Outline of cryogenic payload compliance with Einstein Telescope LF

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on behalf of the payload group in Rome

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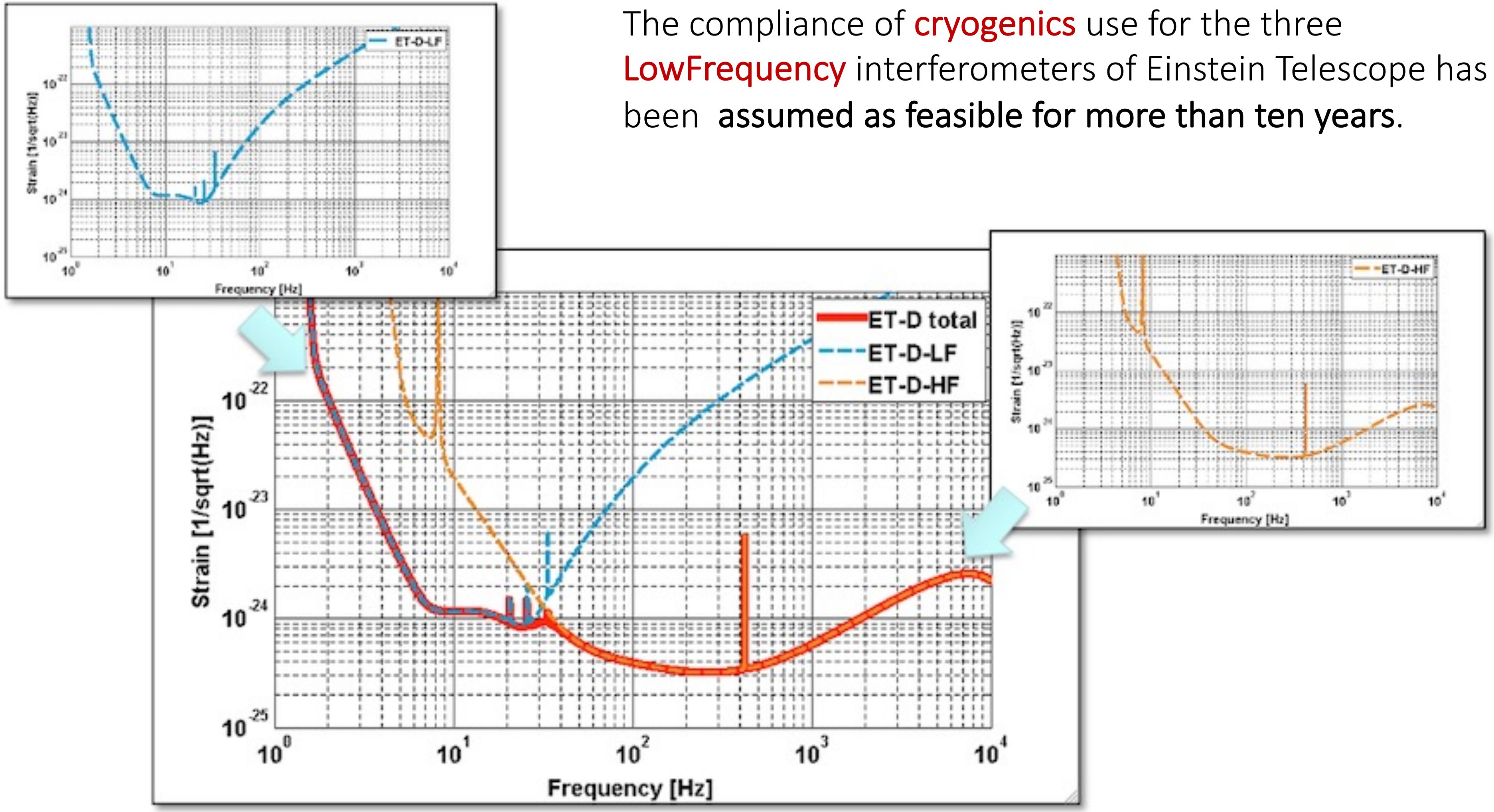
Room-temperature and Low-temperature ET interferometers

The compliance of cryogenics use for the three LowFrequency interferometers of Einstein Telescope has been **assumed as feasible for more than ten years**.



A sustainable approach

Analyse carefully the target

Experience with present detectors

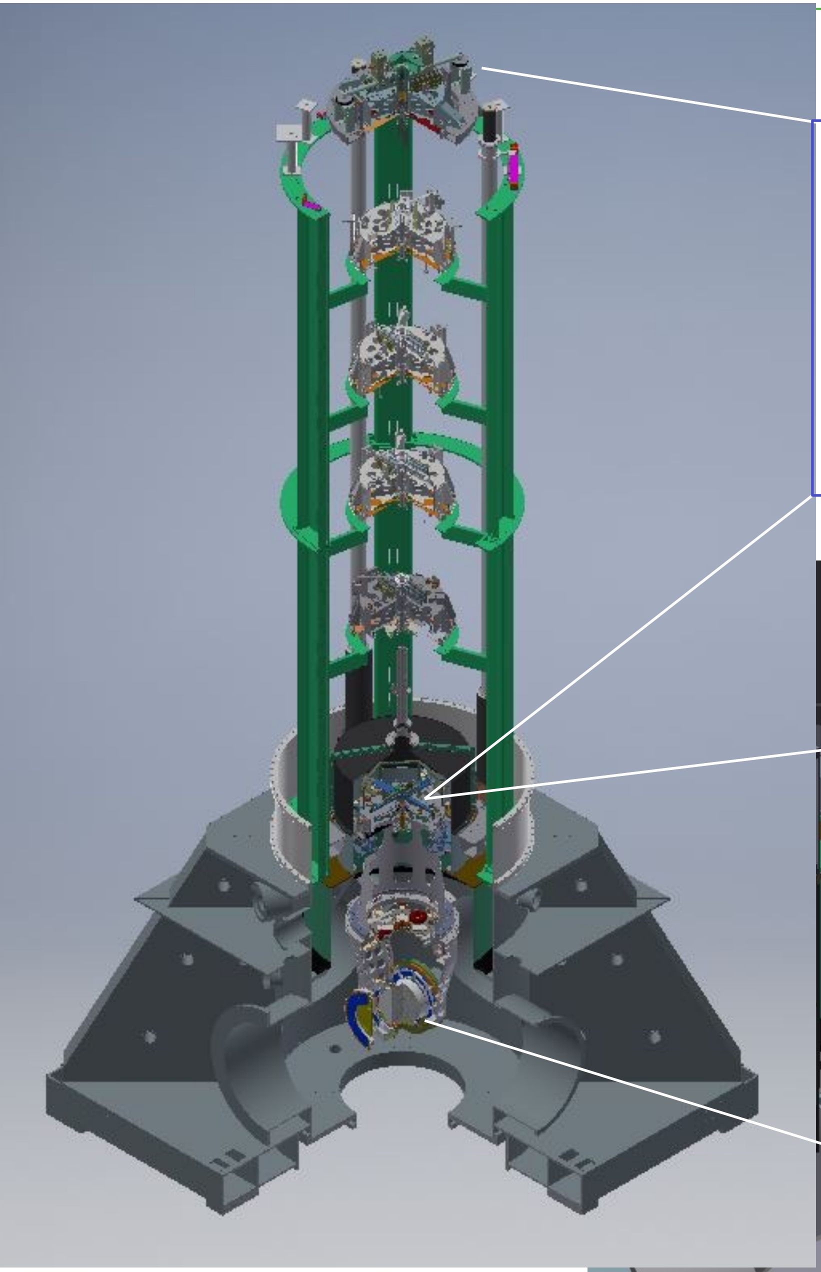
Widening the collaboration and gathering financial resources

Develop experimental facilities and identify the know-how

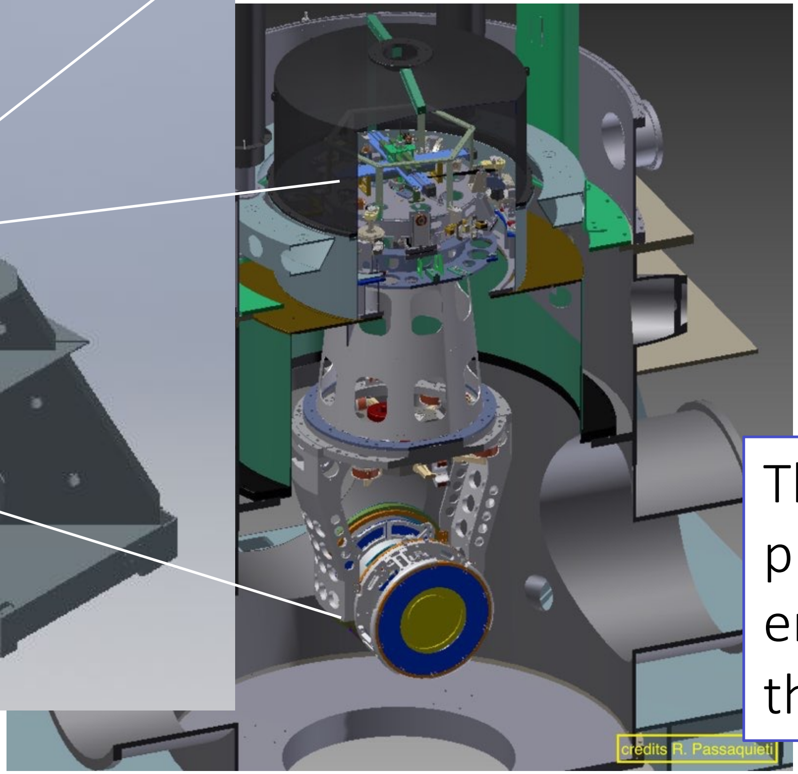
Aligning priorities and wisely schedule viable R&D milestones

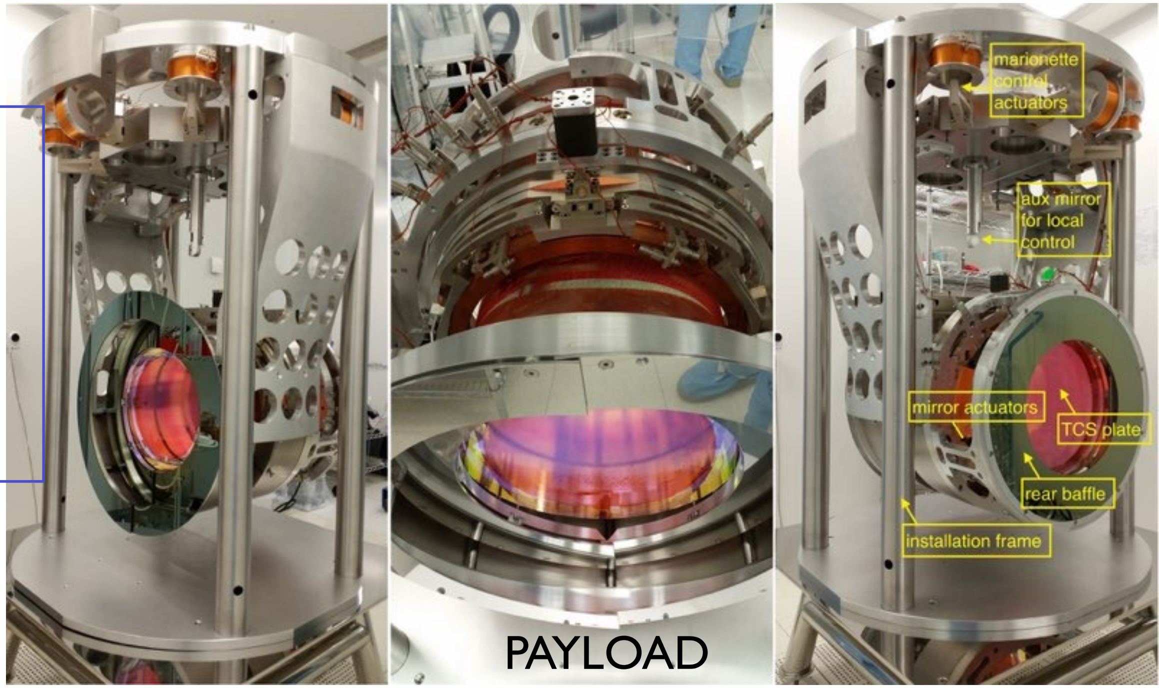
a meaningful TD ?

Test mass suspensions and seismic isolator in Virgo: overall system



In AdV the first 5 stages of the Super-attenuator (horizontal and vertical) are roughly the same **designed 20 years ago** !!

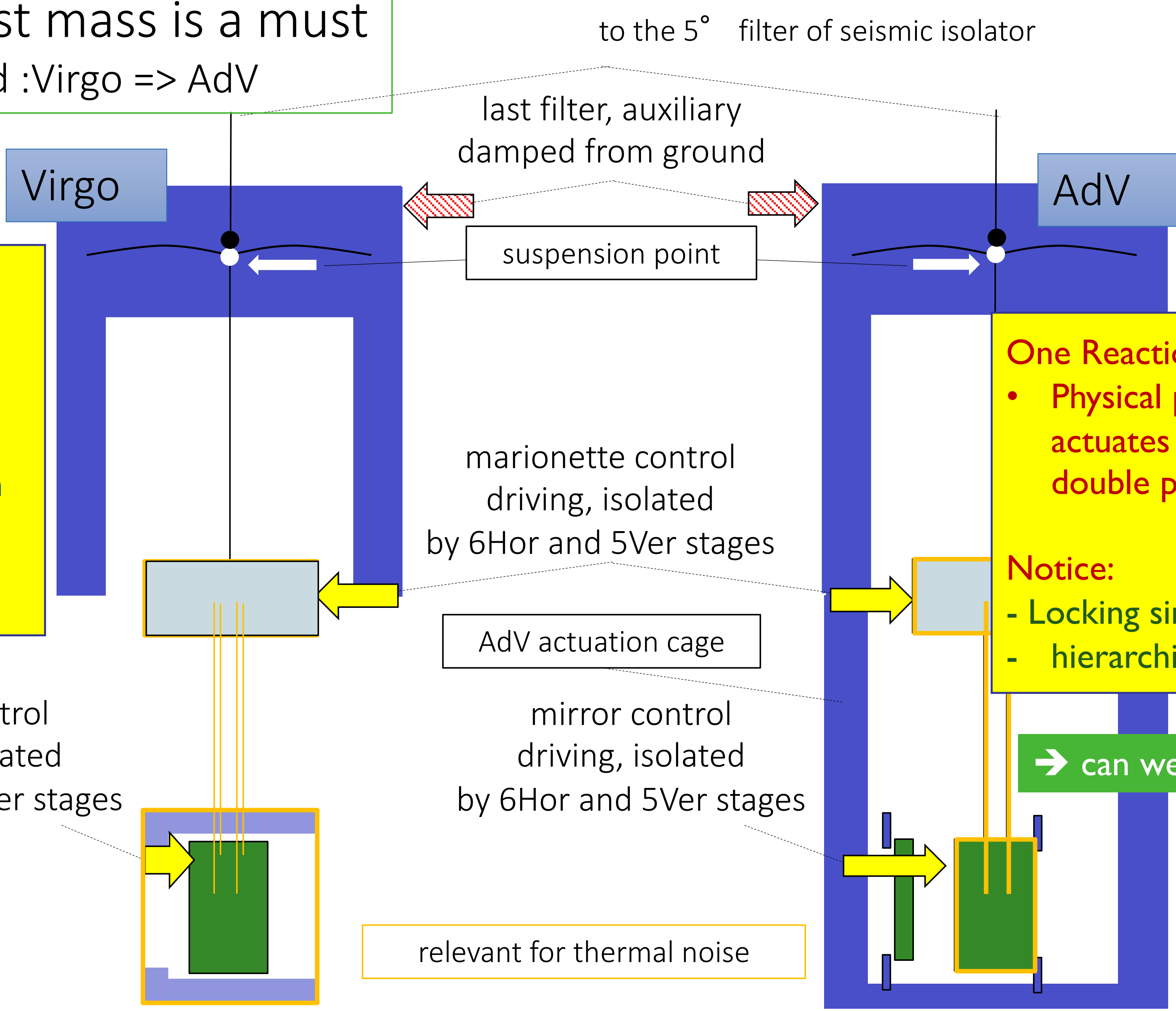




The last filter of the Super-attenuator, prolonged downwards, is in the same vacuum environment of the payload and surrounds it: the “actuation cage”.

Position Control of test mass is a must

Scheme Last filter + Payload :Virgo => AdV



Two Reaction Bodies:

- Physical pendulum for the marionette
- Pendulum for the mirror

Notice:

- Lock-Acq using just reaction mass on mirror, simple
- hierarchical control not so easy

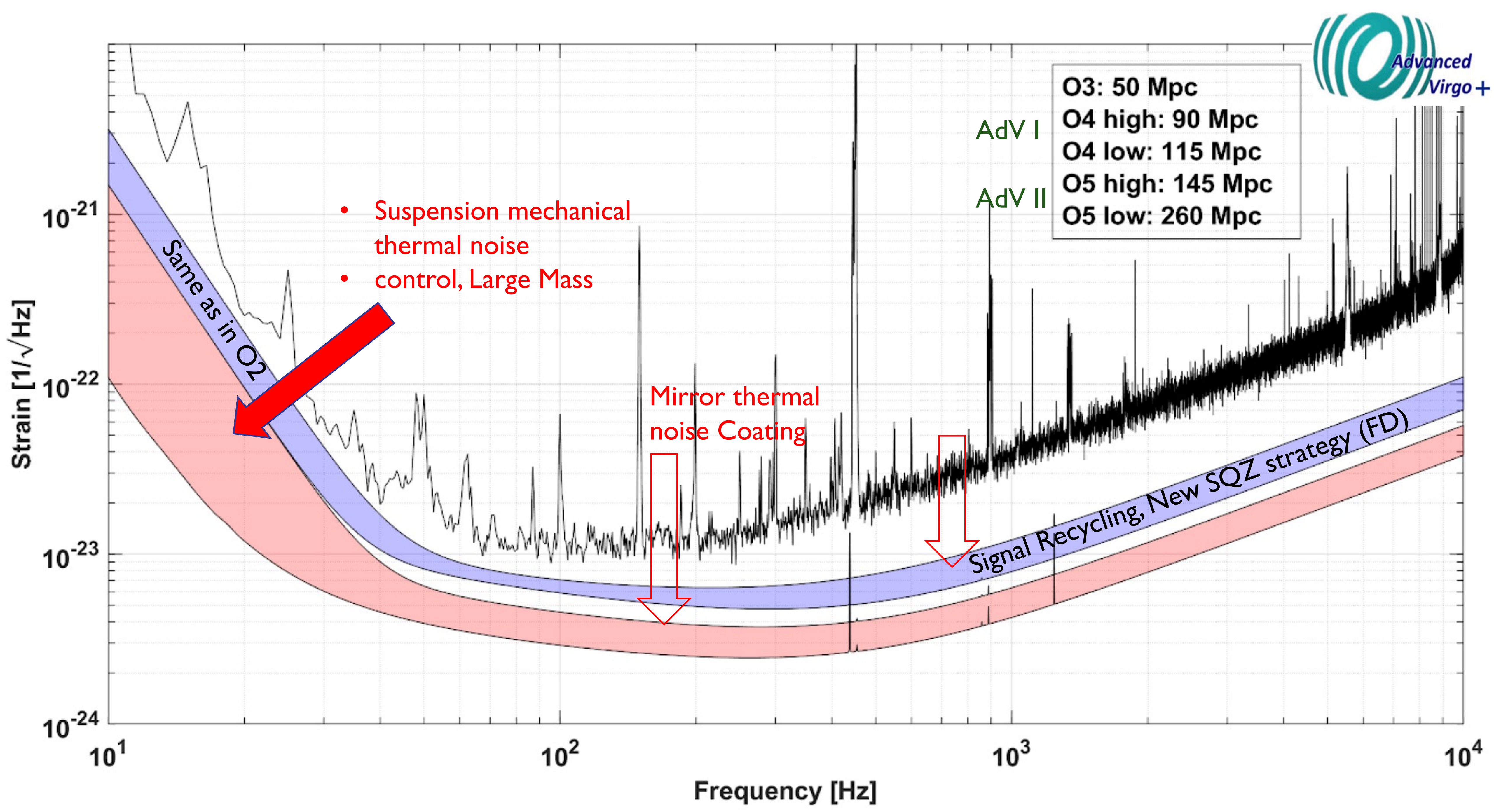
One Reaction Body

- Physical pendulum actuates on a simple double pendulum

Notice:

- Locking simple,
- hierarchical control easy

→ can we port it to ET ?



Advanced Virgo+
O3: 50 Mpc
O4 high: 90 Mpc
O4 low: 115 Mpc
O5 high: 145 Mpc
O5 low: 260 Mpc
AdV I
AdV II
Suspension mechanical thermal noise
control, Large Mass
Same as in O2
Mirror thermal noise Coating
Signal Recycling, New SQZ strategy (FD)
Strain [1/√Hz]
Frequency [Hz]
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{1}
10^{2}
10^{3}
10^{4}

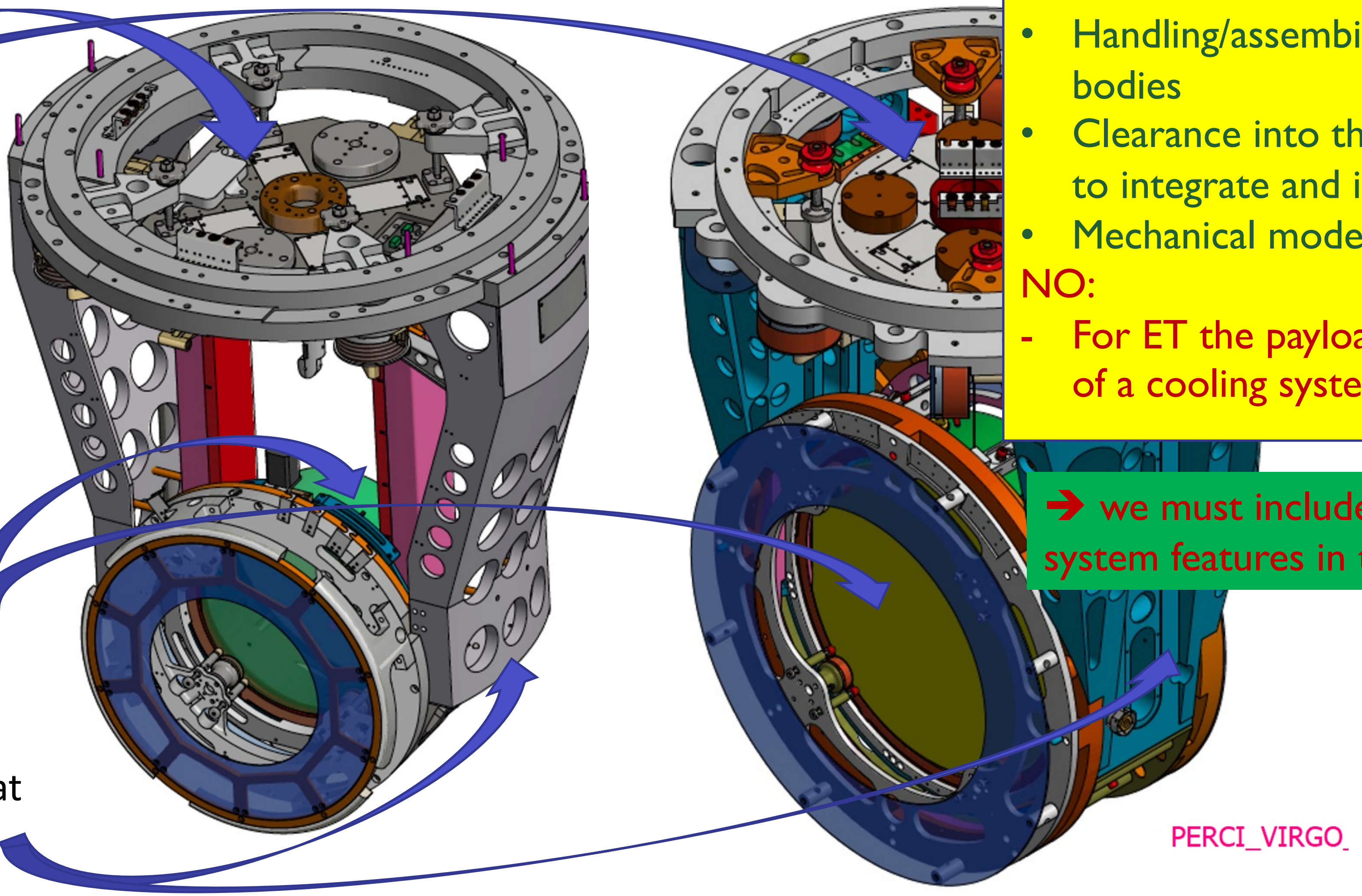
AdV+: payloads with Large Mass

The marionette is conceptually simple but it serves for variuous functions:

- Mechancial: from single point to four point suspension
- Orientate the mirror in DC, motors
- Controlled orientation in AC and FabryPerot lock

The mirror a bulky cylinder suspended through four silica fibres to the marionette lock

Actuation cage, rigidly fixed at the last filter of the seismic attenuation chain, surrounds the payload and carries aux optical elements



Does LM payload project go in the direction of ET ?

YES:

- Handling/assembing heavy bodies
- Clearance into the cryostat to integrate and inner size
- Mechanical modelling OK

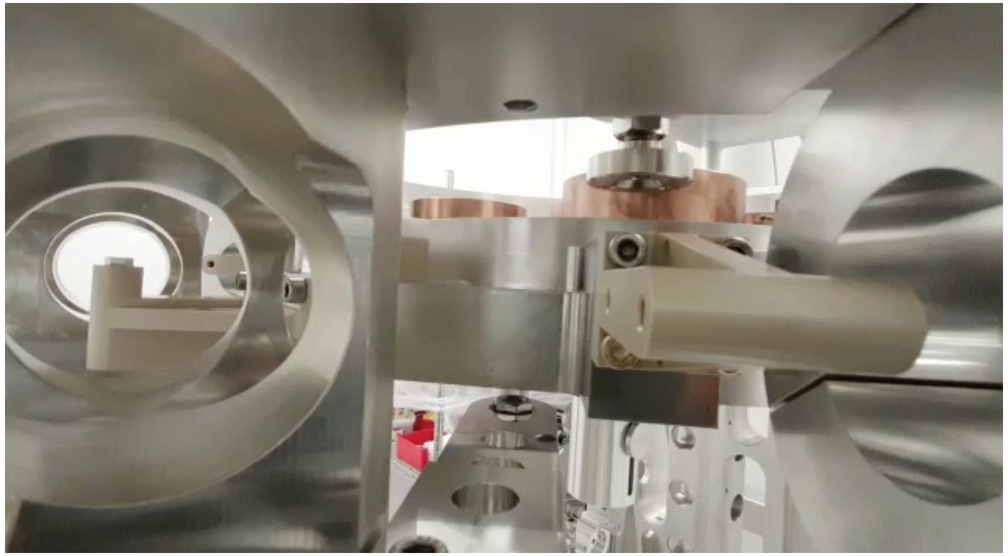
NO:

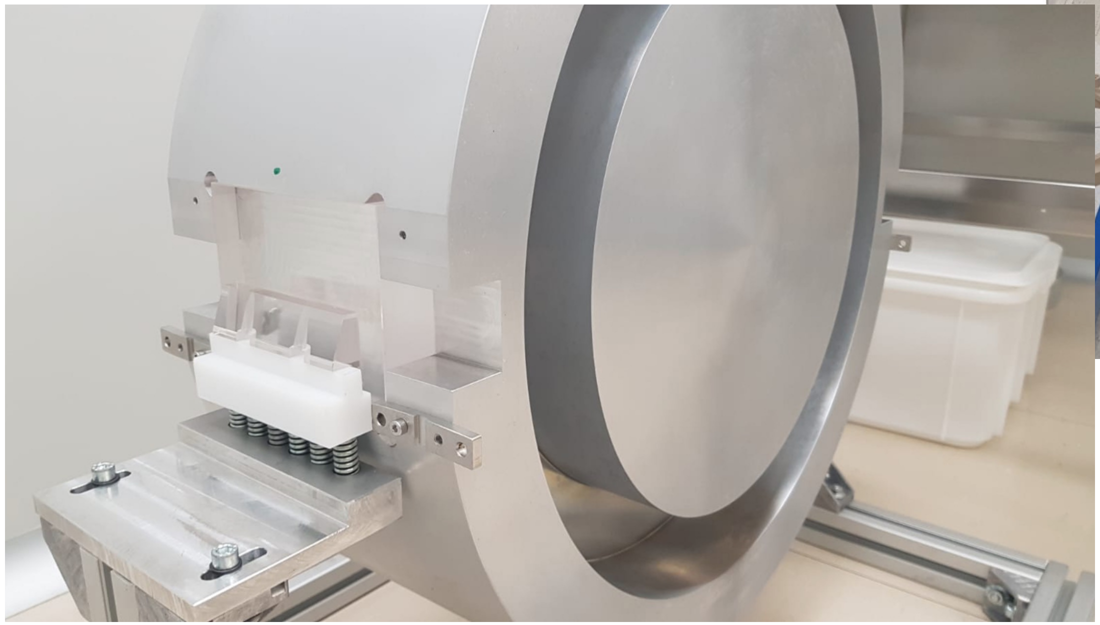
- For ET the payload is a part of a cooling system

➔ we must include cooling system features in the payload

Prototype Readiness

Milestones OK





AdV marionette is a rather complex body and this may make the fulfilment of intrinsic-noise performance for ET difficult. We consider two options as seed.

Split in two parts

Single body made of different materials

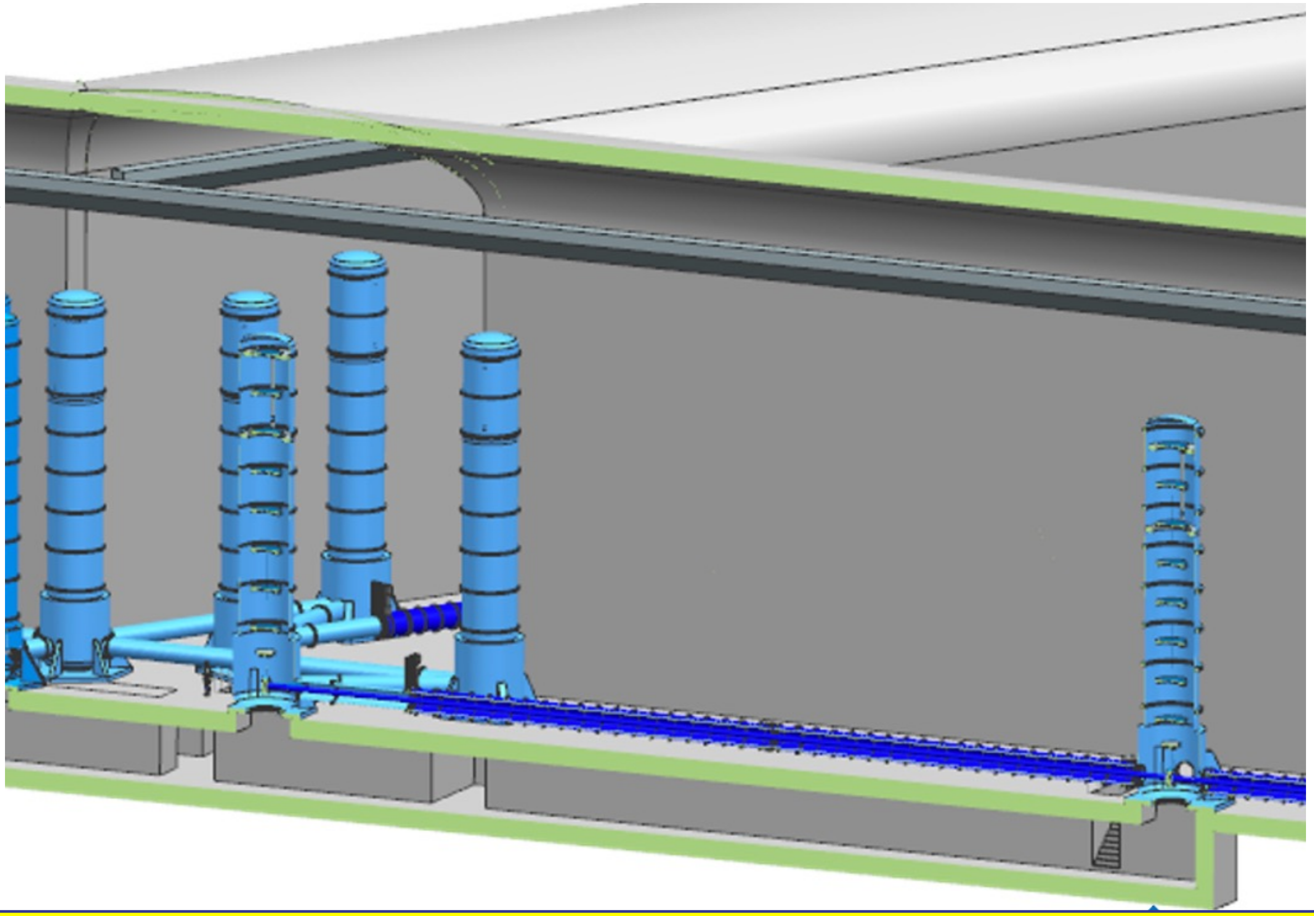
We study the problem at three levels

- Mechanical controllability
- Heat extraction
- Thermal noise
- Technical noise

→ Inner Cryostat environment

AdV+: payloads with Large Mass

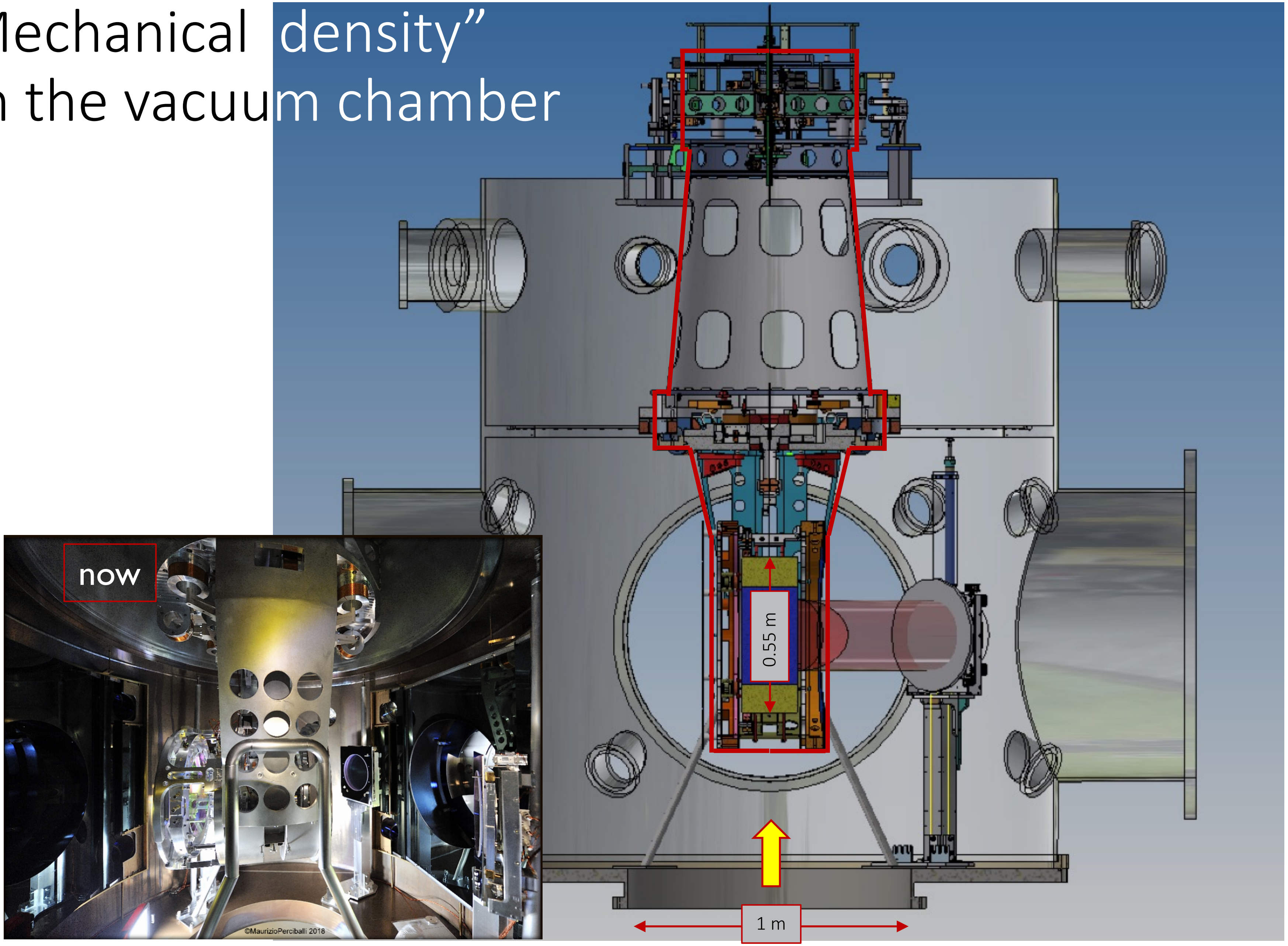
Physical (MKS) (using NE as ref.)	**Adv**	**LM Heavy**
Mirror mass	42	**104.4**
Mirror moment of inertia Ixx	0.46	2.34
Mirror moment of inertia Iyy	0.463	2.34
Mirror moment of inertia Izz	0.64	3.97
Marionette mass	103.7	**182.6**
Mario moment of inertia Ixx	2.06	3.80
Mario moment of inertia Iyy	3.65	6.33
Mario moment of inertia Izz	1.88	4.01
F7 mass (total)	315	**341.3**
○ Body+interface	120	120
○ Actuation_cage	195	**221.3**
F3 mass	140	140
F2 mass	165	165
Mirror wire diameter	400e-6	640e-6
Marionette wire diameter	1.85e-3	2.4e-3
F7 wire diameter	2.7e-3	3e-3
IP flex joint diameter	32.65e-3	34.06e-3
Mirror wire distance X	0.178	0.278
Mirror wire distance Z	0.02	0.02
Marionette CM	8.35e-3	1.06e-3
Total mass below F7 blades	145.7	287
Total mass below F4 blades	460.7	**628.1**



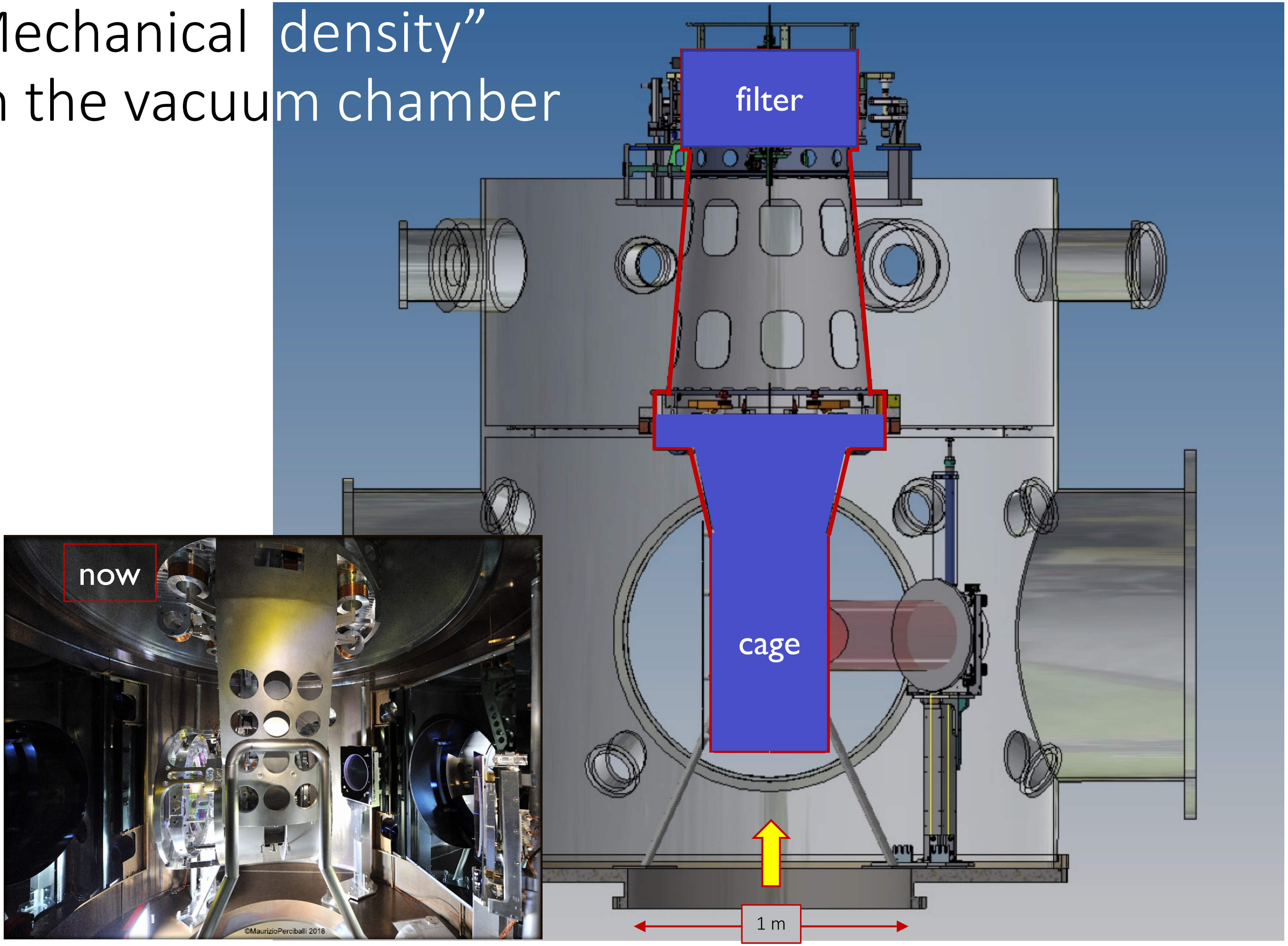
Inserted form the bottom!!!

- **we enter in the vacuum chamber from the bottom, possible but non-trivial in a cryostat**
- **Clean rooms or clean booths close to each SA ?**

“Mechanical density” In the vacuum chamber

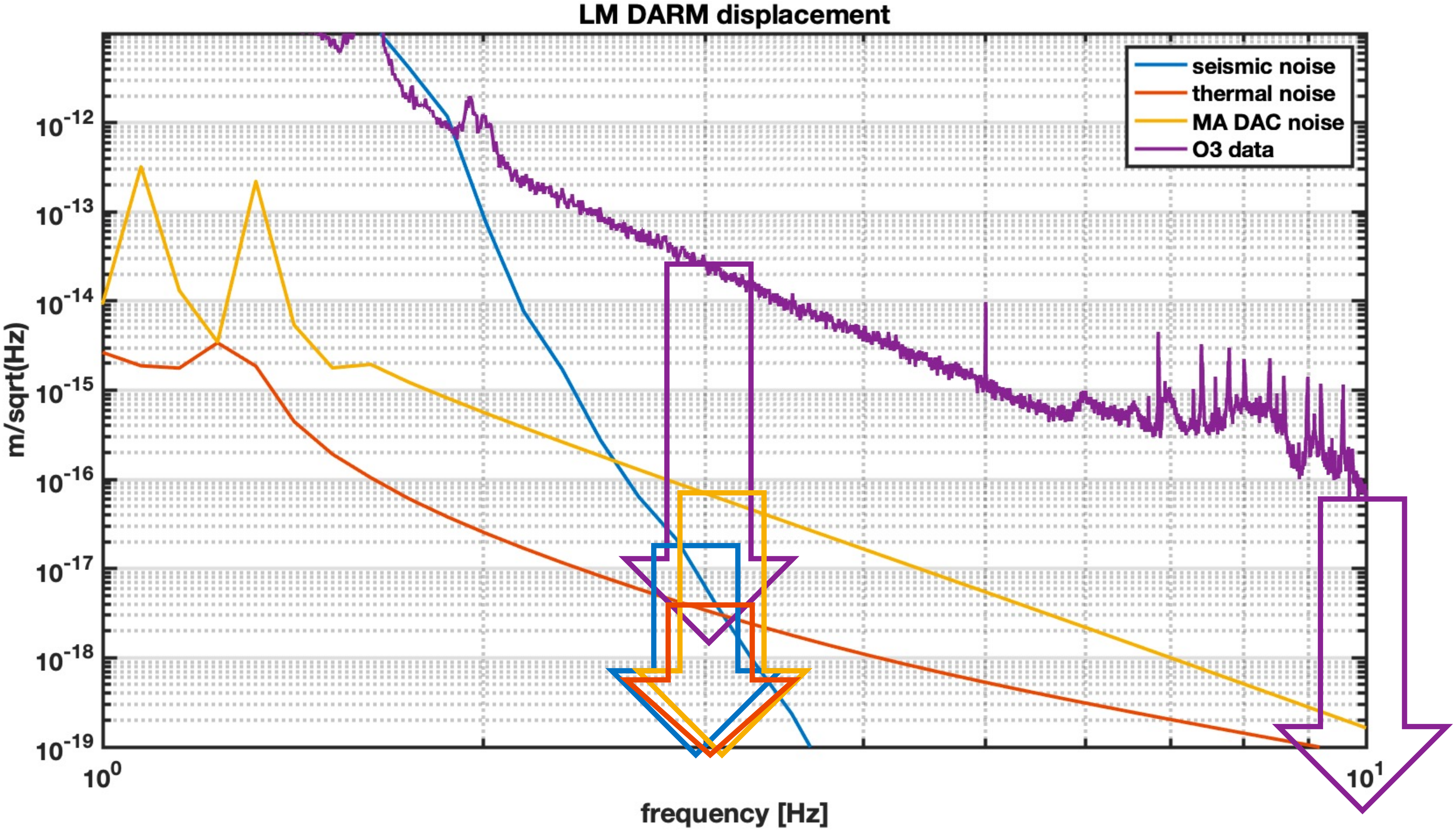


“Mechanical density”
In the vacuum chamber

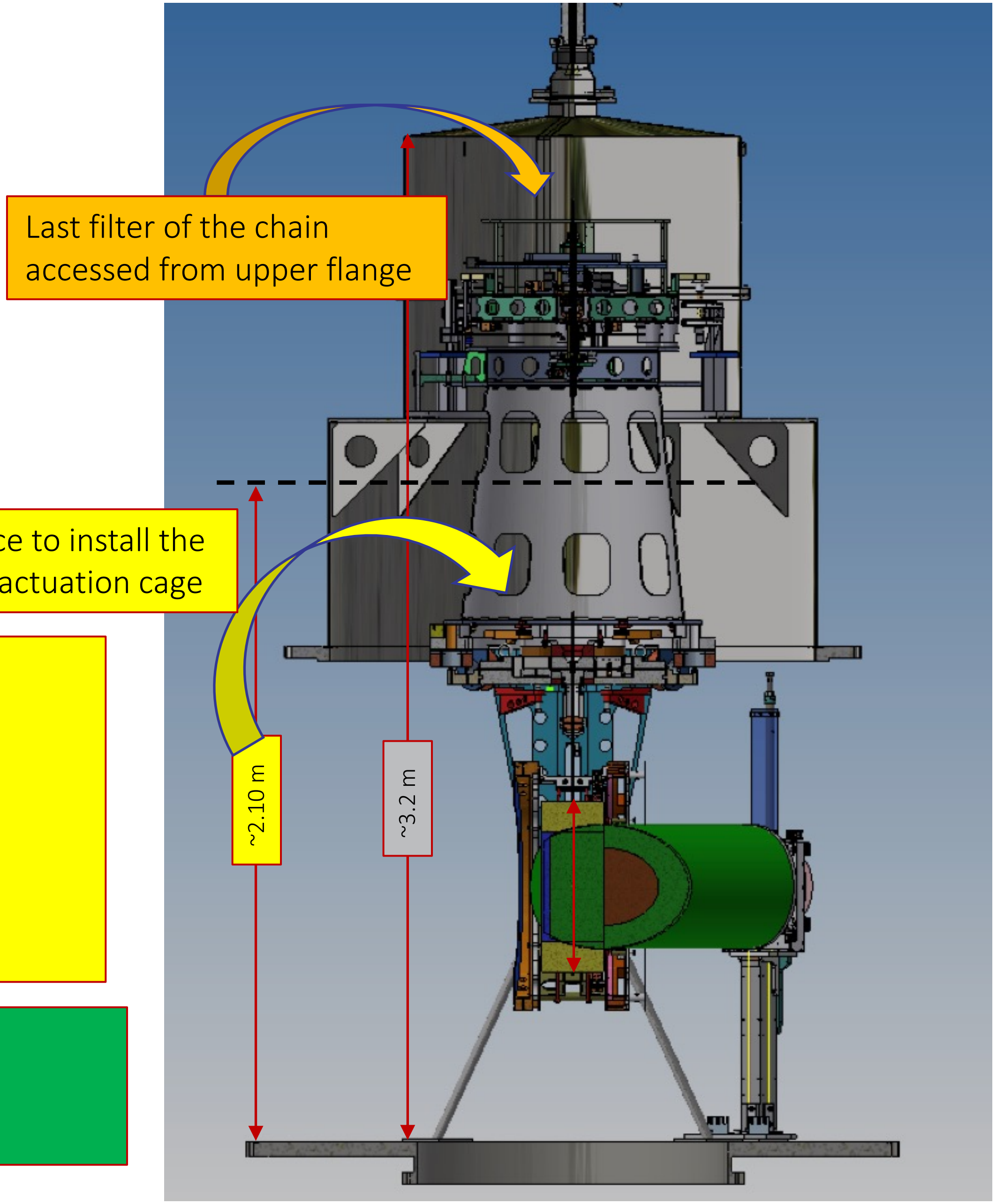


Advanced Virgo +

From Room Temperature prospective: A) two issues TN (intrinsic),
B) Driving technical noise (electromechanical design a study is possible at RT) ➔ Let's track the intrinsic



“Mechanical density” In the vacuum chamber



<u>Remarks and possible «seed choices»</u>
<u>criterion: **from inside to outsize**</u>

Inner chamber should be:

- **reasonably compact** (by eye I like 2.5 m)
- suitable to host a “**good payload**”
- suitable to host **2 persons** to install it

➔ next questions:

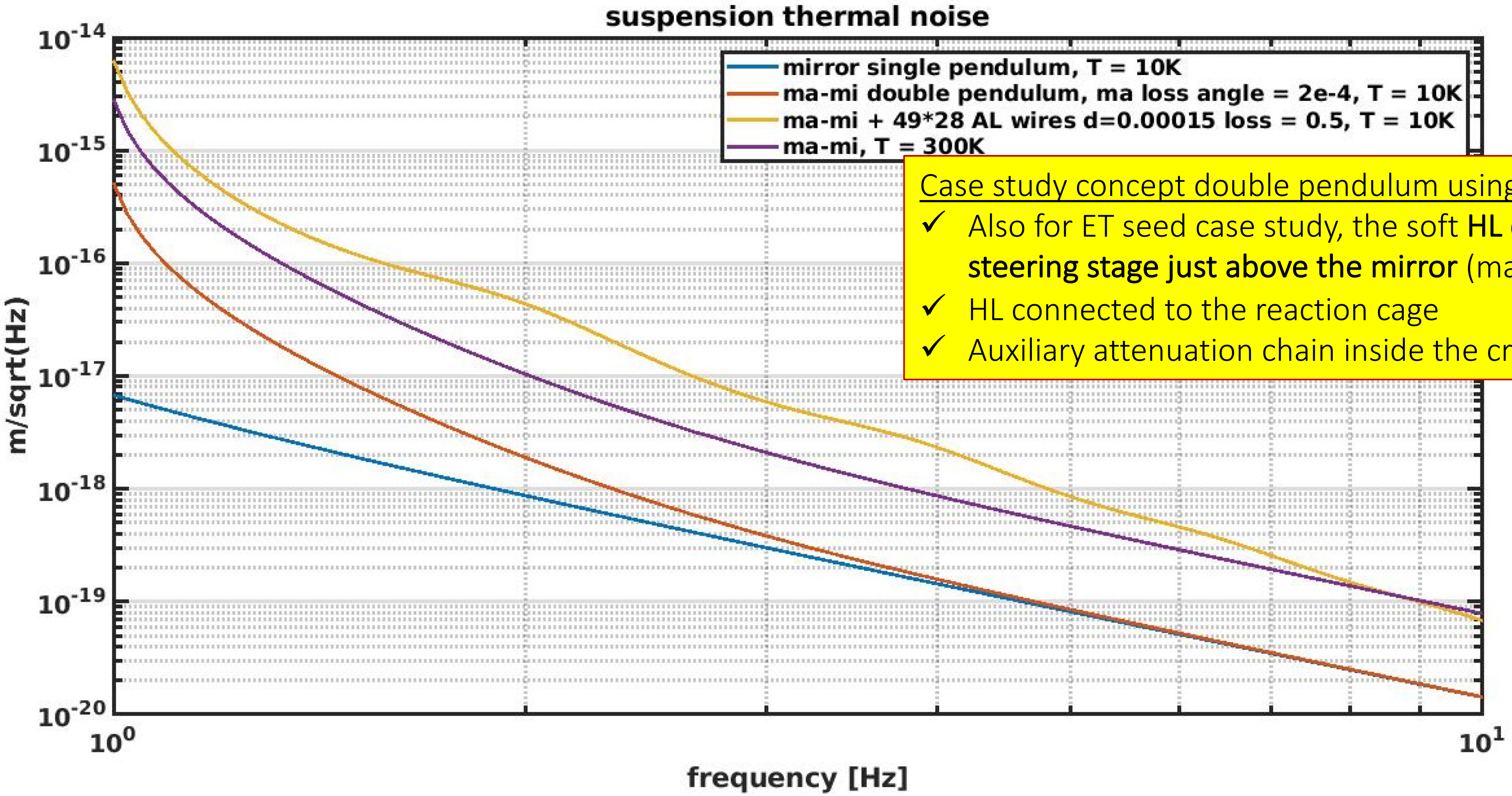
Horizontal clearance ?
Vertical filter into the cryostat ?

Seed modelling for a “good payload”

- Analytical Modelling[1] now includes soft heat Links[2]
- Structural modelling and TN in interfaces requires FEM

- Good to attenuate cryostat vibration injection
- Bad concerning violin modes and related thermal noise

[1]**P. Ruggi**, Thesis VIR-0020A-21 (2003), [2]T. Yamada, “High Performance Heat Conductor with Small Spring Constant for Cryogenic Applications”, arXiv:2003.13457 (2020); [2]Gabriela I. Gonzalez and Peter R. Saulson, “Brownian motion of a mass suspended by an anelastic wire”, J. Acoust. Soc Am 96 (1) (1994)



<u>Case study concept double pendulum using Al_2O_3 and Al6N multiwire</u>

- ✓ Also for ET seed case study, the soft **HL cannot be connected to the steering stage just above the mirror** (marionette) (agrees with KAGRA)
- ✓ HL connected to the reaction cage
- ✓ Auxiliary attenuation chain inside the cryostat expected

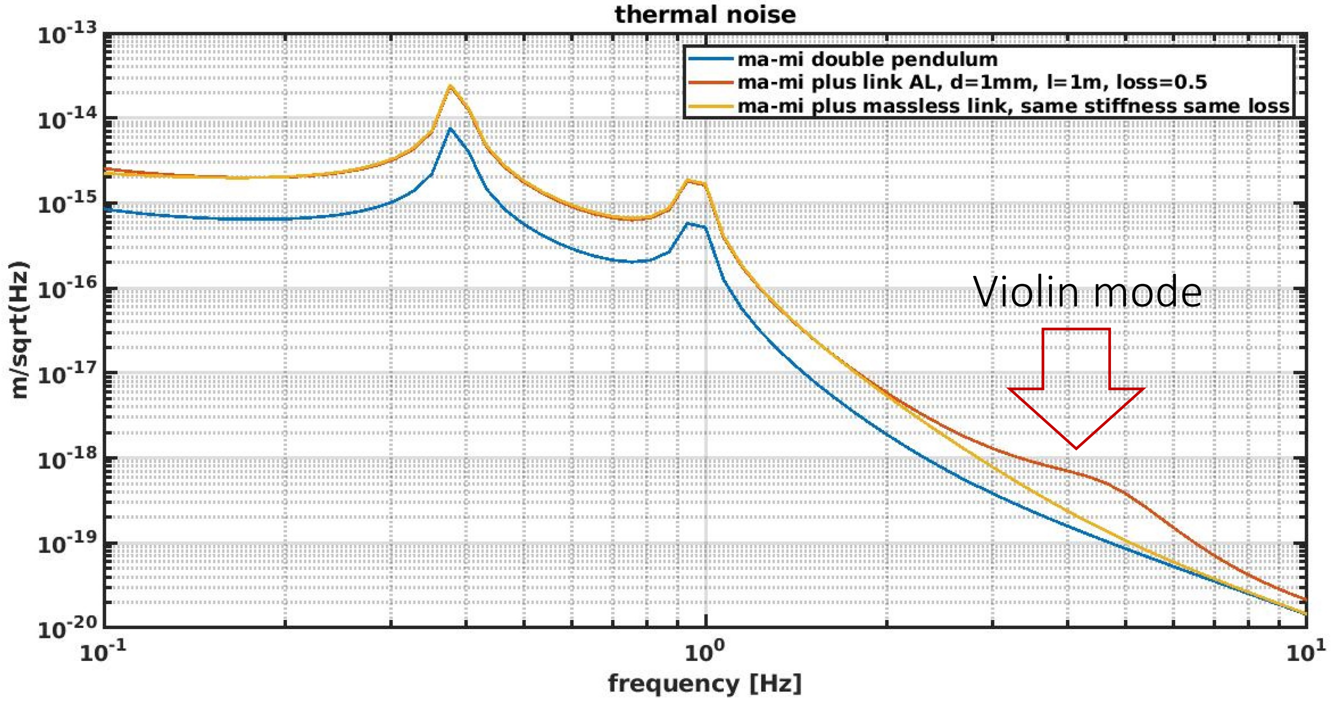
Seed modelling of cryo-payload

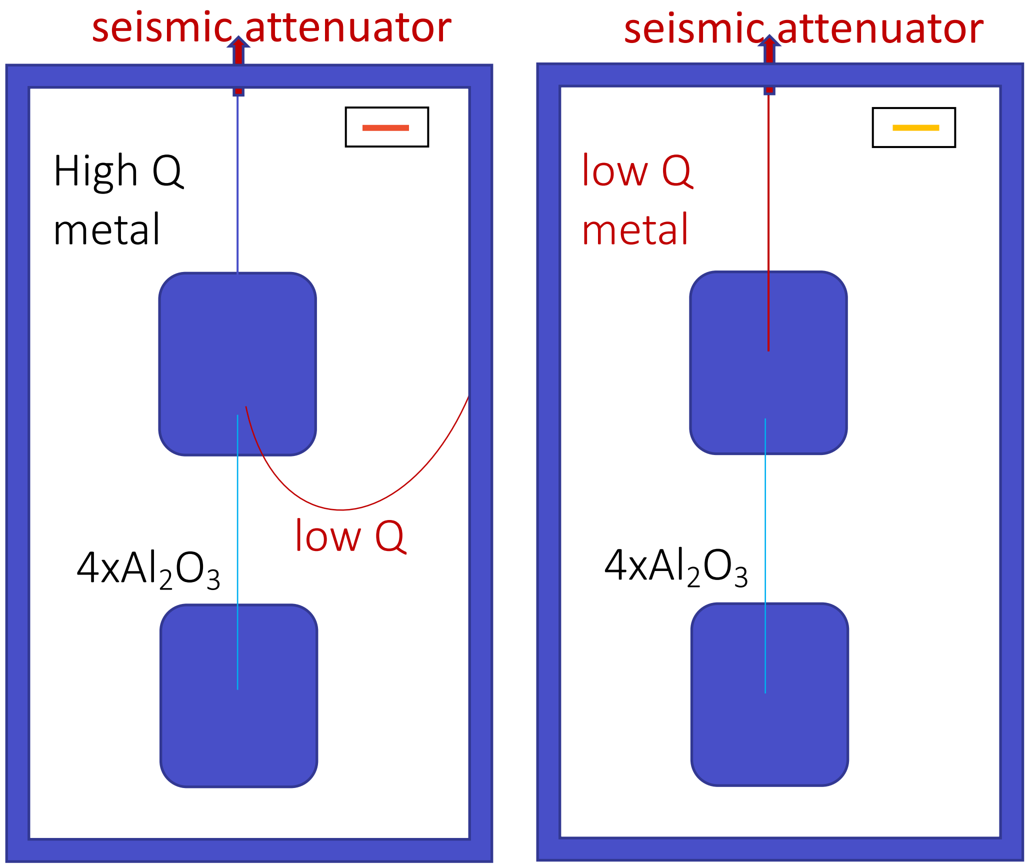
Case study: let’s suppose a simple marionette suspension (e.g. Virgo maraging)

<u>concept: 1mm dia Al wire (braid)</u>

- ✓ Low tension thermal conductors attenuate the drag but are not OK for thermal noise

➔ HL yields a very high TN as the suspension penultimate suspension wire had a very low Q

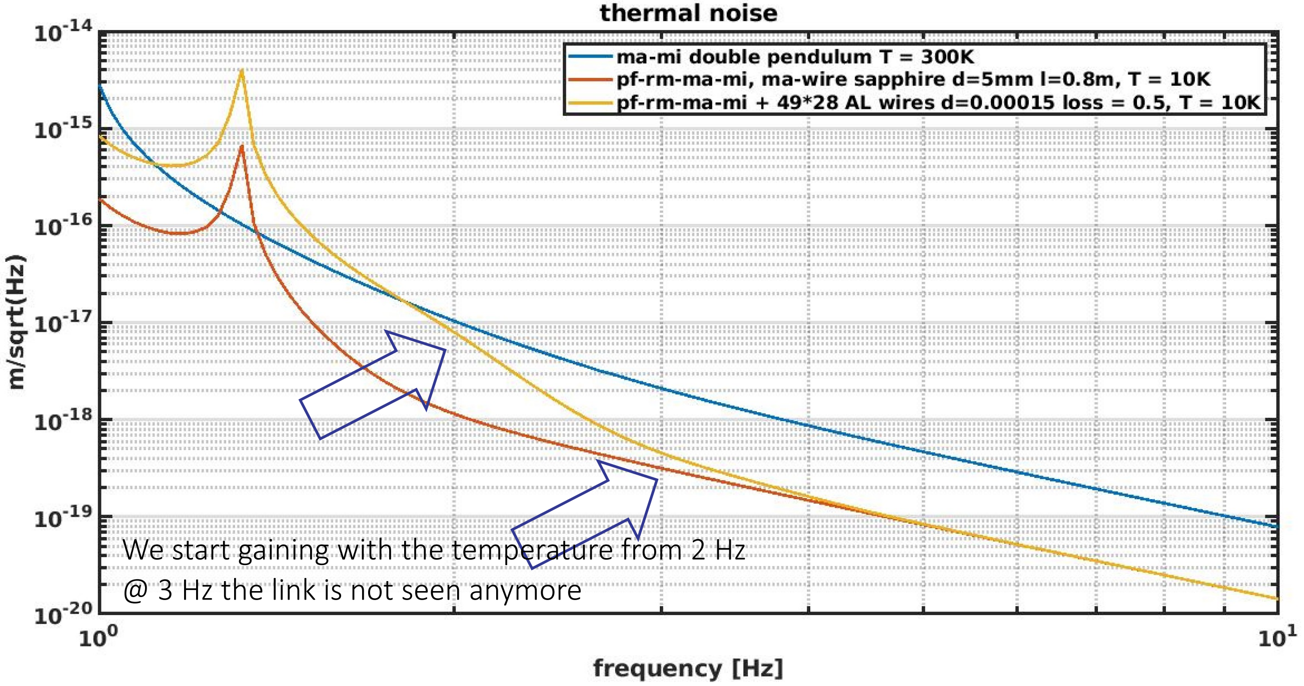


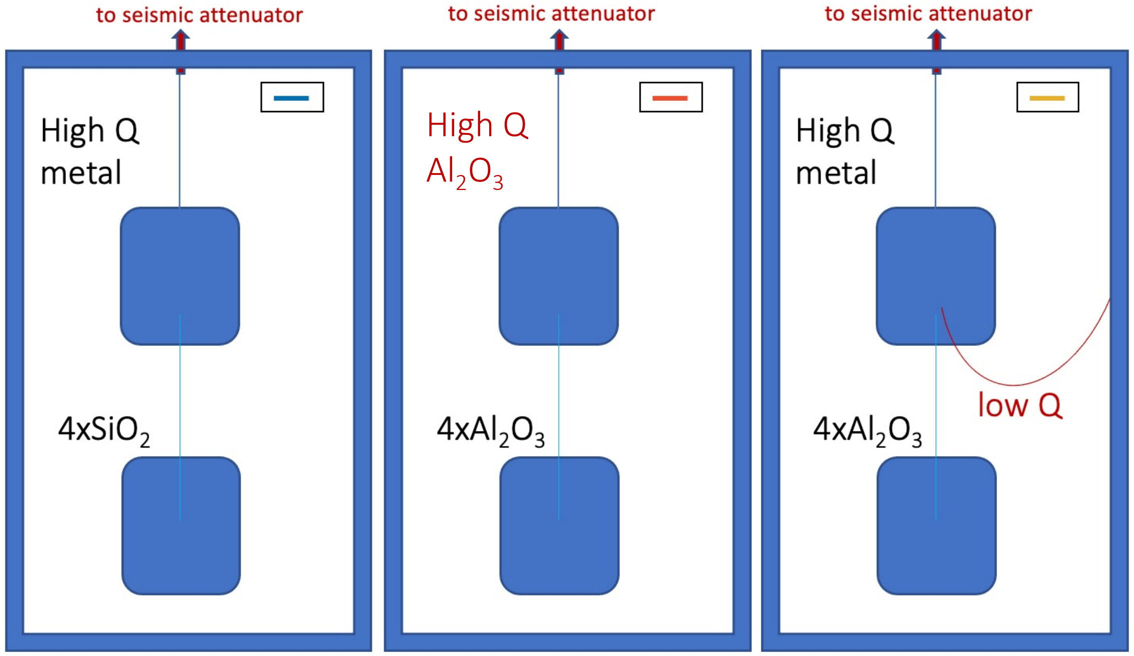


Seed modelling for a "good payload": height needed

- ✓ TN projection of lumped bodies not so bad ! Seed parameters of Inertia found
- ✓ **2.8 m preferable** (for both installing and accessorial instrumentation, optical baffles etc..)
- ✓ Reaction cage (RC) suspended using 3 metal wires
- ✓ Simple enough to be effective
- ✓ Height, enough to host an alternative configurations (also under study)
- ✓ Single massage to Room T (20 mm dia pipe ?)
- ✓ Auxiliary attenuator for the HL surely needed

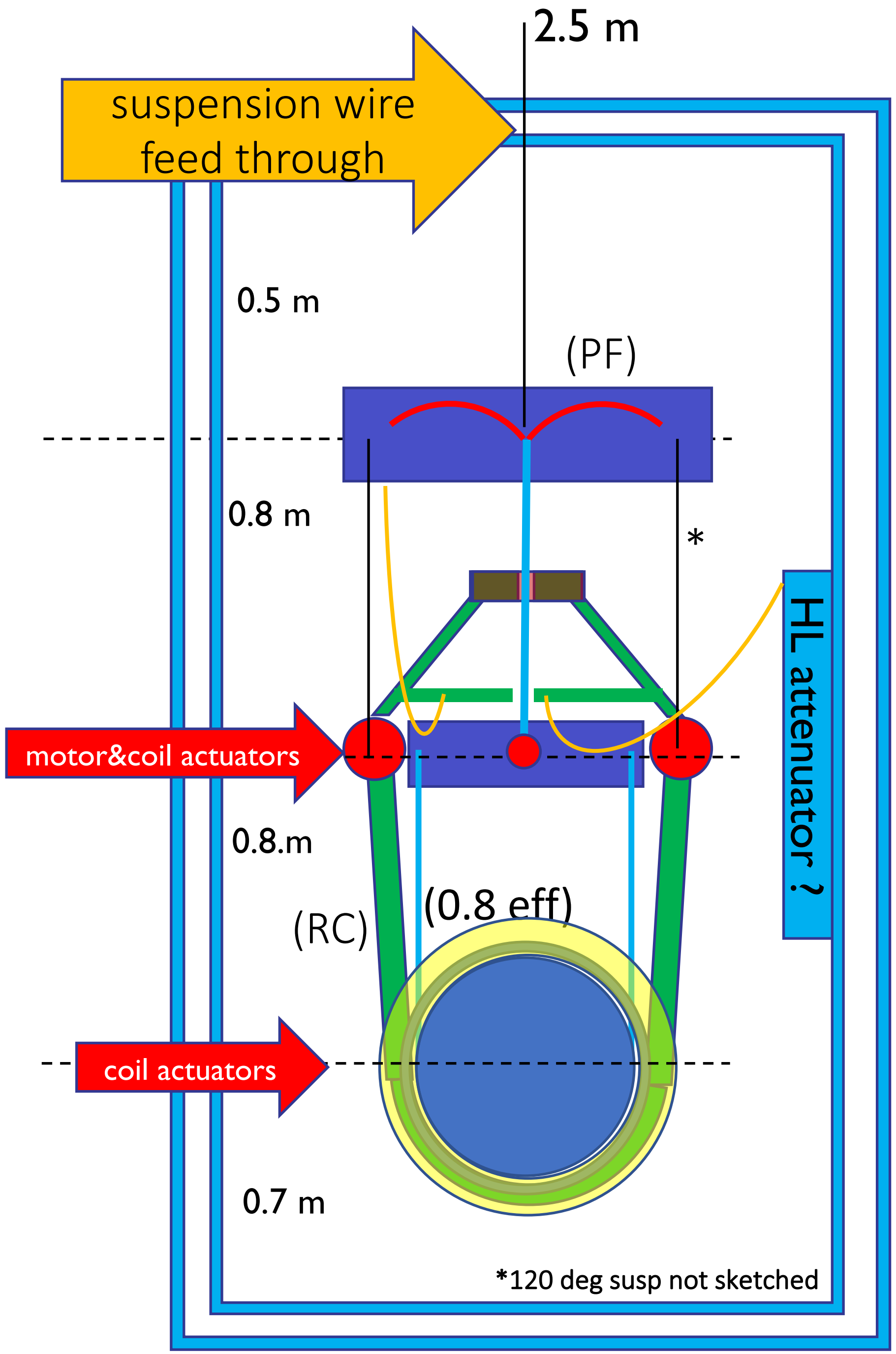
- Thermal extraction rescaled (TBC): Al6N HL, capability of building 80-90-cm-long Al_2O_3
- Similar case Silicon_{MA} /Sapphire_{Mi} to allow larger yield and safer torsion ?

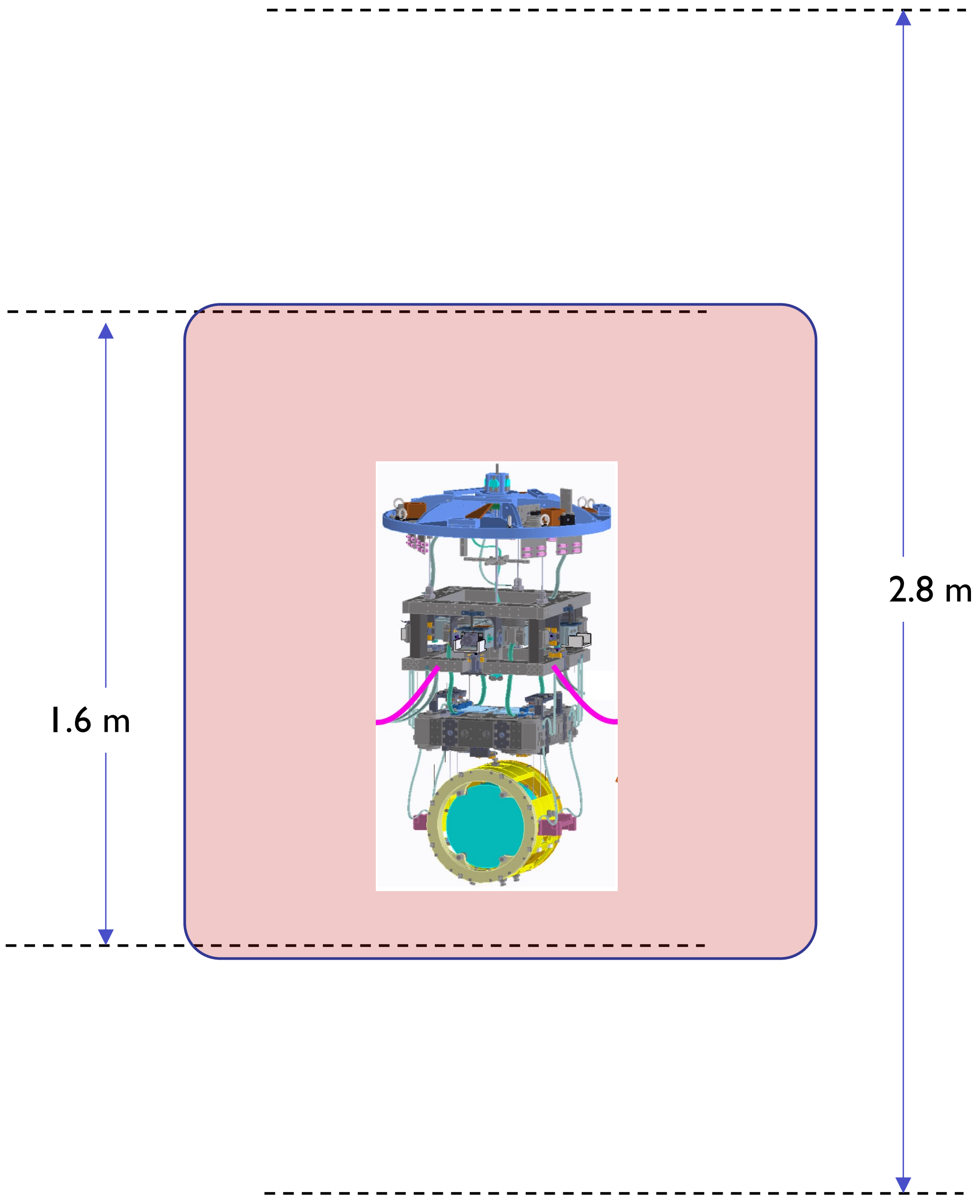




XXL

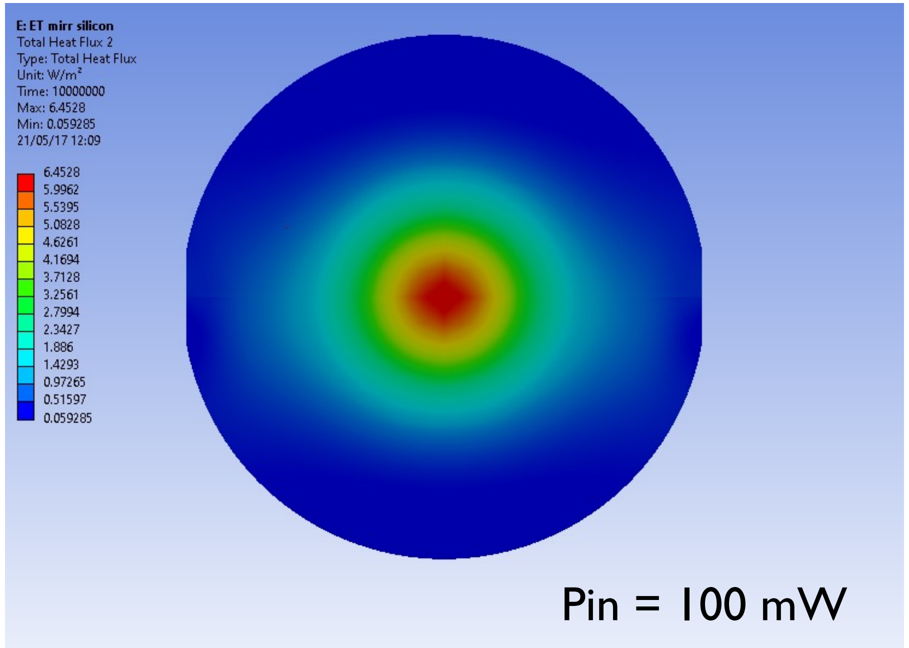
First set of seed parameters

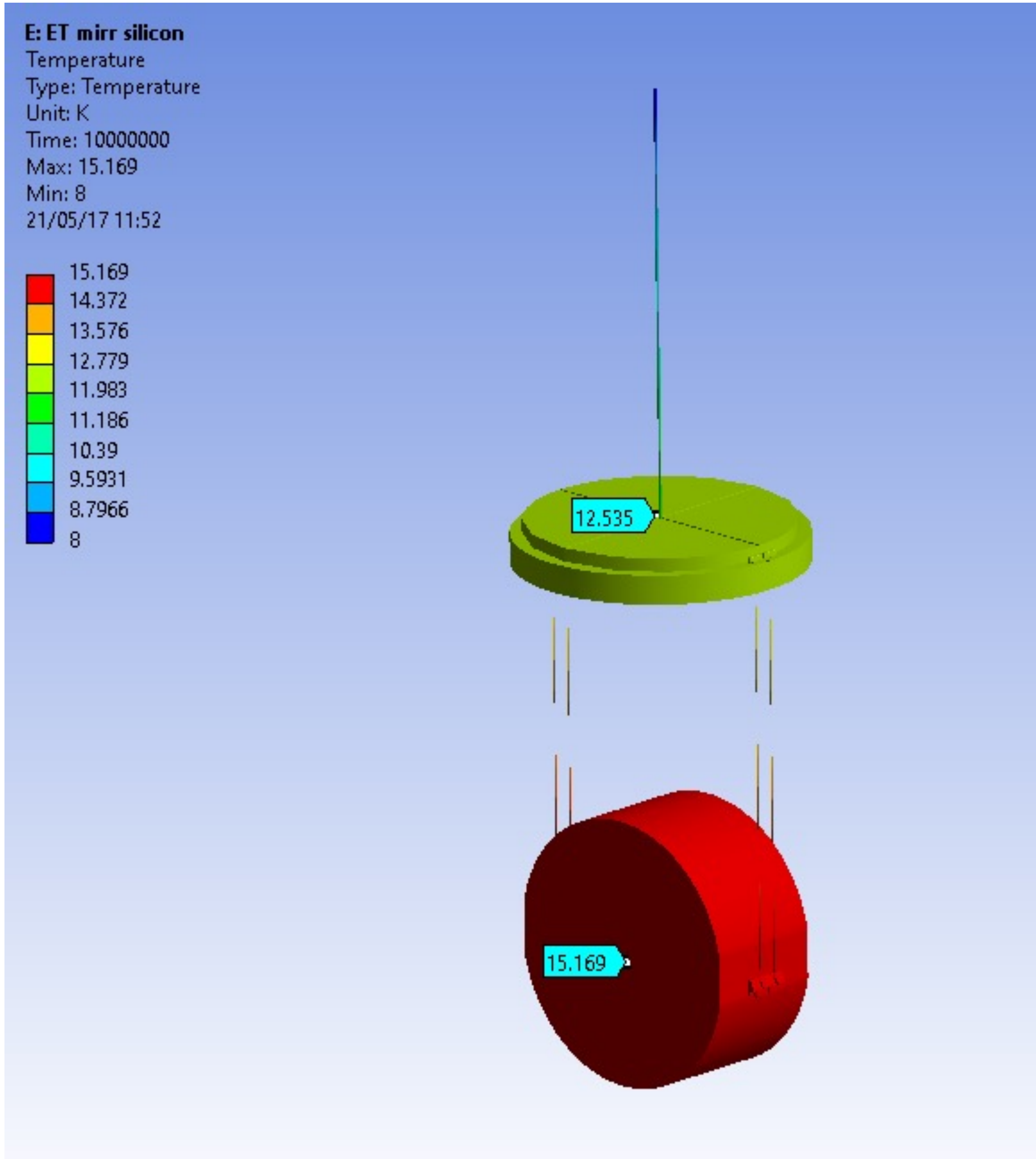




Using sapphire rods

- Si Test Mass: 140 kg (Sapphire 150 mm thick also tested)
- TM Sapphire wires: 2.2 mm Ø - Length: 0.8 m + $2\lambda_{bending}$
- Marionette Wire: Sapphire Diam 5.4 mm (safe strength)
- Upper point: 8K
- Radiation component not included so far

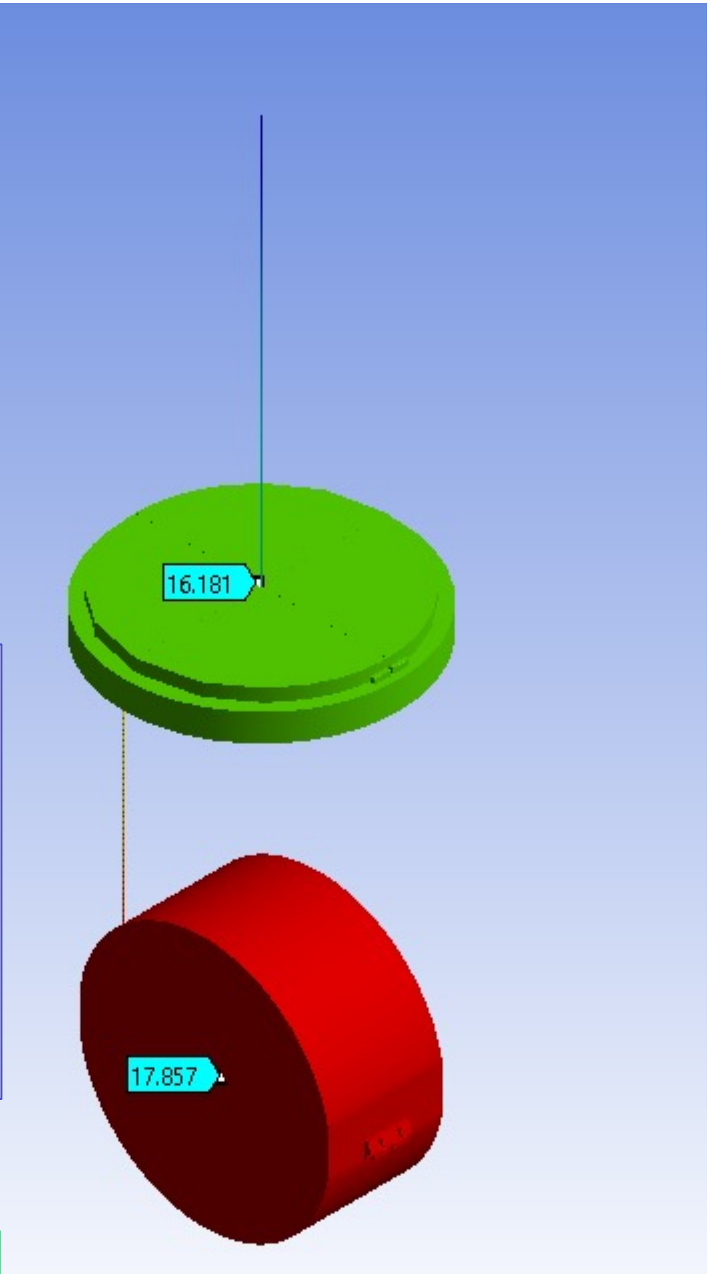


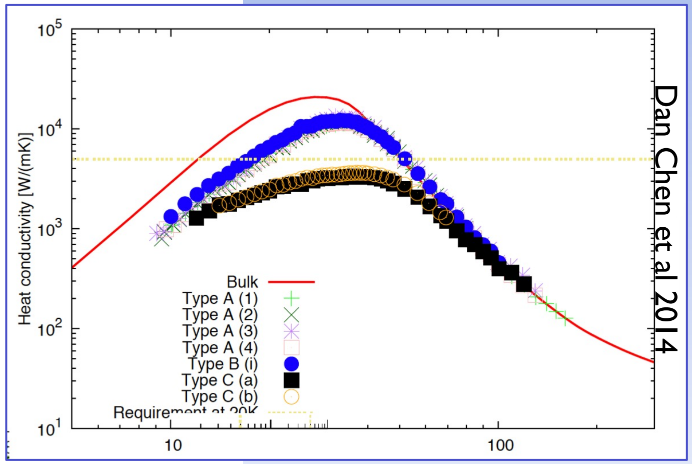


Steady State Thermal

Using sapphire rods

- Si Test Mass: 140 kg (Sapphire 150 mm thick also tested)
- TM Sapphire wires: 2.2 mm ∅ - Length: 0.8 m + $2\lambda_{bending}$
- Marionette Wire: Sapphire Diam 5.0 mm
- Upper point: 14K
- Radiation component not included so far

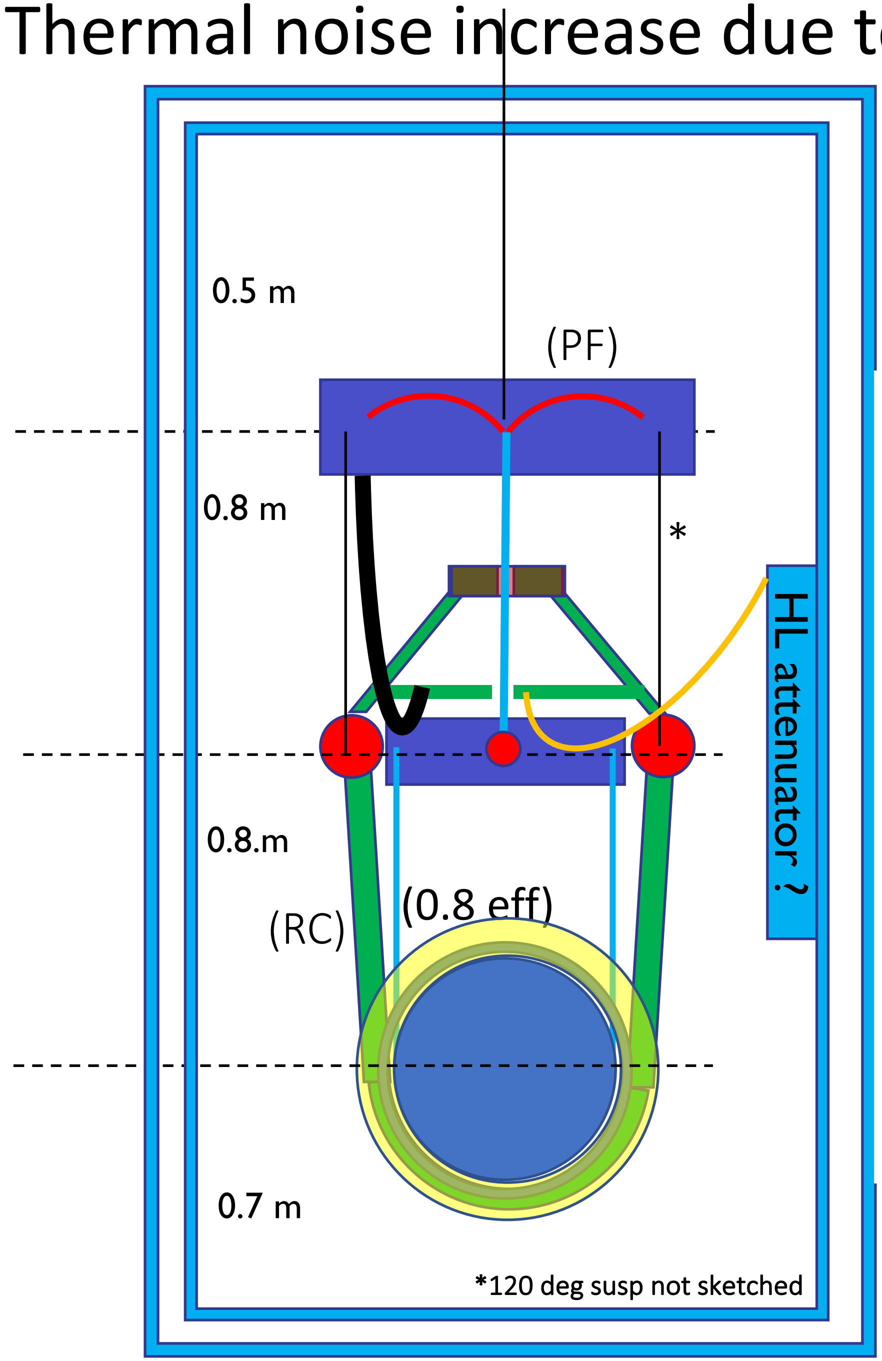




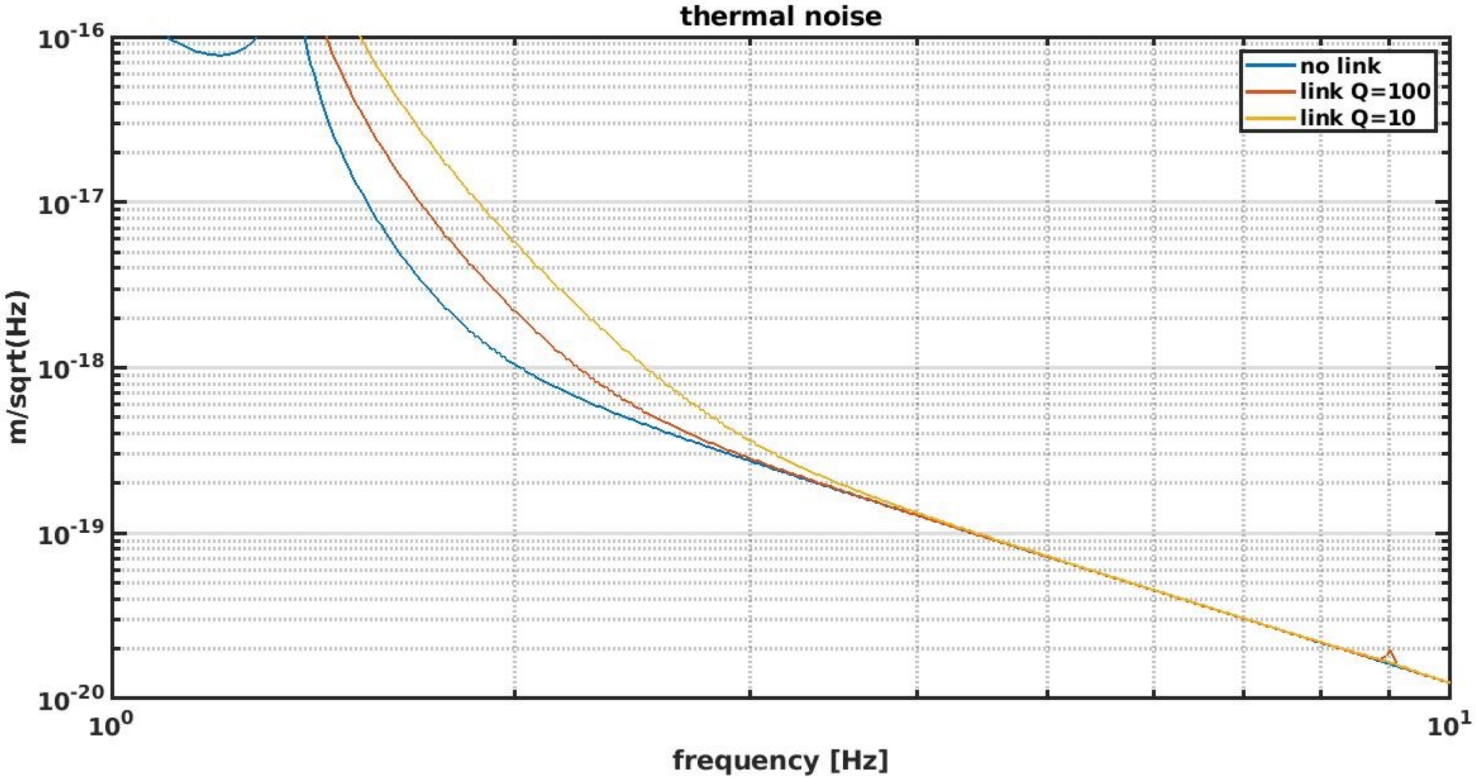
- ➢ The system can be cooled down.
- ➢ Notice the realtively massive marionette (for AdV+ we adopt 180 kg).
- ➢ Consistent with the cryostat room
- ➢ The system works for both Si and Sapphire
- ➢ Al6N HL, capability of building 80-90-cm-long Al_2O_3

- No HL included
- No radiation included, so far

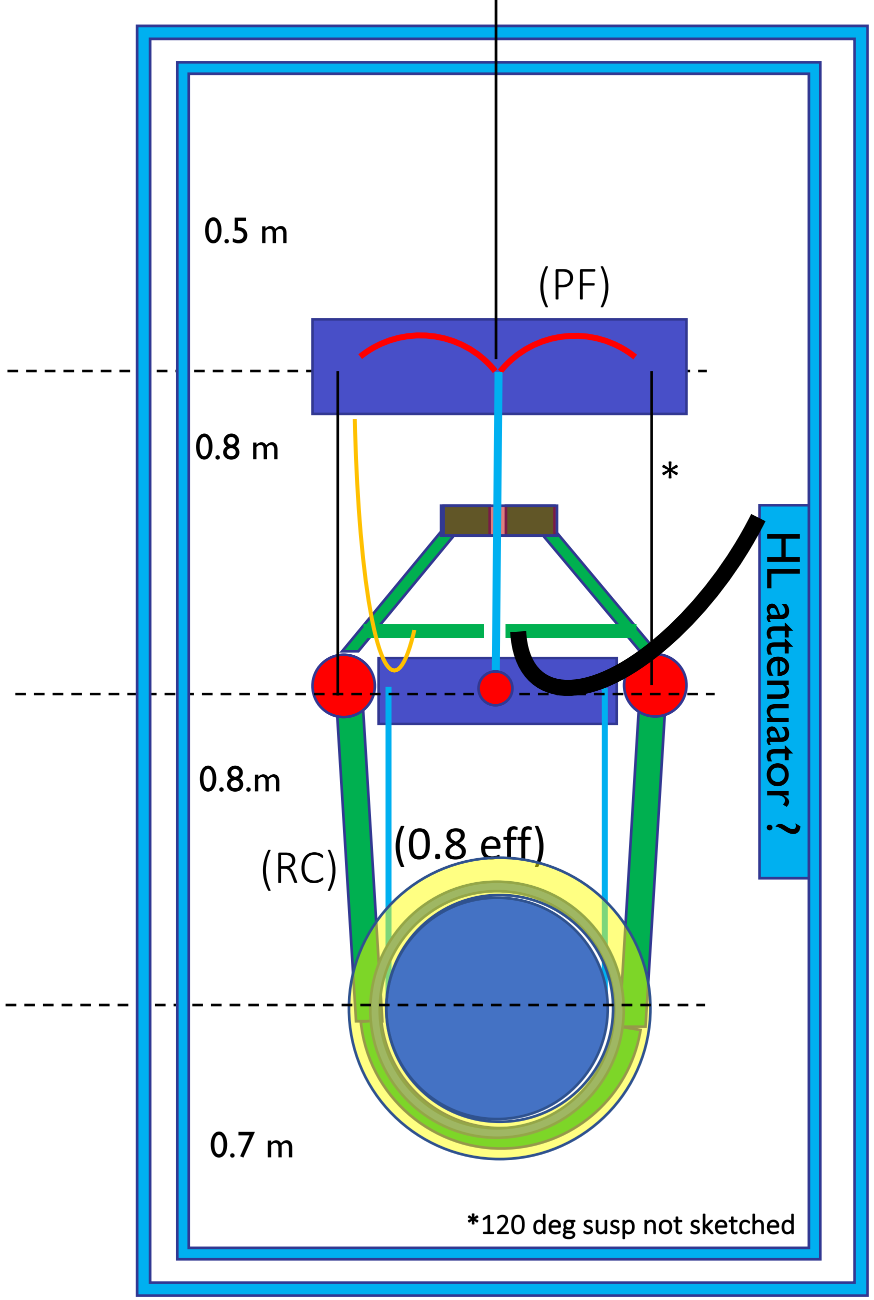
Thermal noise increase due to cryogenic link



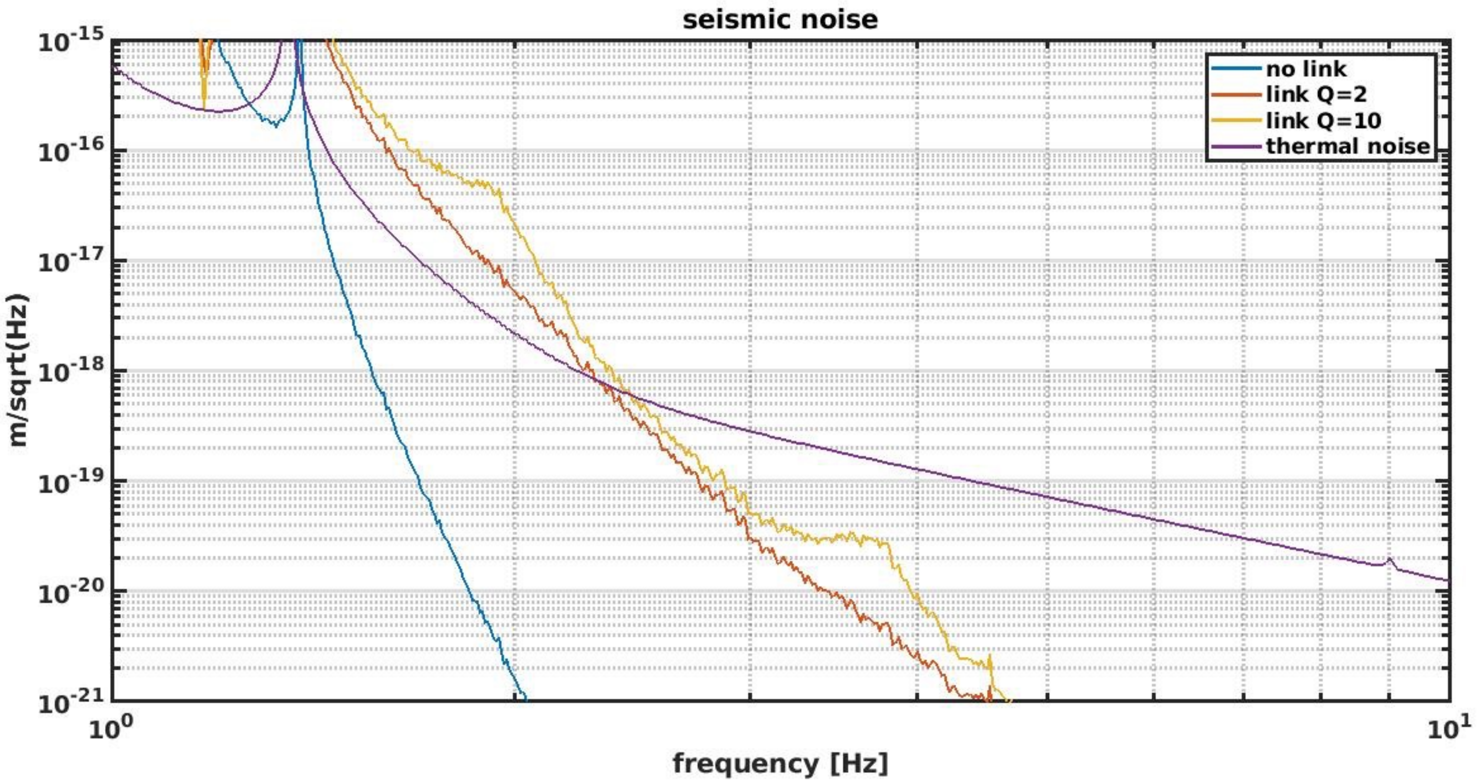
Link RM - PF: AL $E=6.9*10^{10}$; $\rho=2700$
L=1m; d=2mm; N=8;



Seismic bkg drag through cryogenic link

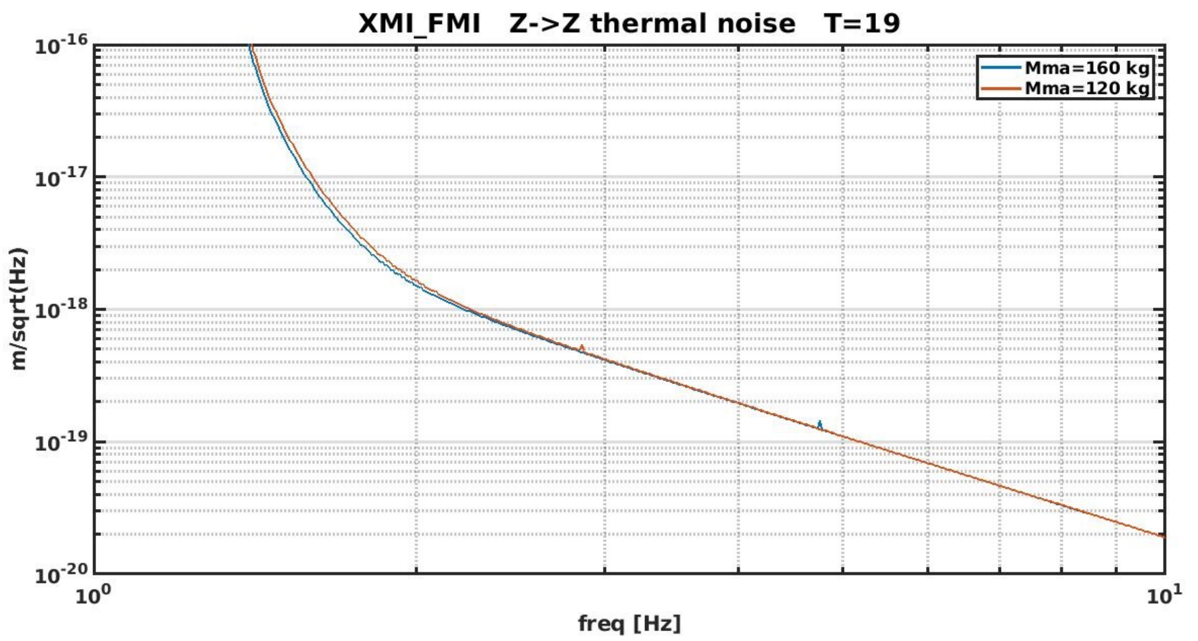


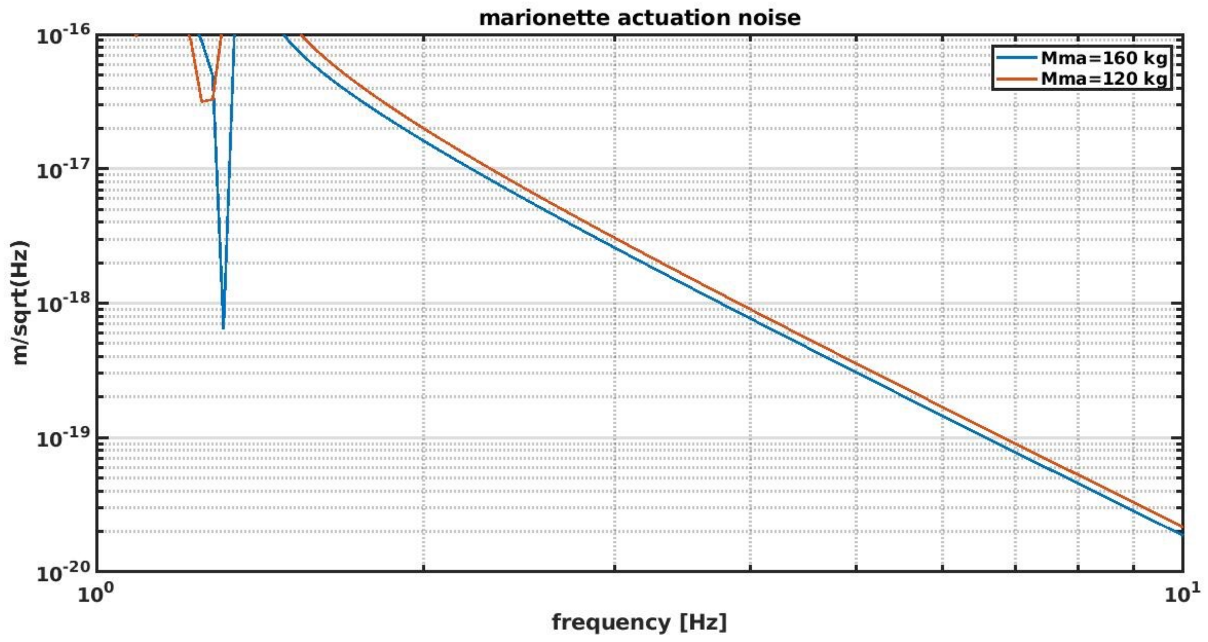
Link ground - RM: AL $E=6.9*10^{10}$; $\rho=2700$
L=1m; d=0.15mm; N=49*28 Al69 (KAGRA like)



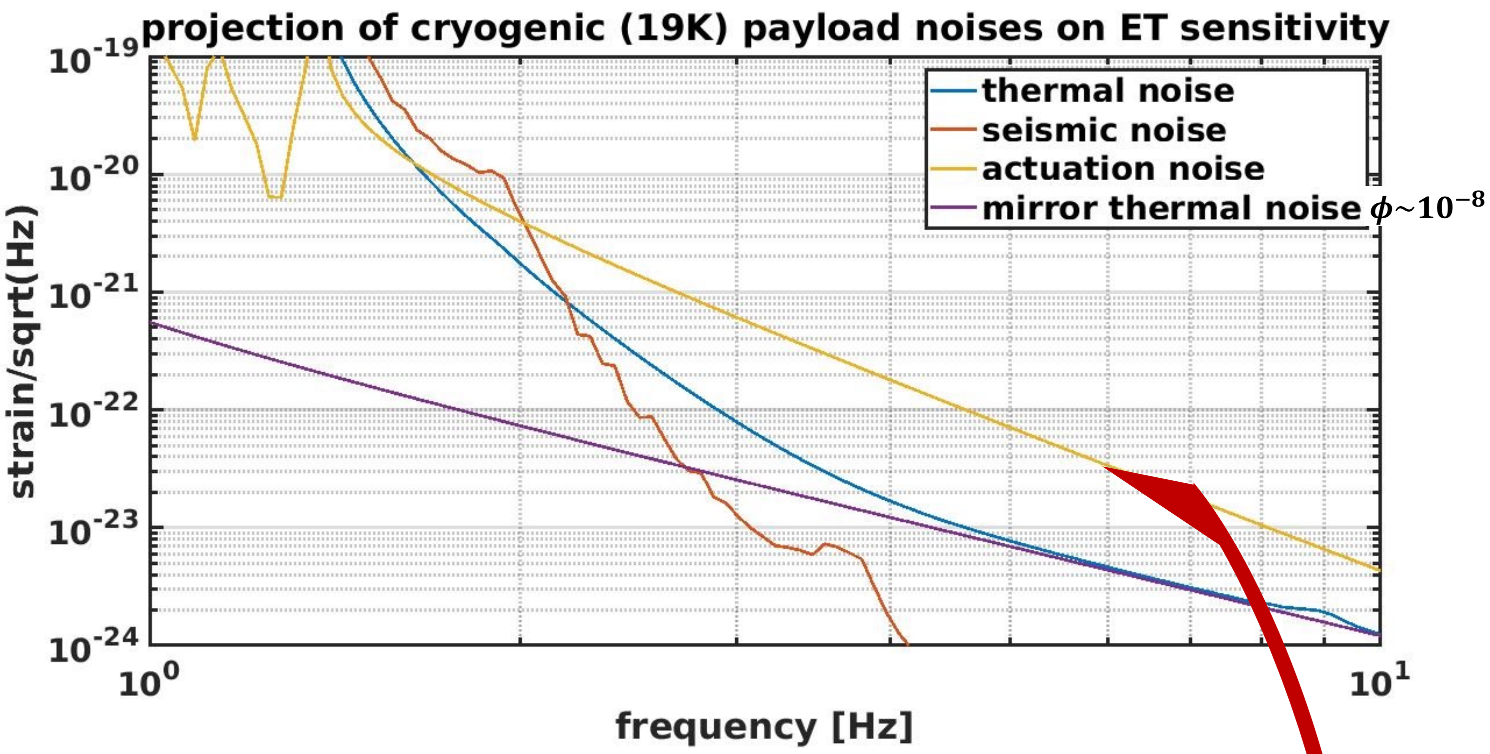
Need of a massive marionette for the cryogenic payload (seed case)

- Not so critical
- Safety factor in breaking strength can be increased
- We could equalize Mi and Ma at 130 kg





Cryogenic payload cooled down TM @19 K



➢ The effort is productive, as both TN and seismic bkg related to cryogenics drag are no longer dominant and reach close to nominal pure simple pendulum (TN below 5-7 Hz

BUT

➢ Further improve is needed, due to another source of technical noise (actuation, not object of this talk)

➢ Motivated by this issue, a different concept, based upon considerations made in this talk is being studied

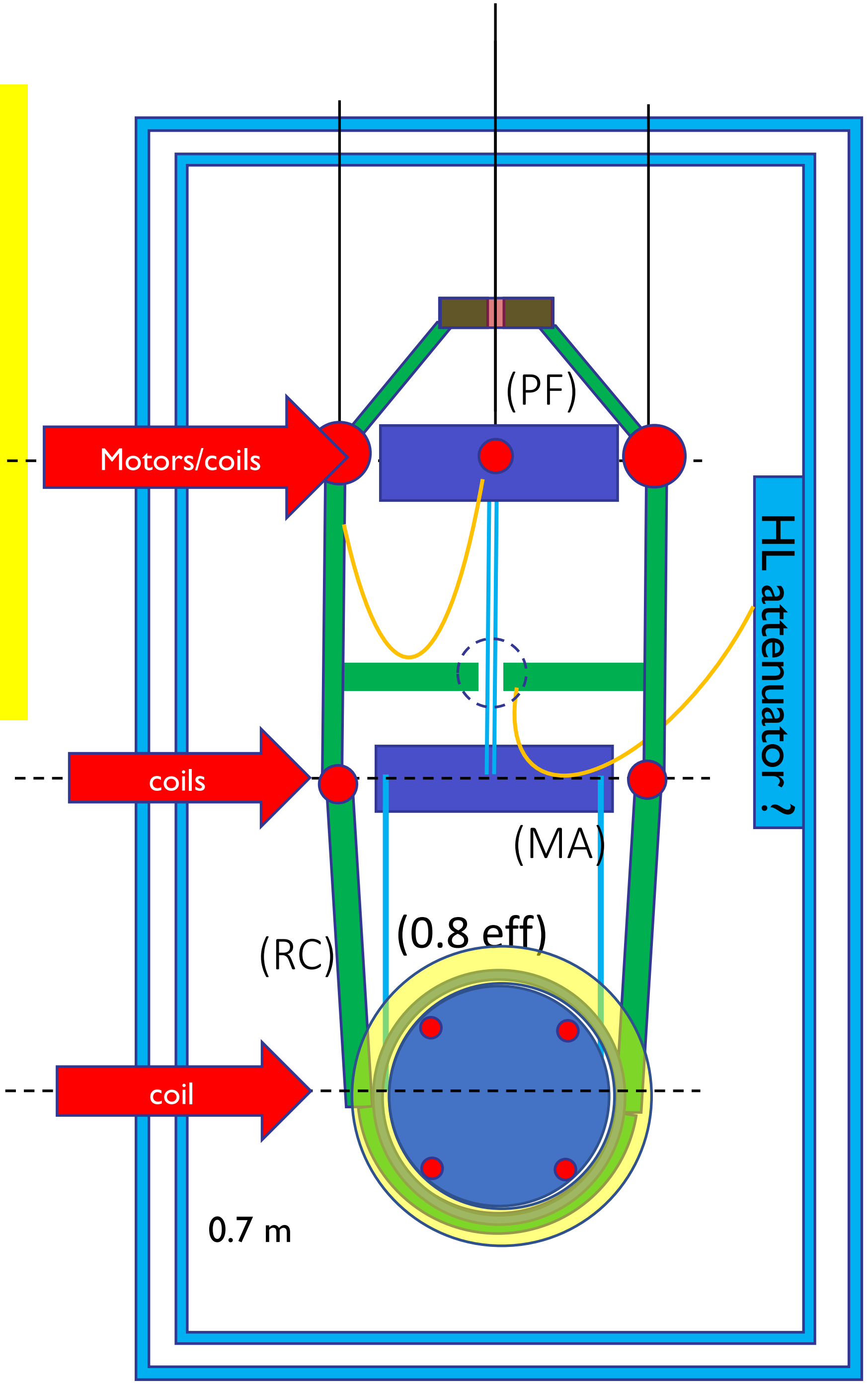
Going ahead: ET Phase2 ;-)

An alternative design is being considered (very preliminary)

1. RM cage suspended to RoomT filter (outside the cryostat)
2. Lower seismic reinjection (without adding aux attenuators)
3. No need of developing cryogenic vertical antispring filter
4. Separation motor/active alignment control

Relies on:

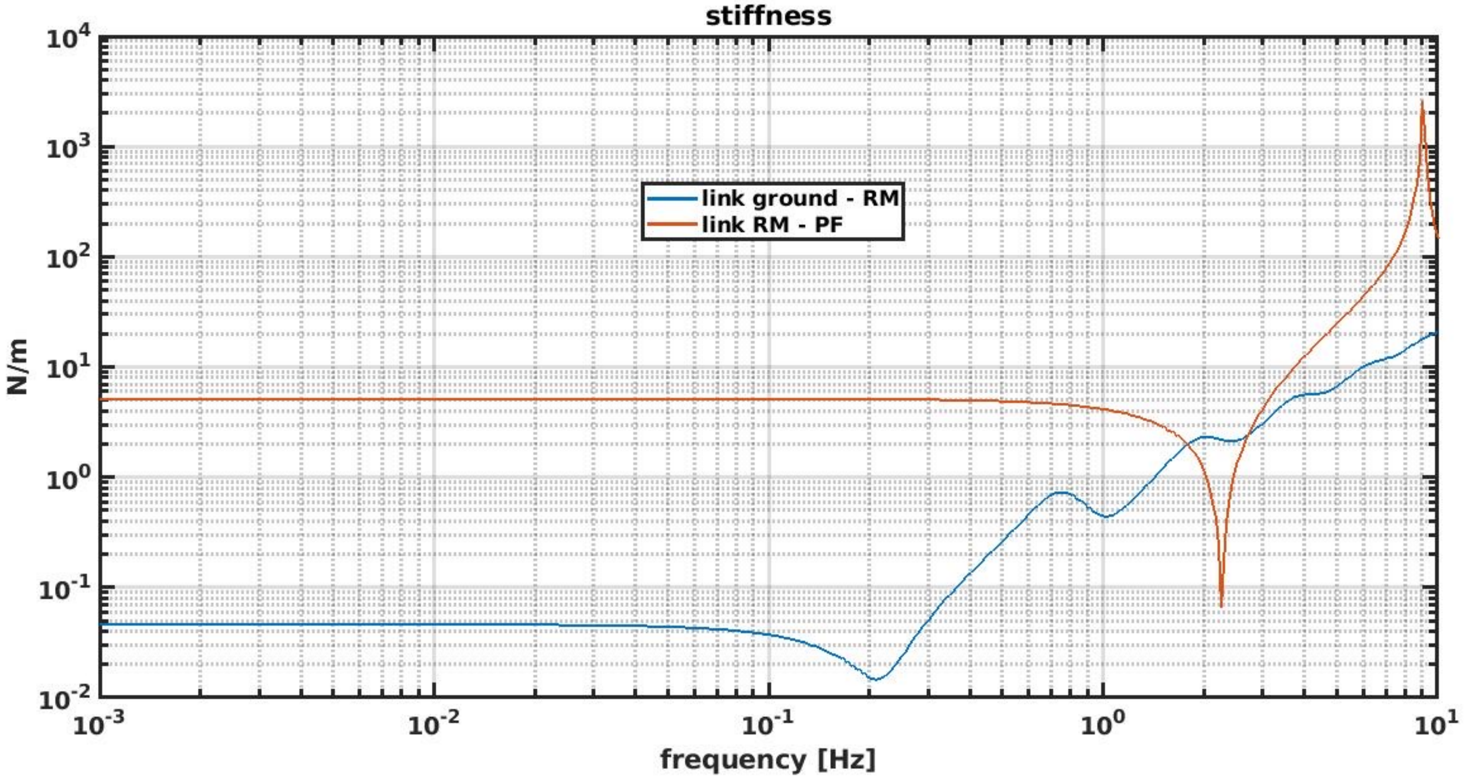
- the feasibility of using 3 Tconductive wires (Al2O3)
- More careful design of the cage (mass and CoM)
- **Four** feedthroughs RoomT/Cryostat (upper stages)



Not used

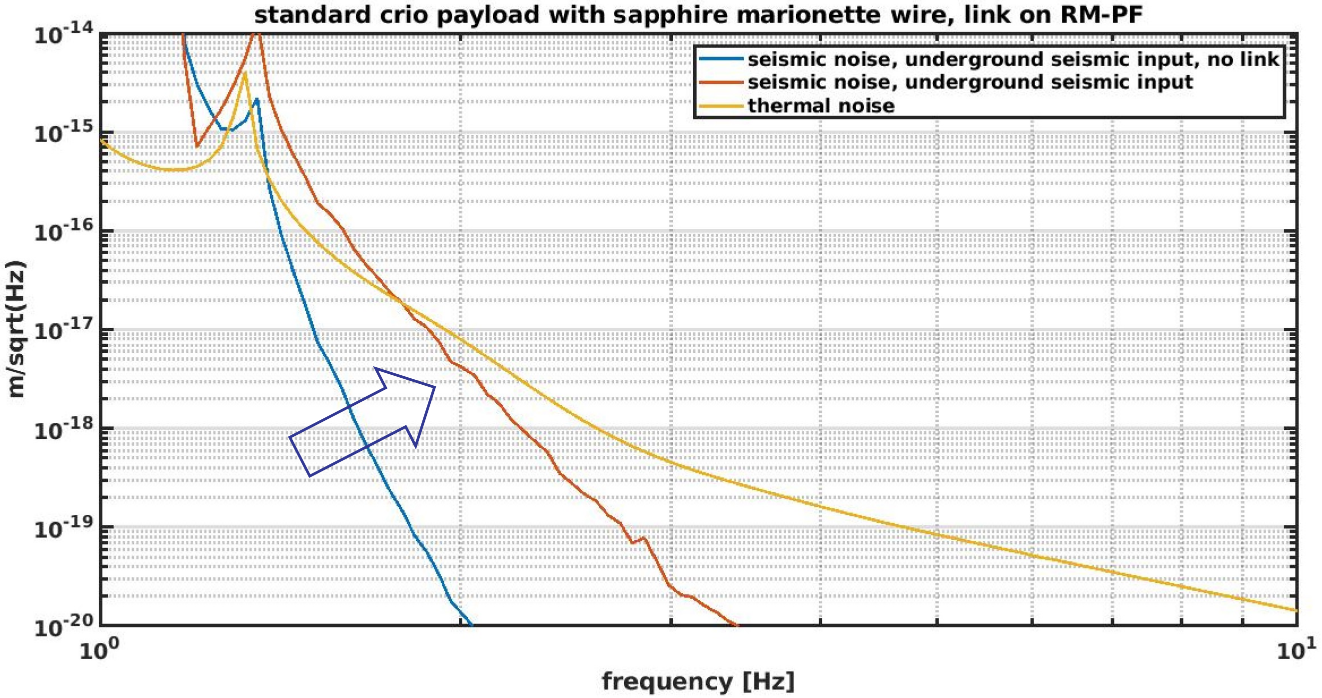
Link **ground - RM**: AL $E=6.9*10^{10}$; $\rho=2700$; Q=2
L=1m; d=0.15mm; N=49*28; s_in=0.7; s_out=-0.2;

Link **RM - PF**: AL $E=6.9*10^{10}$; $\rho=2700$; Q=100
L=1m; d=2mm; N=8; s_in=-0.2; s_out=-0.2;



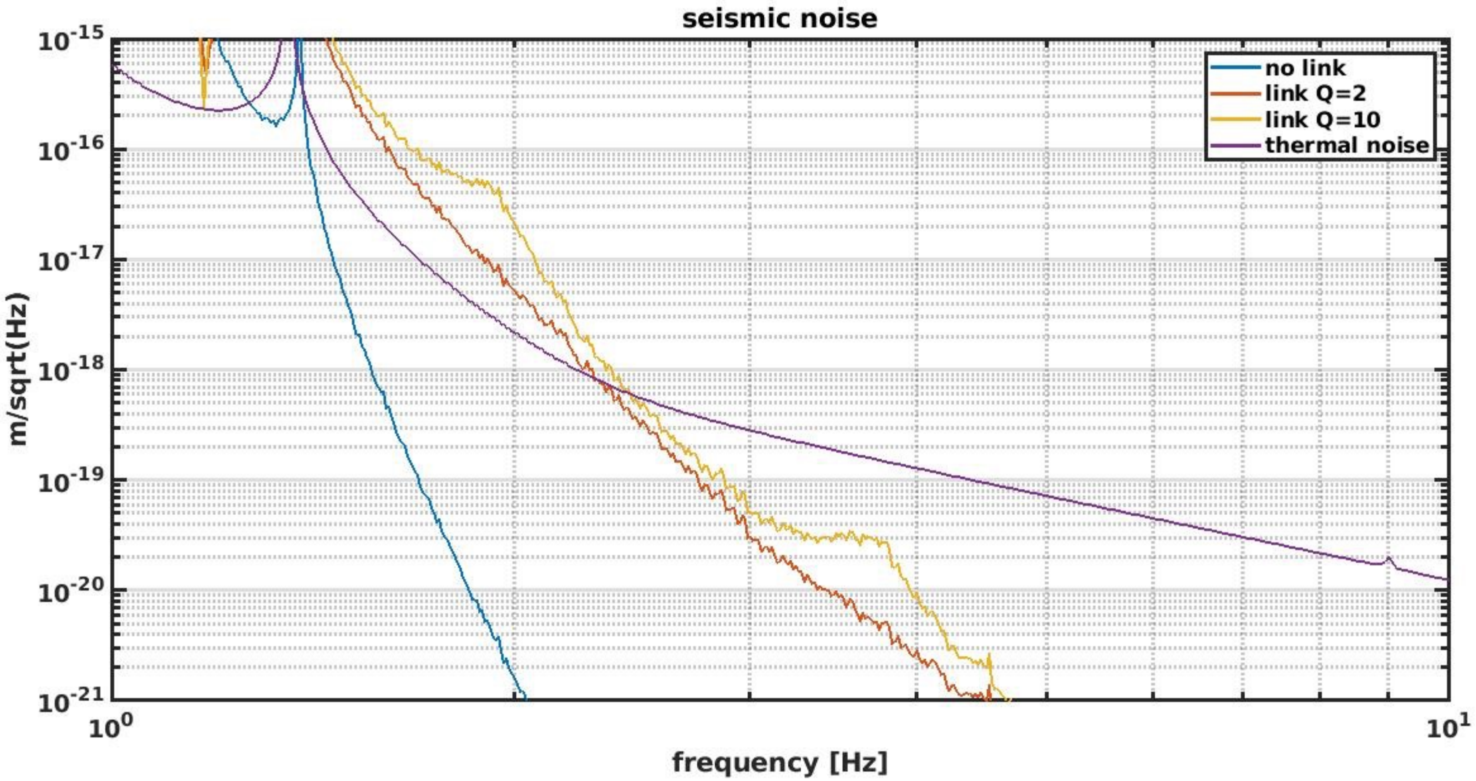
Seed modelling for a “good payload”: seismic check (SoS Enattos)

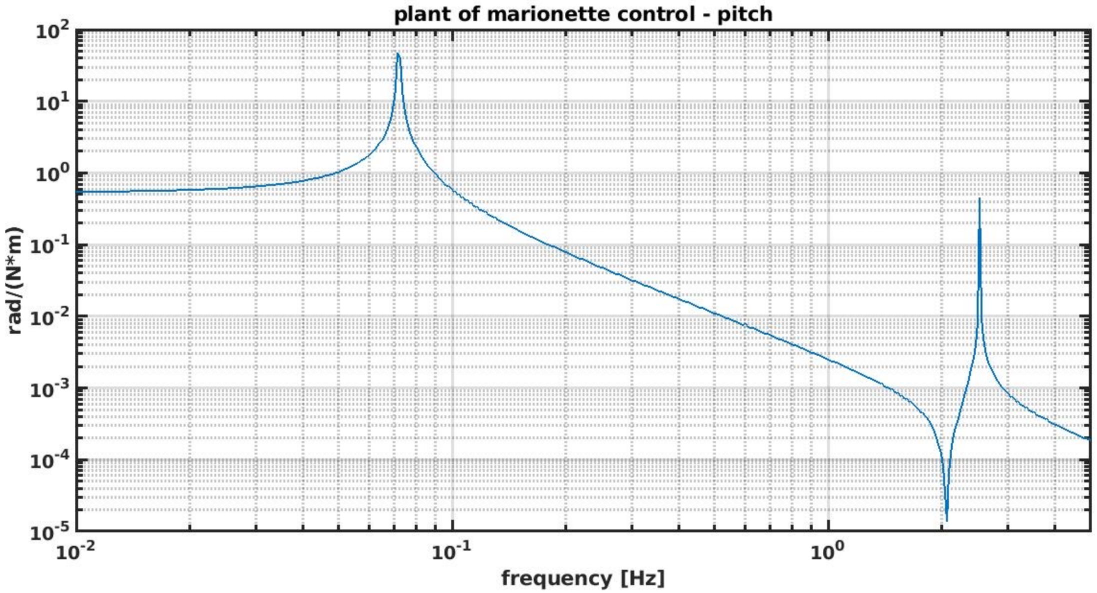
- ✓ **Seismic check OK (!!!)** (background noise drag)
- ✓ We must carefully study the overall mass to be cooled down: *heavy* means PF+RC+MA+MI = 600-800 kg.

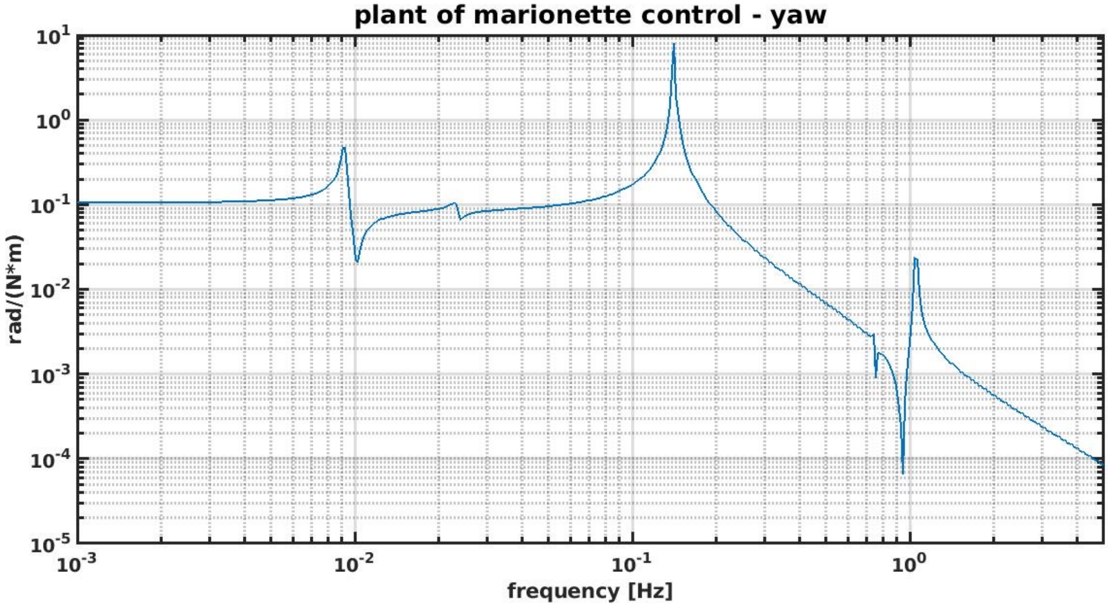


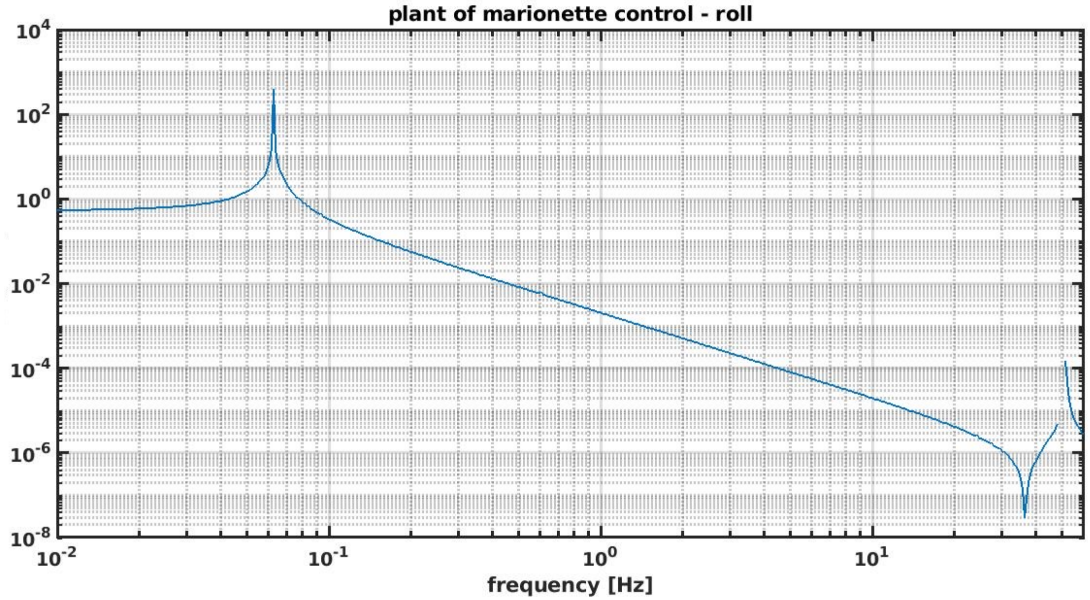
- ✓ We have another configuration, in the simulation (PF at room T), 4 passages through the cryostat, other constraints
- ✓ so far, the room required would be similar to the one presented.

Link ground - RM: AL E=6.9*10^{10}; ρ=2700
L=1m; d=0.15mm; N=49*28; s_in=0.7; s_out=-0.2;




plant of marionette control - pitch
rad/(N*m)
frequency [Hz]


plant of marionette control - yaw
rad/(N*m)
frequency [Hz]


plant of marionette control - roll
frequency [Hz]