Control of the KAGRA Cryogenic Vibration Isolation System

Koki Okutomi

Sokendai / NAOJ / KAGRA VIS subgroup

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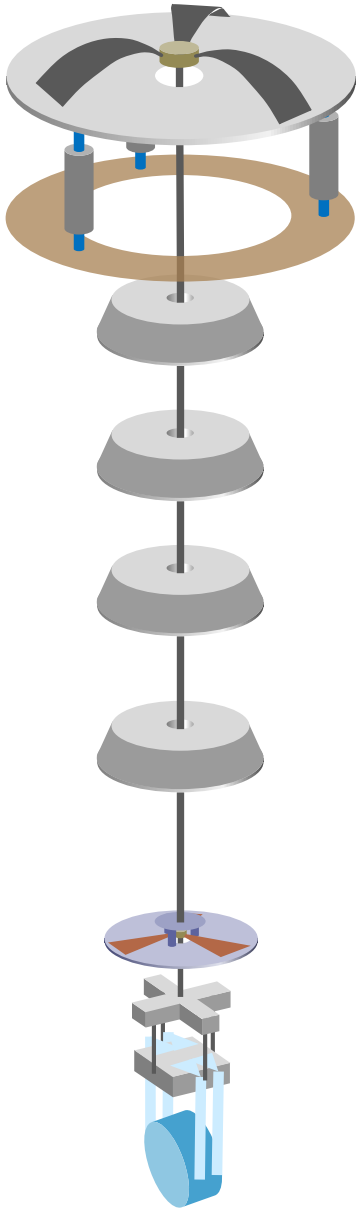
Contents

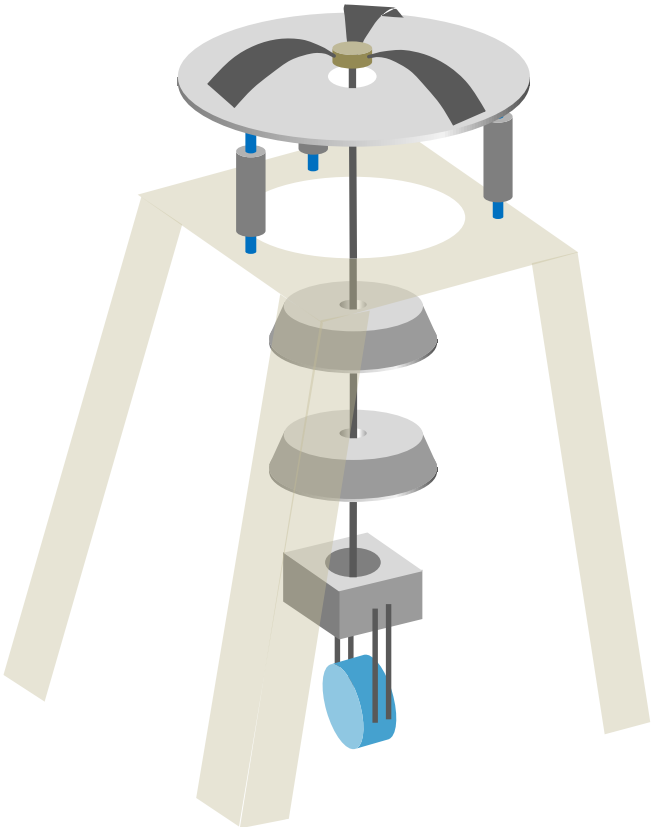
- KAGRA cryogenic suspension: Type-A SAS
- Modal damping control of Type-A SAS
- Cryogenic and underground issues

Seismic Attenuation Systems in KAGRA

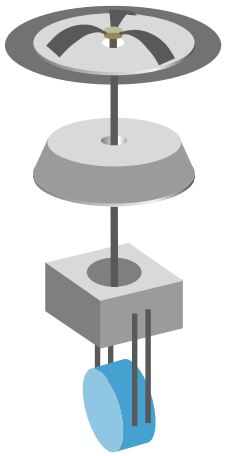
Type-A



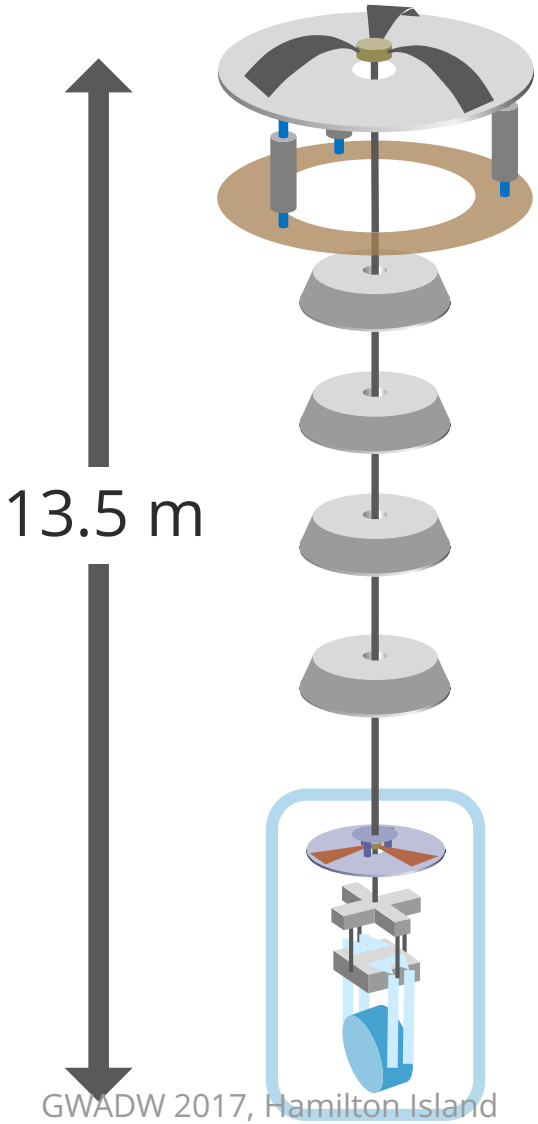
Type-B

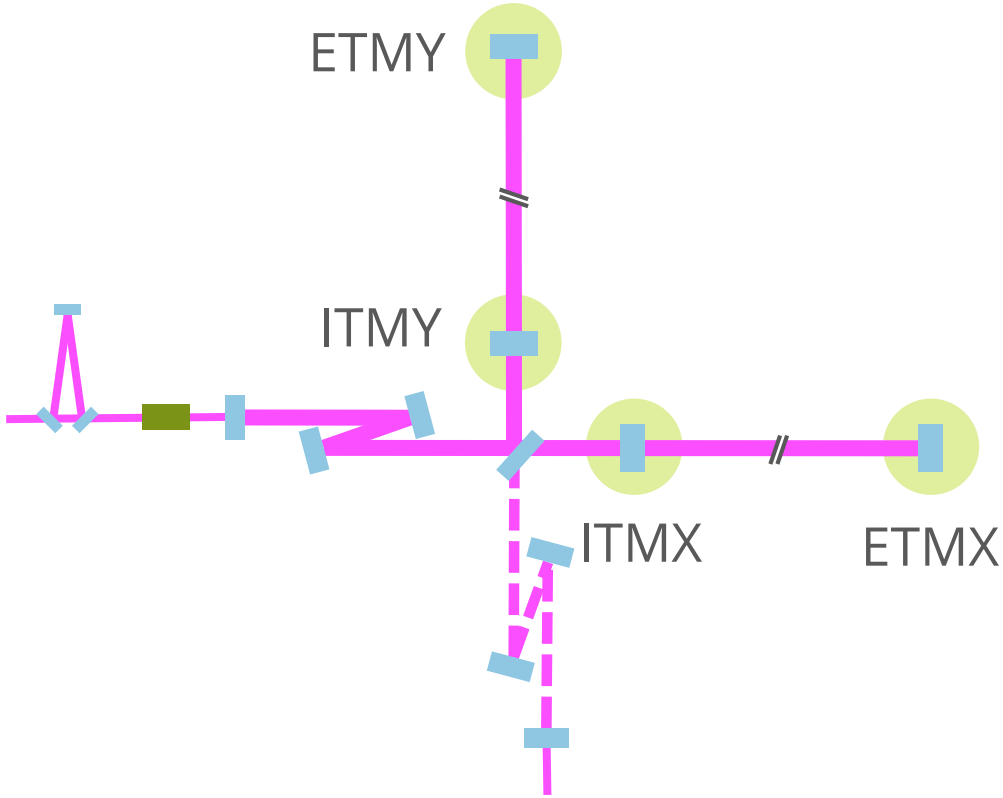


Type-Bp



Type-A SAS

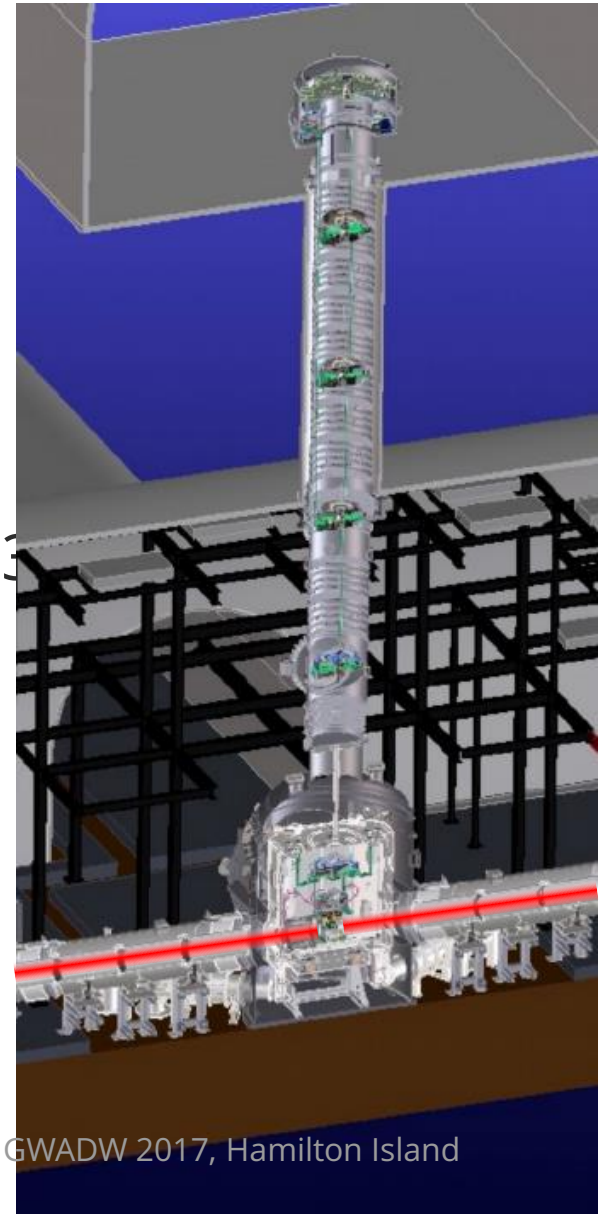


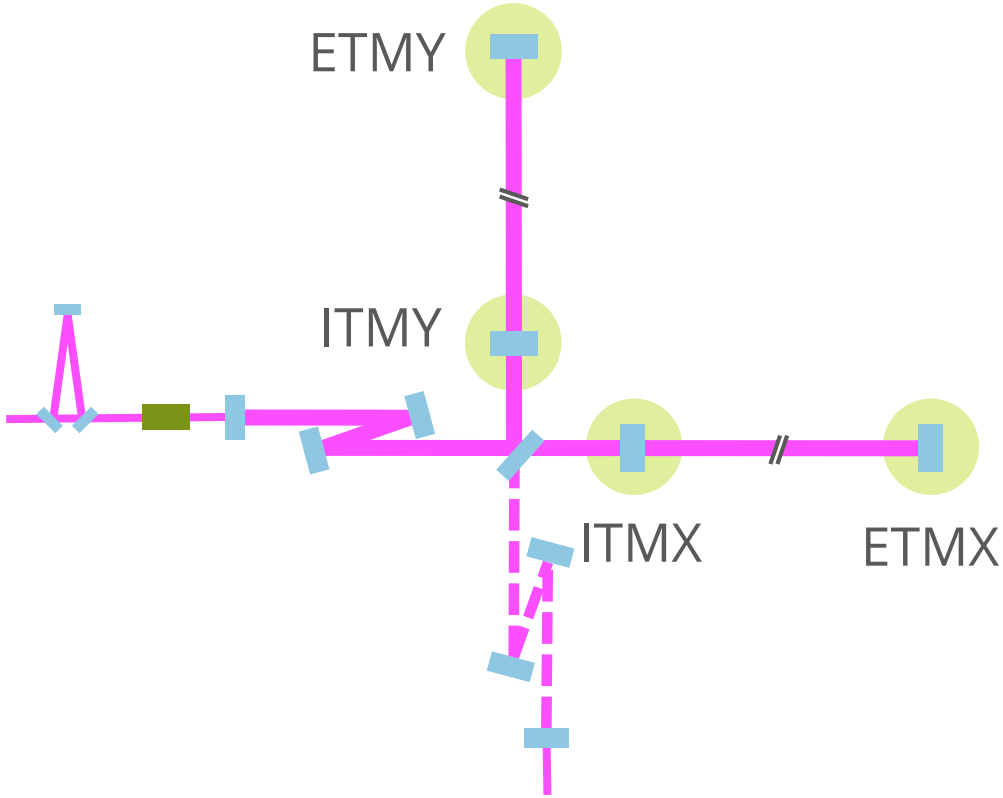


Suspension for arm cavity mirrors

- Tower (room temperature)
- Cryogenic payload

Type-A SAS



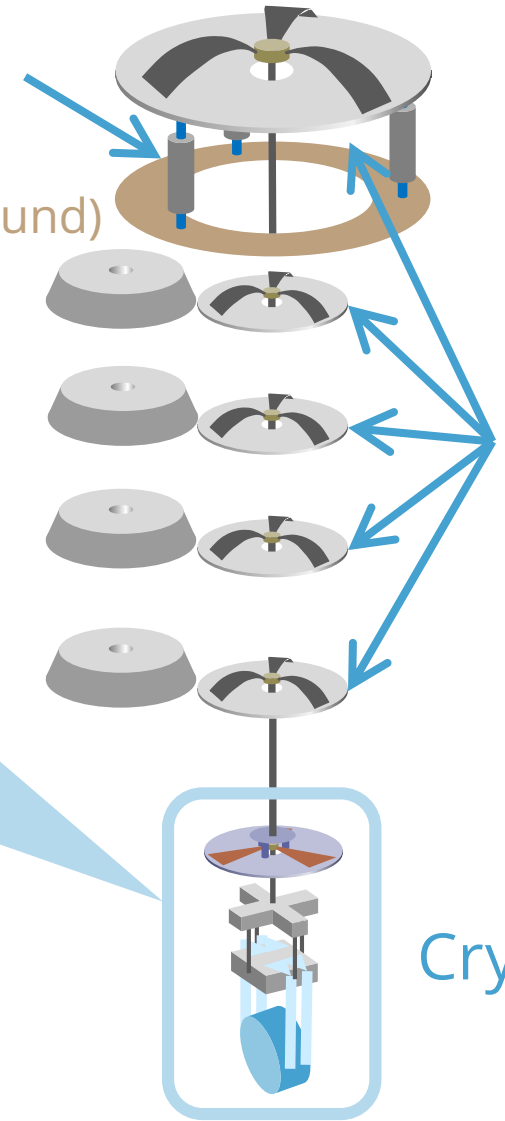


Suspension for arm cavity mirrors

- Tower (room temperature)
- Cryogenic payload

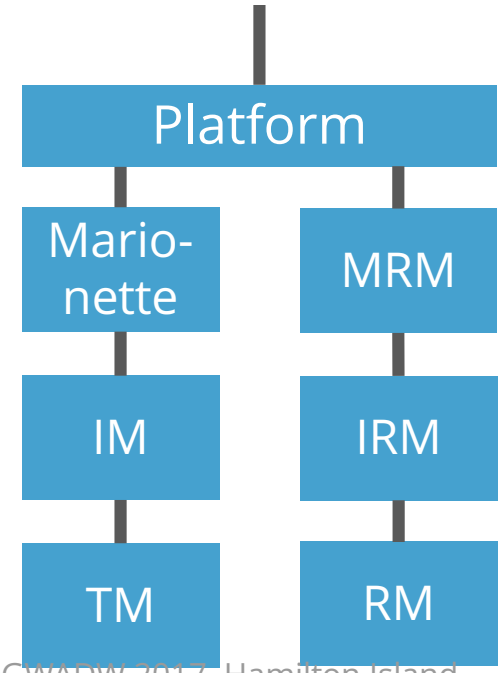
Features of Type-A SAS

Inverted pendulum legs



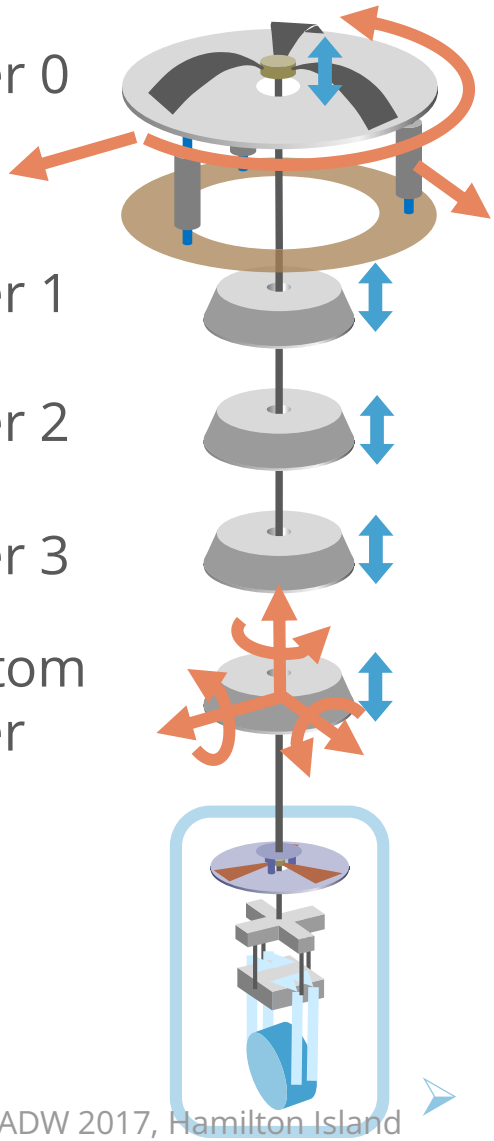
Geometric Anti-Spring (GAS) filters

Parallel chain



Cryogenic payload

Observable DoFs (Tower)



F0 Long., Trans., Yaw

- LVDT
- Accelerometer

GAS relative Vertical

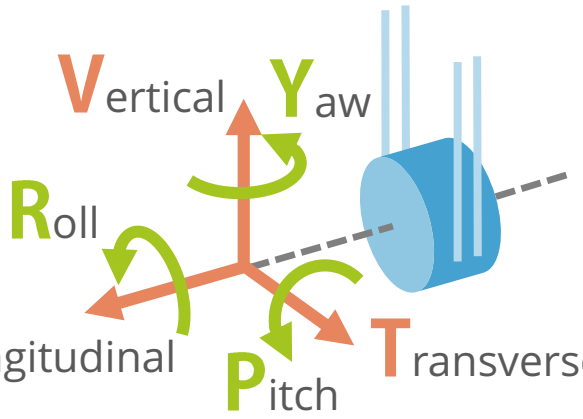
- F0-F1
- F1-F2
- F2-F3
- F3-BF
- BF-PF

- LVDT

BF 6DoFs

- (BF) LVDT

* From ground
or mass relative



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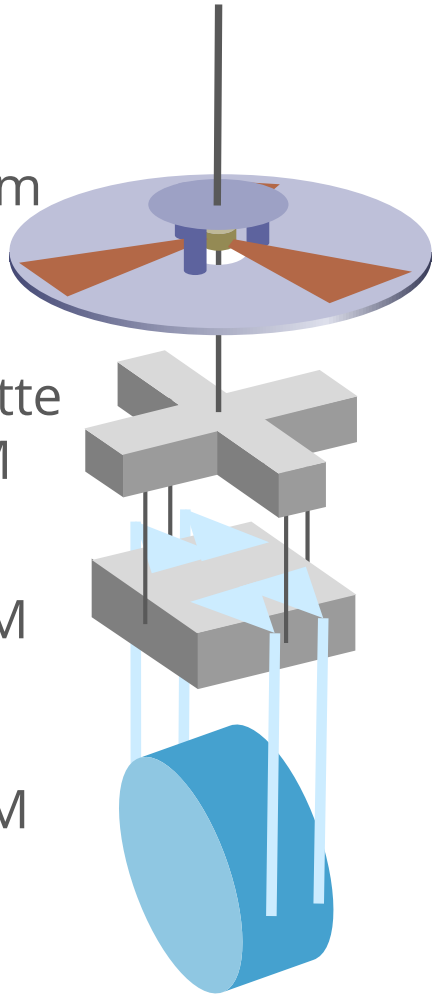
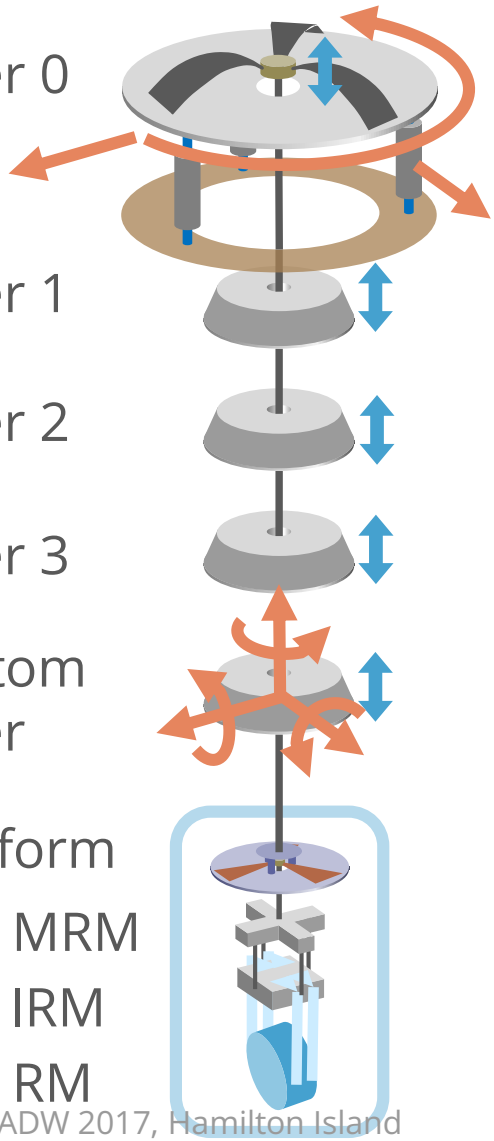
Observable DoFs (Payload)



PF Roll, Pitch, Yaw	• Optical lever
MN Roll, Pitch, Yaw	• Optical lever
MN-MRM 6DoFs	• Photo-sensor
IM-IRM 6DoFs	• Photo-sensor
TM Pitch, Yaw	• Optical lever

* From ground
or mass relative

Controllable DoFs



F0 Long., Trans., Yaw

GAS relative Vertical
- F0-F1
- F1-F2
- F2-F3
- F3-BF
- BF-PF

BF 6DoFs

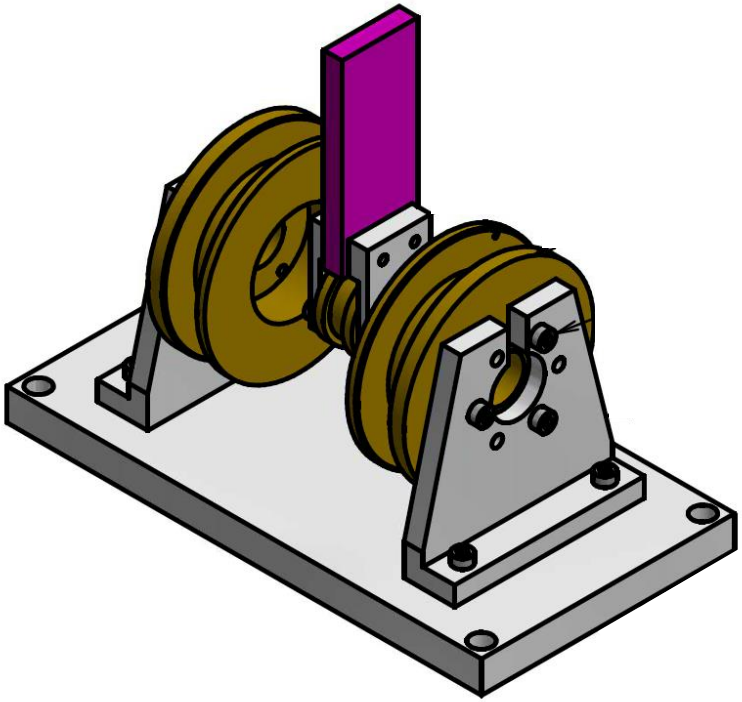
MN-MRM 6DoFs

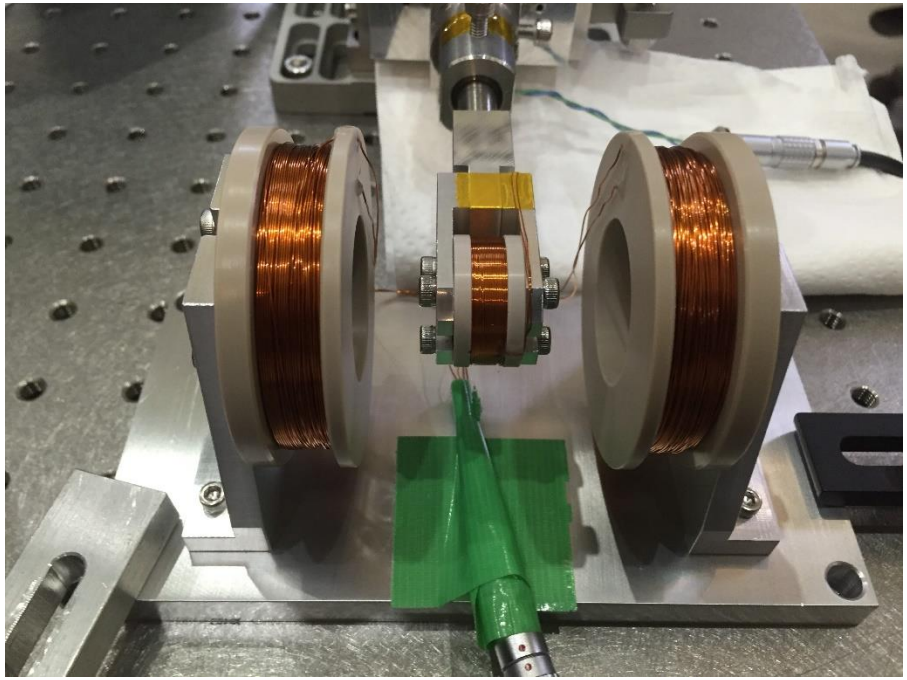
IM-IRM 6DoFs

TM-RM Long., Pitch, Yaw

Coil-magnet actuator (all)

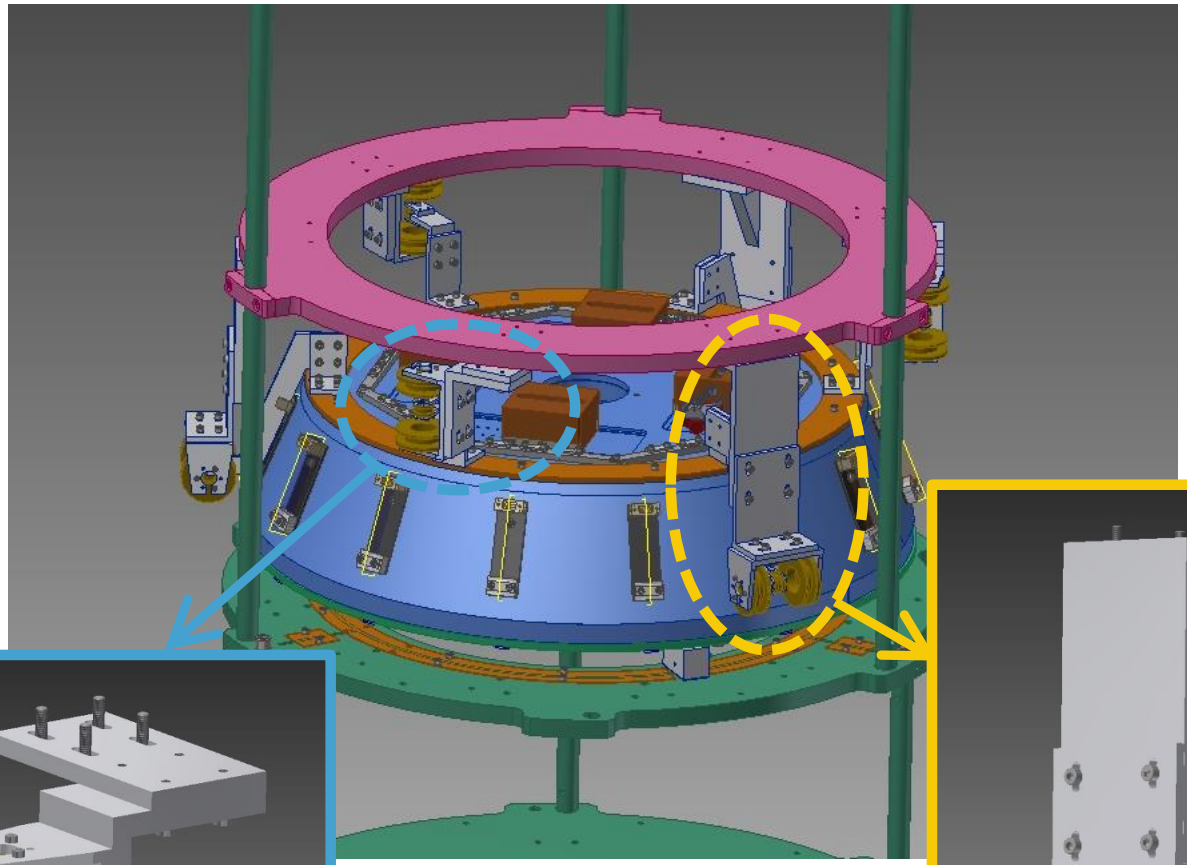
BF LVDT

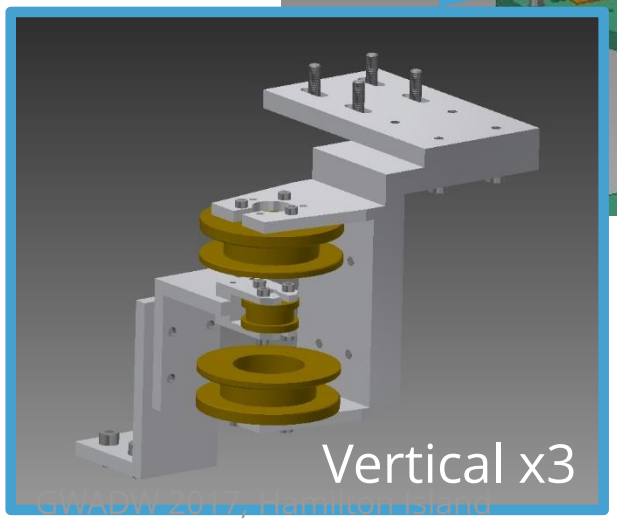


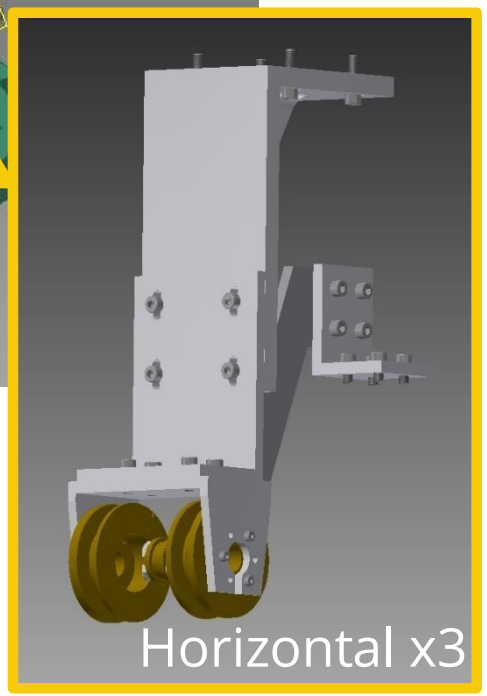


F7 LVDT in Adv. Virgo → re-designed for KAGRA

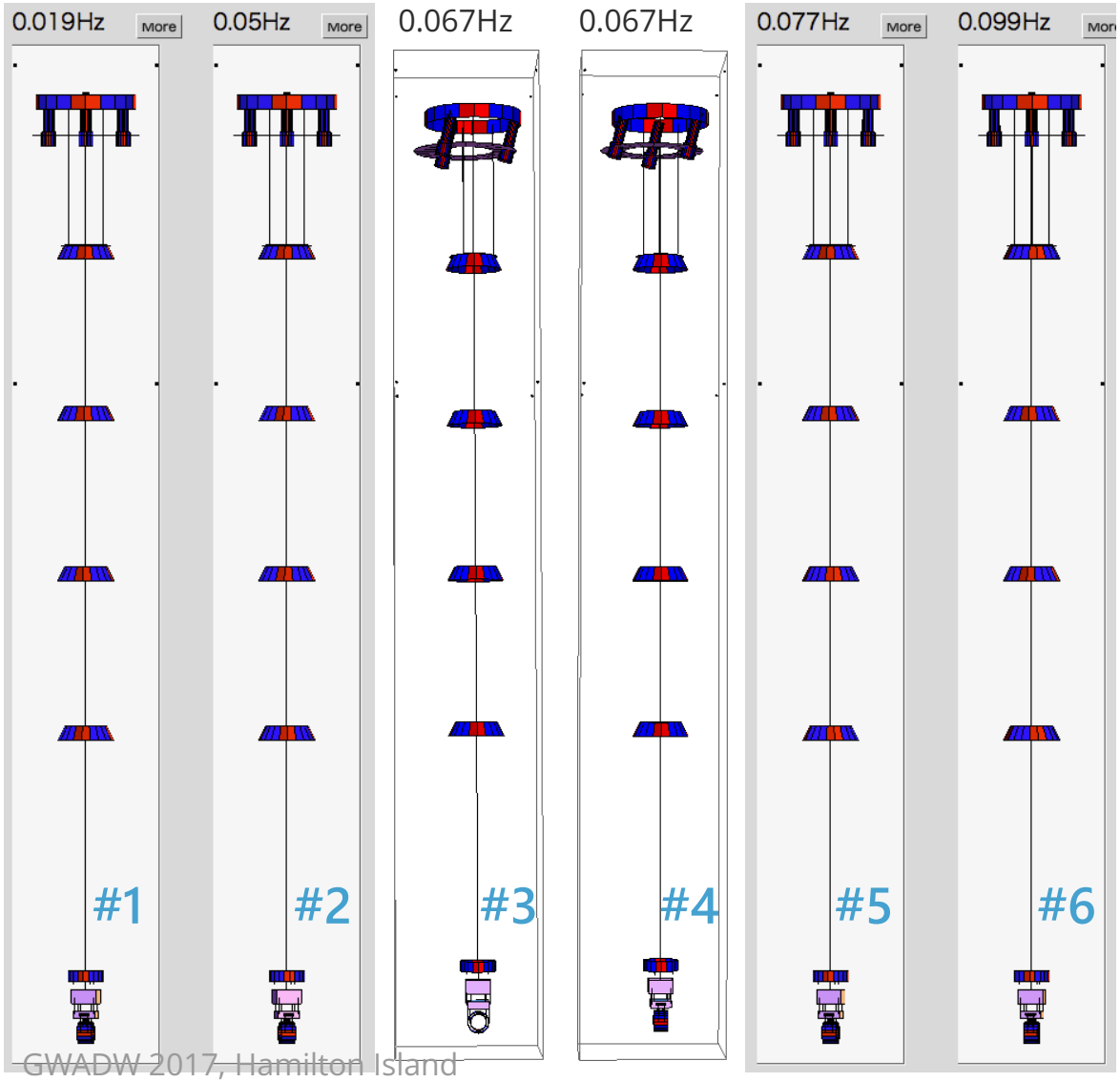
Configuration of BF LVDT







Eigenmodes in Type-A



#1: Y whole chain 0th

#2: Y whole chain 1st

#3: T whole chain 0th
IP translation

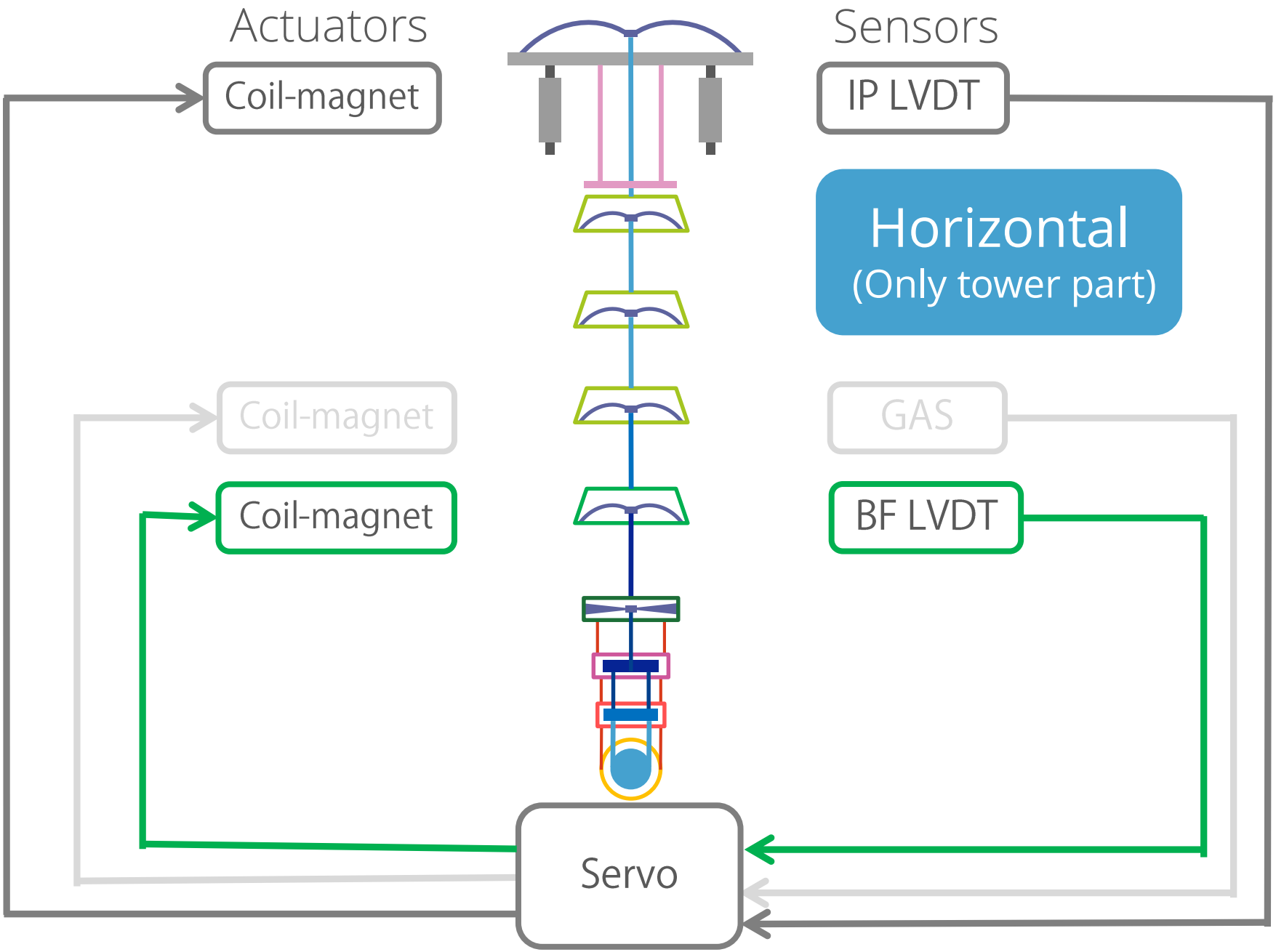
#4: L whole chain 0th
IP translation

#5: Y whole chain 2nd

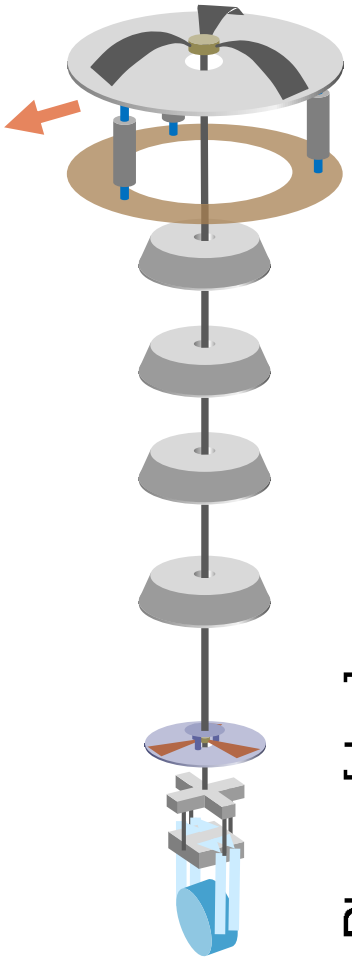
#6: Y whole chain 3rd

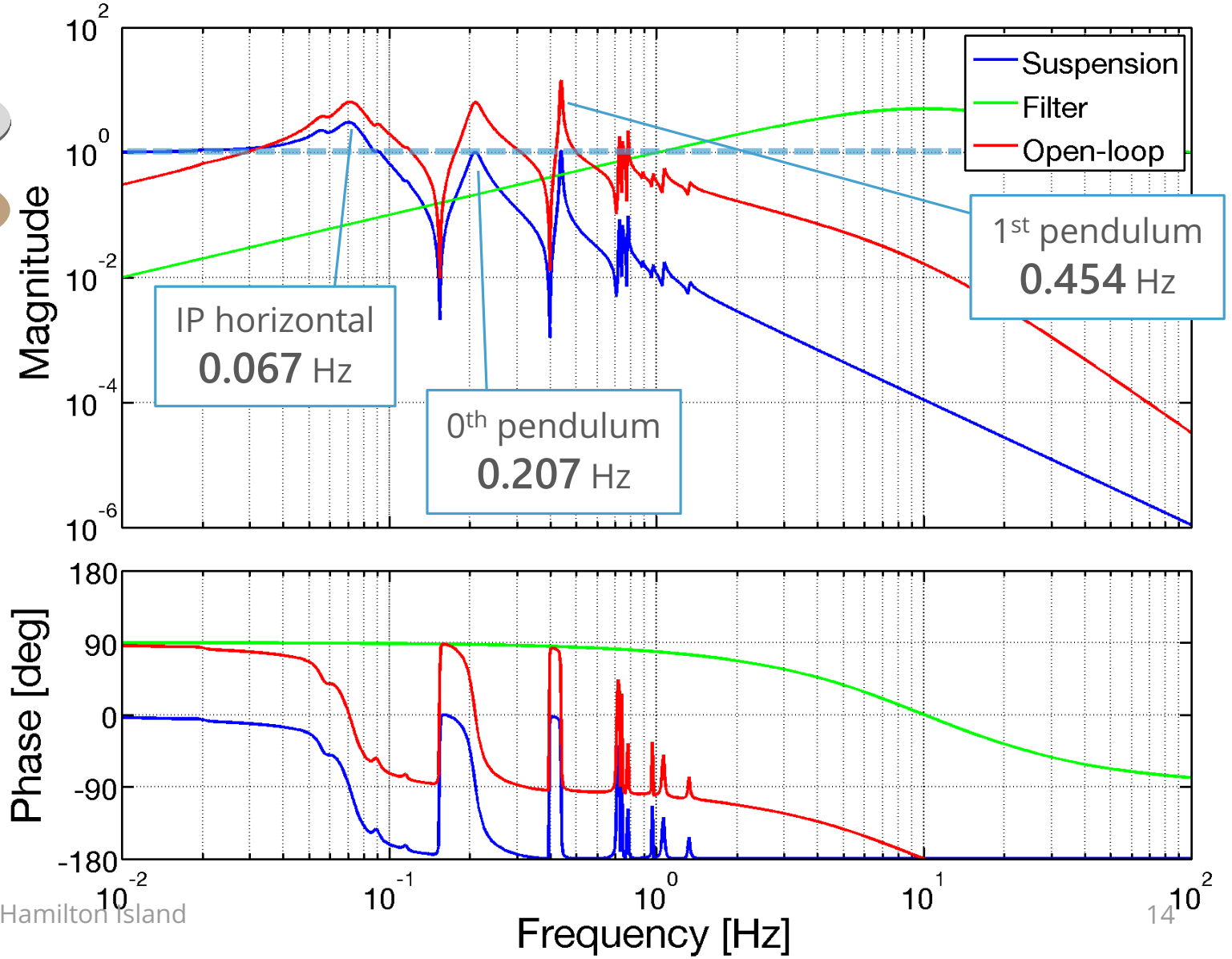
⋮ ⋮

Totally
75 eigenmodes

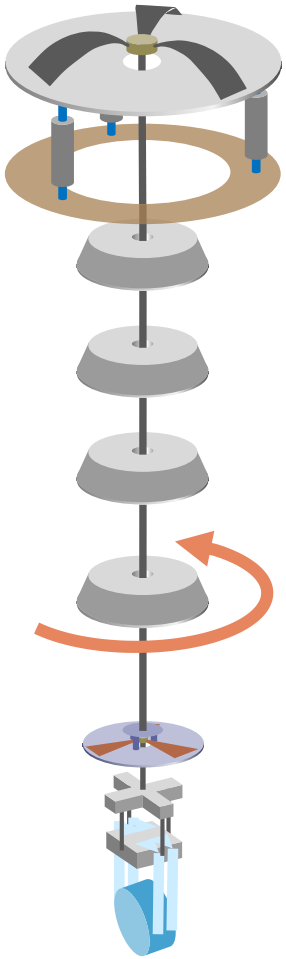

Actuators
Coil-magnet
Sensors
IP LVDT
Horizontal
(Only tower part)
Coil-magnet
GAS
Coil-magnet
BF LVDT
Servo

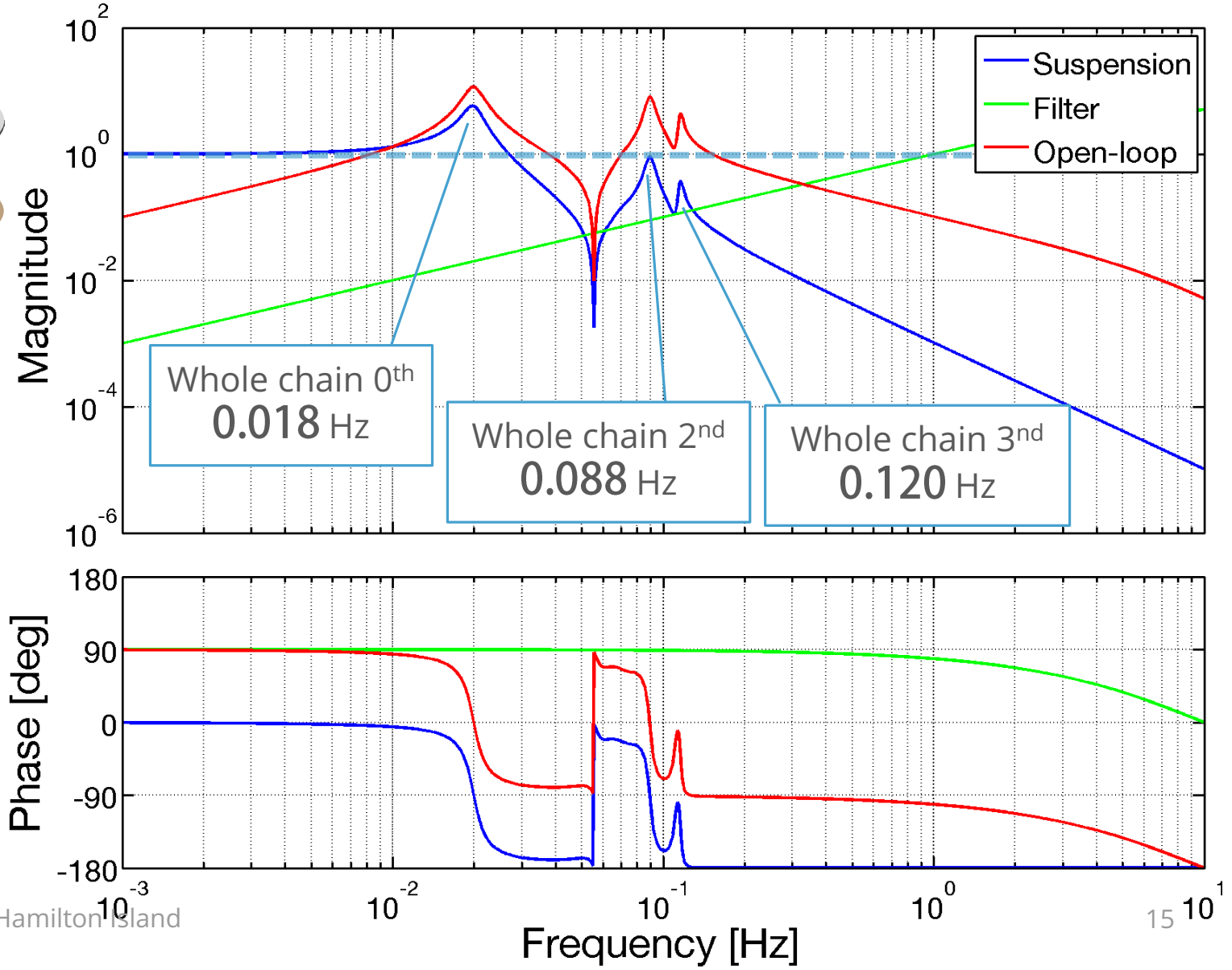
Open-loop TF (F0 Longitudinal)

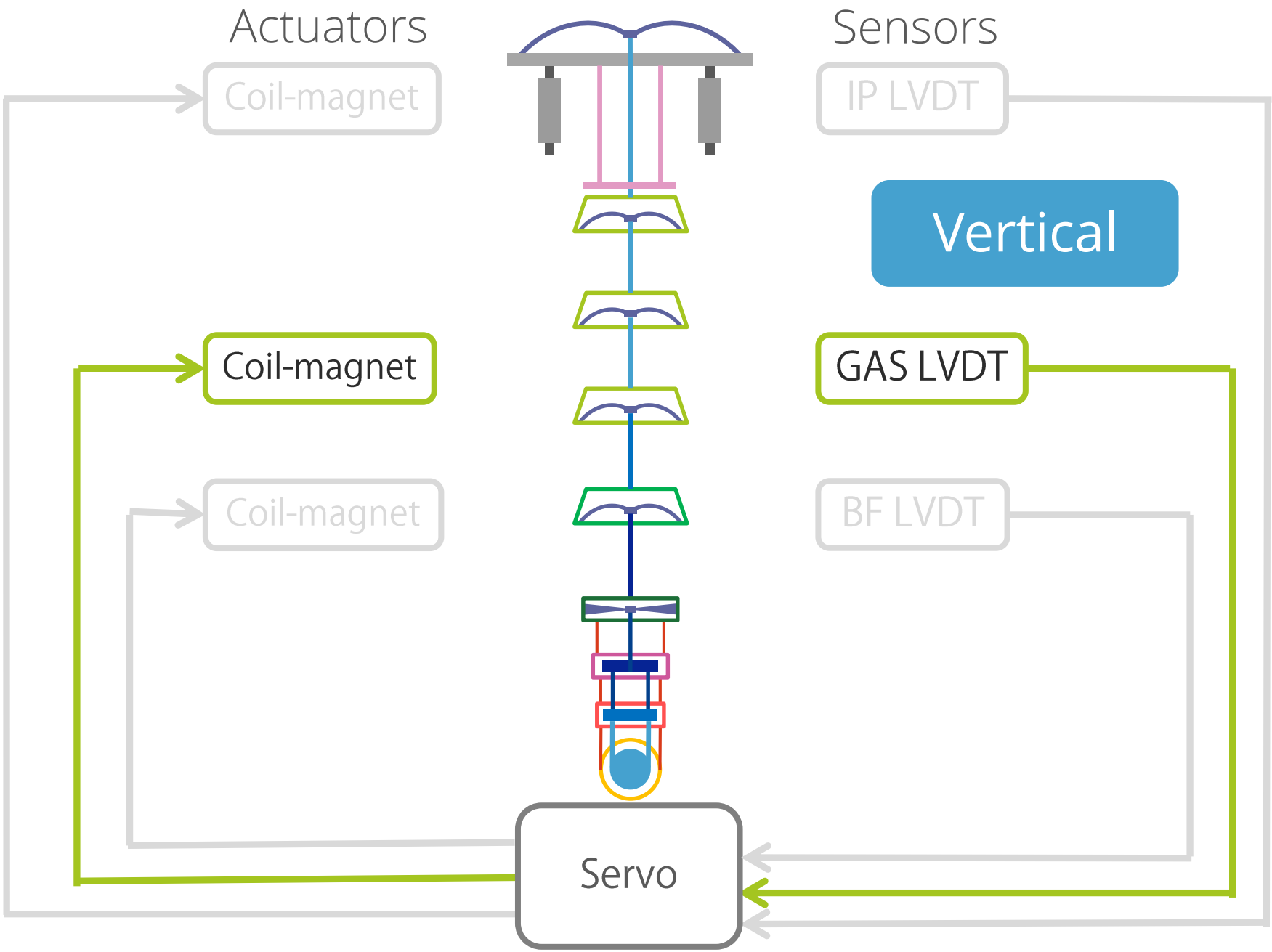




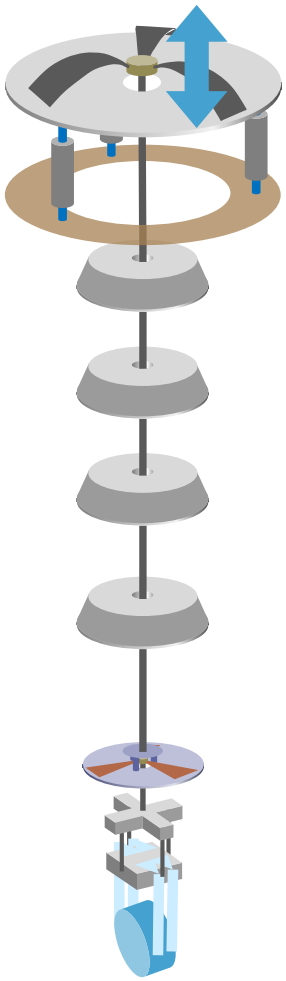
Open-loop TF (BF Yaw)

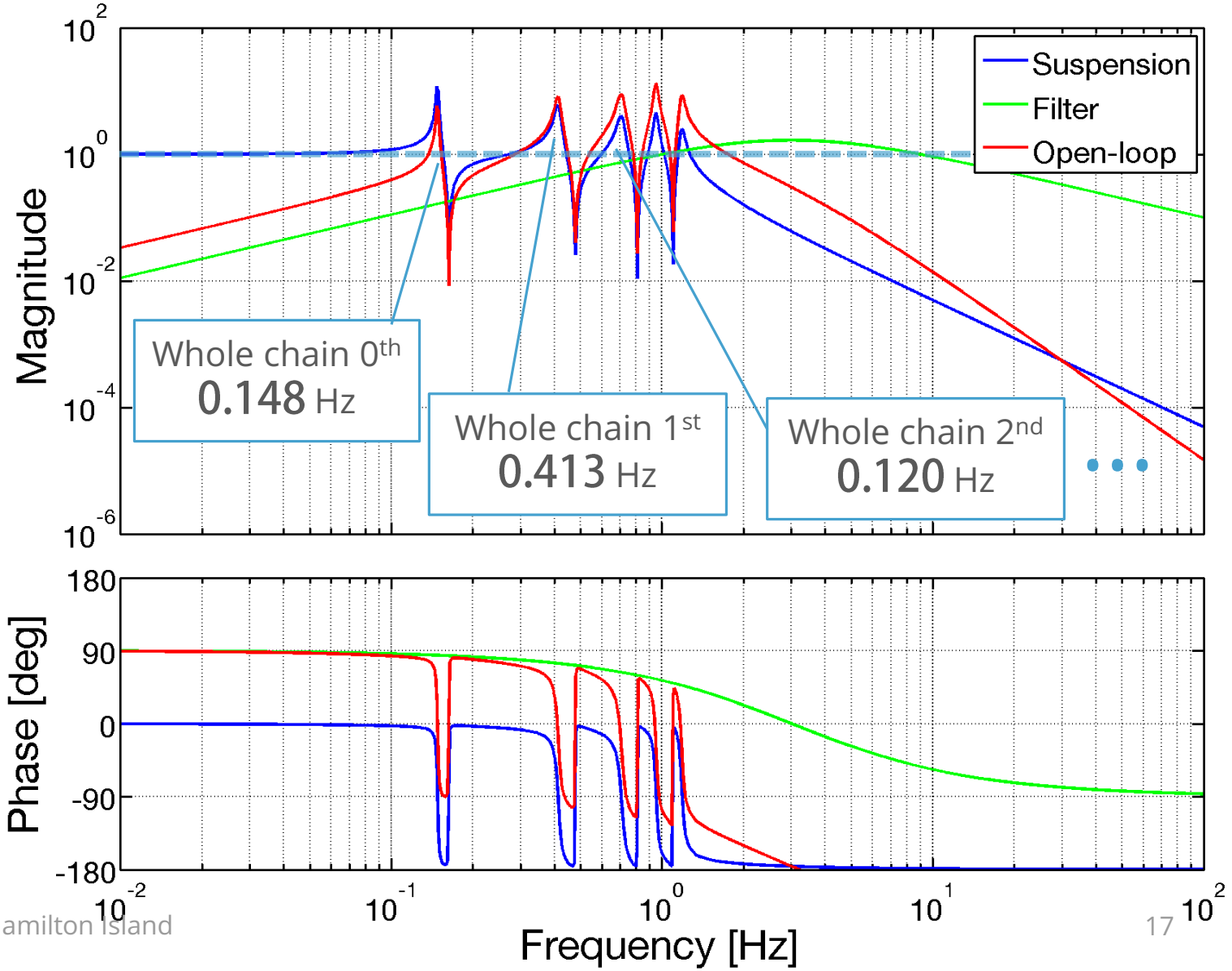




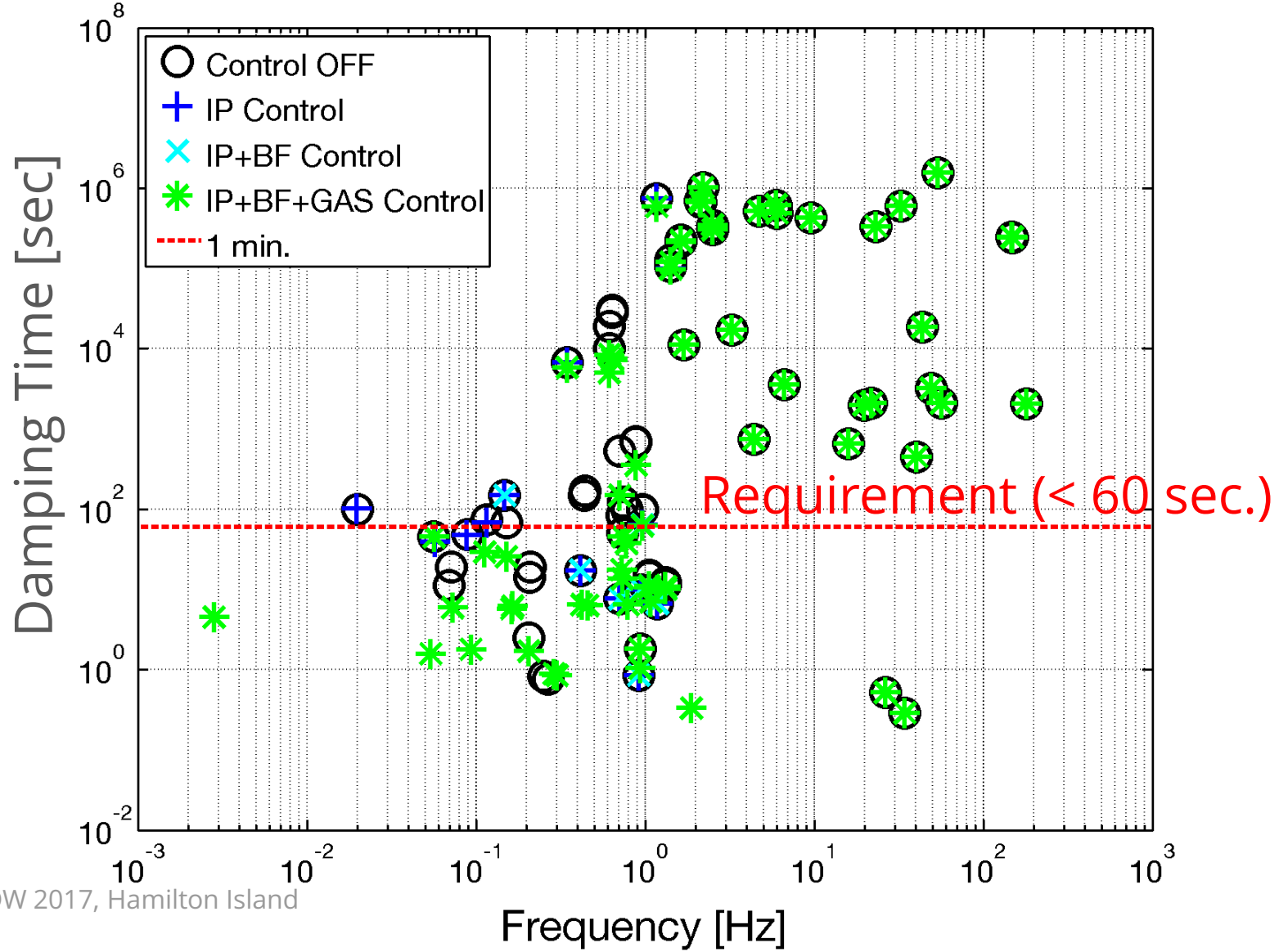

Actuators
Sensors
Coil-magnet
IP LVDT
Vertical
Coil-magnet
GAS LVDT
Coil-magnet
BF LVDT
Servo

Open-loop TF (GAS F0 Vertical)





Decay Time (IP + BF + GAS Damping)



Next To-do

Sensor blending on IP control

- LVDT displacement sensor + Accelerometer

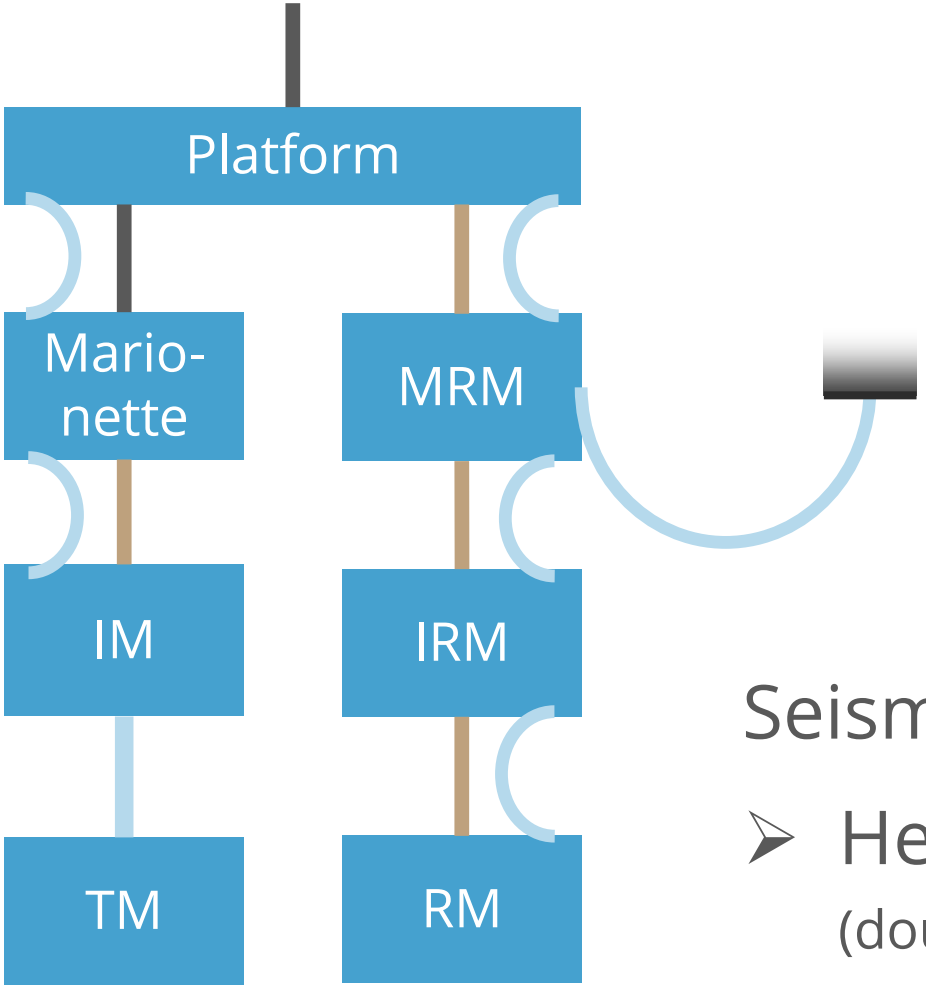
Seismic re-introduction from BF control

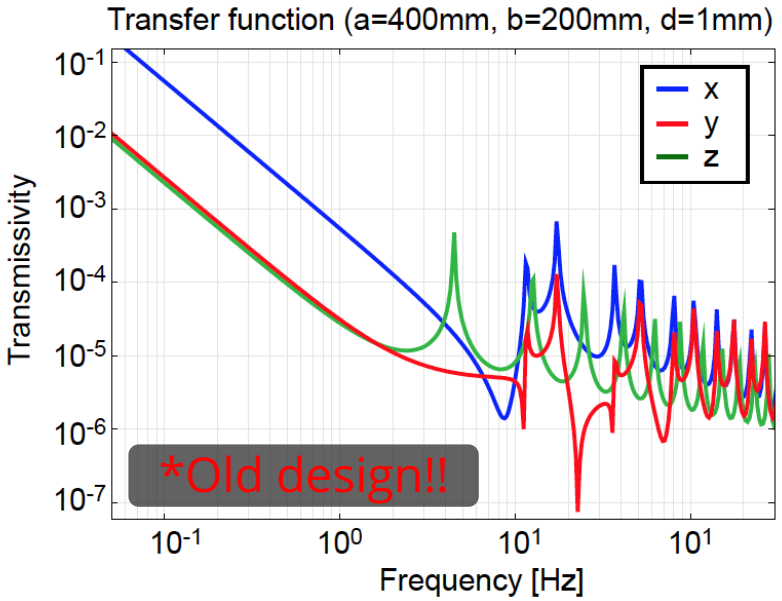
- EQ-stop mechanical eigenmode analysis
- Sensor/Actuator decoupling

Damping strategy in cryogenic payload

Cryogenic and Underground Issues

Impact of Heat Link

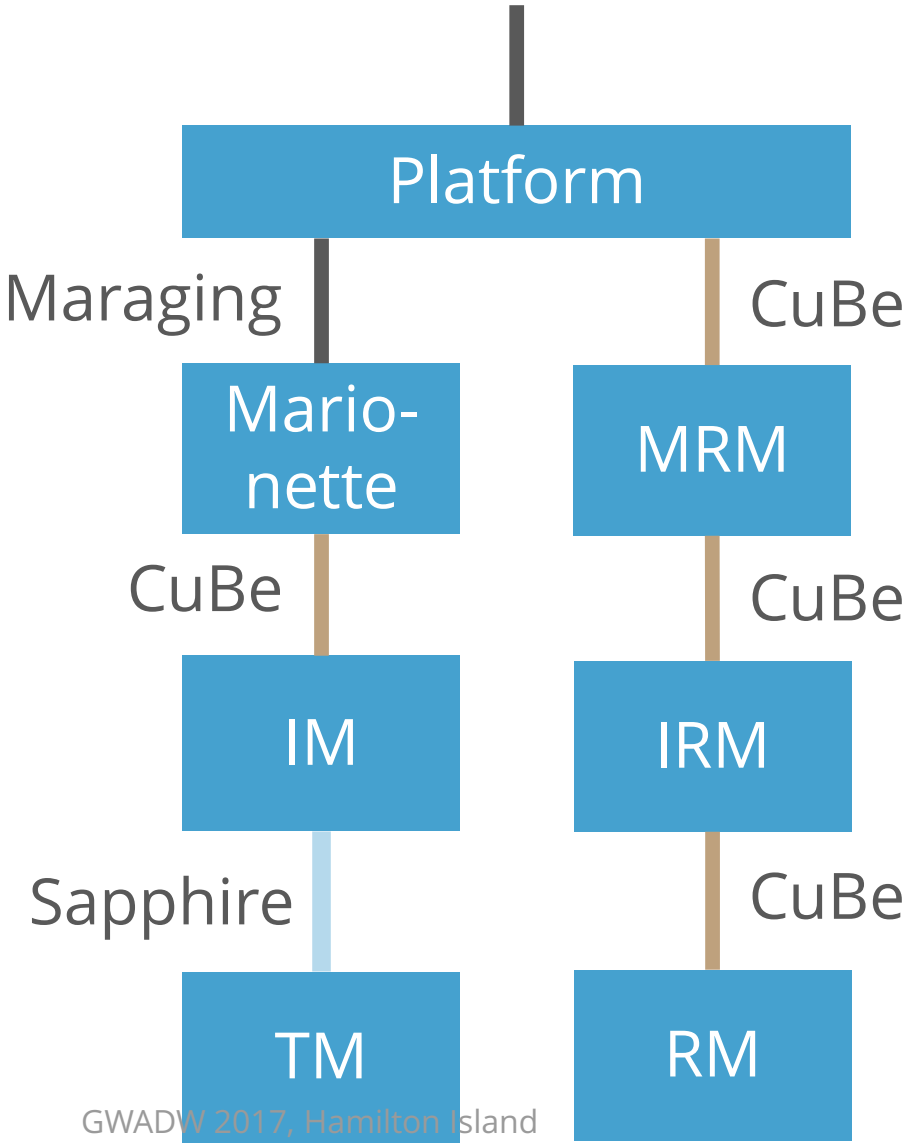




Seismic noise from HL

- Heat-link suspension
  (double pendulum)

Wire Shrinkage



- Total wire shrinkage for each chain

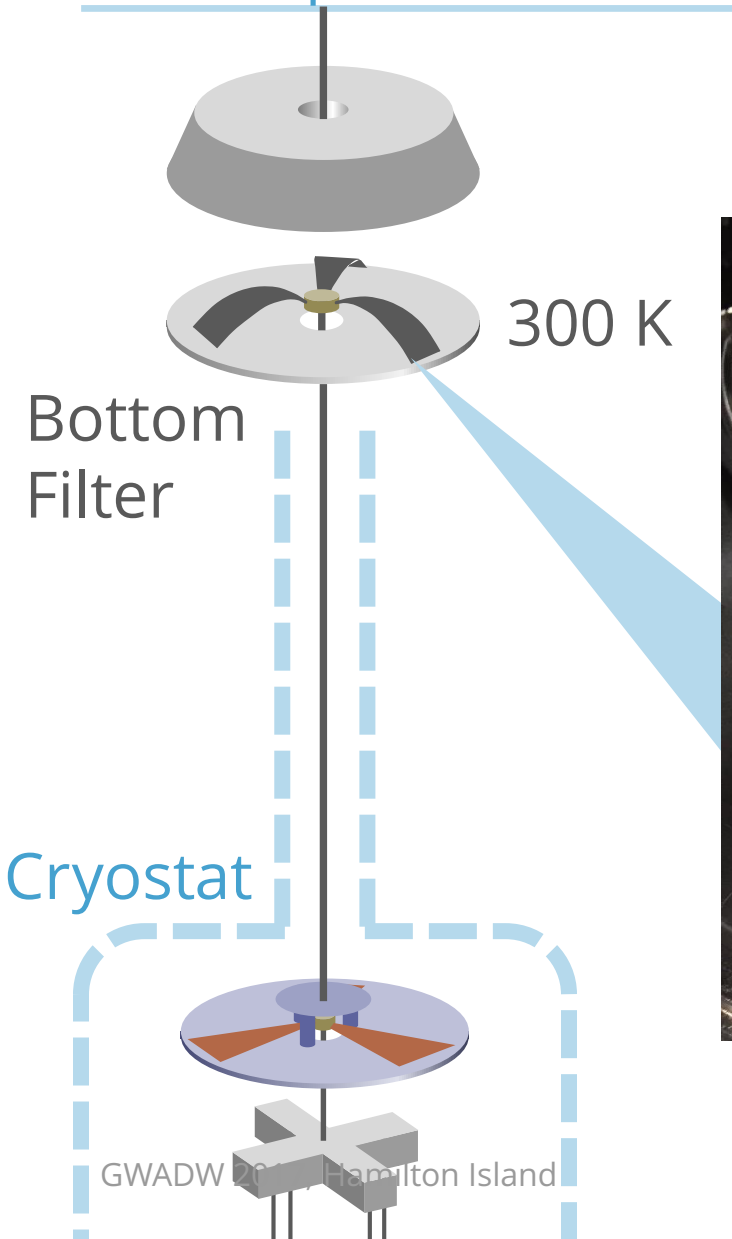
  ~ 1.5 mm

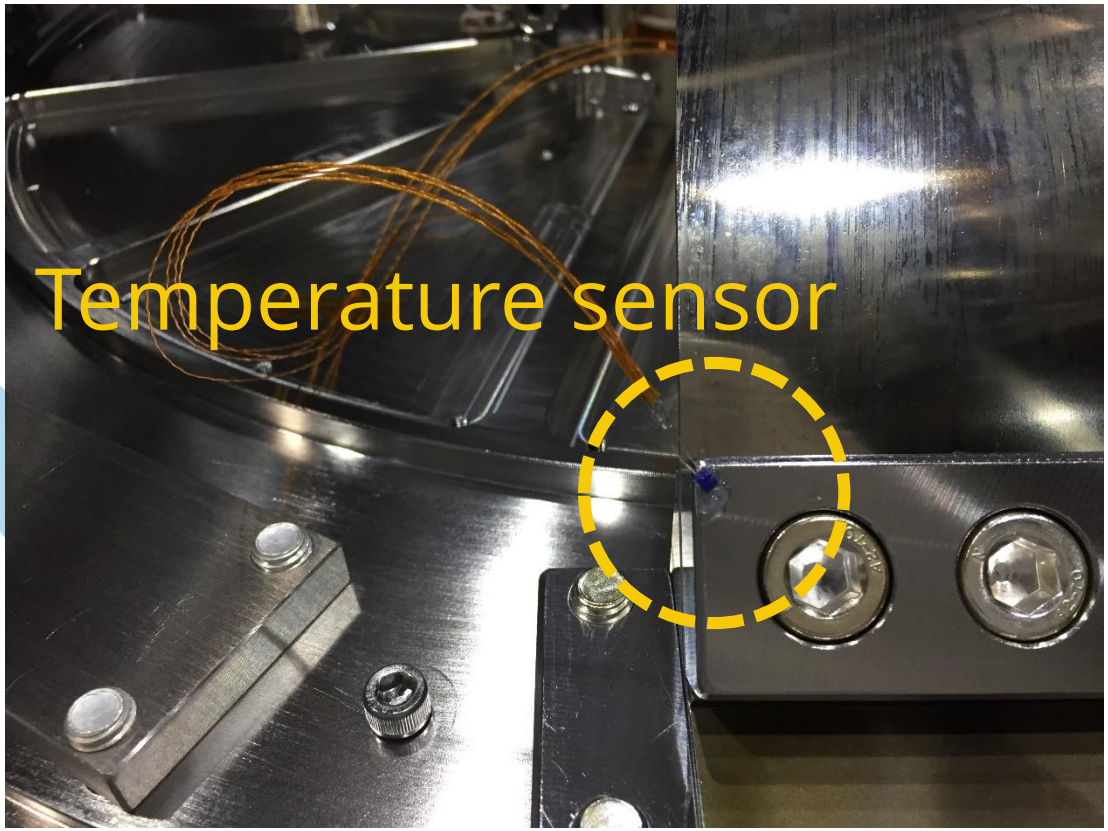
- Relative shift

  ~ 0.1 mm ✓

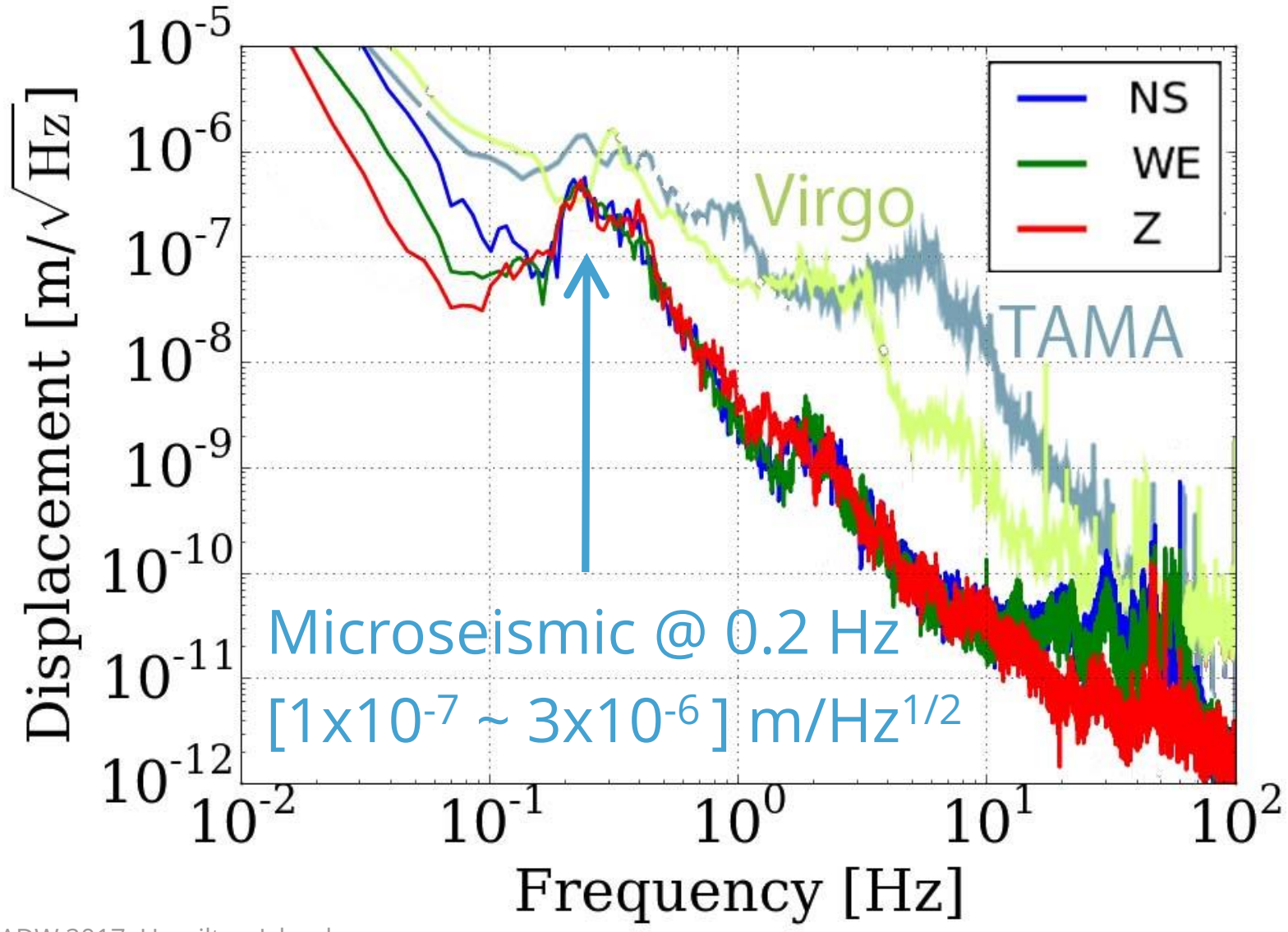
* Rough estimation

Temperature Gradient



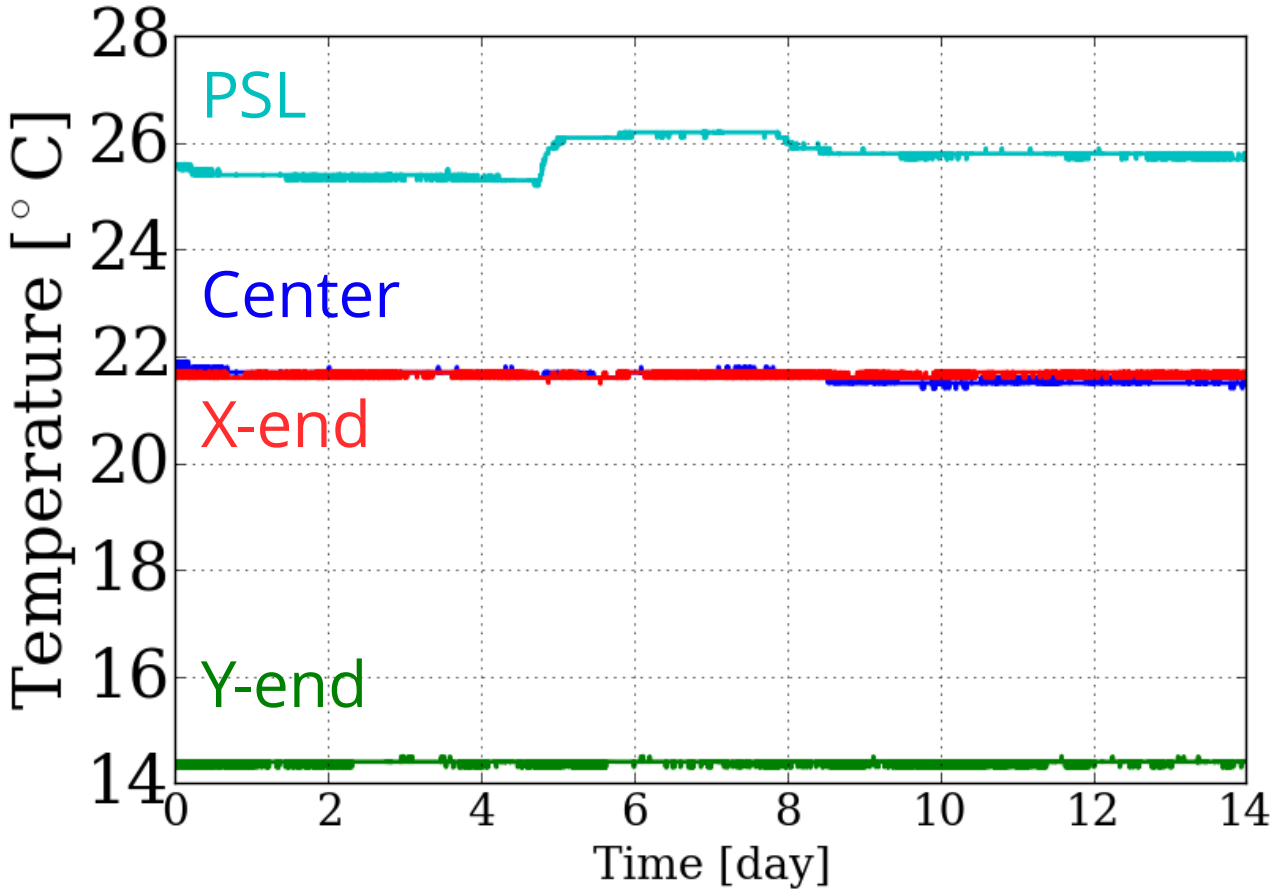


Seismic in Underground



A. Shoda, Poster in GWADW 2016

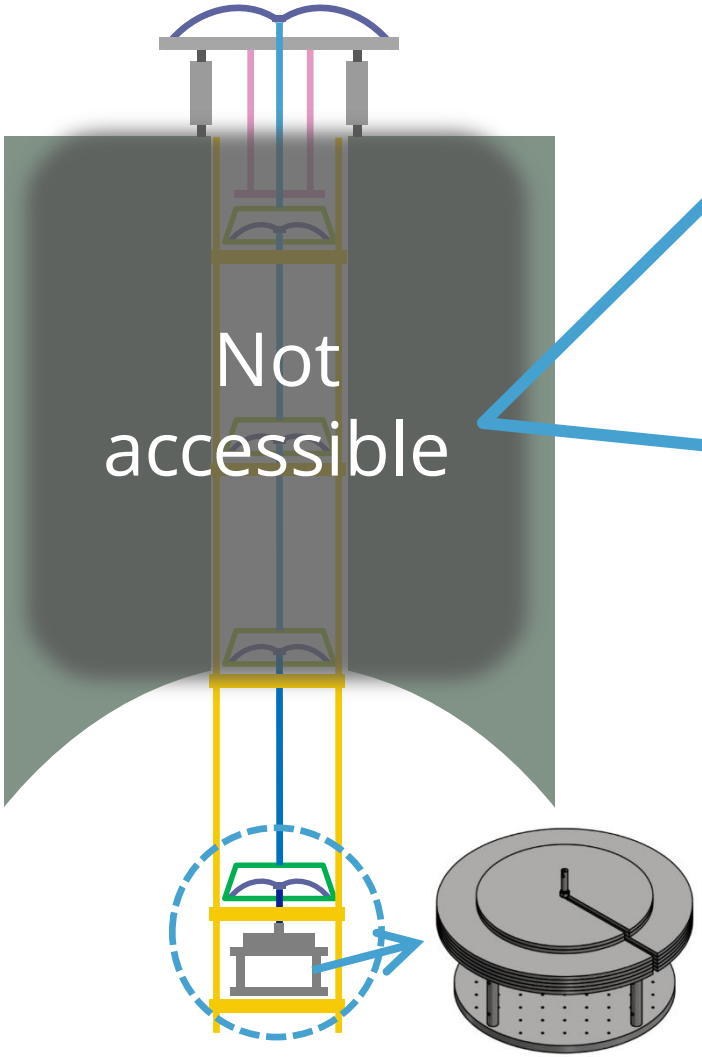
Temperature in Underground

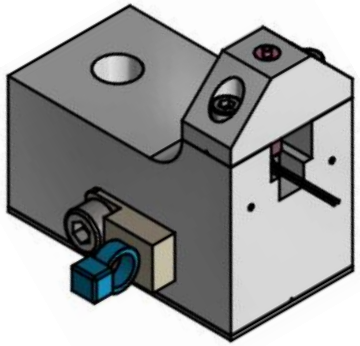


A. Shoda, Poster in GWADW 2016

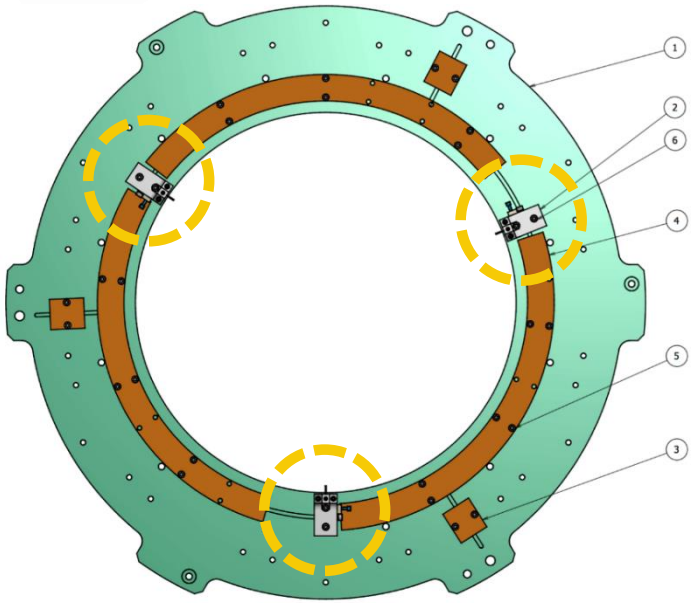
GAS thermal drift ➢ $\Delta z / \Delta T = 0.69$ mm [mm/K]

Practical Problem on Installation





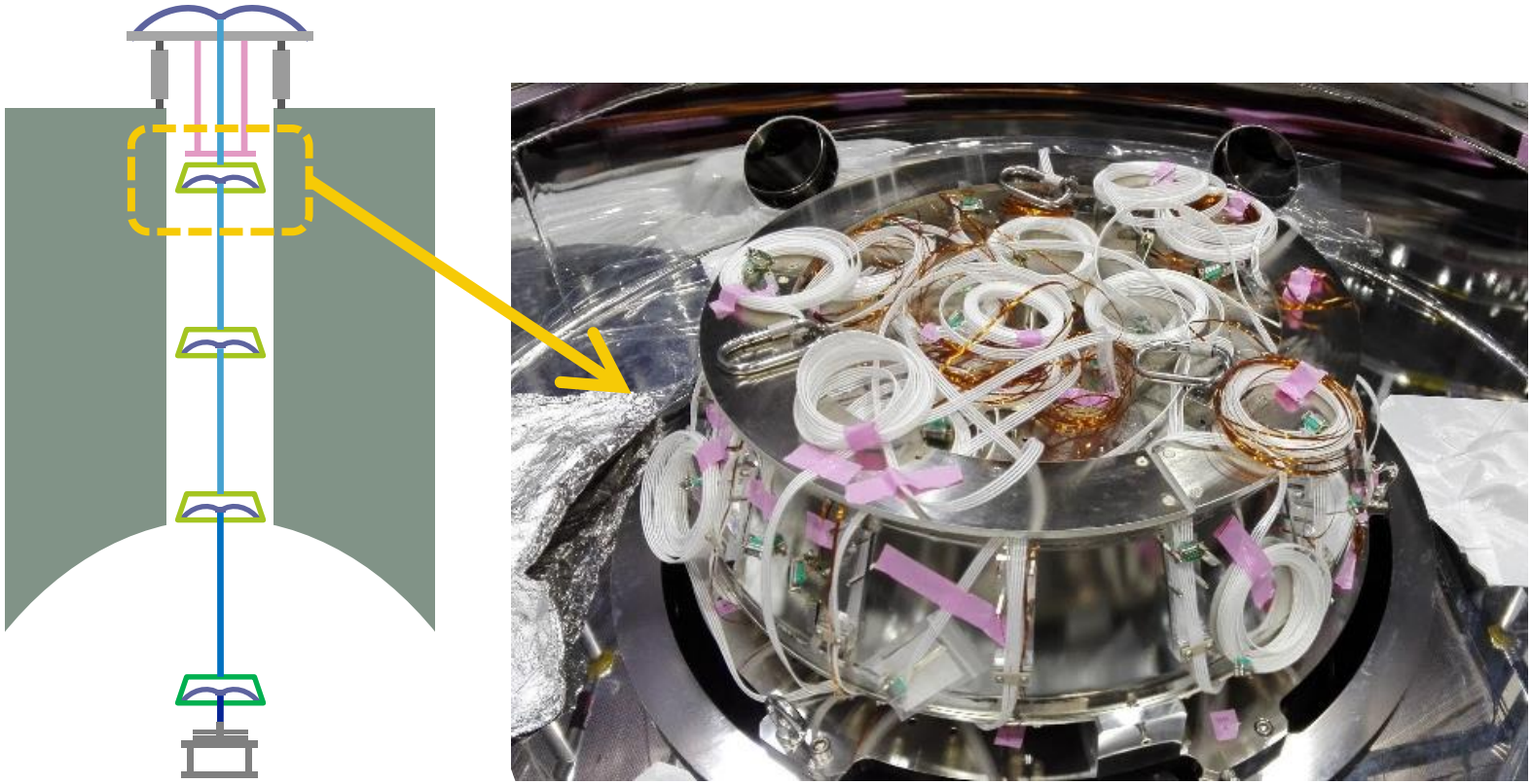
Release Sensor
(ON/OFF)



JGW-D1605452

Dummy Payload

How Is Type-A SAS Now?



Klog 2737

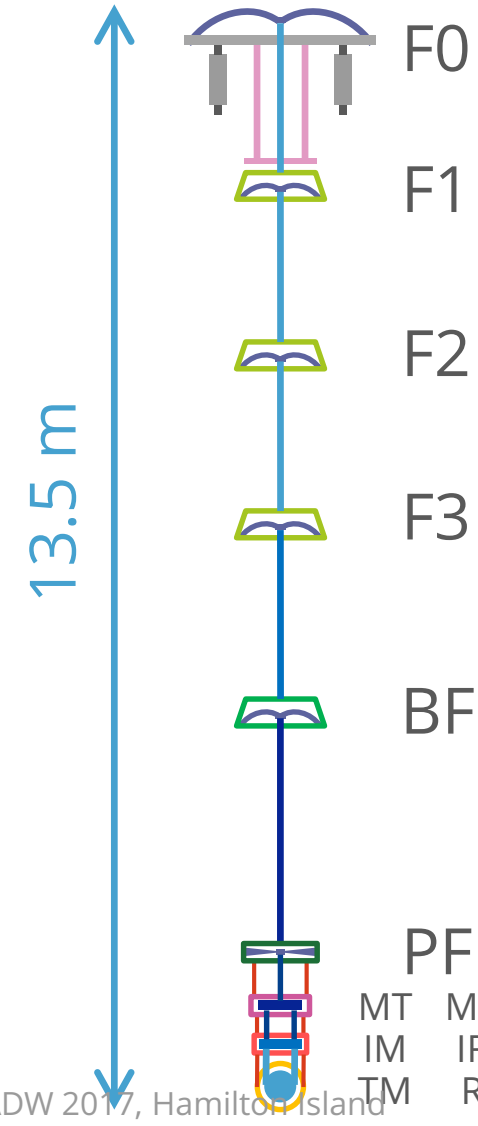
- F1 is sitting on the 2nd floor chamber

Summary

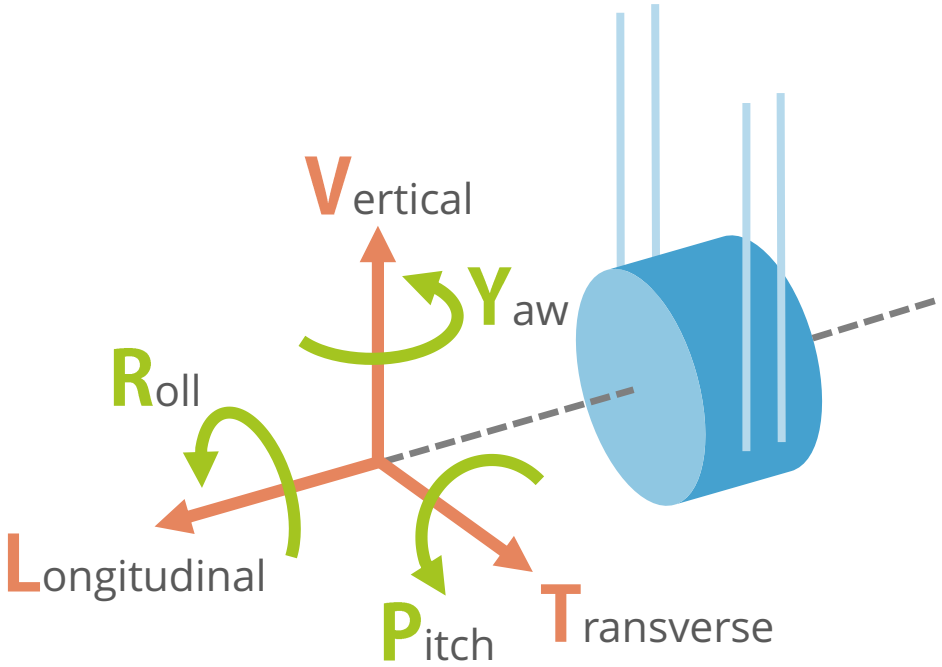
- KAGRA Cryogenic suspension: Type-A SAS
  - Under installation
  - Damping control design for tower ✔
  - Tuning of the control along w/ noise estimation
- Cryogenic and underground issues
  - Vibration analysis of the heat links
  - Treatment of cooling effects on the suspension
  - Implementation of underground monitors into control

Backup Slides

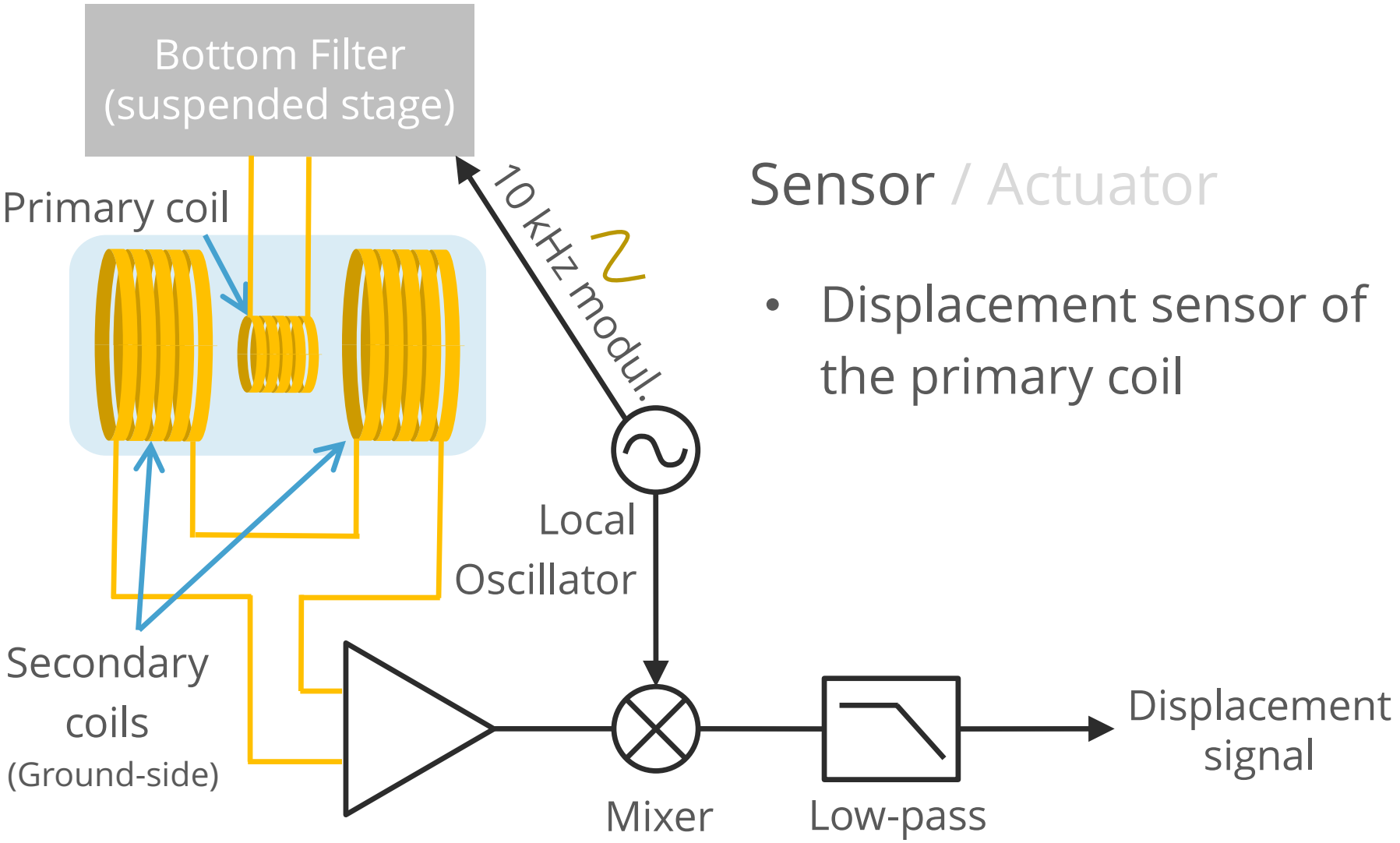
Stage Configuration



- Coordinate difinition



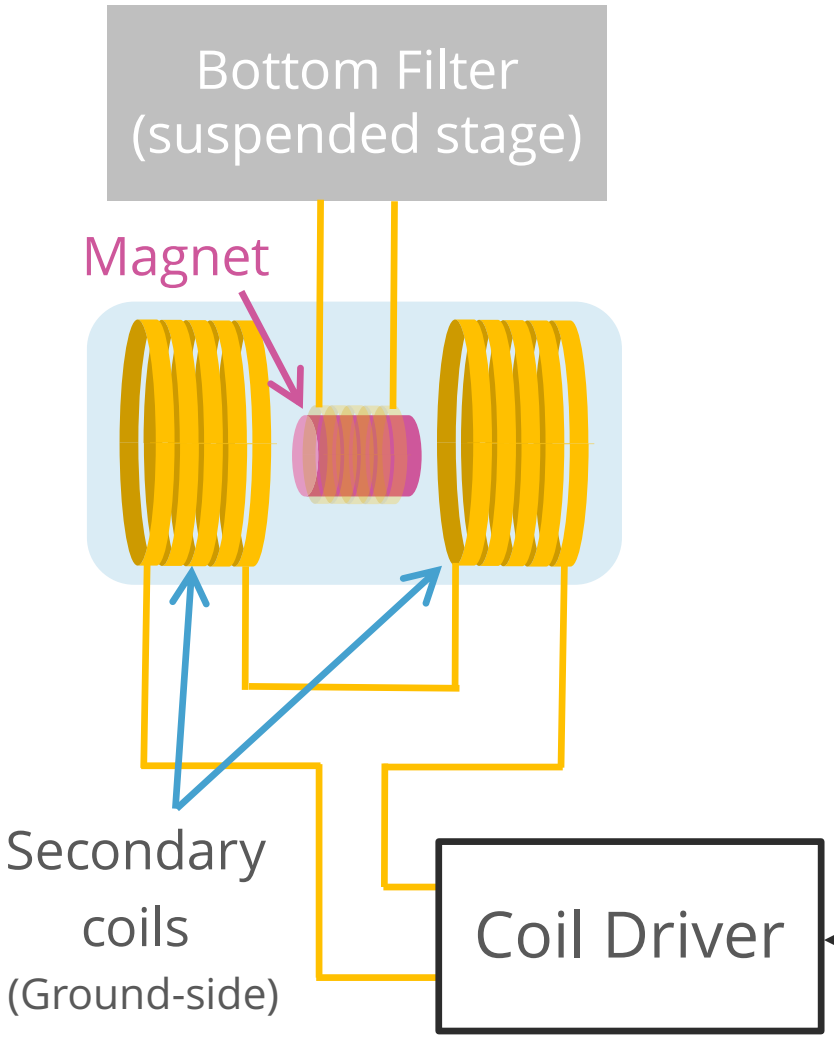
Bottom Filter LVDT



Sensor / Actuator

- Displacement sensor of the primary coil

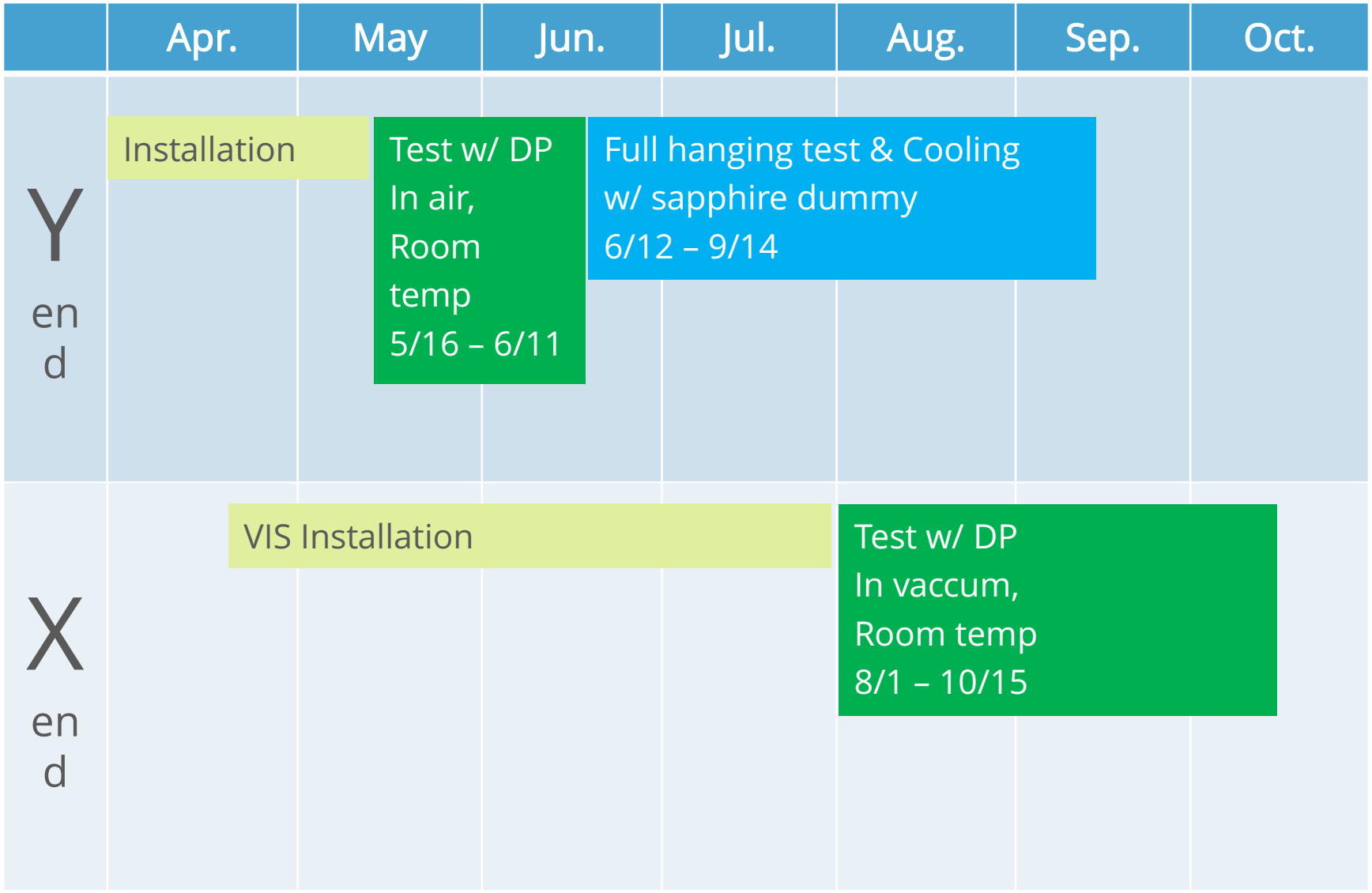
Bottom Filter LVDT



Sensor / Actuator

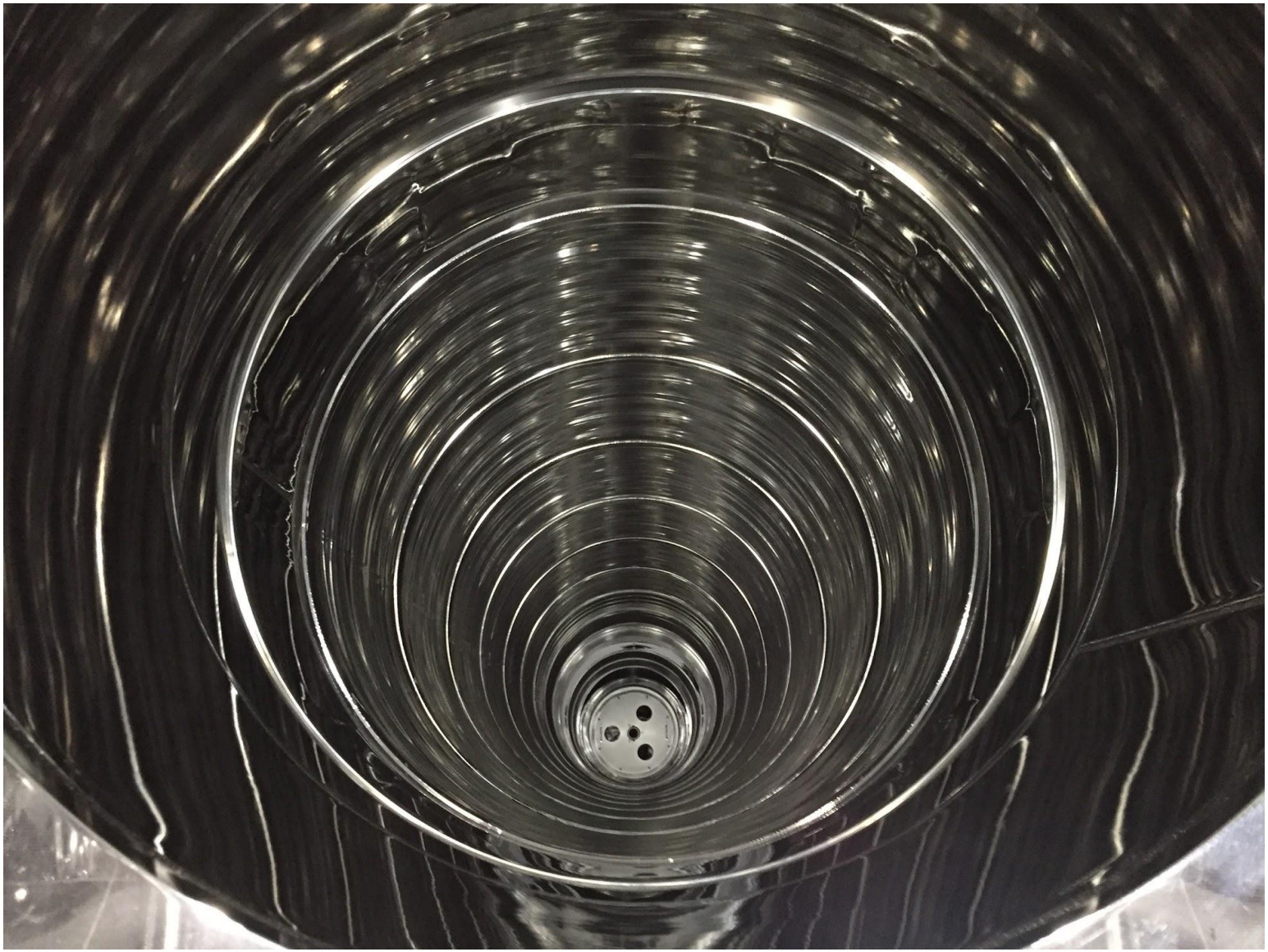
- Coil-magnet actuator
- Driving-frequency separation
  - Sensor: 10 kHz (high)
  - Actuator: < 10 Hz (Low)

Test Schedule



KAGRA EYV Room

Vertical Chamber Opened



Future update

- System identification test
  - Real-system modeling
- Implementation of Kalman filter
  - Estimation of system parameters
- Feedback design optimization with machine learning
  - LQ regulator + Machine learning → weight optimization
- Feedforward control with underground environmental monitors