The Current Status of TOBA

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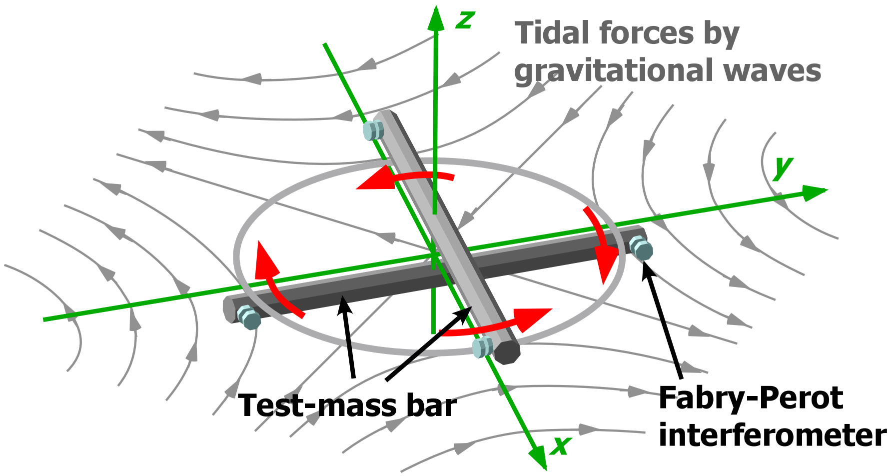
18/05/21 GWADW2021 @ online

Torsion Bar Antenna (TOBA)

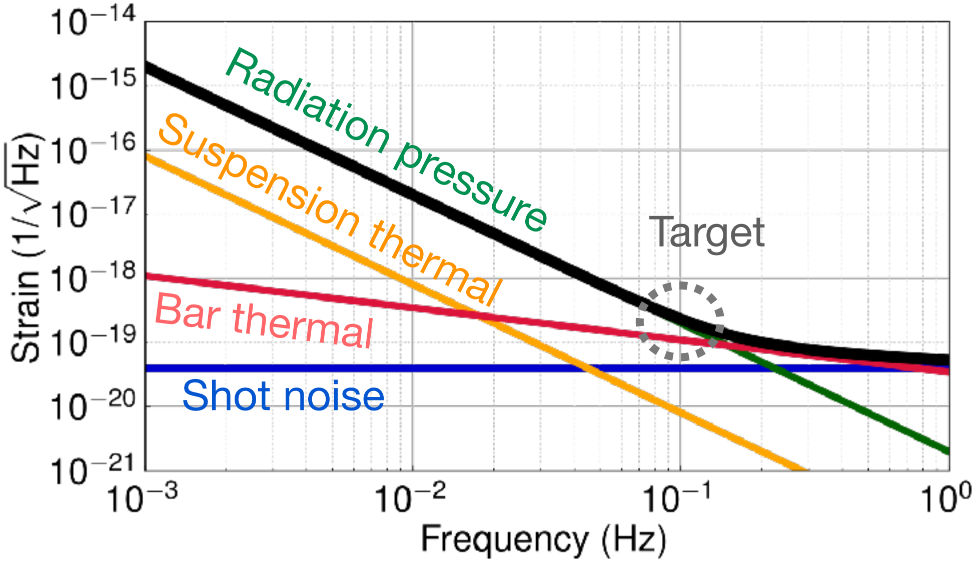
TOBA : TOrsion-Bar Antenna

- Gravitational wave detector using two torsion pendulums
- Resonant frequency of torsion pendulum ~ mHz

  → Sensitive to **low frequency** (~ 0.1Hz)
- Target sensitivity **h ~ 10^{-19} / √Hz** @ 0.1 Hz with **10 m** bars



M. Ando+ (2010)



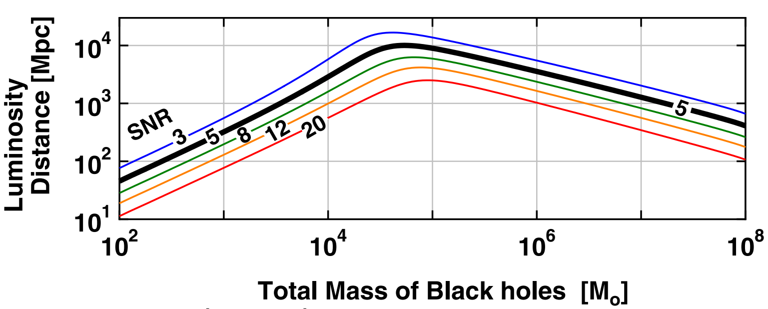
Design sensitivity of TOBA

Science of TOBA

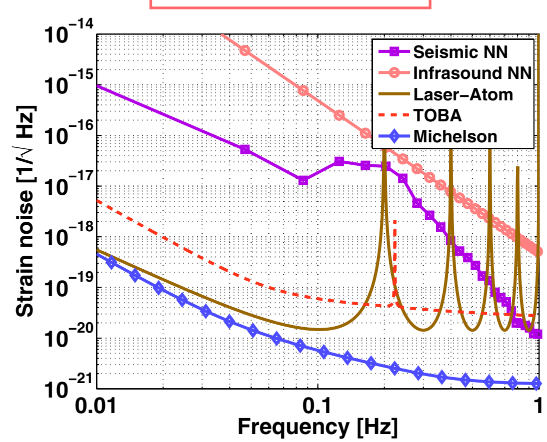
TOBA

- Astrophysics
  - IMBH Binary Merger
  - GW Stochastic Background
- Geophysics
  - Newtonian Noise
  - Earthquake Alert

10 Gpc for $10^5\ M_\odot$



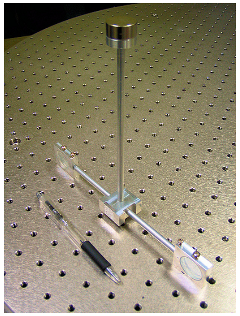
M. Ando+ (2010)



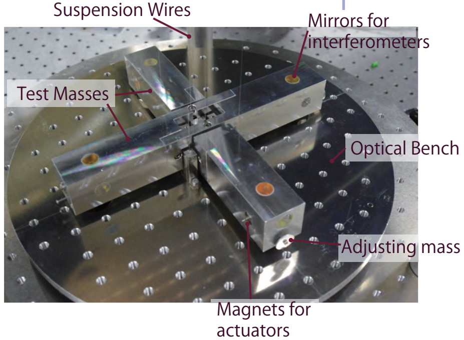
J. Harms+ (2012)

Development Plan

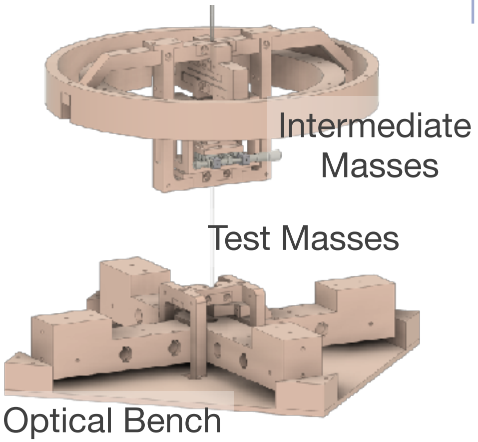
Phase-I (2009) / Phase-II (2015)	Phase-III (Now)	Final (Target)
Principle Test	Cryogenic Test	Goal
$10^{-8}/\sqrt{Hz}$ @ 0.1 Hz (Established)	**$10^{-15}/\sqrt{Hz}$** @ 0.1 Hz (Design)	**$10^{-19}/\sqrt{Hz}$** @ 0.1 Hz (Target)
- Room Temp. - 25cm TM(s)	- **Cryo. Temp.** (4K) - 35cm TMs	- **Cryo. Temp.** (4K) - **10m** TMs

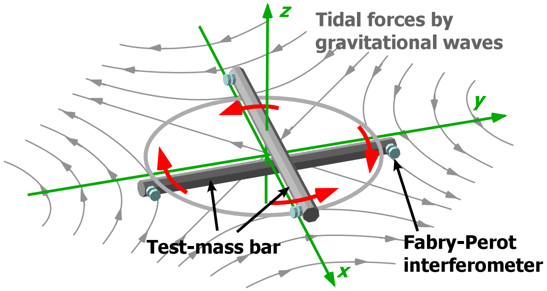


K. Ishidoshiro
Ph.D Thesis



A. Shoda
Ph.D Thesis

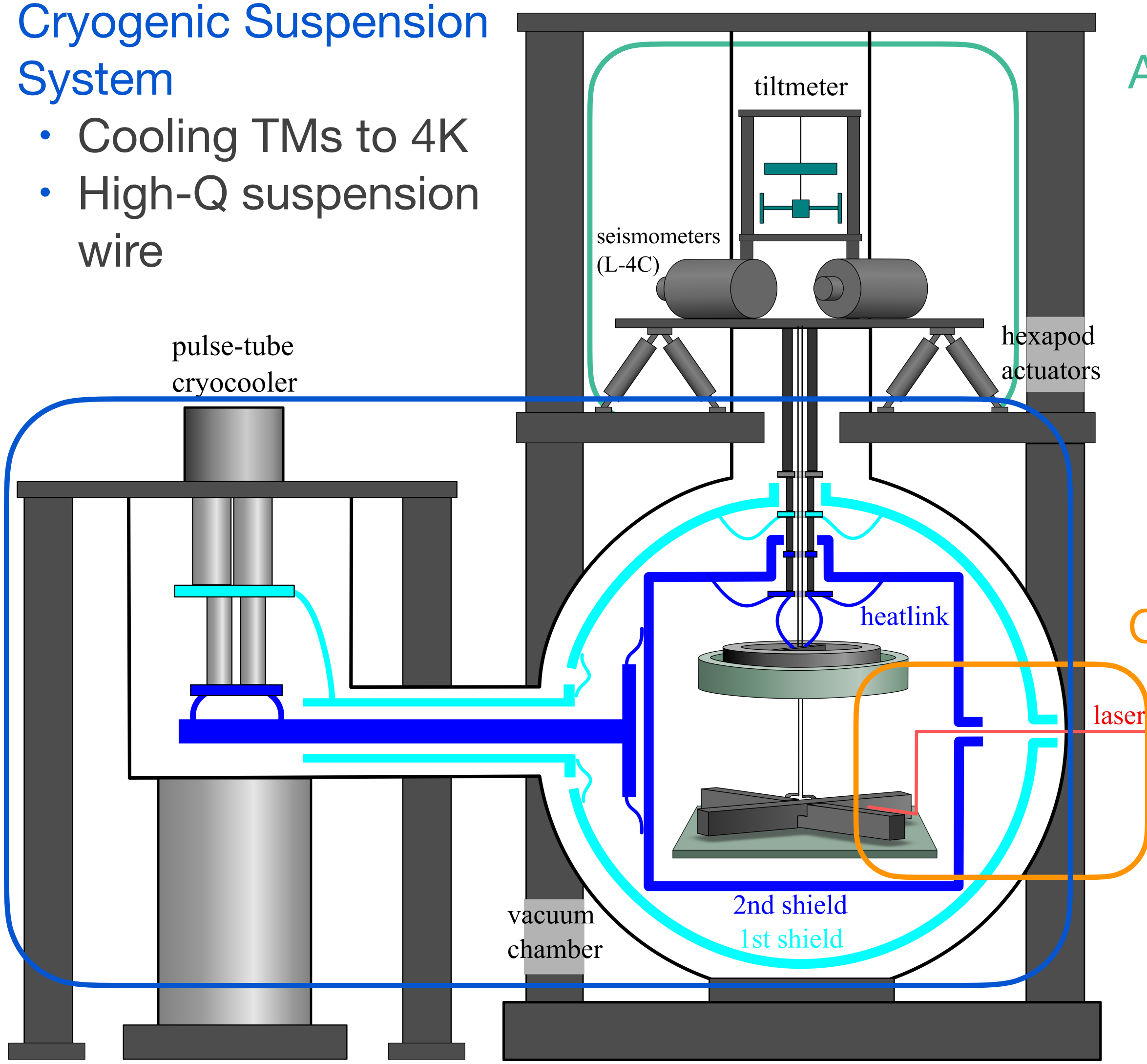




Setup of Phase-III TOBA

Cryogenic Suspension System

- Cooling TMs to 4K
- High-Q suspension wire



Active Vibration Isolation System

- Reduction of vibration at the suspension point
- Reduction of vibration induced cryocooler

Optical System

- Rotation measurement by high-sensitive wave front sensor
- Beam jitter control in order to follow the incident beam to the optical bench

Cryogenic Suspension System

Cryogenic Cooler

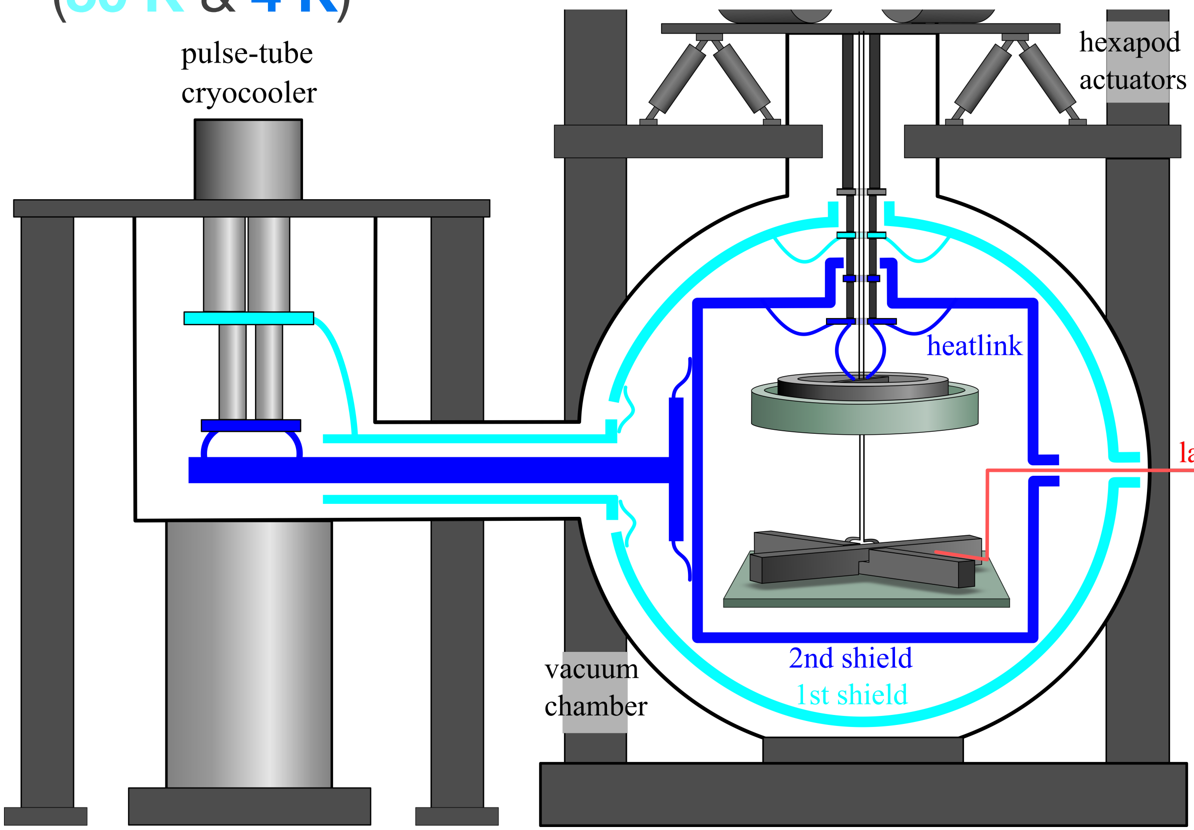
- Cool down TMs to 4 K
- Two radiation shields (50 K & 4 K)

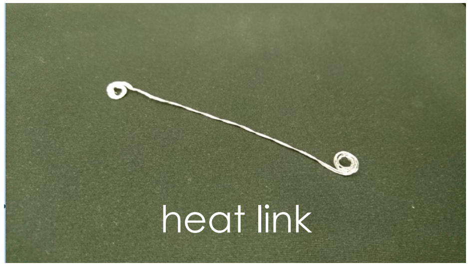
Suspension wire

- Si wire
- High Q value (>10^8)

Heat Links

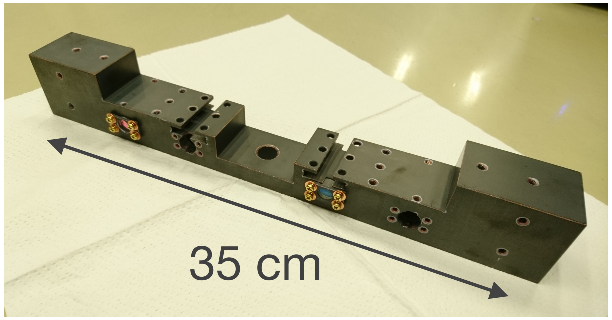
- High-purity aluminum
  - ▶ Conductive cooling



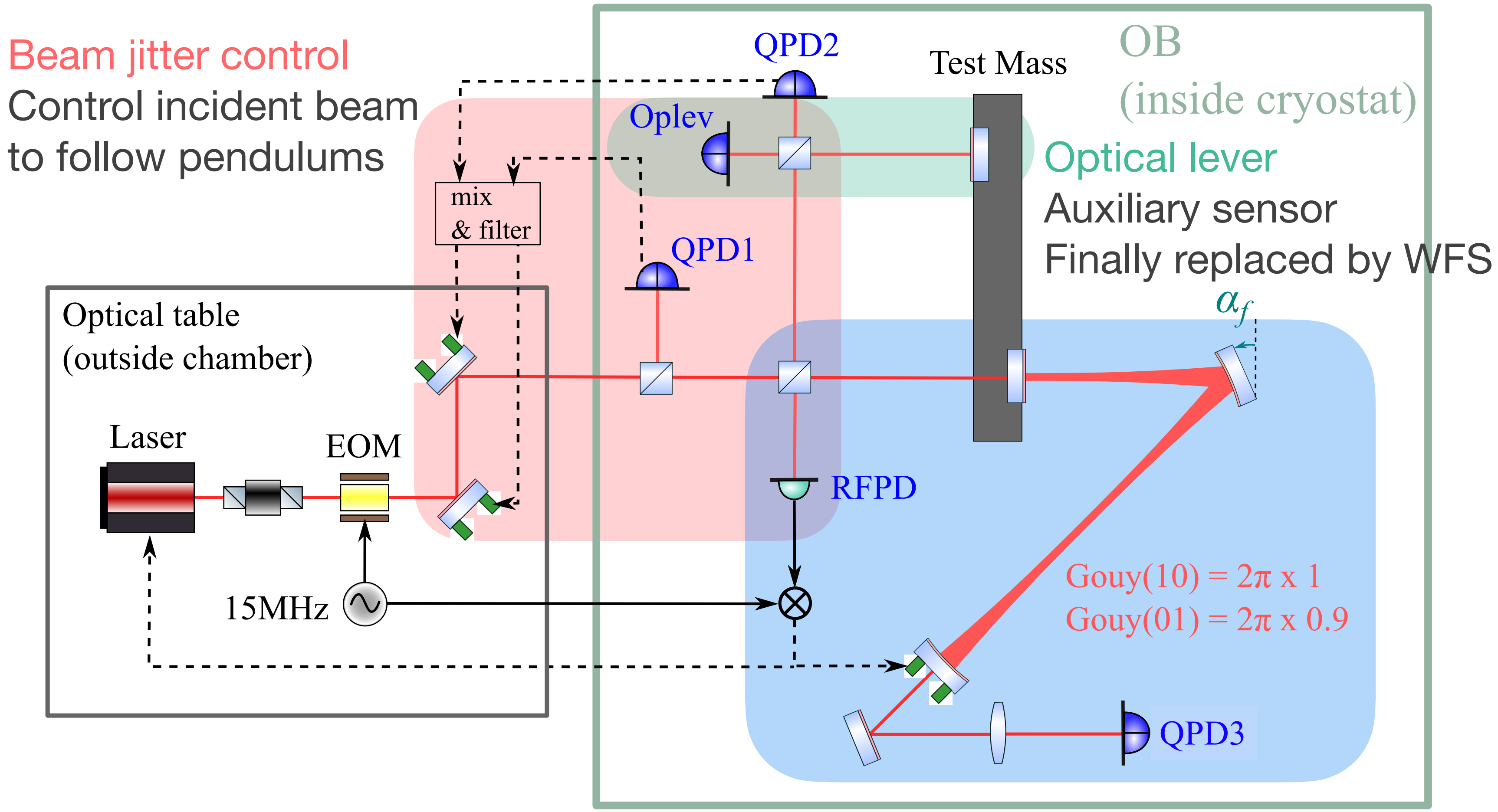


TMs

- Copper
- Surface is oxidized



Optical System



High sensitive angular sensor
Measure HG10 mode
induced by rotational motion

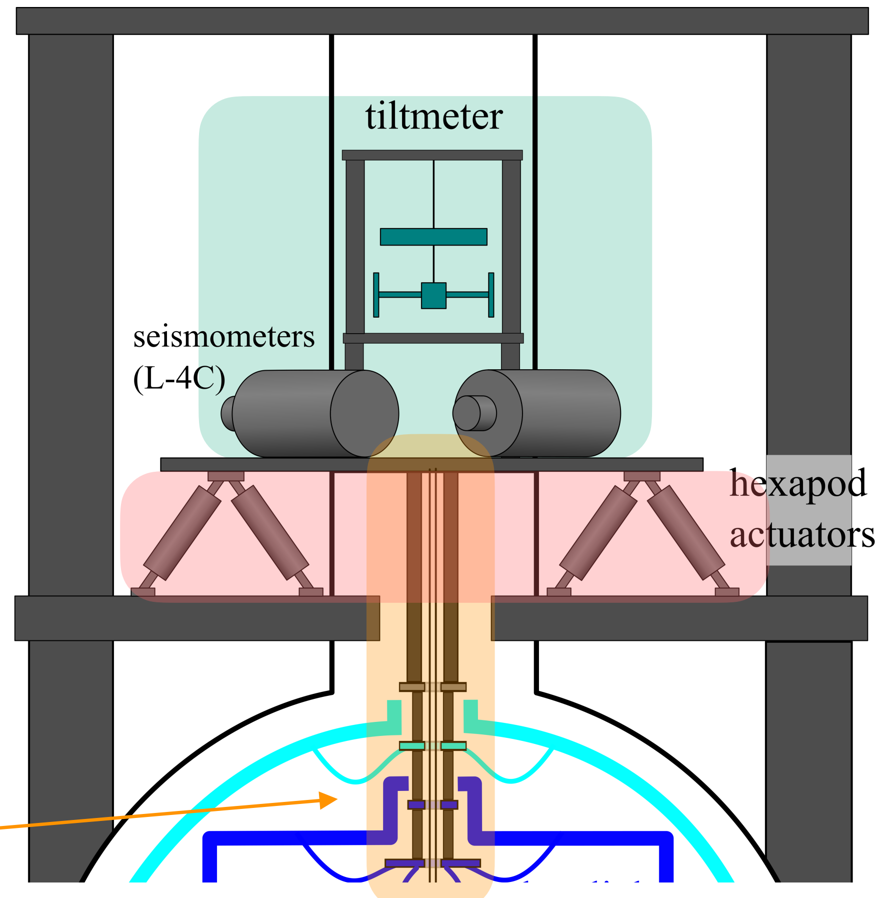
Active Vibration Isolation System

- Reduction of seismic vibration
  - Coupling from horizontal vibration
    - 10^{-7} m/√Hz @ 0.1 Hz
  - Nonlinear coupling
    - 10^{-10} m/√Hz @ 1 Hz

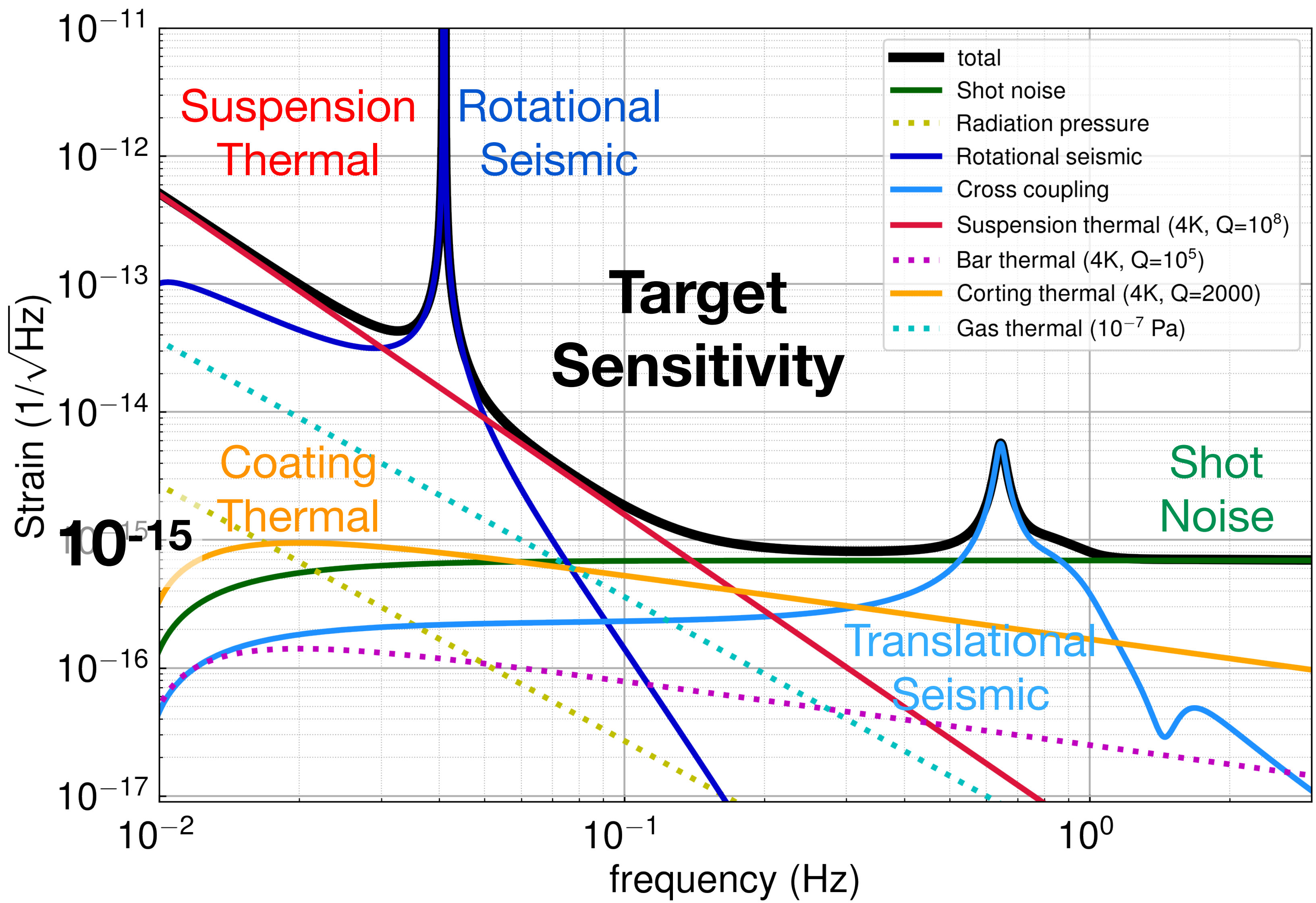
Measure motion at the suspension point by seismometer & tilt meter

Feedback the signal to actuators to cancel out the motion

- Reduction of vibration induced by cooler



Design Sensitivity



Development Items

- Cryogenic Suspension System
  - Cooling System
  - High-Q suspension wire → Ching Pin's Poster (ID: 66)

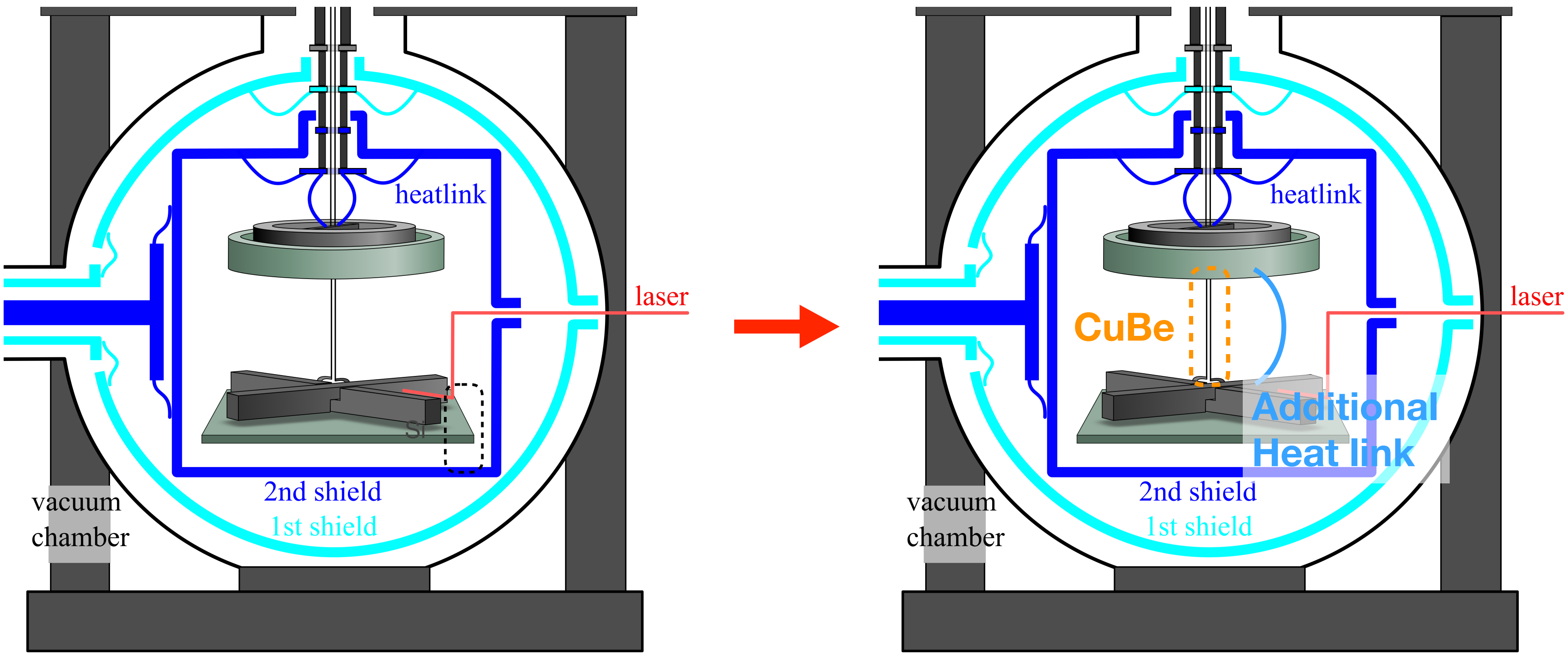
- Optical System
  - New angular sensor with higher sensitivity → Yuka's Poster (ID: 39)

- Active Vibration Isolation
  - Reduction of translational seismic noise
  - Reduction of vibration induced by cooler

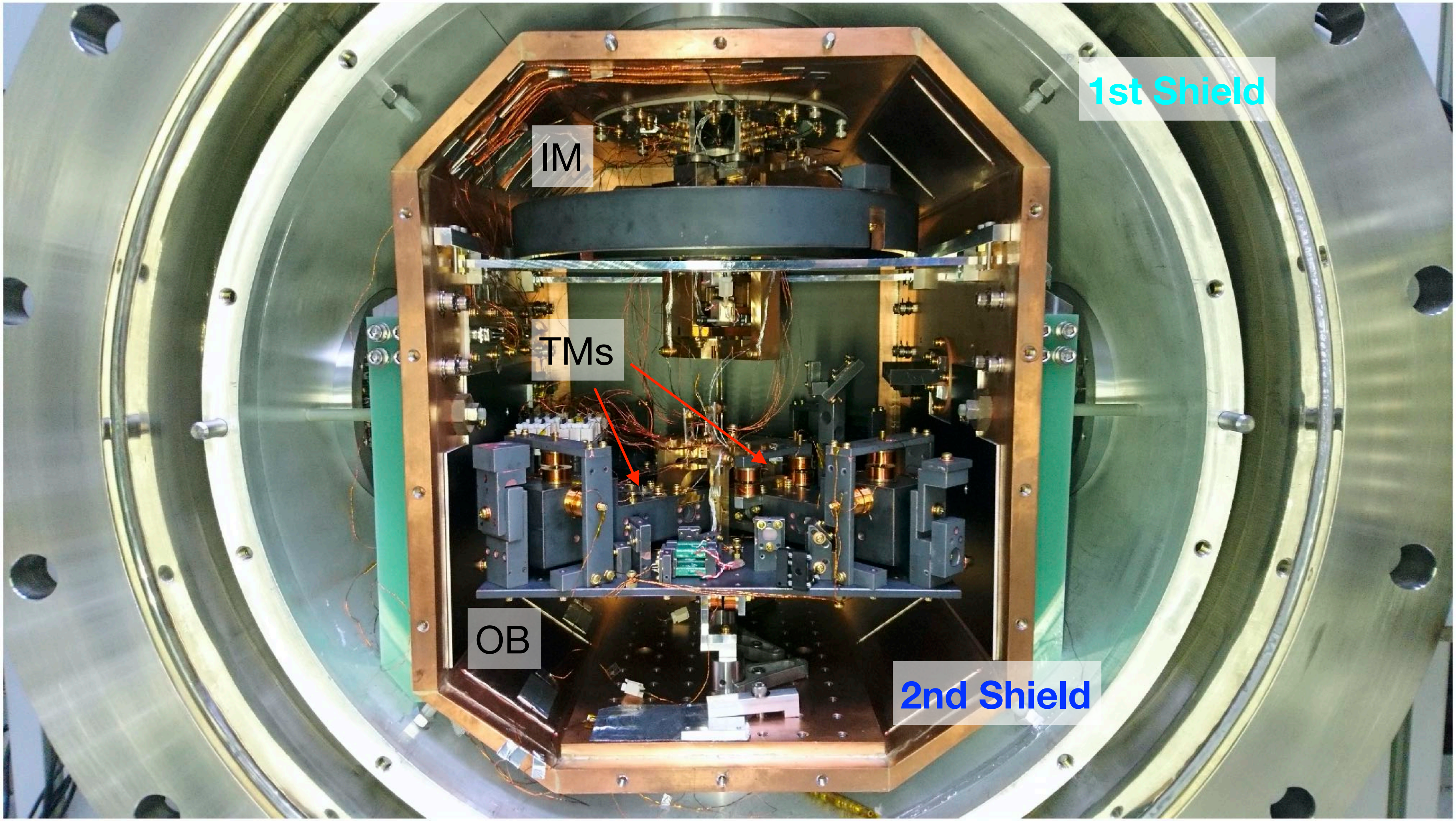
Current Suspension System

Test for cryogenic, simplified configuration

- Silicon fiber → CuBe wire
- Heatlinks between IM and TMs
- Readout: only optical levers

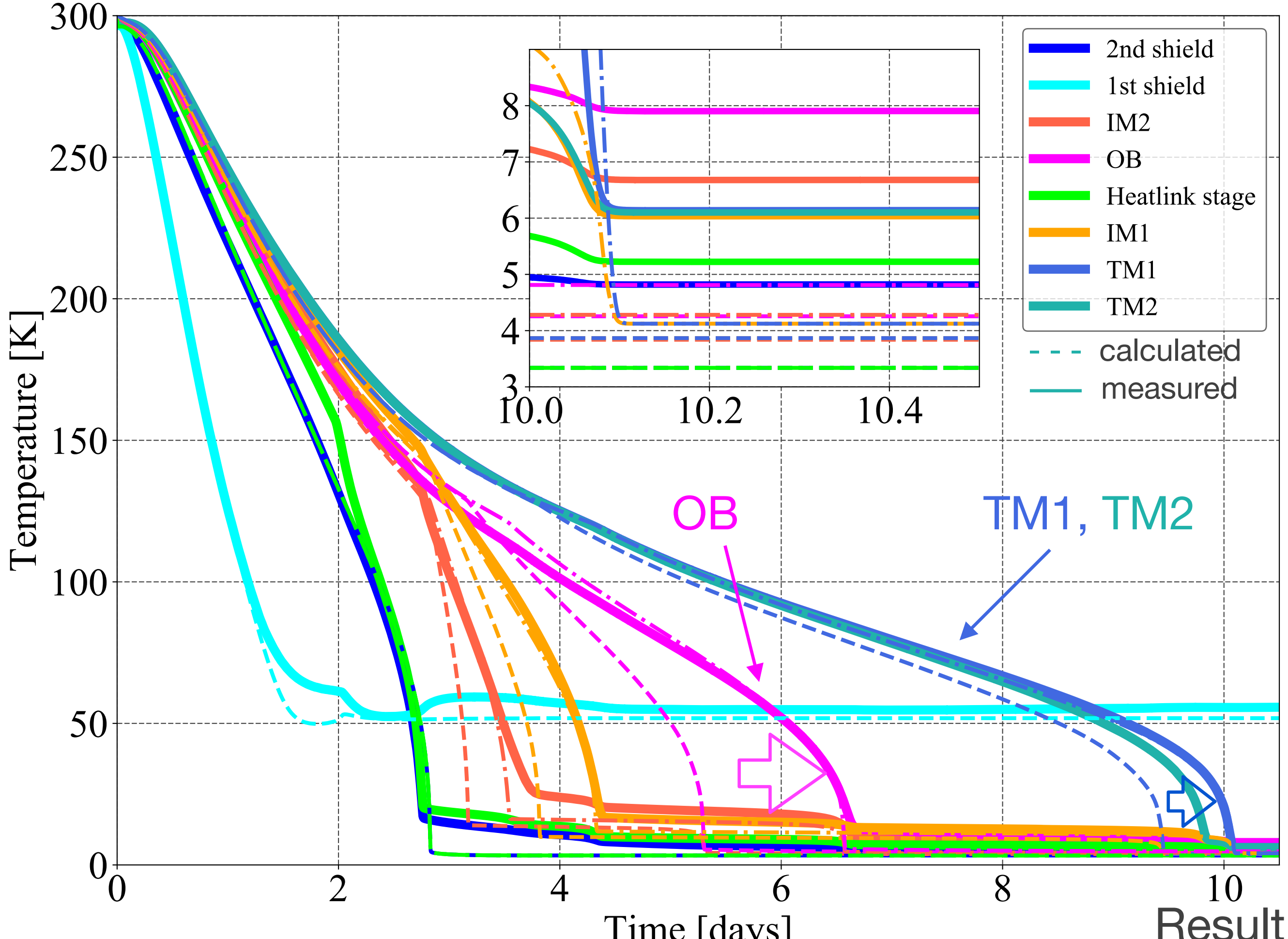


Current Setup



Cooling Result

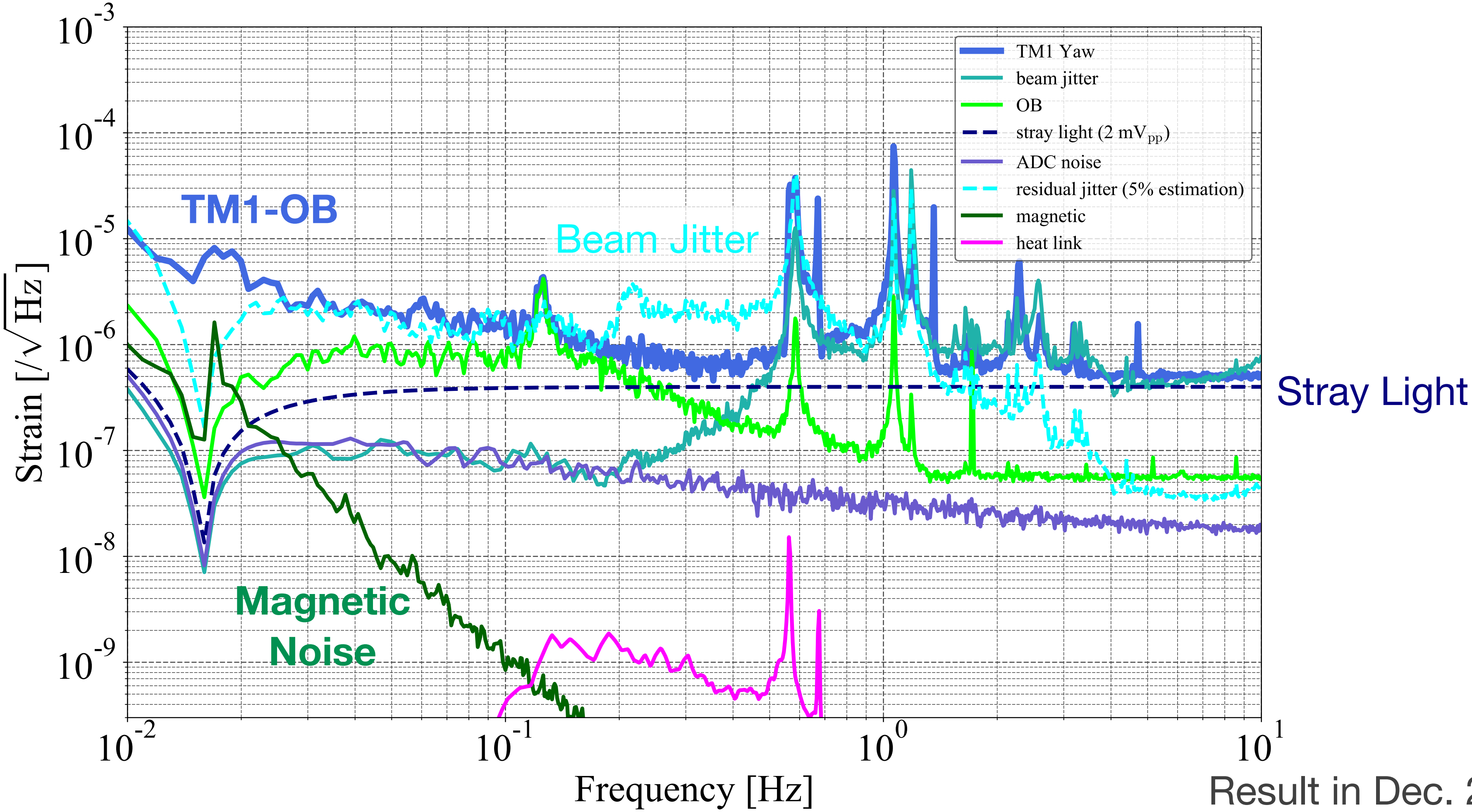
- **Cool down to 6.1 K**
- Slower cooling speed → Bad heat contact?



Result in Dec. 2019

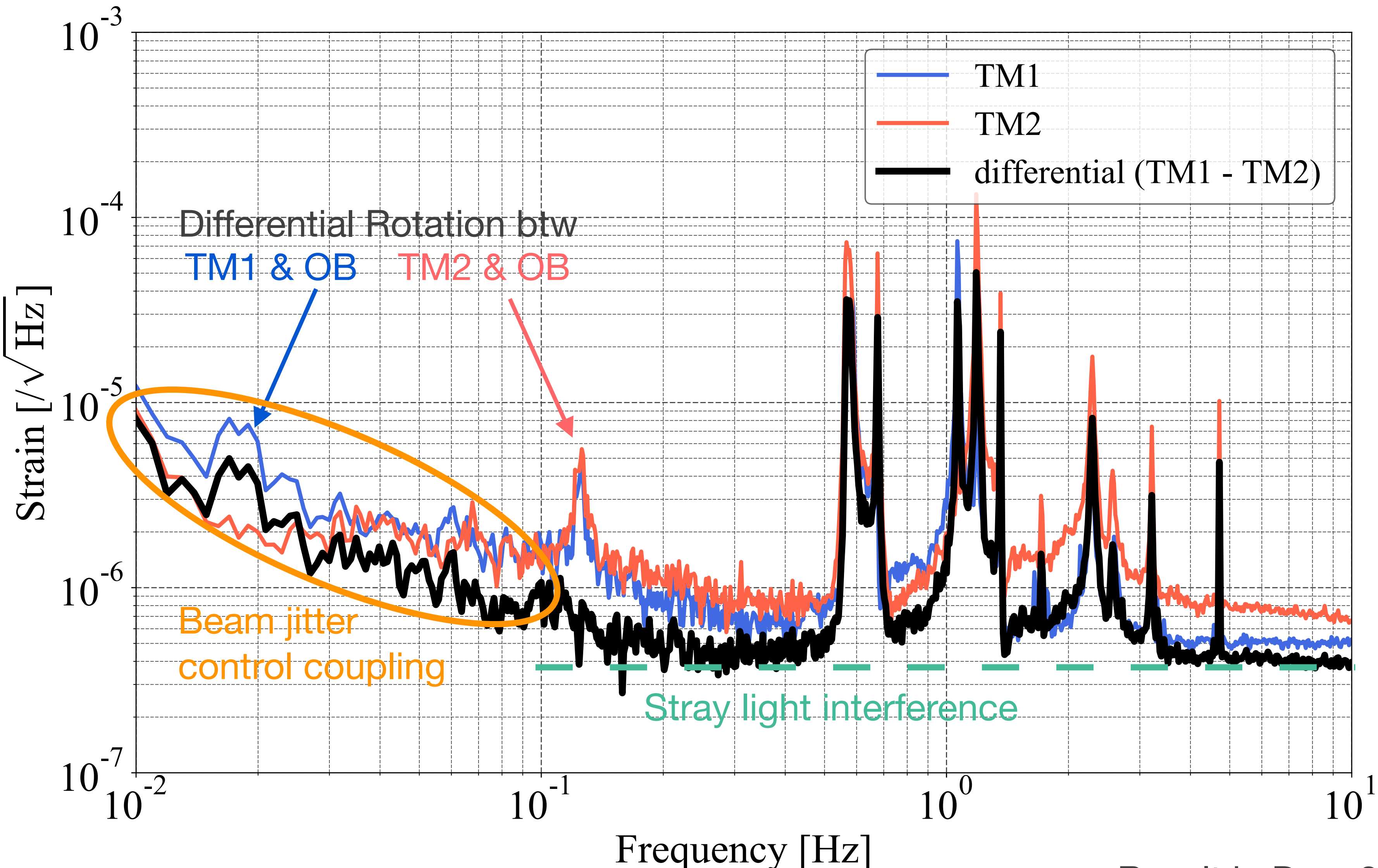
Sensitivity of one TM

- Limited by **beam jitter**, **interference of stray light**
- Unexpected noise: **magnetic noise** due to eddy current flowing TM



Result in Dec. 2019

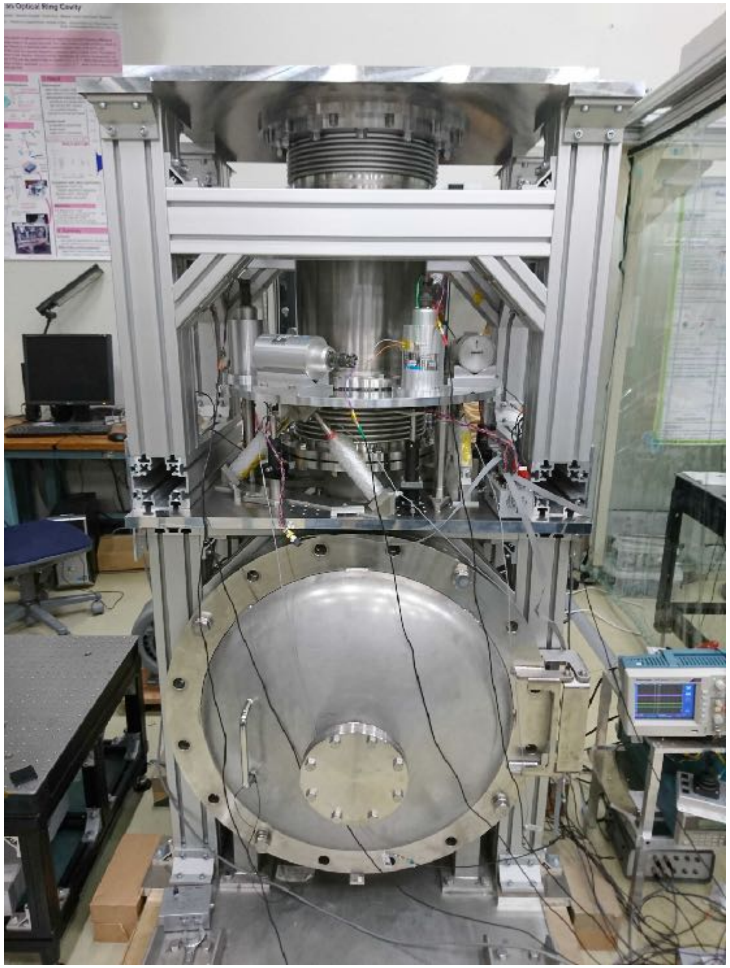
Sensitivity of differential motion



Result in Dec. 2019

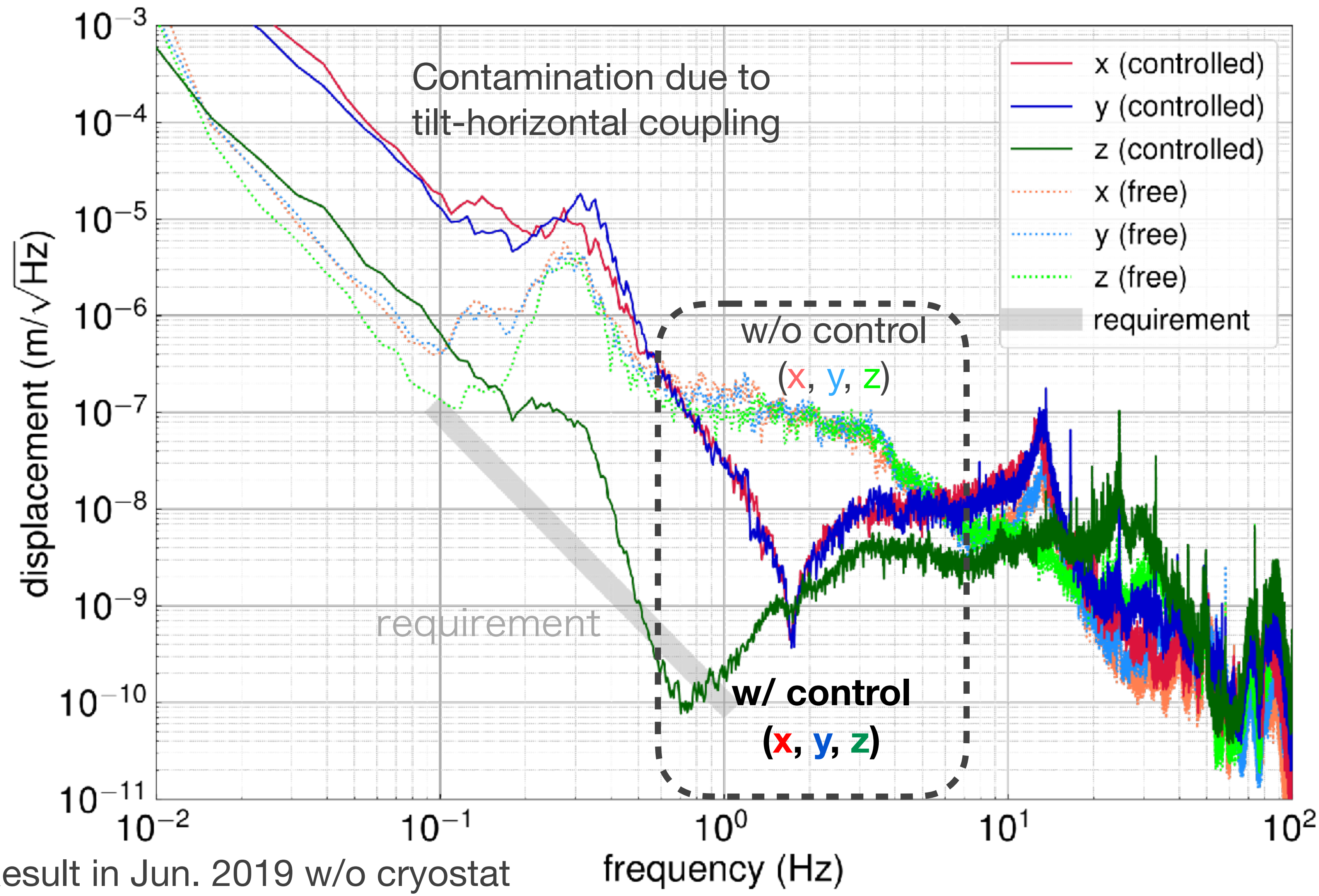
Active Vibration Isolation System

- Tested w/o the suspension and the cryostat
- Tiltmeter is not install



- Sensor: L4C (inertial) x6, PS (local) x6
- Actuator: PZT (range: ~60μm) x6

Performance of AVIS



Result in Jun. 2019 w/o cryostat

Current achievements

- Cryogenic Suspension System
  - Cooling System
    - Succeeded in cooling doen to 6.1 K
    - Cooling speed is slower than expected

- Active Vibration Isolation
  - Reduction of translational seismic noise
    - Succeeded in controlling 3 DoF simultaneously
    - Need to decouple tilt from horizontal motion
  - Reduction of vibration induced by cooler
    - Test with cryostat

Update Plans

Next update:

- ▶ Improvement of optical system, magnetic noise reduction

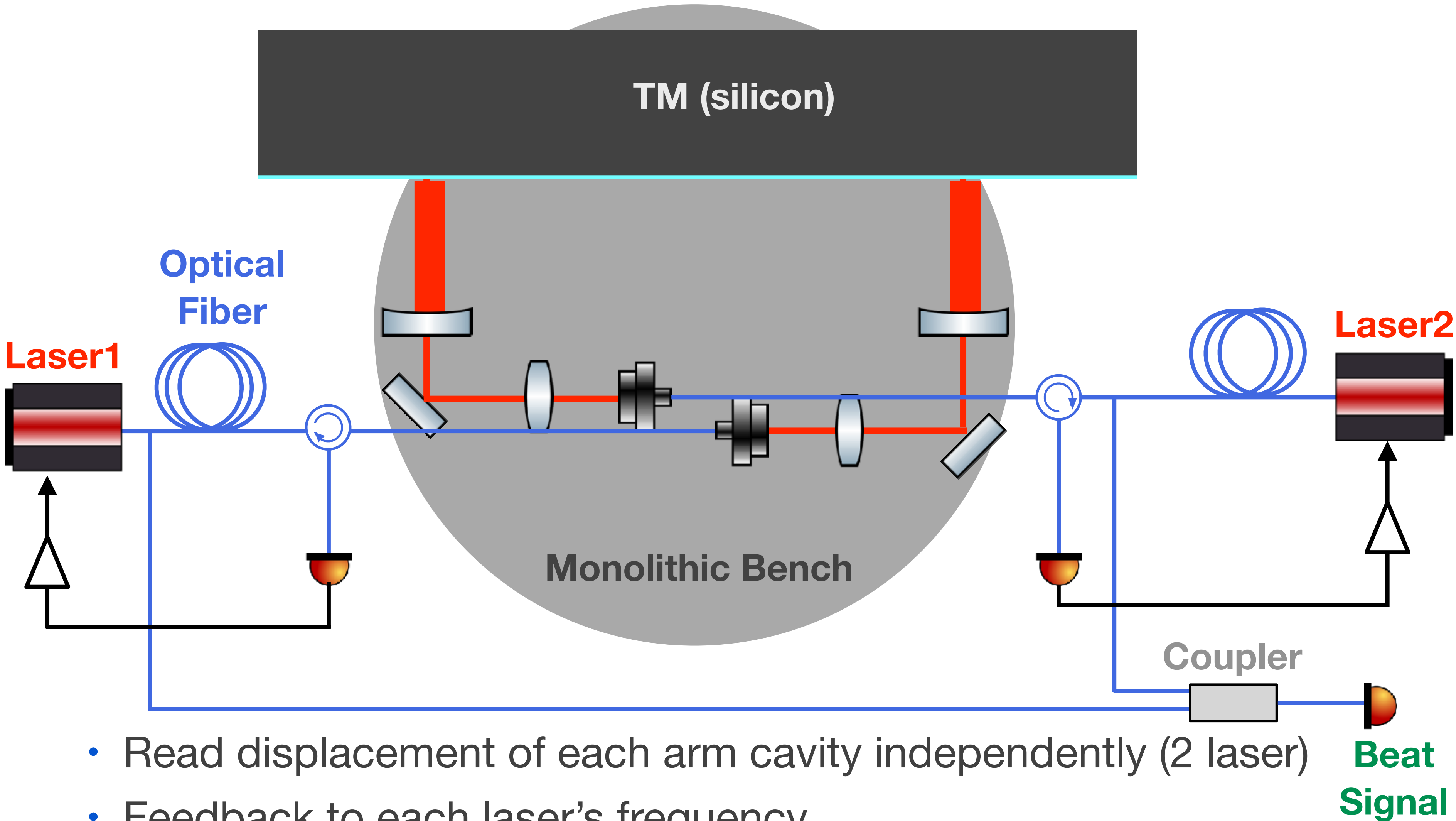
Mitigation of Magnetic noise

- Reduction of eddy current → silicon TM
  - ▶ Improvement of optical system & magnetic noise reduction

Improvement of optical system

- Introduce light to OB via optical fibers
- Make OB as a monolithic interferometer

Basic Optical Design



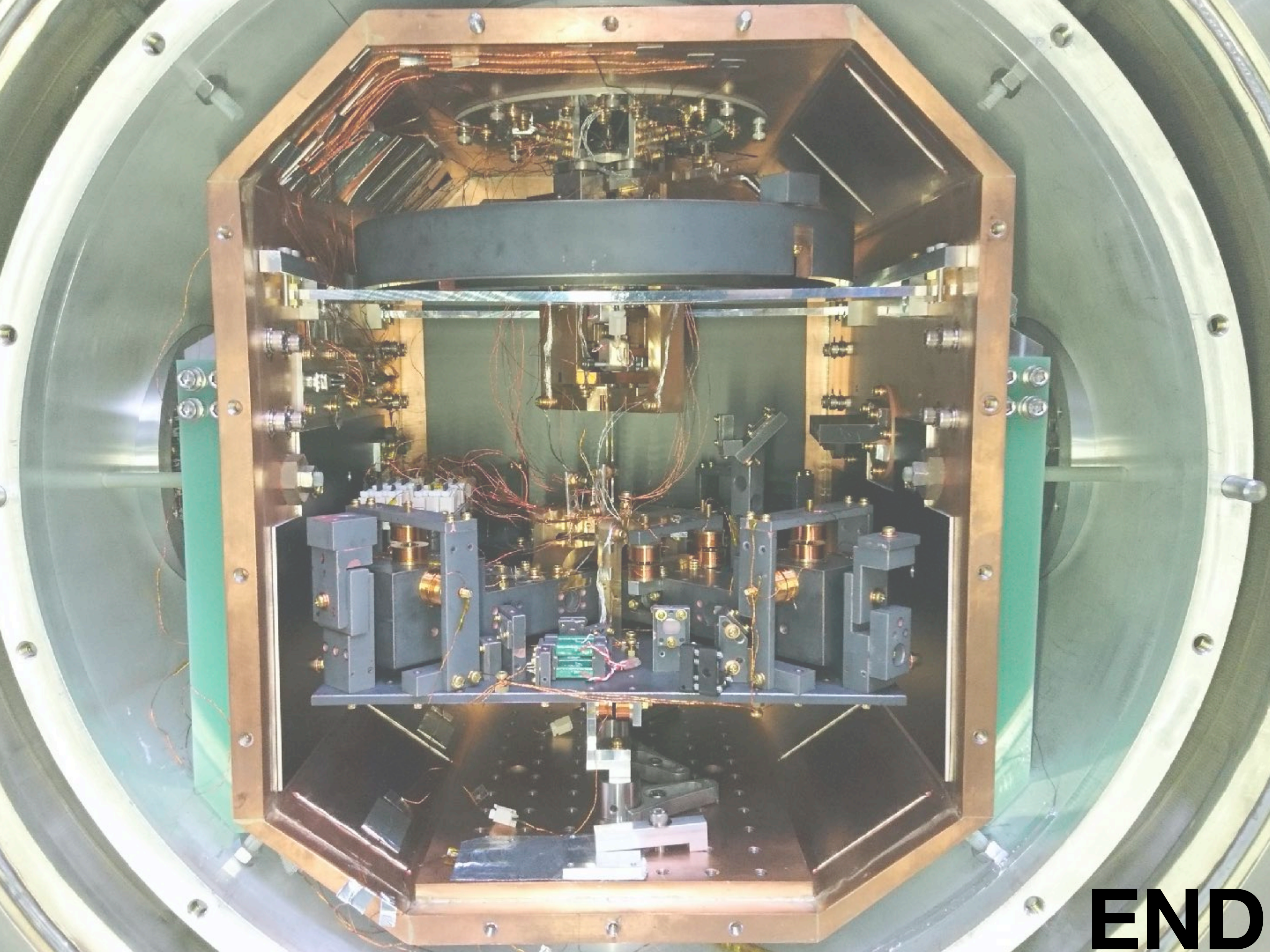
- Read displacement of each arm cavity independently (2 laser)
- Feedback to each laser's frequency
- Measure beat frequency to read differential motion

Summary

- Current achievement
  - ◉ Cryogenic → basically demonstrated
    - ▶ Need some improvements (cooling speed, achieved temp.)
  - ◉ Active isolation vibration → 3 DoF controlled
    - ▶ Decouple tilt motion from horizontal translation

- Update Plan
  - ◉ Silicon TM
  - ◉ Monolithic optical system

- On-going issues
  - ◉ Development of high-Q silicon fiber
  - ◉ Demonstration of coupled WFS

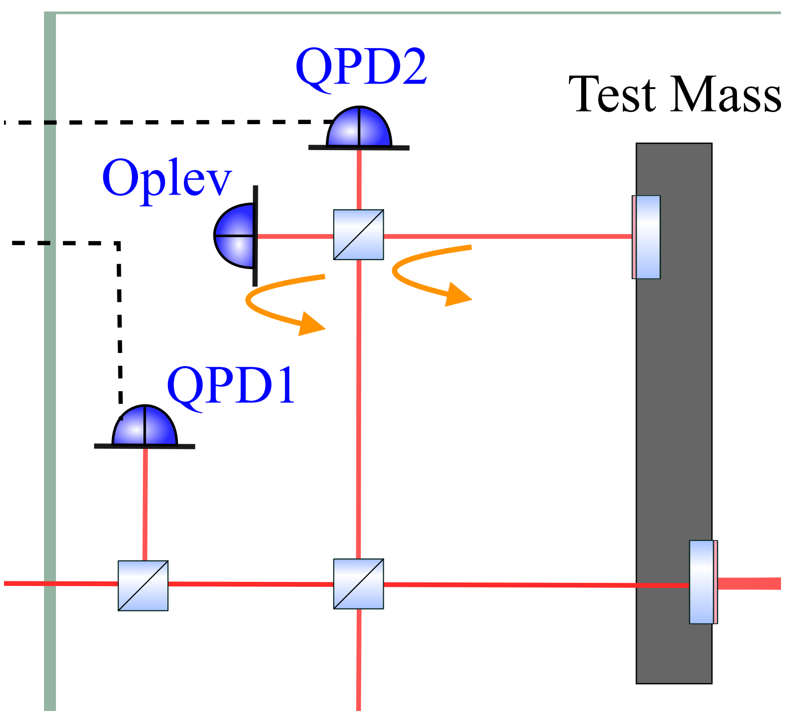


END

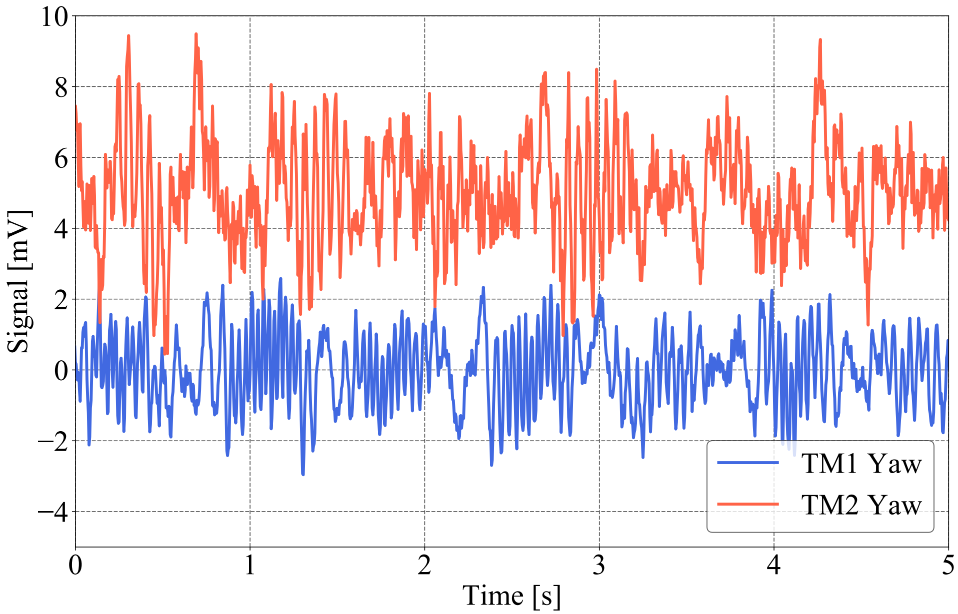
Stray Light Problem

Front reflection at

- Cube BS
- QPD surface
  - Stray light



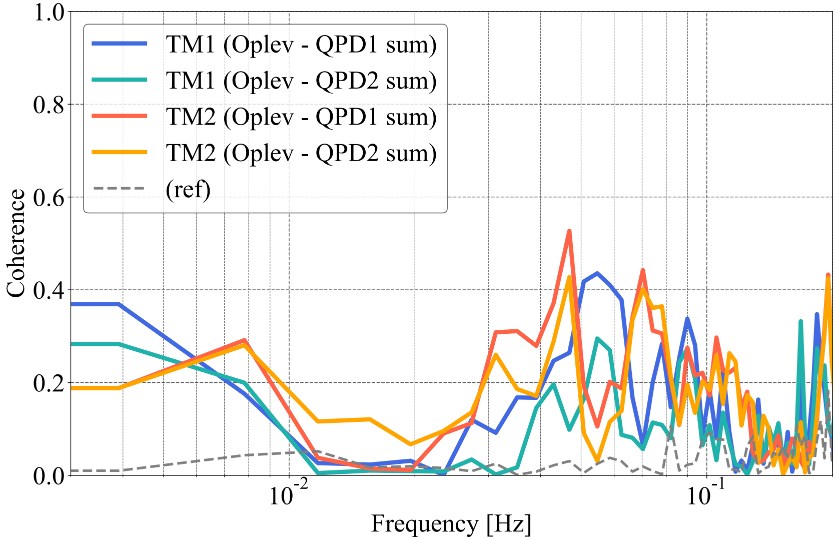
Interference with stray light contaminates oplev signal

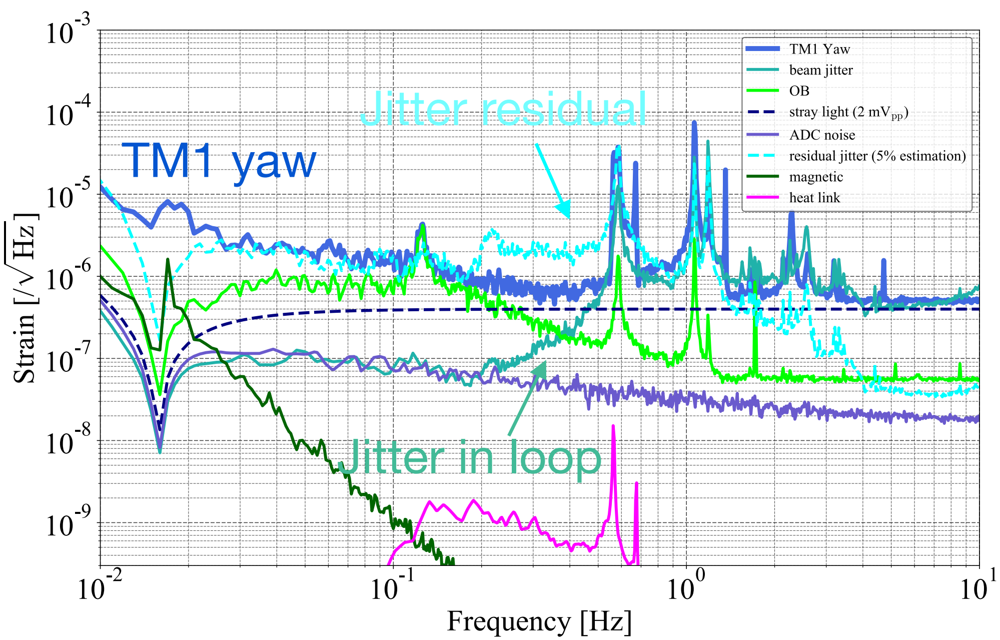


Beam Jitter Control Noise

- Some coherence btw TM oplev yaw & Jitter QPD sum
  - ▶ Beam jitter control signal shakes beam additionally
  - ▶ Contaminates oplev signal

Coherence btw
TM oplev yaw & QPD sums



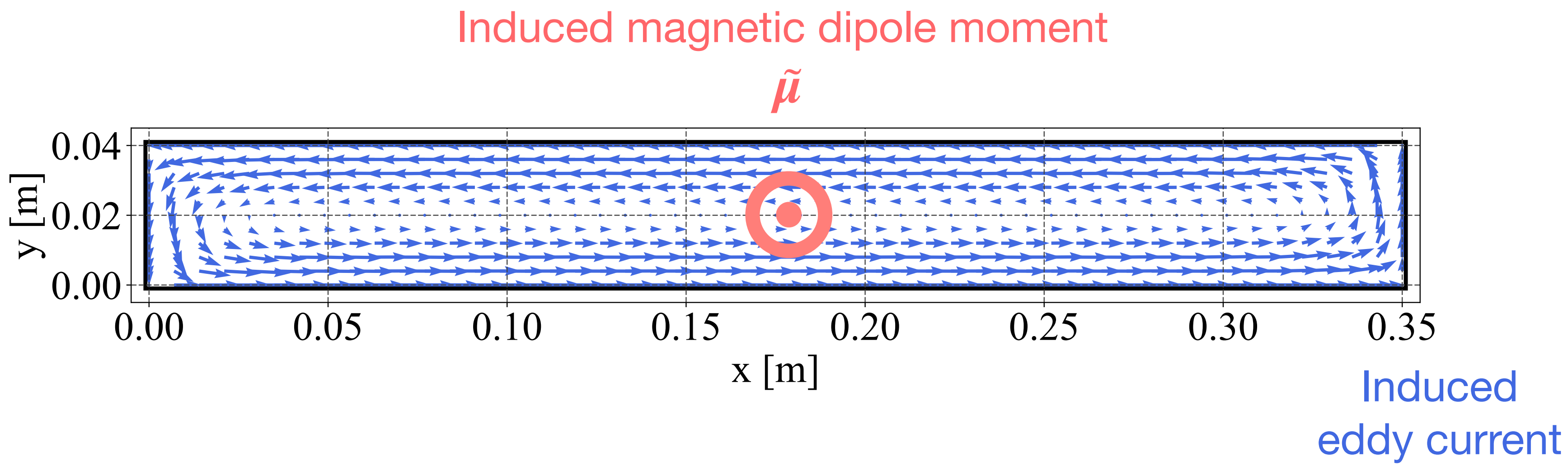


5% residual assumption

- ▶ can be explained the noise budget well

Magnetic Noise Due to Eddy Current

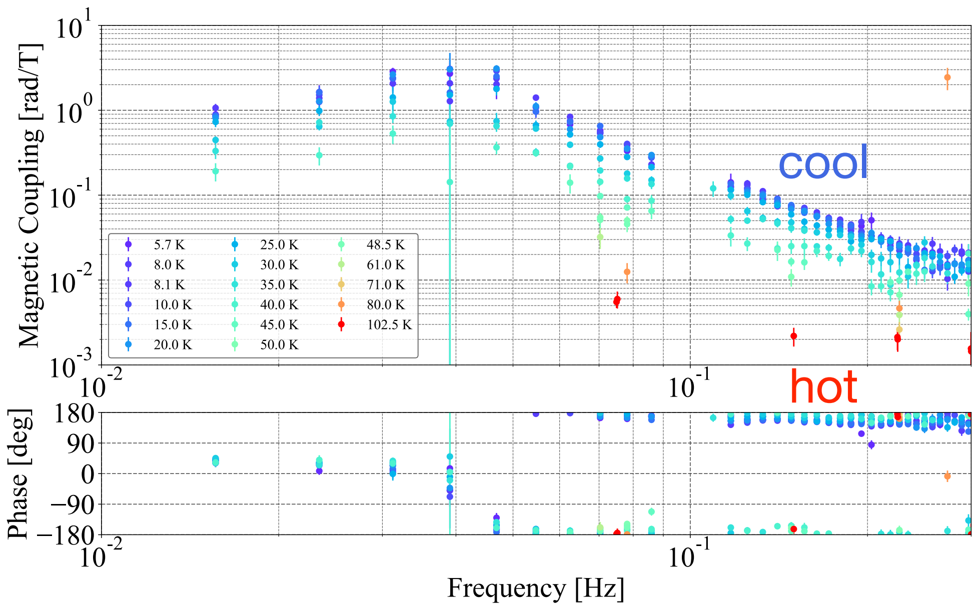
- Ambient magnetic fluctuation induces eddy current
  - TM has magnetic dipole moment $\tilde{\mu}$



  - This $\tilde{\mu}$ induces torque noise $\tilde{\boldsymbol{\mu}} \times \boldsymbol{B}$ with DC magnetic field $\boldsymbol{B}$

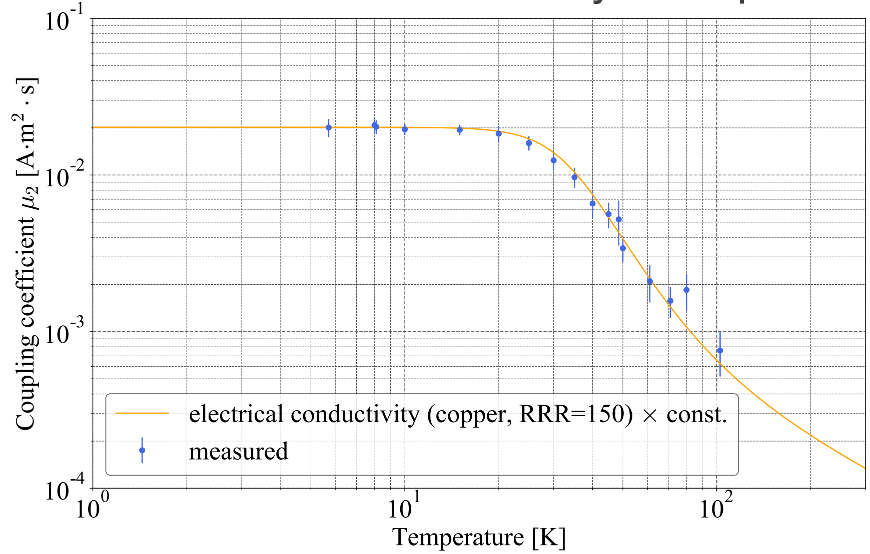
Magnetic Noise Due to Eddy Current

- Induced eddy current ∝ electric conductivity
- For metals electric conductivity gets larger when cooled down
  - ▶ Coupling gets larger at lower temperature



Transfer function
from magnetic fluctuation to TM yaw

Electrical conductivity of coper



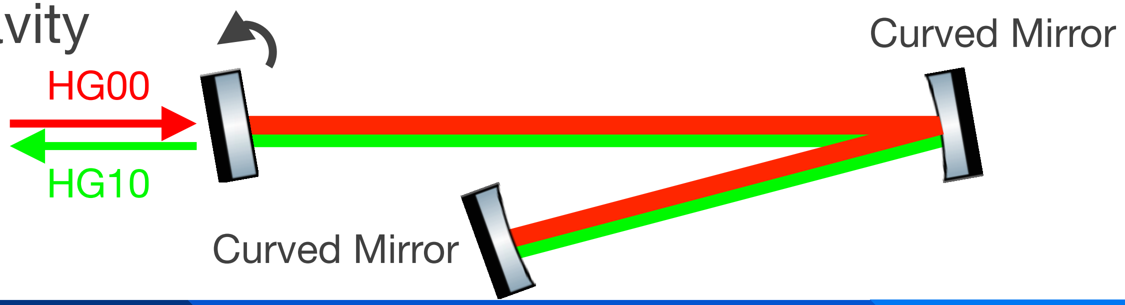
High Sensitive Angular Sensor

Cavity-enhanced wave front sensor (new idea)

- Compensate Gouy phase difference between HG00 and HG10
  - HG10 mode resonates as well as HG00
  - Induced HG10 is enhanced
  - Higher sensitivity than normal WFS

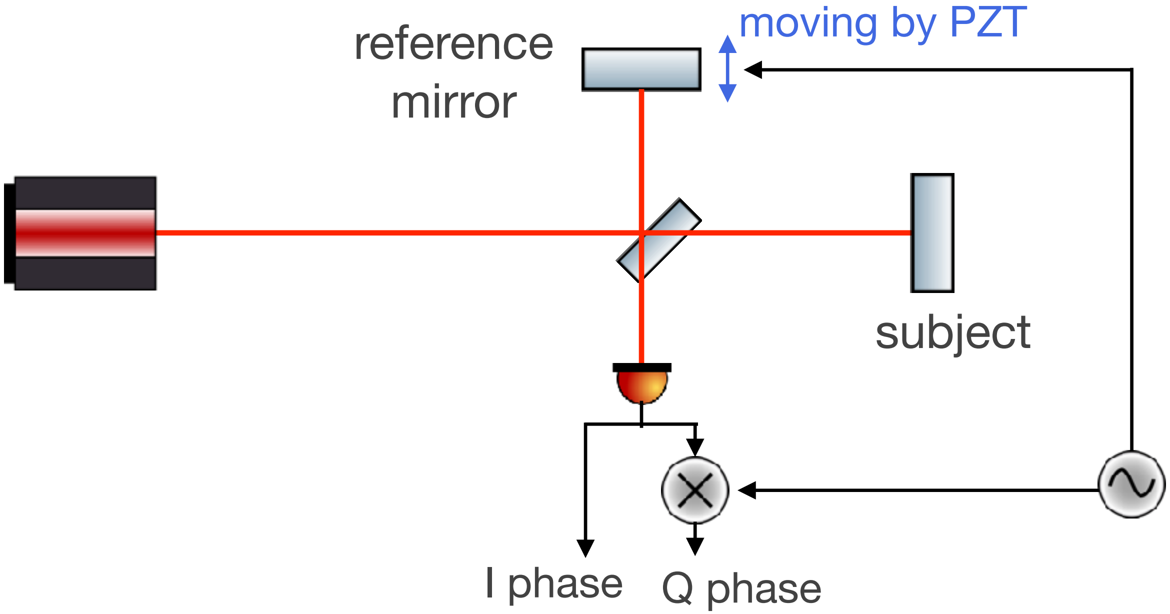
    5×10^{-16} rad/$\sqrt{\text{Hz}}$ @ 0.1 Hz
- How to compensate
  - Auxiliary cavity

  - Folded cavity

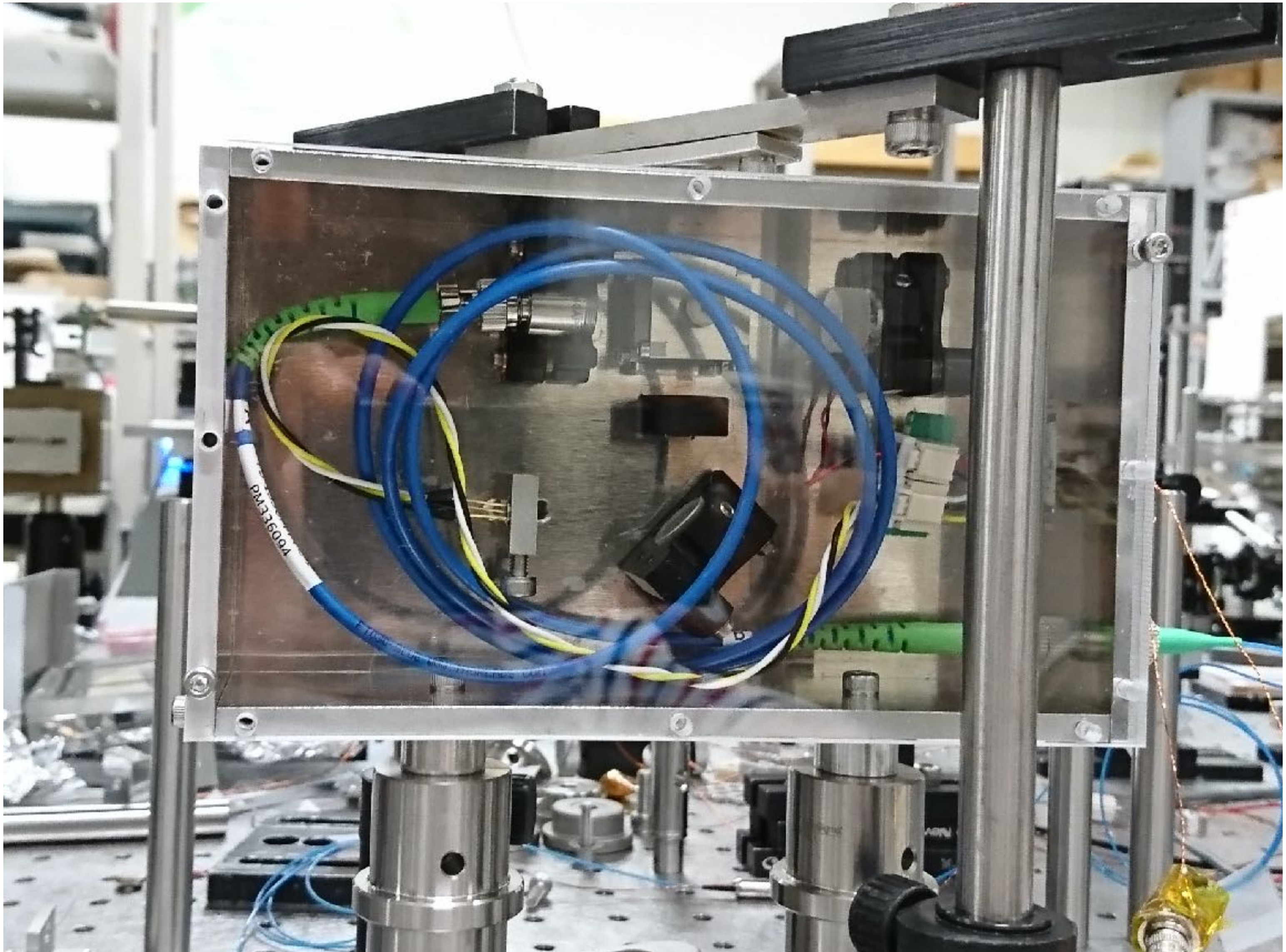


Local Quadrature Interferometer

- Quadrature Interferometer for a local sensor of AVIS
- Michelson interferometer with a dithered reference mirror
  - Resolution: same as Michelson interferometer
  - Range: ∞ (ideally)
- No polarization optics
- Generate quadrature signal by moving reference mirror



Picture



Performance