Development of Rotation Sensors for Gravitational Wave Detectors

Shoshana K. Apple

GWANW June 2024

UNIVERSITY *of* WASHINGTON

Seismometer & BRS Background

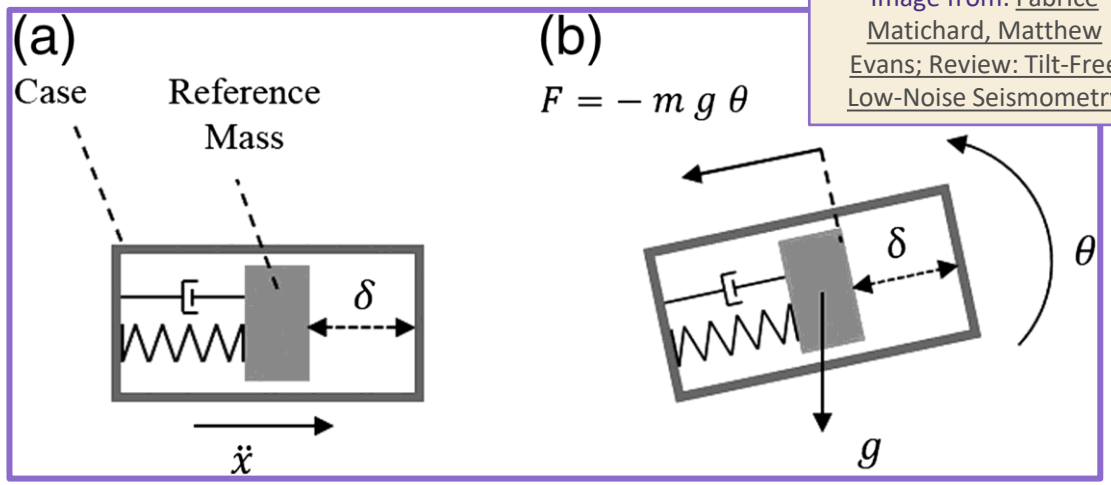
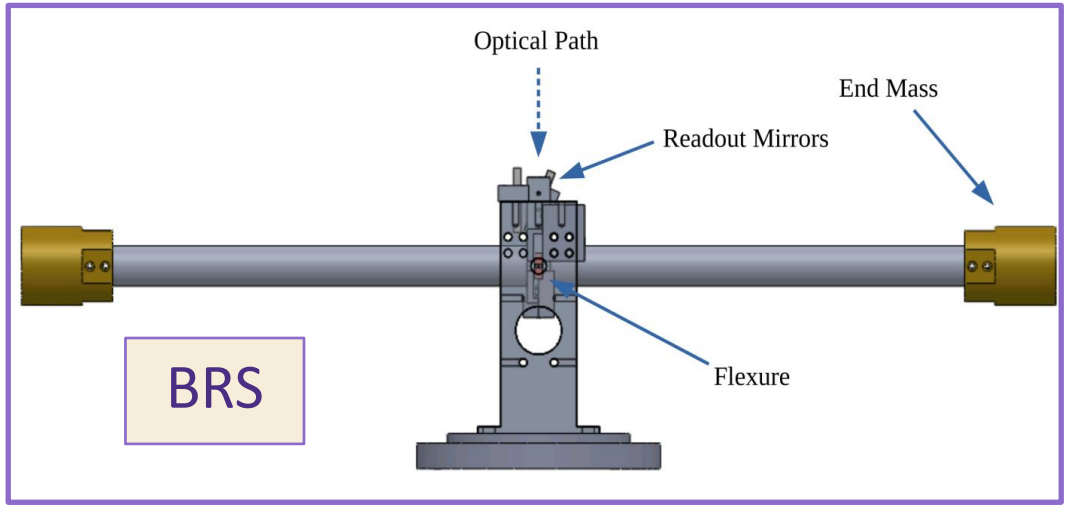


Image from: Fabrice Matichard, Matthew Evans; Review: Tilt-Free Low-Noise Seismometry



- Seismometers do not work correctly when it experiences tilt
  - Detects tilt as horizontal motion
- High winds → ground tilts → ground seismometers inject noise → can't observe
- Solution: Add rotation sensor to feedback loop

How do we deal with rotations of the actual platform in chamber?

BRS Background

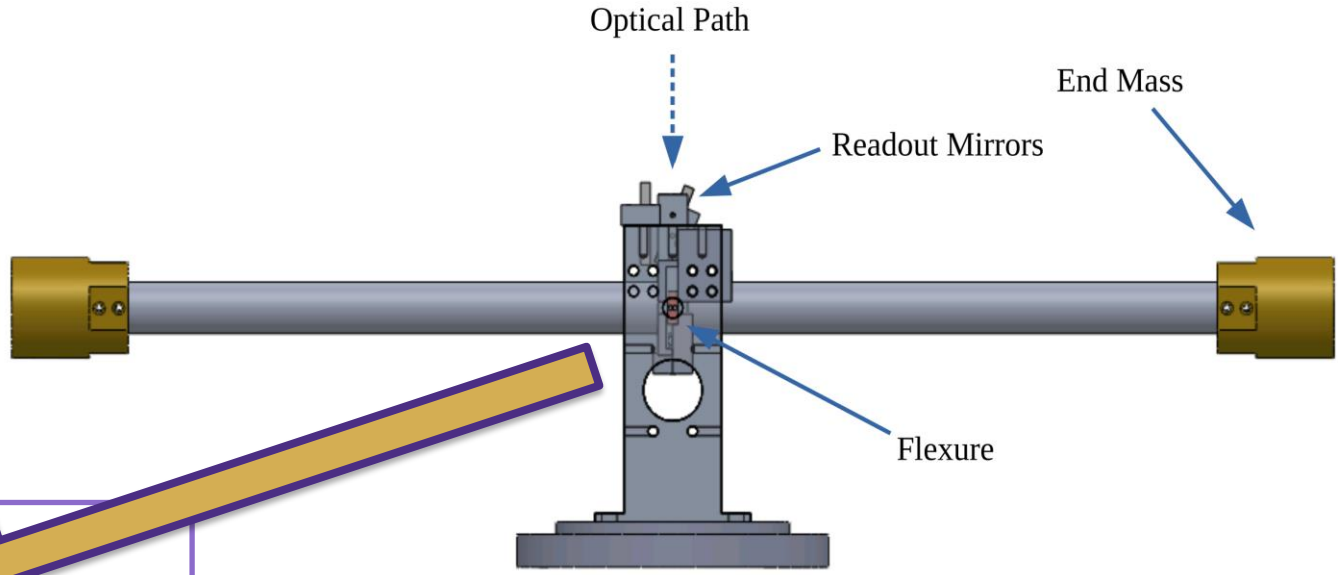
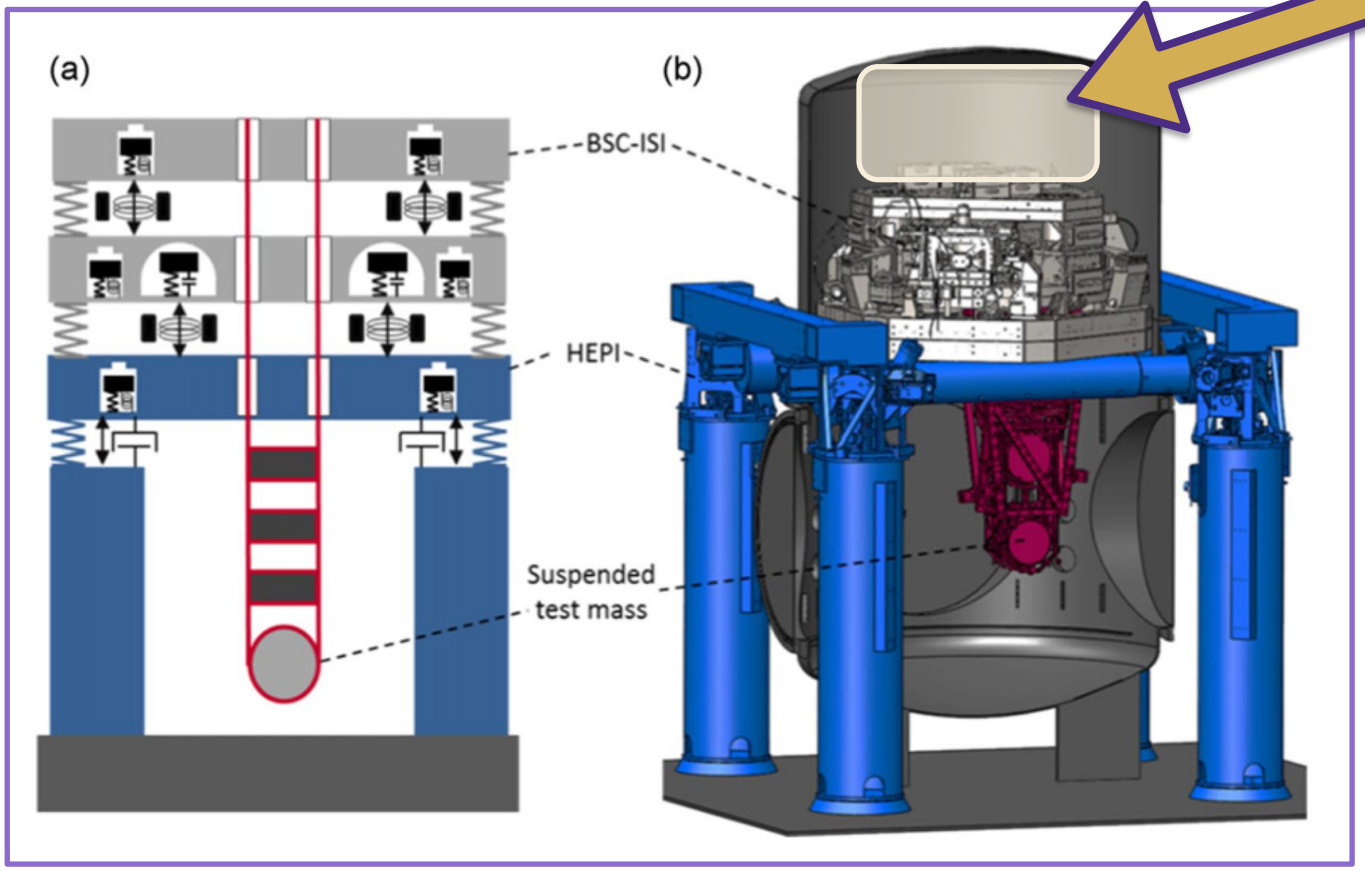


Image adapted from: F Matichard *et al* 2015 *Class. Quantum Grav.* **32** 185003



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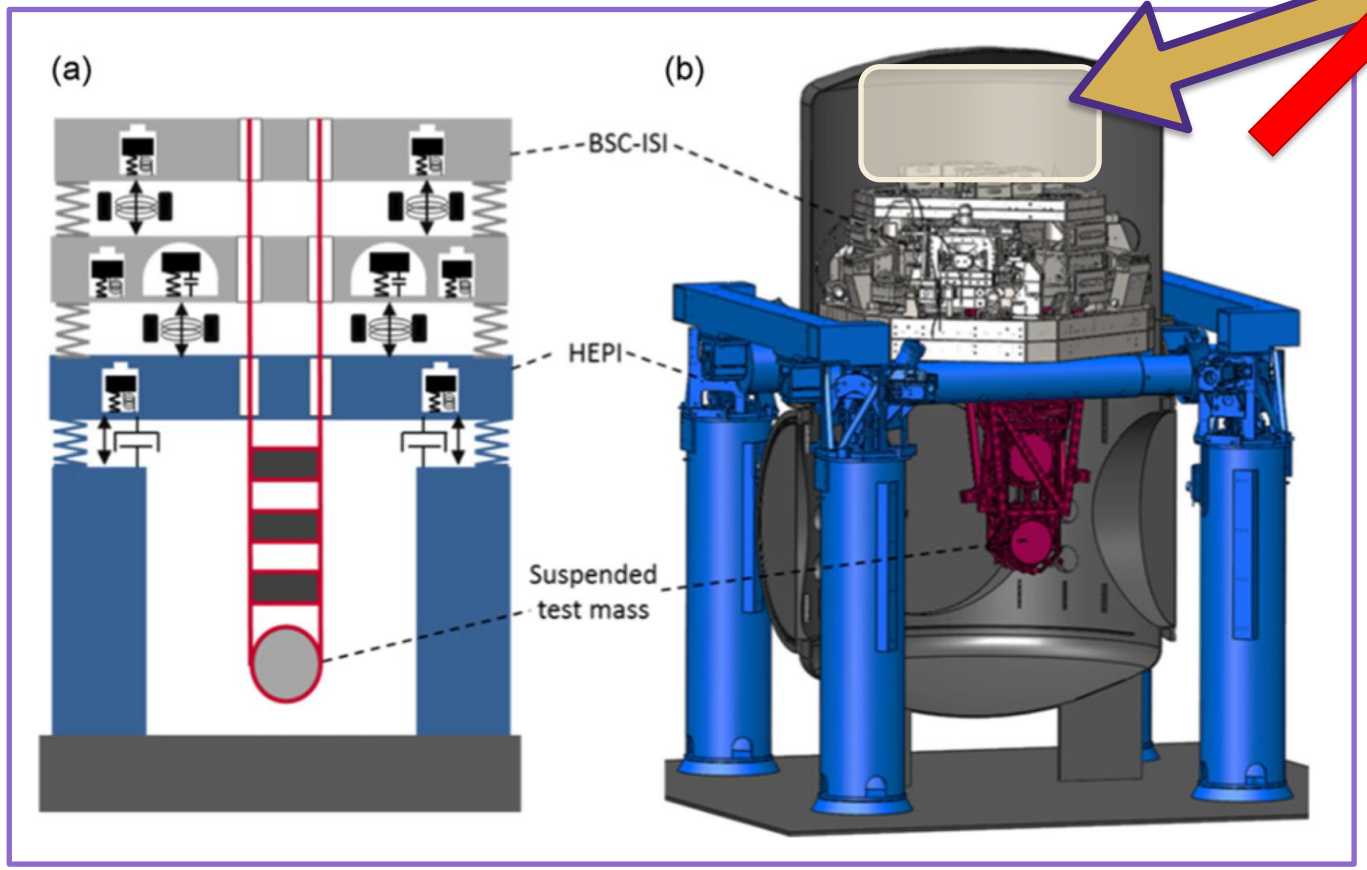
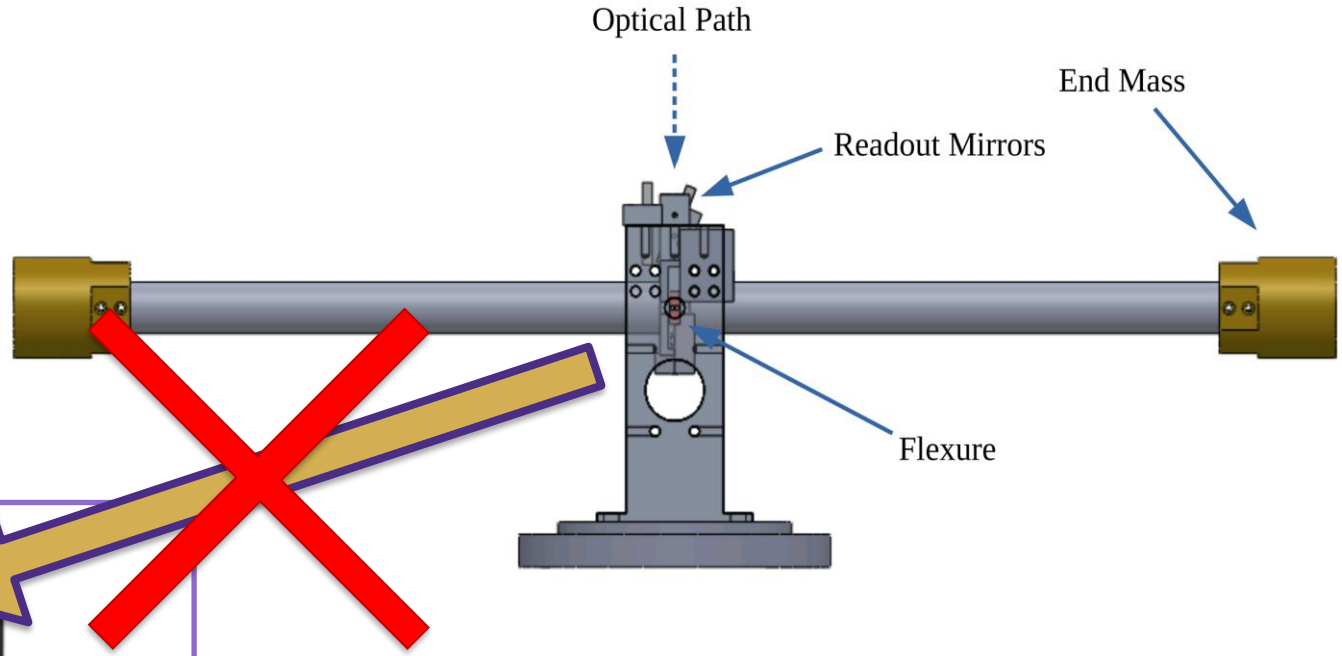


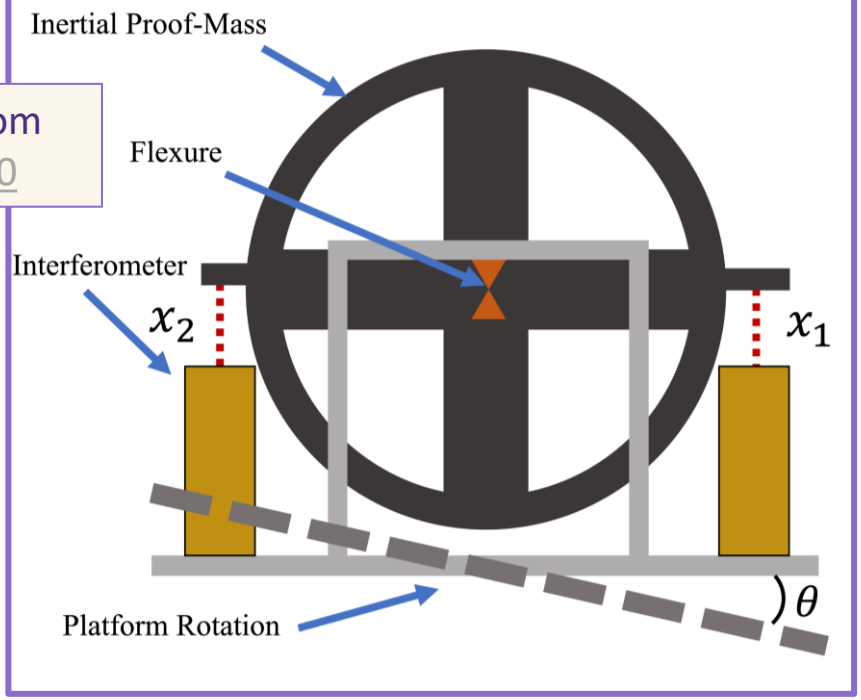


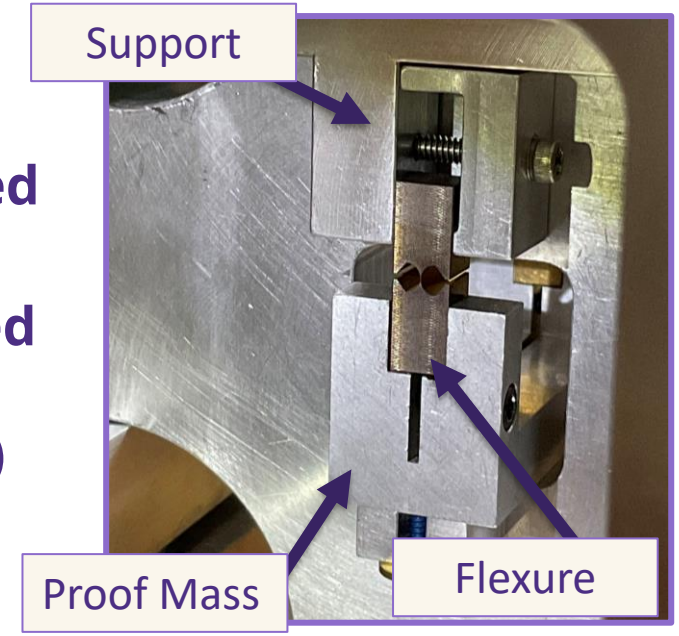
- **Needs to fit on platform (~30cm)**
- **Needs to be operated remotely**
- **Needs to be LIGO vacuum okay**

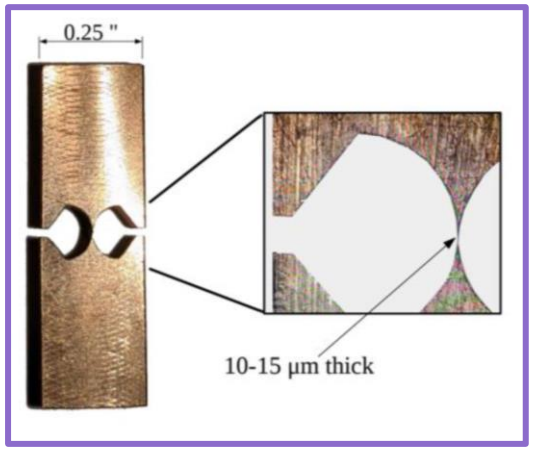
CRS Design

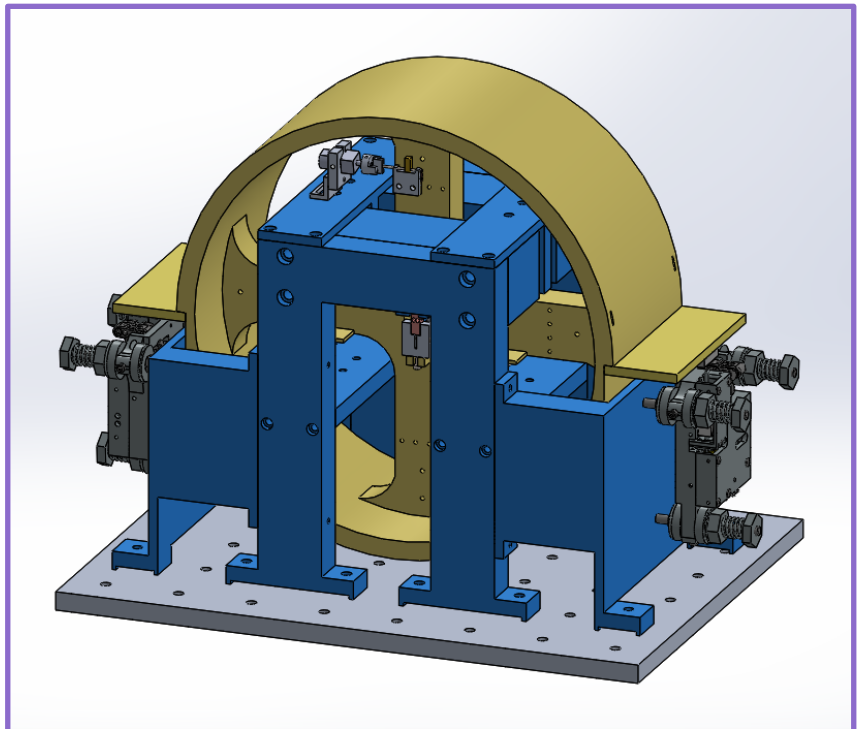
- Proof mass (~5kg, Al) suspended by two flexures
- Proof mass rotationally isolated from support/platform above resonance frequency (~17mHz)
  - Platform rotates but proof mass remains stationary
- Interferometers measure distance from wing to platform → calculate the rotation angle

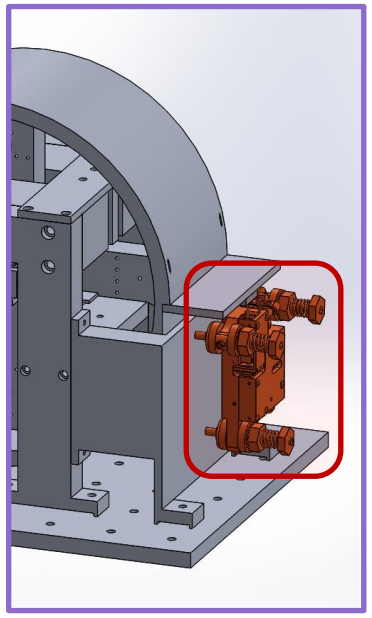
Image adapted from arXiv:2307.05710

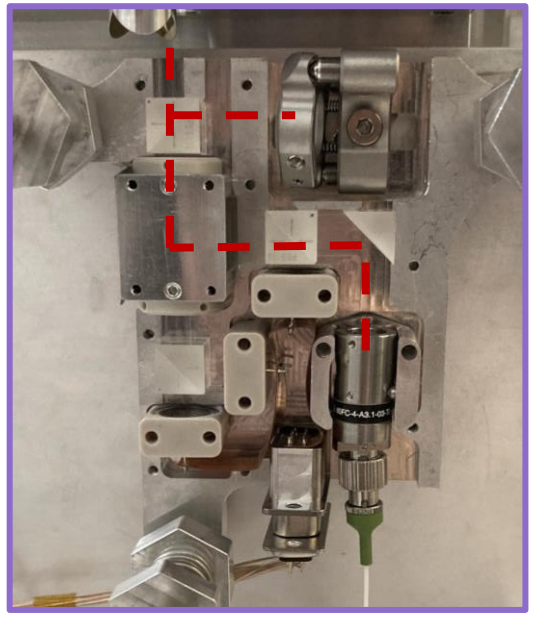


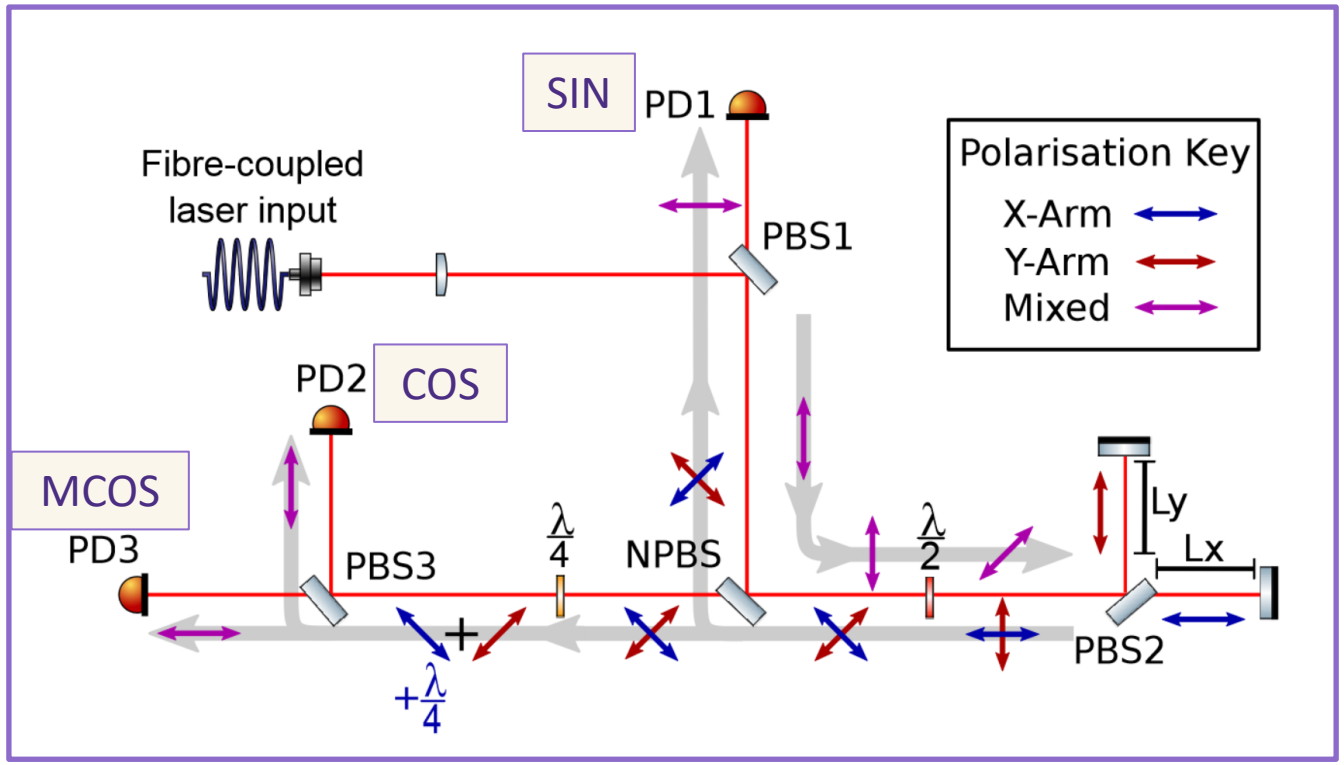










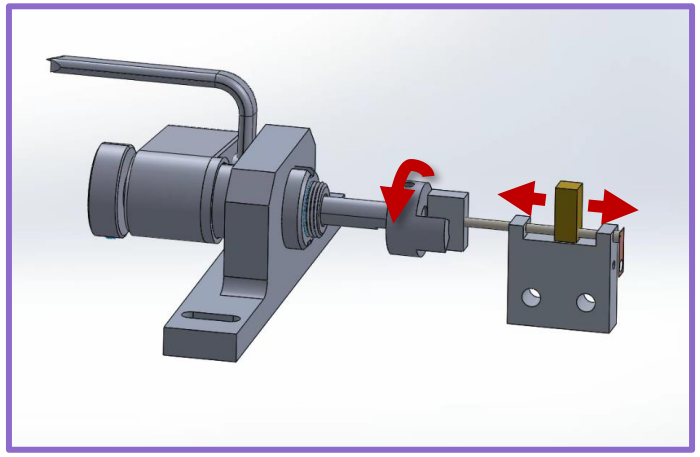


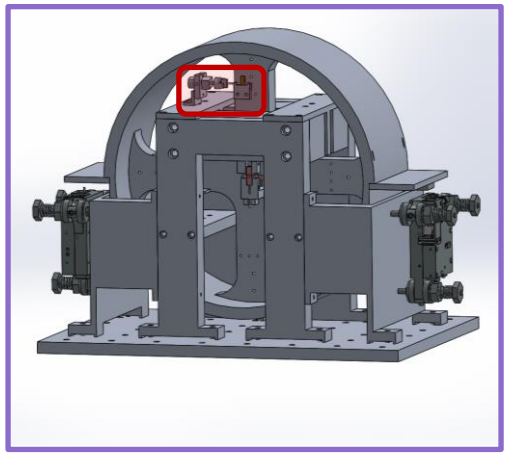
Optical Readout (HoQIs)

- Homodyne Quadrature Interferometer (HoQI) [arXiv: 1710.0593]
- Developed at Vrije Universiteit Amsterdam & University of Birmingham

$$\frac{P_{PD1} - P_{PD2}}{P_{PD1} - P_{PD3}} = \tan(\Delta\phi)$$

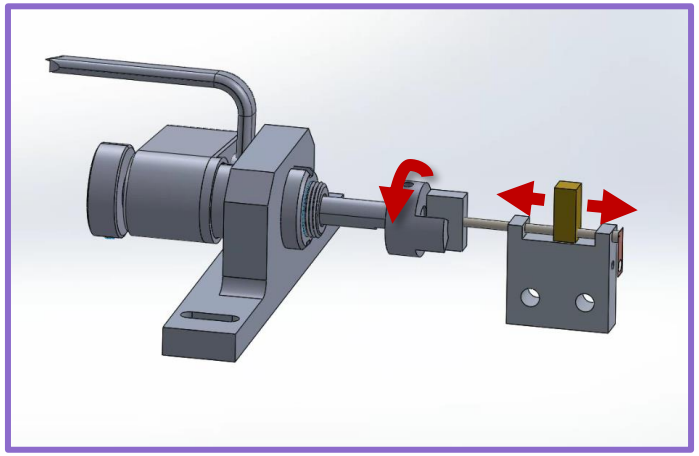
Mass Adjusting

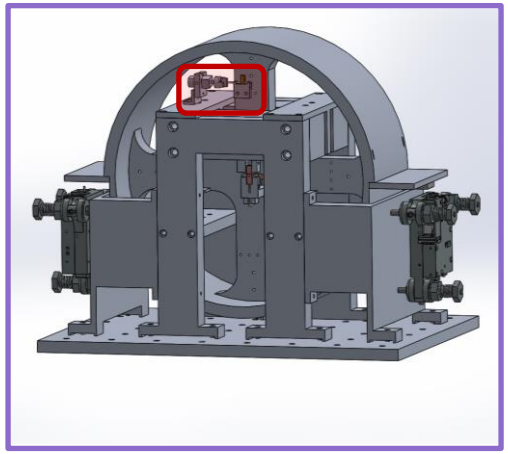




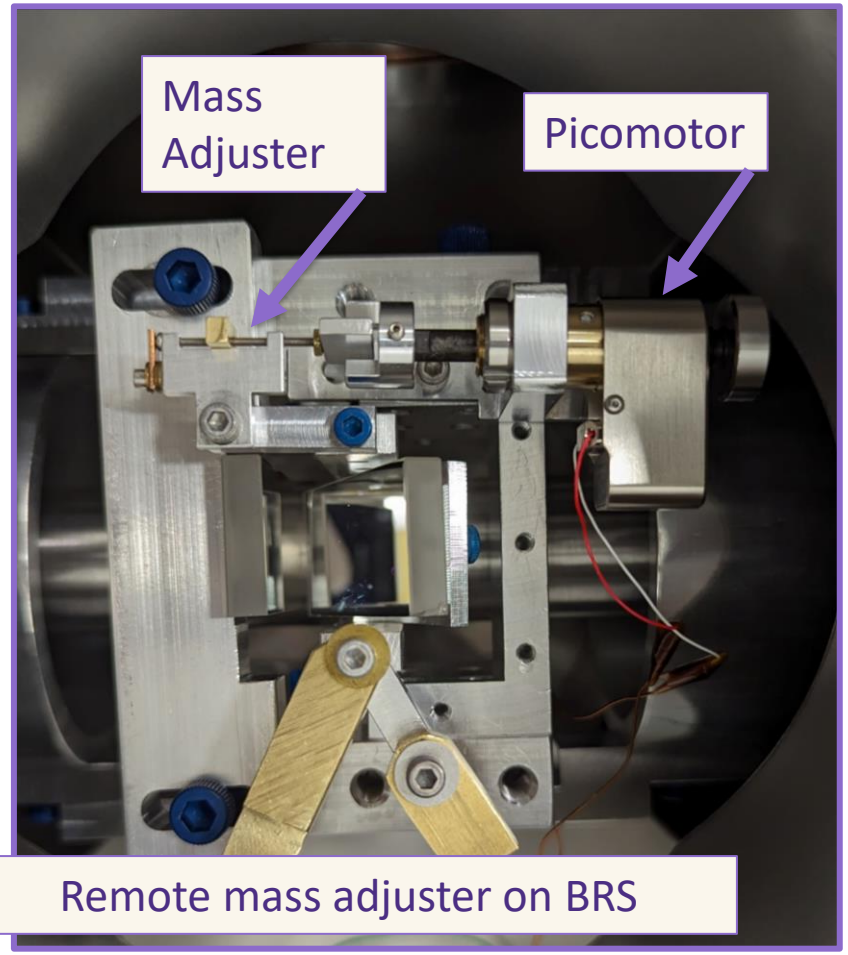
- Center of mass can shift (temperature, etc.)
- Decoupled by backing off motor
- Issue: How do we rebalance while in chamber?
  - Knowing if it's coupled
  - Knowing if the mass is close to being on the edge
- Did this in a lower stakes situation!

Mass Adjusting





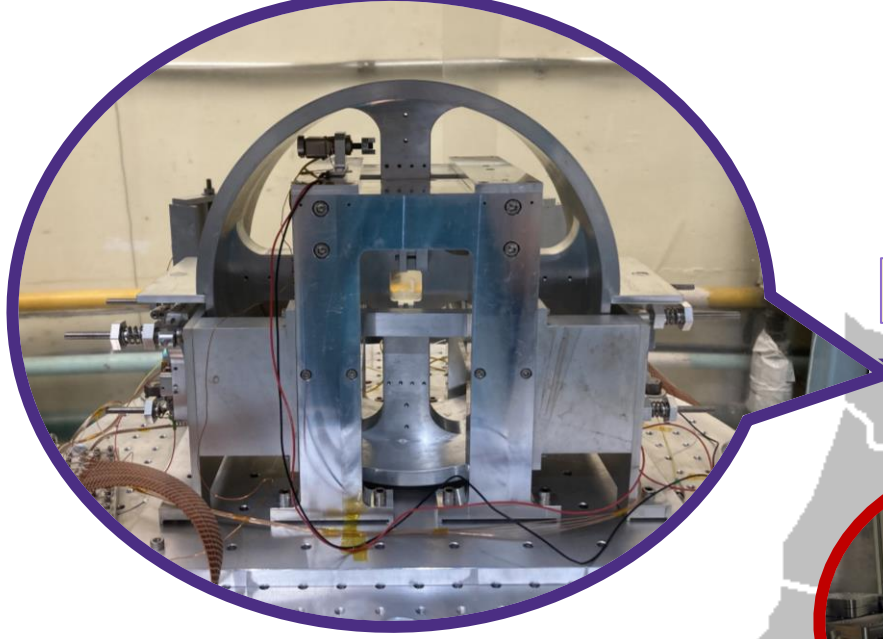
- Center of mass can shift (temperature, etc.)
- Decoupled by backing off motor
- Issue: How do we rebalance while in chamber?
  - Knowing if it's coupled
  - Knowing if the mass is close to being on the edge
- Did this in a lower stakes situation!
- Installed remote mass adjuster on a BRS (ETMX, LHO), plans to install on other 5
  - Easy to tell if coupled to a trained eye
  - Currently keeping log of steps moved

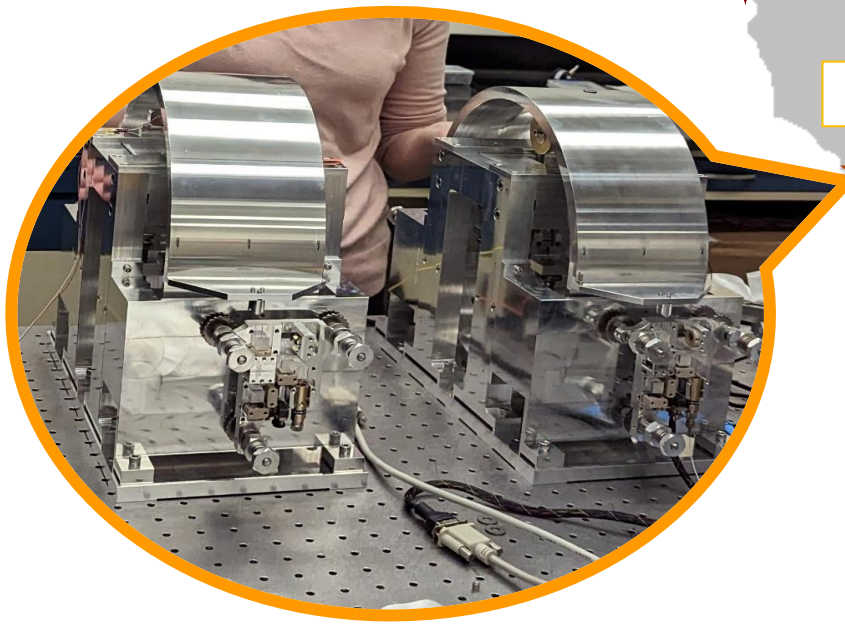


Remote mass adjuster on BRS

Current Updates

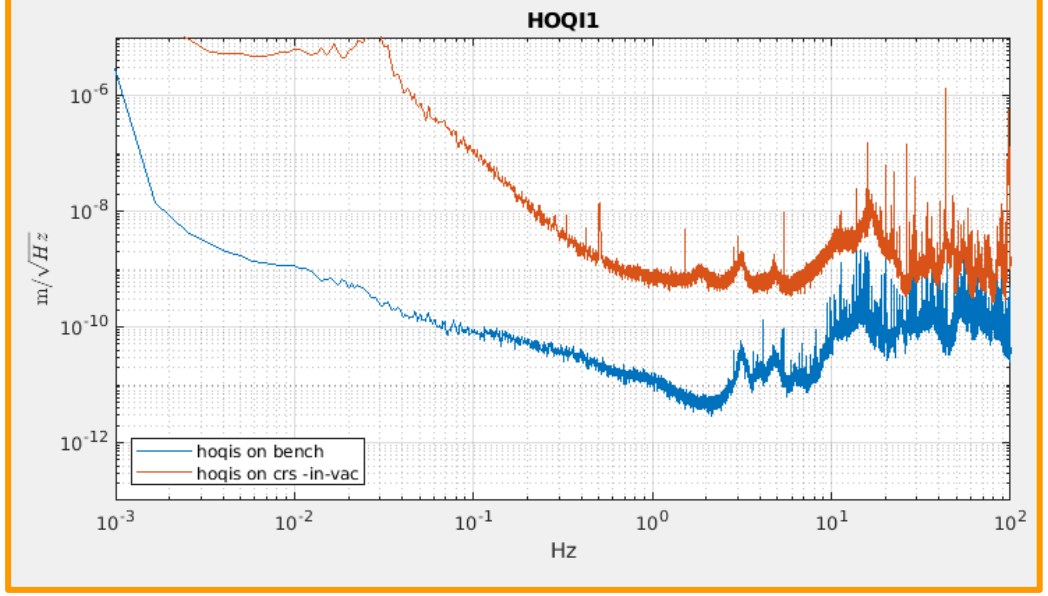
- 3 CRSs built
- UW
  - Finished last data run in January
  - Being used to test QoL updates
- Caltech (x2)
  - 2 CRSs
  - Built in October, November-December
  - Lead by Arnaud Pele
  - Troubleshooting

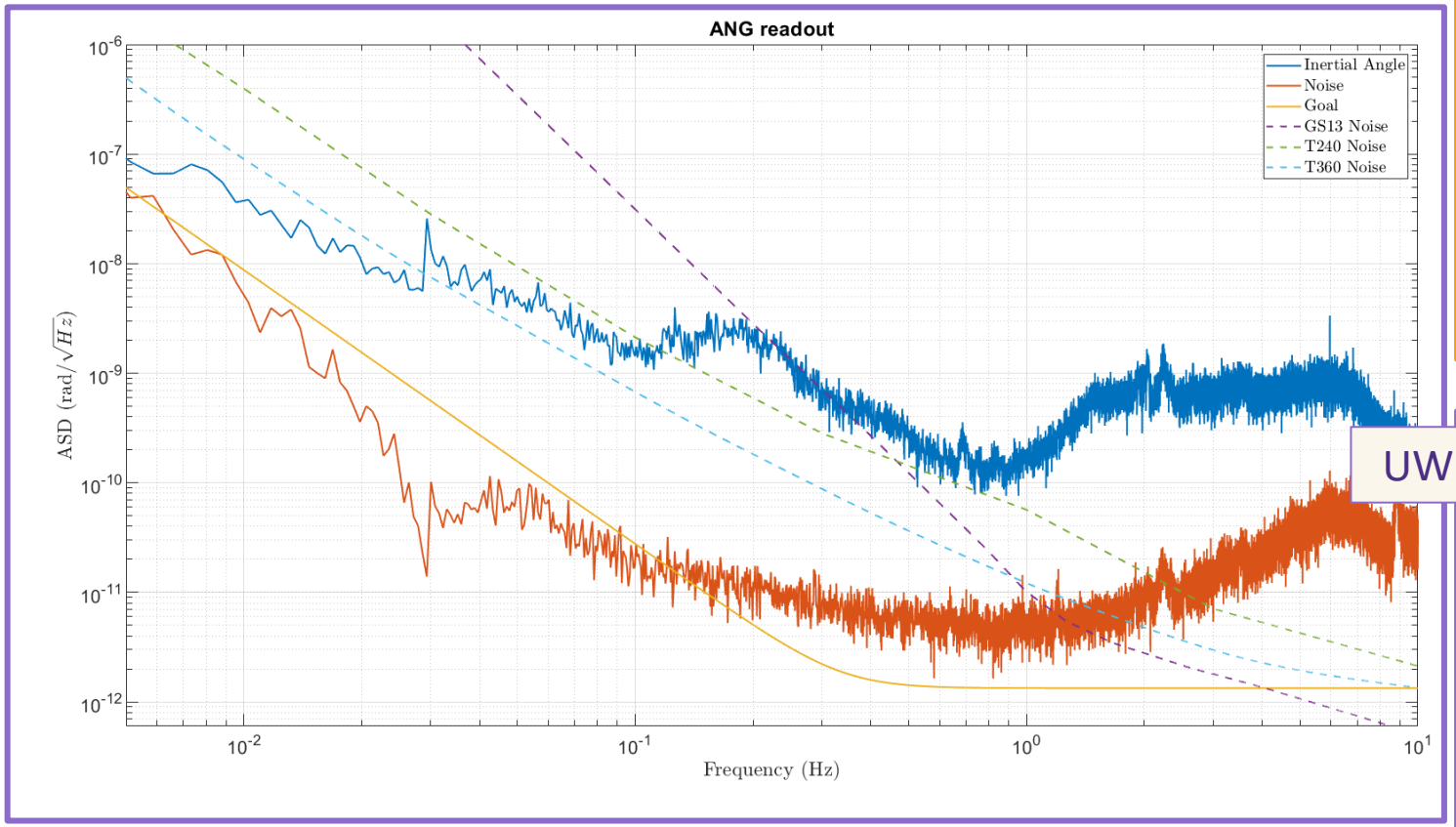




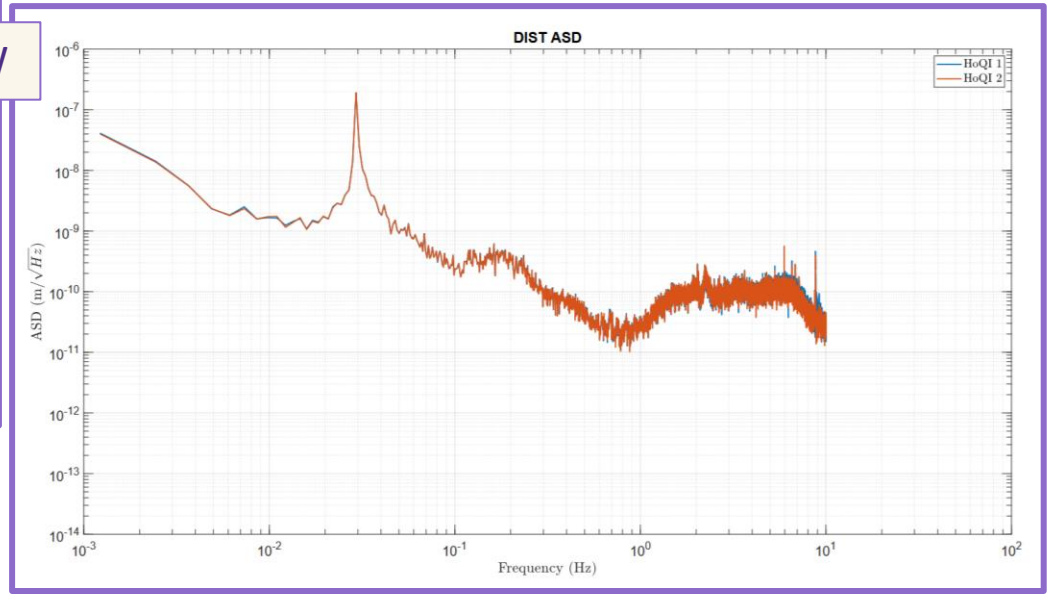
Noise Results

CIT



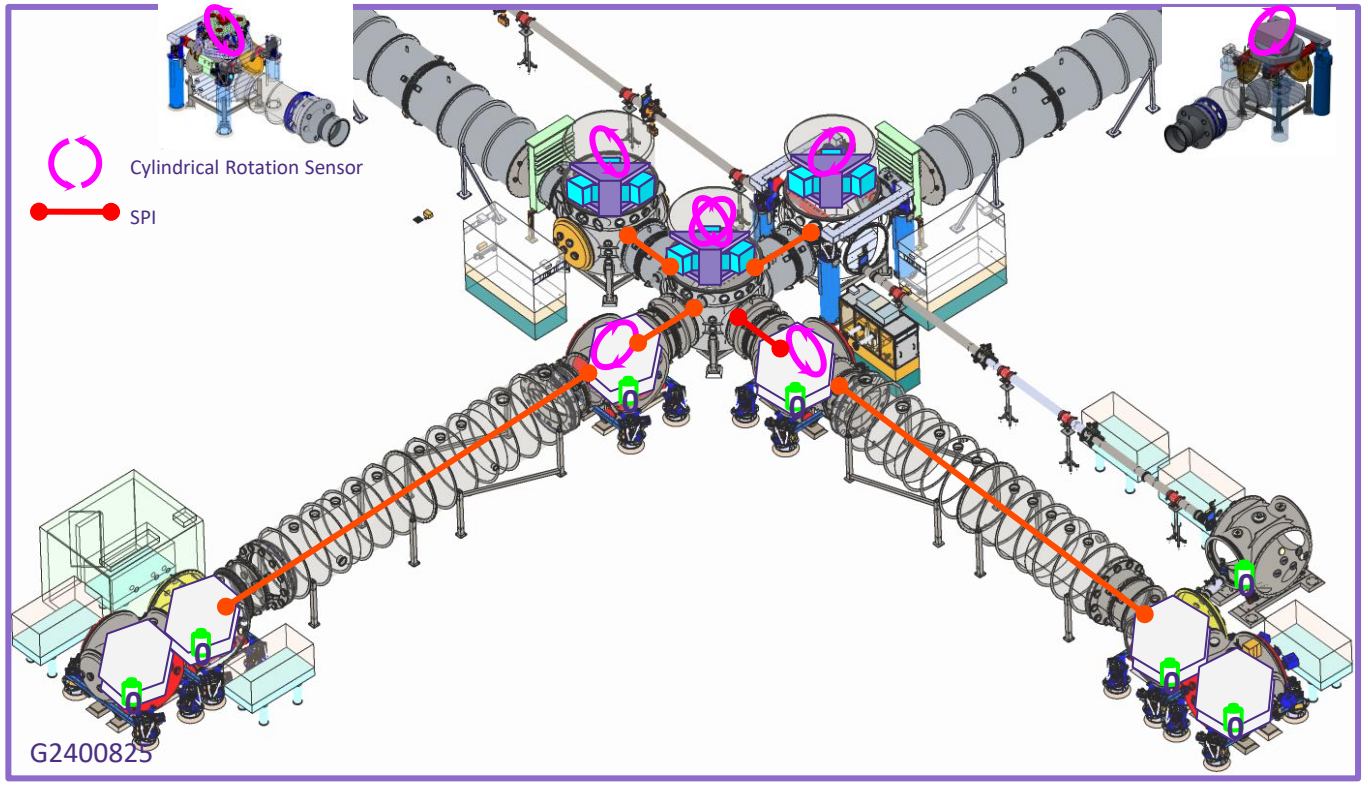


UW



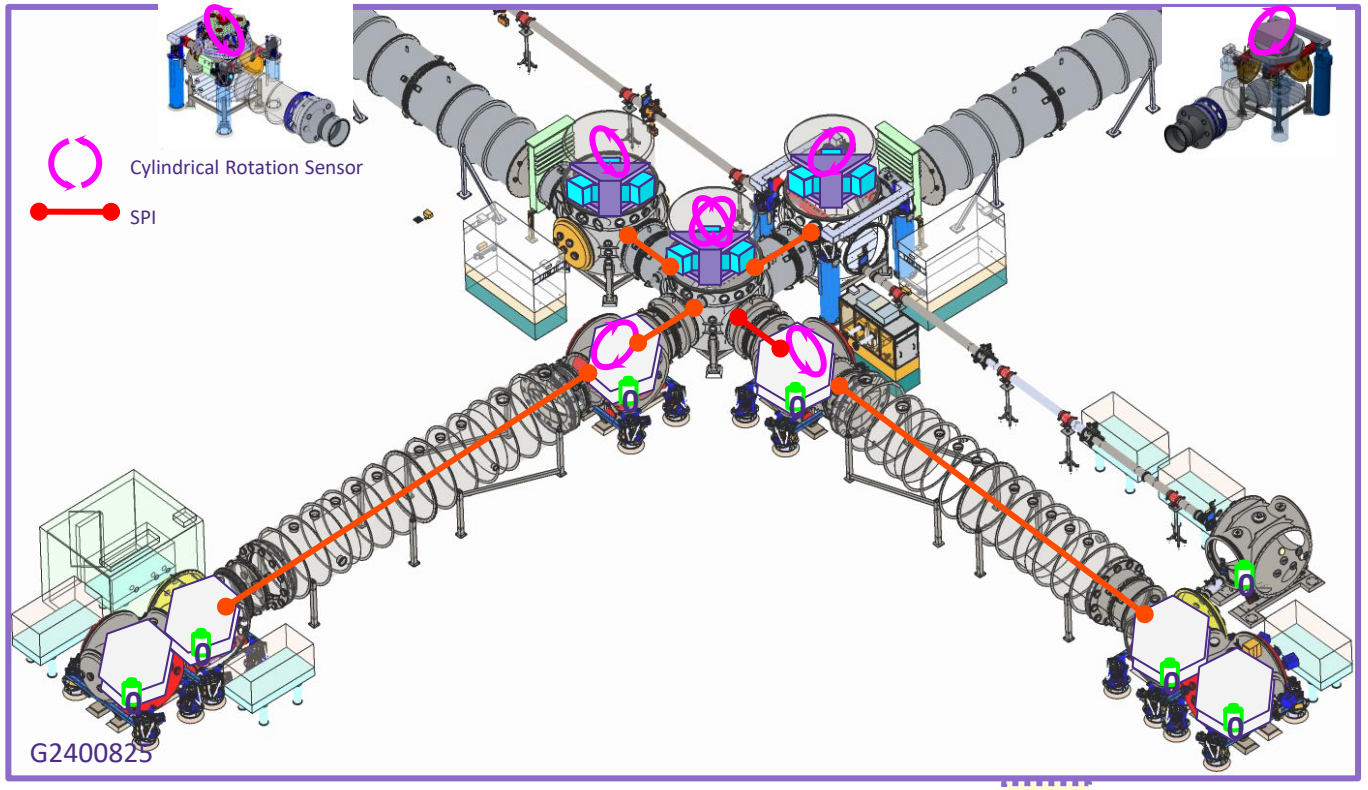
Next Steps

> **Finding space?**



Next Steps

- Finding space?
- Installation timeline?



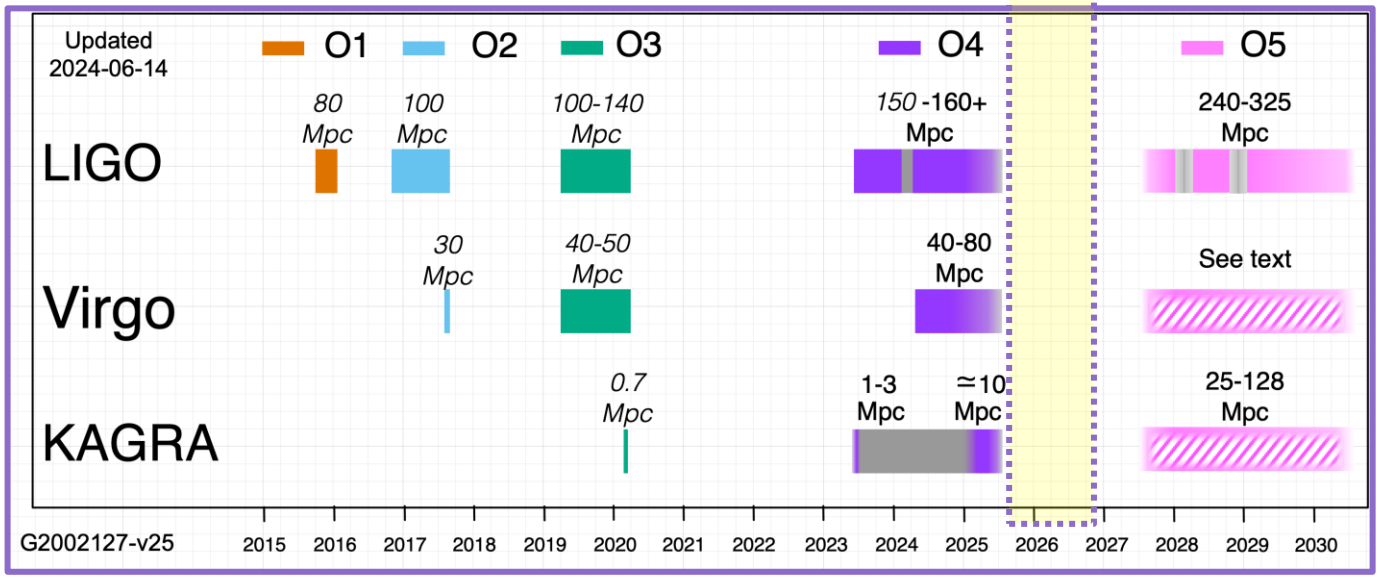
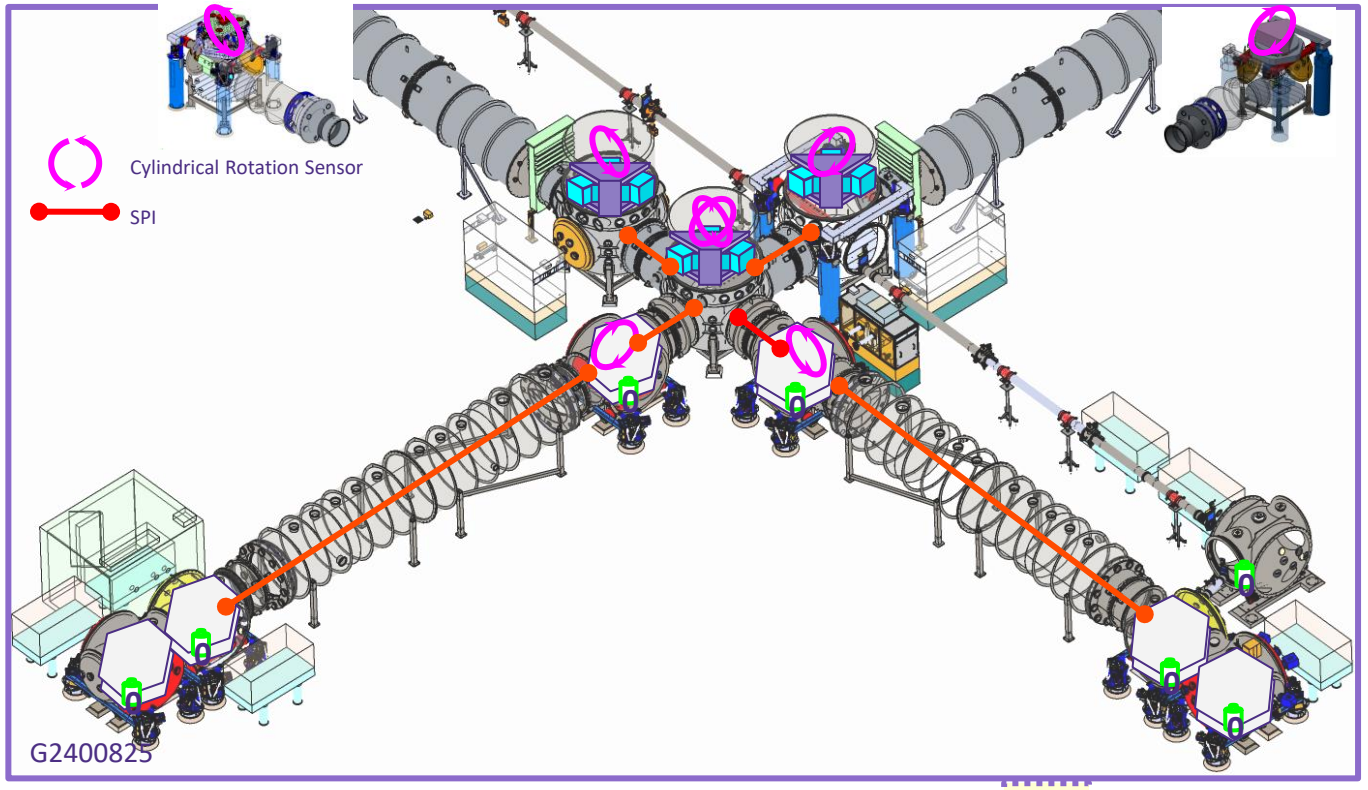
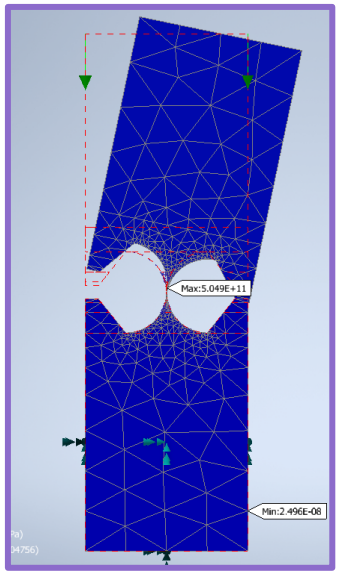


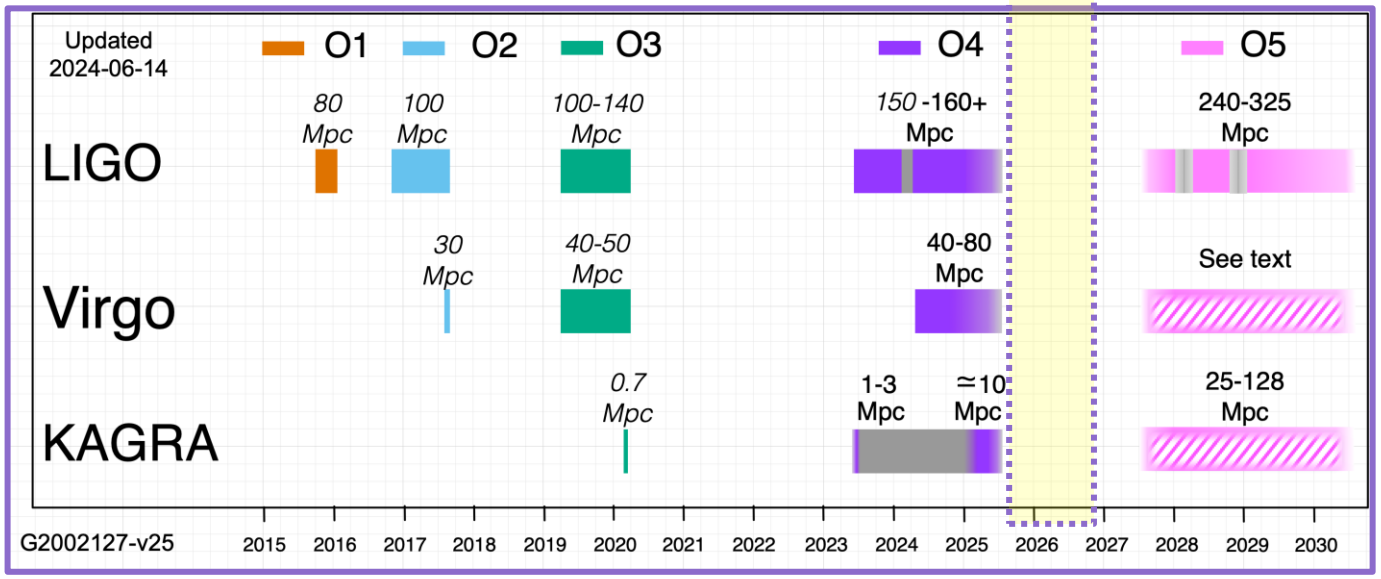
Image from: https://observing.docs.ligo.org/plan/

Next Steps

- Finding space?
- Installation timeline?
- Flexure characterization?







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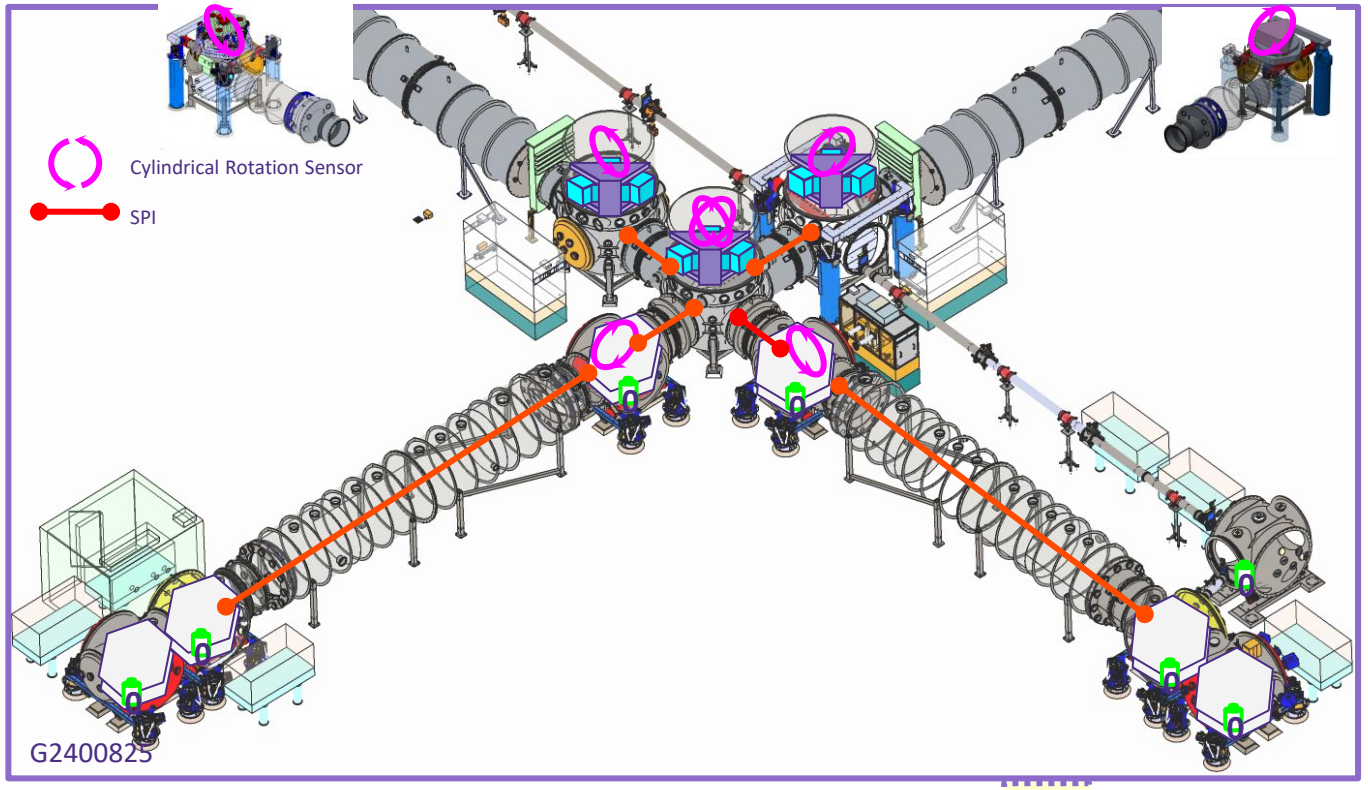
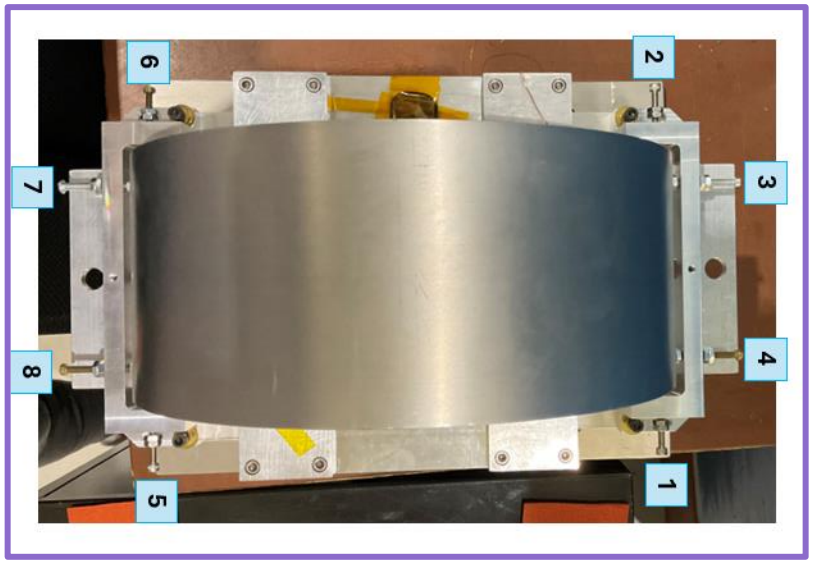
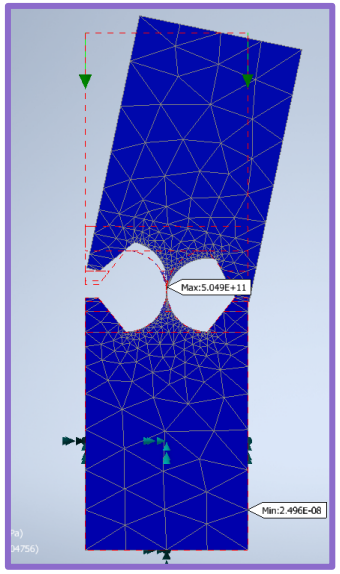
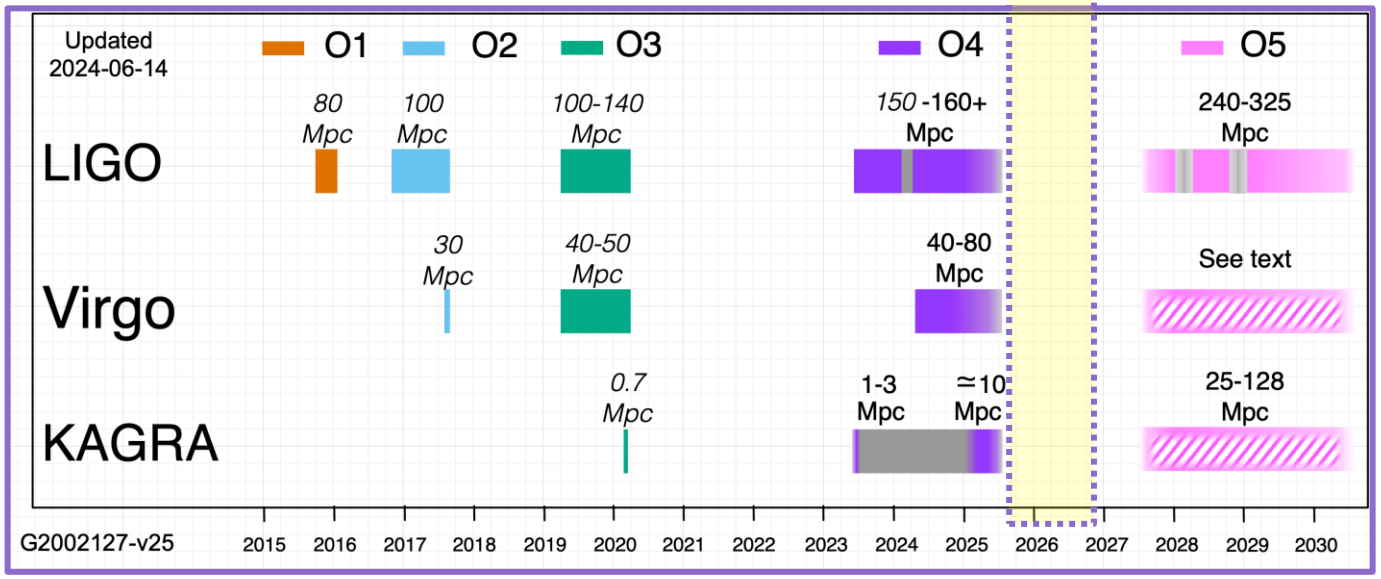
Next Steps

- Finding space?
- Installation timeline?
- Flexure characterization?
- Moving it?









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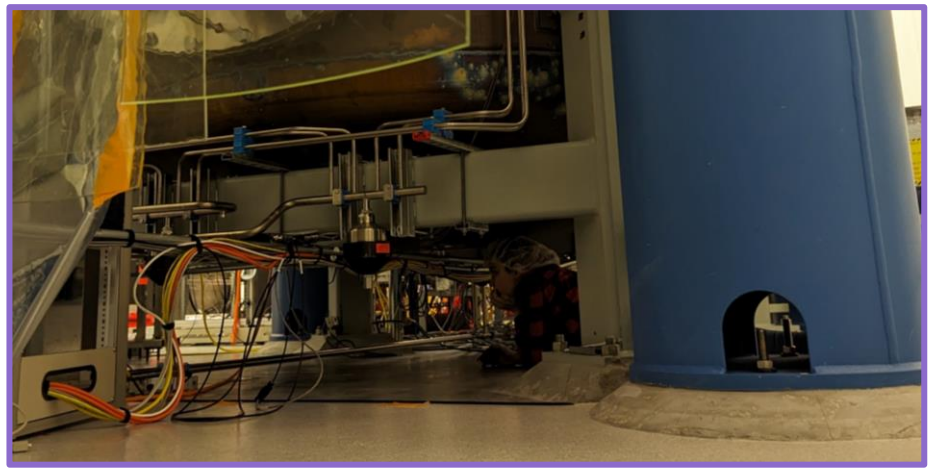
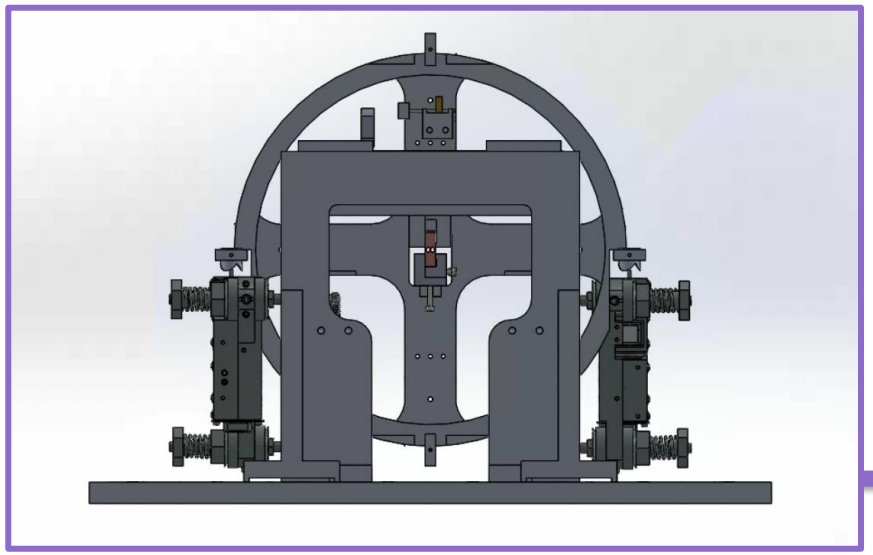
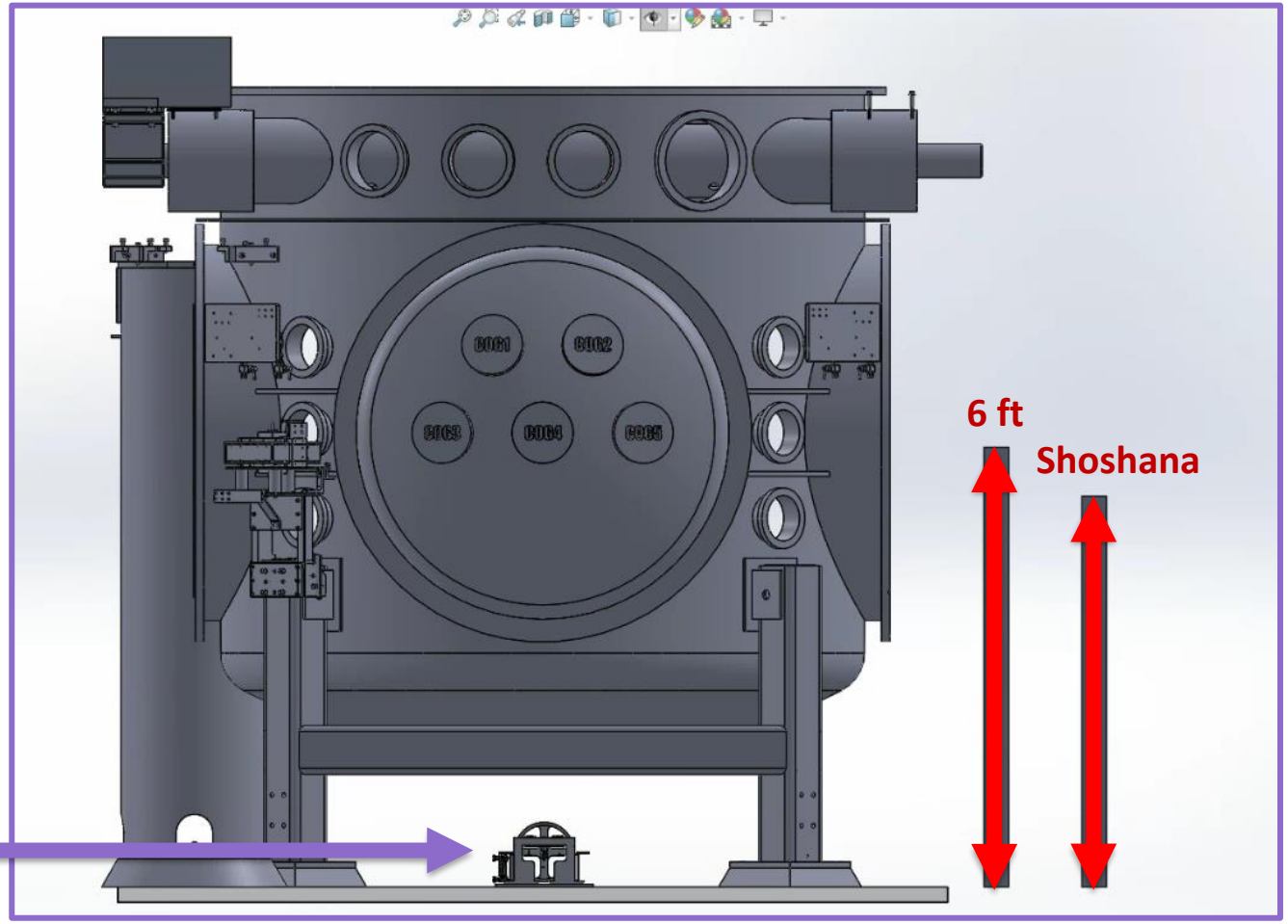
Next Steps (Newtonian Noise)



- New rotation sensor to (hopefully) go under test mass chamber
- Slightly smaller than CRS
- Different target frequency
- QoL improvements





Thank You

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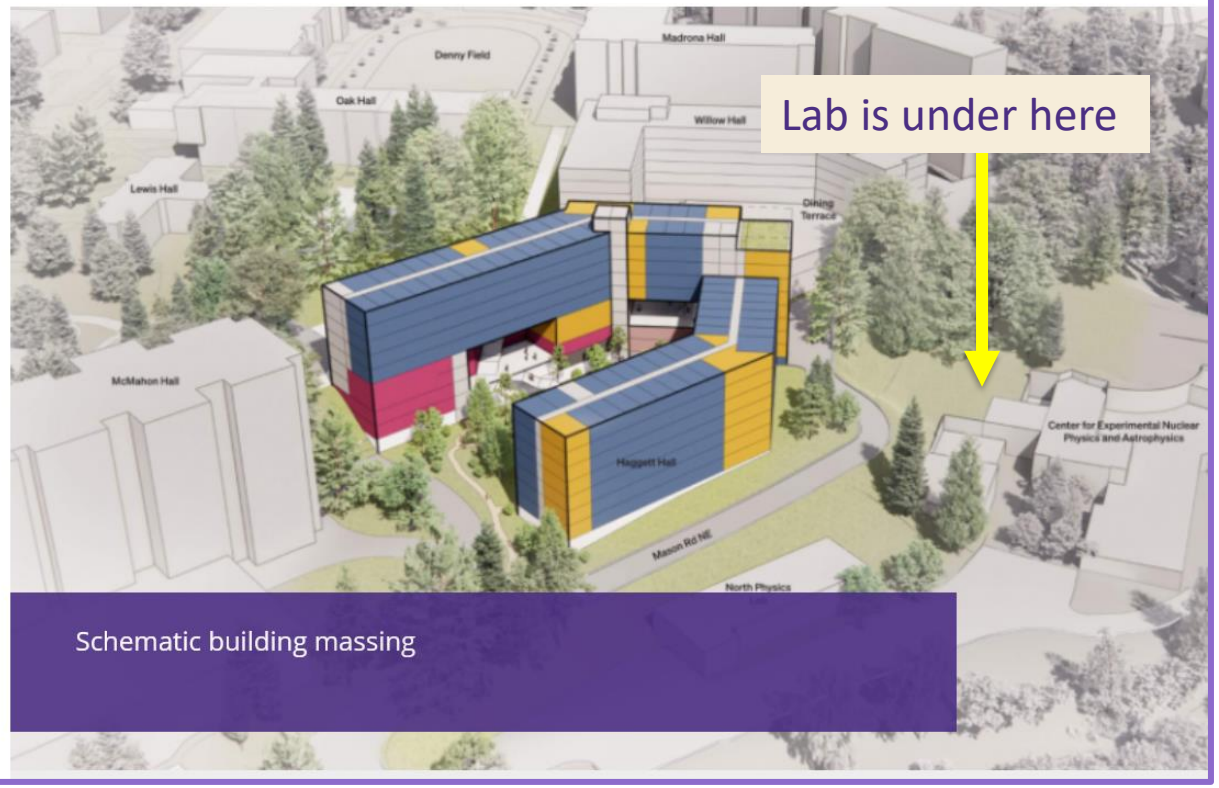
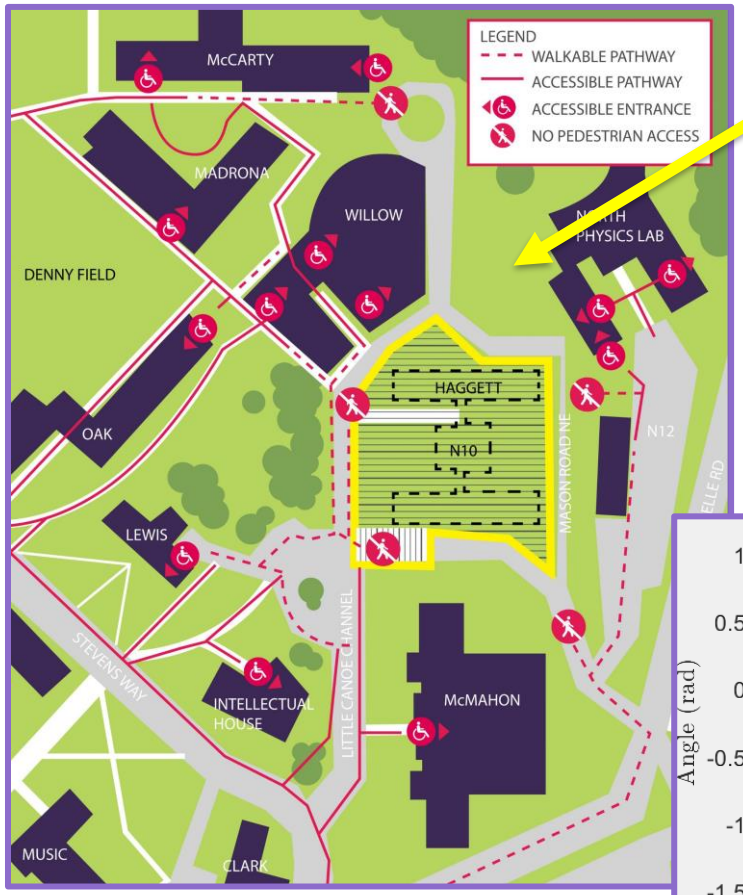
“Why is the New UW Noise Worse?”

Projects › Current major projects › Haggett Hall Demolition and Replacement

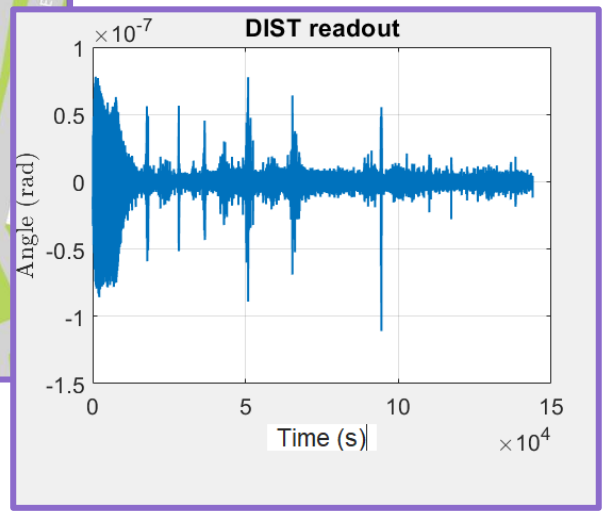
Haggett Hall Demolition and Replacement



Schematic building massing



Lab is under here



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Extracting Δϕ from HoQI

$$P_{PD1} = \frac{P_{in}}{8}(1 + a\sin(\Delta\phi))$$

$$P_{PD2} = \frac{P_{in}}{8}(1 - a\cos(\Delta\phi))$$

$$P_{PD3} = \frac{P_{in}}{8}(1 + a\cos(\Delta\phi))$$

Photodiode measurements

$$P_{PD1} - P_{PD2} = \frac{\sqrt{2}aP_{in}}{8}\sin\left(\Delta\phi + \frac{\pi}{4}\right)$$

$$P_{PD1} - P_{PD3} = \frac{\sqrt{2}aP_{in}}{8}\sin\left(\Delta\phi - \frac{\pi}{4}\right)$$

Manipulation

$$\frac{P_{PD1} - P_{PD2}}{P_{PD1} - P_{PD3}} = \tan(\Delta\phi)$$

Extracting Δϕ