R&D Activities on Superattenuators

Advanced VIRGO-ET Pisa

Internal Workshop

Pisa – May 22-23, 2024

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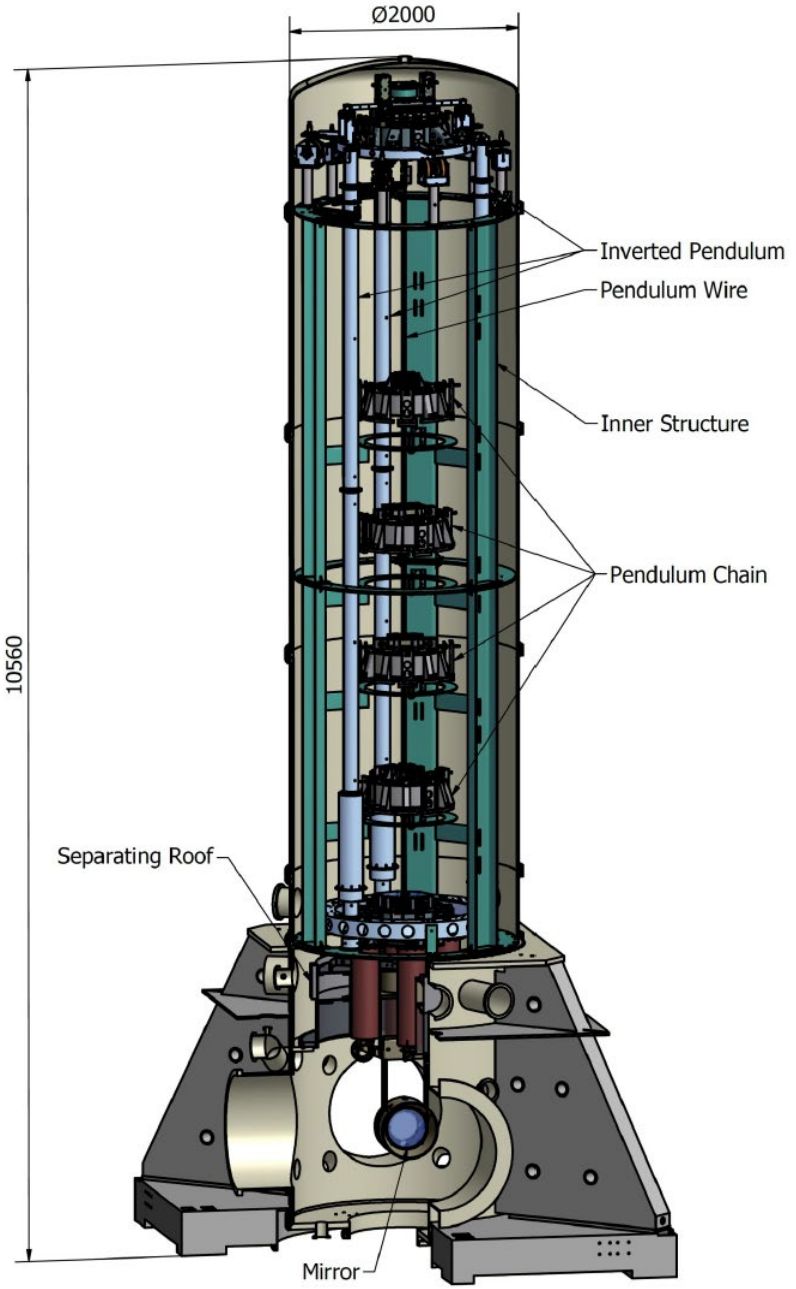
Introduction

The **INFN Pisa Group** has long and consolidated tradition in the development and operation of complex structure (**Superattenuator**) devoted to filtering seismic noise and local disturbances at the level of optical components for laser interferometric detectors of GW.

- The **performance of the Superattenuator Systems** is completed with the **feedback control electronics** for the development of which the Group has piled up a fundamental expertise for the present and future operations of GW detectors (see A. Gennai presentation);

- A more than 20-years-long experience is fundamental in the design of future **Advanced VIRGO upgrades** as well as in the development of 3rd generation detectors for GW as **Einstein Telescope (ET)**.



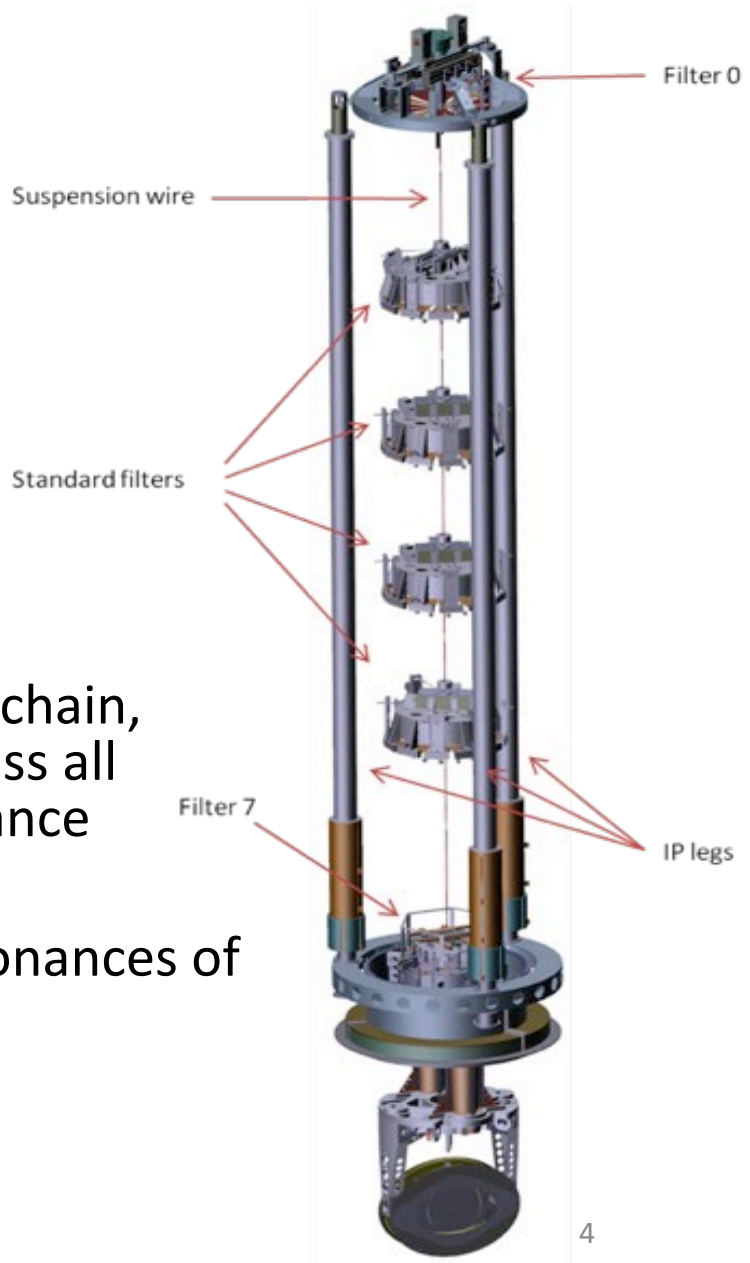
INFN Group Involvement

The INFN Pisa Group is involved in different activities/projects:

- **NGSA** (New Generation of SuperAttenuators) – “Open Call of CSN5” for improving the passive performance of the mechanical filters and investigate the introduction of a new IP in Nested configuration (NIP);
- **CAOS** (**C**entro per **A**pllicazioni sulle **O**nde gravitazionali e la **S**ismologia) – PNRR-ETIC Project @ University of Perugia; Design, construction and operation of two long Supeattenuators (about 15 m high) for future GW detectors (ET);
- **“Slim SA”** (proposal under evaluation) Development and Construction of Superattenuators based on the AdV approach/philosophy with reduced diameter; AdV upgrade with short Stable Recycling Cavities (sSRC);
- **AdV SA** Operation, maintenance and upgrades of the Superattenuator Systems for 2nd generation ITF
- **ET_Italia** development and prototyping of different relevant technologies for the design and construction of the Superattenuators of ET Gravitational Waves Detector;
- …….

New Generation of Super-Attenuators (NGSA)

NGSA goal: Improvement of vibration isolation performance for 3rd generation detectors of GW – Einstein Telescope (ET) underground giant laboratory: **improve the current sensitivity by a factor 10 and extending the observation bandwidth in the low frequency region around 2 Hz**



- The Traditional experimental line @ INFN Pisa:
- based on the **AdV mechanical structure** (Inverted Pendulum, Filters chain, heavy/cryogenic payload) with the intent to better distribute the mass all along the suspension chain, improving vertical attenuation performance (**nMAS**) and keeping the total length of the structure around 12 m;
- re-design the mechanical filter structure mitigating the spurious resonances of the cross-bar with the possibility to suspend heavier loads.

NGSA: Experimental Activities

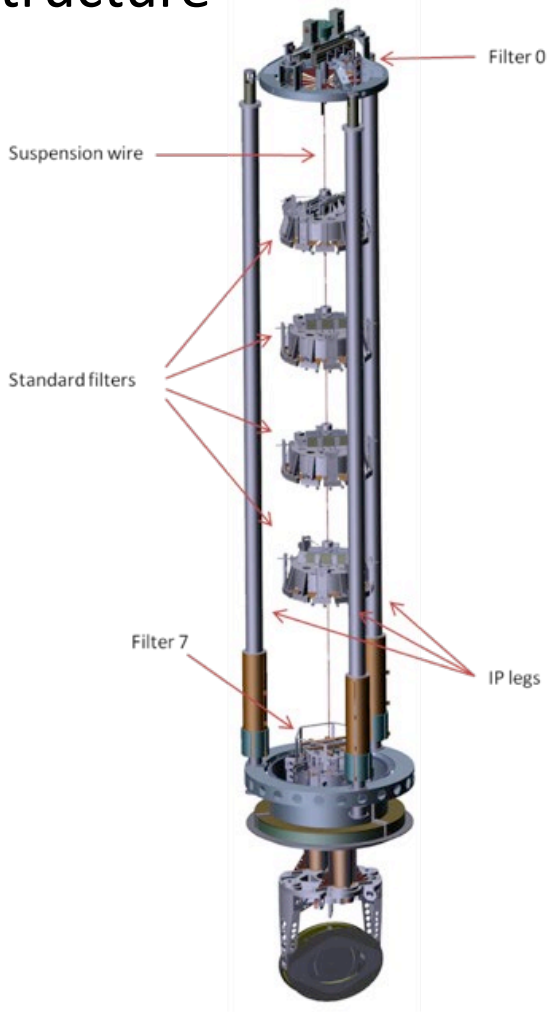
Define guidelines for future seismic isolation systems down to 2 Hz, while the present mechanical system of the SA (2nd generation) is considered compliant with 3rd generation detector (see ET Conceptual Design).

Two different experimental lines:

1. Based on the **AdV mechanical structure** (Inverted Pendulum, Filters chain, heavy/cryogenic payload) with the intent to better distribute the mass all along the suspension chain, improving vertical attenuation performance and keeping the total length of the structure around 12 m
2. Based on the use of a **two-stage Nested Inverted Pendulum (NIP)**: evident advantages from the point of view of the horizontal pre-isolation stages but never put in operation with many open questions (stability, automatic control, cross coupling of different d.o.f., vertical and tilt noise at ground level, …)

NGSA: Experimental Activities Details

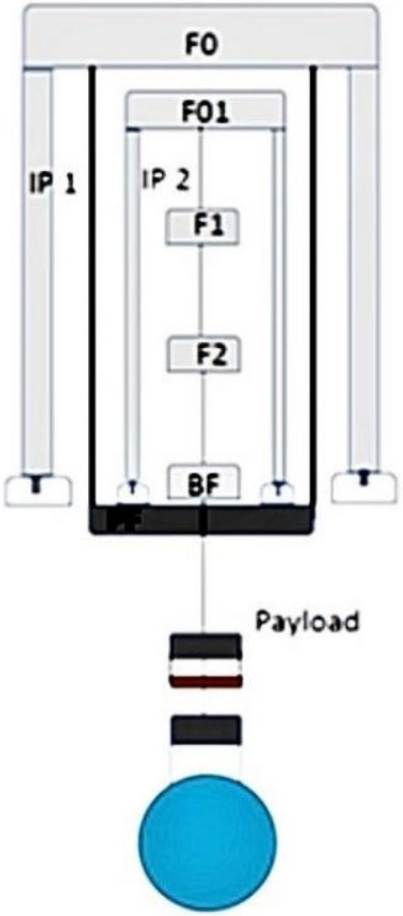
1. Based on AdV mechanical structure



Common Goal: fulfil the ET attenuation requirements keeping the whole length of the mechanical structure around 12 m

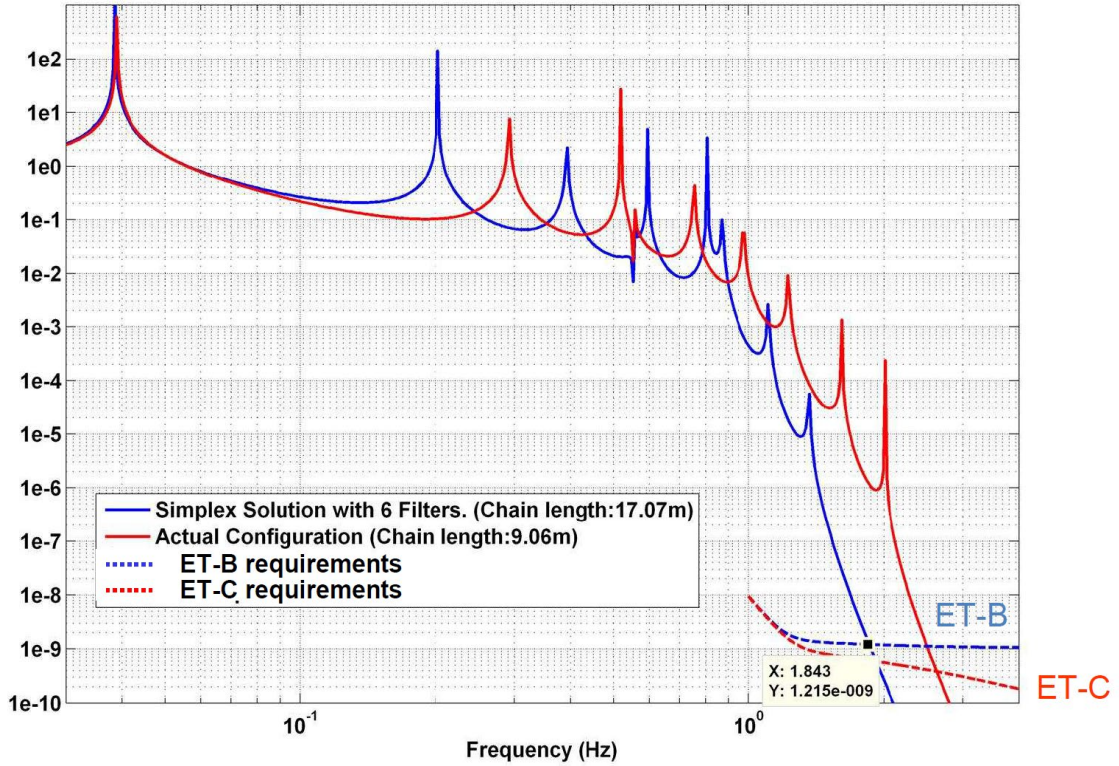
Great impact on the excavation cost of the caverns

2. Based on two-stage NIP



The Superattenuator: a passive-active system as reference solution for ET

- Within the **ET Conceptual Design** (2011 and 2020 update) a **reference solution** for a seismic vibration isolation system has been studied;
- Same technology used for AdV-SA (**passive-active system**):
  - height 17 m (9 m AdV)
  - cut-off frequency~2Hz (~3Hz in AdV).
  - single IP
  - 6 stages **"equal-spaced"** configuration
- No change on the VERTICAL d.o.f.
  (cross coupling HOR-VERT to be improved)

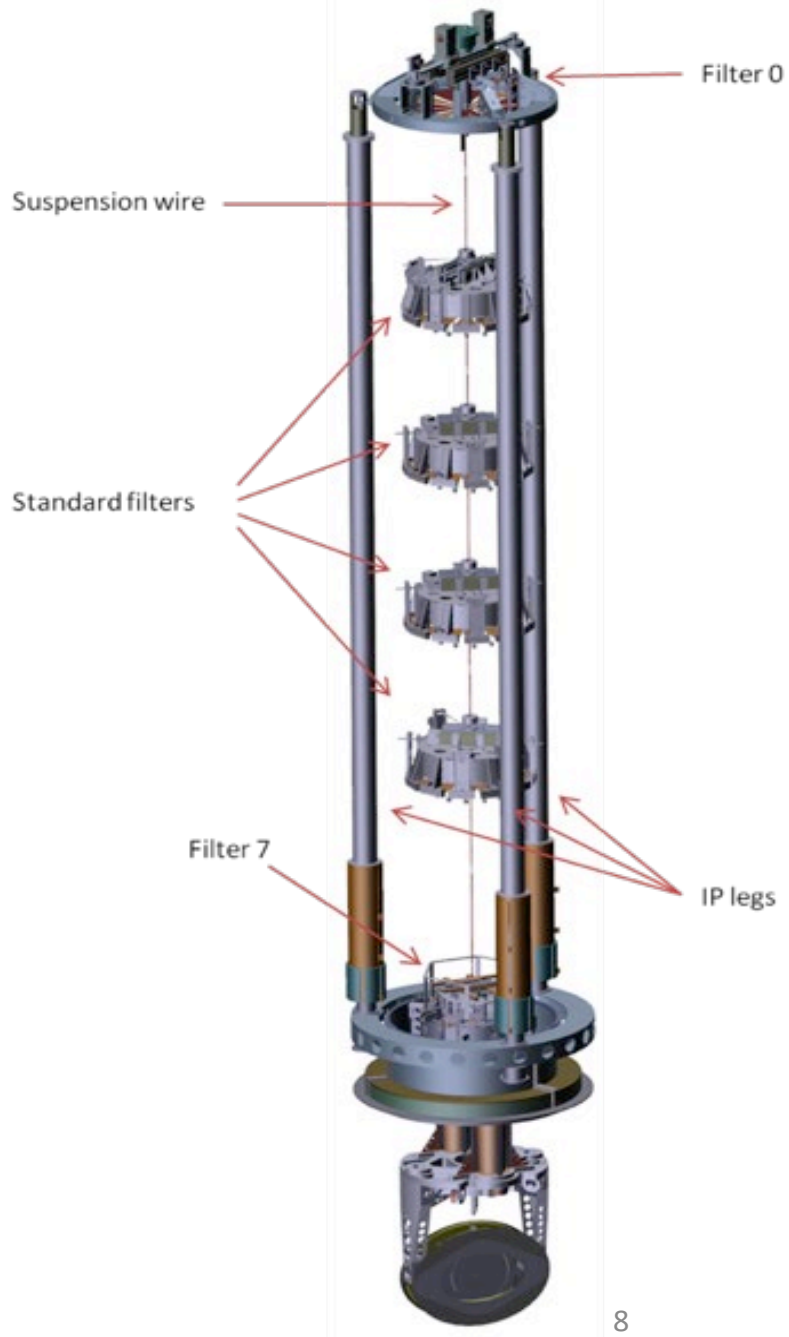


[see: S. Braccini, F. Frasconi et al., "Einstein gravitational wave Telescope conceptual design study ", The ET science team, M. Abernathy et al., 28 June 2011]

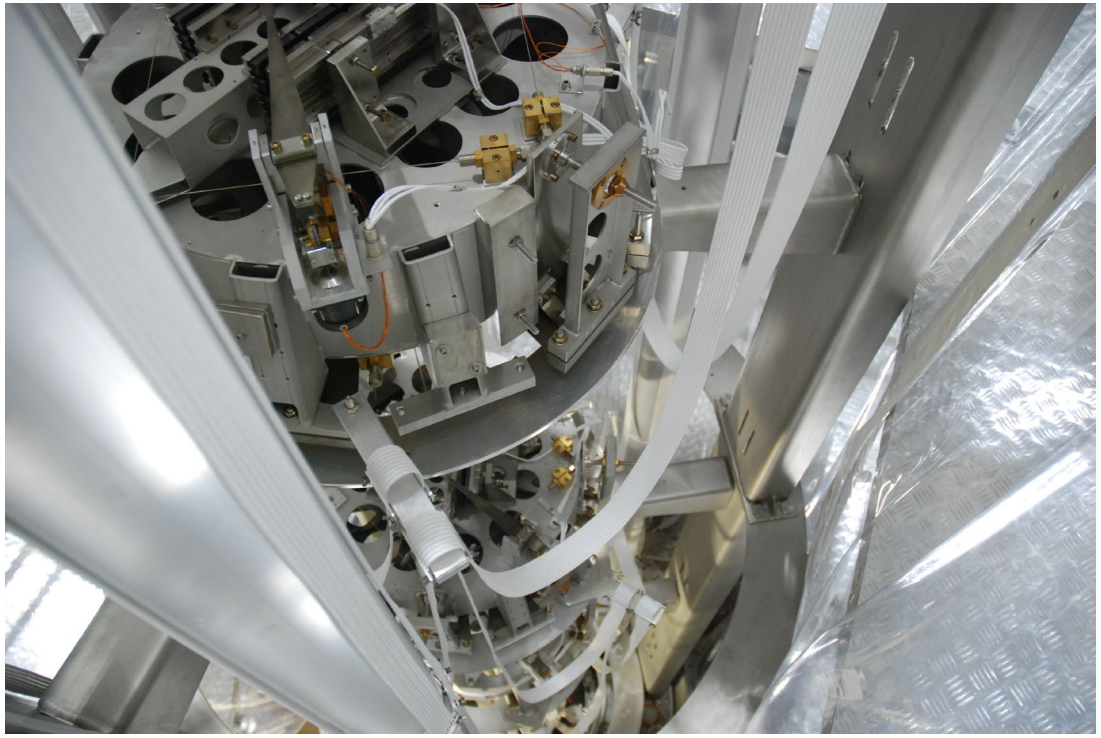
The AdV active-passive Superattenuator

- The **Super-Attenuator** (**SA**) is the mechanical structure adopted to isolate the optical components from seismic noise and local disturbances. It is based on the working principle of a **multistage pendulum** supported by a pre-isolator stage based on the working principle of an **Inverted Pendulum**;
- **Hybrid** system:

  - active control below 3 Hz
  - **passive** attenuation starting from 3 Hz.

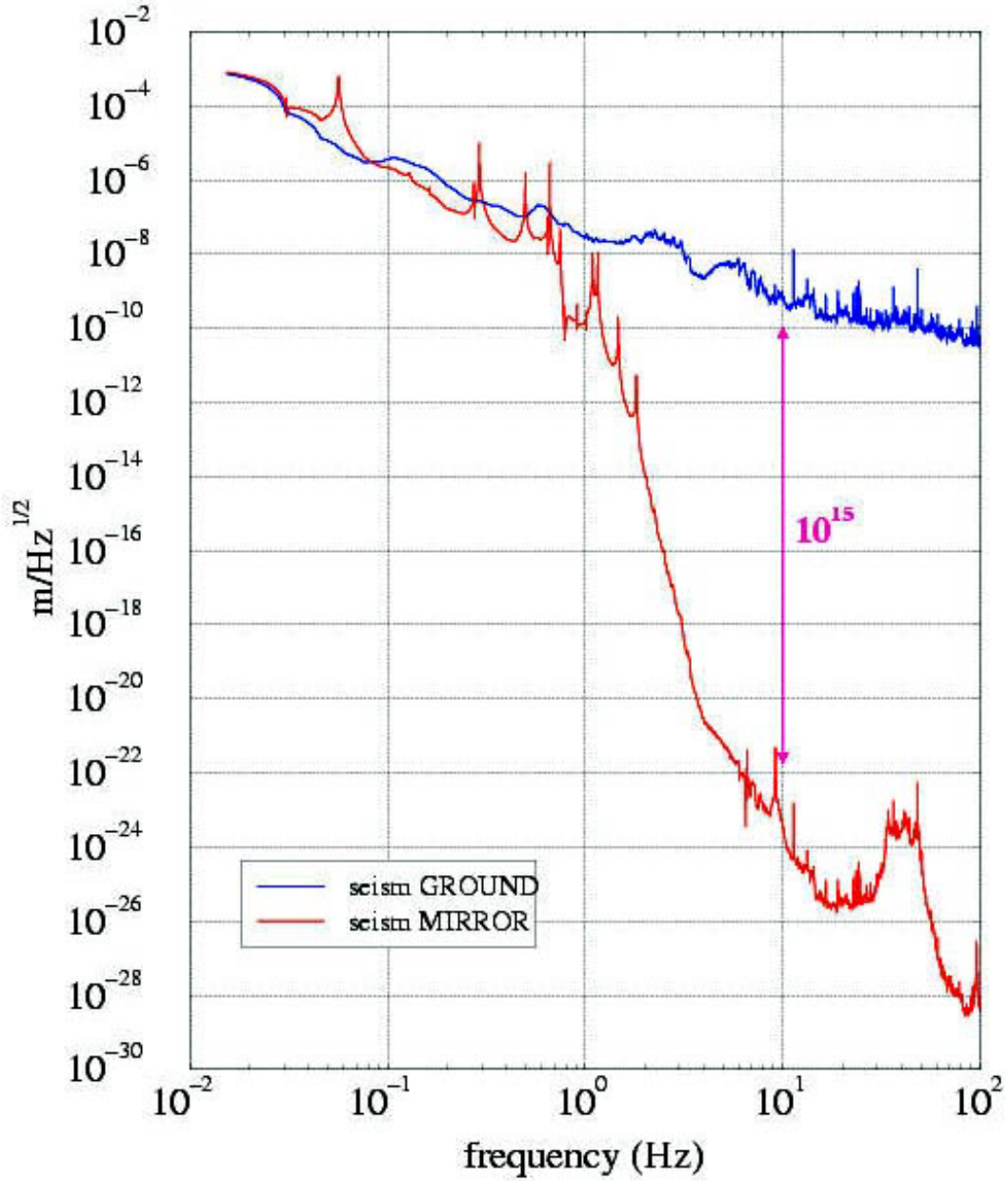


Main features of the SA

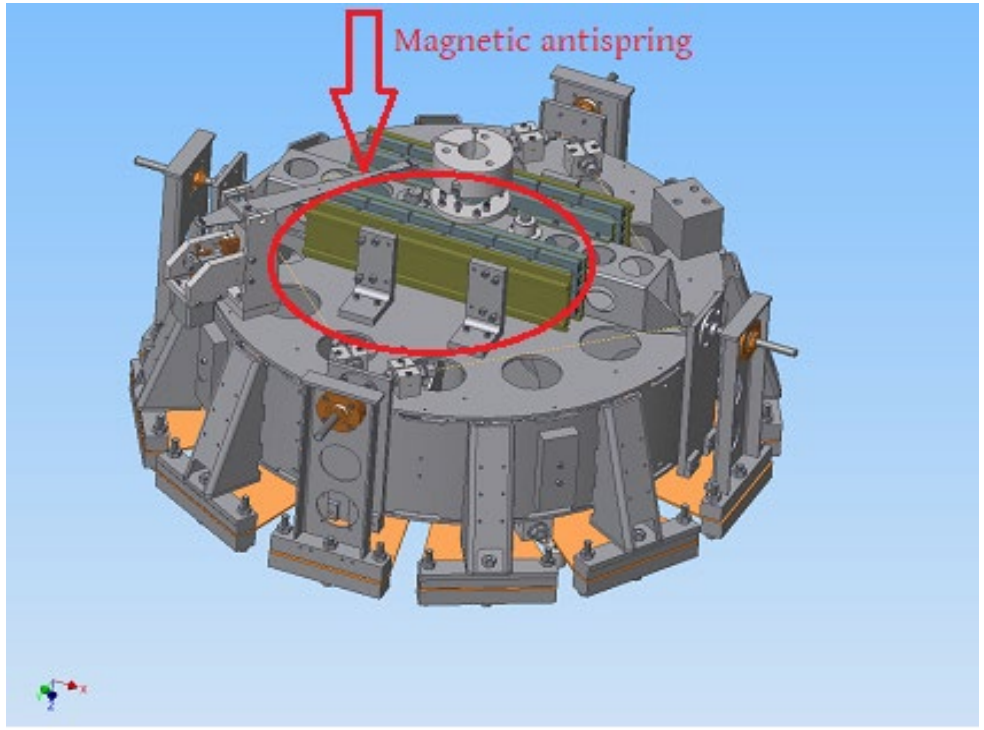


Measured attenuation upper limit ("stage by stage" method): 10^{15} at 10 Hz (**detection band extended in the low frequency region**)

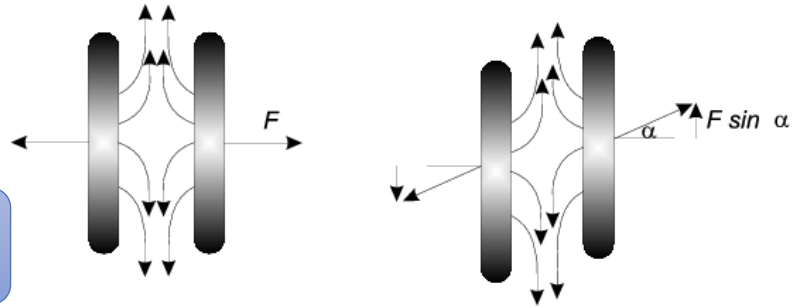
[see: G. Ballardin et al., Rev. Sci. Instrum., vol. 72, n. 9, Sep. 2001]



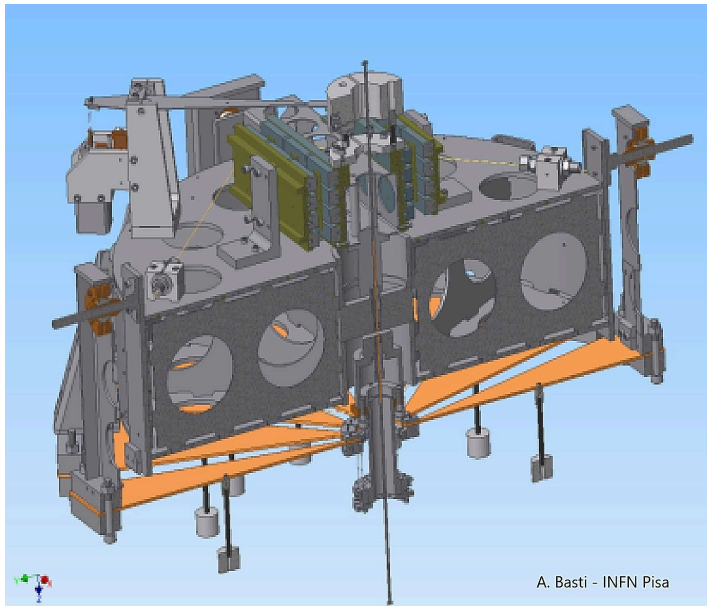
The Mechanical Filter: present design & working principle



- The Magnetic Anti-Spring (MAS) installed on the movable apparatus (**cross-bar**) of the Filter with permanent magnets in repulsive configuration;
- MAS is one of the “elastic” element of the Filter working in synergic way with **blades** (Maraging) and **suspension wires** (Maraging);
- Each Mechanical Filter is connected to the next one by means of a suspension wire, forming a multi-stage pendulum chain.

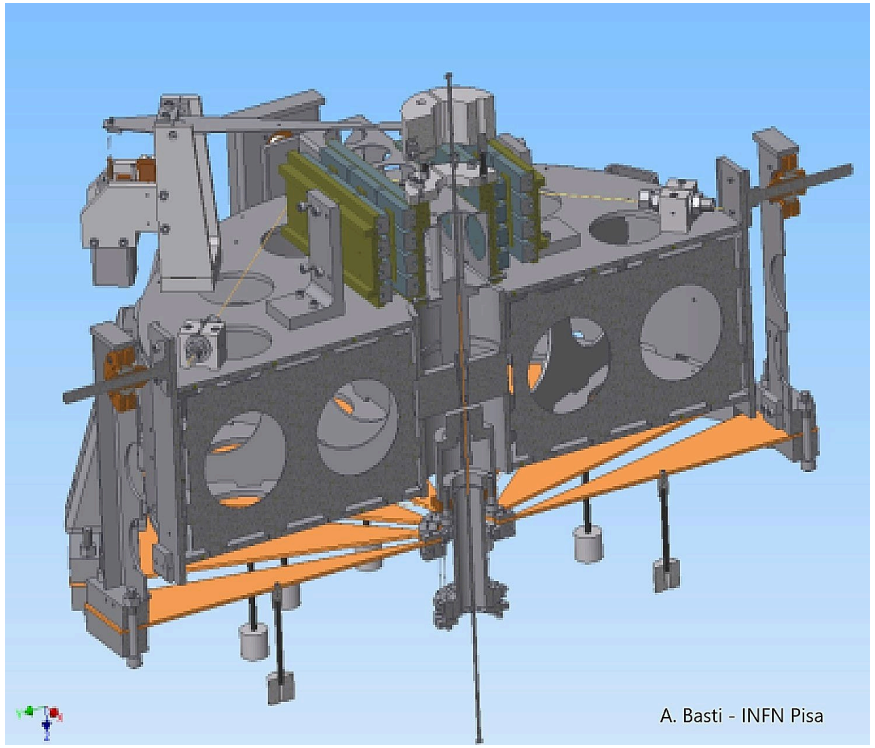


[see: M. Beccaria et al., Nuc. Inst. and Meth. A , vol. 394 , 3, (1997) 397-408]

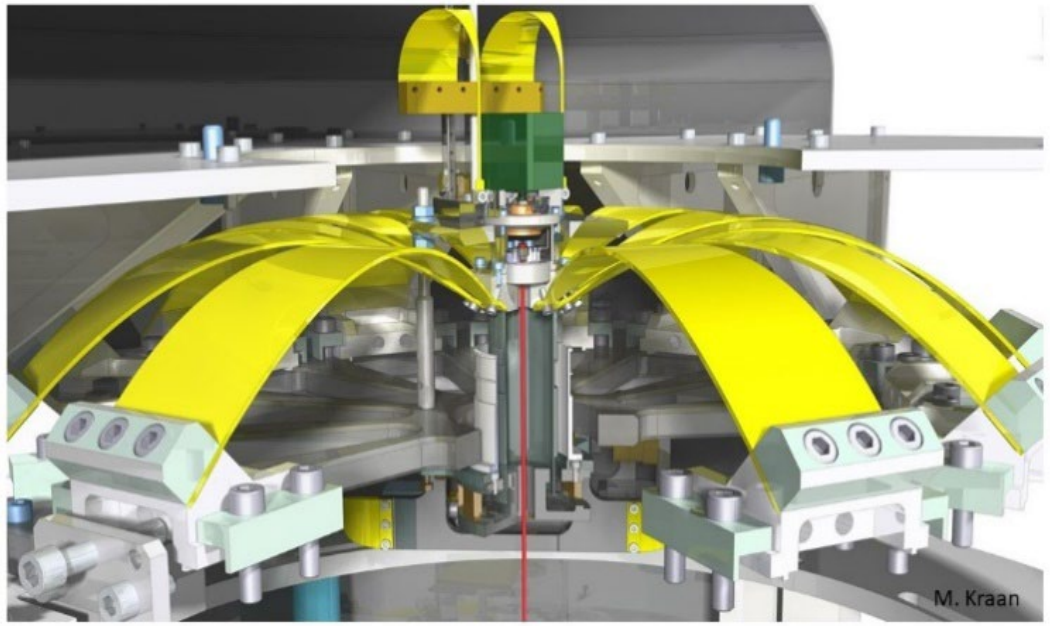


Magnetic Anti Spring (MAS) – Geometric Anti Spring (GAS)

- **AdV SA** adopted a combination of triangular blades and **MAS** to inhibit seismic noise transmission in **Vertical Direction**



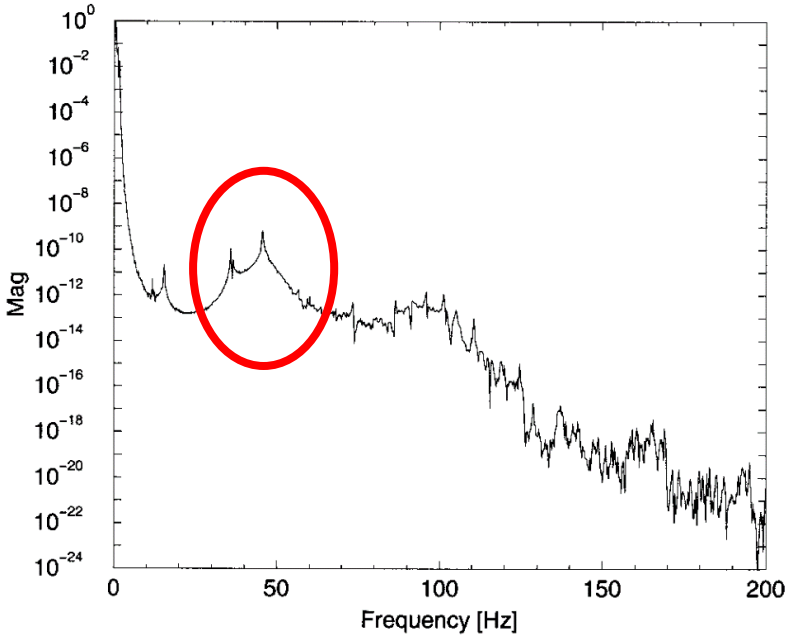
- KAGRA adopted mechanical filters equipped with triangular blades with Geometric Anti-Spring (**GAS**) effect: applying a pushing force on the base of the triangular cantilever blade (not bent) installed into the mechanical structure

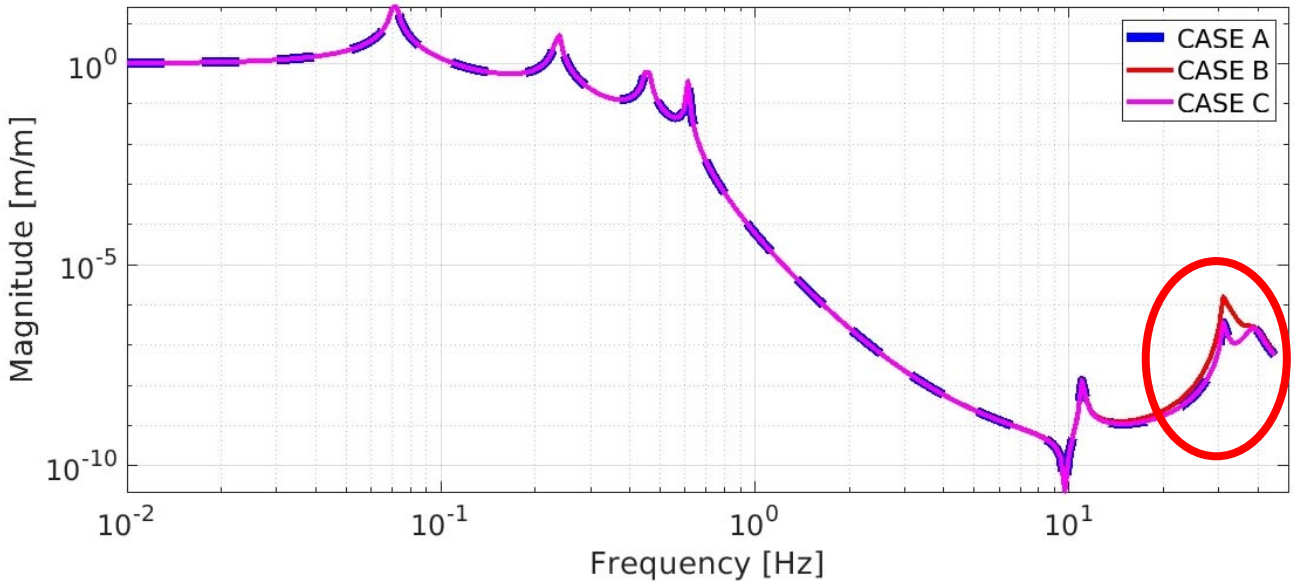


The Vertical Transfer Function (VTF)

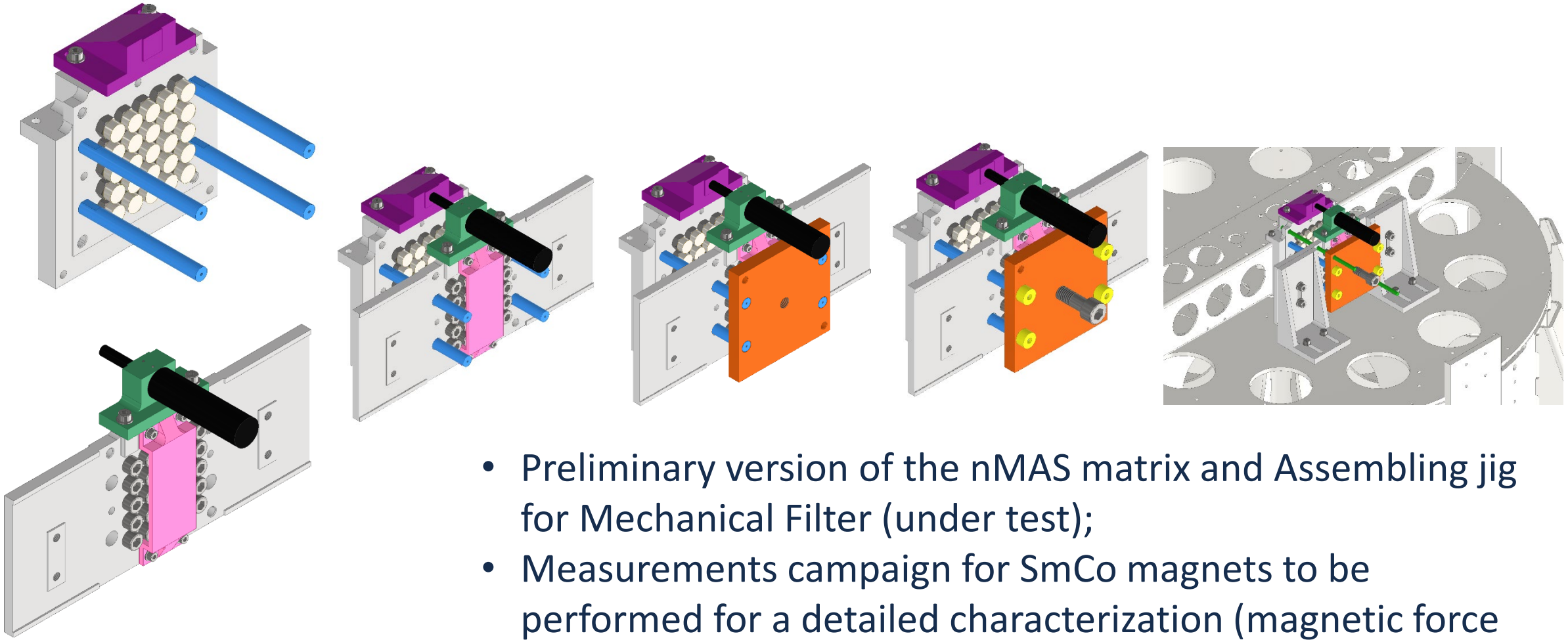
Analysing the experimental data (AdV) and thanks to results of the simulation activity, it turns out that the attenuation performance of the SA in **Vertical direction** (**VTF**) depends on the MAS installed on board of each Mechanical Filter;

- **Improving VTF** → minimizing the total weight of the movable apparatus (cross-bar);
- **Re-design the geometry** of the movable apparatus (mitigating spurious resonances) and the passive filter in view of a more accurate mass distribution all along the multi-stage pendulum chain (details on L. Lucchesi talk)





Assembling jig & nMAS installation on Filter



- Preliminary version of the nMAS matrix and Assembling jig for Mechanical Filter (under test);
- Measurements campaign for SmCo magnets to be performed for a detailed characterization (magnetic force vs distance) of the system.

CAOS and the Superattenuator

The main focus for **CAOS** will be:

- prototyping new test mass suspension (payload);
- new material and strategy construction for last stage suspension;
- low noise control system;
- possible seismological applications.

Activity based on an **optical cavity** (two Superattenuators) about 8 m long in vacuum environment, as a test bench for **ET Technologies.**

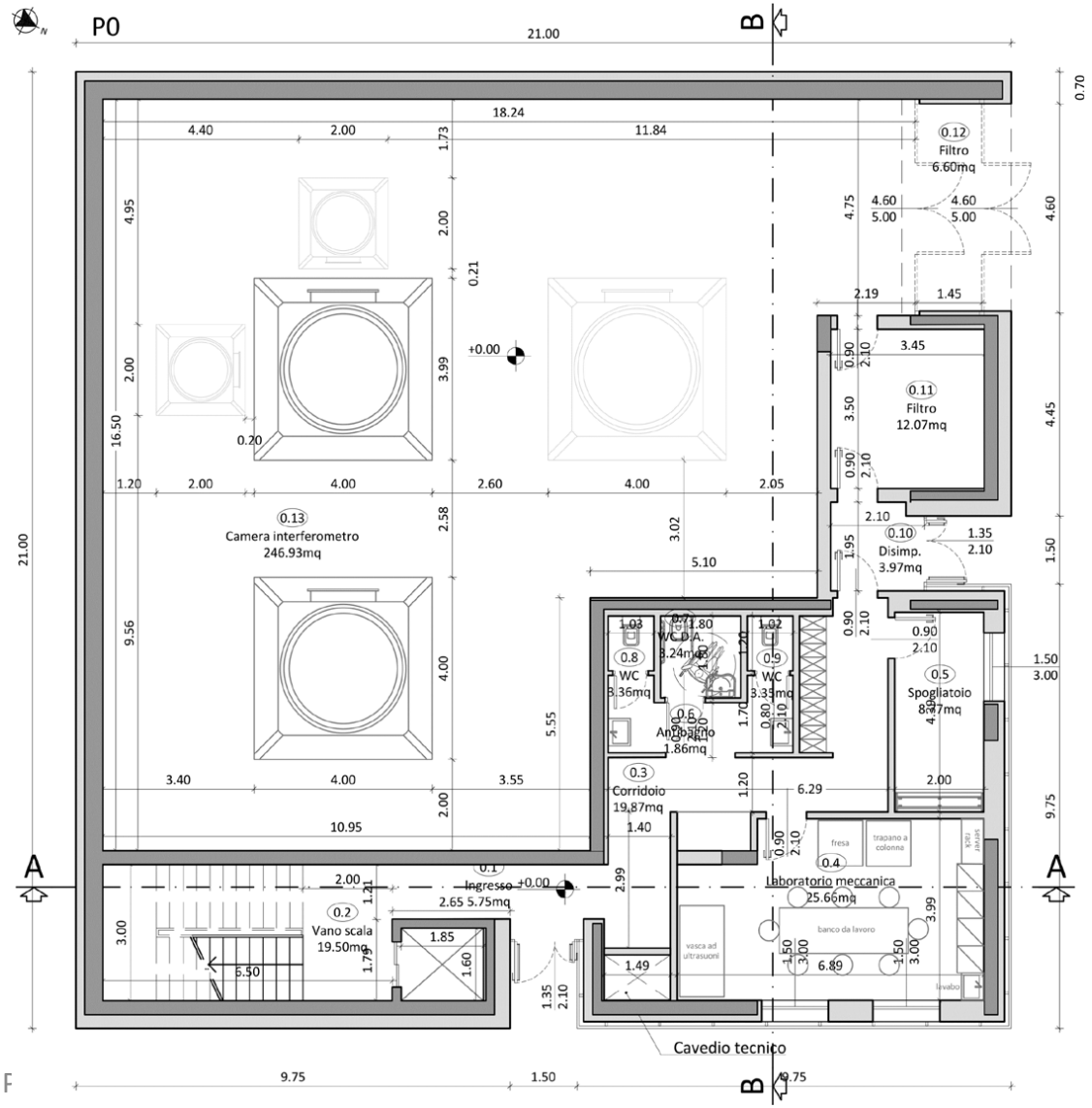
New mechanical filters, with rare-earth permanent magnets (nMAS) will be used on the Superattenuators for CAOS (test of a complete chain in full scale)

The CAOS Project @ University of PG

The project is meant as a facility where it will be possible to test and validate technological solutions for next generation detectors of ground based ITF.

It will be used as playground for future generations of researchers acquiring experience and developing prototypes of different items relevant for the detector design:

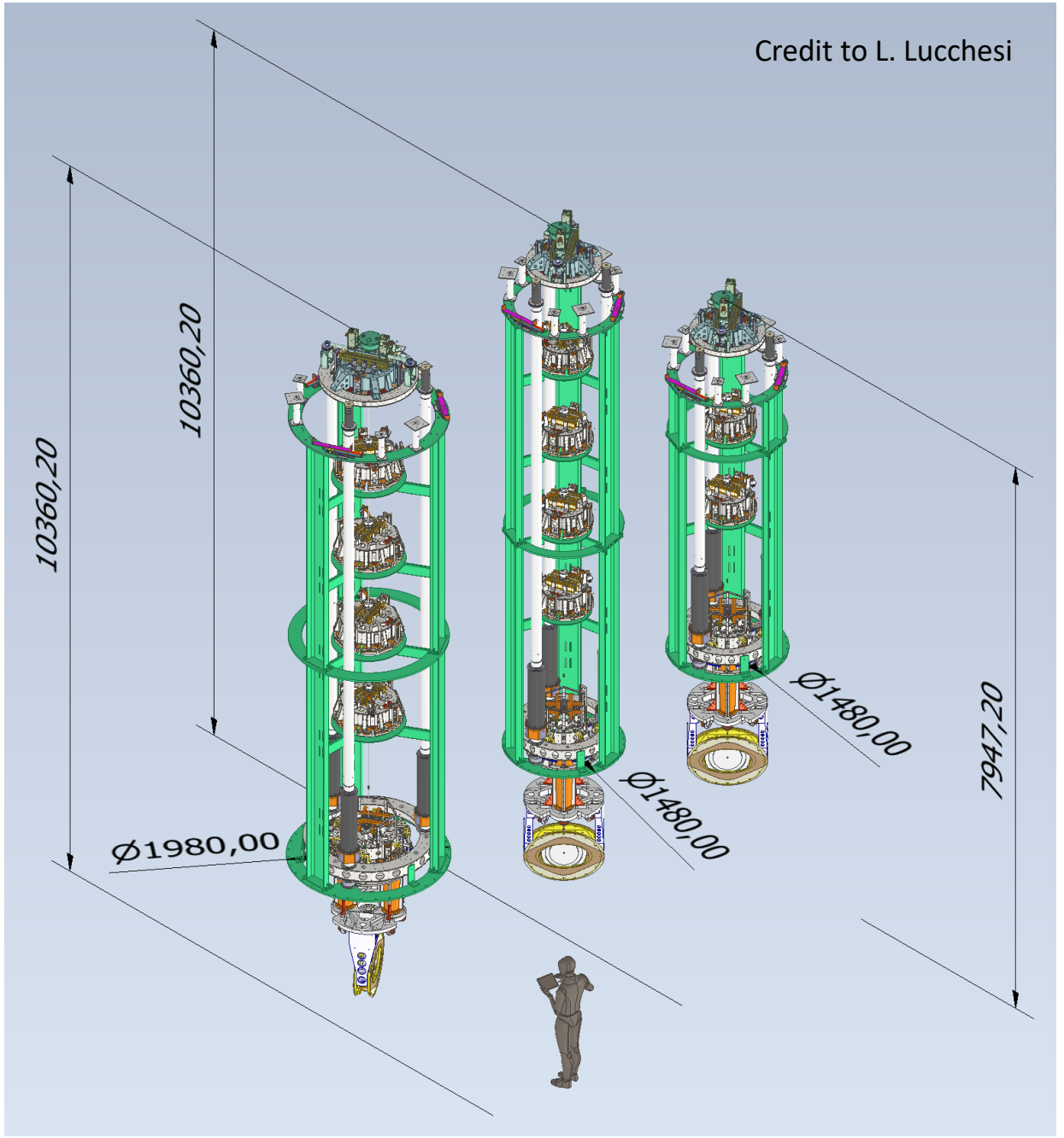
- a full scale seismic isolation system will be available within an optical cavity;
- possibility to test the novelties of our Superattenuator in a full scale system;
- check alternative solution of the interfaces with the vacuum system and other subsystem (cryostat and cryogenic payload).



The “Slim SA”

Recently, thanks to the activity around seismic isolation systems for CAOS and ET interferometers, the INFN Pisa Group is preparing a proposal for the **AdV ITF Upgrade** to be equipped with two short Stable Recycling Cavities (**sSRC**).

- The idea is to use our **Superattenuatos**, with a reduced diameter **(passing from 2.0 m to 1.5 m),** as mechanical support for mirror and benches;
- **Some difficulties** in accommodating the mechanical structure within an adequate vacuum vessel (to be shrinked too);
- **Rearrange the tower positions** in the small space available of the Central Building (crowded area).



ET_Italia: experimental activities

Under this label different activities are going on:

- Development of an **Active Platform** equipped with Piezoelectric actuators acting in vertical direction as a base structure of IP (see F. Spada and L. Orsini talks);
- Project of a **Real Control System** based on a real control boards and DSP (see P. Prosperi talk) ;
- New concept of **accelerometric sensor with optical read-out** (see F. Spada talk);
- New top stage **DiskZero** equipped with positioning sensors, accelerometers and actuators to substitute Filter0 on future Superattenuator (see L. Lucchesi talk)

Final Considerations

The experimental activity of the INFN Pisa Group is spread out over many items in view of conceiving the next generation detector for seismic noise suppression in Gravitational Waves Physics;

The mechanical Superattenuator and the feedback control system complementing the performance of our instrument represent the best “active-passive” system conceived and operated successfully for more than 20 years on a ground based ITF;

The collected experience together with the new technologies available are the pillars of our effort in improving the system performance for future detectors;

Advanced VIRGO interferometer represents a fundamental opportunity for young generation researchers, while test-benches and playgrounds are “growing” to investigate around innovative solutions.