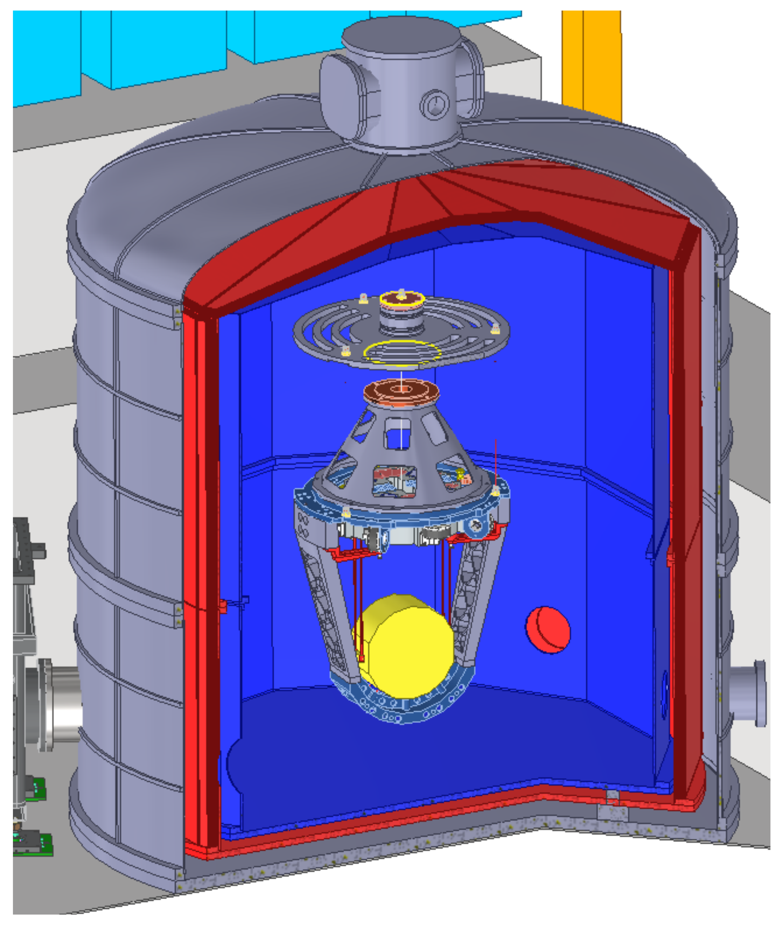
Cryogenic payload prototype at ARC

A. Cruciani[2], V. L. Hoang[1,2], E. Majorana[1,2], V. Mangano[1,2], L. Naticchioni[2], D. Pasciuto[2], M. Perciballi[2], S. Pirro[3], P. Puppo[2], P. Rapagnani[1,2], A. Rezaei[1,2], F. Ricci[1,2], M. Ricci[1,2]

1. Department of Physics, University of Rome Sapienza, Italy 2. INFN Sezione di Roma, Italy 3. INFN Laboratori Nazionali del Gran Sasso, Italy

Following the modelling concerning solid conduction cooling-down case outlined by Koroveshi et al.[1], Majorana[2] and Puppo[3], it is not trivial to validate the mechanical parts involved in the cryogenic suspensions. The aim of this research is to determine what can be achieved in the short/middle term, selecting a few key technologies that are useful for cryogenics applications in the ET design. At first glance, the priority given to sapphire may seem unusual. However, this material offers extraordinary properties and still requires further R&D efforts, especially when considering the suspension elements. Other laboratories, such as ILM Lyon, are also pursuing sapphire developments.



Talk by M. Ricci and V. Mangano

The Amaldi Research Center (ARC), which is part of Sapienza University of Rome, will host the first experiment of a cooling system. The initial prototype of this system consists of a cryostat with a full-scale cryogenic payload and two low-vibration conductive refrigeration lines. The INFN project ETIC will use the ARC facility to conduct research and development for the Einstein Telescope (ET-LF). This system is funded by both ETIC and ARC, and it might eventually be integrated into the Einstein Telescope .

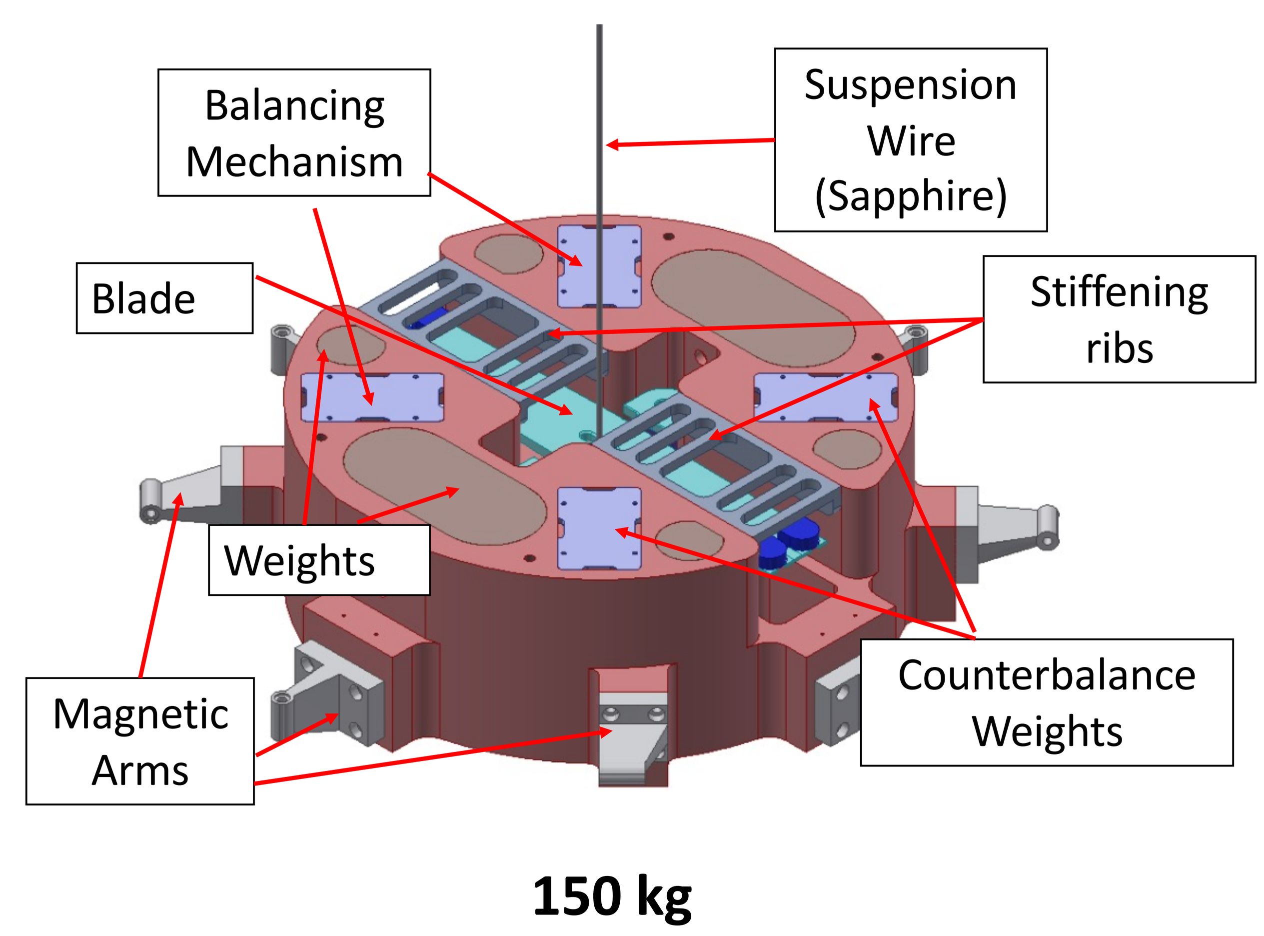
The infrastructure hosting the large cryostat under development does not allow the implementation of a seismic isolation system. While considering the overall design of the final cryogenic payload within the context of the seismic attenuator case, the implementation of the suspension elements involved in heat extraction can be studied separately. It should be assumed that the soft thermal links need to respect the isolation provided by a potential attenuator suspending the room temperature wire at the top of the cryostat.

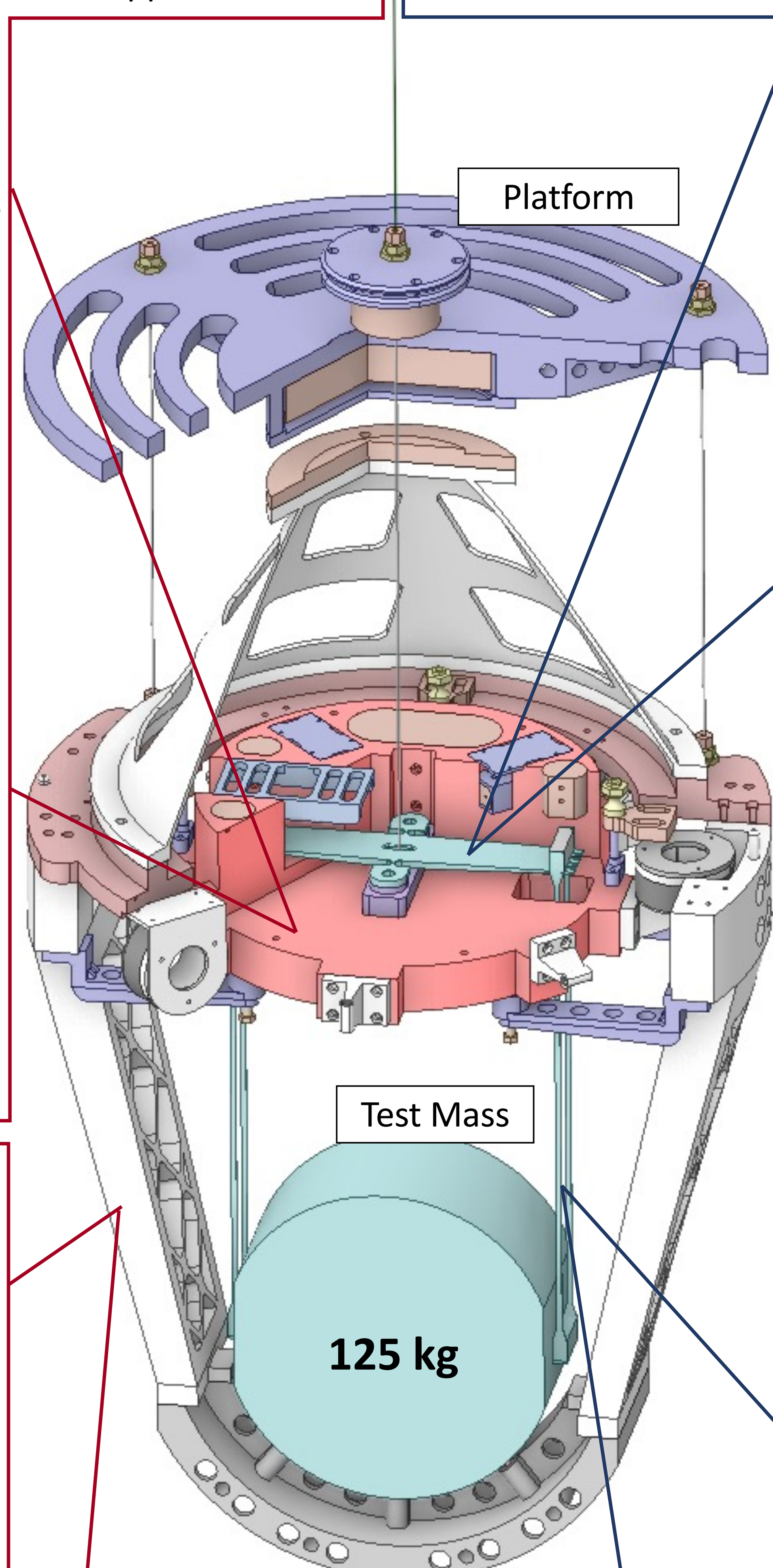
Marionette

High thermal conductivity materials are selected to maximize the extraction of heat during both the cooling and experimentation stages:

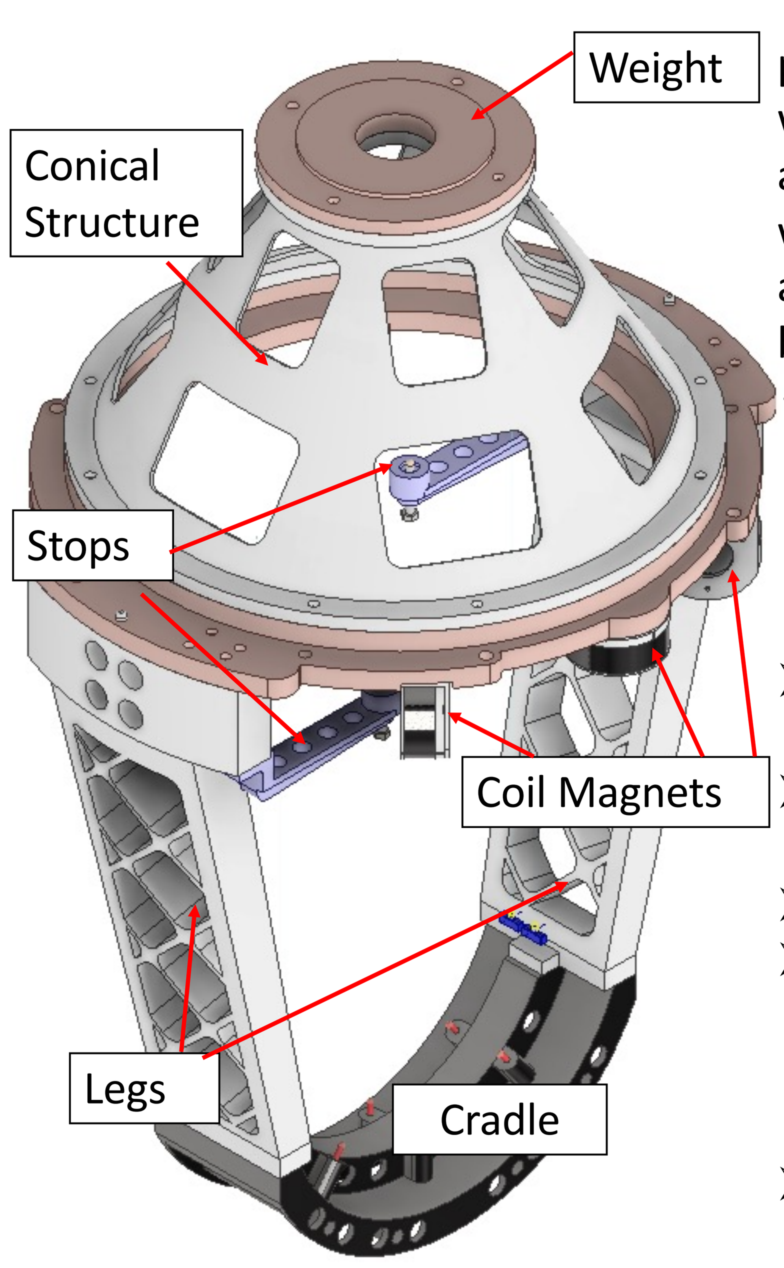
- The majority of the assembly's components was primarily made of aluminum, while the weights were specifically made of copper. Additionally, sapphire inserts are foreseen to be coupled to suspension components, improving heat transfer efficiency.
- Care in CoM (Center of Mass) positioning and bending points WRT to it (within 0.5 mm).
- The marionette is connected to the (dummy) Test Mass equipped with Sapphire flats and suitable ears to hook crystalline suspension elements.

The incorporation of a spring blade in the suspension system results in the distinctive shape of the marionette body. This design decision, however, generates undesired modal characteristics, which are addressed by the introduction of stiffening elements.





Actuation Cage

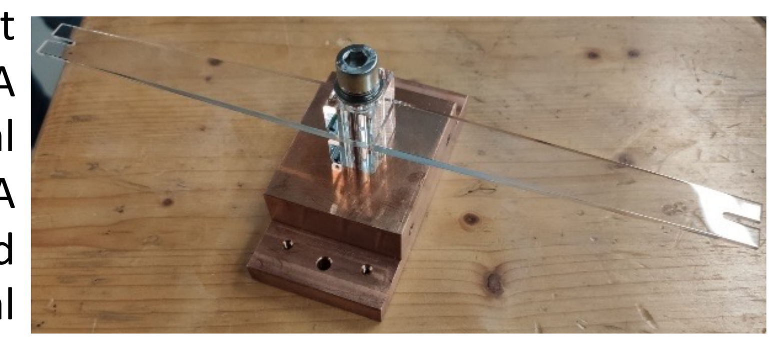


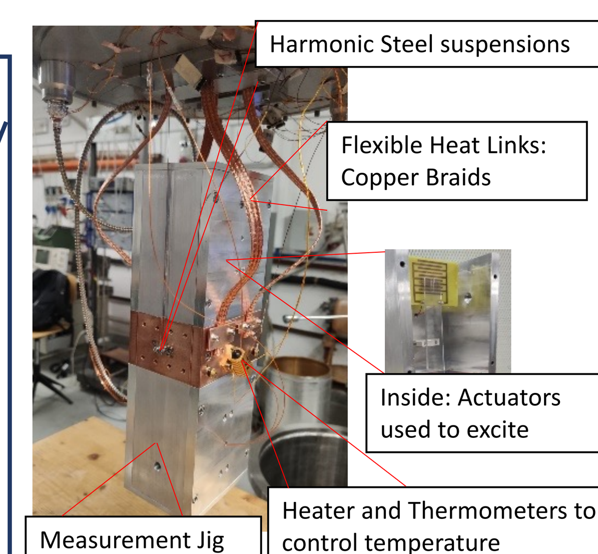
The cage is hung from the platform by three Cu-Be wires. This structure may also serve as a support for wide angle straylight baffle and other accessorial parts, but in the prototype at ARC the payload will be focused just on mechanical and thermal issues. The actuation cage acts also as a safe casing for the mirror and marionette, providing support in the event of suspension component failure.

- The cage will be assembled, with the payload, on a dedicated frame.
- The actuation cage has a set of coil/magnet actuators (shown only those for marionette).
- The cage CoM is close to the marionette CoM.
- Al6N links from the cooling line will be connected to the actuation cage and, from there, reach the platform, hosting the marionette suspension crystal. The clamping setup is under investigation.
- High emissivity coating under study (Solblack, …).

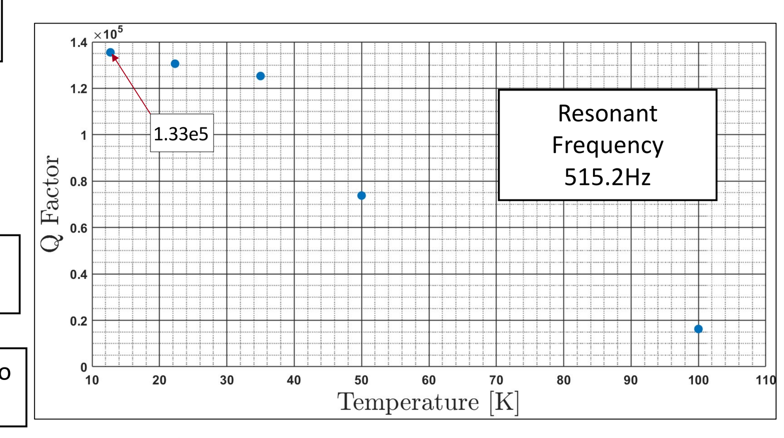
Butterfly Blade measurements

According to the measurements developed at Sapienza[4], sapphire blades used in the KAGRA detector are characterized by significant mechanical dissipation at the clamping point (~1.3E5 at 15 K). A new, more compact, symmetric blade was designed and tested: it is meant to be clamped at the central section of the marionette.





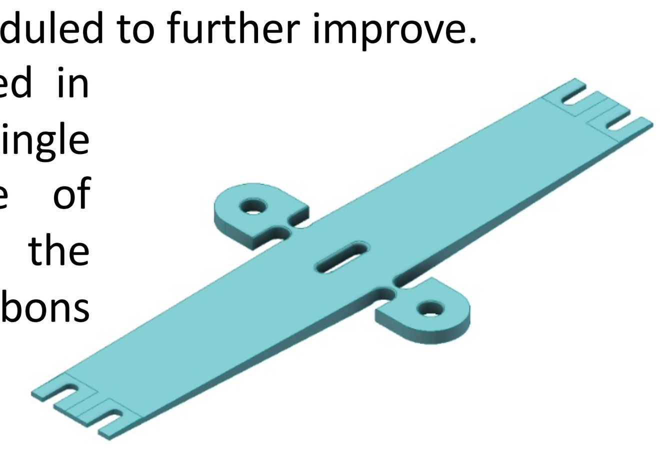
Quality Factor measurements has been performed on a KAGRA mirror sized butterfly blade.



Value of Q Factor = 1.33E5 at T = 12.7 K

To improve Q Factor:

- Al_2O_3 bulky clamp will be machined in the next version, due to the excellent properties of sapphire[5], this seem now more feasible than in the past
- HCB at the clamp has been scheduled to further improve.
- This idea was further expanded in the context of ET, with a single sapphire component capable of sustaining the full weight of the mirror. It can be adapted to ribbons or rods with anchors.



- Initial numerical simulations were performed on the blade intended for the ARC facility to gather insights into its mechanical behavior, particularly its natural frequency and bending strength.
- The expected fundamental natural frequency is estimated to be between 6 and 7 Hz, and the maximum bending strength is estimated to be around 160 MPa, both of which are in line with the component's envisioned performance parameters.

Suspensions

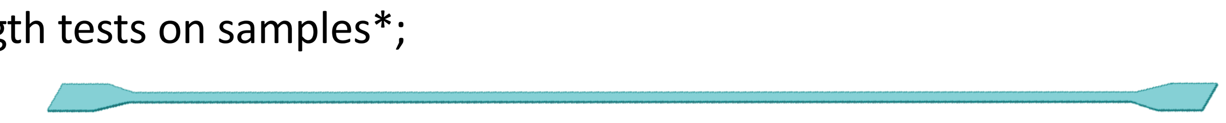
The cryostat under development at ARC Sapienza is meant to envisage just viable solutions to be adopted to suspend a crystalline TM. The cryostat is designed to host a payload with mass up to 200 kg.

- On the vein of Virgo Large Mass payloads our first design considers Al_2O_3 45 cm diam, 125 kg, and plan to exploit the significant lesson provided by KAGRA. Two sets of suspensions lengths will be studied. The first choice is Sapphire, Silicon adaptation will follow as the technology advances.

Dist /mat	Top-PF (m)	PF-MA (m) COMs	MA-MI (m) COMs	note
Short	1.2/ Cu-Be	0.7/ Al_2O_3	0.7/ Al_2O_3	ribbon
Long	1.0/ Cu-Be	0.85/ Al_2O_3	0.85/ Al_2O_3	ribbon/rod

Our planned campaign of tests finalized to the prototype payload design:

- Marionette suspension Al_2O_3 strength of a new concept of rod head clamping;
- HCB Na_2SiO_3 shear strength tests on samples*;
- Ribbons;
- Feasibility[5].



* Tests will be performed using a Shimadzu AGS-X 10 kN universal mechanical test machine.

1. X. Koroveshi et al. (arXiv:2305.01419v1)
2. E. Majorana, GWADW (2021)
3. P. Puppo, GWADW (2022)
4. *T. Yamada, E. Majorana Dep. of Physics, Sapienza (2019)*
5. *T. Yamada JGW-T2314883-v1 (2023)*
6. *A. V. Cumming et al. CQG 31 (2014)*

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