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An exchange-gas vibration Isolation system for a general-purpose 4K research cryostat

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An exchange-gas vibration isolation system for a general-purpose 4K research cryostat

Motivation

- Sensitive SQUID sensors
- ADR temperature < 50mK
- Future: ultralow temperatures and vibration

- General purpose research cryostat
- Large 4K experimental space (35 liters)
- 45A superconducting magnet, iron and lead shielding (20 kg)
- Cryogen free
  - Pulse-tube refrigerator
  - High power dissipation at 65K
  - Good thermal coupling at 4K

Vibration isolation approaches

- Flexible links (+active cancellation)

  T. Tomaru, *Cryocoolers* **13**, 695-702 (2005)
  S. Caparelli, *RSI* **77**, 095102 (2006)

- Self cancellation

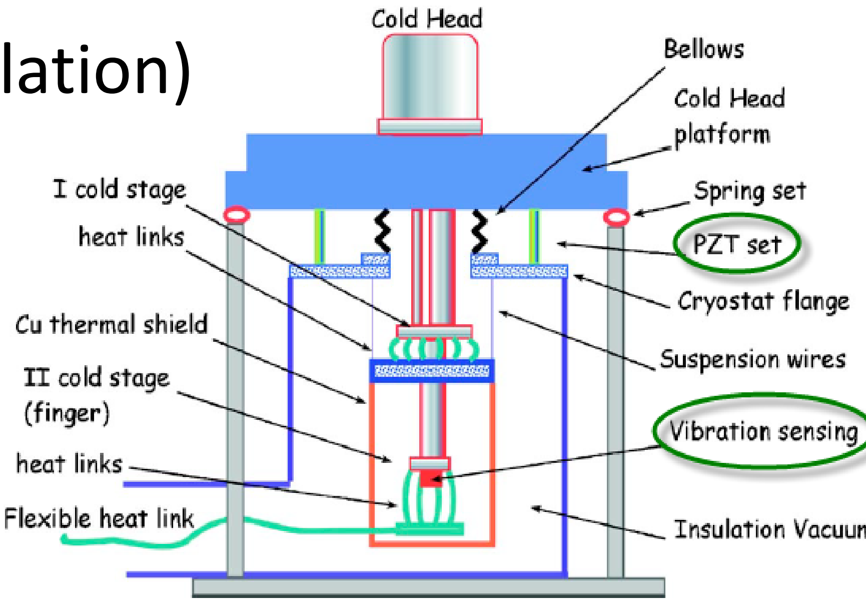
  T. Suzuki, *Cryo Prague* (2006)

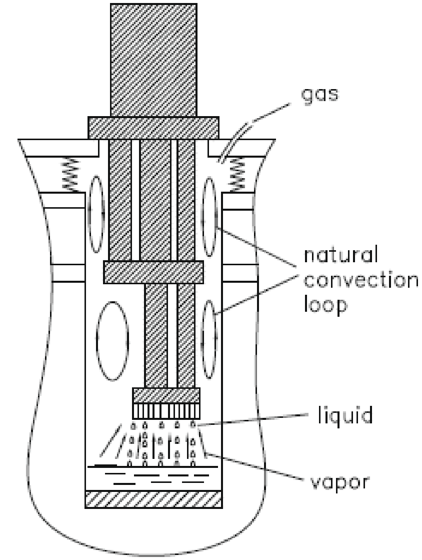
- Exchange gas

  R. C. Longsworth, US Patent No. 3,894,403 (1975)
  P. Boolchand, *RSI* **66**, 3051 (1995)
  R. Wang, G. Dick at JPL (1998)

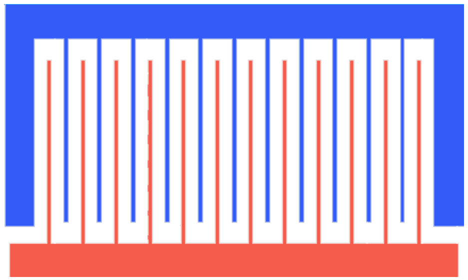
- Exchange gas / Reliquefication

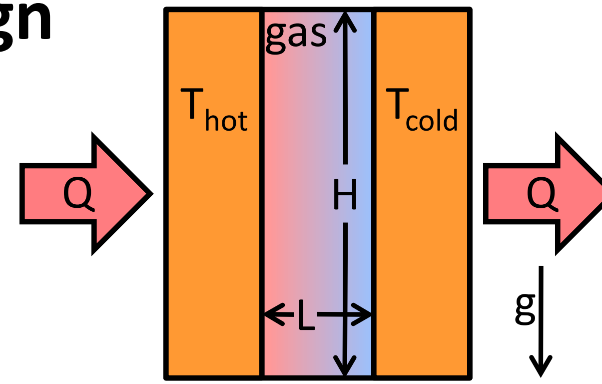
  C. Wang at Cryomech, *Cryogenics* **50,** 336–341 (2010)



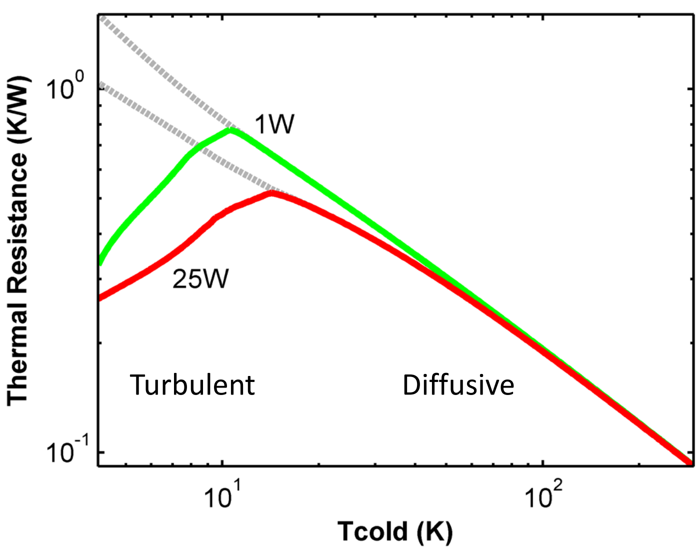


Heat Exchanger Design





- Goal: Gas impedance better than PTR source impedance
- Model as closed parallelepiped with vertical hot and cold surfaces
- Nusselt number: $Nu = \dfrac{\sigma_{Convective}}{\sigma_{Diffusive}}$



$$\mathrm{Nu} = \max\left(\mathrm{Nu}_{ct}, \mathrm{Nu}_{l}, \mathrm{Nu}_{t}\right),$$

$$\text{where } \mathrm{Nu}_{ct} = \left[1 + \left\{\frac{0.104\,\mathrm{Ra}^{0.293}}{1+\left(6310/\mathrm{Ra}\right)^{1.36}}\right\}\right]^{1/3},$$

$$\mathrm{Nu}_{l} = 0.242\left(\mathrm{Ra}\,L/H\right)^{0.273}, \text{ and}$$

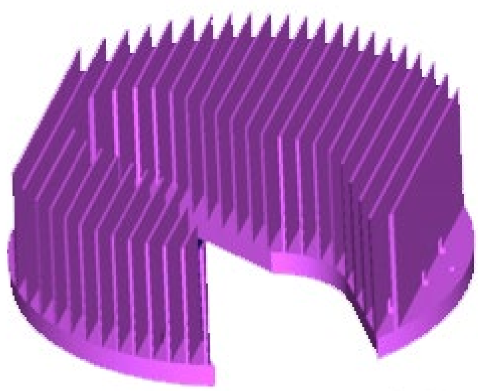
$$\mathrm{Nu}_{t} = 0.0605\,\mathrm{Ra}^{1/3}.$$

S. M. ElSherbiny *et al.*
Handbook of Heat Transfer

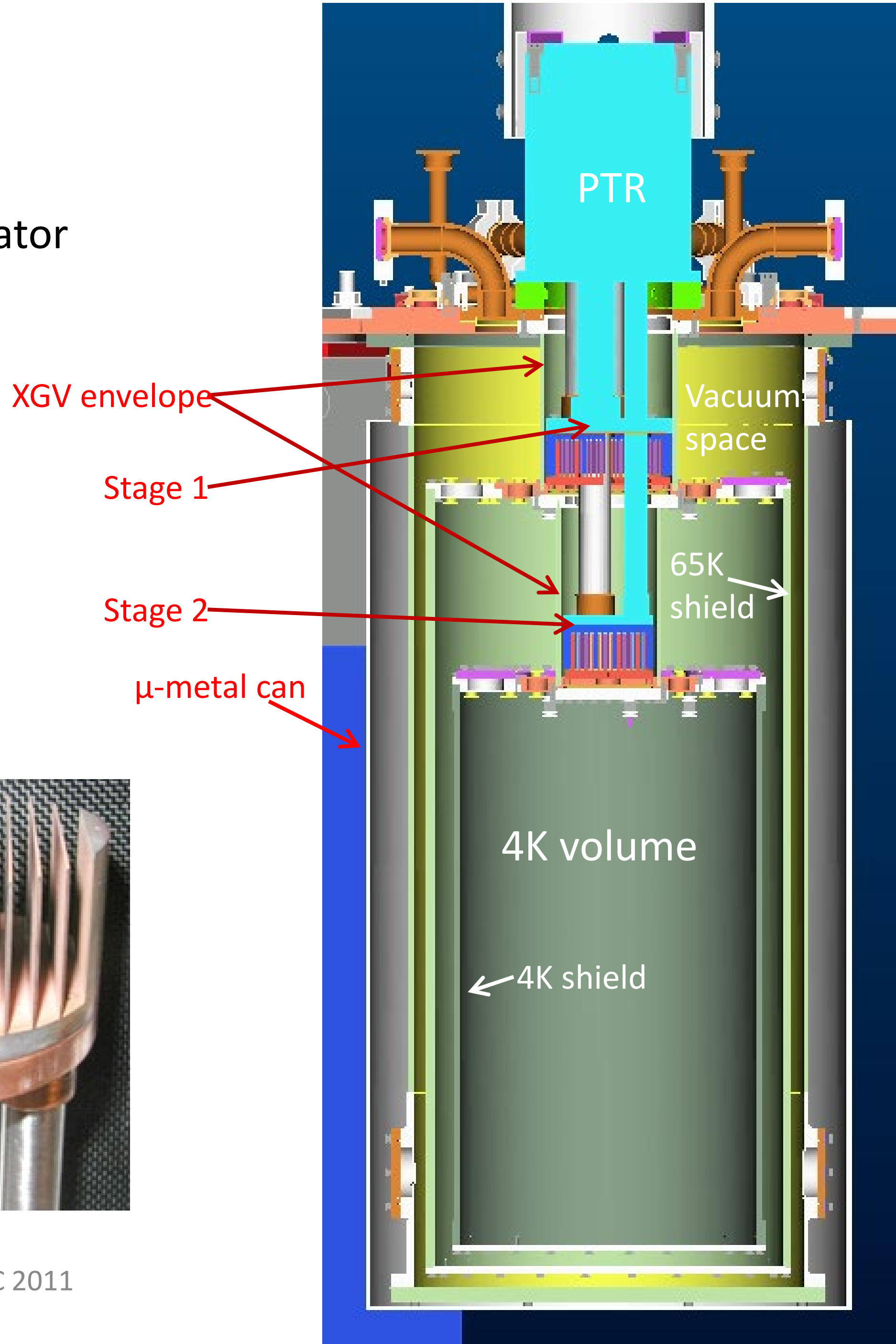
Implementation

- •Cryomech Inc PTR-405 pulse tube refrigerator
- •OFHC Cu heat exchangers
- •Gas Gap: 1.47 mm
- •XGV envelope made from G-10 tubes

Stage 1
Area: 1038 cm^2



Stage 2
Area: 580 cm^2



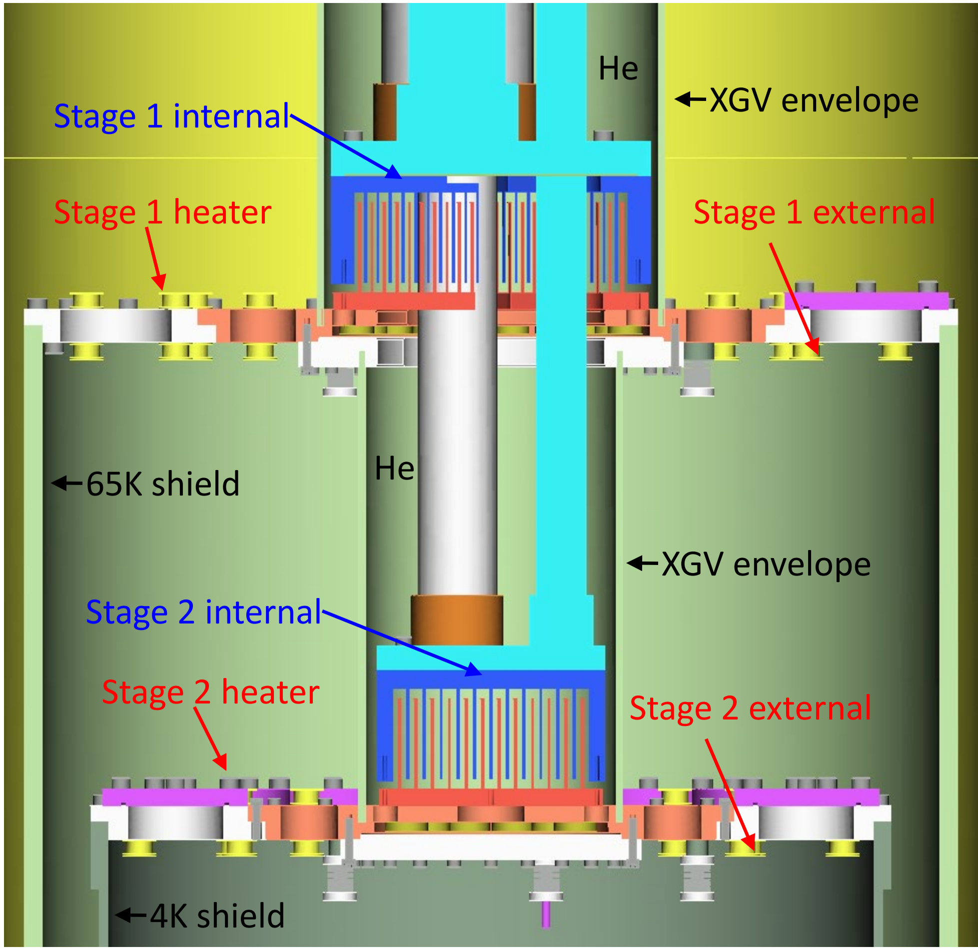
Instrumentation

Thermal management

- Cernox and Si-diode temperature sensors
- 25 W heater on stage 1 (external)
- 1 W heater on stage 2 (external)
- Software PI control

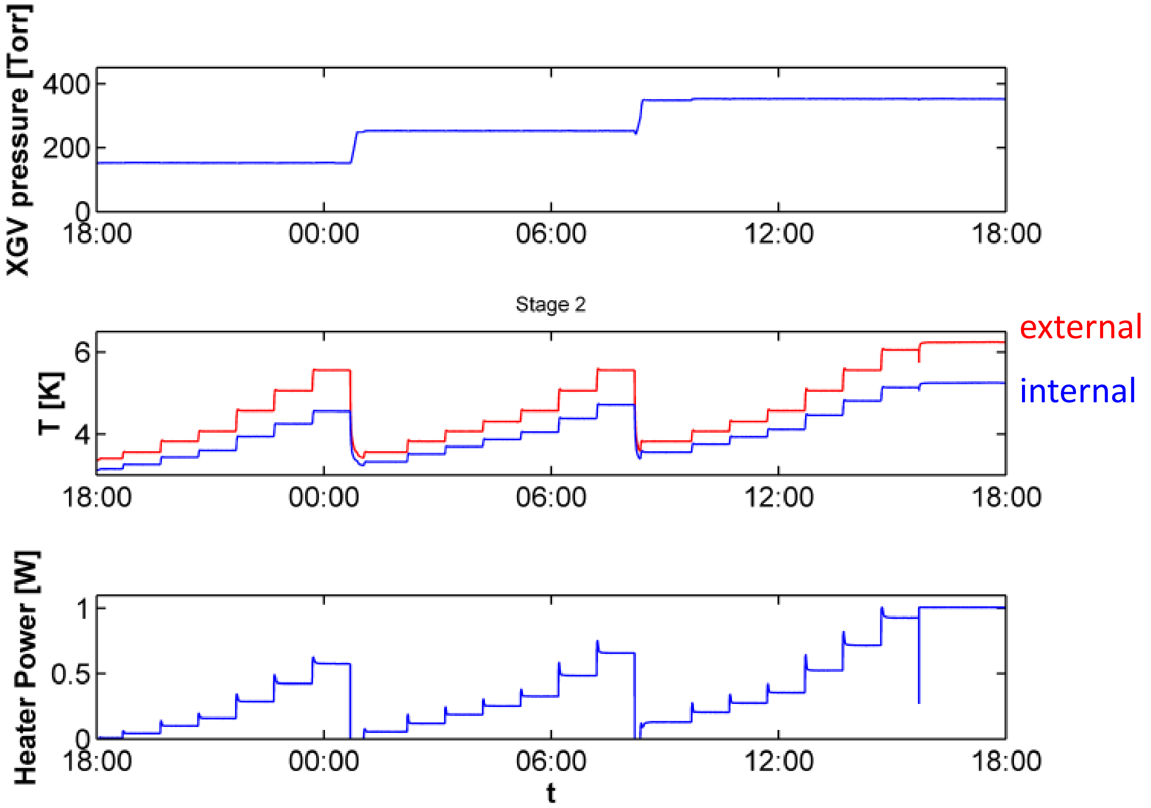
Exchange gas control

- MKS Baratron 626, 1000 Torr
- Automated fill- and pump-valves
- Pressure regulated within 3 Torr



Thermal Performance Study

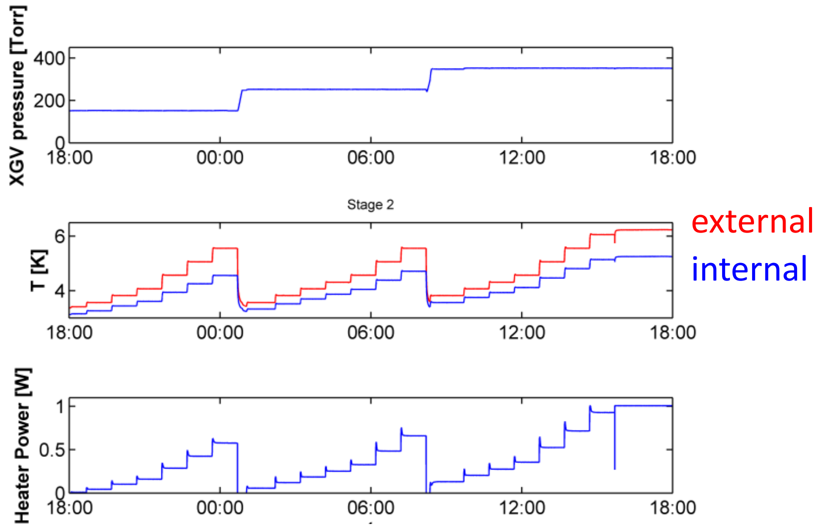
- Measurement process:
  - Regulate XGV pressure & stage 1 and 2 *external* temperatures
  - Record external and internal temperatures & servo powers



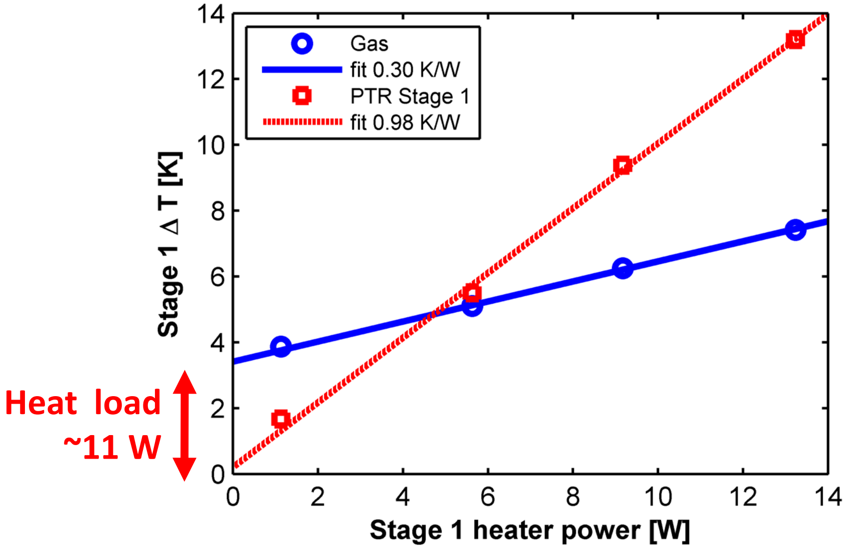
- Extract equilibrium heater powers and thermal standoffs

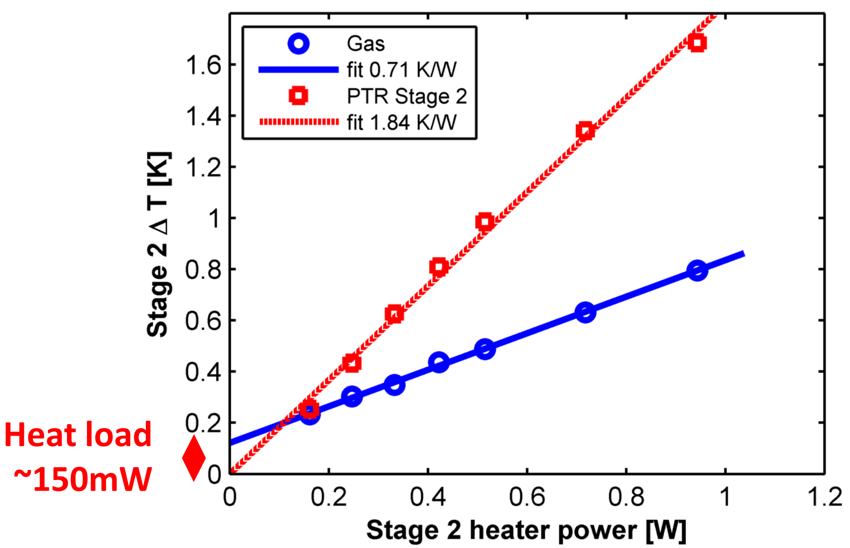
Thermal Performance Study

- Measurement process:
  - Regulate XGV pressure & stage 1 and 2 *external* temperatures
  - Record external and internal temperatures & servo powers



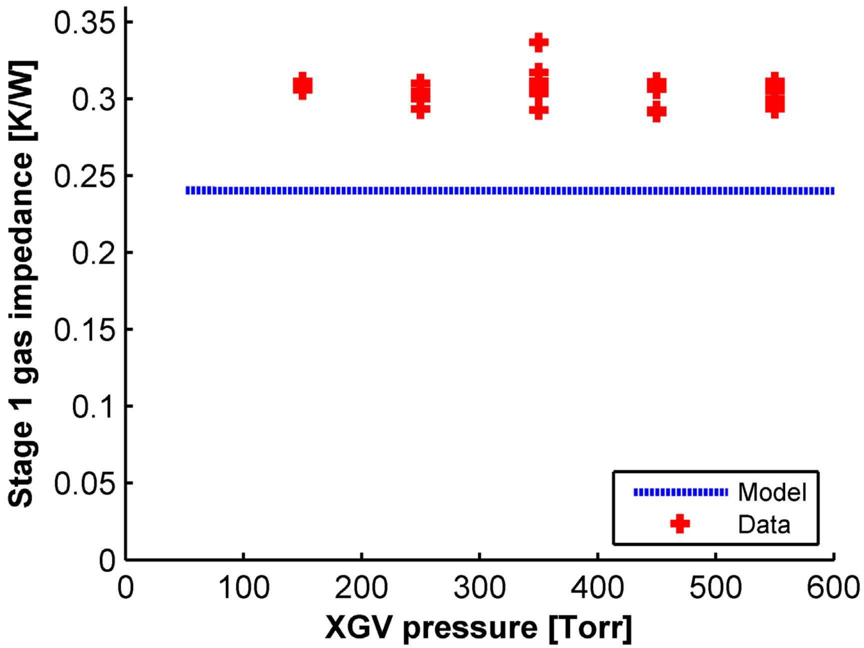
- Data reduction





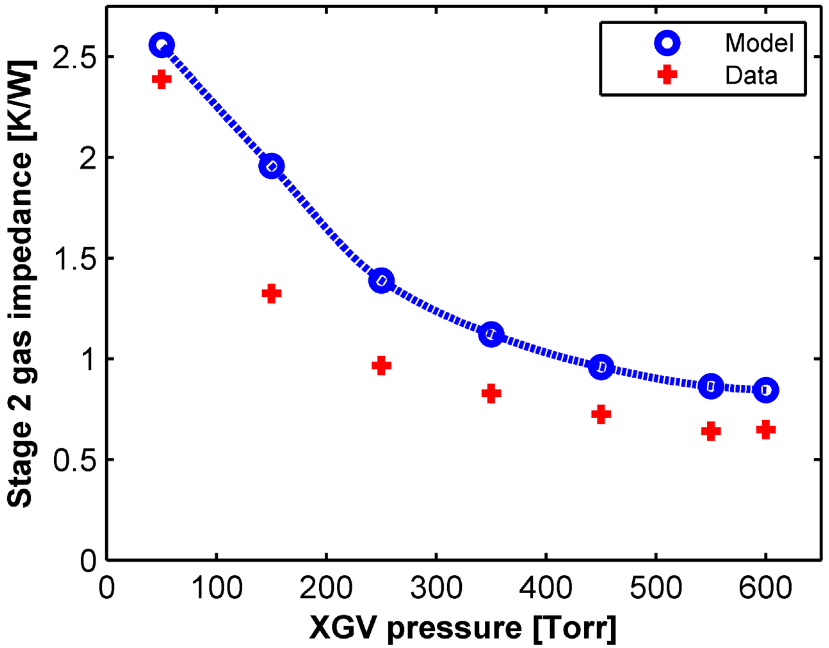
Gas Thermal Impedance

Stage 1



Gas	0.31 K/W
Source	0.98 K/W

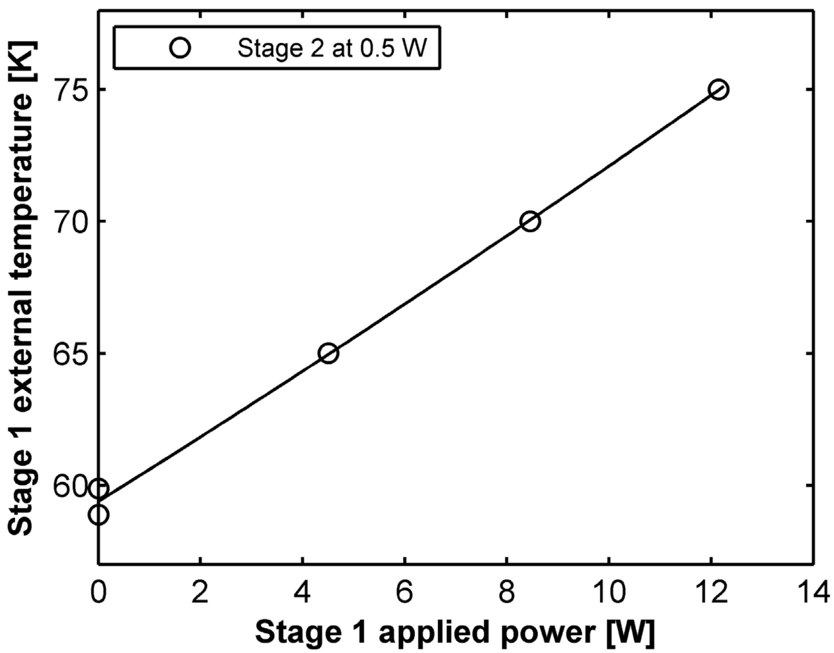
Stage 2



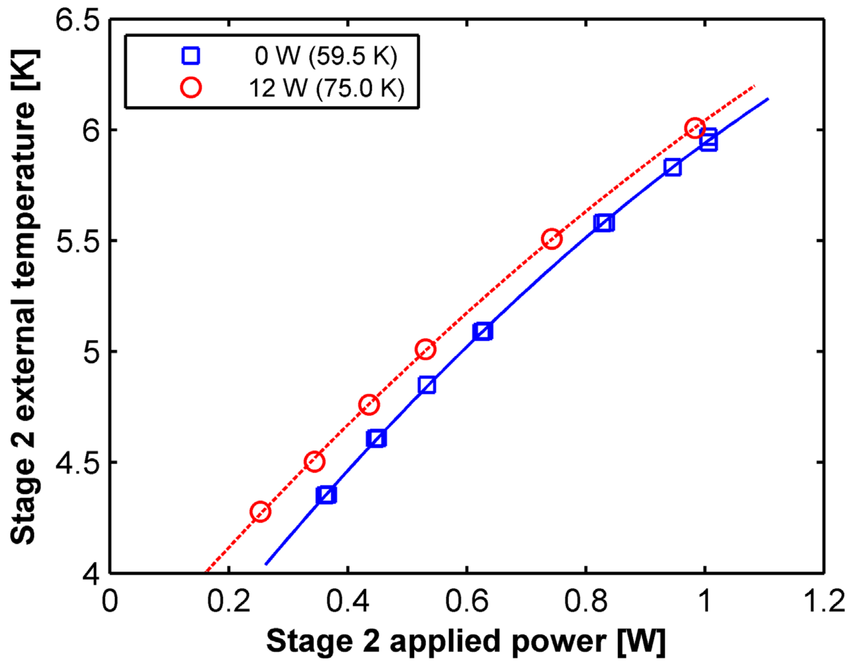
Gas	0.67 K/W
Source	1.8 K/W

External Temperatures versus Heat Load

Stage 1



Stage 2

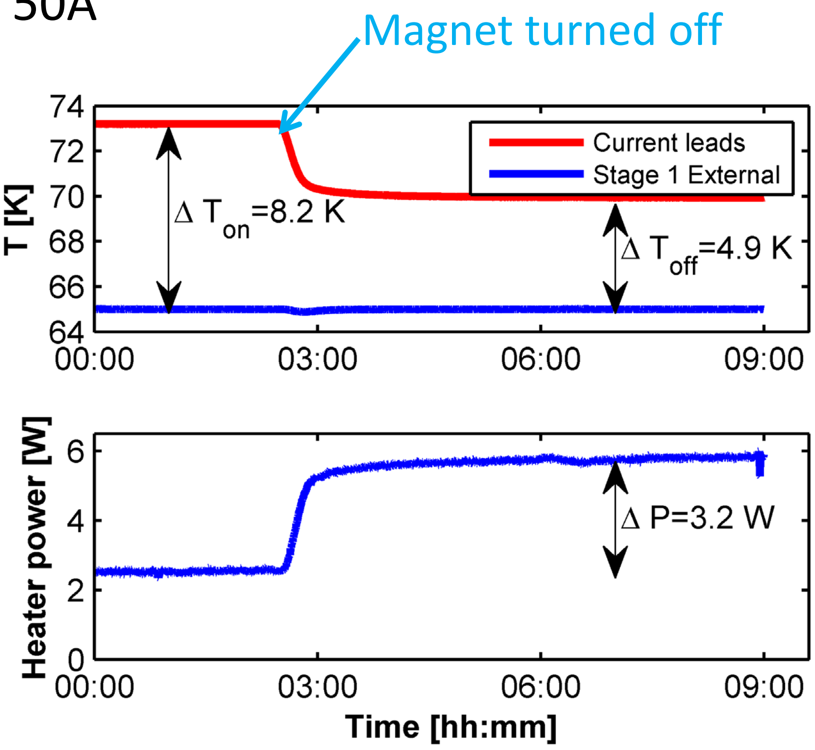


T < 4.8K for 0.5W

Running a 45A Magnet

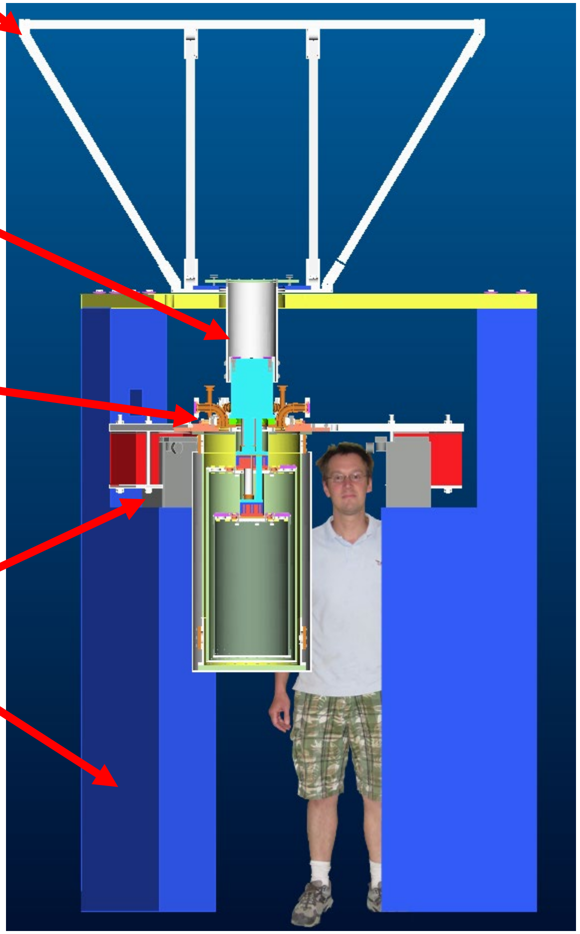
- Hi-T_C current leads: HTS-110 Cryosaver, 100A
- Brass leads from room temperature to stage 1
  - optimized for lowest power at 50A

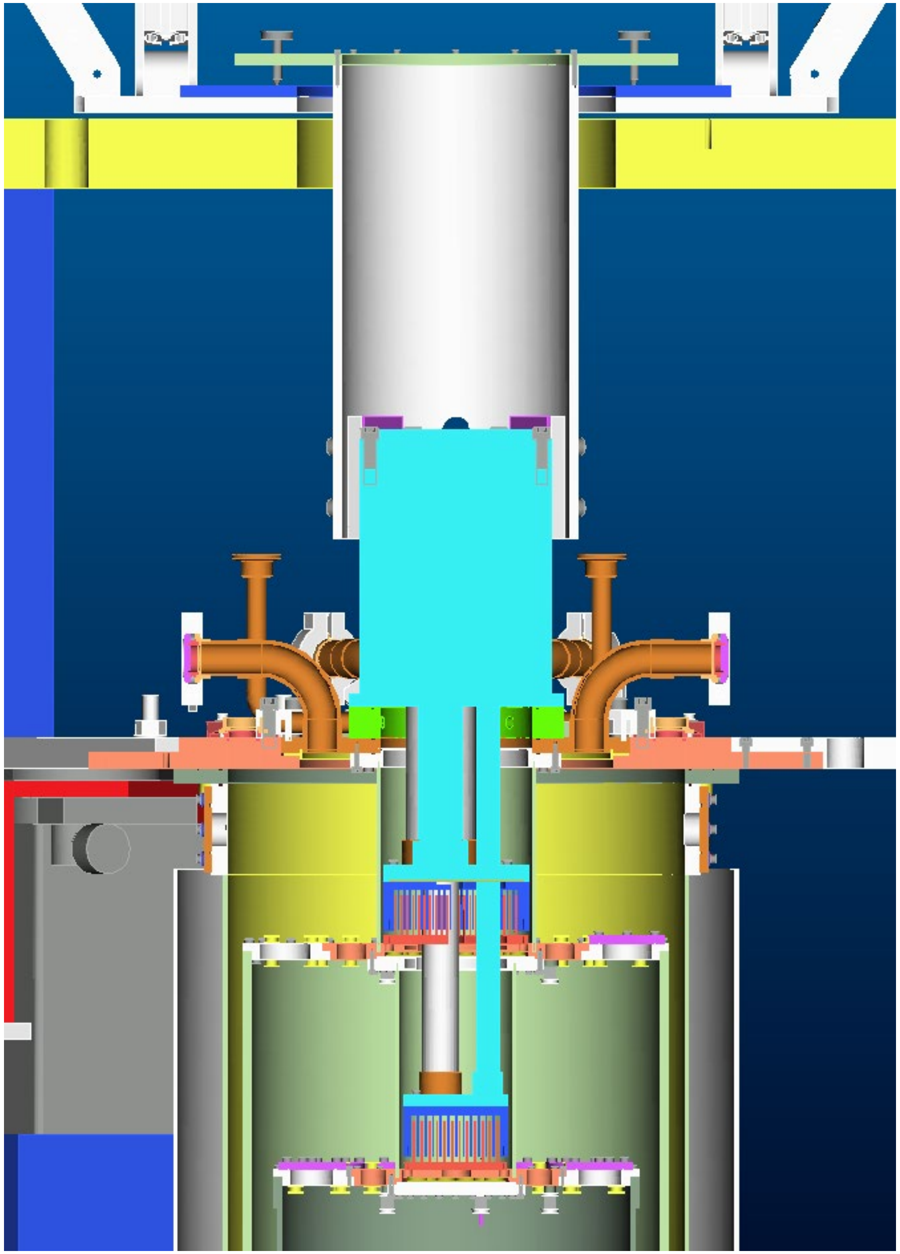
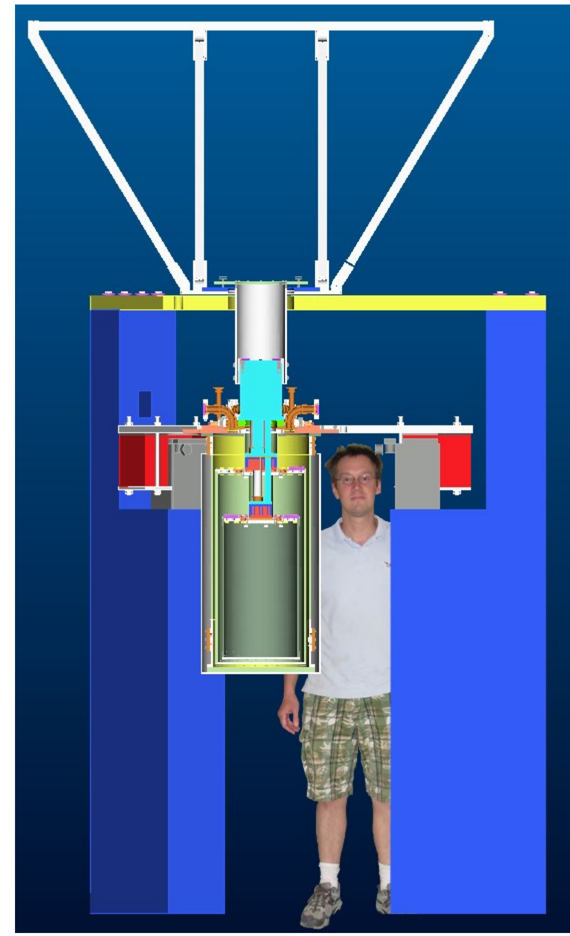
Joule heating at 45A: 3.25W
Thermal impedance: 1.0 K/W
Heat leak through brass: 4.93 W

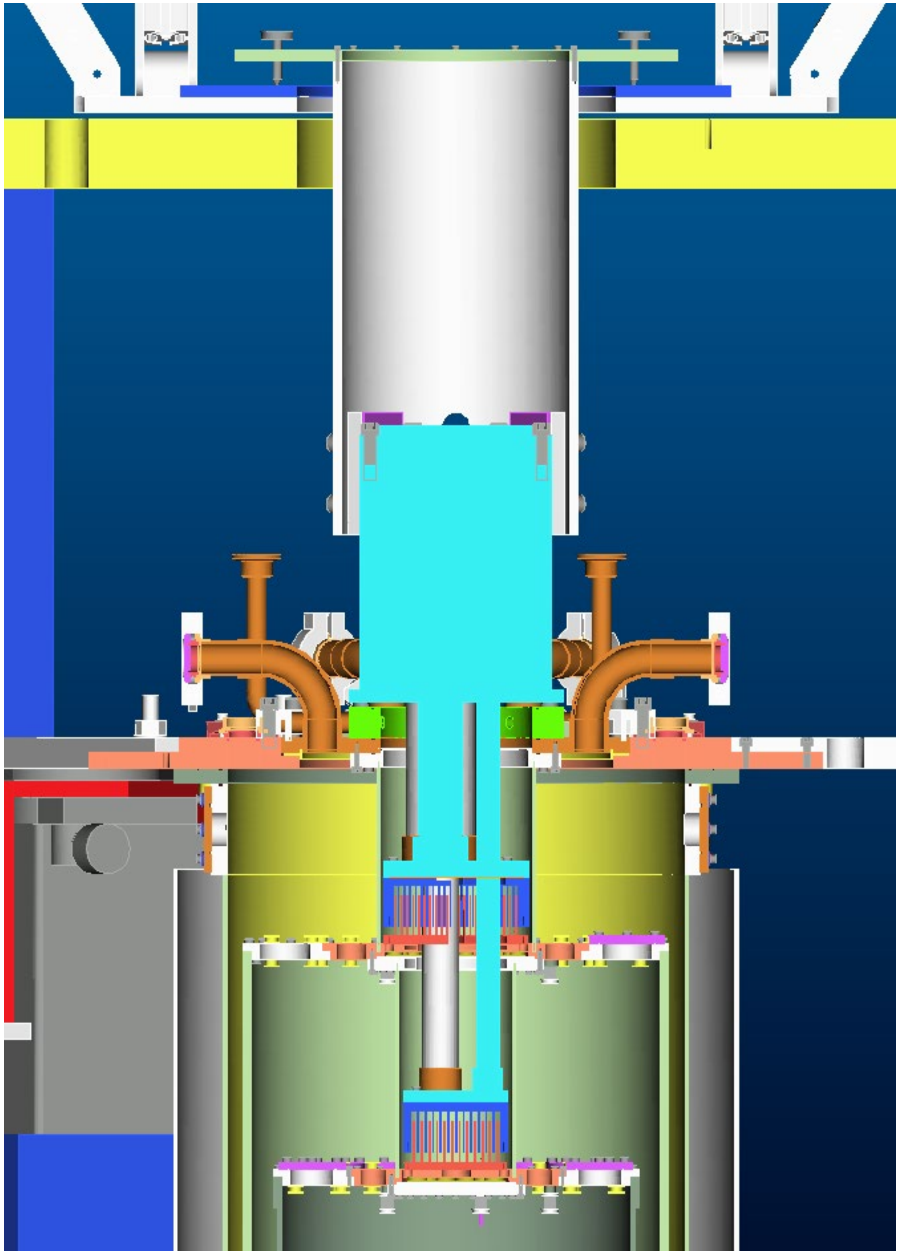


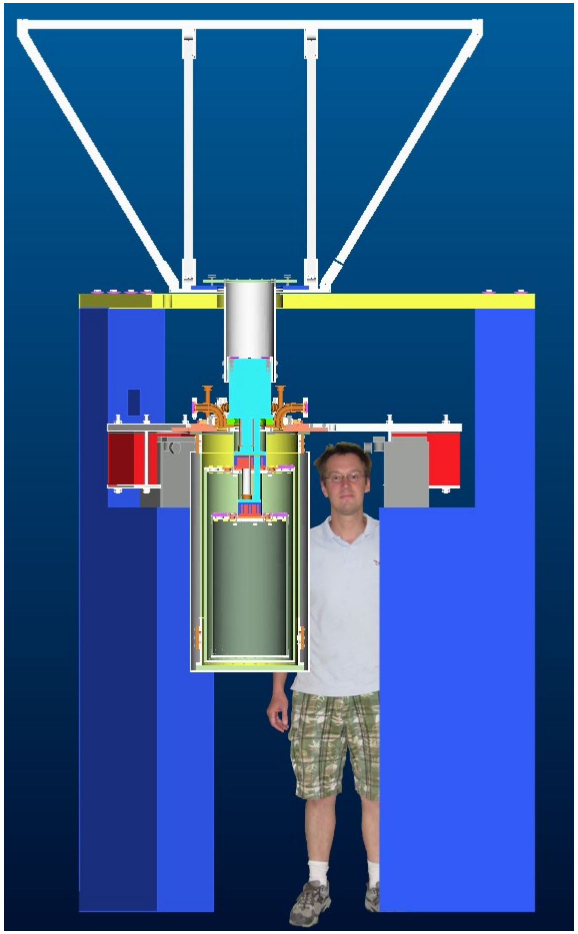
Vibration measurements

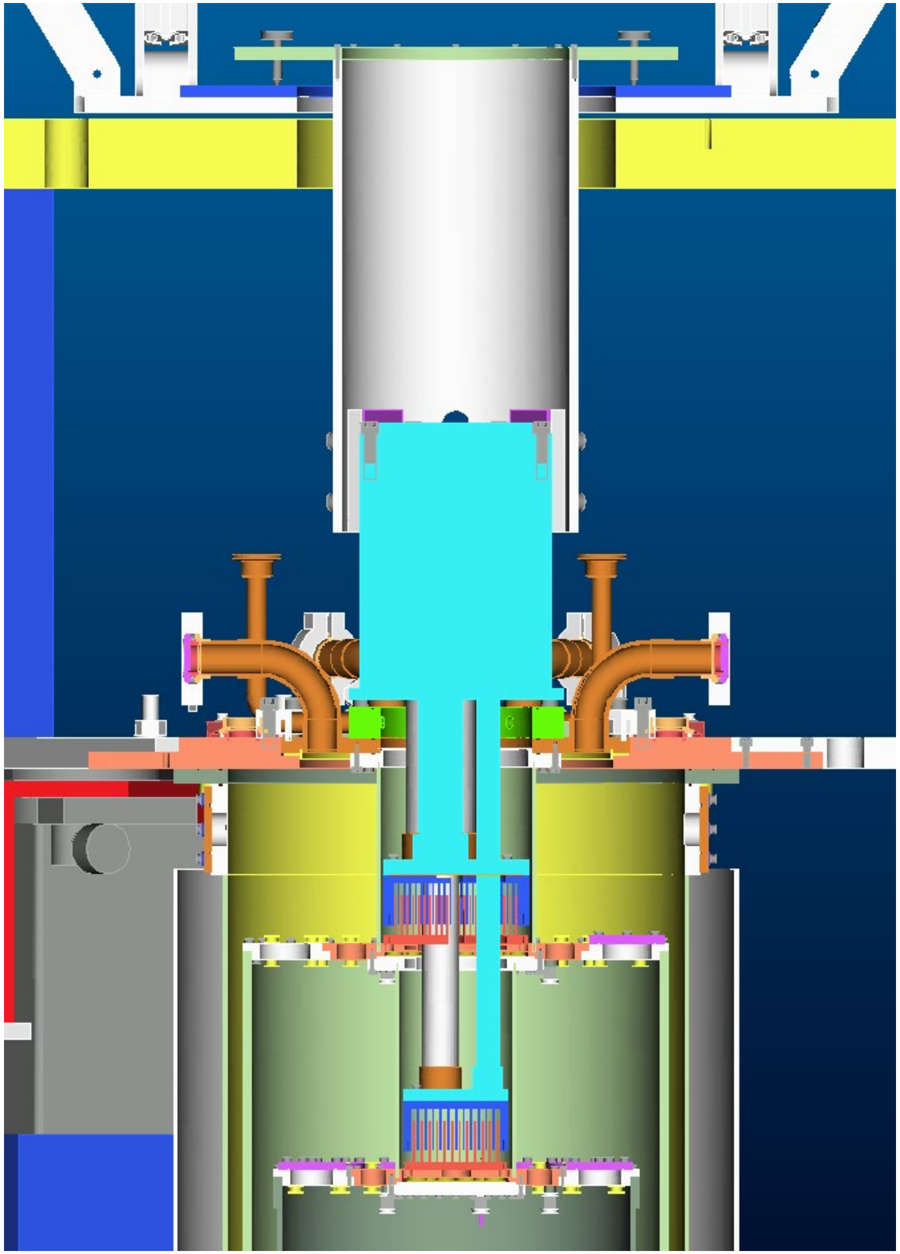
- three HS-1 geophones
- low noise preamplifier
- PTR separately supported from roof
- XGV under slight overpressure

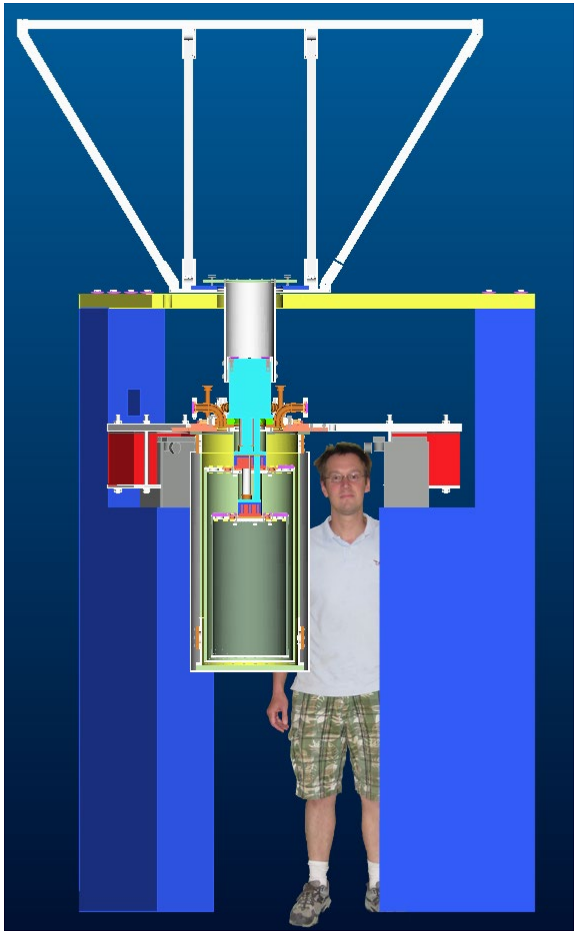


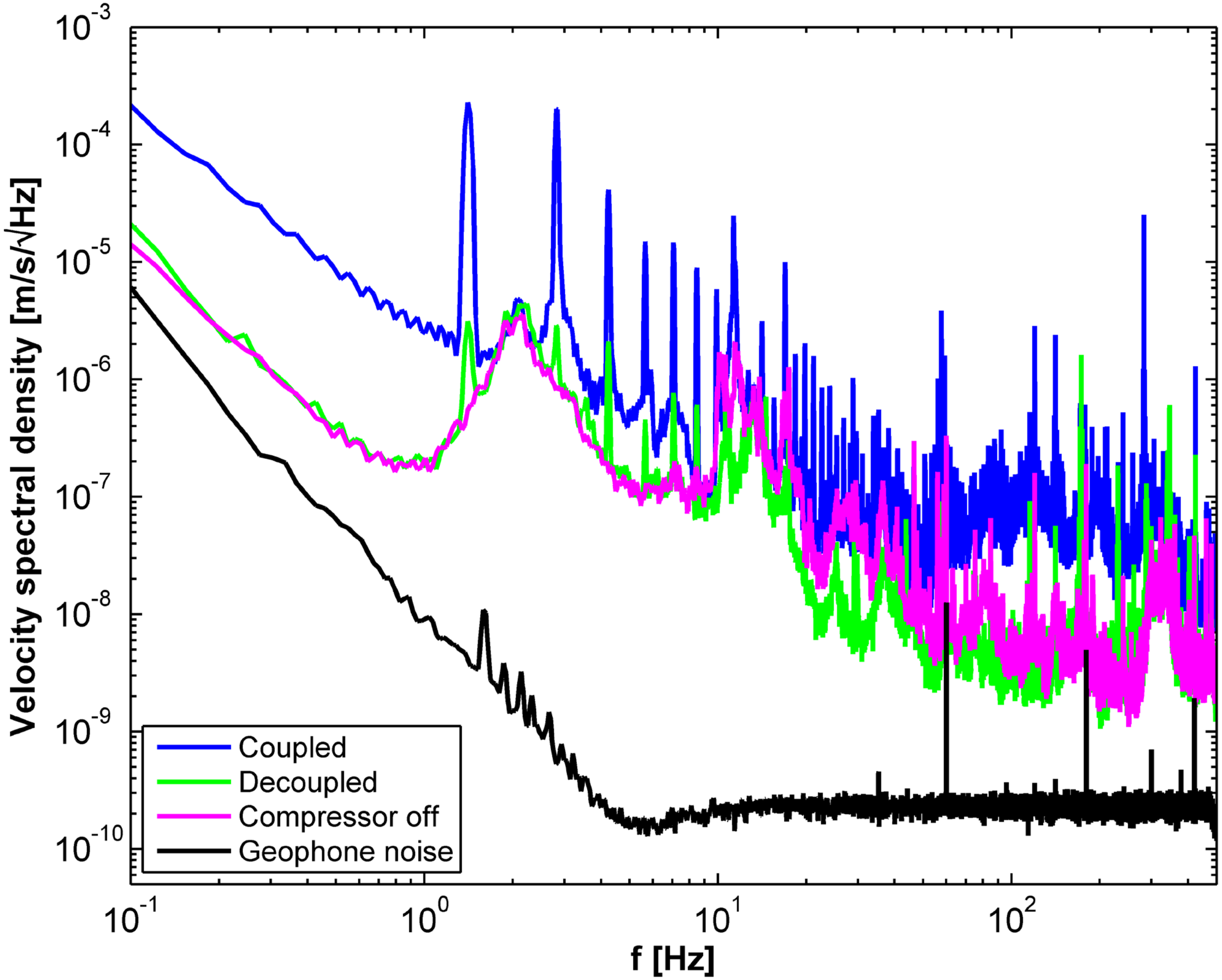








Vibration isolation

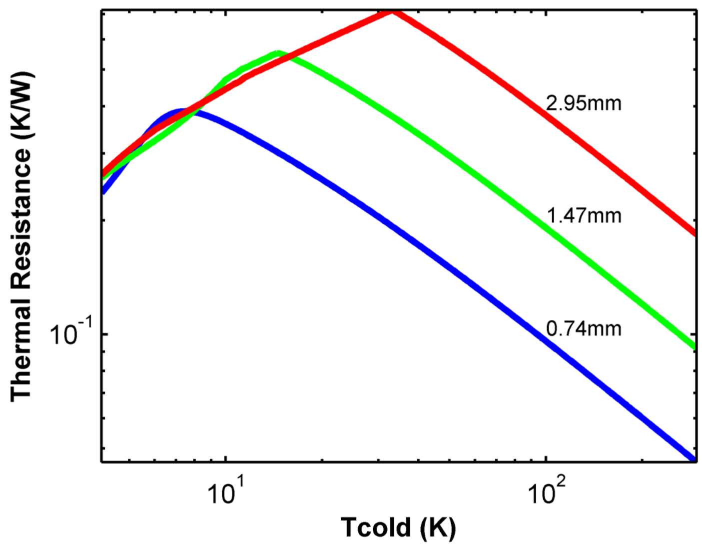


Summary

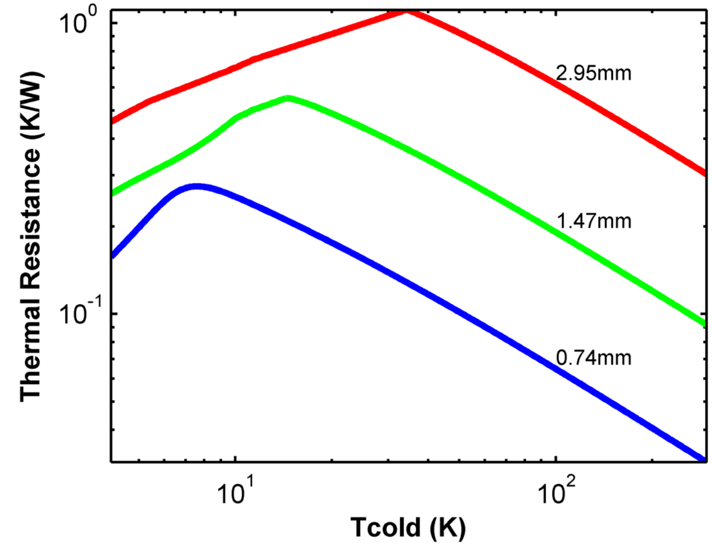
- Exchange-gas approach appears feasible for larger general-purpose cryostats
  - Thermal impedance agrees with design calculations
  - Preserves cooling power and base temperature well
    - Good conductance through exchange gas
    - No evidence of Taconis oscillations or convection rolls
- Promising initial vibration isolation results
  - PTR noise already negligible compared to floor noise
  - Clear path to further improvement:
    - Increase stiffness of PTR support plate
    - Increase damping of cryostat floating table's eigenmodes
- E-mail for manuscript: stpboyd@unm.edu

Thermal Impedance Estimate

Fixed total fin area



Fixed heat exchanger volume



High T, small Ra, laminar boundary layer -> diffusive
Low T, large Ra, turbulent convection

- At 65K, gap matters more
- At 4K, convection boosts 5-fold