The Superattenuator and the Inverted Pendulum mechanical structure

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Introduction

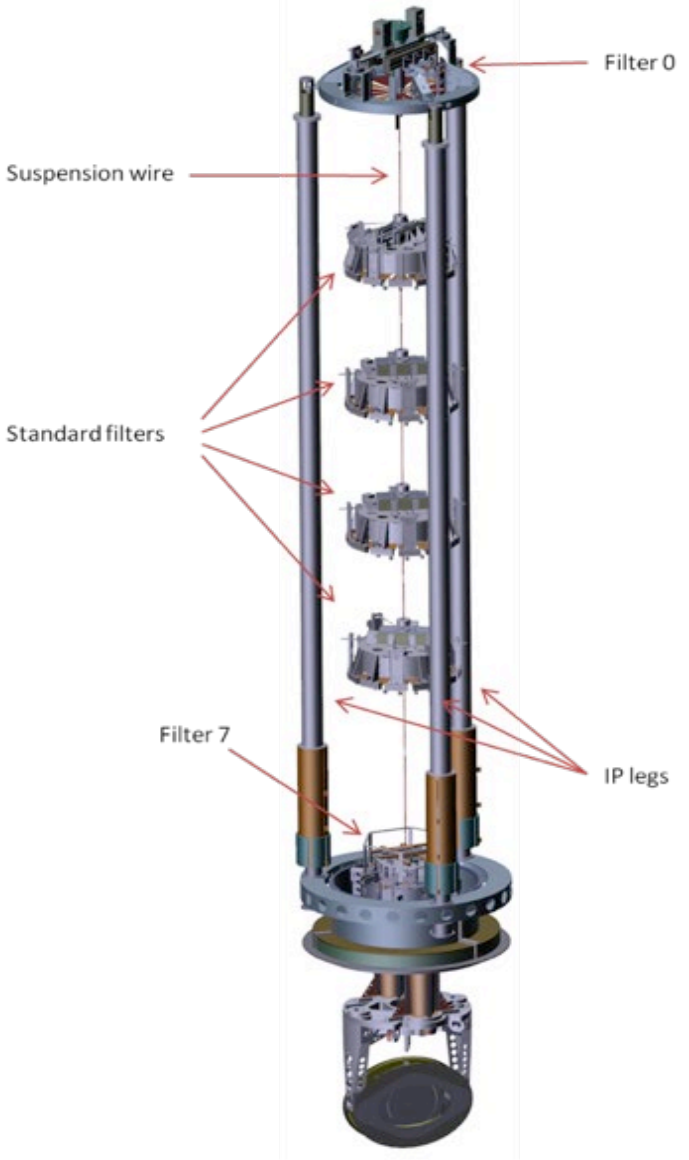
- The "traditional" research line based on the AdV Superattenuators (Inverted Pendulum, Filter Chain, Payload) is currently considered the **baseline solution in the ET Conceptual Design**.
- For the High Frequency Interferometer (HFI), the AdV Superattenuator with 6 filters in an "equally spaced" configuration is considered compliant with the ET requirements (total pendulum length of about 9 meters);
- For the Low Frequency Interferometer (LFI), the Superattenuator proposed for the HFI is not sufficient to meet the ET requirements: the total pendulum length needs to be increased to approximately 17 meters with the intent to extend the detection bandwidth down to 3 Hz;
- **Experimental activities are in progress at INFN Pisa Laboratory to test technical solutions to be used in the final design of the Superattenuator:**

  - New magnetic Anti-Spring

  - New active platform – IP basering

  - New Filter0/Disk0 on top of the structure

  - CAOS facility as fundamental test-bench for 2 AdV based Superattenuators 15 m hight, supporting a Fabry-Pérot optical cavity for ET research developments.



The SA and the IP

- The **Superattenuator** is the mechanical structure adopted to isolate the optical components from seismic activities and local disturbancies. It is based on the working principle of a multistage pedulum and consists of:

  - Inverted Pendulum (IP) – a three legs mechanical structure

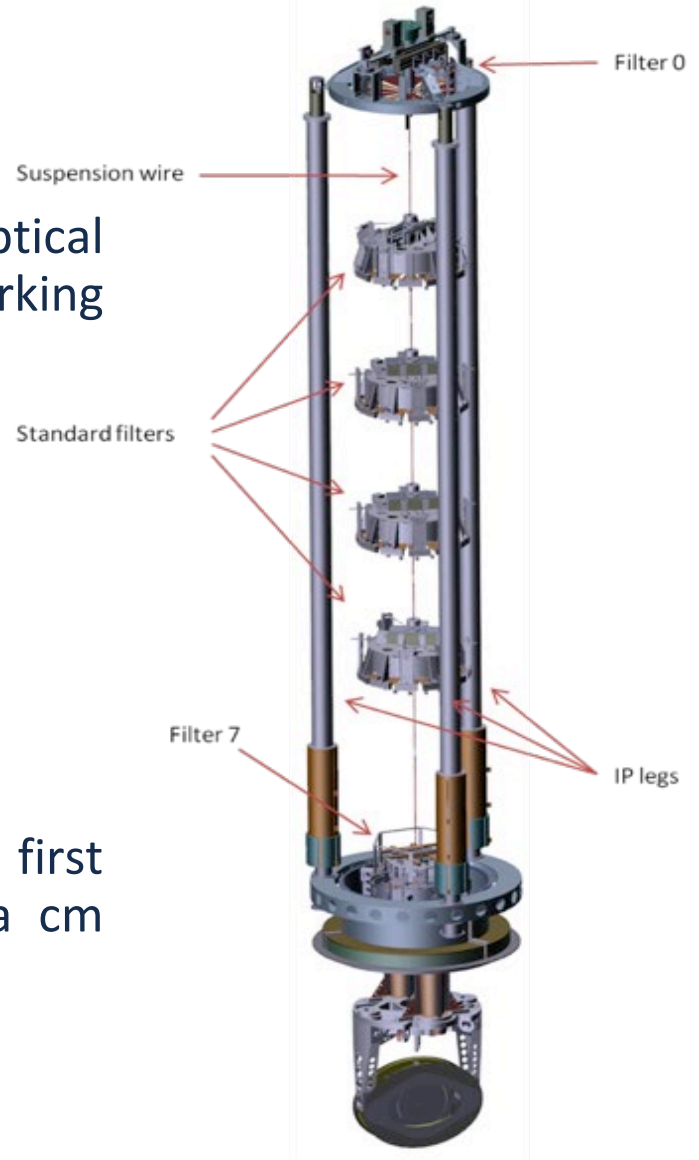
  - 6 or 3 Seismic Filters (SF)

  - Payload or Last Stage (LS)

- Two important roles of the IP:

  - pre-isolation stage in horizontal direction (two d.o.f.)

  - precise monitoring of the tidal effect on the suspension point and first feedback compensation action with small forces (a few Newton per a cm displacement of 1 ton)

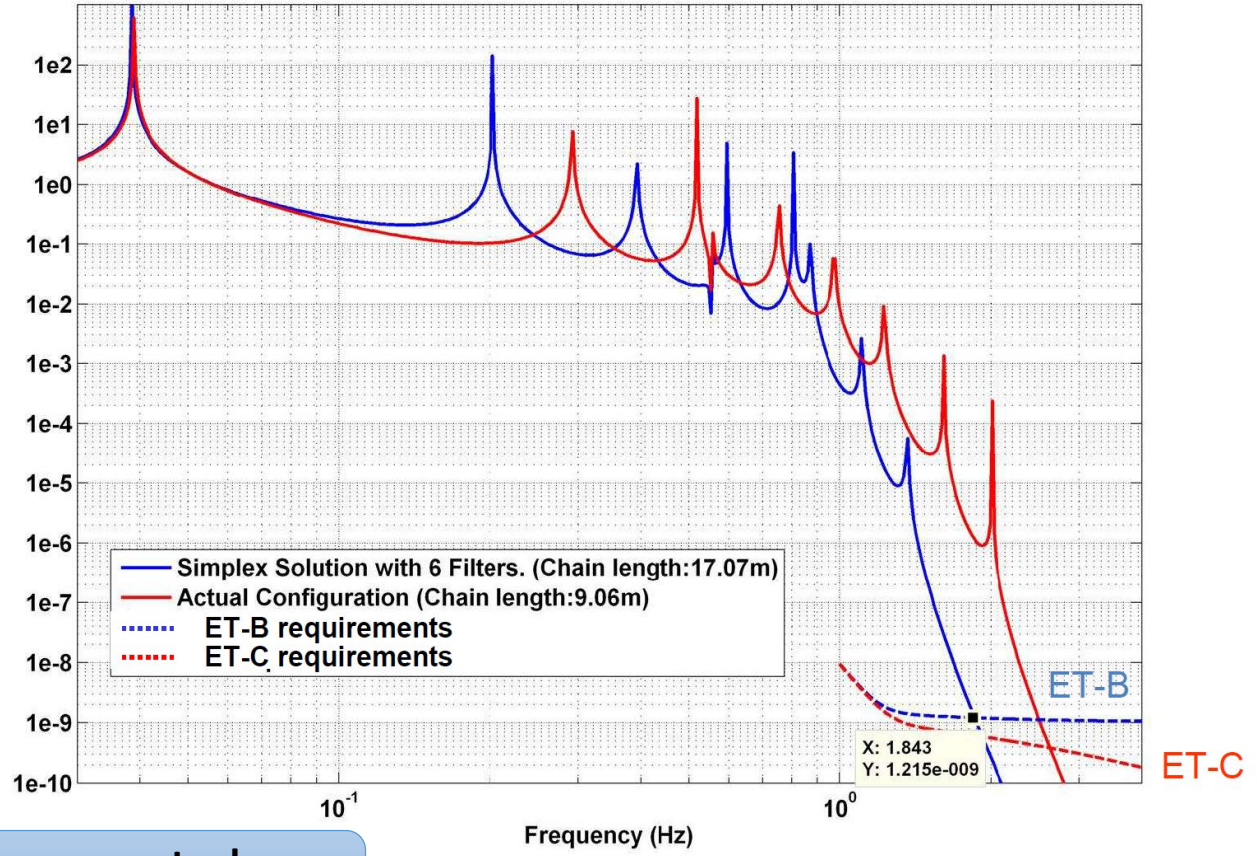


A reference solution for ET

- Within the **ET Conceptual Design** (2011) a **reference solution** for a seismic vibration isolation system has been studied;
- Same technology used for SA (**passive and active system**):

  - height 17 m (9 m AdV)
  - cut-off frequency~2Hz (~3Hz in AdV).
  - single IP
  - 6 stages **“equal-spaced”** configuration

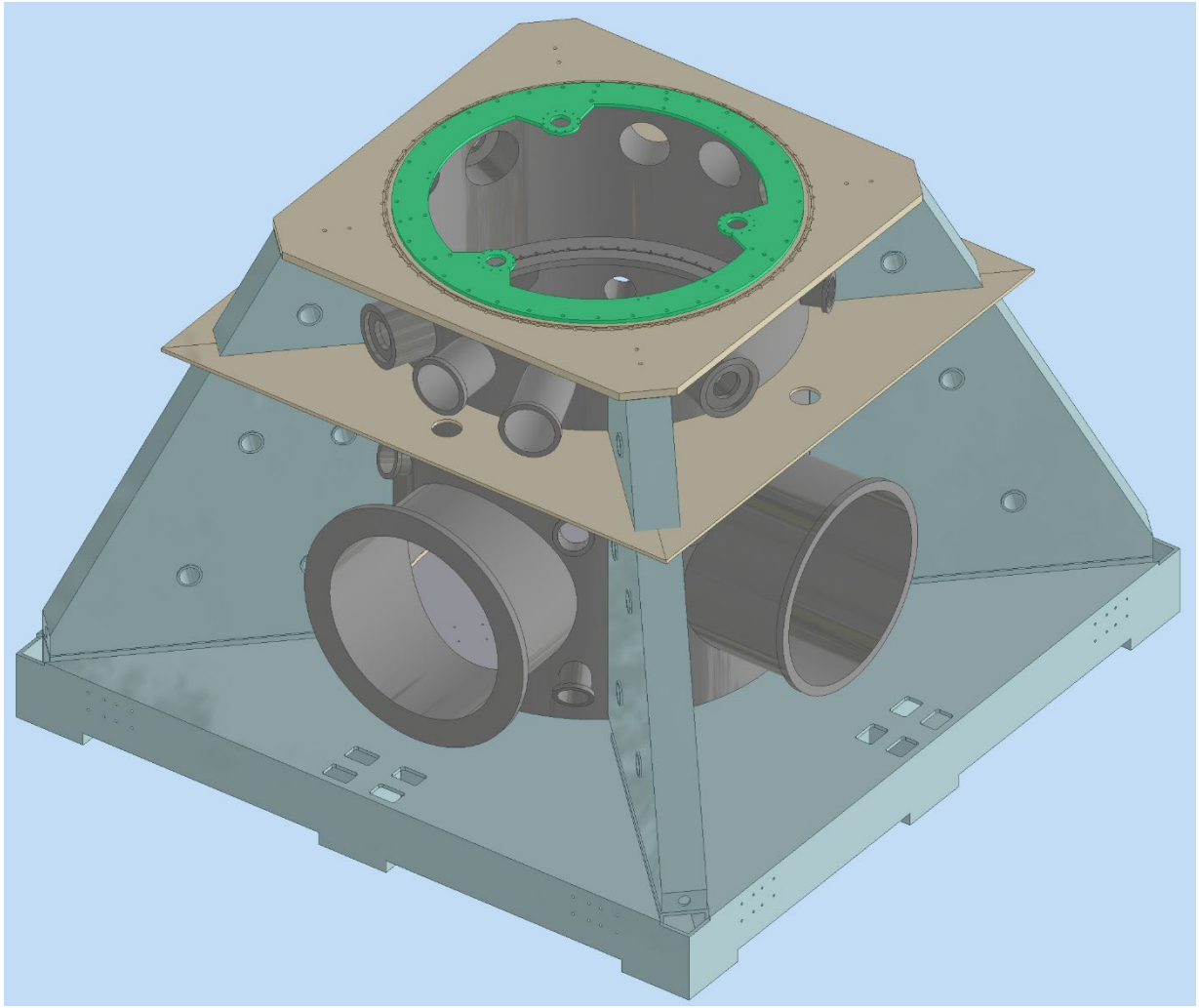
- No change on the VERTICAL d.o.f.
  (cross coupling HOR-VERT to be improved)



[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]

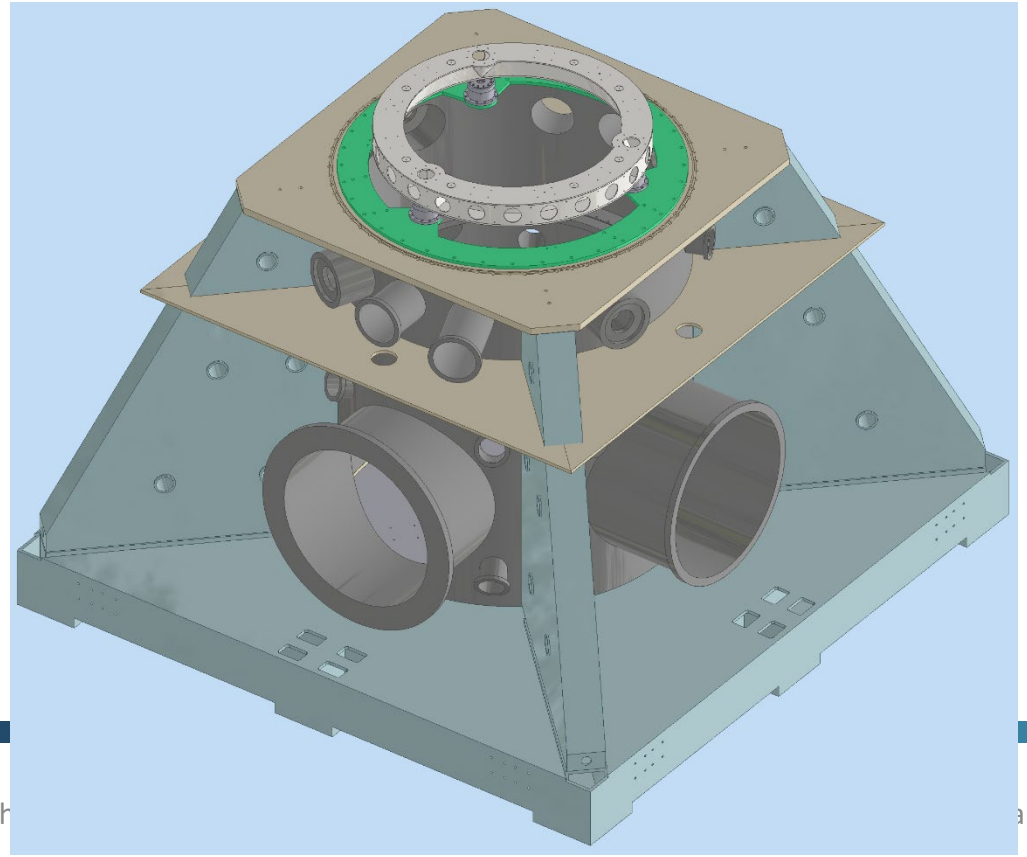
The IP and the Vacuum System

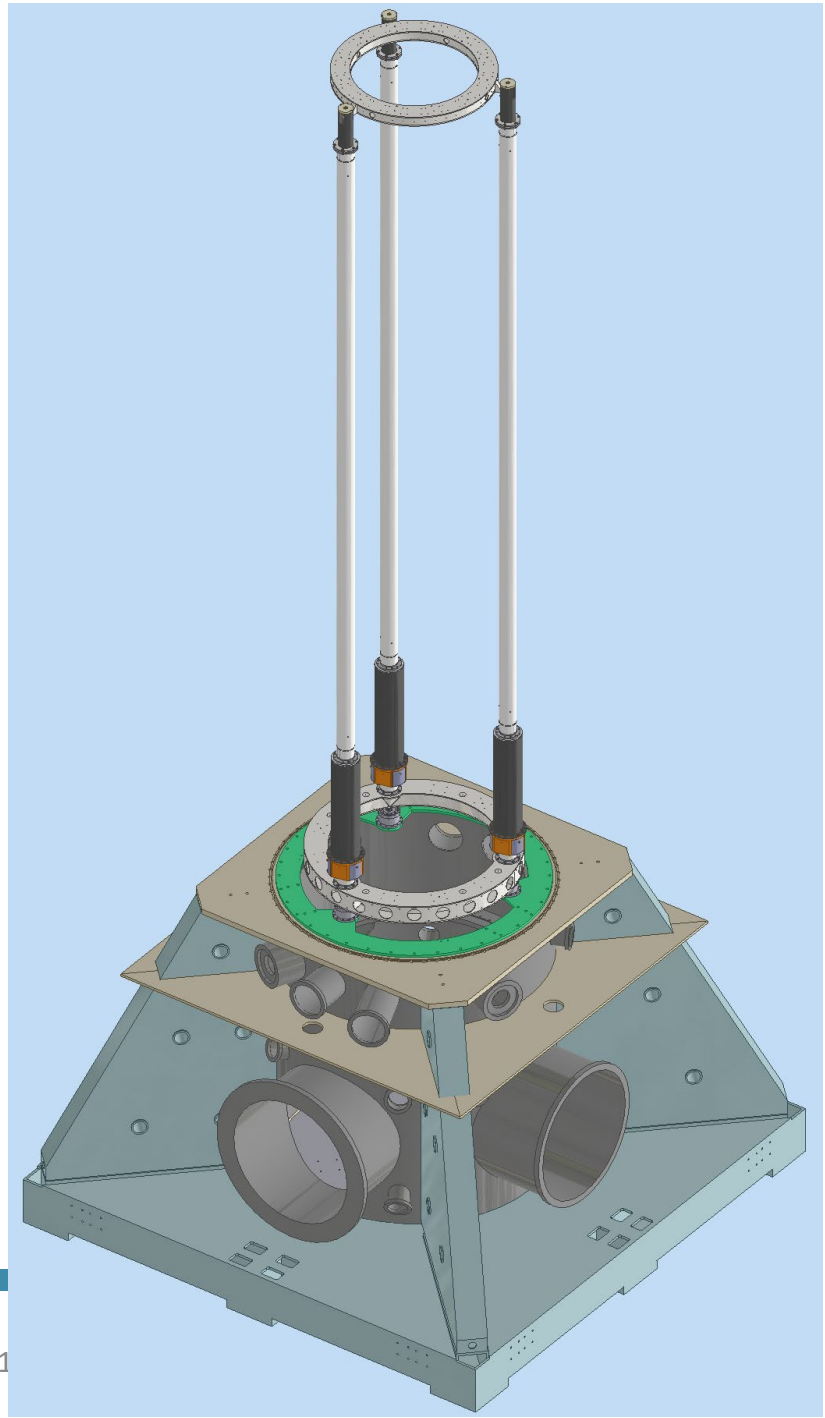
- Following the AdV approach, the base-ring of the **Inverted Pendulum, is the interface with the vacuum system;**
- The base-tower is an open volume towards the tower upper part where the Superattenuator is installed;
- The Payload is confined into the base tower vacuum chamber;
- Particular care is due to the LFI where the presence of cryostat demands an adequate material selection close to the interface: **Maraging alloy can not be used in cryogenic environment for machining thin suspension wires.**



The IP assembling procedure

- The base-ring of the IP is bolted to the base tower/cryostat representing the ground reference for the whole Superattenuator
- The base-ring is equipped with **vertical actuators** (PZT) to compensate tilt ground motion (3D) if an adequate tilt sensor will be available (sensitivity of the order of 10^{-8}mrad/sqrt (Hz)@50 mHz)

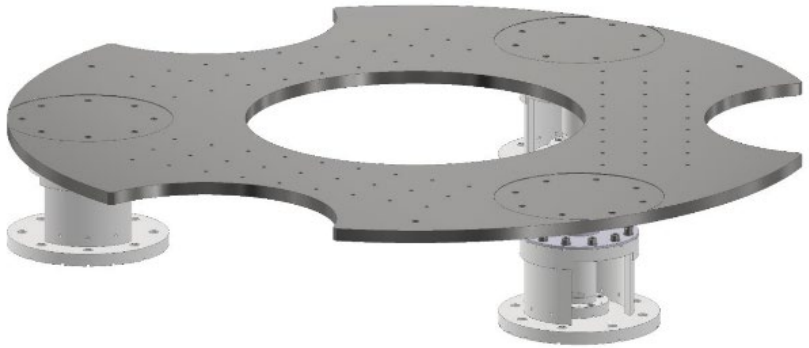




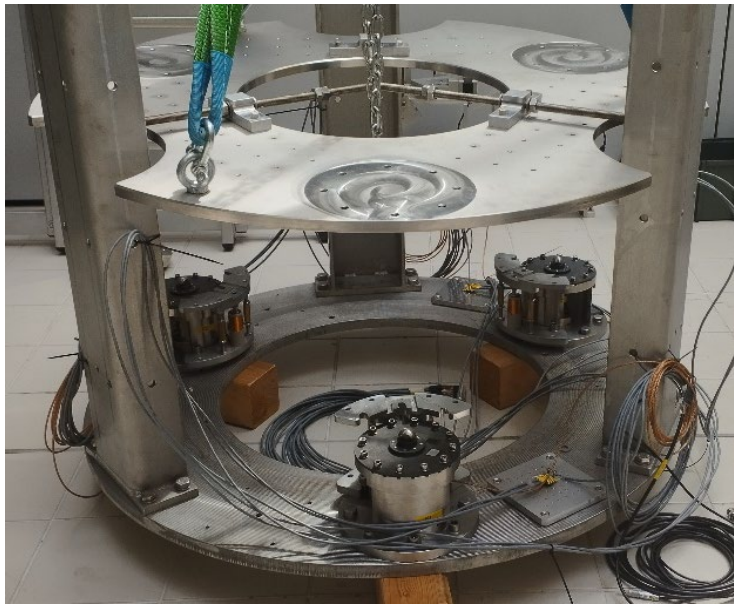
Activity in progress: Active Platform

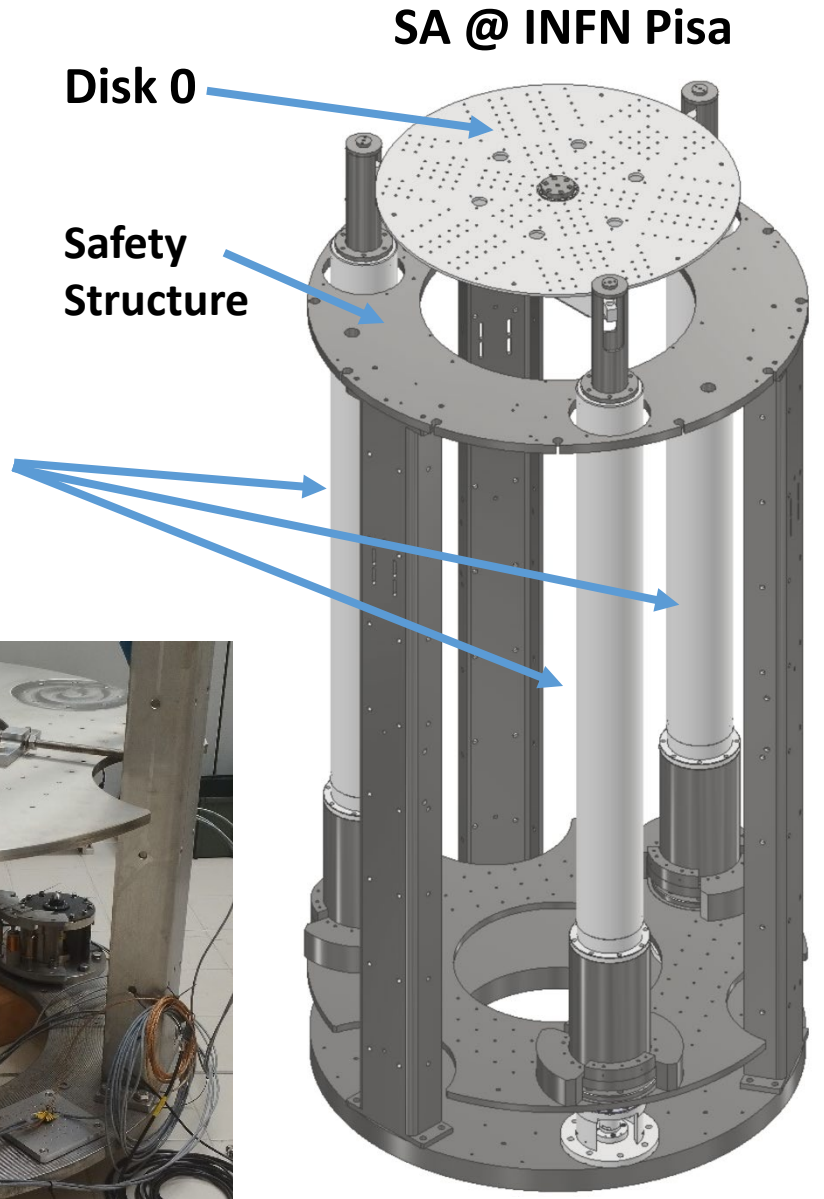
- Some studies are in progress at INFN Pisa Laboratory: a SA 2 m high with 1 m diameter is used as prototype to test
  - Safety Structure (SS), **Active Platform** , Inverted Pendulum
  - **Disk0** prototype construction is going on
  - Filter with new Magnetic Anti-spring (**new crossbar design**)

  Goal: development of an Active Platform with the possibility to include horizontal feedback action for future application



Active Platform and feet equipped with PZT





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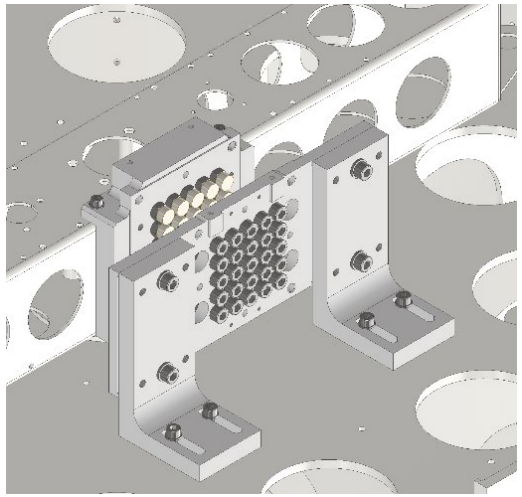
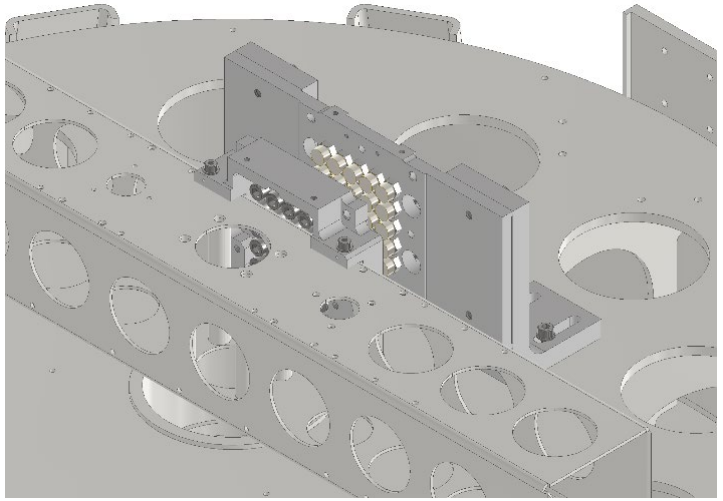
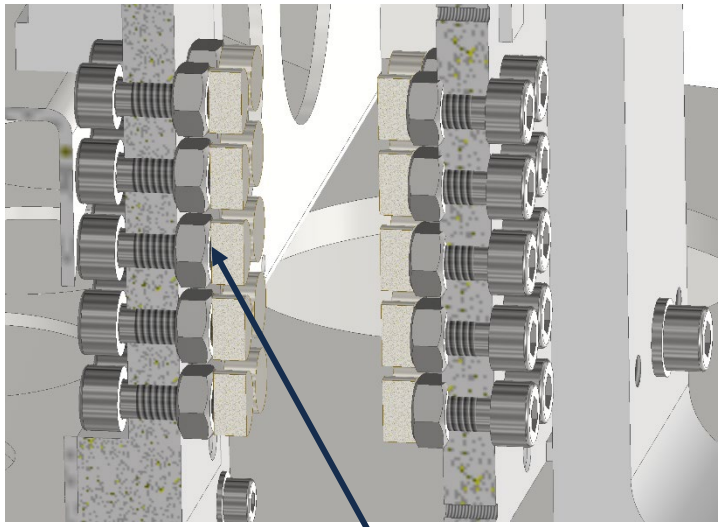
New Magnetic Anti-Spring design

R&D on new MAS

- Modular layout during the R&D phase (possibility to easily assemble up to 5x5 magnets per matrix): easy and quick re-configure the nMAS changing the number of magnets.
- High-vacuum compatible design (permanent magnets Ni plated).
- More compact volume of the magnets on the crossbar side wrt AdV (110mm vs 375mm; 0.472kg vs 1.319kg).

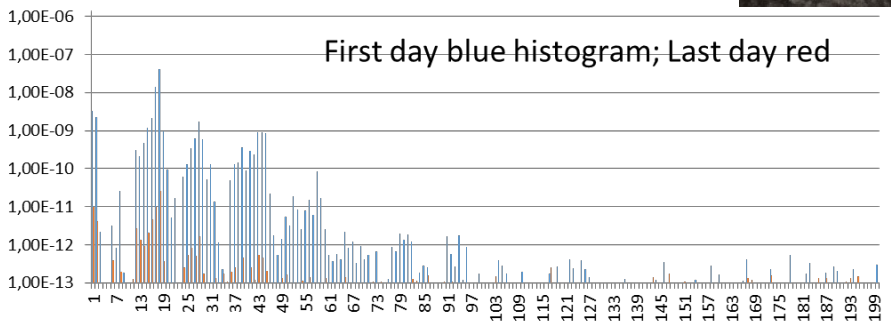






Cryogenic, high-vacuum compatible adhesive 3M 2216

Thanks to the design of an assembling jig, the procedure has been tested and a precise process defined



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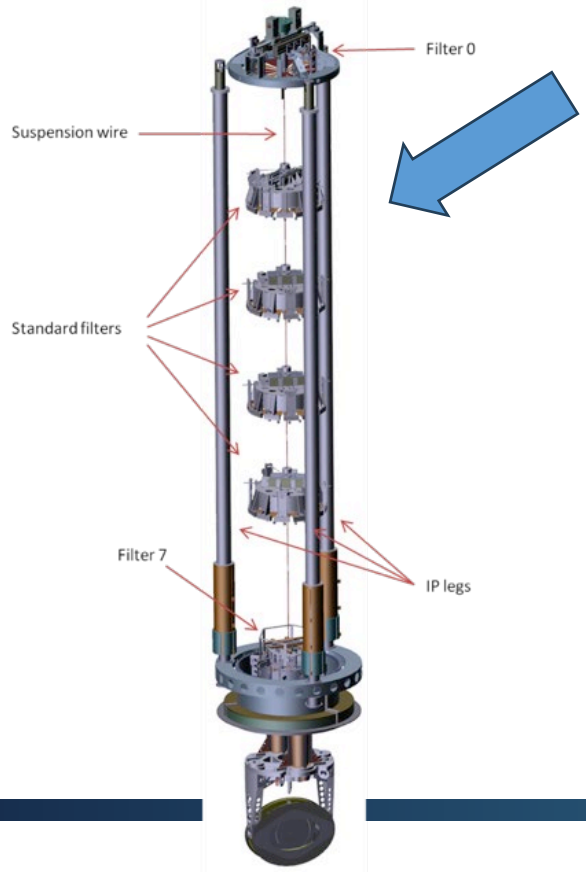
The R&D program on SA

NGSA New Generation of Superattenuator: R&D program financed by CSN5

Inolvelvement: INFN Pisa, INFN Napoli and University of Sassari

Goal: A Seismic Isolation System for 3° generation detectors of GW – Einstein Telescope (ET) underground Giant Laboratory **improving the current sensitivity by a factor 10 and extending the observation bandwidth in the low frequency region around 2 Hz**

1. Traditional: based on AdV mechanical structure



Improving passive filter chain

- Optimization of filter chain masses and length distribution;
- Improved Magnetic Anti-Spring (MAS) for vertical isolation.

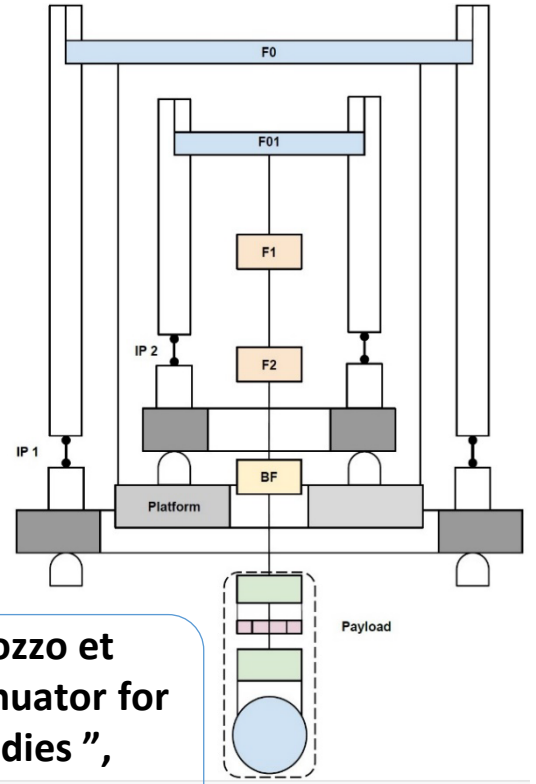
Improving pre-isolation

- Active per-isolation
- Two-fold inverted pendulum in nested configuration (NIP)

To keep in mind:

- Never put in operation
- Tilt and vertical to longitudinal Cross talk
- Noise of control systems
- ……

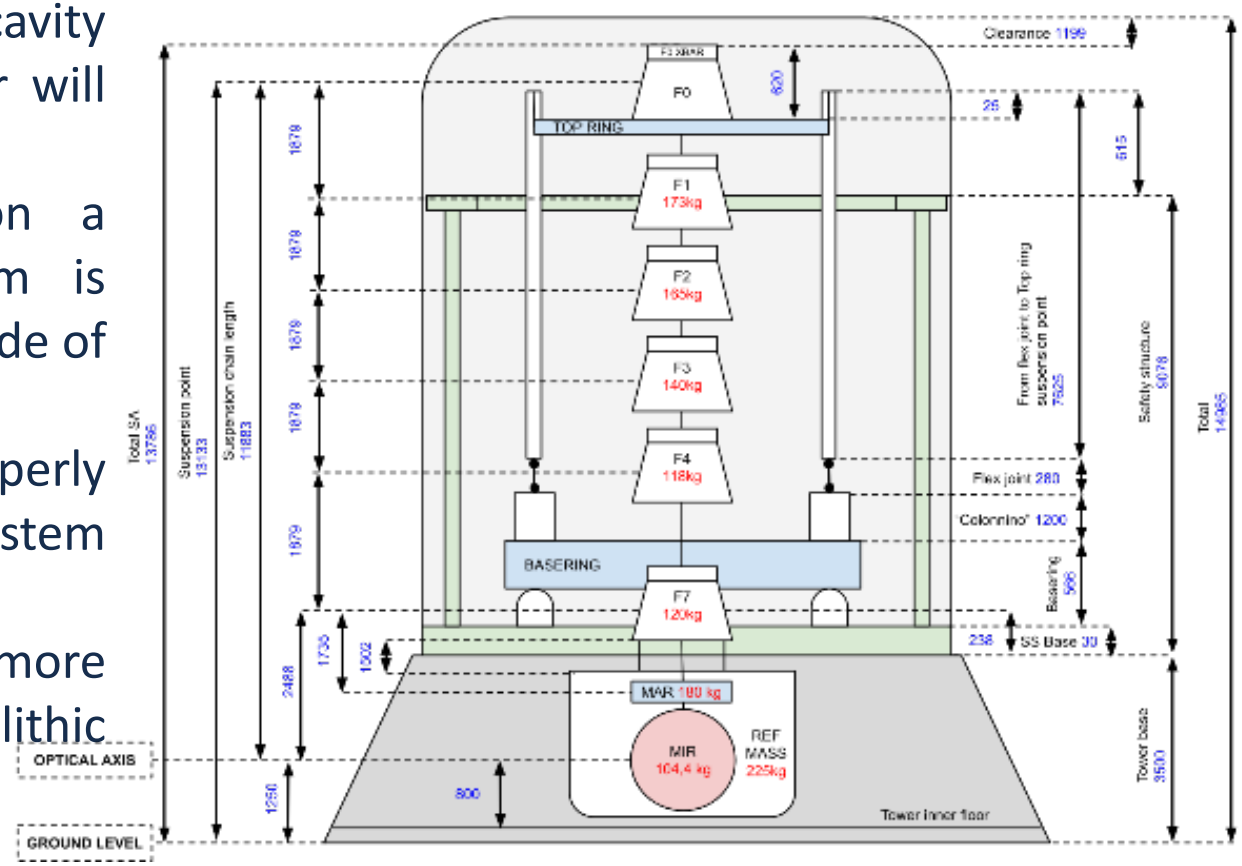
2. Based on two-stages NIP



[see: A. Bertocco, F. Frasconi, L. Trozzo et al., "New Generation of Superattenuator for Einstein Telescope: preliminary studies ", CQG 41 (2024) 117004 (14pp)]

Two Superattenuators for CAOS

- Two long Superattenuators, about **15m tall**, will be installed in CAOS facility at Perugia University;
- They will be used to suspend a Fabry-Perot cavity where future technlogies for ET interferometer will be tested and validated;
- The Superattenuator structure is based on a traditional scheme where an Inverted Pendulum is used as mechanical structure from which a cascade of passive filters and payload are hung;
- The conical base-tower is meant to support properly the vacuum vessel and the Seismic Isolation System in view of the Einstein Telescope;
- A larger base-tower vacuum volume will be more adequate for different geometries of the monolithic suspension/payload.



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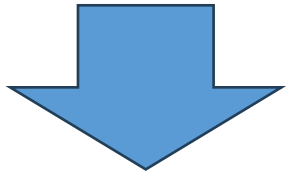
Passive and Active Actions

- The **SA**, representing the reference solution for ET detector, has been conceived confining all the resonance modes in the region below 3 Hz;
- Passive attenuation is enough but in the frequency range 0.04 Hz< f < 2 Hz the chain resonance modes induces tens of micron mirror swings

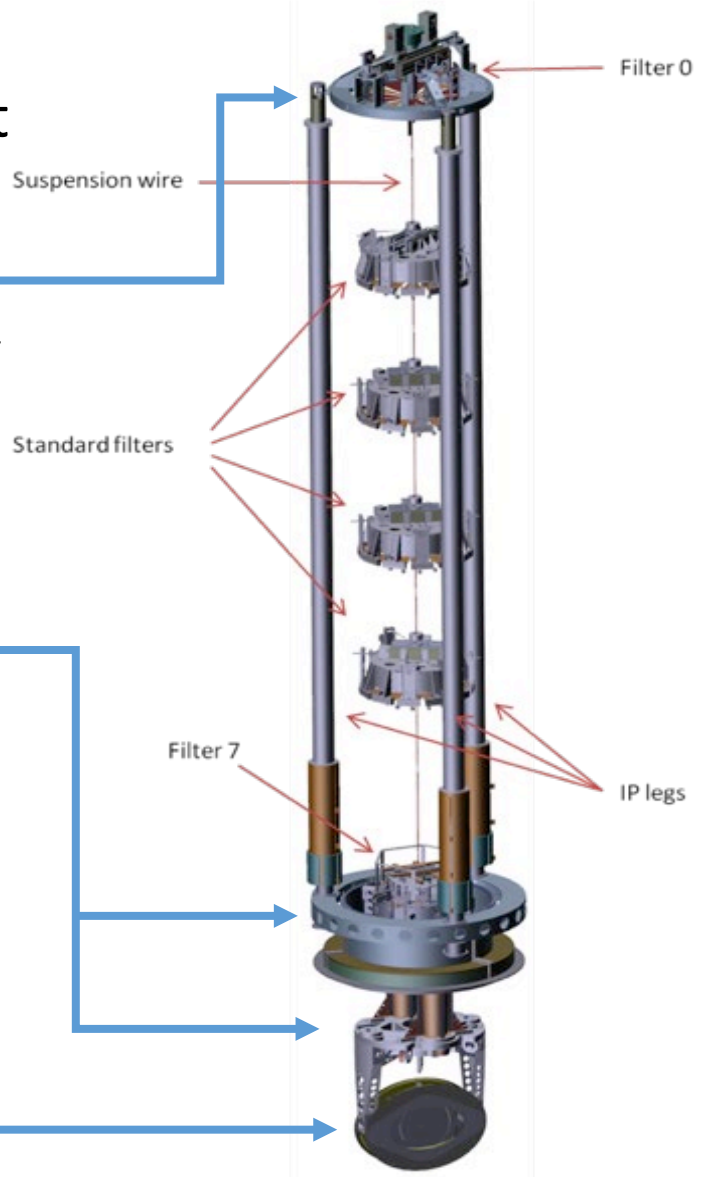


Active **M**ode **D**amping (AMD) & Hierarchical Controls

Mirror Suspension Control: AdV experience

A **hierarchical feedback control** is implemented in 3 different points along the chain;

1. **Inertial Damping** on IP:
   - tidal control of the suspension point and its drift of any origin
   - AMD of the SA normal mode for seismic noise depression
2. **Local Control** on F7-Marionette:
   - Active Pre-Damping on F7 as back-action effect when feedback control engaged on Payload
   - z displacement and angular displacements reduced down to fraction of mrad;
3. **Local Damping** on Mirror (MIR):
   - viscous damping and locking acquisition



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Final Considerations

- The SA scheme is considered the reference solution for Next Generation Superattenuators (NGSA) with the possibility to extend the detection bandwidth down to 2 Hz;
- Lesson learned so far:
  - **hybrid technology** (passive and active) has reached very good reliability (impressive stability for AdV). **A SA 17 m high is considered a conservative solution**
  - **single IP** structure as pre-attenuation stage equipped with sensors and actuators is a well consolidated technology for suspension point positioning and feedback control
  - possibility to include a double Inverted Pendulum in nested configuration (**NIP**) is under study (NGSA prototype at INFN Na to be installed)
  - **vertical attenuation** performance for seismic noise filtering to be improved with nMAS (activity in progress at INFN Pisa)
  - possible **improvements on feedback controls** performance developing new sensors/actuators, new elettronics boards and new control strategy (active platform,etc.)