Towards Low Frequency Gravitational Force Sensing

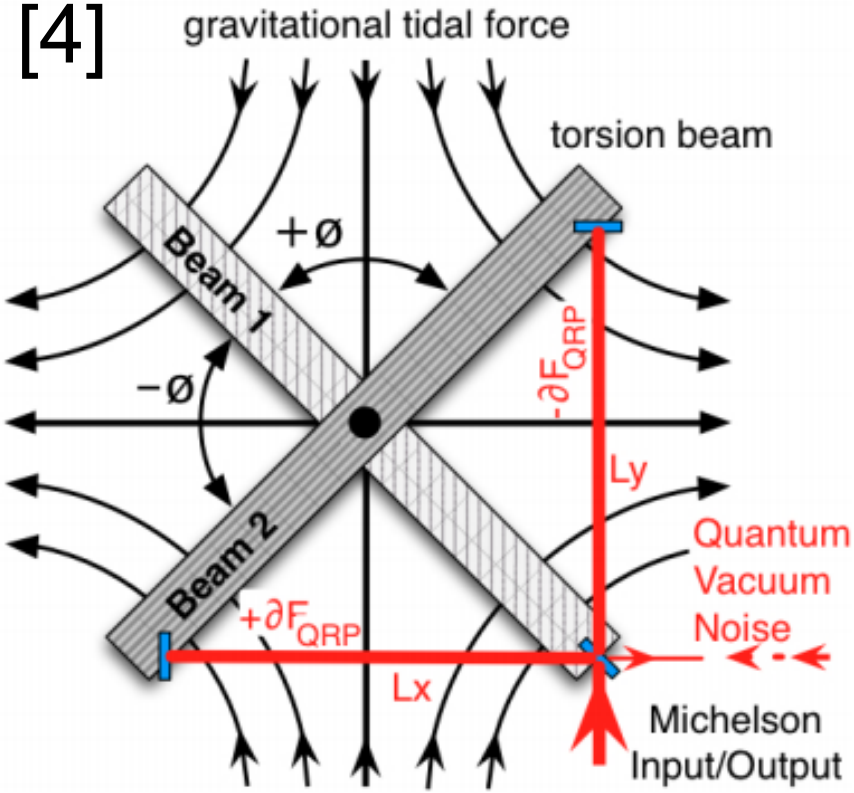
Bram Slagmolen
Centre for Gravitational Physics,
The Australian National University

Low Frequency

- aLIGO/AdvVIRGO
  - Frequency range 2 Hz to ~30 Hz
  - Newtonian noise (Seismic or Atmospheric induced)
- Low-Frequency Gravitational Force Sensor
  - Range 2 mHz to 5 Hz
  - Target sensitivity ~10^{-15} /rtHz @ 0.1 Hz

TORsion PEndulum Dual Oscillator

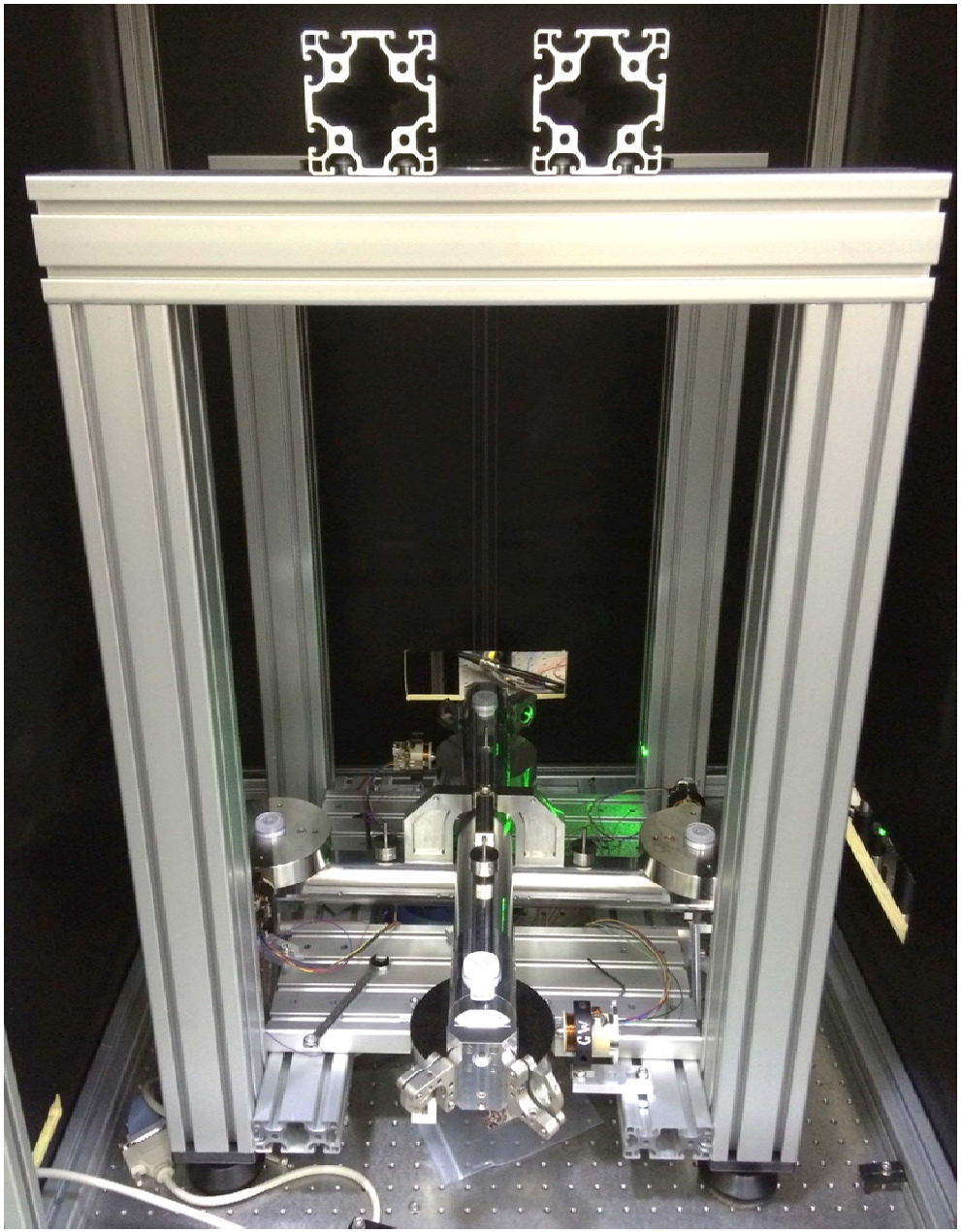
- GW Detector [1]
- Measuring Newtonian Noise [2]
- Earthquake Early Warning System [3]
- Testing semi-classical gravity [4]
- Measure Quantum Radiation Pressure Noise



[1] M. Ando, et al. “Torsion- bar antenna for low-frequency gravitational-wave observations”. Phys. Rev. Lett., 105(16), 2010
[2] J. C. Driggers, et al. “Subtraction of newtonian noise using optimized sensor arrays”. Phys. Rev. D, 86:102001, Nov 2012.
[3] J. Harms, et al. “Transient gravity perturbations induced by earthquake rupture”. Geophys J Inter, 201(3), 2015.
[4] H. Yang, et al. “Macroscopic quantum mechanics in a classica spacetime”. Phys. Rev. Lett., 110:170401, Apr 2013.

TORPEDO

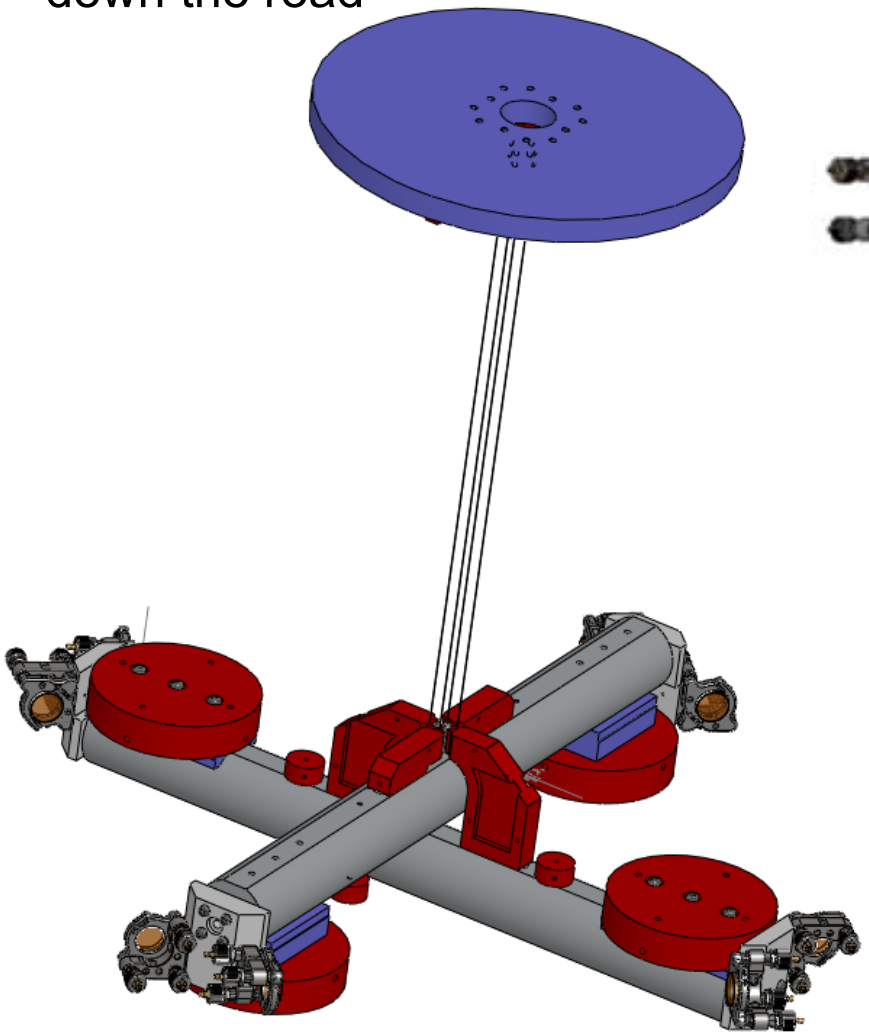
- Based on the TOBA, with two perpendicular suspended bars [1]
- Large Mechanical Common Mode Rejection
  - Centre Of Mass co-incident
  - Co-linear axis of rotation
  - Identical (tuned) moment of inertia



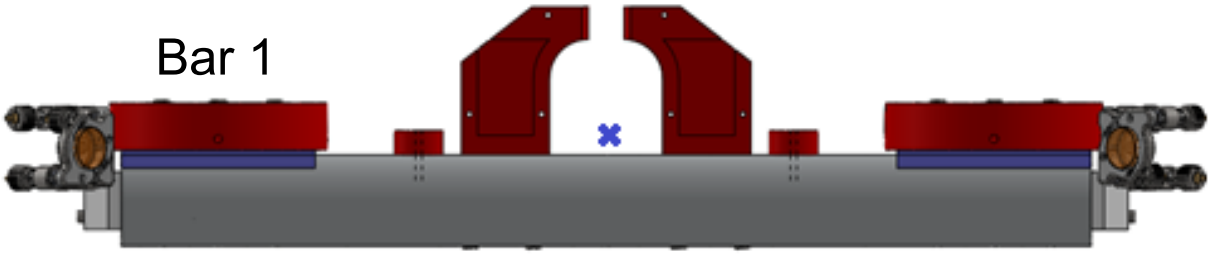
[1] M. Ando, et al. “Torsion- bar antenna for low-frequency gravitational-wave observations”. Phys. Rev. Lett., 105(16), 2010

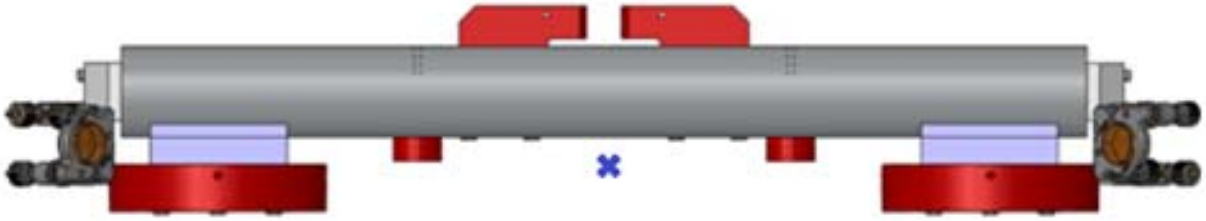
TORPEDO Design

- Various design iterations
- Still design adaptations
- Some initial design choices trouble down the road



Bar 1

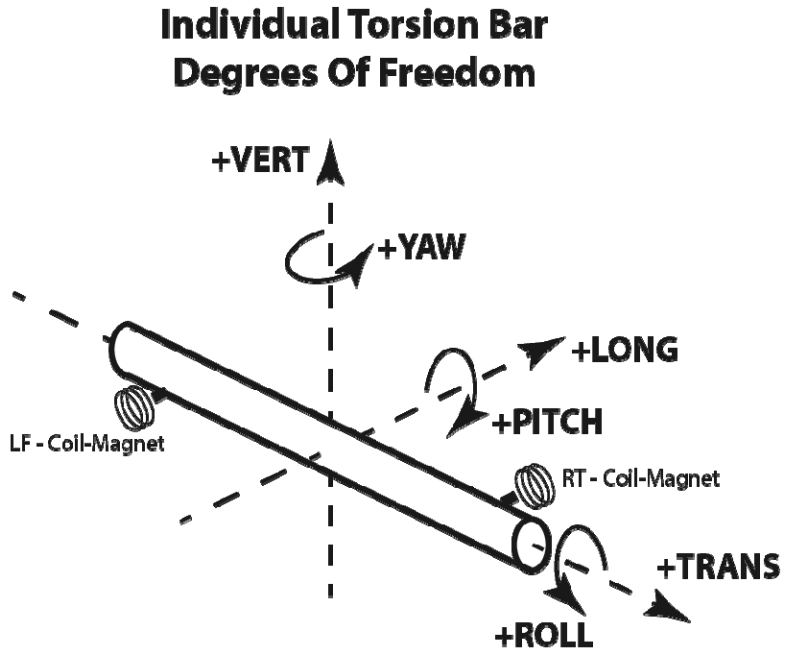


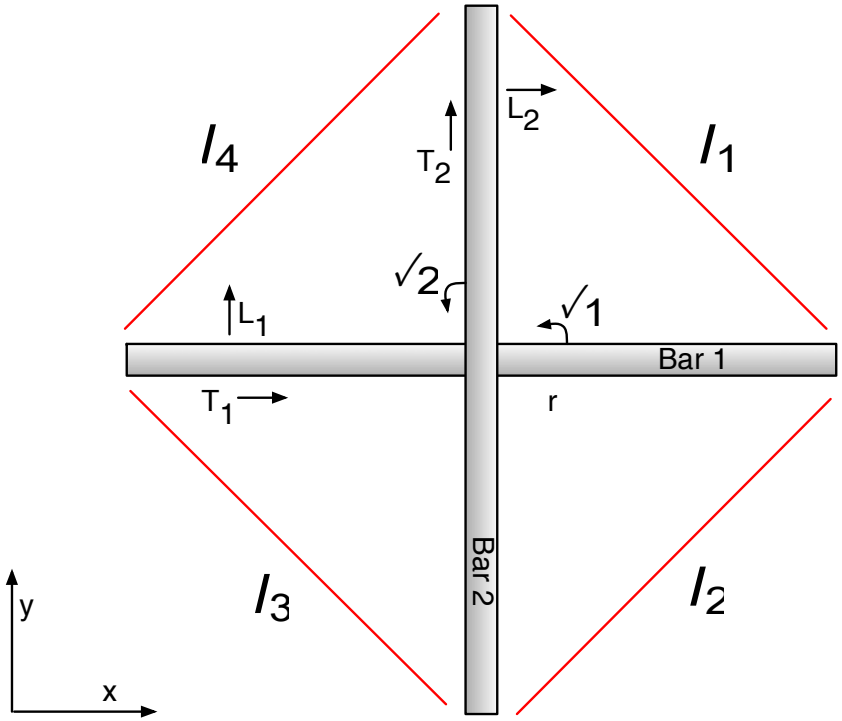


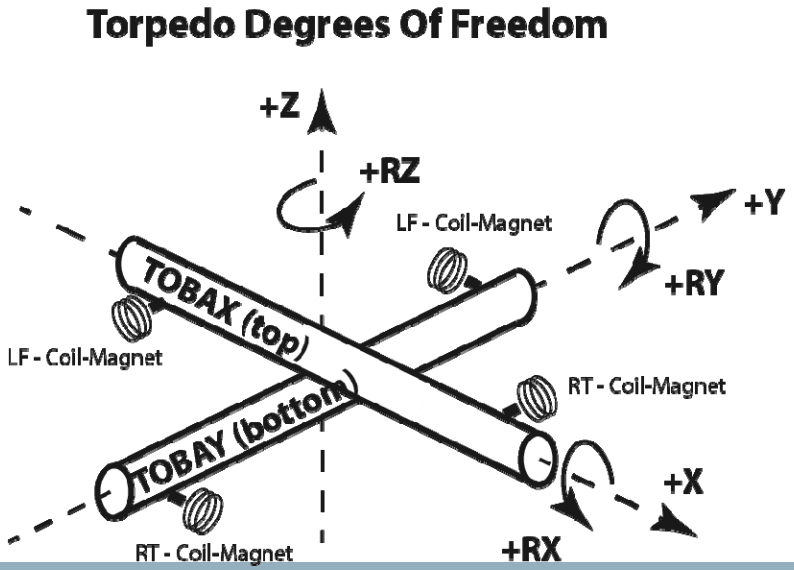
Bar 2

	Bar 1	Bar 2
Mass (kg)	13.249	13.128
Iyy (kgm^2)	0.6372 - 0.6507	0.6391 – 0.6558
Ixx (kgm^2)	0.2015	0.2447
COMy (mm)	31.67 to 32.05	-31.75 to -32.13
Izz (kgm^2)	0.6508	0.6434
f (mHz)	35.8 to 36.2	35.5 to 35.9

Degrees of Freedom







$$\delta_1 = 2r\sqrt{} + \frac{1}{2}p\,Y + \frac{1}{2}p\,X$$

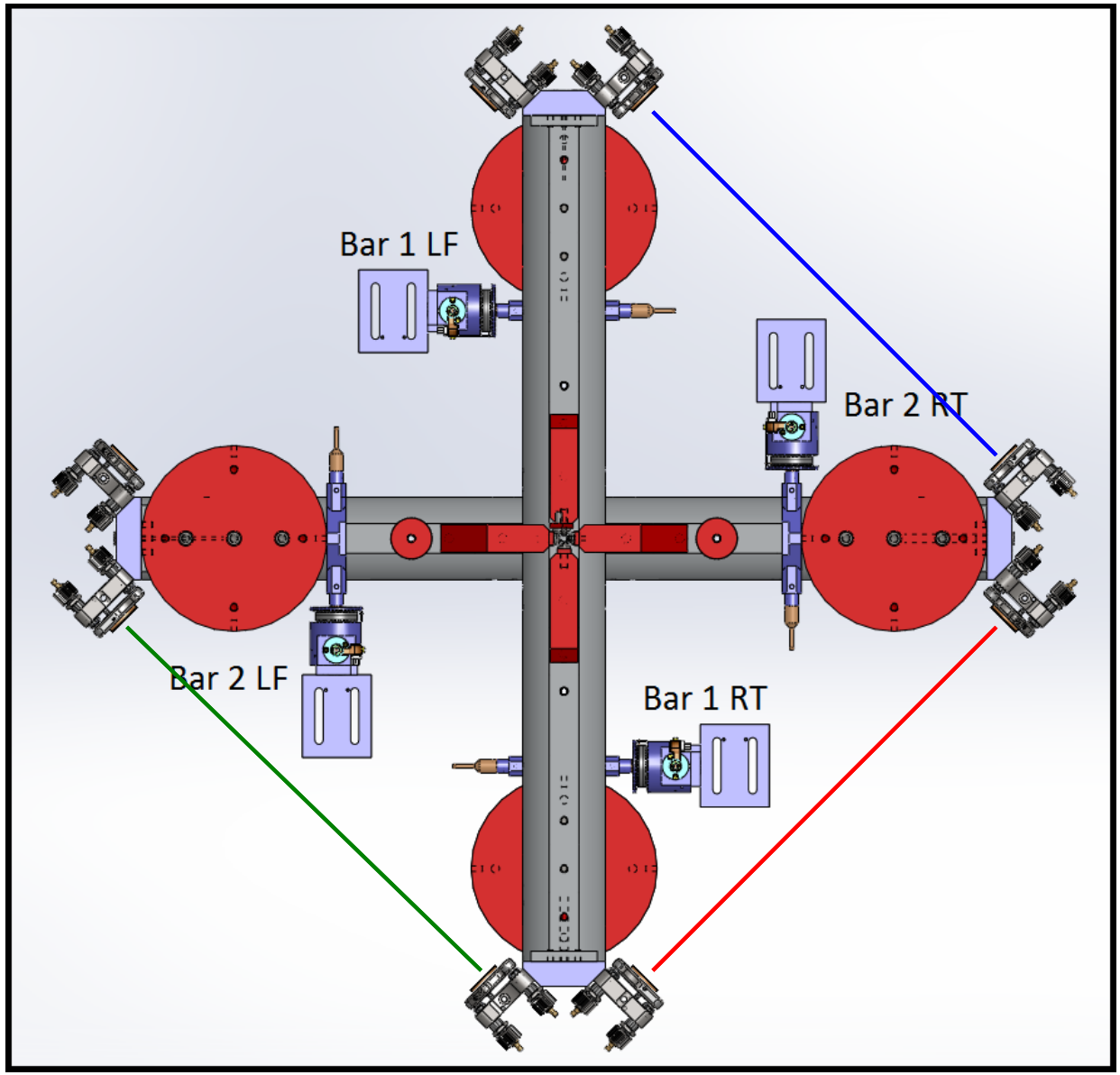
$$\delta_2 = -2r\sqrt{} - \frac{1}{2}p\,Y + \frac{1}{2}p\,X$$

$$\delta_3 = 2r\sqrt{} - \frac{1}{2}p\,Y - \frac{1}{2}p\,X$$

$$\delta_4 = -2r\sqrt{} + \frac{1}{2}p\,Y - \frac{1}{2}p\,X$$

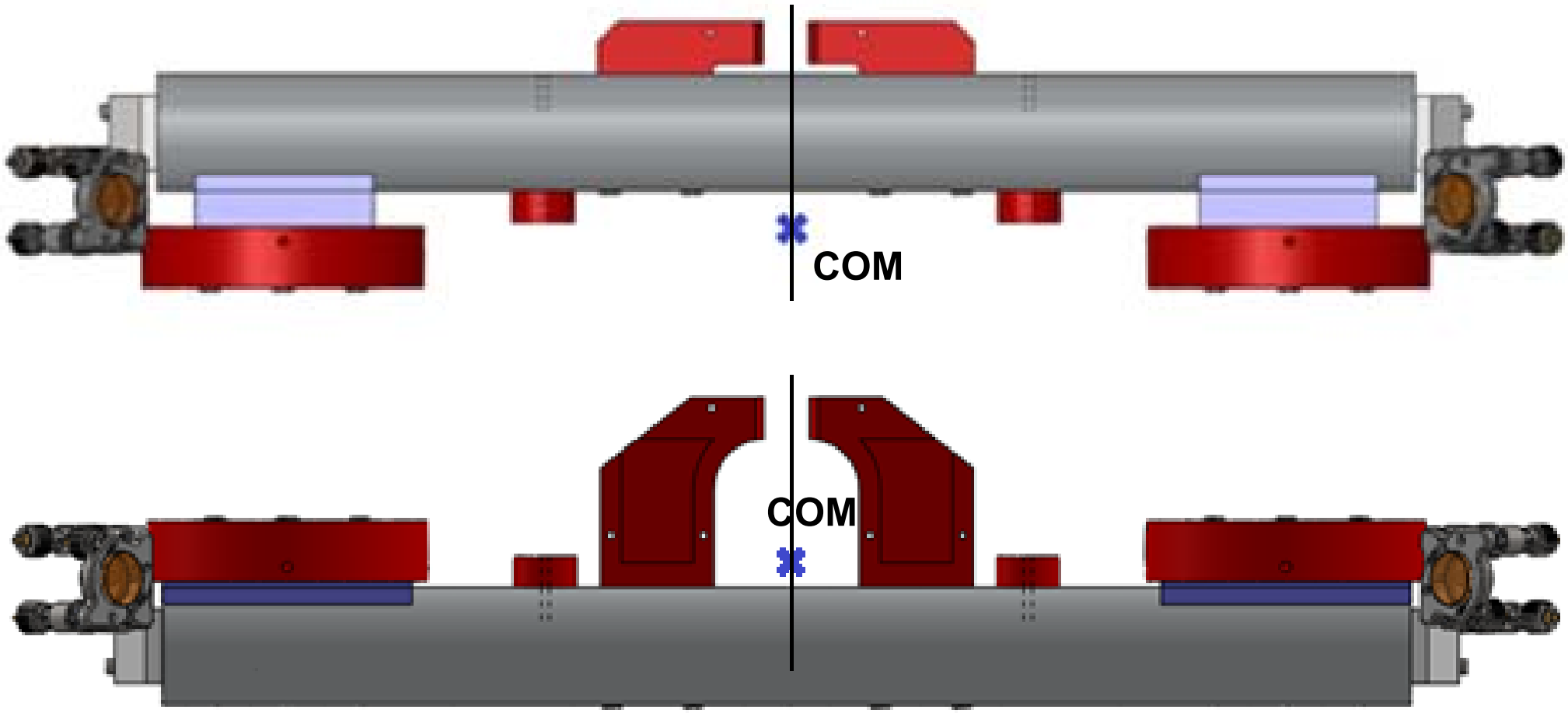
Sensor/Actuation/Control

- Four BOSEMS mounted to rigid frame
- Magnets/Flags mounted to bars
- Cavity mirrors at ends of each bar.
- Four cavities total, with three operational (almost).



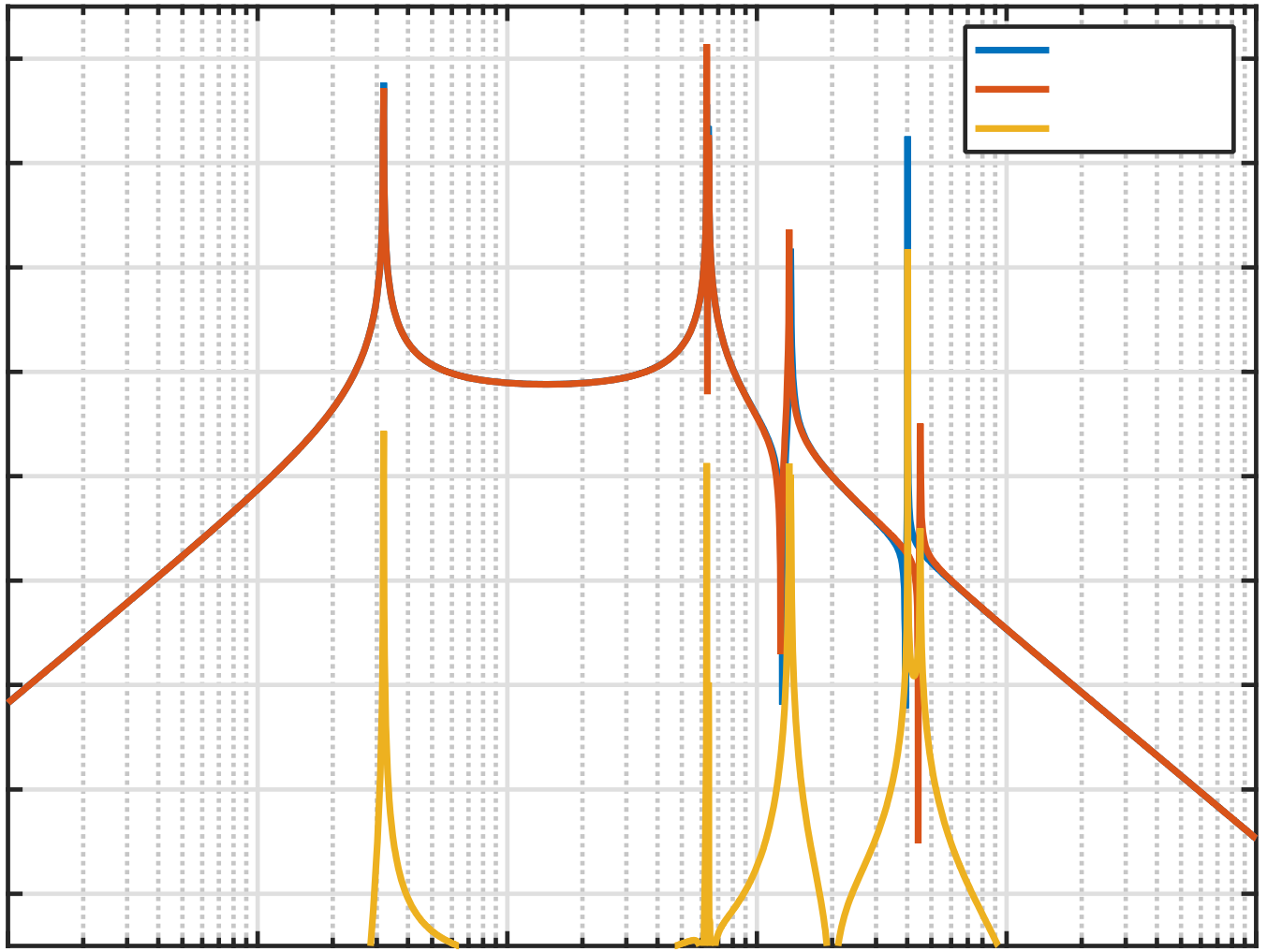
Transfer Function - Coupling

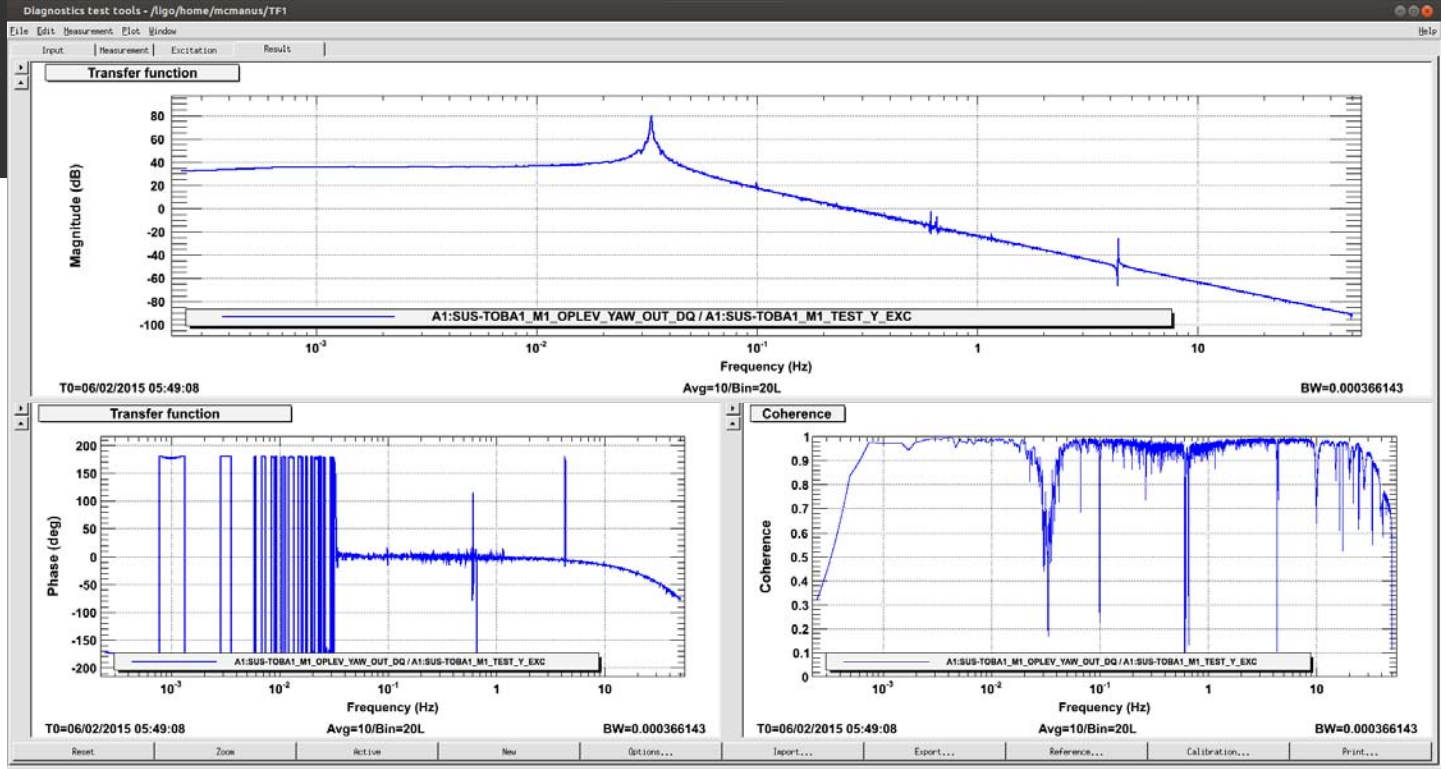
Δ μ μ

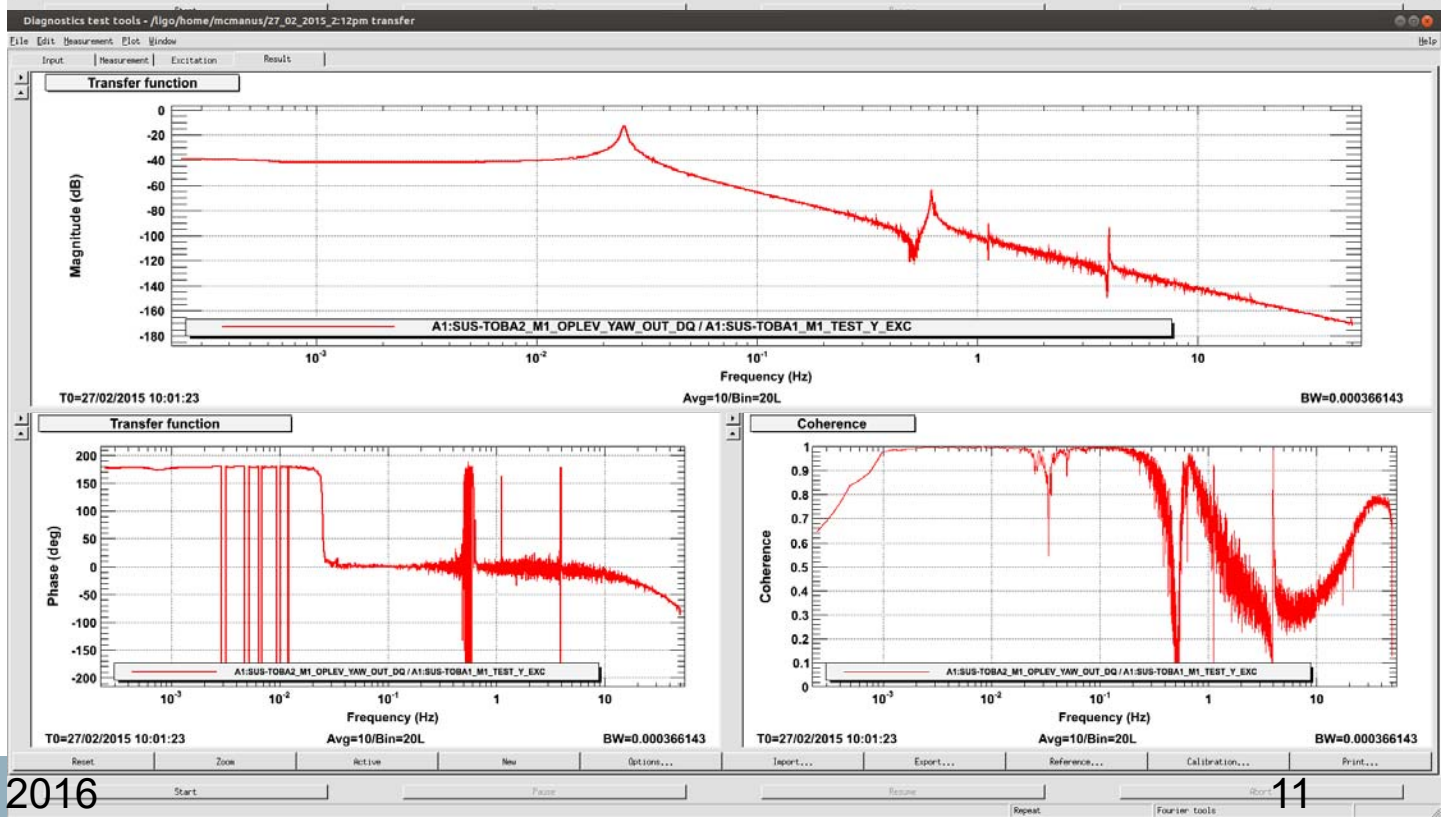


Cross Coupling

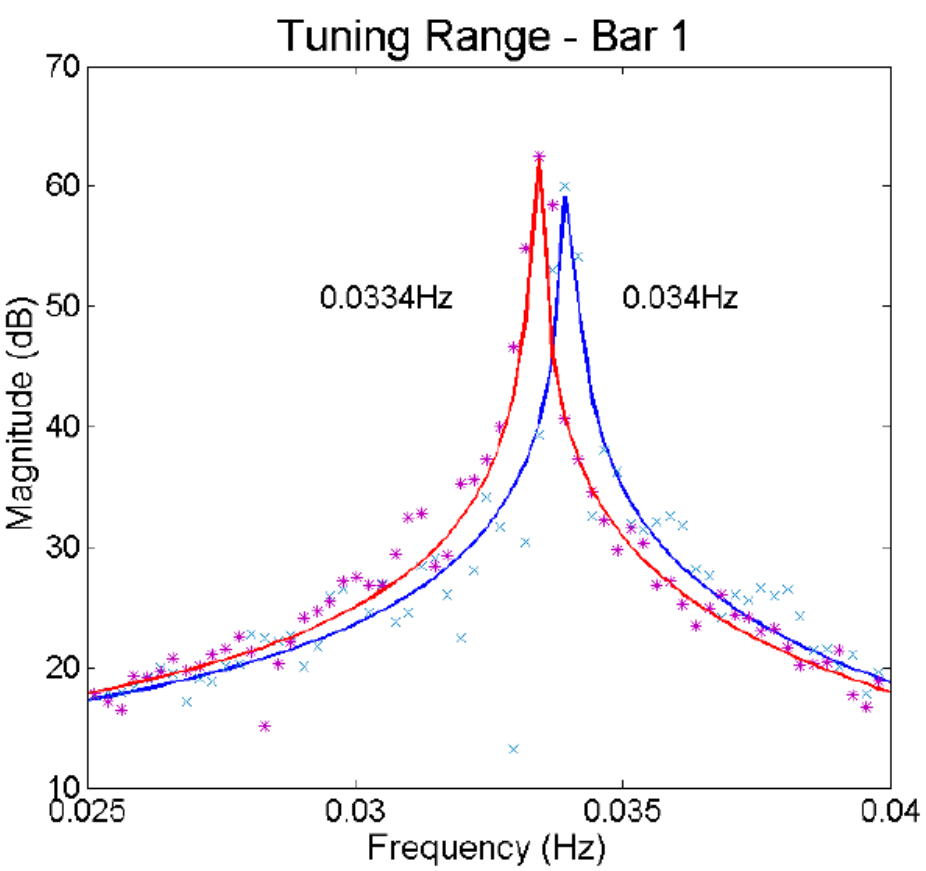
Δ μ μ

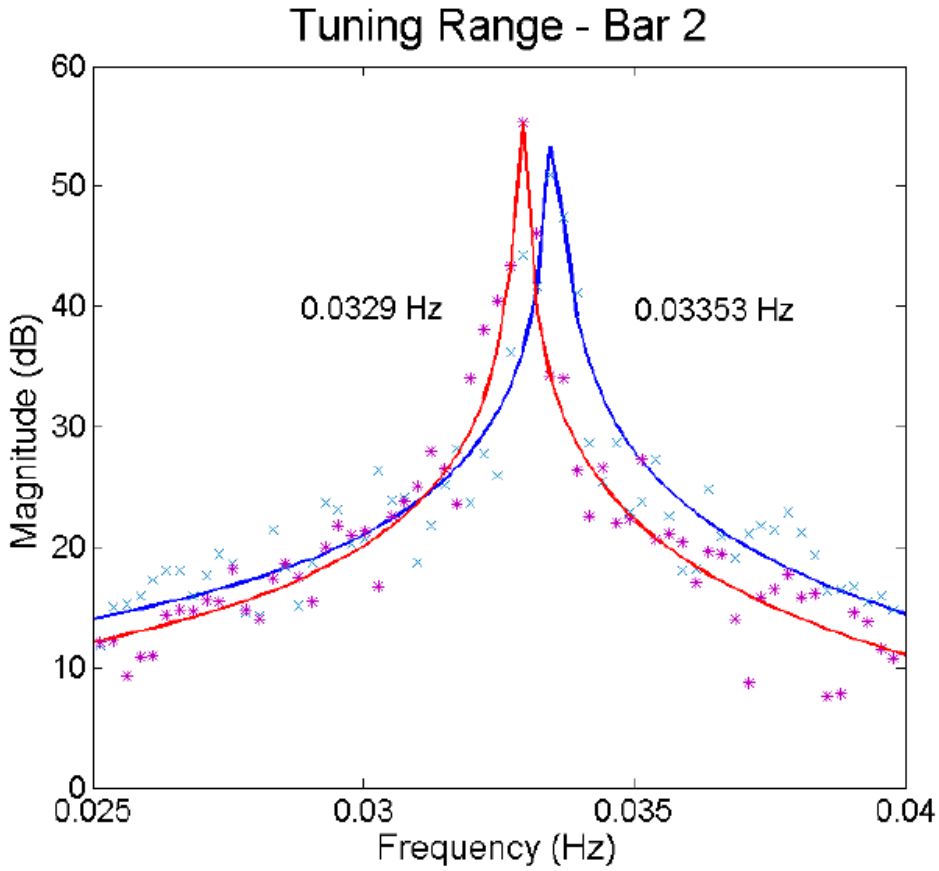


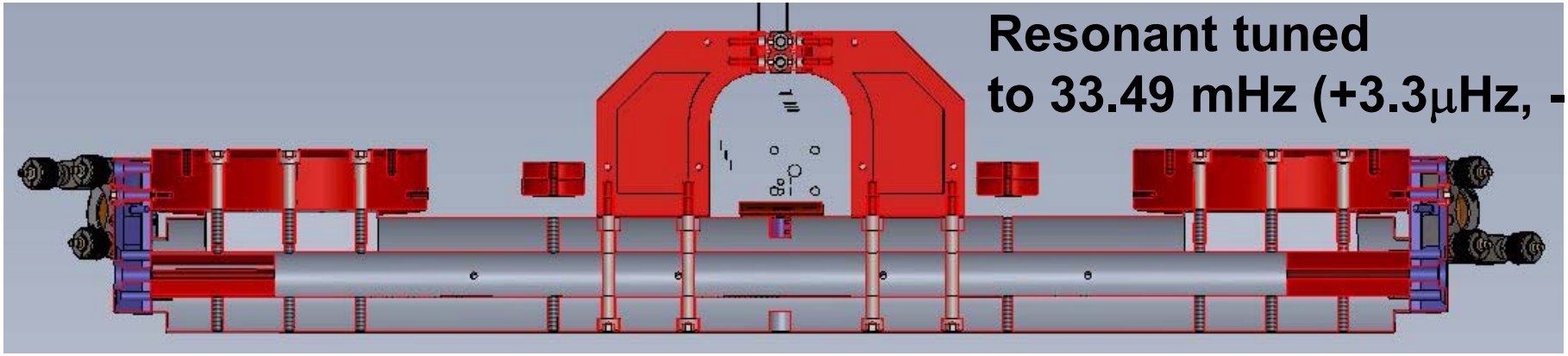

Diagnostics test tools - /ligo/home/mcmanus/TF1
Transfer function
Magnitude (dB)
A1:SUS-TOBA1_M1_OPLEV_YAW_OUT_DQ / A1:SUS-TOBA1_M1_TEST_Y_EXC
Frequency (Hz)
T0=06/02/2015 05:49:08
Avg=10/Bin=20L
BW=0.000366143
Transfer function
Phase (deg)
Coherence
Coherence
Reset
Zoom
Active
New
Options...
Import...
Export...
Reference...
Calibration...
Print...


Diagnostics test tools - /ligo/home/mcmanus/27_02_2015_2:12pm transfer
Transfer function
Magnitude (dB)
A1:SUS-TOBA2_M1_OPLEV_YAW_OUT_DQ / A1:SUS-TOBA1_M1_TEST_Y_EXC
Frequency (Hz)
T0=27/02/2015 10:01:23
Avg=10/Bin=20L
BW=0.000366143
Transfer function
Phase (deg)
Coherence
Coherence
Reset
Zoom
Active
New
Options...
Import...
Export...
Reference...
Calibration...
Print...
Start
Pause
Resume
Abort
Repeat
Fourier tools

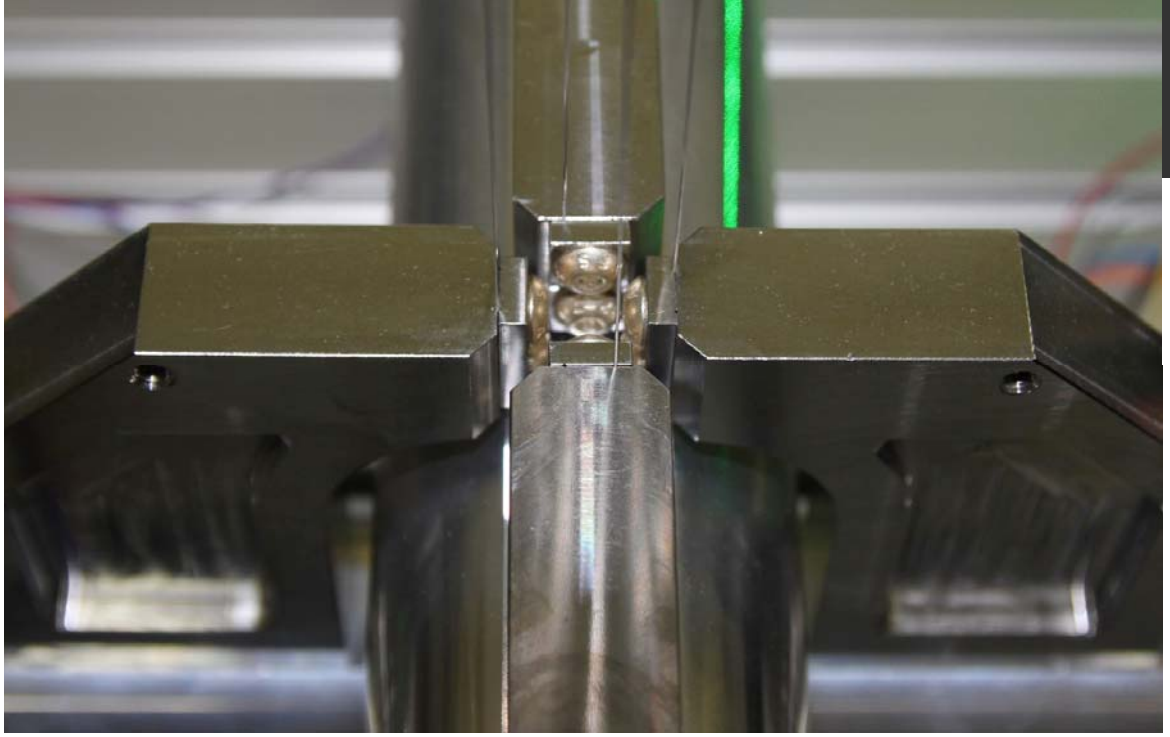
Mechanical Performance Tuning

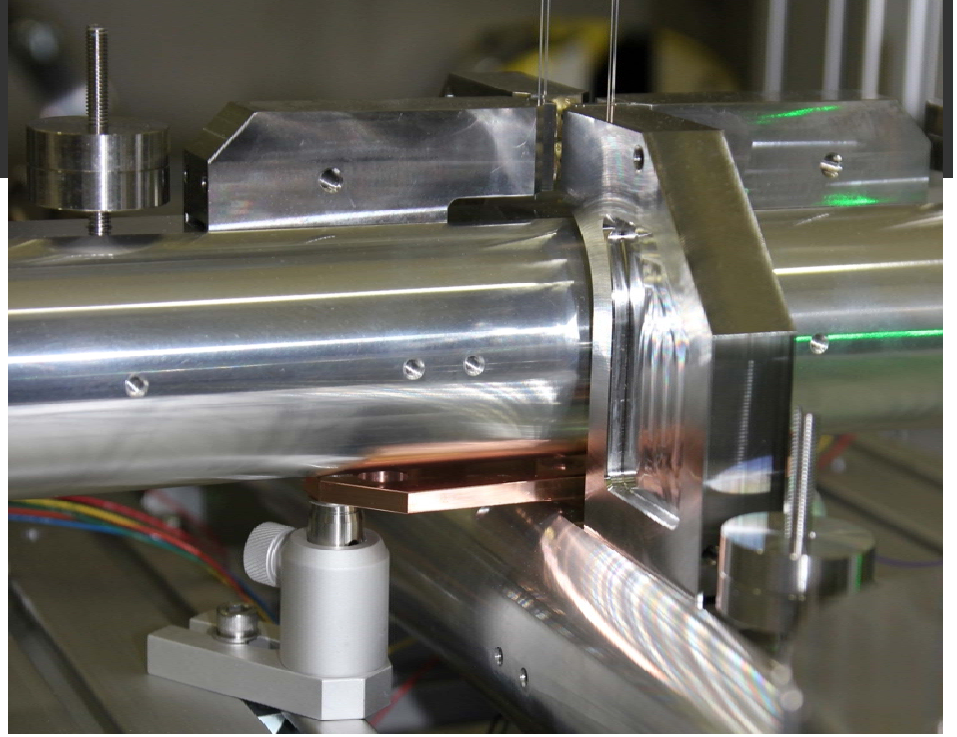


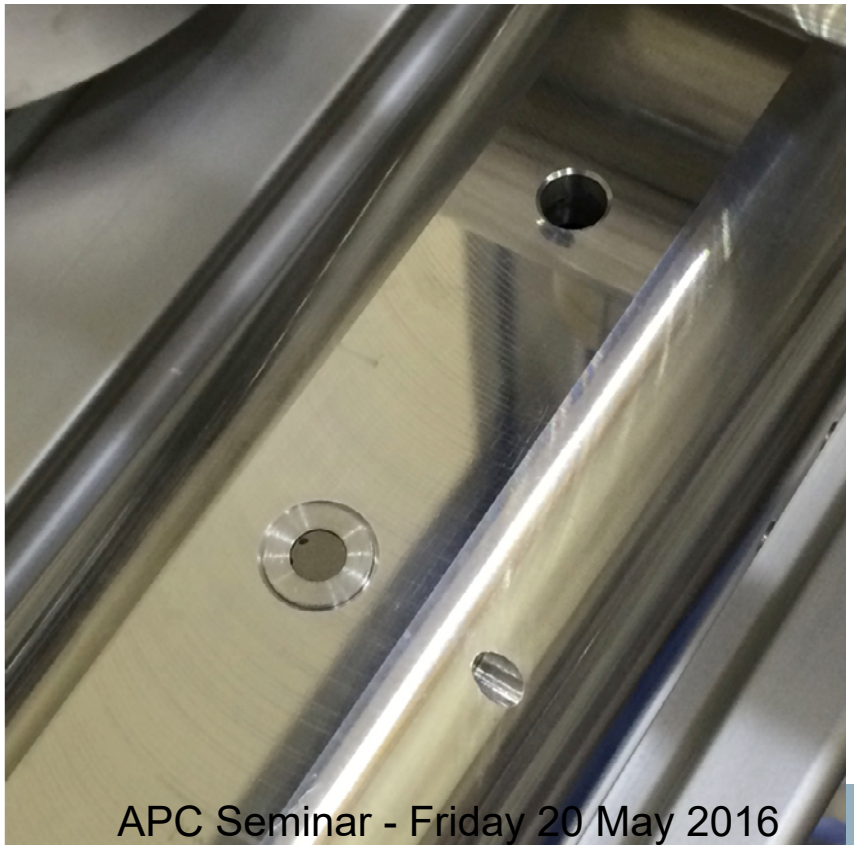


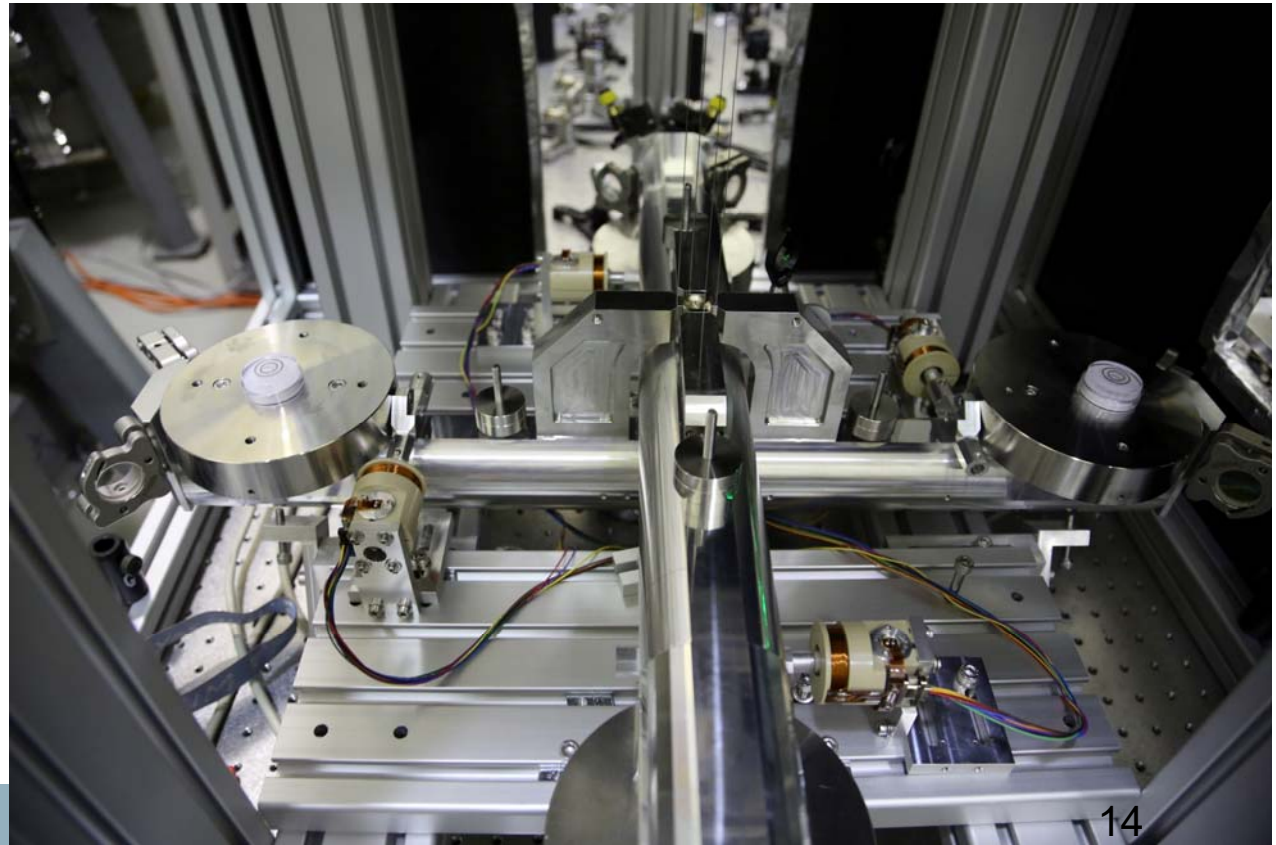


Resonant tuned to 33.49 mHz (+3.3μHz, -1μHz)

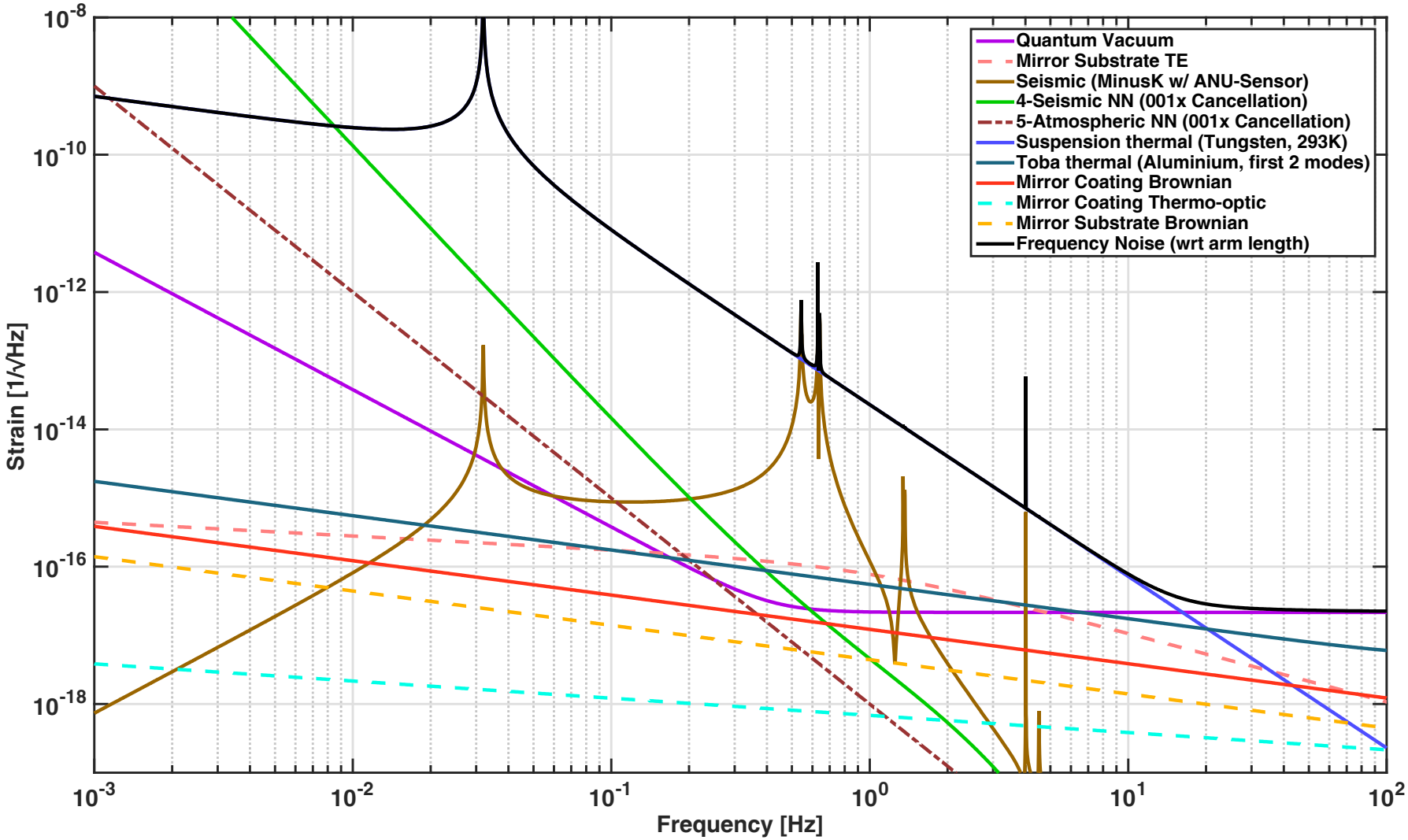




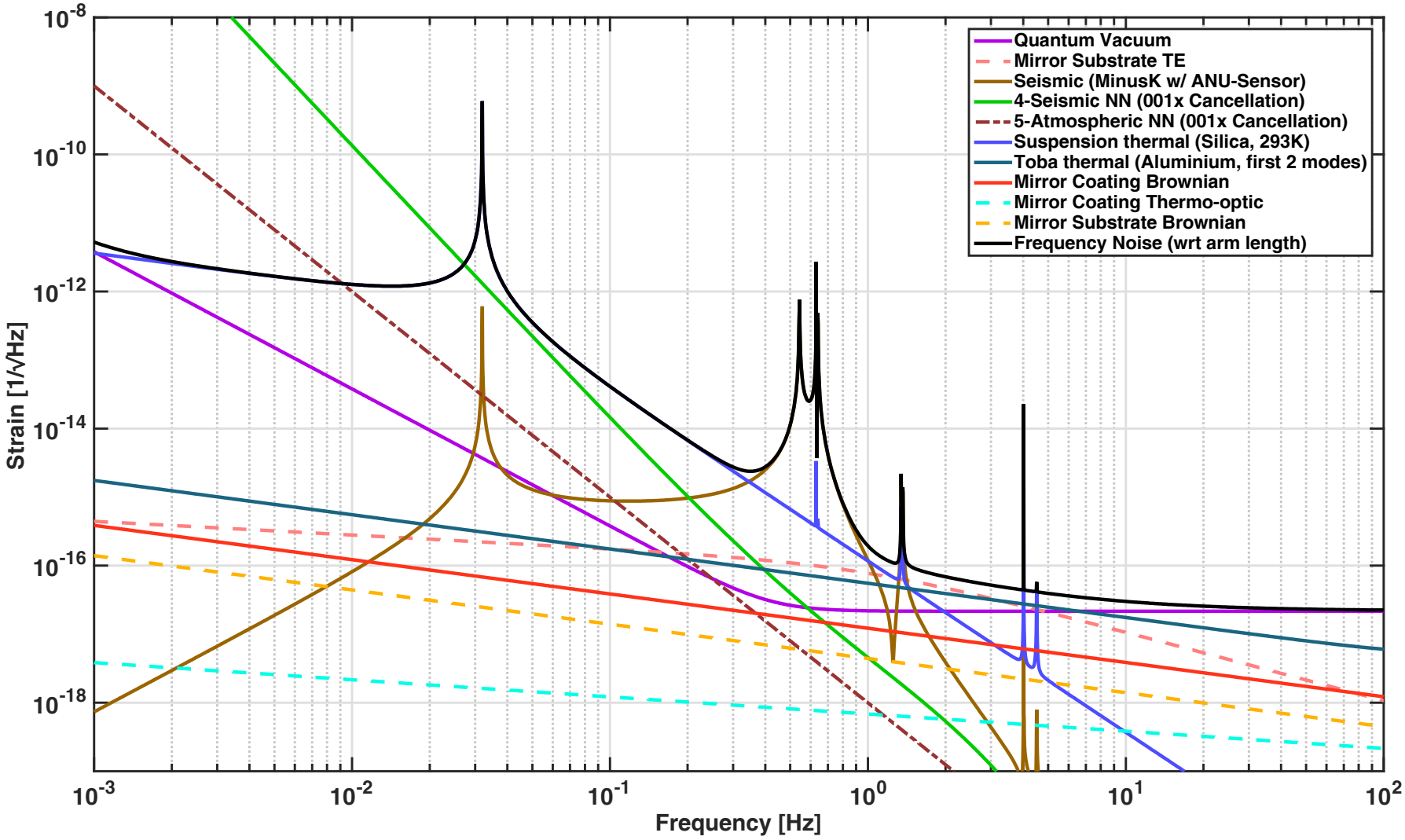




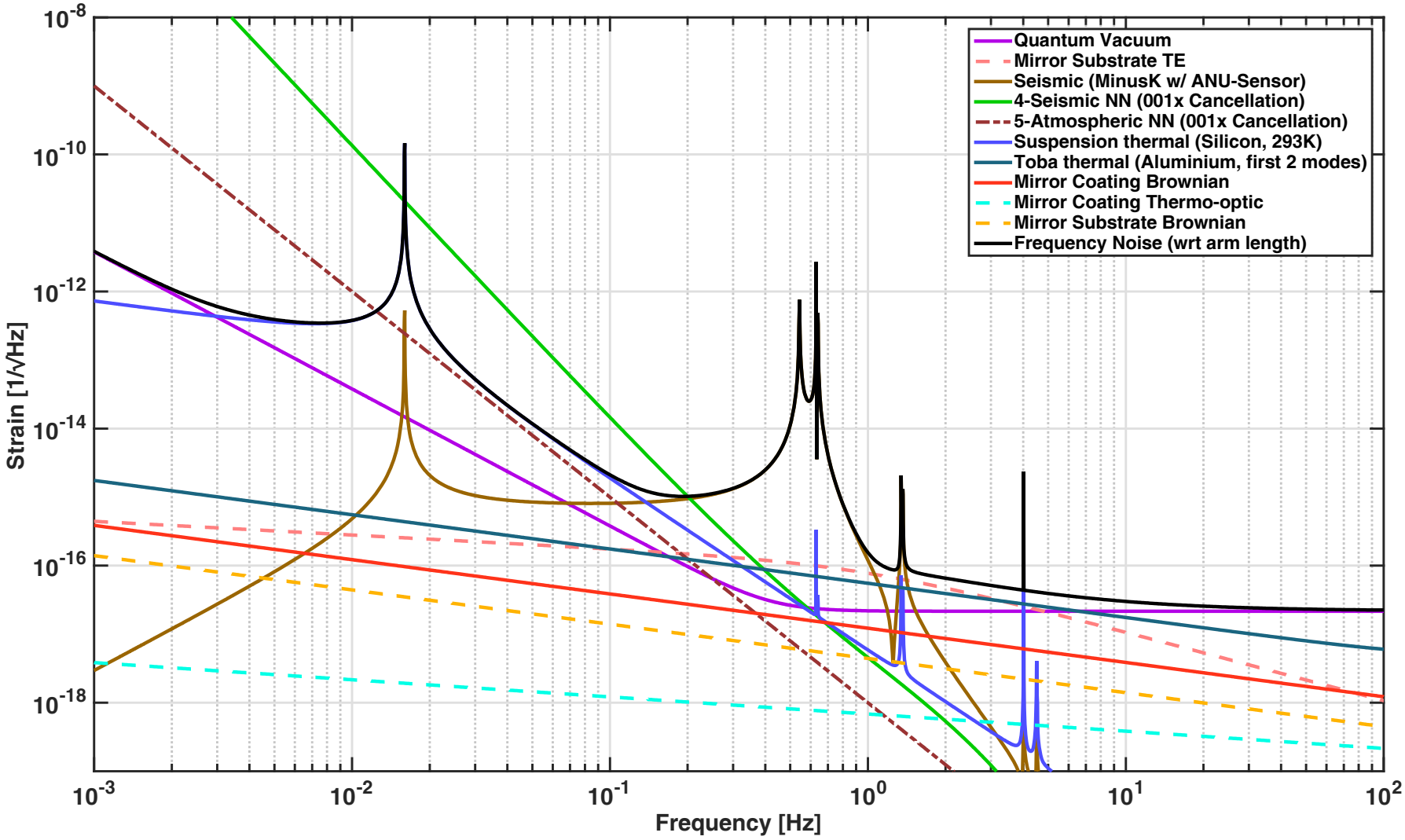
Tungsten Suspension Wires



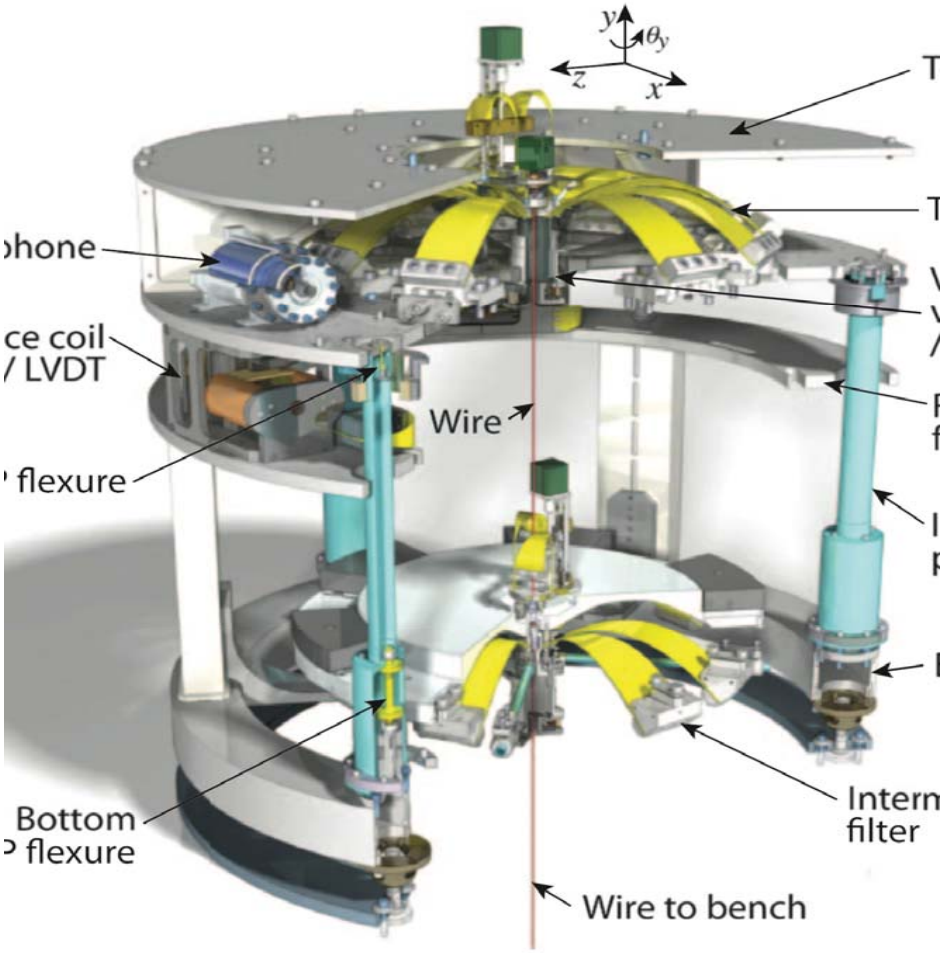
Fused Silica Suspension Wires



Silicon Suspension Wires



Suspension Point Isolation

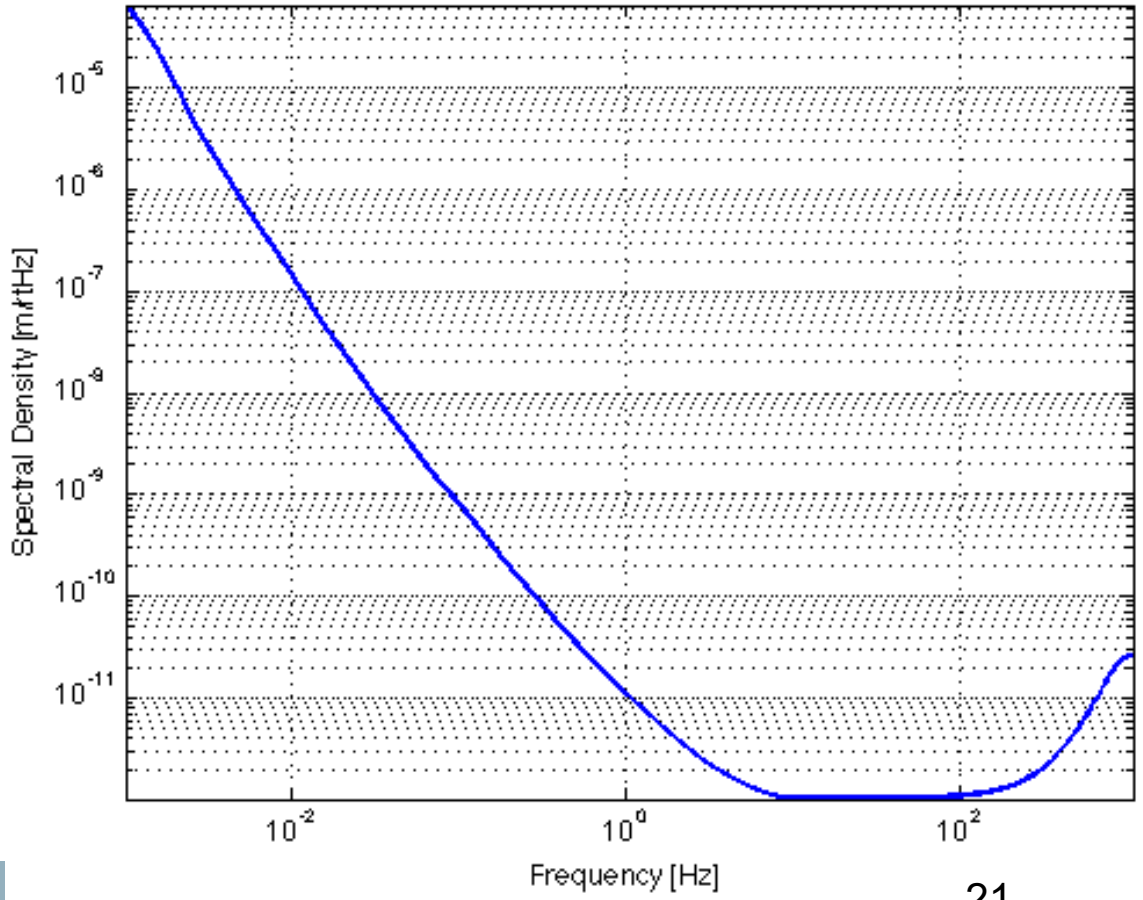


- Goal: 10^{-15} /rtHz at 100 mHz.
- Require 6 order of mag isolation at 100 mHz.
- Install current single stage pendulum into vacuum
- Acquire soft isolation system (MulitSAS, Nikhef/InnoSeis)

M. G. Beker, et al. “State observers and kalman filtering for high performance vibration isolation systems”. Rev of Sci Instr, 85(3):–, 2014.

What we (I) need

- Improving sensor sensitivity at lower frequencies (1 mHz to 1 Hz), by >2 -4 order of magnitude.
  - Inertia Sensors
    - Displacement
    - Acceleration
    - Tilt
  - Combination of readout technique (interferometric?) and mechanical system.



Mechanical System consideration

- Assume readout noise is below Thermal noise (e.g. shot noise limited)
- Thermal noise of the fabrication material
  - Use of different material
  - System built with combined materials
  - Silicon – machine or etch

Questions