

New Generation SuperAttenuator (NGSA) for seismic noise suppression

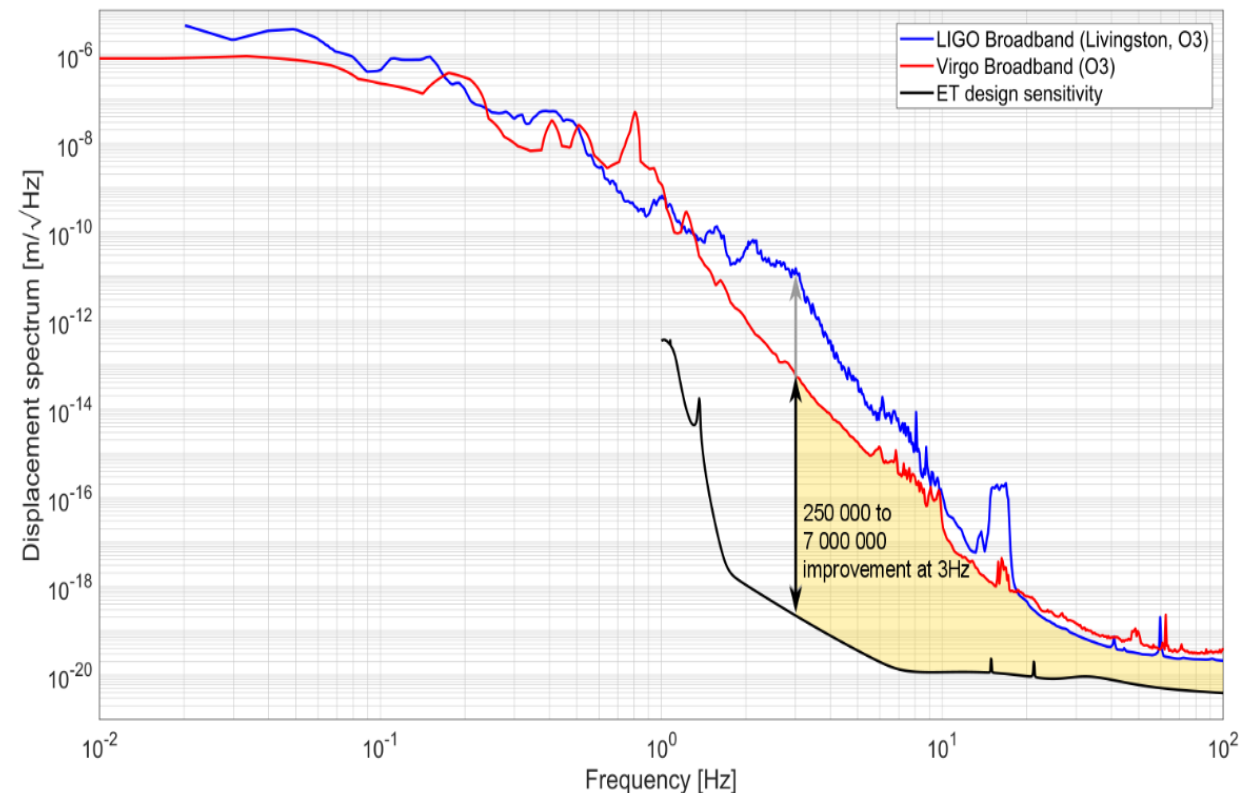
“Open Call” CSN5 for R&D Program on Third Generation Gravitational Wave
Detector Einstein Telescope (ET) – Giant Laboratory

F. Frasconi – INFN Pisa

July 6th, 2023

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**

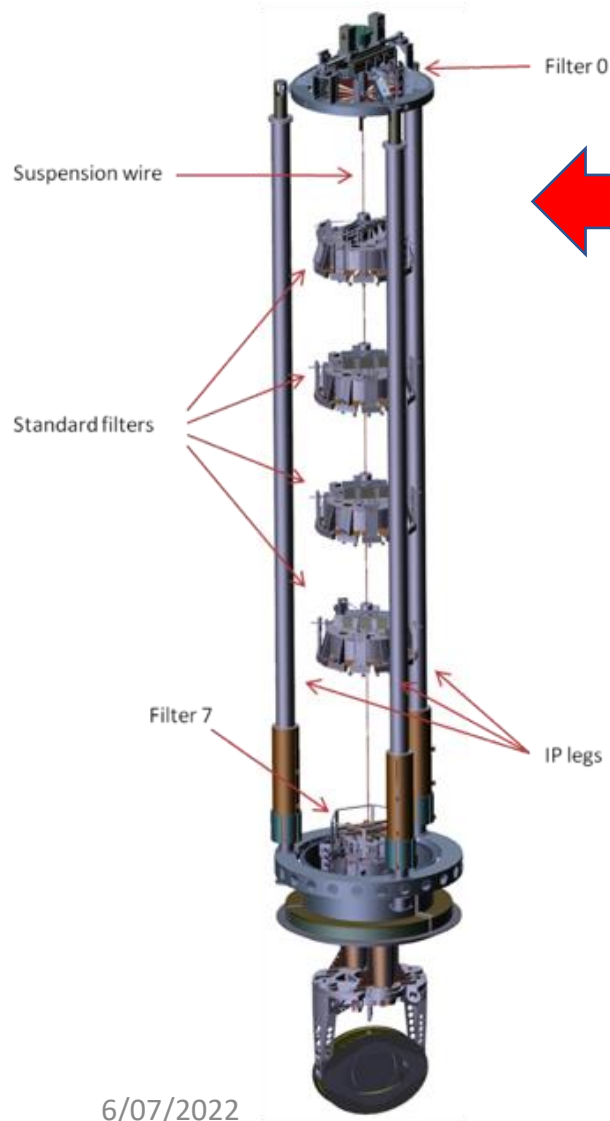
- Displacement sensitivity of the 2nd generation detectors (O3 - Observation run 3) and ET design sensitivity
- Extending the bandwidth in the low frequency region around 2 Hz, requires an improvement with respect to the present experimental limits of more than 5 order of magnitude



NGSA: EXPERIMENTAL PROGRAM

- Define guidelines for future seismic isolation systems to be extended down to 2 Hz: seismic noise is the dominant noise source in the low frequency region
- **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, ...)
- **Present mechanical system of the SA (2nd generation) is considered compliant with 3rd generation detector (see ET Conceptual Design)**

1. Traditional: based on AdV mechanical structure



NGSA: TWO EXPERIMENTAL LINES

Improving passive filter chain

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

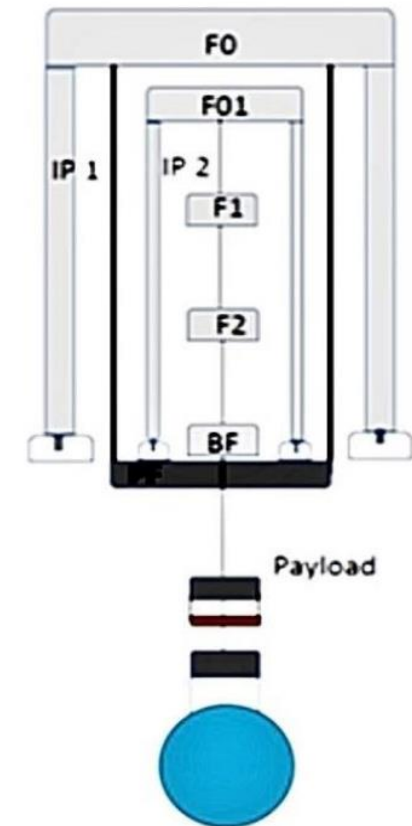
Improving pre-isolation

- Active pre-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-stage NIP



NGSA: PROJECT ORGANIZATION

- **Collaboration Project:** INFN Pi, INFN Na, LNS/SS; **Resp. Naz.:** L. Di fiore (INFN Na)
- **WP1 Simulation & Optimization of the Superattenuator (SIM)**
 - Coordinator: L. Trozzo (INFN Na)
 - Modeling and simulation studies of Superattenuators in different configurations
- **WP2 Mechanical Filter with new Magnetic Anti-Spring (MAS)**
 - Coordinator: F. Frasconi (INFN Pi)
 - Development and design of new Magnetic Anti-Spring (MAS) for passive attenuation of seismic noise
 - Design and optimization of mechanical filter based on new MAS with rare-earth magnets
- **WP3 Development and test of a Nested Inverted Pendulum (NIP)**
 - Coordinator: R. De Rosa (INFN Na)
 - Mechanical system design based on two Inverted Pendulum in Nested configuration (NIP)
 - Prototype construction of NIP in reduced scale to be installed at INFN Napoli Laboratory
- **WP4 Sensing & Control (S&C)**
 - Coordinator: A Gennai (INFN Pi)
 - Devices selection and procurement of a test station for feedback control application (LabView based)
 - Preliminary set-up/configuration test in view of feedback control system to be used on NIP

NGSA: WP1 details

- **WP1 Simulation & Optimization of the Superattenuator (SIM) - L. Trozzo (Na)**
 - Simulation in continuous update process: used for the preliminary design of the prototype (WP3)
 - Iterative process to finalize NIP and new MAS designs (WP2)

The optimization studies make use of different tools:

- A simplified analytical model that, once fixed total mass, payload mass and suspension length, allows to define an optimal distribution of masses and length along the chain (Europhys. Lett. 40 (1997) 601-606);
- A software tool, based on the impedance matrix formalism (Octopus), already developed, validated and tested, on AdV Superattenuators. It allows to compute the system mechanical TF by:
 - defining the impedance matrix of each single SA element (mass, blade spring, wire, IP flex joint and legs,...)
 - evaluation of the mechanical TF from/to any stage of the SA in 6DOF
 - taking into account servo loops for controlling and damping the SA

Paper titled: «New Generation of Superattenuator for Einstein Telescope: preliminary studies», almost ready to be submitted to CQG very soon

NGSA: WP2 details

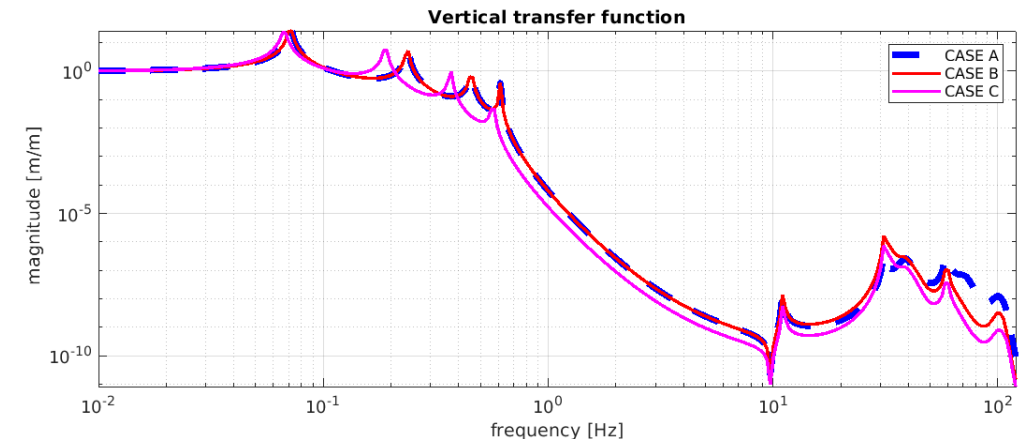
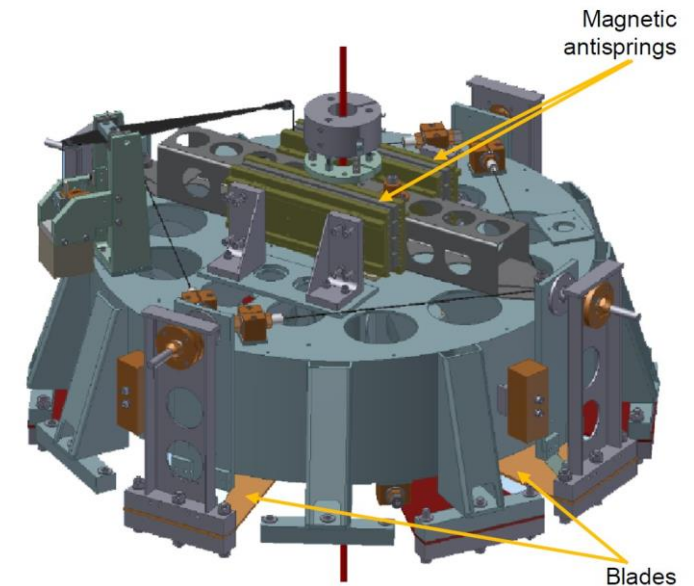
- **WP2 Mechanical Filter with new Magneti Anti-Spring (MAS) – F. Frasconi (Pi)**
 - Good indication from SIM on improvements: reduced load of the movable apparatus (cross-bar)
 - Rare-earth magnets selected (SmCo, NdFeB): material procurement in progress
 - Vacuum compatibility test to be performed soon; Magnetic field measurements to be done

The mechanical filters of AdV SA are equipped with blade springs to support the load of the next stages. The Magnetic Anti-Springs (permanent magnets) mounted in repulsive configuration are used to decrease the vertical oscillation frequency of each stage at the level of the horizontal one.

For ET we need to suspend large masses (up to 600 kg payload) improving the Vertical Attenuation performance: rare-earth permanent magnets (SmCo, NdFeB) to reduce the load of cross-bar.

6/07/2022

F. Frasconi - INFN Sez. di Pisa - Pre

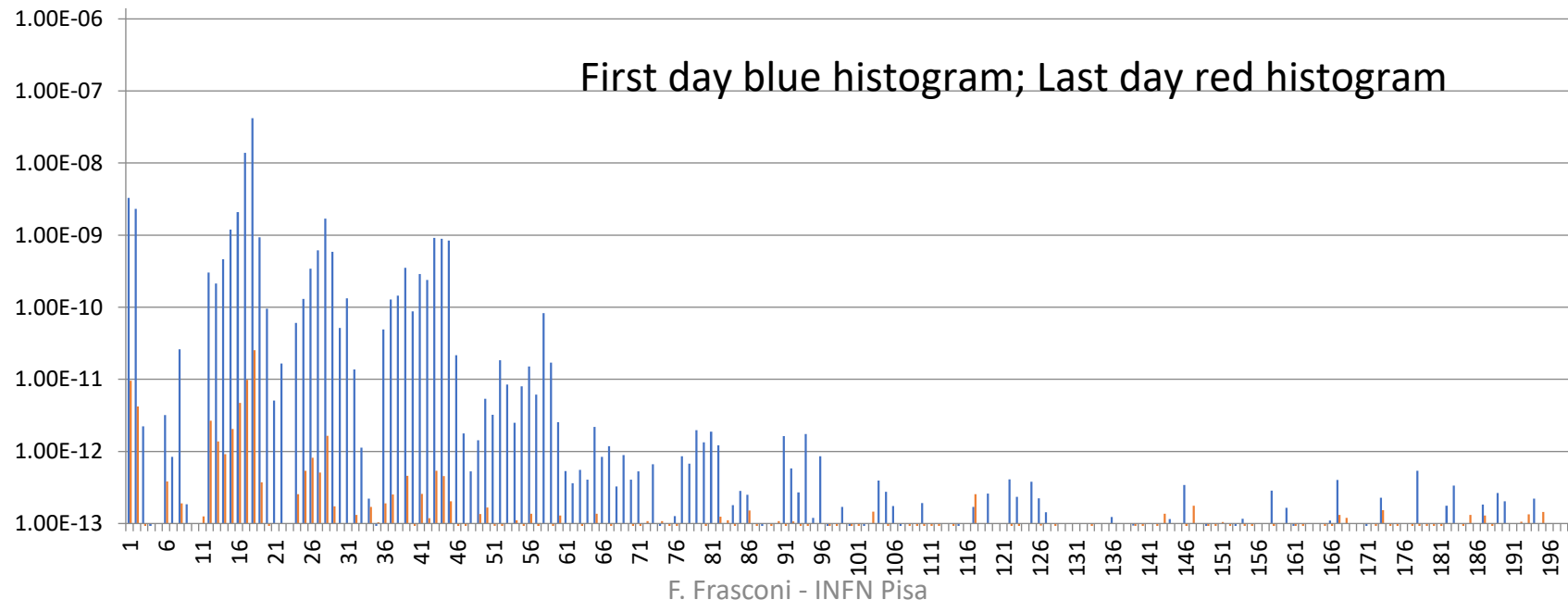


NGSA WP2: Magnetic Anti-Spring (MAS) Studies

- 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; $B \approx 0.8$ T along the cylindrical axis of the magnet)
- Mechanical support for the testing machine (@INFN Pisa Laboratory) ready for the first prototype of the MAS (L. Lucchesi)
- 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 CONCLUDED**
- Preparation of the magnet testing machine: to be used for the optimization geometry of MAS

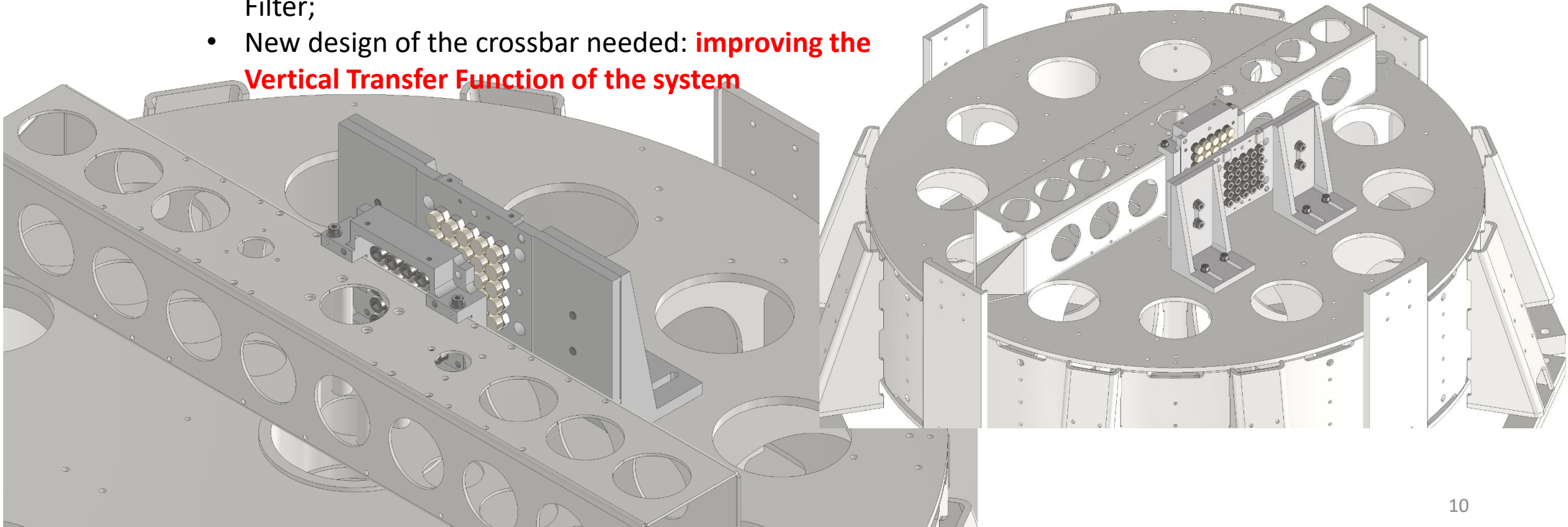
NGSA WP2: Outgassing Test Results - SmCo Nickel Coated

- A set of 100 permanent magnets **SmCo_NiCoated** has been tested for UHV compatibility with **very good results**.
 - SmCo encapsulated with Nickel coating (**BEST RESULTS**)
- Residual Gas Analysis: time evolution of **Partial Pressure [mbar] vs Atomic Mass Number**



NGSA WP2: New MAS design – From AdV to the Future

- A preliminary set-up of the new MAS with **SmCo_NiCoated** will be assembled on an old AdV mechanical filter for test purpose. Activity in progress
 - New MAS bolted on top of an AdV mechanical Filter;
 - New design of the crossbar needed: **improving the Vertical Transfer Function of the system**



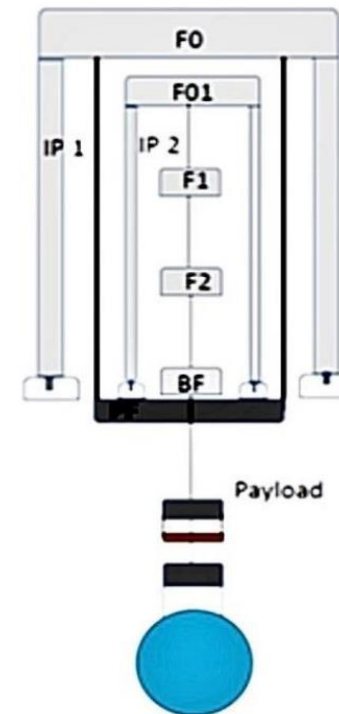
NGSA: WP3 details

- **WP3 Development and test of a Nested Inverted Pendulum (NIP) – R. De Rosa (Na)**
 - Clear indication from SIM for a preliminary design of a prototype in reduced scale
 - Vacuum tank @ INFN Na equipped with pumping system
 - Crucial contribution of the INFN Pi personnel to the NIP design

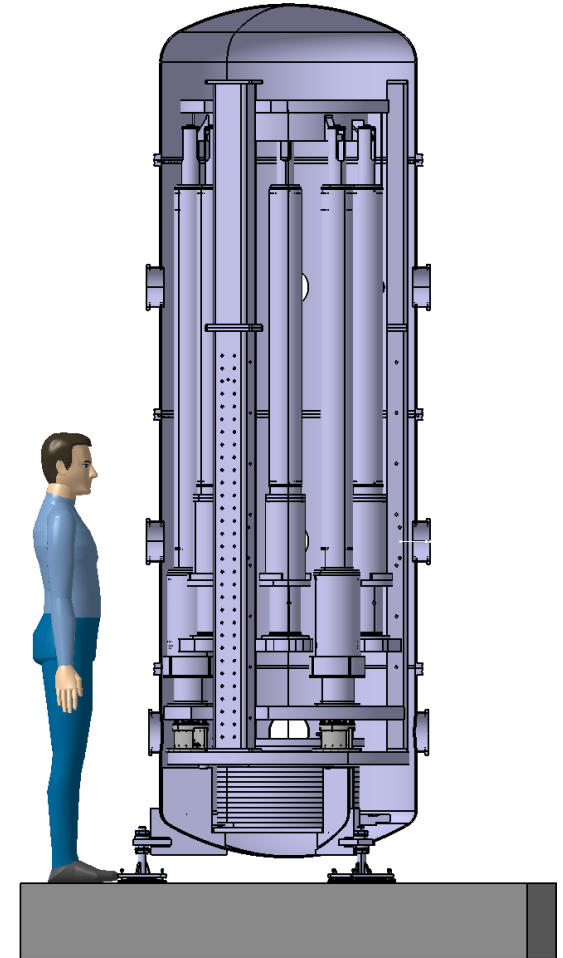
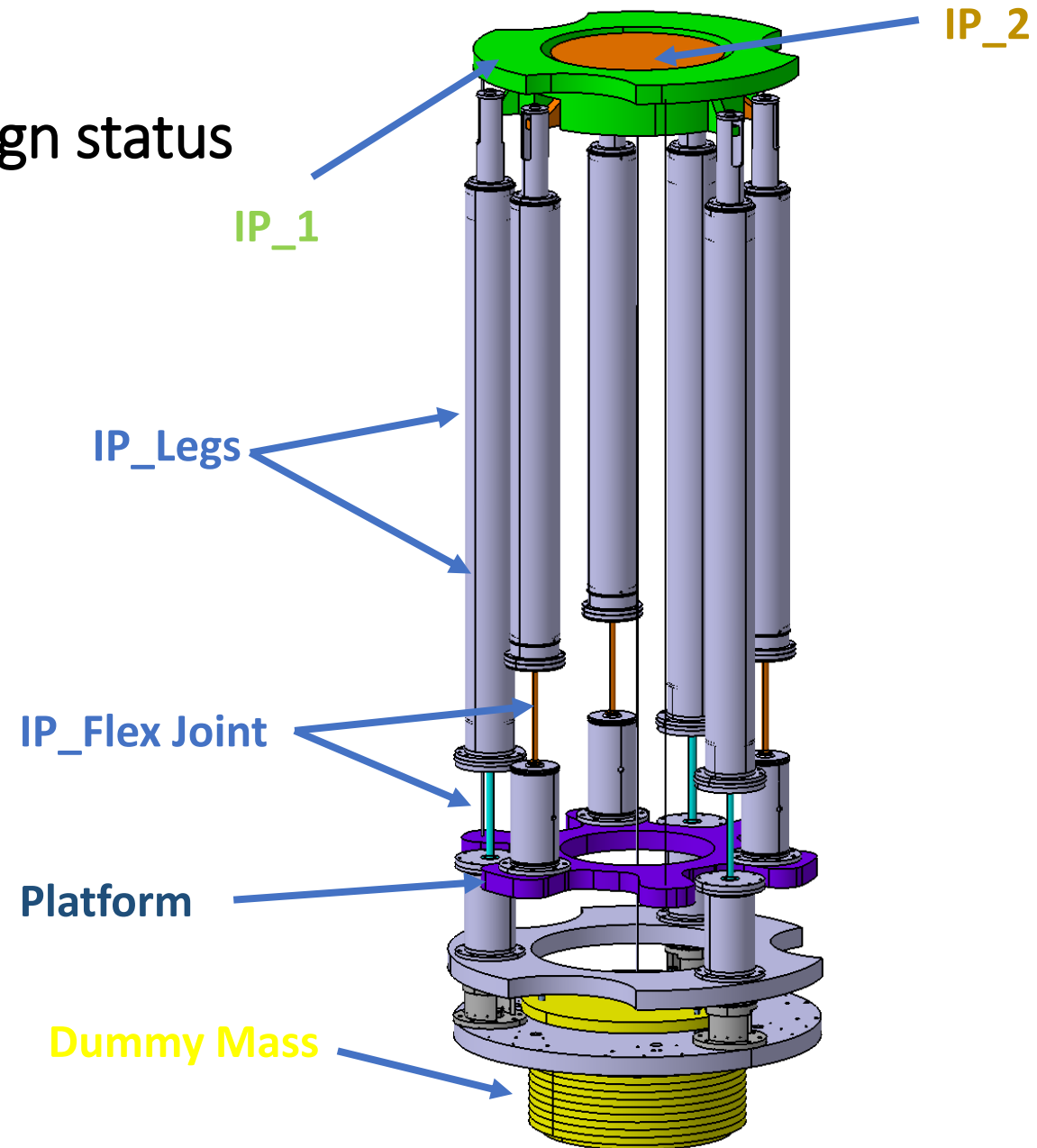
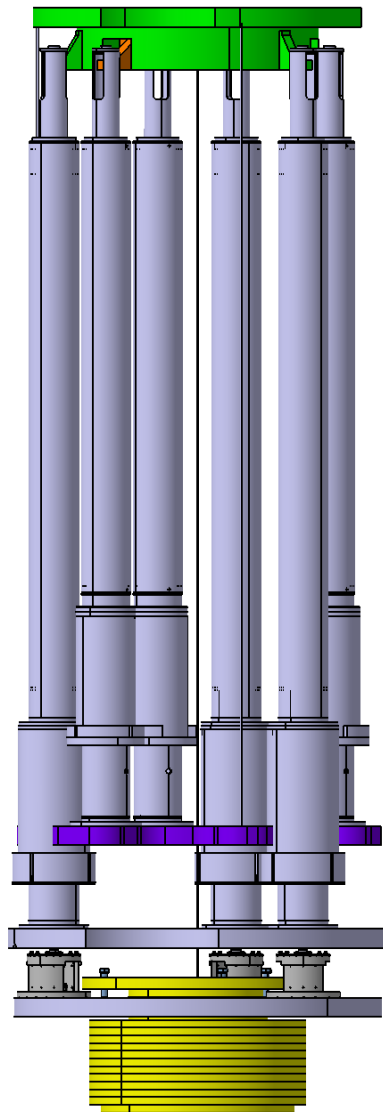
The NIP prototype will be assembled at INFN Na
Due to the limited space in the laboratory and to the available vacuum chamber it will represent a prototype on scale 1:2 with:

- NIP legs length about 2m
- Dummy load 600 kg (representing filter chain and payload)
- Total mass about 1200 kg

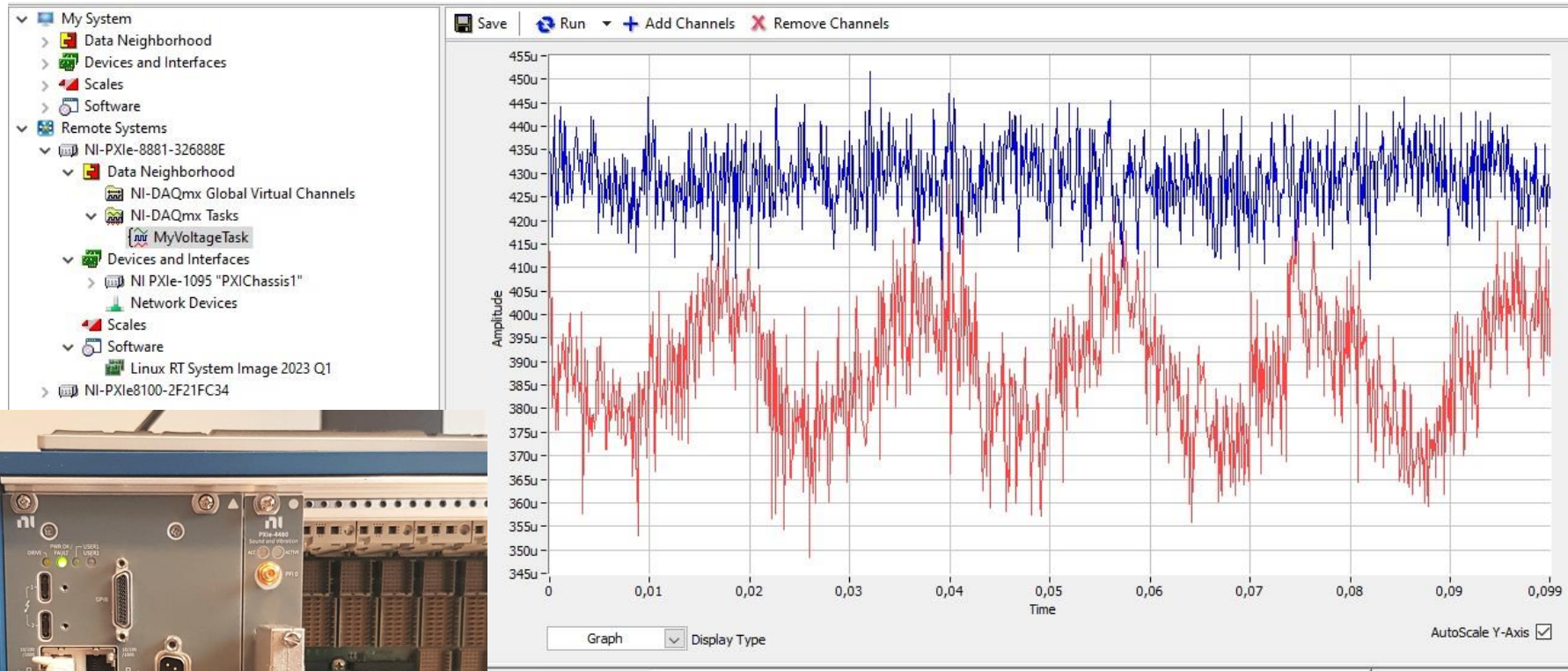
Possible extension (1 year - 2025) of the project due to structural works around the INFN Na Laboratory (PNRR-ETIC)



NGSA WP3: NIP Design status



NGSA WP4: Sensing & Control (S&C)



ELECTRONIC SETTINGUP

- Checked the capability to correctly read analog input channels;
- Checked the capability 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. Order placed in February 2022. Most of material shipped within the end of 2022 but DAC module **just delivered**. Risk for future orders.

NGSA: PERSONNEL (Preliminary) & Services Requests

Name	Research Unit	FTE	Contribution to Work Packages
Franco Frasconi	INFN Pisa	0.5	WP1, WP2, WP4
Alberto Gennai	INFN Pisa	0.2	WP1, WP3, WP4
Federico Pilo	INFN Pisa	0.2	WP2
AdR#2 (*)	INFN Pisa	1.0	WP2, WP4
Total	INFN Pisa	1.9	

(*) Competition Notice for AdR#2 to be published soon

Strong impact of PNRR-ETIC Personnel on the project: L. Lucchesi, P. Prosperi, F. Spada INVOLVED

Services Request

- Standard support from “Alte Tecnologie People” for Laboratory daily life
- Mechanical workshop for construction of small mechanical parts for MAS prototype and mechanical filter prototype [1mU/year]

NGSA: Budget for 2024 - PRELIMINARY

- **Budget so far (2023)**

- Licenze Software: 14 kEuro (sj) DA SBLOCCARE
- Impianti (Costruzioni Apparati): 10 kEuro + 47 kEuro **ASSEGNAZIONE FONDI IN CORSO D'ANNO**
- Personale: 31kEuro DISPONIBILE per Bando AdR (1 anno) + 6 mesi (residuo anno 2022)

- **Budget Request for 2024 – VERY PRELIMINARY**

- Consumi: 45 kEuro [raw material per filtro (35), cabling (10)]
- Licenze Software: 5 kEuro [ANSYS, Comsol]
- Impianti (Costruzioni Apparati): 10 kEuro [sensori, attuatori, drivers]
- Missioni: 8 kEuro [meeting di collaborazione, assembling prototipo]
- Personale: 31 kEuro - Bando AdR (Ultimo anno)

TOTALE: 99 kEuro