New Generation Super Attenuator for Einstein Telescope-NGSA: status of the project

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Speaker: L. Trozzo (INFN-NA)

Outline

- Introduction
- NGSA: Scientific goals and organization
- Present status of the project
- Next steps and perspective

NGSA: New Generation of Super-Attenuator

- NGSA is an R&D project started at the beginning of 2022, approved and funded by INFN commission 5.

- The project is expected to last 3 years

- The research group includes 3 INFN research units: (INFN-Pisa, INFN-Napoli, INFN-LNS/UniSS) and a participation by EGO.

- It is strictly connected to Einstein Telescope (ET): it is devoted to the study of a seismic isolation system for 3rd generation GW antennas.

Outline

- **Introduction**
- NGSA: Scientific goals and organization
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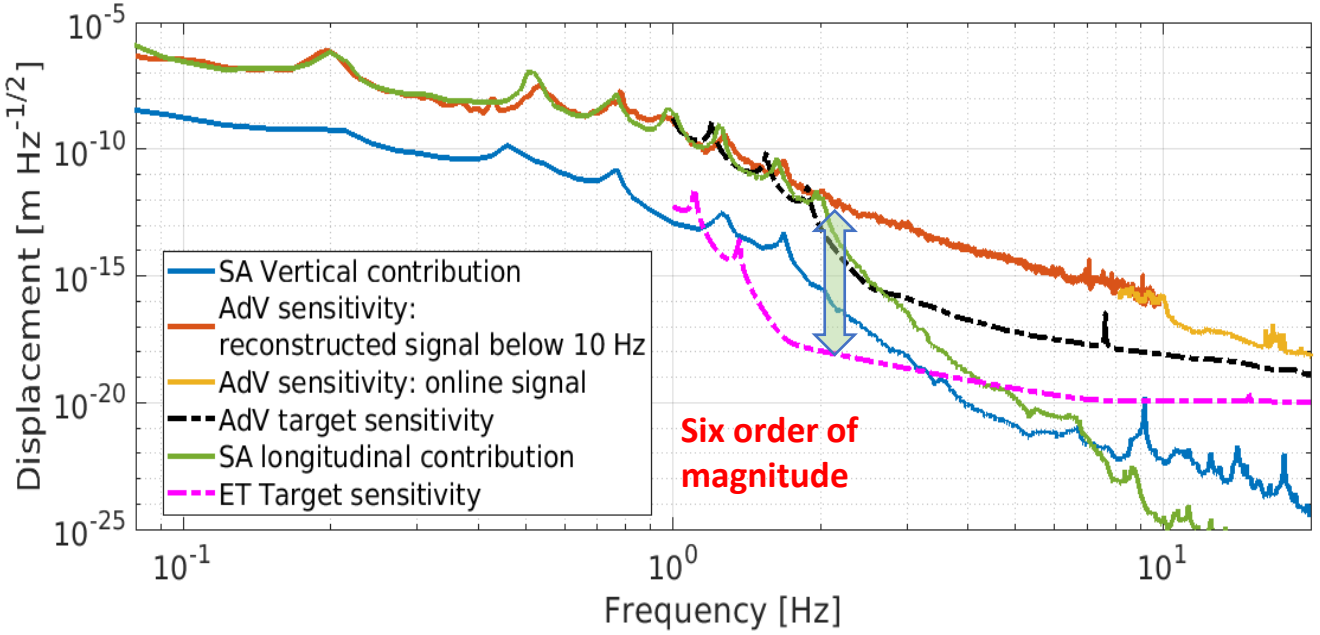
Introduction

✓ Object of NGSA project is the development of a new vibration isolation system (Superattenuator) for the mirrors of the ET (LF) gravitational Wave antenna

➢ ET goal is to improve the sensitivity by more than one order of magnitude extending the detection band to the low frequency, down to 2-3 Hz, with respect to the 2nd generation detectors

✓ Reaching the ET design sensitivity is an ambitious task requiring enormous technological development on all the aspect of the detector

➢ Seismic vibration is one of the most relevant noise limiting the low frequency ET sensitivity ➔ to reduce this noise, underground operation and an improved seismic isolation system will be required.



Outline

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- **NGSA: Scientific goals and organization**
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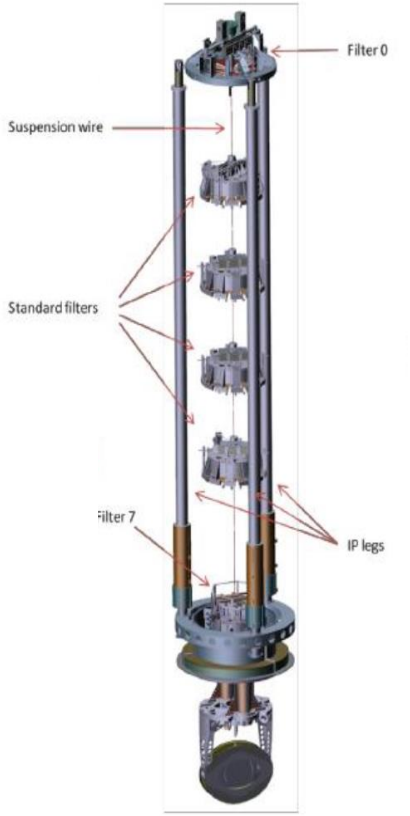
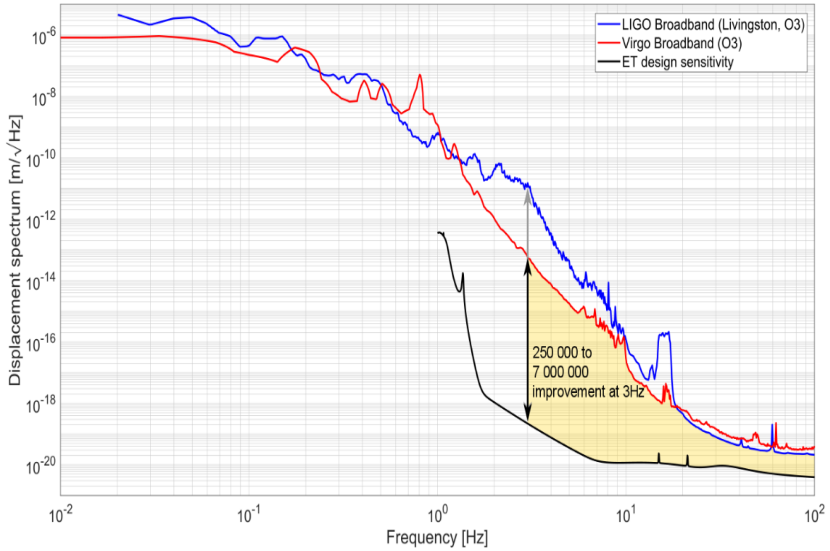
From Virgo to ET

We will focus on seismic isolation, starting from the Virgo heritage



The Virgo Super-Attenuator is the best seismic isolator in the world. It is the result of years of R&D in INFN and was crucial to allow the extension of the antenna detection band down to 10 Hz.
The SA is made by a pre-isolator (inverted-pendulum), a passive filter chain and a Payload (mirror and control elements). The total length is about 9 m.

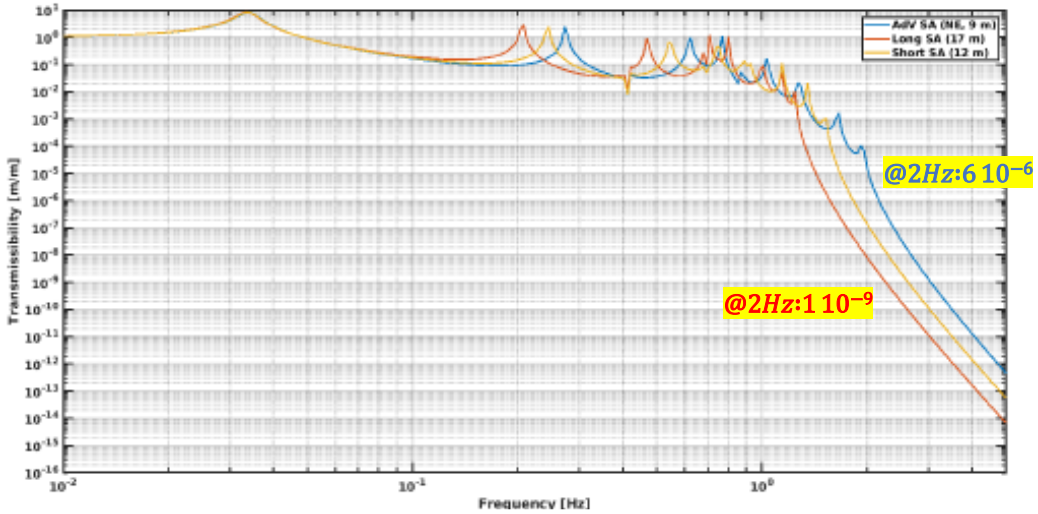


INFN holds a consolidated leadership on this subject

Keeping and improving this expertise will be essential for the development of ET.

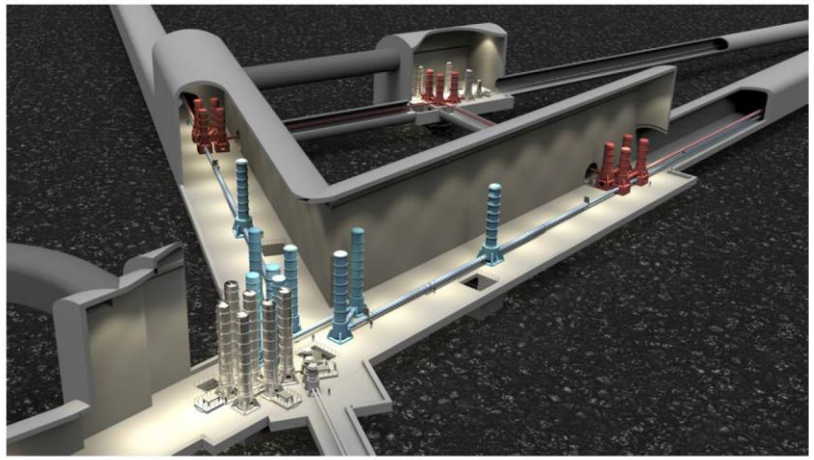
From Virgo to ET

Hystorical solution, carried out in the framework of the 2011 ET Conceptual Design is a SA with a total length of 17 m



- This implies very large caverns (~ 30 *m* in height), with big cost and complexity.

Improving the length doesn't improve vertical isolation

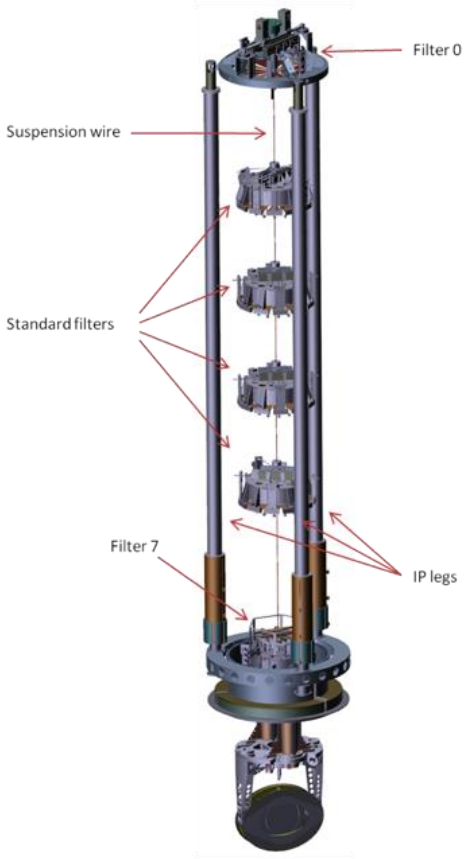


✓ In order to fulfill the ET requirements, while keeping the total SA length around 10÷12 m, a dedicated R&D program is needed

NGSA goals → **Reducing the height of the SA tower will have a huge impact on excavation cost and SA reliability.**

From SA to NGSA

How can we improve seismic isolation keeping a shorter SA?



1) Improving pre-isolation

- Active per-isolation
- Two-fold inverted pendulum (NGSA)

2) Improving passive filter chain

- Optimization of filter chain masses and length distribution (NGSA) [1]
- Improved Magnetic Anti-Spring for vertical isolation (NGSA)

Constrains..

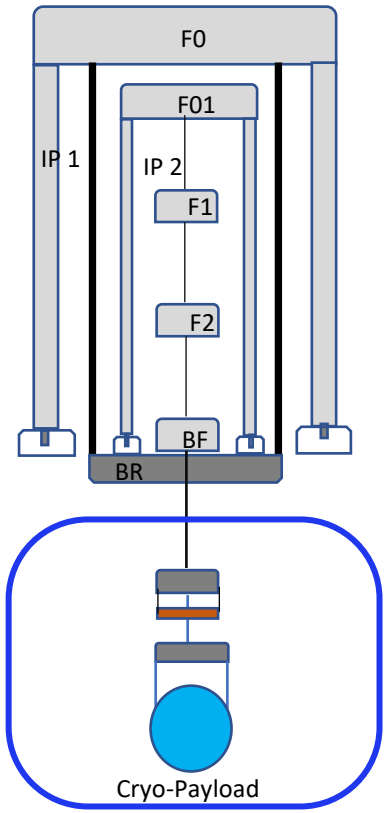
- Complex, heavy cryogenic payload (~ 600 kg) will be surrounded by a big cryostat
- The legs of the inverted pendulums must start above the cryostat

Shorter IPs legs (~ 4.5 m) **Larger SA total mass**

To keep in mind:

- Tilt and vertical to longitudinal Cross talk
- Noise of control systems

Schematic view of a suspension adopting a double nested inverted pendulum



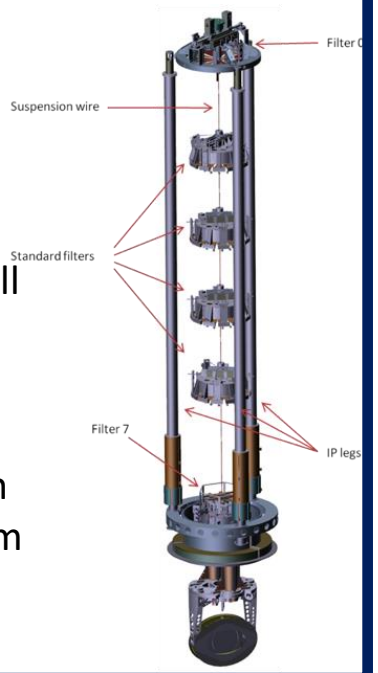
[1] A. Bove et al 1997 EPL 40 601

NGSA research lines

The project is organized in two parallel experimental lines:

1) Traditional solution

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



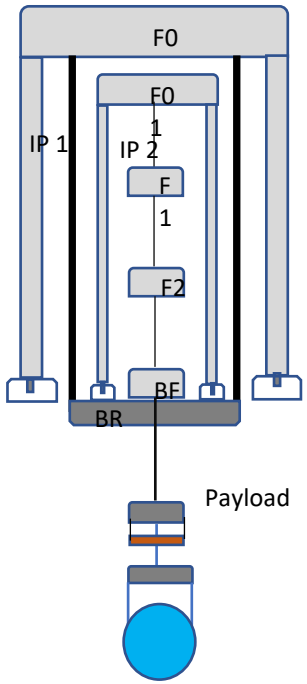
2) Innovative solution

✓ **Goal is to keep the total SA length around 10 m**

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, …)

➢ A dedicate NIP prototype (in 1:2 scale) will be realized to experimentally validate this configuration

Schematic view of a suspension adopting a double nested inverted pendulum (NIP-SA)



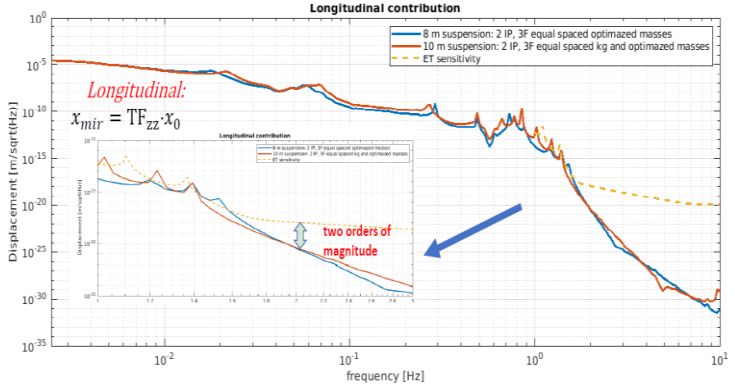
➢ **Final goal, after comparison of the two alternatives, will be the definition of a Conceptual Design of the SA for the ET Antenna.**

NGSA organization

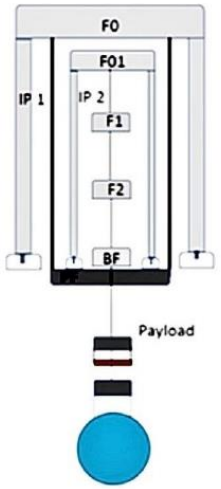
PI of project: L. Di Fiore (INFN-NA)

The project is organized in 4 WPs:

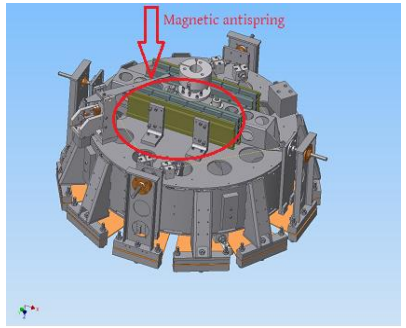
WP1 – Simulation and optimization of the Superattenuator
Coordinator: L. Trozzo (INFN-NA)



WP3 – Development and test of a Nested Inverted Pendulum (NIP)
Coordinator: R. De Rosa (INFN-NA)

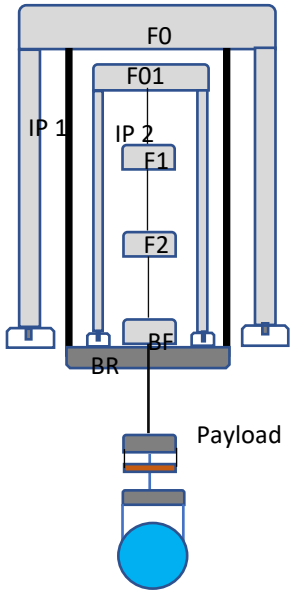


WP2 – Mechanical filter with improved Magnetic Anti-Spring (MAS)
Coordinator: F. Frasconi (INFN-PI)



WP4 – Sensing and Control (S&C)
Coordinator: A. Gennai (INFN PI)

WP1 – Simulation and optimization of the Superattenuator



Simulation's tool

A MATLAB code (**OCTOPUS**), based on the impedance matrix approach, has been developed and applied for studying and upgrading the VIRGO seismic attenuators [2,3].

This code, together with the mass optimization method described in the paper [1], will be extensively used to study the coupling terms between degrees of freedom. In such a way should be possible to define suitable parameters to optimize the performance of the system.

Reference

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

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

We performed preliminary **longitudinal, tilt coupling,** and **vertical** transfer functions of a **NIP-SA**, from ground to mirror, in three different configurations:

CASE A:

I. **Total length :8 m**
II. **Total mass: 2650 Kg**

CASE B:

I. **Total length :10 m**
II. **Total mass: 2650 Kg**

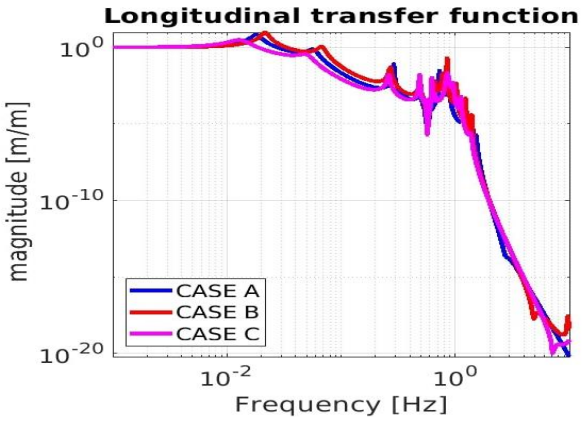
CASE C:

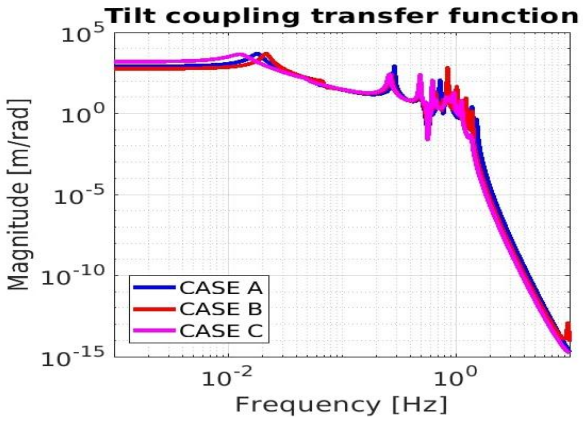
I. **Total length :10 m**
II. **Total mass: 3250 Kg**

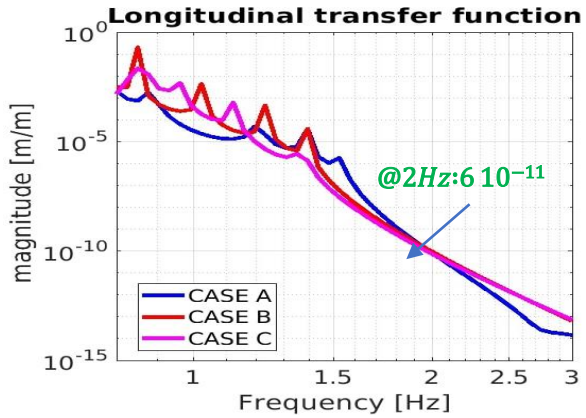
The vertical transfer function, from ground to mirror, is calculated assuming four standard filters like those of Virgo's SA (F01, F1,F2,BF) [2,3].

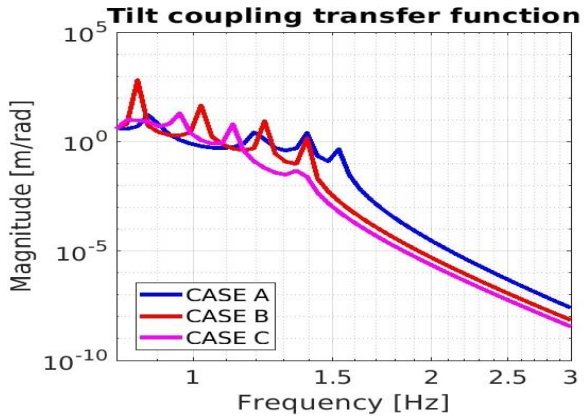
WP1 – NIP-SA preliminary results

NIP-SA: Longitudinal and Tilt coupling transfer functions

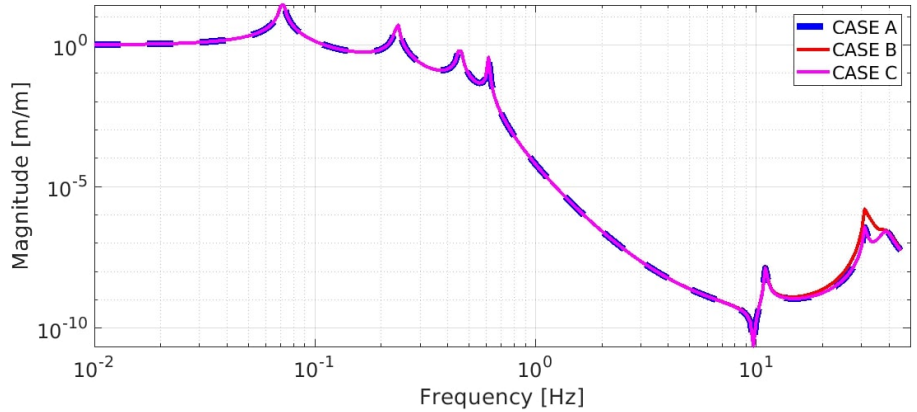








NIP-SA: Vertical transfer functions

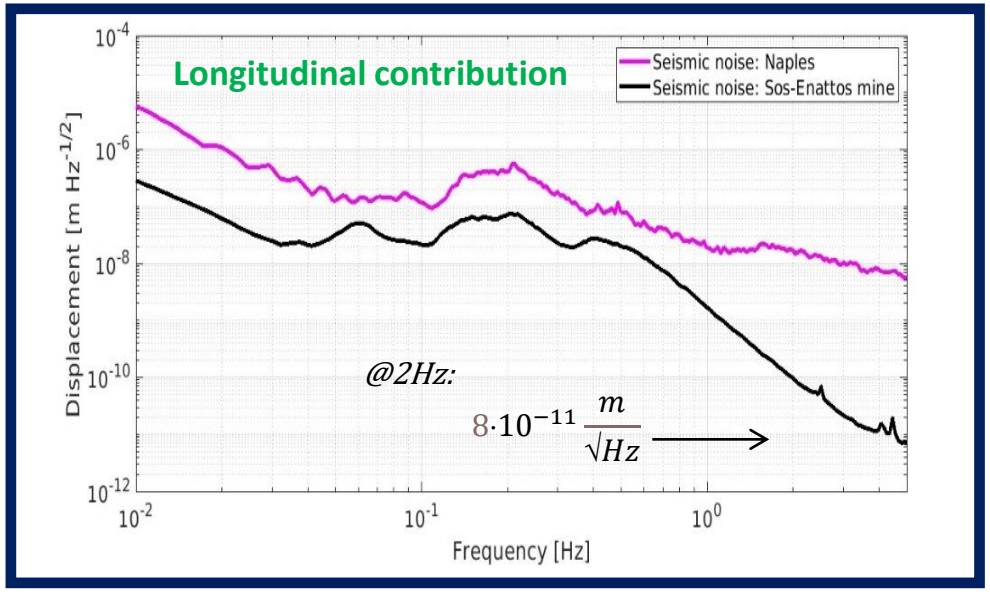


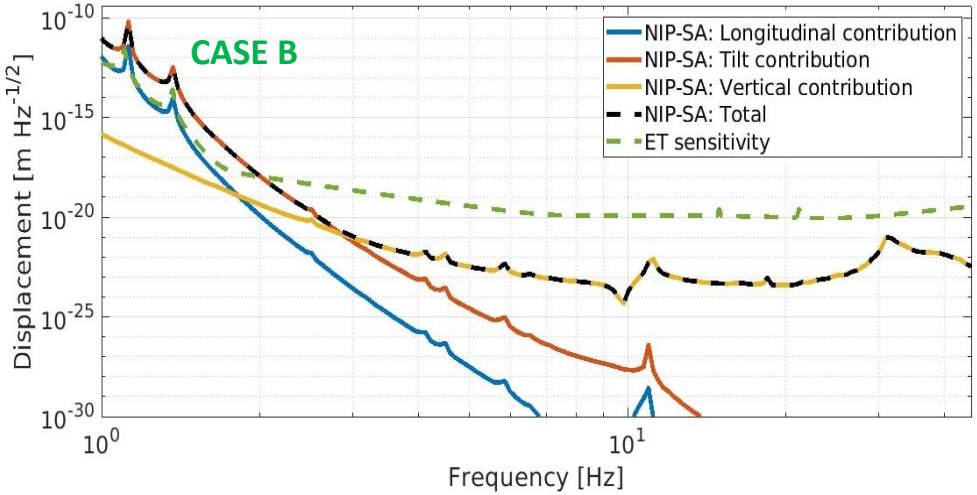
What we learned…

- ✓ **Longitudal d.o.f: the attenuation @ 2 Hz reach same value in all the configurations**
- ✓ **Tilt coupling @ 2 Hz:**
  - ➢ **A→ B reduced by a factor of 5.5**
  - ➢ **A→ C reduced by a factor of 16**
- ✓ **Vertical d.o.f: the attenuation @ 2 Hz reach same value in all the configurations**

WP1 – NIP-SA preliminary results

Residual seismic noise from longitudinal and tilt contribution, transmitted to the test mass and compared to the ET sensitivity curve, is shown.





Tilt contribution

At the moment, there is no direct ground tilt measurement, but it is possible to estimate a lower limit by using the following empirical formula: $\alpha_0 = \frac{\omega}{v} \cdot x_0$

Assuming the values of **v** (seismic wave speed) and x_0 (longitudinal ground motion) to be about 3000 m/s and $8 \cdot 10^{-11} m\, Hz^{-1/2}$ respectively, the estimated value of α_0 is about : $3 \cdot 10^{-13} \frac{rad}{\sqrt{Hz}}$ @2Hz

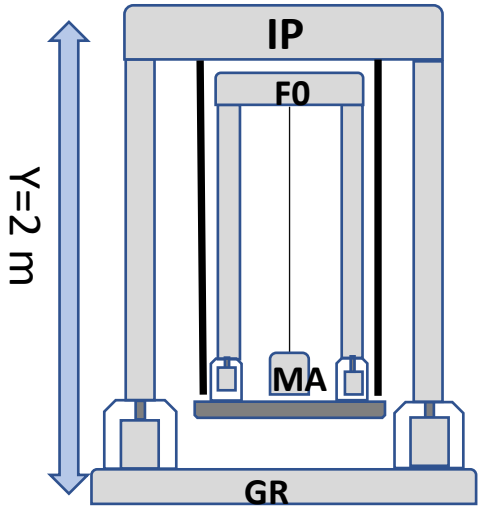
What we learned…

Horizontal seismic noise on the Test mass is limited by

- ✓ **Tilt coupling:**
  - ➢ **Tilt to longidunal noise <3 Hz**
- ✓ **Vertical to longitudinal coupling:**
  - ➢ **Vertical noise issue > 3 Hz**
  - ➢ **Crossbar resonance issue around 30-40 Hz**

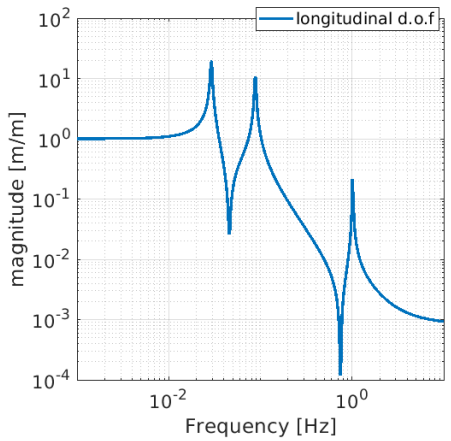
➢ Simulate the NIP prototype behavior

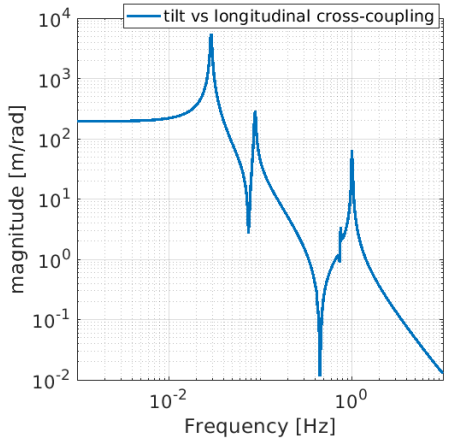
- Simulation tools are crucial to evaluate the effect of mechanical design choices on system performance
- Masses, flex-joints, legs, etc. have been defined
- This was the starting point for the mechanical design of the prototype



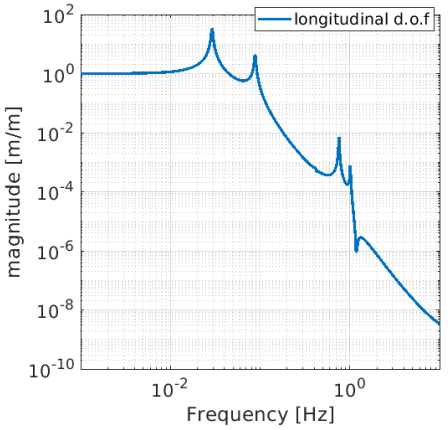
- IP and F0
- Platform (BR)
- Dummy mass of 600 Kg (MA)

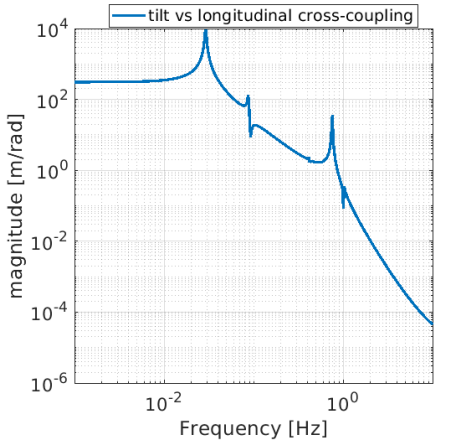
TF: ground to IP





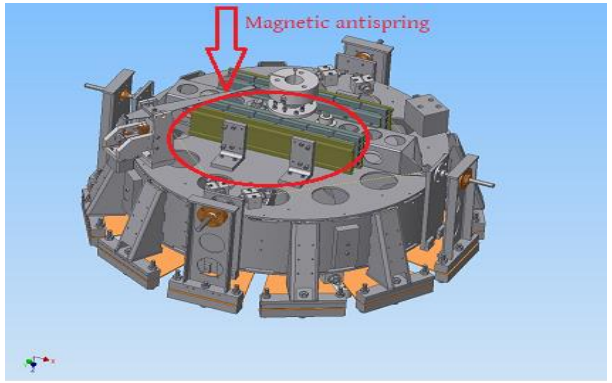
TF: ground to MA





WP2 – Mechanical filter with improved Magnetic Anti-Spring (MAS)

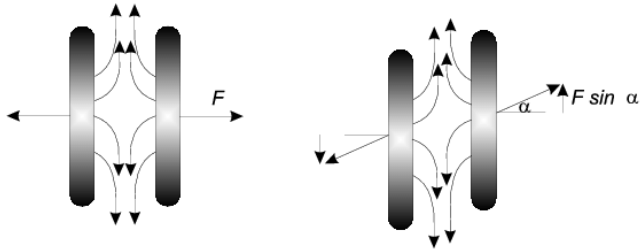
➢ **Improve the present MAS design**



The ideas is to replace ferrite magnets (0.35 T) with rare earth (SmCo or NeFeB) magnets (0.8 T)

The advantage is the larger Magnetic flux density providing:

- **Large anti-stiffness with a reduced volume**
- **Lower filter resonance**
- **New cross-bar design to move its resonances at higher frequency**

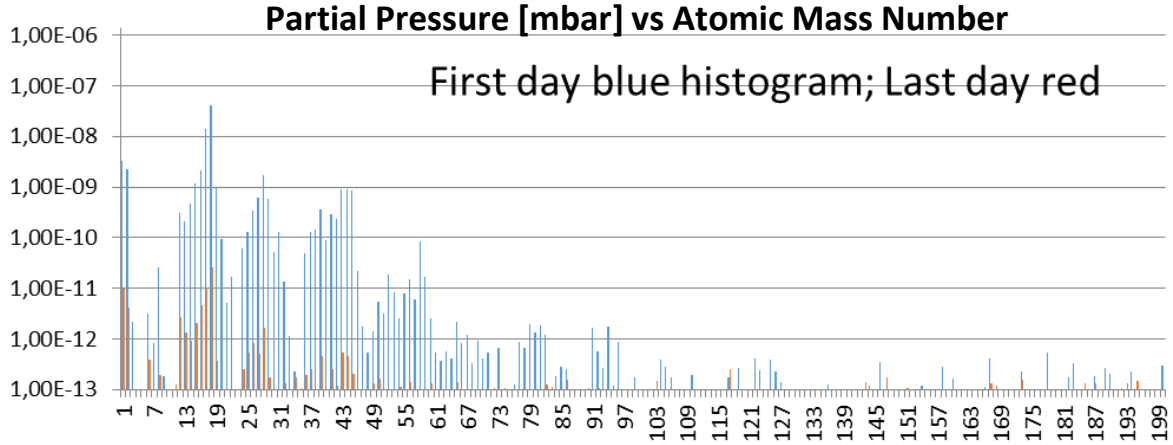


WP2 – Selection and test of rare-earth magnets

✓ Three sets (100 magnets each set) of permanent magnets (Rare Earth) have been tested for UHV compatibility with **very good results:**

- NdFeB encapsulated with Nickel coating
- SmCo without any coating
- SmCo encapsulated with Nickel coating (**BEST RESULTS**)

✓ All magnets have a cylindrical shape (10.5 mm in diameter and 5 mm thick; B ≈ 0.8 T along the cylindrical axis of the magnet)

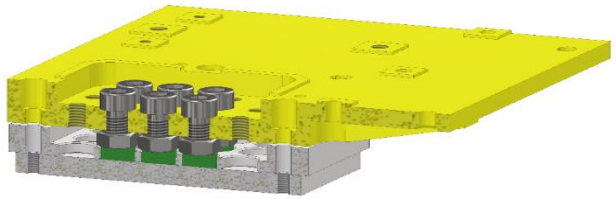


➢ Precise analysis of data (collected during the tests) in progress.
➢ Additional test for a better comparison is starting

WP2 - New Magnetic Anti-Spring (MAS) Prototype

- Mechanical support for the testing machine (@INFN Pisa Laboratory) ready for the first prototype of the MAS

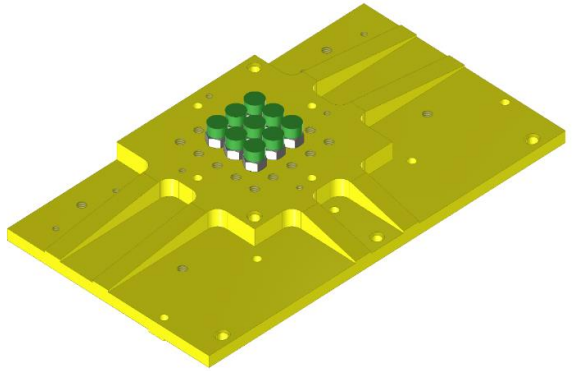
- Gluing of the first SmCo magnets (encapsulated) on the aluminum support has been done. Two different glues used: **(A) 3M 2216 grey** ; **(B) HYSOL 9394 AERO** – Outgassing test ongoing
- Preparation of the magnet testing machine: to be used for the optimization geometry of MAS

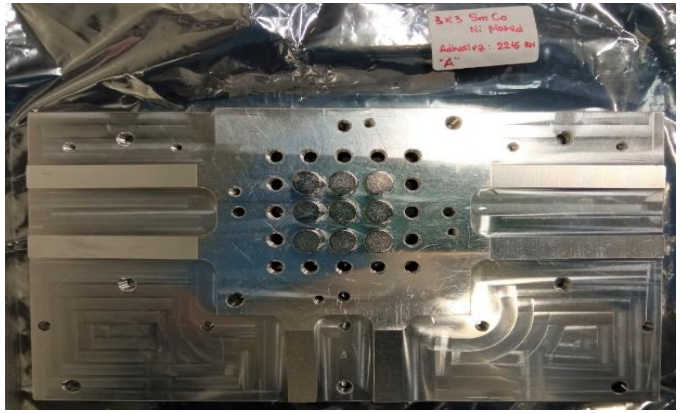


MAS Prototype

- Preliminary set-up of encapsulated SmCo magnets on aluminum support for the magnet test machine at INFN Pisa Laboratory

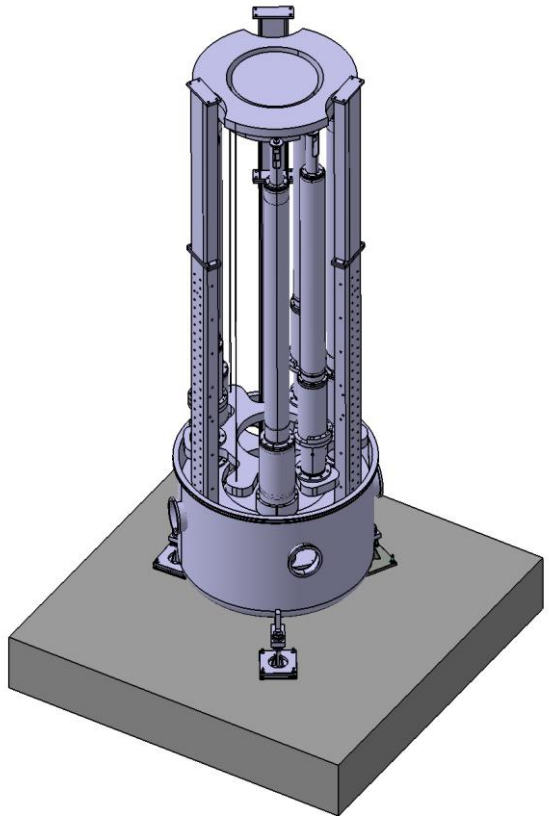
- Outgassing test of the complete set-up validating the assembling process and materials (magnets, Al support and glue – sample A) is in progress





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

➢ **Build a prototipe of NIP in 1:2 scale, in the Gravitational Physics Laboratory at INFN-Napoli**



✓ **The design is based on preliminary studies with OCTOPUS**

- Total mass 1200 kg
- Legs of about 1.7 and 1.4 m (excluding flex joints)
- Dummy mass = 600 kg

✓ **The mechanical design is supported by Octopus and FEM simulations**

The design is quite advanced:

- ✓ Vacuum chamber base and feet (order placed for construction)
- ✓ Base ring
- ✓ Flex joints and legs
- ✓ IP top stage (in progress)
- ✓ Platform (in progress)
- ✓ FO (in progress)
- ✓ Dummy test mass

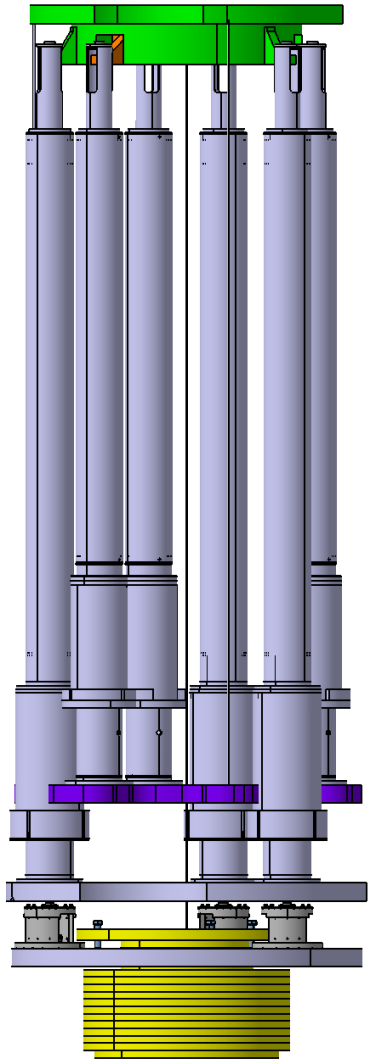
To do:

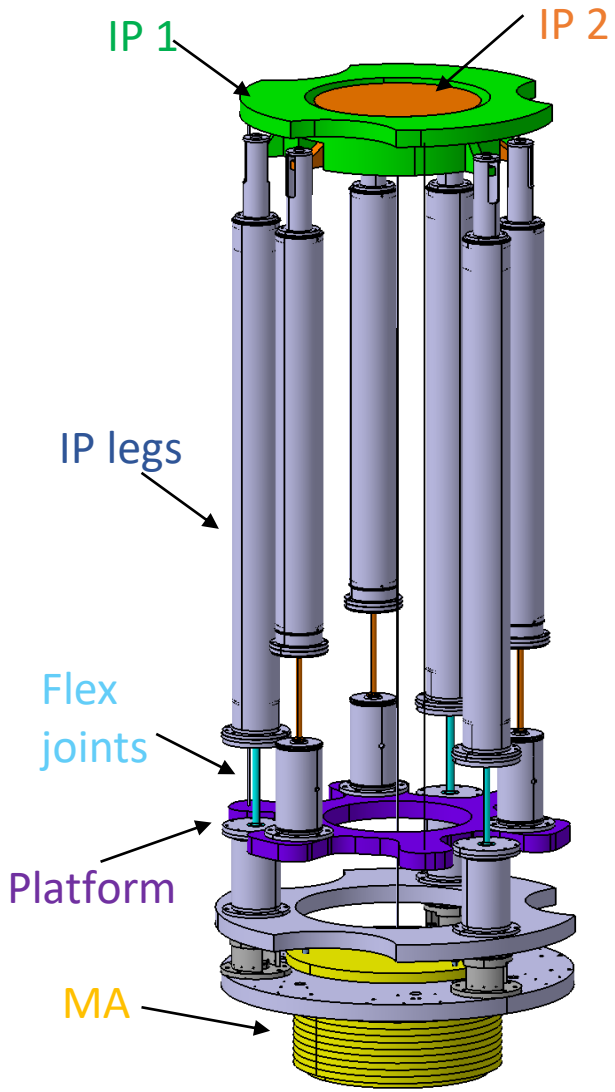
- ➢ Sensors supports and interfaces
- ➢ Wire supports and junctions
- ➢ Safety structure

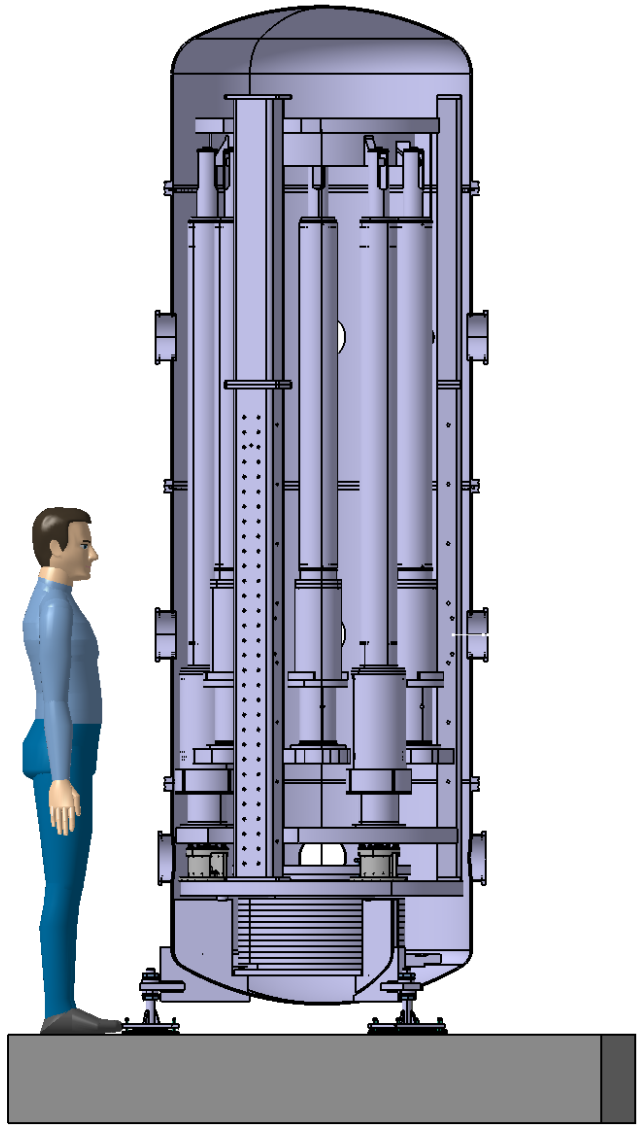
We plan to:

- ➢ complete the design in the next to months and start construction mechanical components
- ➢ Installation should start at the beginning of 2024

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







A first list of type of sensors, actuators, motors, ADC, and DAC channels is available

Stadio	LVDT	Accelerometri	ORO	ADC	DAC-A	DAC-B	Bobine/ magneti	Motori
IP	3	3 (monoassiali)	-		3	3	3	3 (per le molle)
BR	-	-	3	9-12	3 (6 ?)	-	3 (6)	6 per ORO
F0	-	-	3	9-12	3 (6 ?)	-	3 (6)	6 per ORO
TM	-	1 (triassiale)	-	3	3			

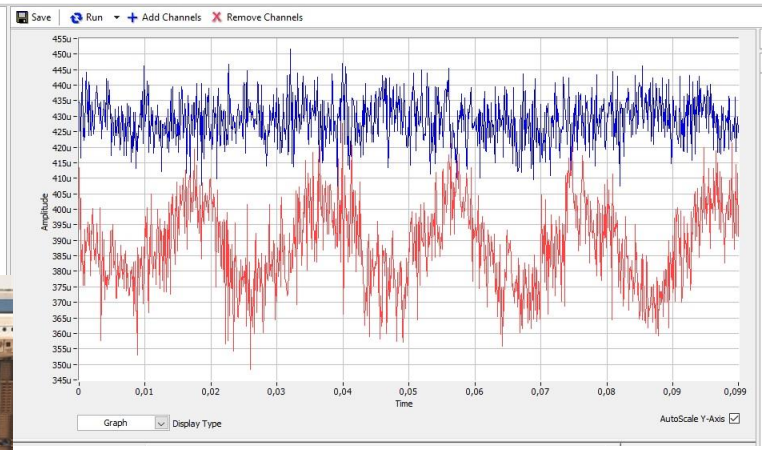
DAC_A 24 bit, 2 channels per card - DAC_B 16 bit, 6 channels per card

National instrument input/output hardware based on LabView software has been identified for the data acquisition and control and ordered:

- Crate, CPU and most relevant components/boards arrived @ INFN Pisa
- DAC board is still missing. Delivery announced for the end of June 2023
- Preliminary configuration and arrangement in progress
- Development and training of LabView in progress waiting for the DAC board
- Preparation of some “acceptance” tests for the HW configuration selected

ELECTRONIC SETTINGUP

- Waiting for digital-to-analog converter module, we checked that we are able to correctly read analog input channels and that we are able to run simple applications on core controller running LabView Real-Time.



- Controller NI PXIe-880 Xeon 8-Core – LabVIEW RT
- Module AI 6 channels 24-bit PXIe-4480 1.25 MS/s
- Module AO (Analog Output), 2 channels 24-bit, PXIe 4463 (to be delivered: June 30th, 2023). Order placed in February 2022. Most of material shipped within the end of 2022 but this module is still missing. **Risk for future orders**.

Conclusions

- ✓ The NGSA is devoted to the development of a new generation seismic isolation system with the goal to reduce the full height od the SA with respect to the present reference solution

- ✓ The project is organized in two research line:
  - ➢ Optimized SA with the AdV architecture and improved MAS
  - ➢ New architecture SA with a two stage NIP (+ optimized chain and improved MAS)

- ✓ A NIP prototype (in 1:2 scale) is under development and will be tested for checking reliability and performance

- ✓ The final outcome will be a conceptual design of the Seismic isolation system for the Einstein Telescope (ET)

- ✓ Results are expected by the end of 2024

Thanks for your attention!