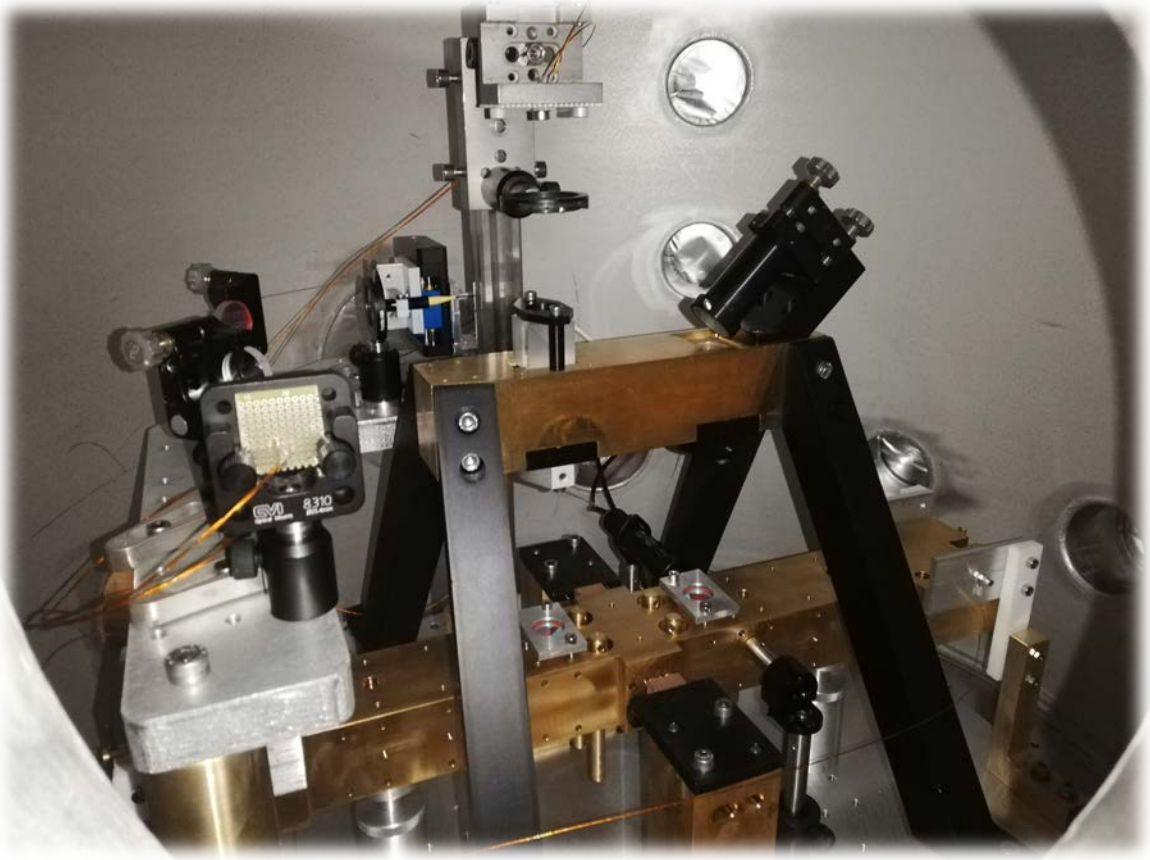


Tiltmeter for NNC

A. ALLOCCA, E. CALLONI, R. DE ROSA, L. ERRICO, M. ESPOSITO, G. PONTORIERE, P. RUGGI

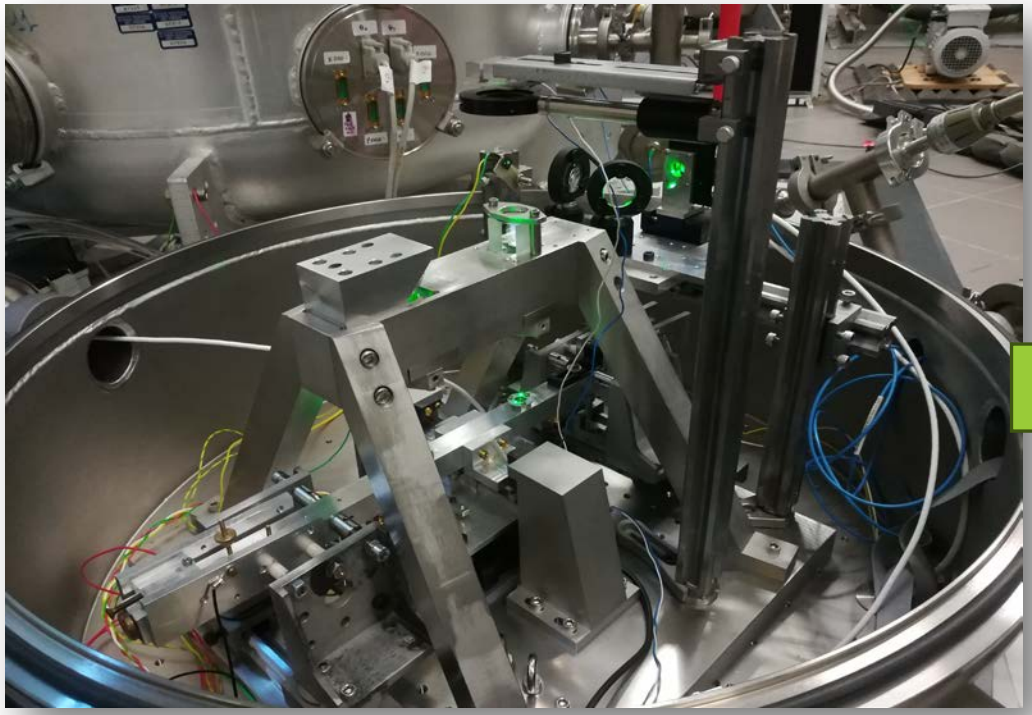
Outline

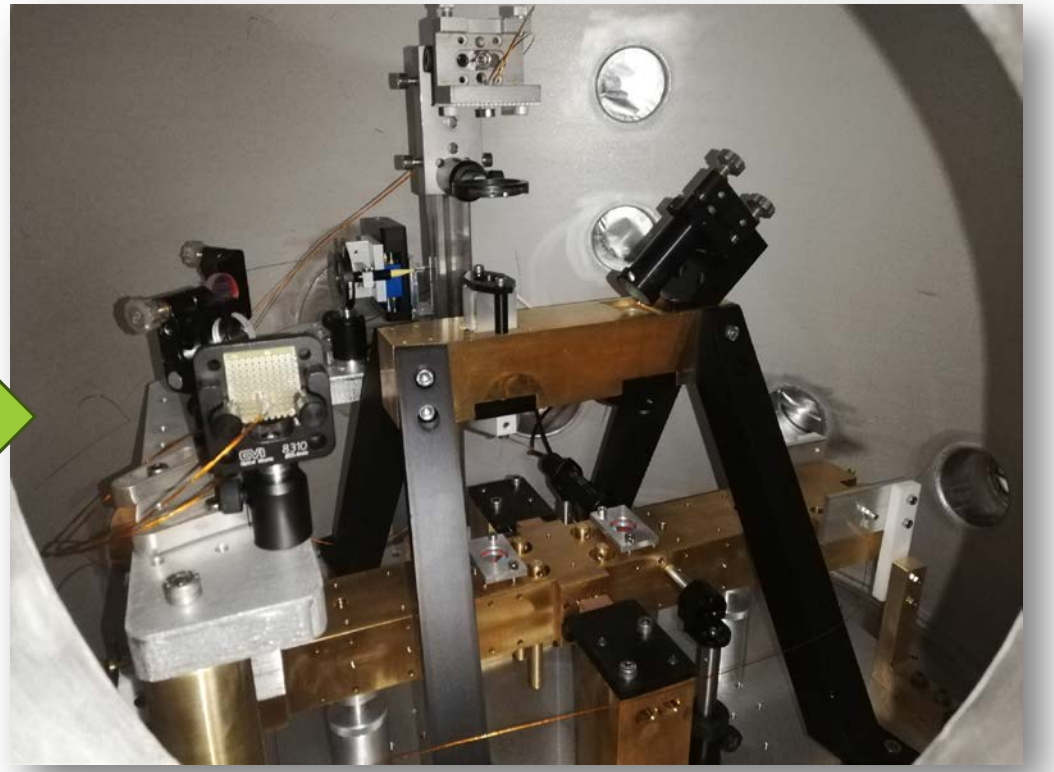
- The Akìnetos tiltmeter: first experimental results
- Next installation of upgraded tiltmeter in Sos-Enattos

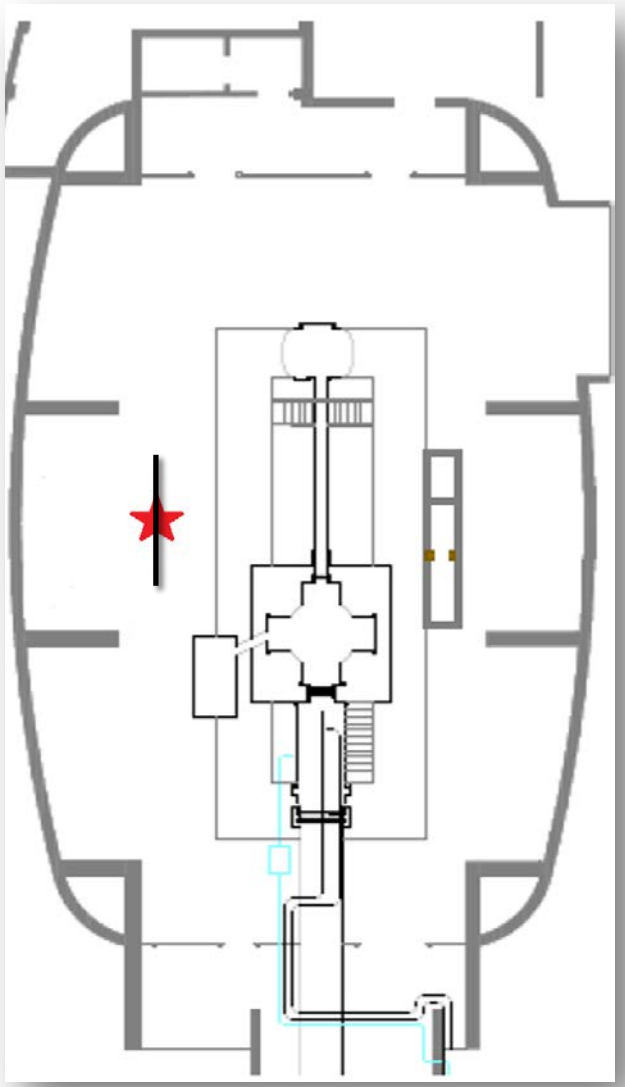
’Ακίνητος: the new tiltmeter

The new tiltmeter exploits the same working principles as the prototype.

Main improvement: arm with much higher momentum of inertia: 13 kg of brass, I = 0.33 kg*m^2, more than one order of magnitude bigger than the previous version, joint size: 0.1x3mm

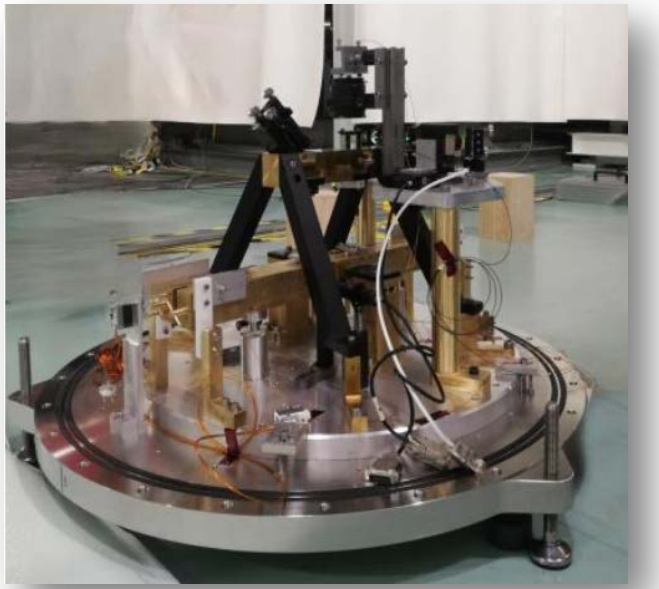




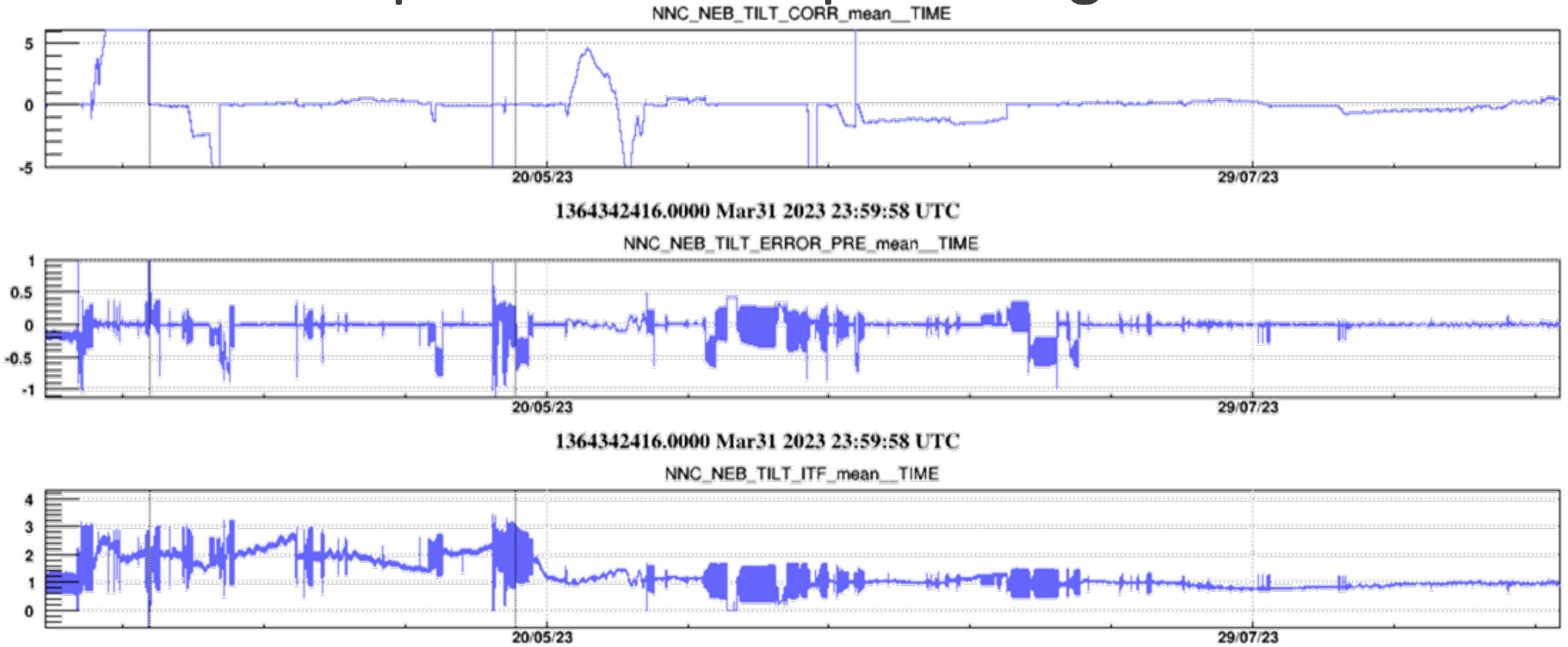


’Ακίνητος: the new tiltmeter

Installed in the NEB, along the arm direction at the end of March 2023

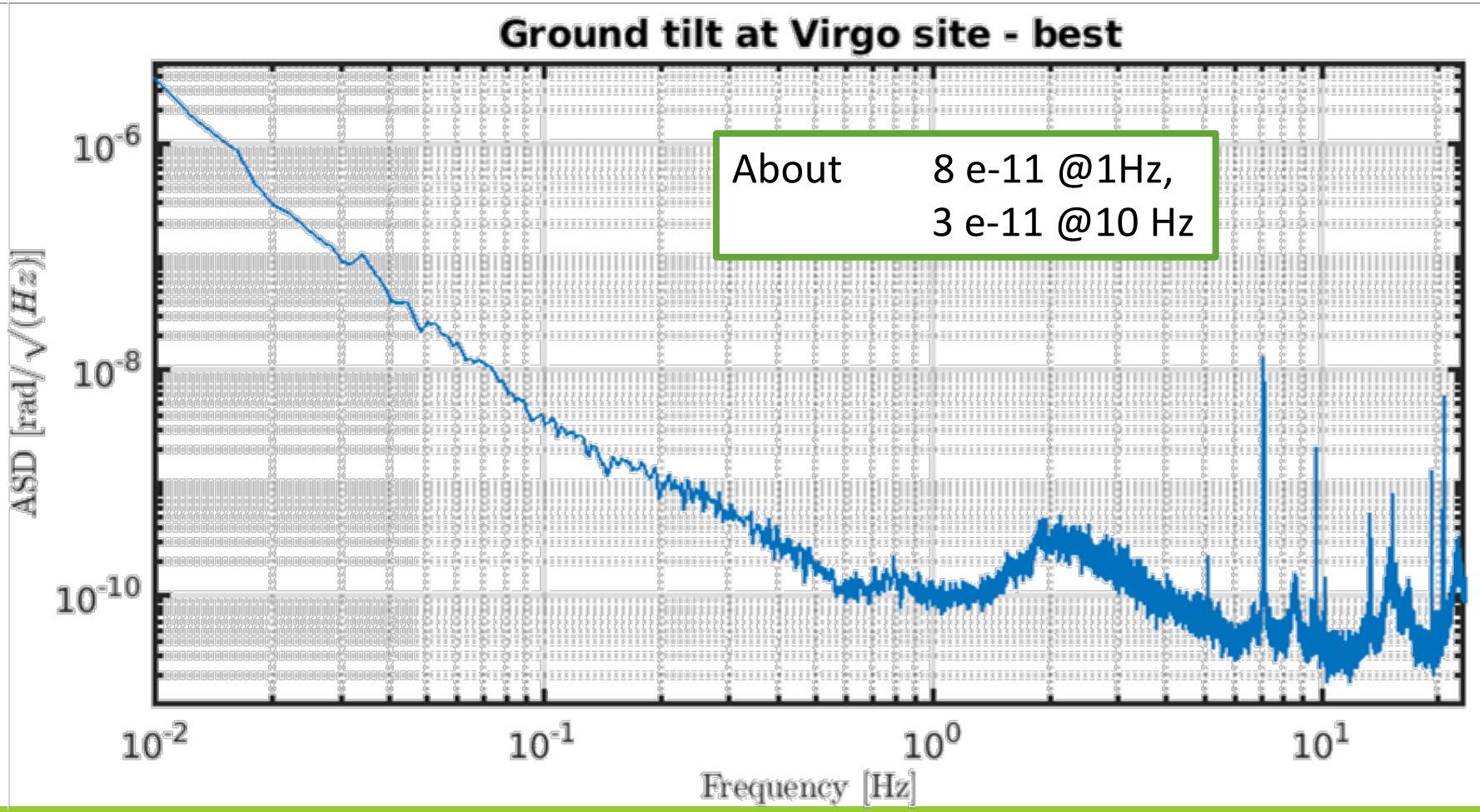


Operation from April to August

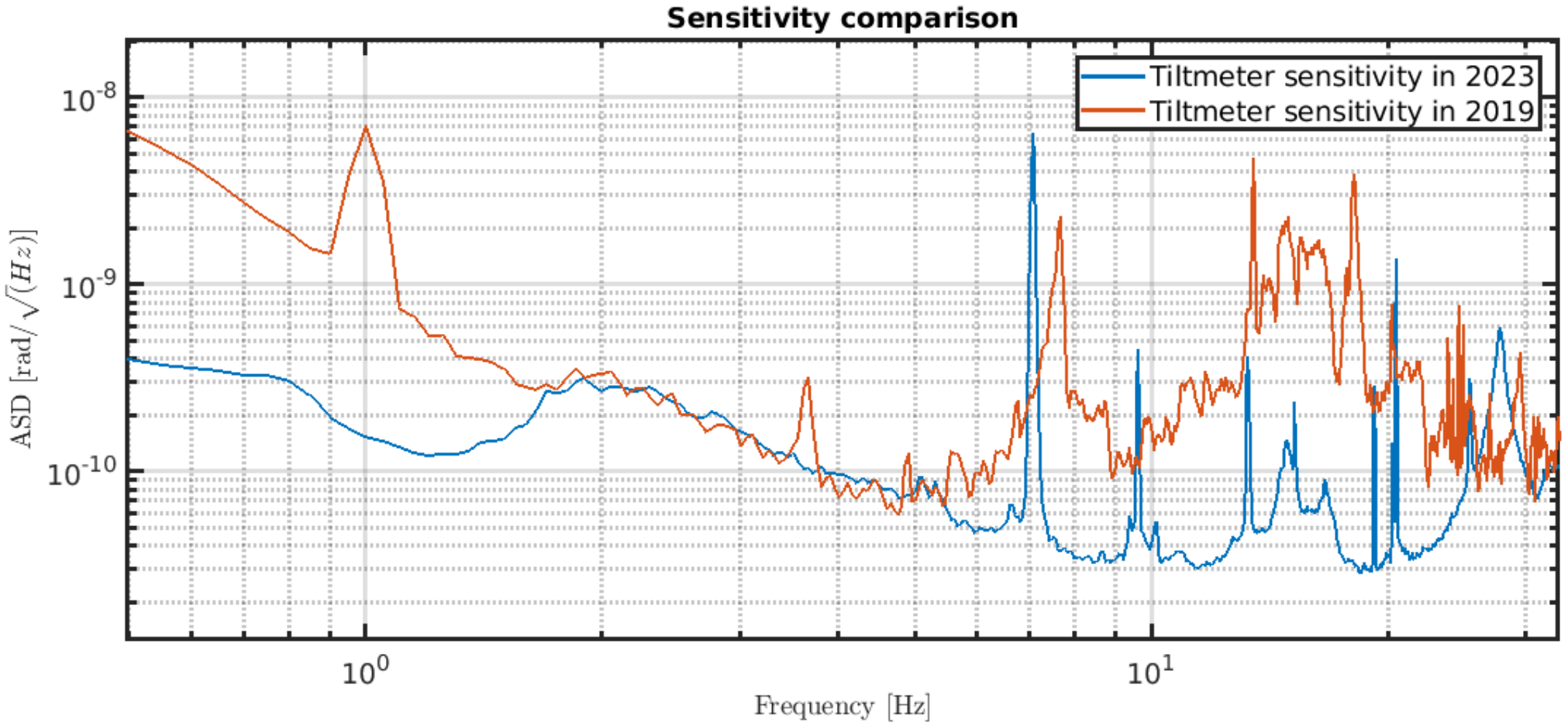


- Duty cycle of more than 50%
- Low correction to hold the beam in position using ITF readout

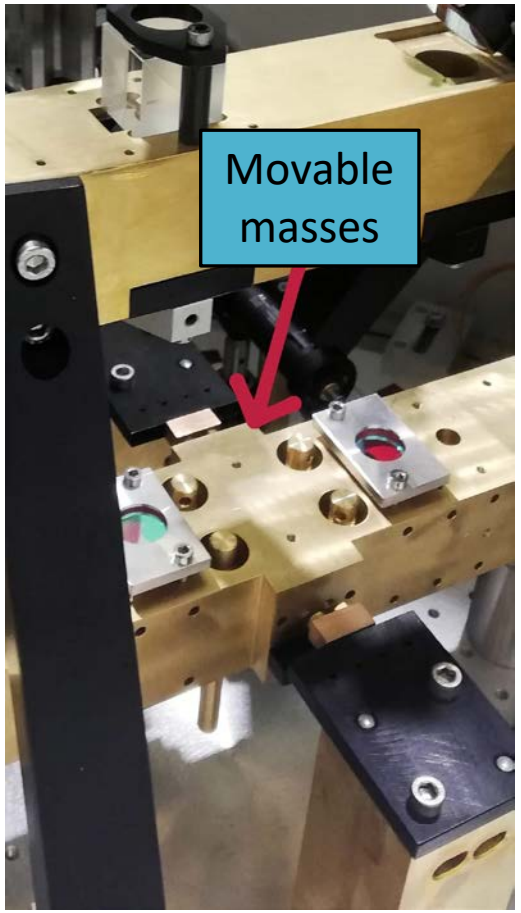
Lowest ground tilt measurement



Comparison between ground tilt measurements with two tiltmeters in 2019 vs 2023

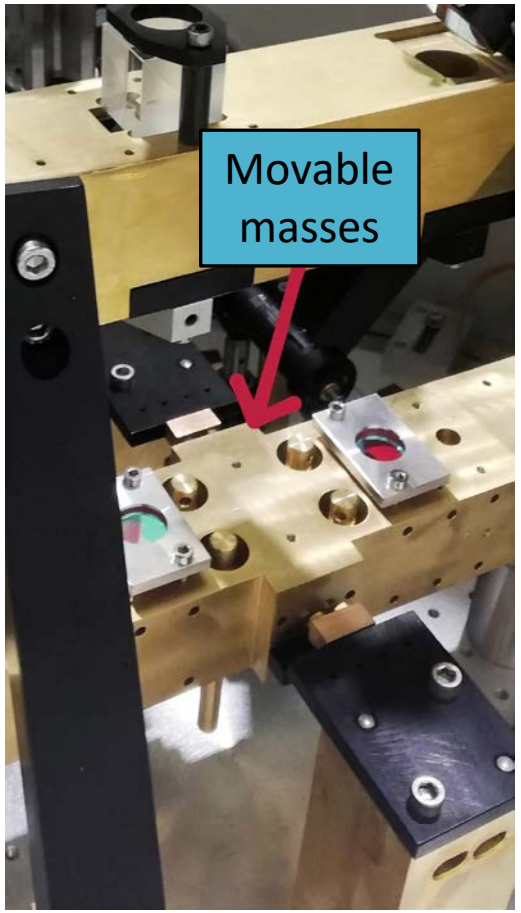


Center of mass raising to reduce the seism-to-tilt coupling

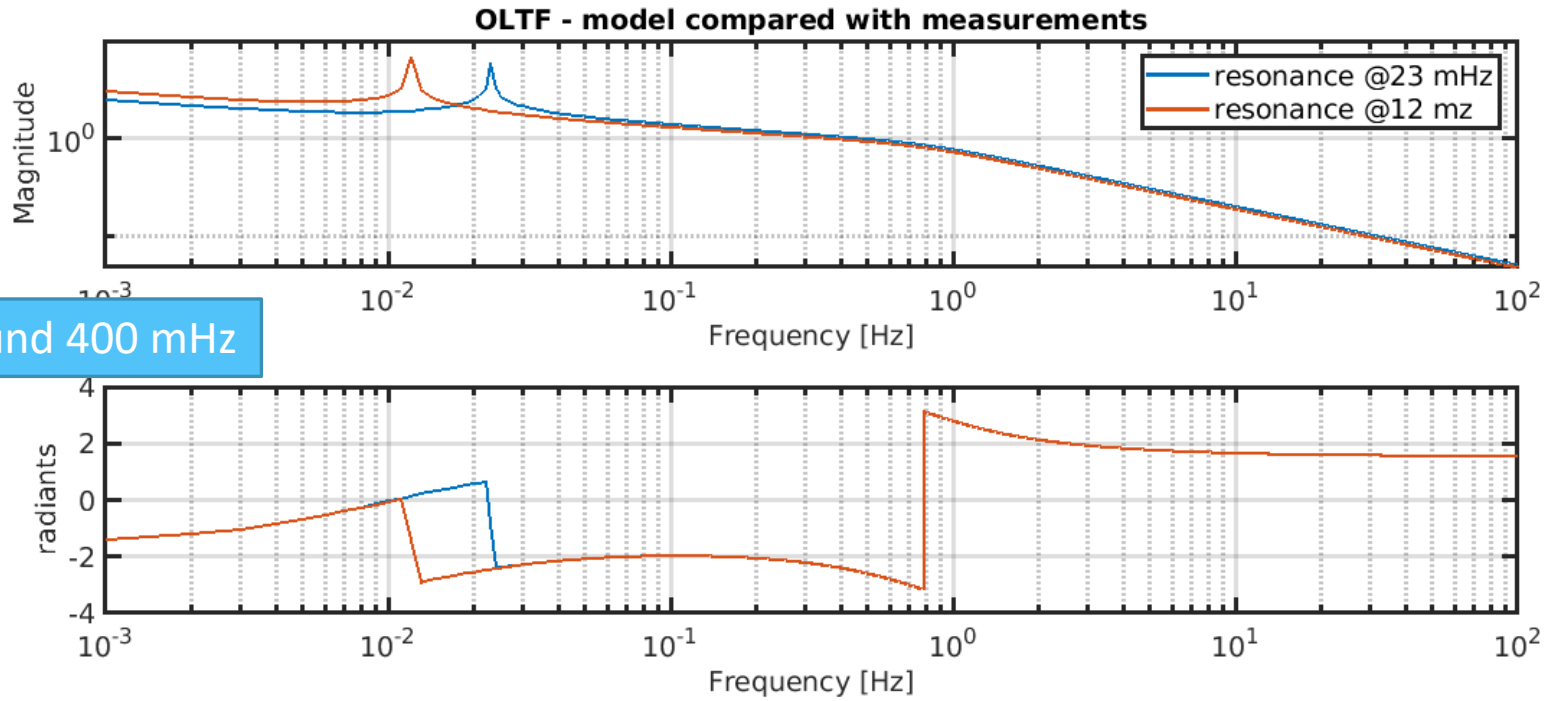


- The tiltmeter behavior simulated with OCTOPUS (P. Ruggi) and tuned to match the measured transverse resonance frequencies – pretty reliable model
- A residual seism-to-tilt coupling along the arm direction has estimated to be a factor of about 1e-3, corresponding to a residual distance between bending point and center of mass of about 50 µm.
- This distance has also been estimated looking at the coherence between the seismometers and tiltmeter signal

Center of mass raising to reduce the seism-to-tilt coupling

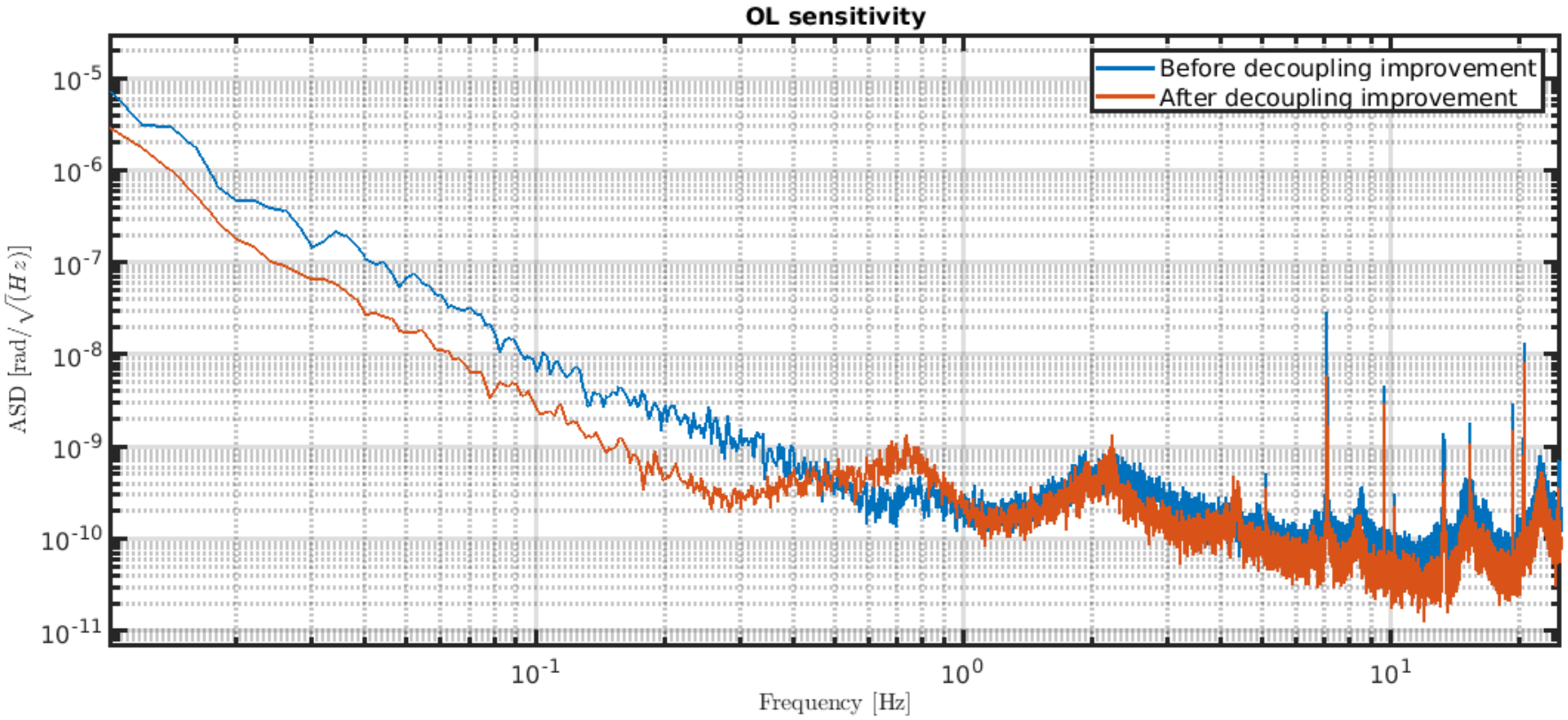


The center of mass was raised by about 35 µm to reduce its distance from the bending point and therefore reduce the seism-to-tilt coupling.
Resonance frequency changed from 23 mHz to 12 mHz

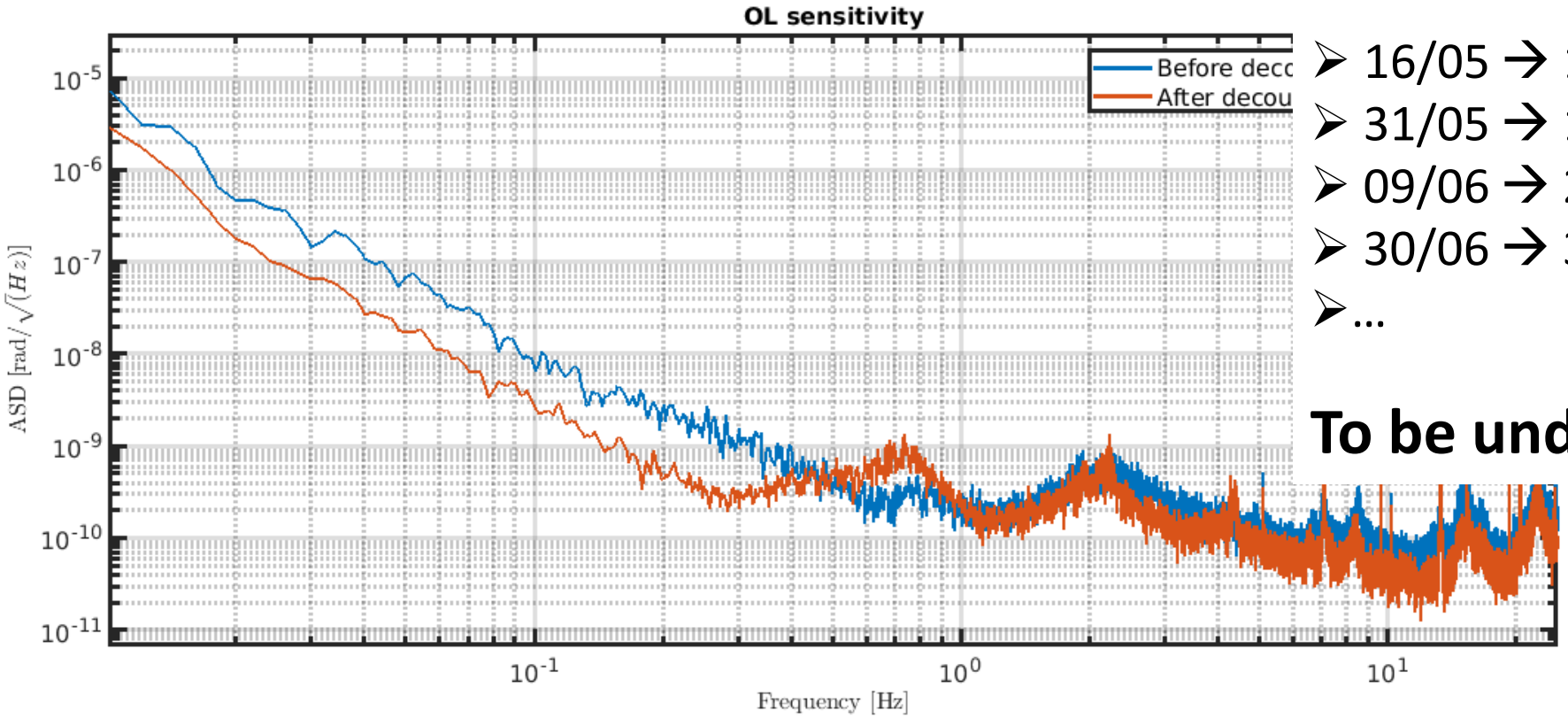


UGF around 400 mHz

Sensitivity before/after decoupling improvement



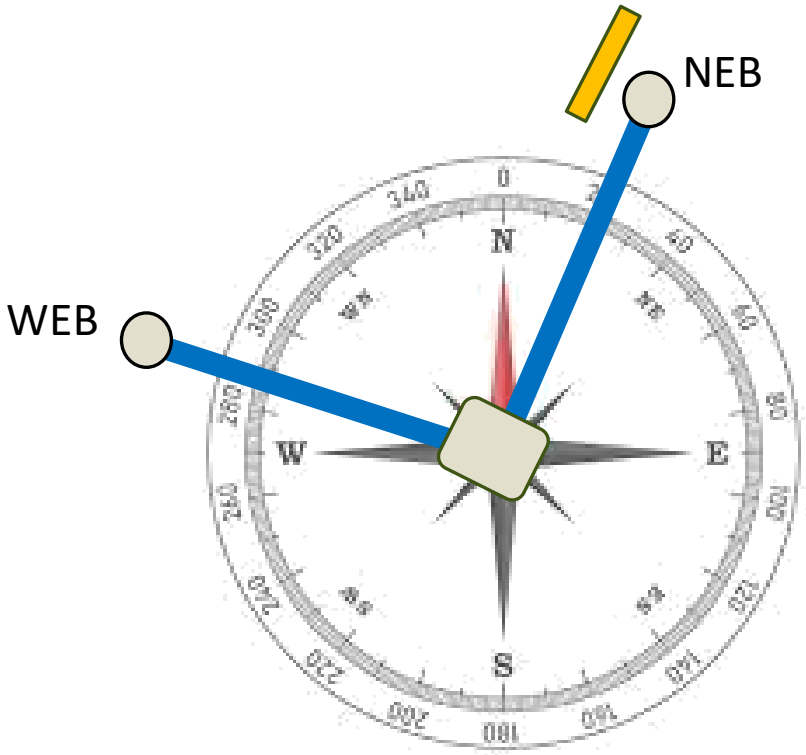
Sensitivity before/after decoupling improvement



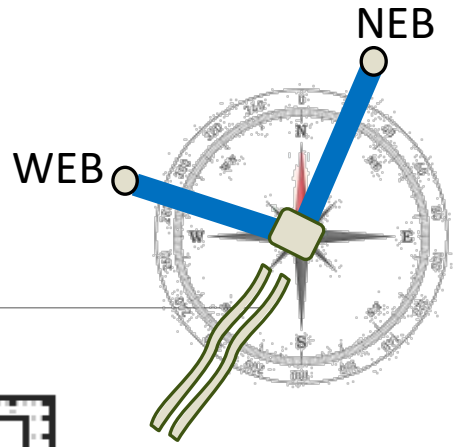
- 16/05 → 12 mHz
- 31/05 → 14 mHz
- 09/06 → 20 mHz
- 30/06 → 30 mHz
- …

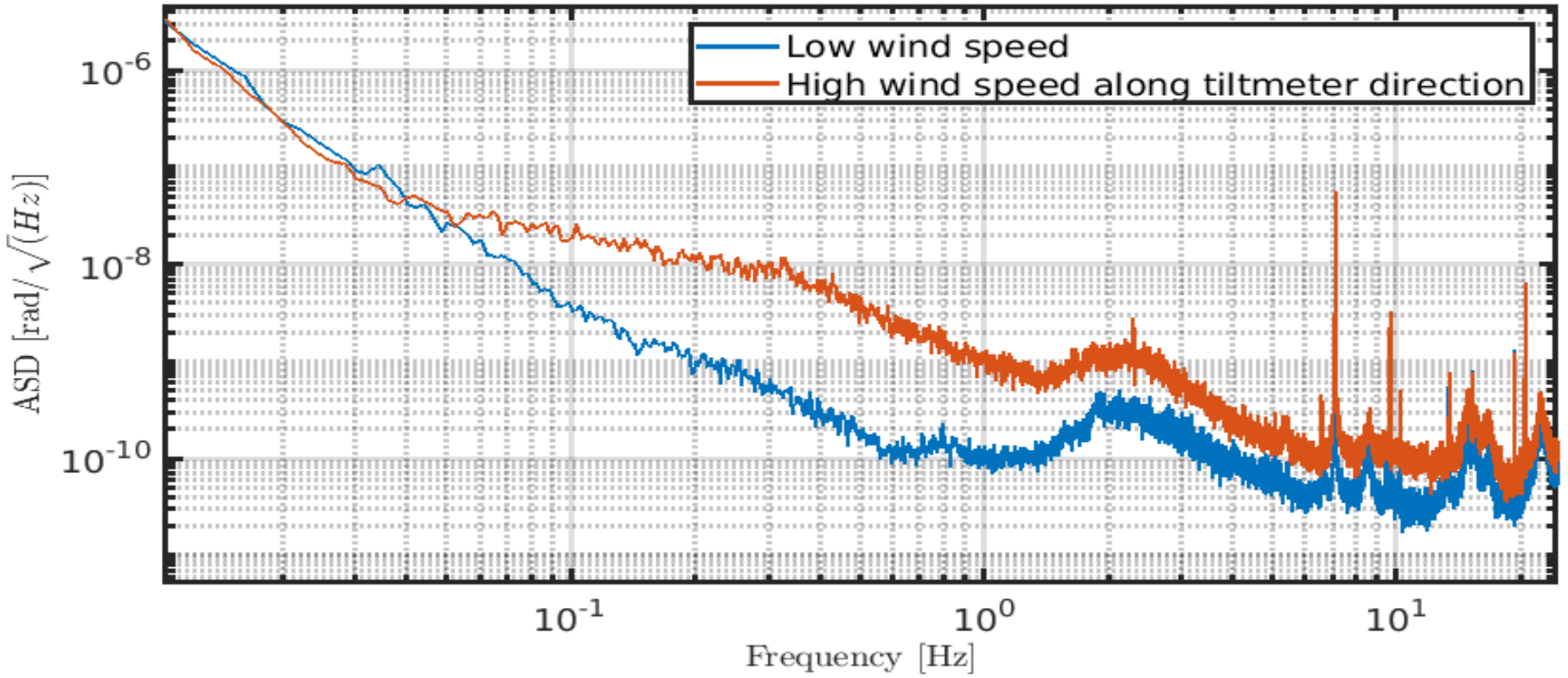
To be understood

Wind effect on the tiltmeter

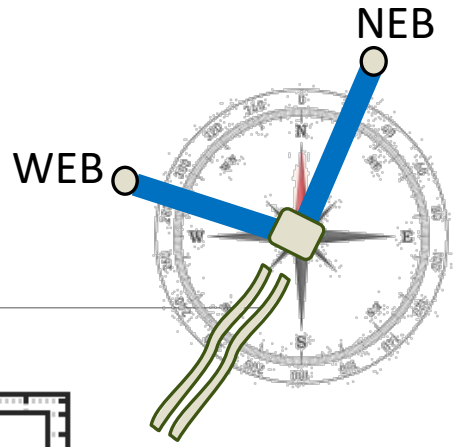


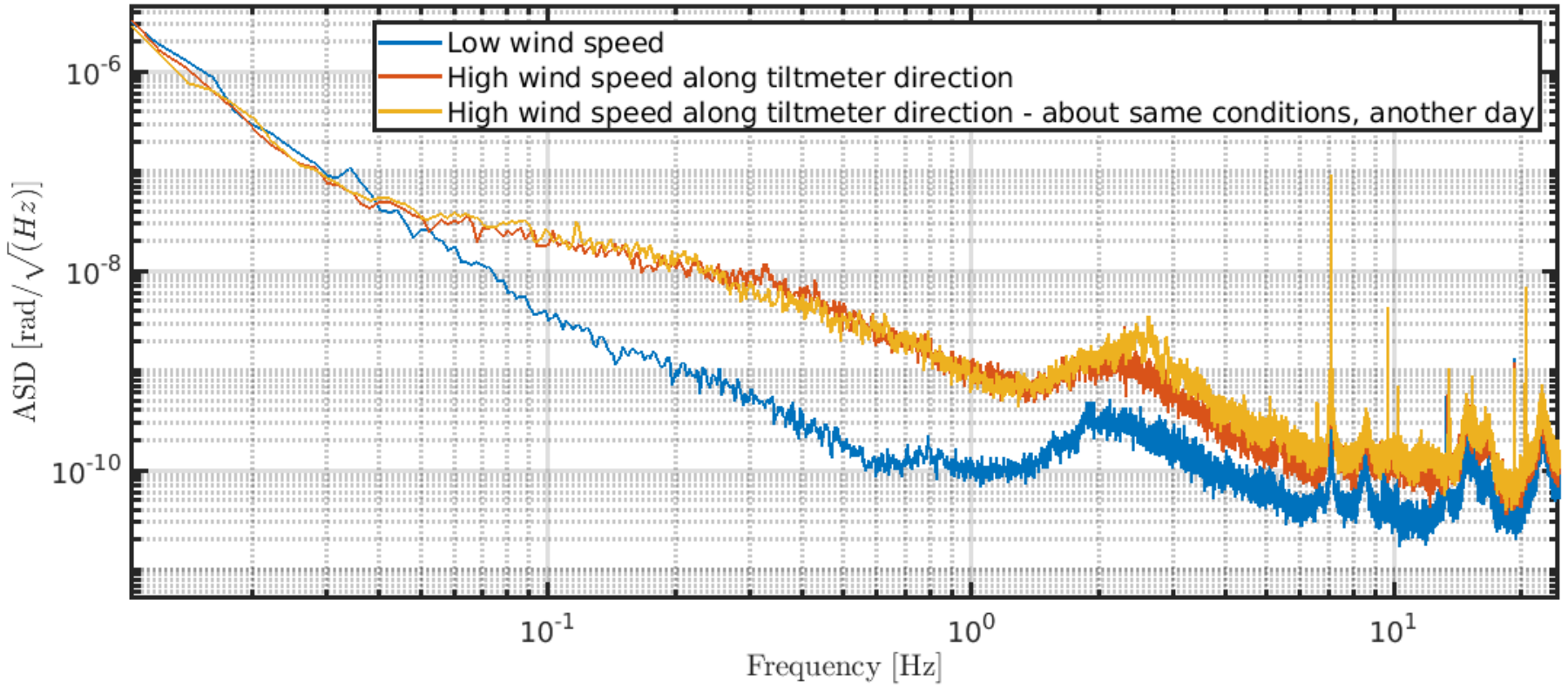
Ground tilt measurement in different wind conditions





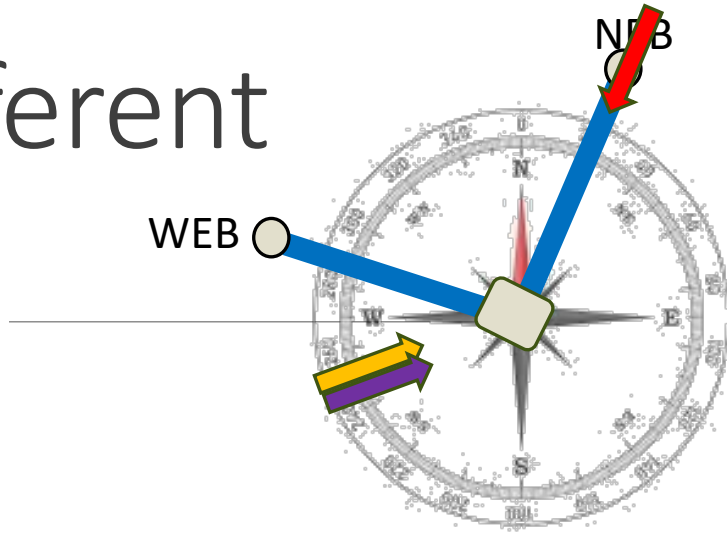
Ground tilt measurement in different wind conditions - repeatability

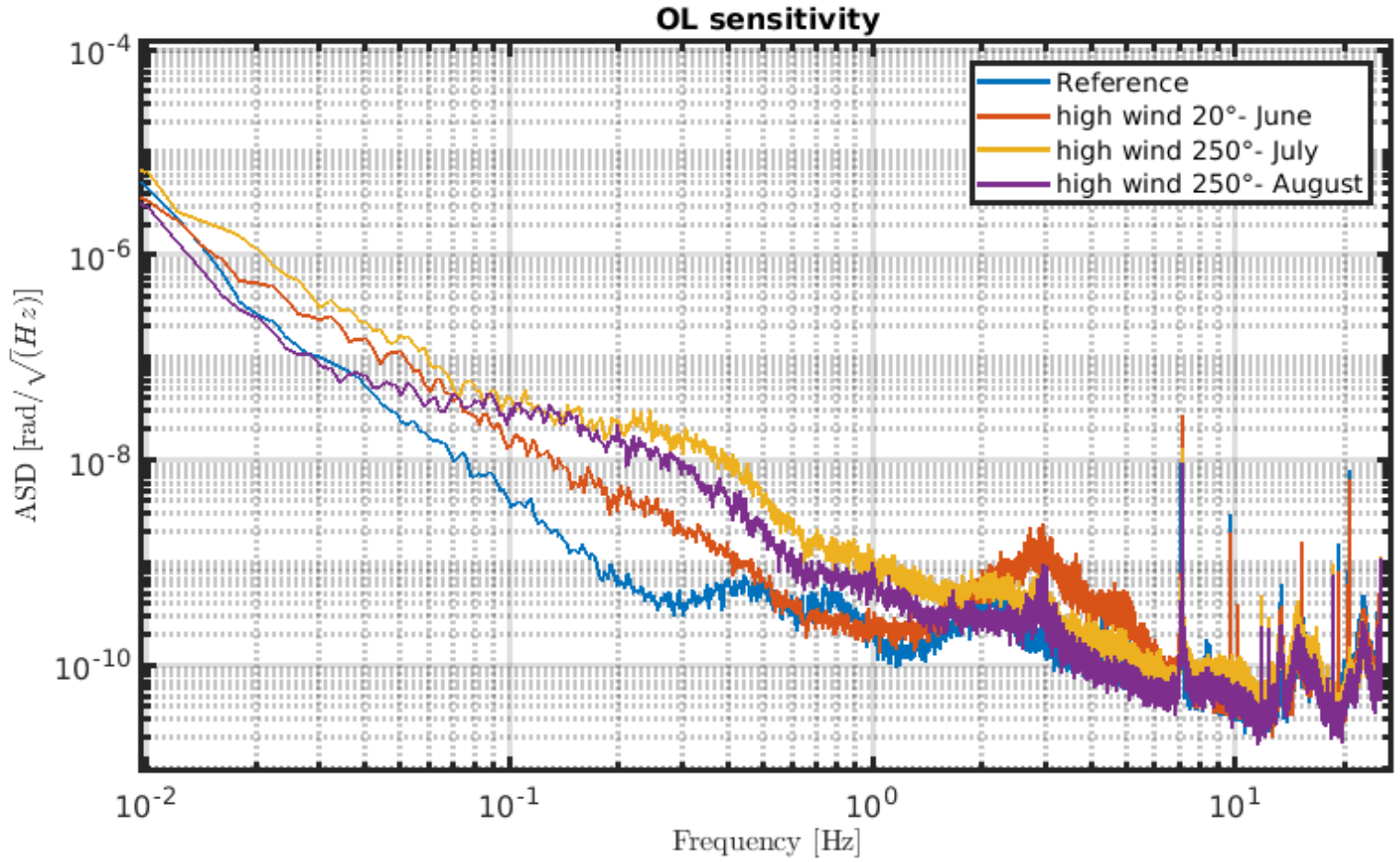




Same spectrum in similar conditions: further confirmation that tilt is actually measured

Ground tilt measurement in different wind conditions





Interpretation not always straightforward…

Current status of Akìnetos

We are not acquiring data since August 28th due to a malfunctioning of the laser, which needs to be replaced

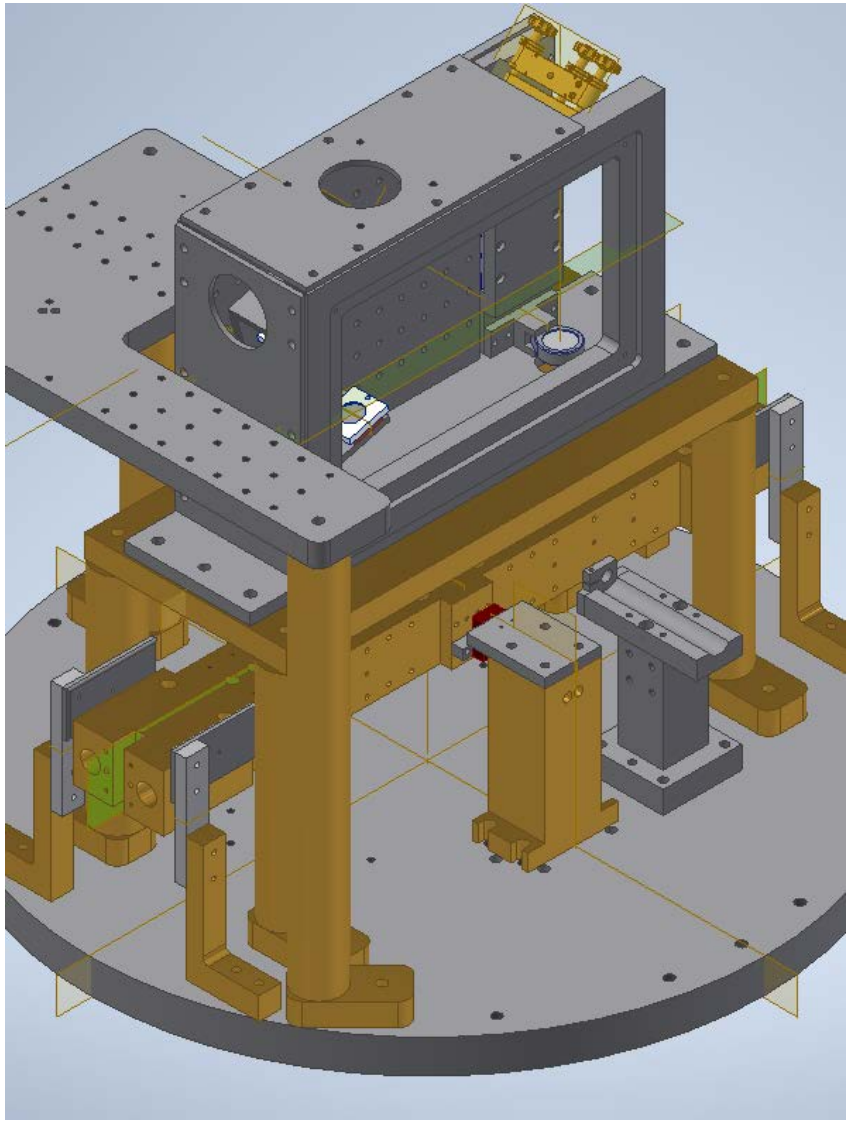
(already ordered a new one, waiting for it to be delivered)

We plan to fix everything and put it back in operation

before Virgo joins O4

Outline

- Akìnetos: first experimental results
- **Next installation of upgraded tiltmeter in Sos-Enattos**



The new tiltmeter in Sos-Enattos

- Improved design to equalize the optical paths of the two interferometer arms → better common noise rejection

- Mirror on the arm spaced by 25cm rather than 10cm → sensitivity improvement by a factor 2.5

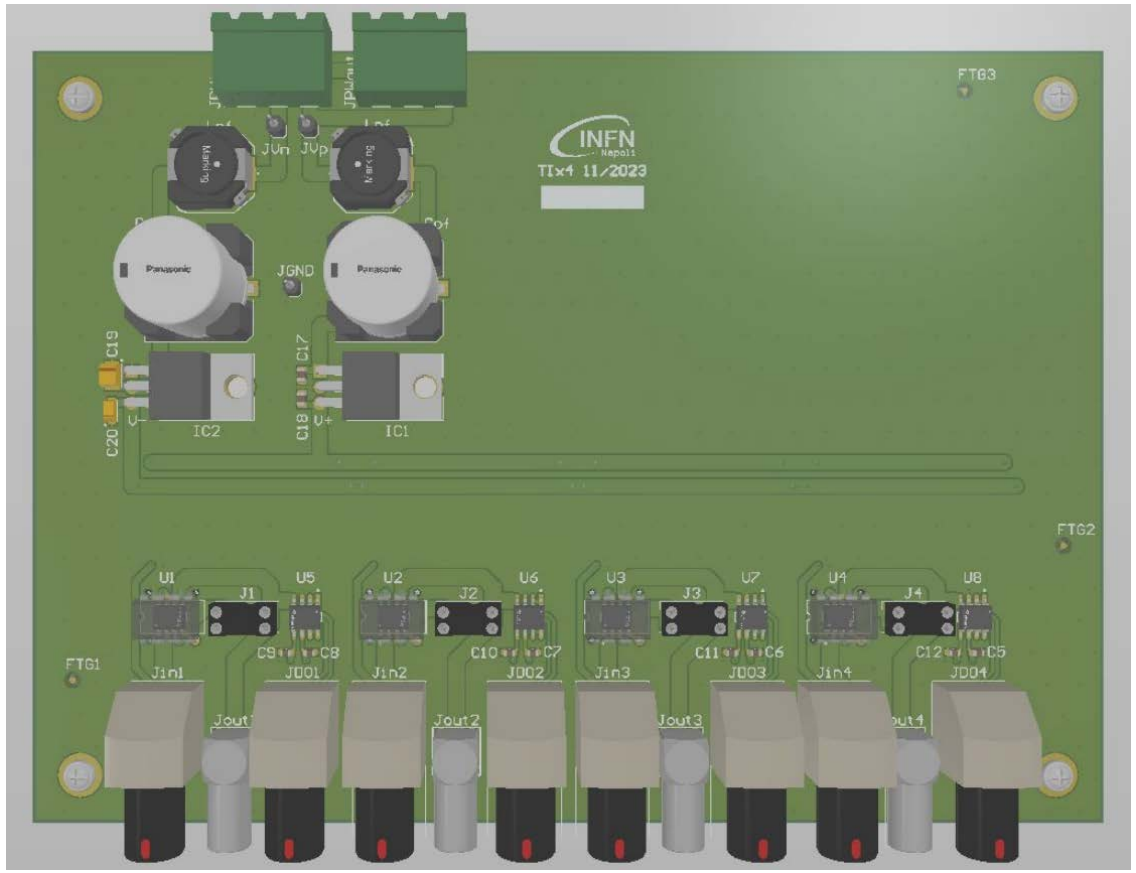
- Optical lever installation to monitor slow drifts

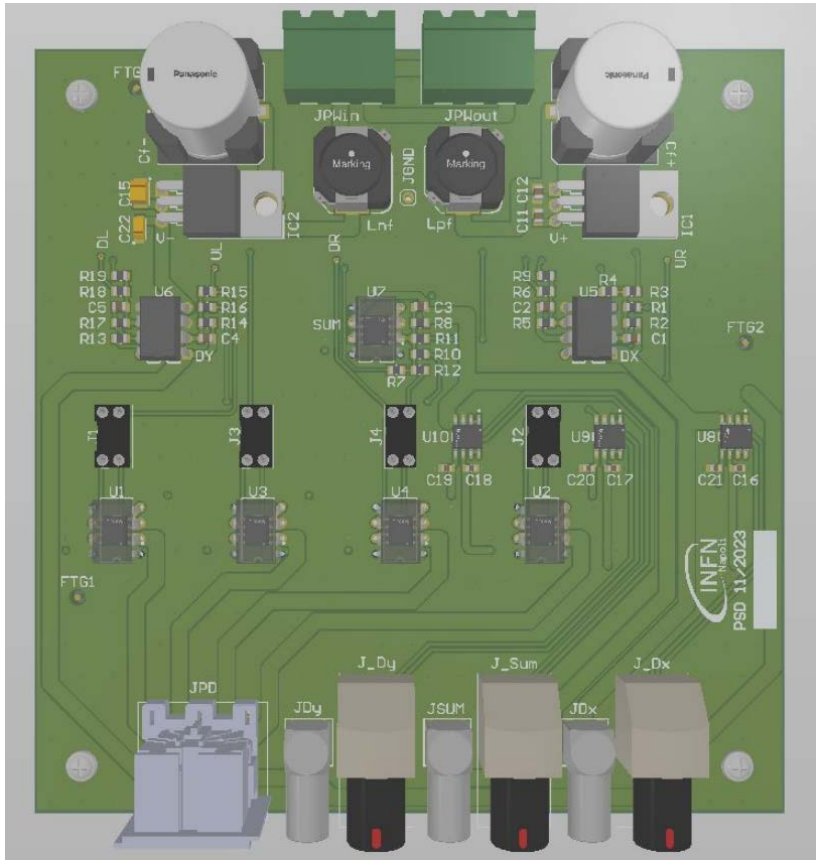
- More screens to prevent scattered light/ghost beams to couple into the ITF main path

- Allow remote control also for the vertical control of the center of mass positioning to improve shift-to-tilt decoupling

- New design of the electronics (on PCB) → lower electronics noises

New design of the electronics (on PCB)





The new tiltmeter in Sos-Enattos

The first installation will be close to the Archimedes experiment. Twofold advantage:

1- compare the reference arm measurement with tiltmeter measurements

2 – compare the tiltmeter measurement with prototype measurements, which is installed about 10 m away, for a better study of the “coherence length”

- ❑ New vacuum chamber already delivered on site
- ❑ Mechanical part construction ongoing, ready by the end of the year
- ❑ First installation at the beginning of 2024

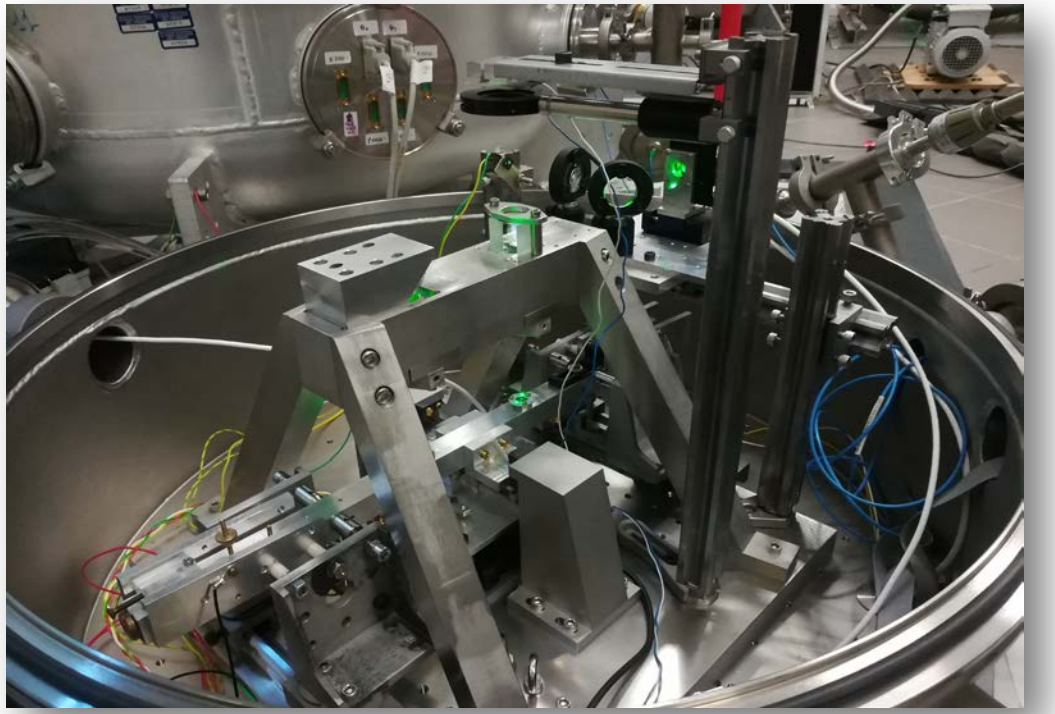
Conclusions and future perspectives

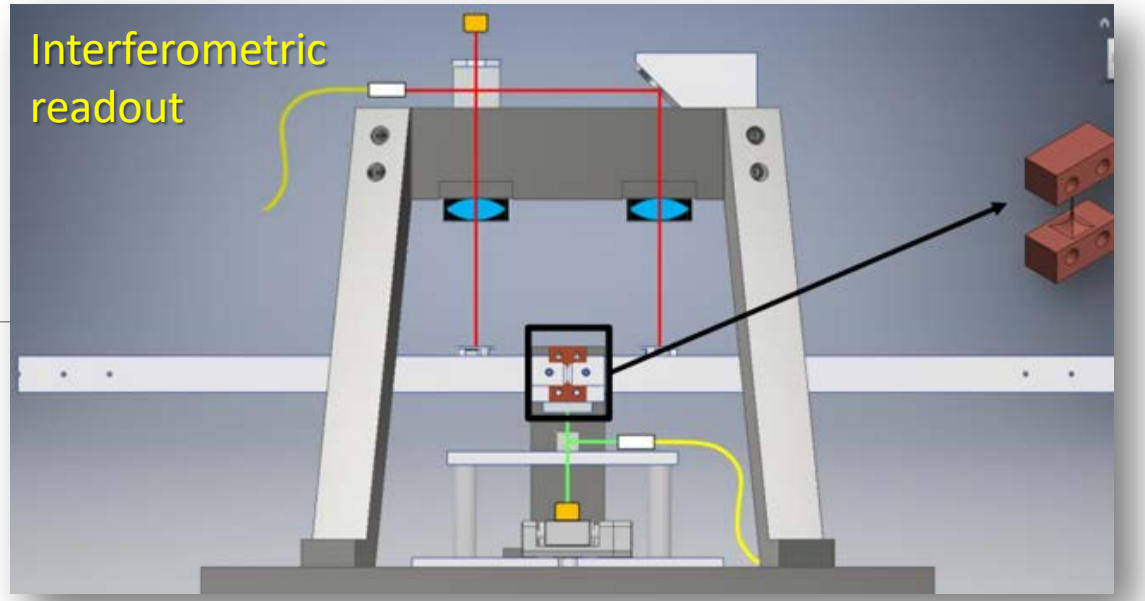
- The **new large-band tiltmeter** has been installed in Virgo will be taking data during O4 close to the North End tower
- **Seism-to-tilt coupling** is still one of the main problems to face, but we know how to act, possibly add a remote control to change center of mass positioning also in Virgo tiltmeter
- **OCTOPUS** simulations will be used to improve the tiltmeter performances
- A **new version of this tiltmeter is being built to be installed in Sos-Enattos**. Many improvments have been foreseen to further reduce power and frequency noise coupling. We expect a much lower noise level than Virgo at the Sos-Enattos site
- Further steps towards a more **compact design** so that, if necessary, a tiltmeter can be inserted directly into the new ET suspension chamber

Extra slides

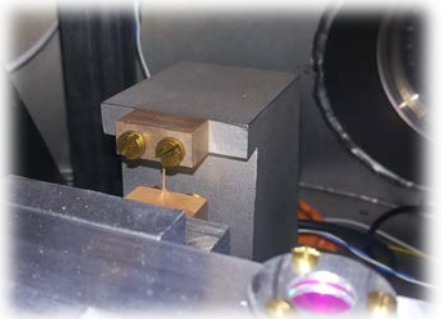
Tiltmeter prototype - mechanics

- **Beam balance,** 50 cm long aluminum arm with brass cylinders 11 cm long inside, with low momentum of inertia (0.02 kg*m^2)

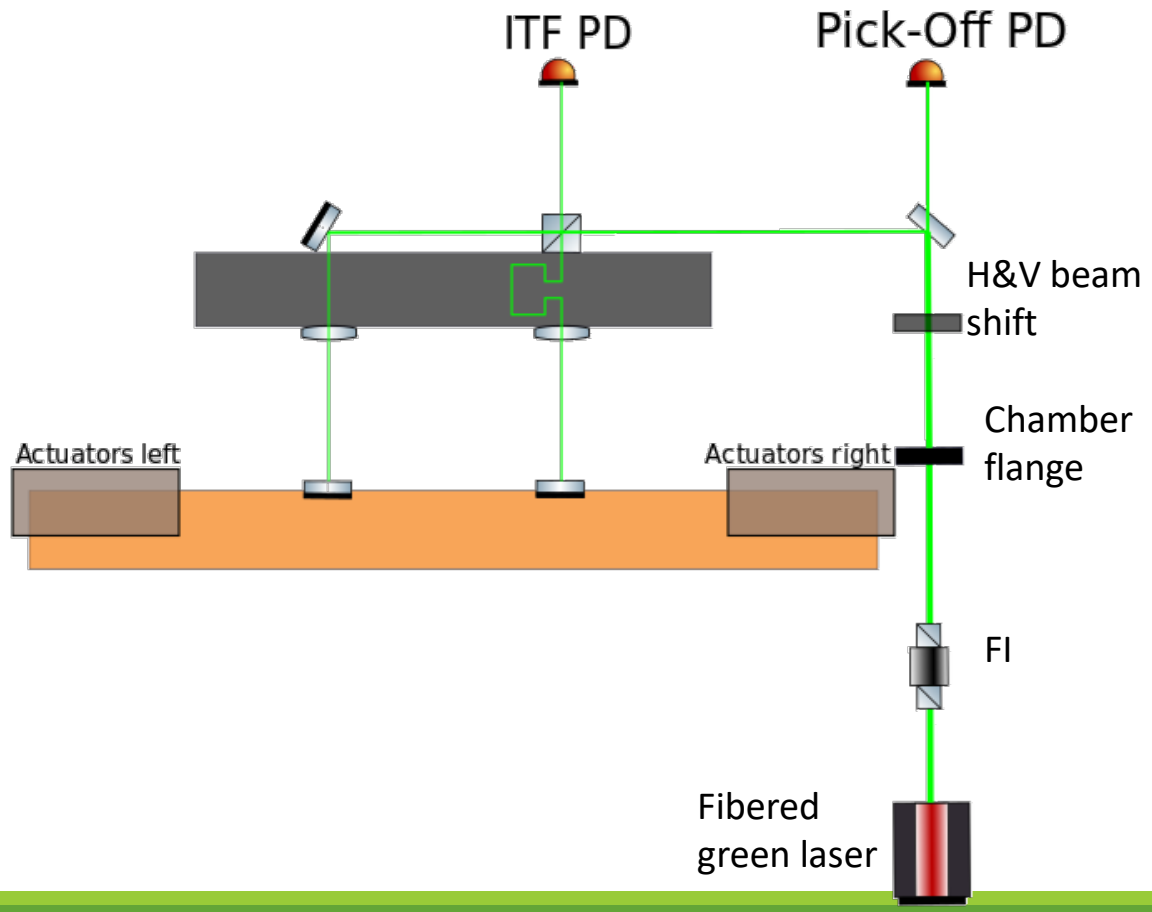


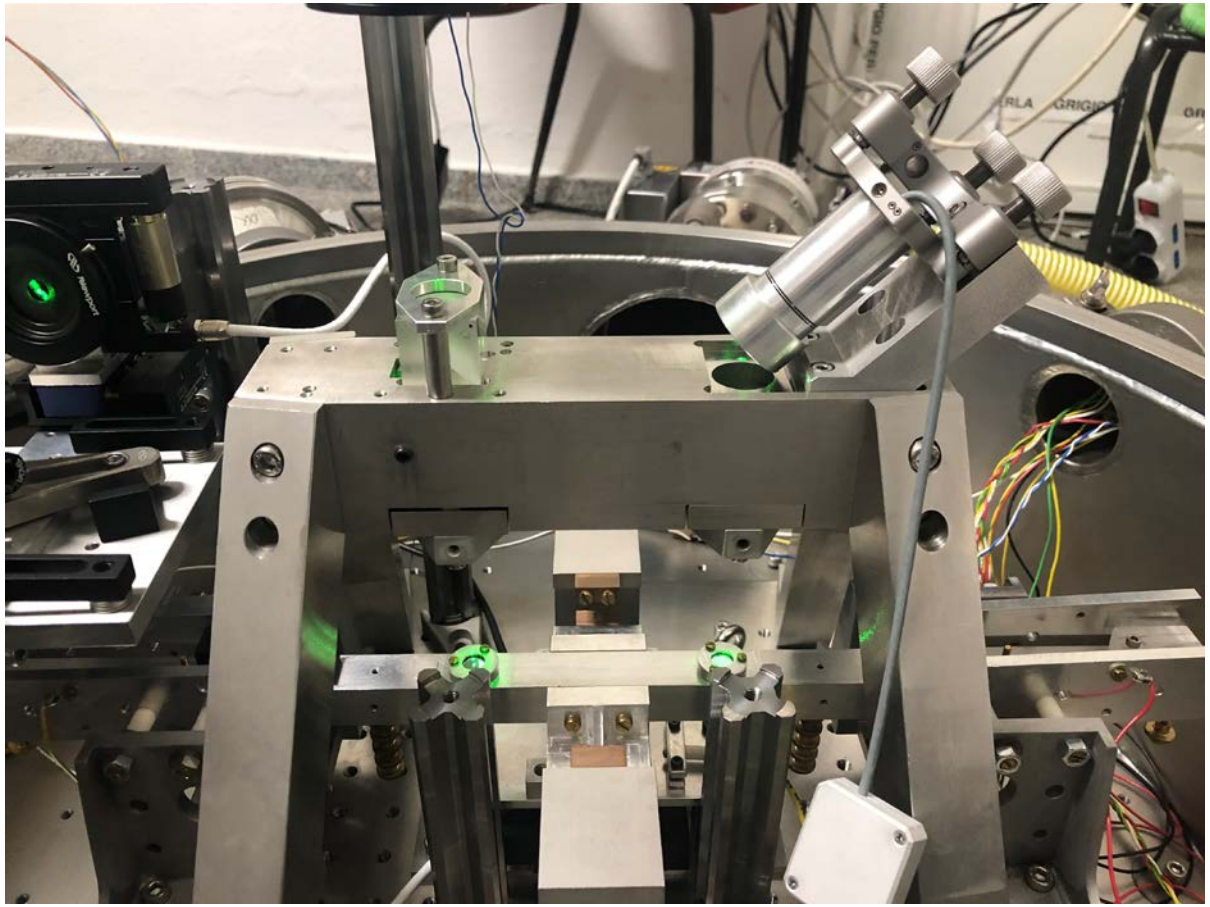


- Tiltmeter arm is suspended through **Cu-Be flexible joints**, **100µm x 500µm in section,** very similar in design to LIGO tiltmeters (*Venkateswara et al., 2014*) which allow to keep **the resonance frequency below 20 mHz**



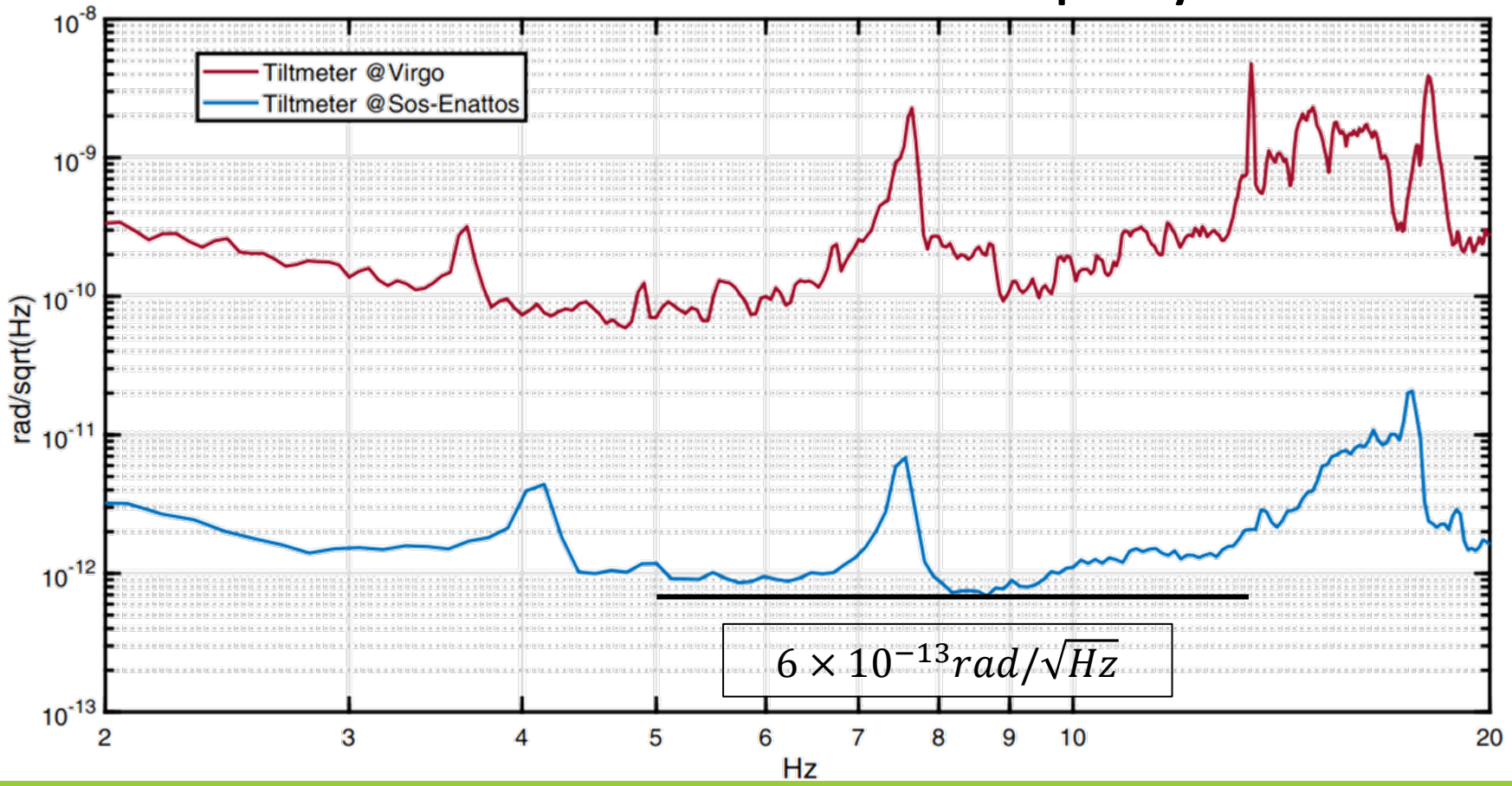
Tiltmeter – first improvements





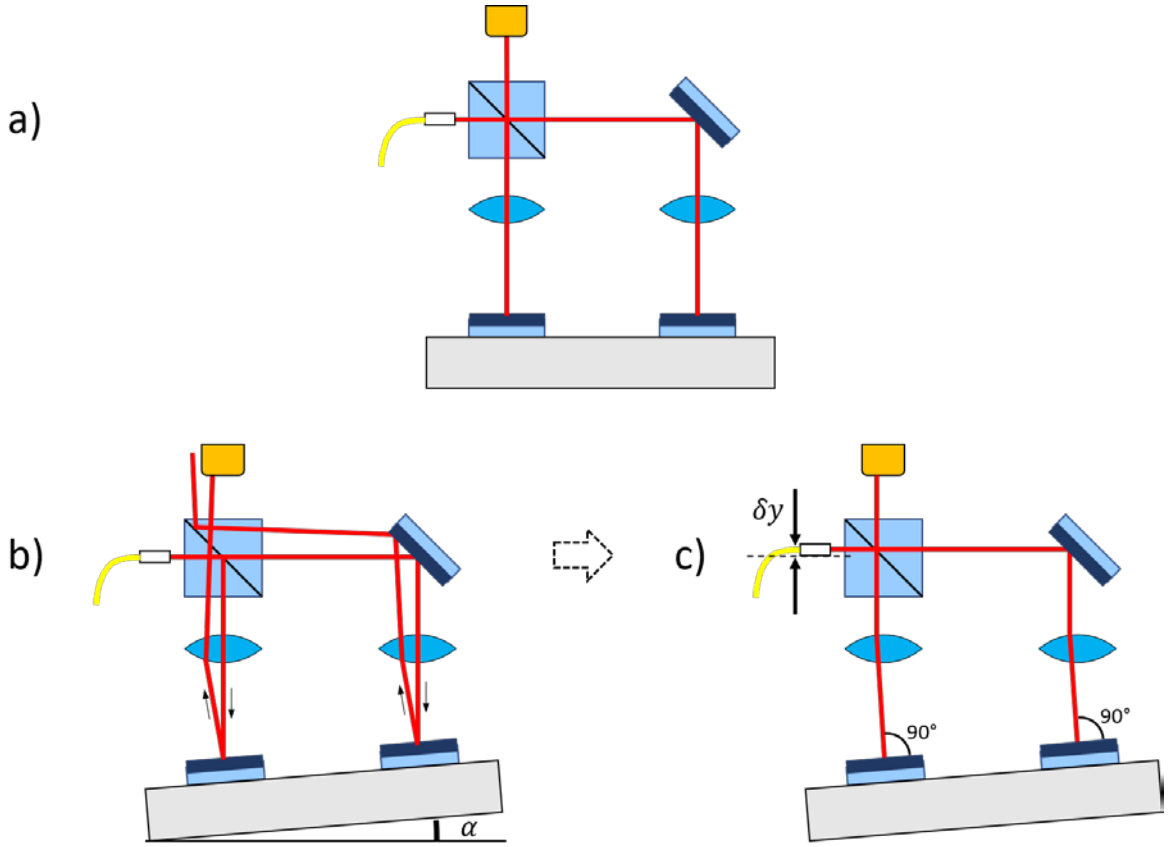
Tilt measurement comparison between Virgo and Sos-Enattos

Most sensitive tiltmeter in the world in the frequency band 2-20 Hz



L. Errico et al, Eur. Phys. J. Plus (2021) 136:1069

ITF robustness against tilts

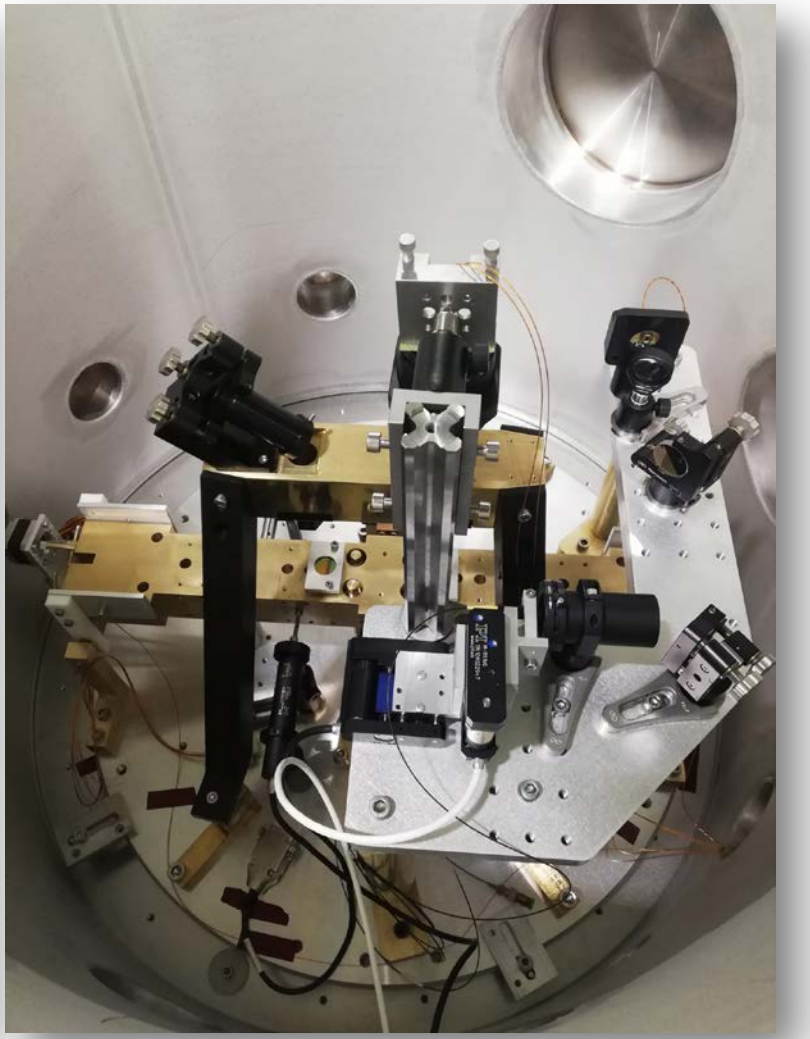


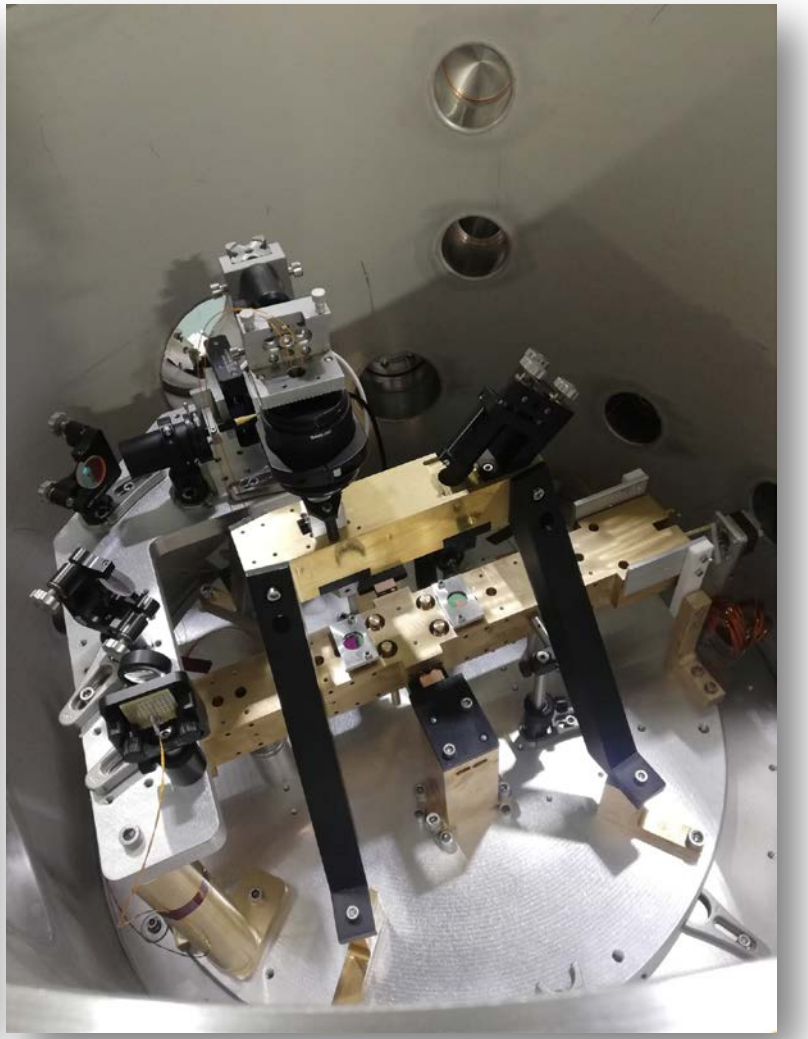
(a) The interferometer is aligned while the balance arm is horizontal

(b) An arm tilt α would misalign the interferometer

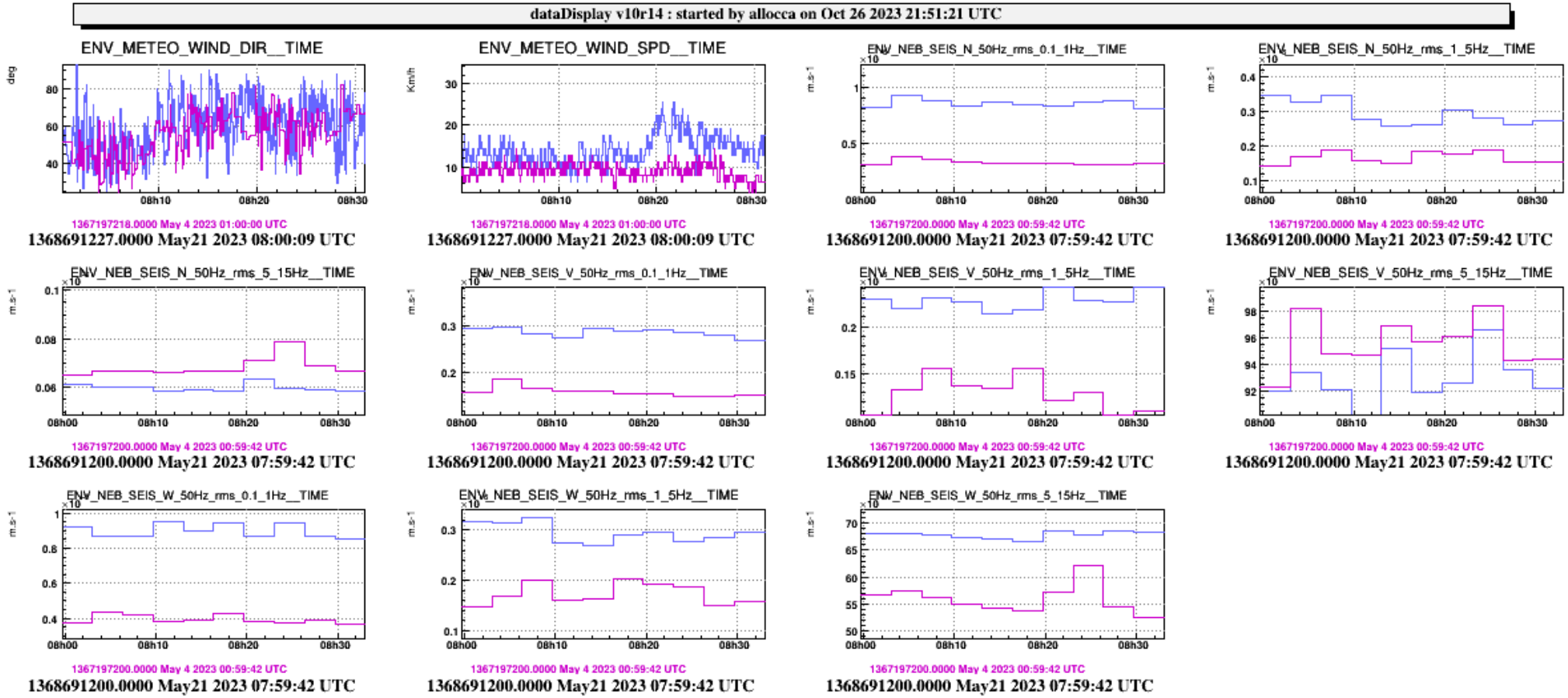
(c) The presence of lenses in both arms permits the realignment by moving vertically by an amount $\delta y = L_f \alpha$ the input laser beam, where L_f is the lens focal length

’Ακίνητος: the large-band tiltmeter

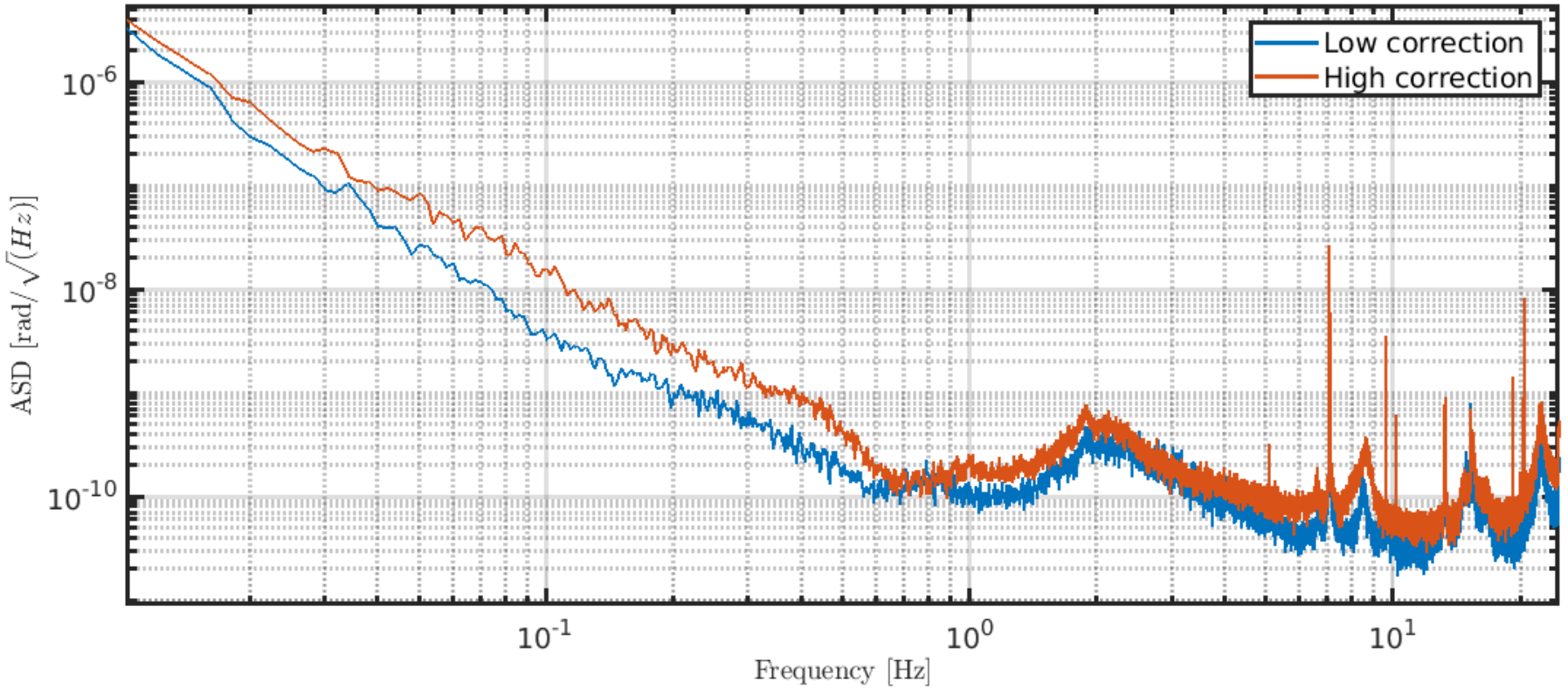




Sensitivity before/after center of mass raising



Effect of actuation noise @low frequency



Effect of actuation noise @low frequency