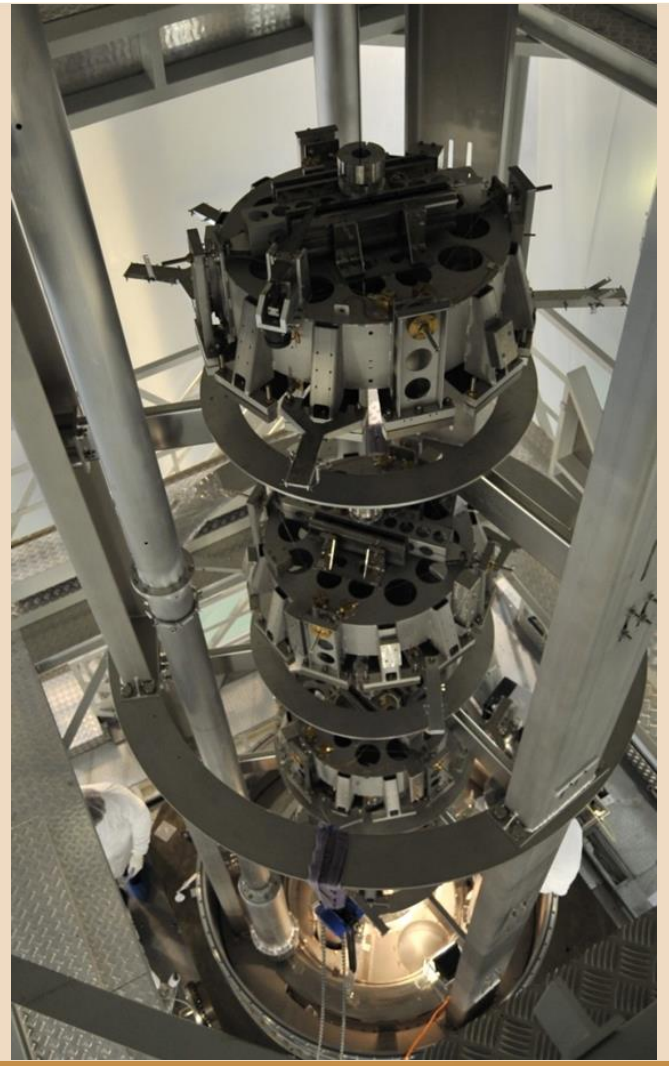
Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

Suspension Status

ET-Italia



Francesco Bianchi (INFN-PG)

Gabriele Capoccia (INFN-PG)

Cagliari, 18-19 March 2025

Suspensions: Overview

Why we need the suspension system?

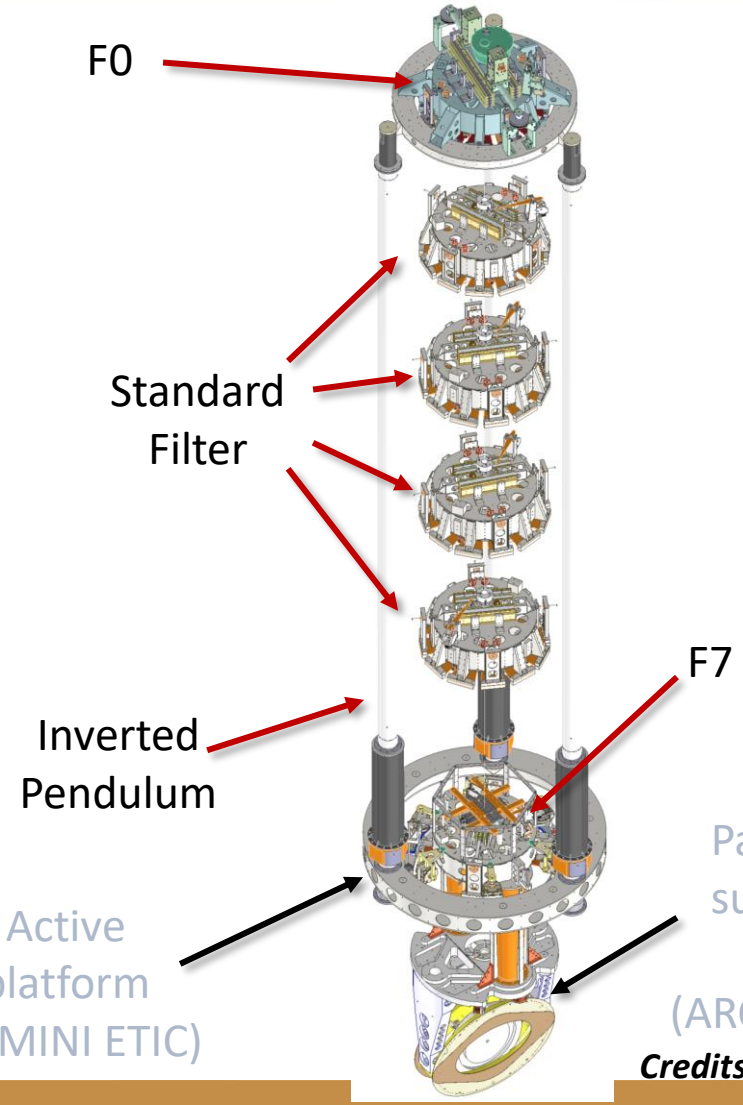
- Put the test masses in a condition of «free fall» **isolated** from the most intense perturbation as the **seismic noise or environmental noise**;

- Put the test mass in the **design working point** for optimal sensitivity;

What characteristics must the suspension system have?

- Avoid reintroduction of noise by actuators;
- Controllability of the system;
- Recovery from high excitation after feedback unlock;
- Reach the required attenuation level:
  - Active isolation;
  - Passive isolation;

Three main Italian projects for the seismic isolation system:
CAOS ETIC
NGSA
PIP

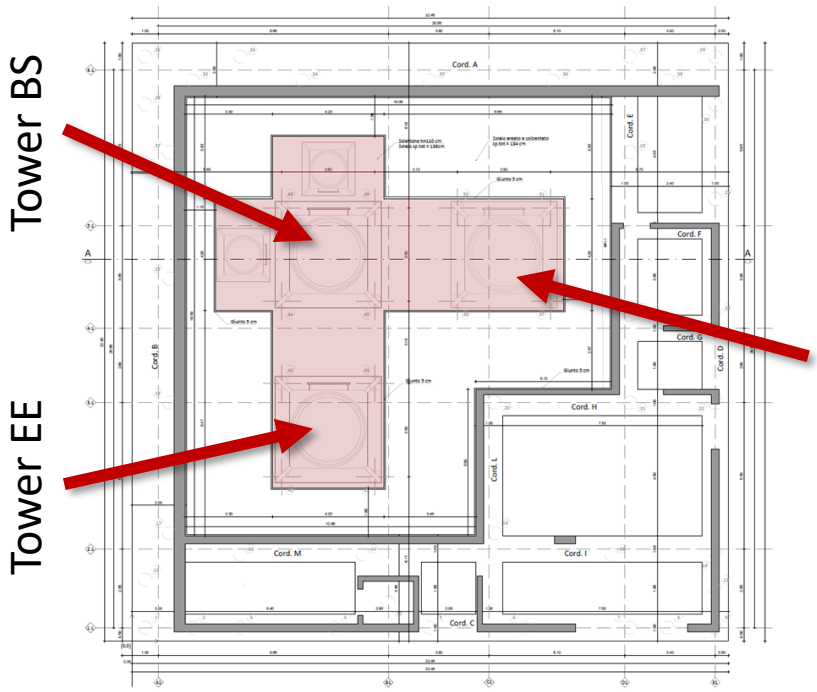


***Credits to**: Lucchesi L.*

Suspensions: CAOS

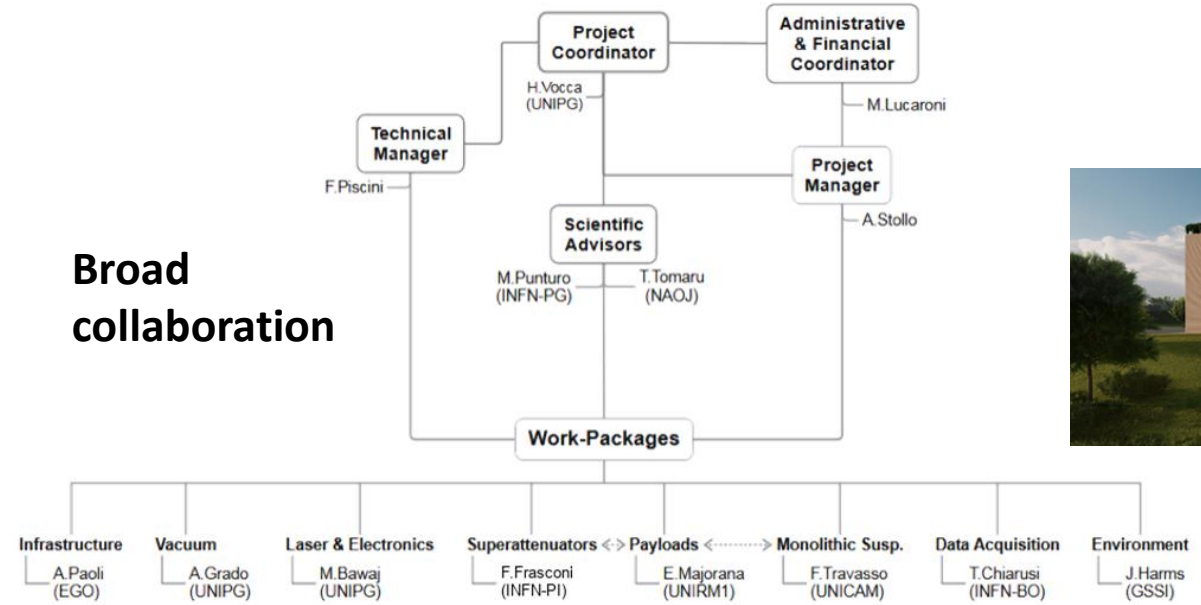
Centro per **A**pplicazioni sulle **O**nde Gravitazionali e la **S**ismologia

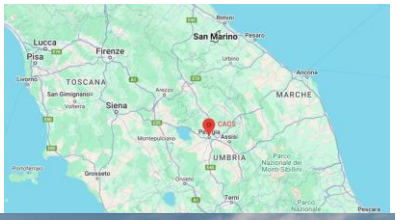
- The "traditional" research line based on the **AdV Superattenuators** (Inverted Pendulum, Filter Chain, Payload) is currently considered **the baseline solution in the ET** Conceptual Design. The **CAOS project** was born within ETIC framework with the aim of following the ET concept.



- Two long Superattenuators, about **13 m tall**, will be installed in CAOS facility at Perugia University;
- They will be used to suspend a **Fabry-Perot cavity** where future technologies for ET interferometer will be tested and validated;

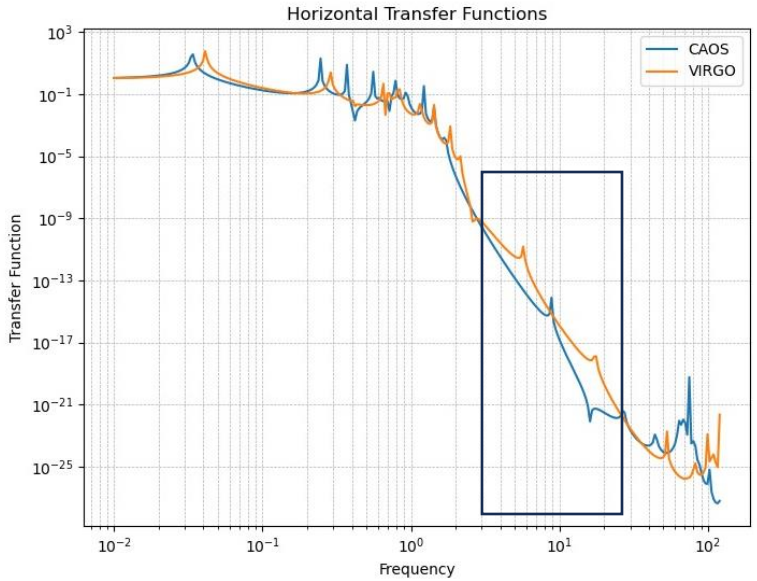
Broad collaboration



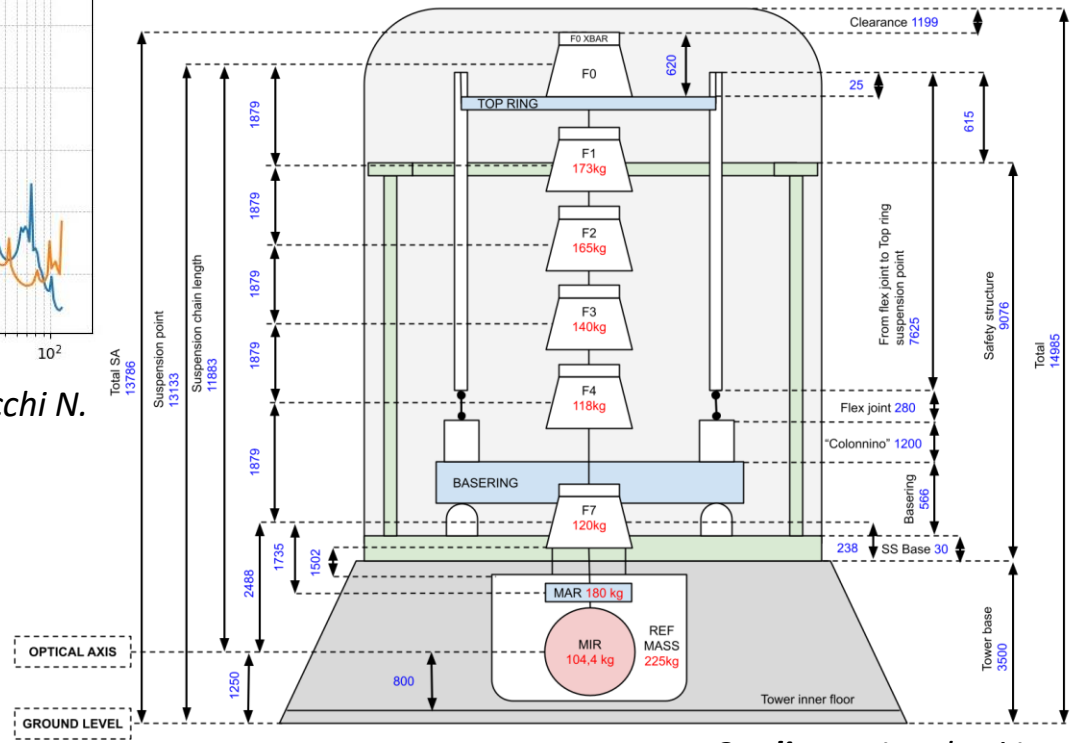


Suspensions: CAOS

- The “Beam Splitter” (BS) SA will be very **similar to the present AdV one** (except for the height);
- The “East End” (EE) SA will be used to perform **dedicated R&Ds** on them. So far we foresee to test:
  - New active platform – IP basering
  - New accelerometers
  - Filter 0 different approach
  - New filters crossbar
  - New epicycloidal Vertical Hoist
- All the mechanical filters for both SAs will be equipped with **new Magnetic Anti Springs** (nMAS);



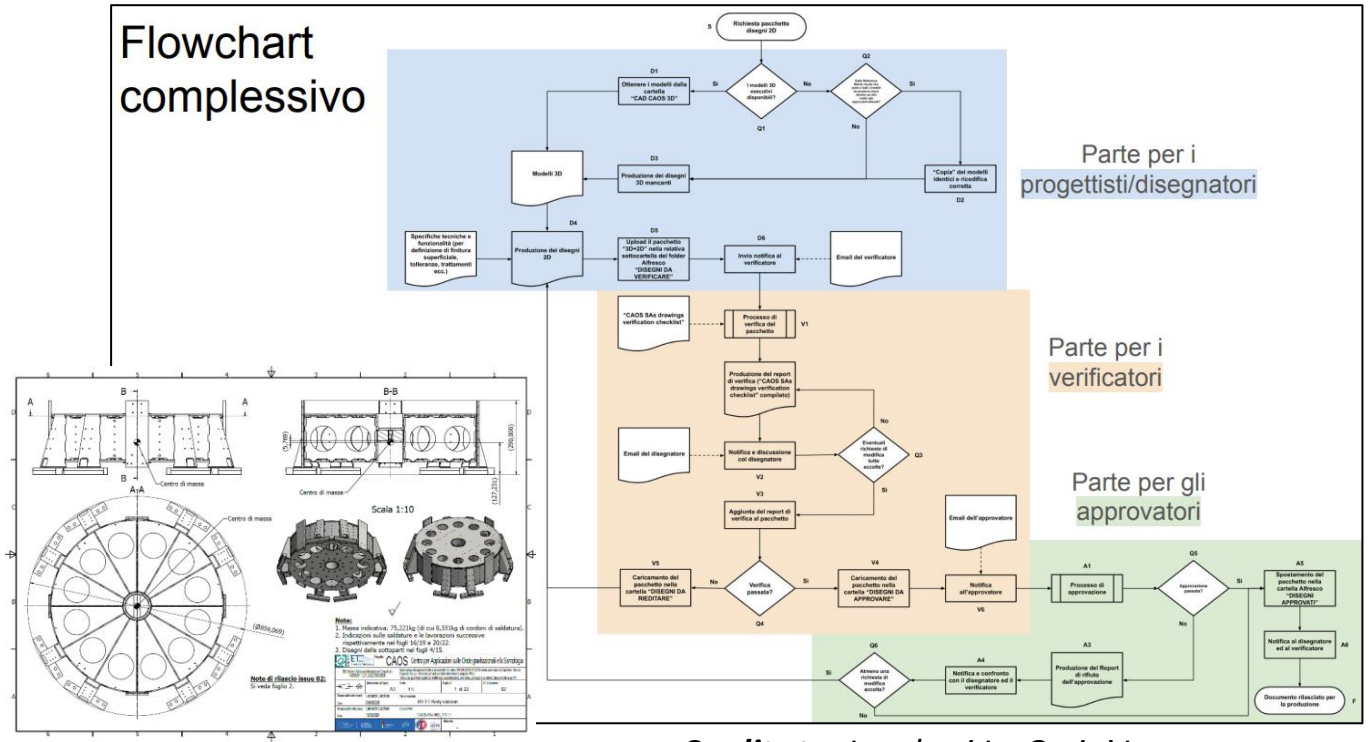
***Credits to**: Baldicchi N.*



***Credits to**: Lucchesi L.*

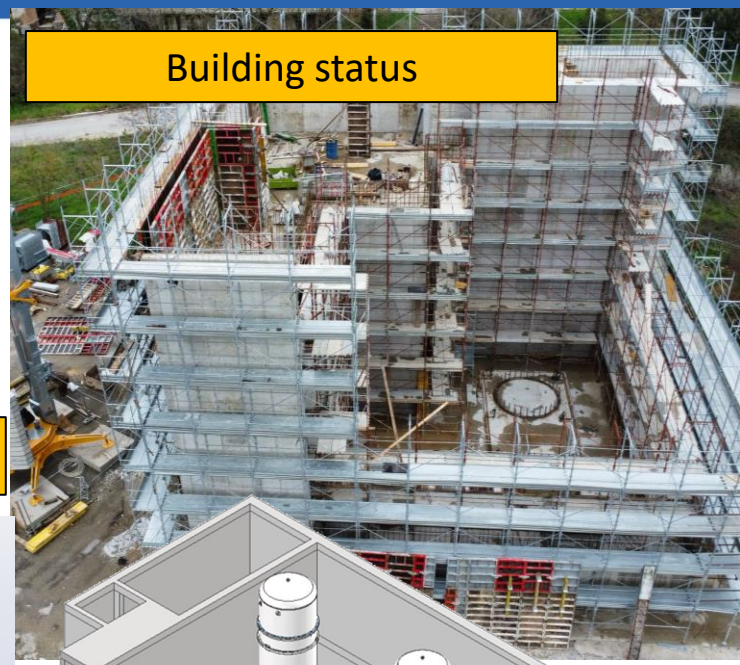
Suspensions: CAOS

Product Brakdown Structure **(PBS)** and Work Beakdown Structure **(WBS)** applied to the drawing and realization of the two SAs for CAOS. Several drawings already sent to Galli & Morelli for the production.

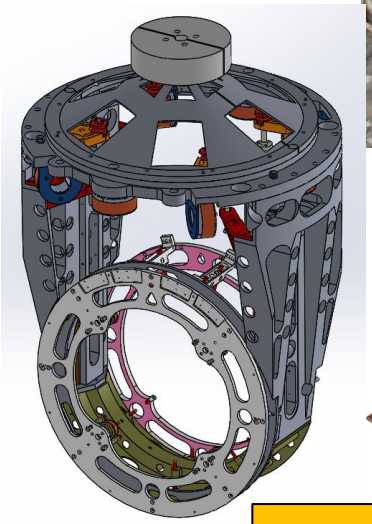


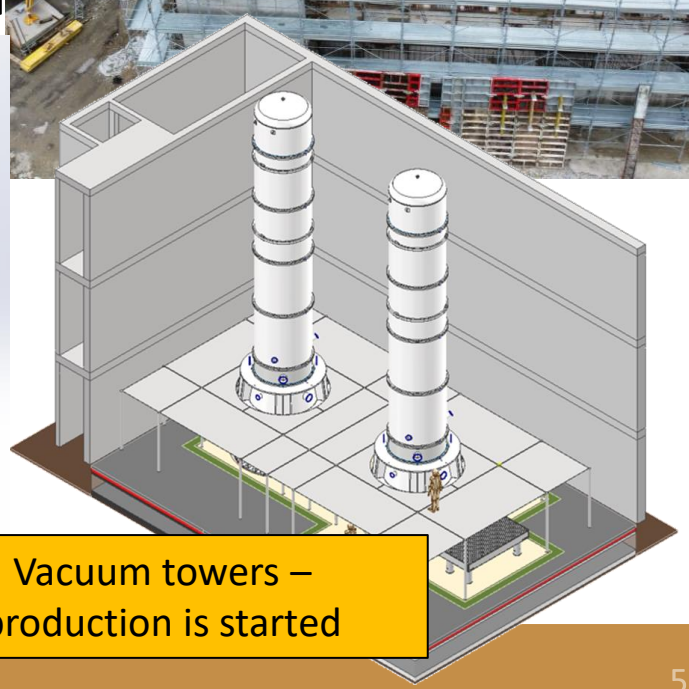
***Credits to**: Lucchesi L., Orsini L.*

Building status



Payload design





Vacuum towers – production is started

Suspensions: NGSA

New **G**eneration of **S**uper **A**ttenuator

- NGSA is an R&D project, approved and funded by **INFN (Call CSN5)**, the project started 2022 and is expected to end in 2025.
- It is devoted to the study of a **seismic isolation system for 3rd generation GW antennas**.
- The research group includes 3 INFN research units: (**INFN-Pisa, INFN-Napoli, INFN-CA/UniSS**) and a participation by EGO.
- The project is organized in **4 WPs**:

- WP1: **Simulation** and Optimization of the Superattenuators (L. Trozzo INFN-NA)
- WP2: Mechanical filter with improved **Magnetic Anti-Spring** (MAS) (F. Frasconi INFN-PI)
- WP3: **Development and test** of a Nested Inverted Pendulum (NIP) (R. De Rosa INFN-NA)
- WP4: Sensing and Control (S&C) (A. Gennai INFN-PI)

- PI of project: L. Di Fiore (INFN-NA)

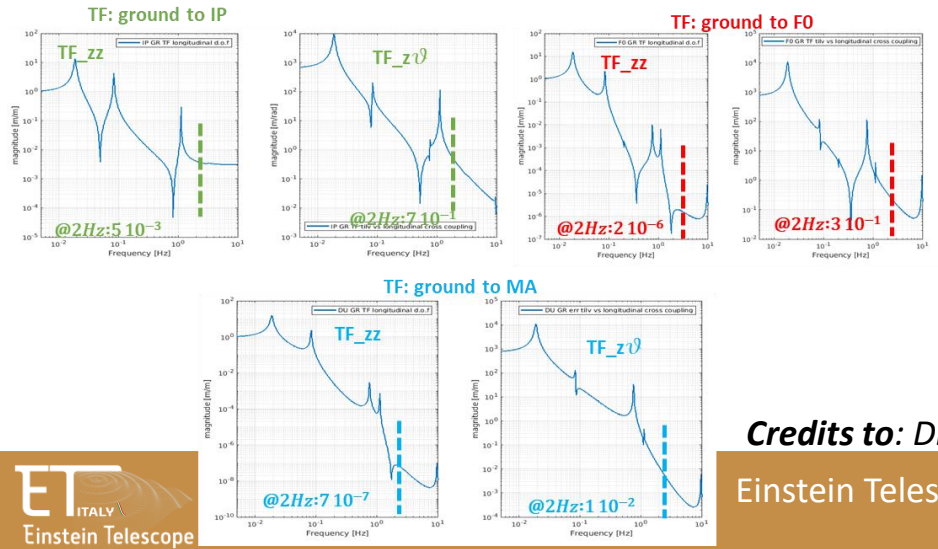
Suspensions: NGSA

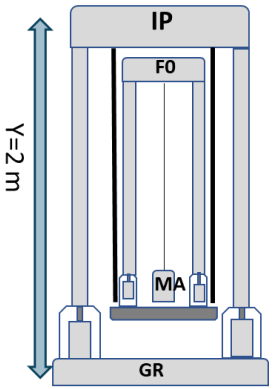
INFN-NA

WP1: Simulation and Optimization of the Superattenuators

Simulation tools are crucial to evaluate the effect of mechanical design choices on system performance:

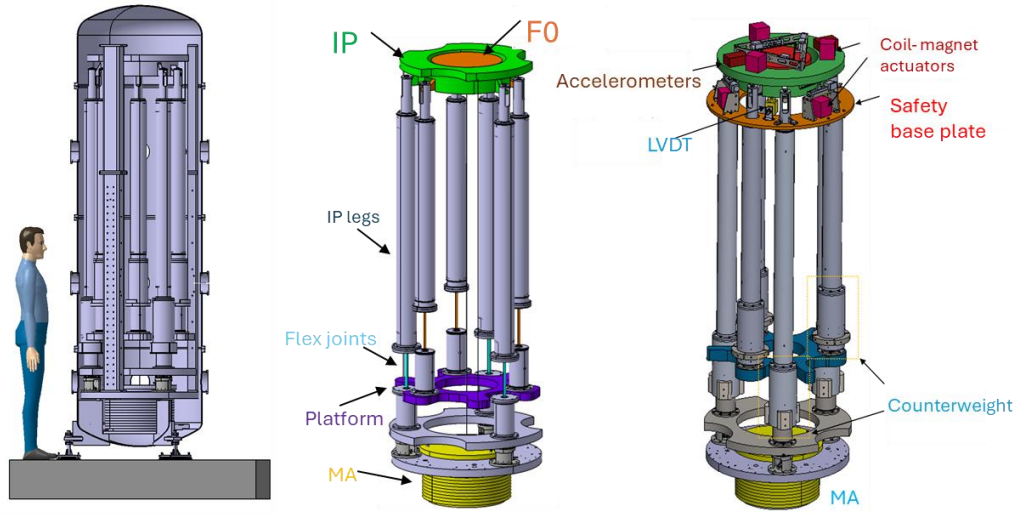
- Masses, flex-joints, legs, etc. have been defined;
- This was the **starting point** for the mechanical design of the **prototype** (NIP);
- A MATLAB code (**OCTOPUS**), based on the impedance matrix approach, has been developed and applied for studying and upgrading the VIRGO seismic attenuators.
- More detail about simulations can be found in references in backup slides.





***Credits to**: Di Fiore L, Trozzo L et al.*

WP3: Development and test of a Nested Inverted Pendulum (NIP)



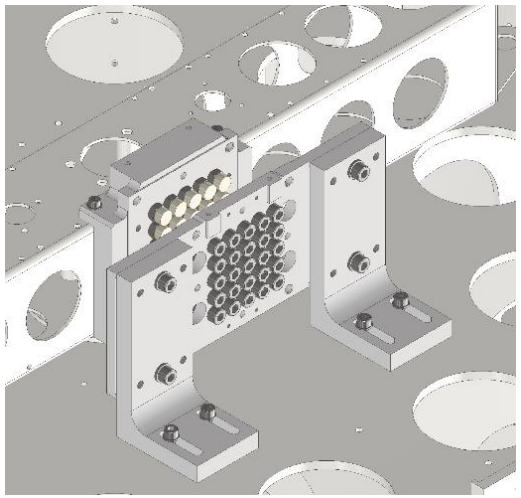
The design is quite advanced:

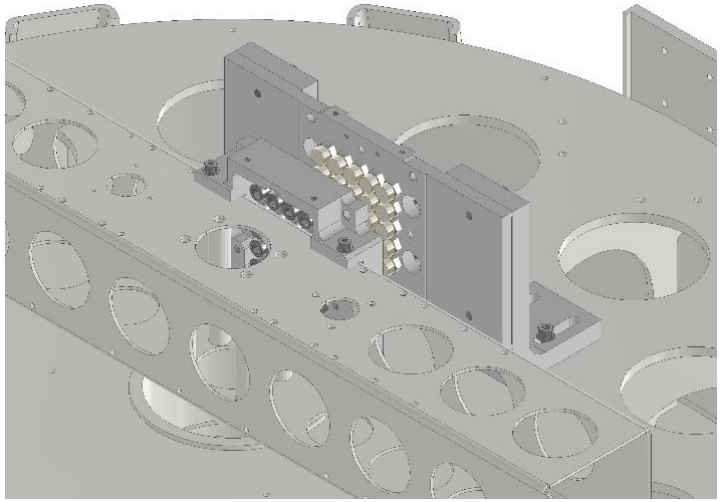
- Vacuum chamber base and feet (installation);
- Base ring, flex joints and legs (ready for the installation);
- Platform, dummy test mass and safety structure (in manufacturing);
- IP top stage and F0 (in the process of being manufactured);
- Sensors supports and interfaces, wire supports and junctions (defined and ready for the manufacturing process);
- Installation should start in the next weeks;
- The apparatus should be in operation by the end of 2025 in **PLANET ETIC** (INFN-NA);

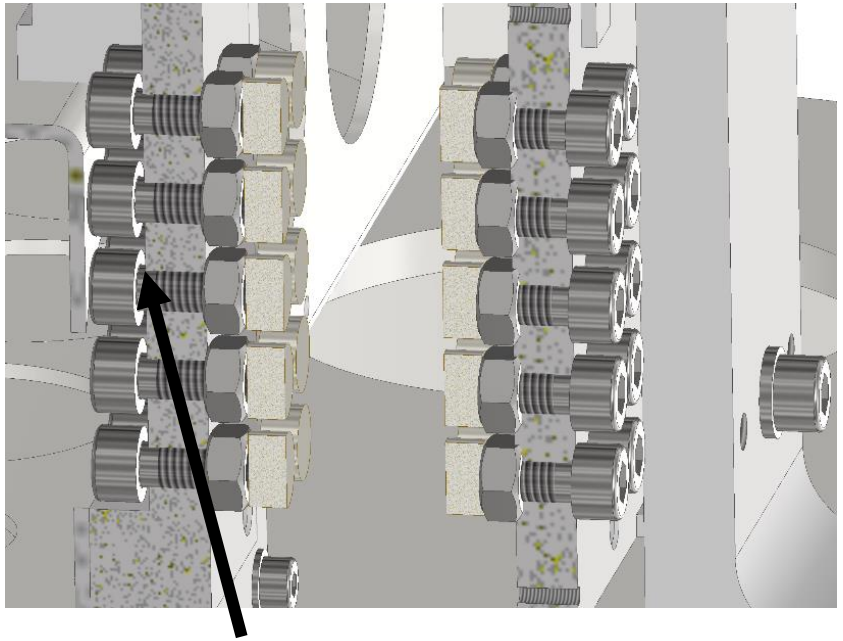
Suspensions: NGSA INFN-PI

WP2: Mechanical filter with improved Magnetic Anti-Spring (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 and 3M 2216 glue).
- More **compact volume of the magnets** on the crossbar side wrt AdV (110mm vs 375mm; 0.472kg vs 1.319kg).





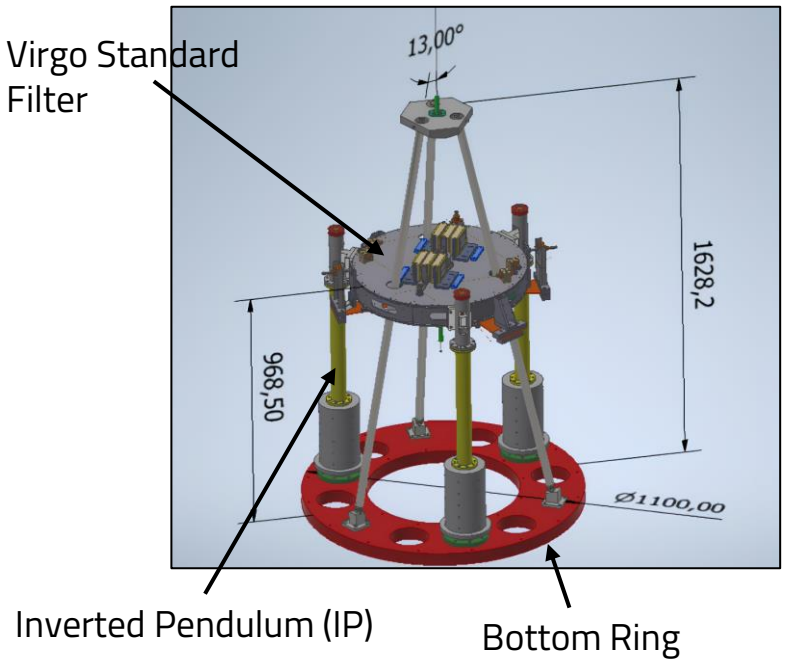


Cryogenic, high-vacuum compatible adhesive 3M 2216

Within NGSA project, INFN-Pisa is also working on **active platform** and **new disk 0** concept

***Credits to**: Frasconi F., Lucchesi L. et al.*

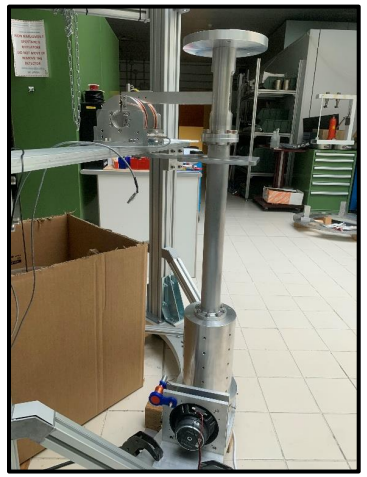
Suspensions: PIP **P**endulum **I**nverted **P**endulum



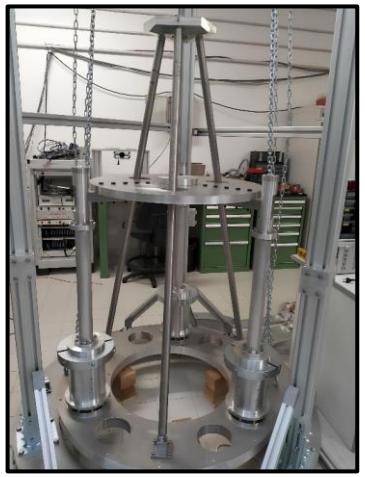
***Credits to**: Fidecaro F, Basti A et al.*

Funded by PRIN - Prototype being tested in Pisa

- PIP expected attenuation: $1/f^4$
  - **Same attenuation level only after two filters** of current SA design
- Chain length is reduced → **Compact Suspension**
- Three PIP could meet ET attenuation requirements
  - **Three PIP chain + payload live in 10m**


IPs Characterization


Ground-Based PIP


Suspended PIP

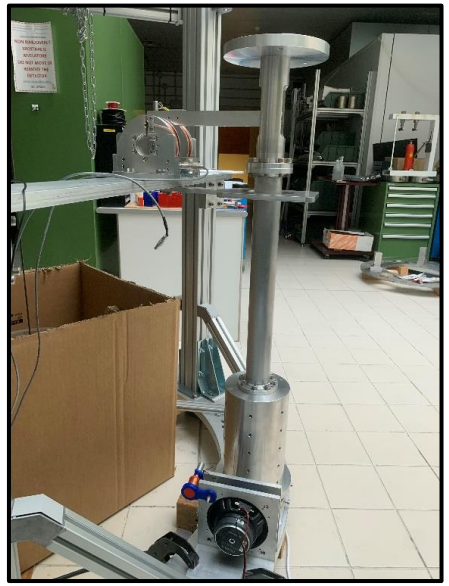
Suspensions: PIP

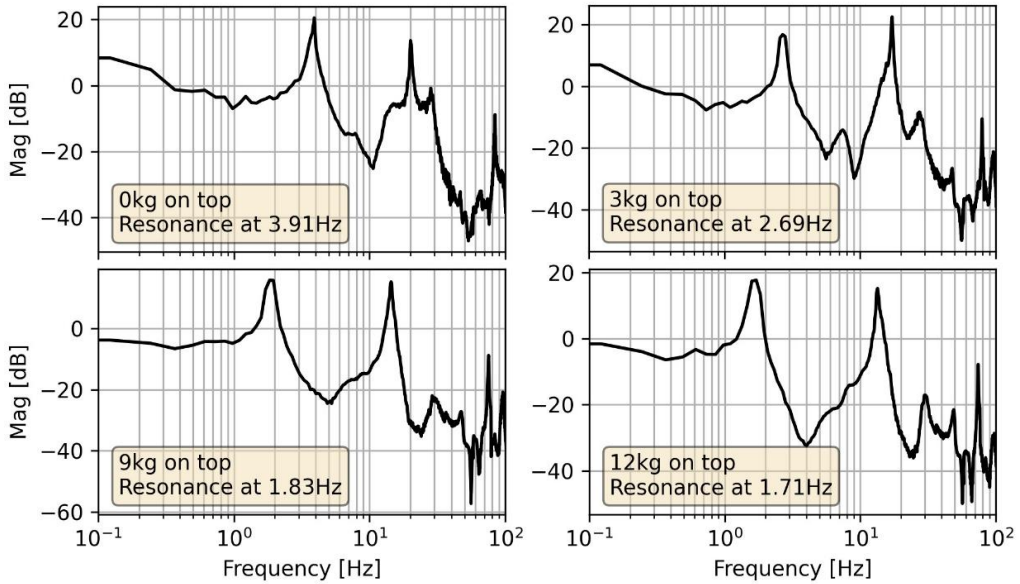
Repeat for all IPs

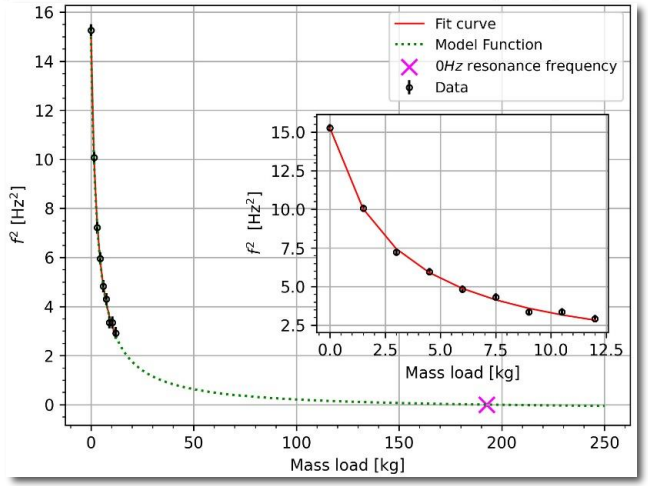
Test IP behaviour:

1. Measure IP transfer function for different loads
2. Identify IP resonance in each spectrum
3. Fit resonance frequencies with:

$$f_0^2 = \frac{1}{4\pi^2}\frac{k-(M+m/2)\,g/L}{M+m/3}$$







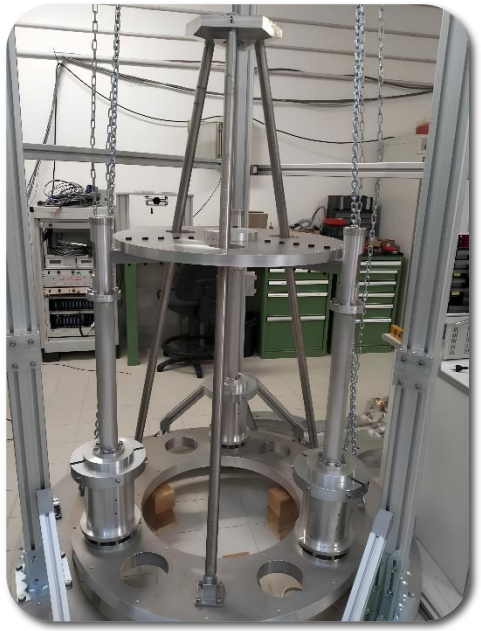
	Joint stiffness k [N/m]	IP leg mass m [kg]
Inverted Pendulum 1	1775 ± 61	8.8 ± 0.4
Inverted Pendulum 2	1816 ± 36	8.9 ± 0.2
Inverted Pendulum 3	1901 ± 20	9.6 ± 0.2

***Credits to**: Fidecaro F, Basti A et al.*

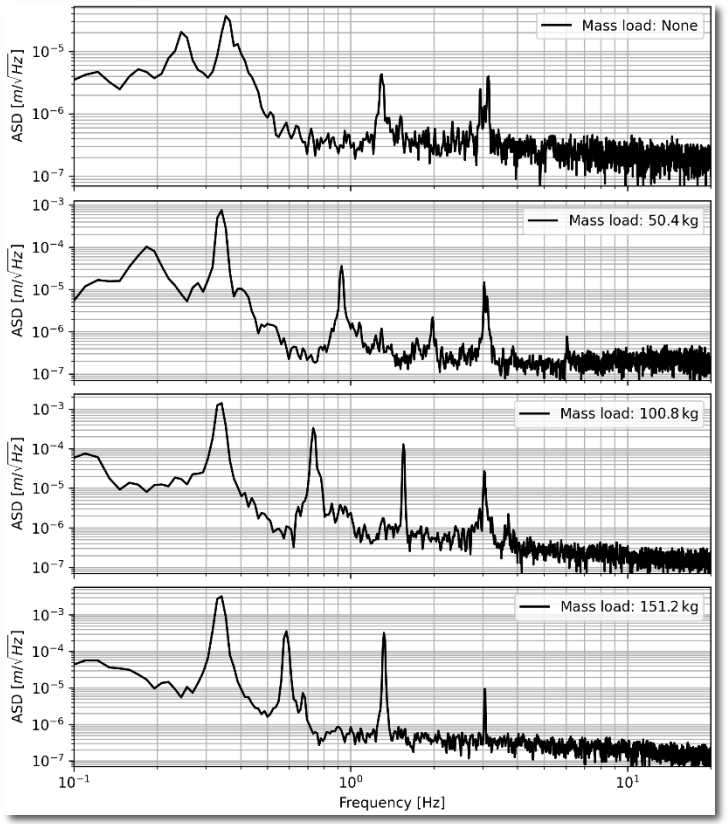
Suspensions: PIP

- Achieving **0.6 and 0.4 Hz** resonance frequencies for attenuation in 1.5 m height;

- Four resonances visible:
  - Two for translation
  - One comes from the suspension structure
  - One is a rotation mode to be cured in Version 2



Spectra for different load mass



R&D activity on seismic isolation systems will continue in next years

***Credits to**: Fidecaro F, Basti A et al.*

Conclusion

- Three major Italian seismic isolation system projects:
  - CAOS
  - NGSA
  - PIP
- Different stages of maturity between them: Manufacturing phase, installation, data acquisition on the prototype.
- **All** of them demonstrate Italy's **great expertise** in this field, which can be very fruitful for the development of the suspension chains of ET.

Backup slides - References

[1] P. Ruggi, *L'attenuazione del rumore sismico nel rilevatore di onde gravitazionali Virgo*, thesis (2003). https://tds.virgo-gw.eu/ql/?c=16268

[2] L. Trozzo, Low Frequency Optimization and Performance of Advanced Virgo Seismic Isolation System , PhD thesis (2018). https://tds.virgo-gw.eu/ql/?c=13271

[3] P. Ruggi, M. Pinto, L. Trozzo et al OCTOPUS: a mechanical simulation tool based on impedence matrices. (under revsion to PRD)

[4] Bertocco et al, New Generation of Superattenuator for Einstein Telescope: preliminary studies", A, *Class. Quantum Grav.* 41 (2024) 117004 (14pp)
*ET TDS link: https://apps.et-gw.eu/tds/ql/?c=17333

[5] L. Trozzo, at al., A Nested Inverted Pendulum as a possible pre-isolator for the ET-LF Seismic Isolation System , Galaxies, 2025,13 (2),21. https://www.mdpi.com/2075-4434/13/2/21