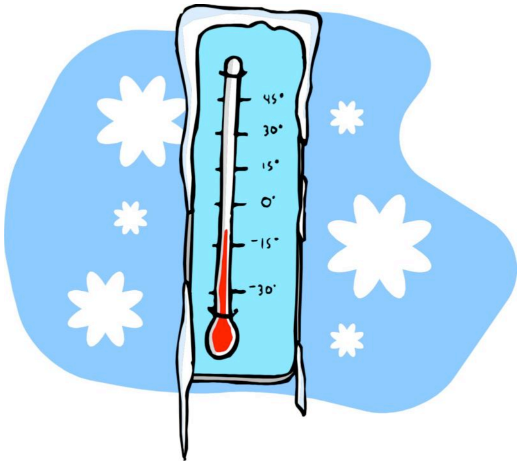
LIGO Voyager Cryogenics at Stanford

Brett Shapiro
Brian Lantz, Edgard Bonilla, Carissa Cirelli, Alex DeMaio

LVC Pasadena– 14 March 2017

Stanford Cryogenic Prototype Goals

- Cool the test mass to 124 K



Stanford Cryogenic Prototype Goals

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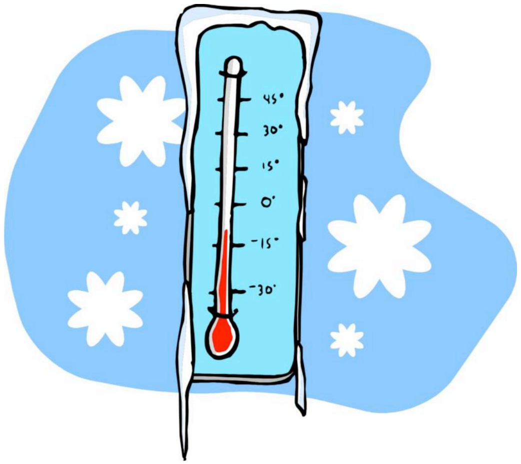
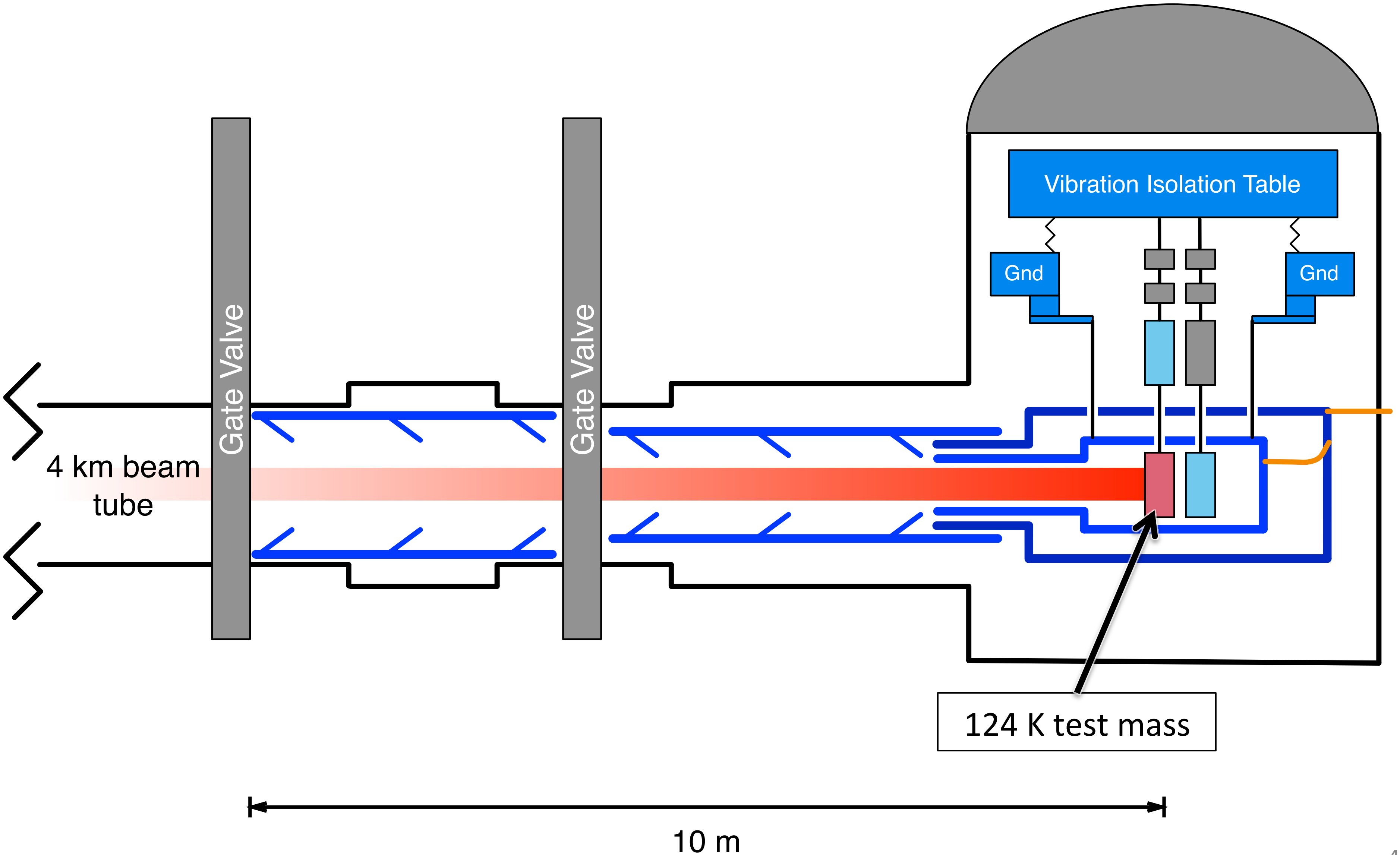
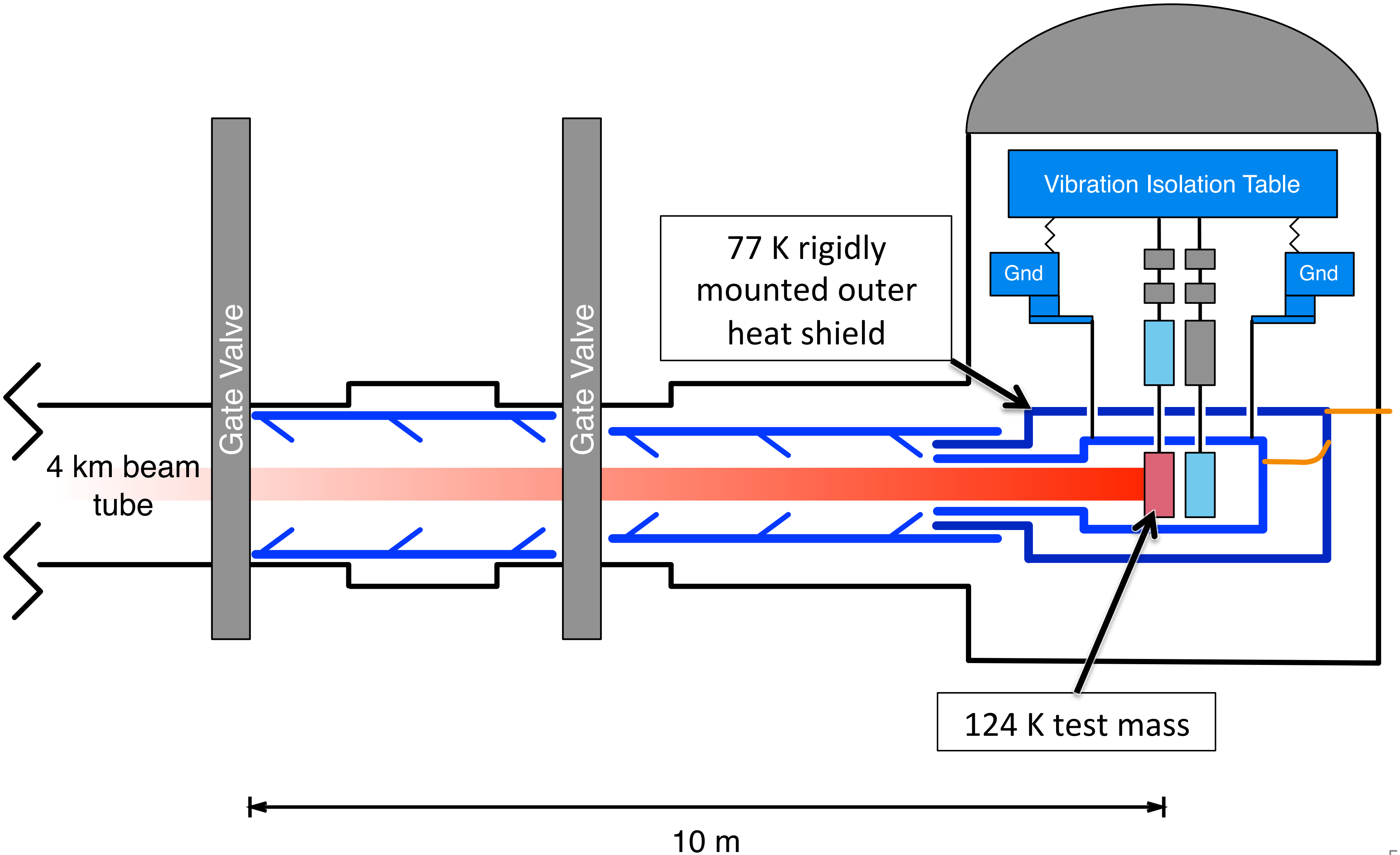


- Don’t let vibration from the cryo system impact sensitivity to gravitational waves

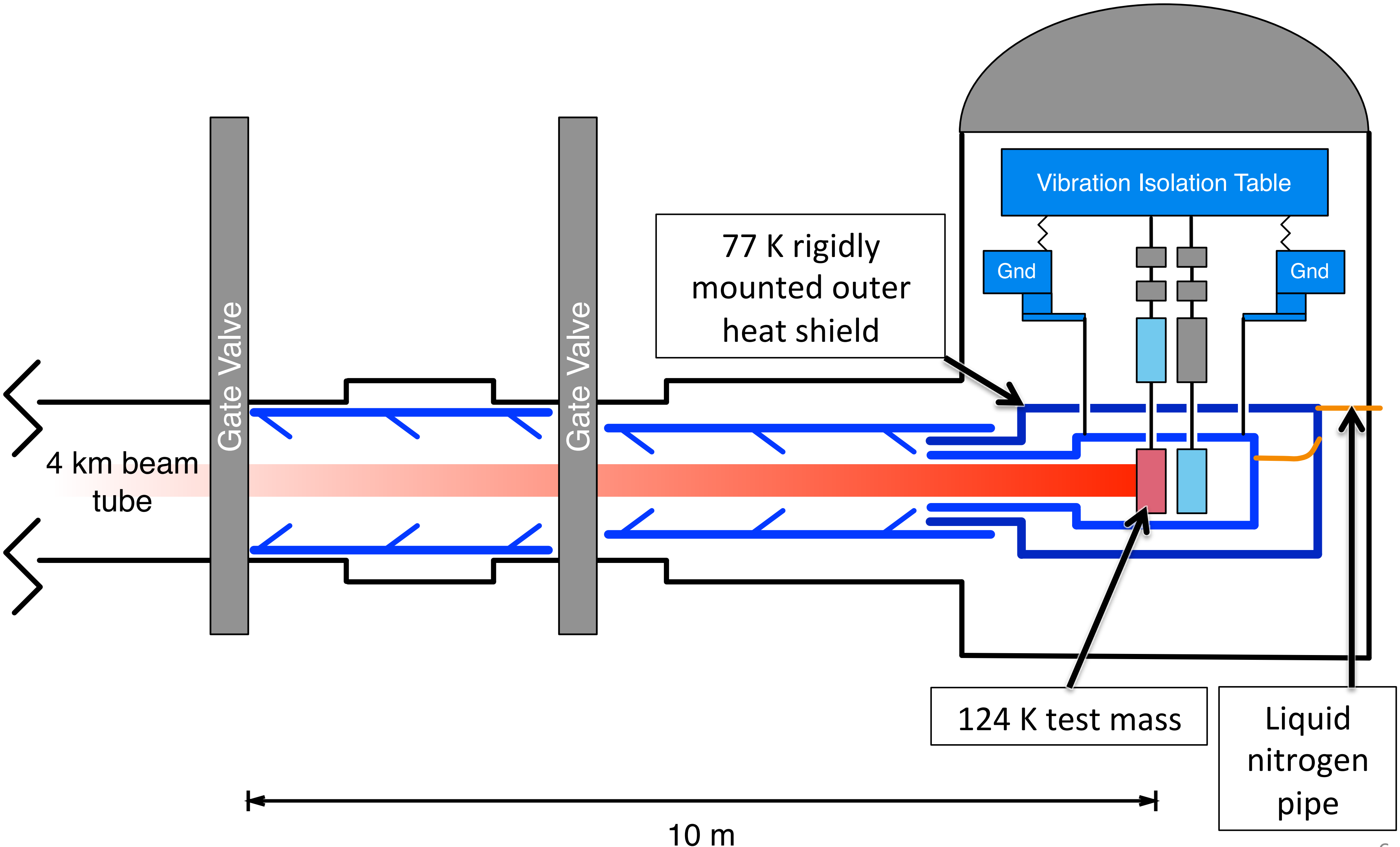
Cryogenic test mass system



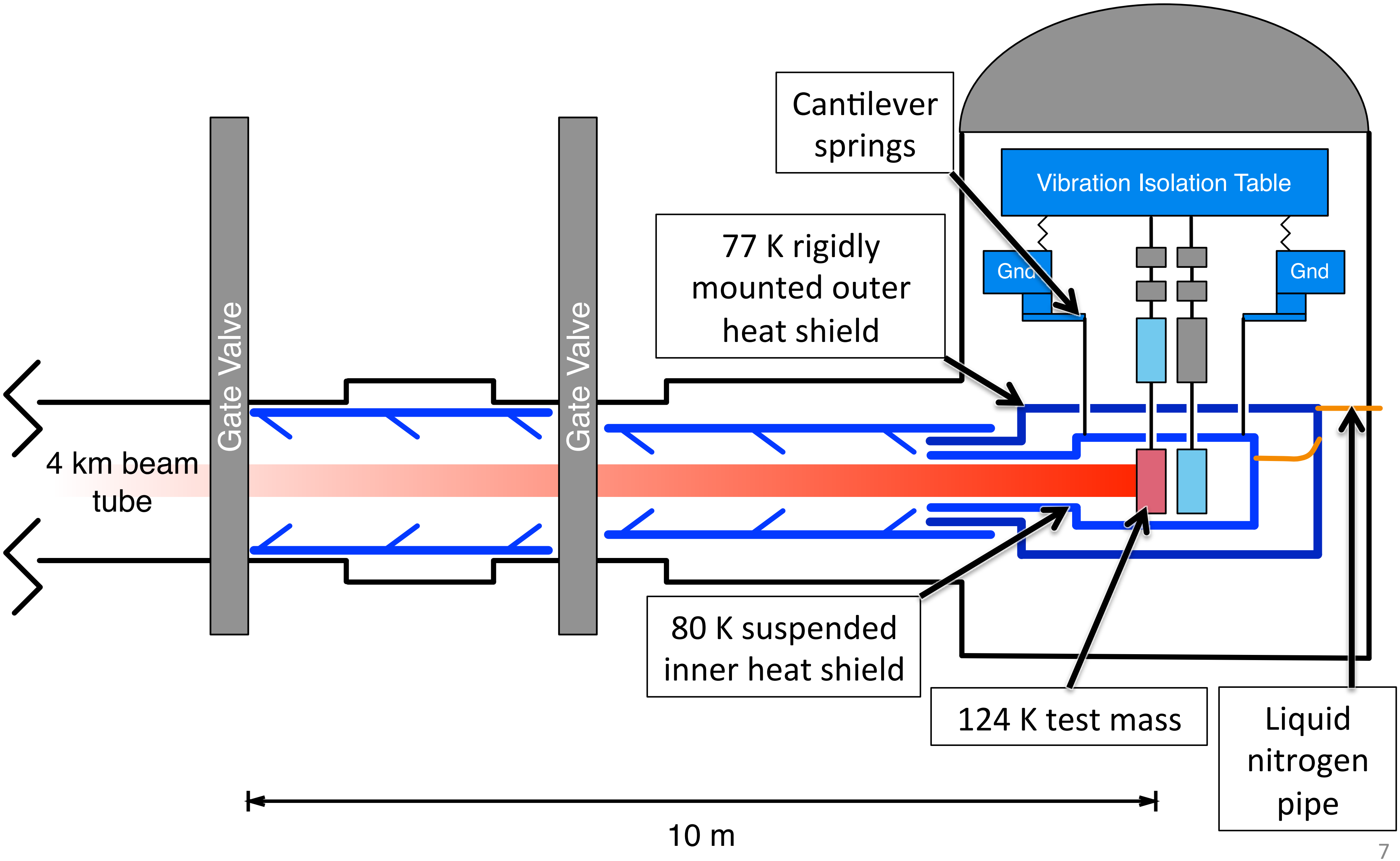
Cryogenic test mass system



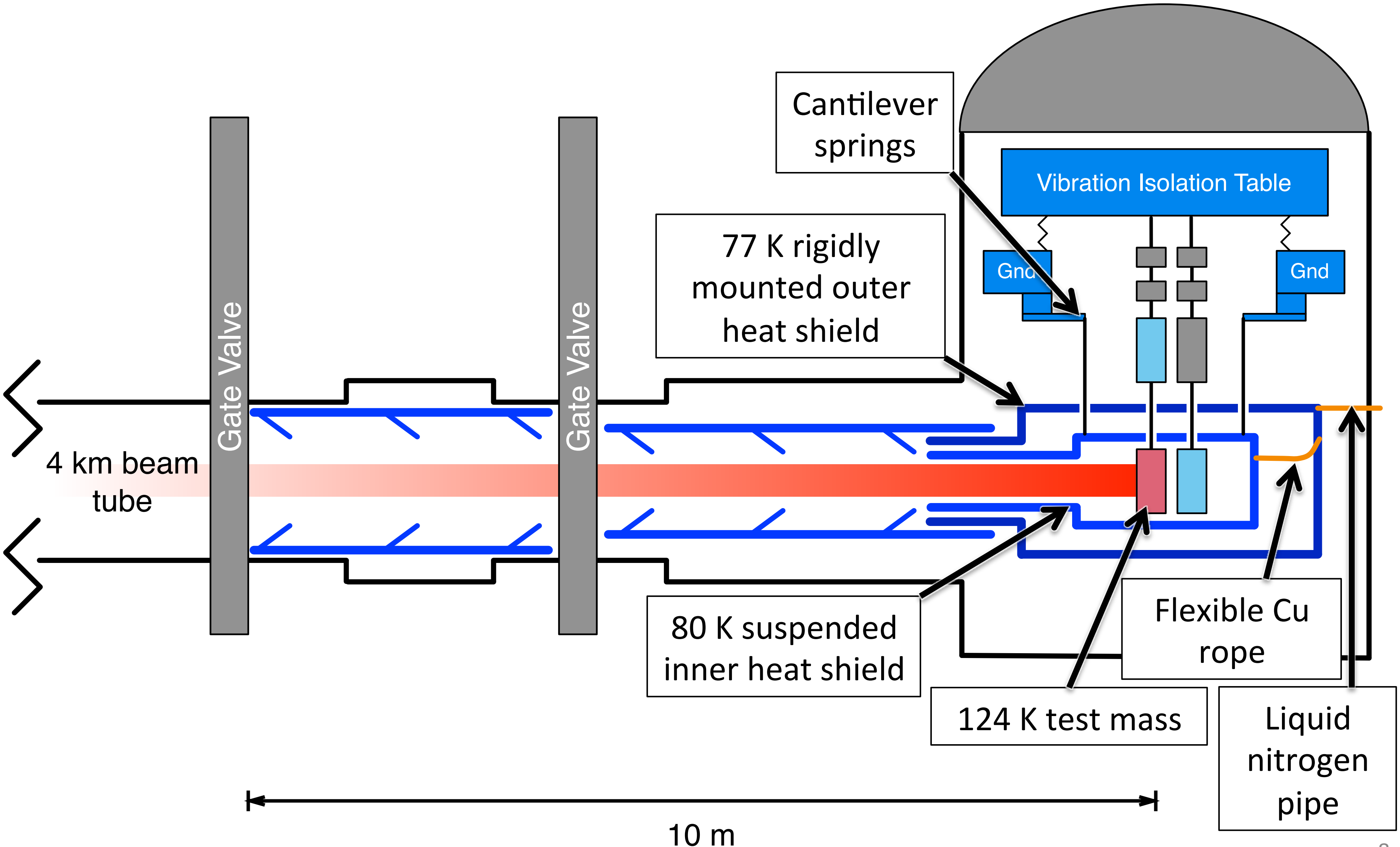
Cryogenic test mass system



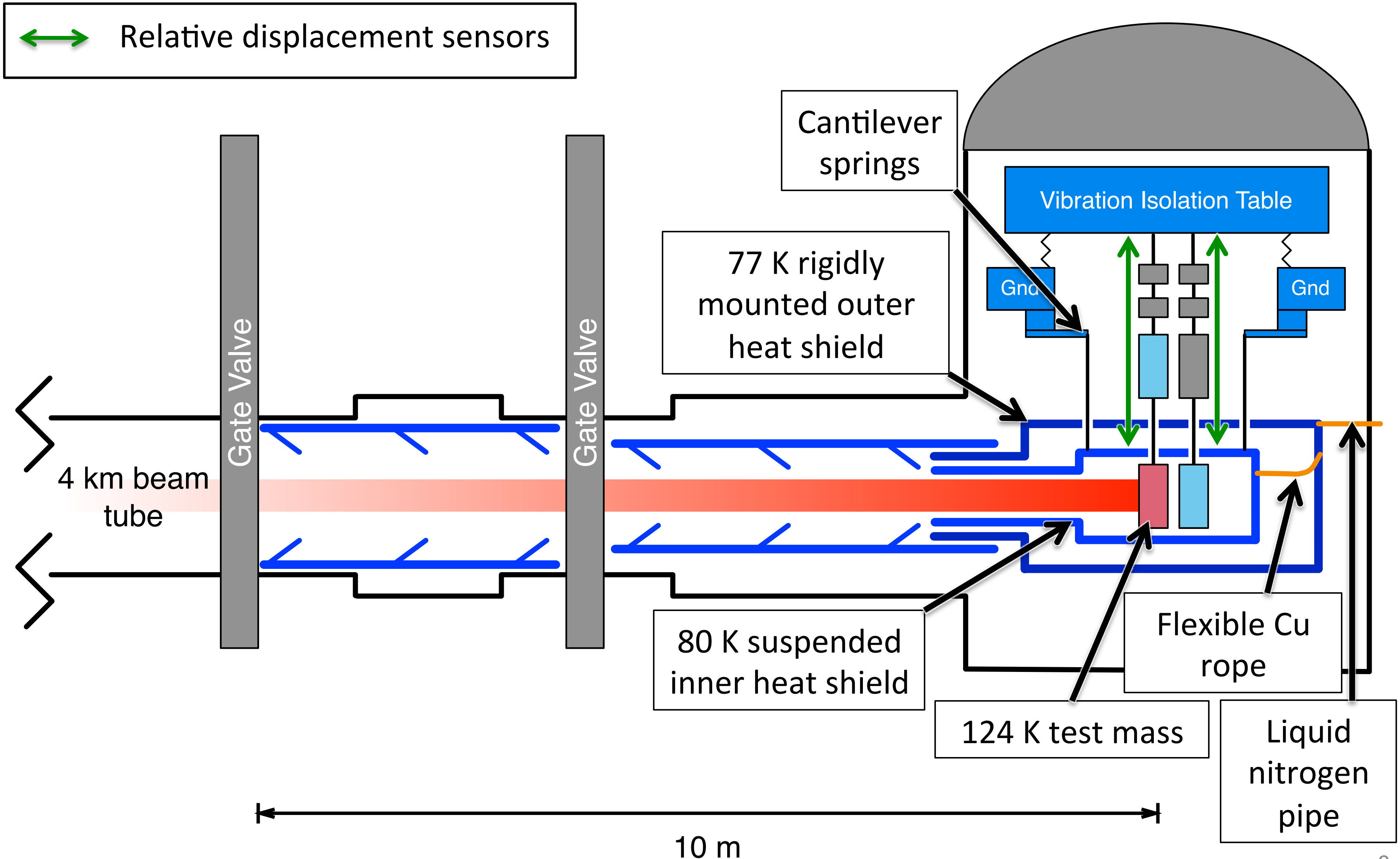
Cryogenic test mass system



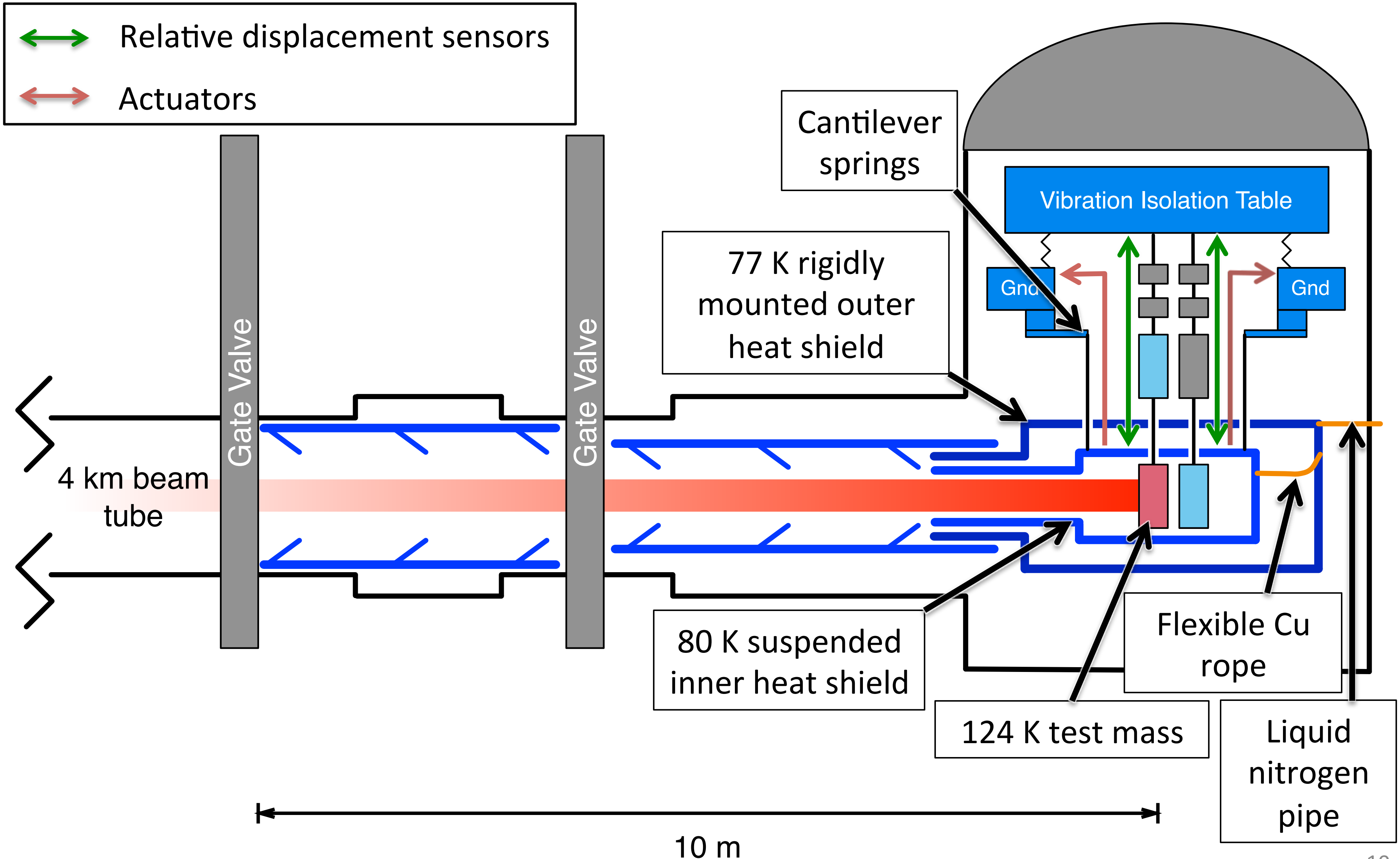
Cryogenic test mass system



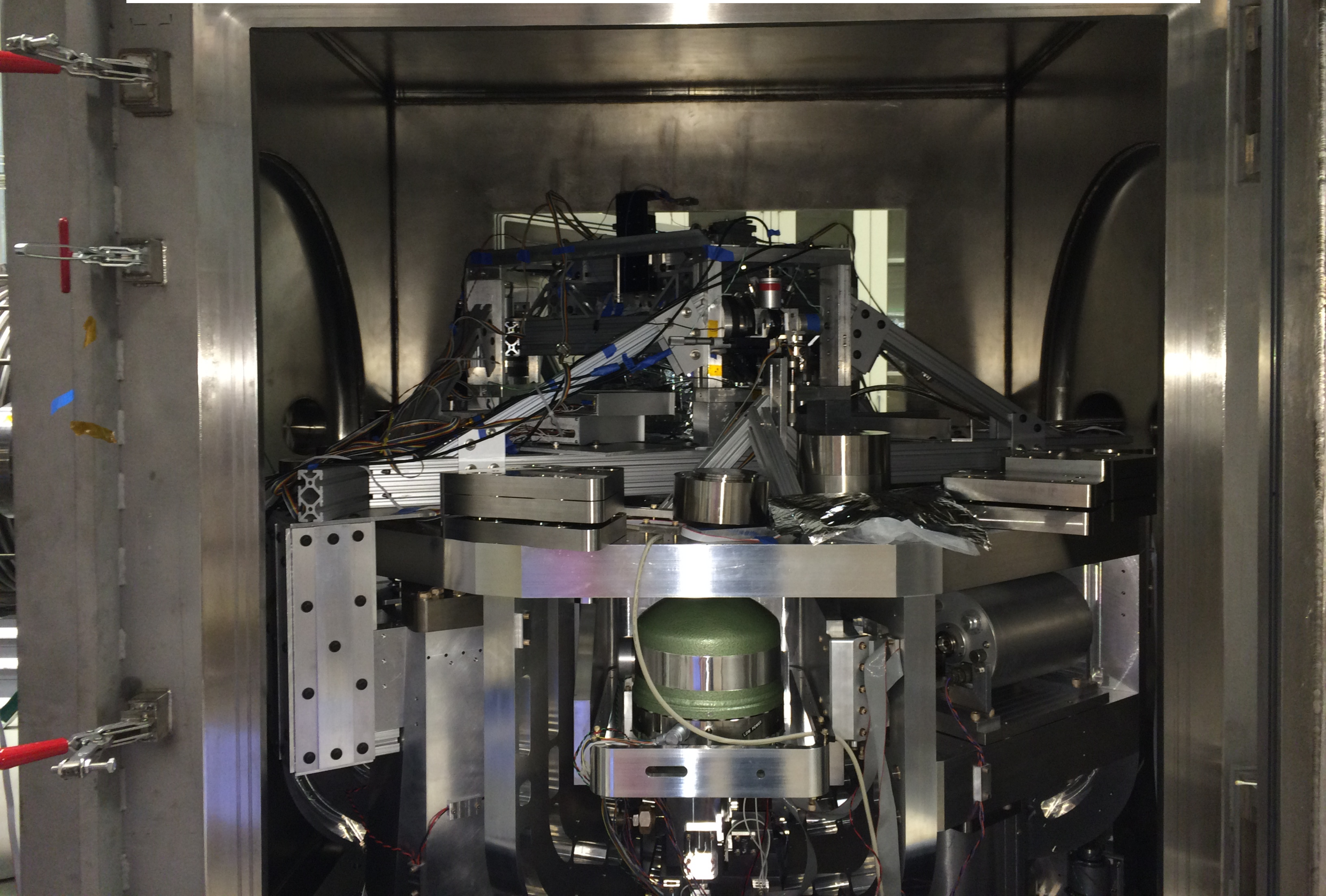
Cryogenic test mass system



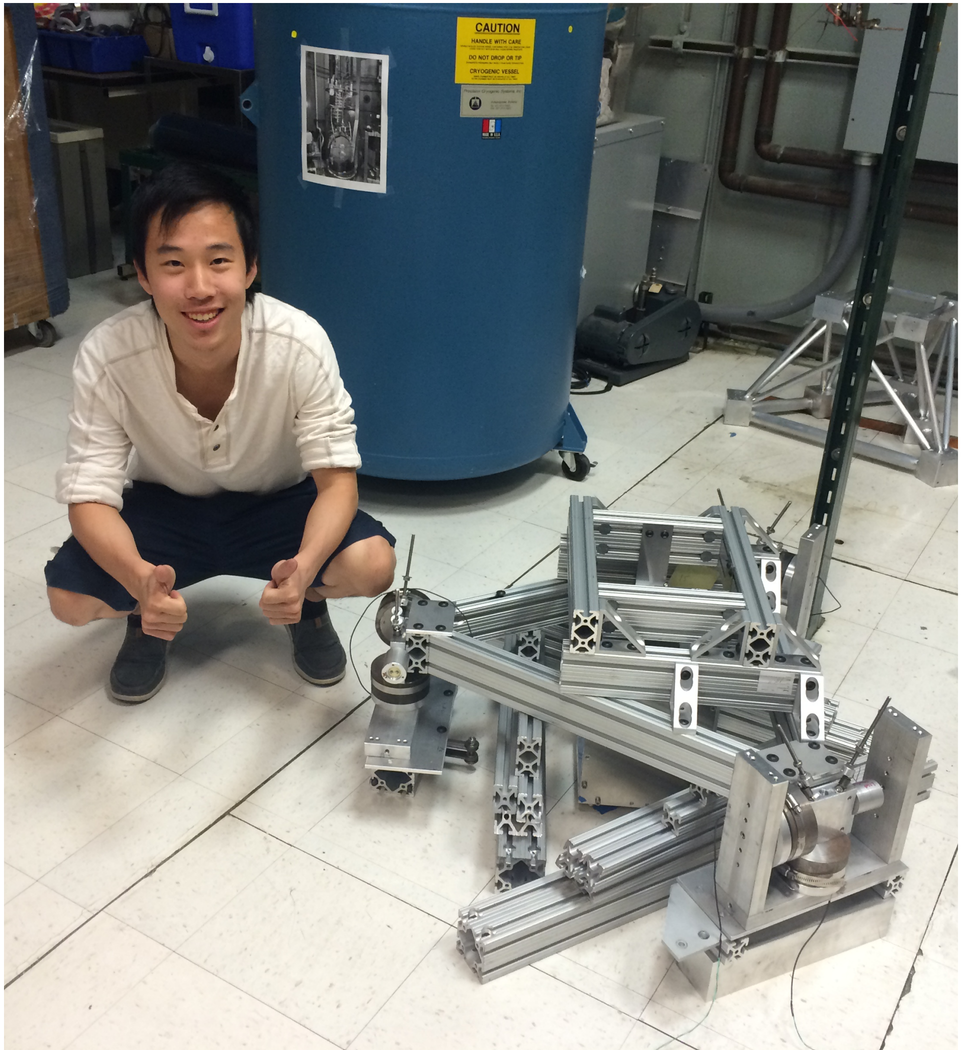
Cryogenic test mass system



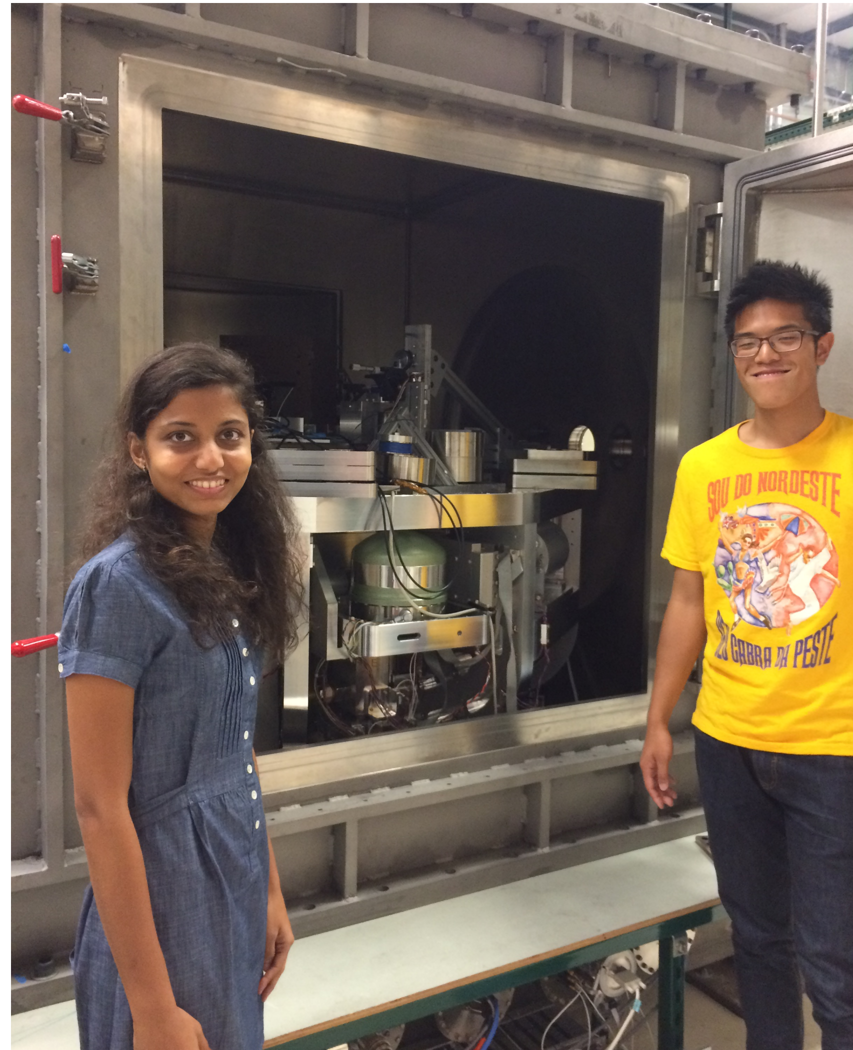
Stanford Cryogenic Test Mass Experiment – 6 August 2016



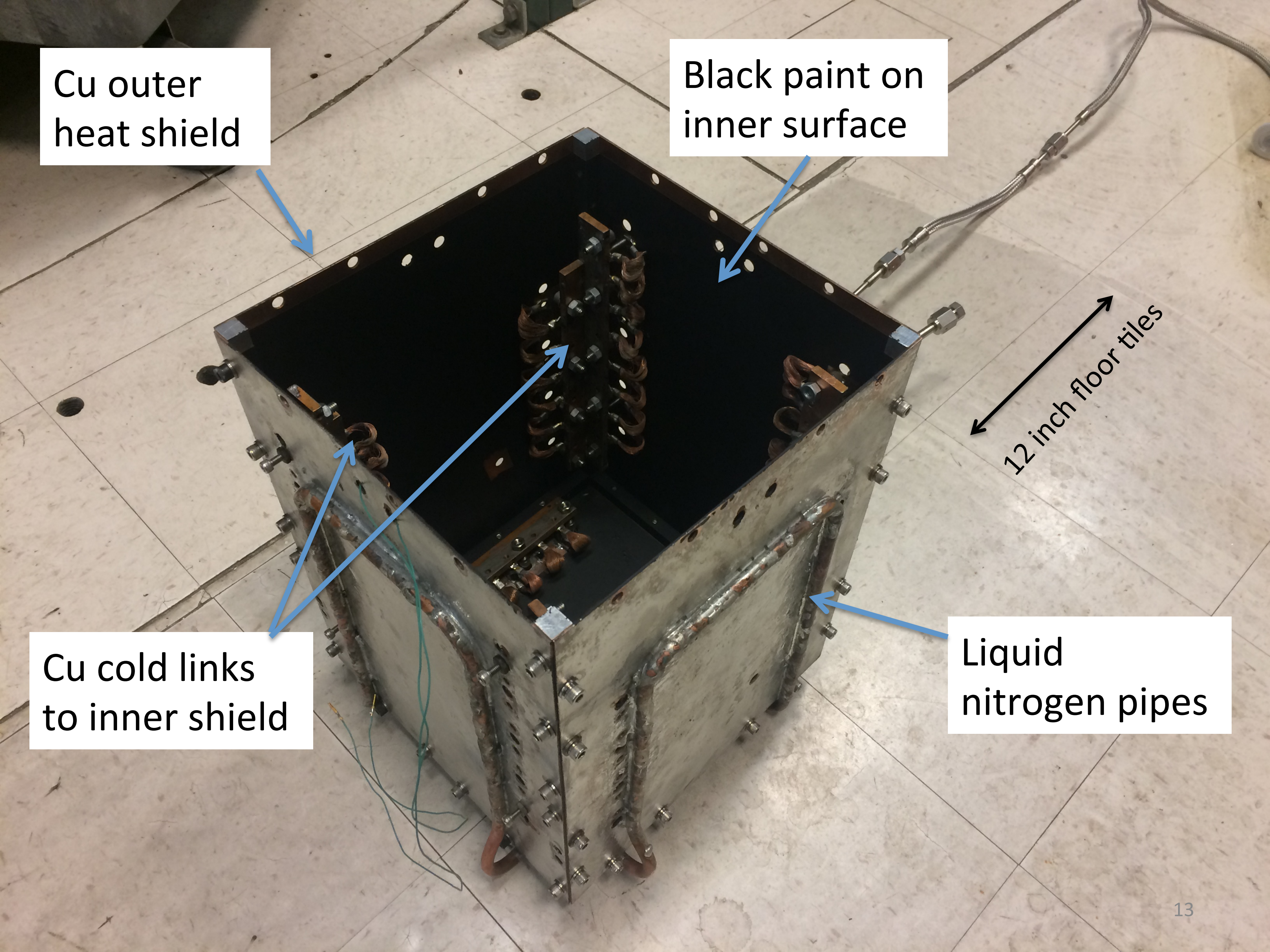
Students in Lab

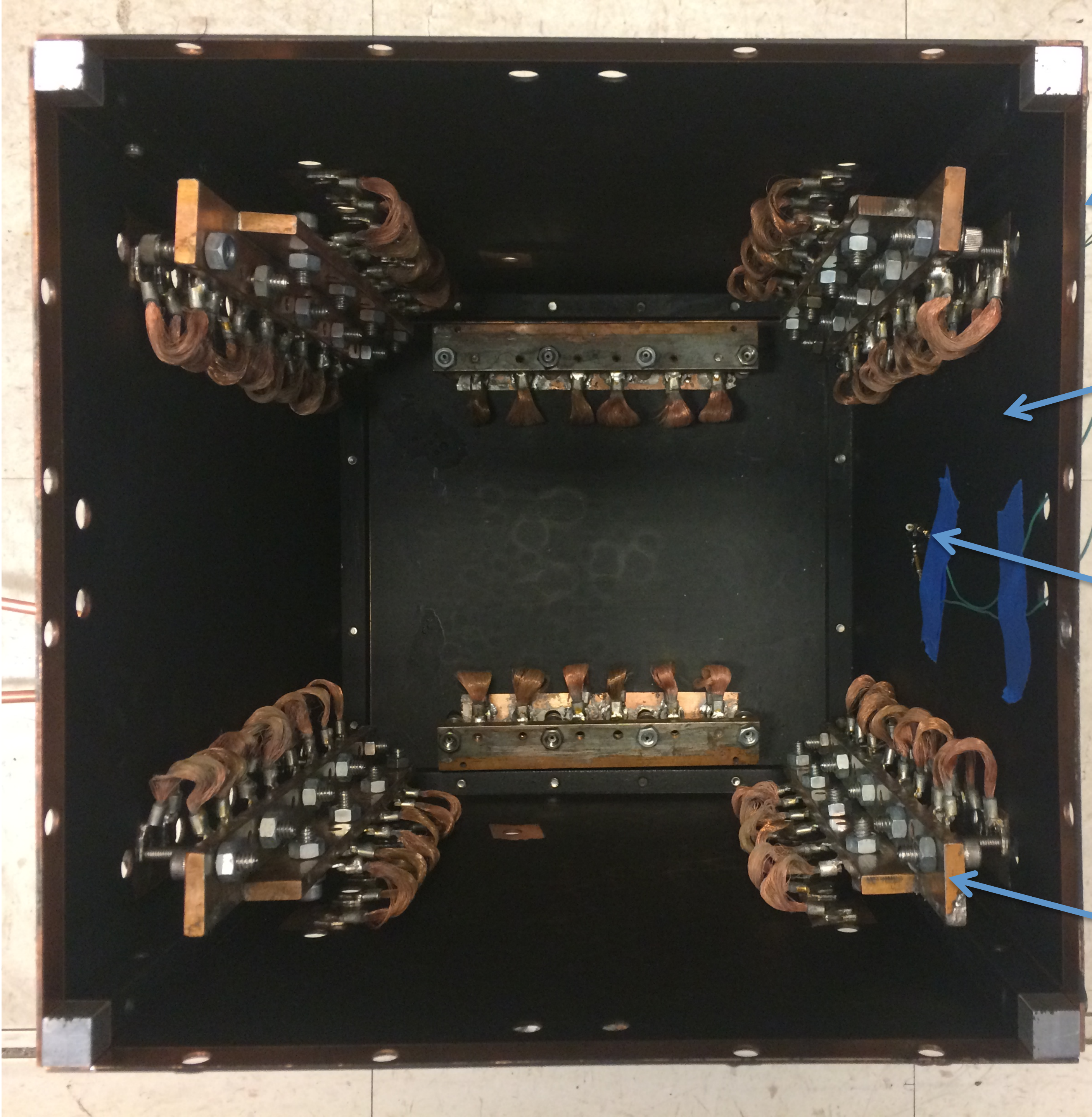


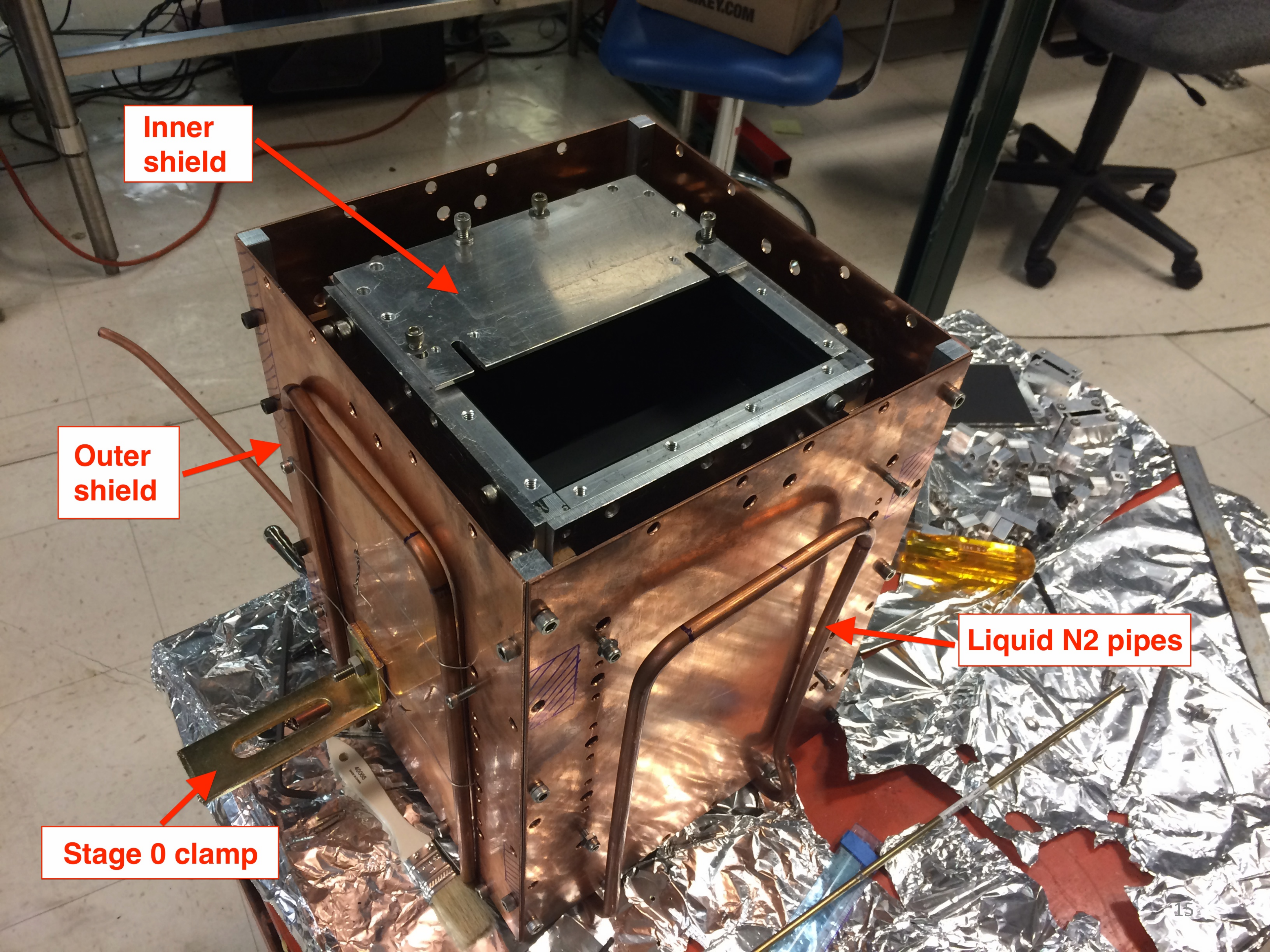
Dan: mechanical engineering undergraduate

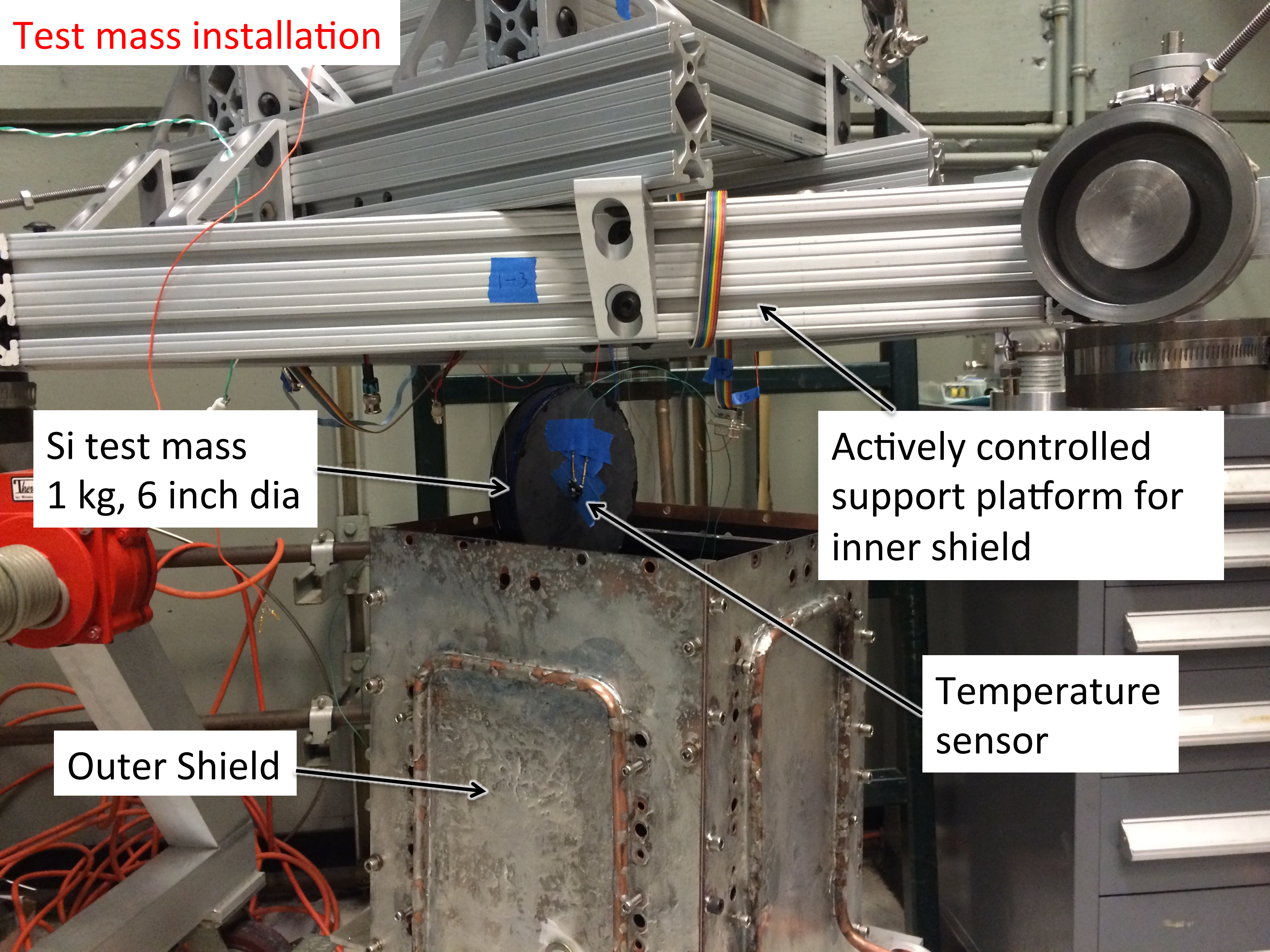


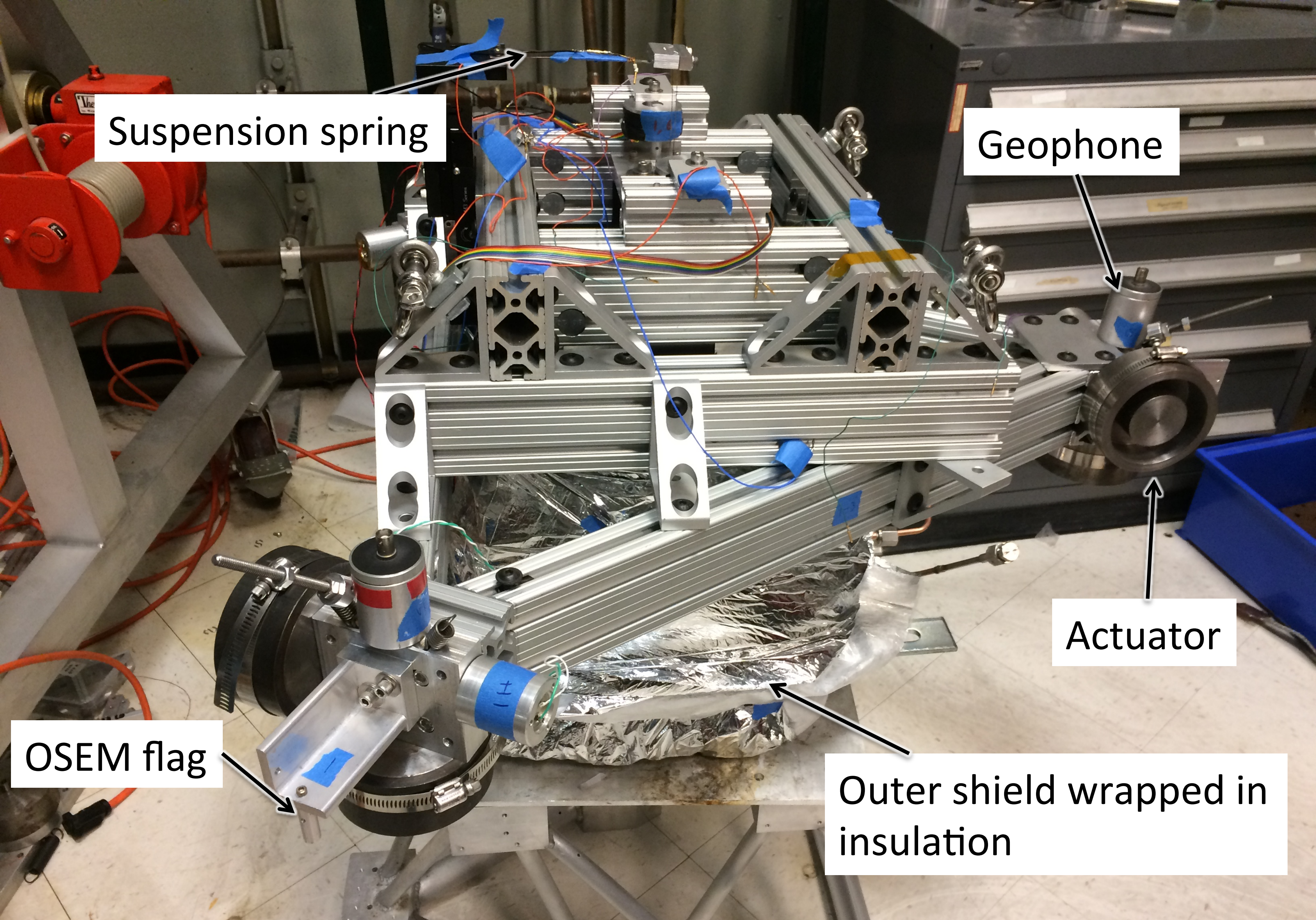
Sanditi: mechanical engineering masters
Litawn: physics undergraduate


Cu outer heat shield
Black paint on inner surface
12 inch floor tiles
Cu cold links to inner shield
Liquid nitrogen pipes


Cu outer heat shield
Black paint on inner surface
Temperature sensor
Cu cold links to inner shield

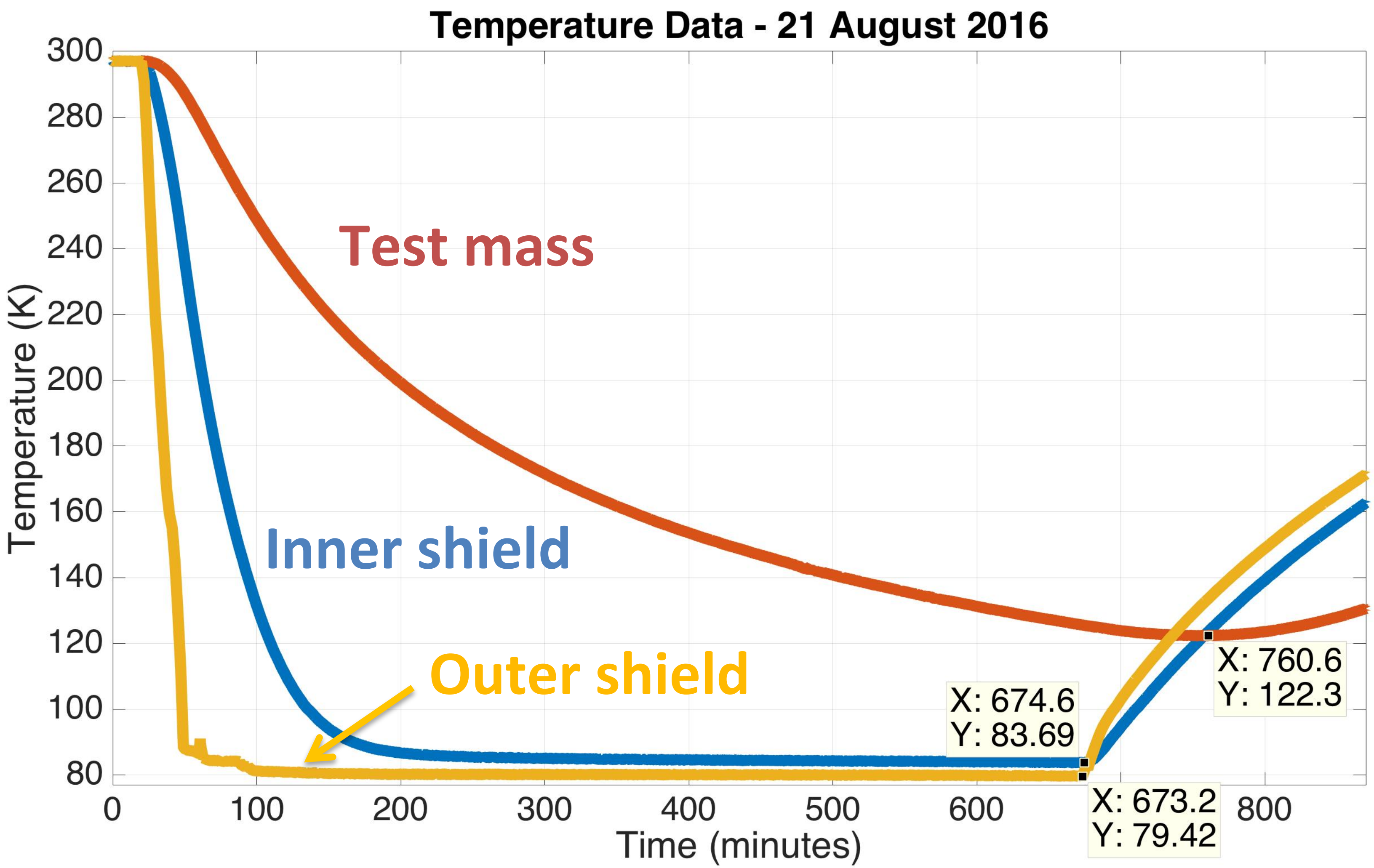

Inner shield
Outer shield
Liquid N2 pipes
Stage 0 clamp


Test mass installation
Si test mass
1 kg, 6 inch dia
Actively controlled
support platform for
inner shield
Temperature
sensor
Outer Shield

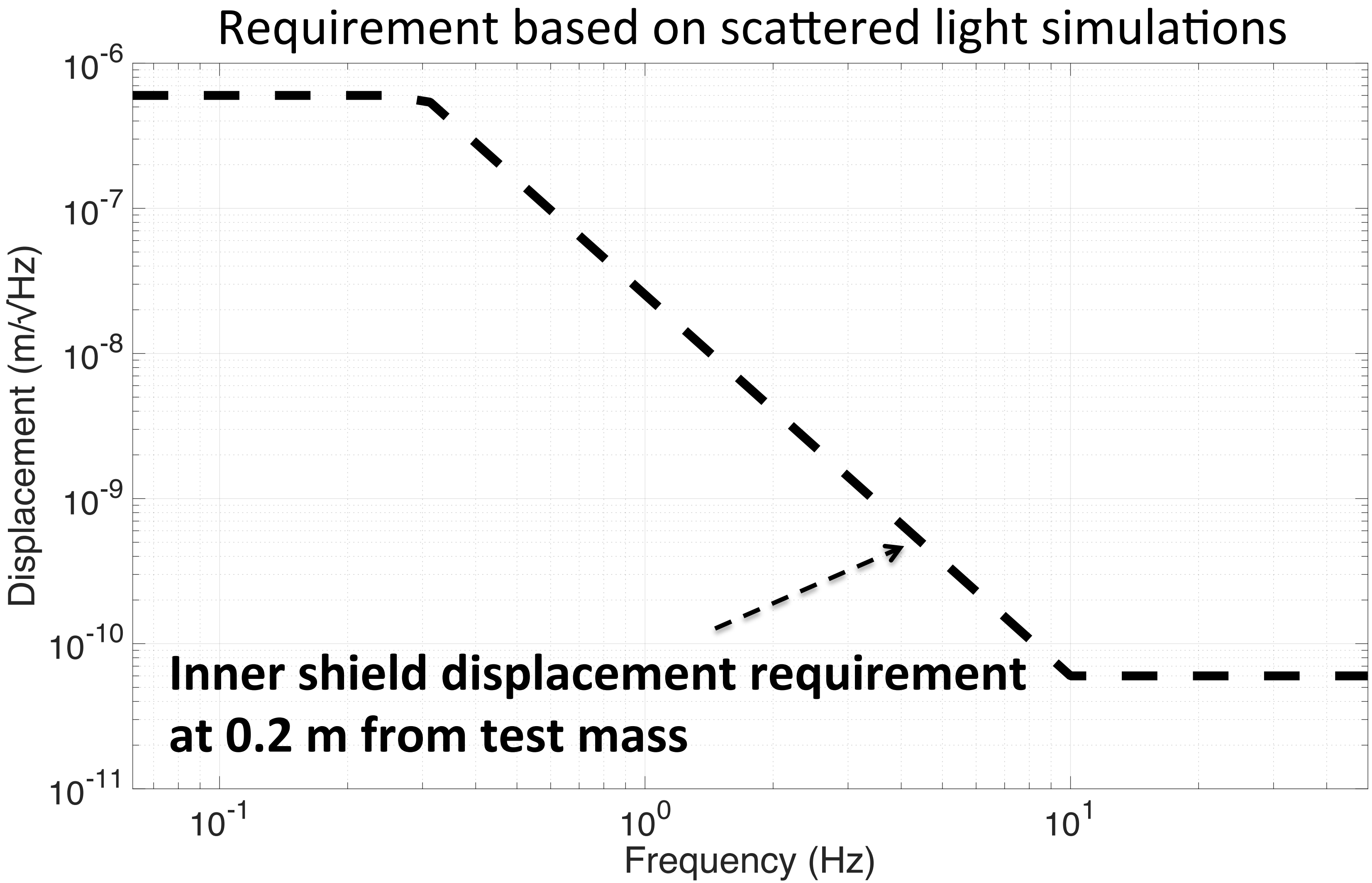


Assembled cryo experiment before installation into chamber

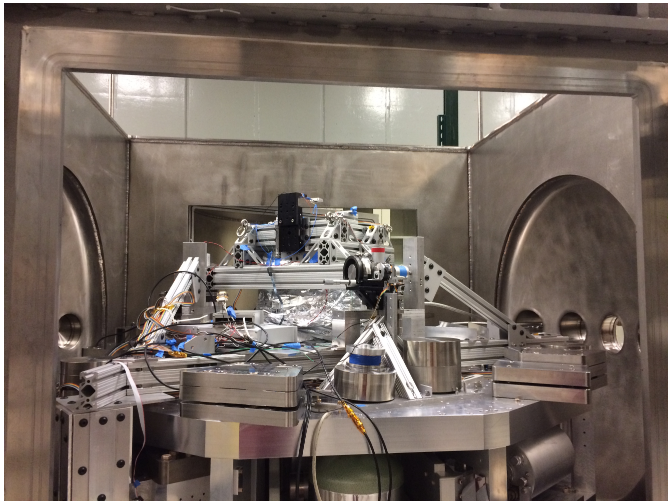
Measured Temperature Response

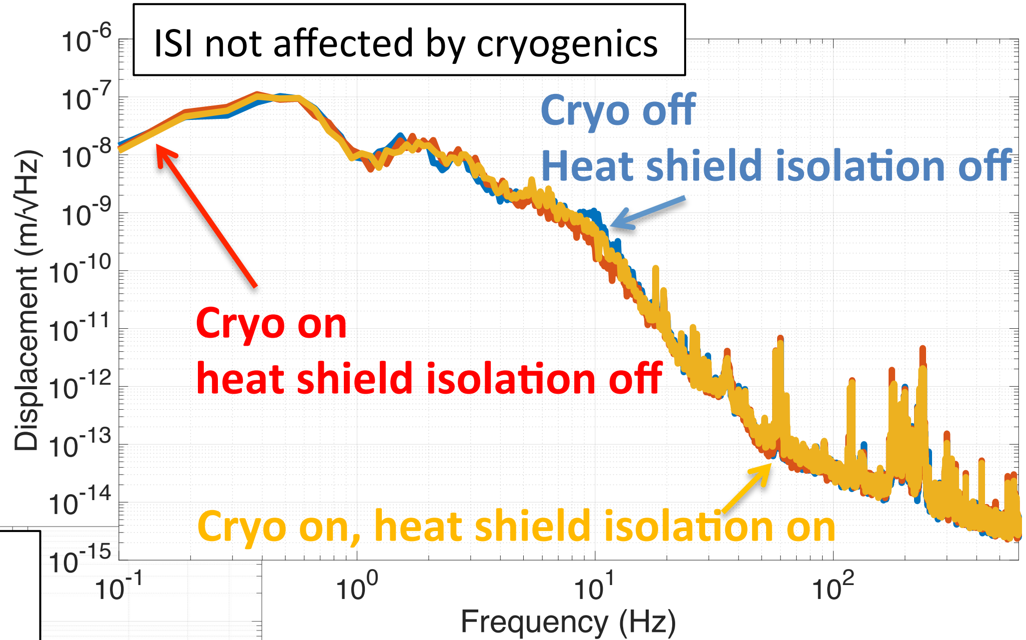


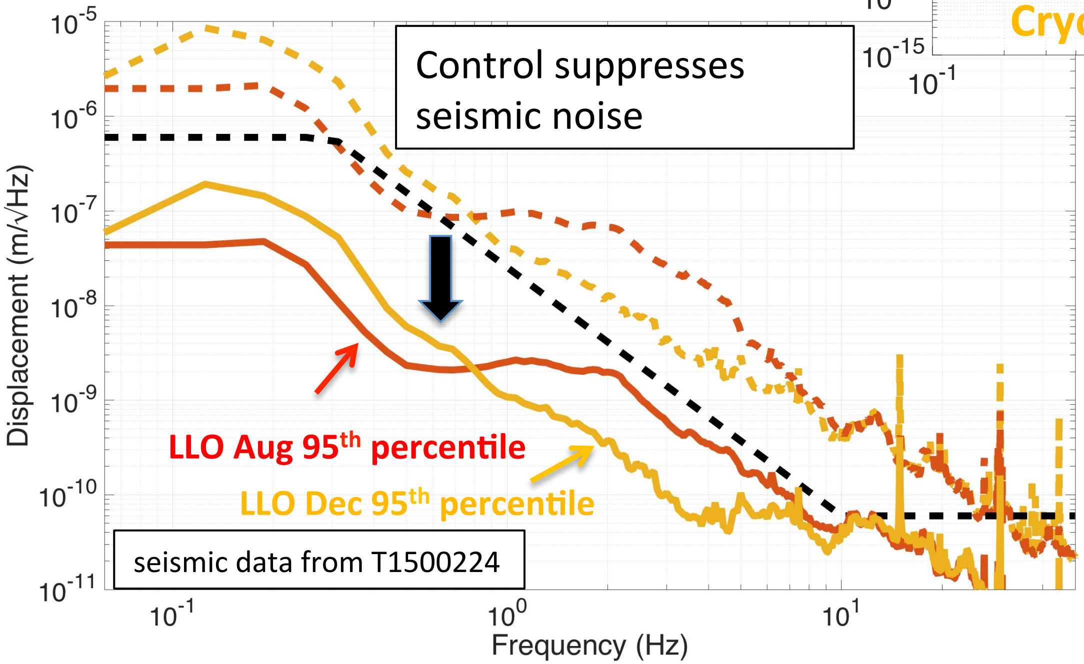
Inner Shield Seismic Isolation



Seismic Isolation Works at Stanford

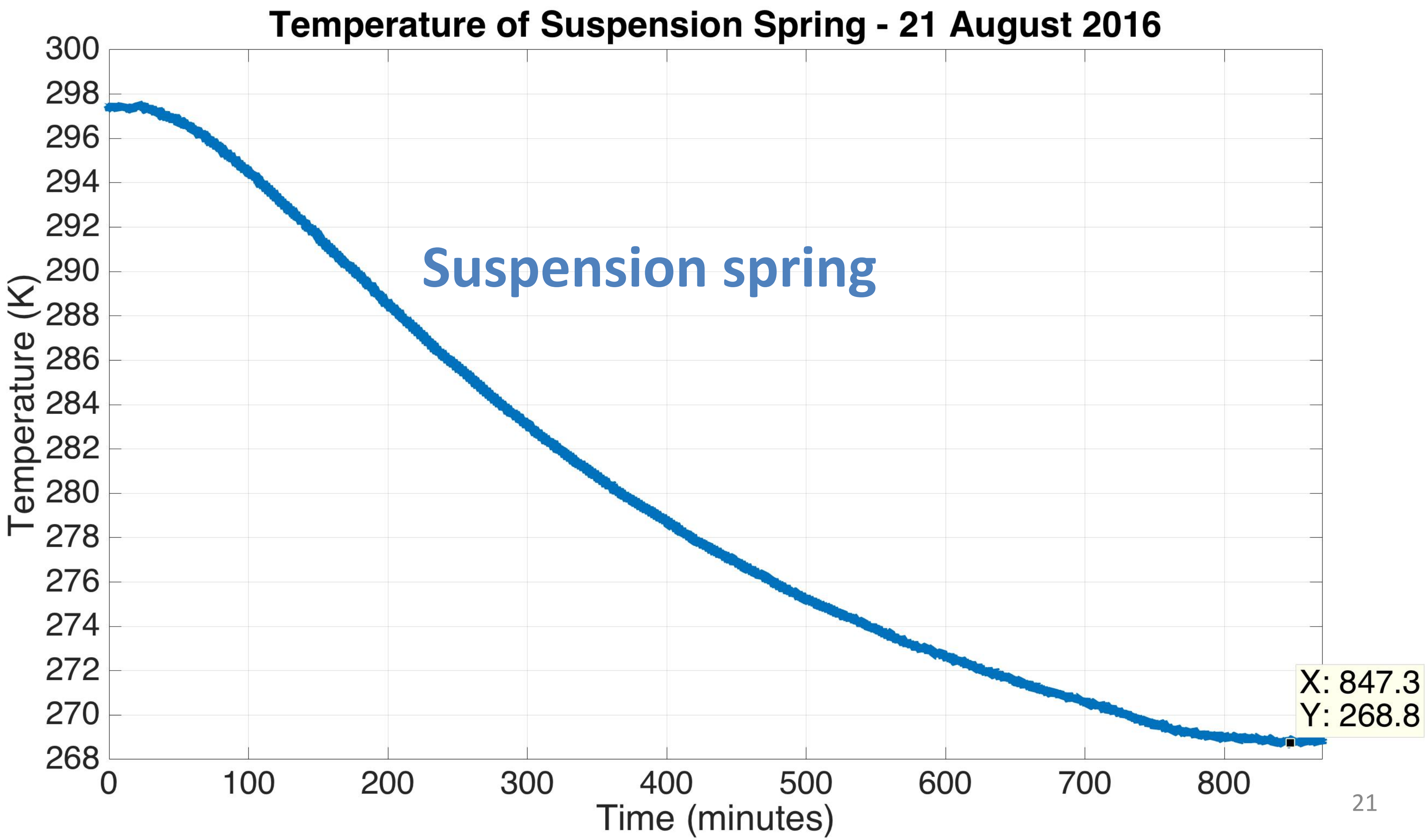




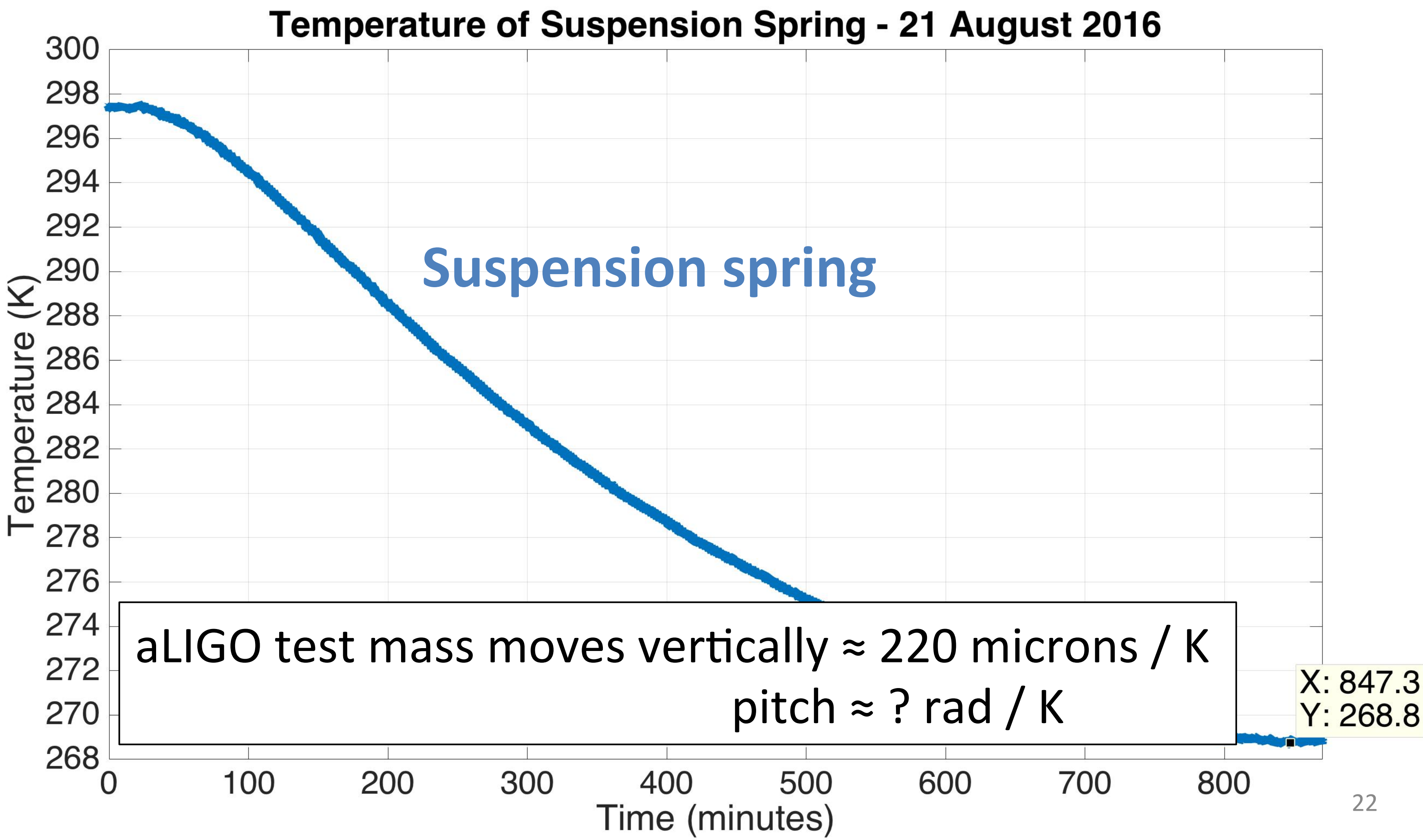


B. Shapiro, R. Adhikari, O. Aguiar, E. Bonilla, D. Fan, L. Gan, I. Gomez, S. Khandelwal,
B. Lantz, T. MacDonald, and D. Madden-Fong. ***Cryogenically cooled ultra low vibration silicon mirrors for gravitational wave observatories***. Cryogenics, 81:83 – 92, 2017

Measured Temperature Response



Measured Temperature Response



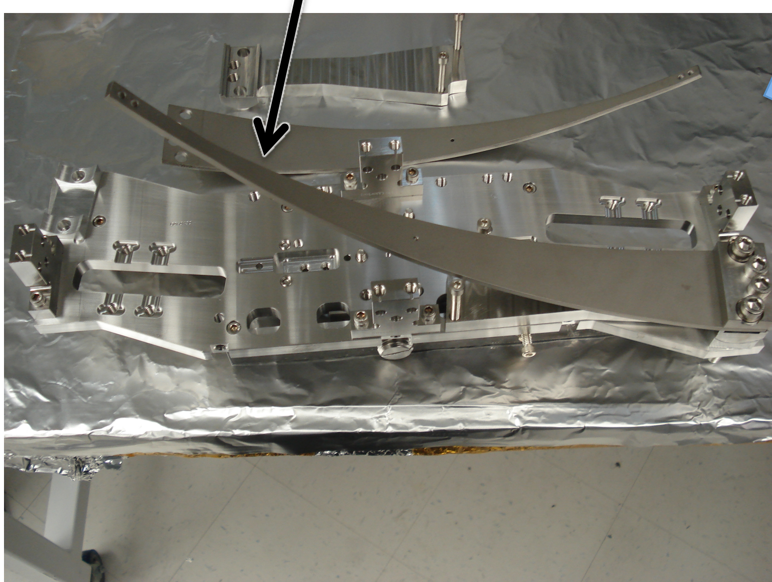
aLIGO test mass moves vertically ≈ 220 microns / K
pitch ≈ ? rad / K

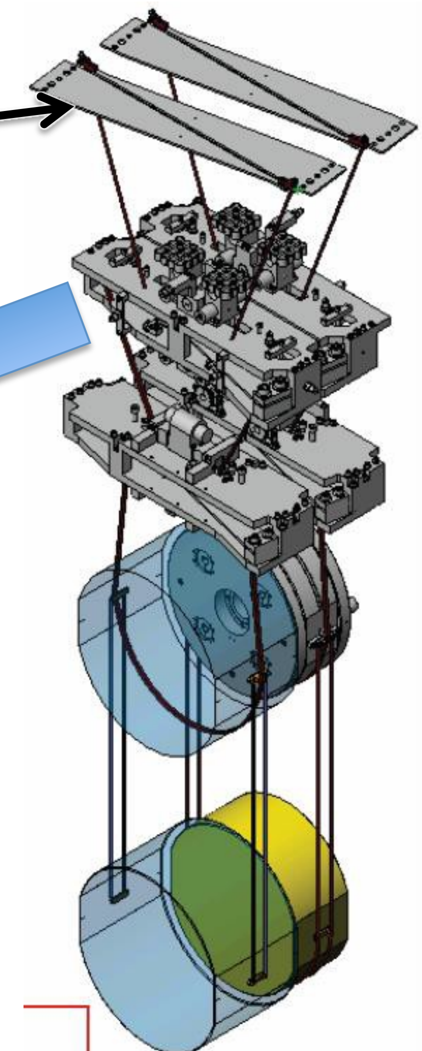
Suspension spring temperature control

Possibly glue heating resistors directly to top springs

Heaters on lower springs must be non-contacting to avoid seismic shorts: radiative, inductive?

Top mass

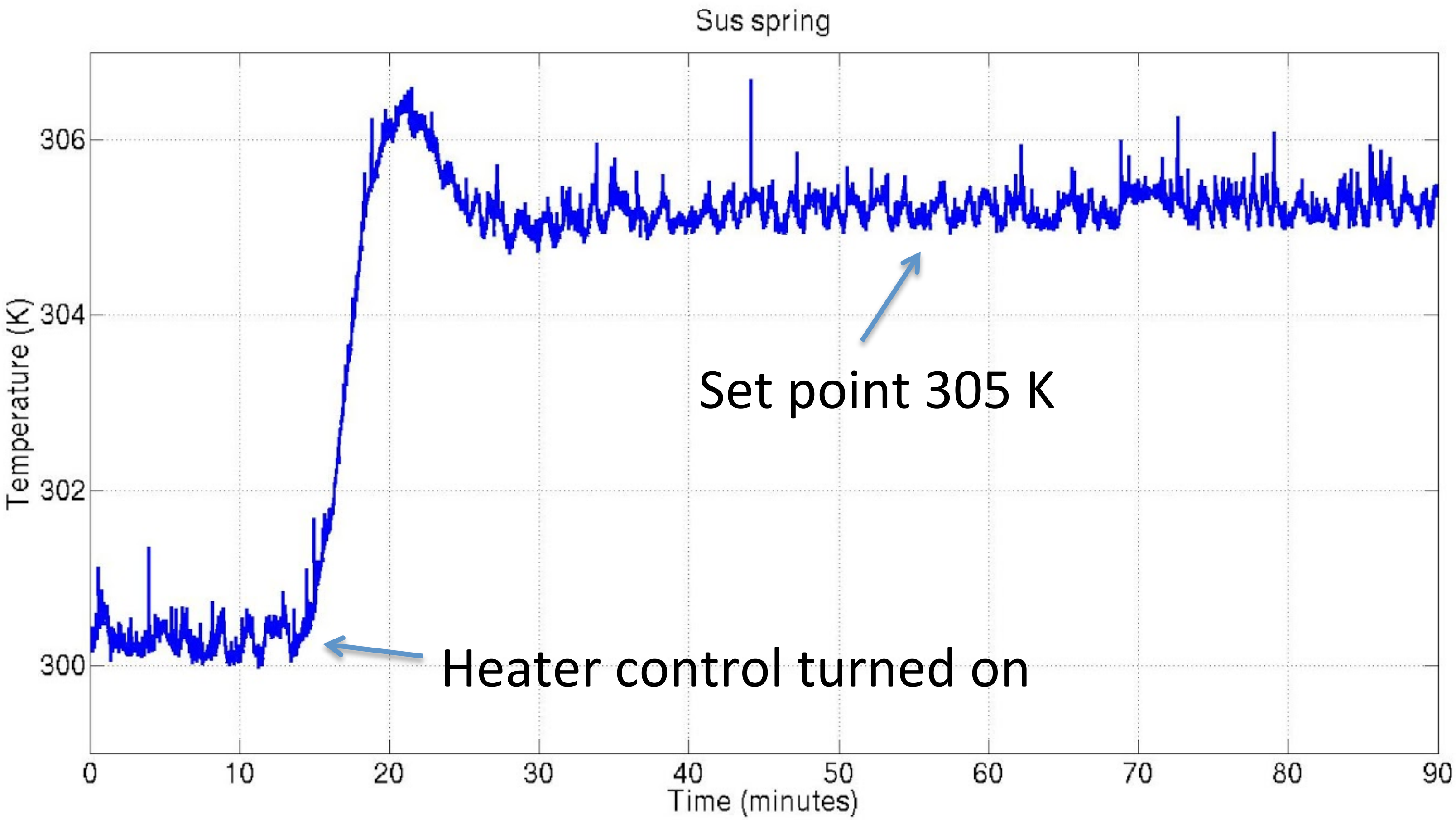




aLIGO test mass suspension

Suspension spring heater control

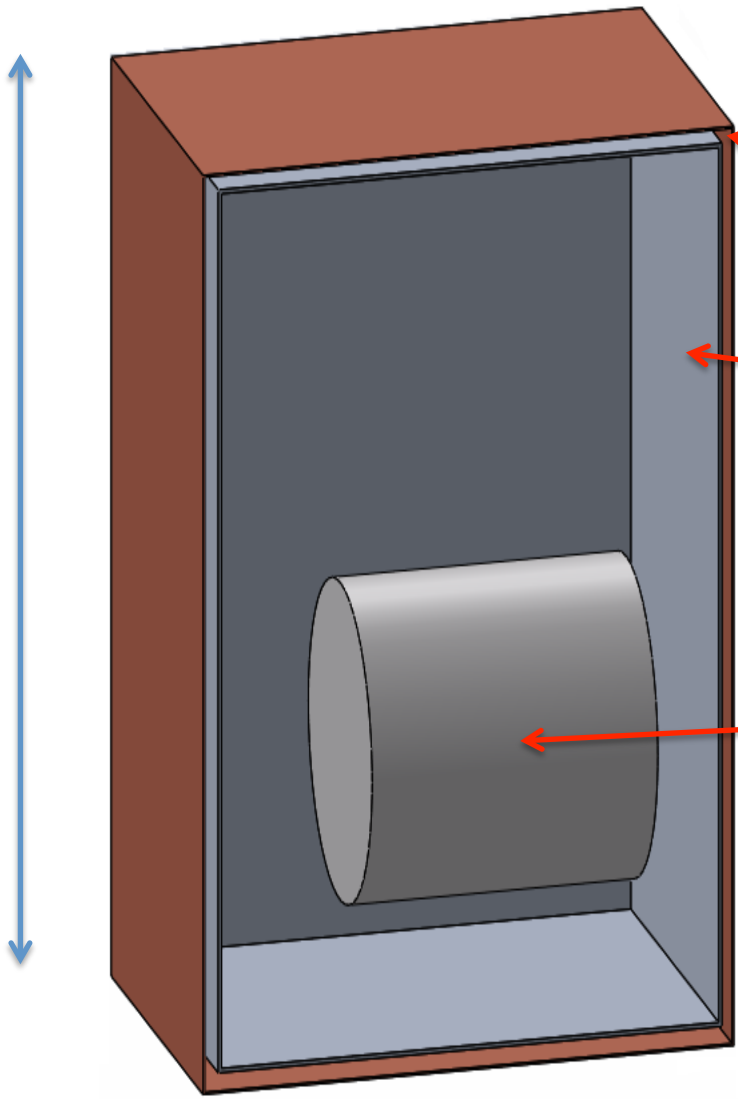
Heater and temperature sensor clamped directly to spring



Newtonian Noise

Courtesy of Edgard Bonilla

Shield Newtonian Noise Simulation



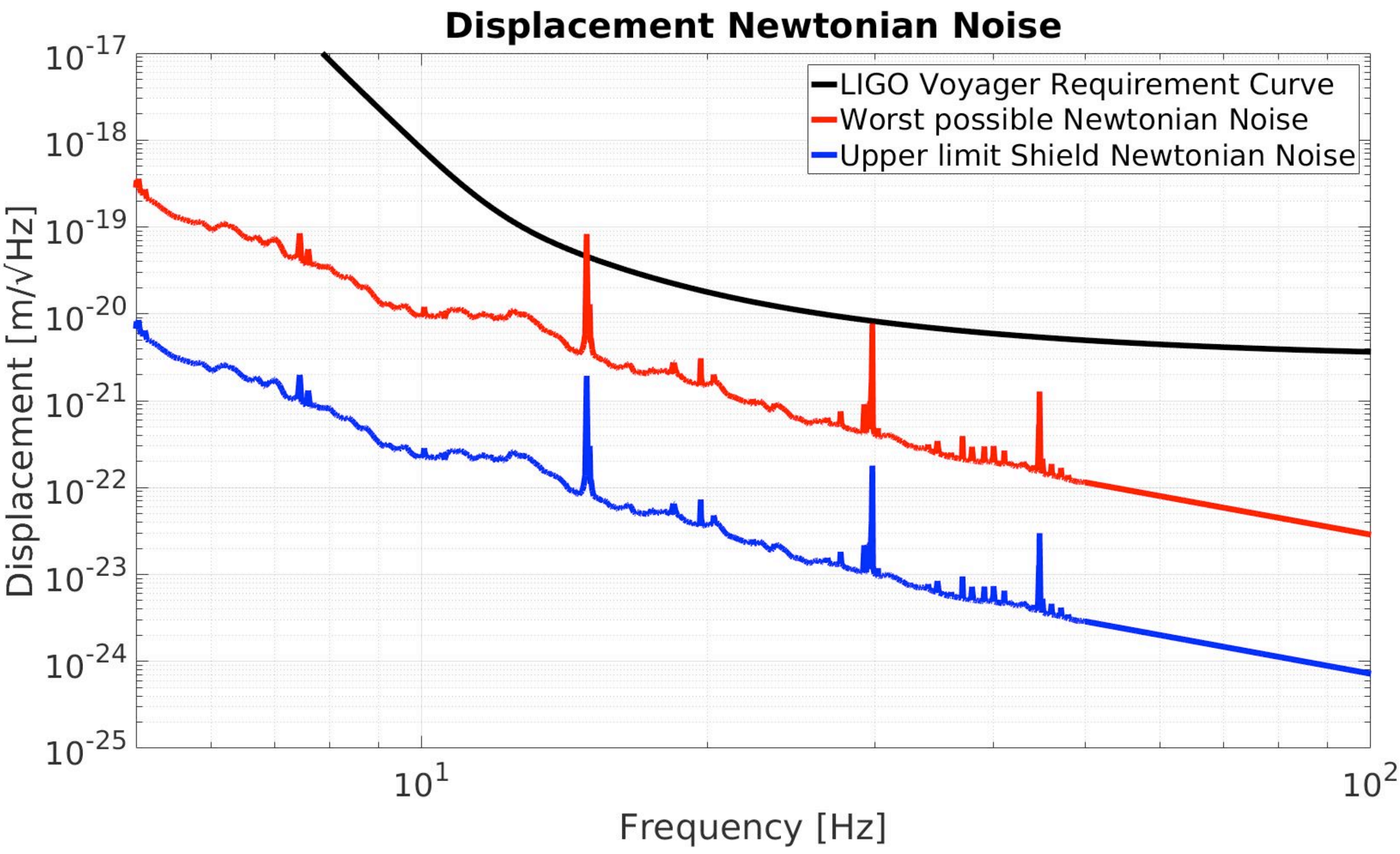
1.25 m

Outer shield
180 kg of Cu

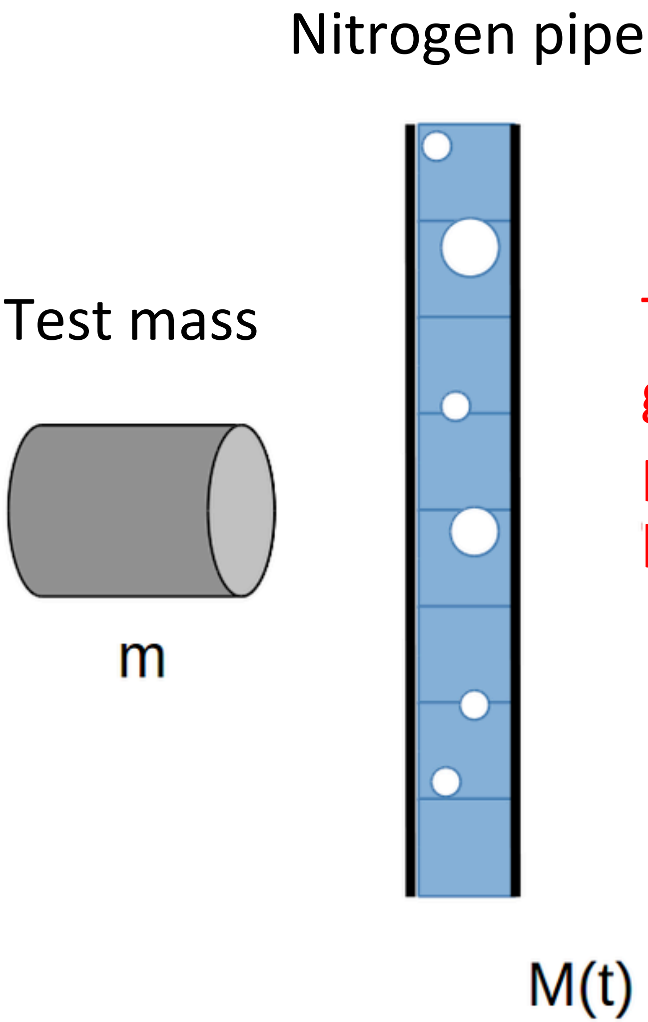
Inner shield
100 kg of Al

Silicon Test Mass
- 45 cm diameter
- 54 cm length
- 200 kg

Shield Newtonian Noise Simulation

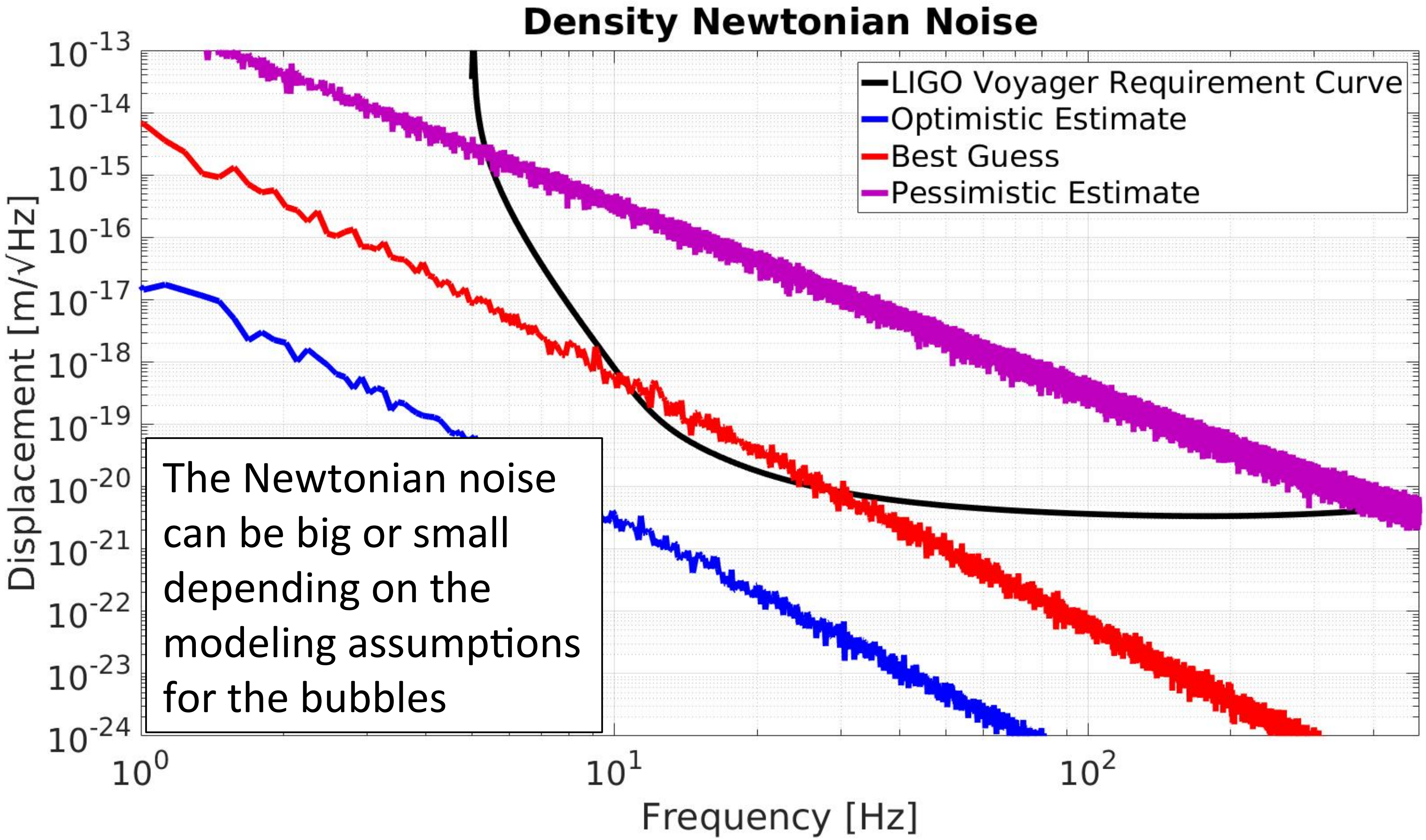


Nitrogen Newtonian Noise



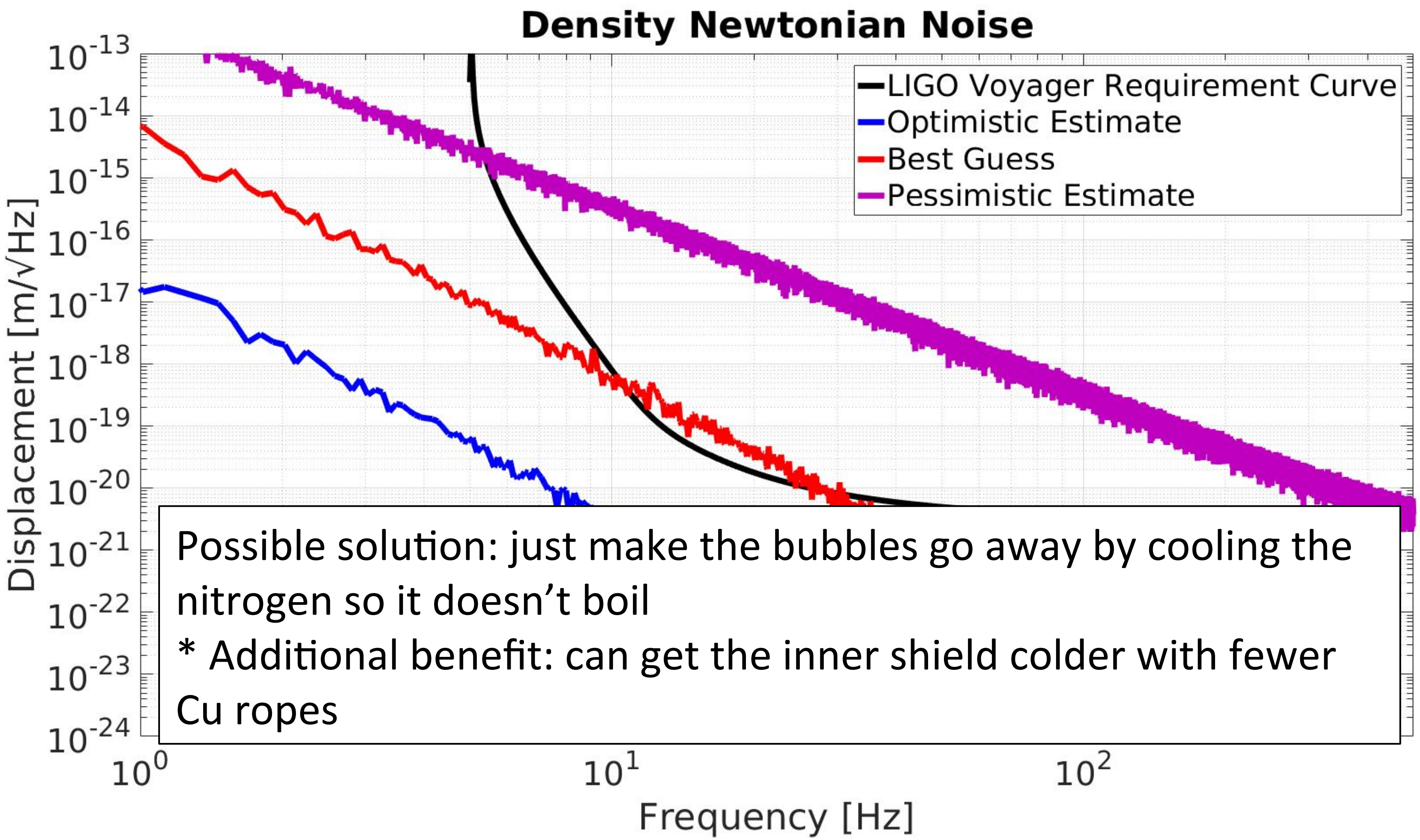
Time varying gravitational force from pipe on test mass as bubbles flow by

LN_2 Newtonian Noise Simulation

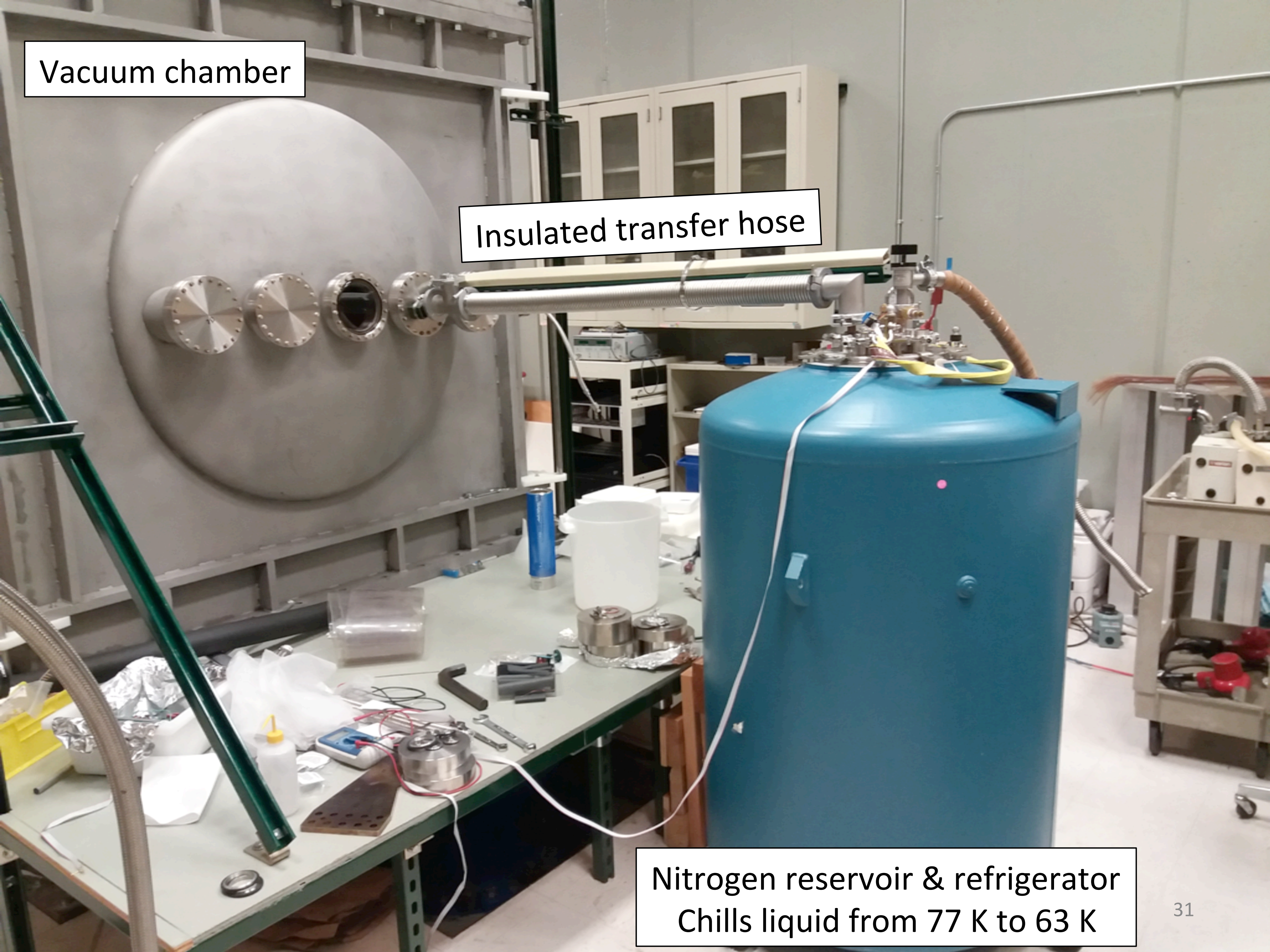


The Newtonian noise can be big or small depending on the modeling assumptions for the bubbles

LN_2 Newtonian Noise Simulation



Possible solution: just make the bubbles go away by cooling the nitrogen so it doesn't boil
* Additional benefit: can get the inner shield colder with fewer Cu ropes


Vacuum chamber
Insulated transfer hose
Nitrogen reservoir & refrigerator
Chills liquid from 77 K to 63 K

Chilling the Nitrogen below boiling

https://www.youtube.com/watch?v=qE_228kk5-A&feature=youtu.be

Conclusions

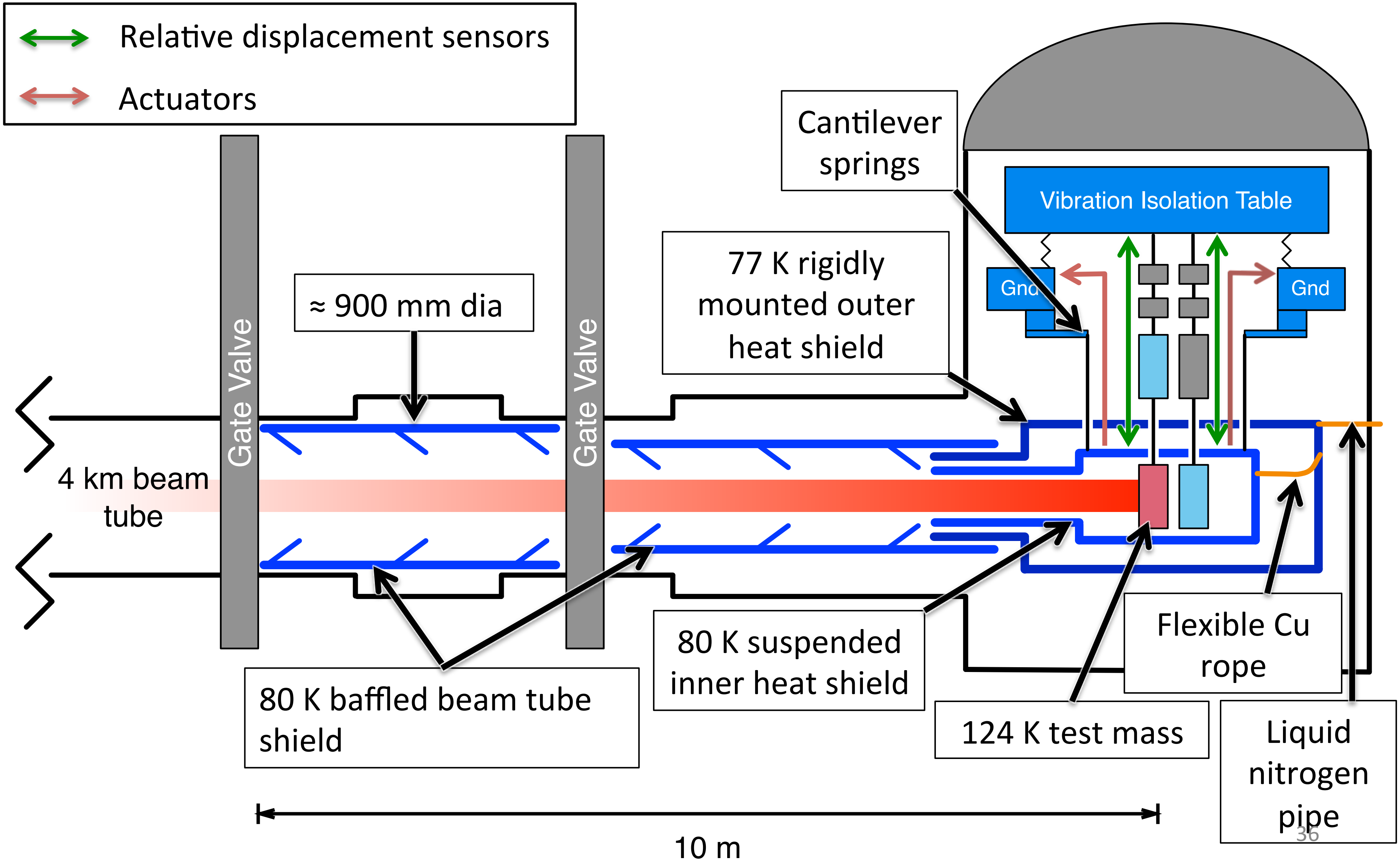
- Cryogenics and seismic isolation working well together
- Newtonian noise from shields OK
- Newtonian noise from Nitrogen flow mitigated by preventing boiling
  - Next step to measure gas/liquid ratio
- More work needed on spring temperature control
- More work needed on initial cooldown – being explored by Odylio's group at INPE, Brazil.

Extra Slides

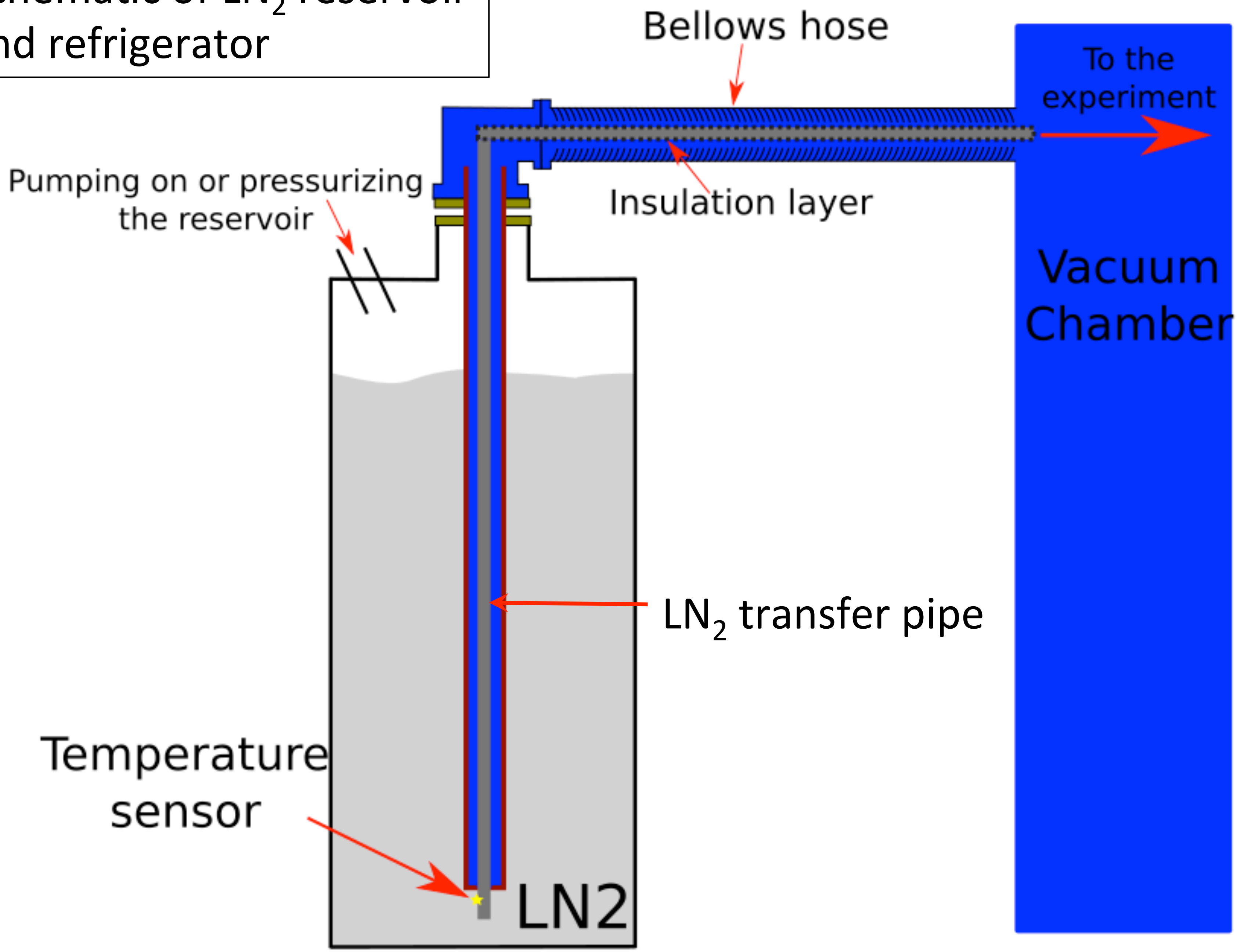
Why Cryogenic Si for Test Masses?

- Lower temperature -> lower thermal noise
- Silicon has **low mechanical loss** at cold temperatures, further lowering the thermal noise outside the mechanical resonant frequencies
- Silicon has **high thermal conductivity** at low temperatures, reducing thermal lensing, permitting higher laser powers (lower shot noise)
- **Thermal expansion goes to 0** at 124 K, also reducing thermal lensing, and eliminating thermoelastic component of thermal noise

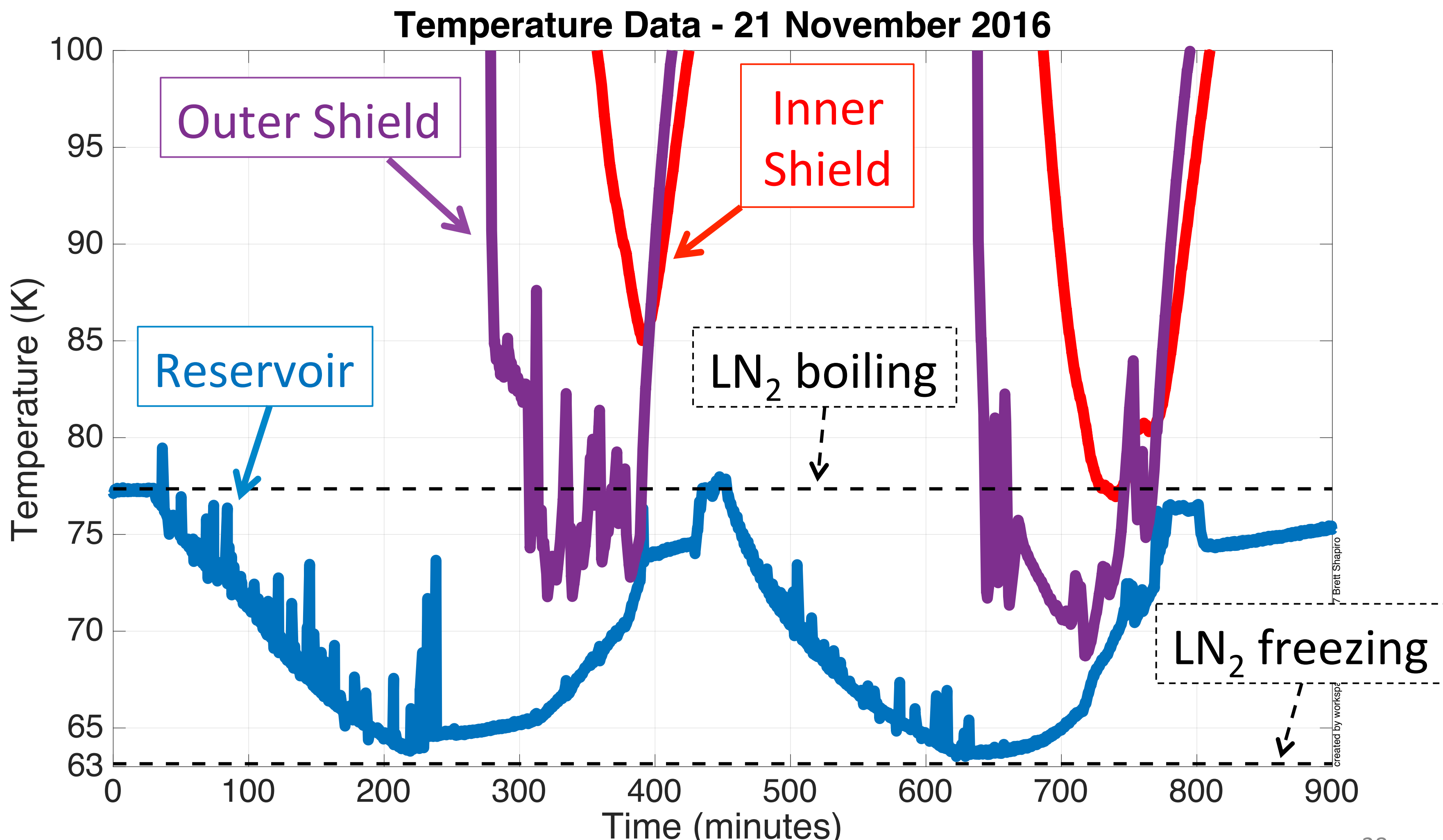
Cryogenic test mass system



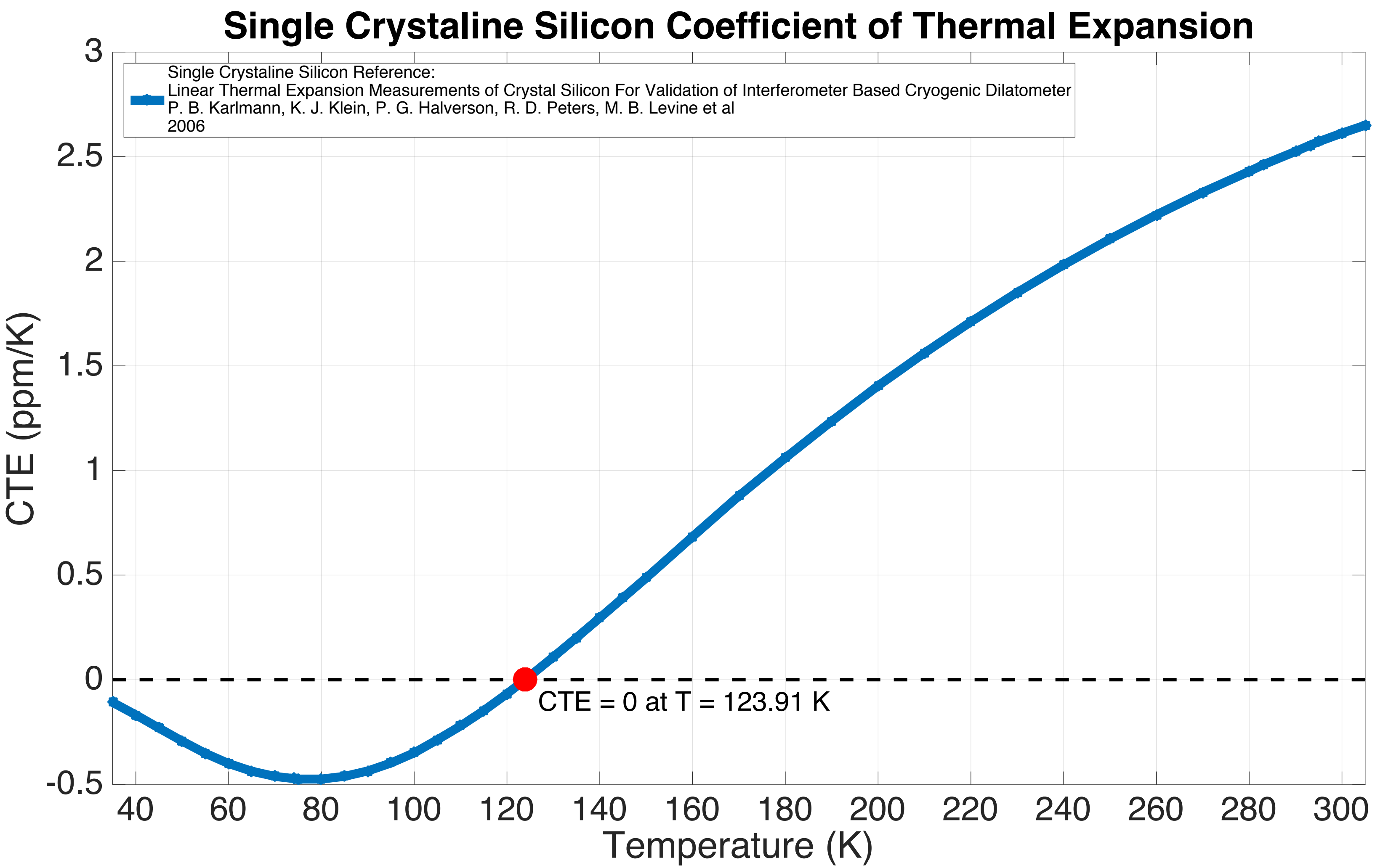
Schematic of LN_2 reservoir and refrigerator



Measured Results

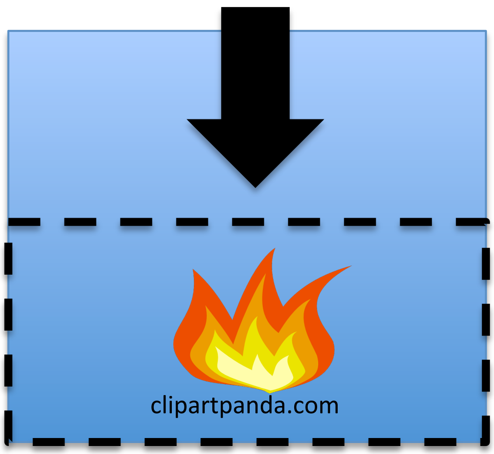


Si CTE vs Temperature

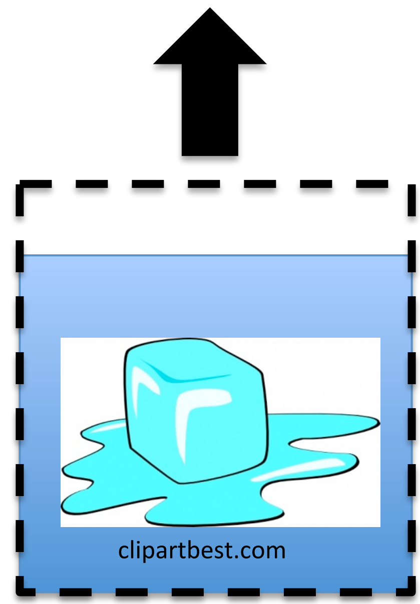


Where does thermoelastic noise come from?

For a positive thermal expansion coefficient (CTE)



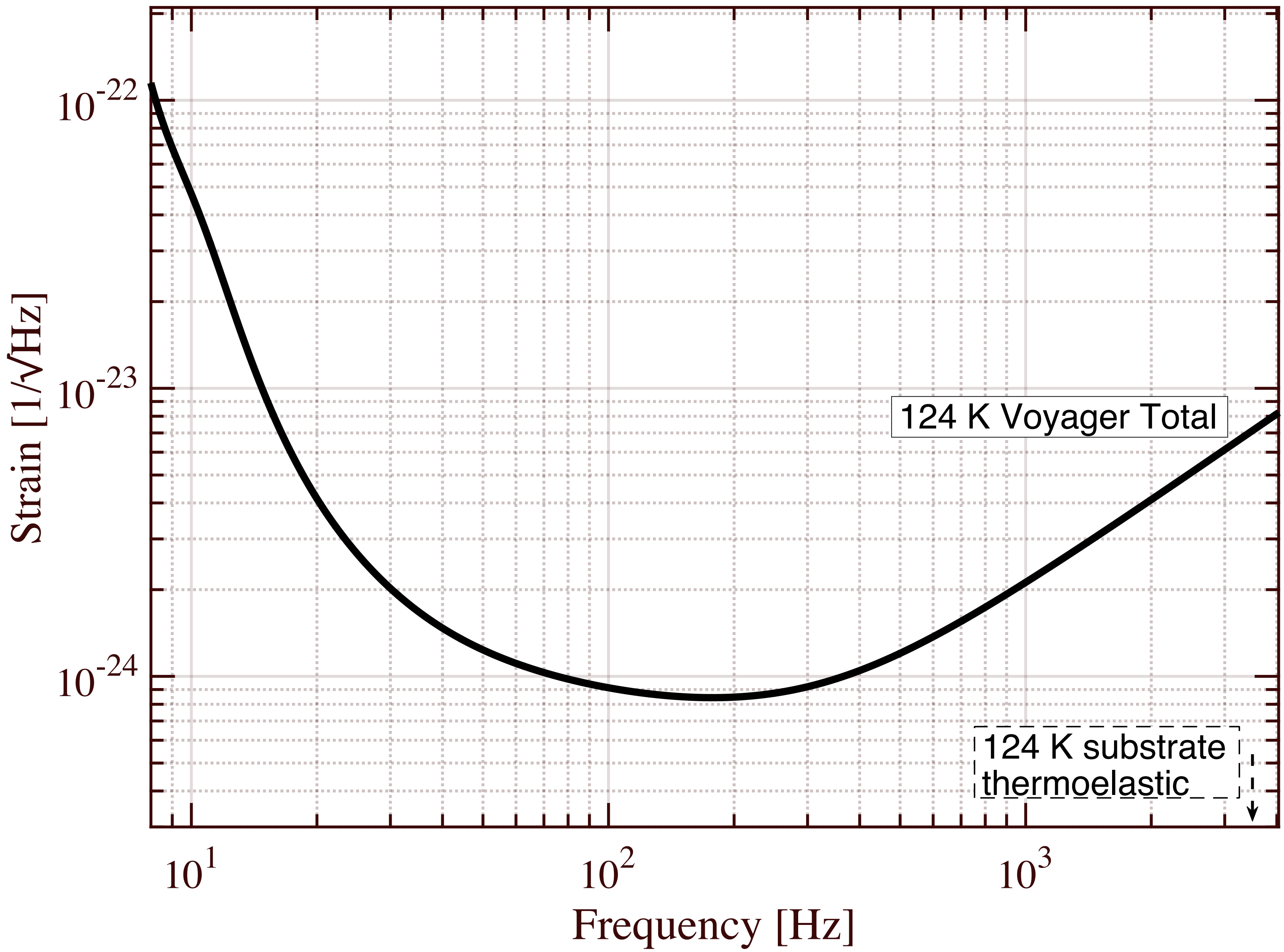
Compression generates heat



Expansion consumes heat

A vibrating mirror has local compressed and expanded regions, generating temperature gradients. Heat flows irreversibly across these gradients, causing damping. More damping results in higher off resonance thermal noise.

Test mass temperature tolerance



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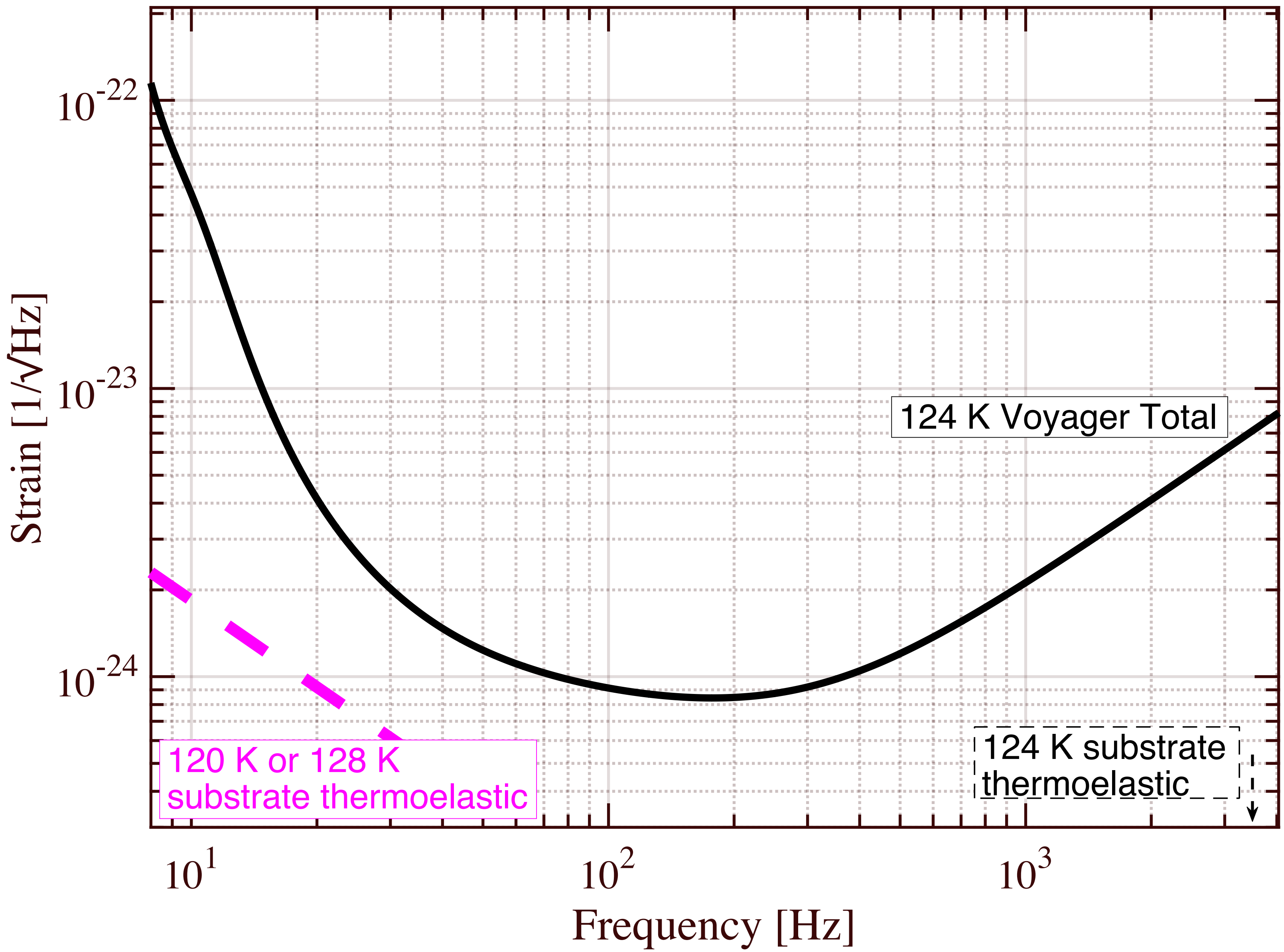

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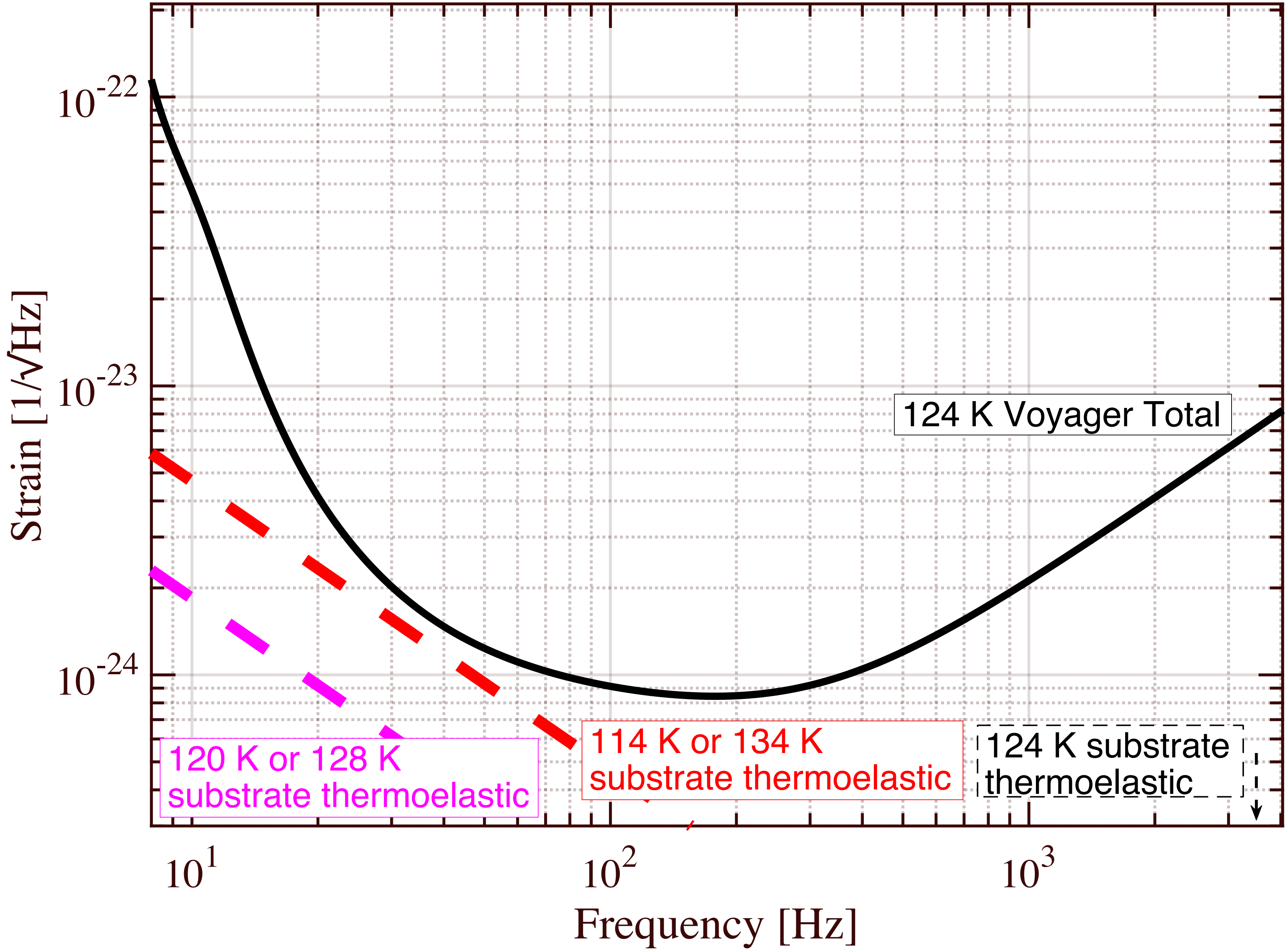
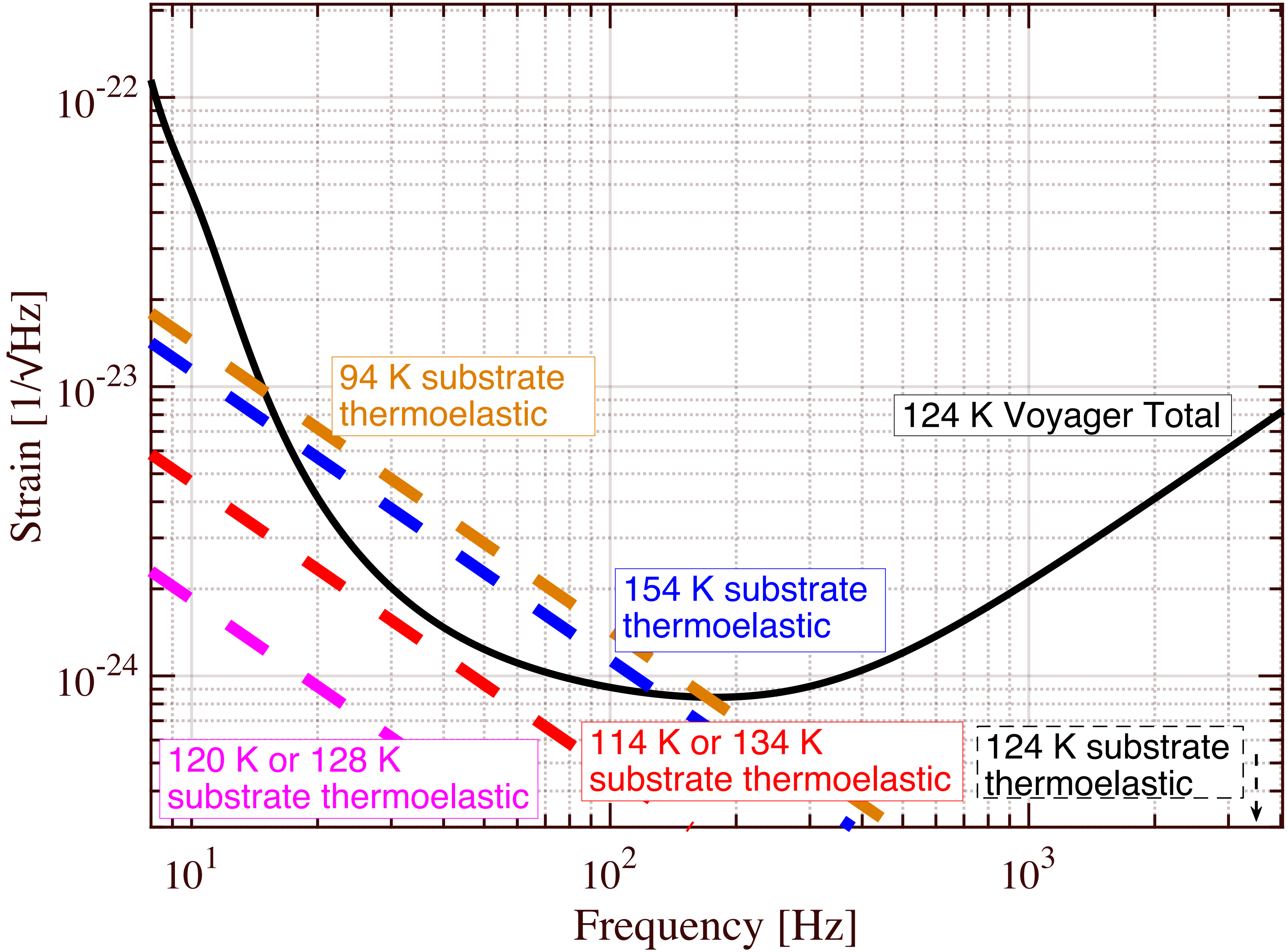
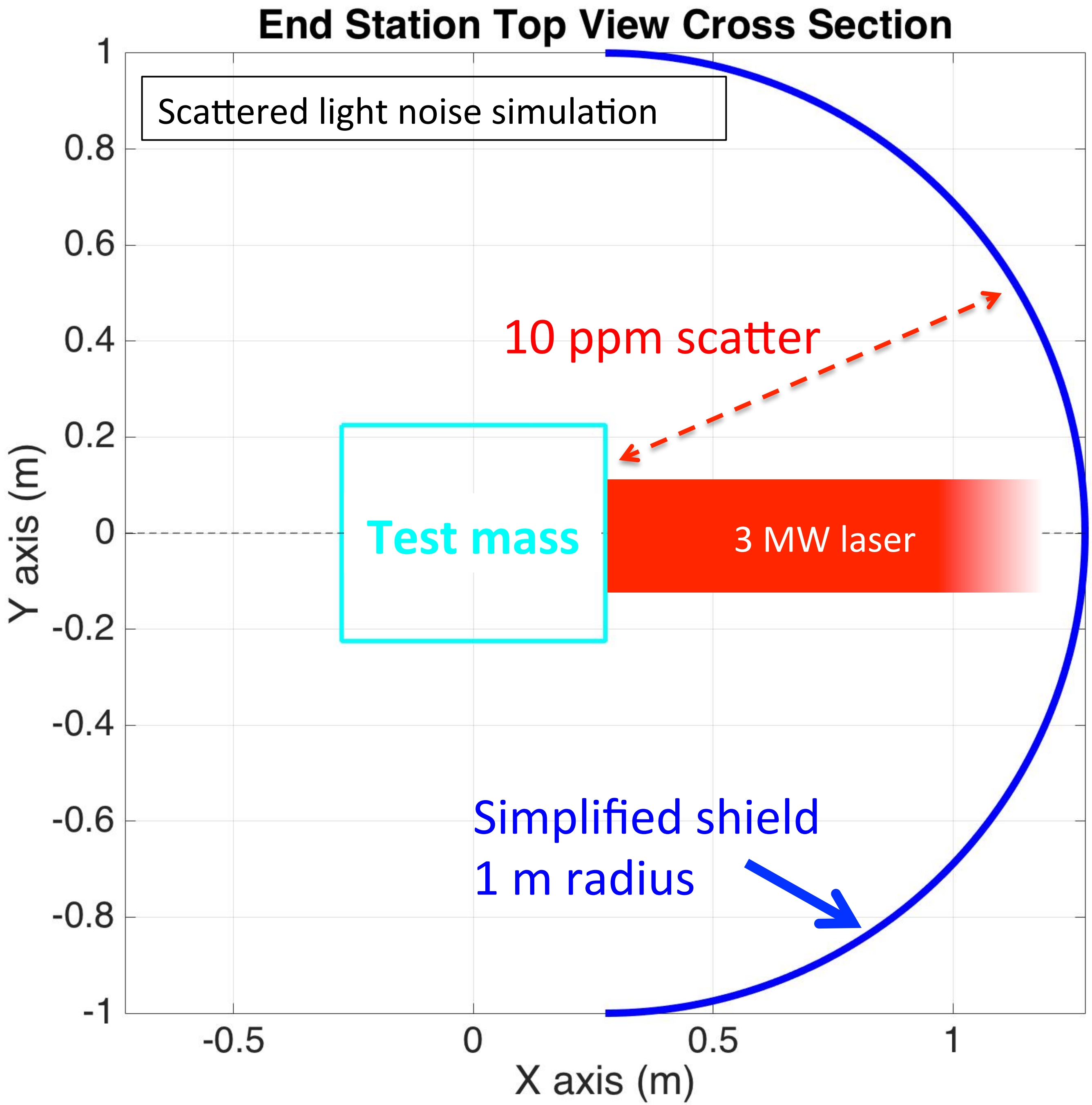
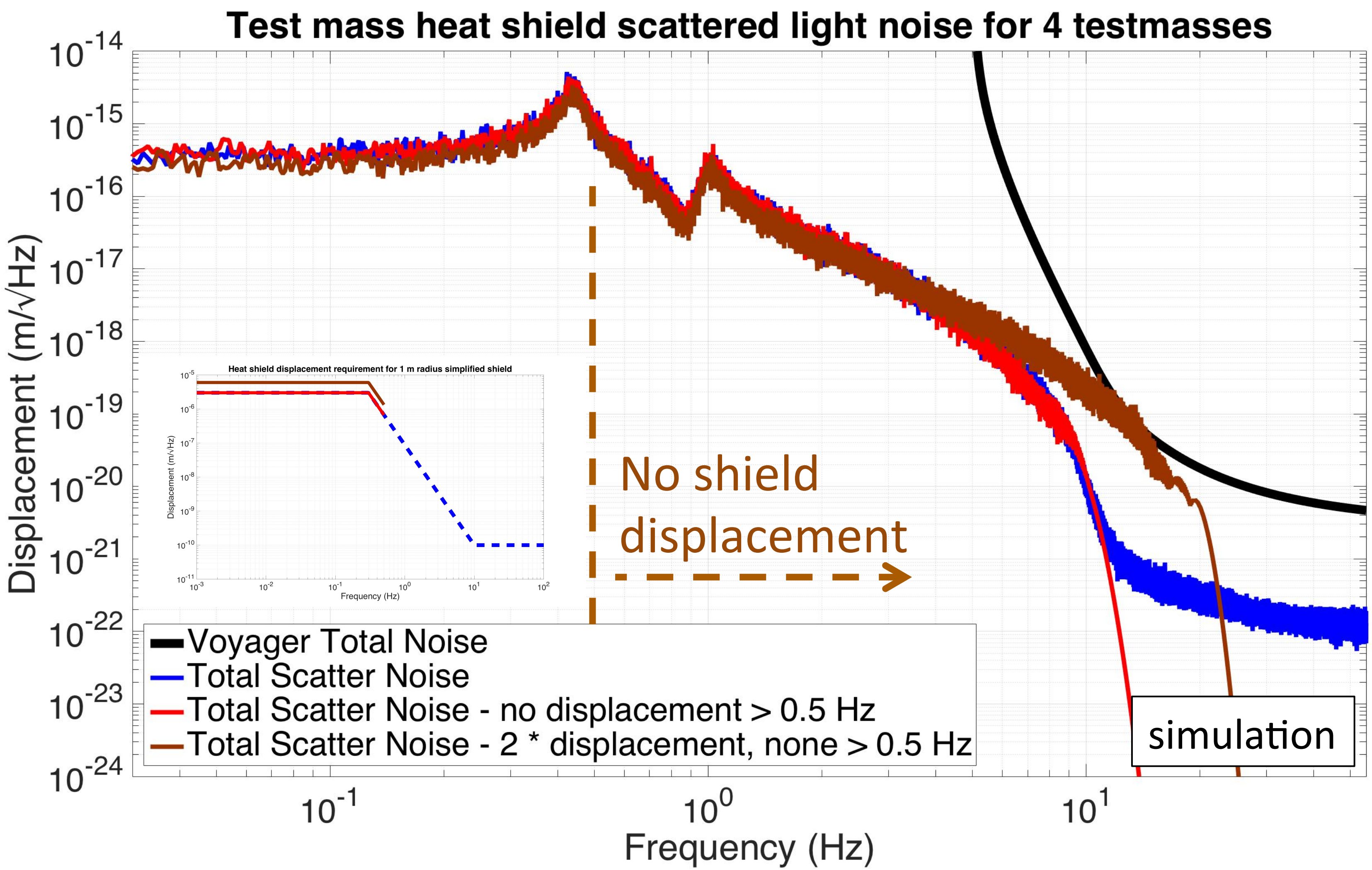


Test mass temperature tolerance

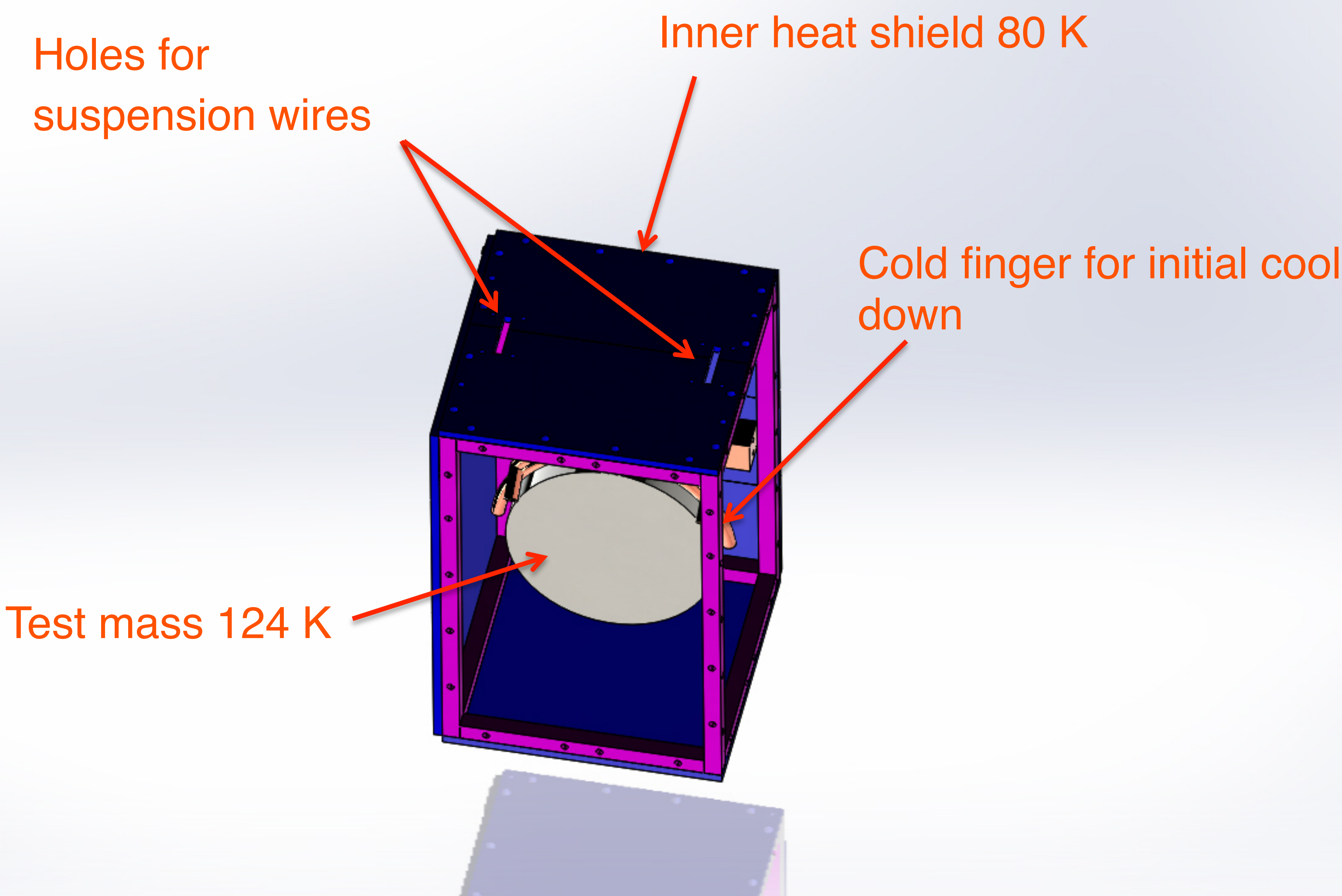



End Station Top View Cross Section
Scattered light noise simulation
10 ppm scatter
Test mass
3 MW laser
Simplified shield
1 m radius
Y axis (m)
X axis (m)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-0.5
0
0.5
1

Scattered light - upconversion

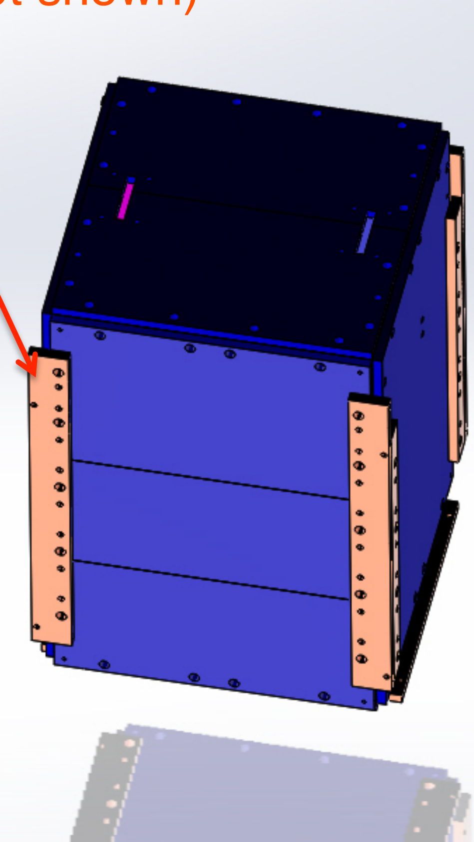


Test mass heat shield

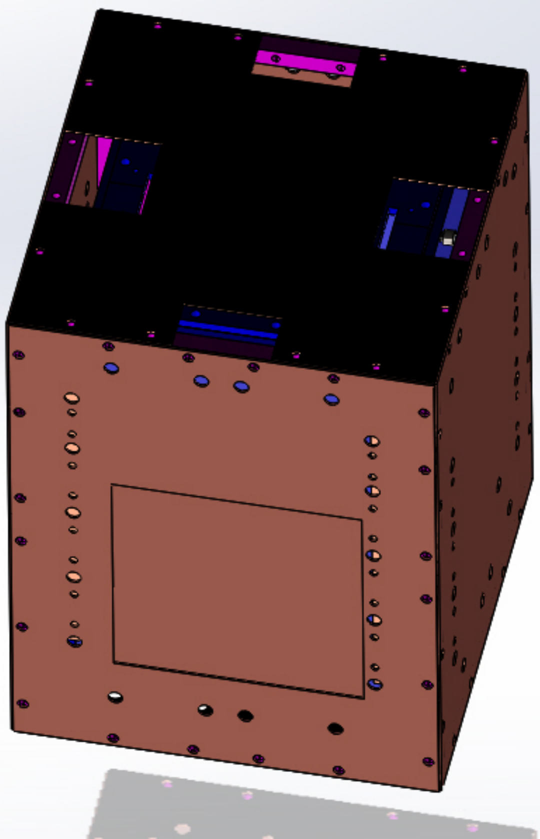


Test mass heat shield

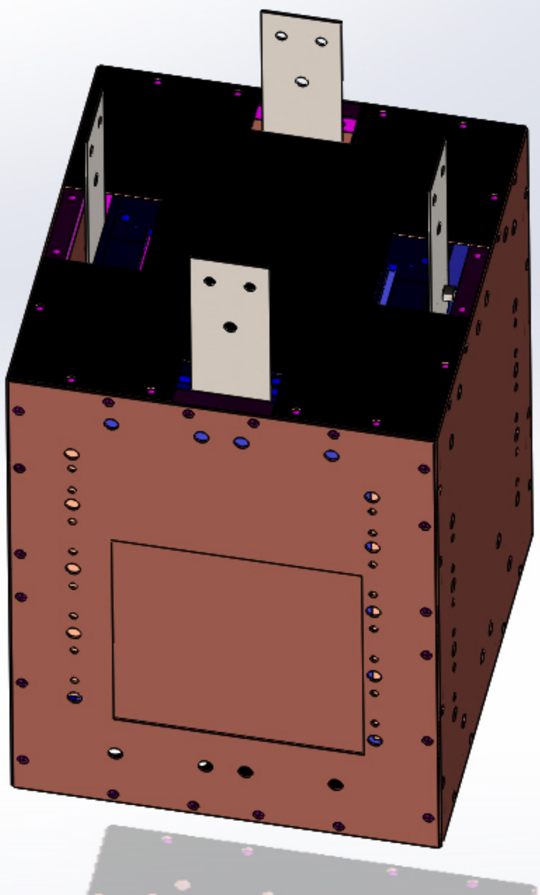
Connections for the Cu cold links that cool the inner shield (cold links not shown)

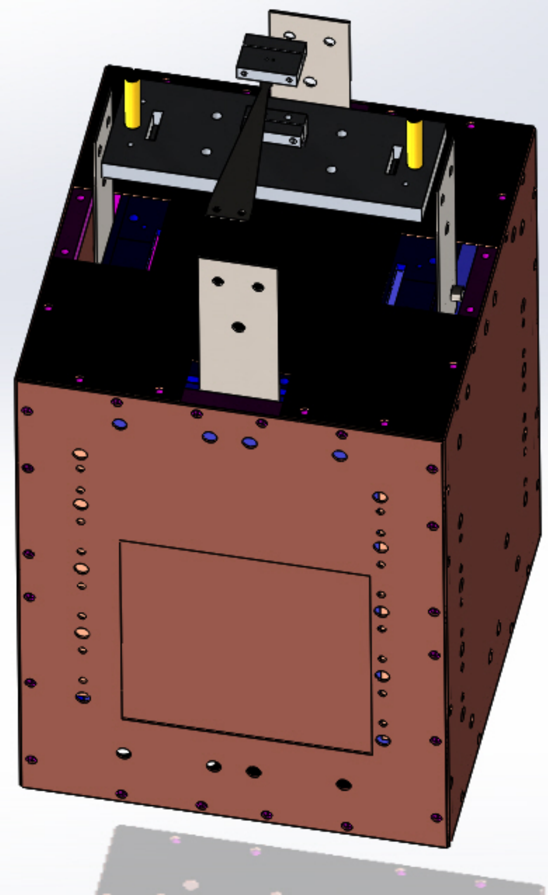


Aluminum low emissivity plates
(ribs boost vibrational frequencies)



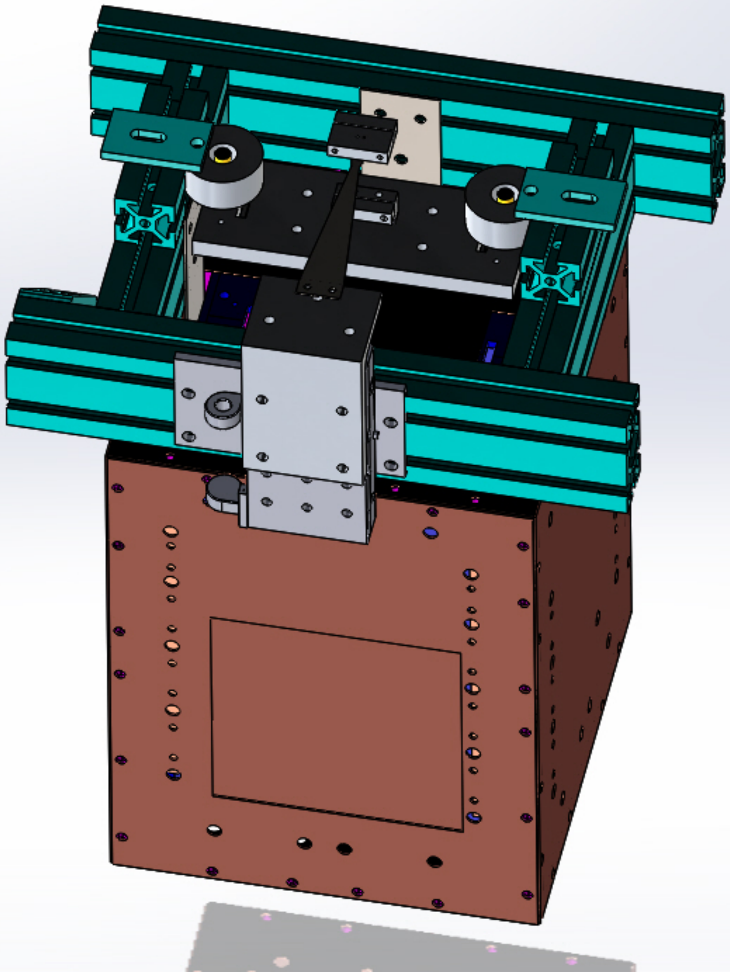
Flexible stainless strips attach the heat shield to its (warm) suspended stage





Vertical suspension OSEMs

Suspension spring mounted to vertical translation stage



The complete heat shield stage