Prototyping a Tilt-Free Seismometer

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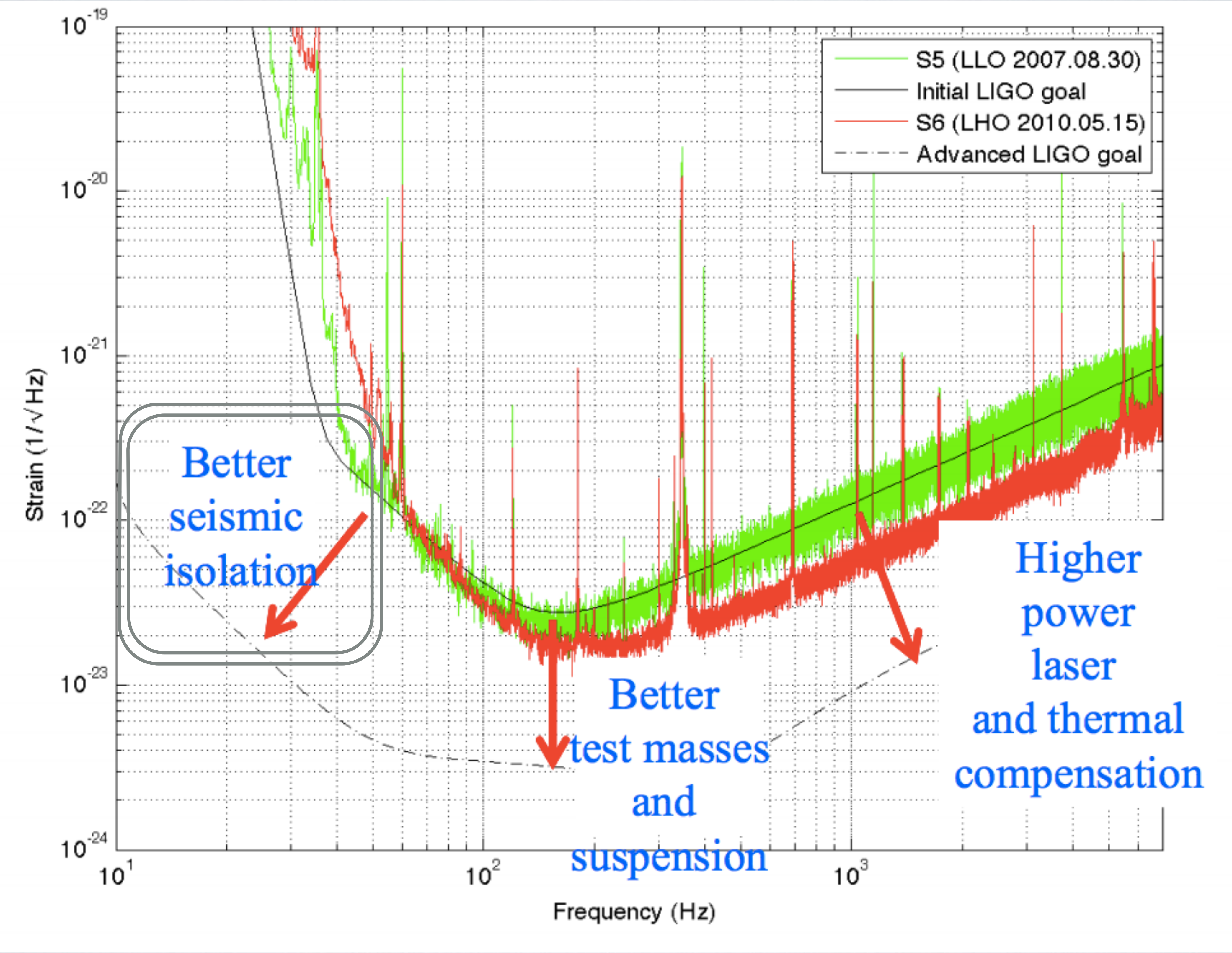
Mentors: Kate Dooley, Rana Adhikari

Outline

- *In theory:*
  - Seismic isolation's relevance to LIGO
  - The problem with ground tilt
  - Solution: "tilt-free" seismometers
- *In practice:*
  - Project goals
  - Current state of the project
  - Future work

LIGO



[1] A. Weinstein, DCC G1500794

Passive vs. Active Isolation

- Passive: damping of ground motion is inherent to the device

- Active: ground motion is measured, then this motion is counteracted via actuators

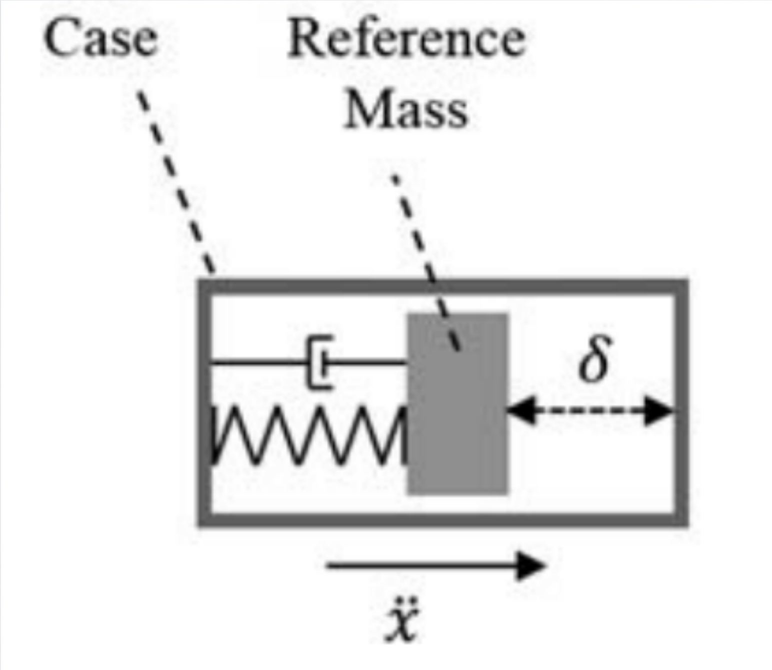
- aLIGO has both passive and active isolation

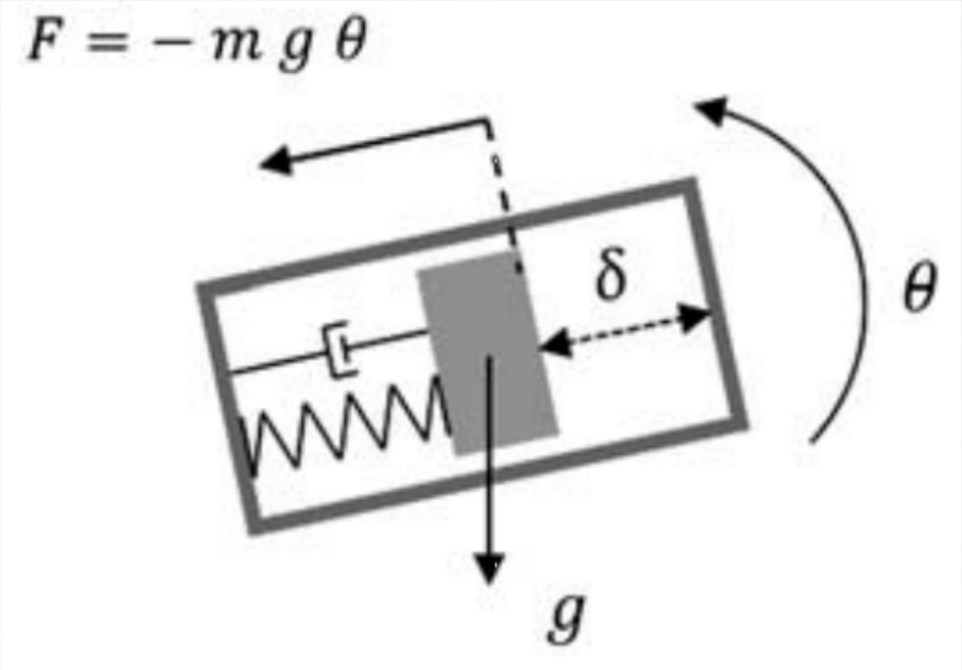
What about ground tilt?

- Ground tilt can come from wind: Livingston in the winter, Hanford all year
- Usual method: measure tilt separately, subtract it out
- Method becomes ineffective at low frequencies (<0.5Hz)
- Need to be insensitive to tilt in the first place

LIGO

Why not regular seismometers?



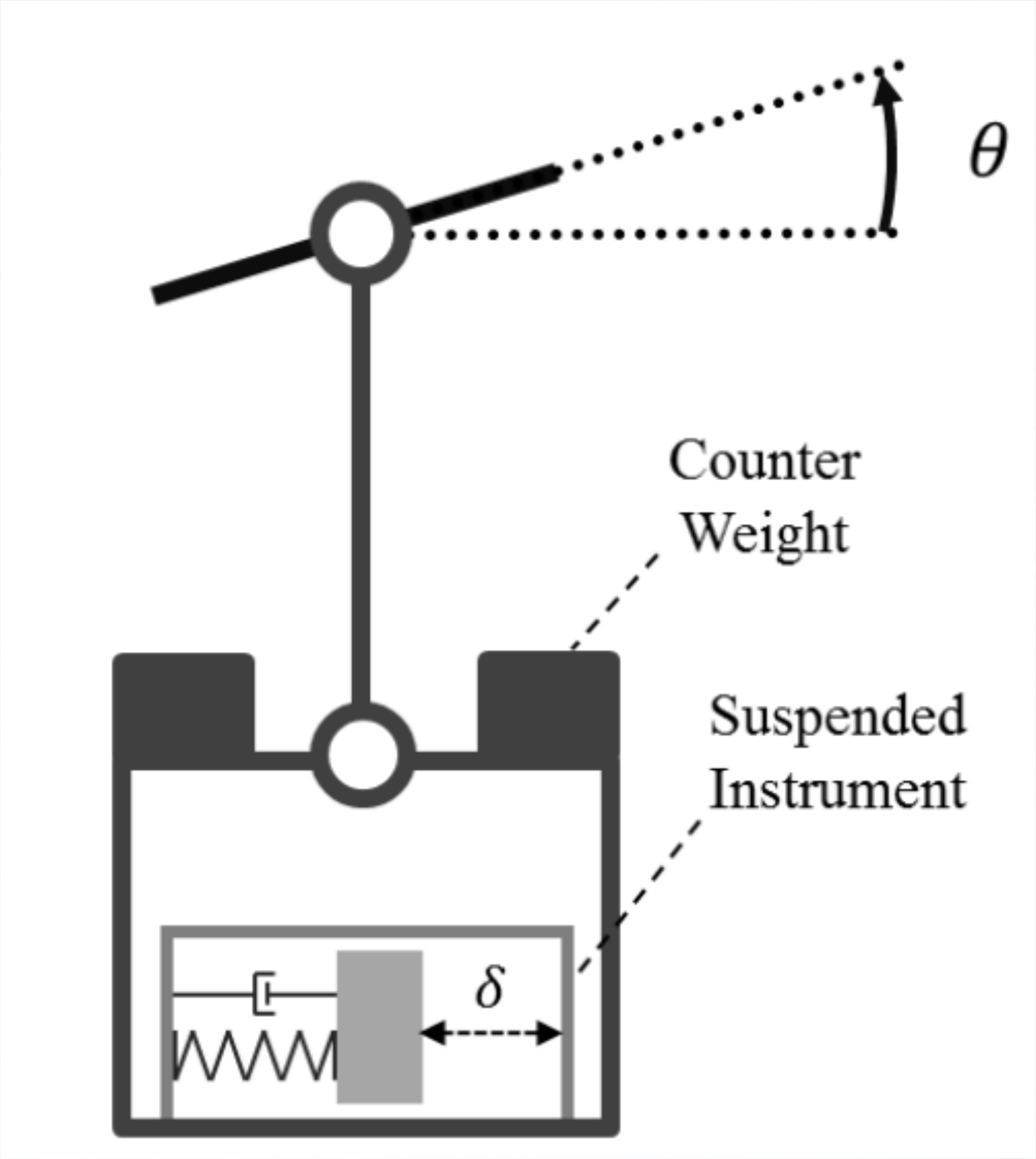


[2] F. Matichard et al., DCC P1200007

- Translation of seismometer and tilt of seismometer produce the same signal
- Present in all intertial sensors: remember the principle of equivalence

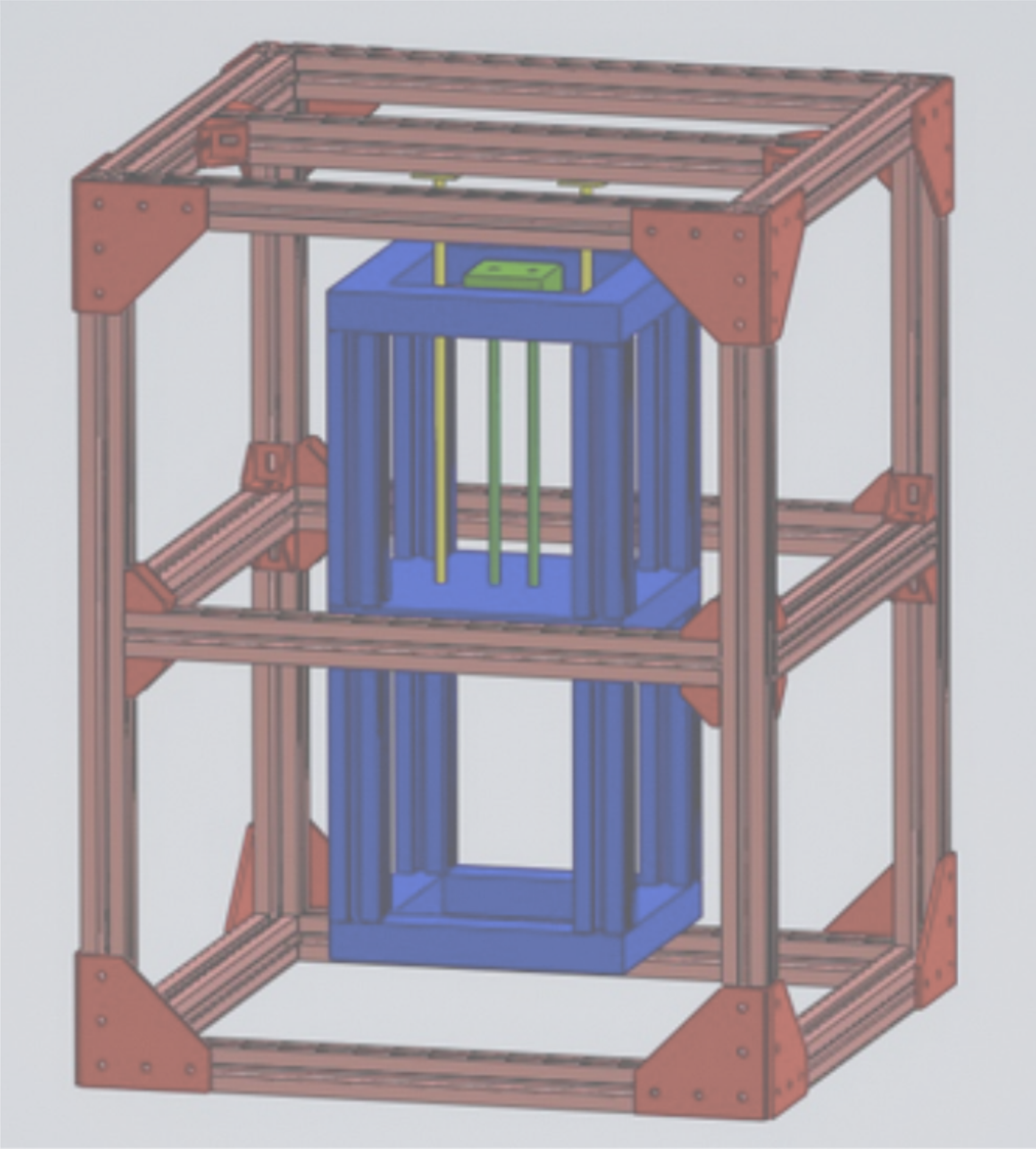
A 'Tilt-Free' Seismometer

- Response of pendulums to tilt motion
- Below resonant frequency: tilt & translation indistinguishable
- Above resonant frequency: effectively 'tilt-free'
- Goal: a very low resonant frequency (mHz)



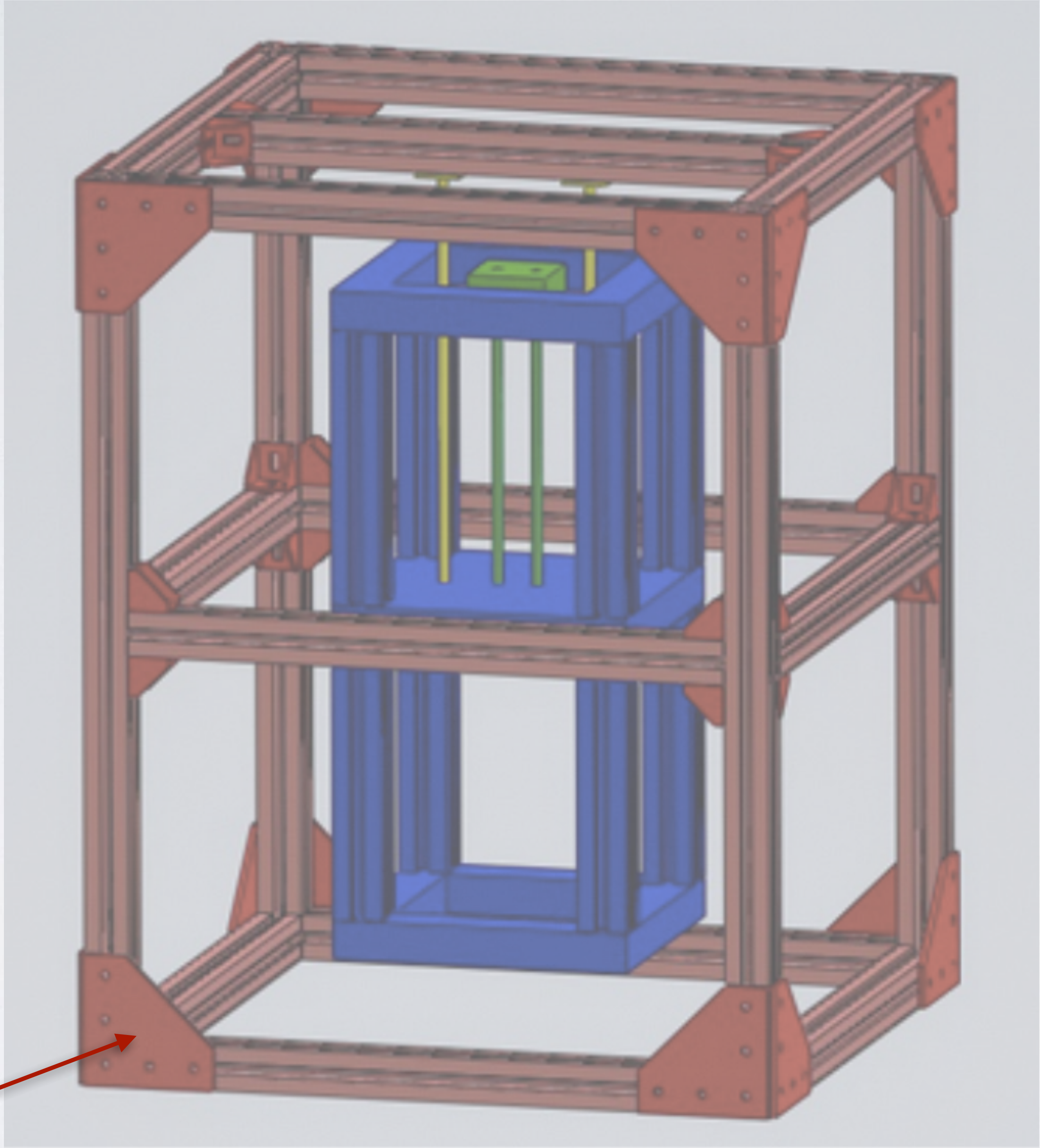
[3] F. Matichard et al., DCC P1400061

Seismometer Design



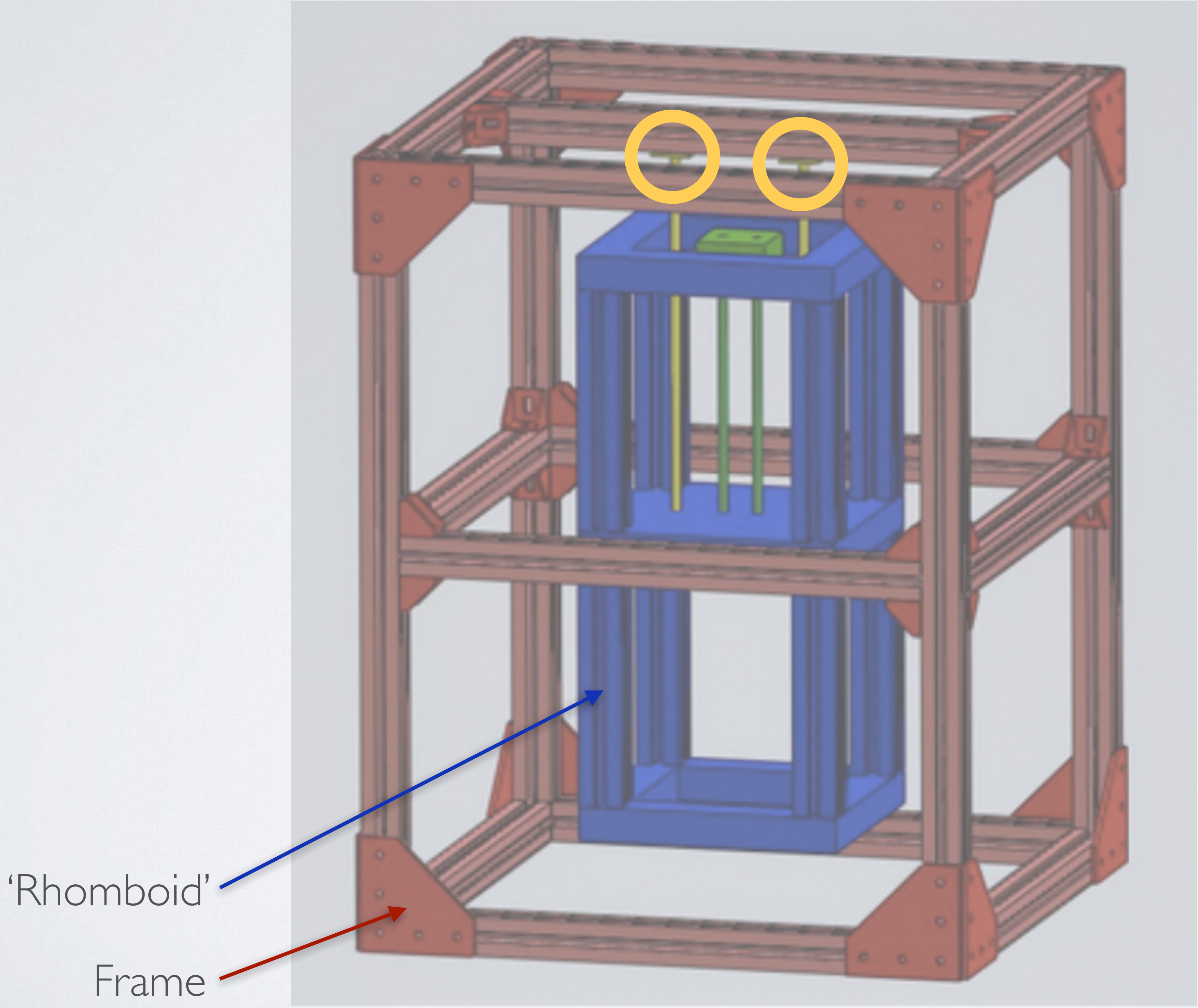
[4] K. Dooley et al., *DCC G1500315*

Seismometer Design



[4] K. Dooley et al., *DCC G1500315*

Seismometer Design



[4] K. Dooley et al., *DCC G1500315*

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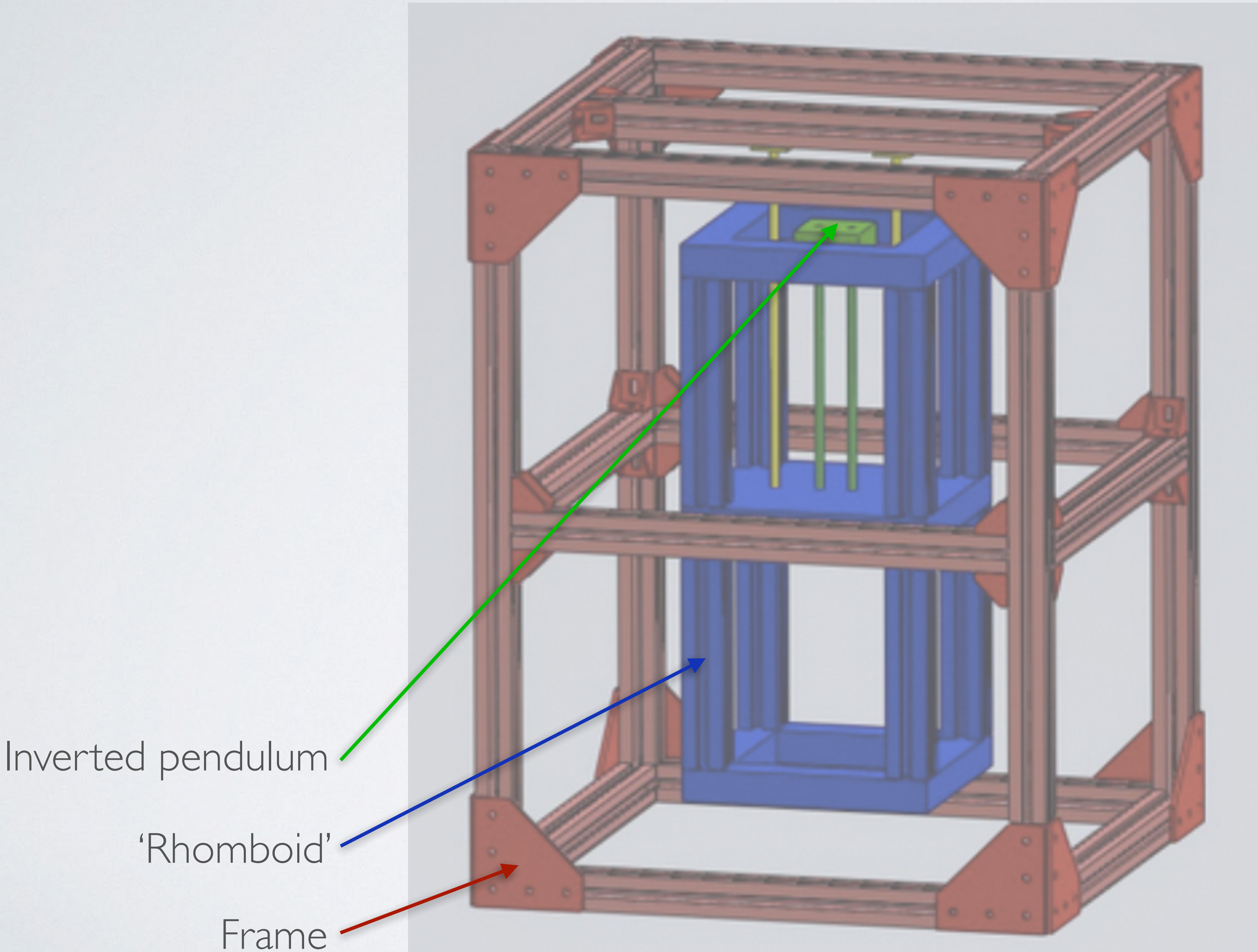
Seismometer Design



[4] K. Dooley et al., *DCC G1500315*

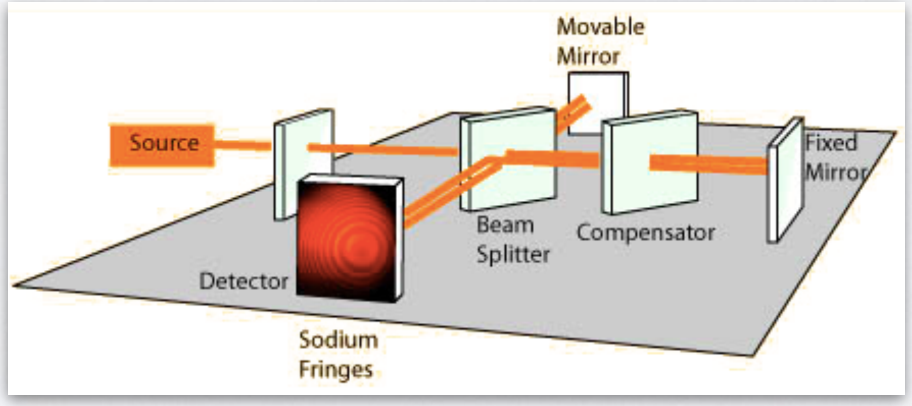
Seismometer Logistics

- How do you measure the relative motion of the rhomboid and the inverted pendulum very accurately?

A Michelson interferometer!

- How do you reduce noise in this system?

Keep the temperature constant: build a thermal housing.

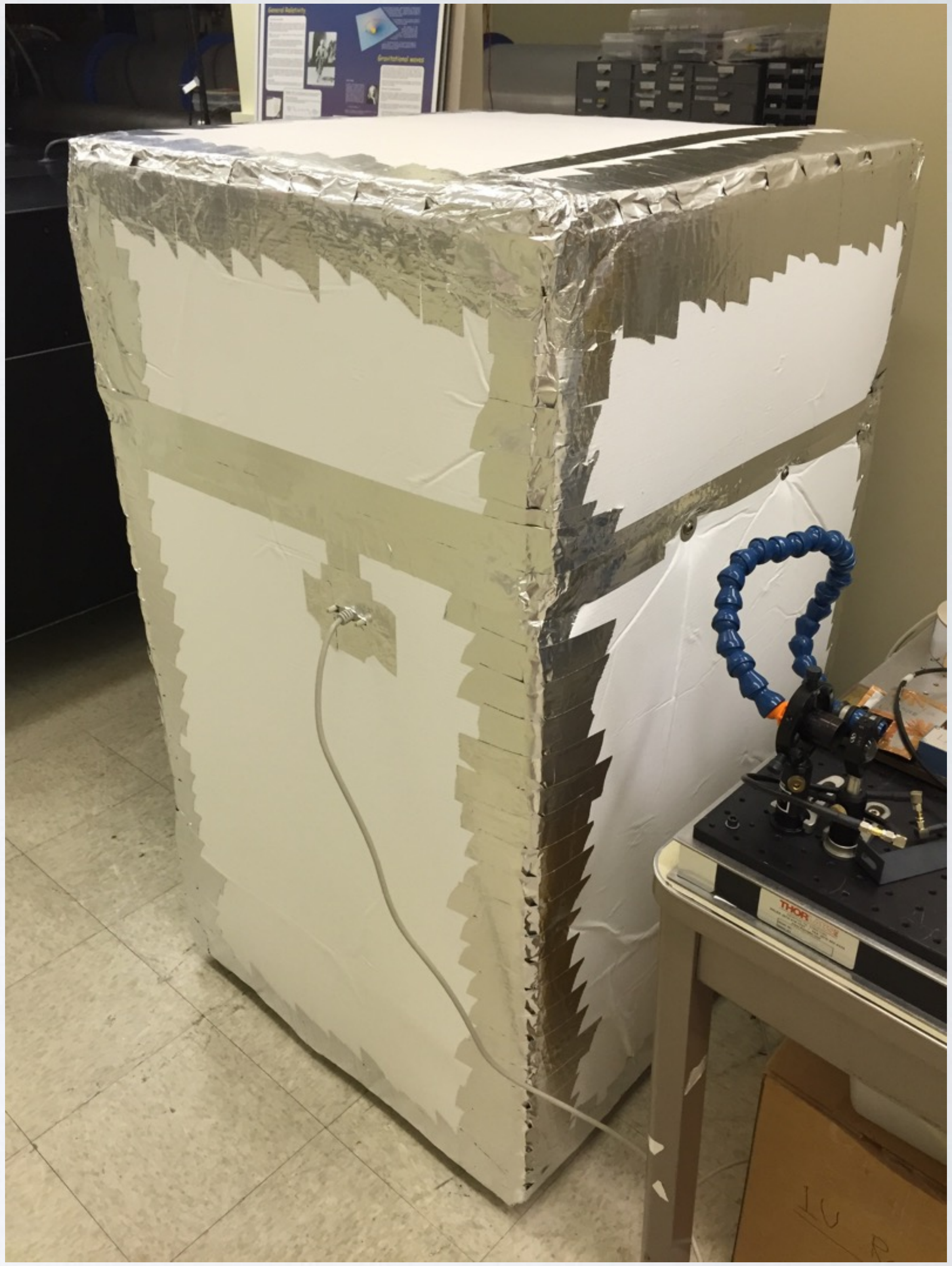


These were the two goals for the summer!

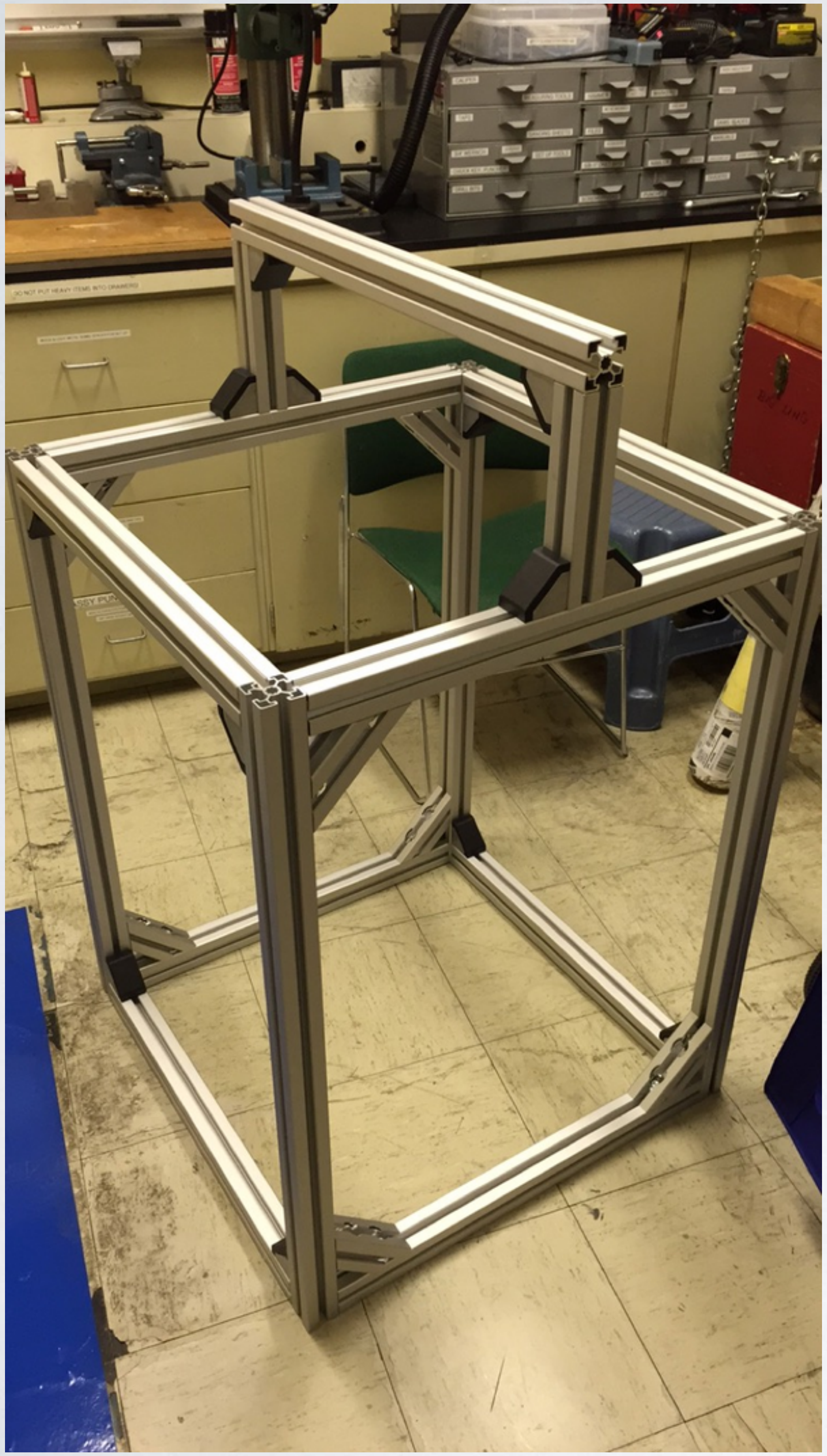
LIGO

Thermal Enclosure Design

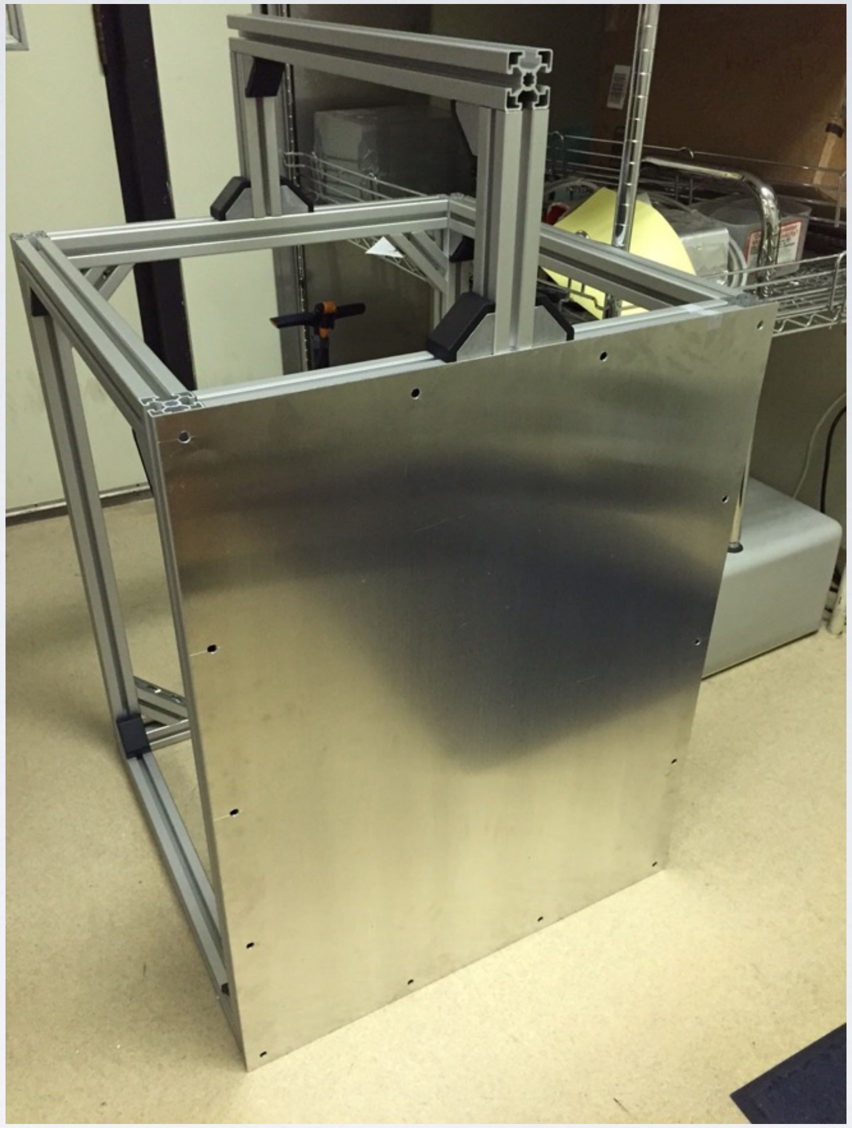
- Aluminum sheeting and melamine foam covering the seismometer frame
- Flexible resistive heaters + thermistors on inside aluminum face
- Controllers to measure the temperature and drive the heaters



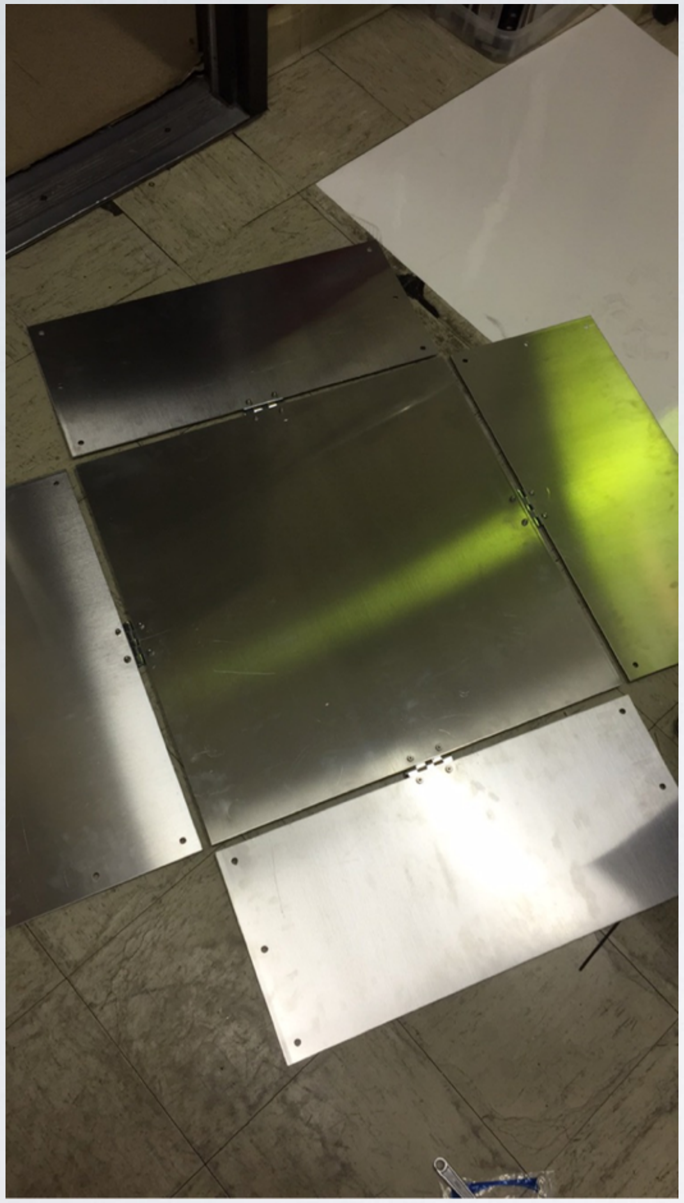
Final Product!

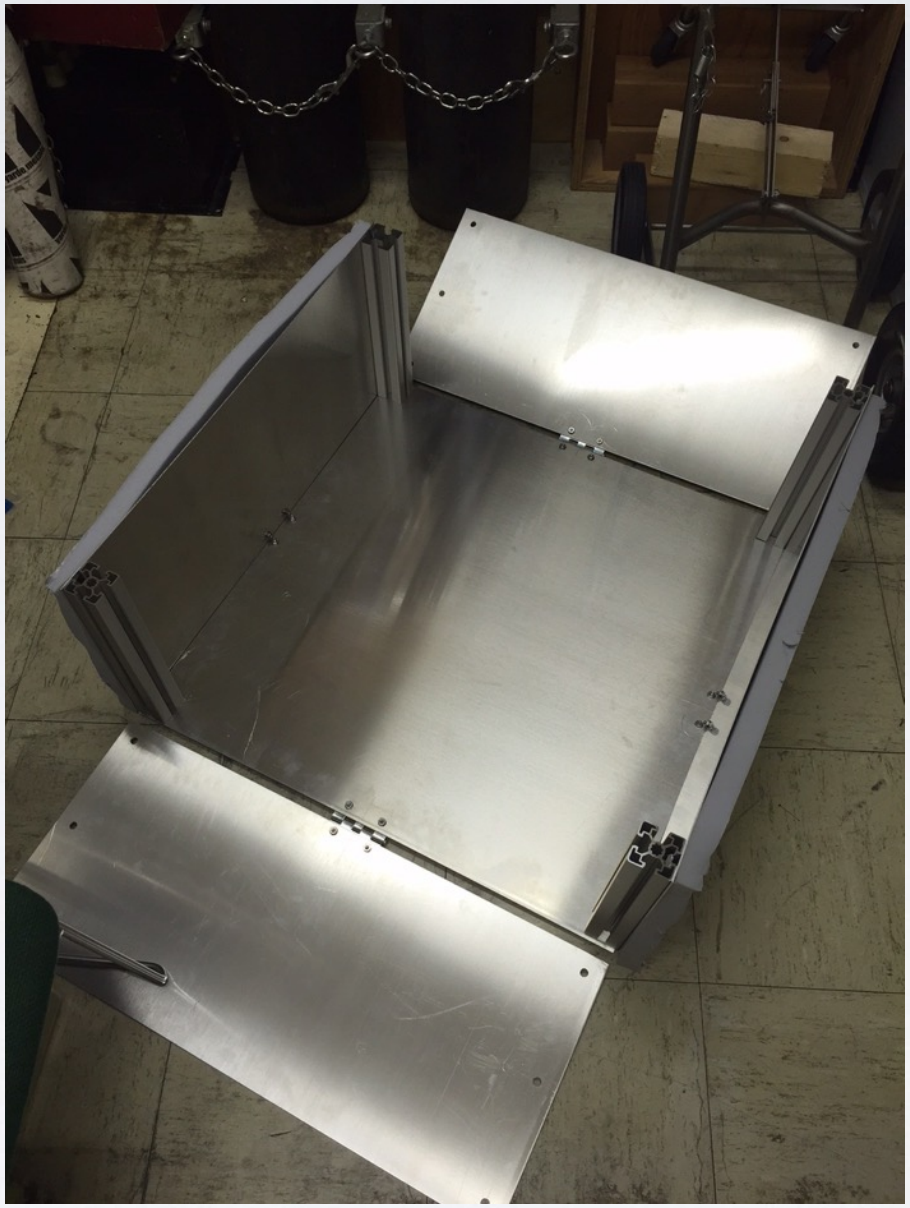


Frame construction



Aluminum sheeting machining



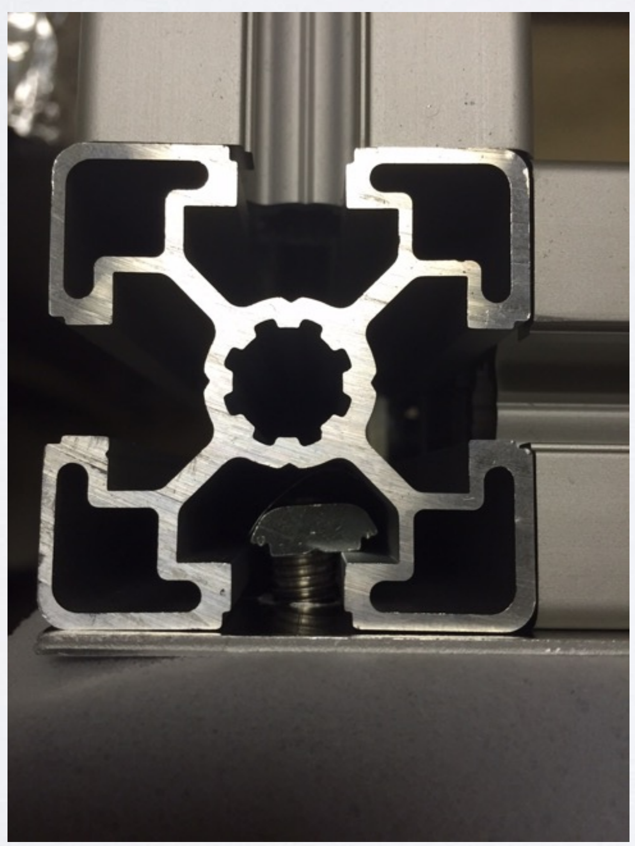


Lid construction: more aluminum machining, foam cutting, and beam attachment

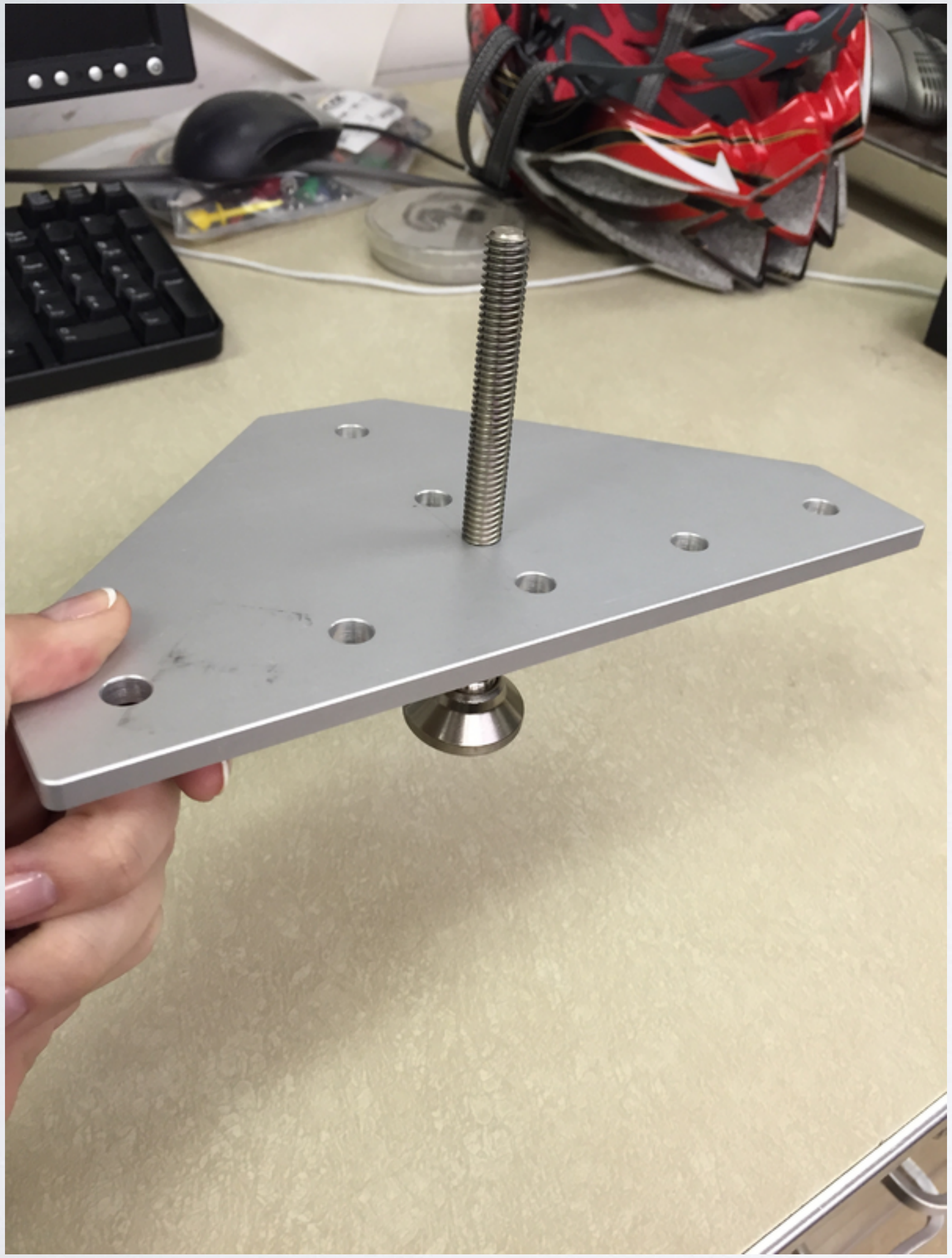
First side put on

All but one side on

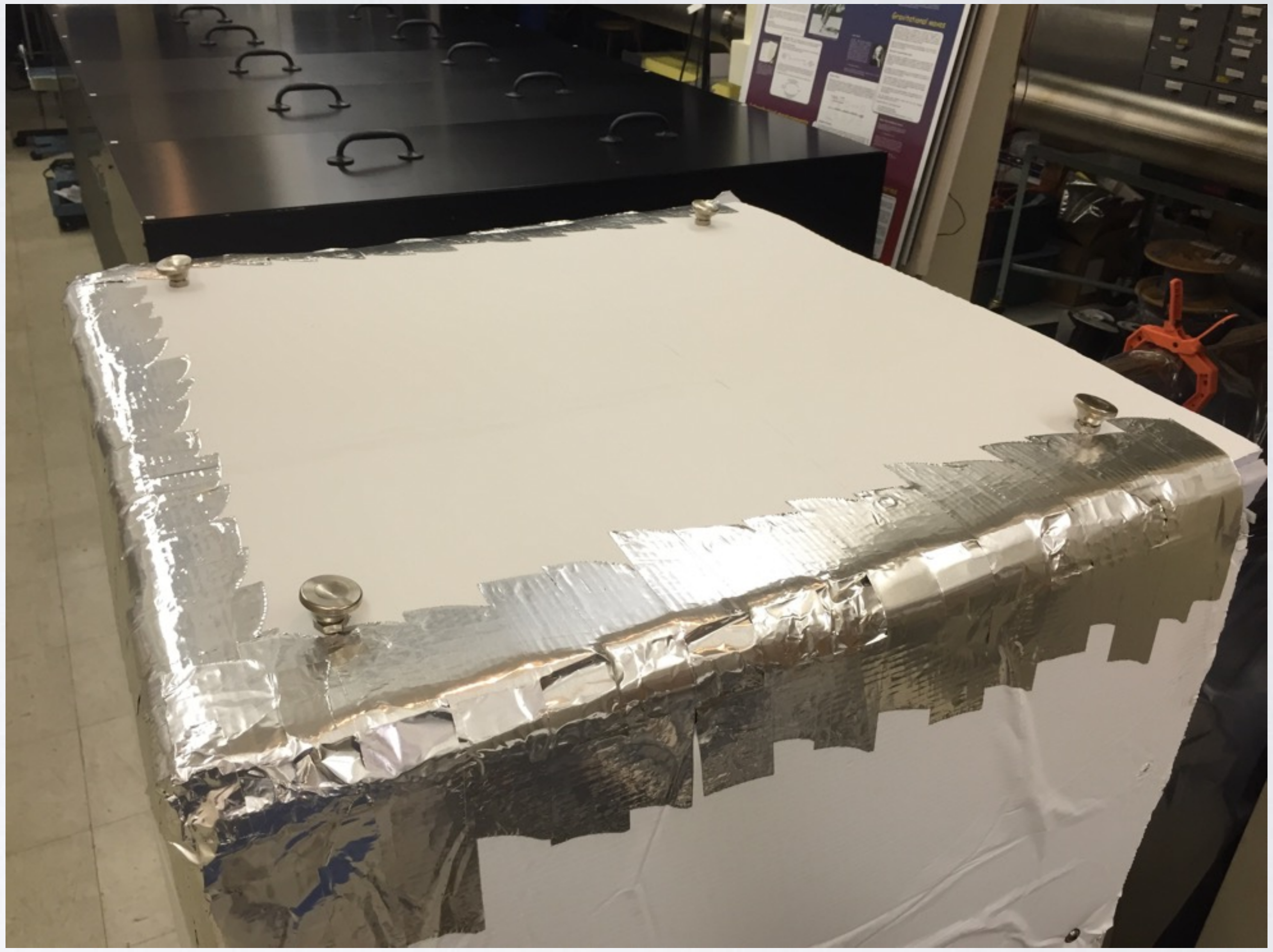
Drop-in fastener
as seen from above



Foam attached to
aluminum!

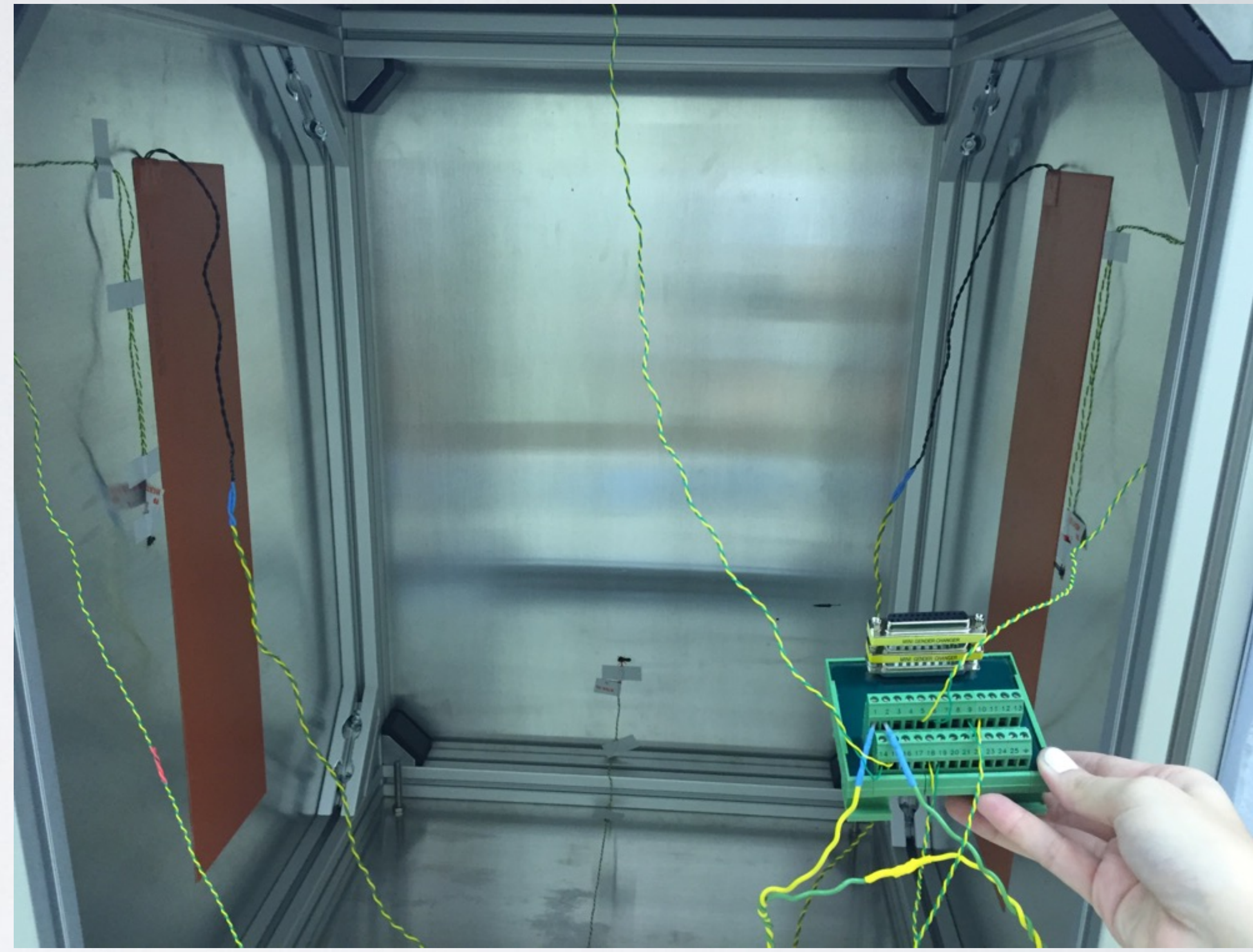


Stainless steel feet,
corner plate to bear weight



Feet + foam attached
to the bottom face

LIGO



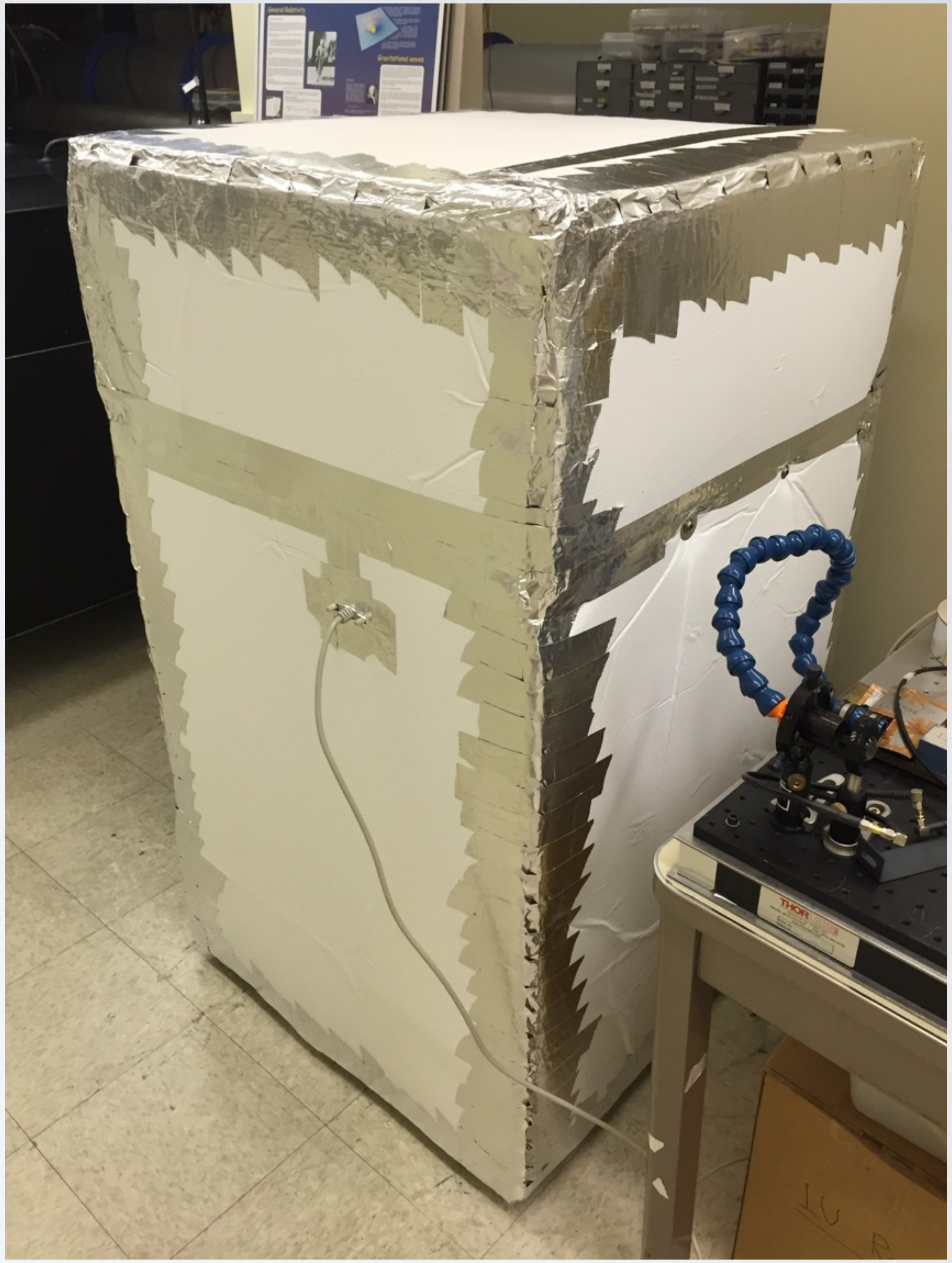
Inside of the enclosure, with all wires to the breakout box

Full-size heater, and thermistor attached with epoxy

LIGO

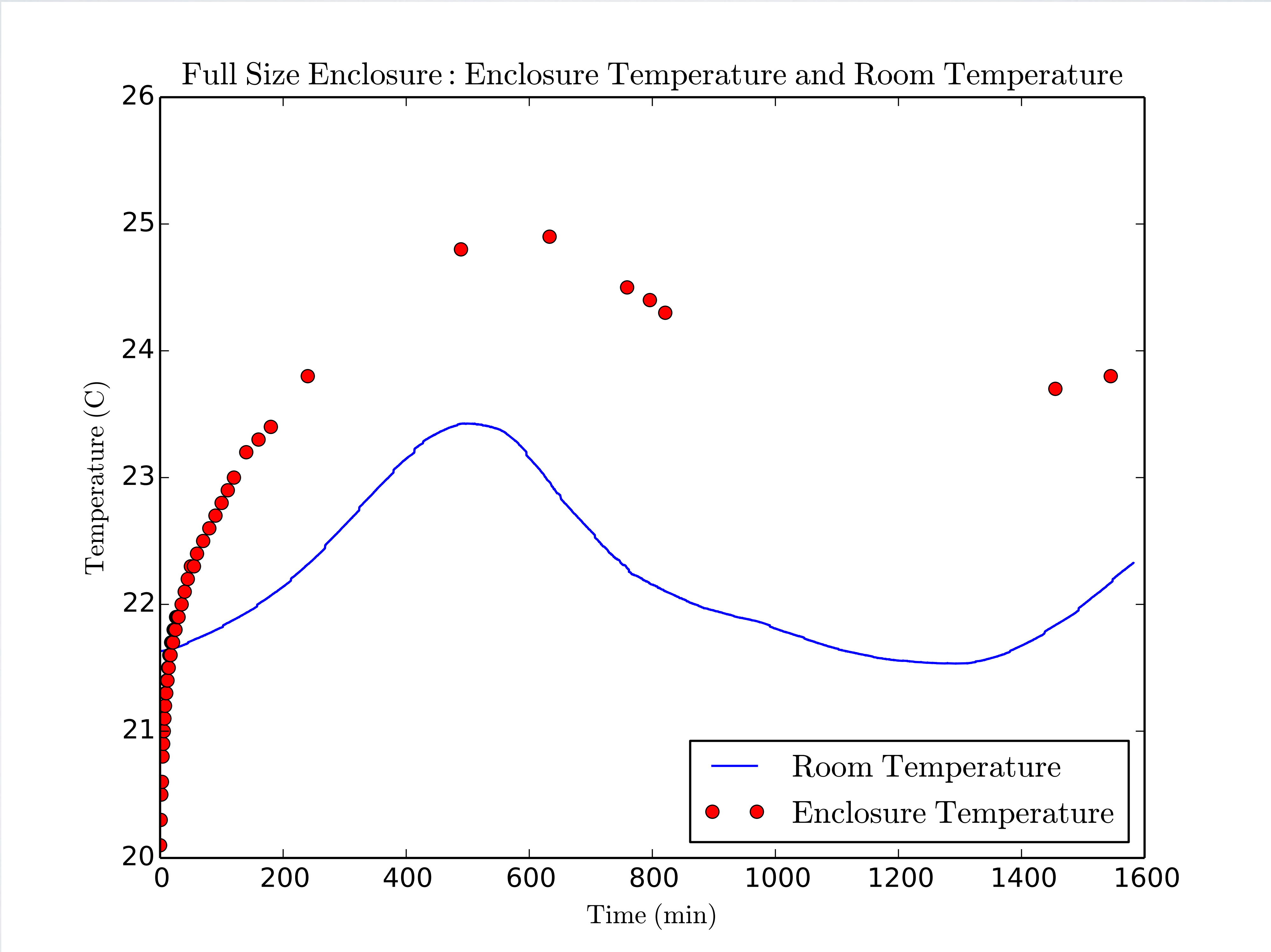
The wiring installed, final side attached

→

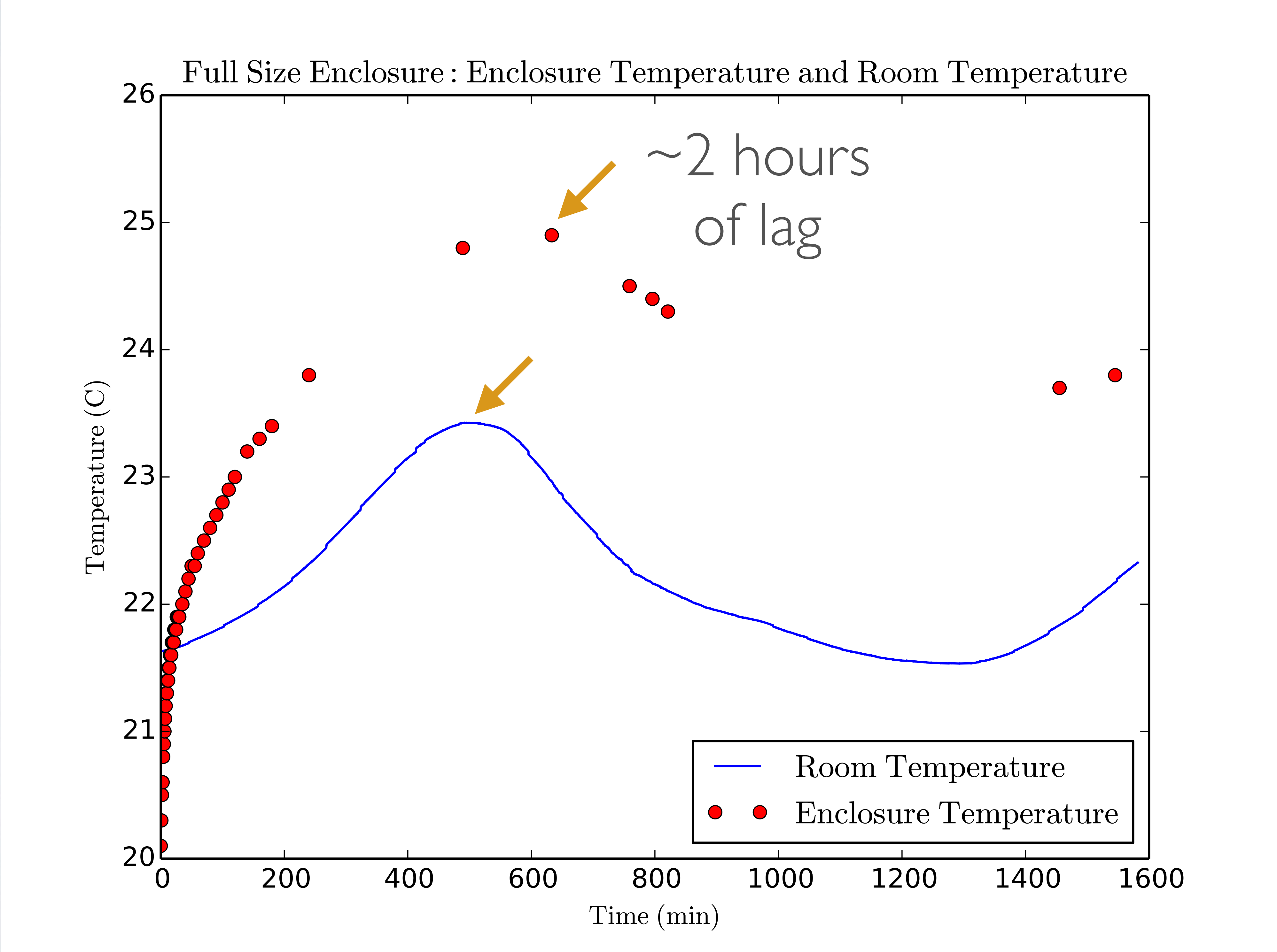


Ready for full-scale test!

First Full-Scale Test



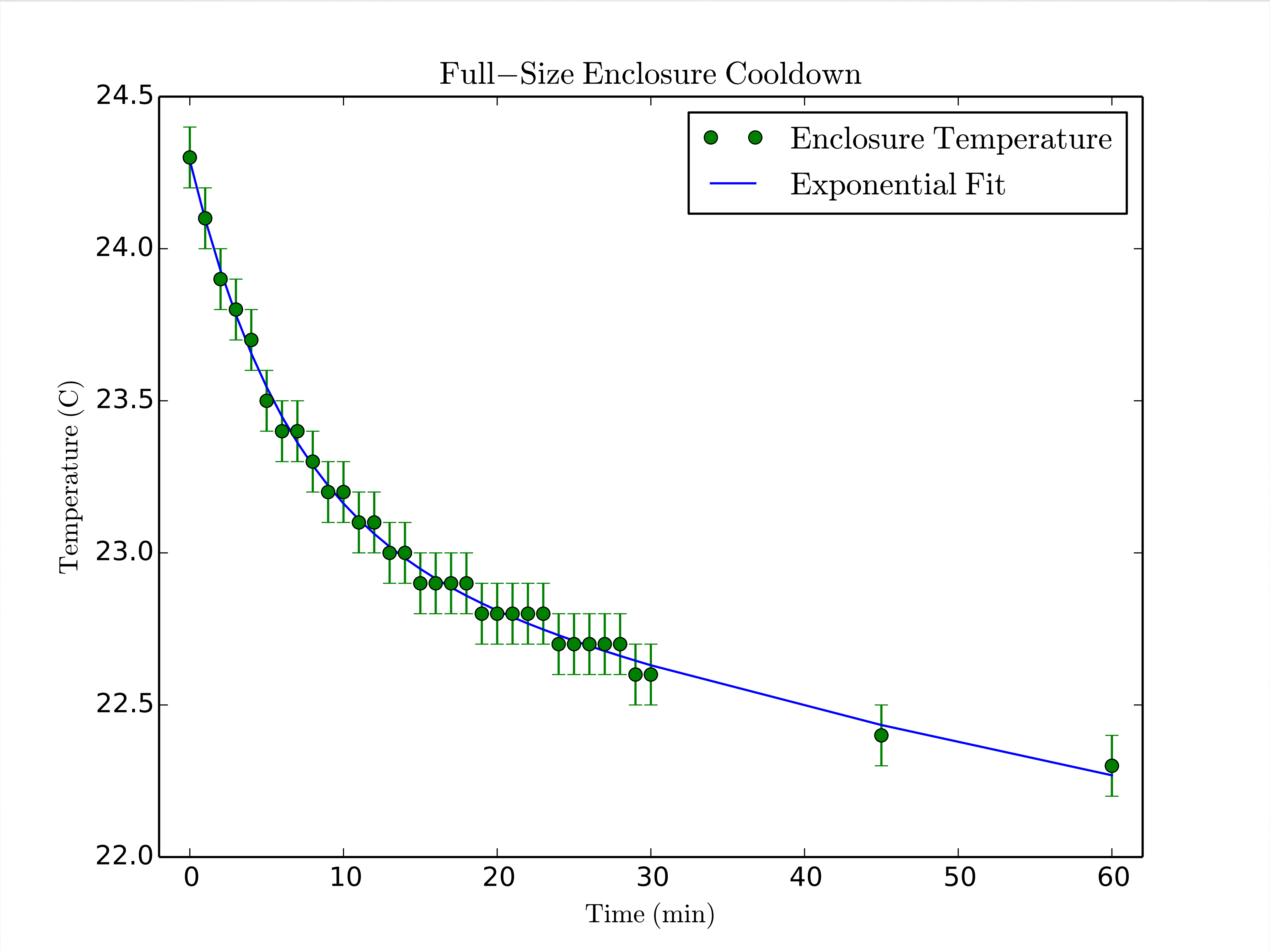
First Full-Scale Test



First Full-Scale Test

- Was unable to reach the set temperature of 35°C
  - $dQ_{out}/dt > dQ_{in}/dt$
- Could only set up a maximum 5°C gradient
- Insulation is able to support a 20°C gradient across it
- Thus: 4x as much heat is escaping than remaining
- Causes: air pockets, aluminum tape contact, foam gaps?

Enclosure Cooldown Test



Enclosure Cooldown Test

- A double exponential fit:

$$T(t) = Ae^{-t/B} + Ce^{-t/D} + F$$

- B and D are two different time constants, corresponding to two regimes of cooling

- Double exponential behavior in cooling curve *and* heating curve

- Causes: heat flow within enclosure before escape, change in heater power

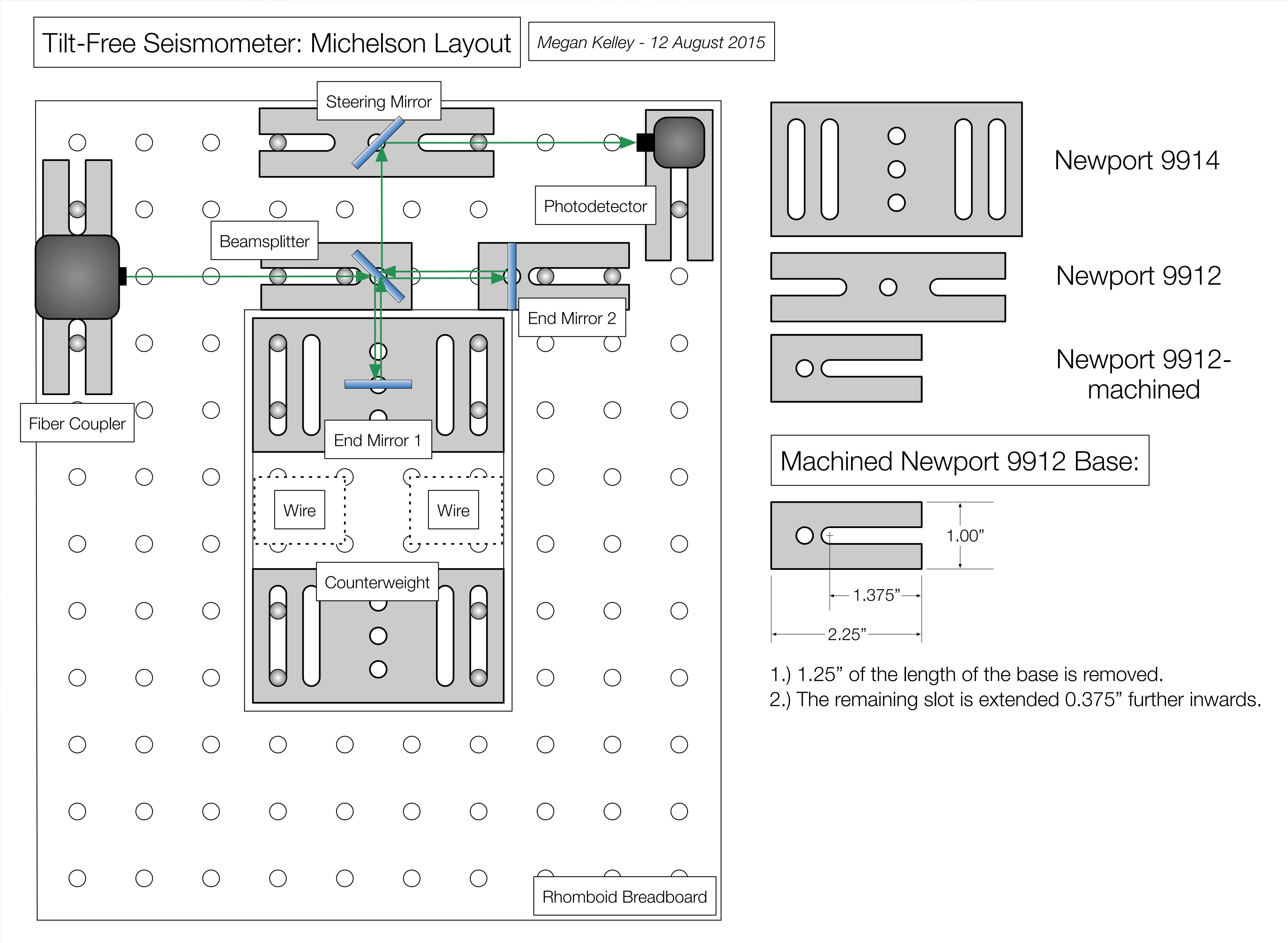
Future Work

- Automatic data recording from the temperature controller
- Analysis of the controller's stabilization properties, adjustment of PID controls
- Enhancing the insulation: find and fix any heat leaks
- Optimization of setup to minimize time constant without damaging the enclosure
  - Bigger heaters? More heaters? More driving power?

Michelson Interferometer Design

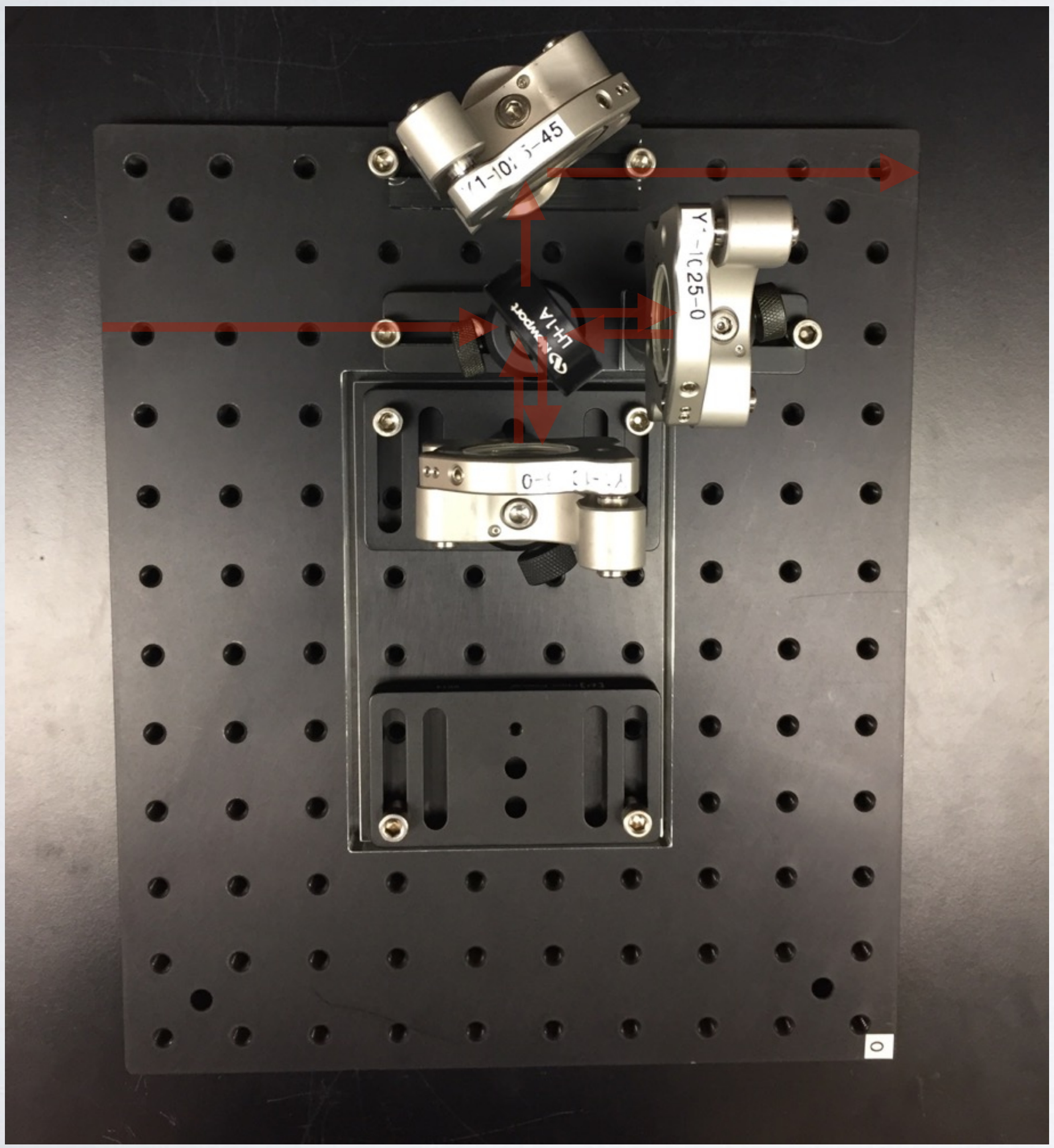
- One end mirror on the rhomboid, other end mirror on the inverted pendulum
- Light must be fiber coupled to the seismometer
- Design must be weight-balanced, and fit on the given breadboard

Final Design Version



1.) 1.25” of the length of the base is removed.
2.) The remaining slot is extended 0.375” further inwards.

Starting the Assembly

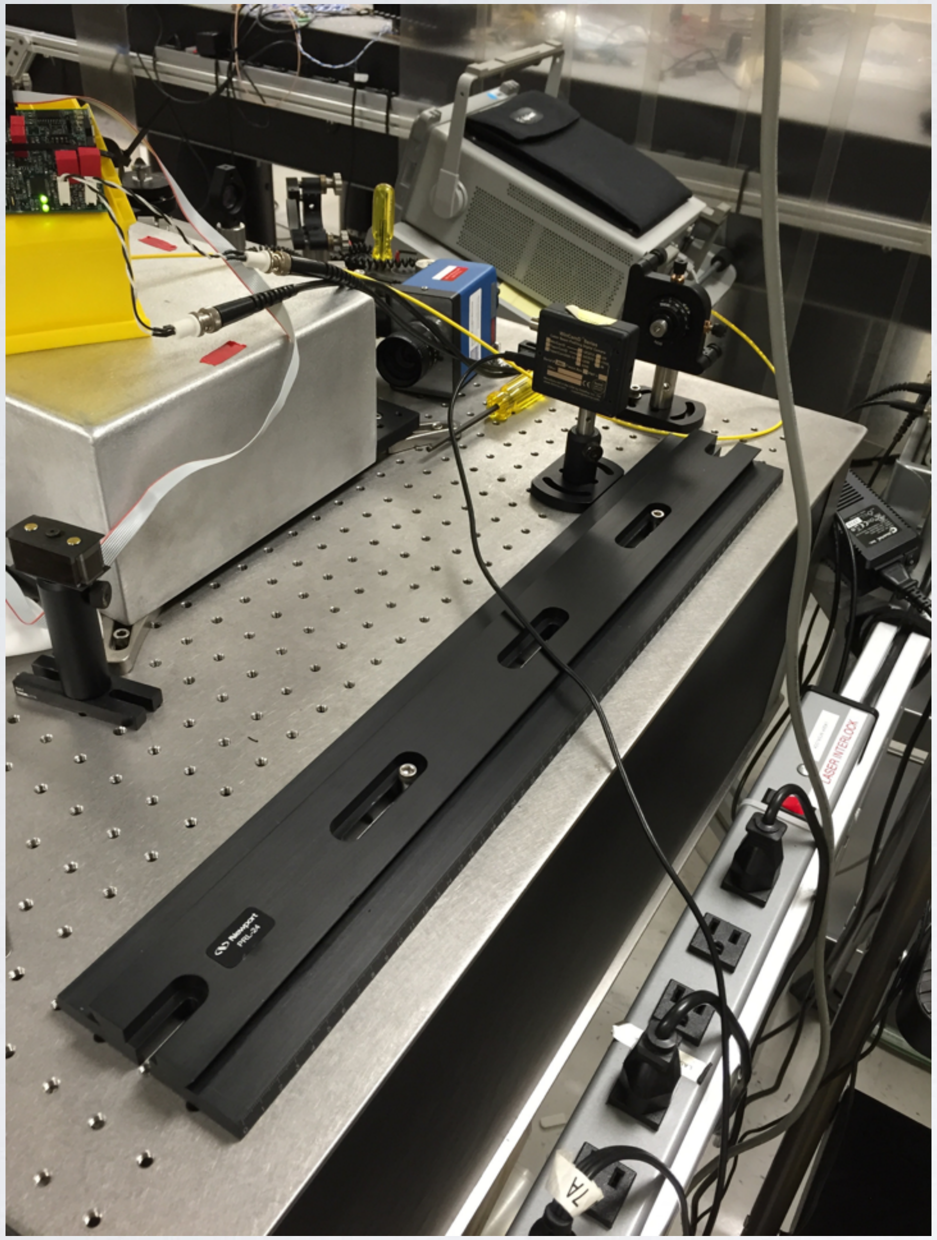


- Breadboards get cramped fast!
- Optics adjustments must take base placements into account
- Thickness of the beamsplitter must be taken into account

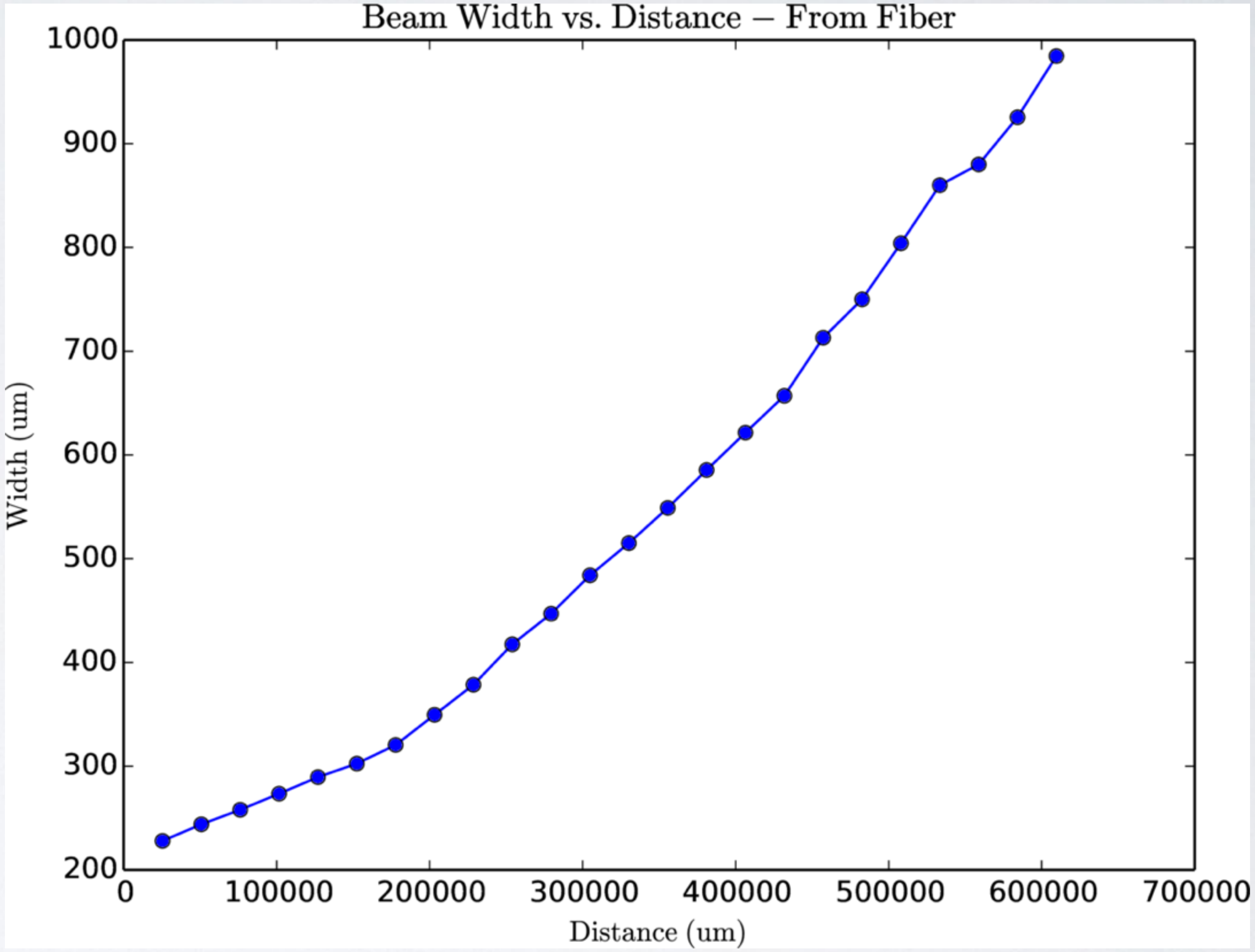
Light to the Michelson

- Light comes from a <500mW 1064nm laser
- Via power reductions: ~60mW into the fiber coupler
- Output of fiber after coalignment procedure: ~20mW, a 30% transmission
- Increase in throughput via mode-matching process

Beam Profile Analysis



Beam scan assembly



Beam profile at fiber output: the mode to be matched at the fiber input

Future Work

- Completion of mode-matching to get the maximum amount of light to the Michelson
- Resolving the issue of the wires going to/from the fiber coupler and photodetector
- Calibration with the inverted pendulum once completed

References

[1] A. Weinstein, *The Search for Gravitational Waves*, DCC G1500794

[2] F. Matichard et al., *Review: Tilt-Free Low-Noise Seismometry,* DCC P1200007

[3] F. Matichard et al., *Using Metal-Wire Suspensions to reduce tilt-Coupling in Inertial Sensors Measurements*, DCC P1400061

[4] K. Dooley et al., *Towards a tilt-free seismometer design,* DCC G1500315

Acknowledgments

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Thanks for listening!