THE MONOLITHIC SUSPENSIONS FOR THE INTERFEROMETER VIRGO+

Paola Puppo

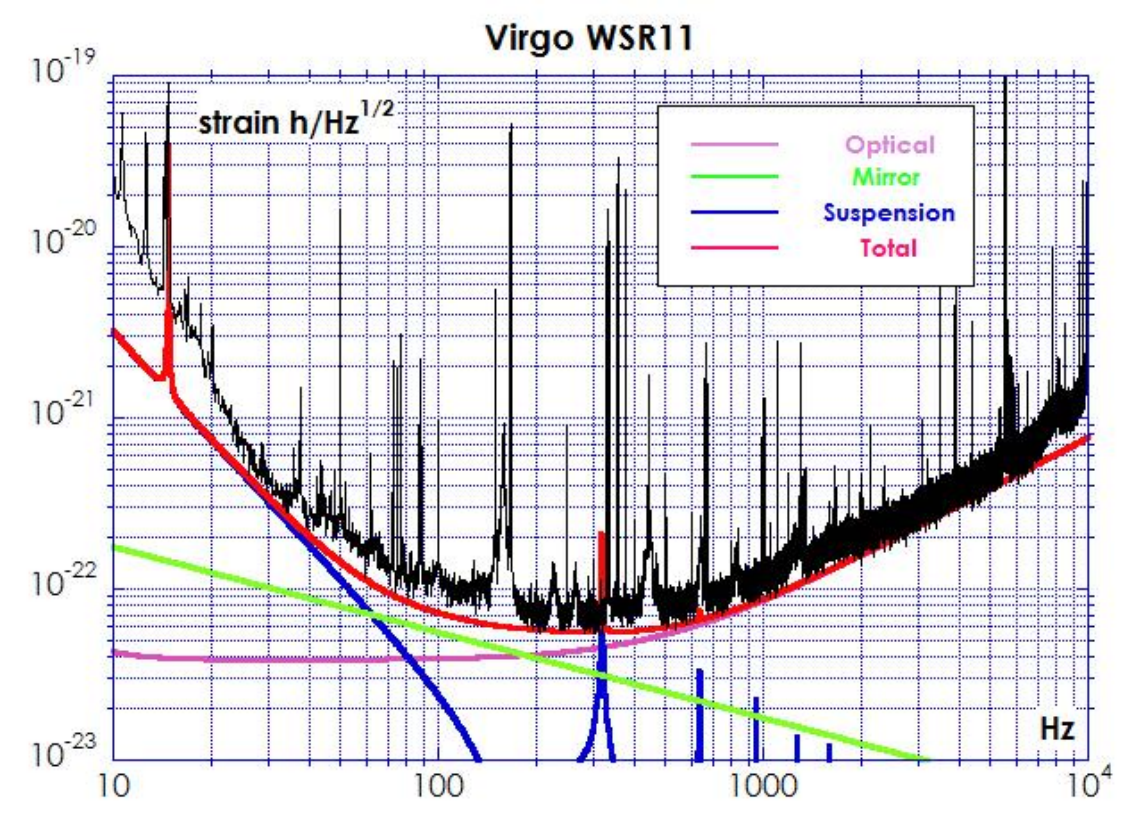
for the Virgo Monolithic Suspension Team

INFN-Rome

VIRGO+ UPGRADES

- New IMC mirror (bigger mass, better coating → reduced rad press effect, easier to lock, reduced optical losses)
- Implementation of the remote control on Faraday Isolator of suspended IB → better correction of thermal effects;
- New laser (P_{in}=50 W)→shot noise reduction
- Thermal compensation → thermal lensing reduction
- Electronics implementation →
  - "DAC noise" reduction of the low freq noise;
  - Actuation control noise reduction;
- New magnets →Eddy currents and magnetic effects reduction;

WHERE WE ARE…



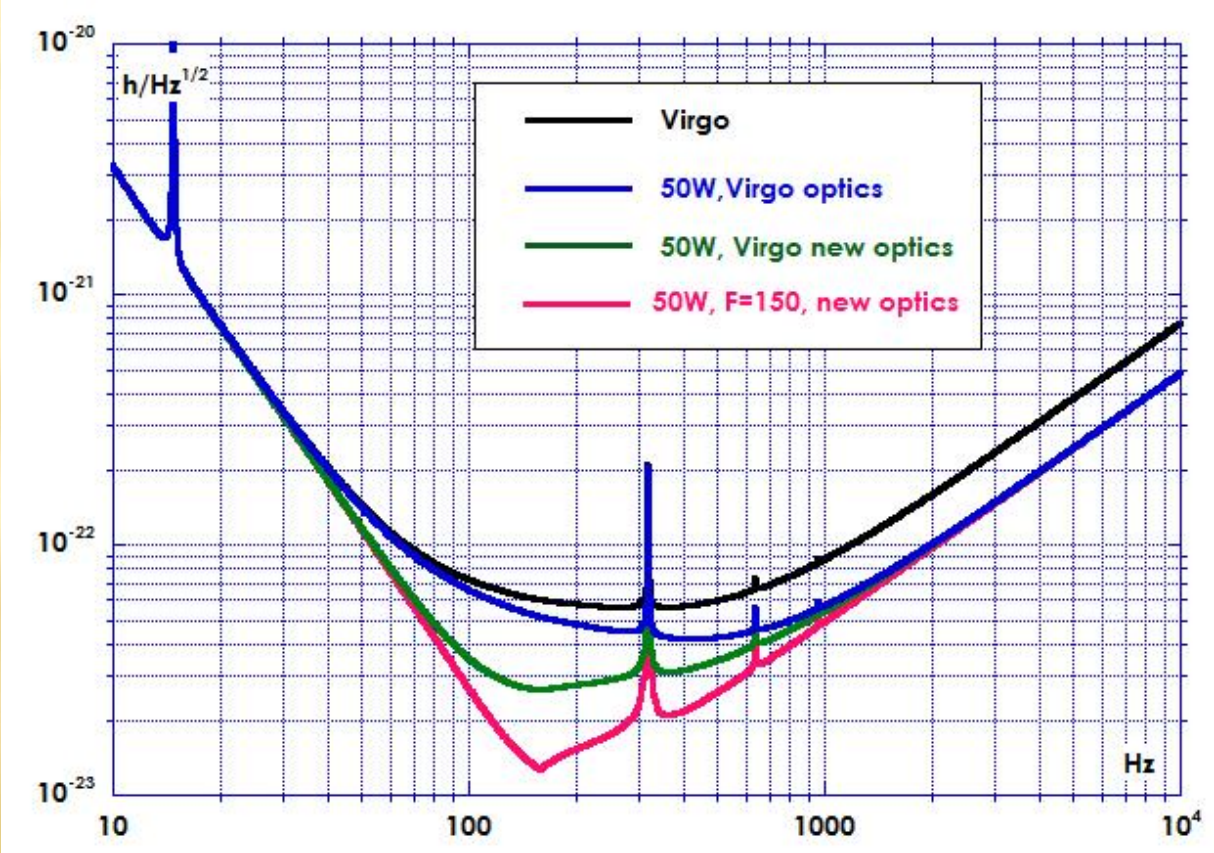
Actual limits:

- **In the 80-200Hz range the high power gain is spoiled by the thermal noise expected for the Virgo Herasil end mirrors**
- **We need to change the mirrors if we want to profit of the larger injected power.**

NEW MIRRORS AND COATINGS

- New Suprasil end and input mirrors
  - According to the Penn's noise model the loss angle expected for this material is about 10^{-9}, a new perspective is open in the middle frequency range;
  - But an higher finesse is needed: F=150 instead of the current 50.

- New coatings (TiO2 dopants: lower mechanical dissipation)
- New cleanliness procedures
  - Use of a special protecting film (Lyon);



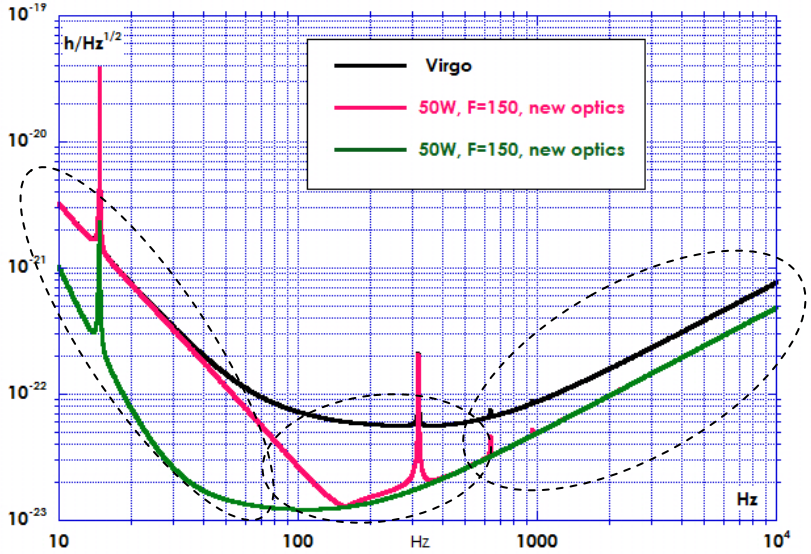
Virgo, 50W, F=150
BNS: 24.7 Mpc
BBH: 126 Mpc

WHY DO WE WANT TO USE THE MONOLITHIC SUSPENSIONS?

new mirrors
(Hi-Q)

new magnets

new recoil mass



Powered injection

new mirrors
(Hi-Finesse)

Thermal deformation
of FP cavity mirrors

Thermal
Compensation

New payloads

G0900619-v1

Virgo+ with monolithic suspension

THE SUSPENSION THERMAL NOISE IS REDUCED WITH THE FS SUSPENSIONS

In the low frequency range, the mirror pendulum thermal noise plays an important role

$$\Phi_{wire} = \Phi_o + \Phi_{th}(\nu) + \Phi_e$$

Thermoelastic Loss Angle

$$\Phi_{th}(\omega) = \Delta \frac{\omega\tau}{1+(\omega\tau)^2}$$

$$\Delta = \frac{Y_{FS}\alpha_{FS}^2 T}{\rho_{FS} c_{FS}}$$

$$\tau = \frac{c_{FS} d_w^2}{2.16 \cdot 2\pi \cdot k_{FS}}$$

d_w	wire diameter
$\Phi_o = 4.1 \cdot 10^{-10}$	loss angle
Y_{FS}	Young modulus
α_{FS}	thermal expansion
c_{FS}	specific heat
ρ_{FS}	density

Cagnoli G and Willems P A Phys. Rev. B, 65, 17

Φ_e **Eccess loss angle**

Frictional losses in the marionetta-wire clamps

Frictional losses in the mirror-wire clamps

Surface losses

$$\phi_{surf} = \phi_{FS}\left(\xi \frac{d_s}{V/S}\right) \approx 2 \times 10^{-7}$$

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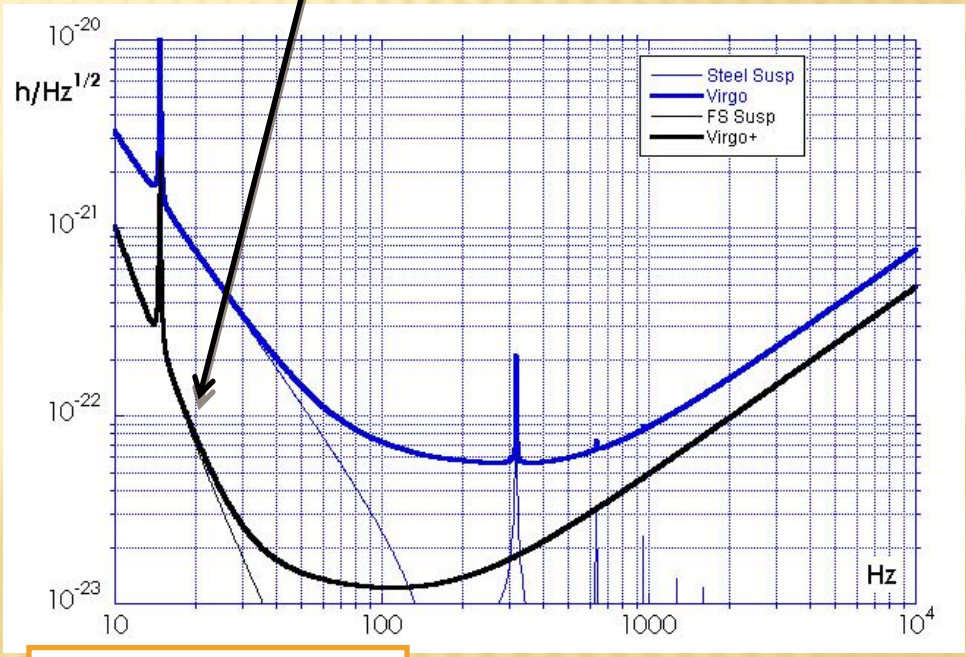
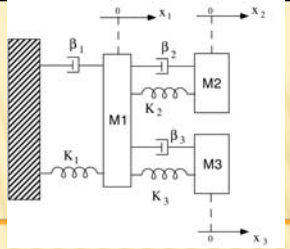
A.M. Gretarsson et al, PLA 270 (2000), 108-114

Thanks to the lower mechanical dissipation of the fused silica, a monolithic suspension promises an excellent performance by reducing all the loss term of Φ_{wire}

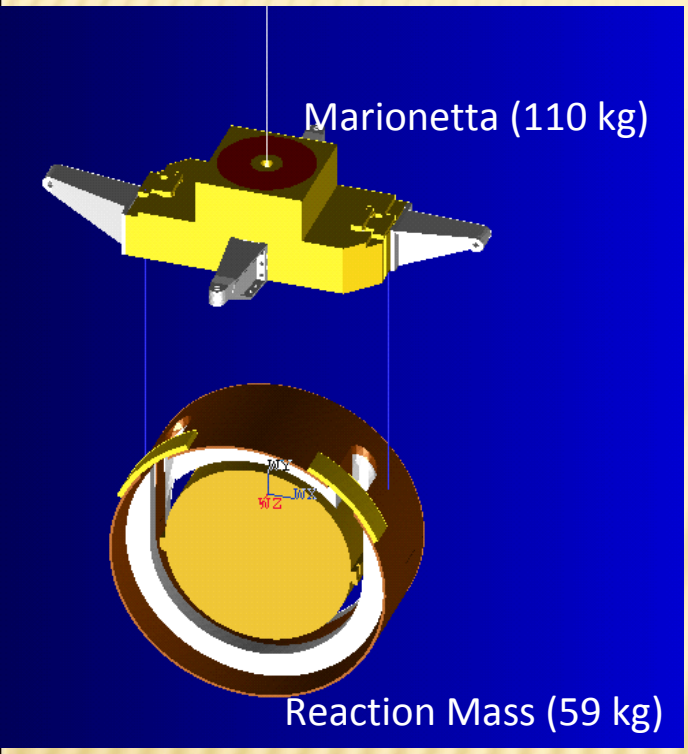


Virgo+ average sight
BNS: 53.6 Mpc
BBH: 284 Mpc

THE NEW THERMAL NOISE MODEL

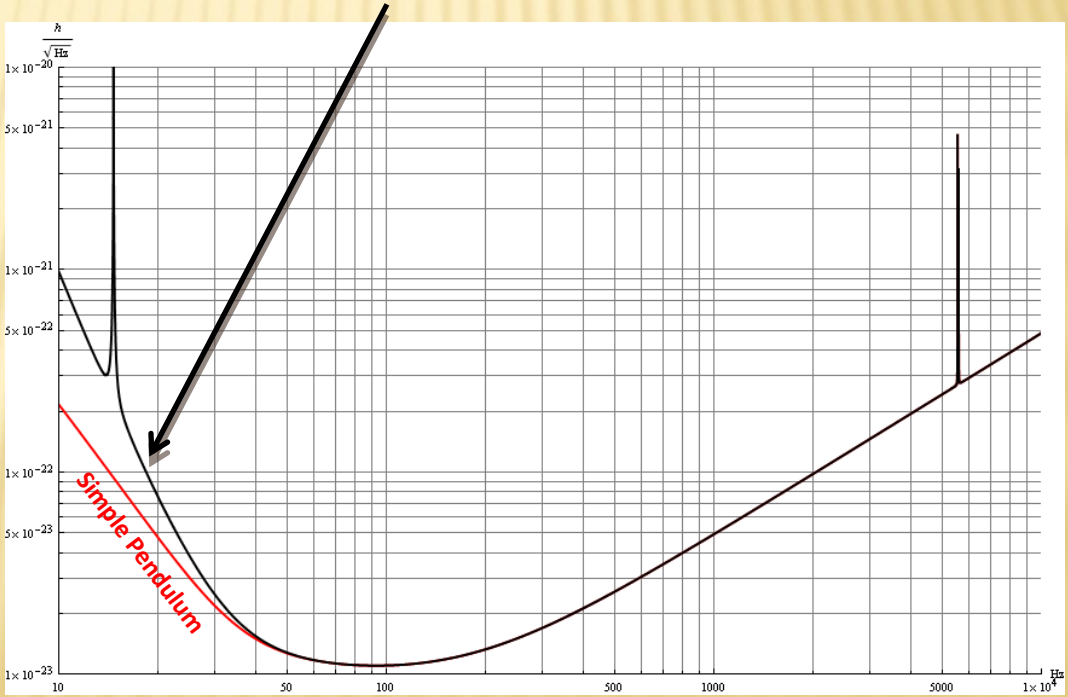


Monolithic suspensions payload



With the low dissipative monolithic suspensions, the contributions of the other last stage suspension elements to thermal noise of the mirror cannot be neglected.
A new thermal noise estimation has been done, it includes the viscous and internal dissipations of the marionette and recoil mass.

It turns out that the marionetta's mechanical losses give a non negligible effect via its recoil, in the off-resonance high-freq. range.



Branched pendulum:
FDT model with violin modes and Normal modes model*.
Vertical modes are included

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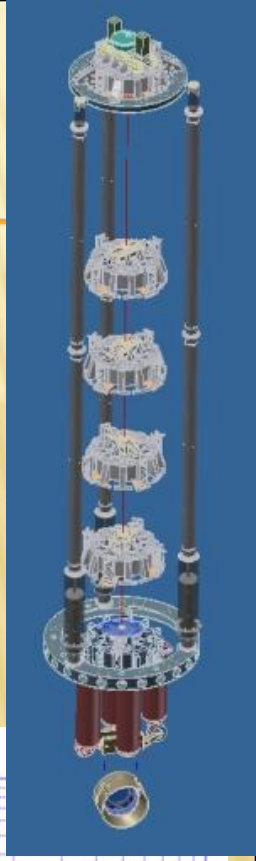
**F. Piergiovanni, M.Punturo, P.Puppo, The thermal noise of the Virgo+ and Virgo Advanced Last Stage Suspension (The PPP effect), Virgo Note: VIR-015A-09.*

THE NEW THERMAL NOISE MODEL



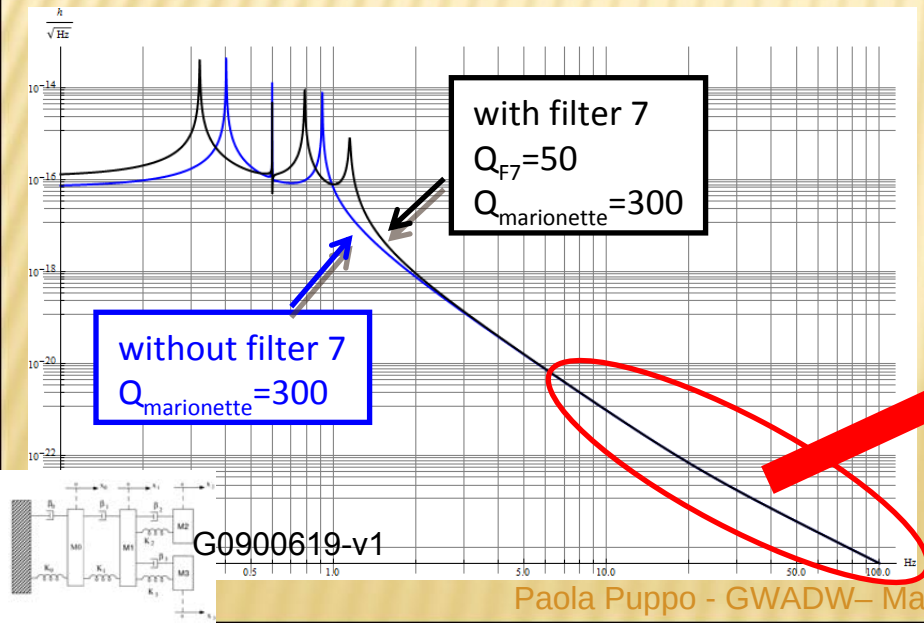
- **The evaluation of the losses of the marionette, is crucial for the correct estimation of the sensitivity curve.**

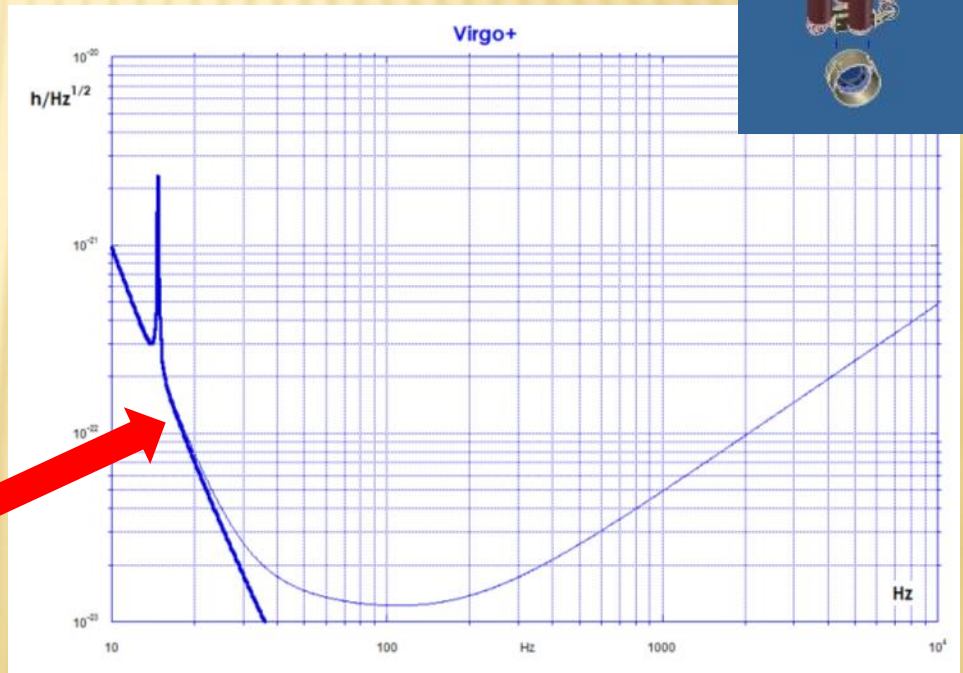
- **It is not possible to measure the marionetta losses on the payload hung to the SA by simply looking at the quality factors of the modes;**
- **They are influenced by the whole SA chain, the quality factors of the SA modes are of order of 50-100;**

- **From the measurements of the quality factor of the modes on our in-air monolithic prototype we can infer a marionette loss of 1000. (without any optimization)**

- **The coupling to the SA chain can modify the marionette losses.**
For this reason a conservative marionette quality factor of 300 is chosen for our thermal noise estimations.

- **The effect of the other lossy SA stages on the thermal noise have been evaluated to be negligible.**

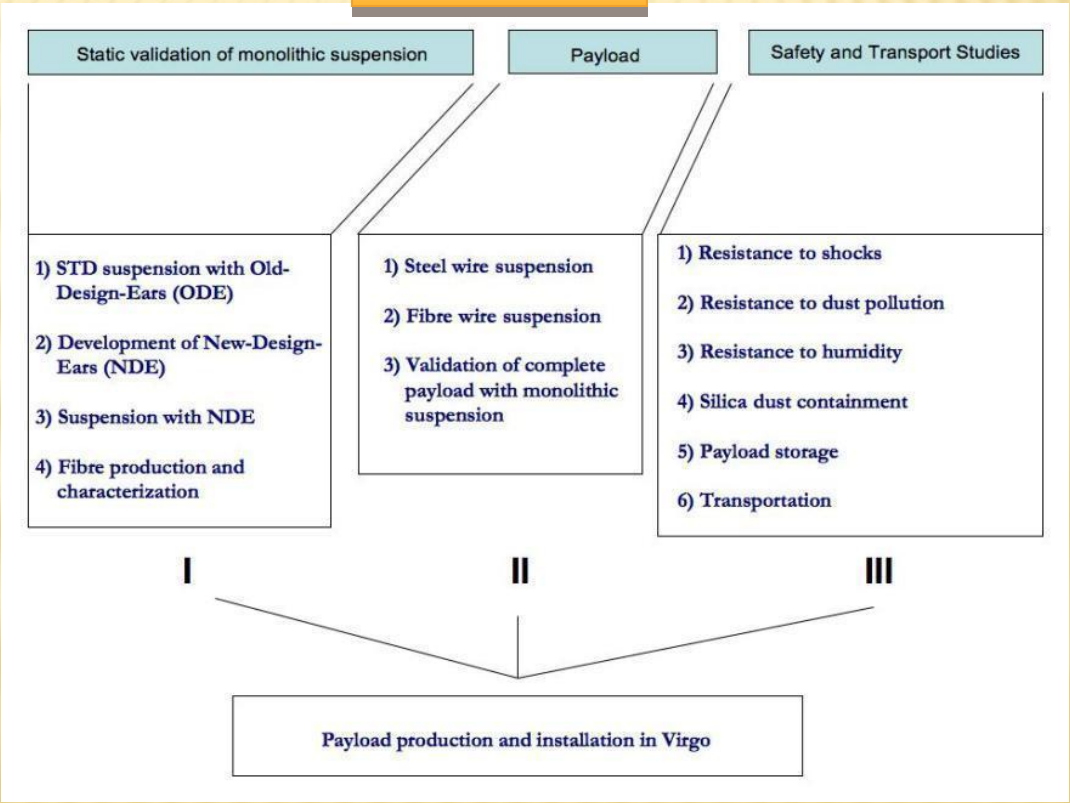




VIRGO+ UPGRADE: MONOLITHIC SUSPENSIONS

- **Monolithic fused silica suspension development is an heavy activity in Virgo**
  - **Joint effort of many Virgo labs (Roma, Firenze, Perugia and EGO)**
- **Activity progressing thanks to the full immersion of the involved group.**

Activity tasks



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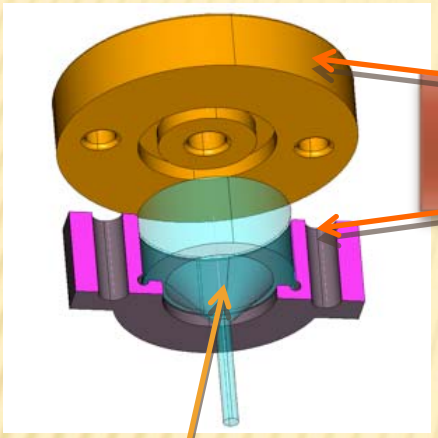
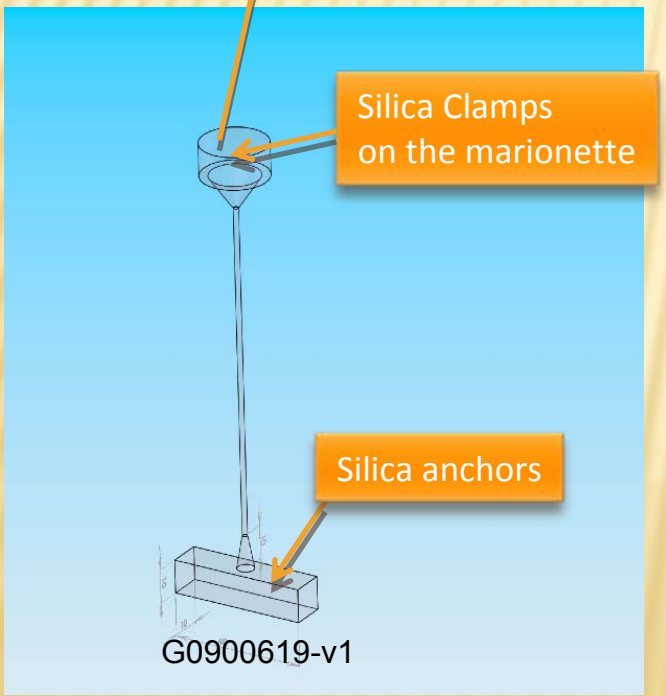
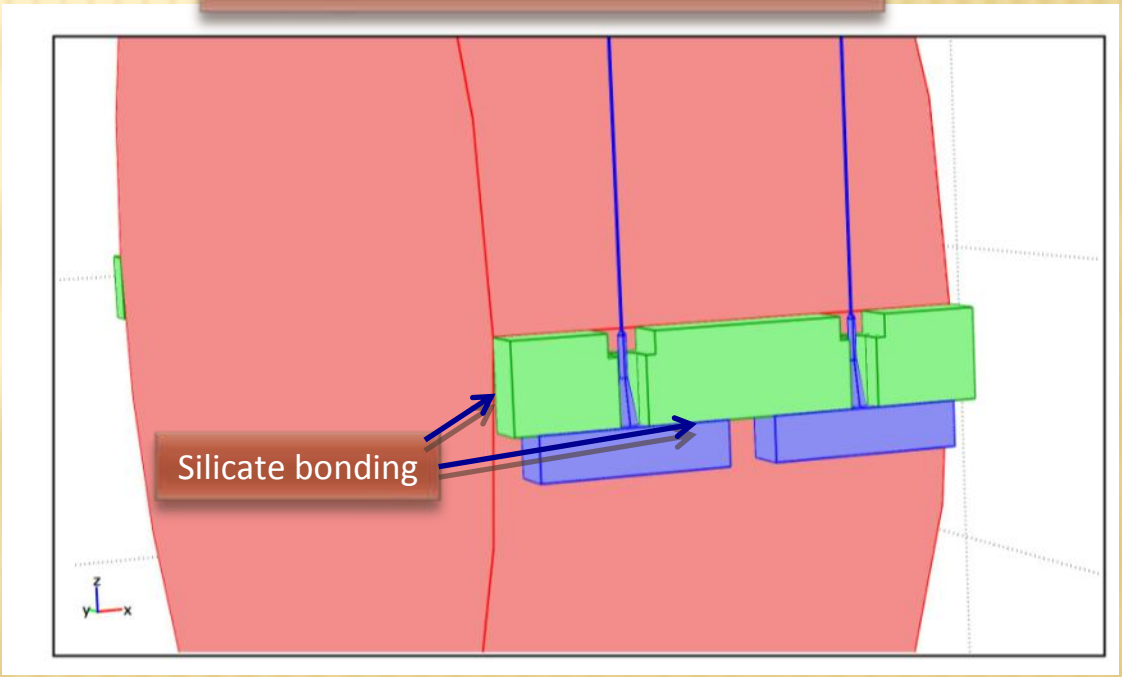
CLAMPS: DESIGN AND PRODUCTION



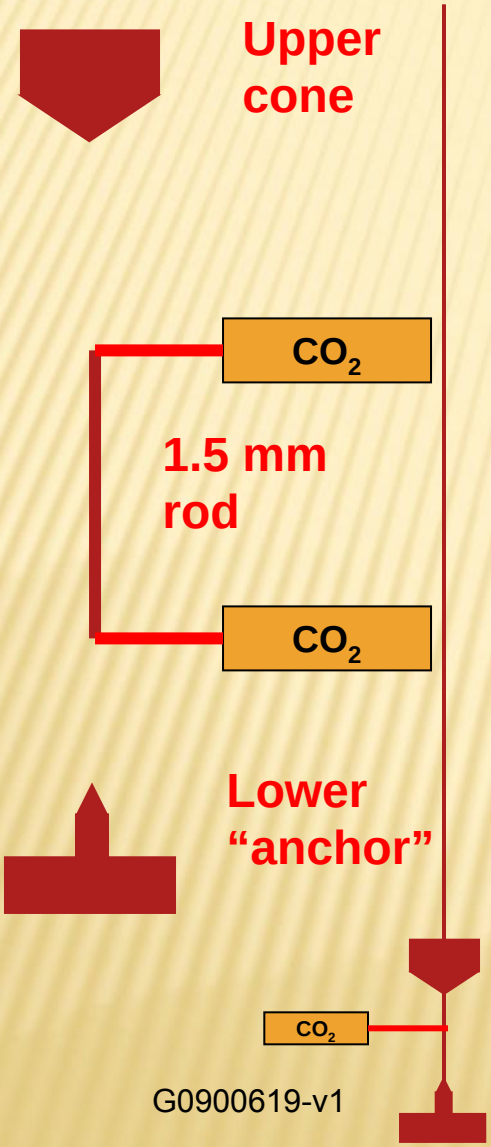
Steel box to host the upper silica clamp on the marionetta



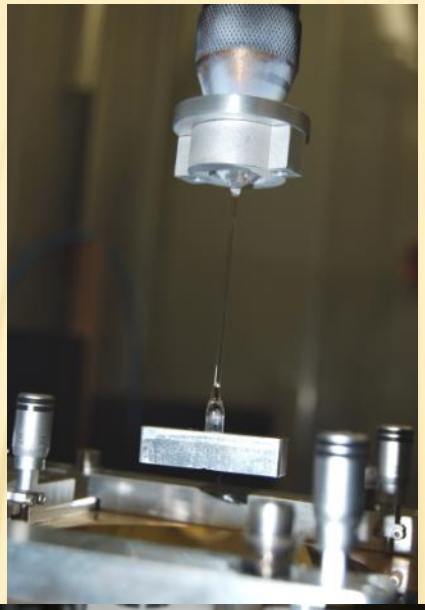
Coupling to the mirror flats with New Ears

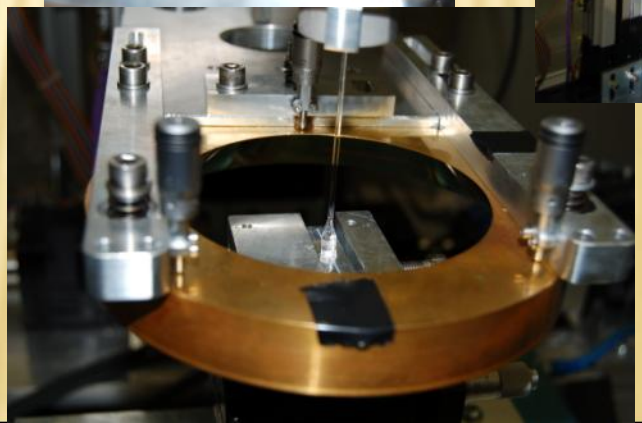


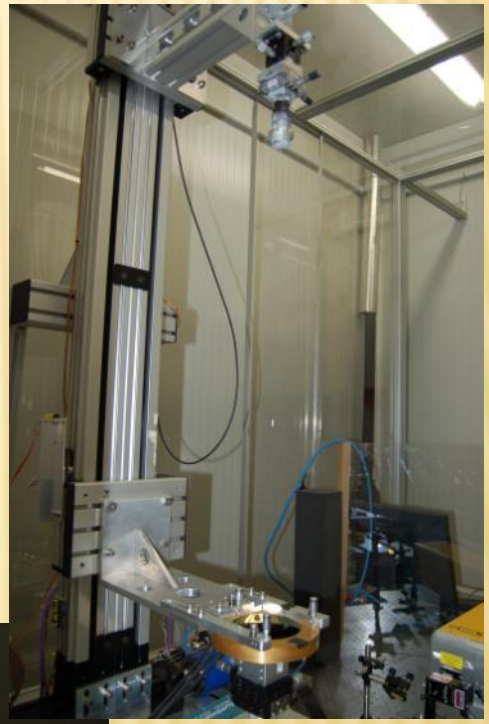
SILICA WIRES: FIBER PRODUCTION AND CHARACTERIZATION



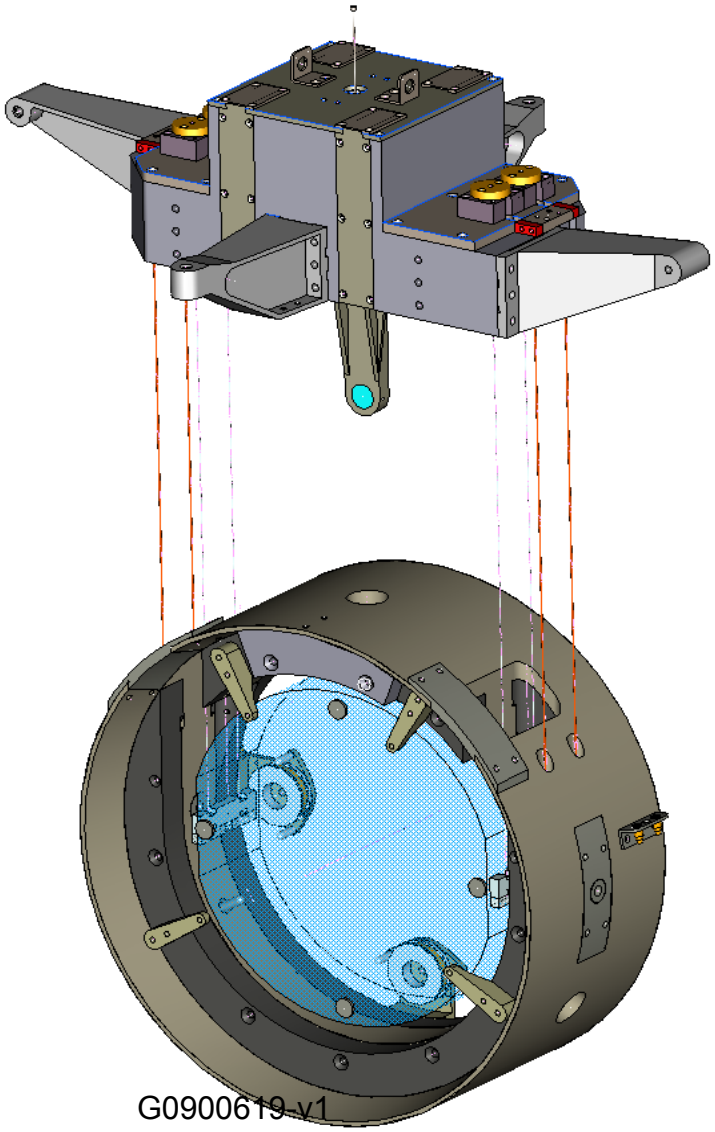
- Fiber production validated
- Implemented the fiber welding with the laser on the lower and upper silica clamps;







THE PAYLOAD



Marionette (110 kg):

- amagnetic steel AISI 316L, dielectric arms (peek)→ no eddy current and magnetization effects;
- designed to be fully compatible with the monolithic suspensions assembly;
- equipped with mirror for LC purposes;
- step motor to displace a balancing weight;

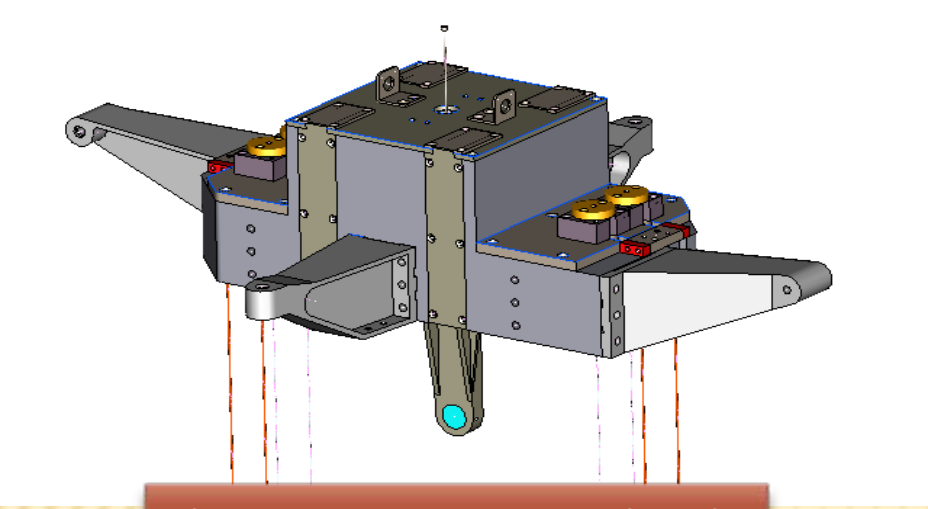
Recoil Mass (60 kg):

- amagnetic steel AISI 316L outer cylindric mass (500 mm diam);
- dielectric inner ring (peek CF30) → no stray currents or magnetization effects
- it carries four coils for e.m. actuation on magnets attached the mirror rear side;
- suspended with steel C85 wires (0.6 mm diam.)
- option: it can carry the markers for the LC purposes
- equipped with safety stop (peek made)

Mirror (21 kg):

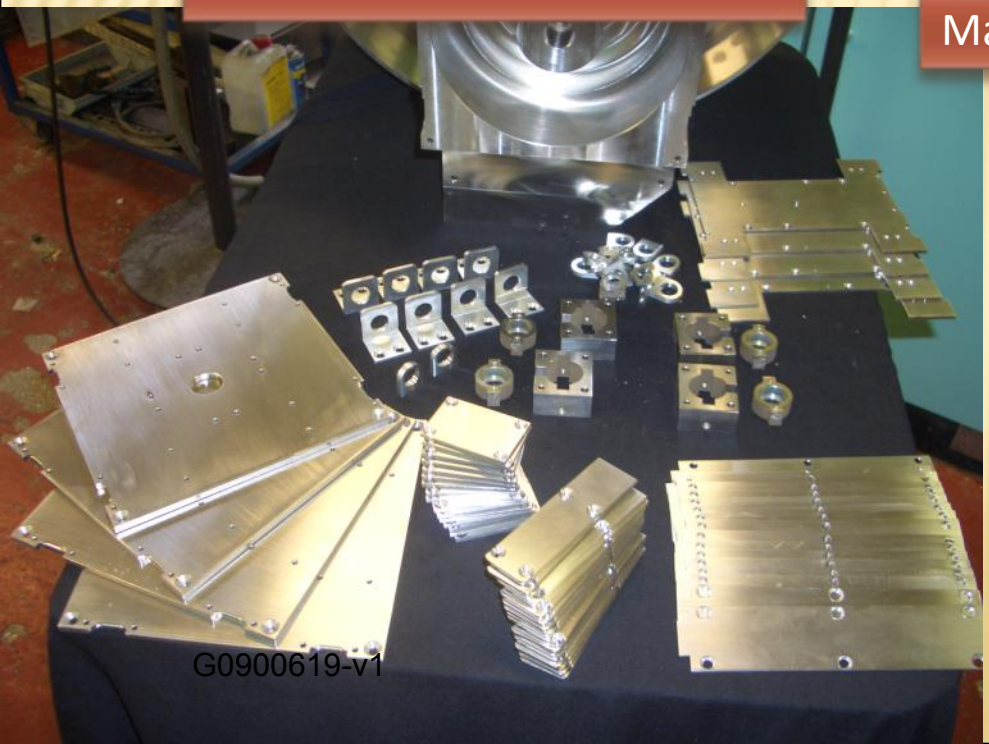
- FS with lateral flats (350 mm diam), silica ears attached with silicate bonding
- suspended with silica wires (285 μm diam)
- magnets attached on rear side
- option: markers attached on front side (LC)

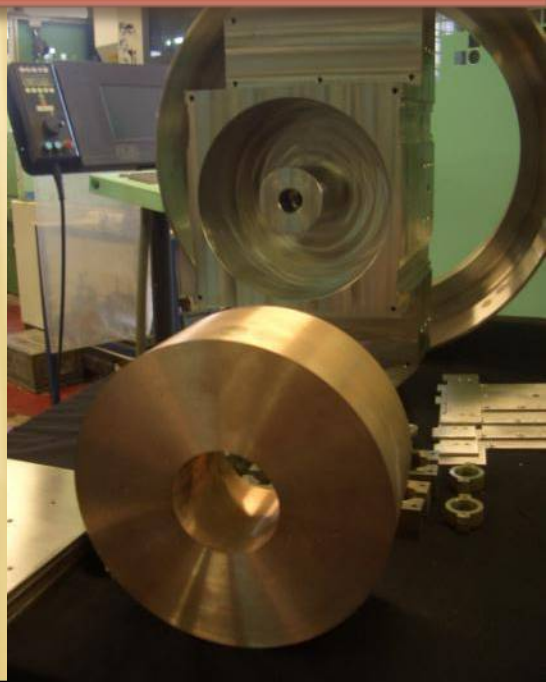
PAYLOADS: THE MARIONETTE



The marionette: some details

Marionette and Copper Tungsten inner mass





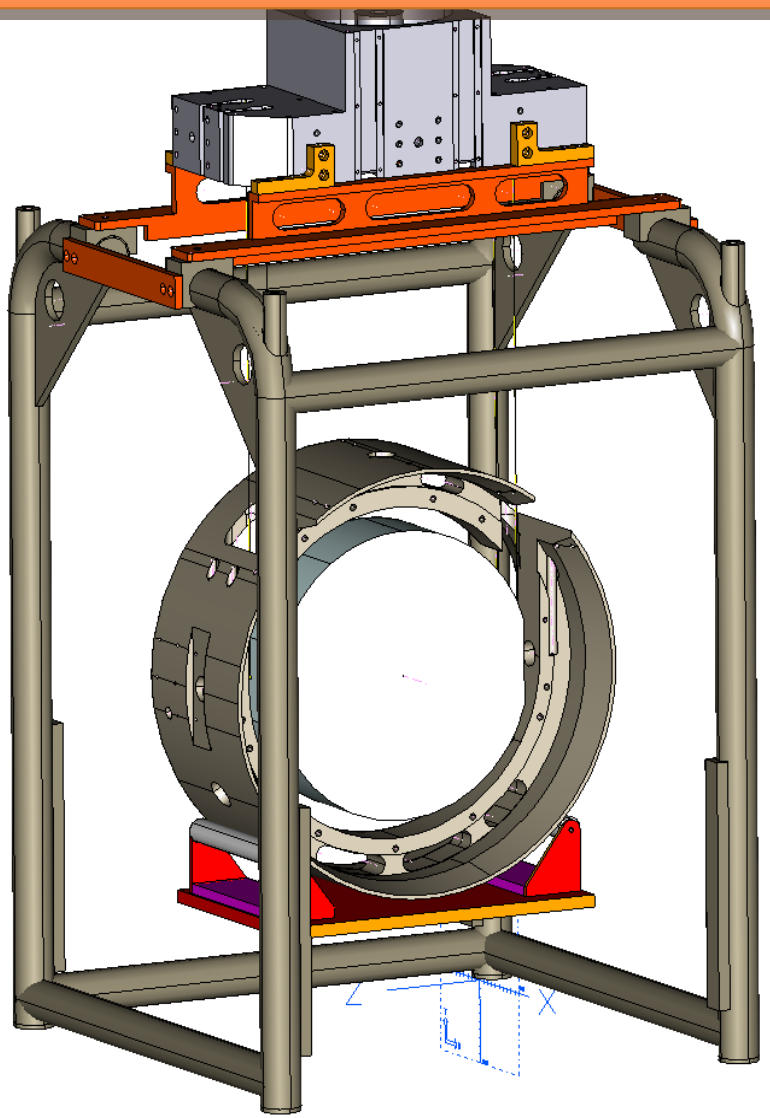
PAYLOAD: REACTION MASSES AND PAYLOAD FRAME

Frame for payload assembly:

- a new frame has been designed on the base of the acquired experience during the tests;
- the precisions required for the positioning of the pieces are respected;
- it is equipped by a vacuum pump clamp the mirror face during trasportation;

The reaction masses are being machined

The frame design is being finalized



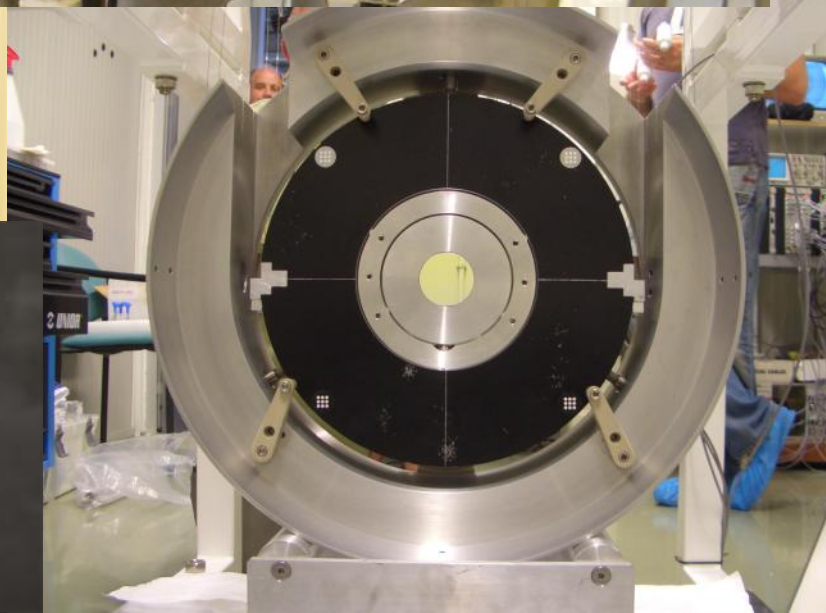
1) Steel wire suspension

2) Fibre wire suspension

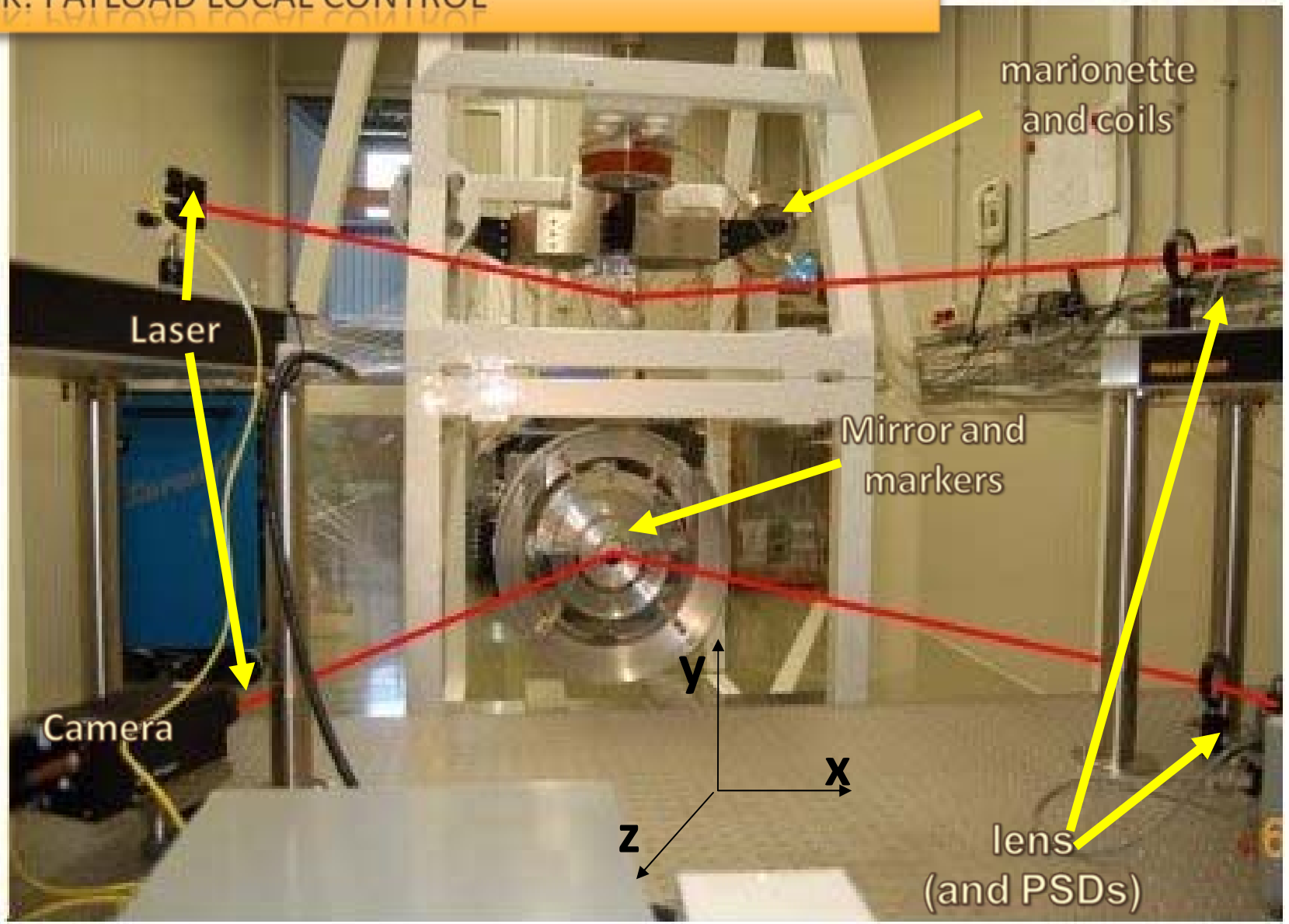
3) Validation of complete payload with monolithic suspension

II TASK:
PAYLOAD SUSPENSION

- Steel AISI304 Marionetta prototype with PVC arms
- Dummy reaction mass, coils with peek supports
- A mirror is inserted in the holder, and the system is balanced.
- All the pieces are secured by safety structures Fibers bending point placed on the marionetta's center of mass



II TASK: PAYLOAD LOCAL CONTROL



Electronic equipment:

- crate with ADCs/DACs, DSP, DOL and 2 timing boards

Monolithic payload prototype tests

1) Steel wire suspension

2) Fibre wire suspension

3) Validation of complete payload with monolithic suspension

Mechanical Assembling using a suspension frame: done in 3 steps

0) STEEL WIRES

- TF meas
- control design
- preliminary

models: analytical and FEM model

STEEL

I) FS with AL ANCHORS and EARS

- assembly procedure (I)
- TF meas
- controlled operation
- model retuning (with FS)

HYBRID

II) FS with FS ANCHORS and EARS

- assembly procedure (I)
- Note: mario baricentre moved upwards in two steps (IIa,IIb)
- TF meas
- controlled operation
- model retuning (with new marionette baricentre)

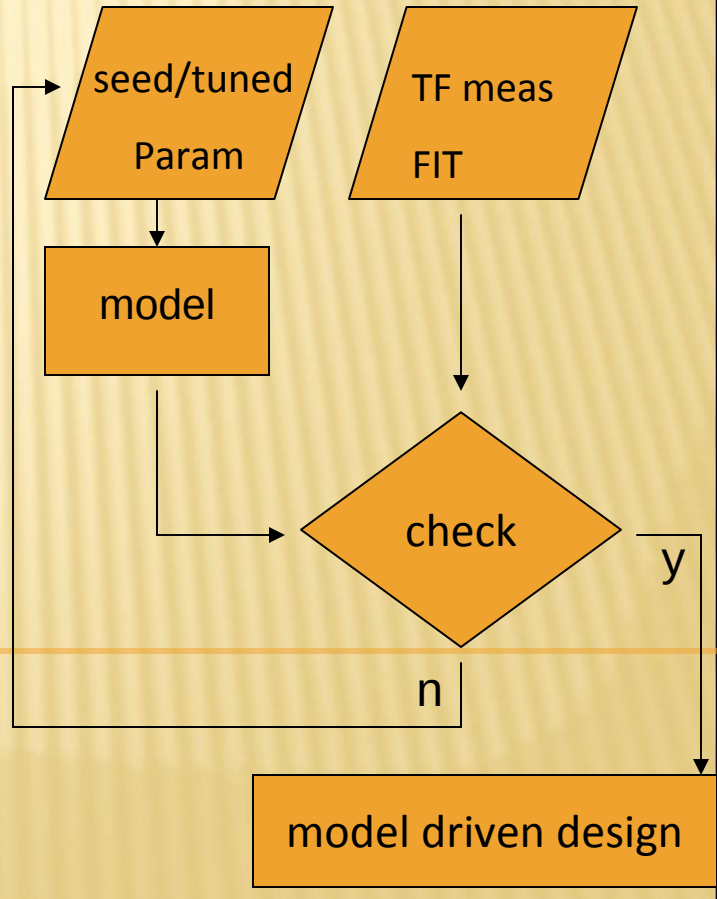
FULL

Example of TF meas results / model

yMa/yCorMa [um/V] (accel PCB 10V/g, vertical)		Q (if double)	Comment
			2.638e-2 um @ 0.2 Hz
Z	0		
Z	0		
P	3.711	570	
Z	3.827	60	
P	5.316 (5.236)	950	
Z	5.518 (5.468)	300	
P	8.124	750	
Z	8.136	700	
P	8.746 (8.854)	900	
Z	15.33 (15.72)	900	
P	19.00 (18.74)	950	
Z	22.89	850	
P	23.00	950	
P	10		

7

vertical (y)
Mario Accel response
VS
Mario exc



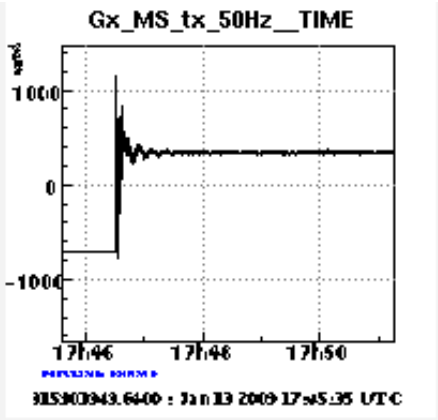
Tuned parameters for lumped-impedance matrix model

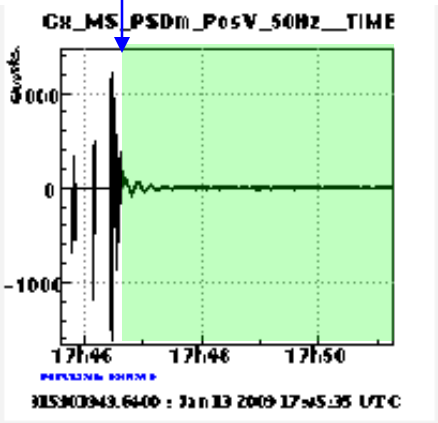
PARAM	Mi	RM	Ma	comment
M [kg]	23 → 22.9	33 → 33.45	116 → 115	
Ixx [kg m2]	0.210 → 0.210	1.07 → 1.085	0.7 → 0.690	
Iyy [kg m2]	0.210 → 0.210	1.05 → 1.060	1.7 → 1.650	
Izz [kg m2]	0.390 → 0.390	1.95 → 1.977	1.61 → 1.596	
l [m]	0.7 → 0.6985	0.7 → 0.6985	1.130 → 1.130	
d [m]	2.85e-4 → 2.93e-4	6e-4 → 6.10e-4	1.85e-3 → 1.85e-3	
Sux [m]	0.1850 → 0.1850	0.22 → 0.2215	0 → 0	
Suy [m]	0 → 0.0015	0 → 0	0 → 0	
Suz [m]	0. → 0.0250	0.0250 → 0.0250	0 → 0	
Sdx [m]	0.180 → 0.1808	0.243 → 0.2437	0 → 0	
Sdy [m]	→ 0	0 → 0.0010	0 → -0.0005	
Sdz [m]	0.0250 → 0.0255	0.0250 → 0.025	0 → 0	

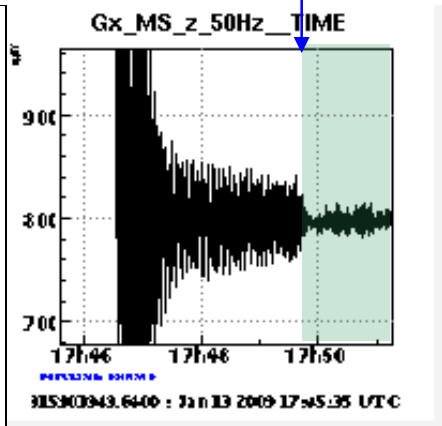
Automated hierarchical activation of controls

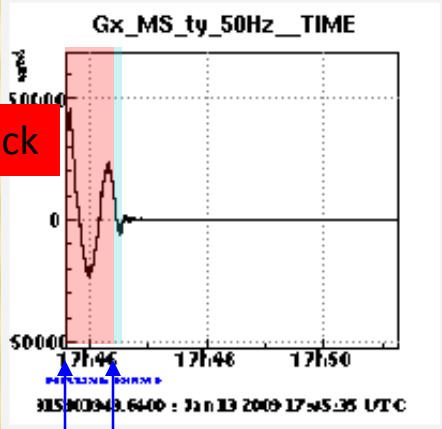
3b: optical lever tx mario =>mario act

5: optical lever tx mirror =>RM act

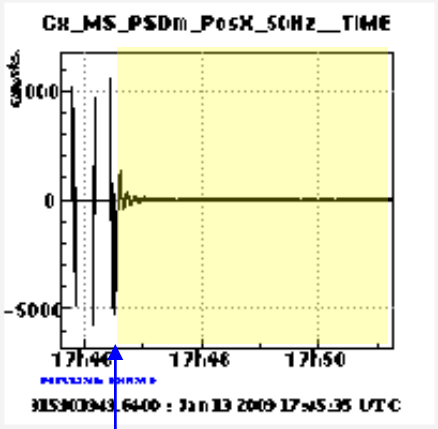


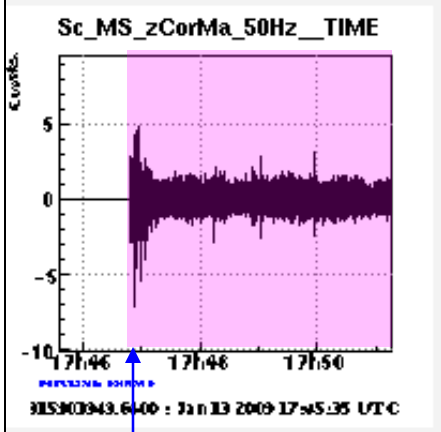






kick





Notes:
- no motors installed in the payload

-environmentally sustained oscillation (5 mrads)

- 8 error signal used, 7 loops activated (5 in this plot + tx ty RM dampers)

- damper from both ground => mario and RM => mirror

- few microrads tx,ty rms accuracy at regime

4: optical lever z mirror =>mario act

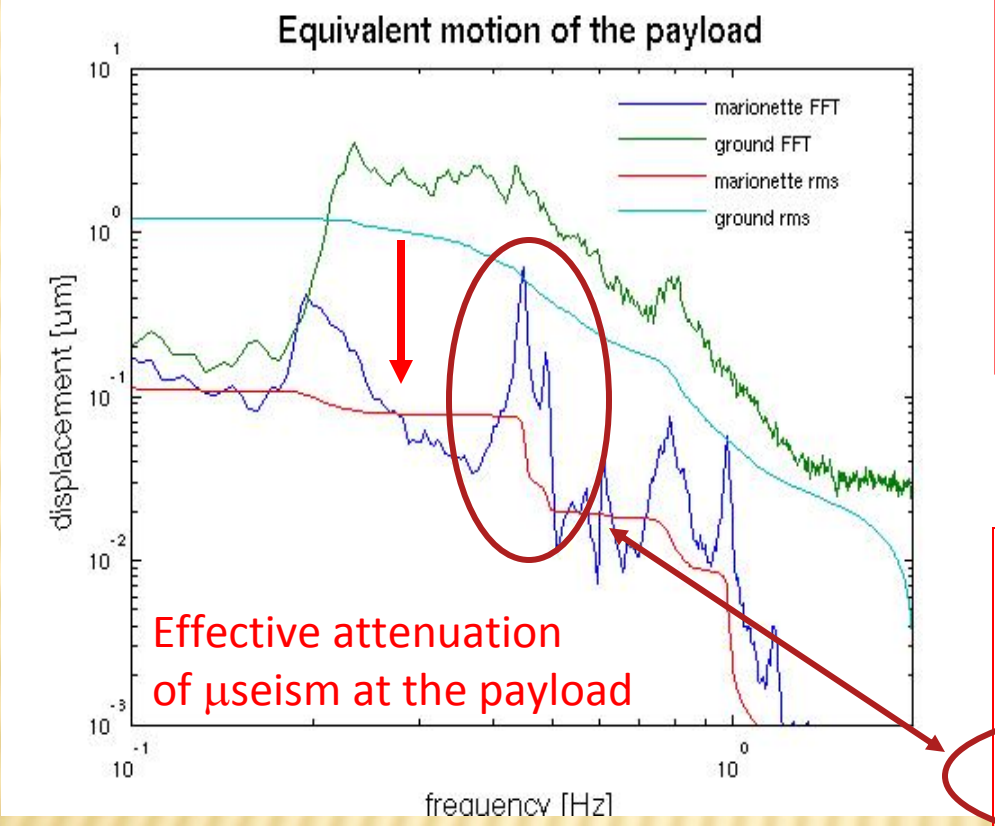
3a: optical lever ty mario =>mario act

2 : optical lever ty mirror =>mario act

1: coarse ty mirror =>mario act

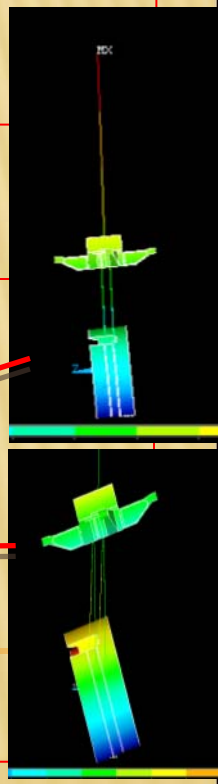
A further check of the modeling process and possible payload optimization

microseism due to sea activity is often active in the range 0.2-0.6 Hz



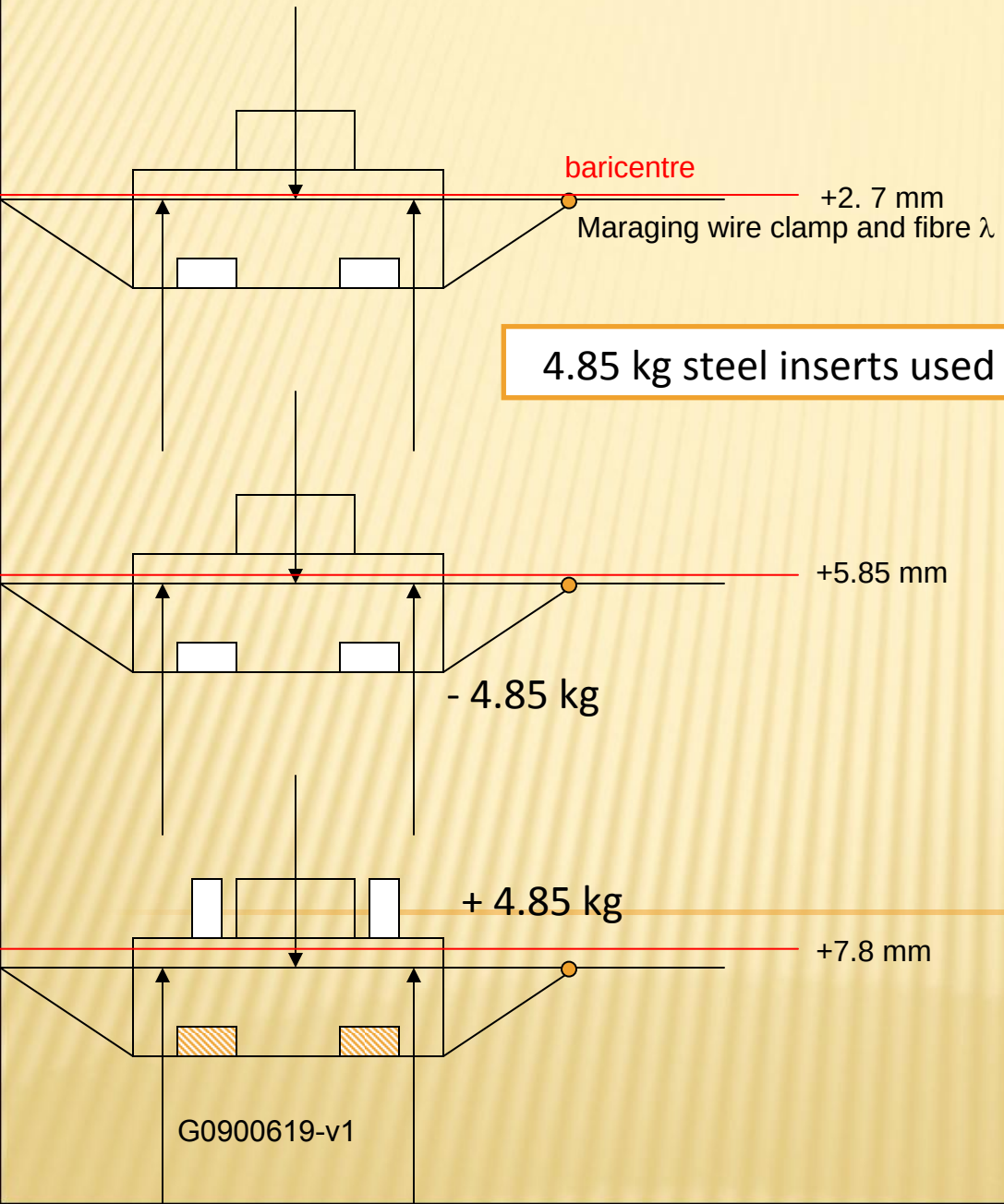
Thanks to IP inertial damping and suspension performance the lock force applied to the marionette corrects the residual payload motion, whose rms above 100 mHz is ~ 1 order of magnitude smaller than the ground motion (MSC,Hannover 25 10 07)

Pitch (in present payload):
g=-88 urad/V (DC);
cp=[0.409 300]
cz=[0.449 60]
cp=[0.4525 60]
cz=[1.705 1500]cp=[1.753 1500]
cp=[3.205 1500]
sp=10



Murphy law: Virgo suspension chain and actual payloads have z/p couples in the same range, which falls in the microseismic band=> pitch alignment suffers …

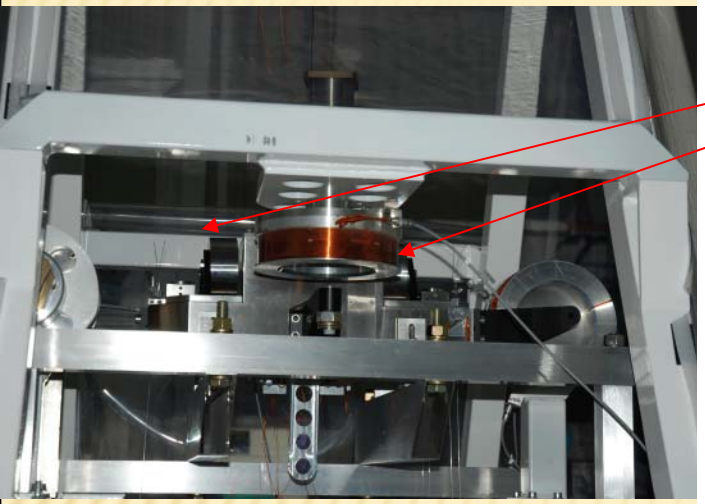
Baricentre move tests in monolithic payload configurations I,IIa,IIb

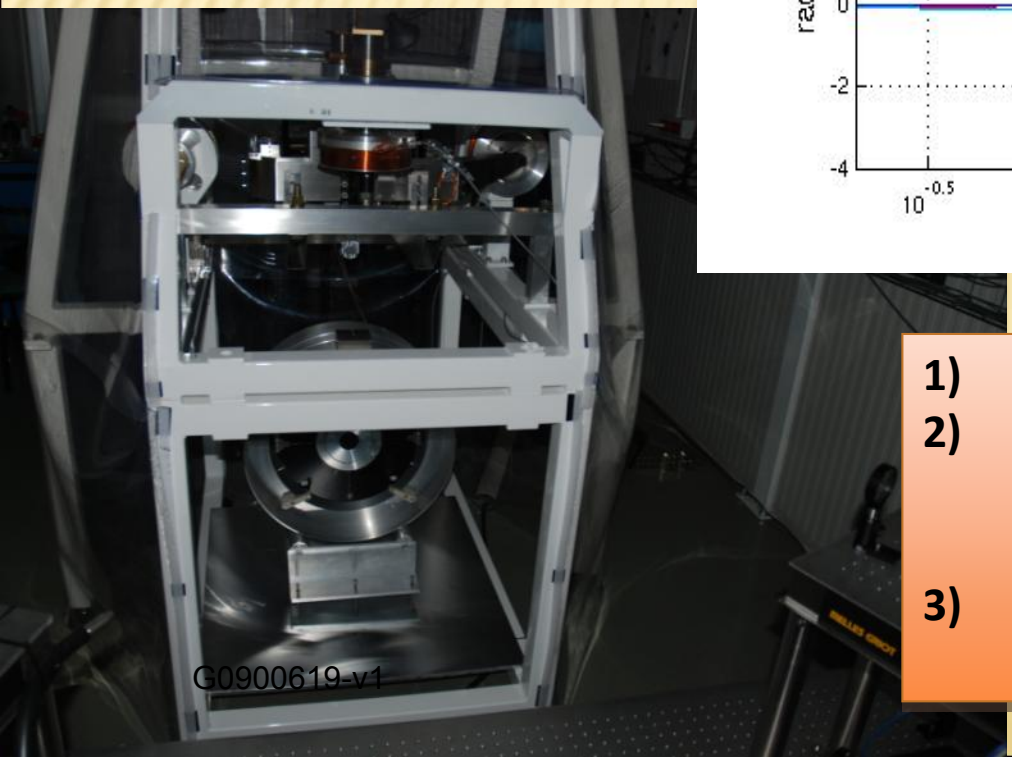


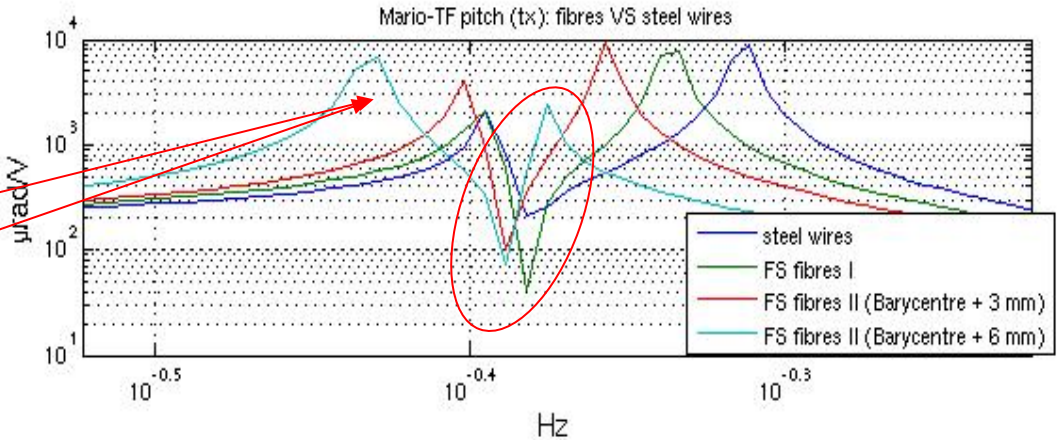
4.85 kg steel inserts used to rise up **artificially** the baricentre

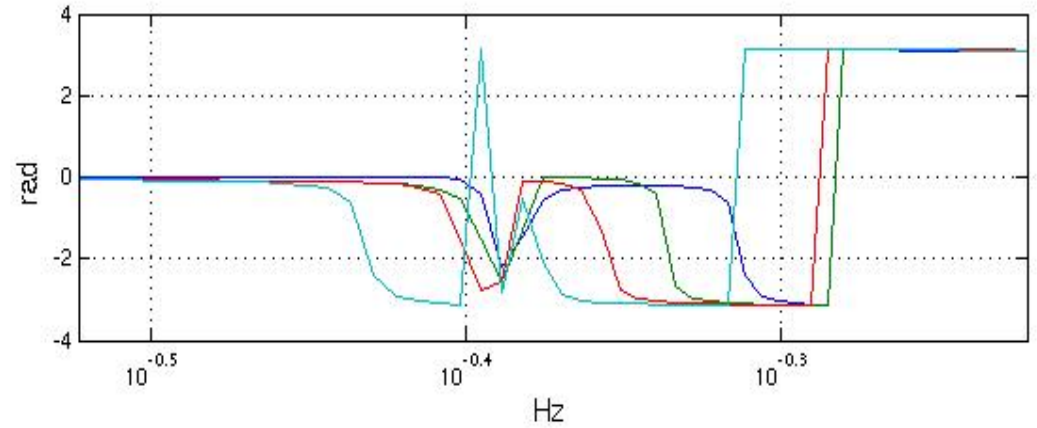
Meas/Model check

The clean way to drive pitch mode in the range 250-300 mHz, reducing z/p couple impact on pitch control accuracy is to bring the bending point of marionette wire closer to the baricentre.







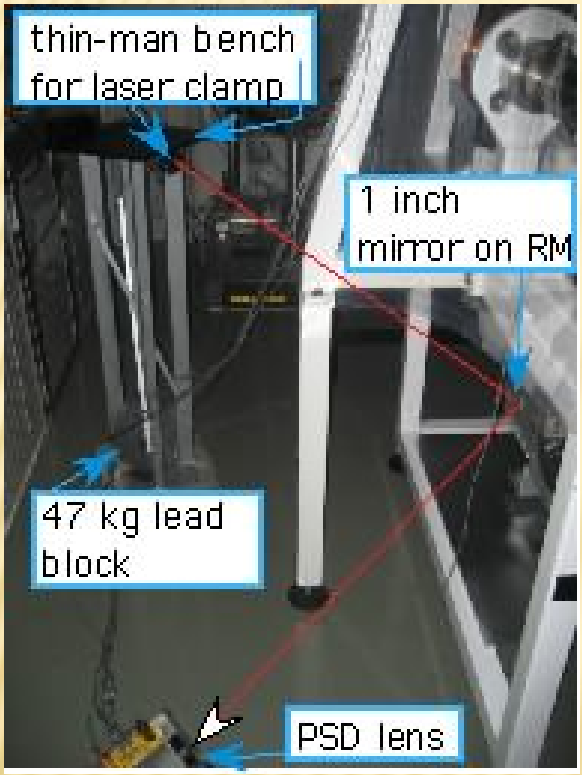


1) **model reproduces** the effect
2) **once consistency** is fulfilled full simulation of the suspension chain will assess the expected TF
3) **the realization** of payload design will need a **fine** tuning

LC IMPLEMENTATION

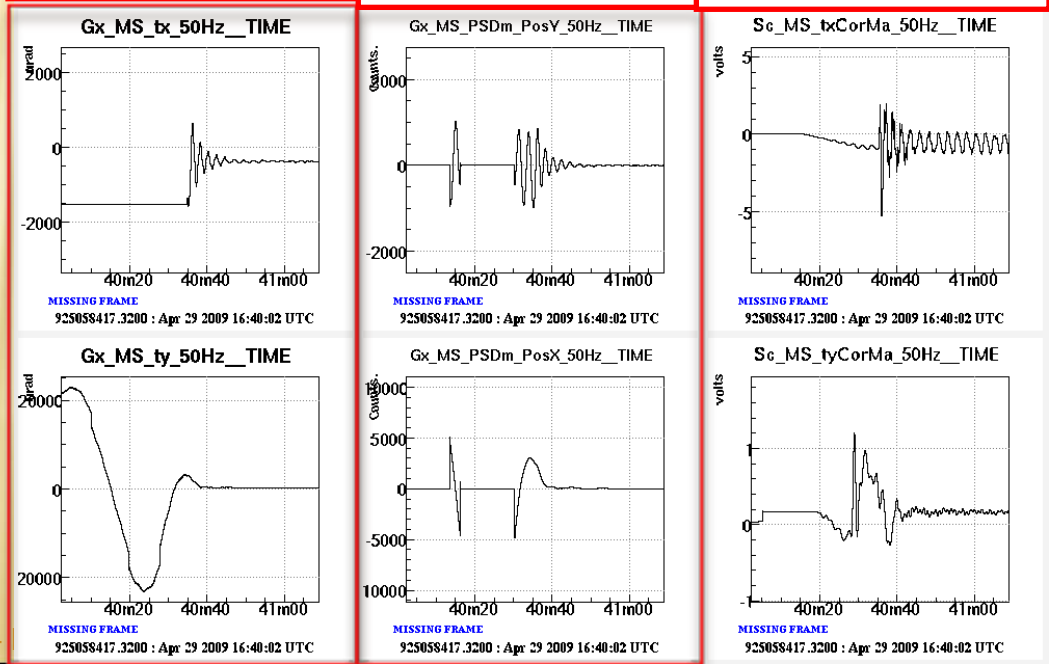
markers on the rear face of RM
(to avoid markers on the mirror front side)

lateral optical lever reading-out x position of RM (transversal pendulum)



actuation under implementation:
the back coils will be used.

RMCCD/MiPSD | Mario PSD | Correction



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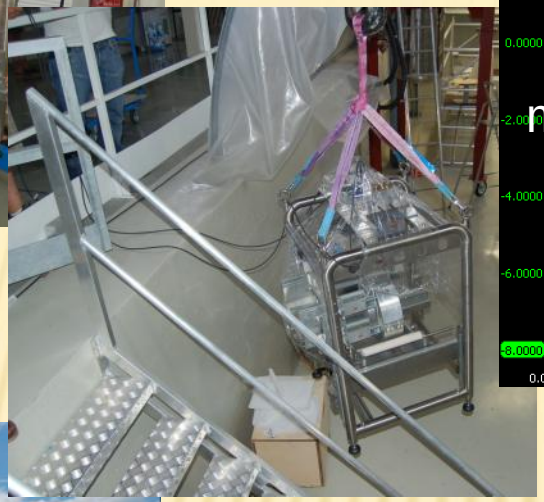
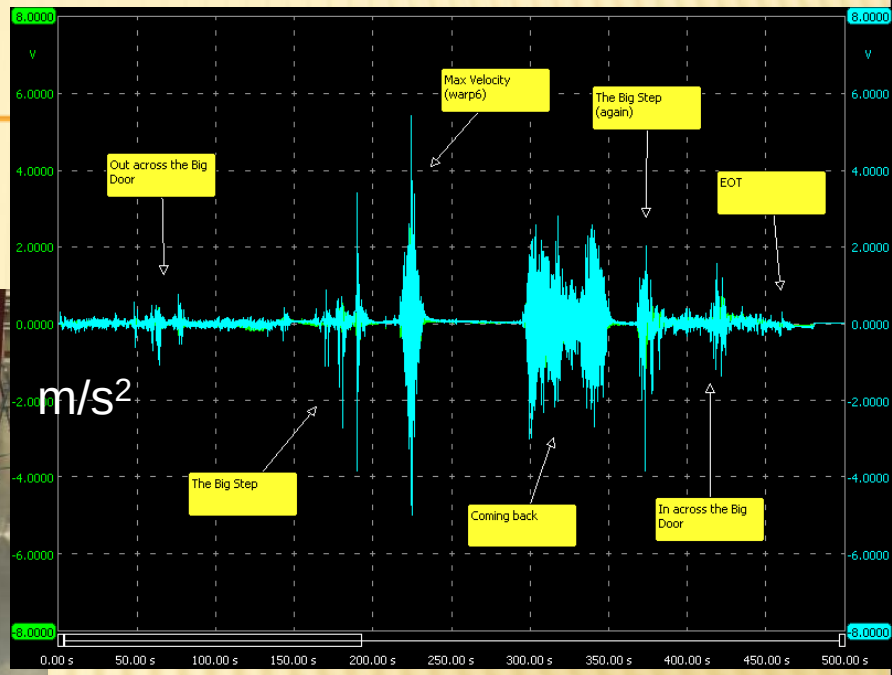
RESISTANCE TO SHOCKS, DUST POLLUTION, TO HUMIDITY





Transportation test):

- On the dummy payload
- Mechanical vibration monitored with accelerometers
- The test was successful (no broken fibers!);

Crash Test : see movie on YouTube (search monolithic crash), fiber robustness tested , weight at the moment of rupture: 70kg

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DUMMY MIRROR SUSPENSION FOR THE MECHANICAL LOSSES MEASUREMENTS

- Dummy Mirror suspended with NDE and silica wires in Perugia labs;
- The aim is to measure the wire mechanical losses with the new clamping system;

Dummy payload and C tool

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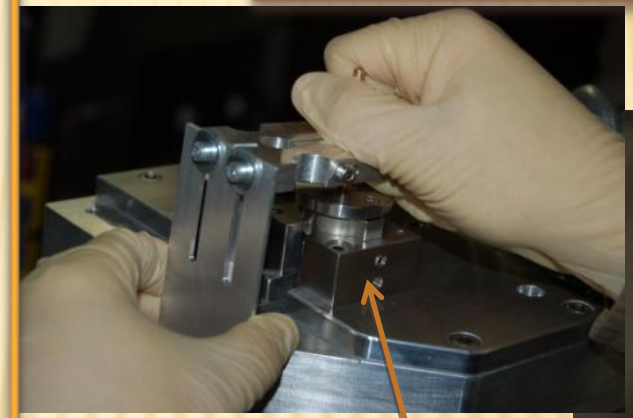
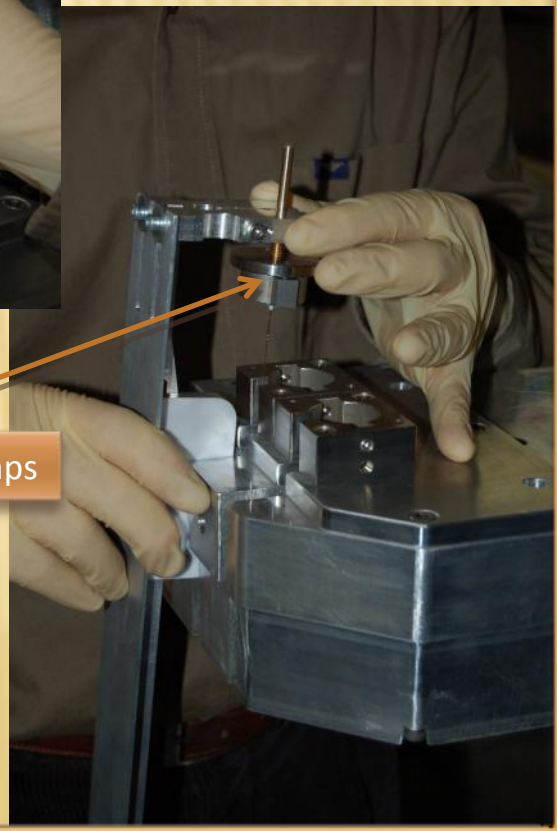
Silica wires installation on the marionette



Steel box for the silica upper clamps



DUMMY MIRROR SUSPENSION FOR THE MECHANICAL LOSSES MEASUREMENTS

- The anchors are glued with water glass on the ears
- The upper clamps are tightly clamped on the dummy marionette

Silica wires installation on the mirror

Silica anchors glued on the ears

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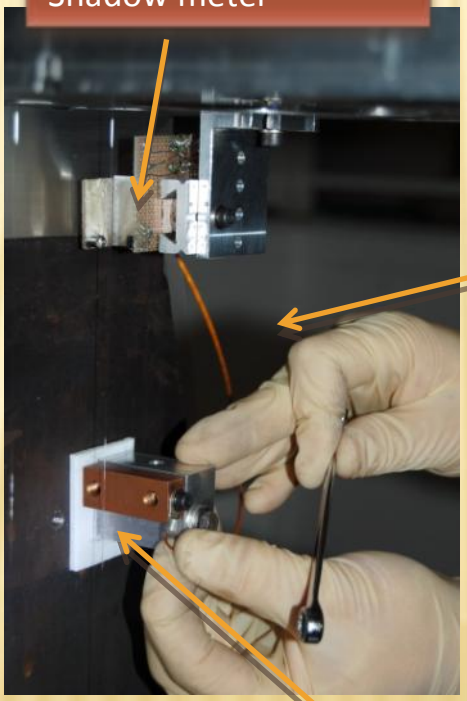
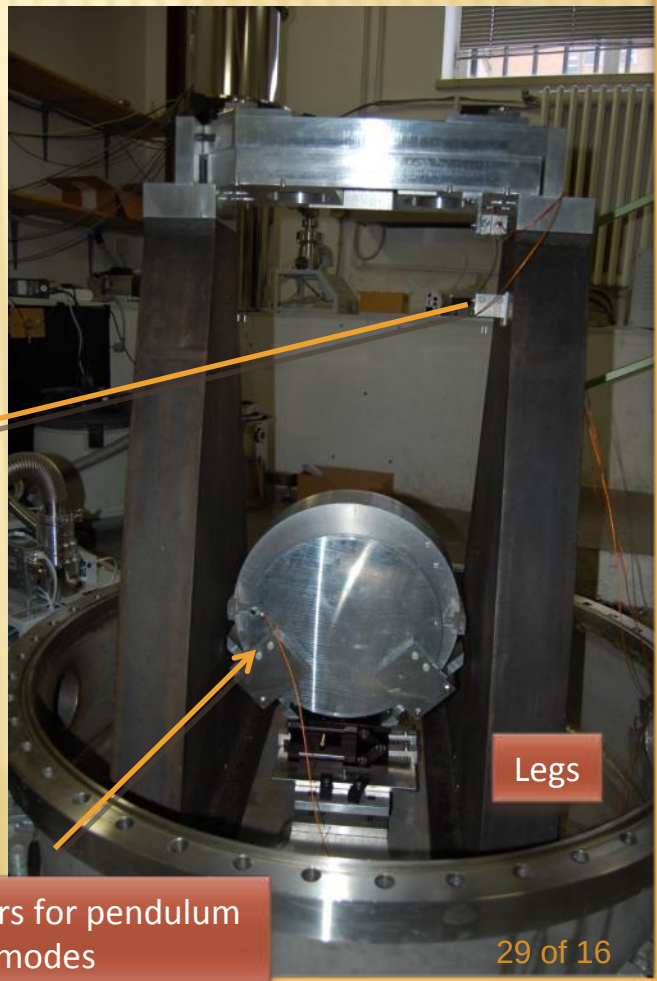
I TASK: DUMMY MIRROR SUSPENSION FOR THE WIRE MECHANICAL LOSSES MEASUREMENTS

- The assembled system is positioned on very stiff legs attached to the ground so that the recoils are negligible, this is a crucial point for measuring the pendulum losses;
- The system is now ready for measurements.

Dummy payload installation in the vacuum chamber





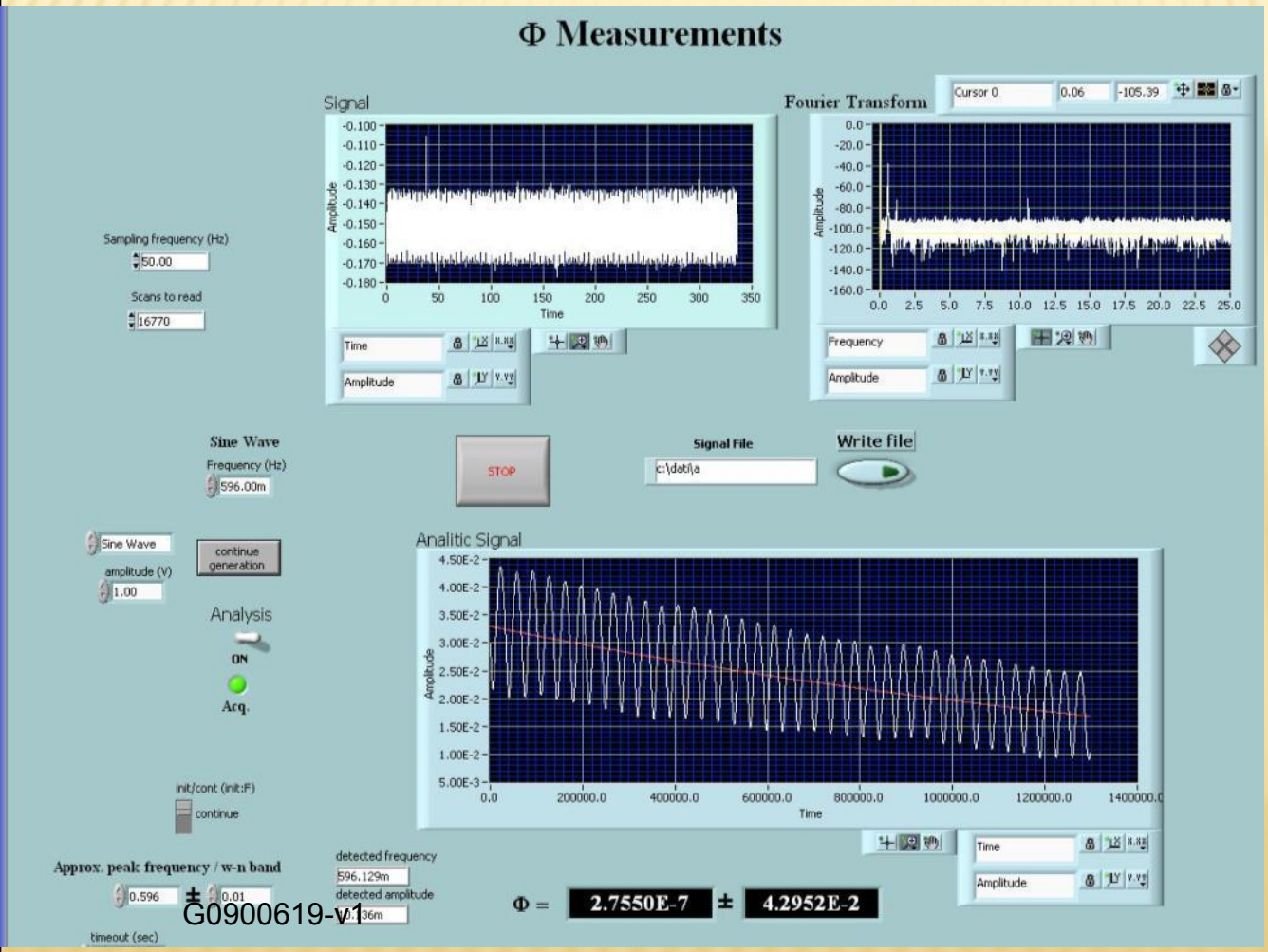
I TASK: DUMMY MIRROR SUSPENSION FOR THE WIRE MECHANICAL LOSSES MEASUREMENTS

1) STD suspension with Old-Design-Ears (ODE)

2) Development of New-Design-Ears (NDE)

3) Suspension with NDE

4) Fibre production and characterization



- First preliminary measurement of the pendulum decay.
- an overall loss angle of

$$\Phi_{overall} = 2.7 \cdot 10^{-7}$$

- the system losses will be identified, probably a new set-up will be used.

CONCLUSIONS

- Fiber production validated;
- Design ready for clamps and ears;
- Payload design ready;
- Local Control:
  - TF measured,
  - developed FEM and lumped-impedance matrix model,
  - angular control & longitudinal hierarchical control implemented
  - with markers on the recoil mass.

NEAR FUTURE STEPS:

- Measurement on the mechanical losses both of the wire clamps (new set up under assembly) and silicate bonding;
- Final design of the assembly structure;

Ready to install at the end of year 2009