Seismic Attenuation System (SAS) in the Kamioka mine

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KAGRA

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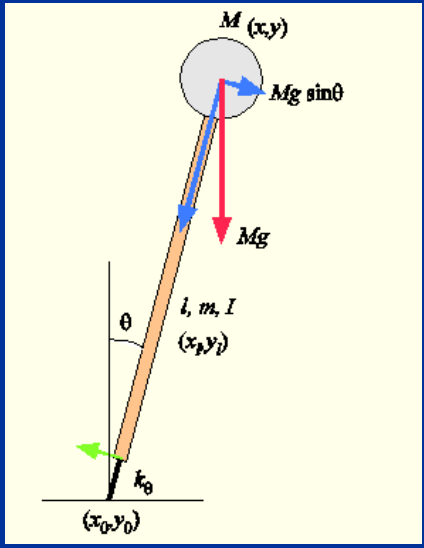
1. Concept of SAS for KAGRA

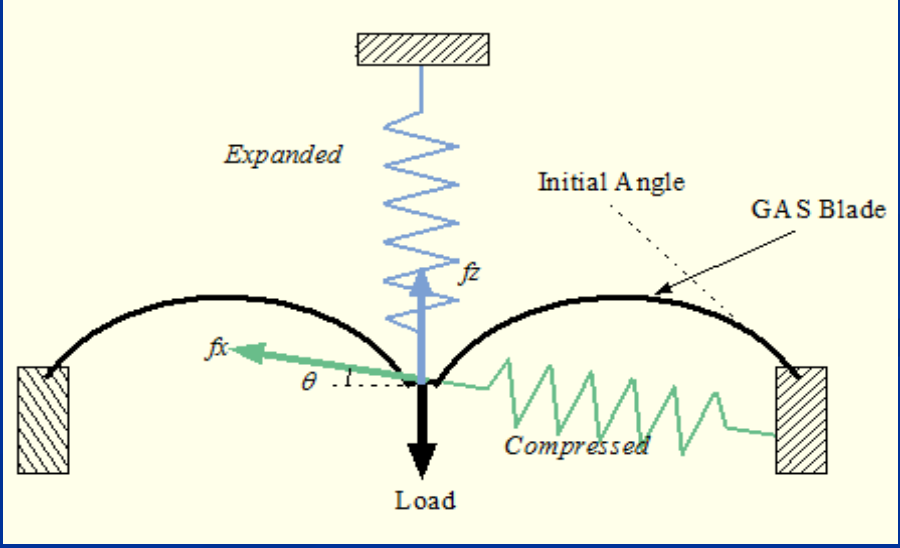
Seismic Attenuation System

We employ the Seismic Attenuation System (SAS) for KAGRA.
The SAS consists of an inveried pendulum (IP)
and geometric anti-spring (GAS) filters.

- Attenuation of seismic noise at the observation band (>10Hz).
  GAS filters and payload (mirror suspension).

- Reduction of RMS motion of mirror at low frequencies (<10Hz).
  Pre-isolator (IP + GAS filter)



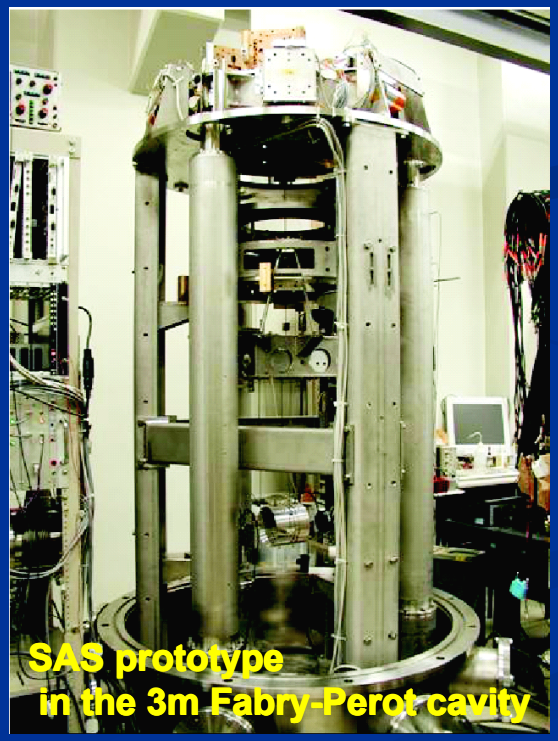


History of SAS R&D

International collaboration with Caltech and Univ. di Pisa

- Started TAMA-SAS study in 2000
- R&D of IP and GAS filter at Caltech by 2001
- R&D using SAS prototype at Univ. of Tokyo by 2003
- Started manufacturing of SAS for TAMA300 in 2003
- Started Installation of SAS into TAMA300 in 2005

R&D at Caltech



SAS prototype
in the 3m Fabry-Perot cavity

SAS for TAMA300

Improvement of sensitivity by SAS

K. Arai, *et al*: CQG 26, 204020 (2009)

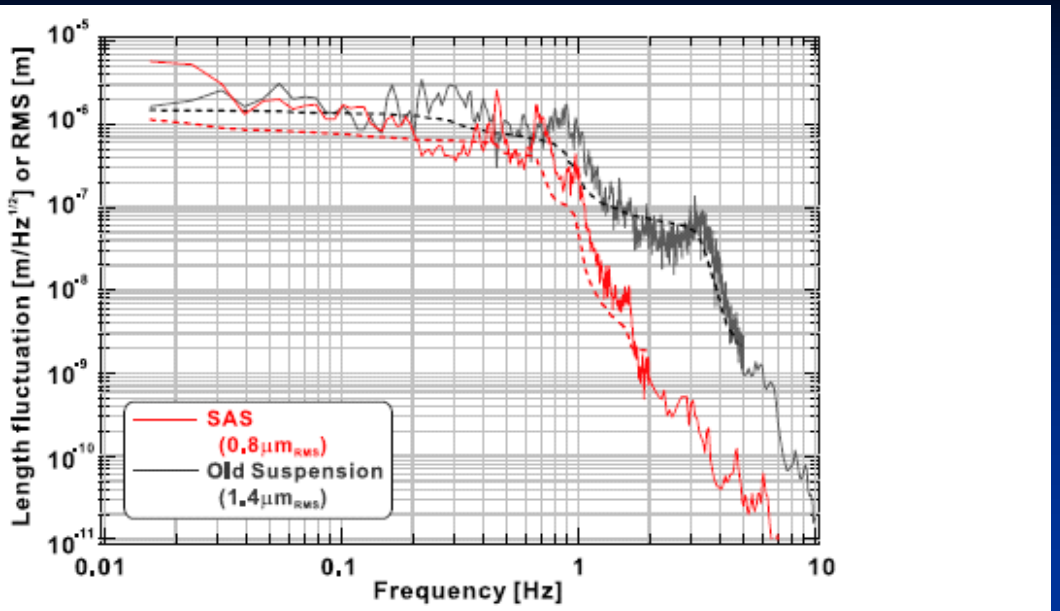


Figure 3. Length fluctuation of the 300 m cavity measured by the feedback signals to lock the cavity. The spectrum density and RMS integrated from 50 mHz are indicated by solid line and dash line, respectively.

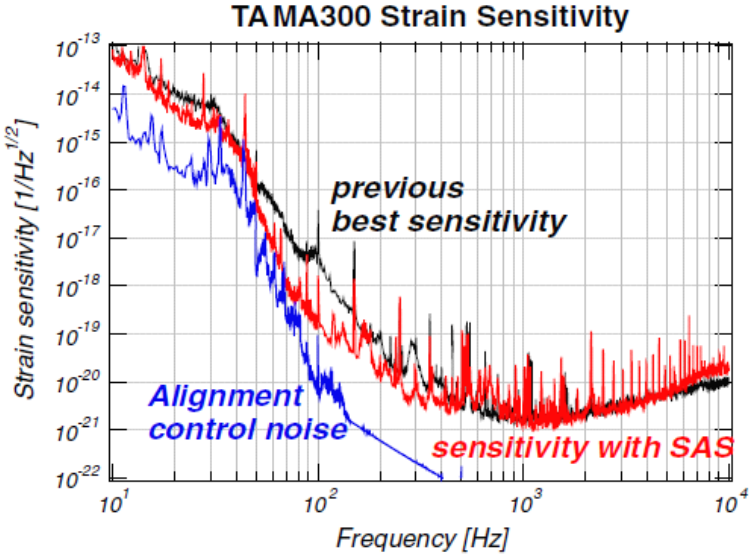
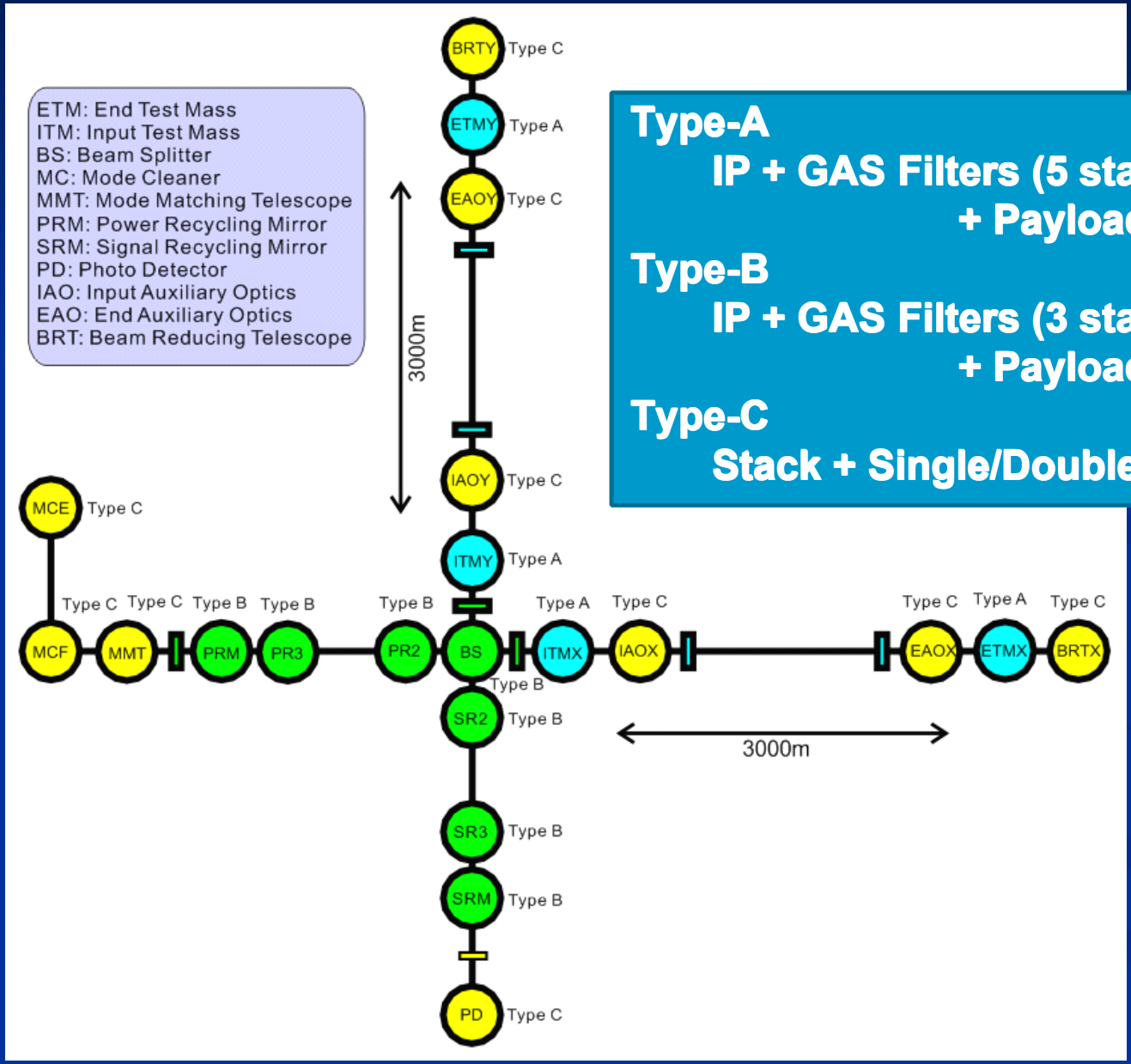


Figure 4. Current strain sensitivity of TAMA300 (red) and the alignment noise level (blue), which is currently limited by DAC noise at around 100 Hz. The previous best sensitivity (black) is also shown.

R. Takahashi, *et al*: CQG 25, 114036 (2008)

2. Configuration of the vibration isolation system for KAGRA

Disposition of vibration isolation system



Type-A

IP + GAS Filters (5 stages)
+ Payload (23kg, cryogenic)

Type-B

IP + GAS Filters (3 stages)
+ Payload (10kg/20kg)

Type-C

Stack + Single/Double-pendulum (~1kg)

Seismic Attenuation System (SAS)

Pre-isolator

Top filter
[Filter0]

Inverted Pendulum (IP)

Filter chain

Filter1 (Filter1~3 in Type-A)

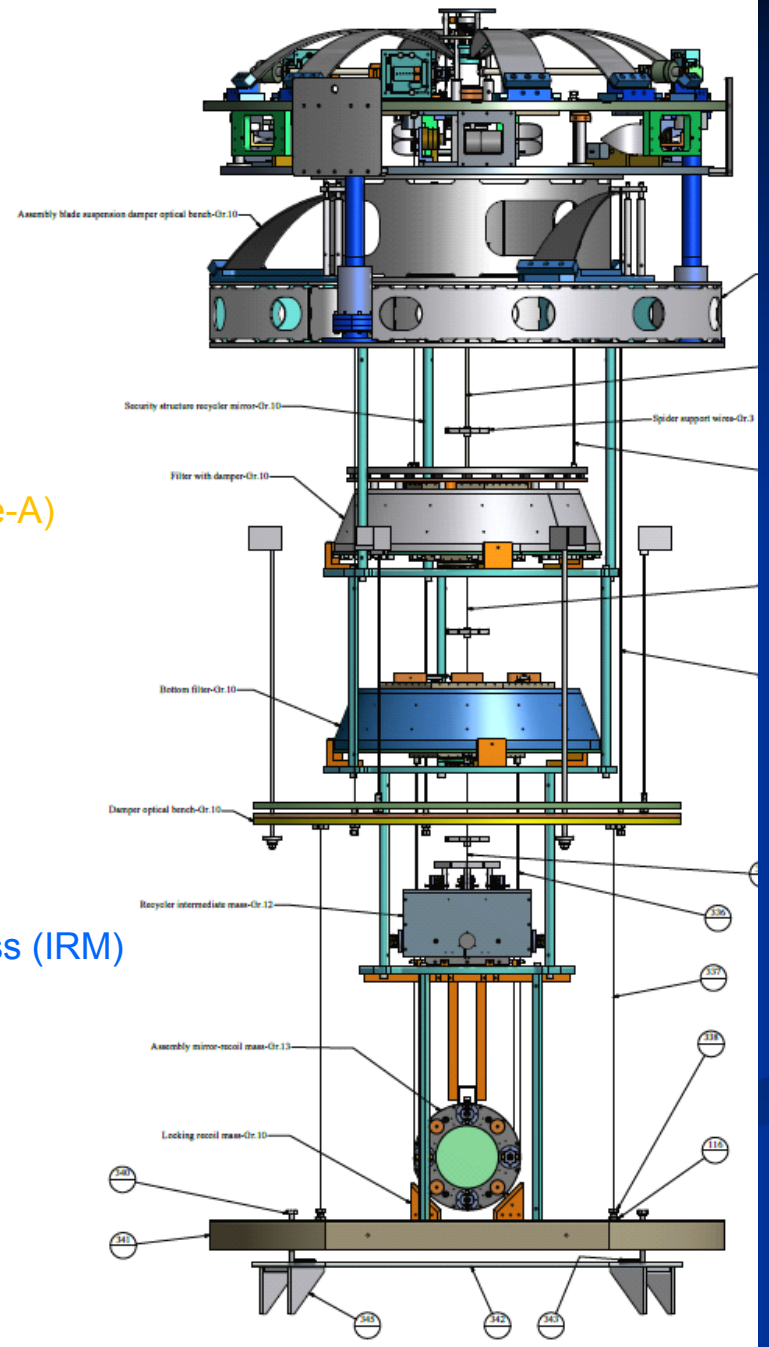
Payload

Bottom Filter (BF)

Intermediate Mass (IM)
Intermediate Recoil Mass (IRM)

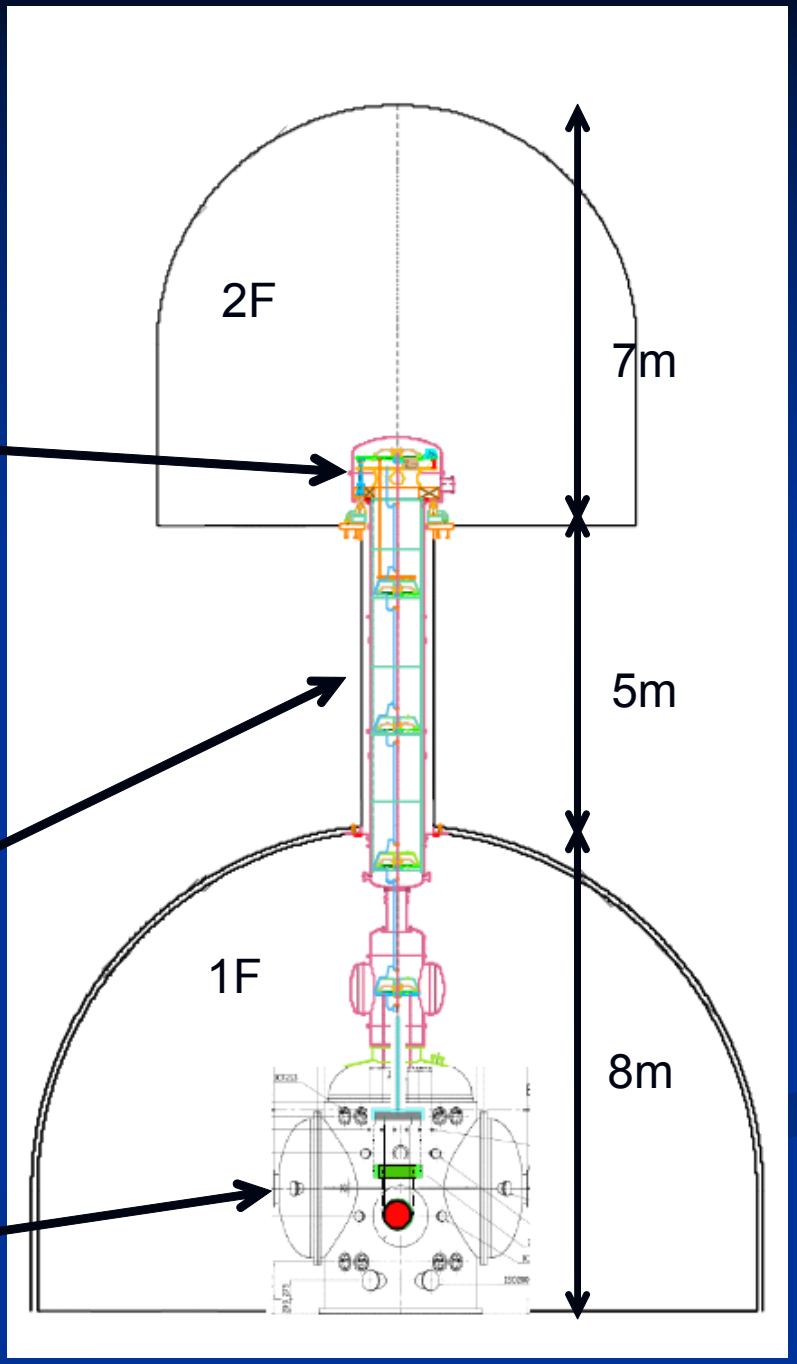
Test Mass (TM)
Recoil Mass (RM)

Optical Bench
[Breadboard]



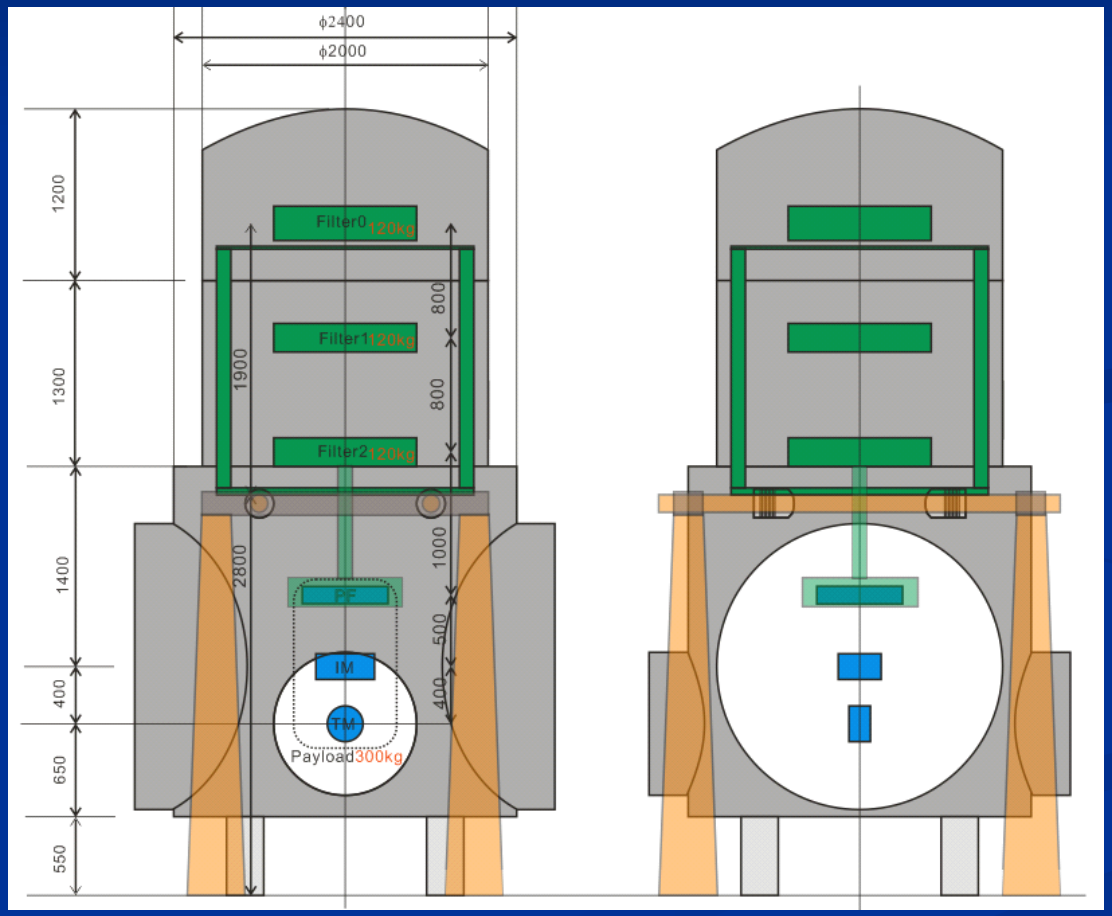
Type-A (2-layer structure)

- Upper tunnel containing *pre-isolator (short IP and top filter)*
- 1.2m diameter 5m tall borehole containing *standard filter chain*
- Lower tunnel containing *cryostat and payload*



Why 2-layer?

- Support structure for SAS tower is not rigid.
- Support rods for IP base have low frequency resonance (~10Hz).



Old Type-A design

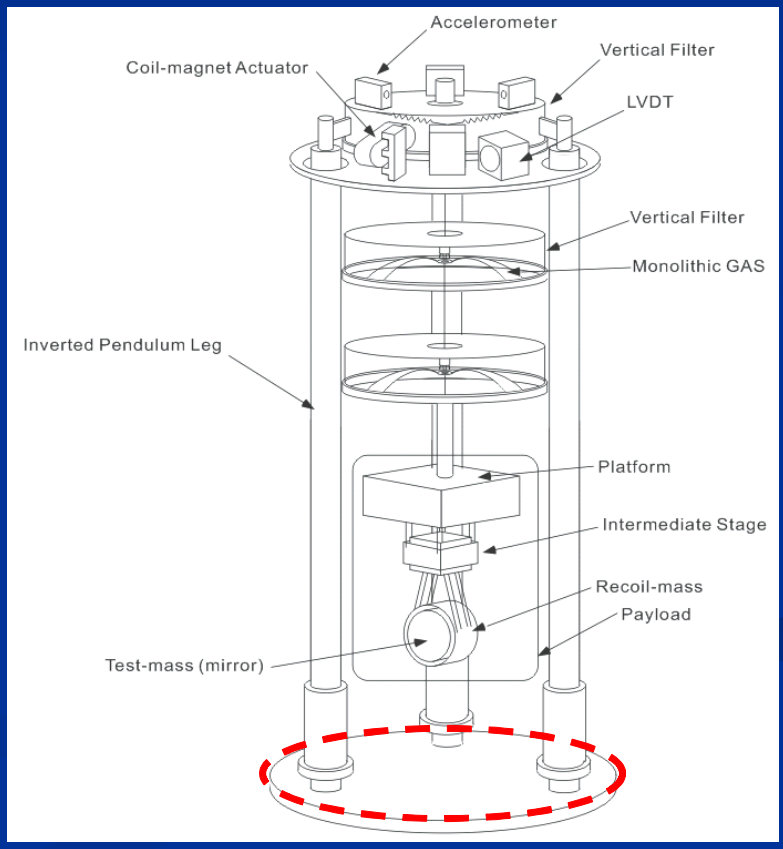
Test of support frame

To obtain rigid base

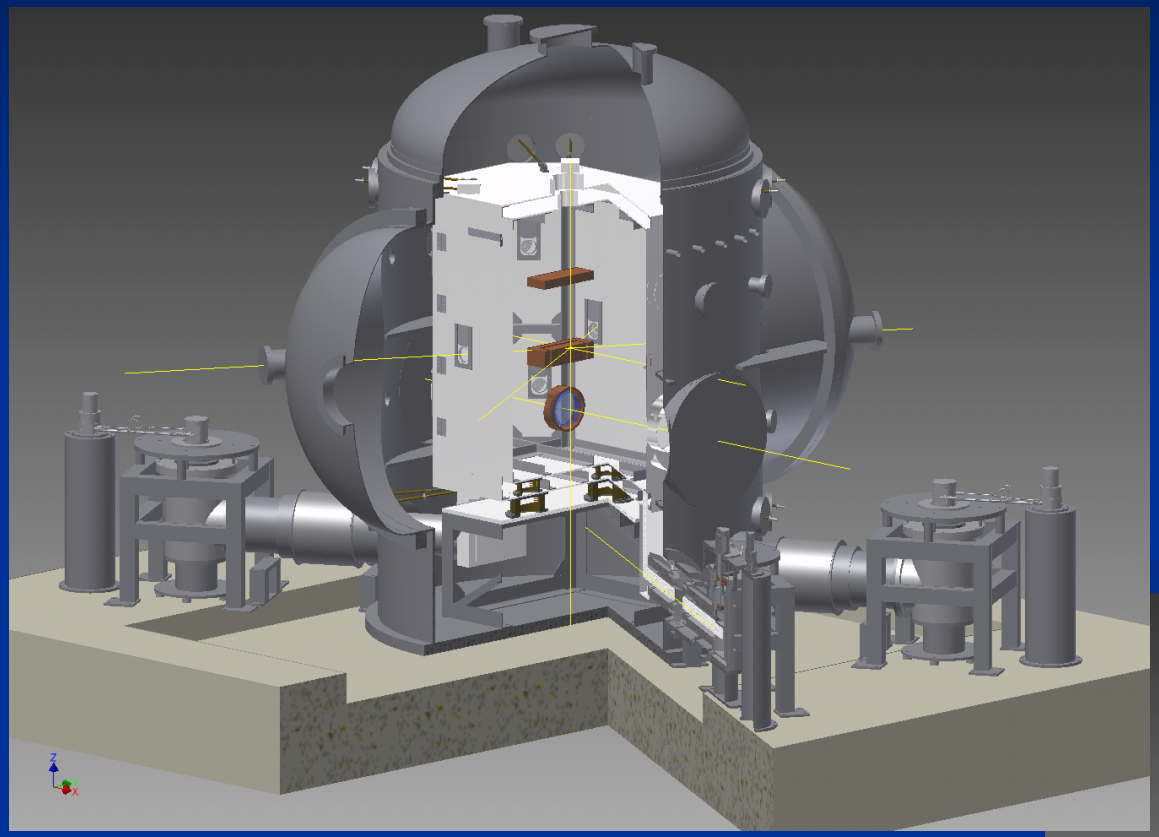
- External rigid structure like Virgo chamber
- IP base put on bottom of the chamber like TAMA-SAS

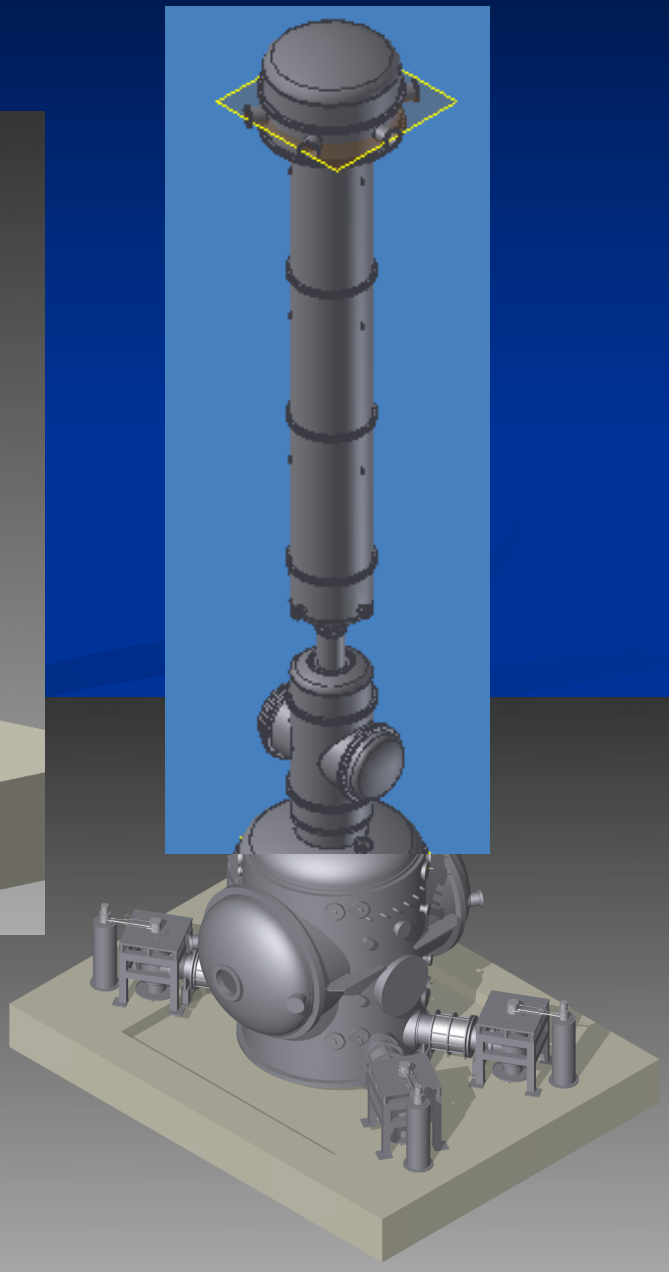
→ It is difficult to apply them to huge cryostat!

→ 2-layer structure



Cryostat with tower

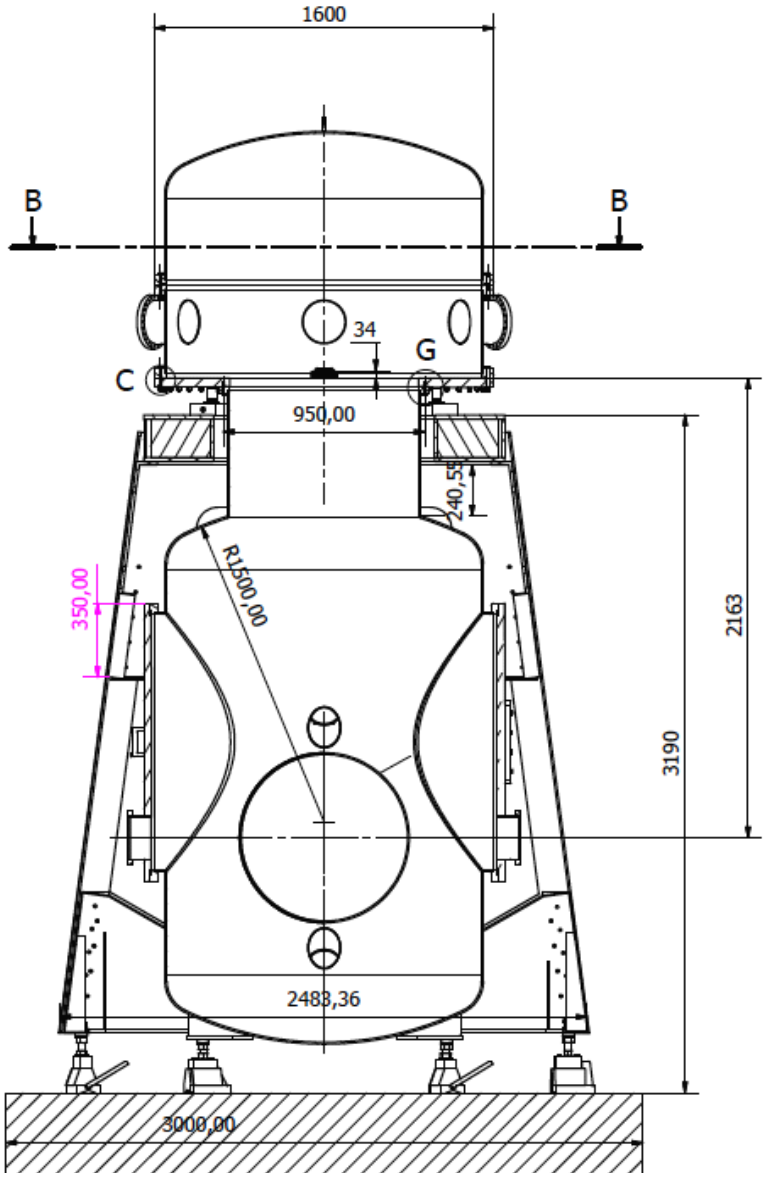


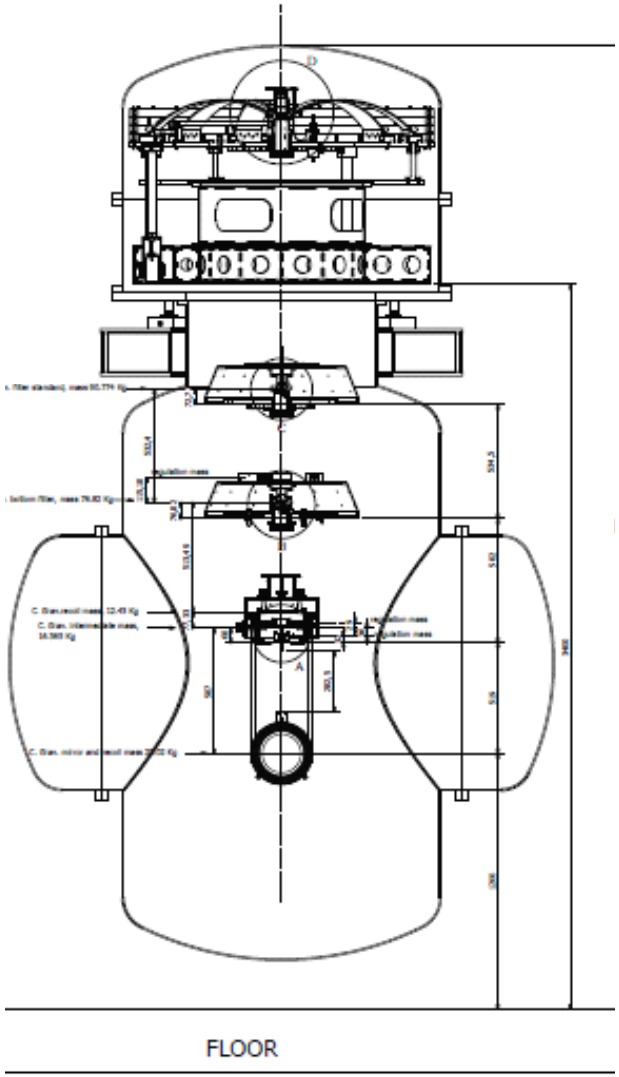


- Double radiation shield
- Low vibration PTC units
- Pure Al heat path

Type-B

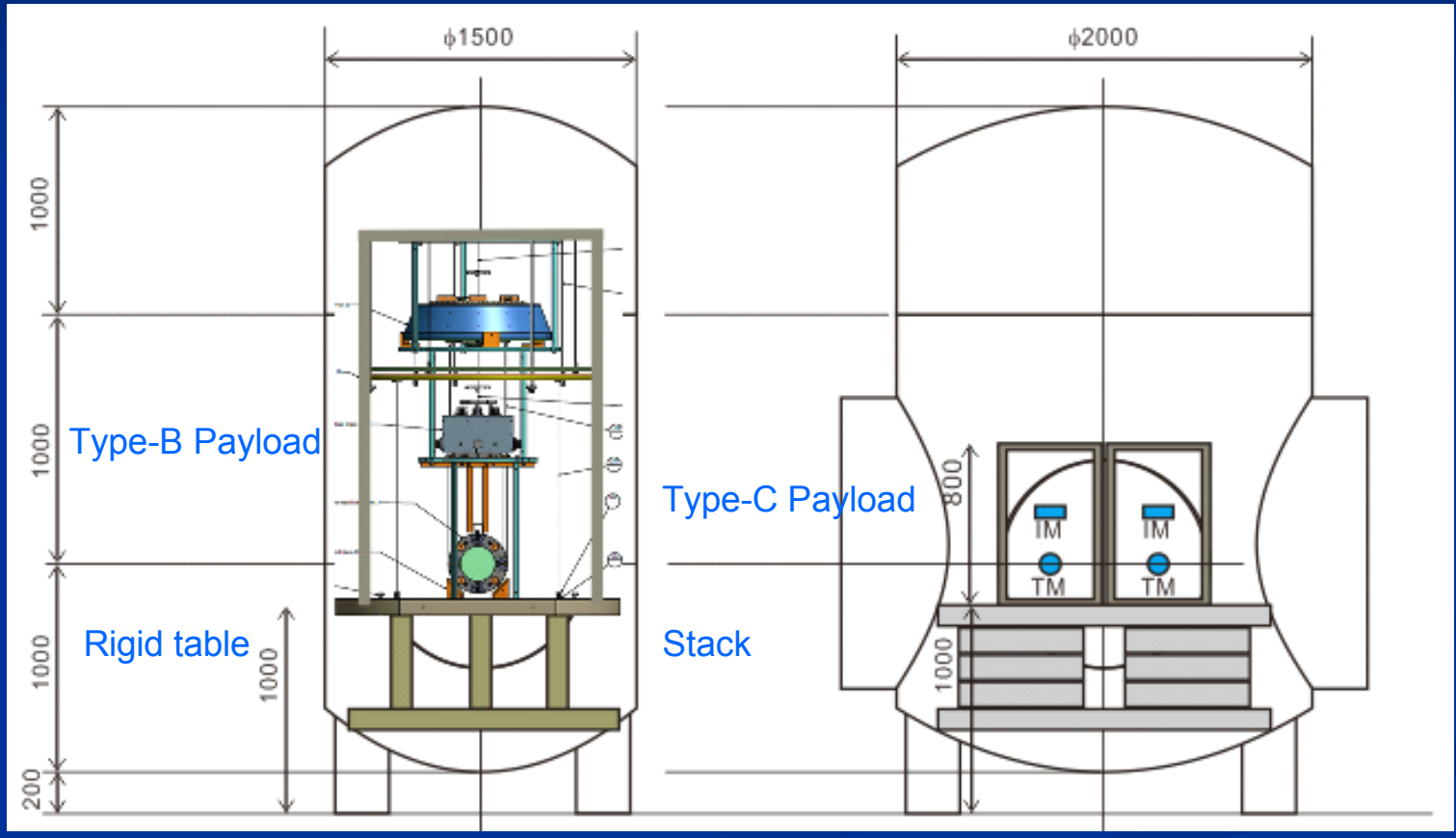
- IP base is supported by the outer frame.
- Pre-isolator is the same as Type-A's.





Type-B payload on rigid table (in iKAGRA)

Type-C

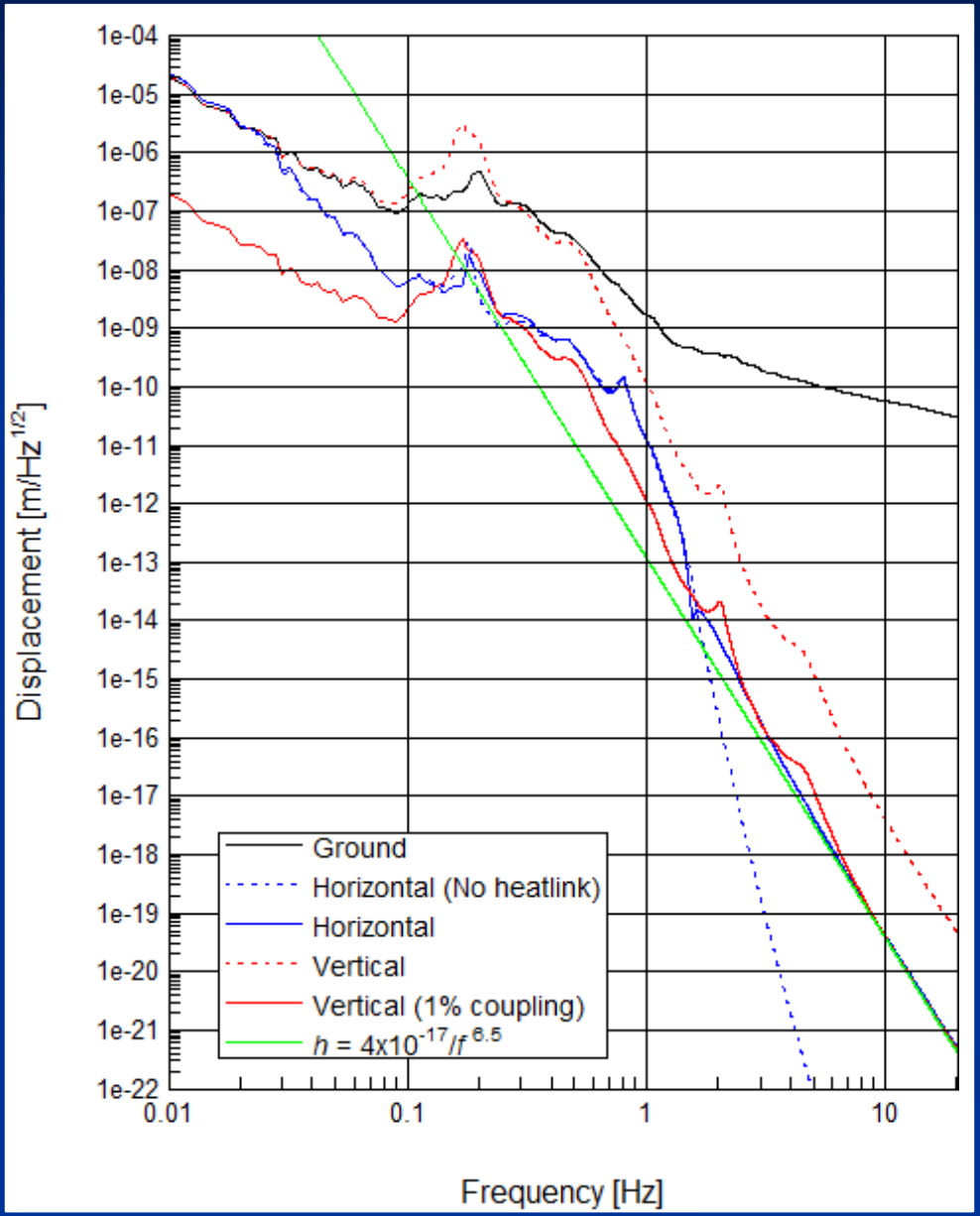


3. Simulation

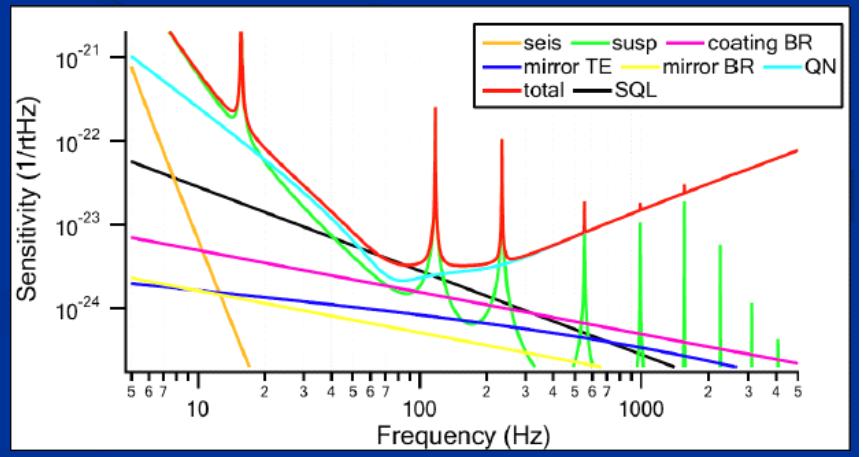
Model calculation has been developed with design works.

- Longitudinal simulation using point mass model (R. Takahashi)
- Full dimensional simulation using rigid body model (T. Sekiguchi & E. Majorana)

Displacement of mirror by point mass model



- The isolation above 2Hz is due to the heat link of 0.03Hz.
- The 1% coupling from vertical displacement is comparable with the horizontal one.
- Predicted displacements are consistent with the IFO noise budget above 5Hz.



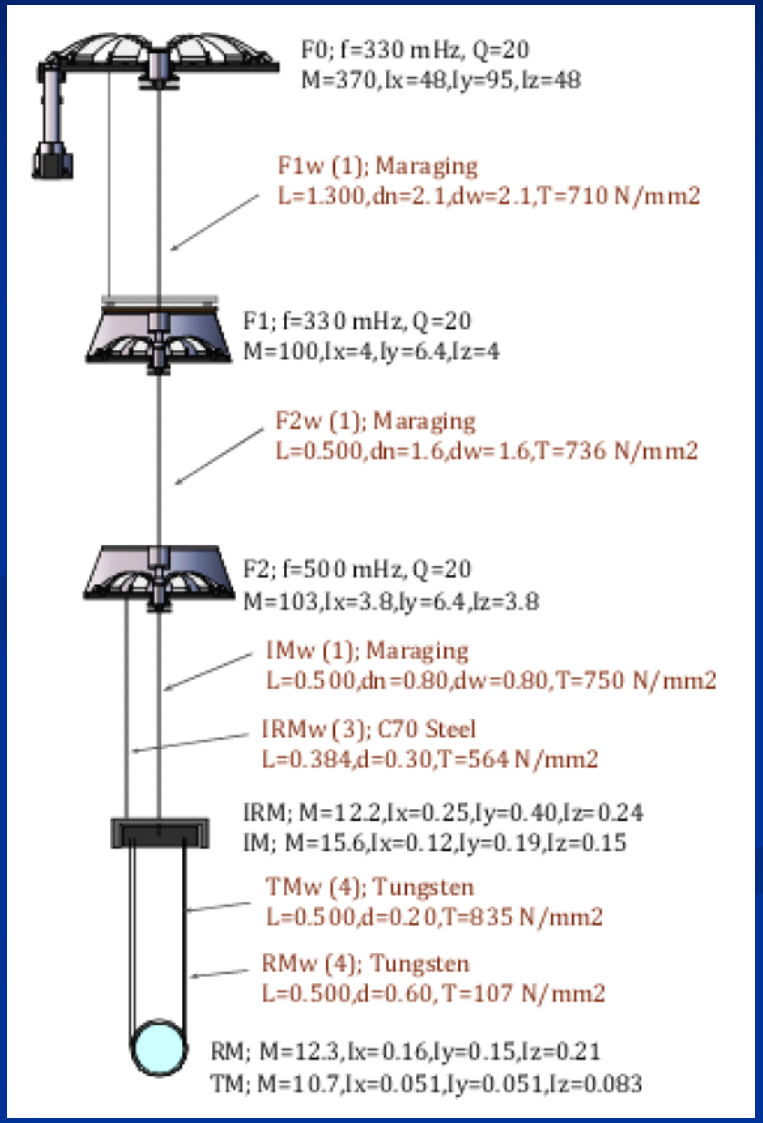
Requirements & Prediction

	iKAGRA		bKAGRA	
	Target	Calculation	Requirement	Calculation
Displacement @10Hz [m/rHz]	→	3×10^{-17}	4×10^{-20}	4×10^{-20}
RMS (velocity) [μm/s]	→	3.1	0.1	0.08
RMS (displace.) [μm]	→	2.2	0.1	0.05

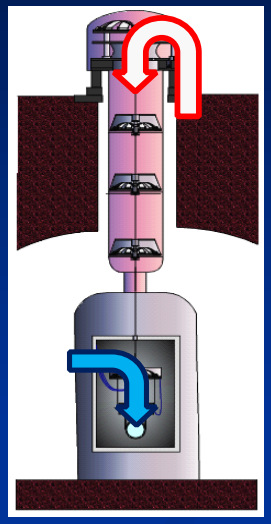
Rigid body model

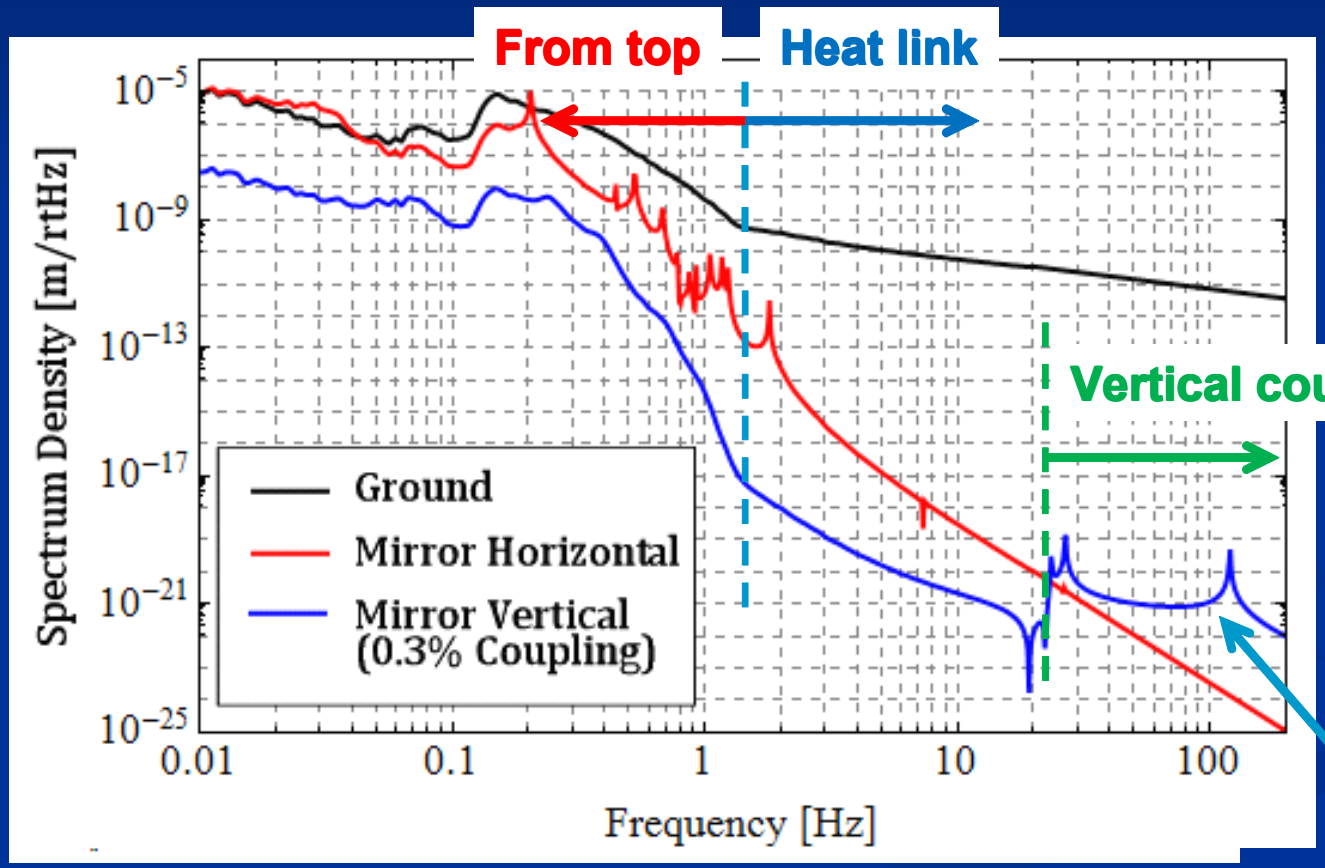
- Each body has 6 DOF (X, Y, Z, θ x, θ y, θ z).
- Wire potential is divided into stretches and torsions.
- GAS works as a one-dimensional ideal spring.
- No deformation of the bodies, no violin motions of the wires.

Type-B



Displacement of mirror in Type-A system

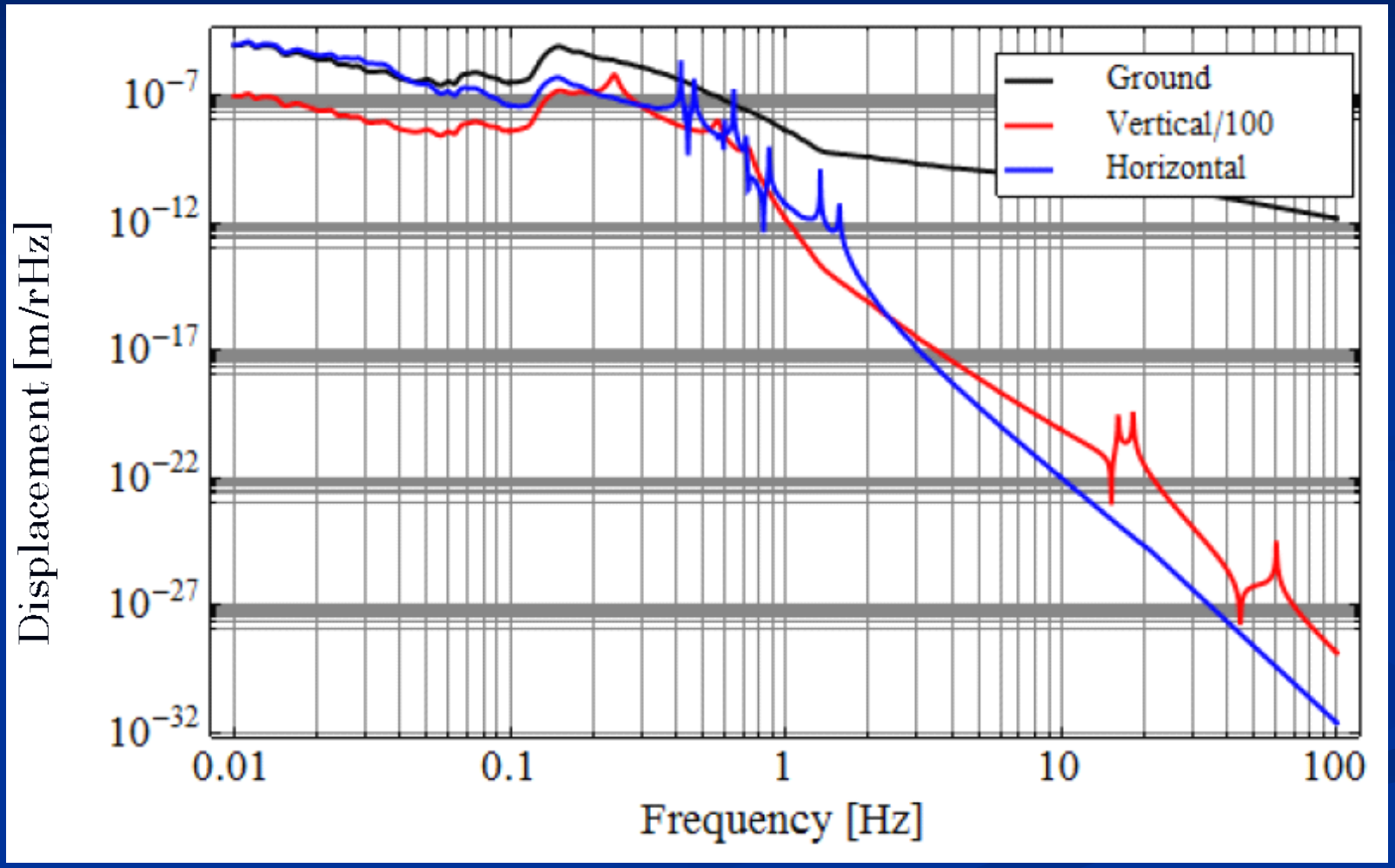




10^{-21} m/Hz$^{1/2}$ at 100Hz

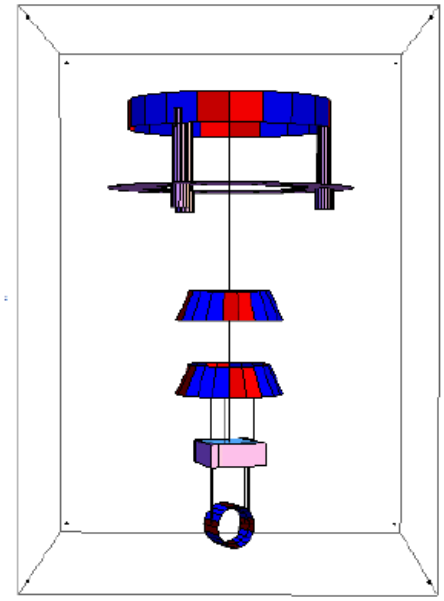
We need additional seismic isolation for the heat link.

Displacement of mirror in Type-B system



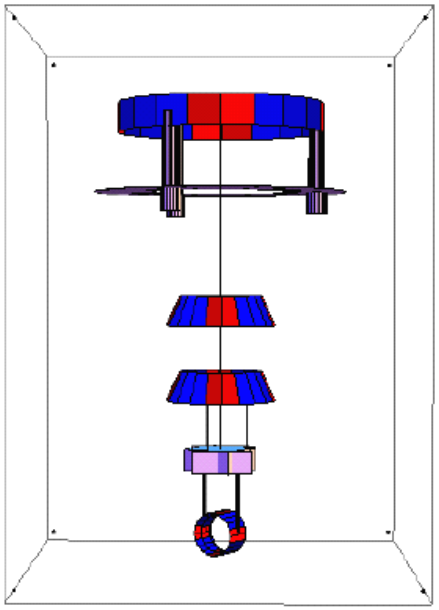
1 Torsion(.012Hz)

eigenplot[eigenv, 1.0, 1]



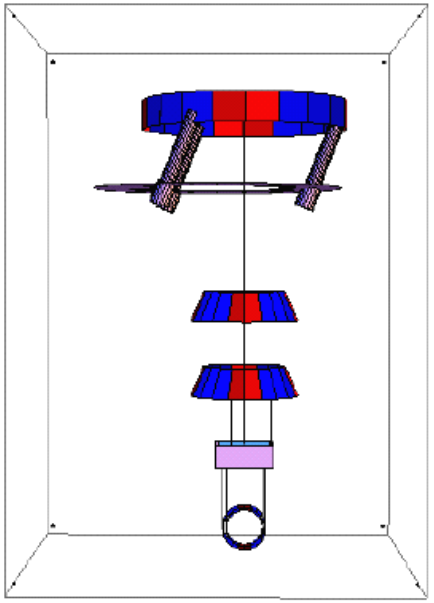
2 Torsion(.020Hz)

eigenplot[eigenv, 1.0, 2]



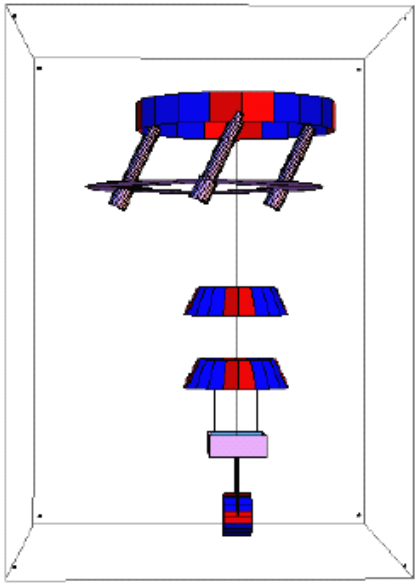
3 IP Trans.(.030Hz)

eigenplot[eigenv, -0.5, 3]



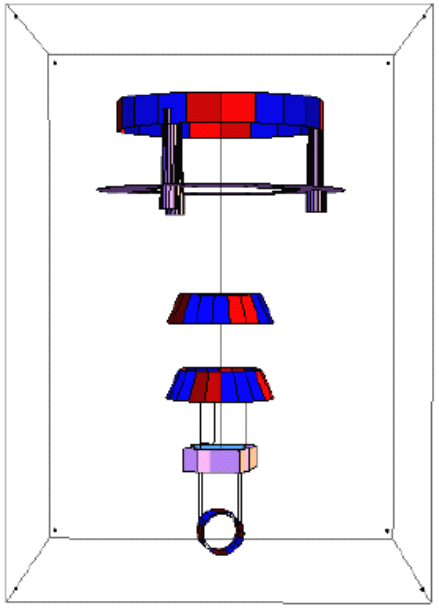
4 IP Long.(.030Hz)

eigenplot[eigenv, 0.6, 4]



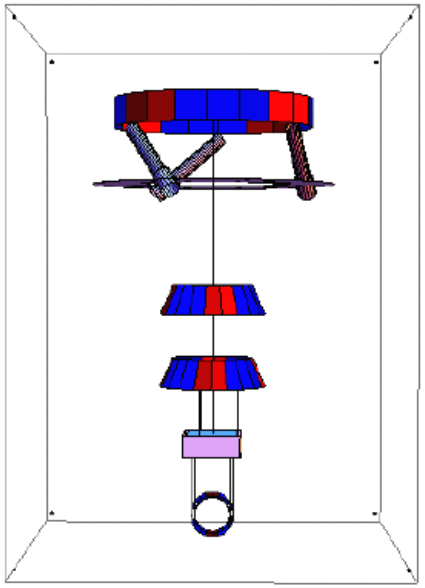
5 Torsion(.032Hz)

eigenplot[eigenv, 0.7, 5]



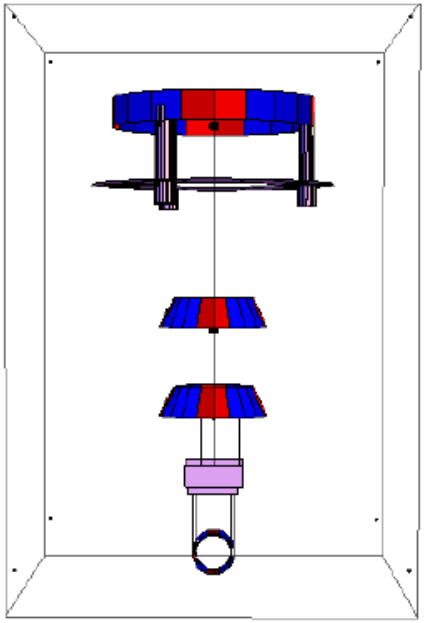
6 IP Yaw(.051Hz)

eigenplot[eigenv, 0.7, 6]



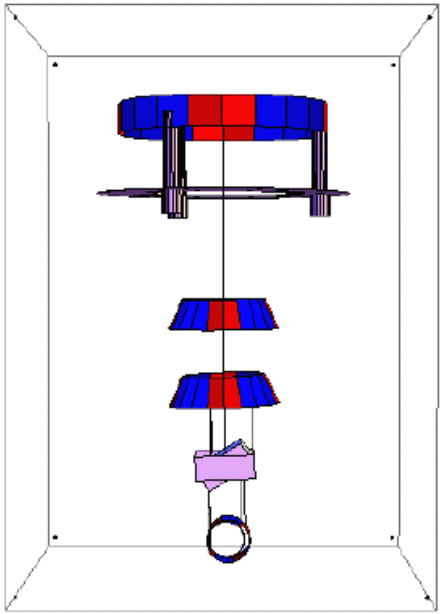
7 Vertical(.239Hz)

eigenplot[eigenv, 0.5, 7]



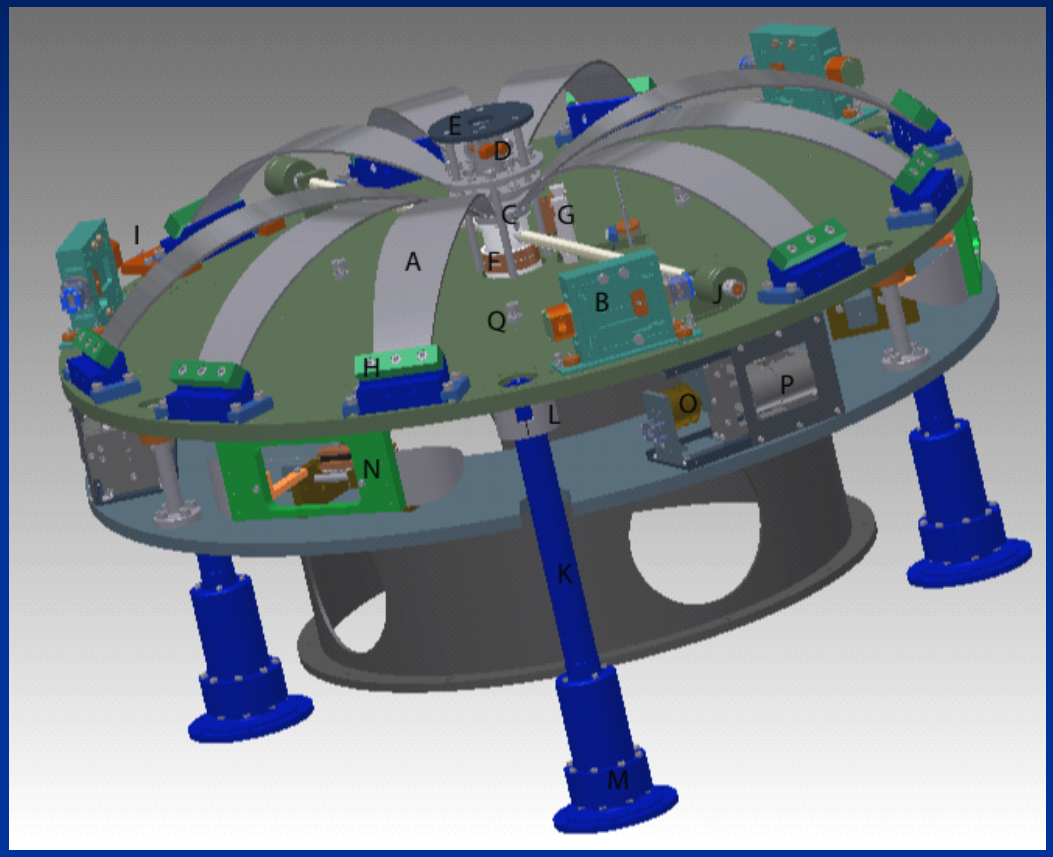
8 Roll(.403Hz)

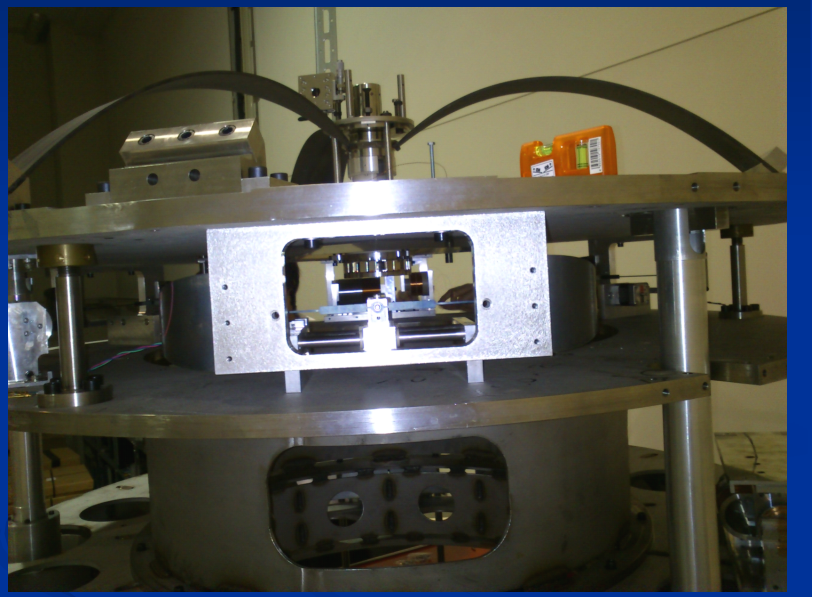
eigenplot[eigenv, 1.0, 8]



4. Design and Test

Design & Test
a. Pre-isolator

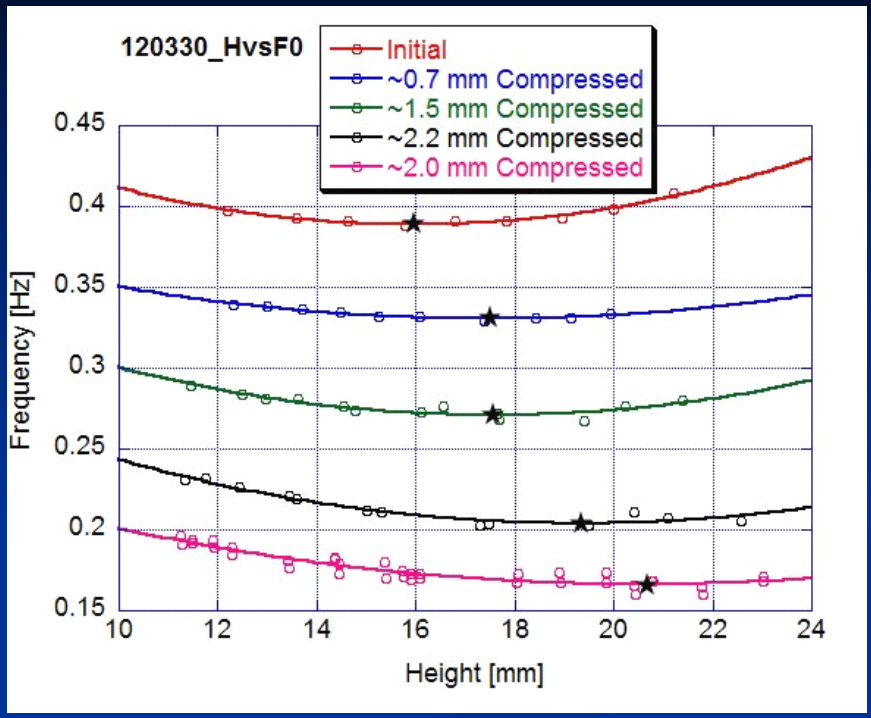


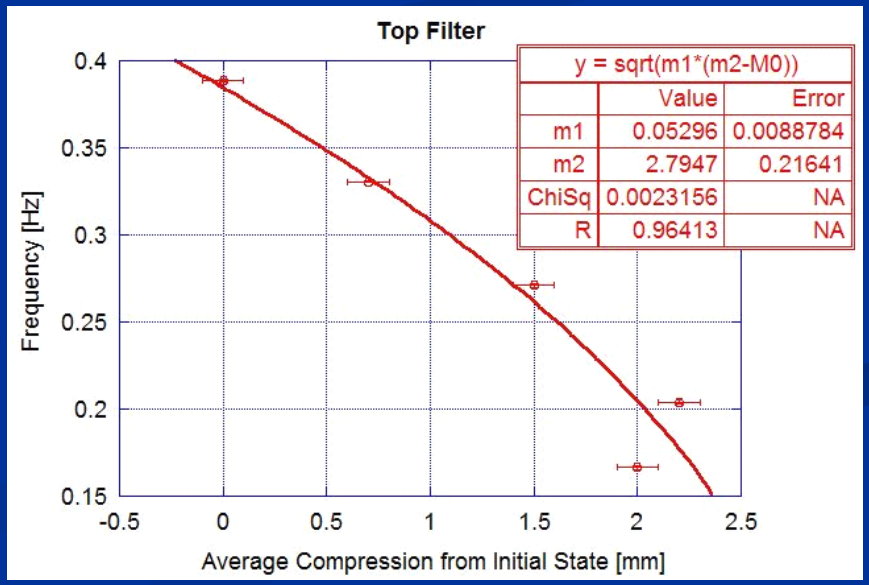


Pre-isolator prototype

GAS blades (A), Horizontal accelerometers (B), Central keystone (C), Motor controlled rotation mechanism (D), Platform for vertical accelerometer (E), Coaxial LVDT and voice coil actuator (F), Motor driven vertical springs (G), Sliding clamps (H), Special tool tuning filter resonant frequency (I), Counterweights for GASF (J), Inverted pendulum legs (K), Magnetic dampers (L), Counterweights for inverted pendulum (M), Motor driven horizontal springs (N), Horizontal LVDT (O), Horizontal voice coil actuators (P), and Hooking points of magnetic damper (Q)

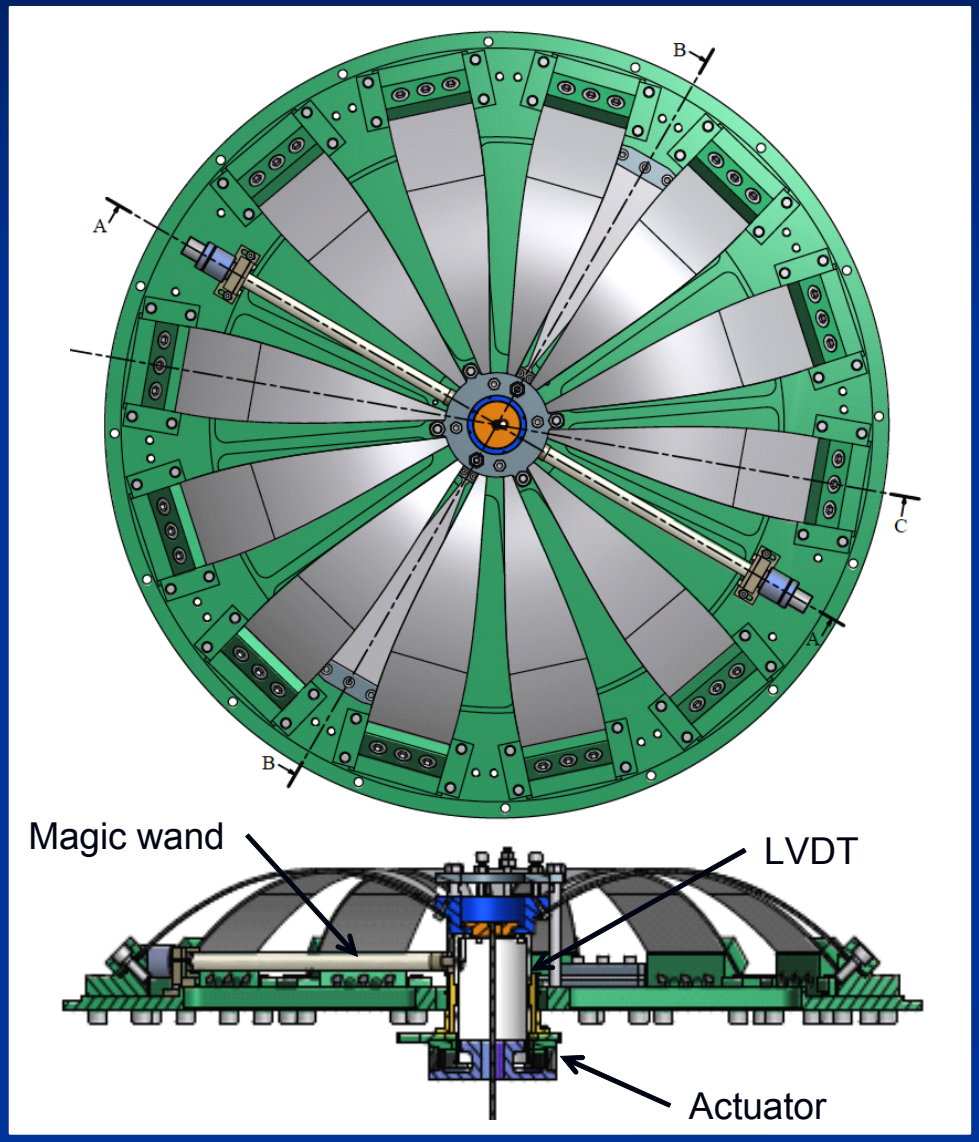
Pre-isolator prototype with digital controller at ICRR

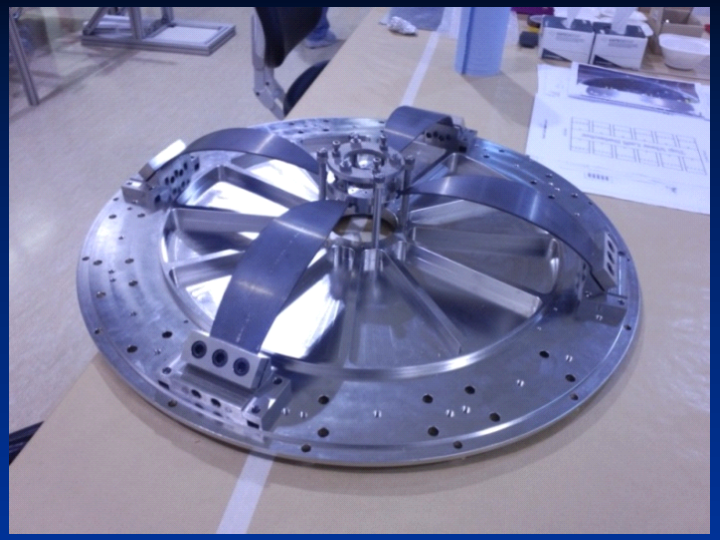


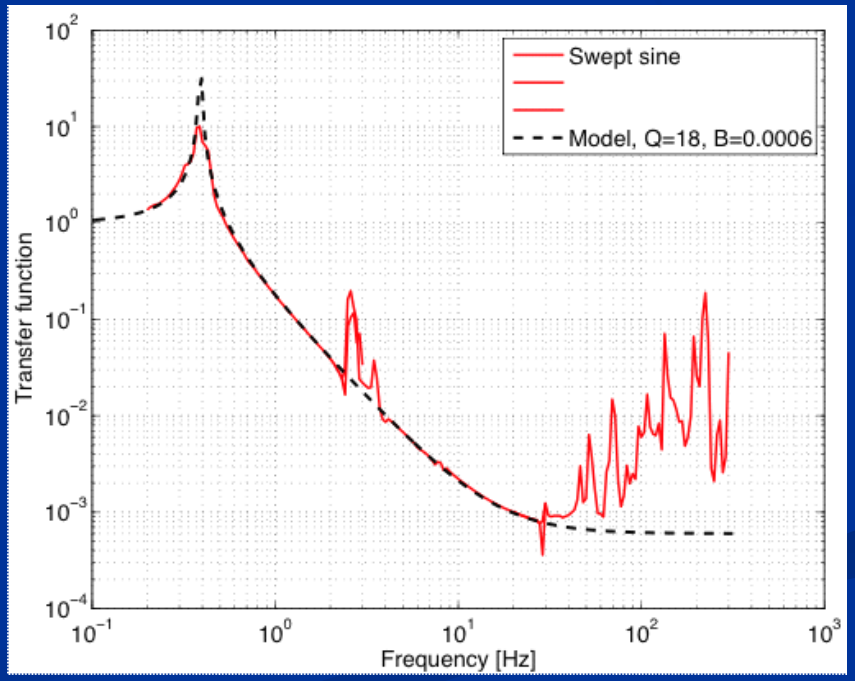


Tunning of top fiter

Design & Test
b. Standard GAS filter

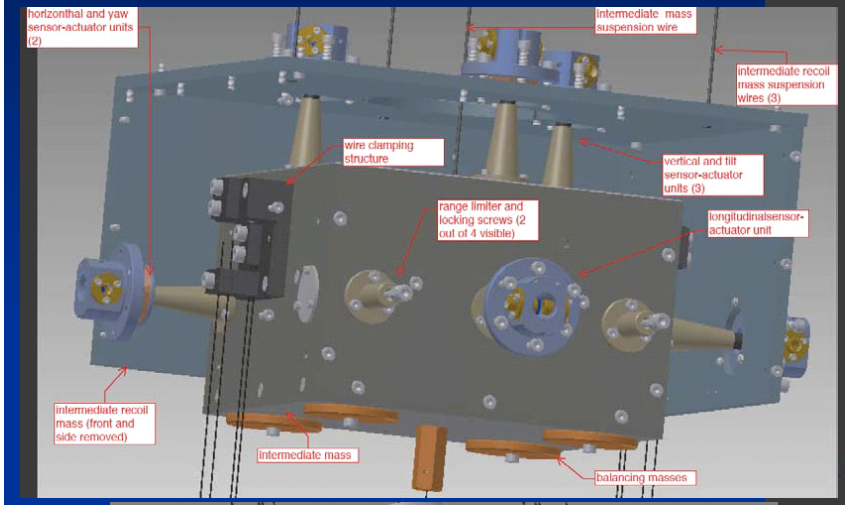


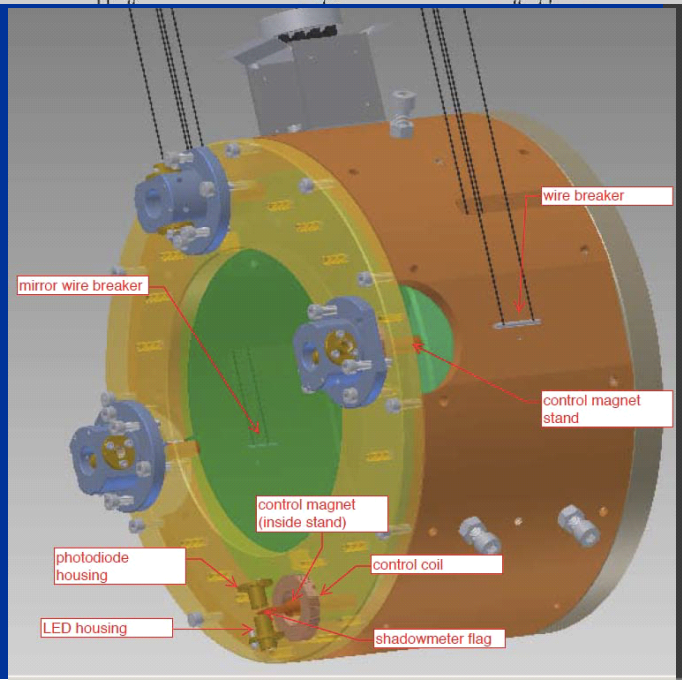


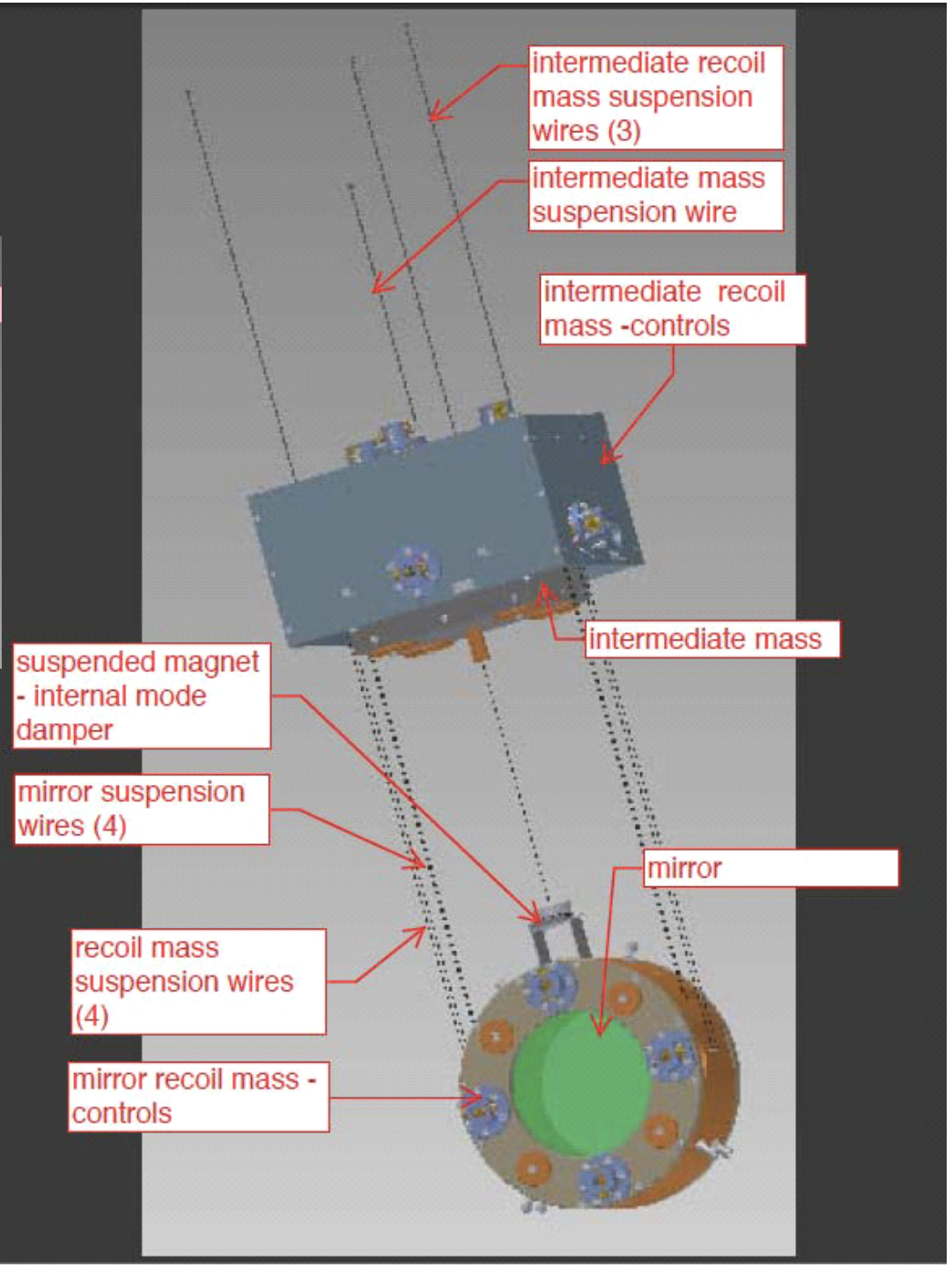


Measured transfer function at NIKHEF

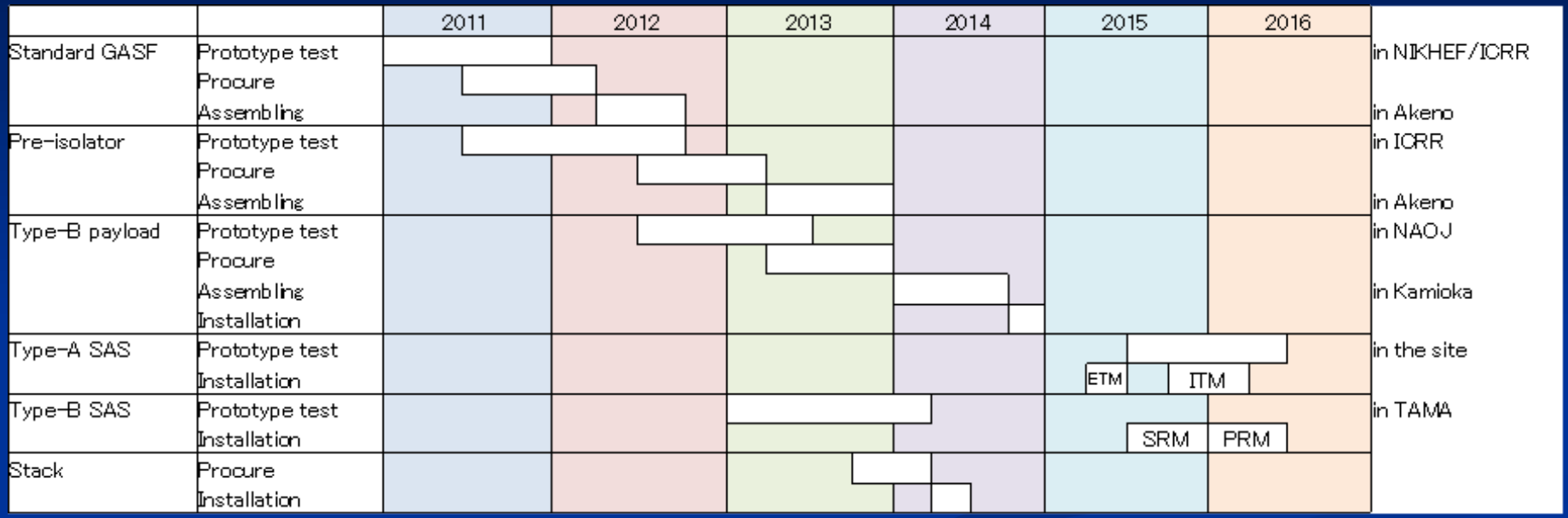
Design & Test
c. Payload







Schedule



Standard GAS filter

Prototype test: 2011.2- (@NIKHEF)
19 units: 2011FY

Pre-isolator

Prototype test: 2011.8- (@ICRR)
6 units: 2012FY

Type-B payload

Prototype test: 2012.8- (@ICRR)
7 units: 2013FY

Type-B full-system

Prototype test: 2013.4- (@TAMA)
3 units: 2014FY

5. Summary

- KAGRA employed the SAS which consists of an inverted pendulum and geometric anti-spring filters.
- The SAS for the main test mass is set in the 2-layer tunnels to obtain a rigid base.
- Model calculation has been developed with design works.
- Prototype tests are now going.