Progress Towards a Cryogenic LIGO mirror

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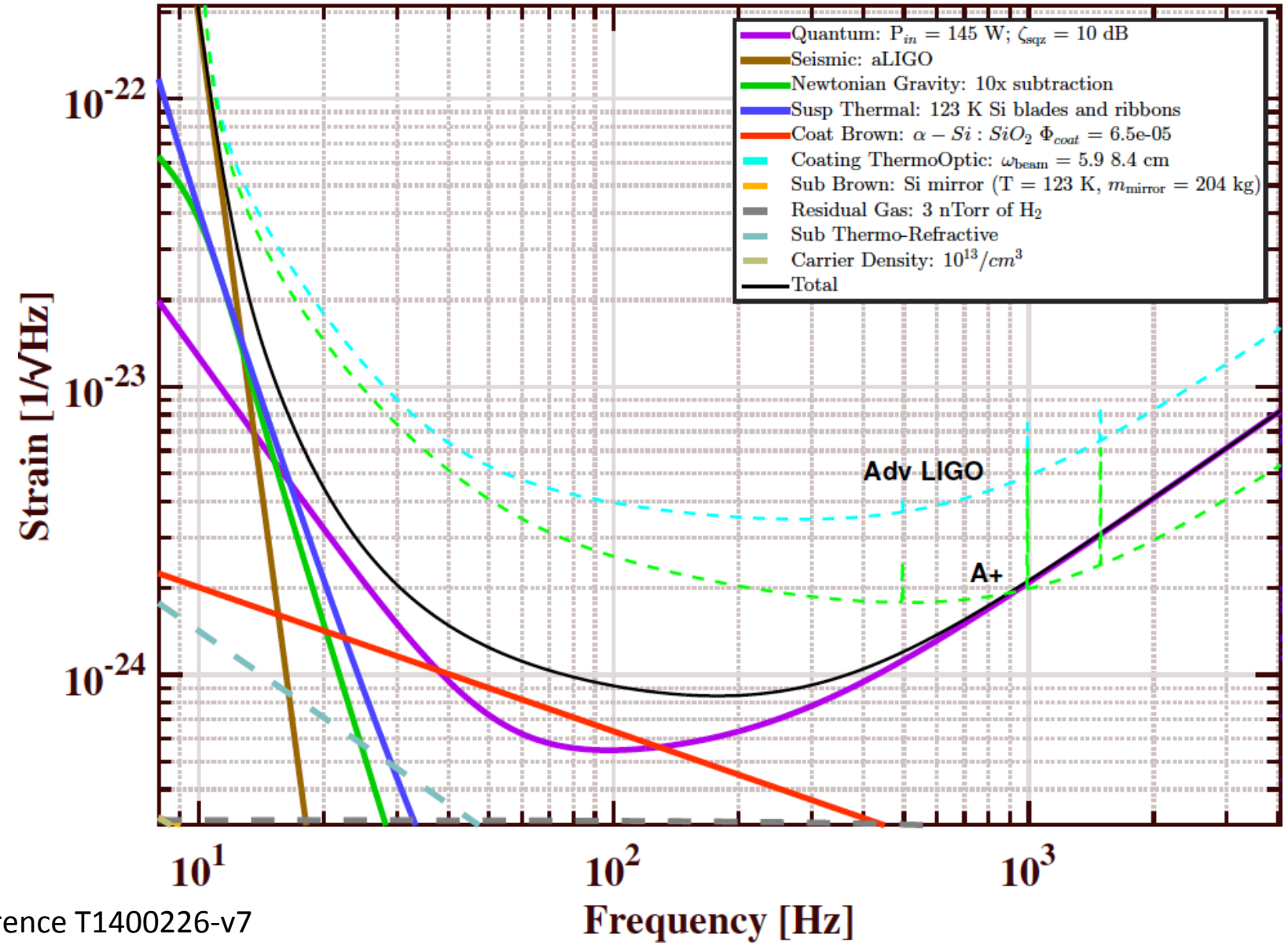
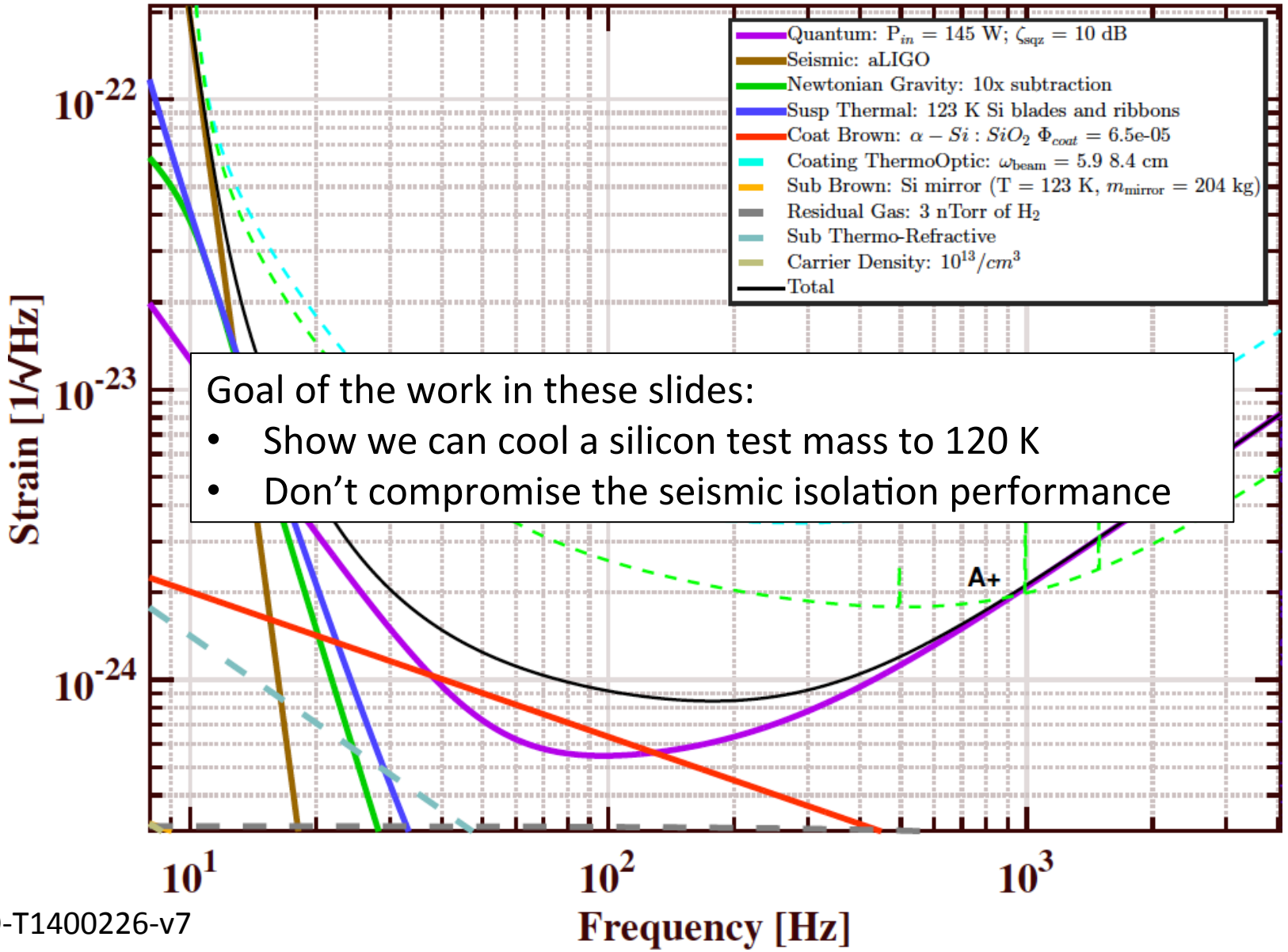
Litawn Gan, Dan Fan, Sanditi Khandelwal,
Brian Lantz
Stanford University

LIGO Voyager baseline noise model



reference T1400226-v7

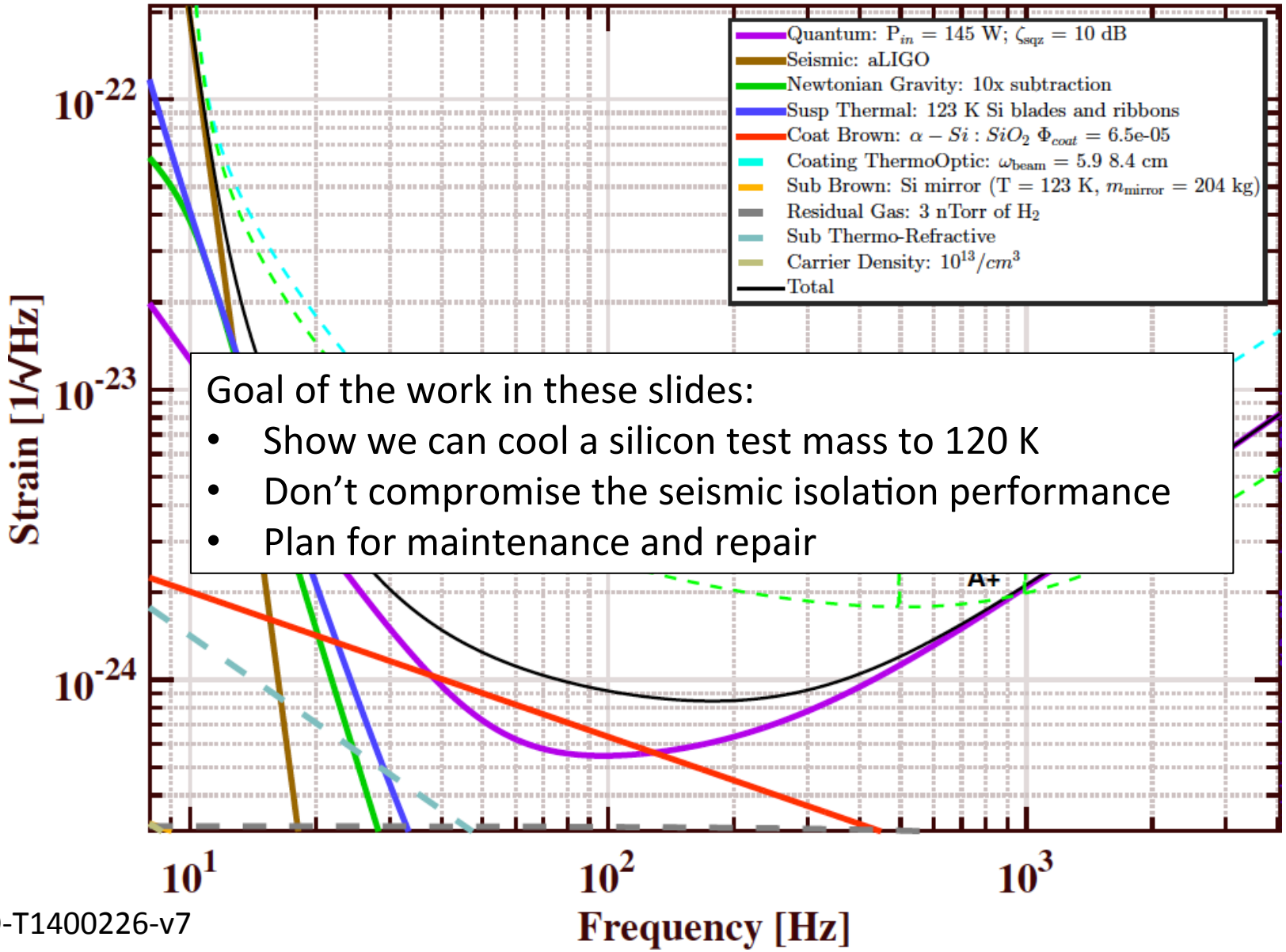
A model of the noise performance of LIGO Voyager



Goal of the work in these slides:

- Show we can cool a silicon test mass to 120 K
- Don't compromise the seismic isolation performance

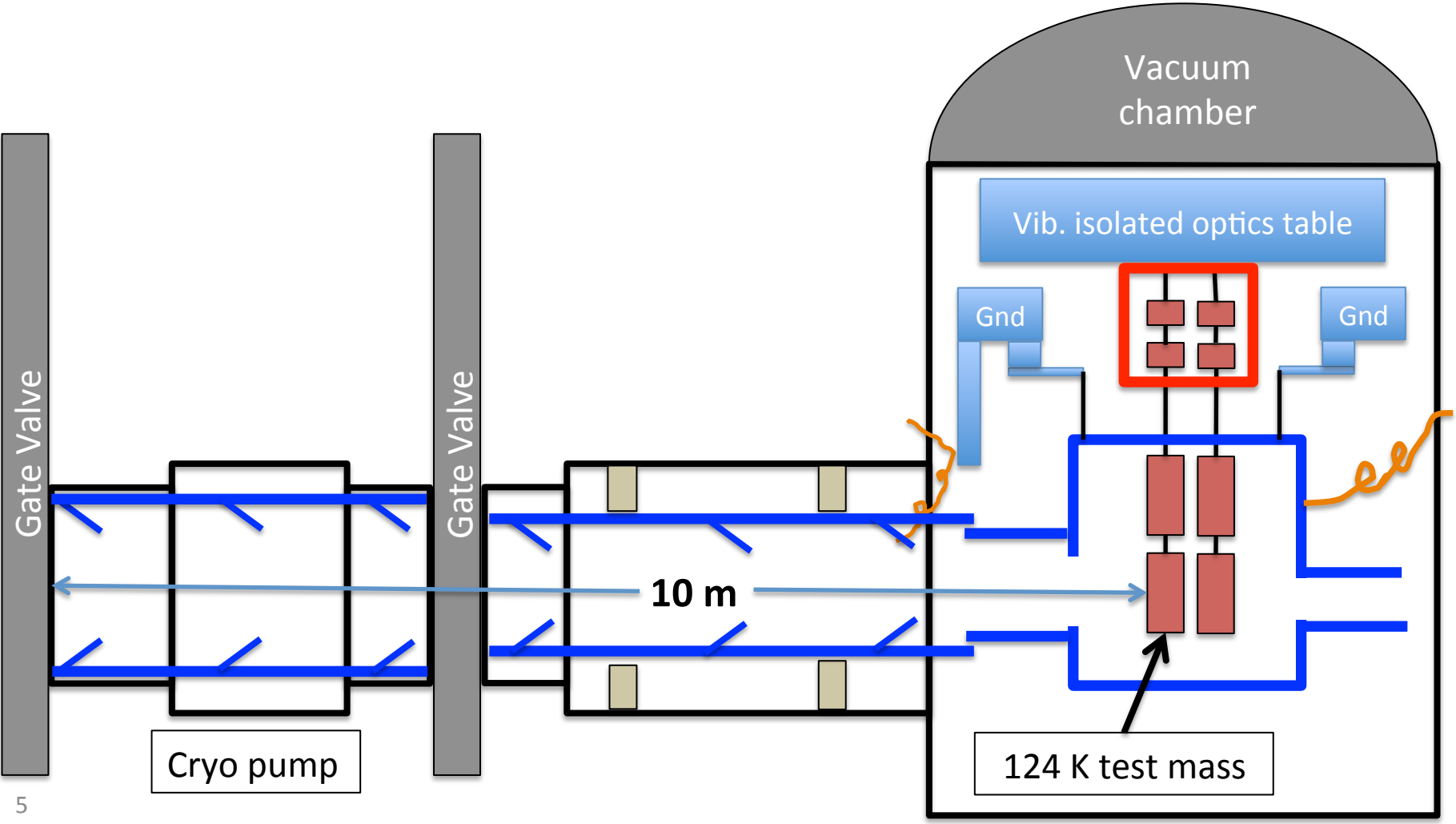
A model of the noise performance of LIGO Voyager



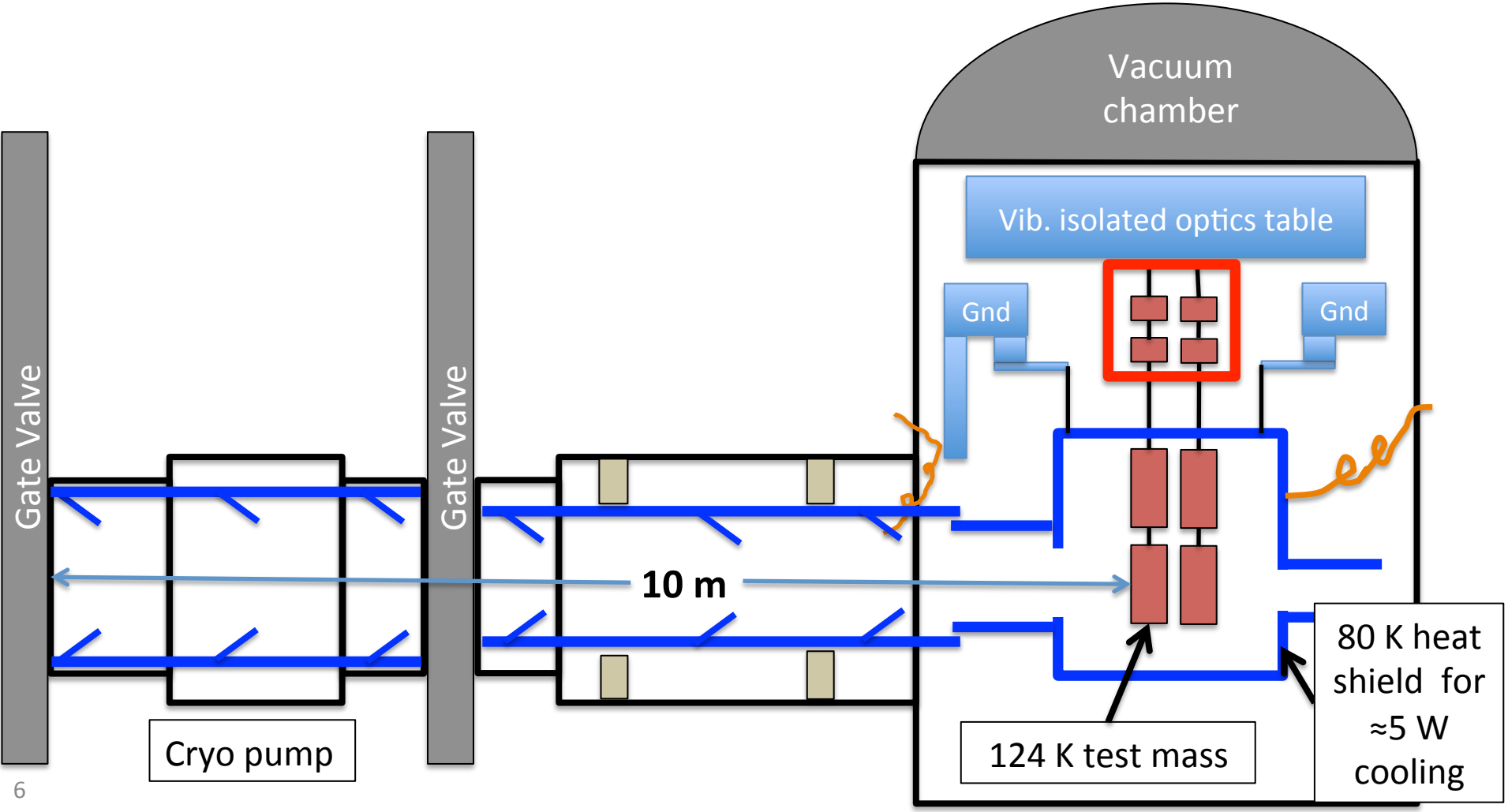
Goal of the work in these slides:

- Show we can cool a silicon test mass to 120 K
- Don't compromise the seismic isolation performance
- Plan for maintenance and repair

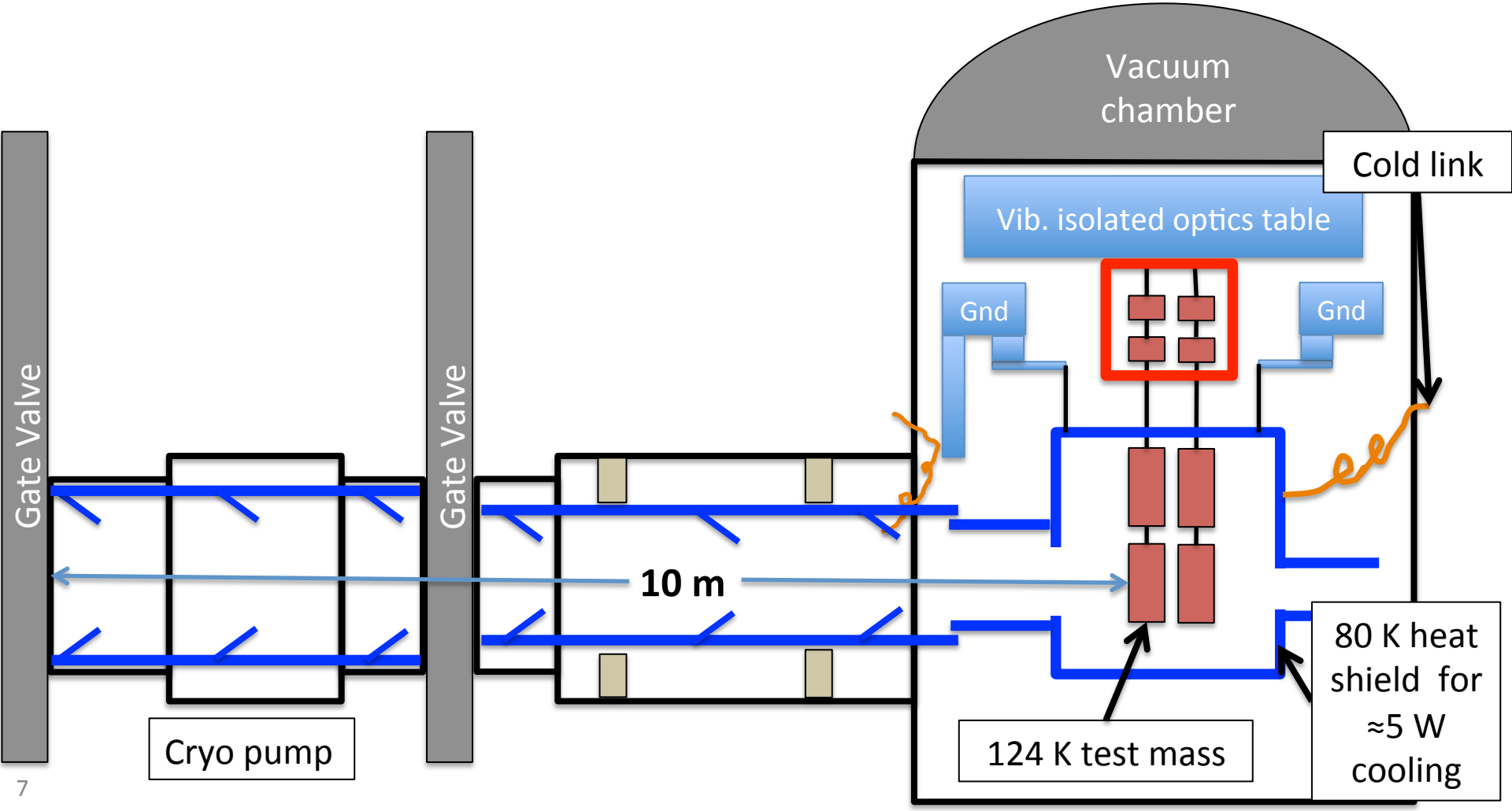
Actively controlled shield (ETM)



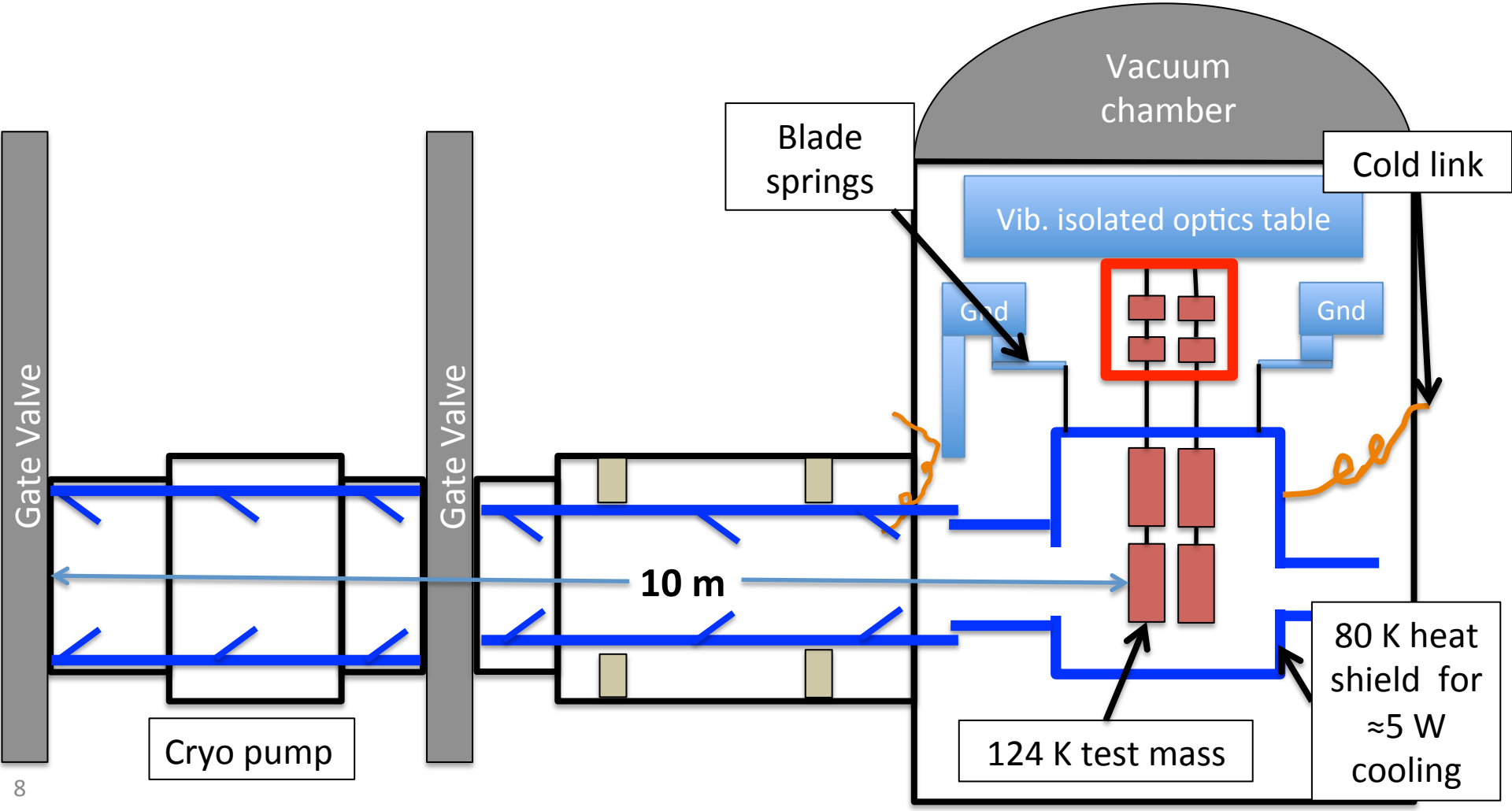
Actively controlled shield (ETM)



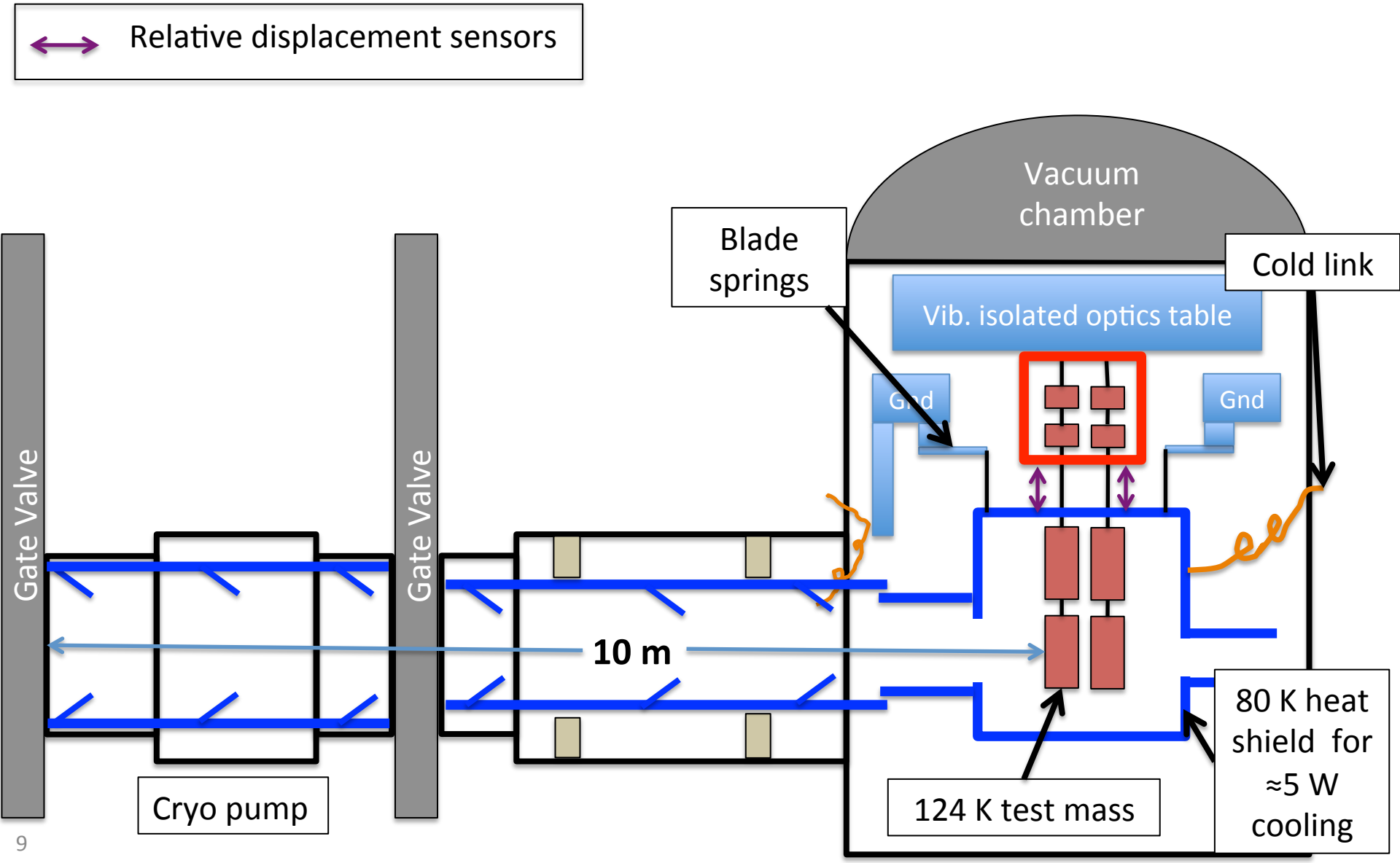
Actively controlled shield (ETM)



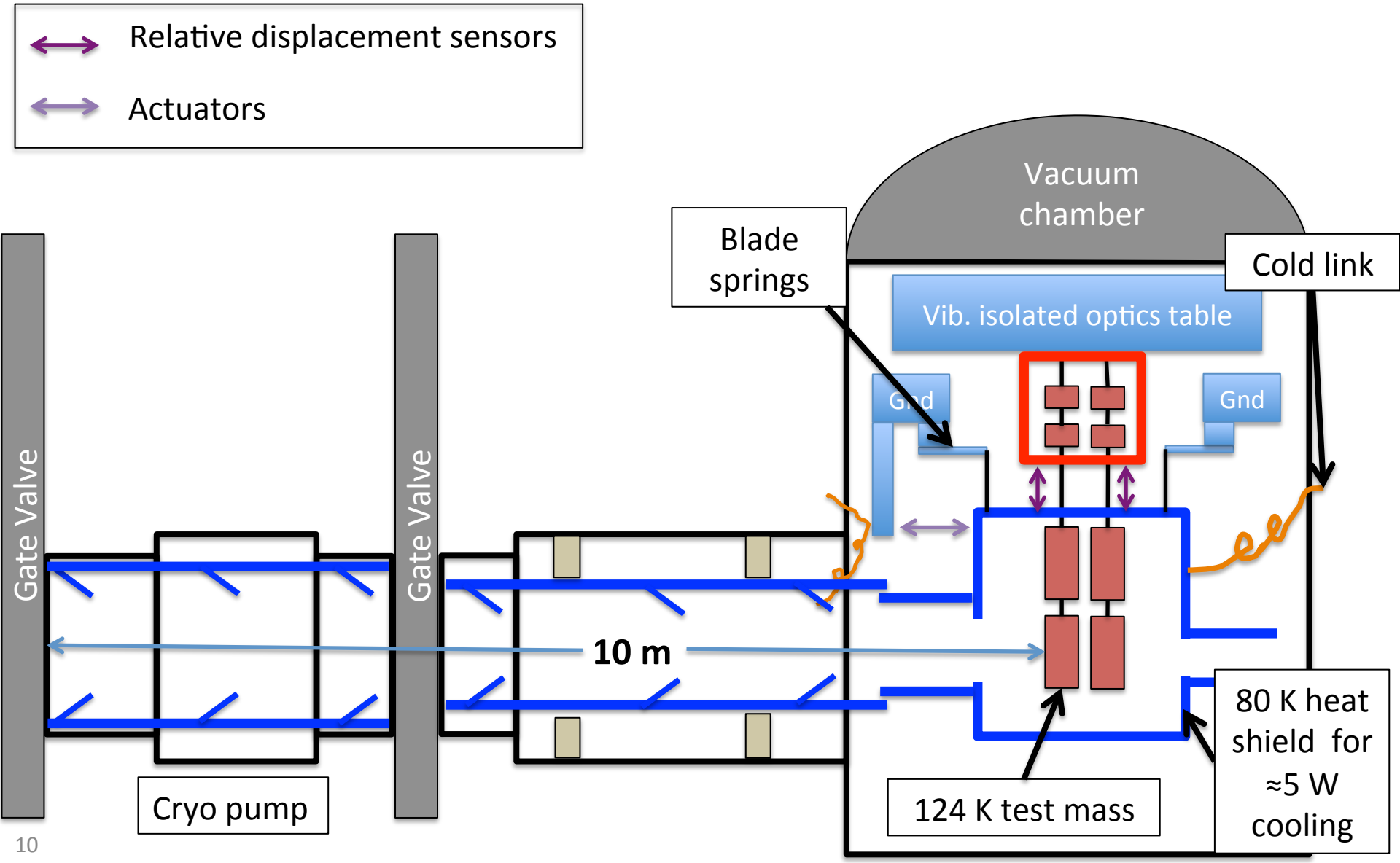
Actively controlled shield (ETM)



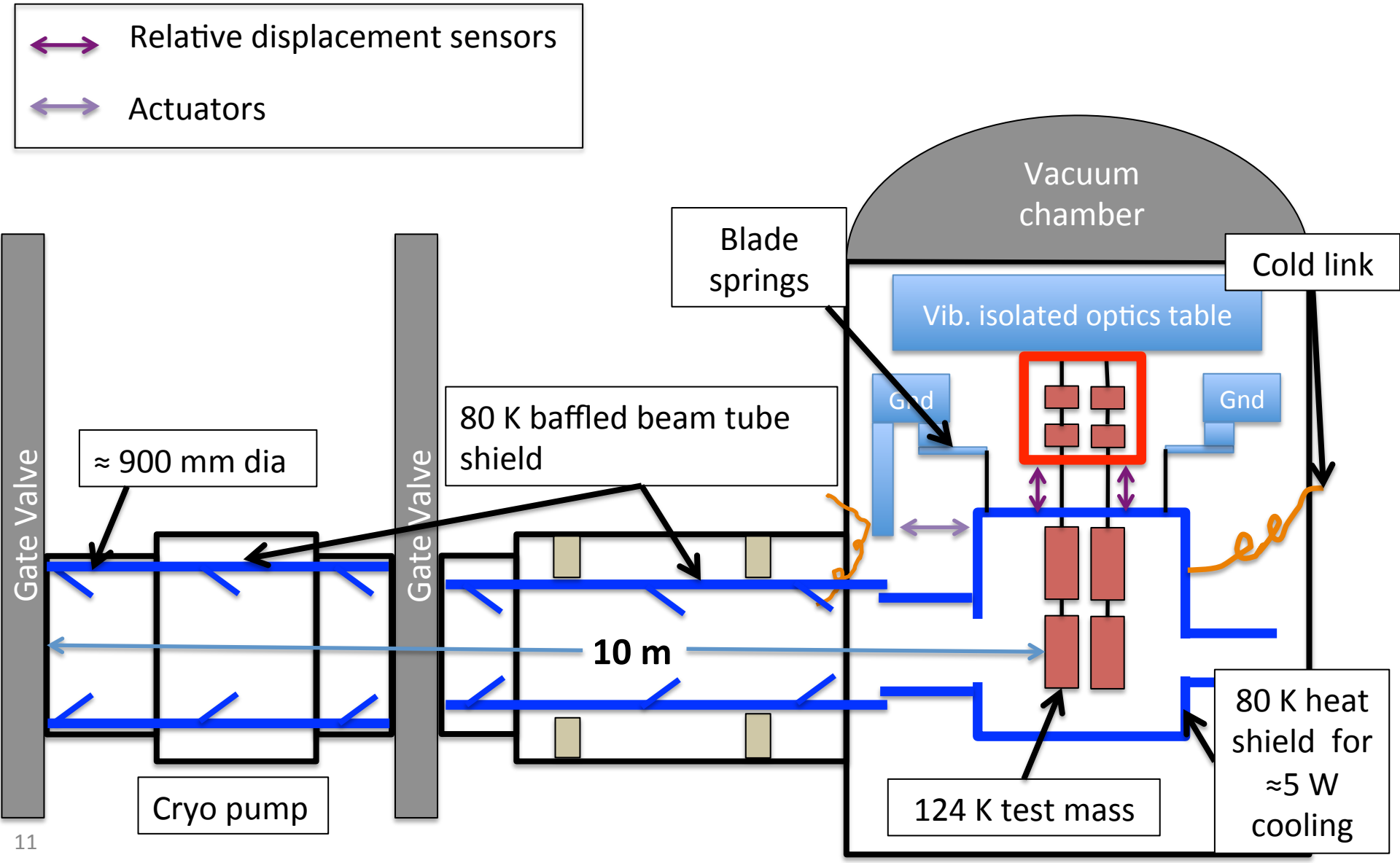
Actively controlled shield (ETM)



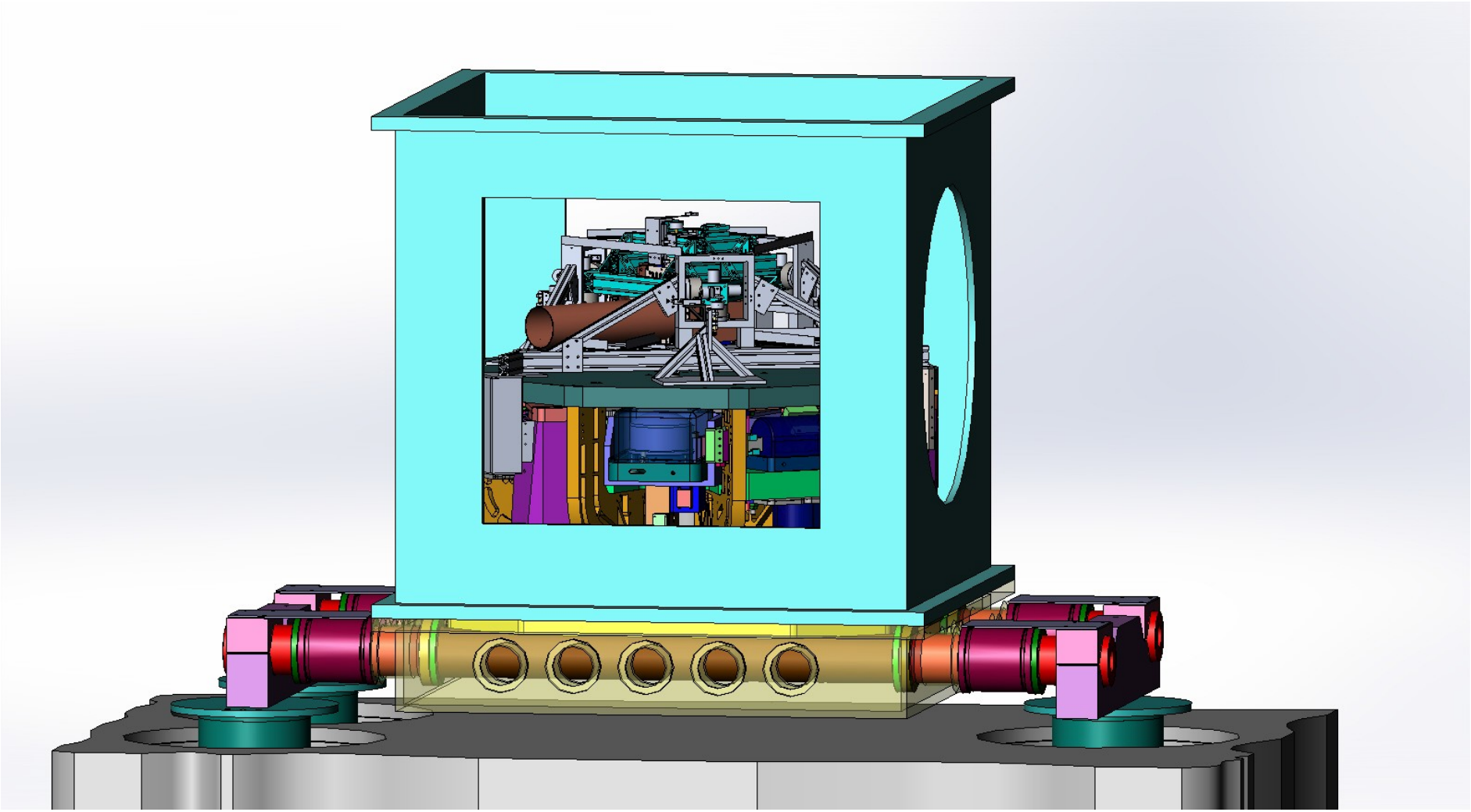
Actively controlled shield (ETM)

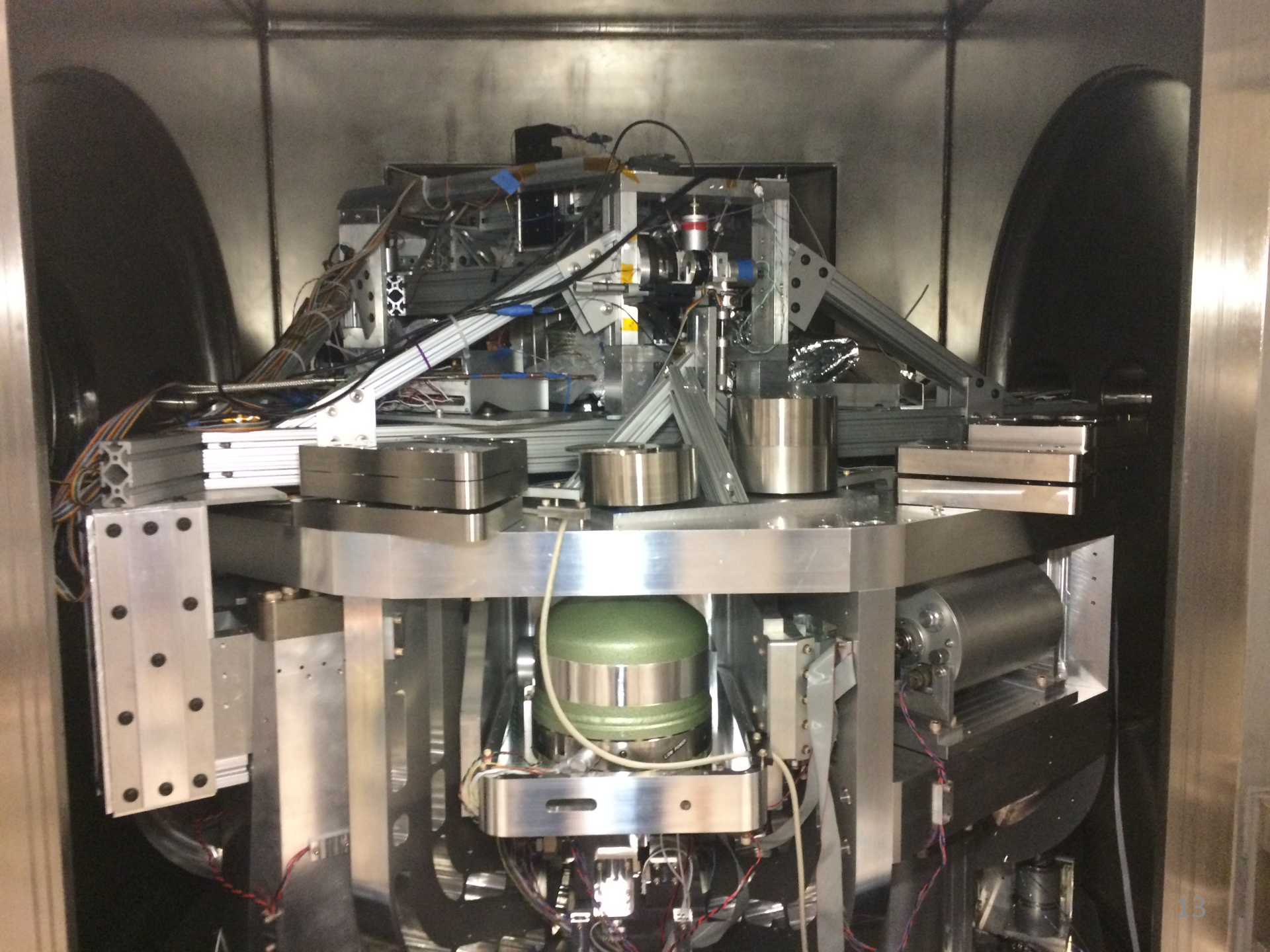


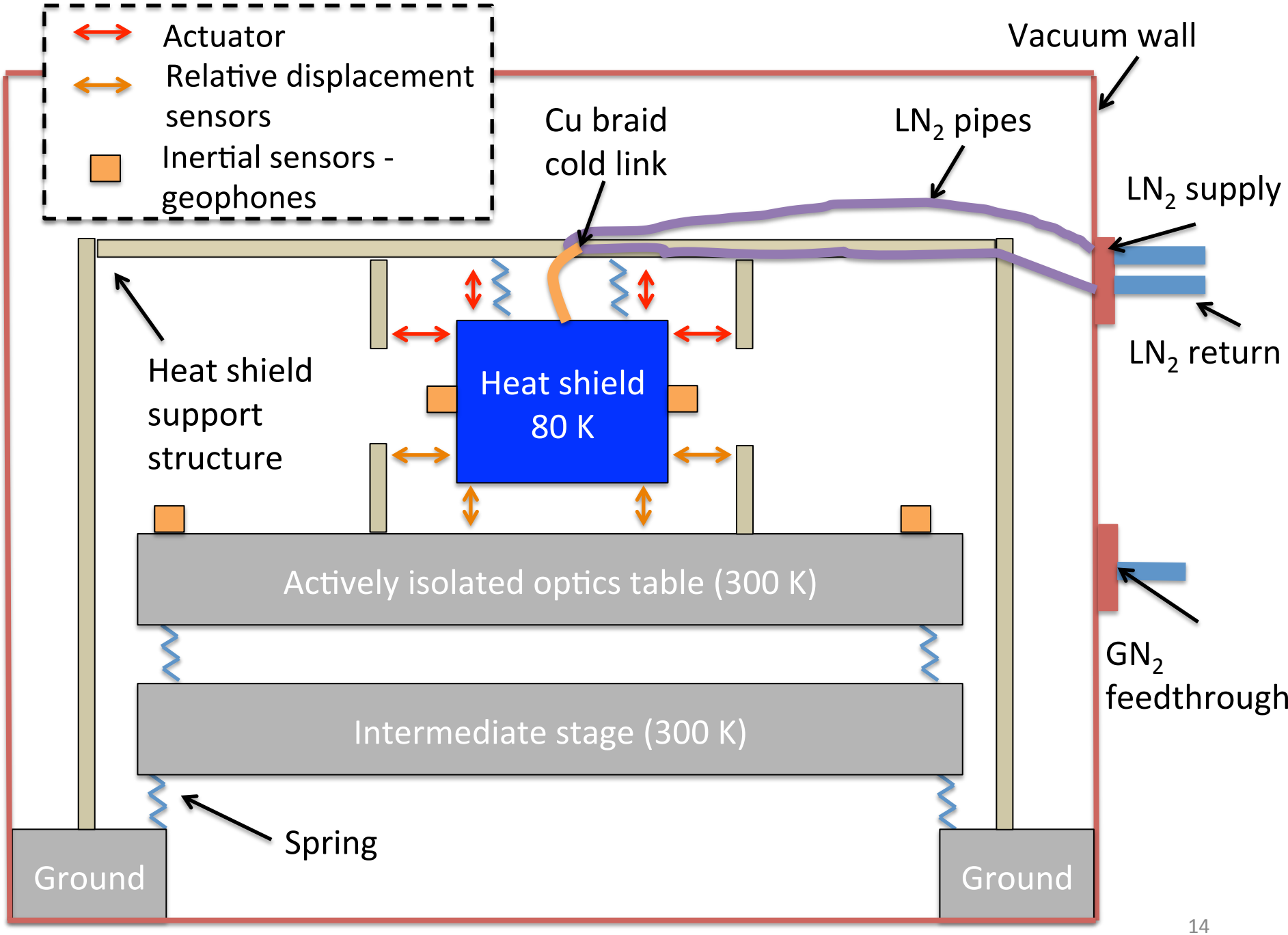
Actively controlled shield (ETM)



Heat shield experiment at Stanford University

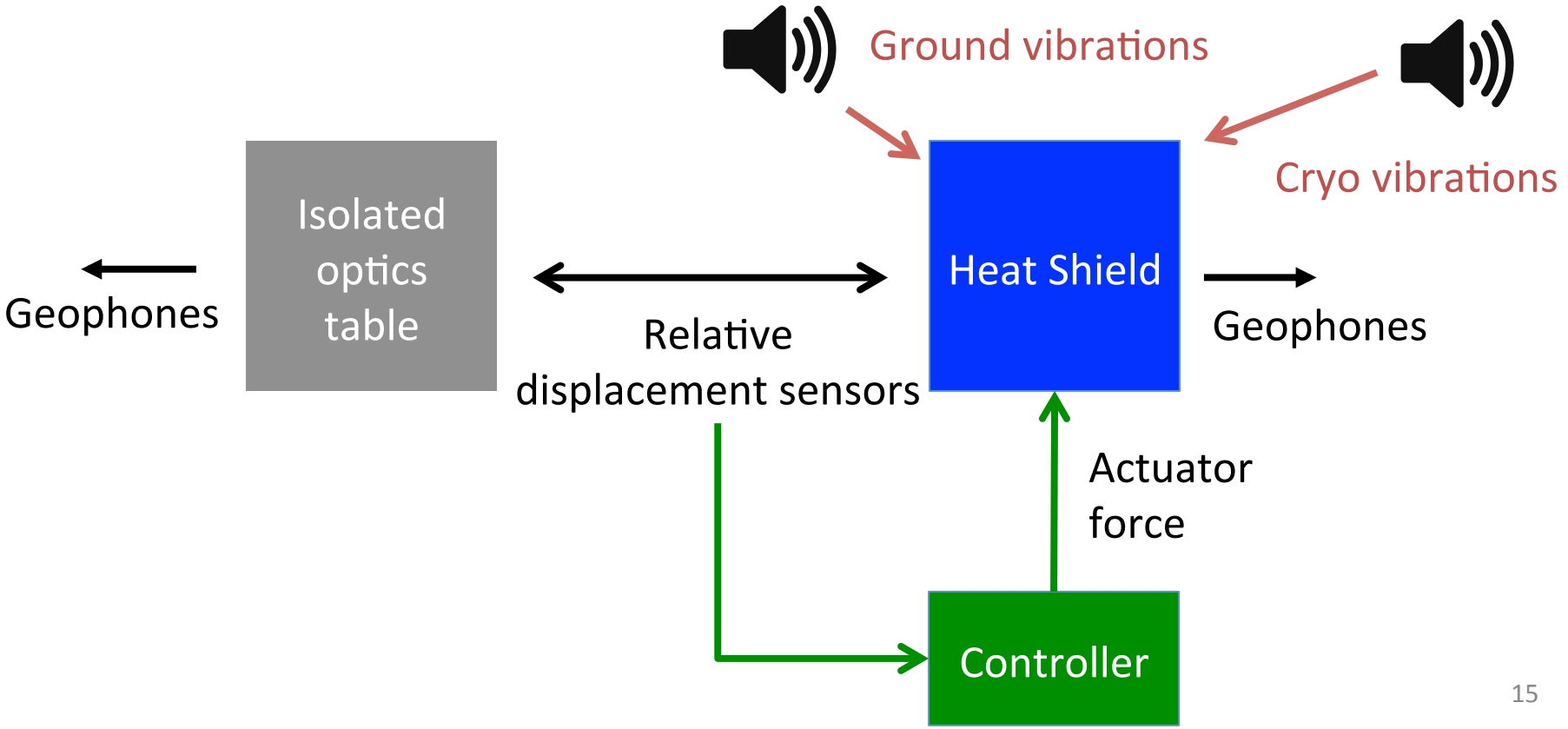





Actuator
Relative displacement sensors
Inertial sensors - geophones
Vacuum wall
Cu braid cold link
LN2 pipes
LN2 supply
LN2 return
Heat shield support structure
Heat shield 80 K
Actively isolated optics table (300 K)
Intermediate stage (300 K)
GN2 feedthrough
Spring
Ground
Ground

Heat shield measurement and control

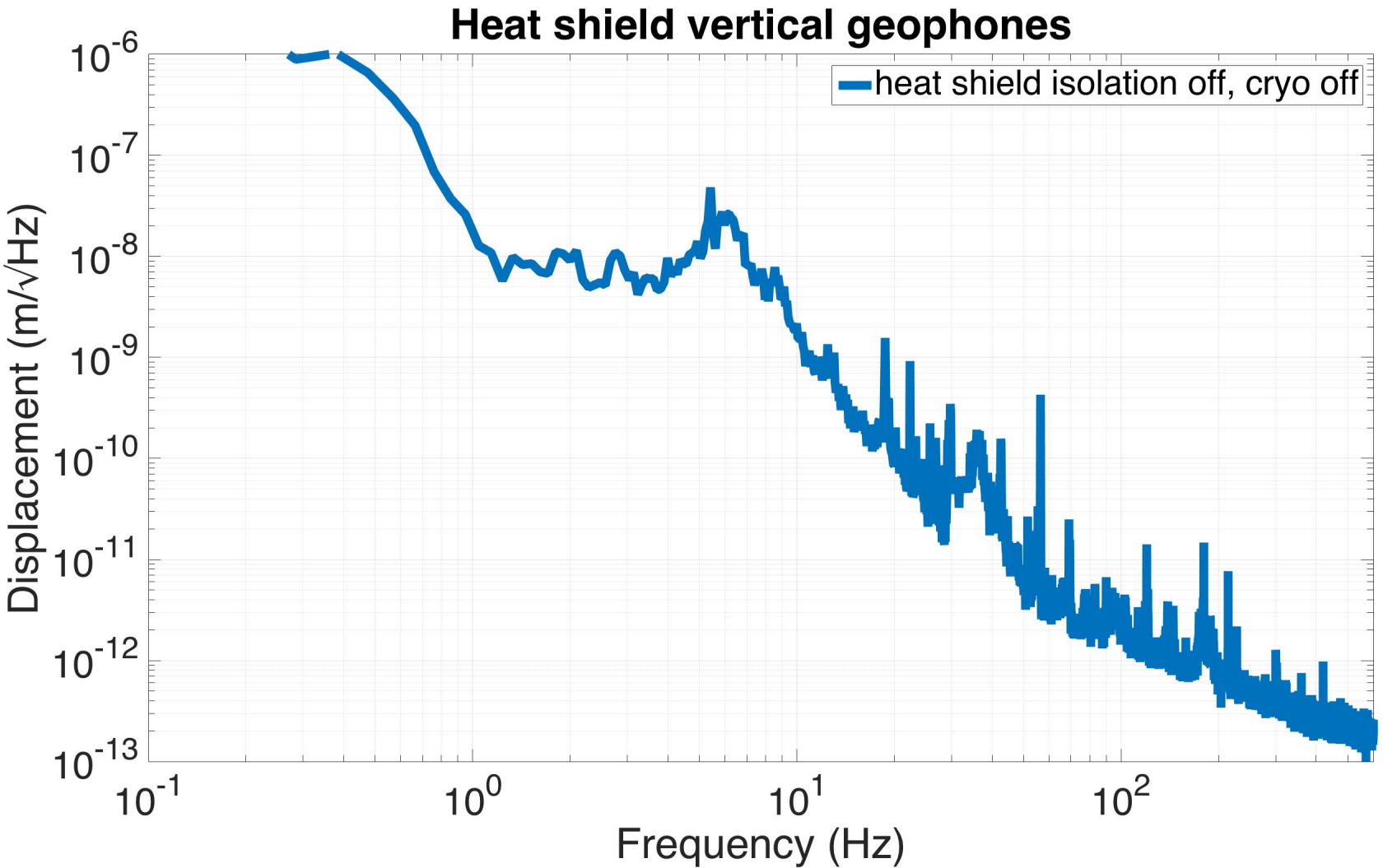
- The controller forces the heat shield to follow the isolated optics table using the relative displacement sensors
- The heat shield's geophones are used to measure how well the control is doing



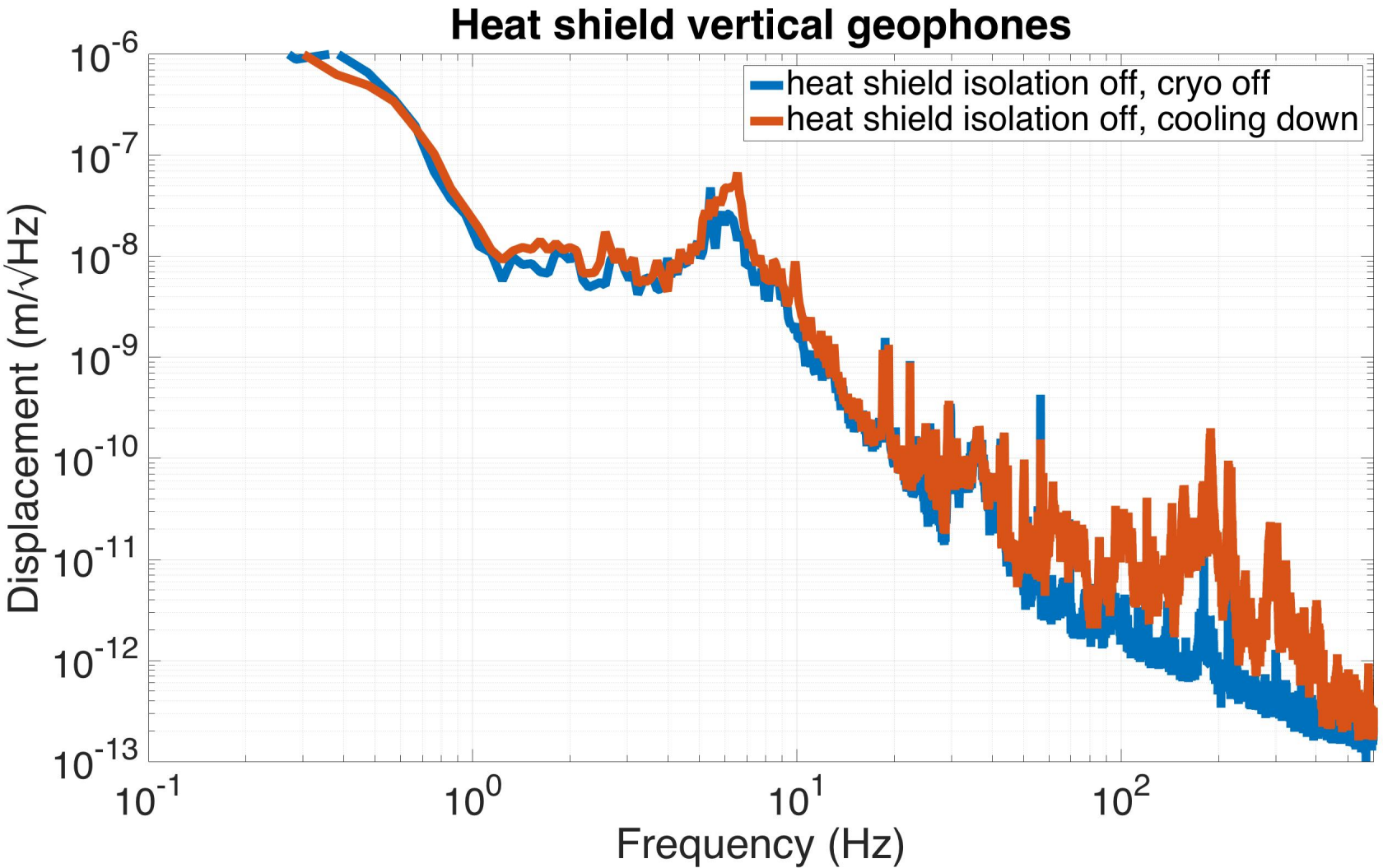
Ground vibrations

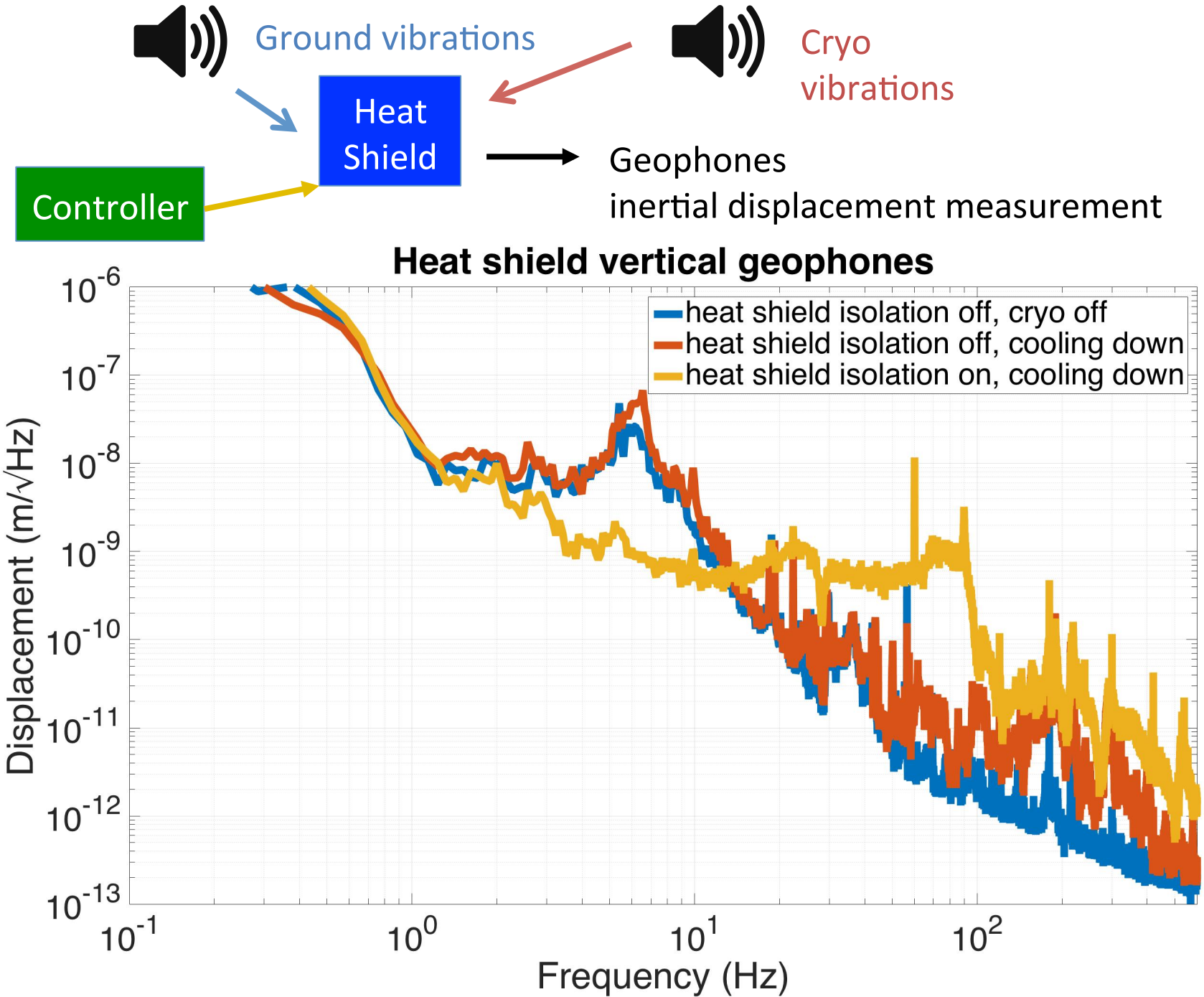
Heat Shield

Geophones
inertial displacement measurement

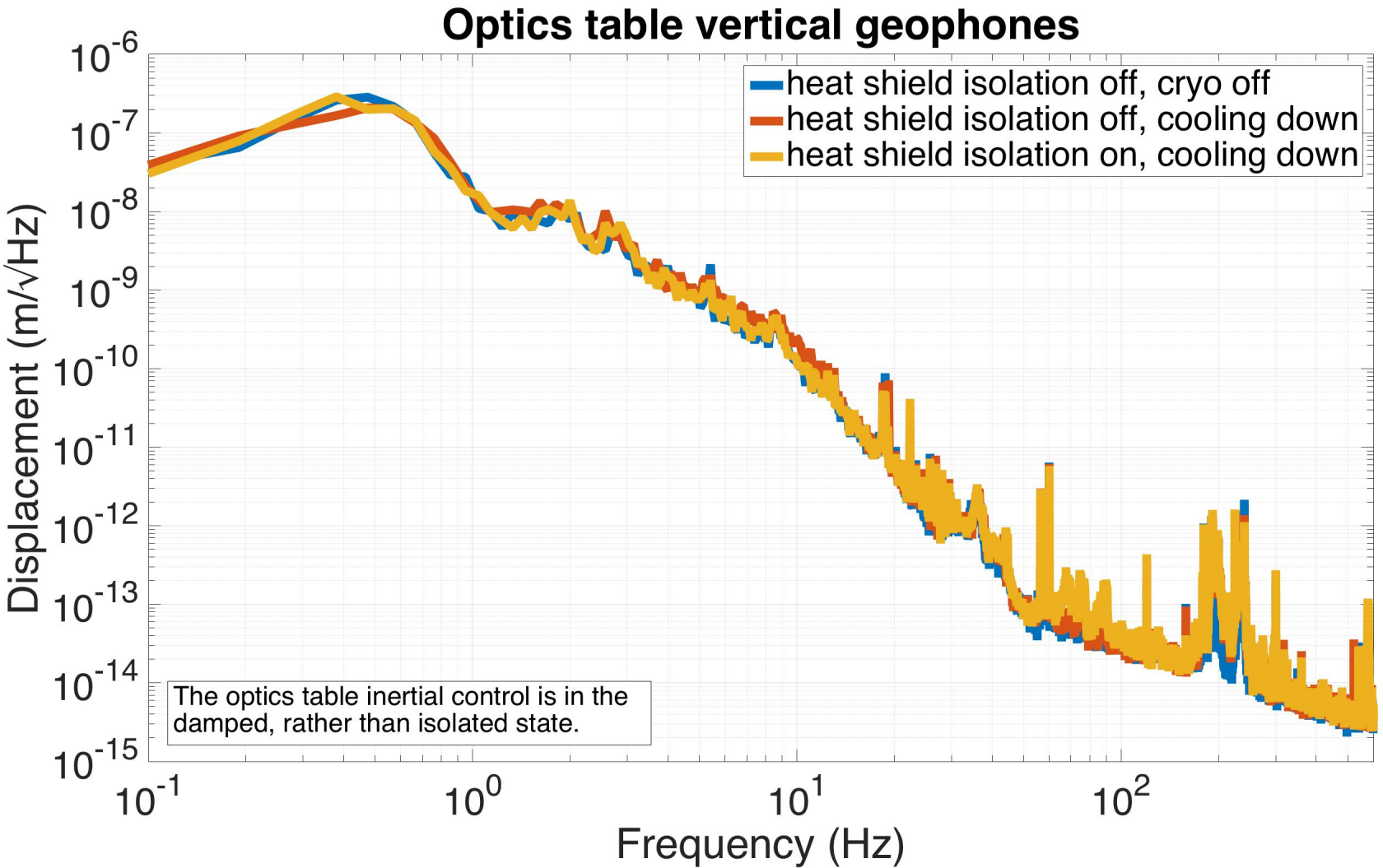


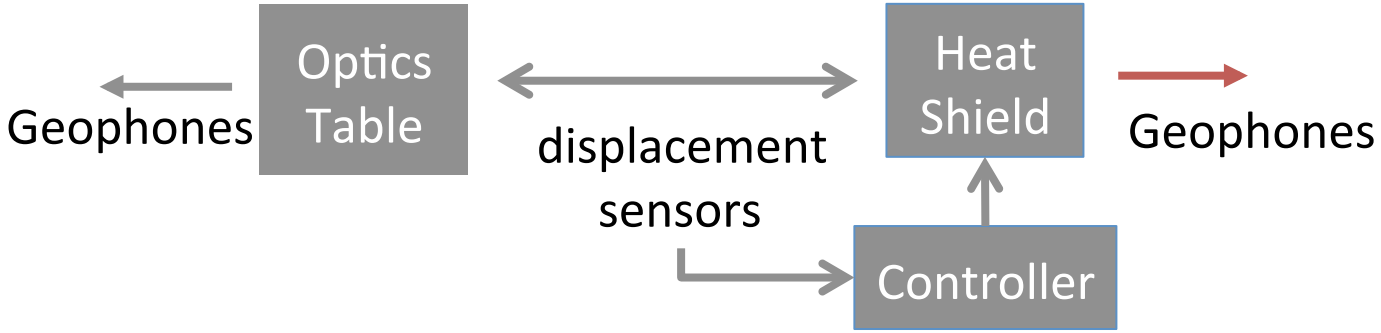
Geophones
inertial displacement measurement

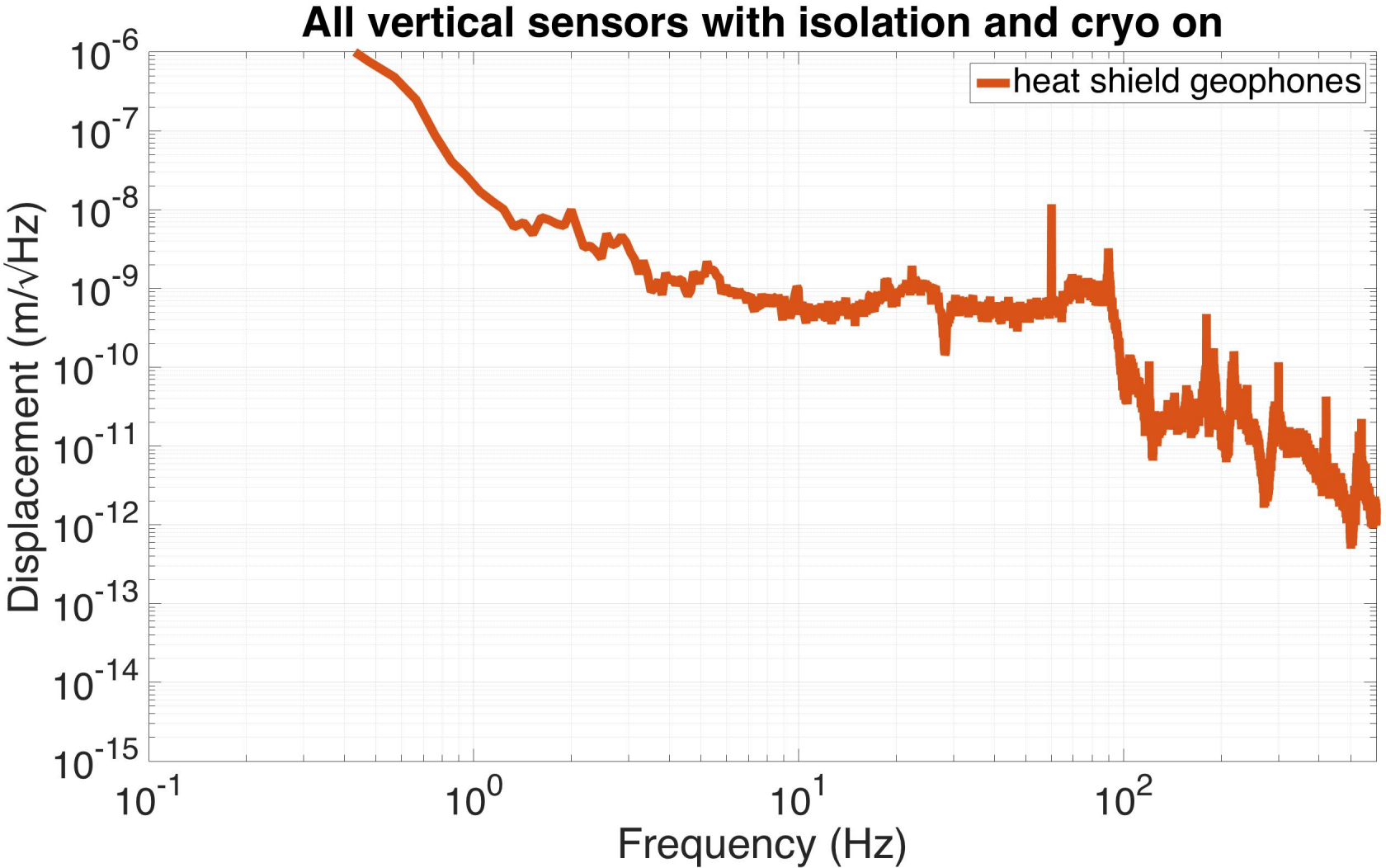


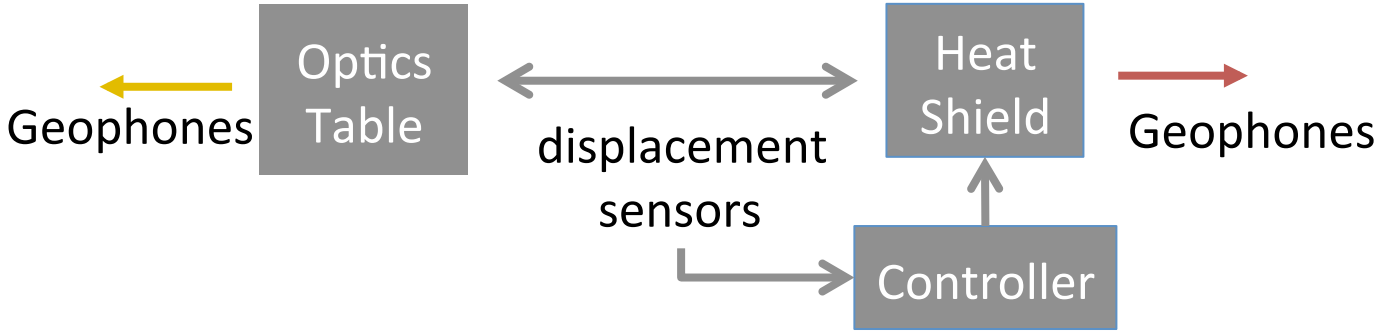

Ground vibrations
Cryo vibrations
Heat Shield
Controller
Geophones
inertial displacement measurement
Heat shield vertical geophones
heat shield isolation off, cryo off
heat shield isolation off, cooling down
heat shield isolation on, cooling down
Displacement (m/√Hz)
Frequency (Hz)
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
10^-1
10^0
10^1
10^2

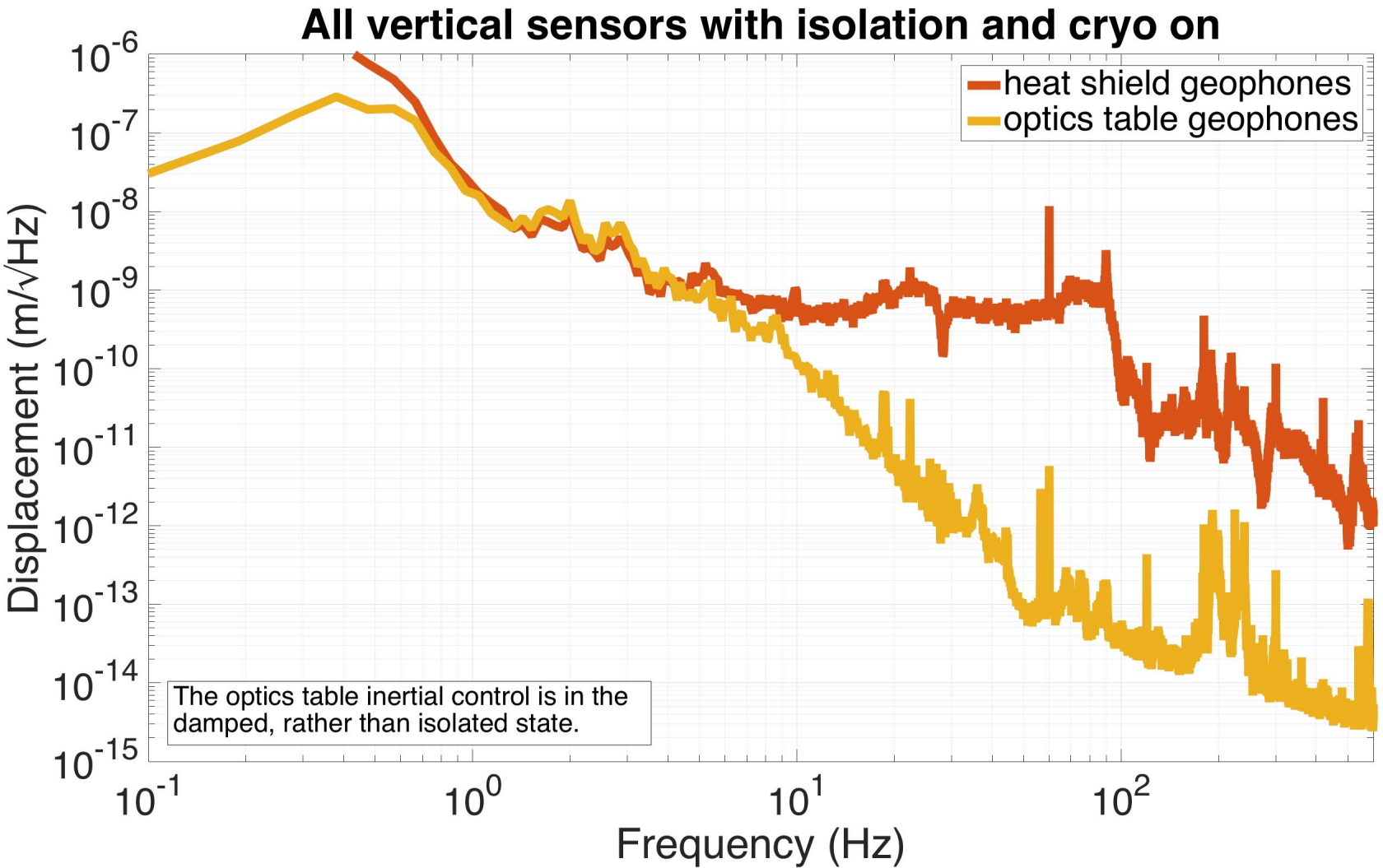
Optics Table → Geophones
inertial displacement measurement

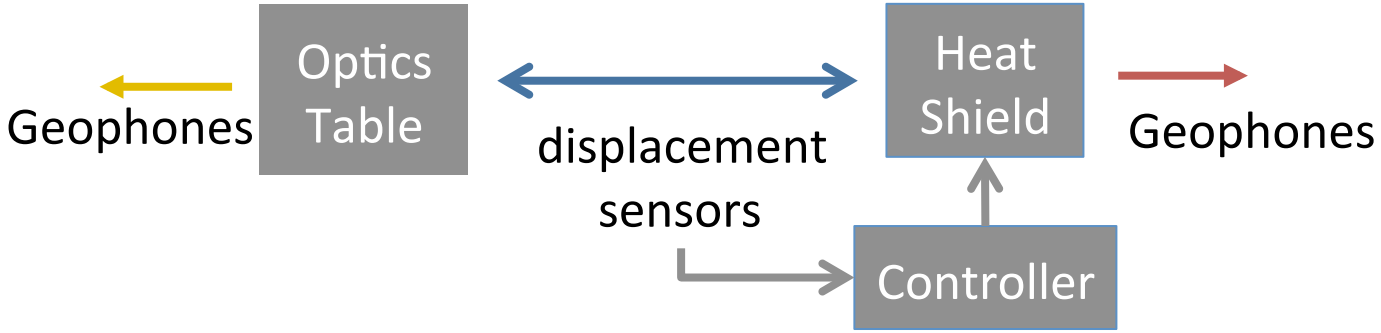


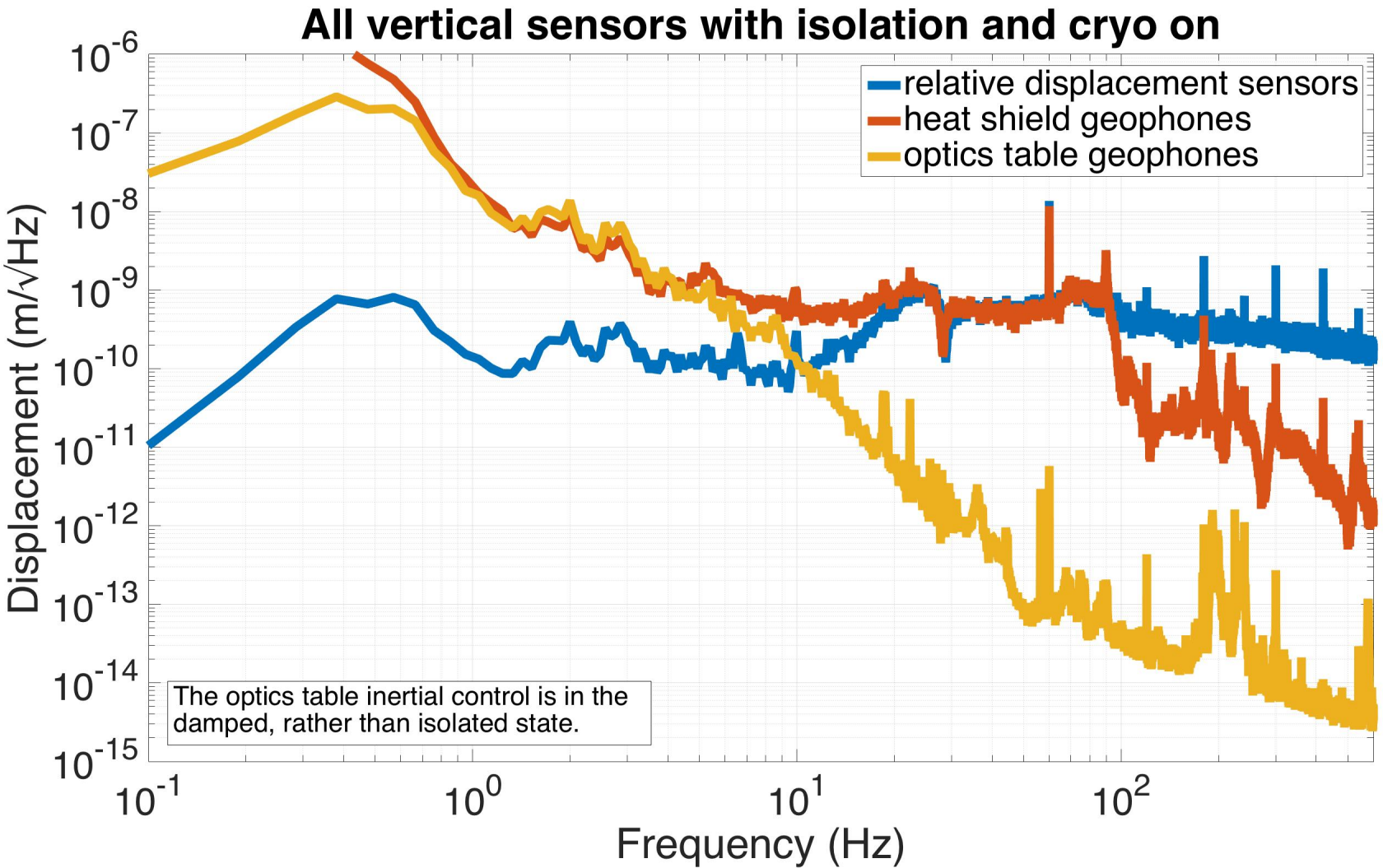

Optics Table
Geophones
displacement sensors
Heat Shield
Geophones
Controller

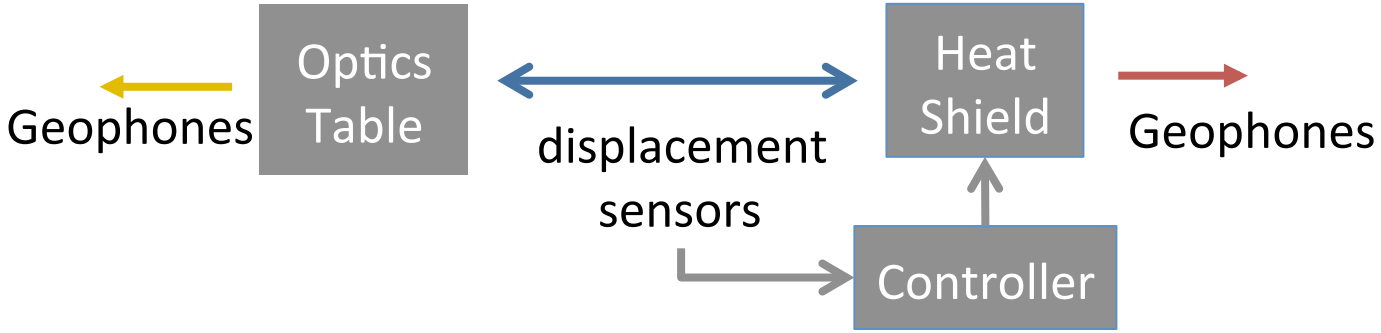

All vertical sensors with isolation and cryo on
heat shield geophones
Displacement (m/√Hz)
Frequency (Hz)
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
10^-1
10^0
10^1
10^2

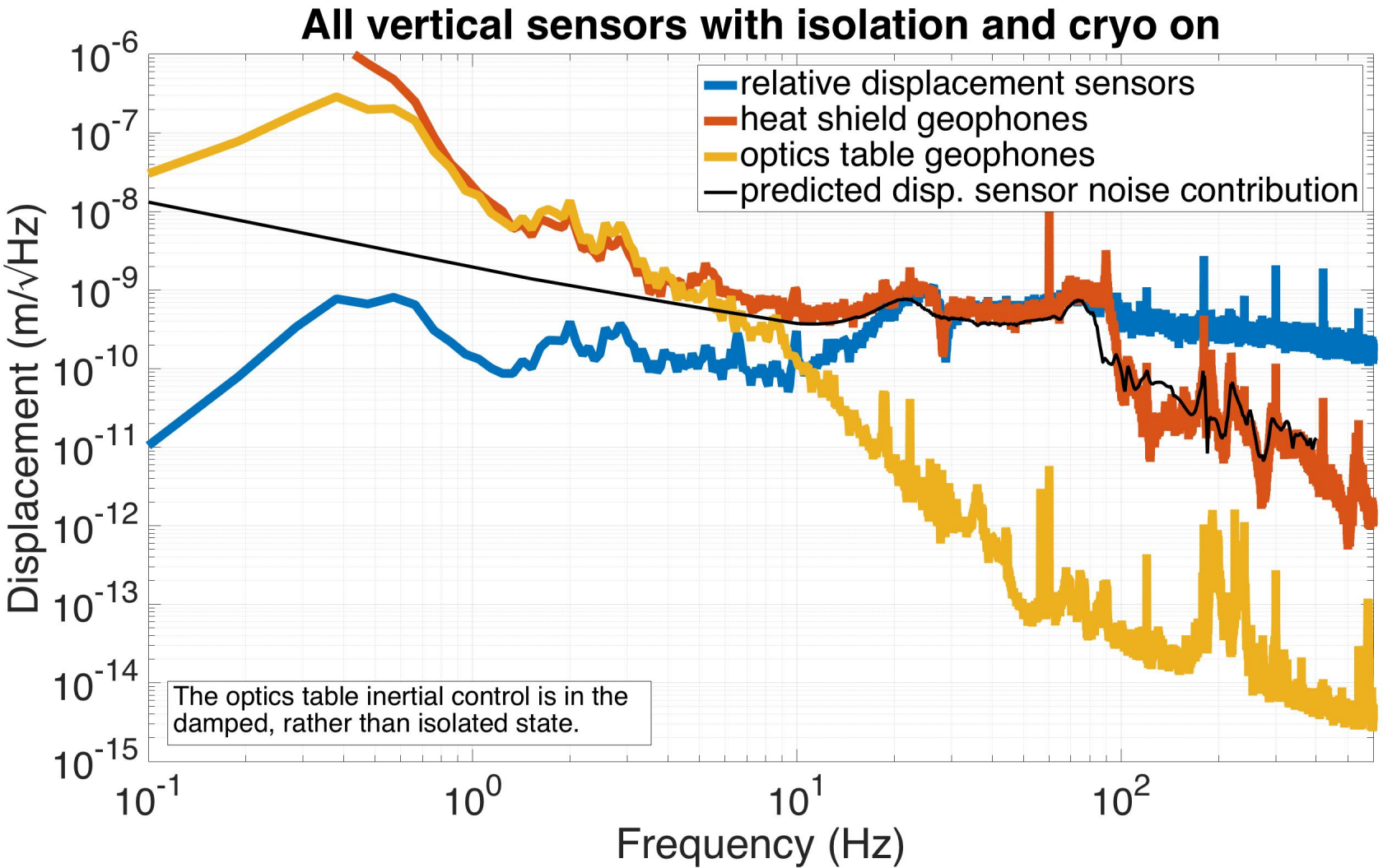

Optics Table
Geophones
displacement sensors
Heat Shield
Geophones
Controller

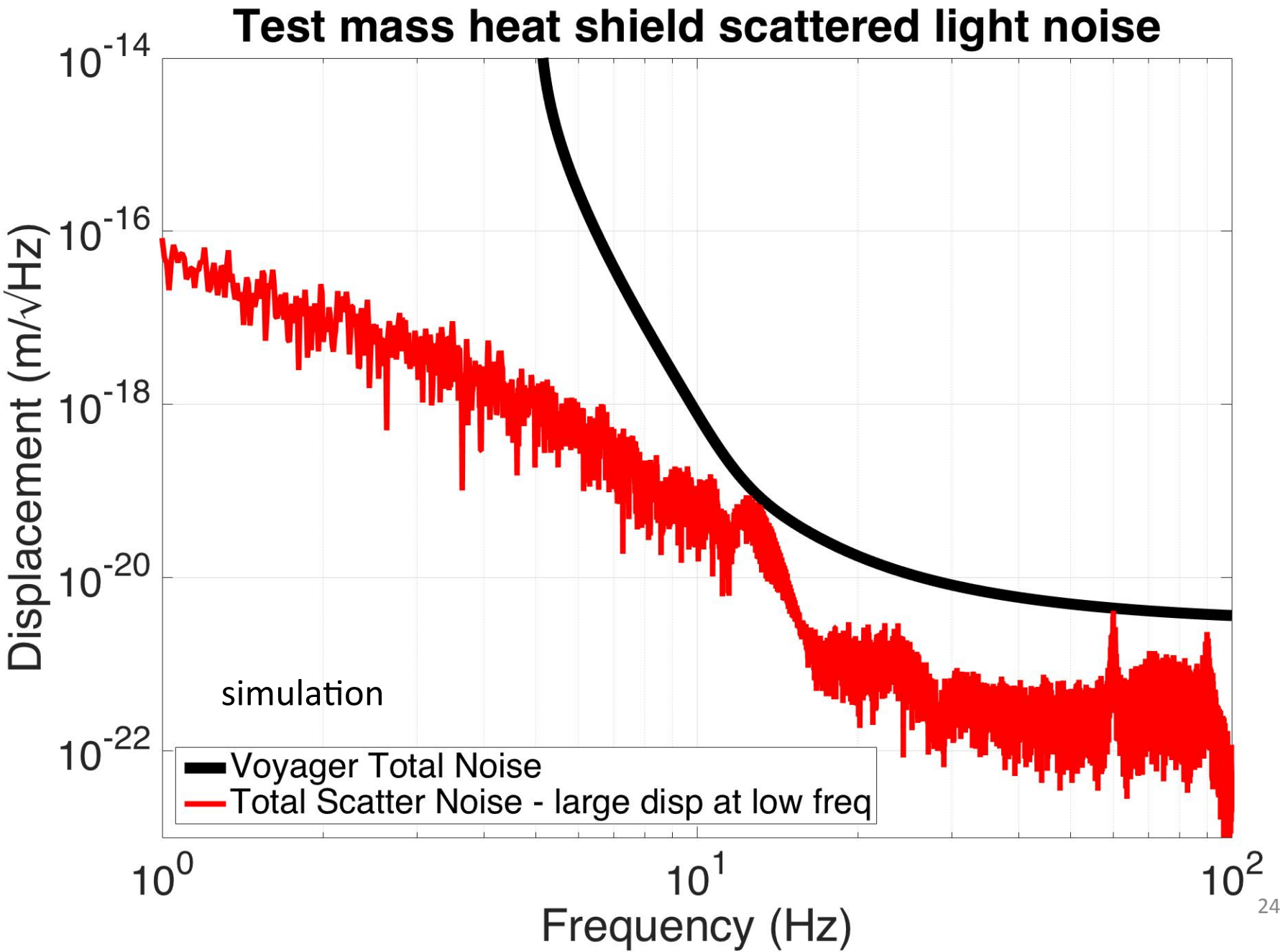

All vertical sensors with isolation and cryo on
heat shield geophones
optics table geophones
Displacement (m/√Hz)
Frequency (Hz)
The optics table inertial control is in the damped, rather than isolated state.

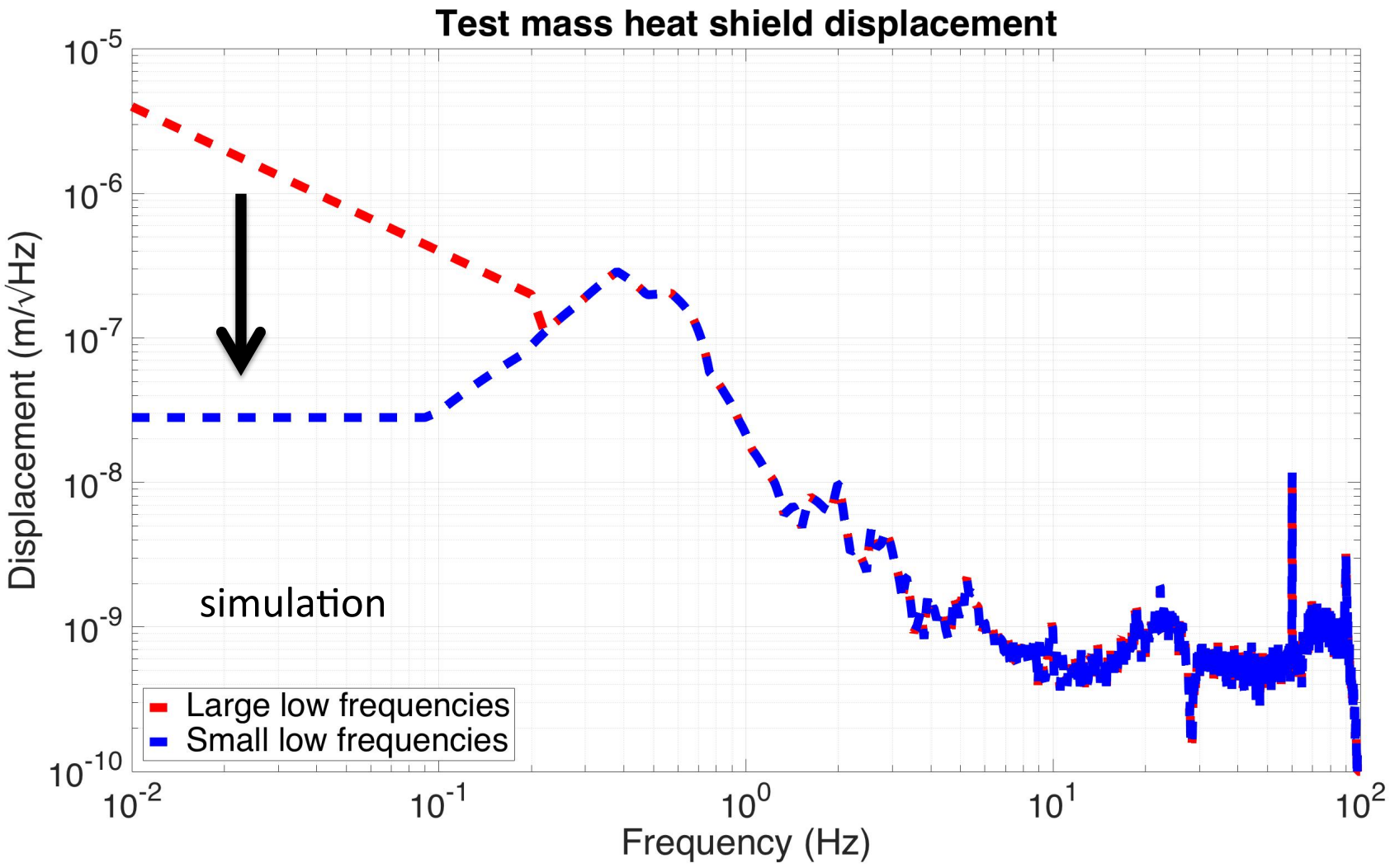

Optics Table
Geophones
displacement sensors
Heat Shield
Geophones
Controller

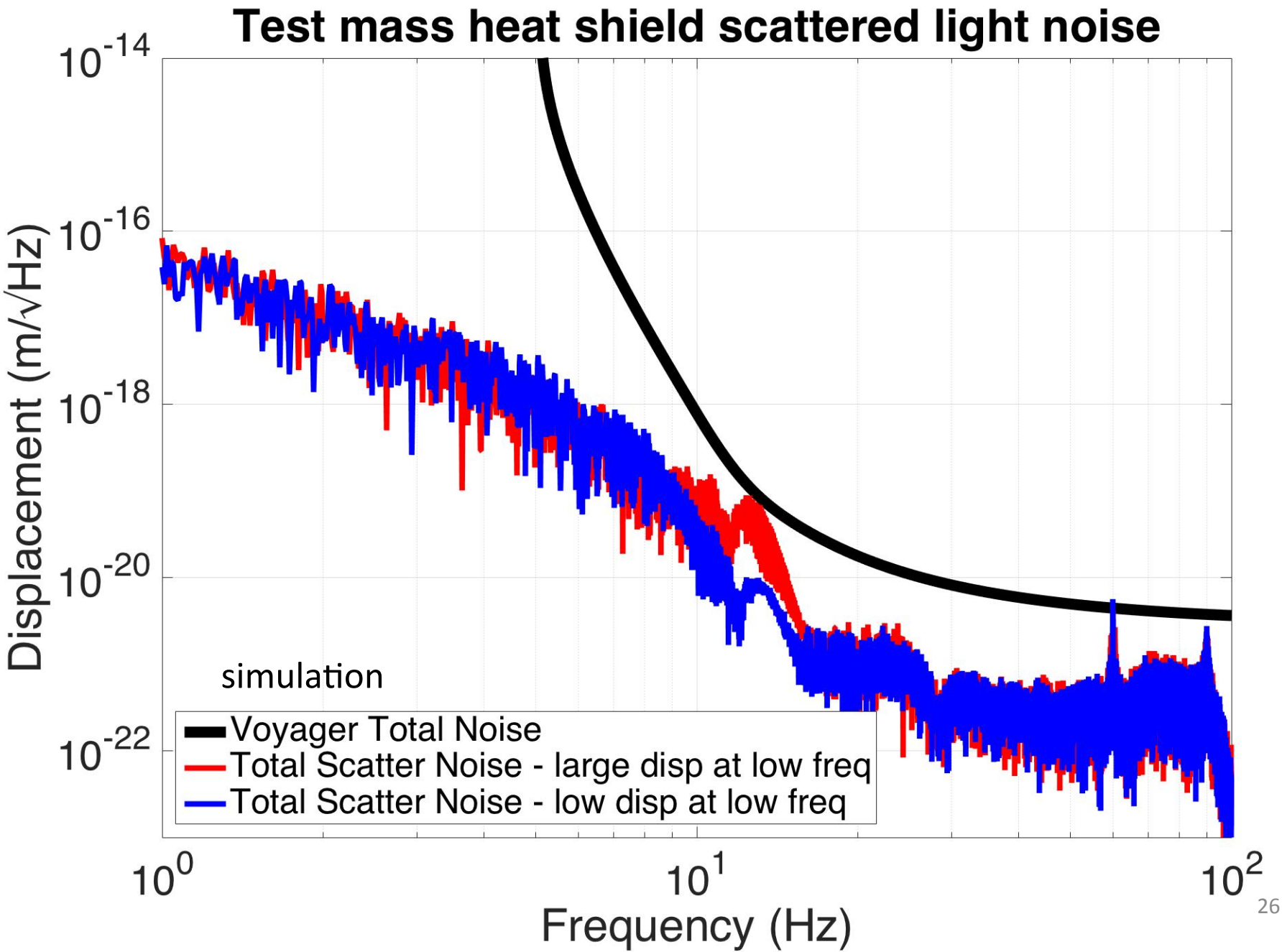

All vertical sensors with isolation and cryo on
relative displacement sensors
heat shield geophones
optics table geophones
The optics table inertial control is in the damped, rather than isolated state.
Displacement (m/√Hz)
Frequency (Hz)
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
10^-1
10^0
10^1
10^2


Optics Table
Geophones
displacement sensors
Heat Shield
Geophones
Controller

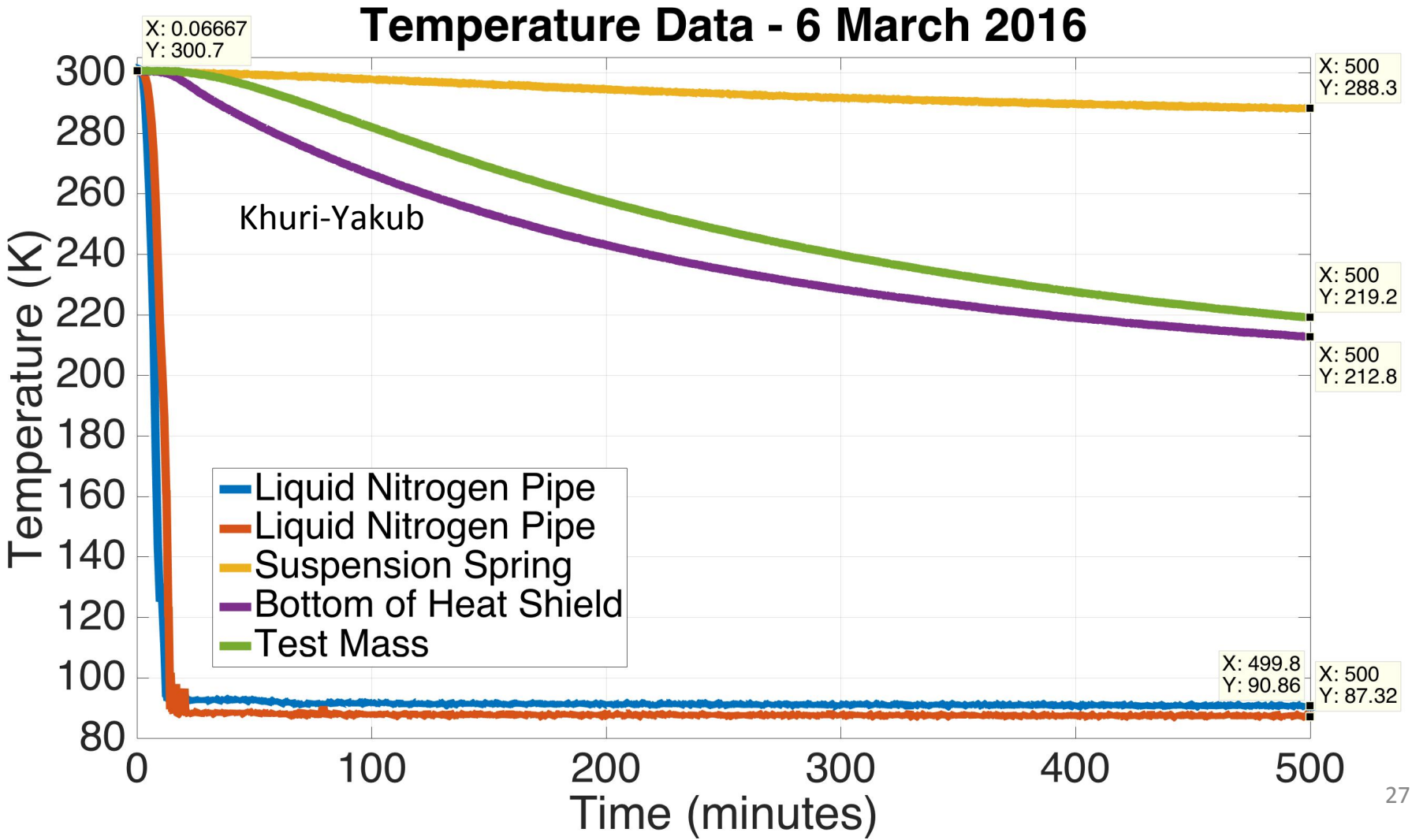

All vertical sensors with isolation and cryo on
relative displacement sensors
heat shield geophones
optics table geophones
predicted disp. sensor noise contribution
The optics table inertial control is in the damped, rather than isolated state.
Displacement (m/√Hz)
Frequency (Hz)
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
10^-1
10^0
10^1
10^2


Test mass heat shield scattered light noise
Displacement (m/√Hz)
10^-14
10^-16
10^-18
10^-20
10^-22
simulation
Voyager Total Noise
Total Scatter Noise - large disp at low freq
10^0
10^1
10^2
Frequency (Hz)

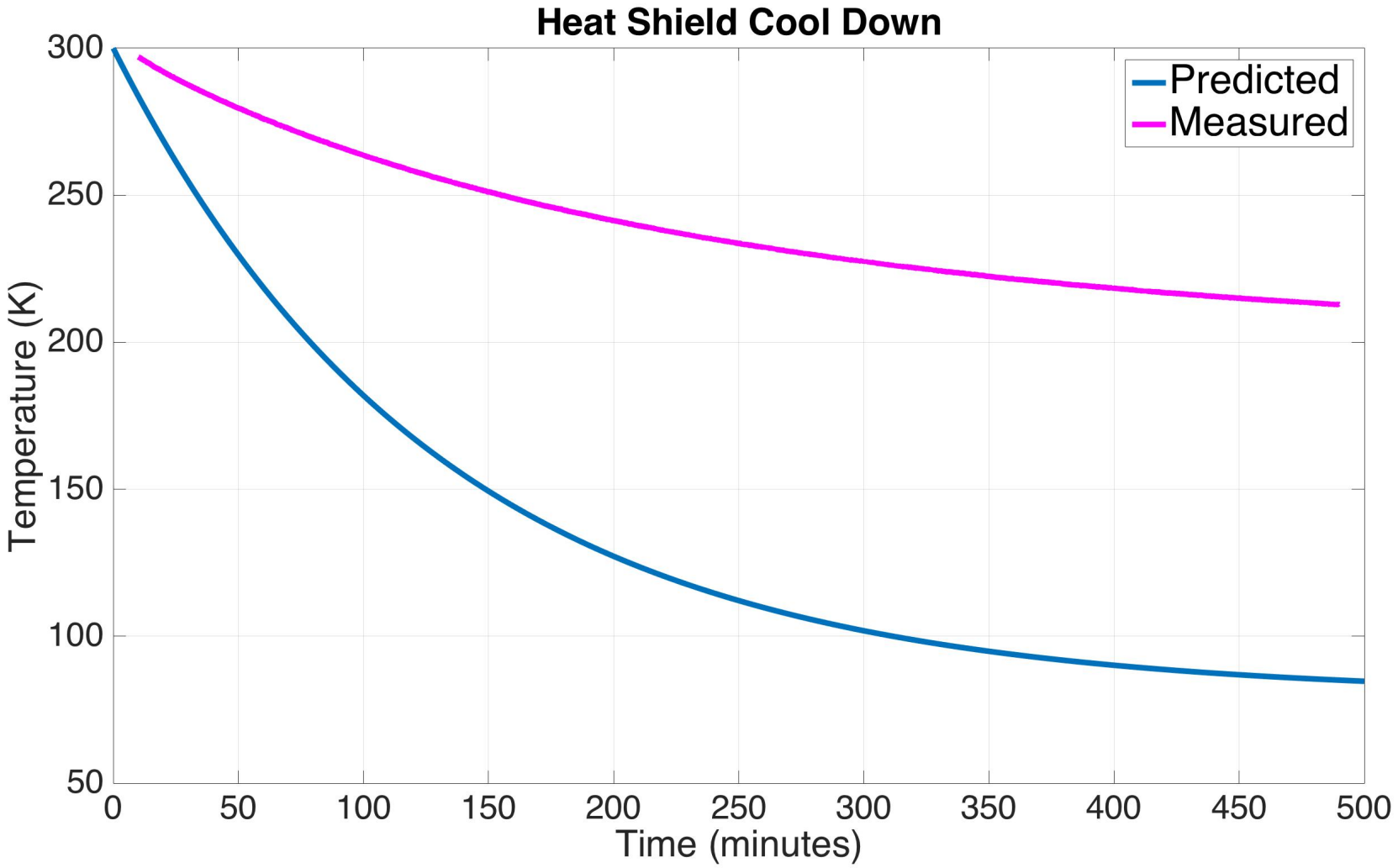

Test mass heat shield displacement
Displacement (m/√Hz)
Frequency (Hz)
simulation
Large low frequencies
Small low frequencies


Test mass heat shield scattered light noise
Displacement (m/√Hz)
10^-14
10^-16
10^-18
10^-20
10^-22
simulation
Voyager Total Noise
Total Scatter Noise - large disp at low freq
Total Scatter Noise - low disp at low freq
10^0
10^1
10^2
Frequency (Hz)

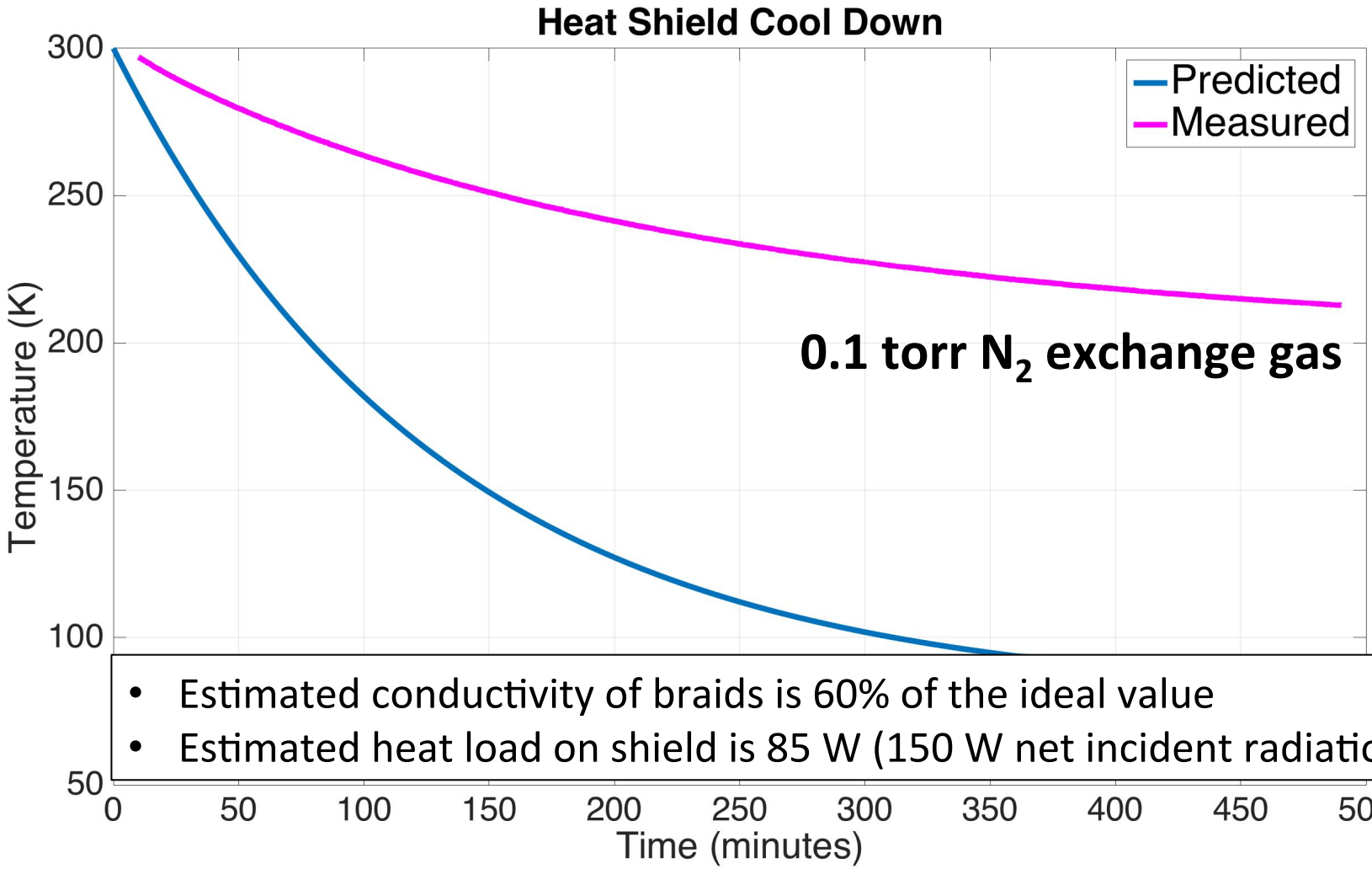
Cool Down Data



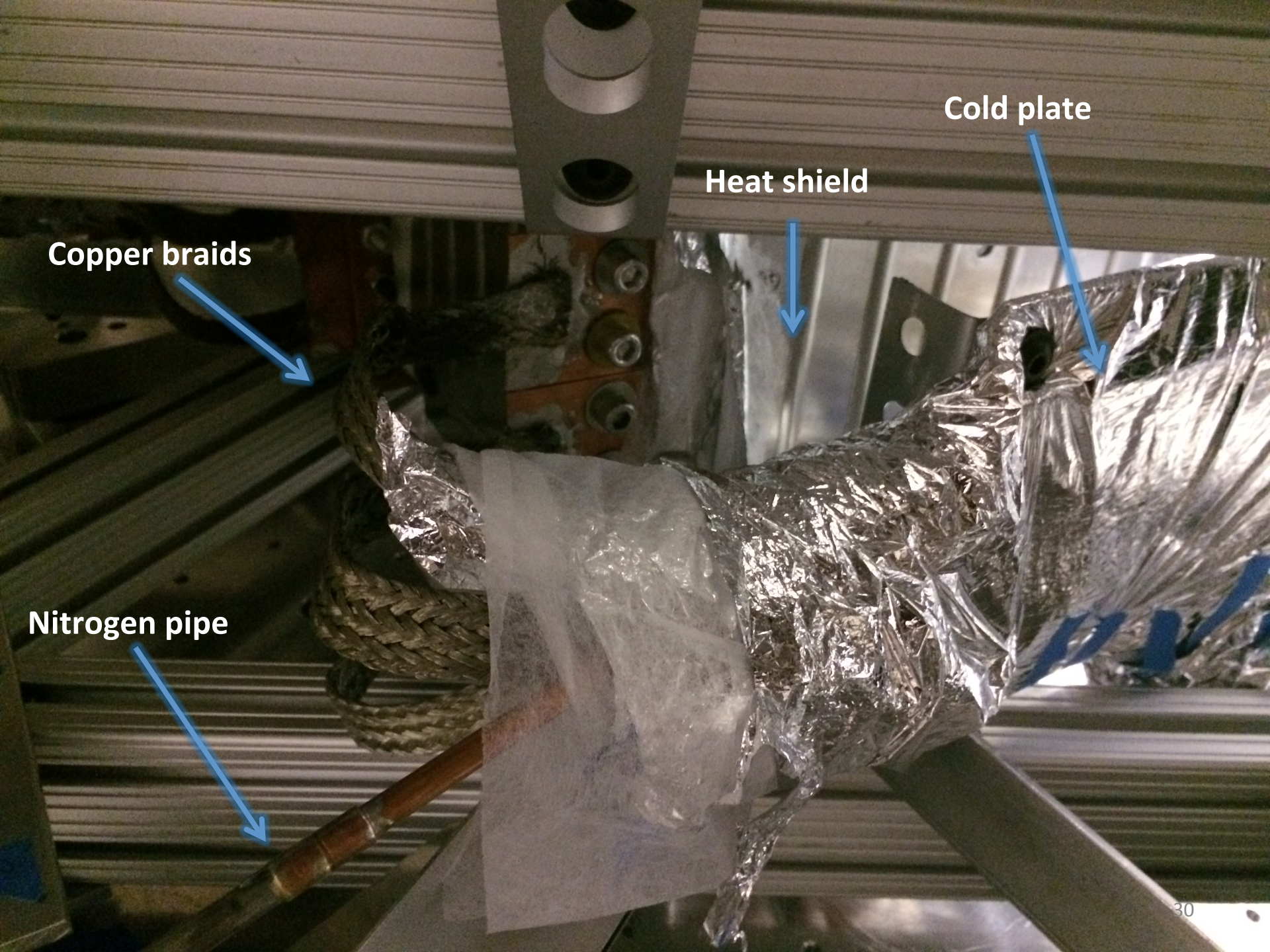
Cool Down Analysis



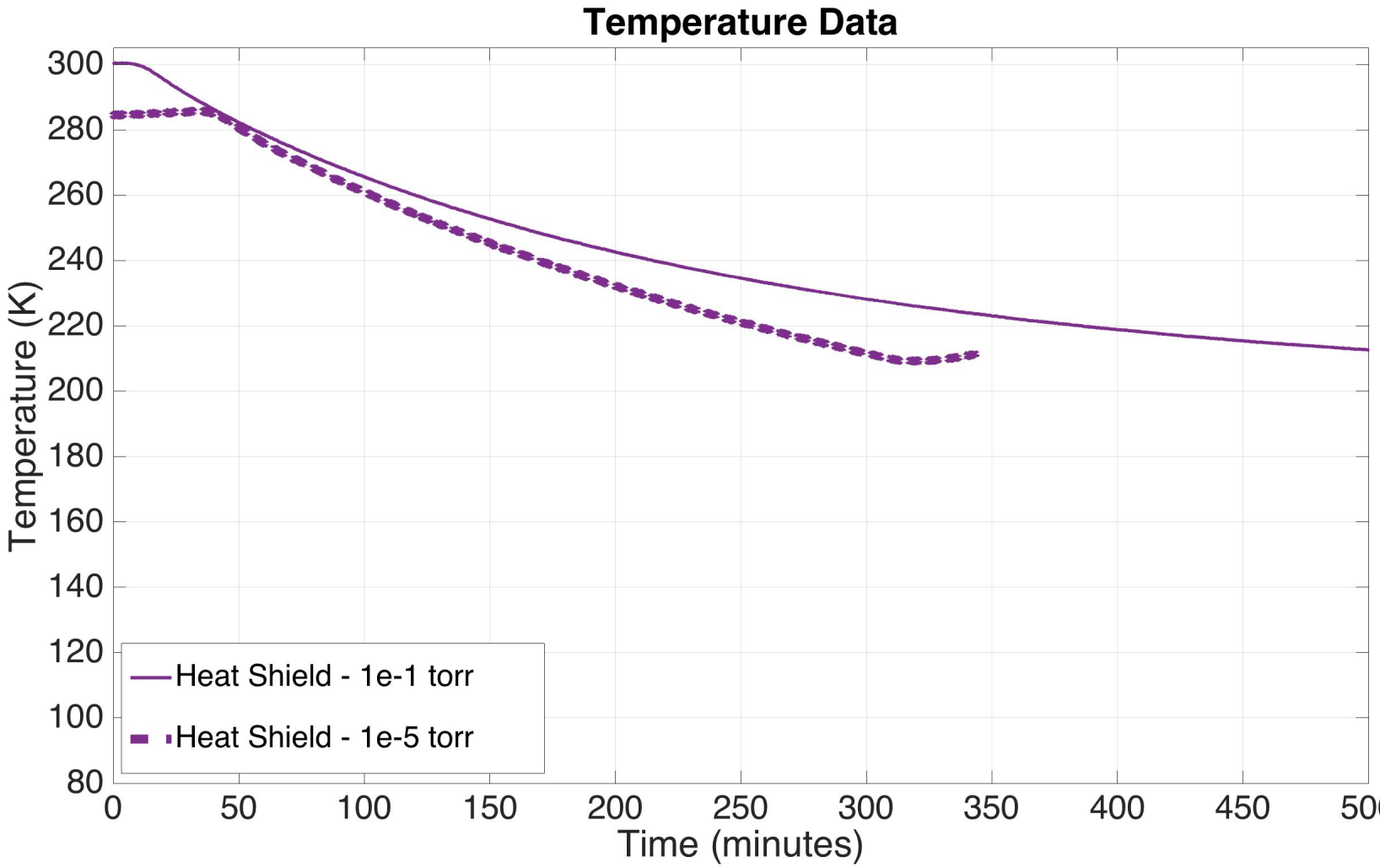
Cool Down Analysis



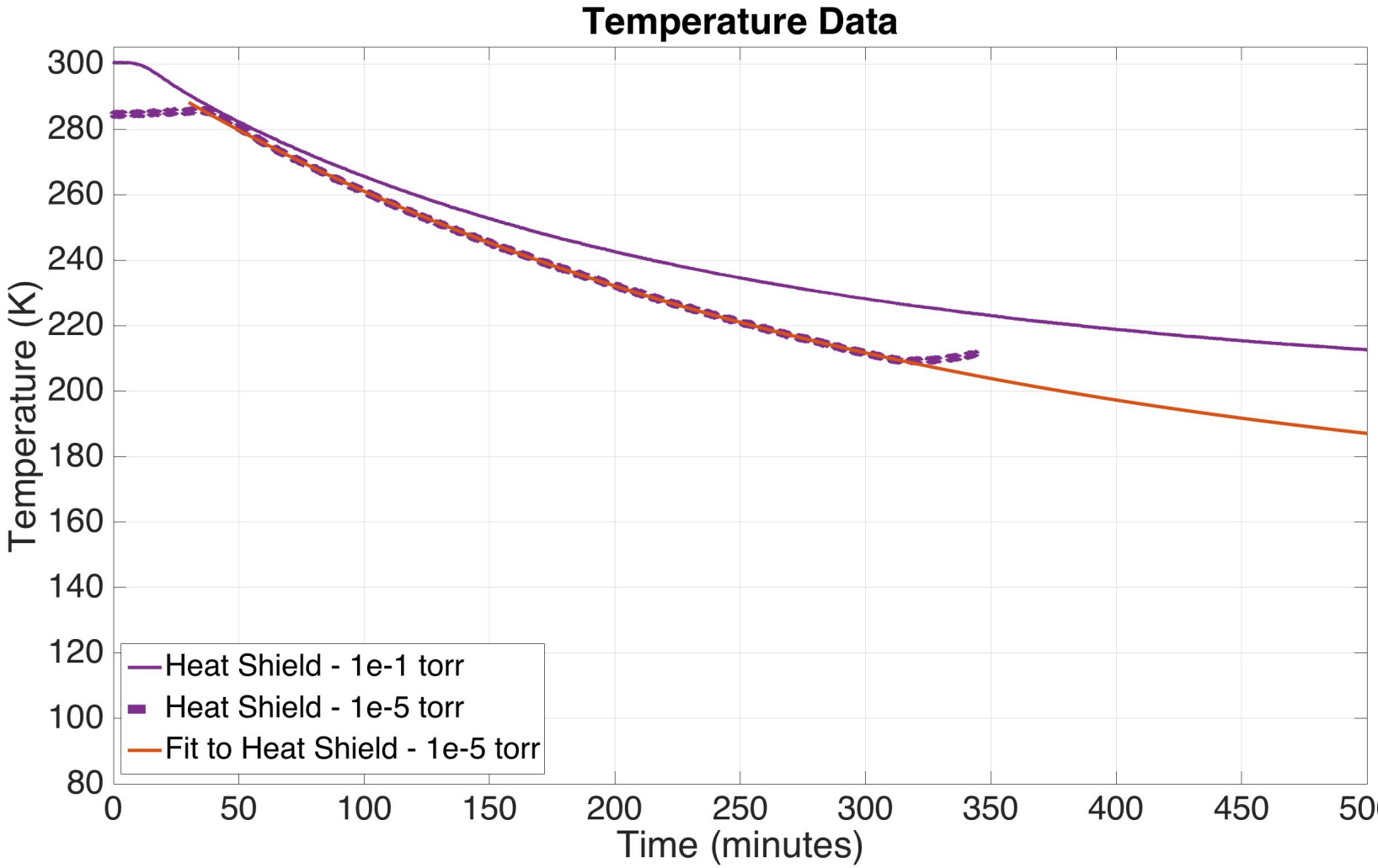
- Estimated conductivity of braids is 60% of the ideal value
- Estimated heat load on shield is 85 W (150 W net incident radiation)


Cold plate
Heat shield
Copper braids
Nitrogen pipe

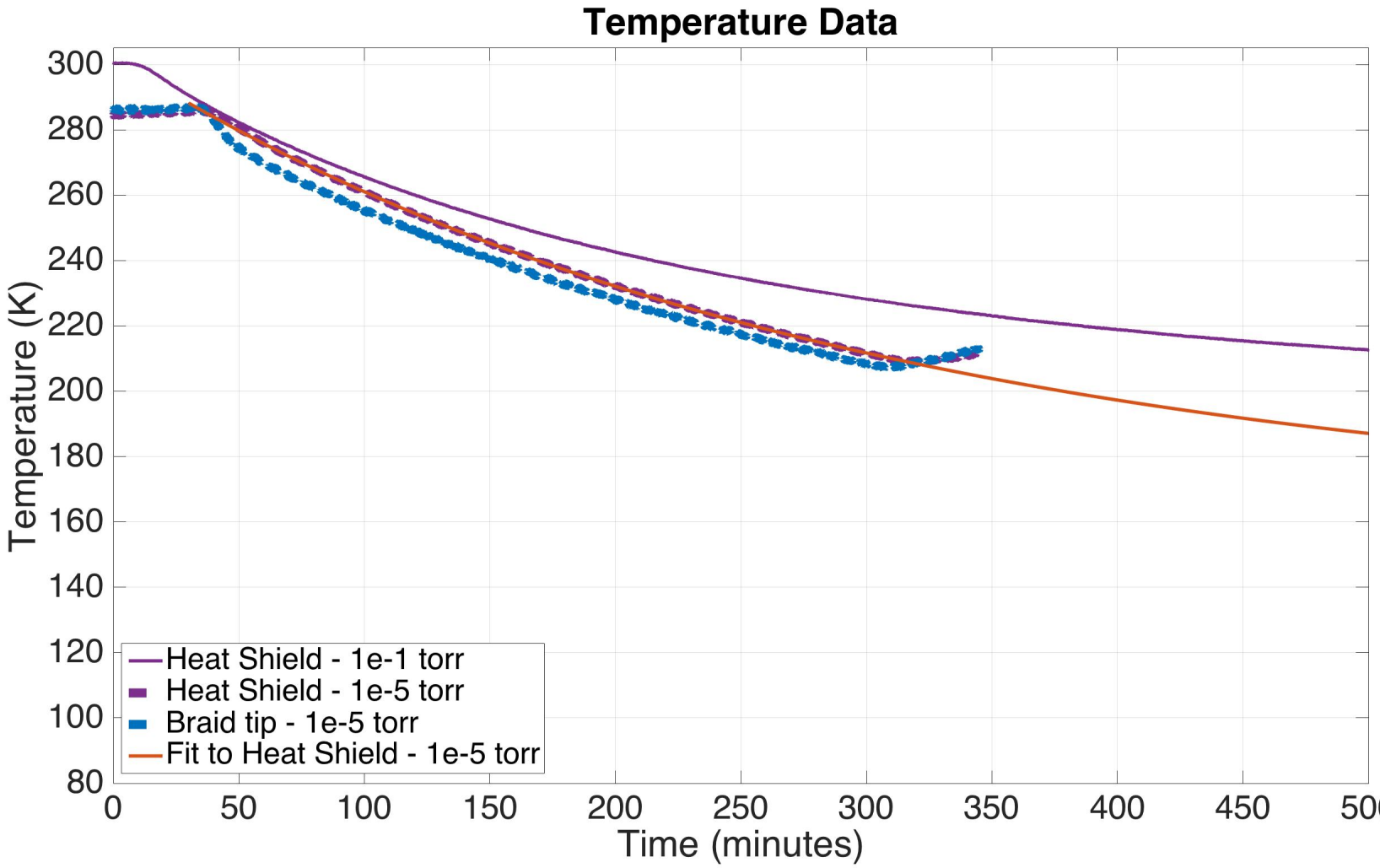
Cool Down Data



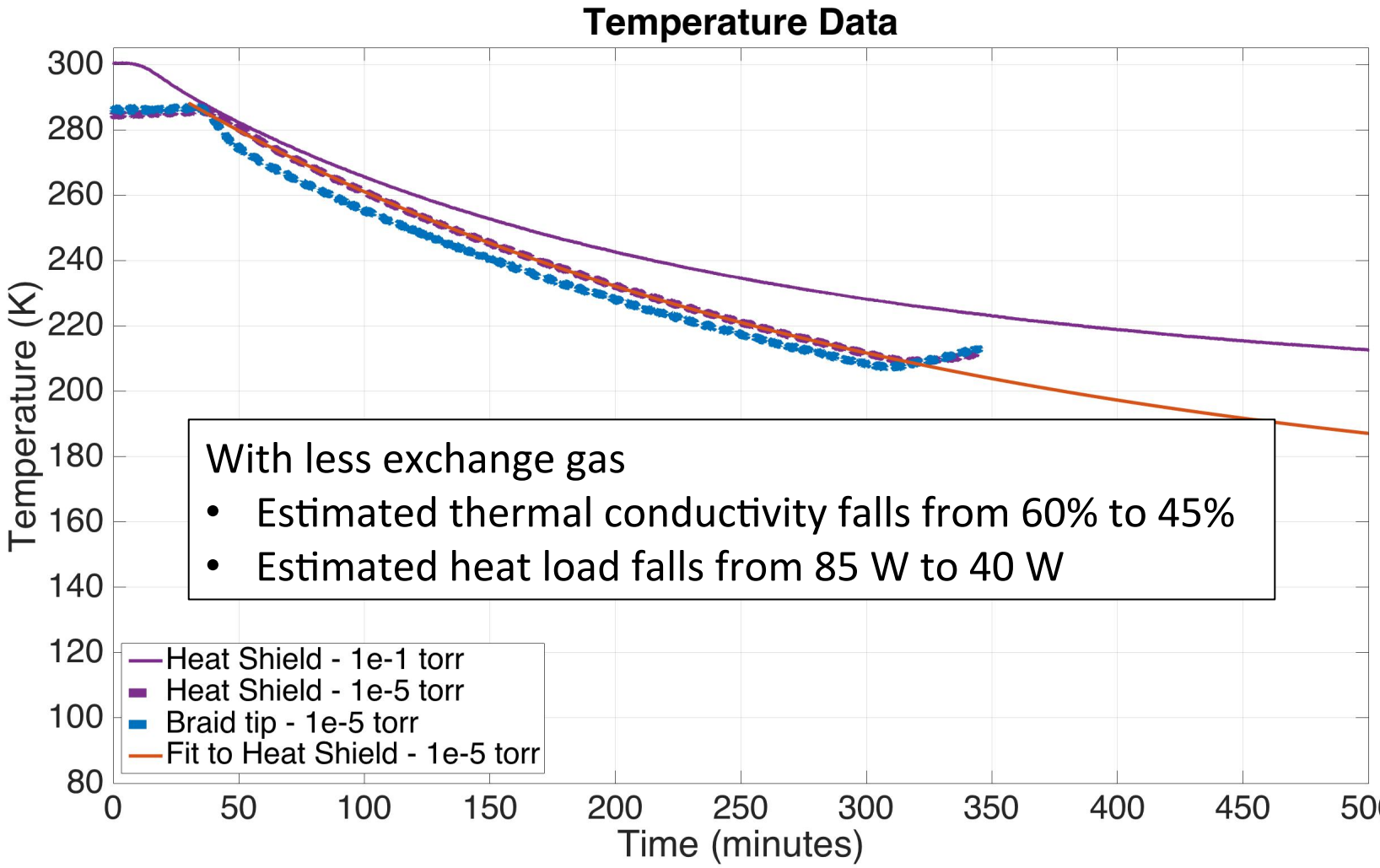
Cool Down Data



Cool Down Data



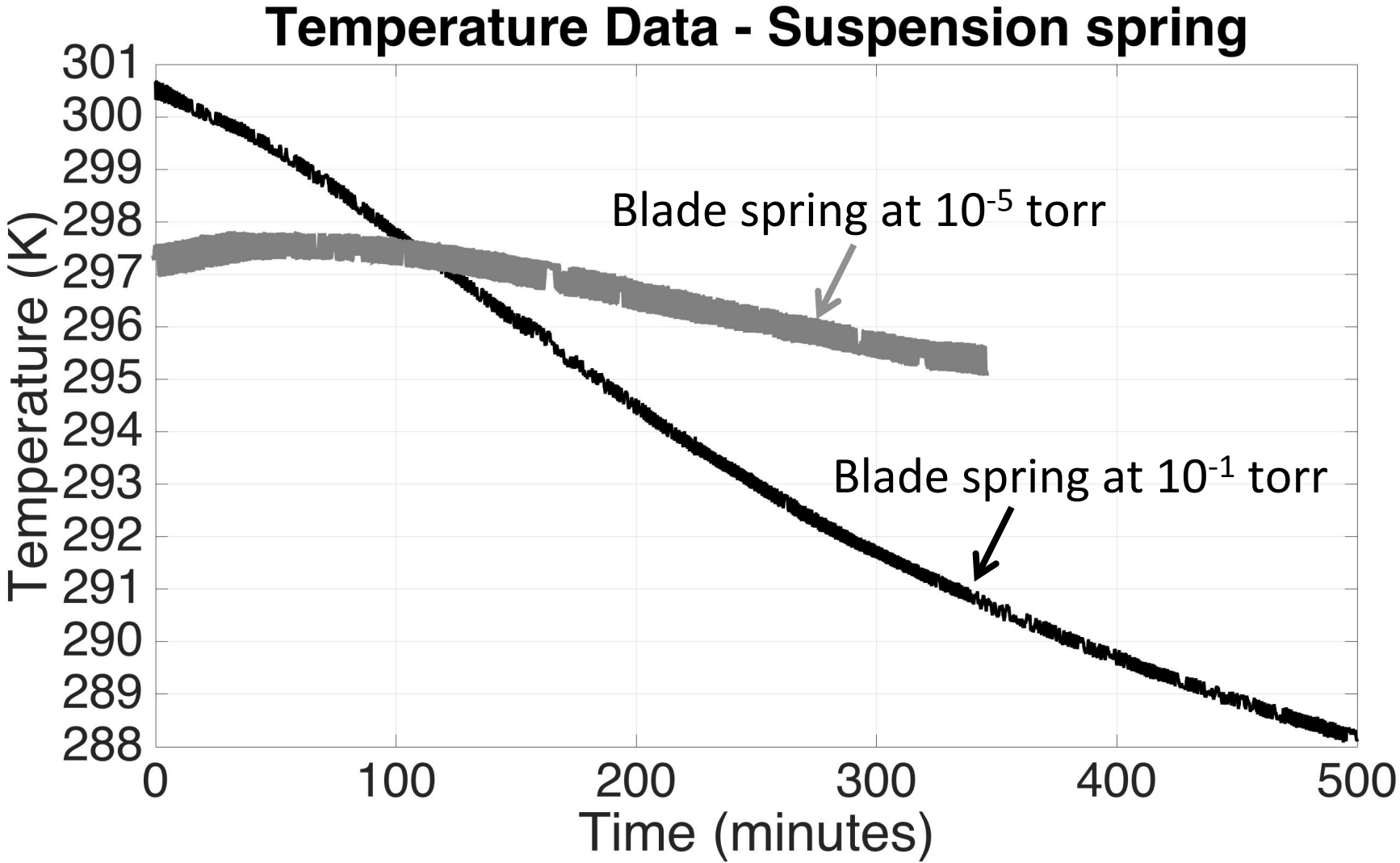
Cool Down Data



With less exchange gas

- Estimated thermal conductivity falls from 60% to 45%
- Estimated heat load falls from 85 W to 40 W

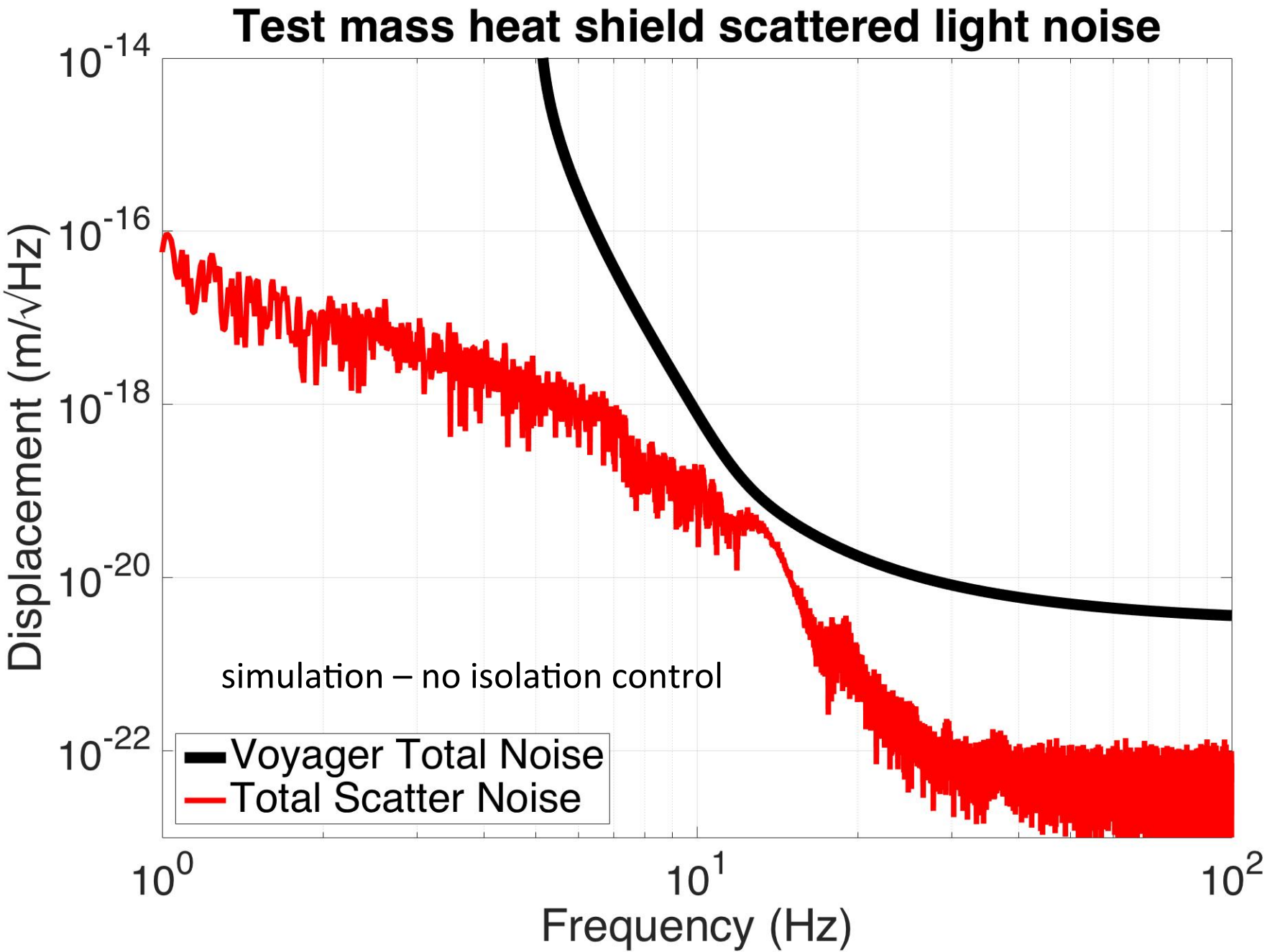
Cool Down Data



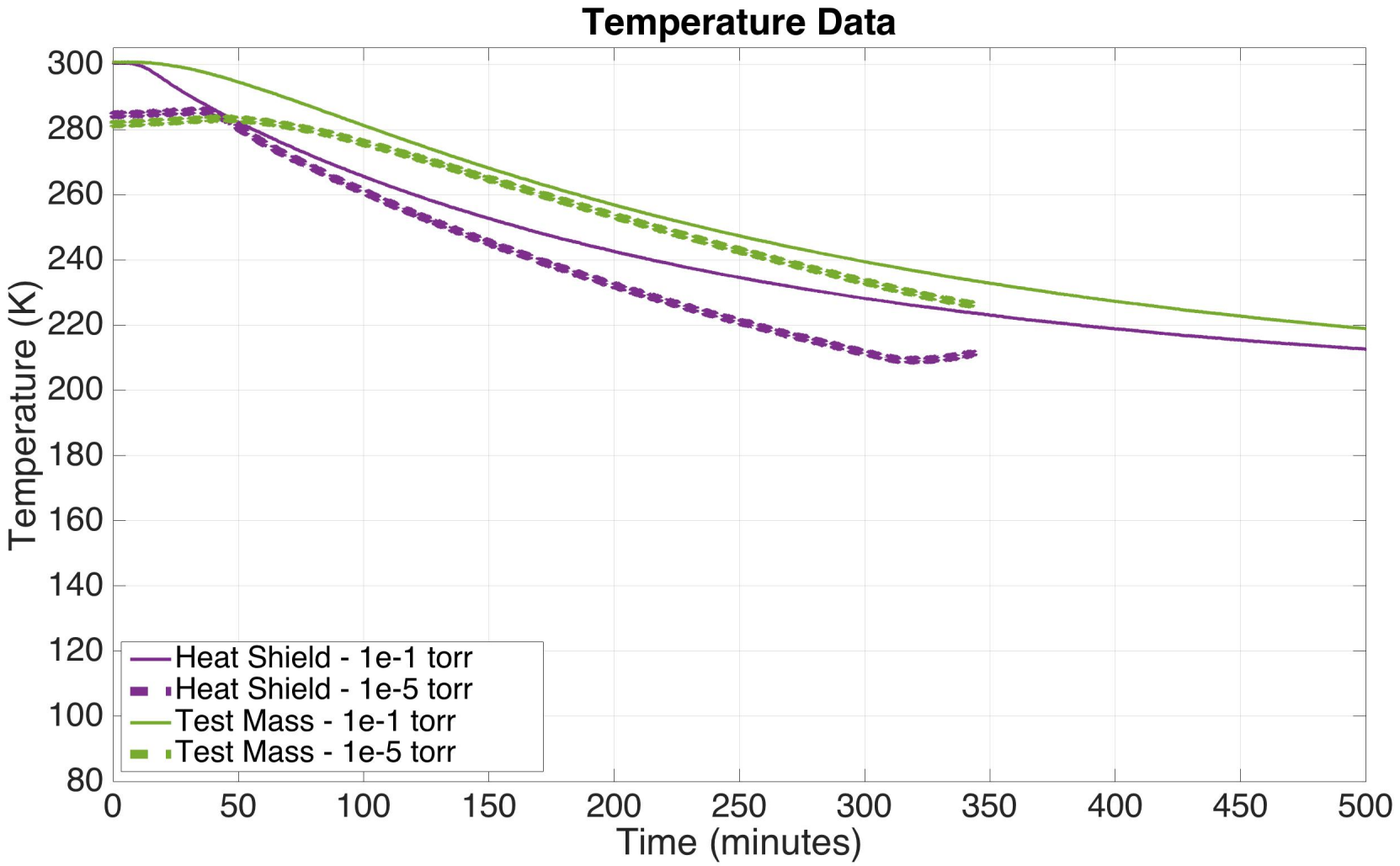
Conclusions

- Learning a lot about how to cool a test mass in a LIGO compatible way.
- Still more work to do.
- Vibration from the liquid nitrogen is not so bad. These measurements suggest
  - Maybe only need control at low frequencies
  - Or, we could be a lot more aggressive with the cryogenics.
- Might want to heat the blade springs

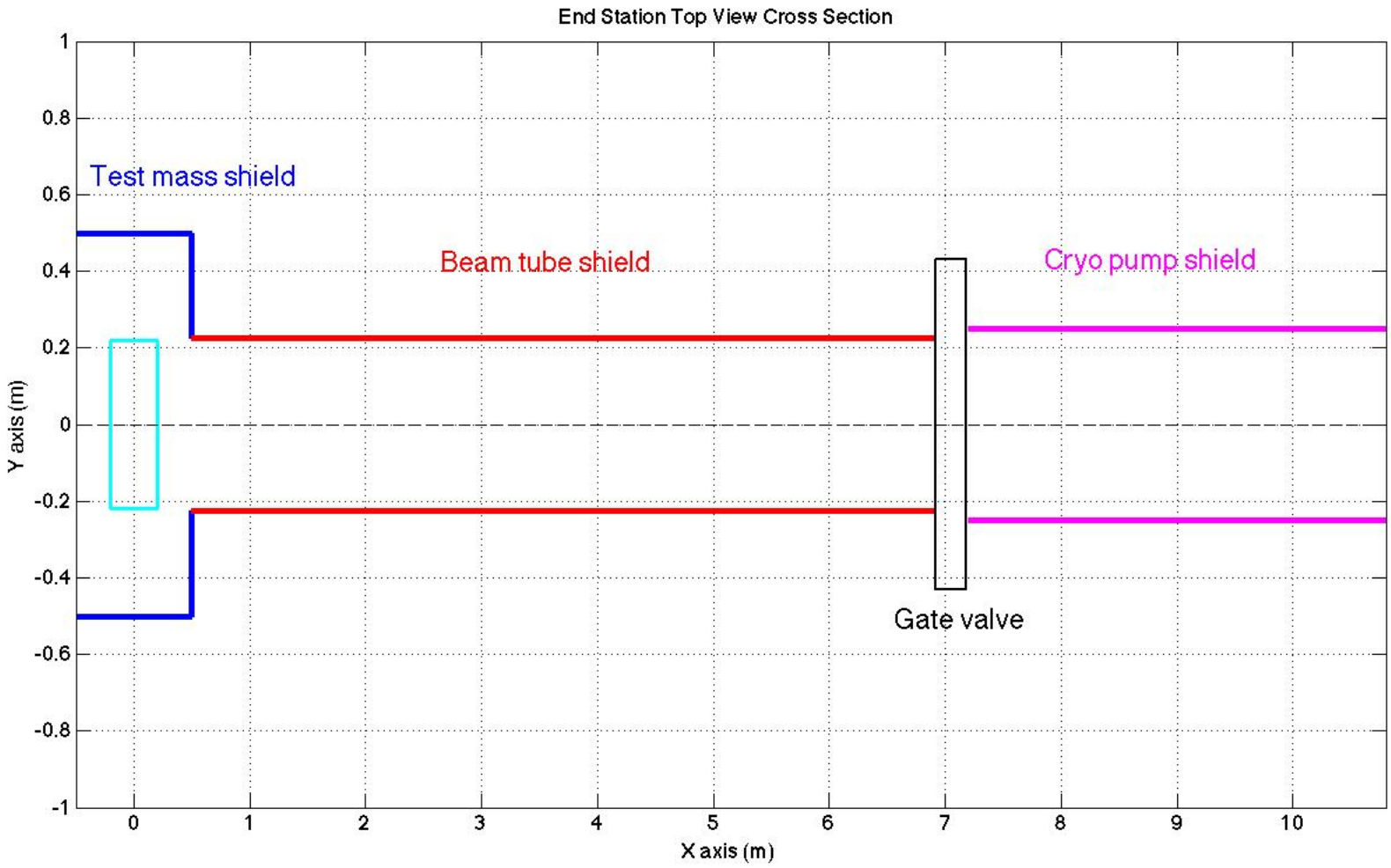
Questions?

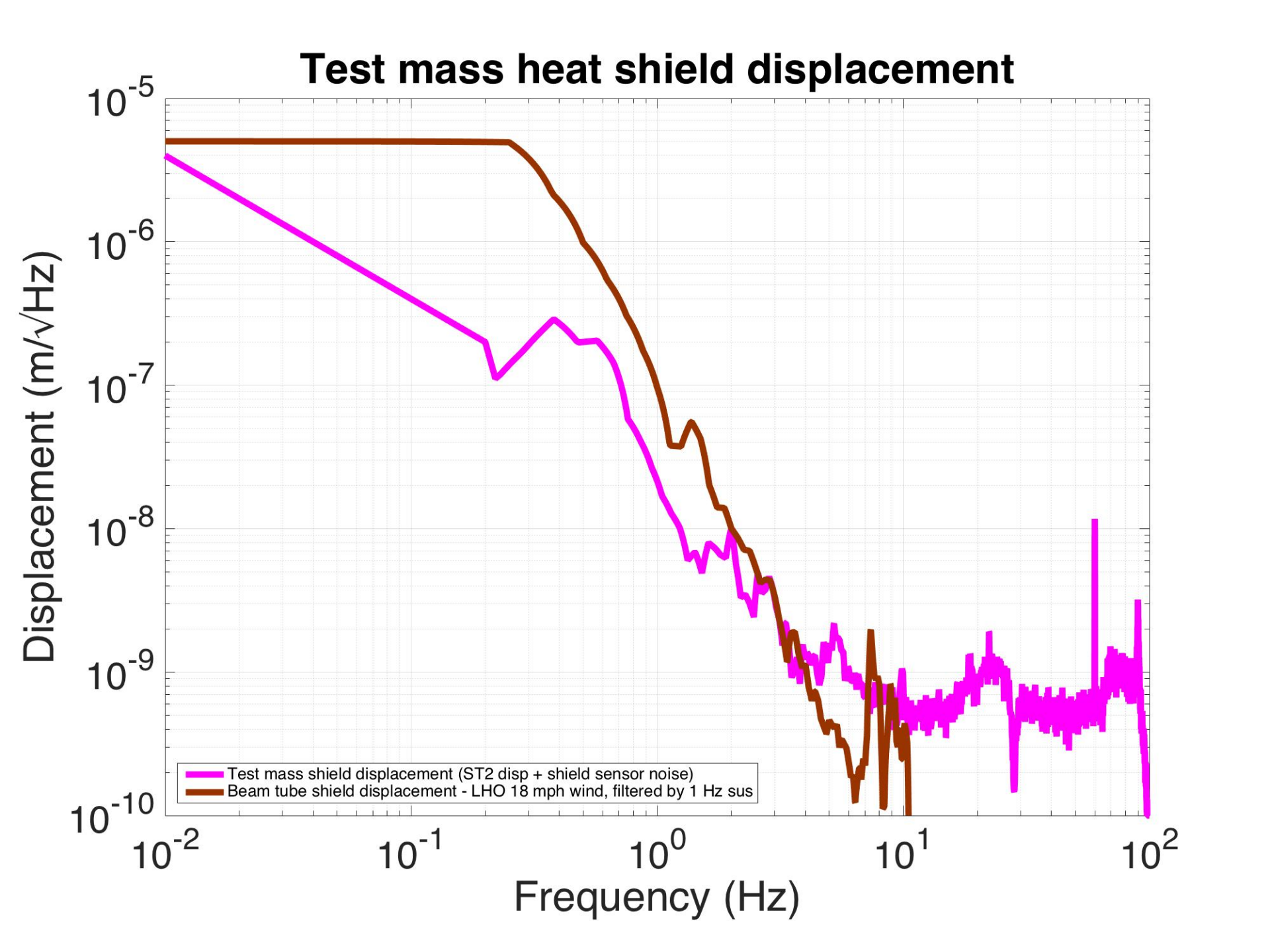

Test mass heat shield scattered light noise
Displacement (m/√Hz)
10^-14
10^-16
10^-18
10^-20
10^-22
simulation – no isolation control
Voyager Total Noise
Total Scatter Noise
10^0
10^1
10^2
Frequency (Hz)

Cool Down Data

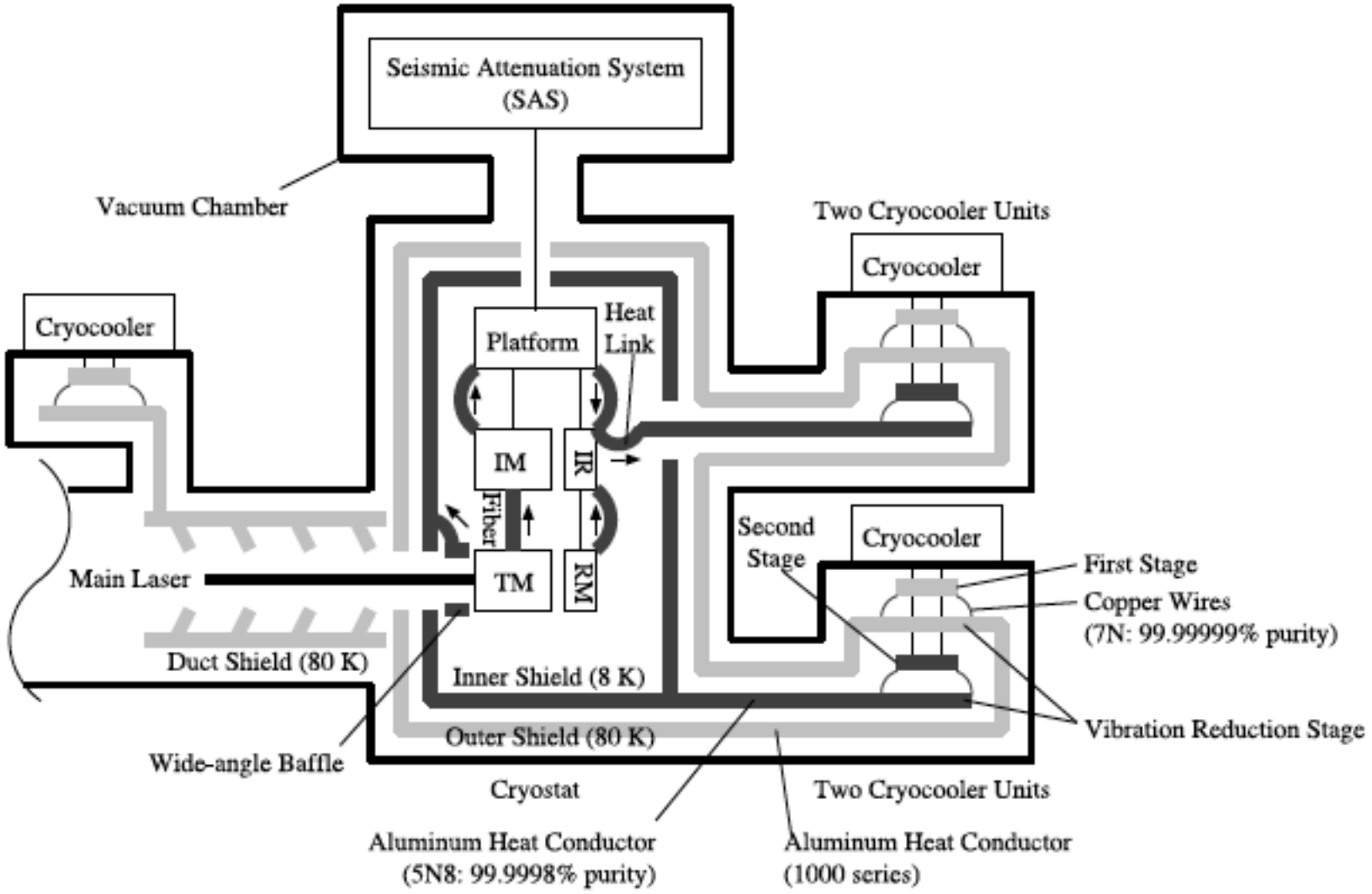


Geometry of heat shields in scattered light simulation

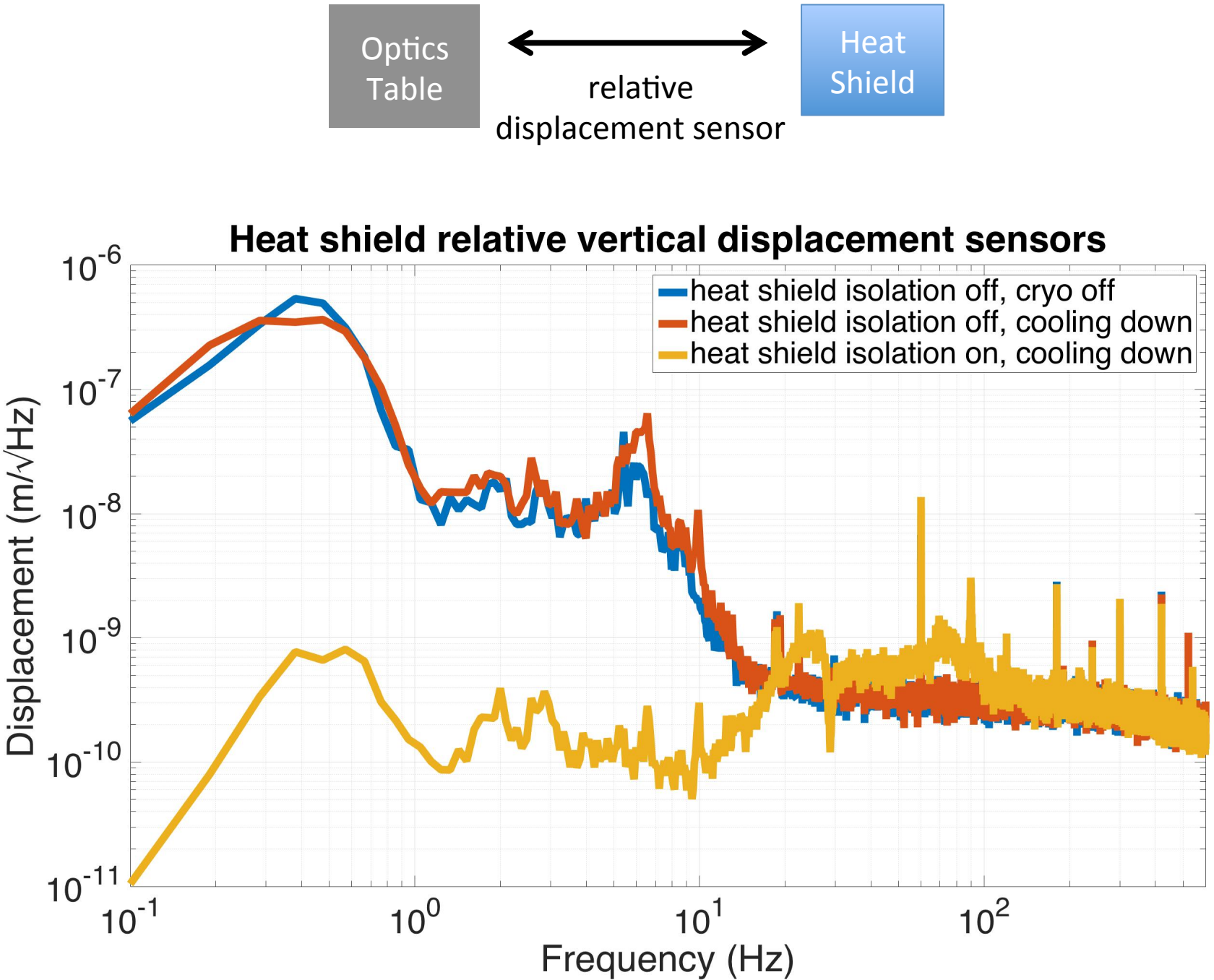


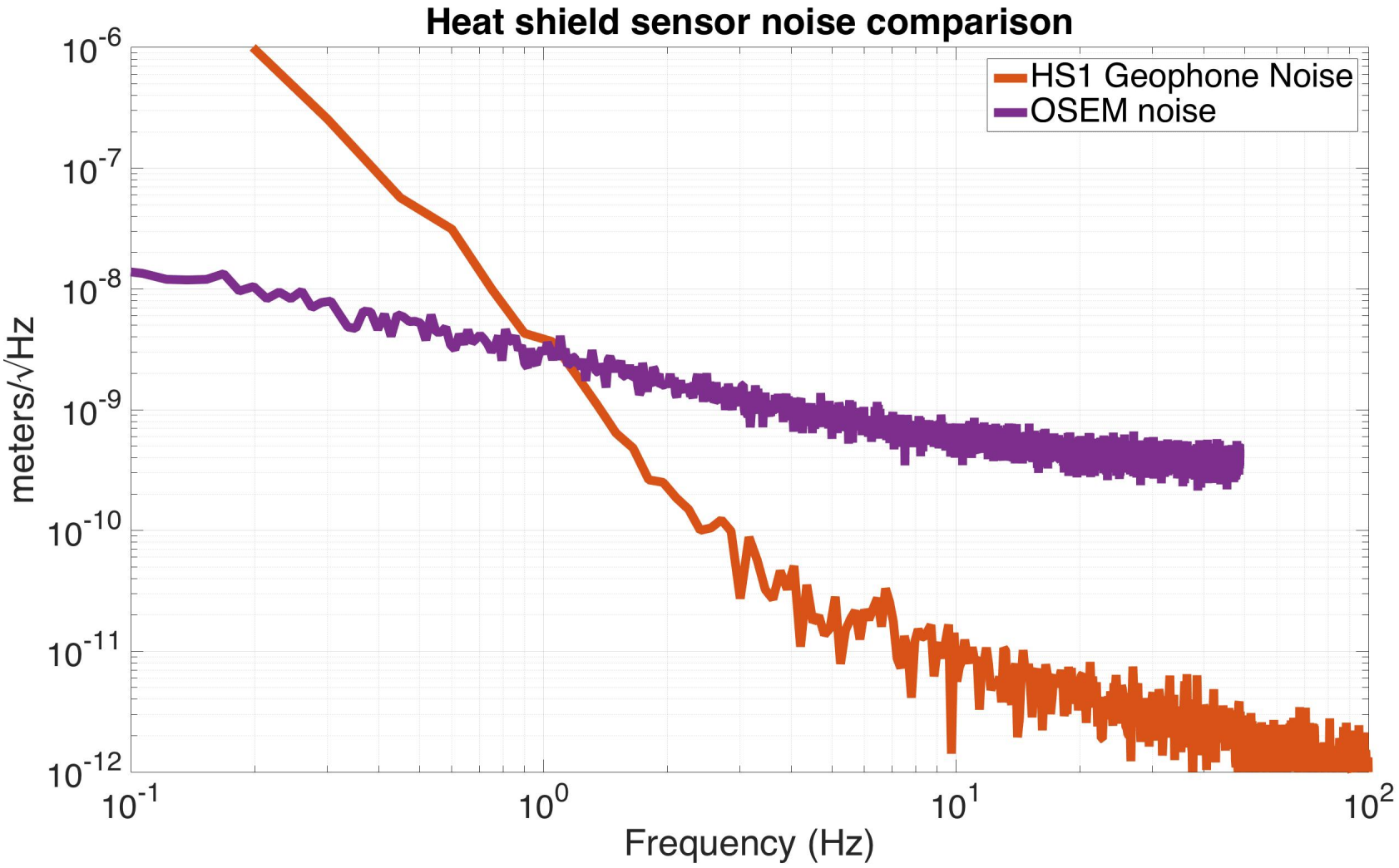

Test mass heat shield displacement
Displacement (m/√Hz)
Frequency (Hz)
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-2
10^-1
10^0
10^1
10^2
Test mass shield displacement (ST2 disp + shield sensor noise)
Beam tube shield displacement - LHO 18 mph wind, filtered by 1 Hz sus

KAGRA Layout

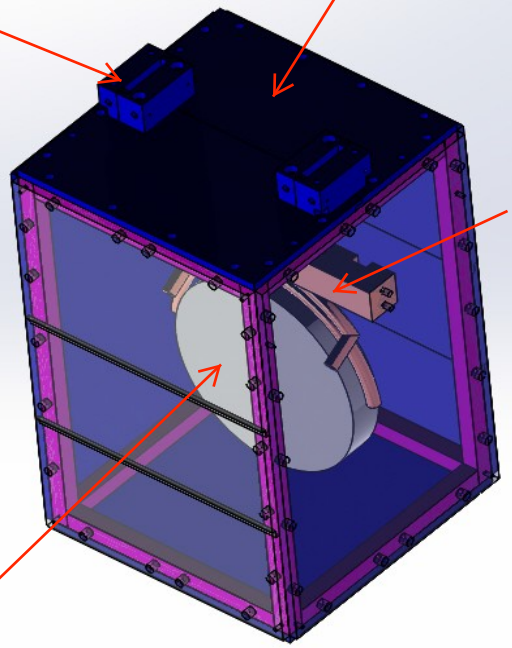


CQG 31 (2014) 224003 – Progress on the cryogenic system fir the KAGRA cryogenic interferometric gravitational wave telescope

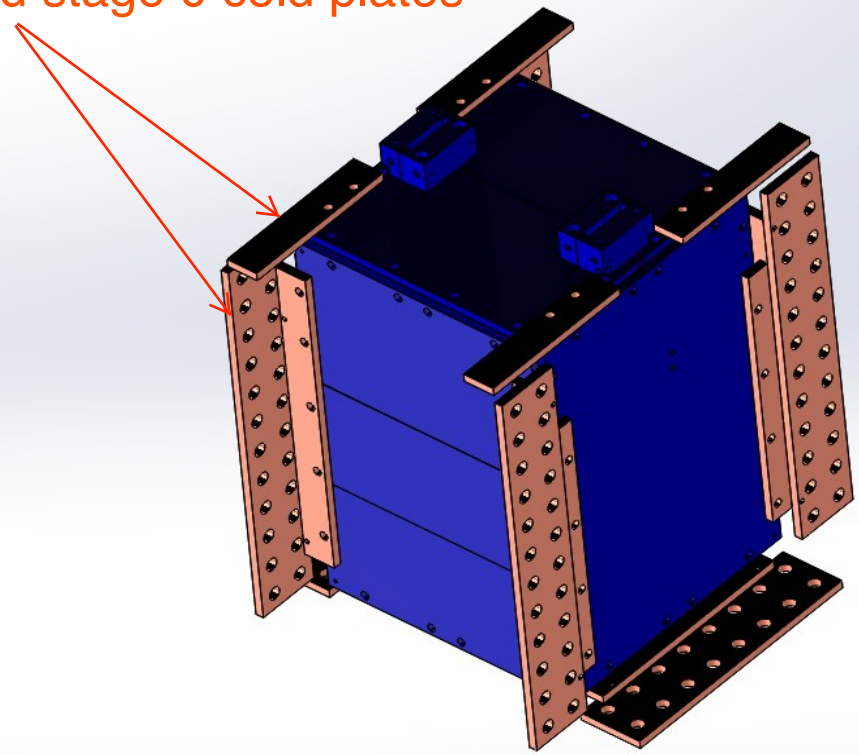

Optics Table
relative displacement sensor
Heat Shield
Heat shield relative vertical displacement sensors
heat shield isolation off, cryo off
heat shield isolation off, cooling down
heat shield isolation on, cooling down
Displacement (m/√Hz)
Frequency (Hz)
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-1
10^0
10^1
10^2


Heat shield sensor noise comparison
HS1 Geophone Noise
OSEM noise
meters/√Hz
Frequency (Hz)
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-1
10^0
10^1
10^2

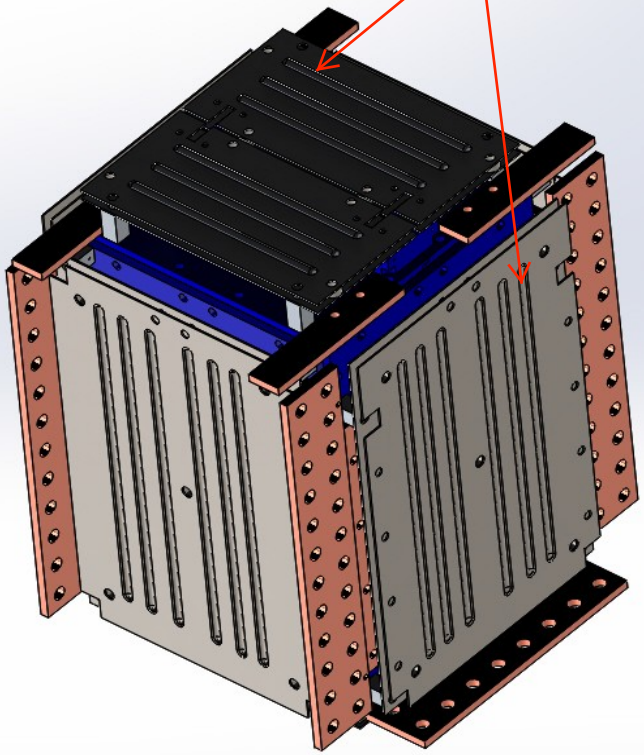
Test mass inside heat shield



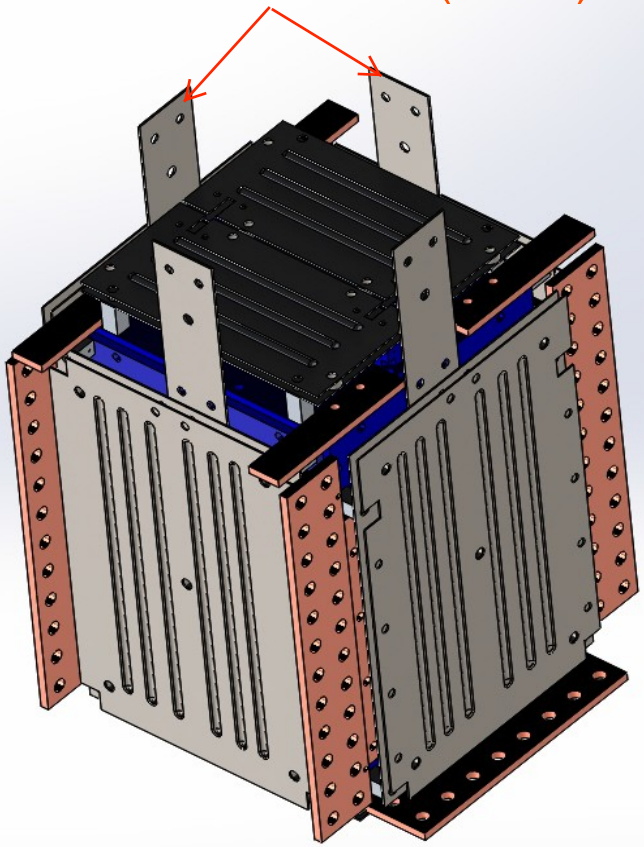
Cu brackets for Cu braids between heat shield and stage 0 cold plates

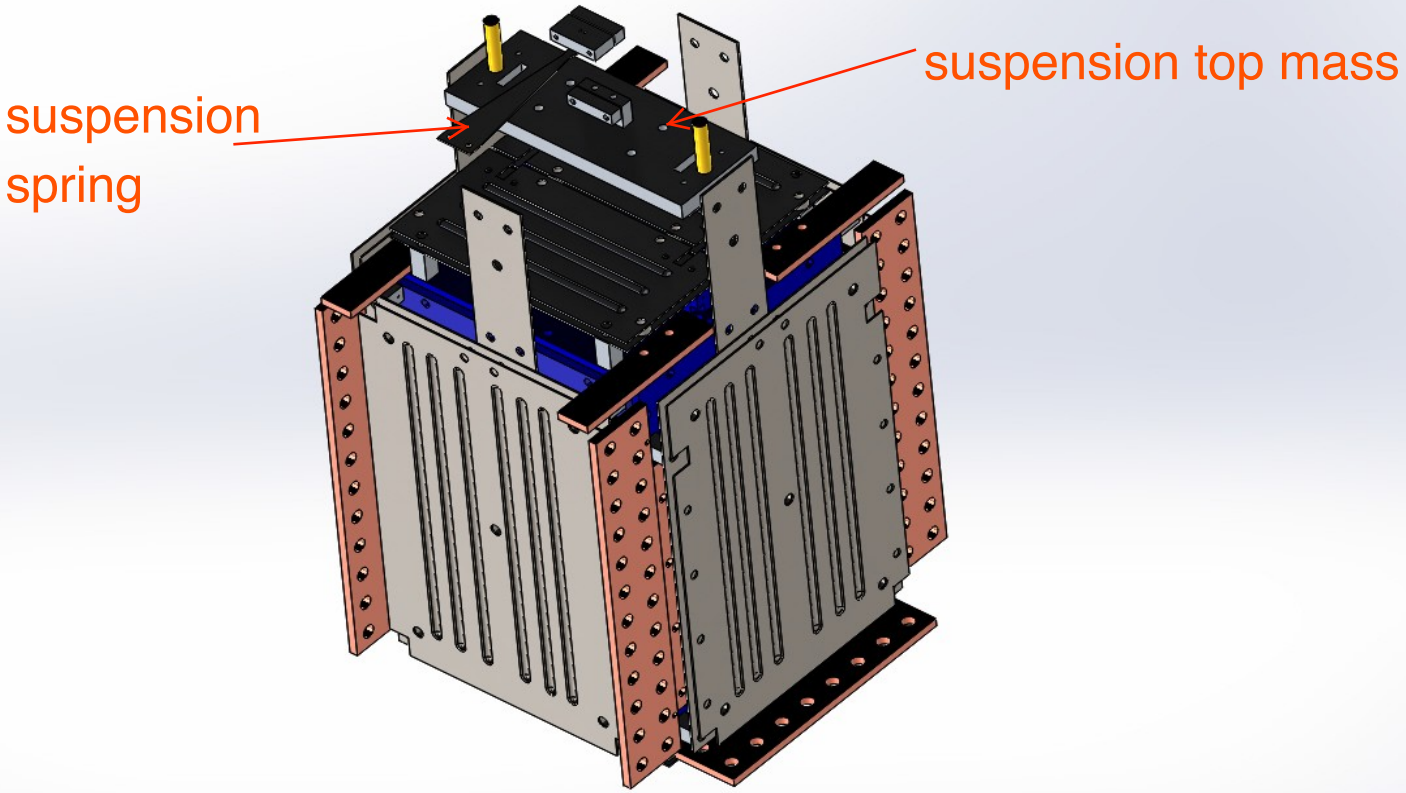


Aluminum low emissivity plates
(ribs boost vibrational frequencies)

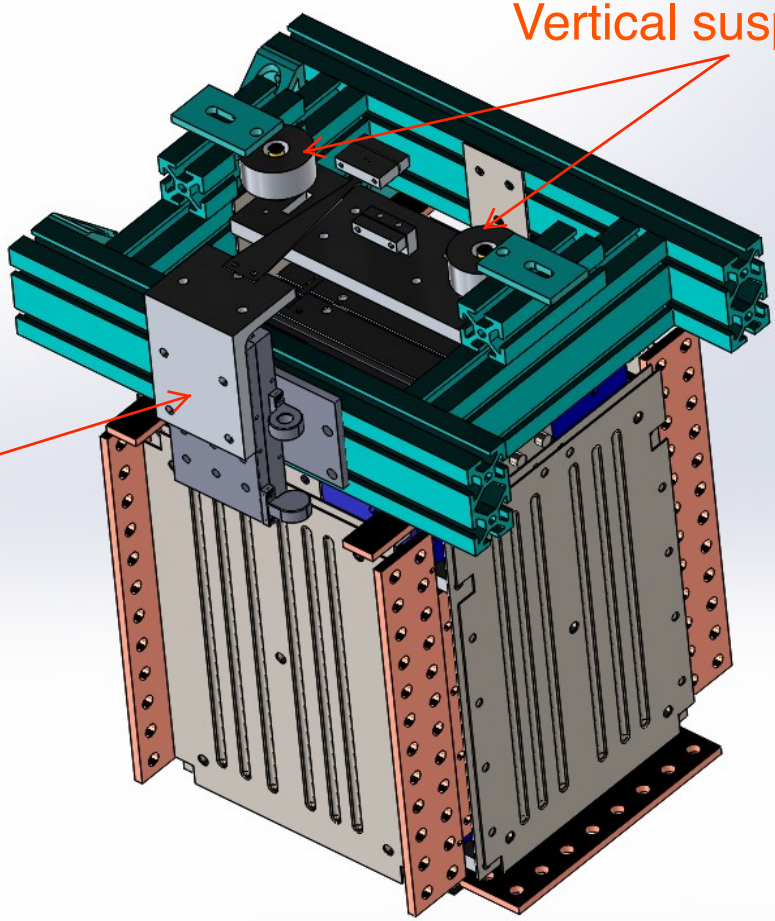


Flexible stainless strips attach the heat shield to its (warm) suspended stage




suspension
spring
suspension top mass

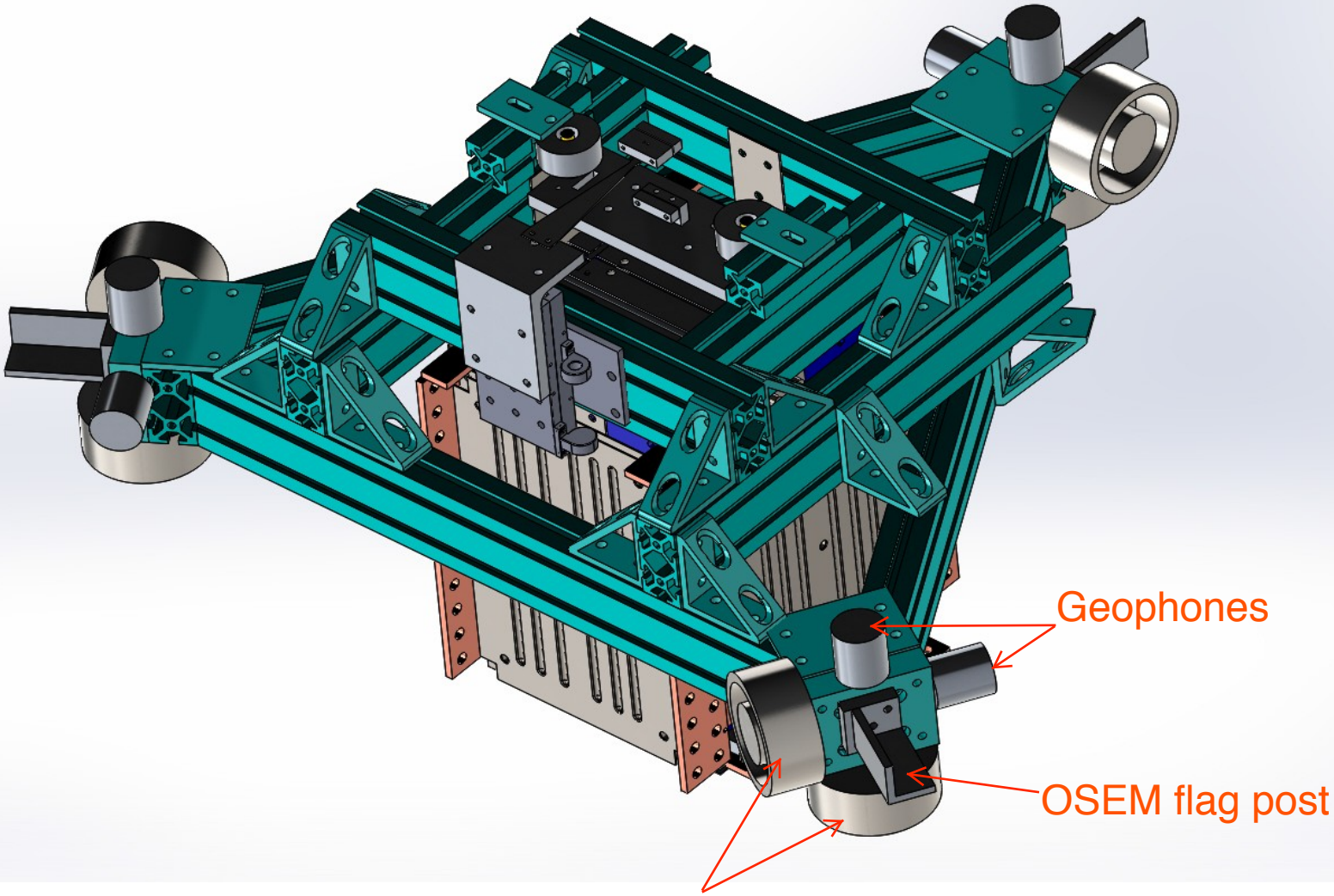
Vertical suspension OSEMs

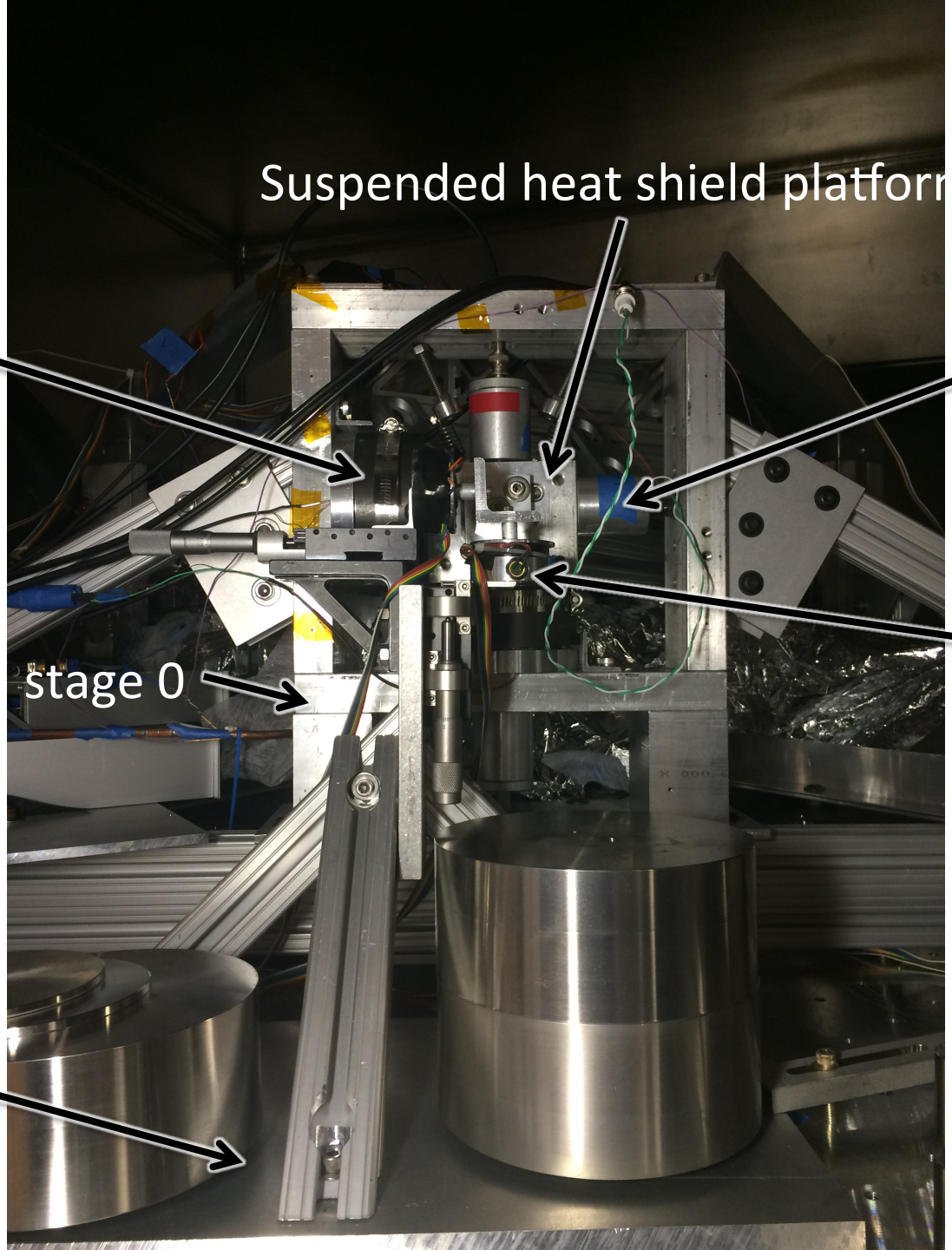


Suspension spring mounted to vertical translation stage

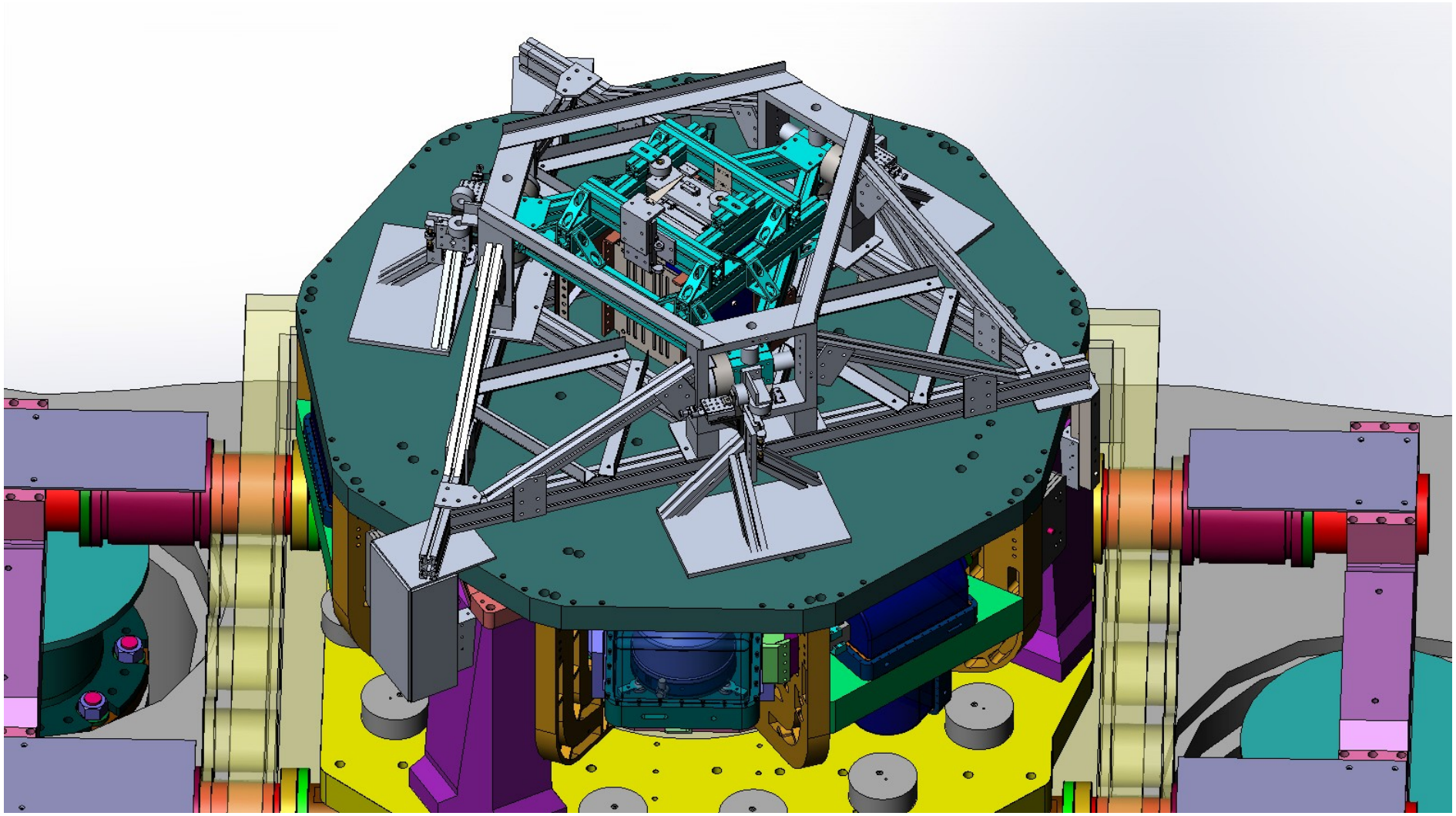
* The OSEMs monitor vertical drift of the suspension due to temperature changes in the spring

The complete heat shield stage

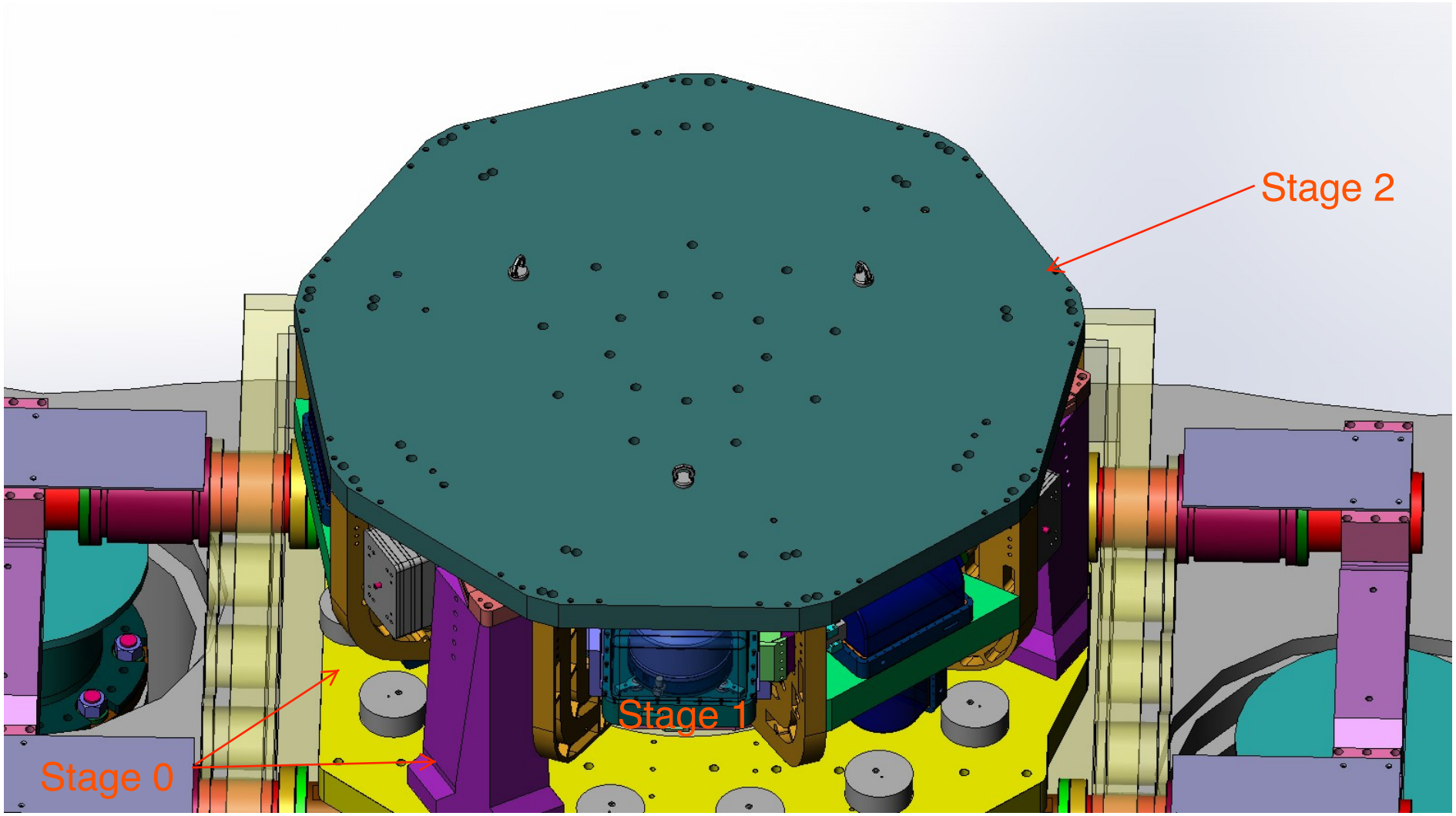



Suspended heat shield platforr
Actuator
HS1 geophone
OSEM
stage 0
ISI stage 2

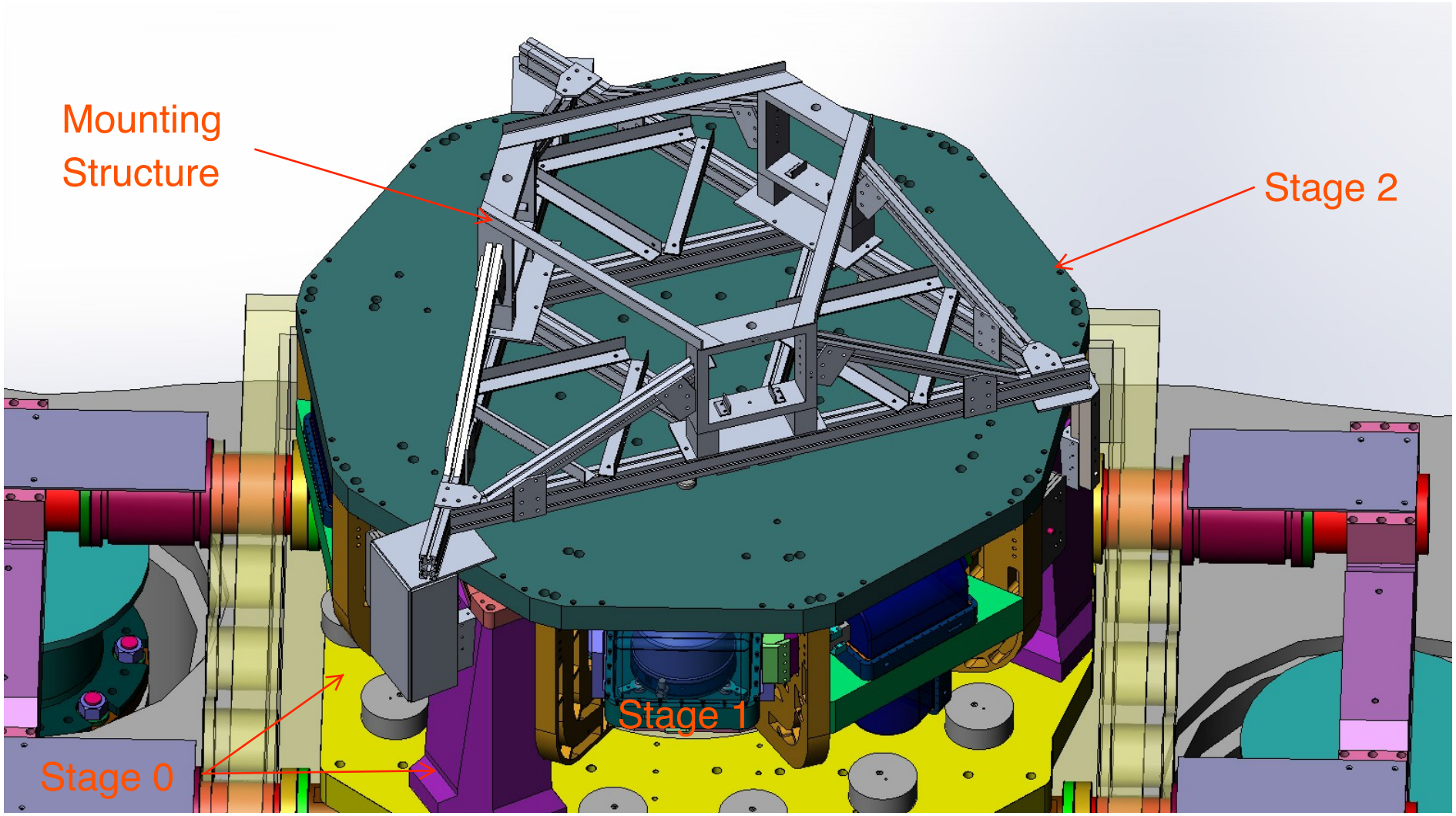
Suspended heat shield stage over Stanford ISI



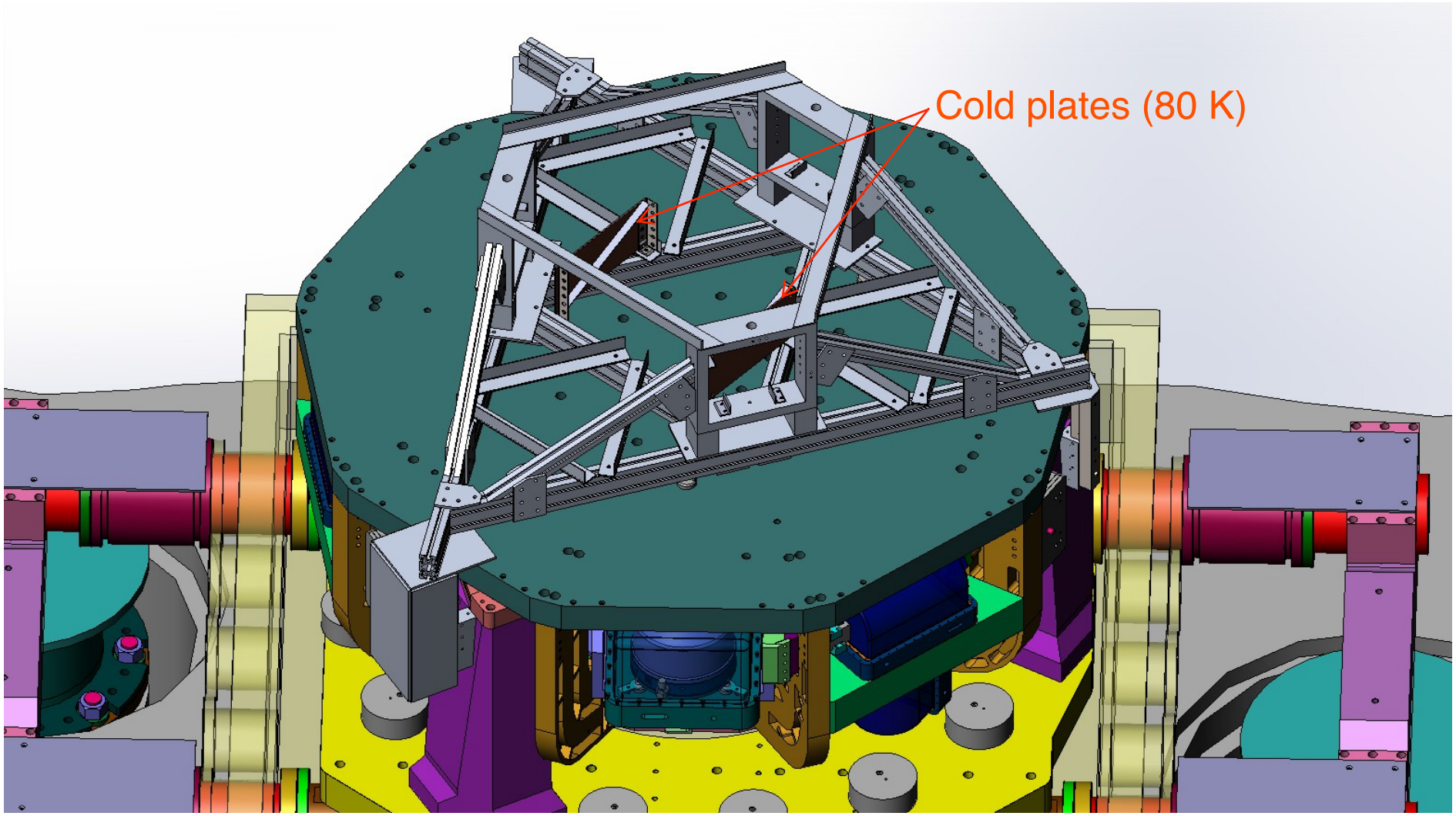
2 stage HAM-like ISI



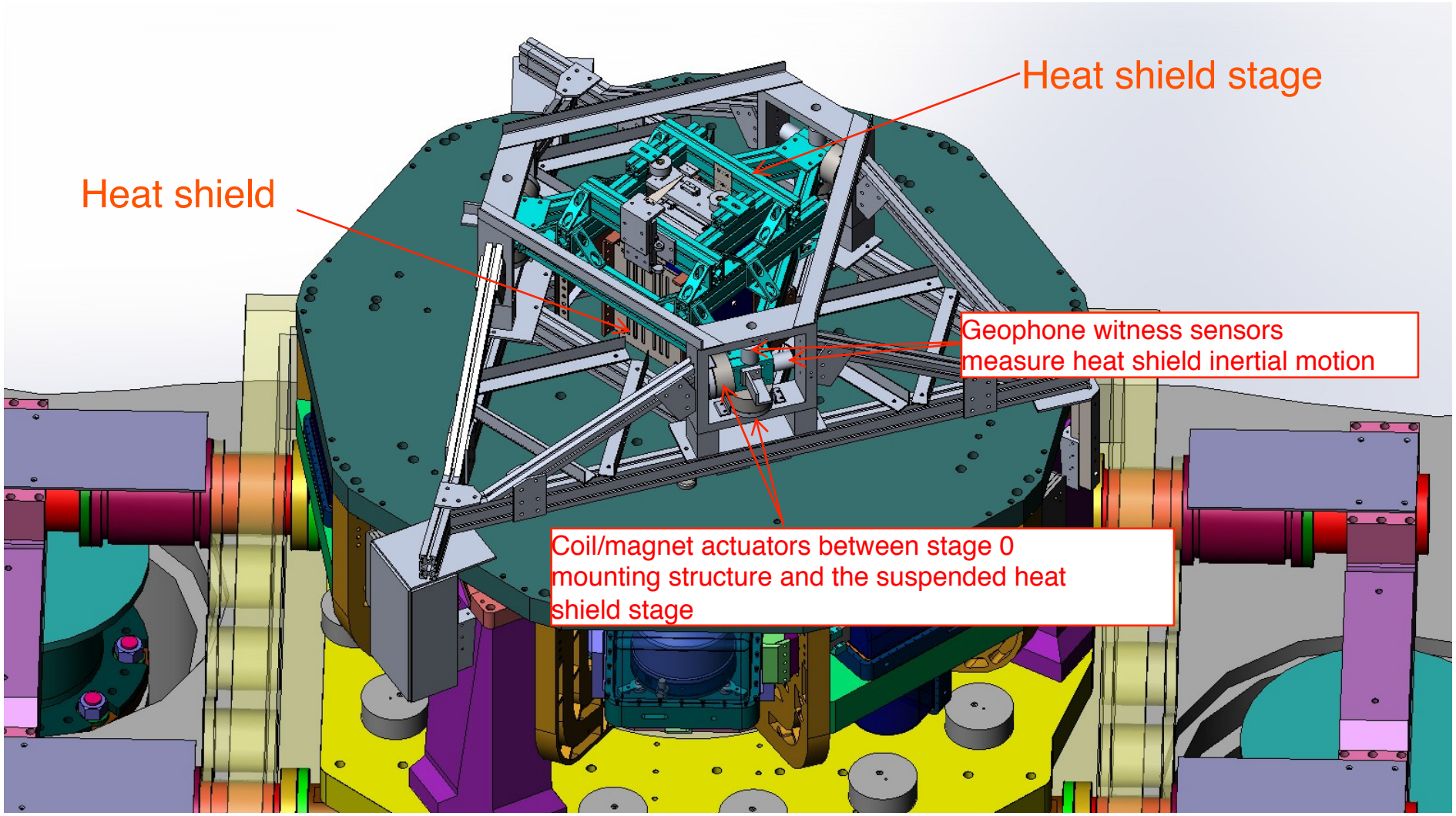
ISI with stage 0 mounting structure for heat shield over stage 2



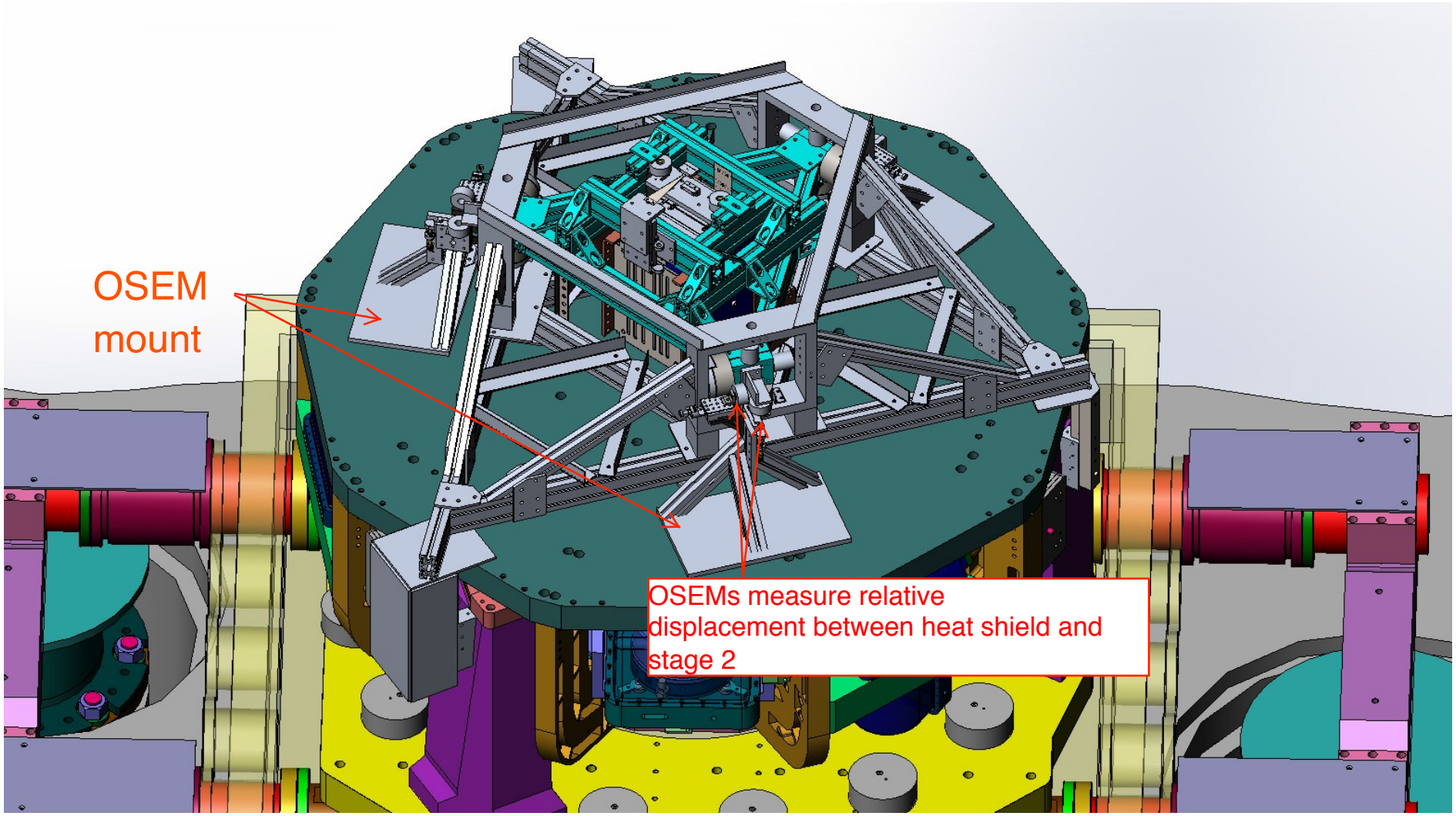
Mounting structure with cryogenic cold plates

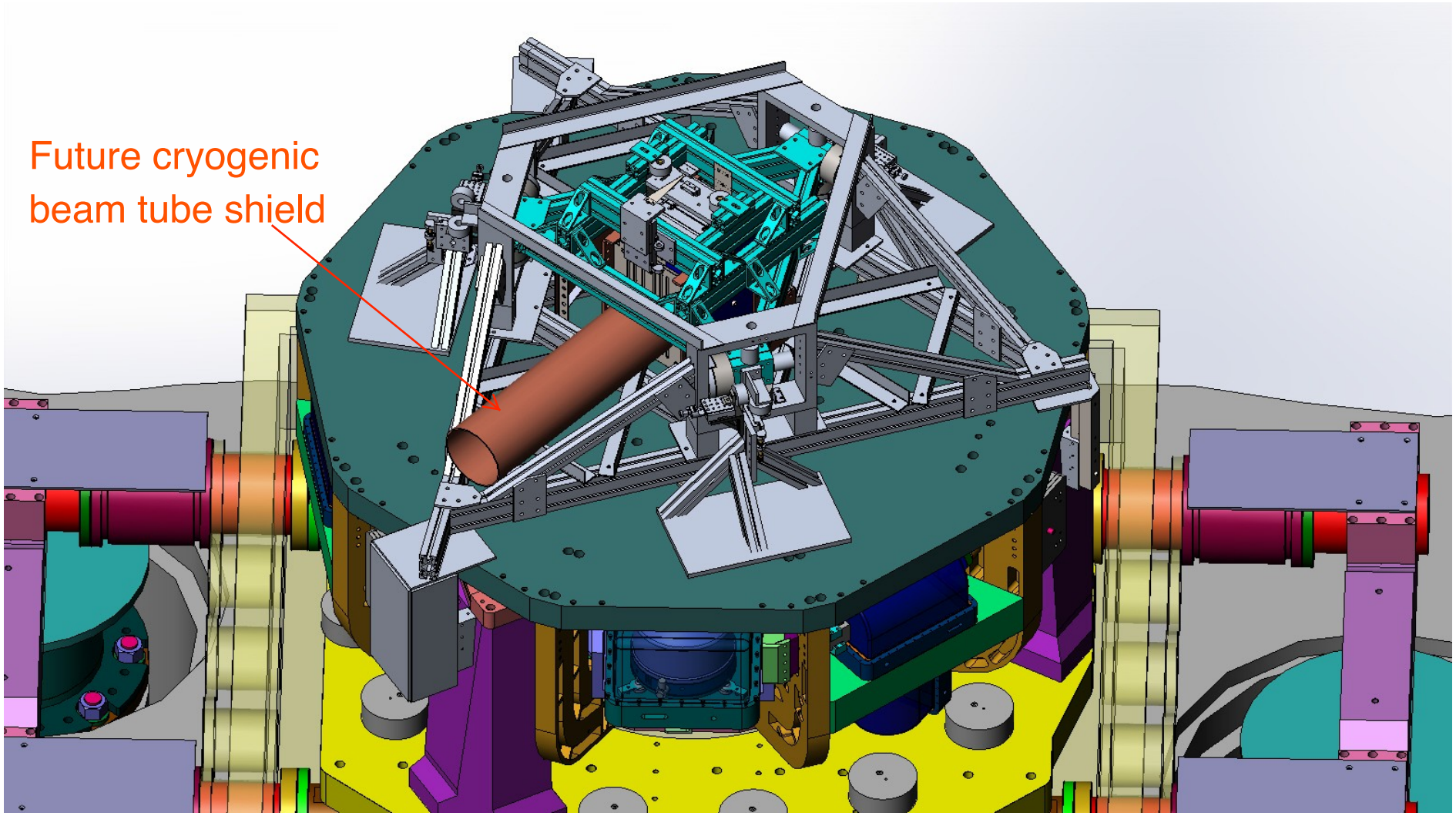


Suspended heat shield stage hanging from mounting structure



OSEM feedback forces the heat shield to follow stage 2




Future cryogenic
beam tube shield