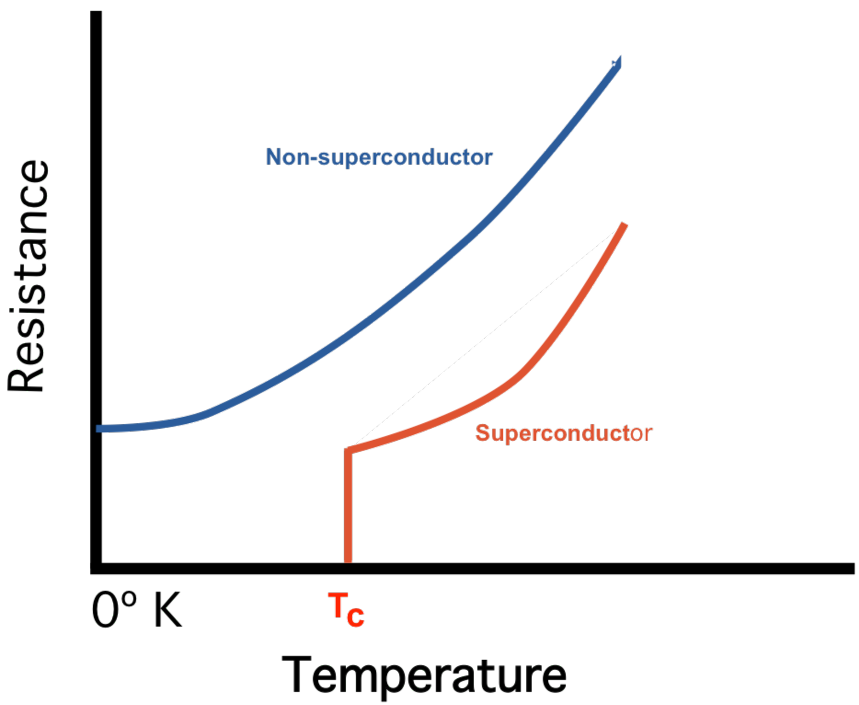
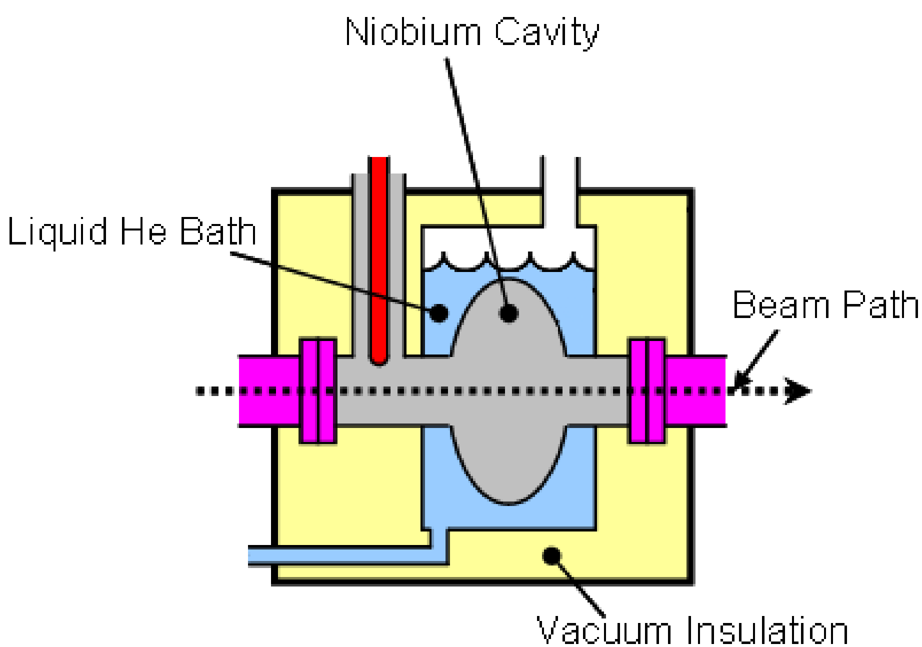
Radio Frequency (RF) Cavities

- Heavily used in research and industry
- Elliptical geometry resonates at a particular frequency
- Particles are accelerated as they move through each cell
- Accelerating gradient E_{acc} quantifies energy particles gain

Superconducting RF (SRF) Cavities

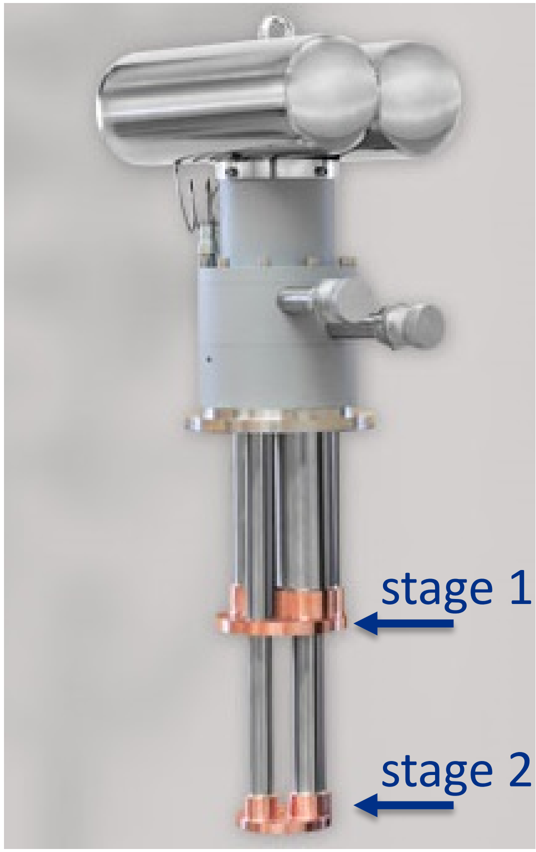
- Superconductors have very low energy losses
- Cavity must be kept below critical temperature (9.25 K for niobium)
- Liquid helium coolant is a major complexity





Conduction Cooling

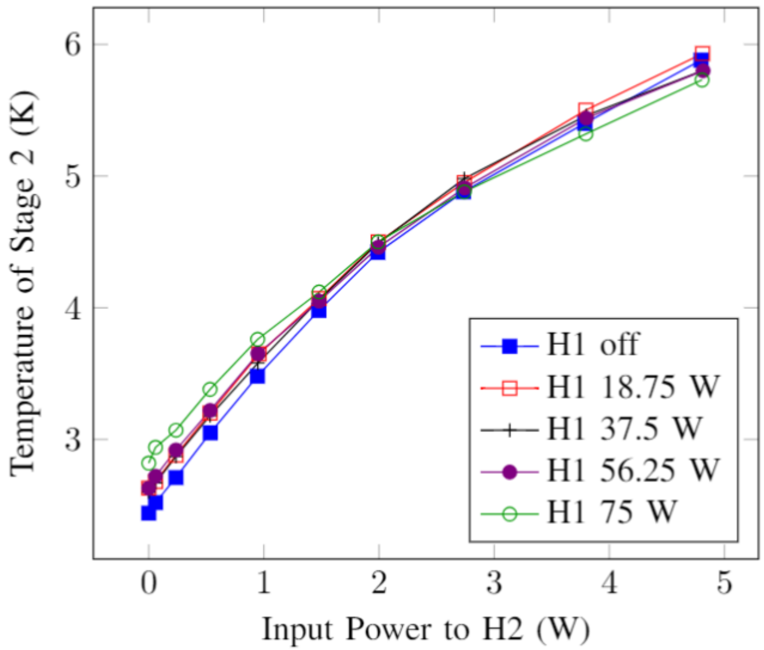
- Replace liquid helium with a cryocooler
- Conduction cooling is a possibility due to technological advancements
  - Cryocoolers are commercially available and can cool to 4 K or below
  - Nb_3Sn coating reduces cavity heat dissipation

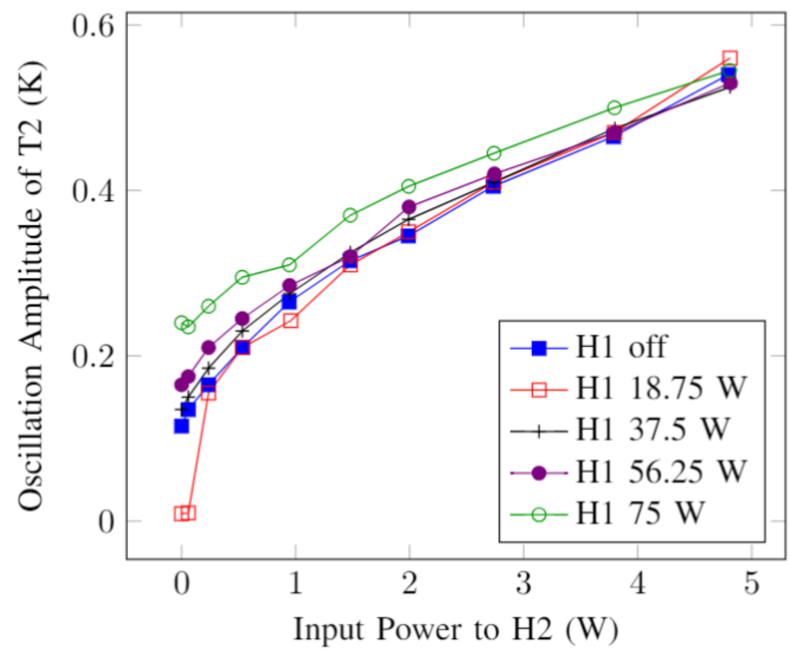


Cryomech PT420 Pulse Tube Refrigerator

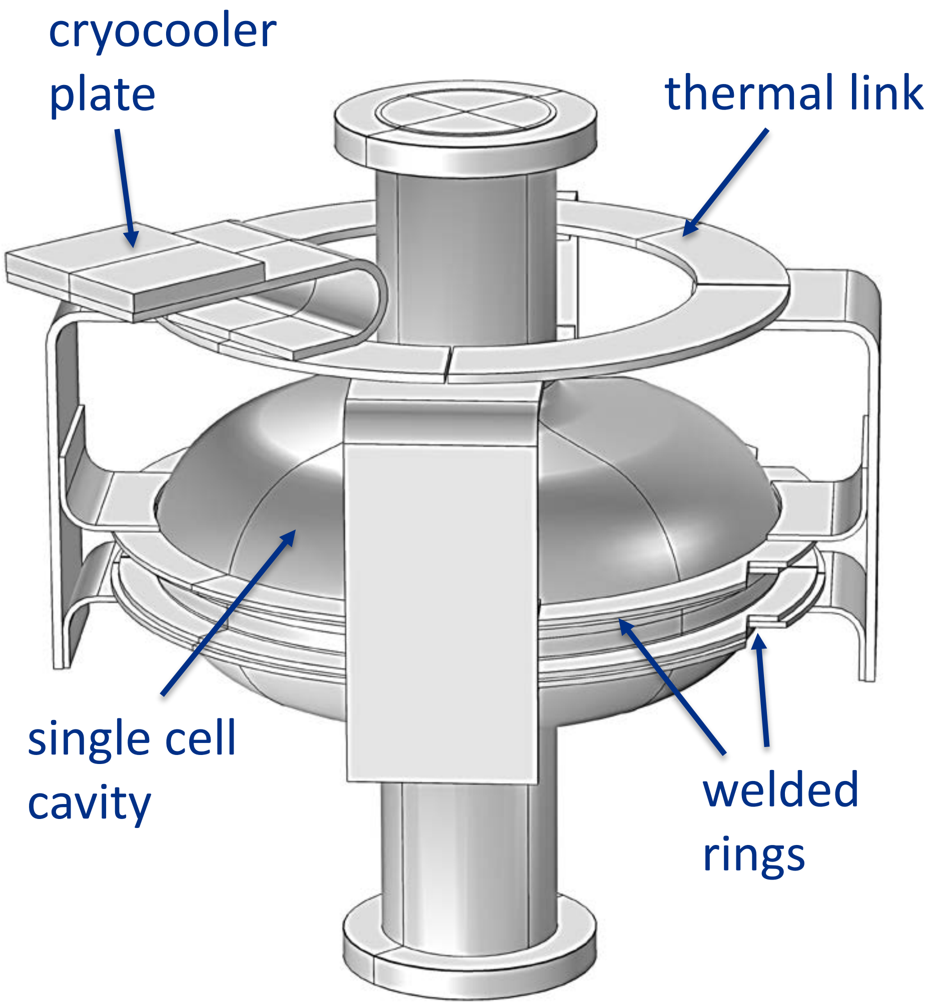
Cryocooler Measurements

- Measured the temperature of stage 2 as a function of heat input to stage 1 (H1) and to stage 2 (H2)
- Measured amplitude of cryocooler temperature oscillations
- Frequency of oscillation is about 1 Hz

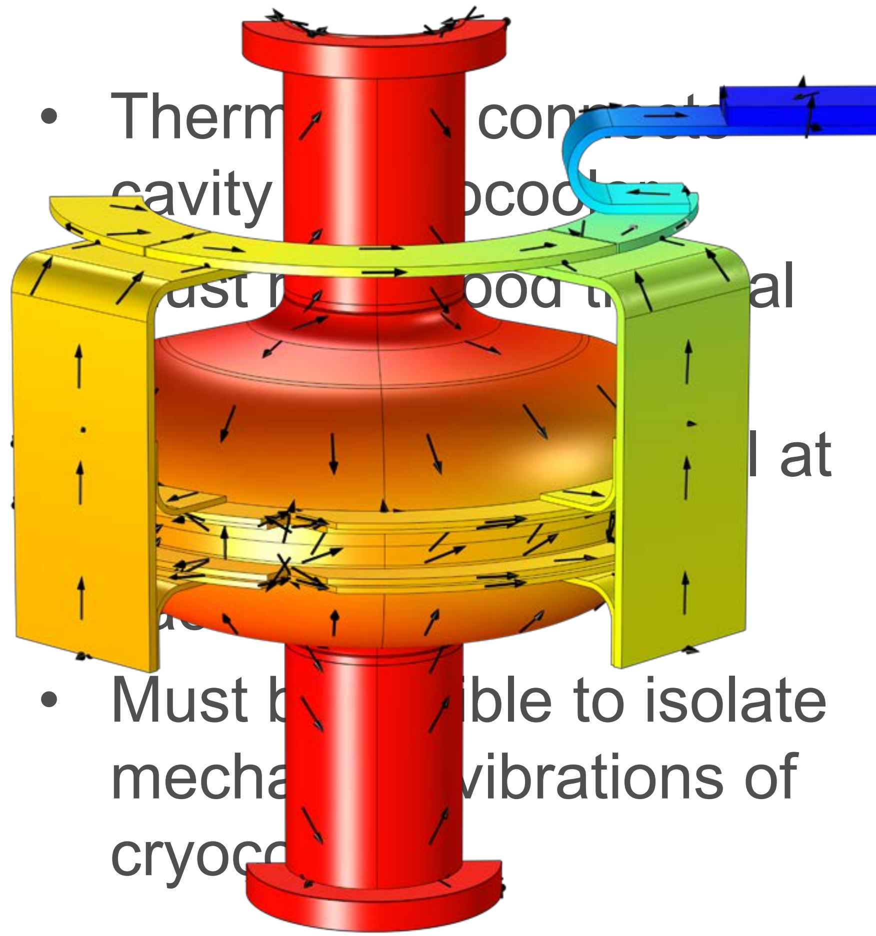




Simulated Geometry

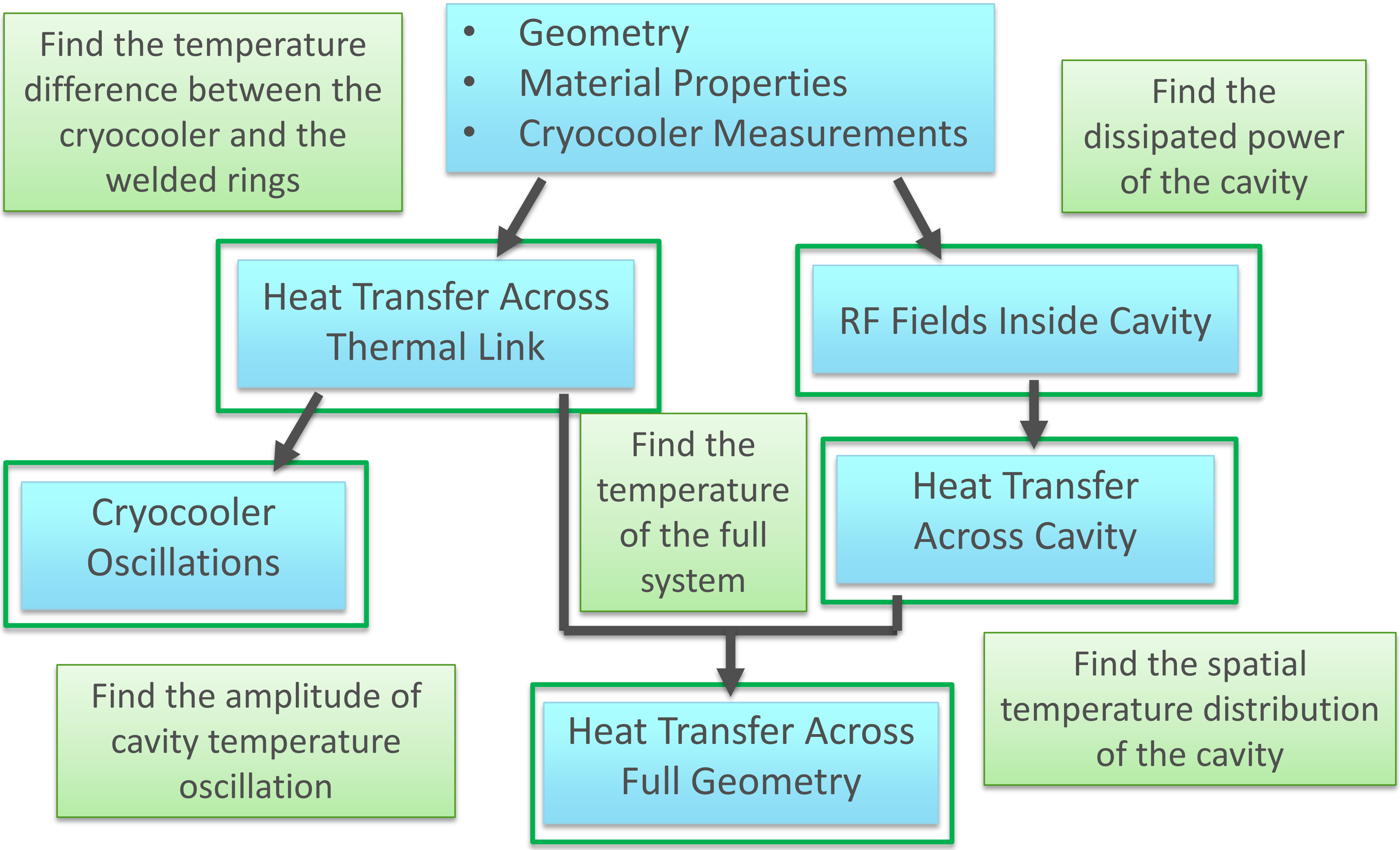


- Therm… conn… cavity … ocoo…
- …ust … ood t… al
- … l at
- Must b… ible to isolate mecha… vibrations of cryoc…



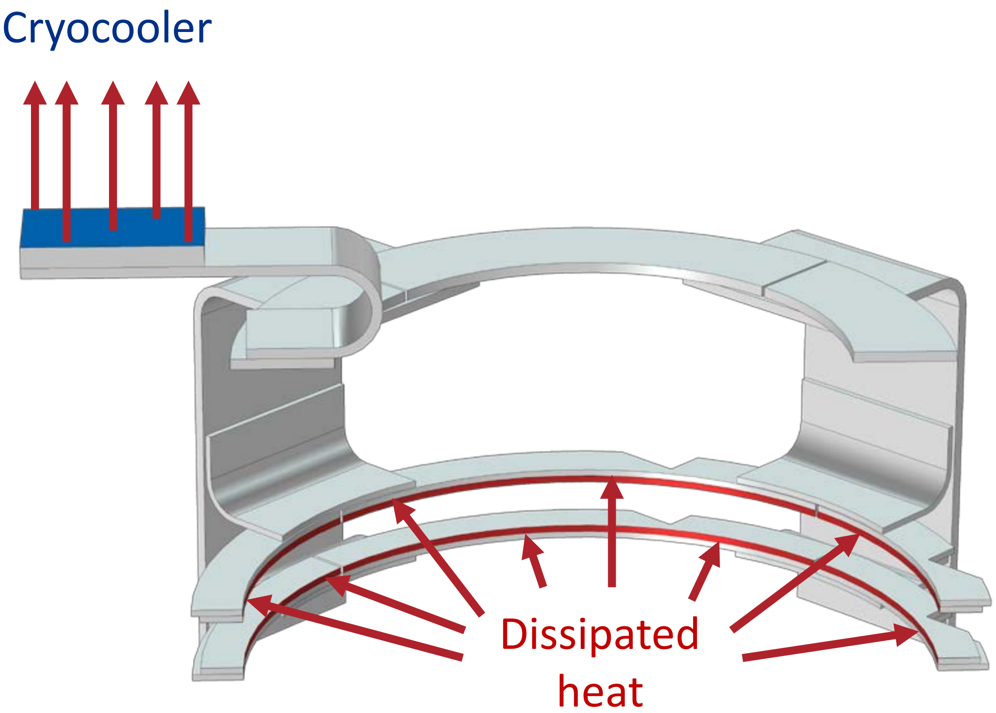
Expected Heat Flow

Simulation Procedure



Heat Transfer Across Thermal Link

- Heat flux is applied at weld faces of rings
- Constant temperature is applied at cryocooler plate
  - Used cryocooler measurements to determine this temperature
- Temperature at weld faces is measured



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Heat Transfer Across Thermal Link

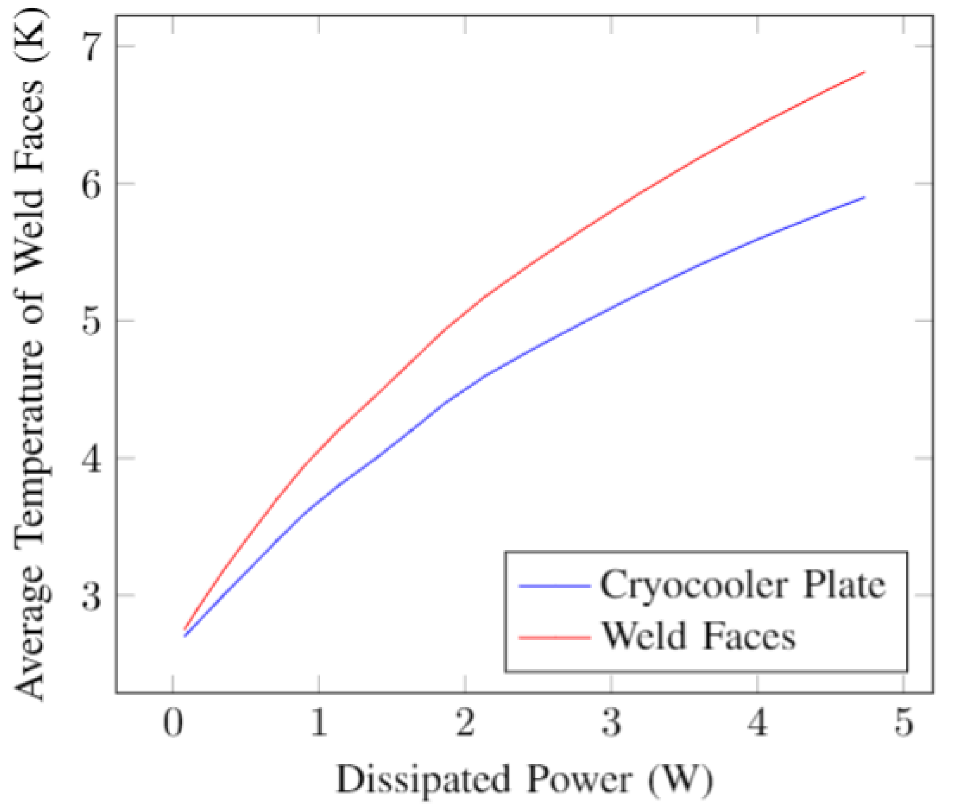
- Cavity temperature rises with dissipated power
- Dissipated power P_d can be approximated from E_{acc}

$$P_d = \frac{d^2 {E_{acc}}^2 R_S}{G\left(\frac{R}{Q}\right)}$$

d = length of cell

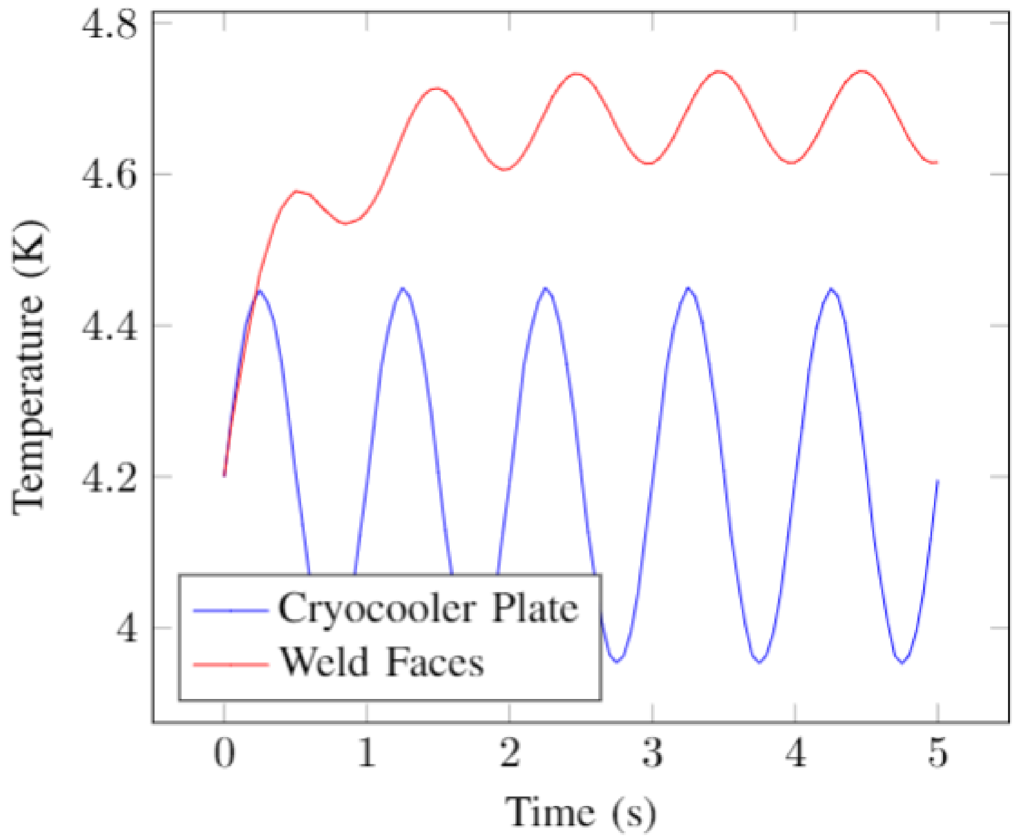
Rs = surface resistance

G, R/Q = known factors

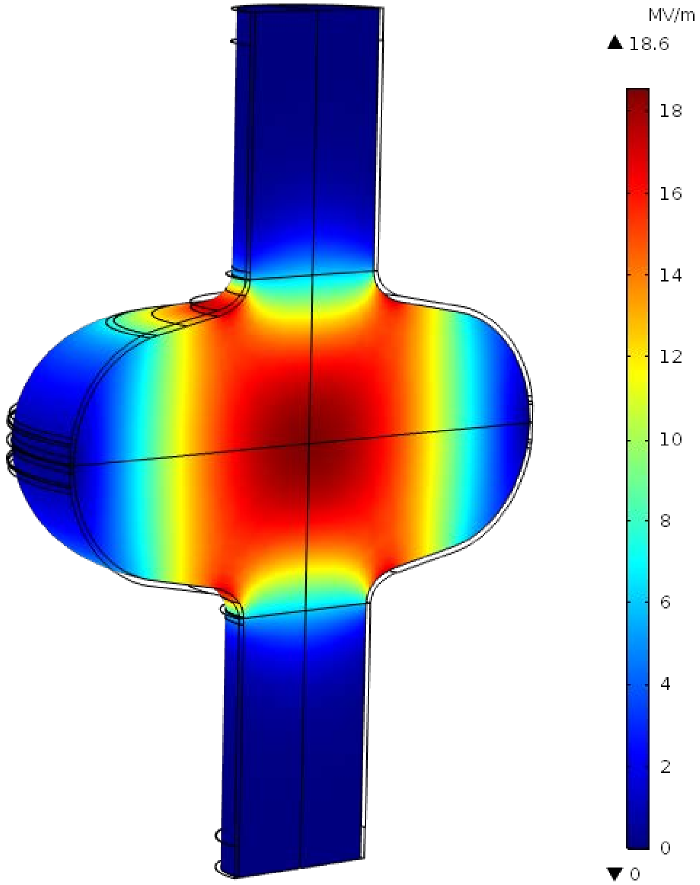


Cryocooler Oscillations

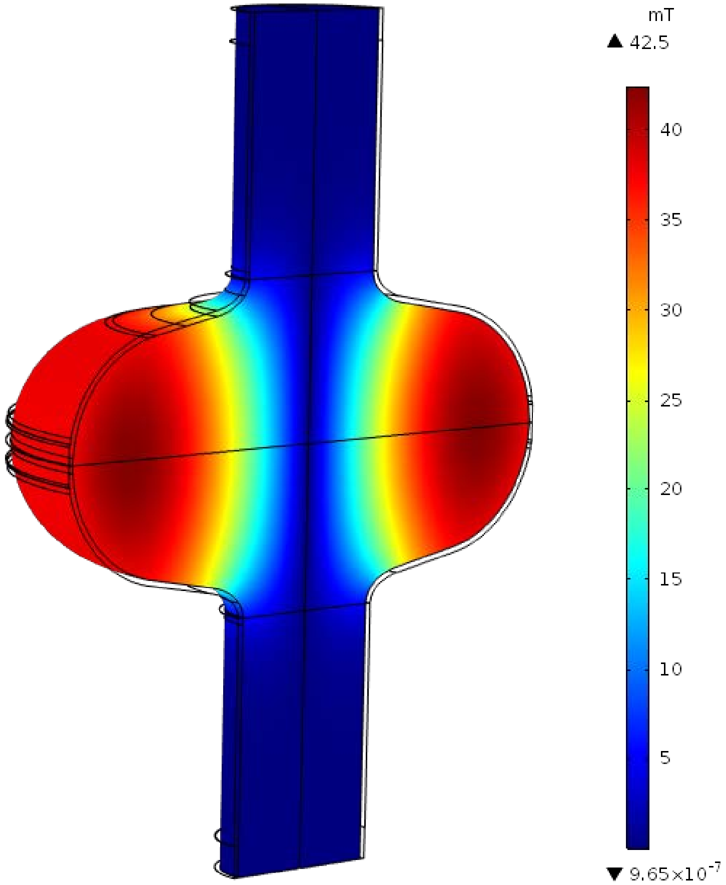
- Apply heat flux at weld faces
- Apply time-varying cryocooler temperature
- Measure time-varying temperature at weld faces
- Oscillations dampen before reaching cavity



RF Fields Inside Cavity



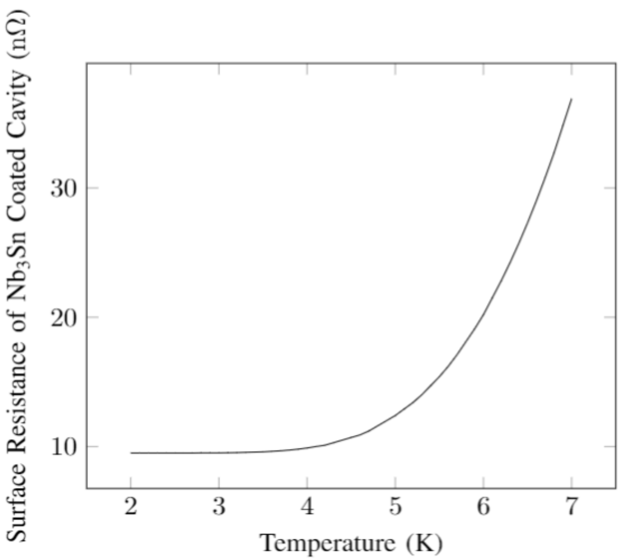
Electric field



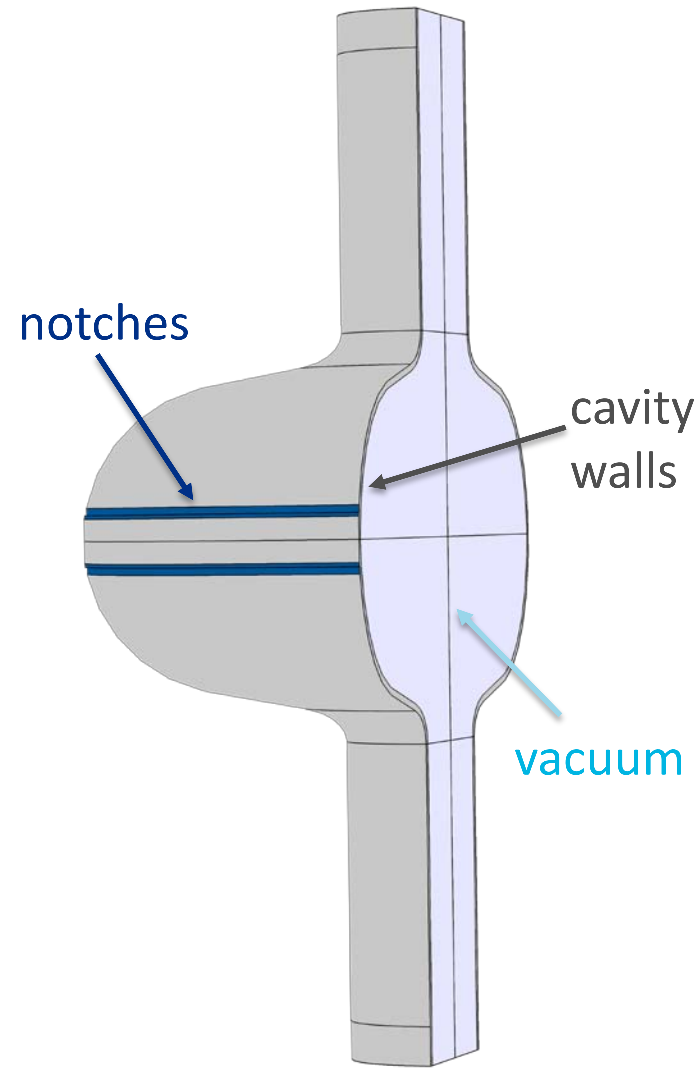
Magnetic field

Heat Transfer Across Cavity

- Use magnetic field *H* to find dissipated power on cavity walls
$$dP_d = \frac{1}{2} R_s |H|^2 dA$$
- Model heat flow from cavity walls to notches at constant temperature T_n

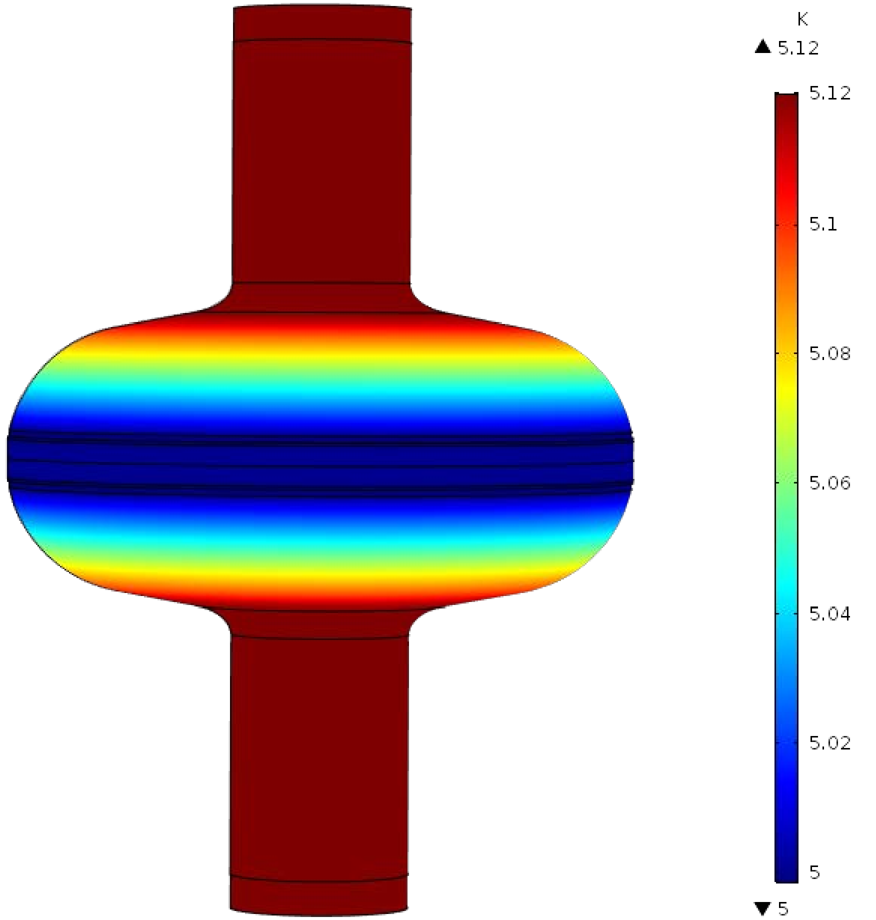


Data courtesy of Sam Posen



Heat Transfer Across Cavity

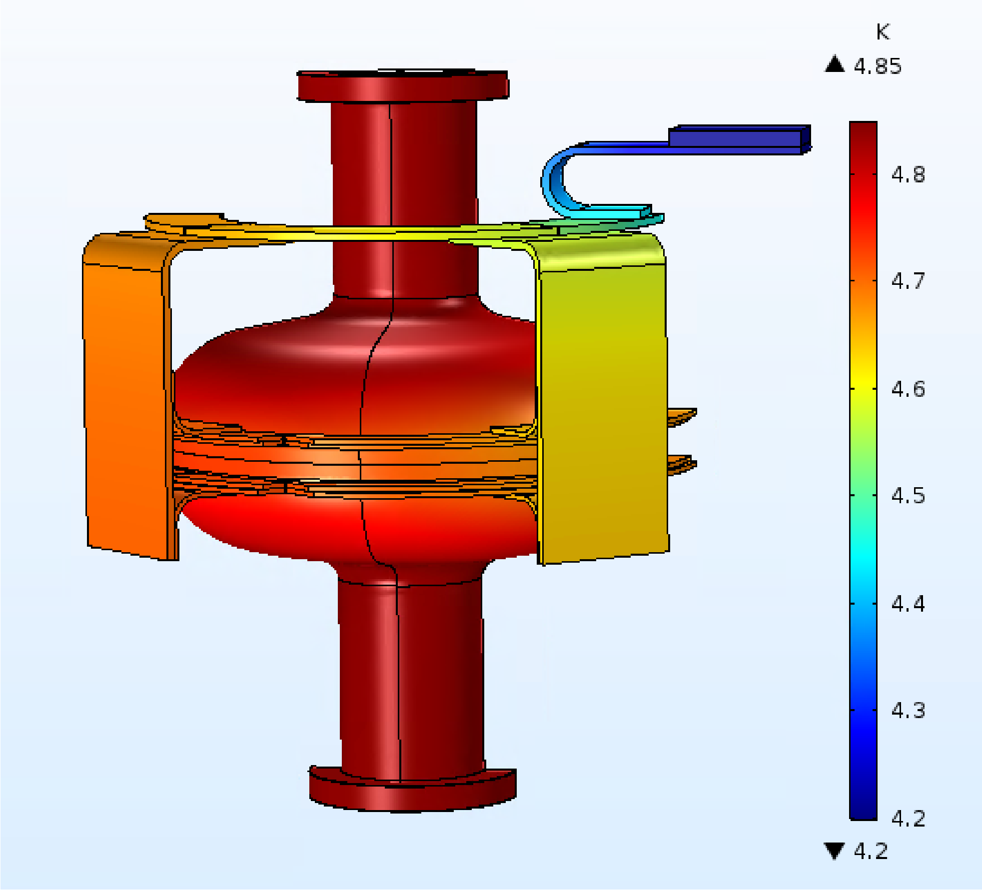
- Average temperature of cavity and maximum temperature of cavity are close to equal
  - Average temperature is a useful measure



Temperature

Heat Transfer Across Full Geometry

- Model heat flow from cavity walls to cryocooler plate
- Temperature difference is sum of difference from previous simulations



Conclusions

- At an accelerating gradient of 12 MV/m or less, the cavity temperature is less than 7 K
- The temperature across the cavity is nearly spatially uniform
- Temperature oscillations in cryocooler dampen before reaching the cavity
- Conduction cooling this geometry with a cryocooler is viable

Acknowledgements

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