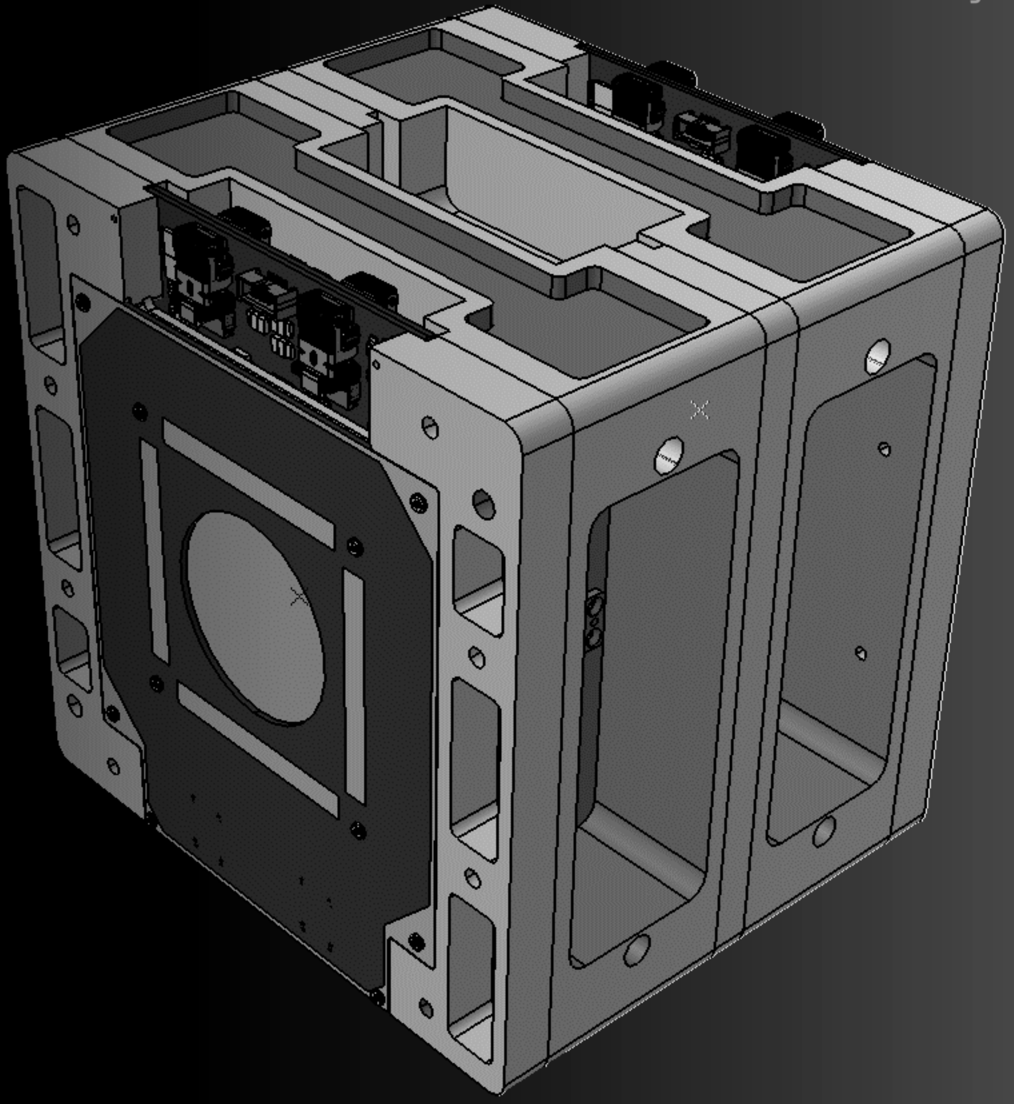
Space-flight readiness assessment of the PAN demonstrator mechanical design

Edoardo Mancini
INFN Perugia

Forum on tracking detector mechanics
Frascati, 8th of June 2022



Penetrating Particle Analyzer

Penetrating Particle Analyzer

The Mechanic Team

- Franck Cadoux – responsible of the mechanics – University of Geneve
- Lorenzo Mussolin – tests – University of Perugia
- Edoardo Mancini – tests – INFN/University of Perugia
- Laurent Nicola - mechanical designer - University of Geneve
- Sylvain Pampaloni – CNC technician - University of Geneve

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Penetrating Particle Analyzer

Speaker introduction

Research grant - INFN office in Perugia

2nd year PhD student – University of Perugia
"Dynamic analysis of space structures"

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SEZIONE DI PERUGIA

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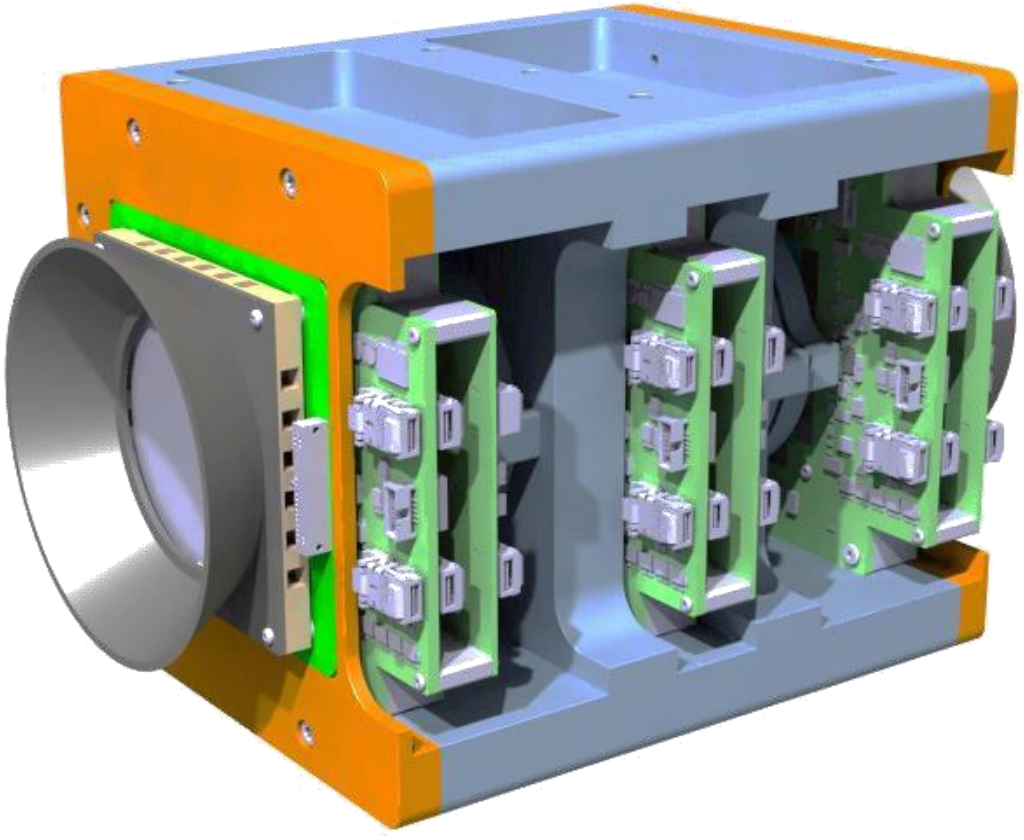
Framework

Project: development of a compact particle detector for space missions

Capabilities:

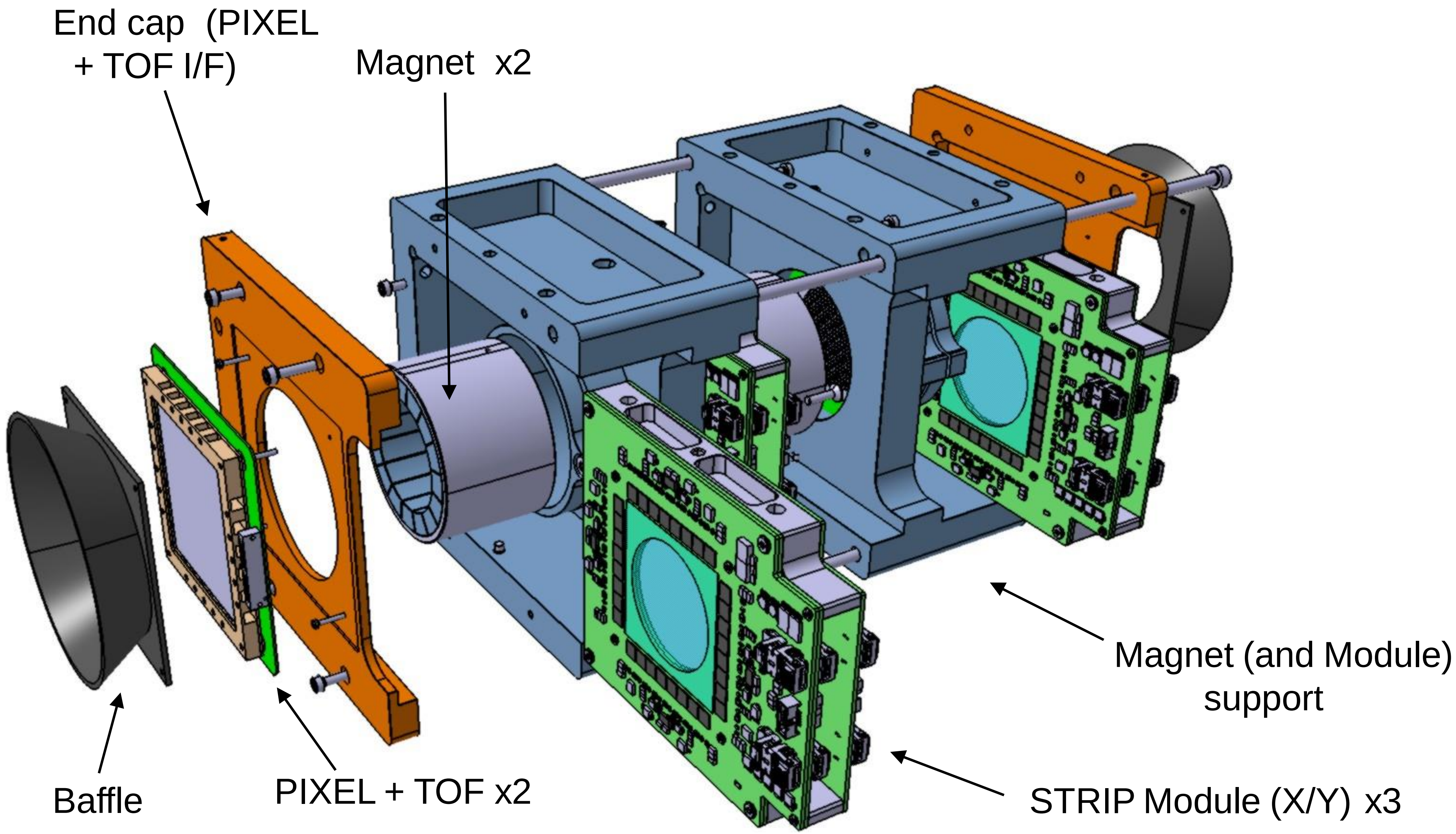
- Detection of highly penetrating cosmic particles (from $100\,\frac{MeV}{n}$ to $20\,\frac{GeV}{n}$)
- Discernment of positive and negative particles



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862044.

Horizon 2020
European Union Funding
for Research & Innovation

The Mechanics of the Experiment



PAN

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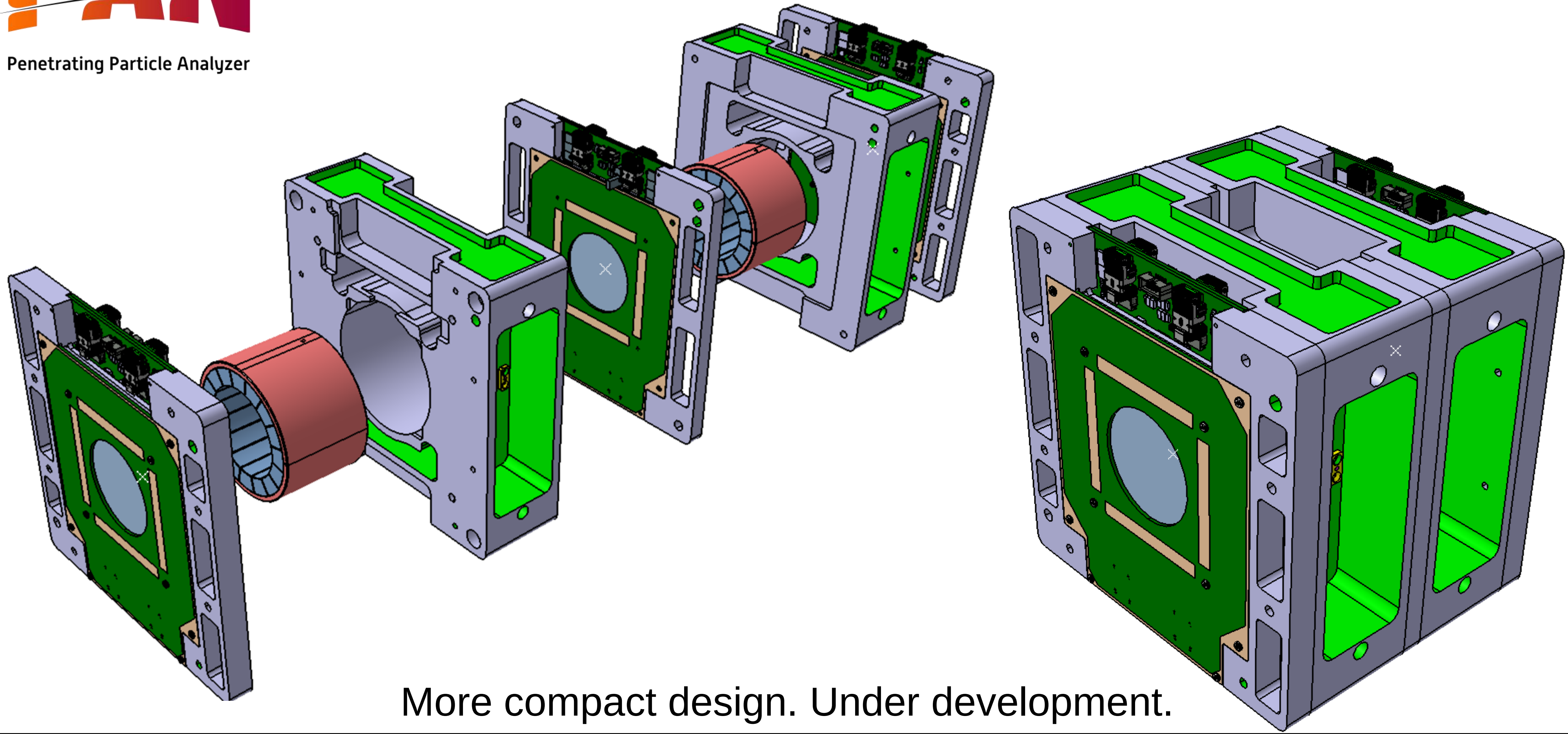
The Updated Mechanics



More compact design. Under development.

Working environment

Penetrating Particle Analyzer

Launch associated loads:

- Static acceleration
- Harmonic vibrations
- Random vibration
- Shocks

Causes:

- Rocket vertical motion
- Rocket-air interaction
- Wind
- Rocket engine combustion transient
- Rocket stages separation

Working environment

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PAN
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Launch loads – static acceleration

- Longitudinal acceleration up to 4/5 g
- Lateral acceleartion less than 1 g

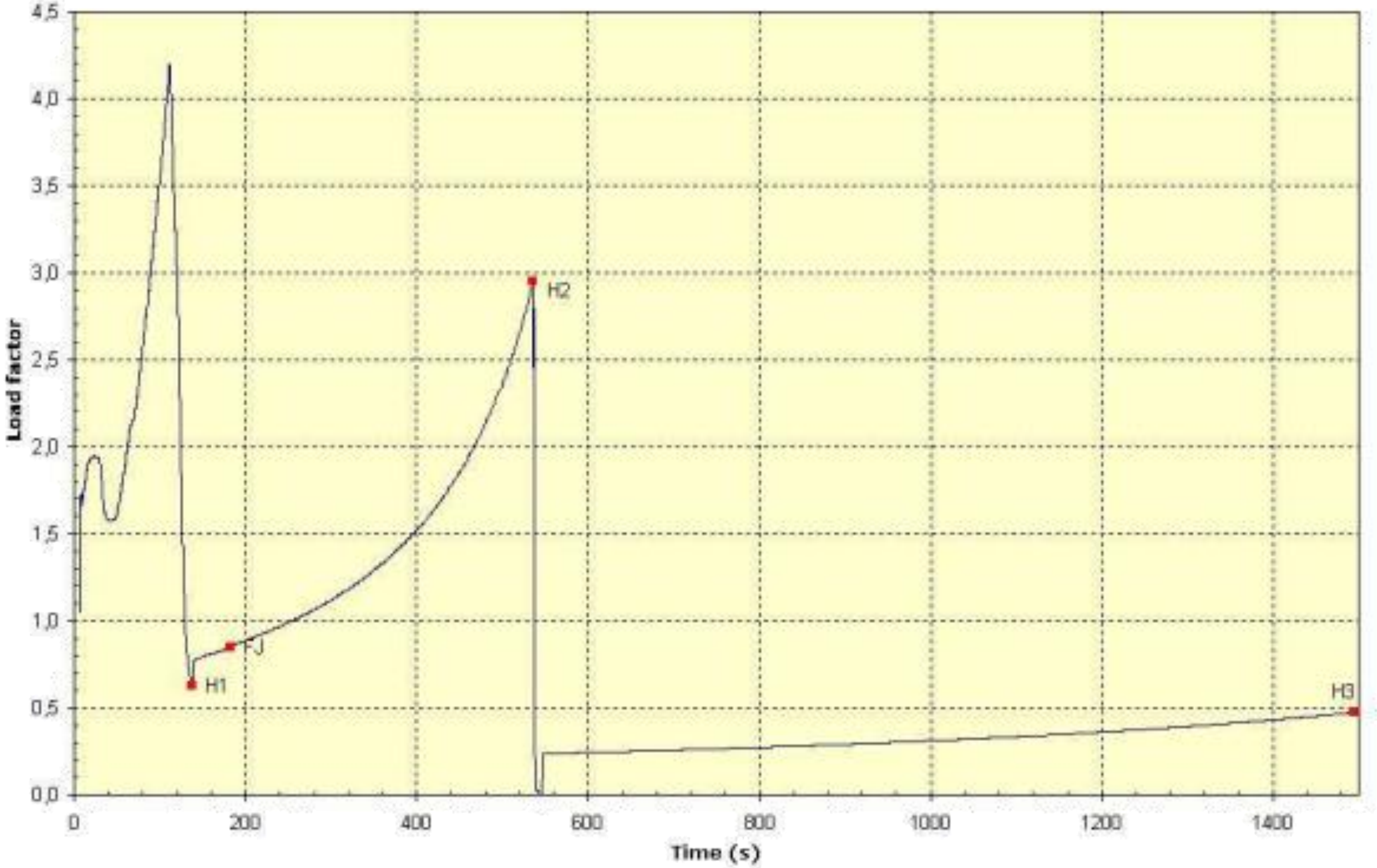


Figure 3.2.1.a – Typical longitudinal static acceleration

Source: Ariane 5 UM [Microsoft Word - MUA5_5_1_INTRO.doc (arianespace.com)]

Launch loads – vibrations

Source: Ariane 5 UM [Microsoft Word - MUA5_5_1_INTRO.doc (arianespace.com)]

Penetrating Particle Analyzer

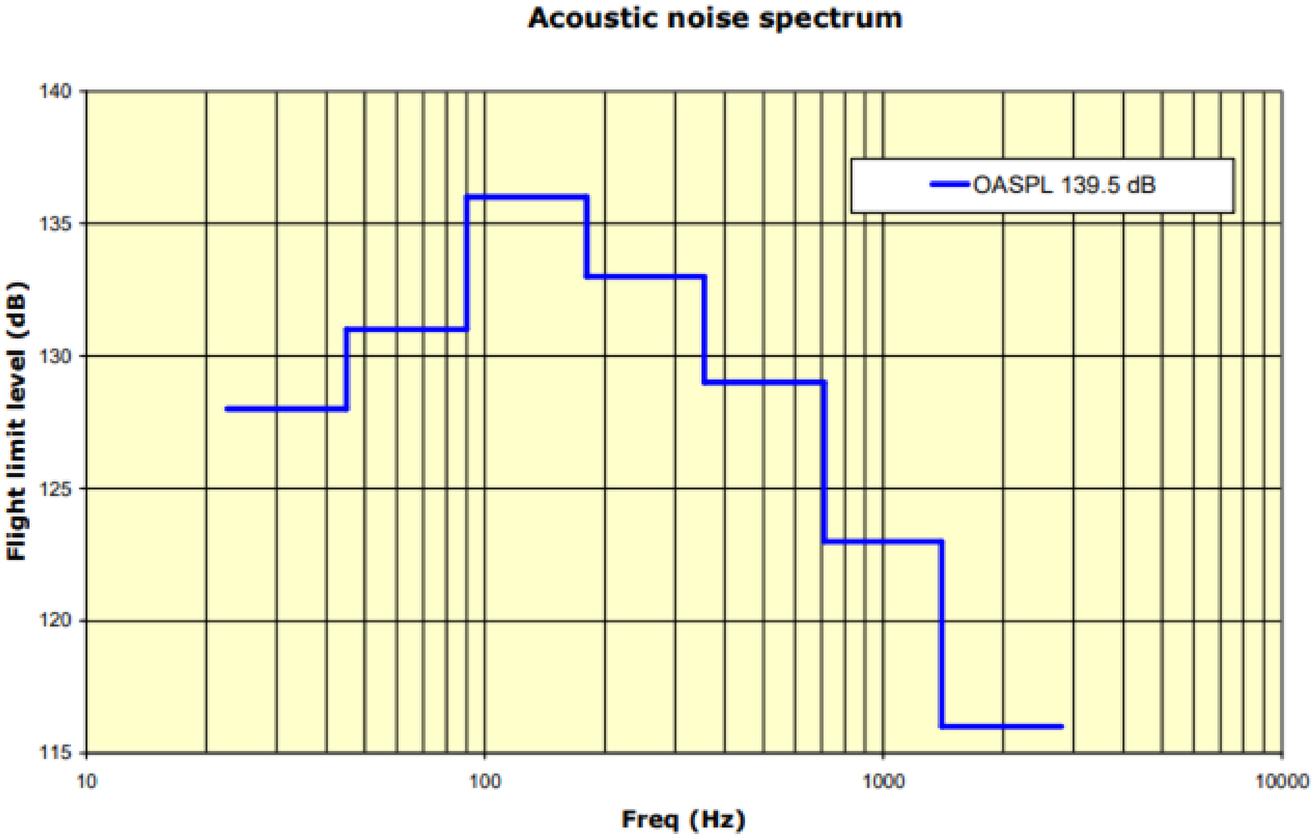


Figure 3.2.5.2.b - Acoustic noise spectrum

Direction	Frequency band (Hz)	Sine amplitude (g)
Longitudinal	2 – 50	1.0
	50 - 100	0.8
Lateral	2 – 25	0.8
	25 – 100	0.6

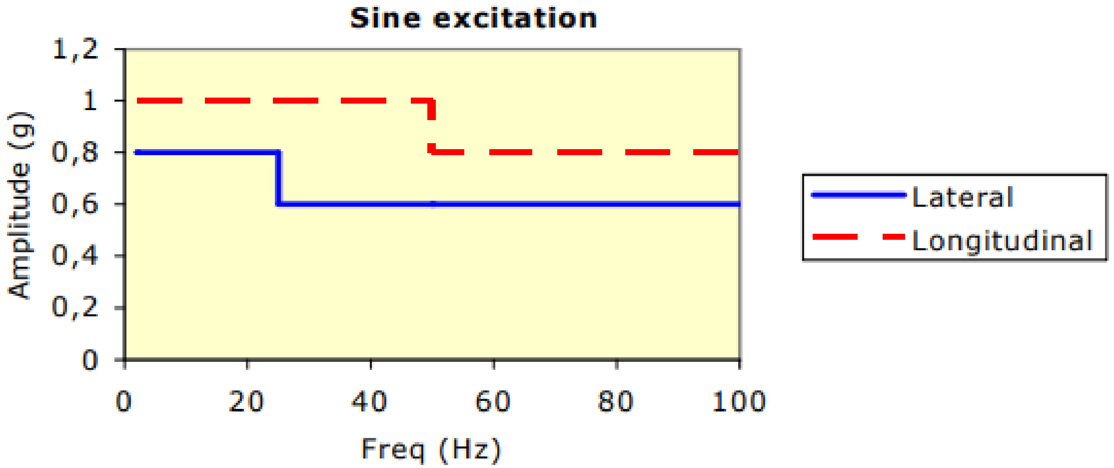


Table 3.2.3.a - Sine excitation at spacecraft base

Launch loads – shocks

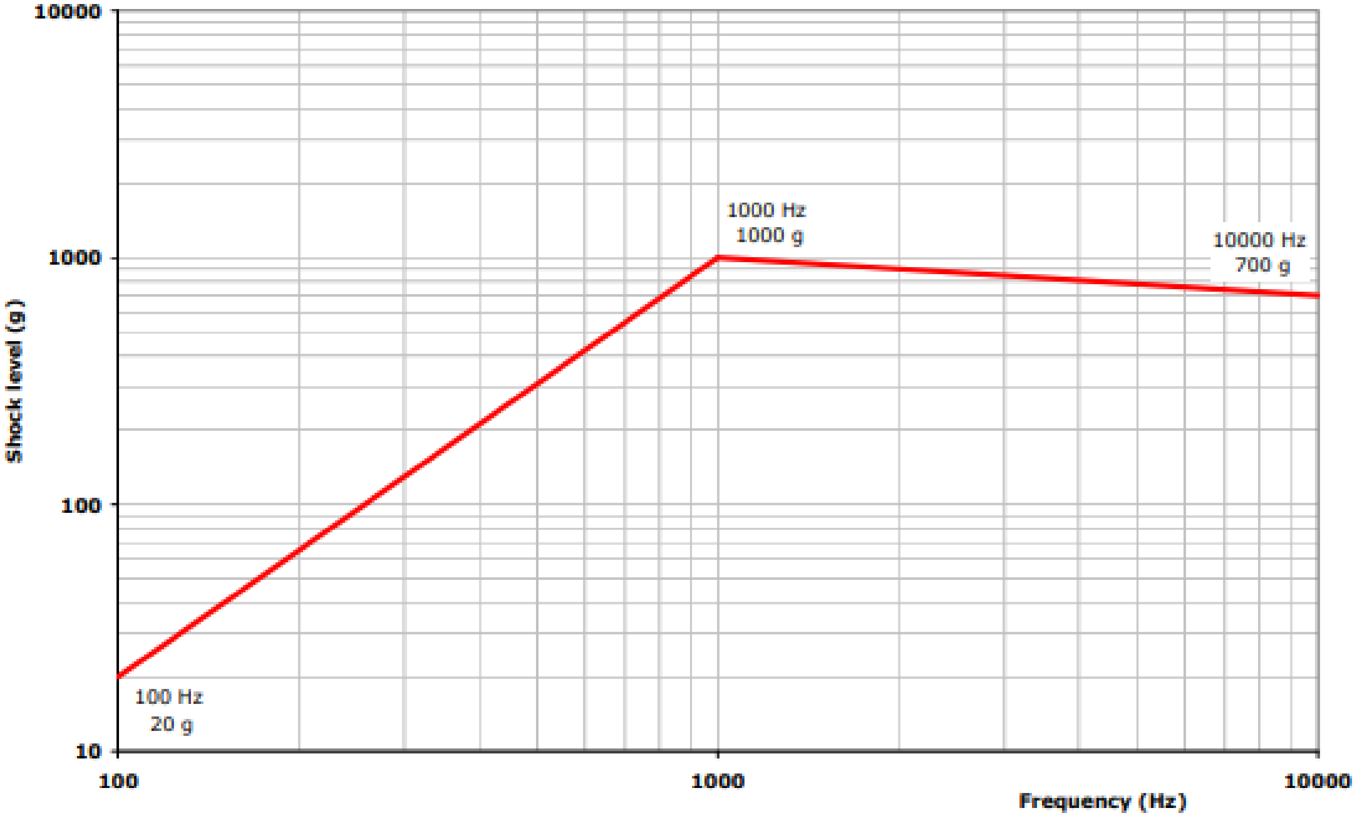


Figure 3.2.6.a Envelope shock spectrum for clampband release at spacecraft interface and for fairing and L/V stage separation events

Source: Ariane 5 UM [Microsoft Word - MUA5_5_1_INTRO.doc (arianespace.com)]

Working environment

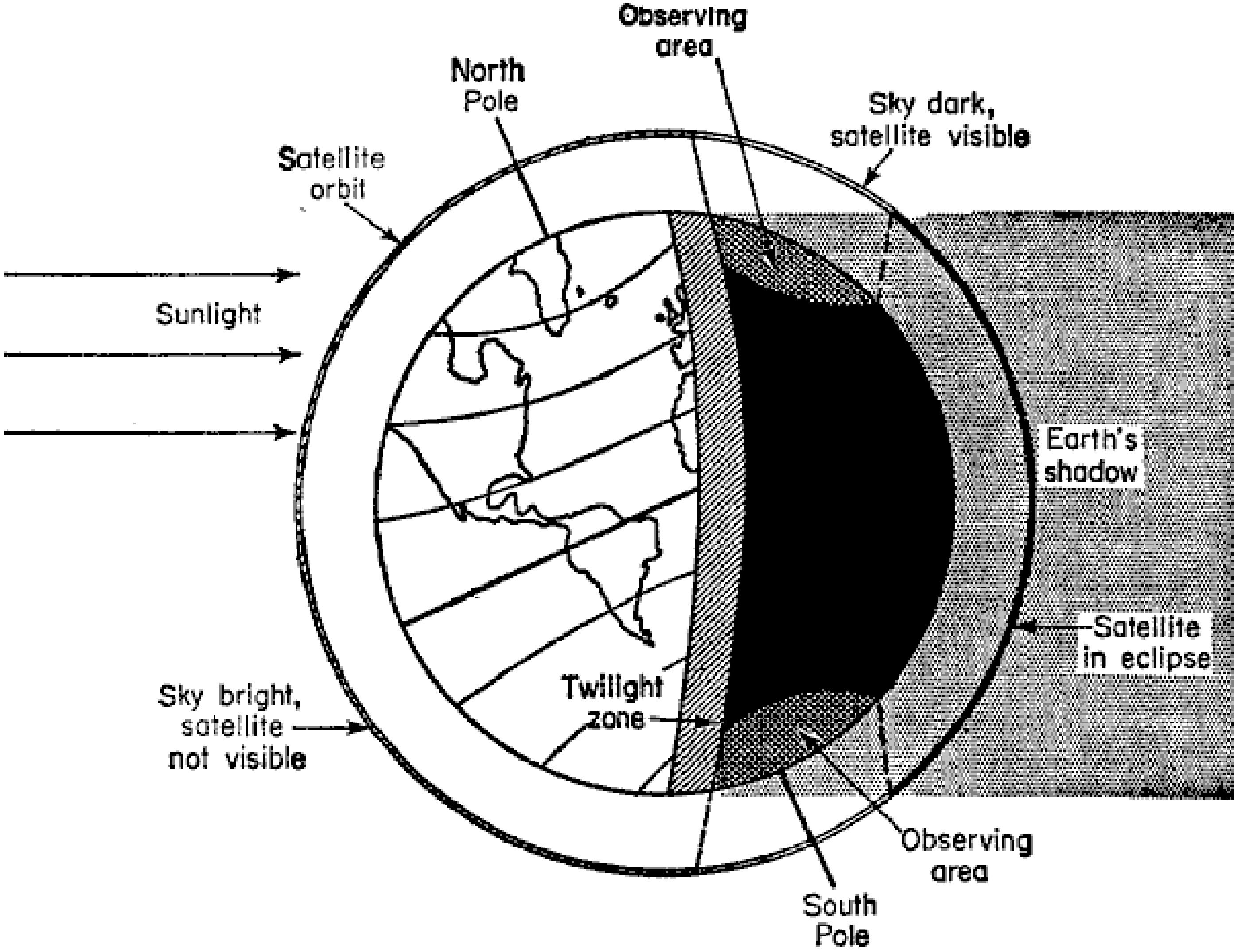
Penetrating Particle Analyzer

On-orbit/operational loads:

- Thermal cycles
- Radiation
- Outgassing

Causes:

- Earth shadowing, sun and umbra phases
- Distance from the boundary of the magenetosphere
- Absence of air



Working environment

On-orbit/operational loads:

- Thermal cycles
- Radiation
- Outgassing

Causes:

- Earth shadowing, sun and umbra phases
- Distance from the boundary of the magenetosphere
- Absence of air

International Space Station (ISS)

- Orbit periond ~ 90 min (1.5 hrs)
- Max T (exposed to the sun) ~ 120 °C
- Min T (shadow) ~ -150 °C

SERMS Laboratories

Penetrating Particle Analyzer

Vibration benches:

- Shaker 3 kN - INFN
- Shaker 10 kN – University of Perugia
- Shaker 49.5 kN – SERMS s.r.l.
- Slip table (2.7 x 2.7 m^2) – University of Perugia

Shock facilities:

- Air cannon – SERMS s.r.l.

Climate and Vacuum:

- Thermo-vacuum chamber ϕ2.1 m x 2.1 m – UniPg
- Climate chambers - UniPg

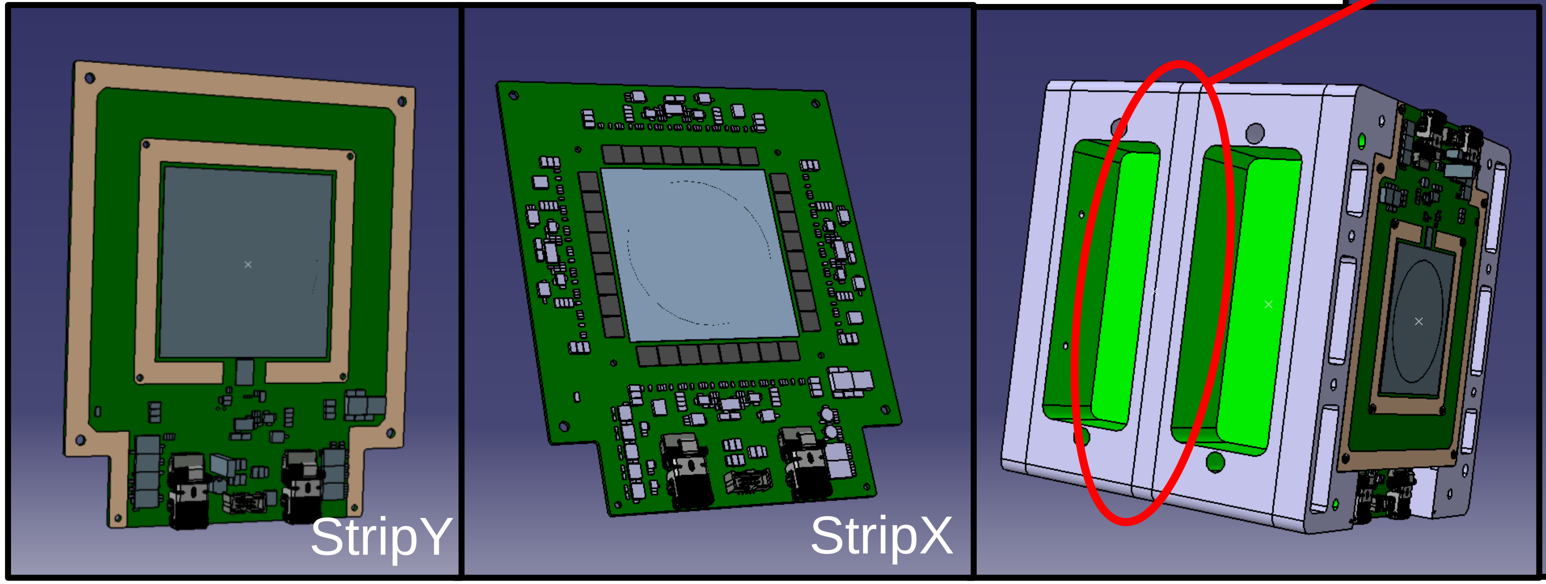
SERMS Lab: synergic collaboration of the INFN, the UniPg and the SERMS s.r.l

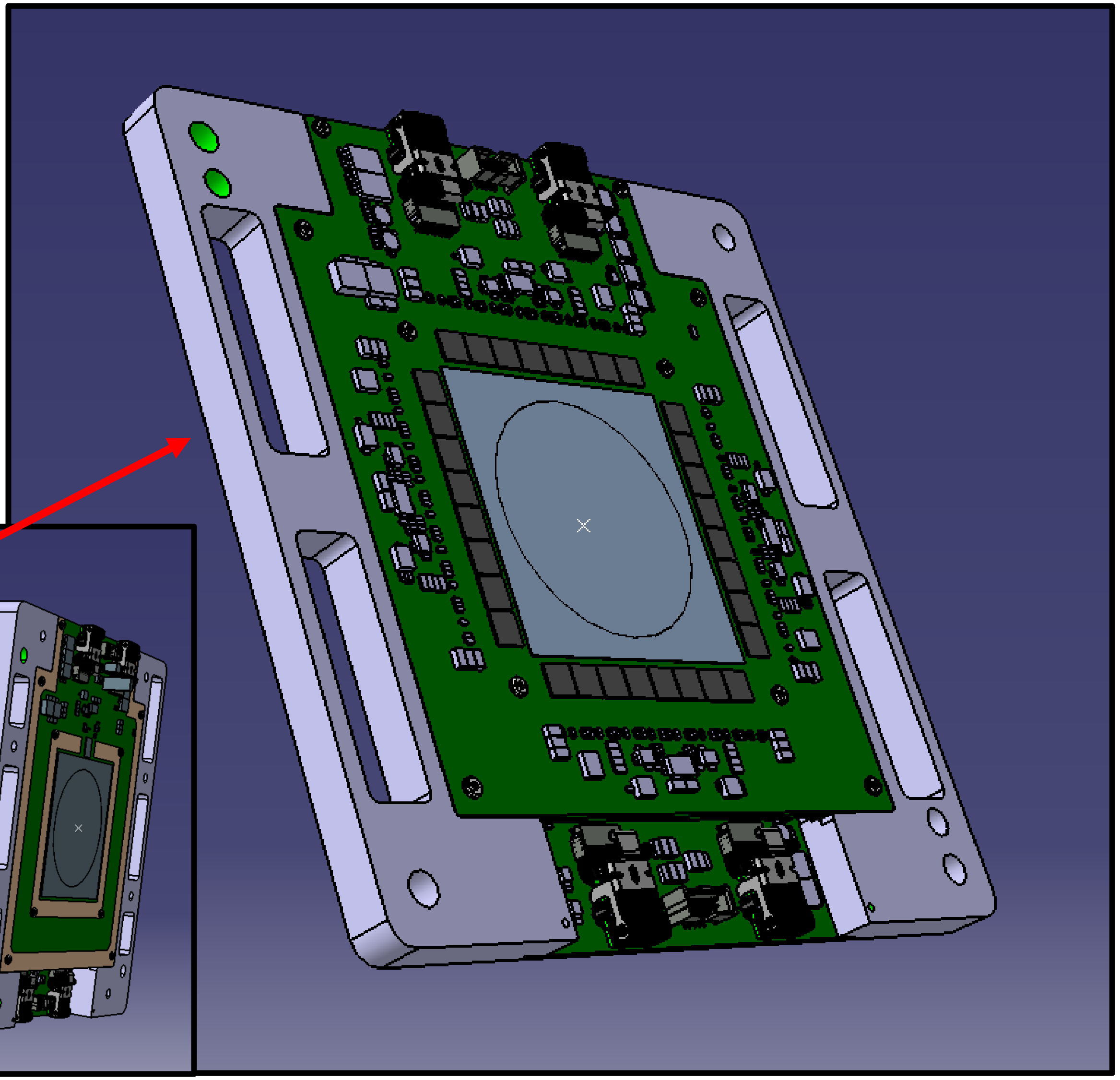
Mechanical tests - SUT

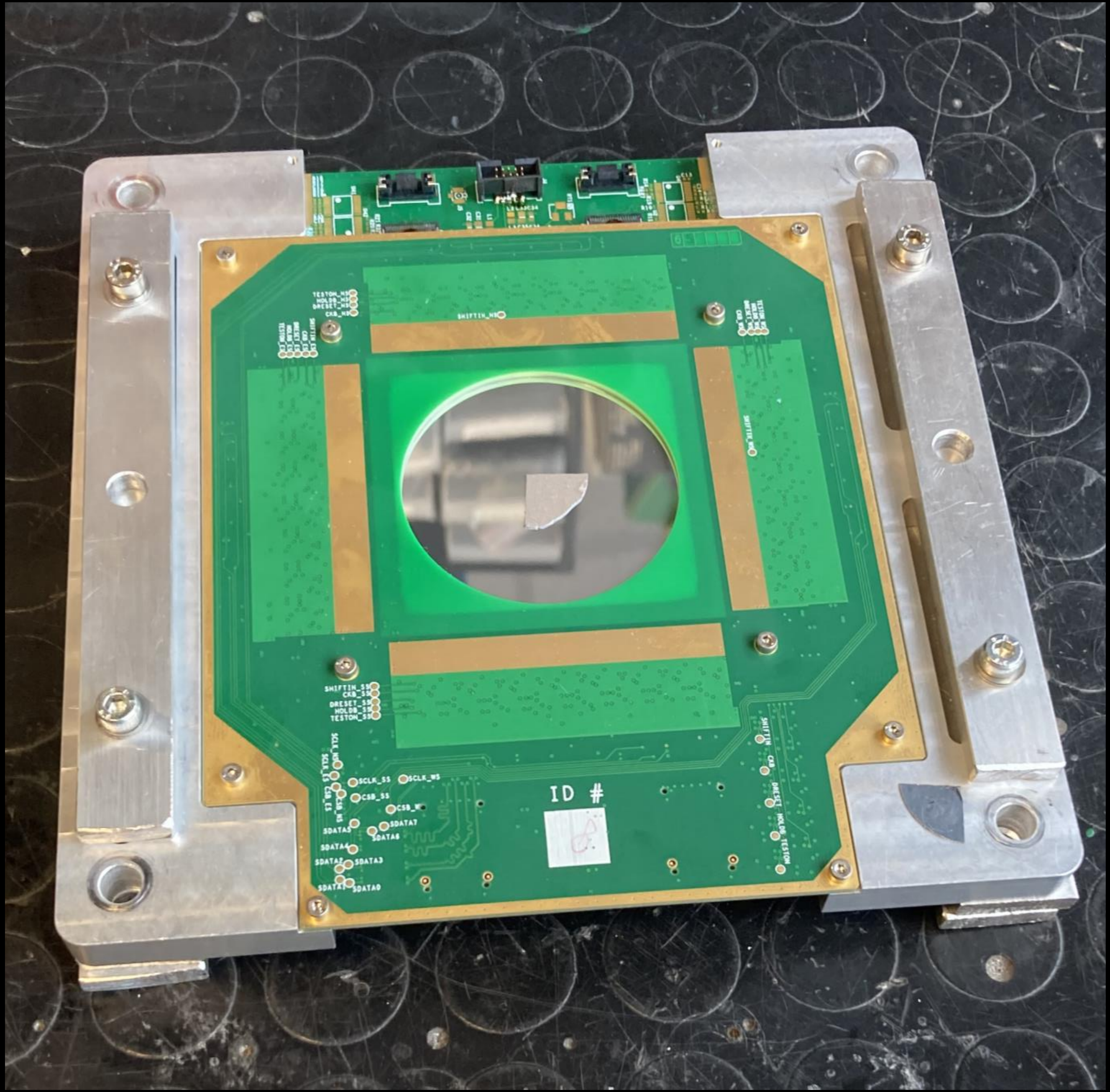
Penetrating Particle Analyzer

Components:

- x2 PAN Strip-X boards
- x1 PAN Strip-Y board
- x1 Support frame



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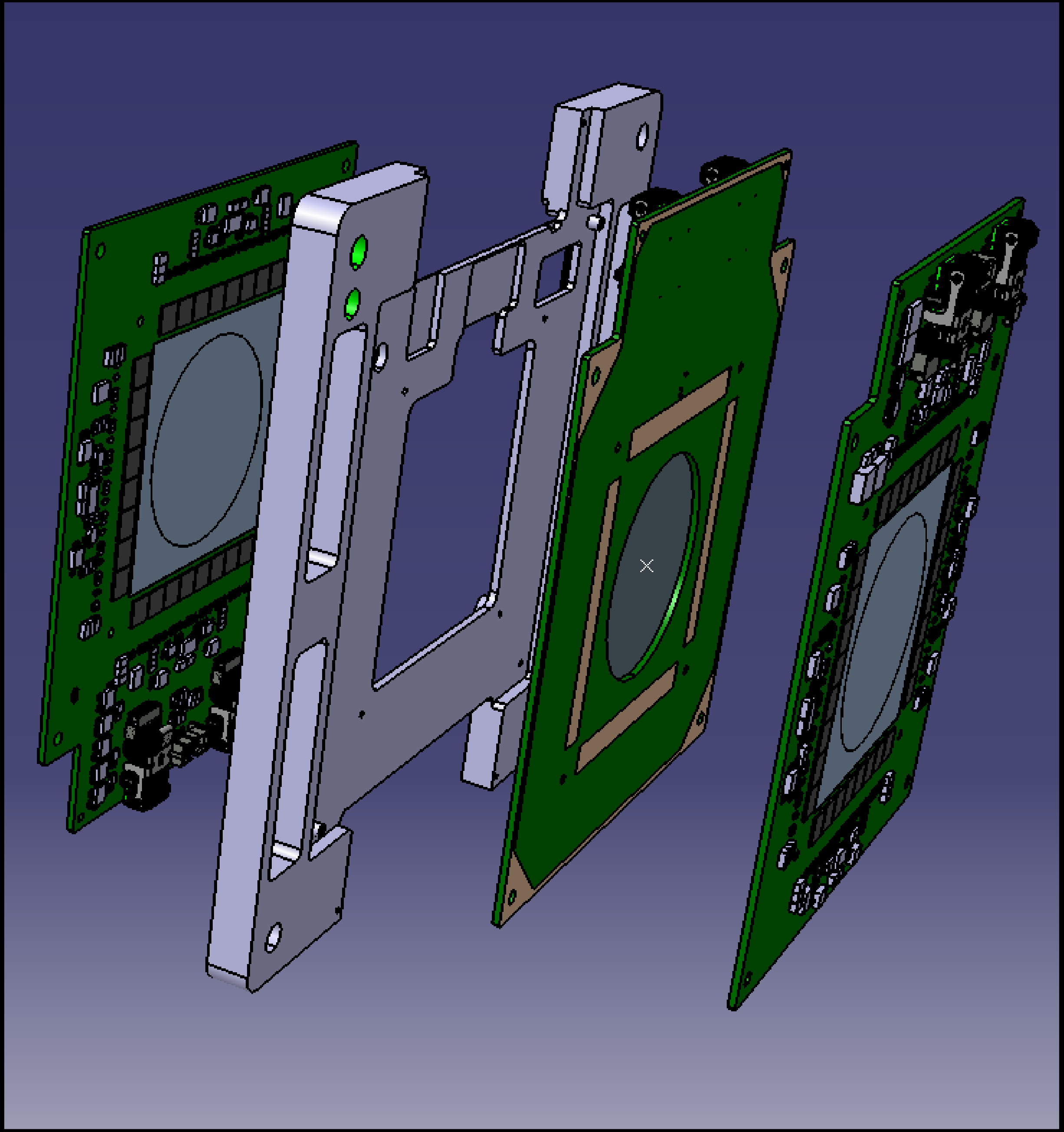

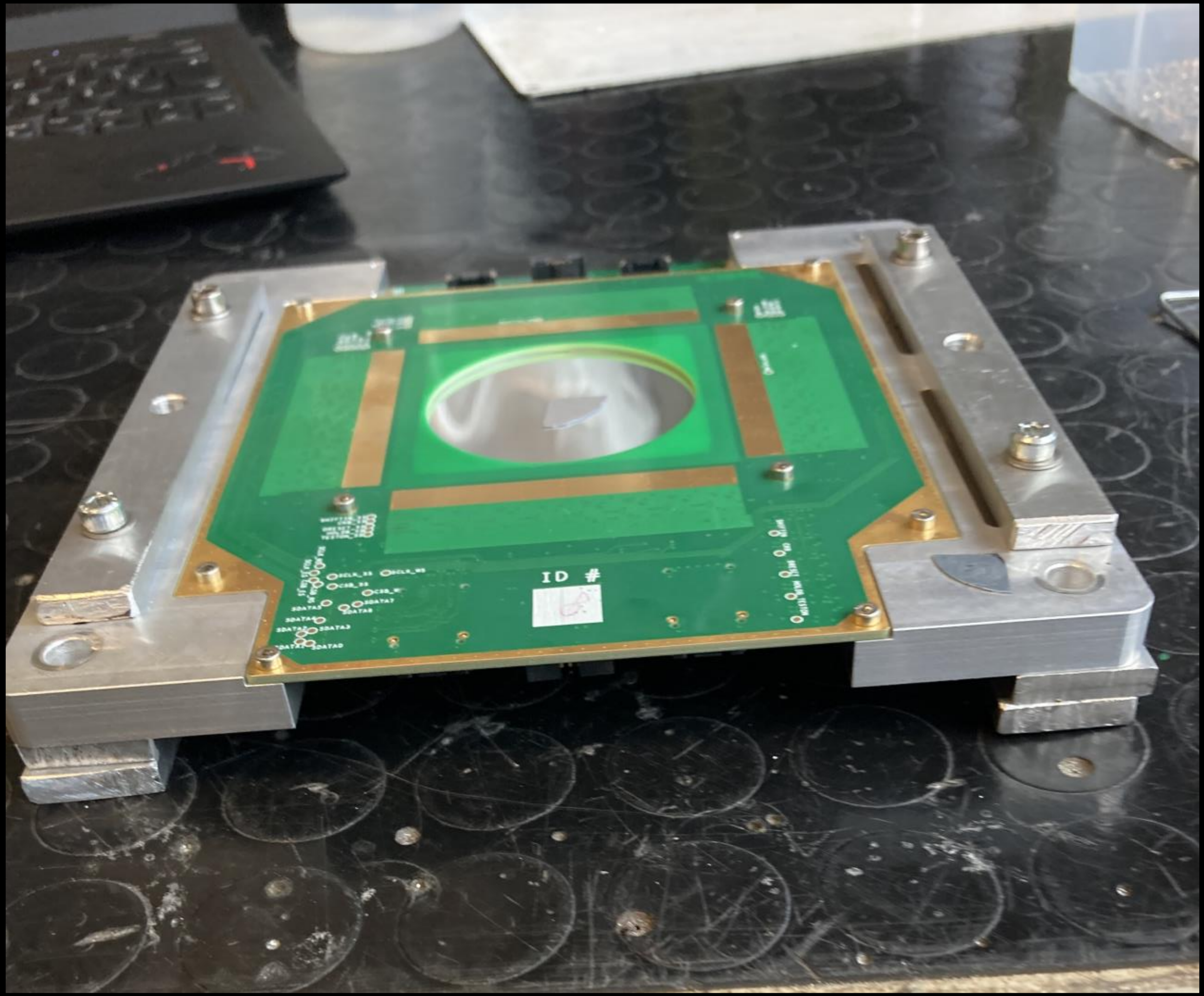
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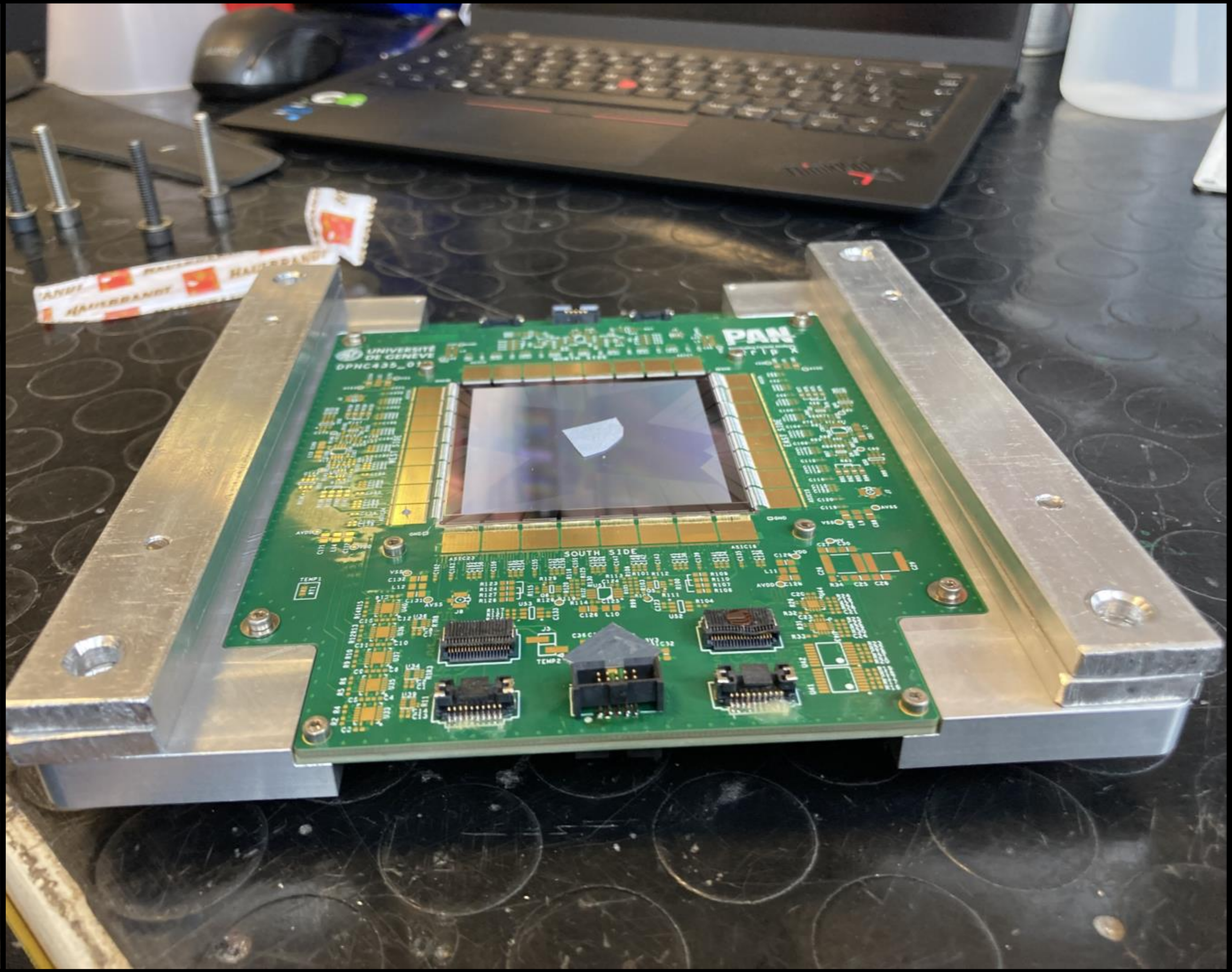
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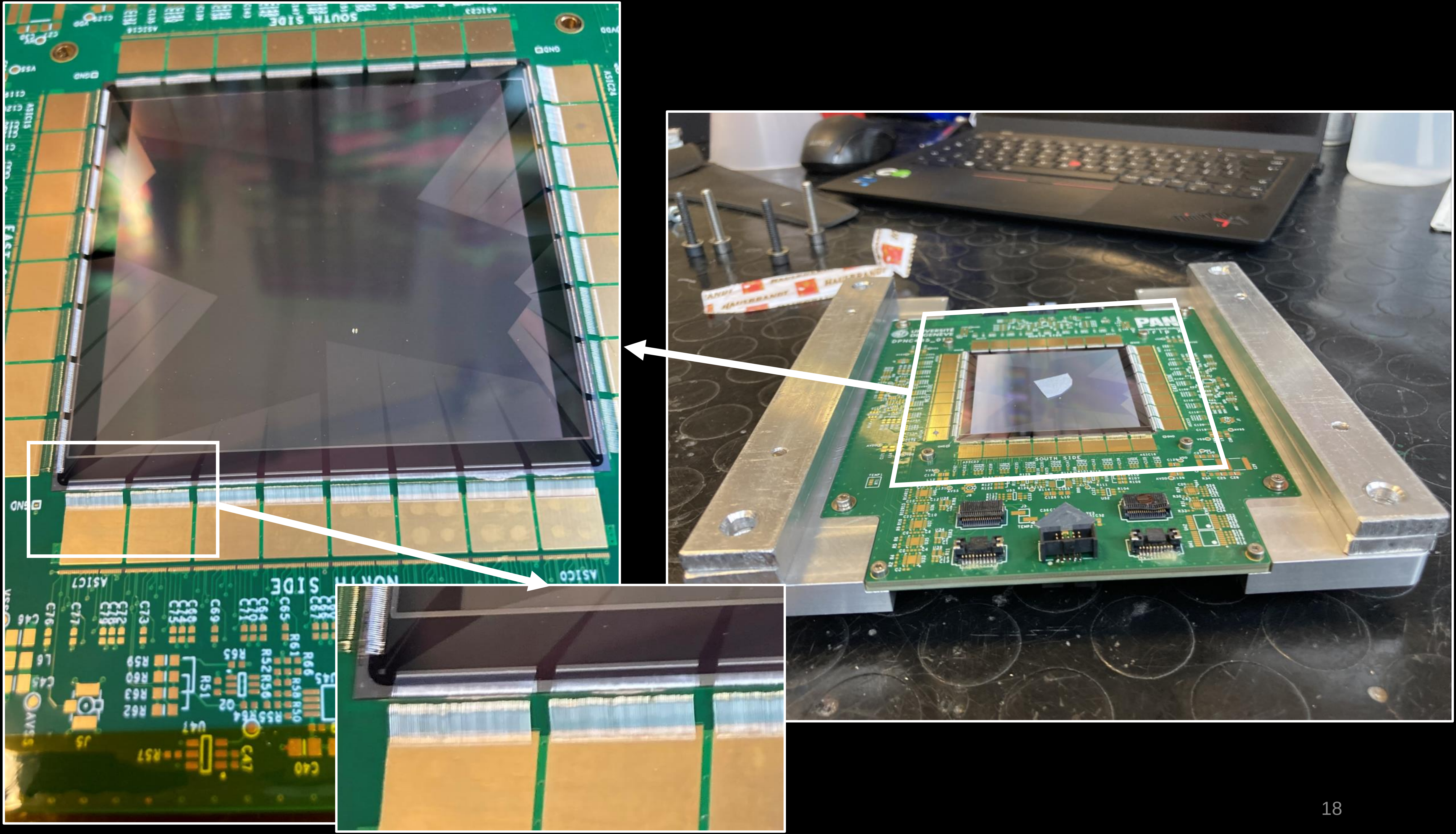
DE GENÈVE
PAN
SOUTH SIDE



Mechanical tests – Test Campaign

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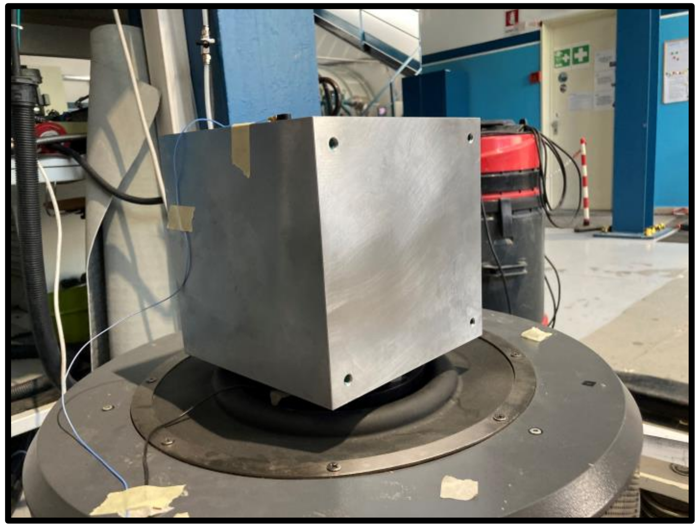
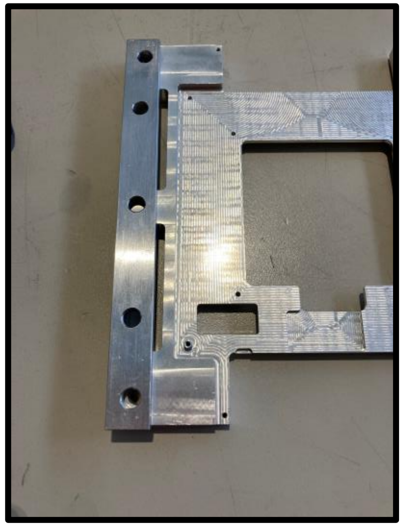
Interface validation → Harmonic test Z → Random test Z → Harmonic test X → Random test X

Profile calibration → Pyro-shock test Z





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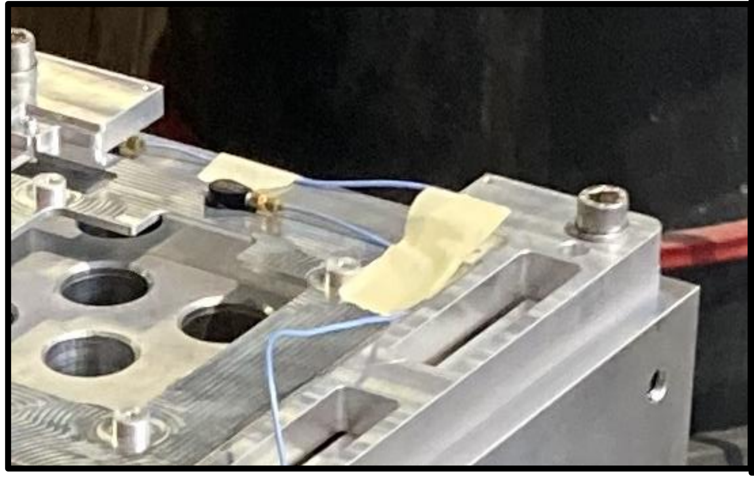
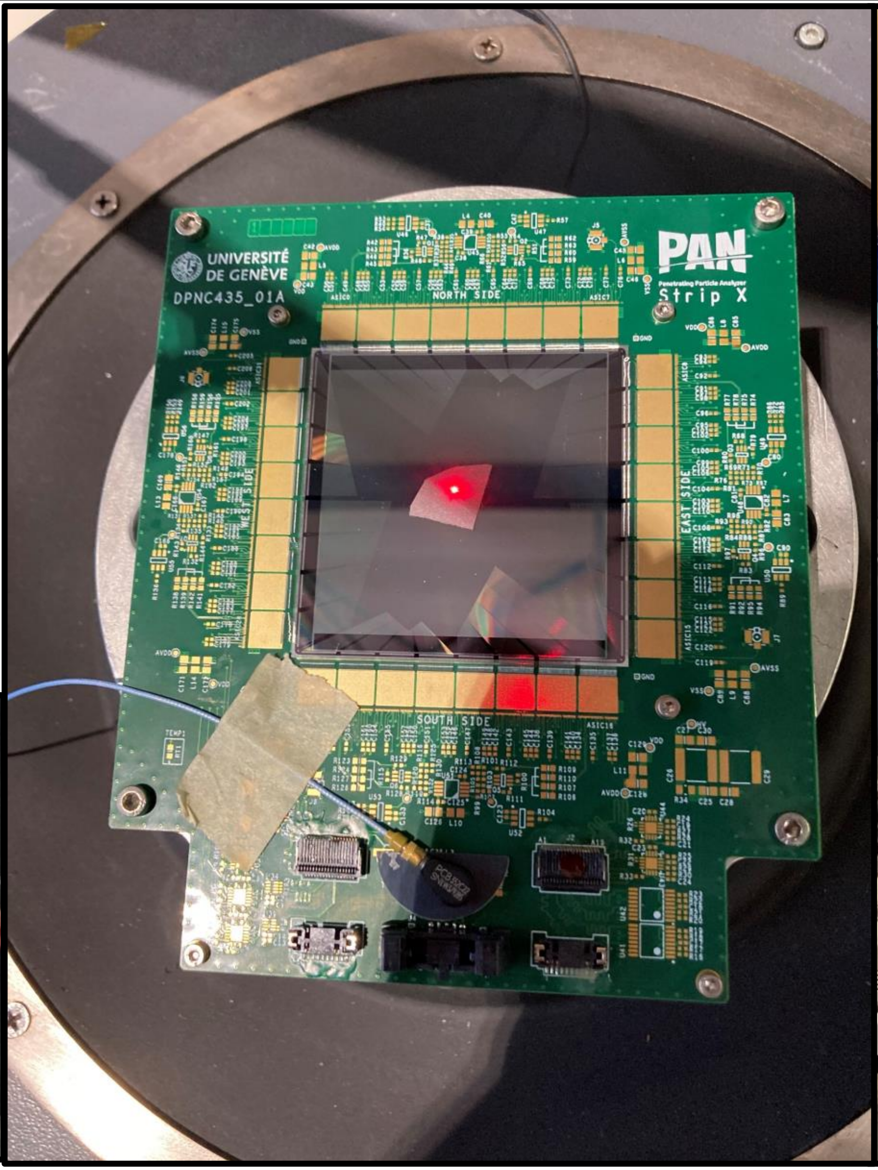
Mechanical tests – Monitoring 1/4

Monitoring:

- Laser interferometer (vibration Z)
- Accelerometers (vibration Z, X and pyro-shock)





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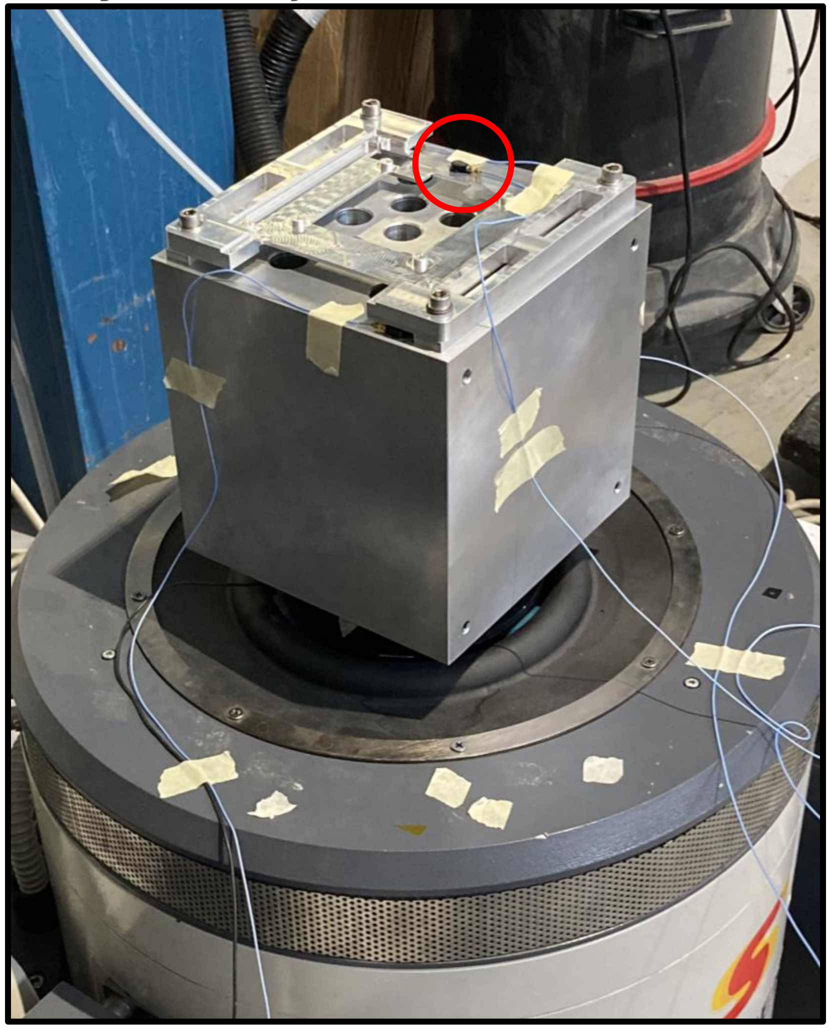
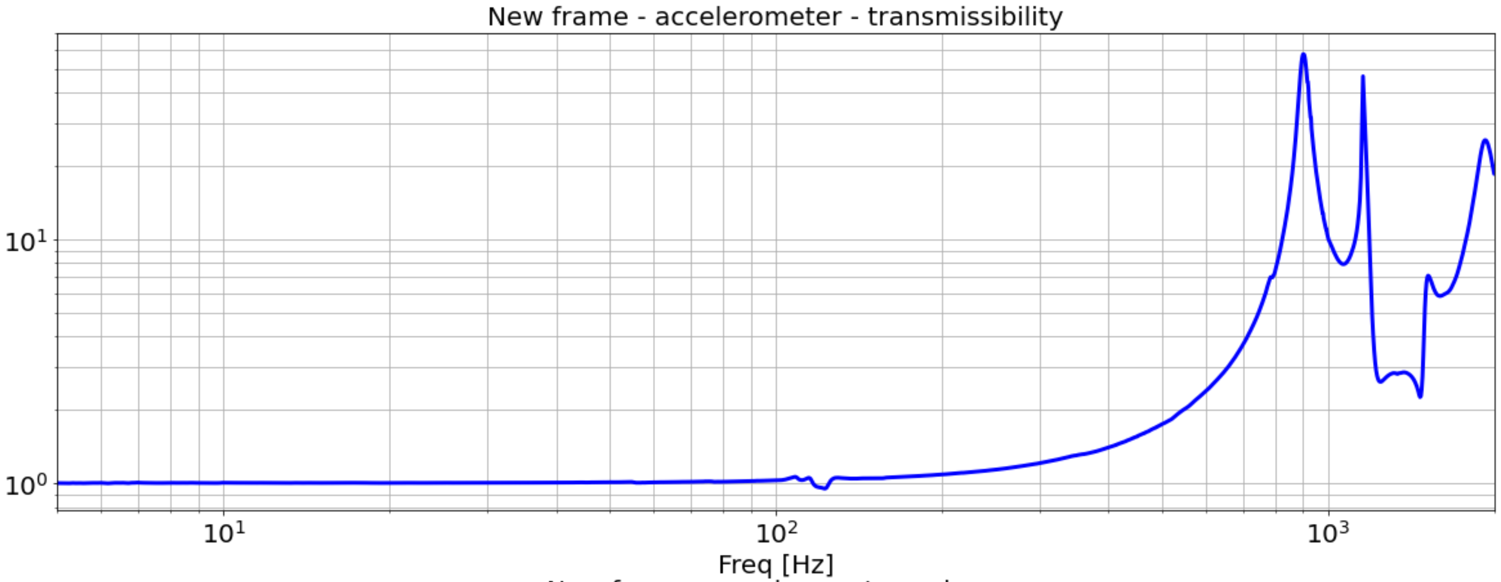
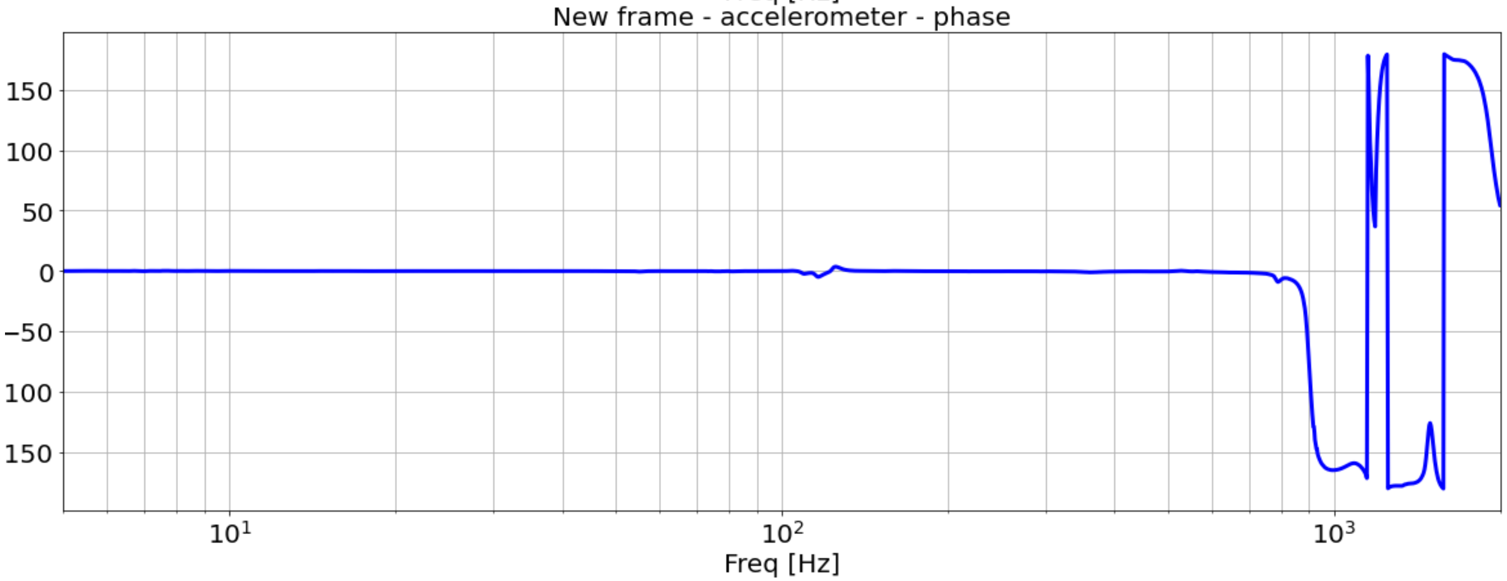
Mechanical tests – Monitoring 2/4







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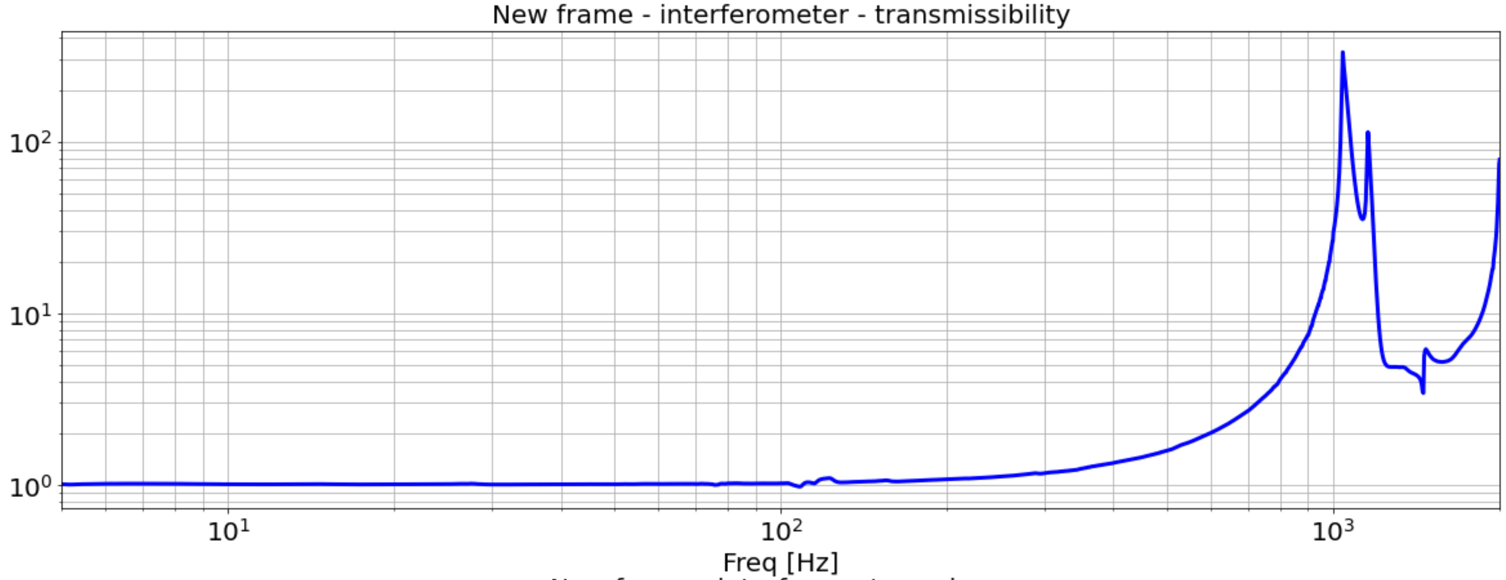
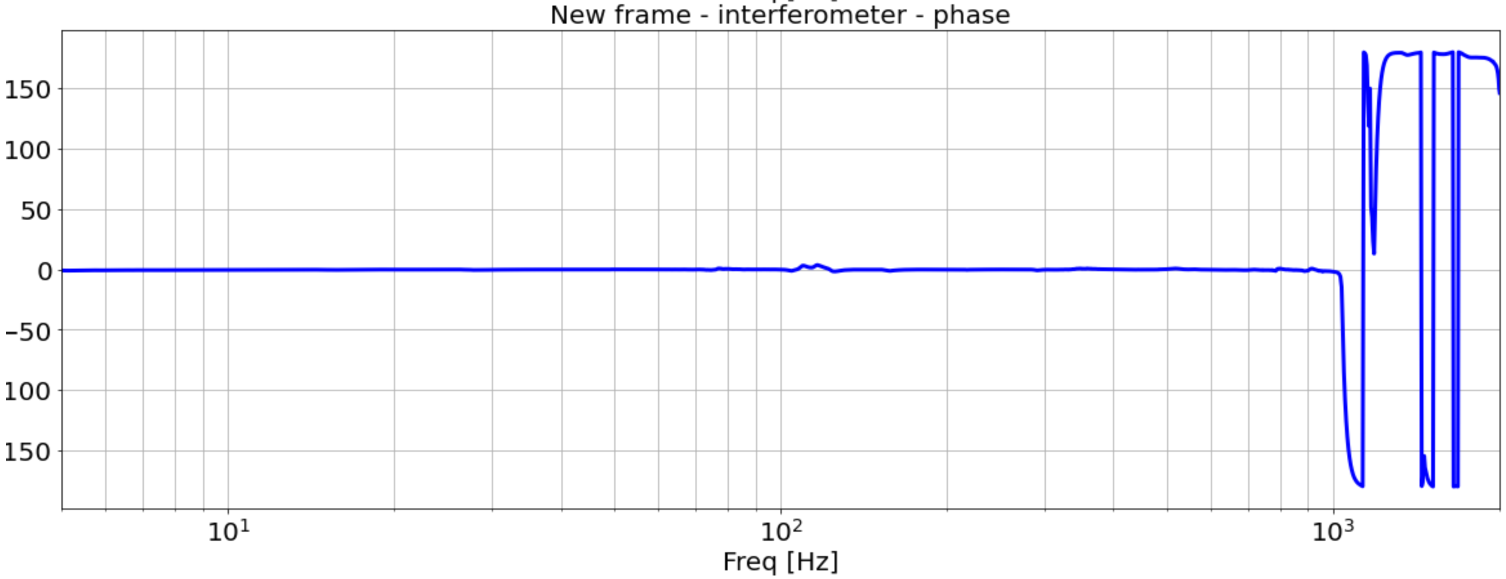
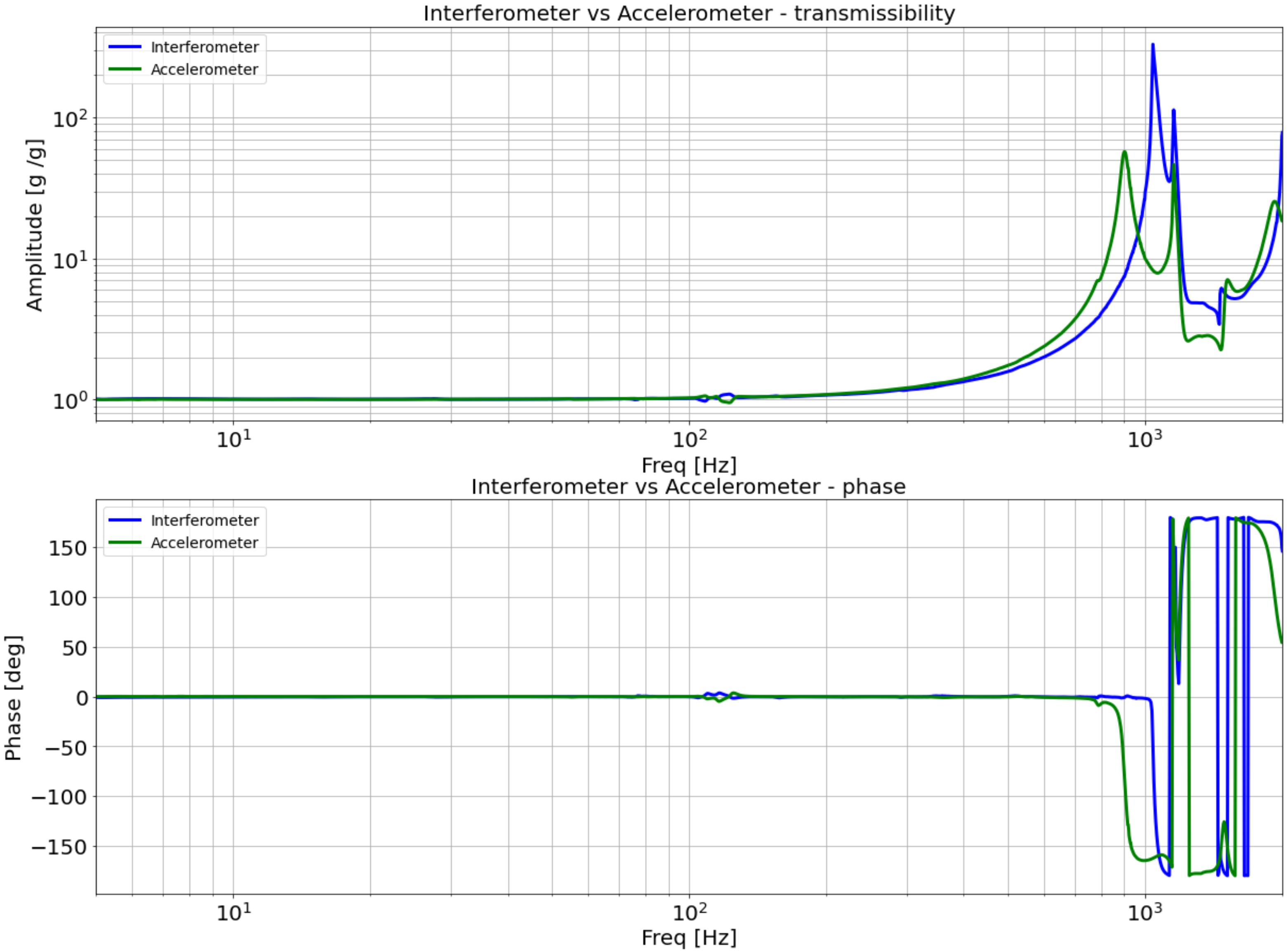
Mechanical tests – Monitoring 3/4





Mechanical tests – Monitoring 4/4

Penetrating Particle Analyzer



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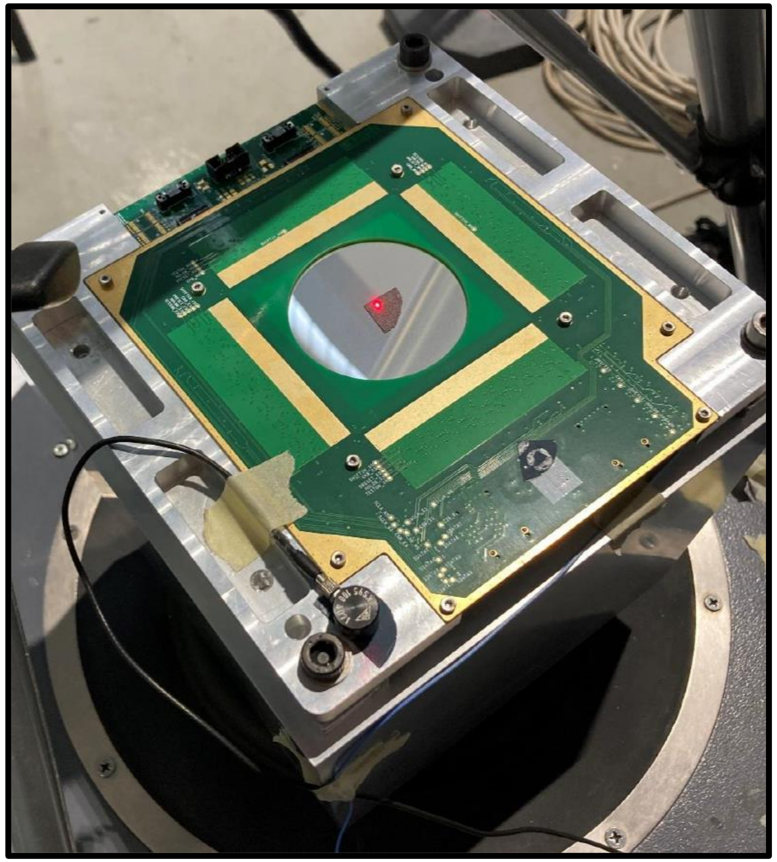
Mechanical tests – vibrations Z

Resonance search Z1 ⇨ Sine Sweep ⇨ Resonance search Z2 ⇨ Random ⇨ Resonance search Z3



Sine sweep (SWP)

Frequency [Hz]	Level
5-20	9.67 mm (0-pk)
20-100	15.6 g
Sweep rate: 2 oct/min	

Random vibration (RNDM)

Frequency [Hz]	Level	
20-100	+3 dB/oct	Axis Z
100-600	0.2 g^2/Hz	
600-2000	-5 db/oct	
Overall: 14.46 g_{rms}		
Duration: 2 min		

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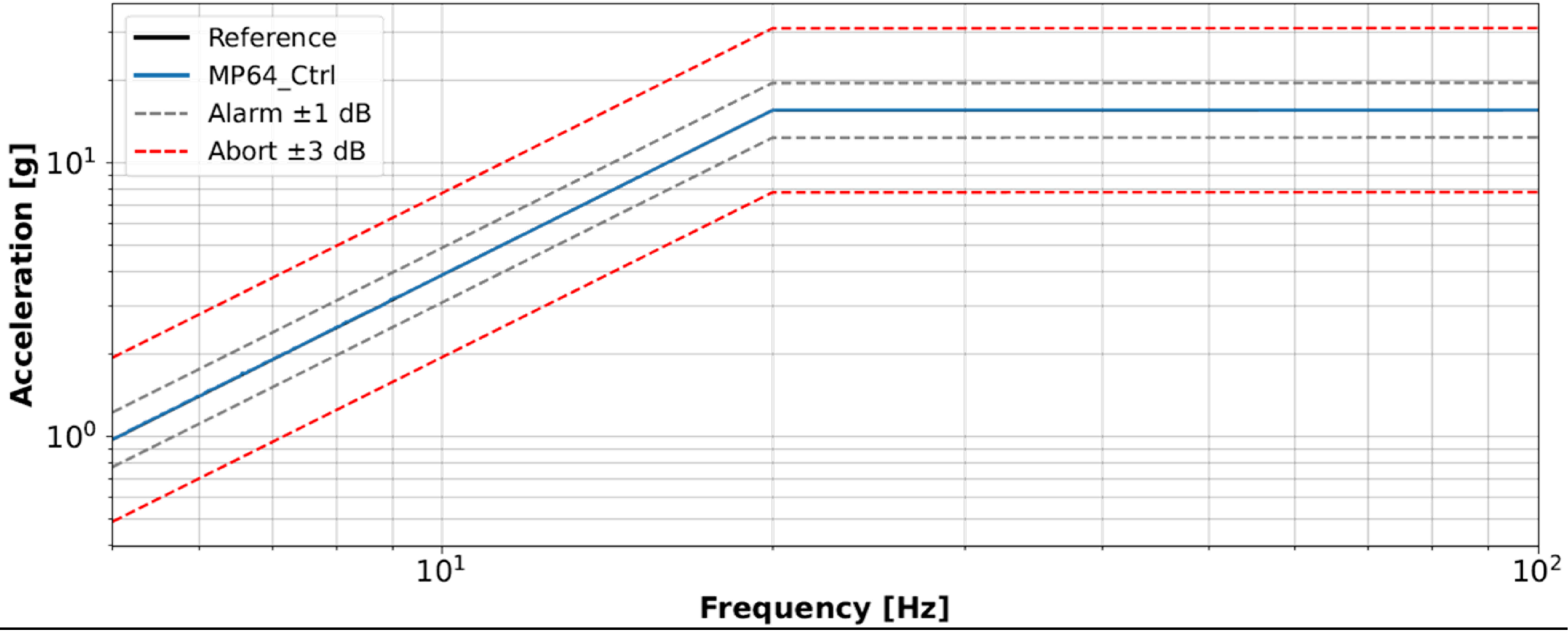
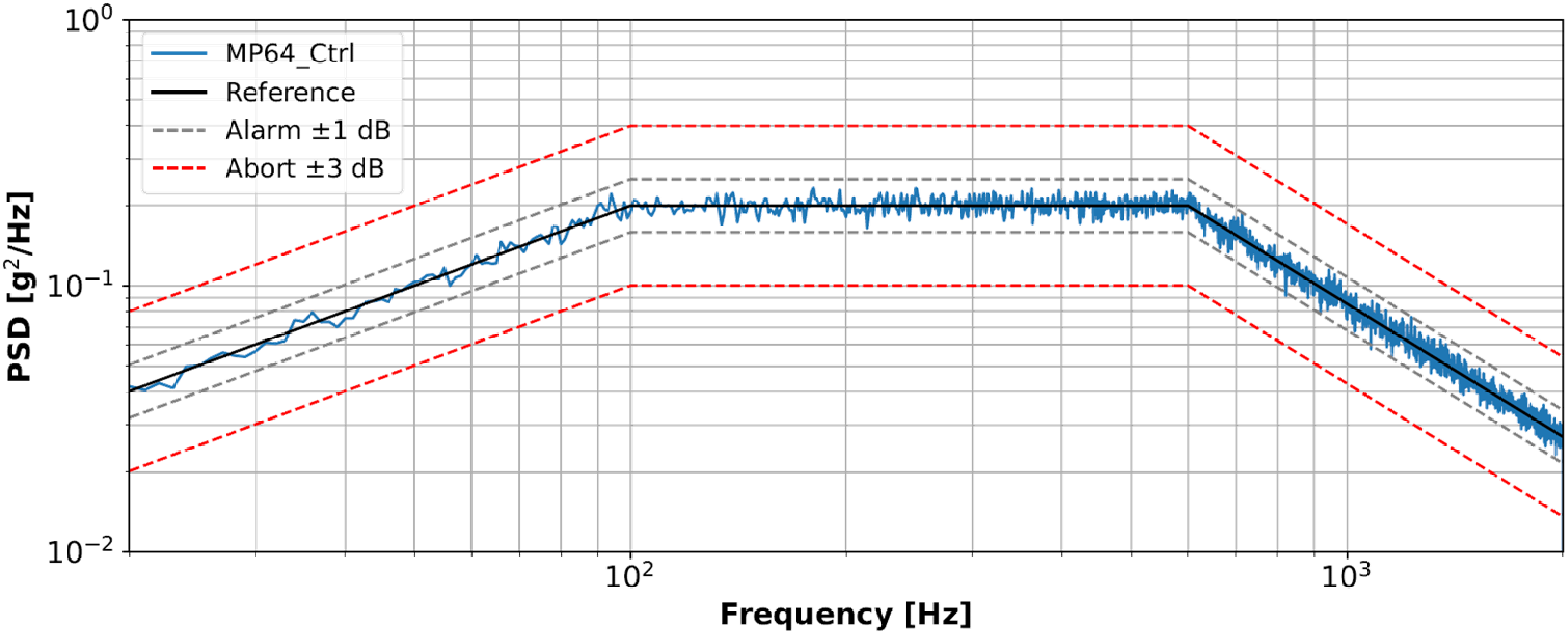
Sine sweep



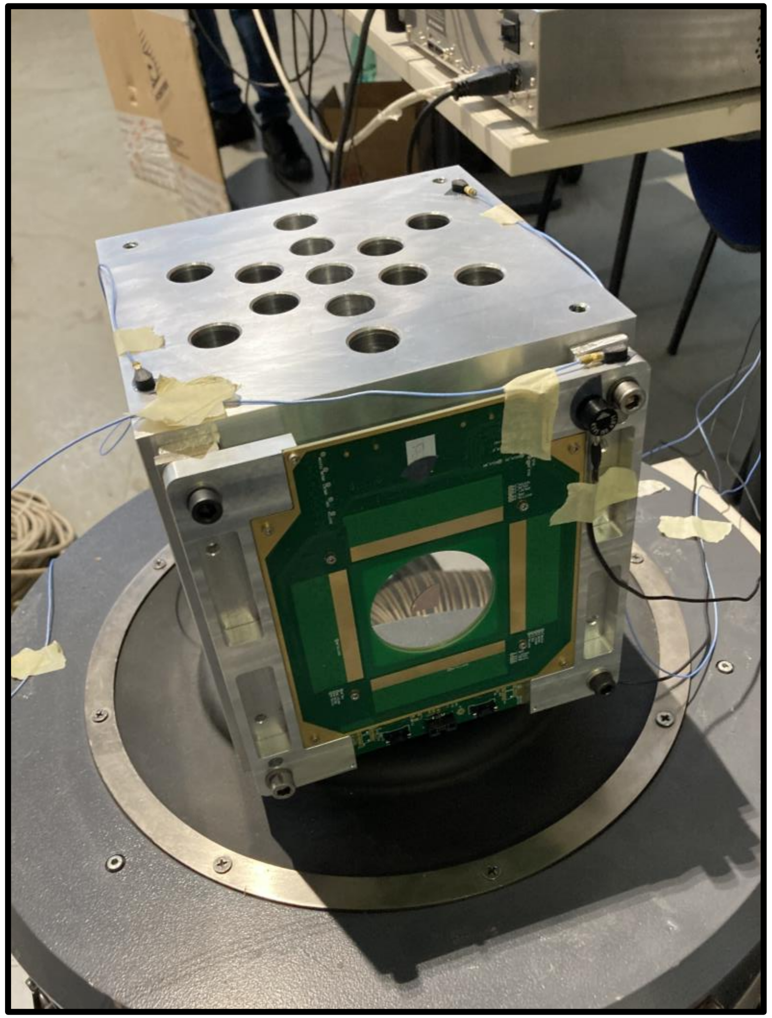
Random



MP64_Ctrl
Reference
Alarm ±1 dB
Abort ±3 dB
PSD [g²/Hz]
Frequency [Hz]
10⁰
10⁻¹
10⁻²
10²
10³

Mechanical tests – vibrations X

Penetrating Particle Analyzer



Resonance search Z1 → Sine Sweep → Random → Resonance search Z3

Sine sweep (SWP)

Frequency [Hz]	Level
5-20	9.67 mm (0-pk)
20-100	15.6 g
Sweep rate: 2 oct/min	

Random vibration (RNDM)

Frequency [Hz]	Level	
20-100	+3 dB/oct	Axis X
100-600	0.1 g^2/Hz	
600-2000	-5 db/oct	
Overall: 10.22 g_{rms}		
Duration: 2 min		

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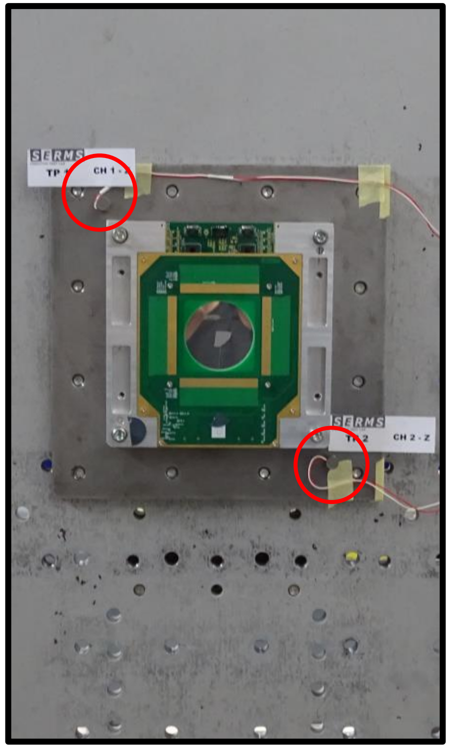
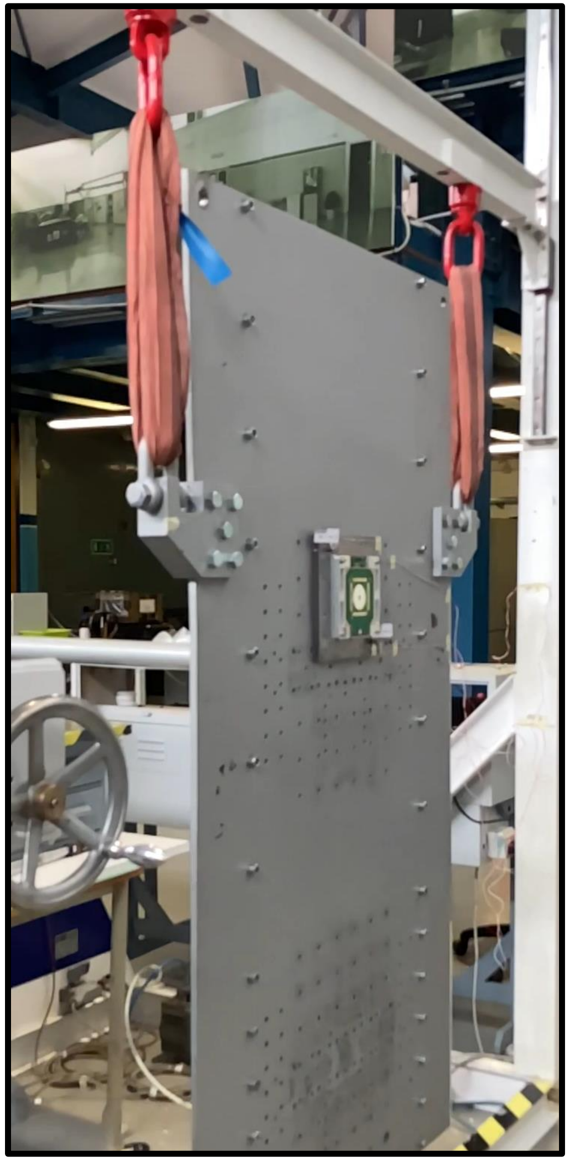
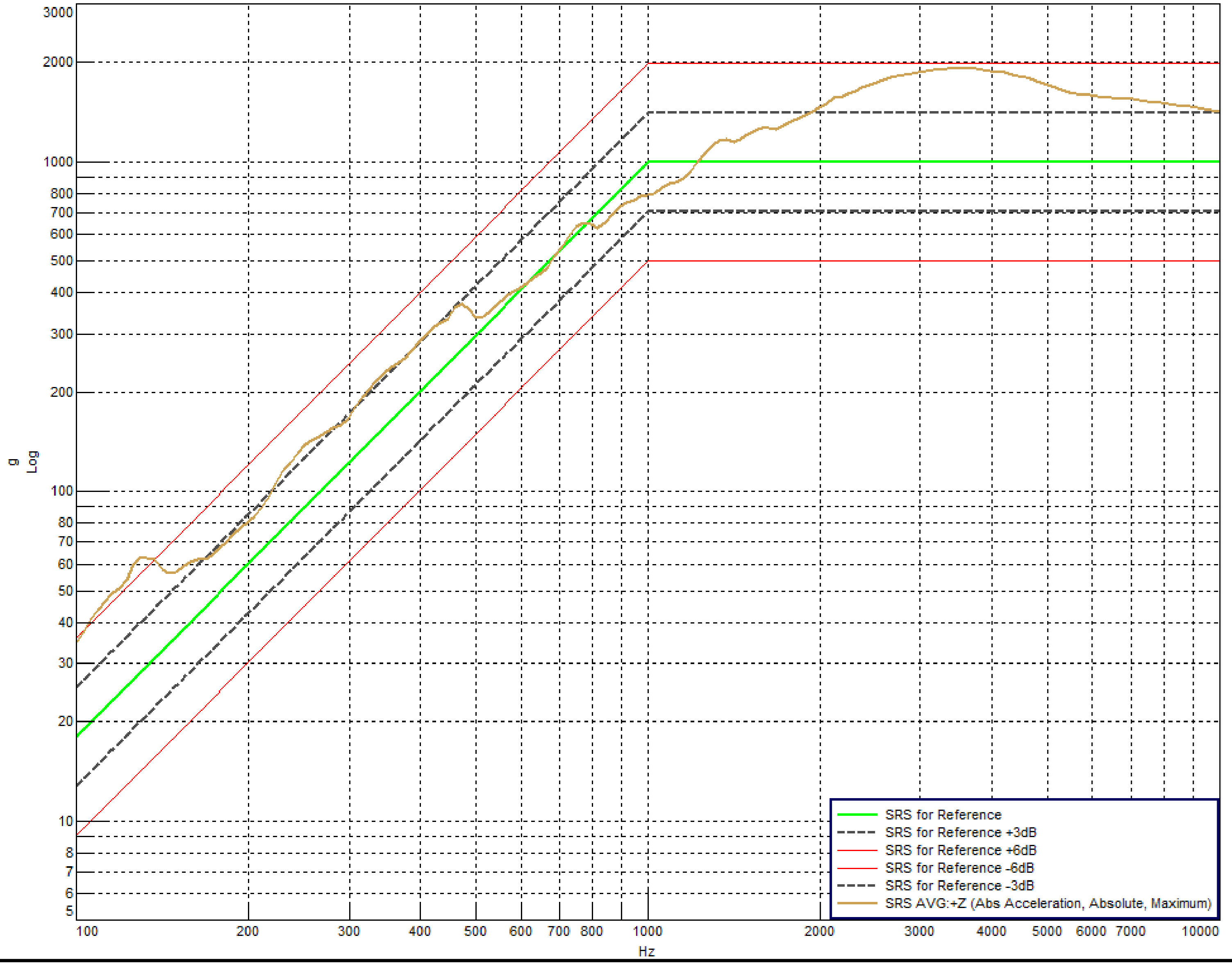
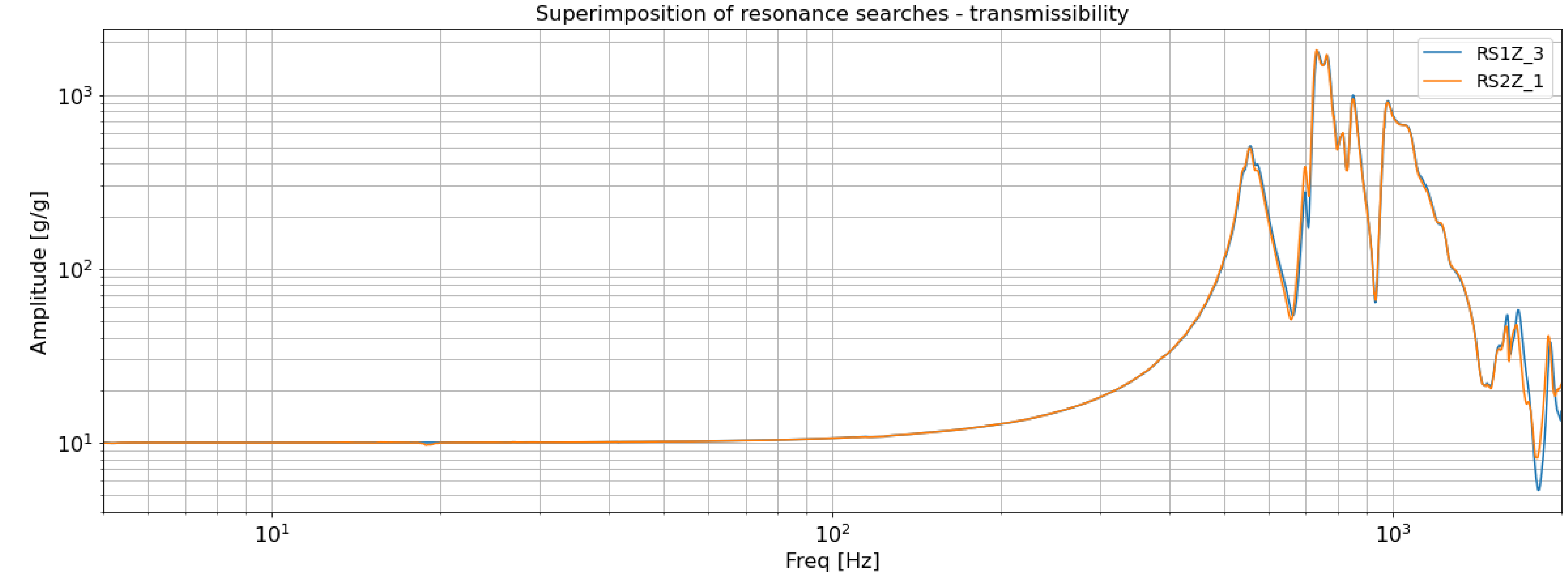
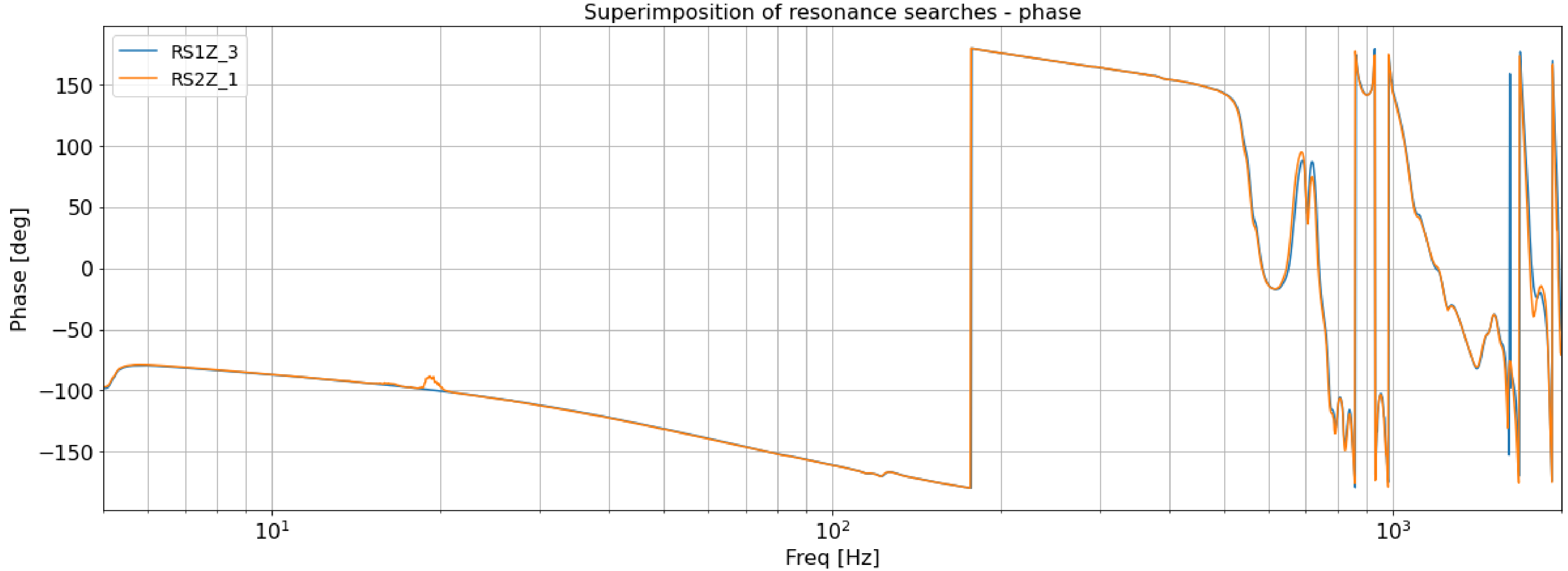
Mechanical tests – Shock in Z - 1/3





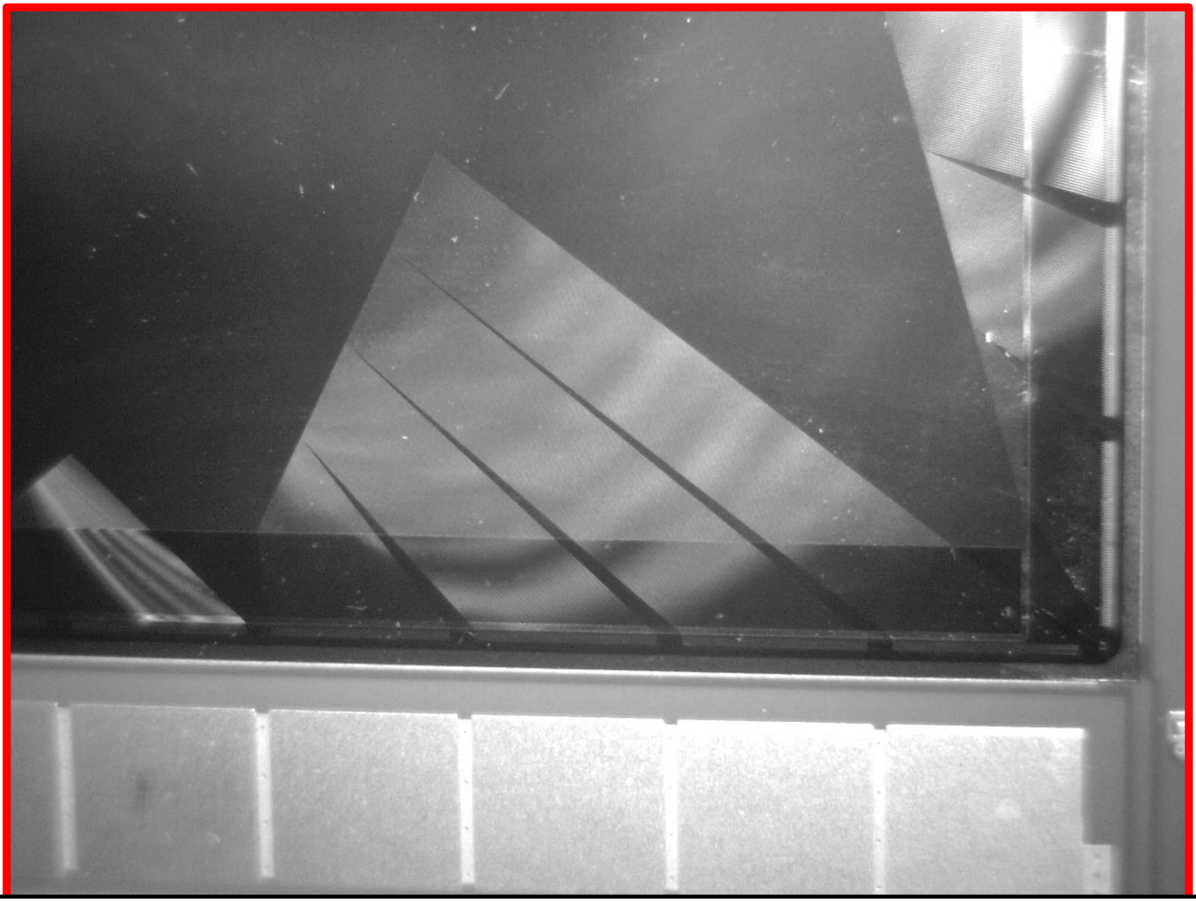



Superimposition of resonance searches - transmissibility
Amplitude [g/g]
Freq [Hz]
RS1Z_3
RS2Z_1
10^1
10^2
10^3

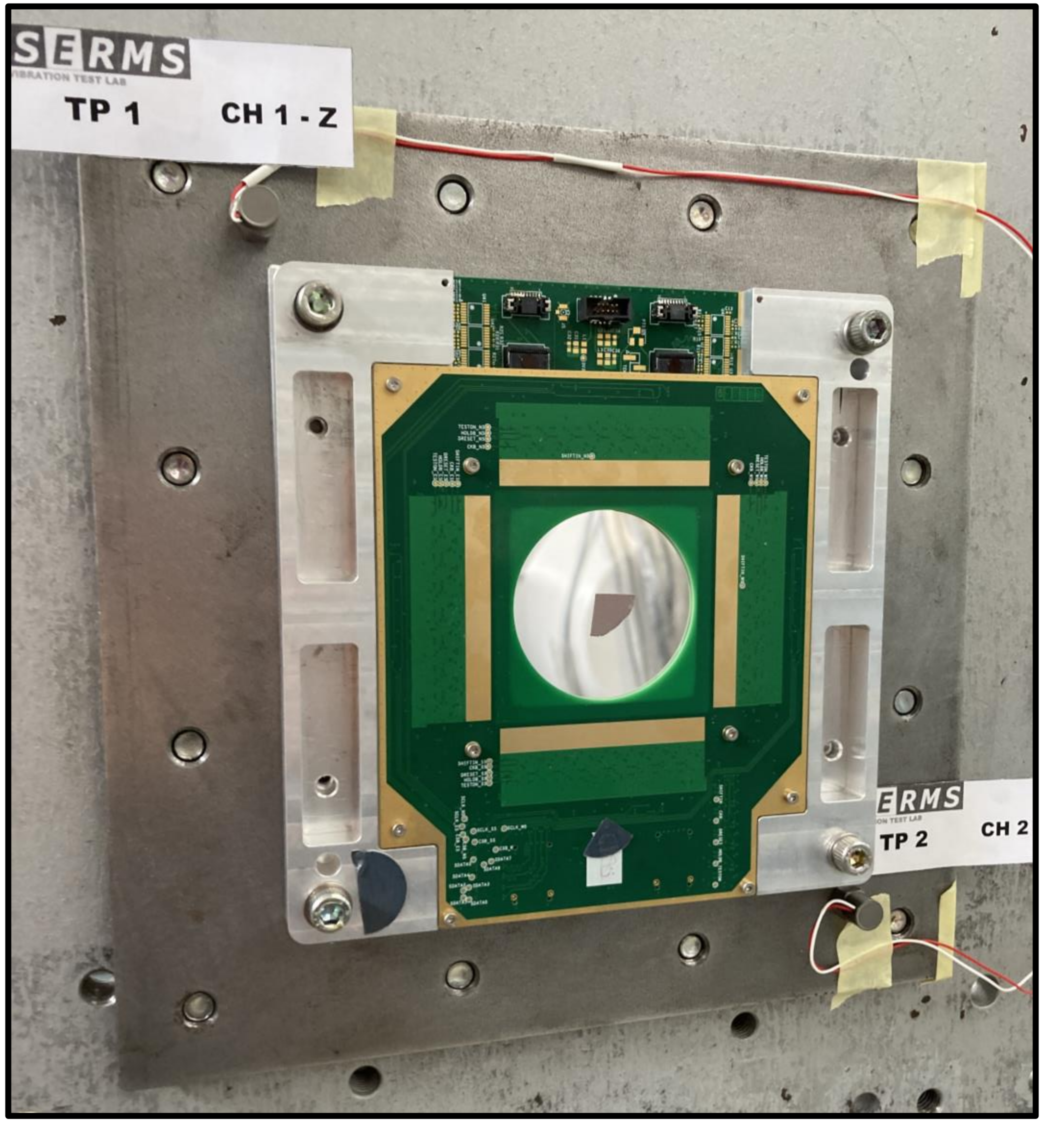

Superimposition of resonance searches - phase
Phase [deg]
Freq [Hz]
RS1Z_3
RS2Z_1
150
100
50
0
−50
−100
−150
10^1
10^2
10^3

Penetrating Particle Analyzer

Inspection after mechanical tests



The optical test showed no signs of failure



Experiment vs Model

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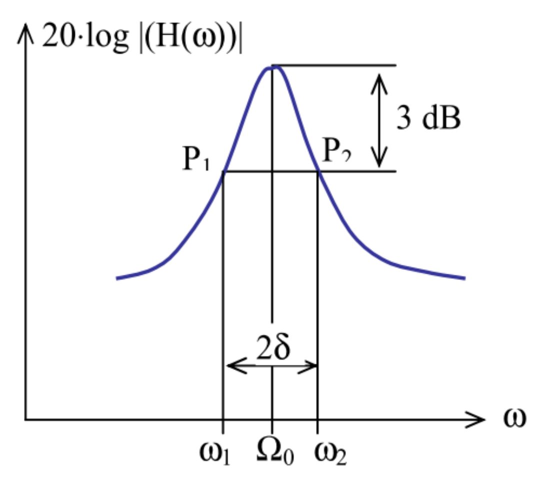
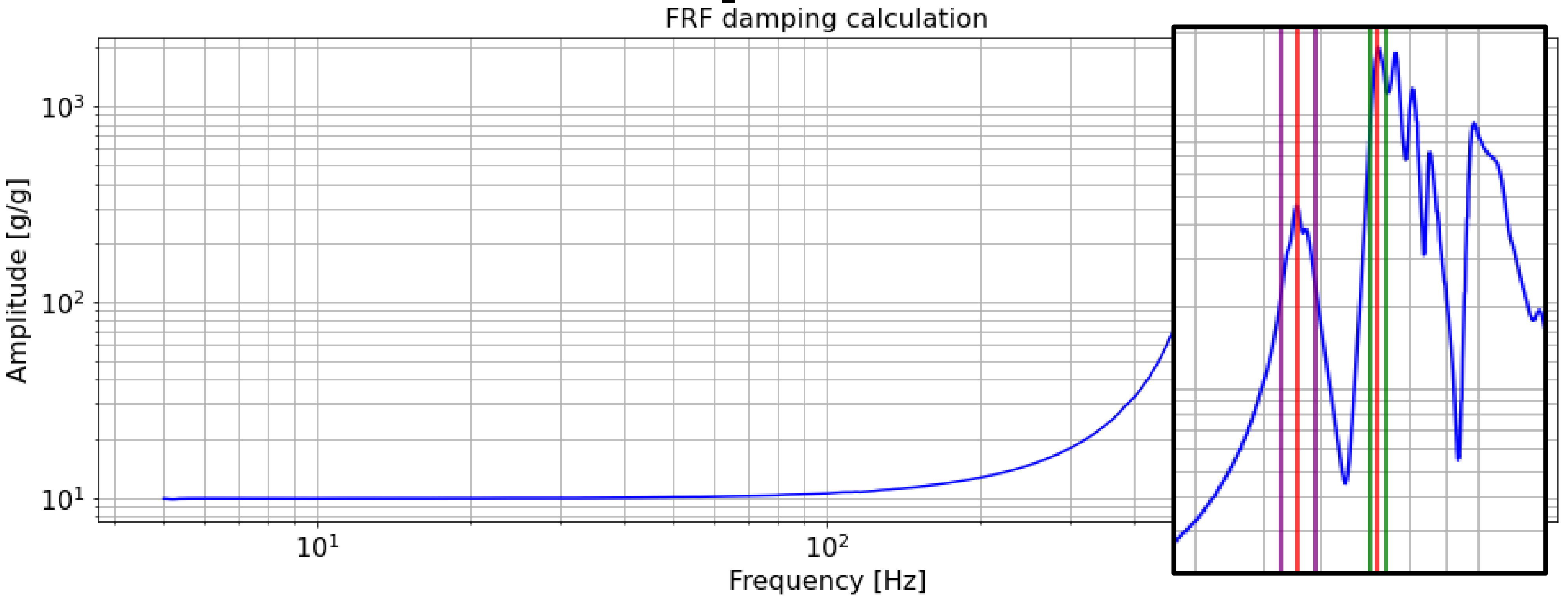


$$\xi = \frac{(\omega_2 - \omega_1)}{2 \cdot \Omega_0}$$



Both results are disturbed by the presence of surrounding peaks

Better results obtained considering only the point on the left

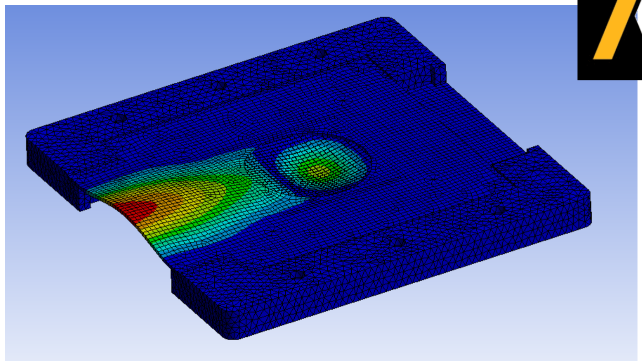
```
csi = 0.046762589928057555
peak freq1 = 556.0
csi = 0.024861878453038673
peak freq2 = 724.0
```

```
csi = 0.05575539568345324
peak freq1 = 556.0
csi = 0.027624309392265192
peak freq2 = 724.0
```

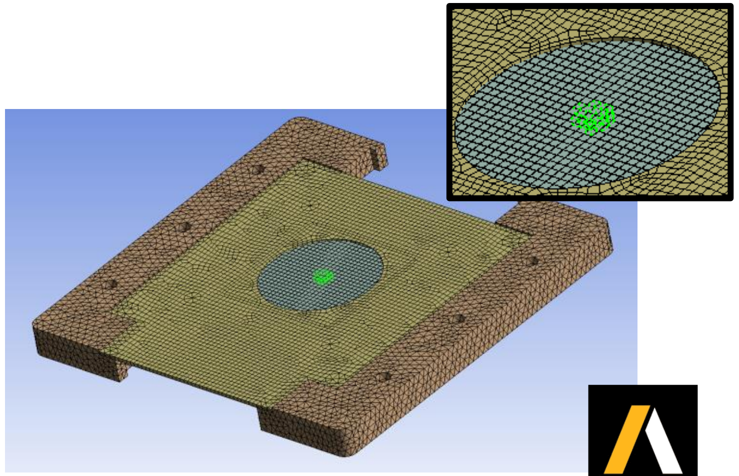
Simulation

Penetrating Particle Analyzer

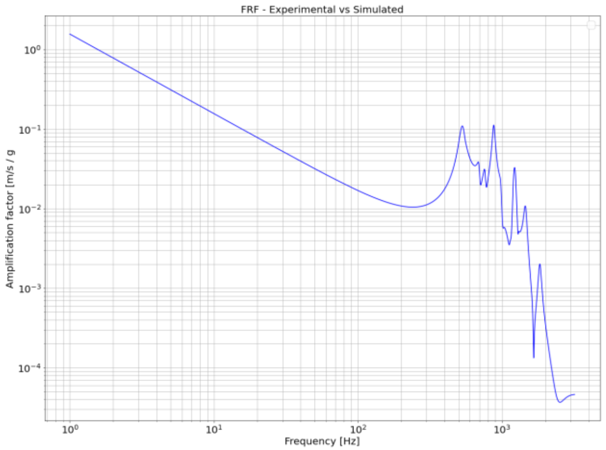
Modal analysis



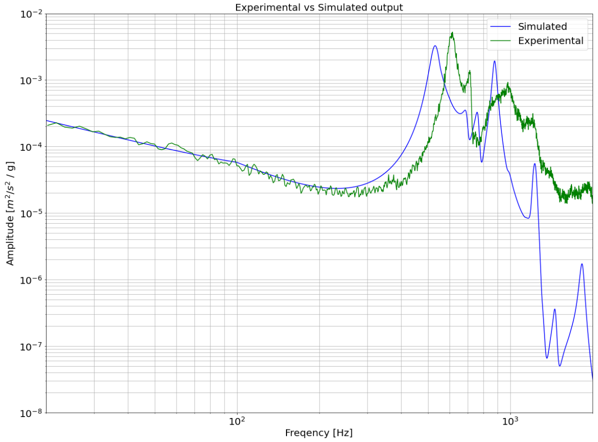
Exctraction of the modal displacement on some nodes of interest



FRF generation



Output PSD -> preliminary structural analysis



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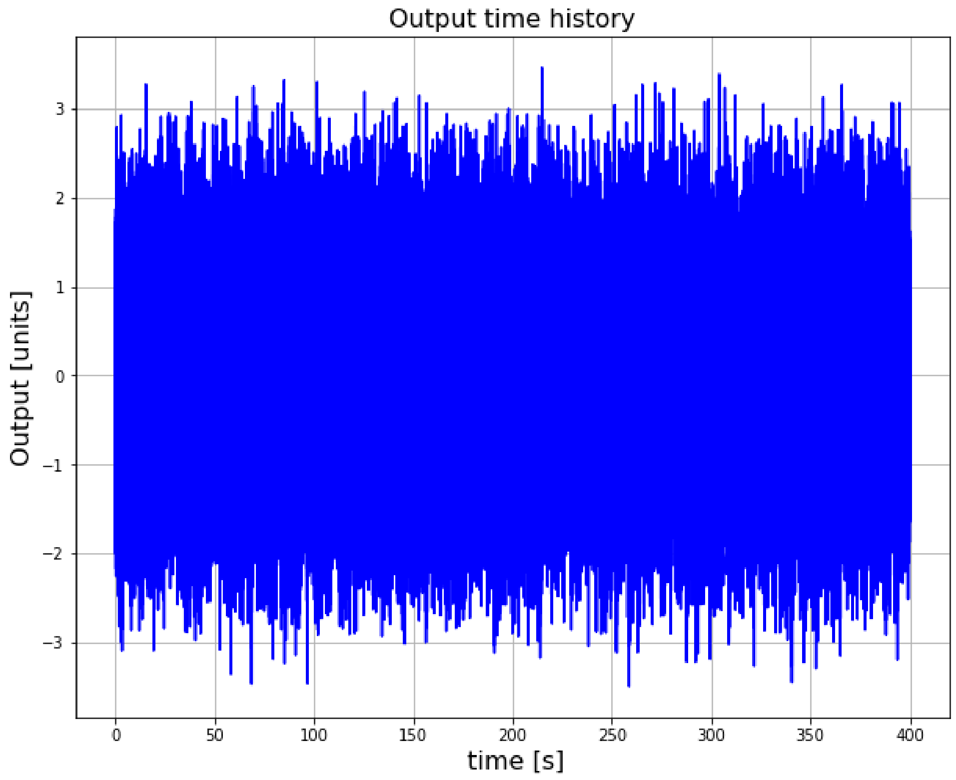
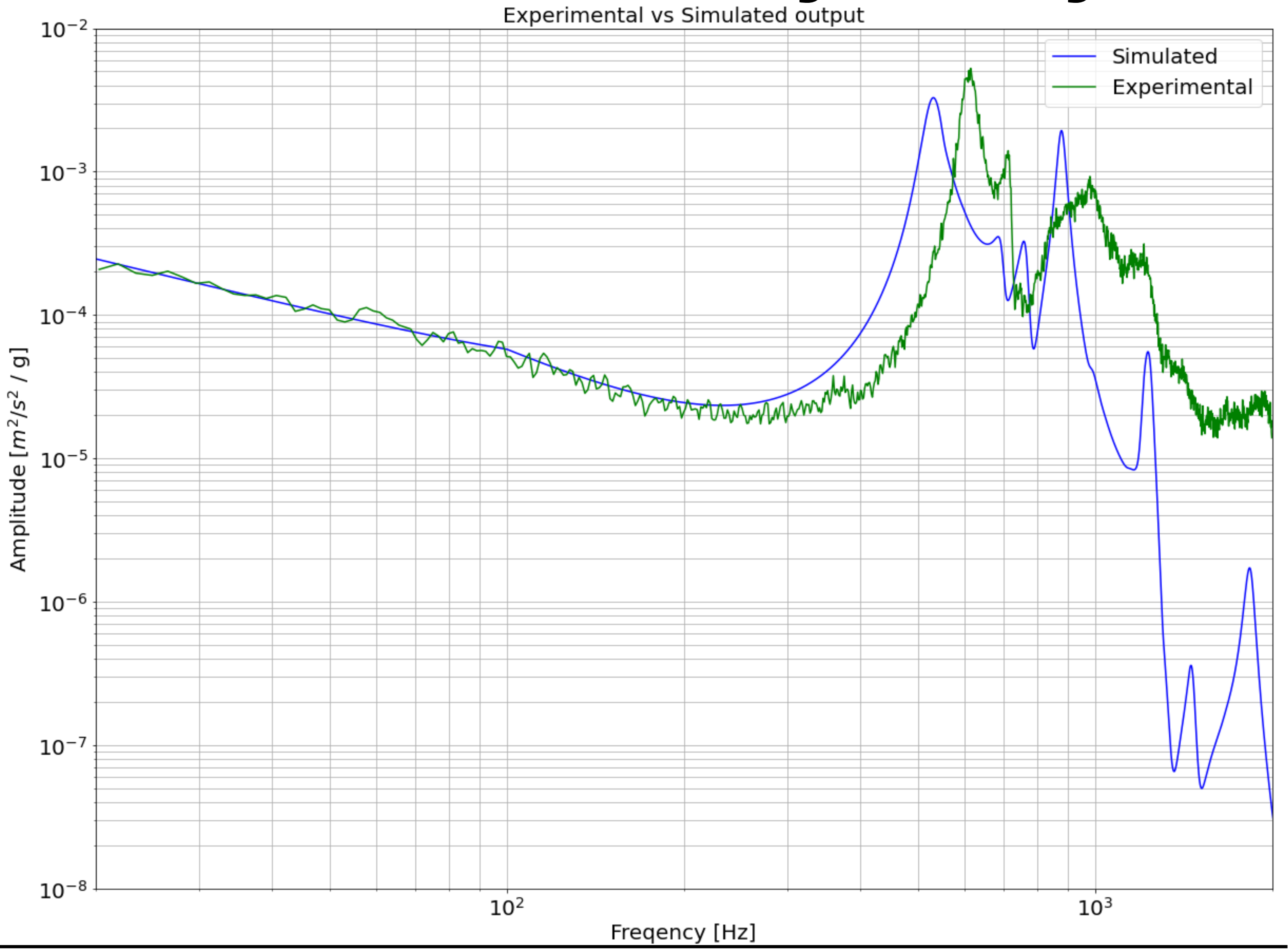
FRF exp. Vs FRF simulation

Test by analysis





Conclusions and prospects

- **Conclusions:**
  - The object is suitable for space-flight from a mechanical point of view
  - Either the silicon and the micro-bonds survived the mechanical vibrations and pyro-shock tests

- **Prospects:**
  - Mechanical test to determine the properties of silicon detectors
  - Thermal test to verify the capability of the object to withstand thermal cycles (CTE mismatch test)

Penetrating Particle Analyzer

Thanks for the attention

Penetrating Particle Analyzer

Backup slides

Penetrating Particle Analyzer

Pull test micro-bonds

- Pull force: 7 g