Magnetic noise in GW detectors and mitigation

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and
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on behalf of the ET ANM – Magnetic noise workpackage

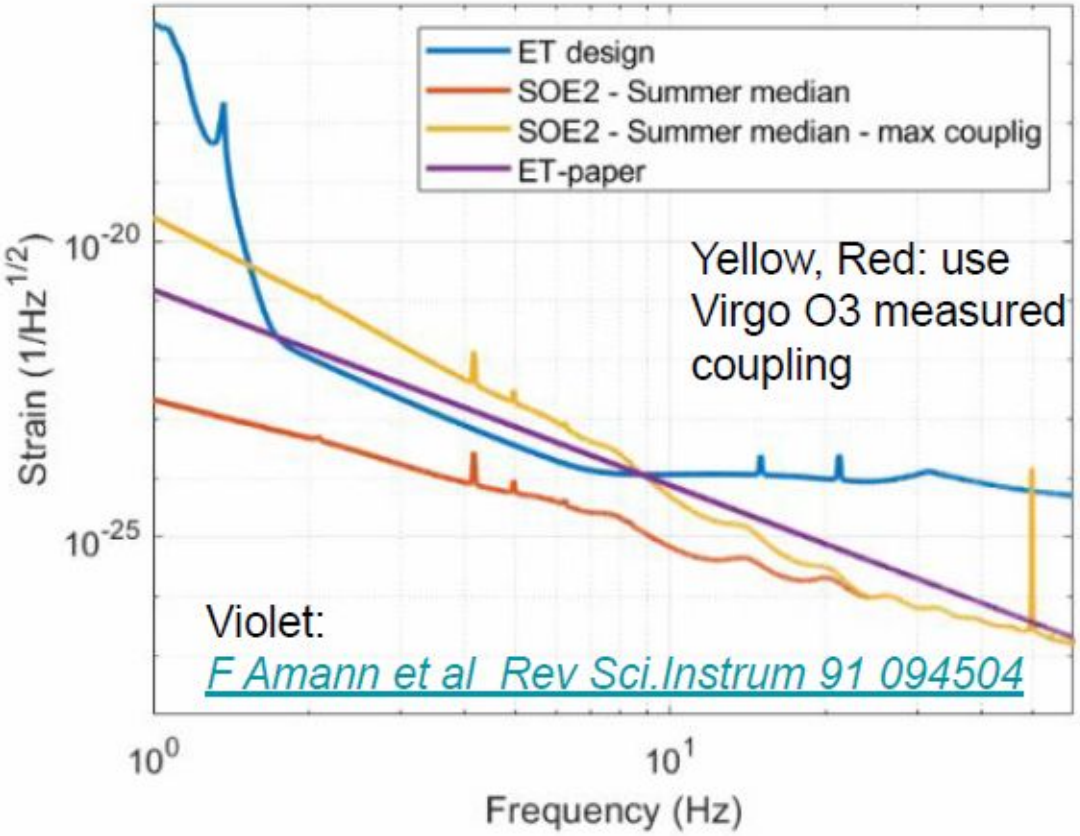
3rd Einstein Telescope Site Preparation Board Workshop in Amsterdam, 6-7 Dec. 2023

Outline

- MN Introduction
- MN WP Status: Virgo Experience
- MN Mitigation Strategies
- Conclusions

Magnetic Noise Introduction

- Limited noise in the frequency range between a **few Hz** and **about 100 Hz** in next GW detectors
- **Sources**: Earth Schumann's Field (~pT) + ITF environmental noises (self-inflicted noise, e.g. electronic boards, electric motors, pumps, magnetized components or conductive materials…)
- **ET target**: improve low-frequency sensitivity by two orders of magnitude compared to Advanced LIGO/Virgo.

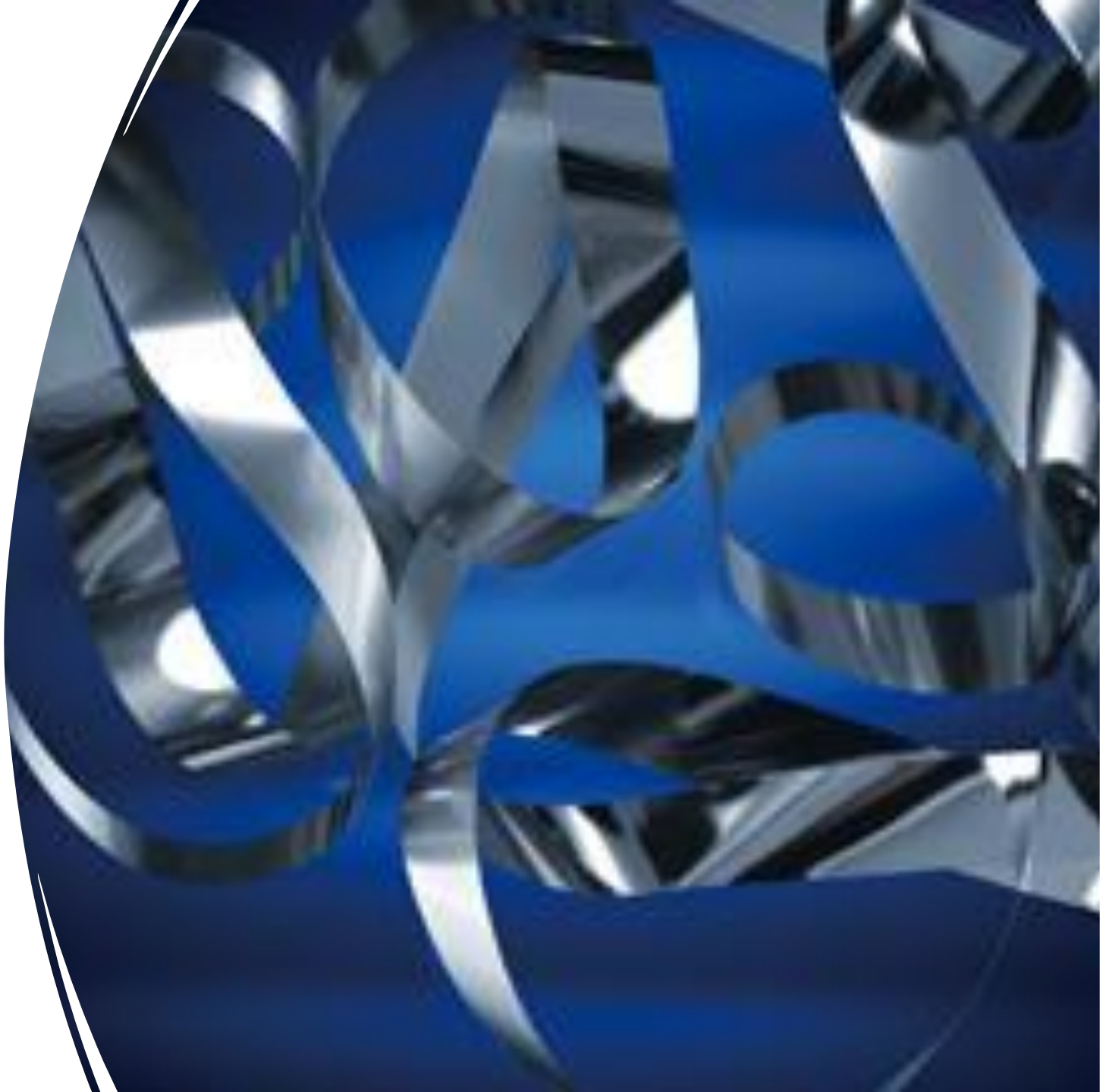


- **Mitigation MN strategies**:

→ lowering the environmental noises at Earth Noise level (any device which carries an electric current);

→ Identify and shield main coupling locations (reduce coupling by a factor 10^2-10^3 wrt current ITFs)

MN WP Status: Virgo Experience



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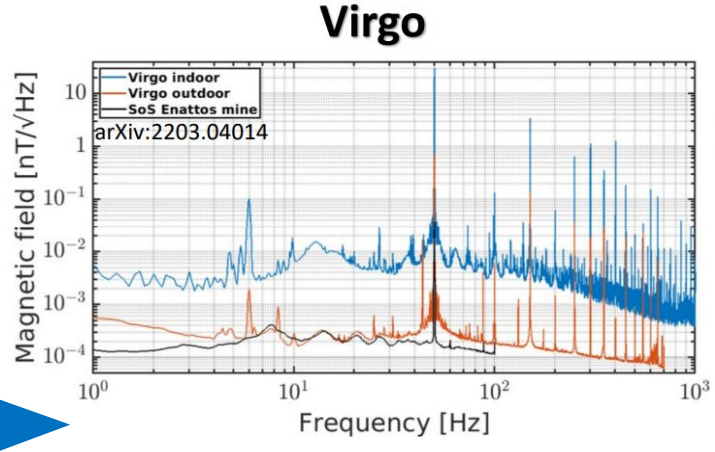
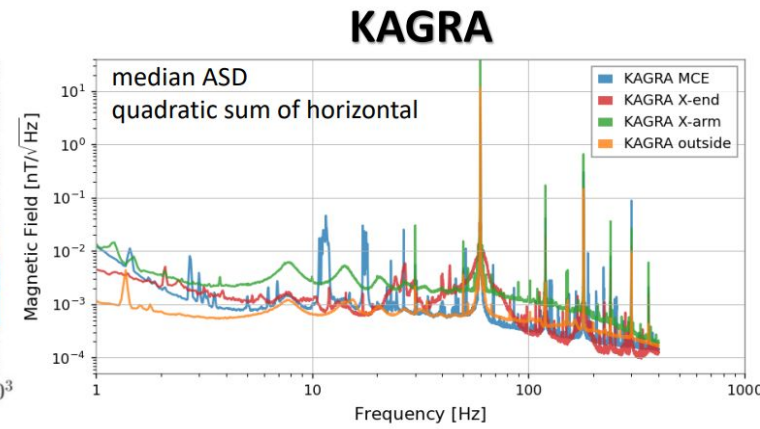
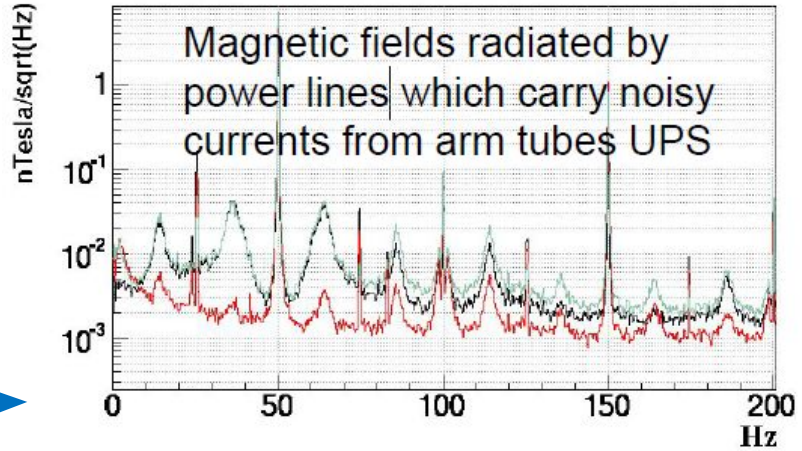
Magnetic noise investigation: Virgo Experience

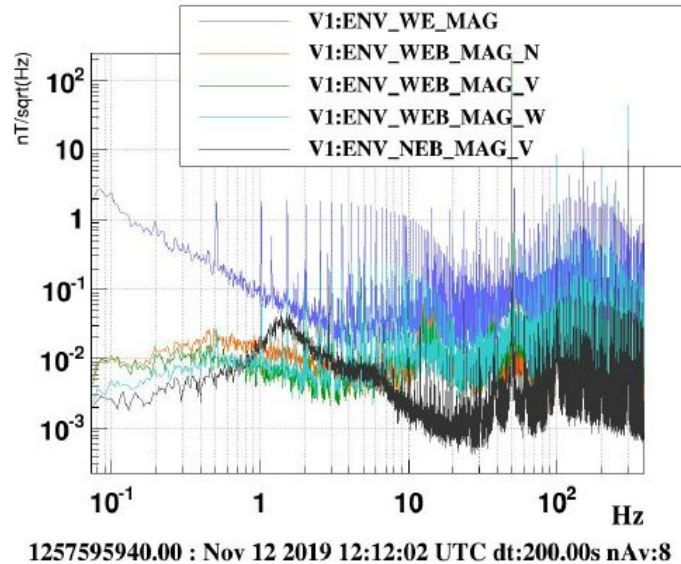
- **Reduce self-inflicted noise**: Virgo is dominated by self-inflicted noise respect to the quieter KAGRA magnetic condition (ET-0165A-22)

- **Power distribution system:** EM fields radiated by cables/wires and magnetic fields from electric and electronic devices (ET-0175A-23)



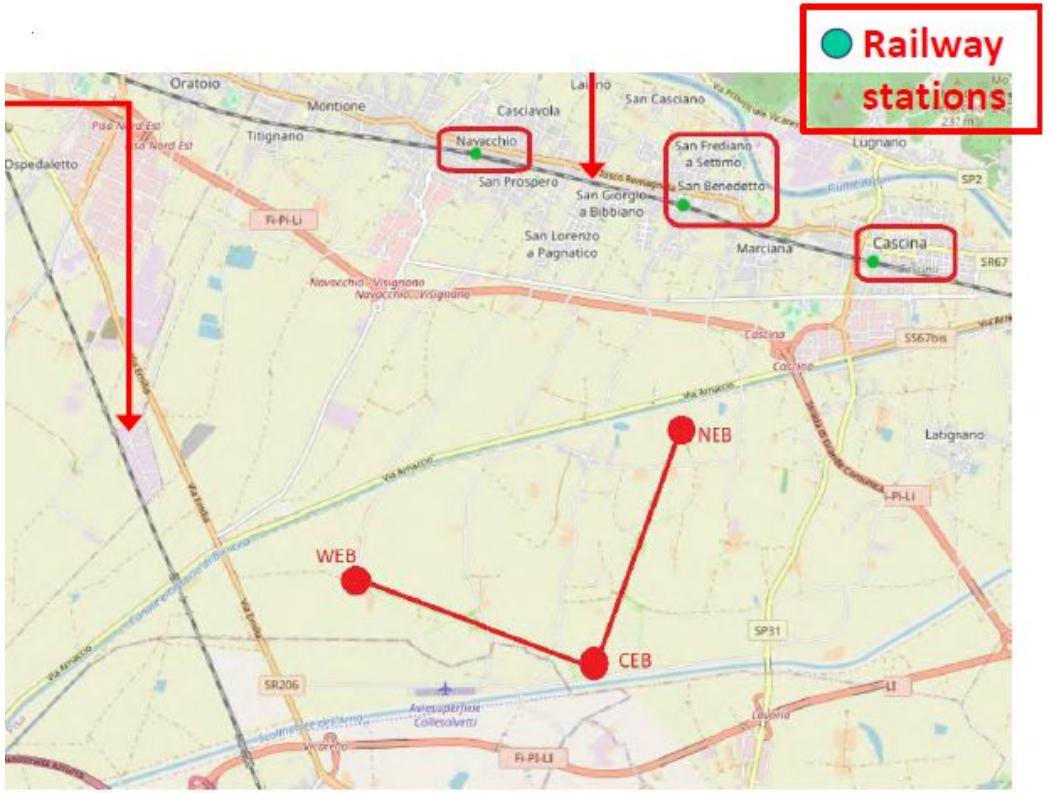




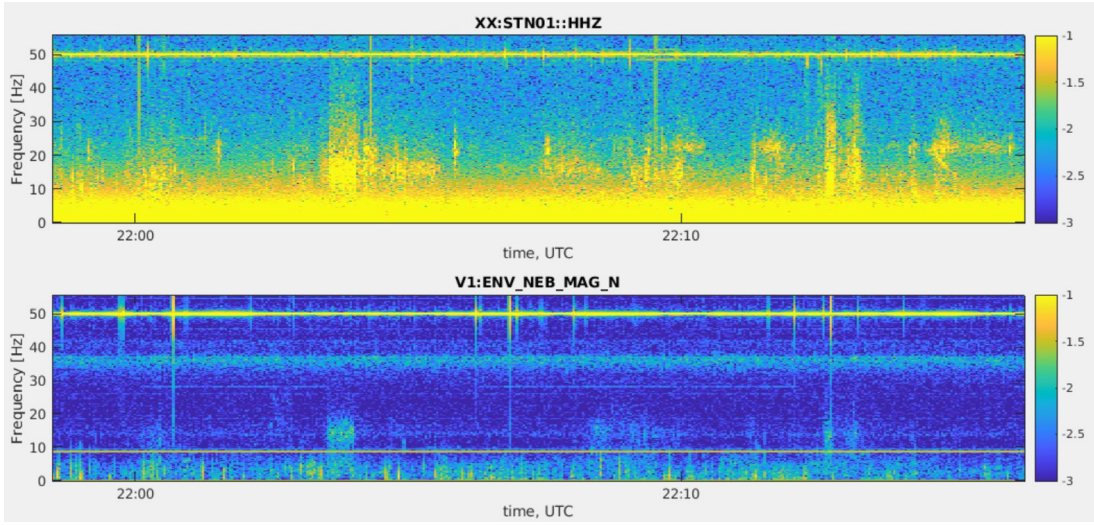


Magnetic noise investigation: Train noise experience in Virgo site

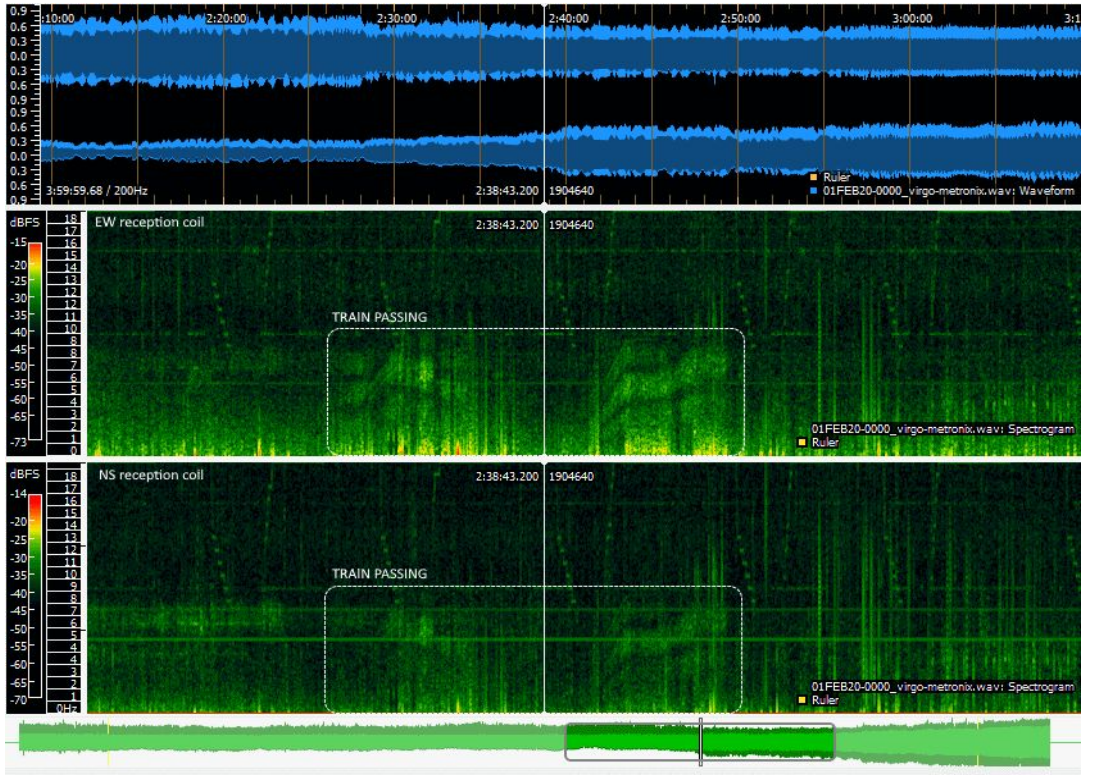
- Source of different types of noise: acoustic, seismic, **Magnetic**.
- **Railways** close to Virgo site: **2km from NEB (passenger + freight)** and 2km from WEB (only freight).
- **Comparison between magnetic measurements** in Virgo NEB and in the closest railway station via magnetometers.



Virgo experience - Train noise



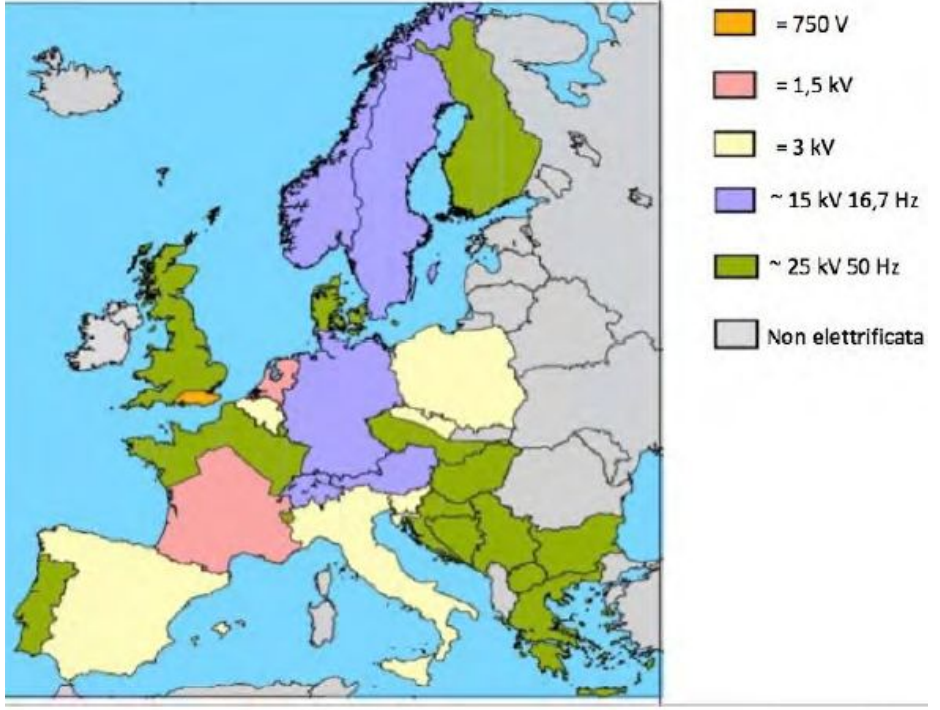
- **Site-wide low-frequency magnetic glitches:** spikes of current travelling on the overhead line and returning to ground via railways and through the ground (F. J. Lowes, 2009)



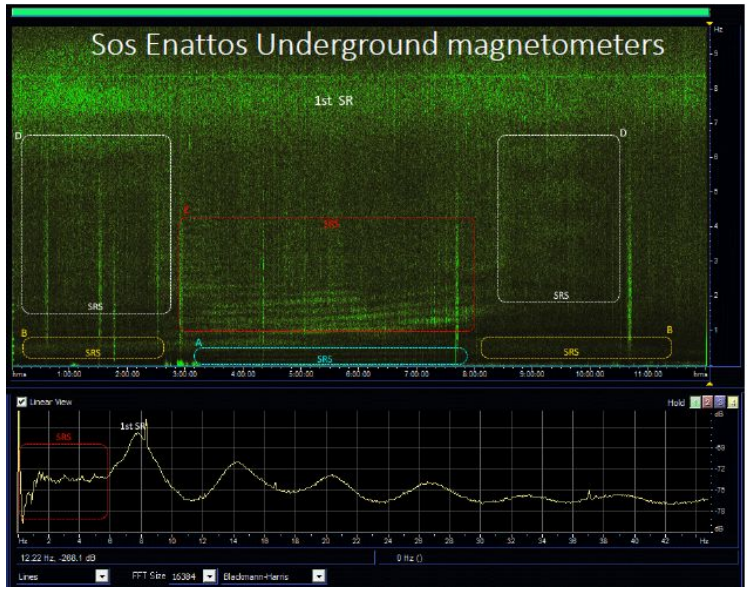
- Virgo external magnetometer - **correlated "butterfly" pattern**: the magnetic pattern of the train change of speed while approaching the station.

Train noise experience: power supply of EU railways

- DC electric railways near **Virgo** use an overhead 3kV line, with power involved as high as few MW, current up to 1kA.
- Magnetic fields generation also due to the not perfectly isolated from ground, producing large EM fluctuations.
- **In EU railways**, magnetic pattern could be different. **Need for a wide measurement campaign to evaluate the effect of trains magnetic emission.**



Kind and distribution in EU of overhead trains supply



Sos Enattos is distant from railways (~30 km from the nearest): the region 0 to 40 Hz is magnetically clean enough to clearly detect up to the sixth Schumann resonance.

Virgo experience: Magnetic Injection

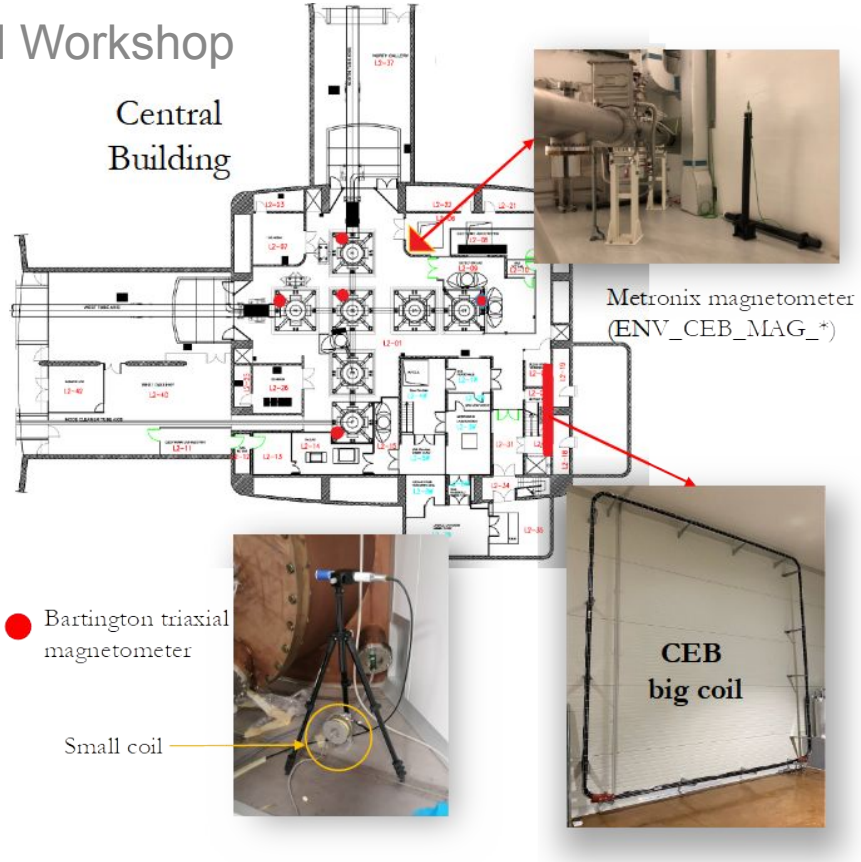
Coupling locations (Test Masses and suspended optical benches (INJ, DET)) during the magnetic injections with big coils (BC):

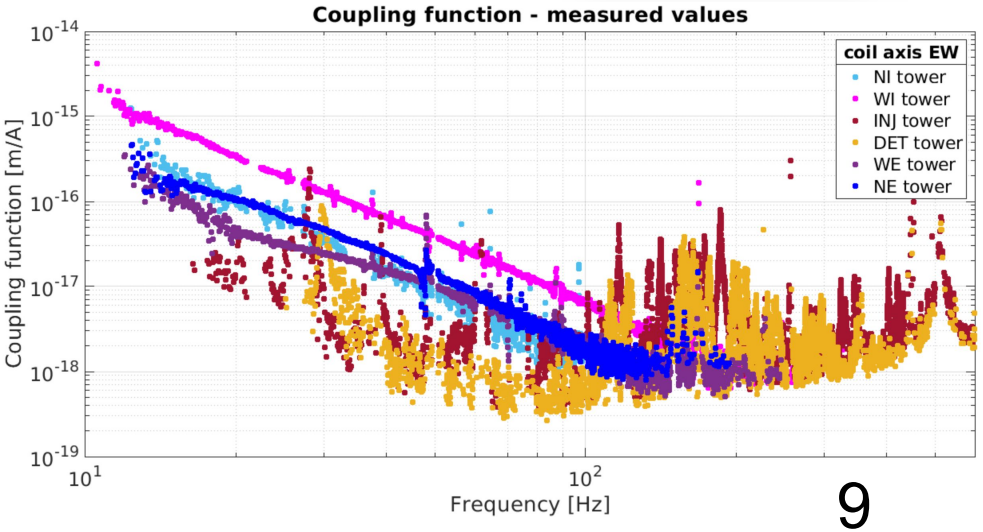
$$CF_{BC}(f) = \sum_i^N \alpha_i CF_{i,SC}(f) \qquad h_{noise}(f) = \sum_i^N \alpha_i \, CF_{i,SC}(f) \, X_{i,bkg}(f)$$

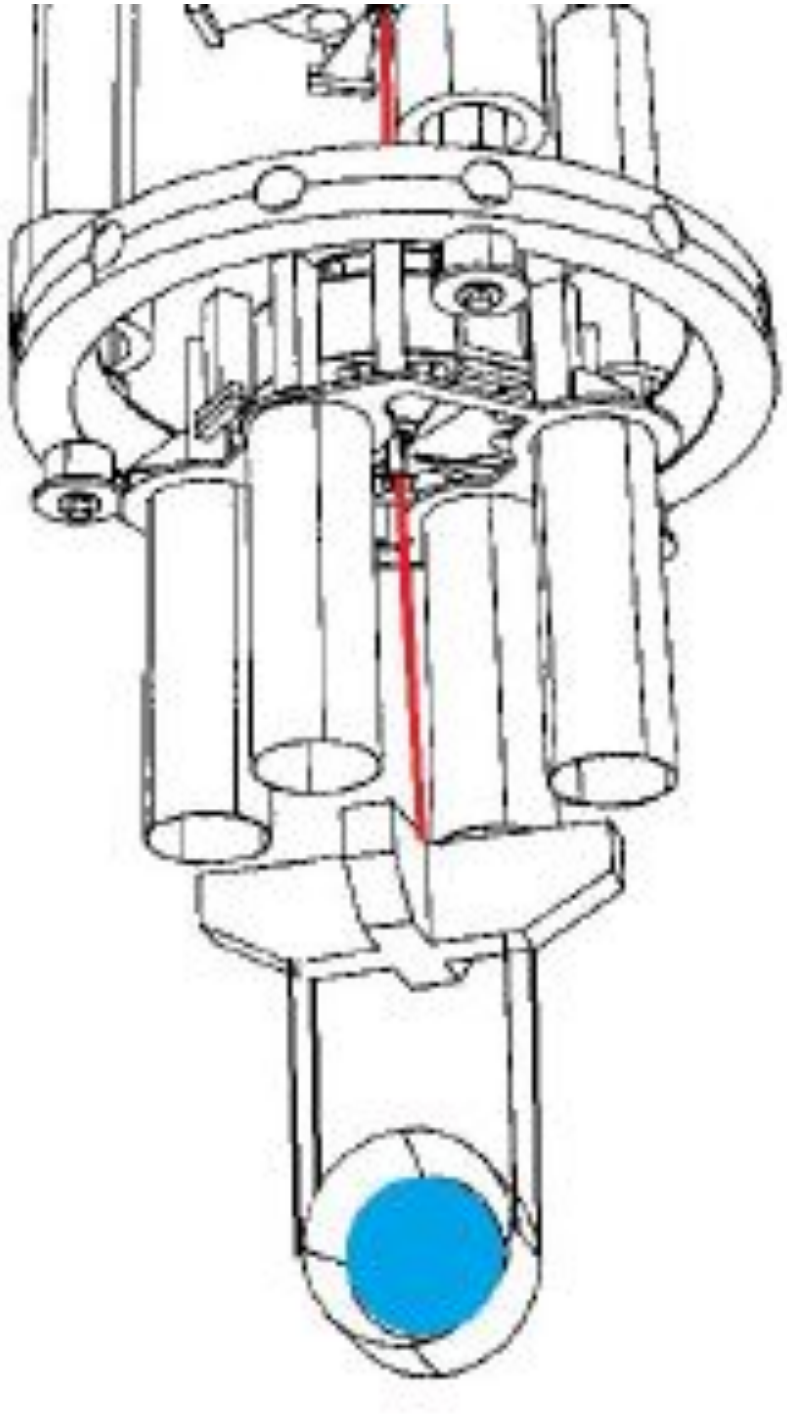
Injection campaigns (VIR-0584A-23):
far-field with large coil and near-field with small coil (SC, coil axis oriented along N, W, V)

Coupling functions (normalized to current) wrt orientations of the small coil:

- up to 100 Hz TMs dominate;
- above 100 Hz INJ and DET benches dominate.







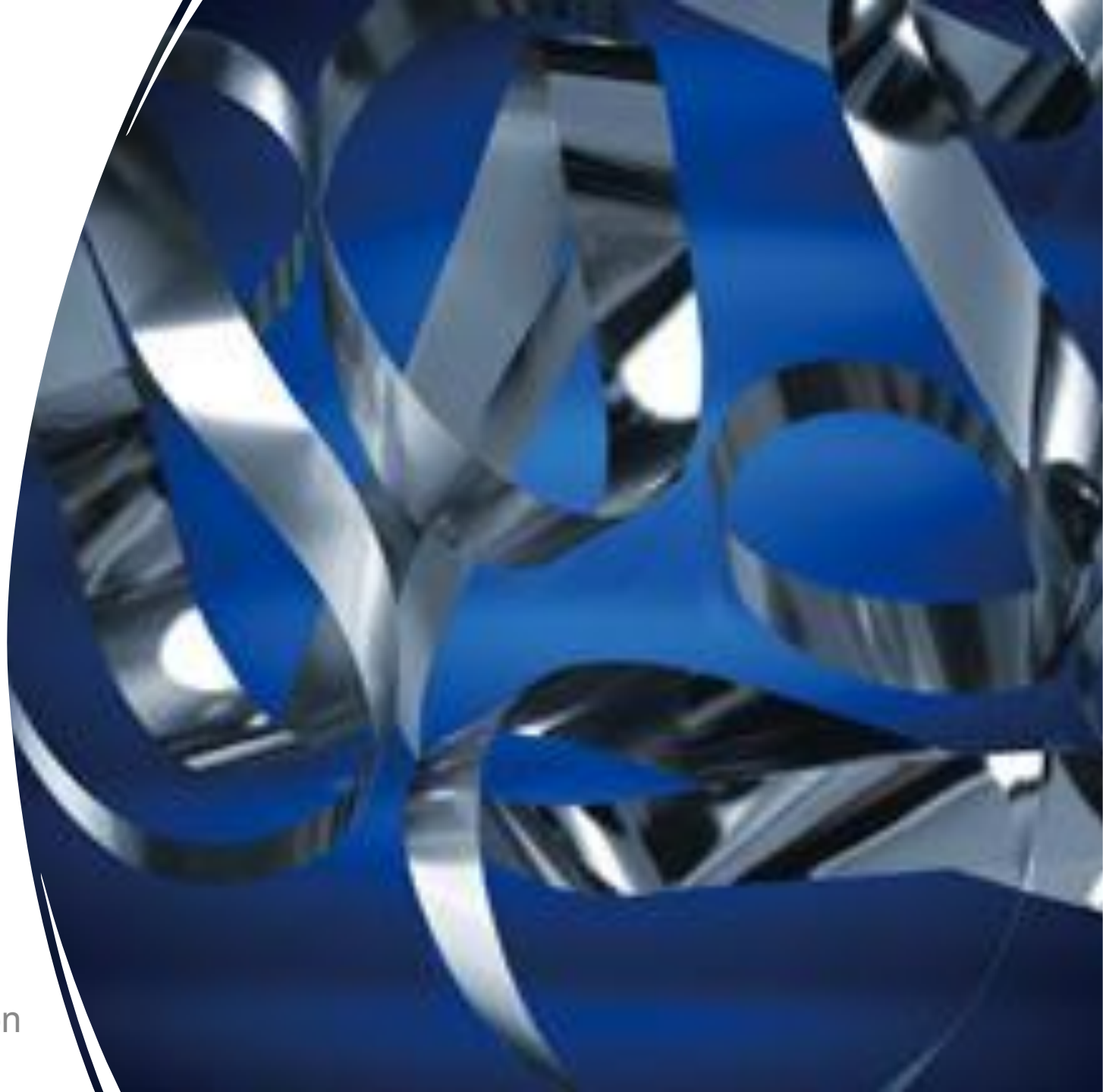
Virgo experience: Magnetic Coupling to the Interferometer

Ambient magnetic fields produce forces on permanent magnets or ferromagnetic materials (**B gradients**) and induced currents into sensitive electronics/within conductive objects (**Eddy currents**) → enhance B gradients.

Critical Components:

- Coil magnet actuators/last stages of suspension systems
- Faraday Isolators onto optical benches (permanent magnet)
- Cables (e.g. coil drivers) / sensitive electronics
- High conductivity materials close to actuation magnet, e.g. payload cage (Eddy currents)

Magnetic Noise Mitigation Strategies



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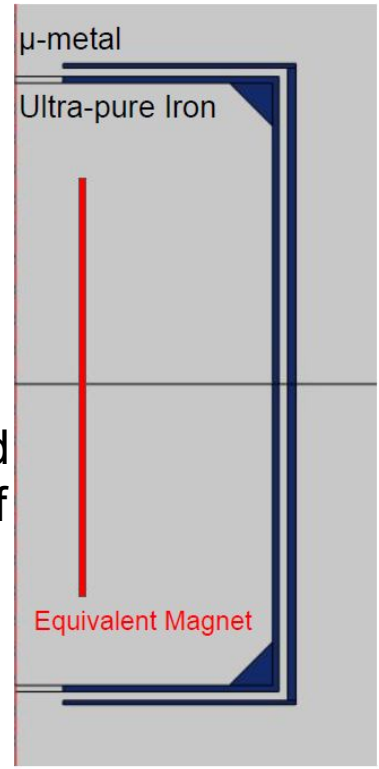
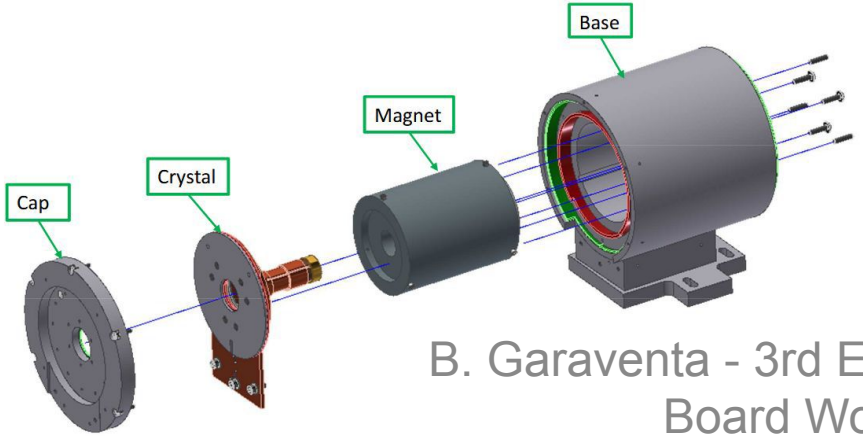
Magnetostatic shield for Faraday Isolators

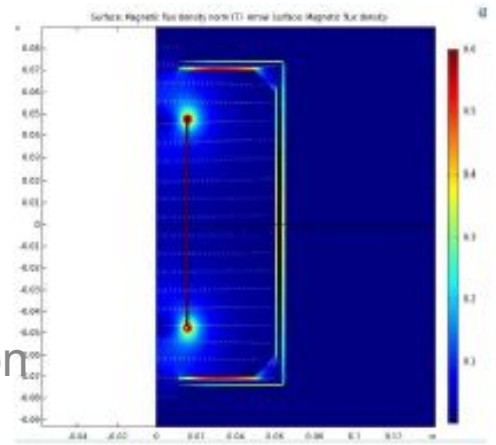
Shield design:

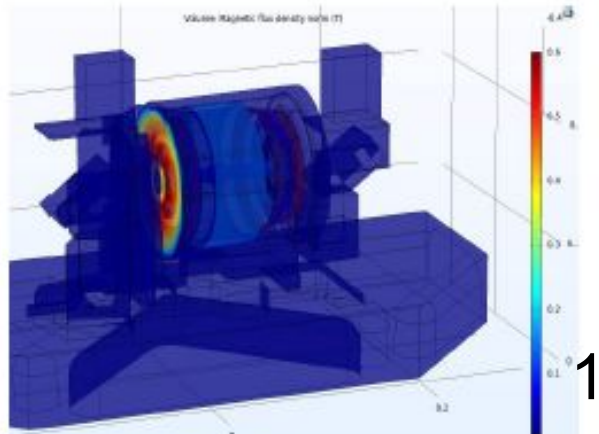
- modelling of the FI magnet;
- double layers (ultra-pure iron and μ-metal) to improve screen attenuation factor;
- from a simple cubic shield to the final screen: Faraday shield prototype produced (achieved a shielding factor on the order of 100 in simulation)
- The final F.I. shield installation is currently foreseen for AdV+ phase II



Axisymmetric screen model







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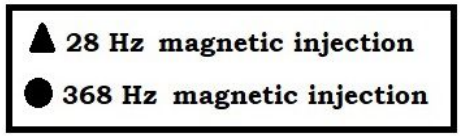
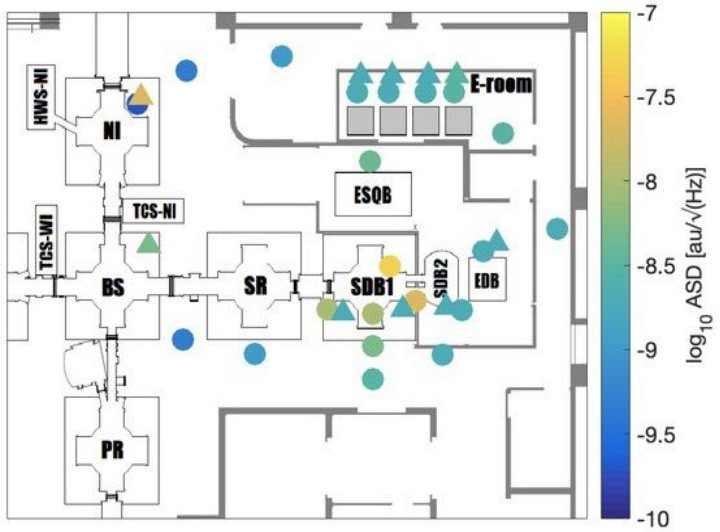




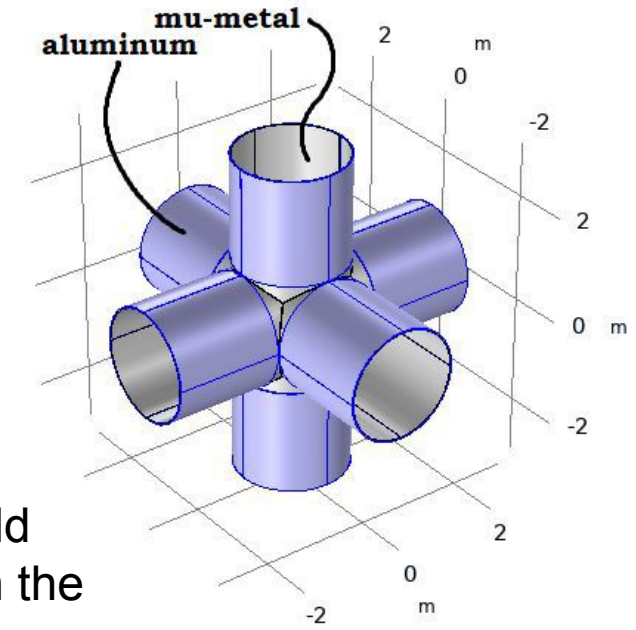
F. Armato VIR-0881A-23

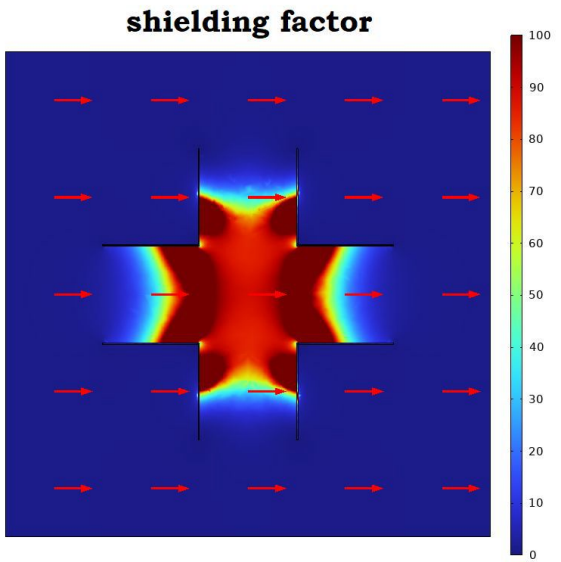
Passive Magnetic shielding for TM Towers

Test-Mass Towers need to be shielded!

Magnetic shielding:

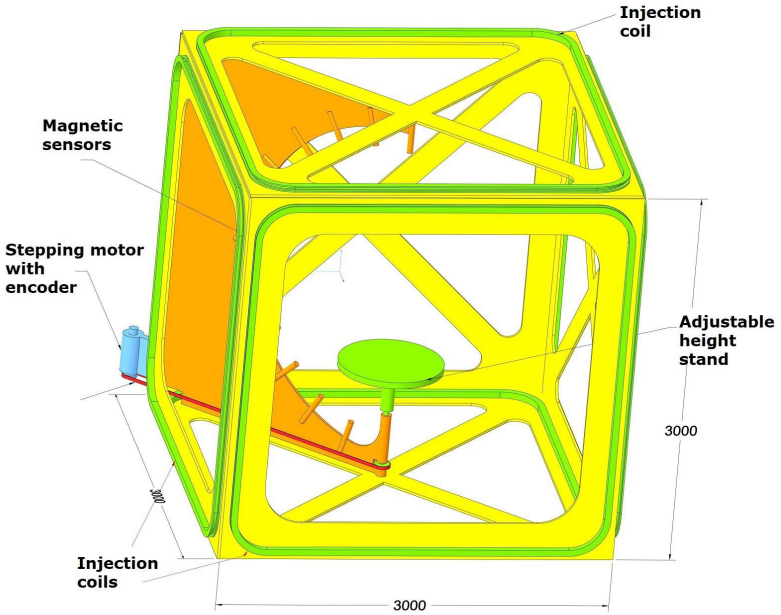
- with μ-metal layer added to steel vacuum chamber;
- with aluminum hollow cylinder (frequency-dependent contribution).
- Response of the system to 100 Hz uniform magnetic field along one arm of the ITF (achieved a shielding factor on the order of 100).





A. Chincarini

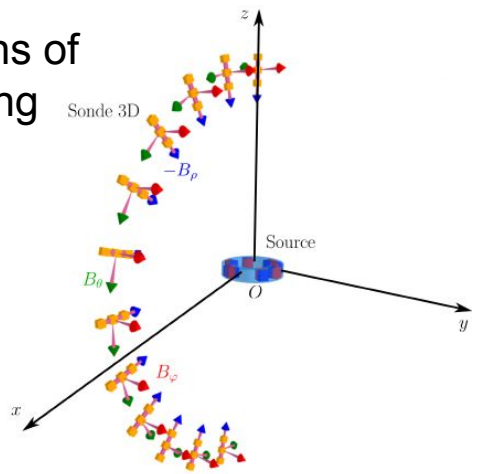
Magnetic Facility: MANET (MAgnetic Noise test facility for ET)

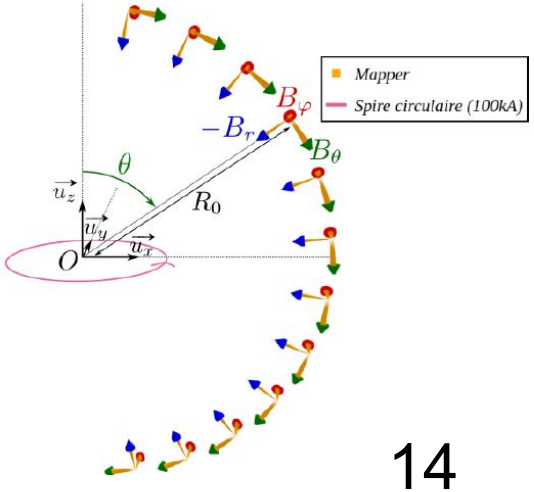


- ***Goals:*** characterization of devices noise emission and test of mitigation solutions
- Small scale laboratory to be realized at EGO
- Design and procurement of parts in progress
- Part of ***ETIC project***.

3D magnetic field mapper for ET

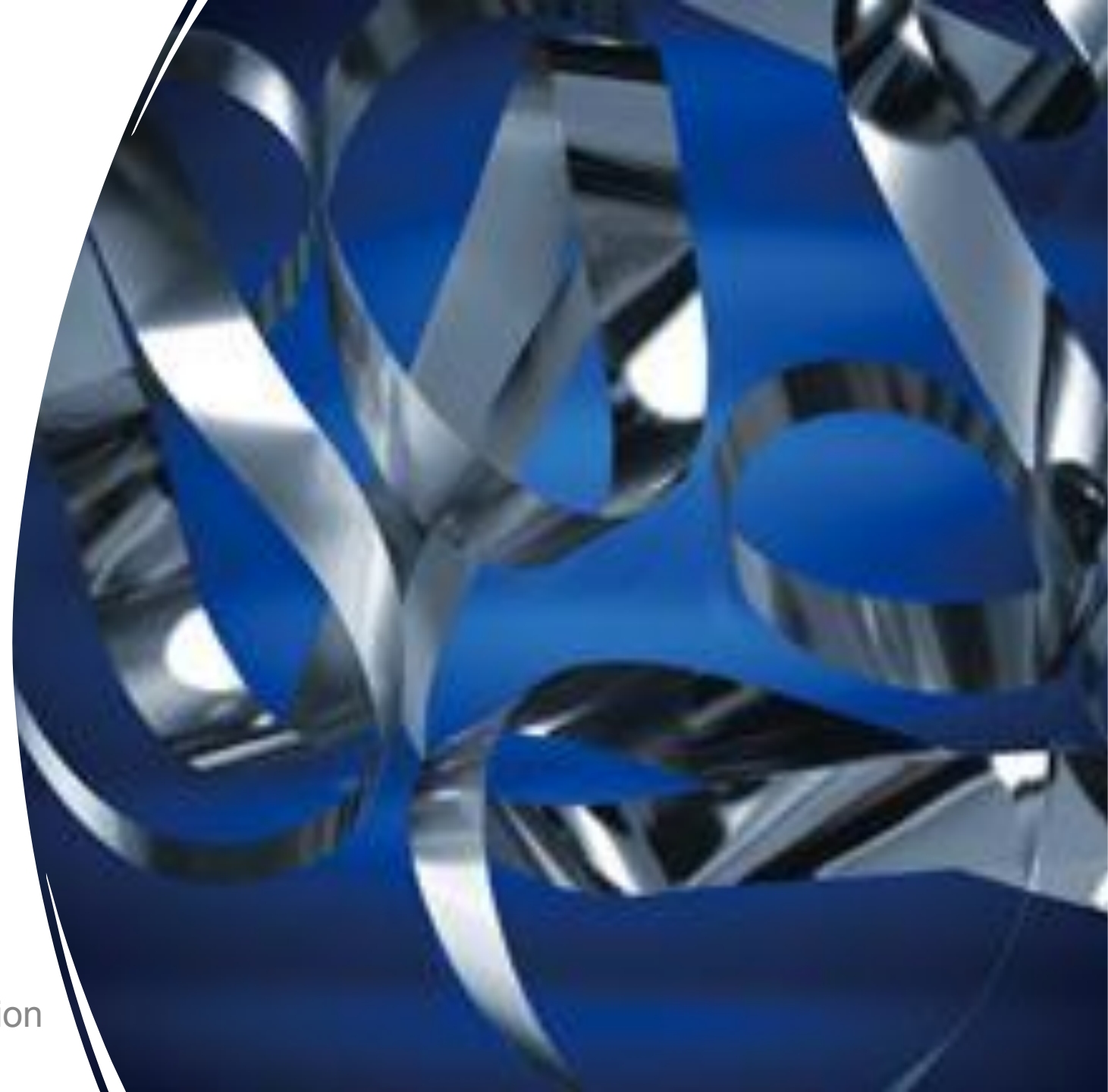
Simulations and optimizations of magnetic field mapper starting from a circular coil and then mapping harmonics from permanent magnet ring.





G. Quéméner, A. Gaillard and E. Le Villain

Conclusions



Goals: reduce the environmental noise at Earth Noise level, decreasing the magnetic coupling by a factor 10^2-10^3 wrt current interferometers.

Mitigation strategies: reduce emissions from disturbing sources; implement global shields for crucial in-vacuum spaces, such as magnetic and eddy current shields; manage power cables and wires.

Next steps:

- need interface with the other ET-subsystems (vacuum, ANM-environmental sensors…);
- a wide measurement campaign to evaluate the effect of trains magnetic emission;
- plan for a lot of simulation works, prototypes and tests (MANET infrastructure at EGO site).

Thanks for your attention!

Any question?

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