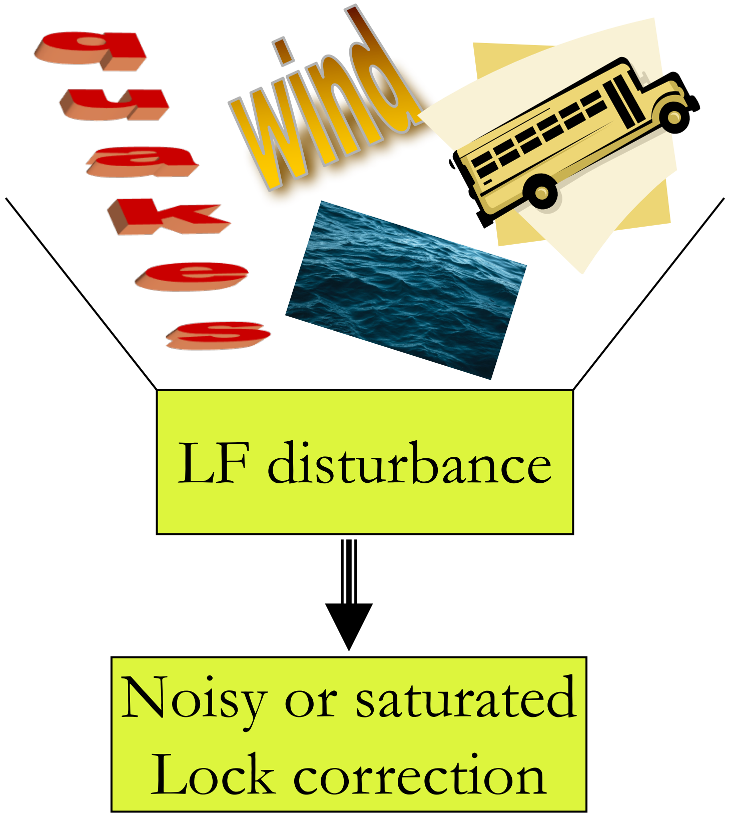


Ruggi's Global Inverted Pendulum Control

E. Majorana for the SUSP commissioning group

VIR-0362A-17

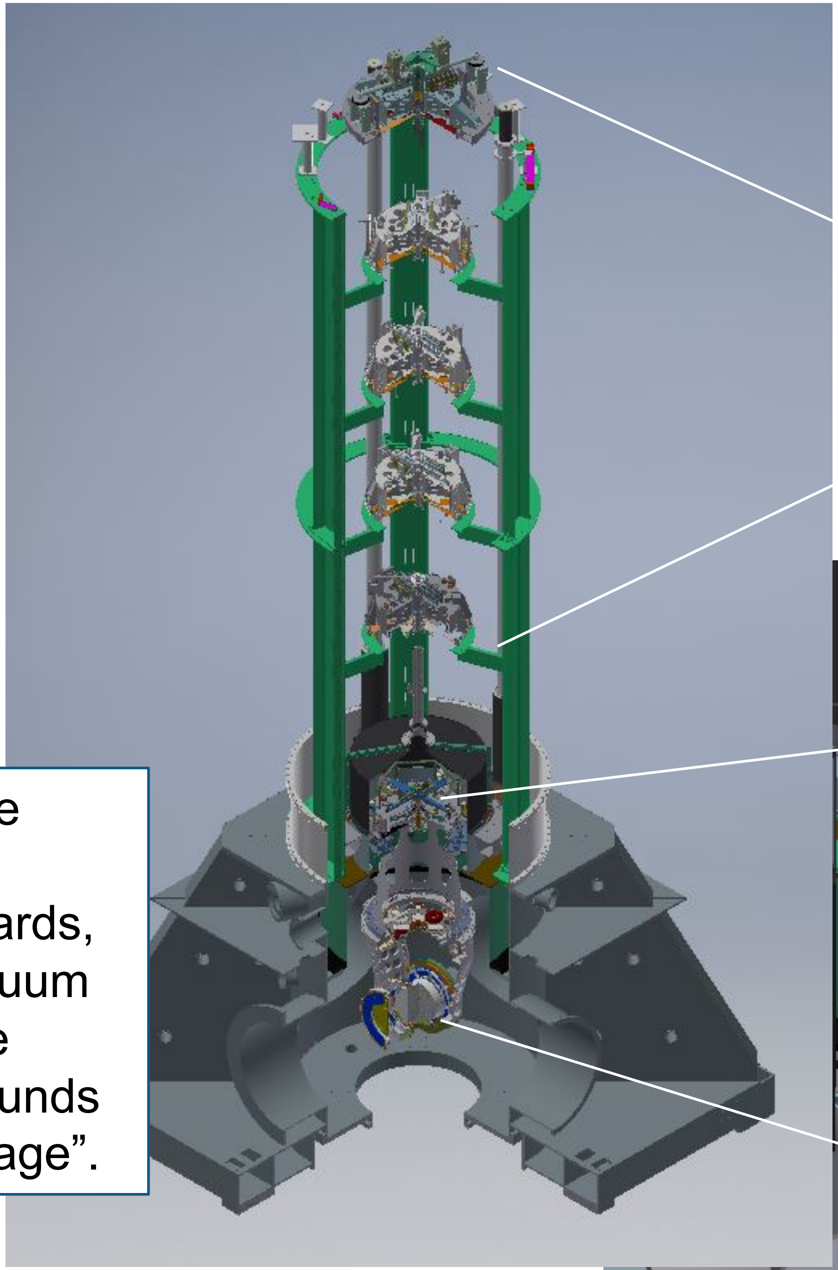
outline

- A quick report on GIPC, the Global Inverted Pendulum Control, developed at Virgo in the past years by P. Ruggi et Al.

- In terms of operation configurations, GIPC is the last strategy implemented, as the stable operation of the whole interferometer is achieved.

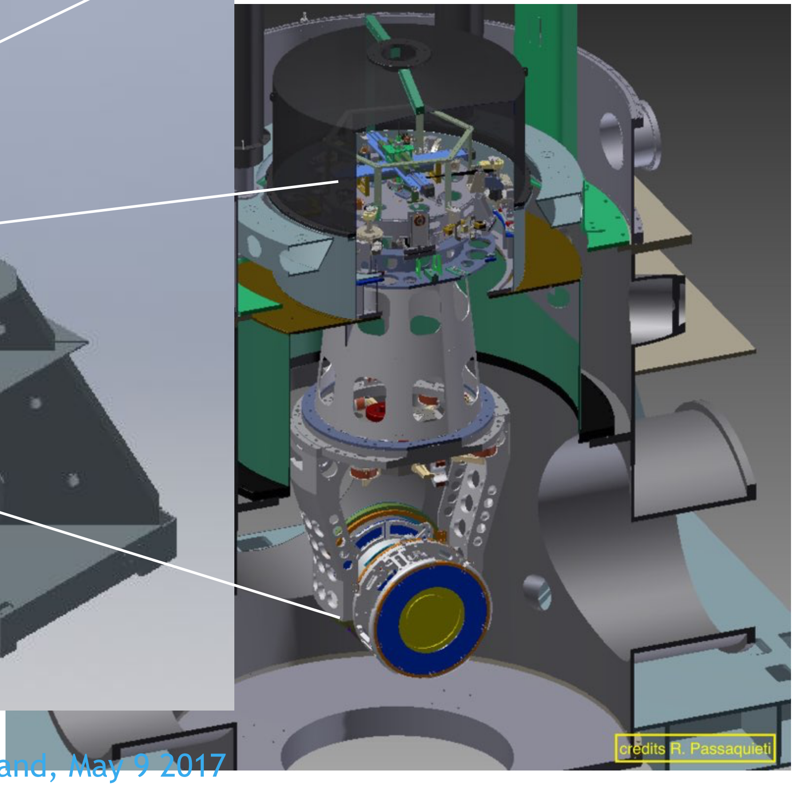
- The work to set again GIPC operation in Advanced Virgo are going on.

Monolithic suspensions: *overall system*



In AdV the first 5 stages (hor and ver) of the Super-Attenuator are the same as in initial Virgo.

The last filter of the Super attenuator, prolonged downwards, is in the same vacuum environment of the payload and surrounds it: the "actuation cage".



Overall Suspension Attenuator: Virgo → AdV

Top-stage floating body:
4D (3H+Vertical),
position ctrl VS ground (or gbl)
and **damping** (acceleration).

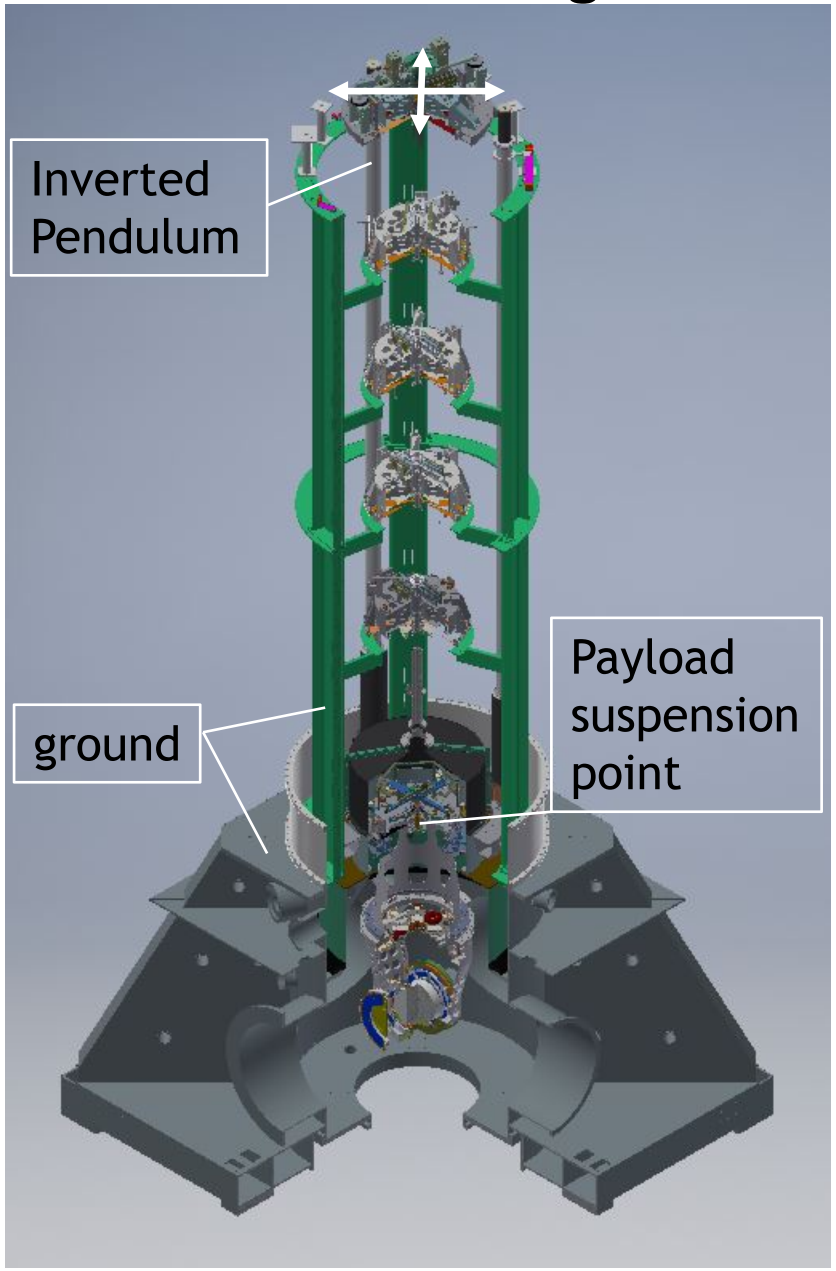
Bottom ring:
3D (tilts+Vertical),
position ctrl VS ground
actuated from ground

TESTED

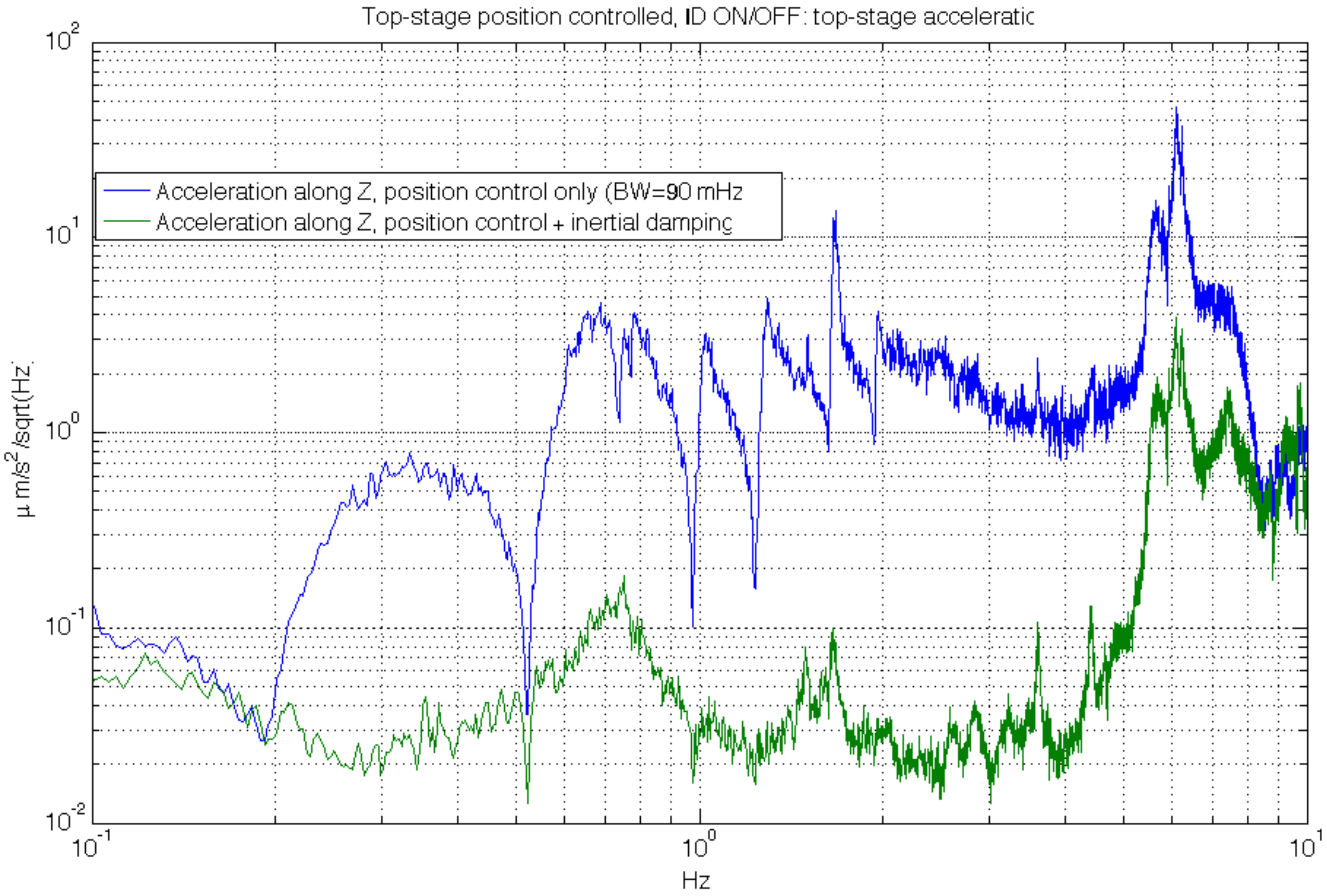
SA last stage:
6D,
position damping VS ground

Payload:
6D,
position ctrl VS ground (or gbl)
actuated from SA last stage

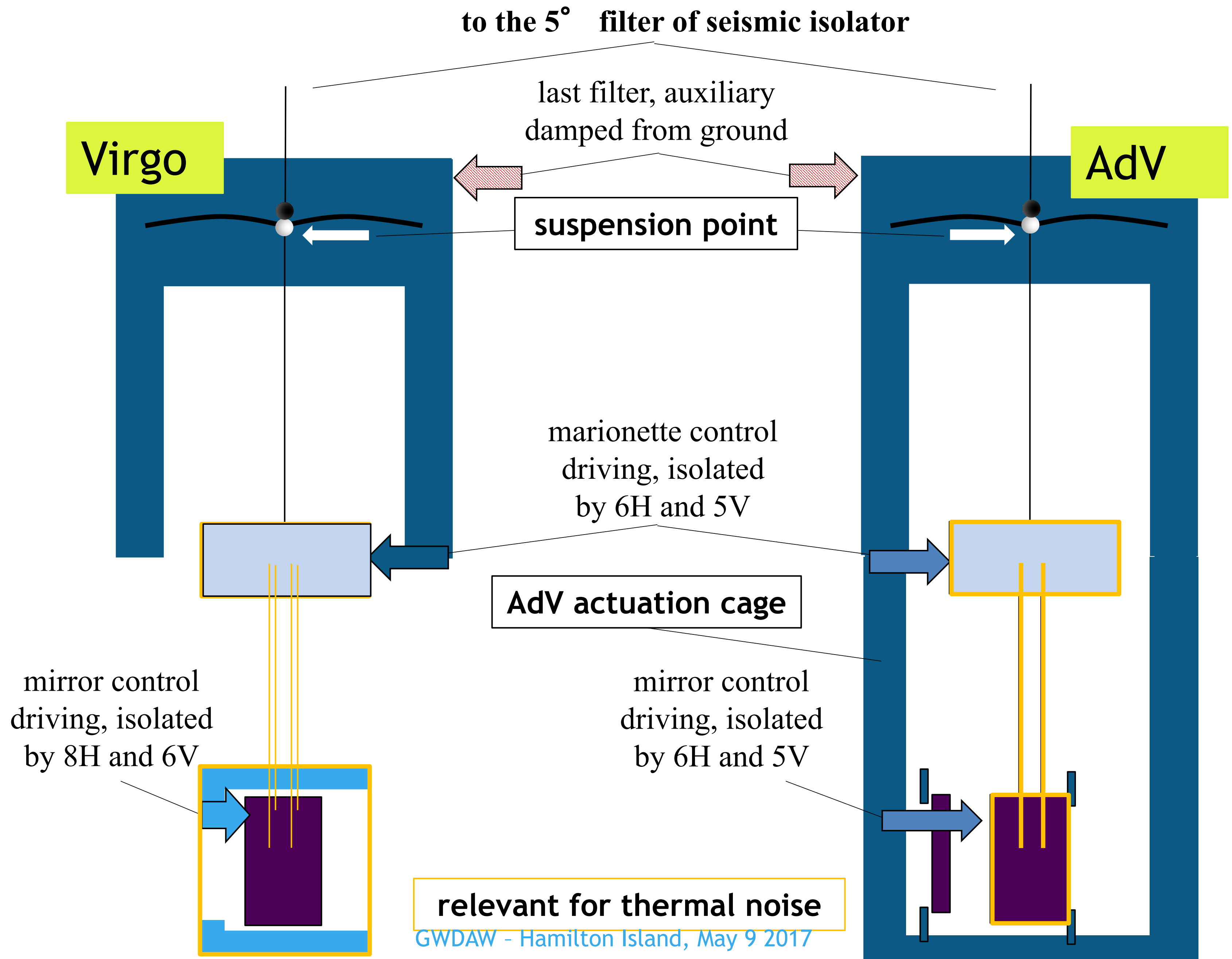
No tilt sensor (so far)



SuperAttenuator: Inertial Damping ON/OFF

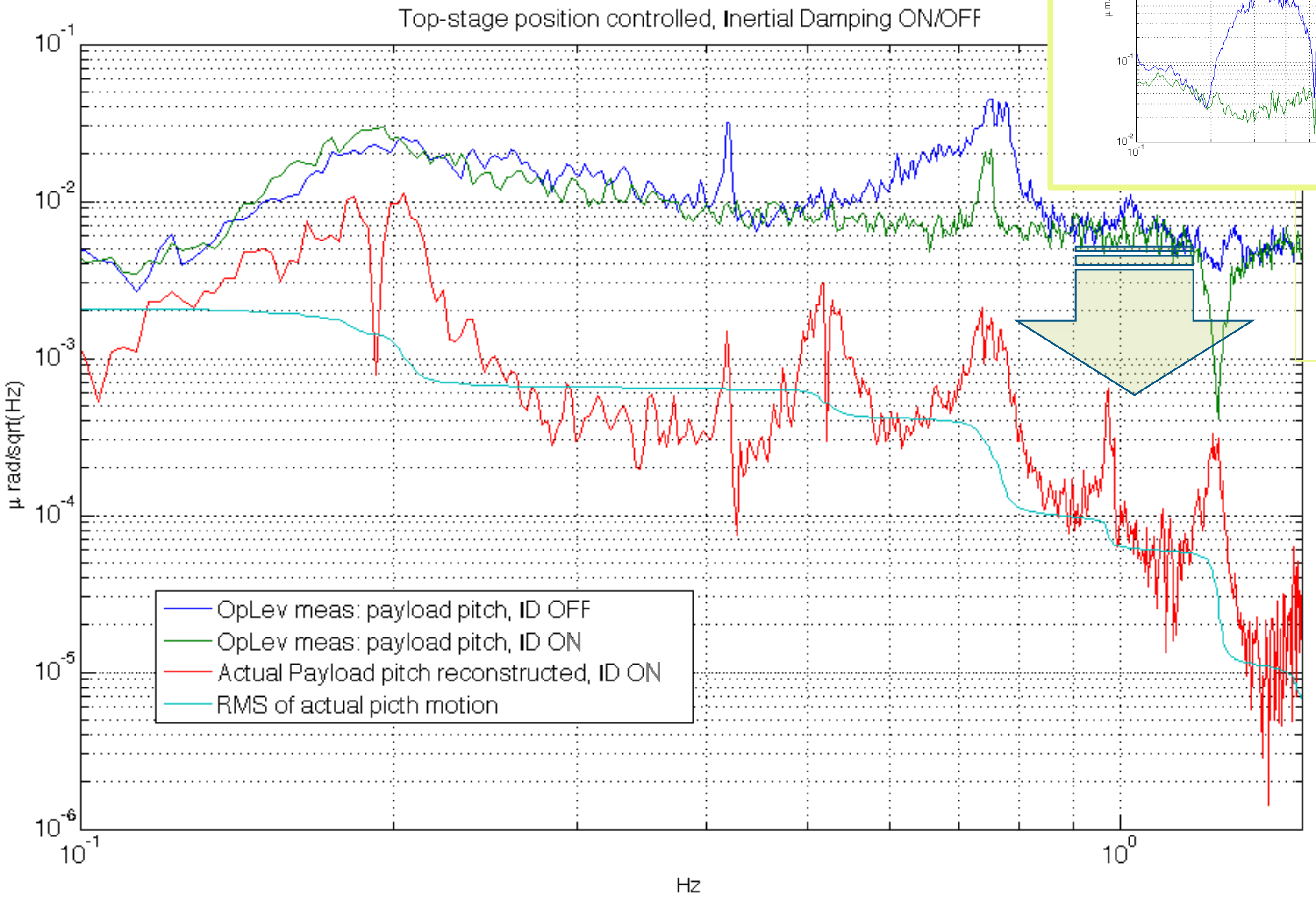


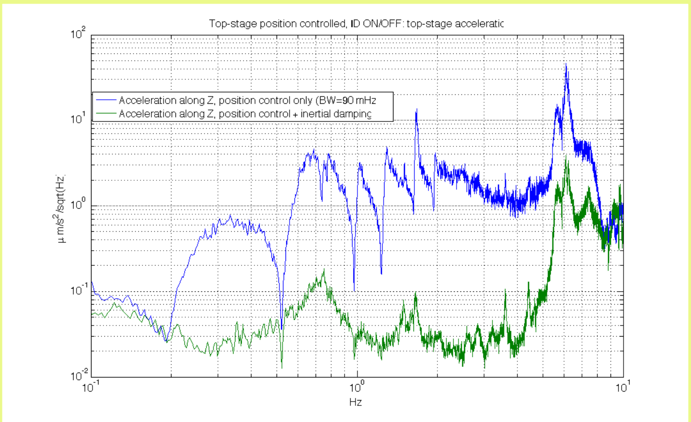
Scheme Last filter + Payload :Virgo → AdV



Payload angular accuracy VS ID

The Inertial damping allows to reduce the residual angular movement ~2 nrad, (only partially seen by ground-based OpLeV)





Reconstruction using ratio ID_ON/ID_OFF

Reducing microseism through Top stage control is crucial

AdV payloads have no or just few resonances in microseism region

Reducing microseism contamination through position sensors in standalone is crucial.

Sensor blending and Low Pass shaping

$x,\ a_x$ = position and acceleration Laplace's Tr.
x_s = seism driven sensor reference
qi = "quasi-inertial"

$$LP(s)\cdot(x - x_s) + s^{-2}\cdot HP(s)\cdot a_x = x_{qi}$$

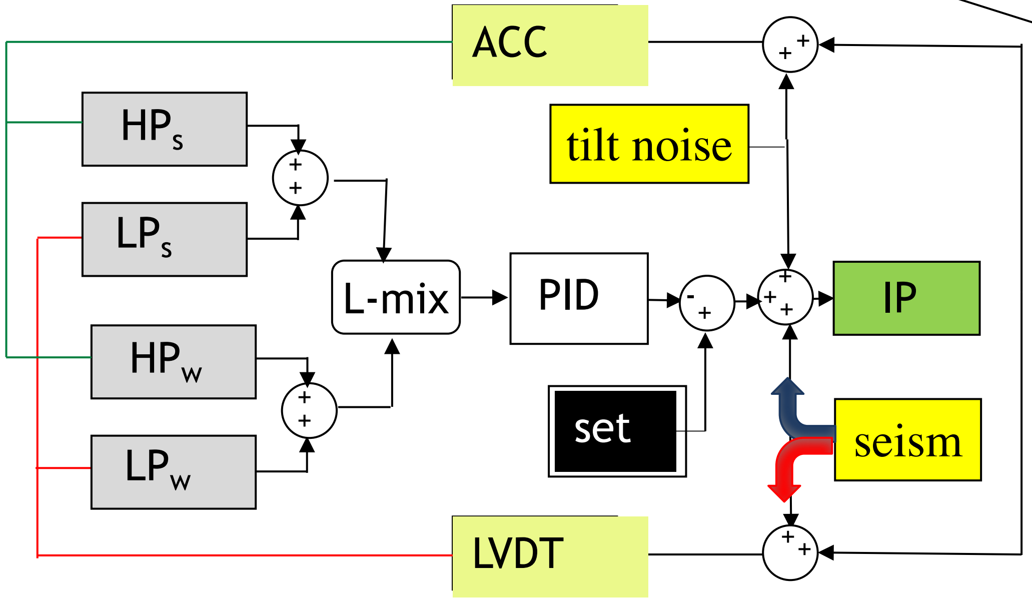
$$LP(s) + HP(s) = 1$$

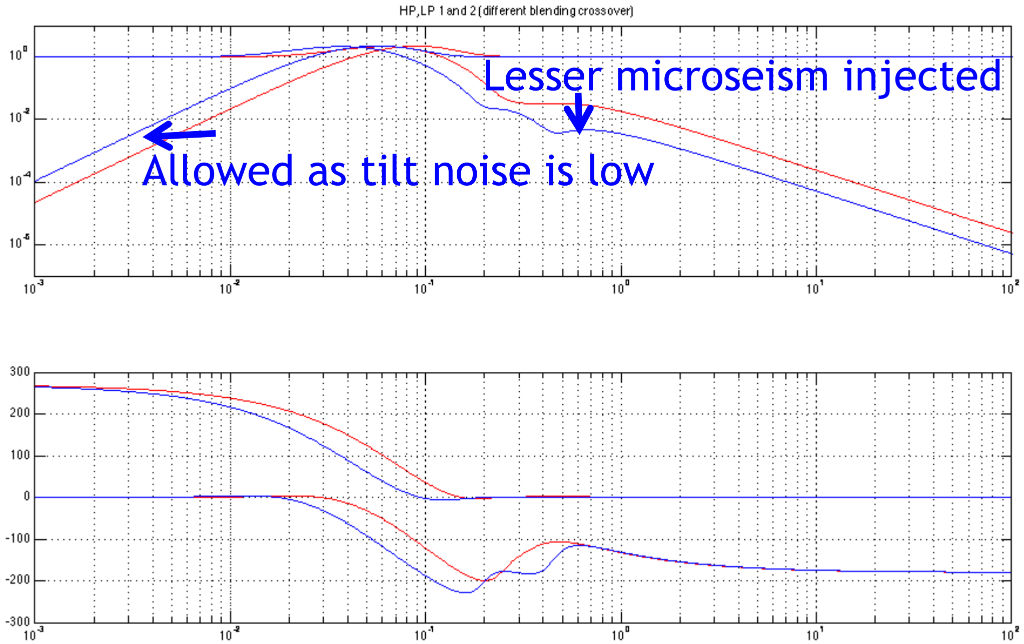
$$x_{qi} = x - LP(s)\cdot x_s$$

Increase LP(s) slope and shaping

Reduce Position/Acc crossover frequency

"Reduce" x_s





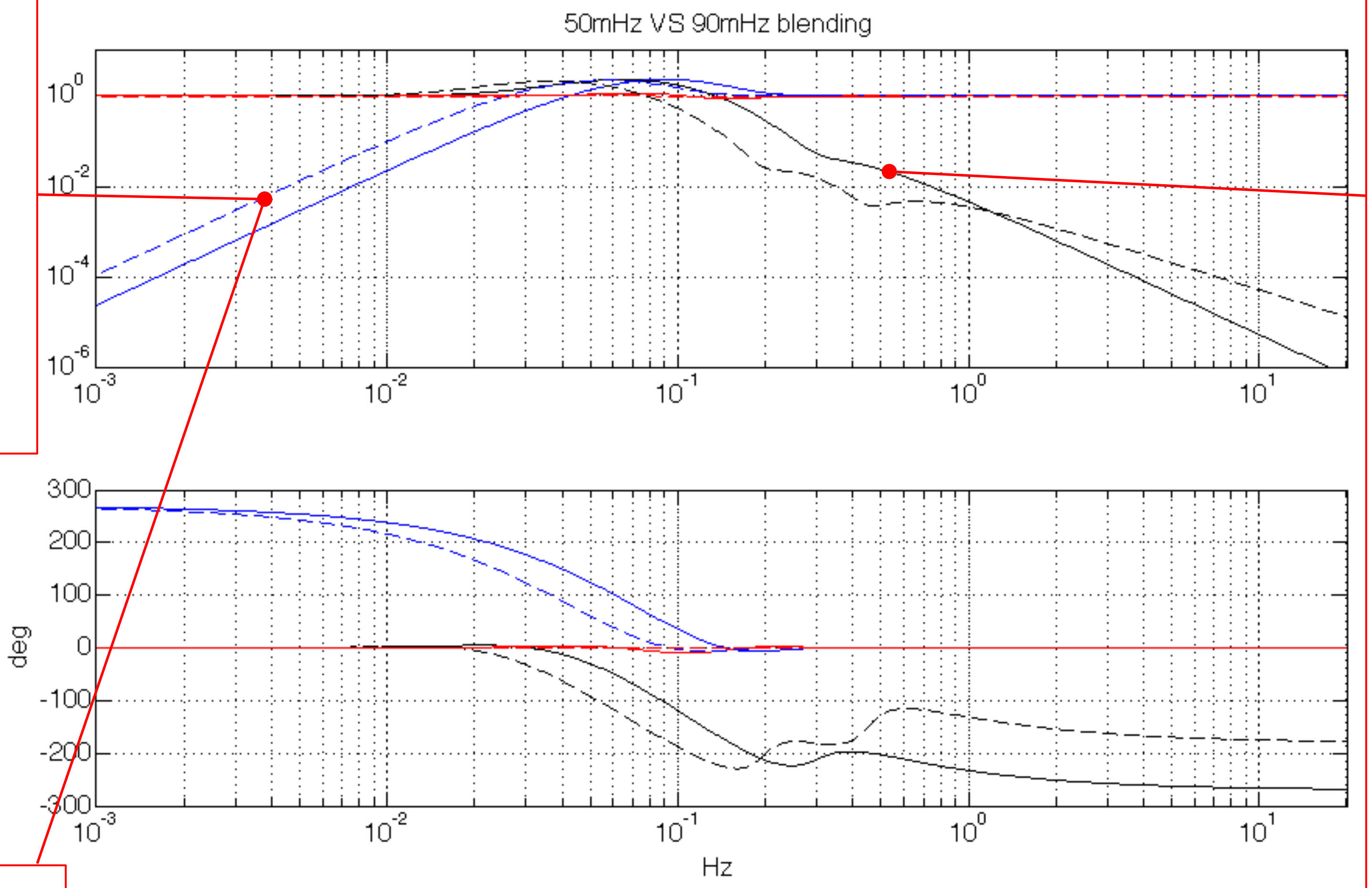
Two blending strategies are available in-line. The choice is presently enabled manually upon weather condition (wind, microseism). In AdV an optimized design strategy to minimize background noise through the sensors to chose properly the blending is applied (L. Trozzo).

Preparatory tests ongoing: recombined FP lock, single arm

ITM S_ATTENUATOR
more "inertial",
reduced position sensor background noise (μseism)

BUT

more affected by background **"tilt noise"**



ETM S_ATTENUATOR
lesser "inertial":
Using local top stage position sensor injects **μseism noise**

IP passive attenuation provides FP a cavity correction signal "cleaned" (~ 0.2) μseism region

- **Blending at higher frequency at ETM is feasible**
- **"tilt noise" through ETM accelerometer negligible**

Top-stage is expected to be shaken more by tilt noise (lock saturation below)

μSeism-Free platform AND Global Inverted Pendulum Control

$$z_{ETM}^{Global} = \frac{z_{Dcorr}}{TF_P}$$

$$\ddot{z}_{NE}^{\mu SF} = \ddot{z}_{NE} - \ddot{z}_{NI} \qquad \ddot{x}_{WE}^{\mu SF} = \ddot{x}_{WE} - \ddot{x}_{WI}$$

$$z_{ITM}^{Global} = \frac{z_{Ccorr}}{TF_P}$$

$$\ddot{z}_{NI}^{\mu SF} = \frac{\ddot{z}_{NE} + \ddot{z}_{NI}}{2} \qquad \ddot{x}_{WI}^{\mu SF} = \frac{\ddot{z}_{WE} + \ddot{z}_{WI}}{2}$$

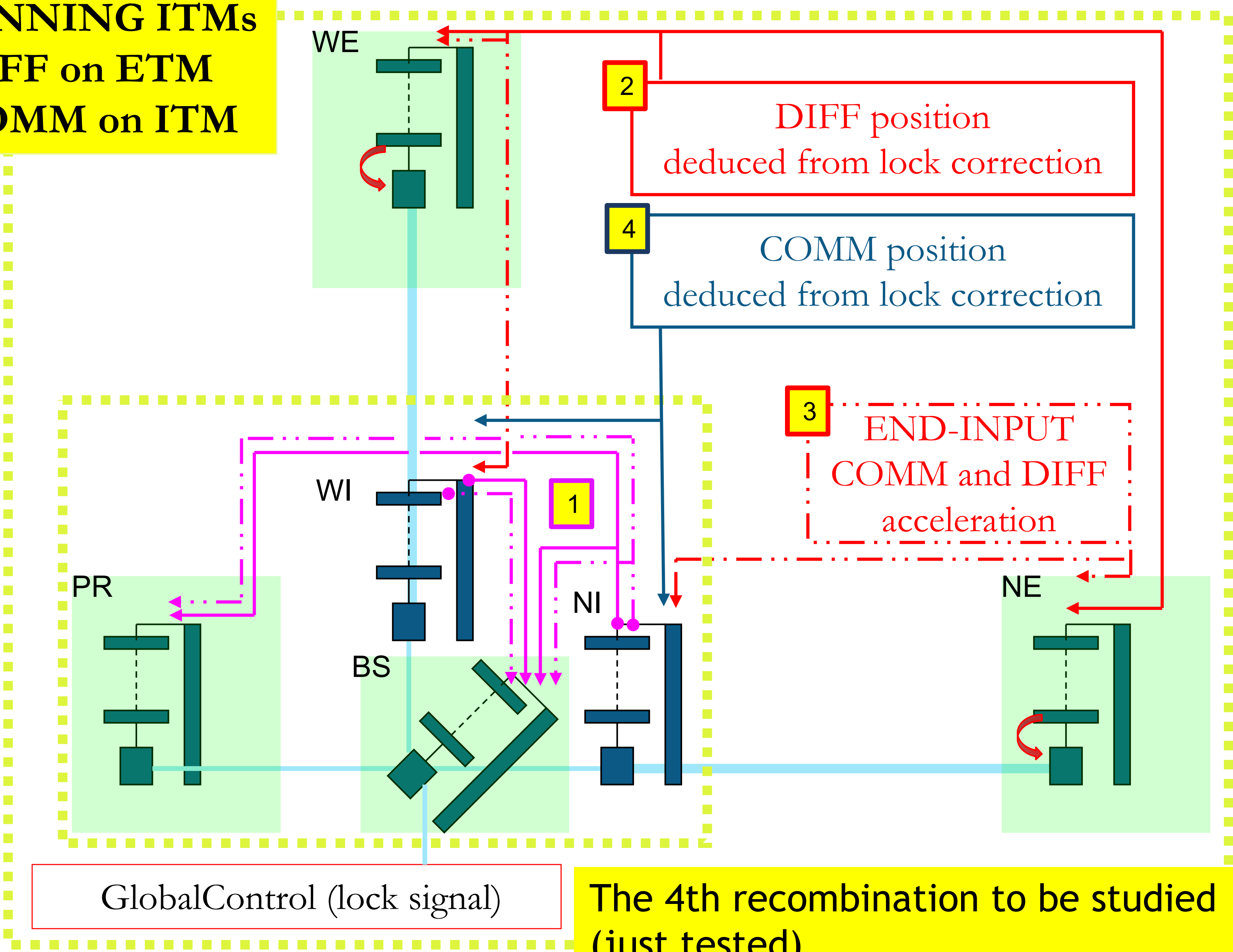
$$z_{PR}^{\mu SF} = z_{PR} - z_{NI} \qquad x_{PR}^{\mu SF} = x_{SR} - x_{WI}$$

$$\ddot{z}_{PR}^{\mu SF} = \ddot{z}_{PR} - \ddot{z}_{NI} \qquad \ddot{x}_{SR}^{\mu SF} = x_{SR} - \ddot{x}_{WI}$$

$$z_{BS}^{\mu SF} = z_{BS} - \frac{1}{\sqrt{2}}(z_{NI} + z_{WI})$$

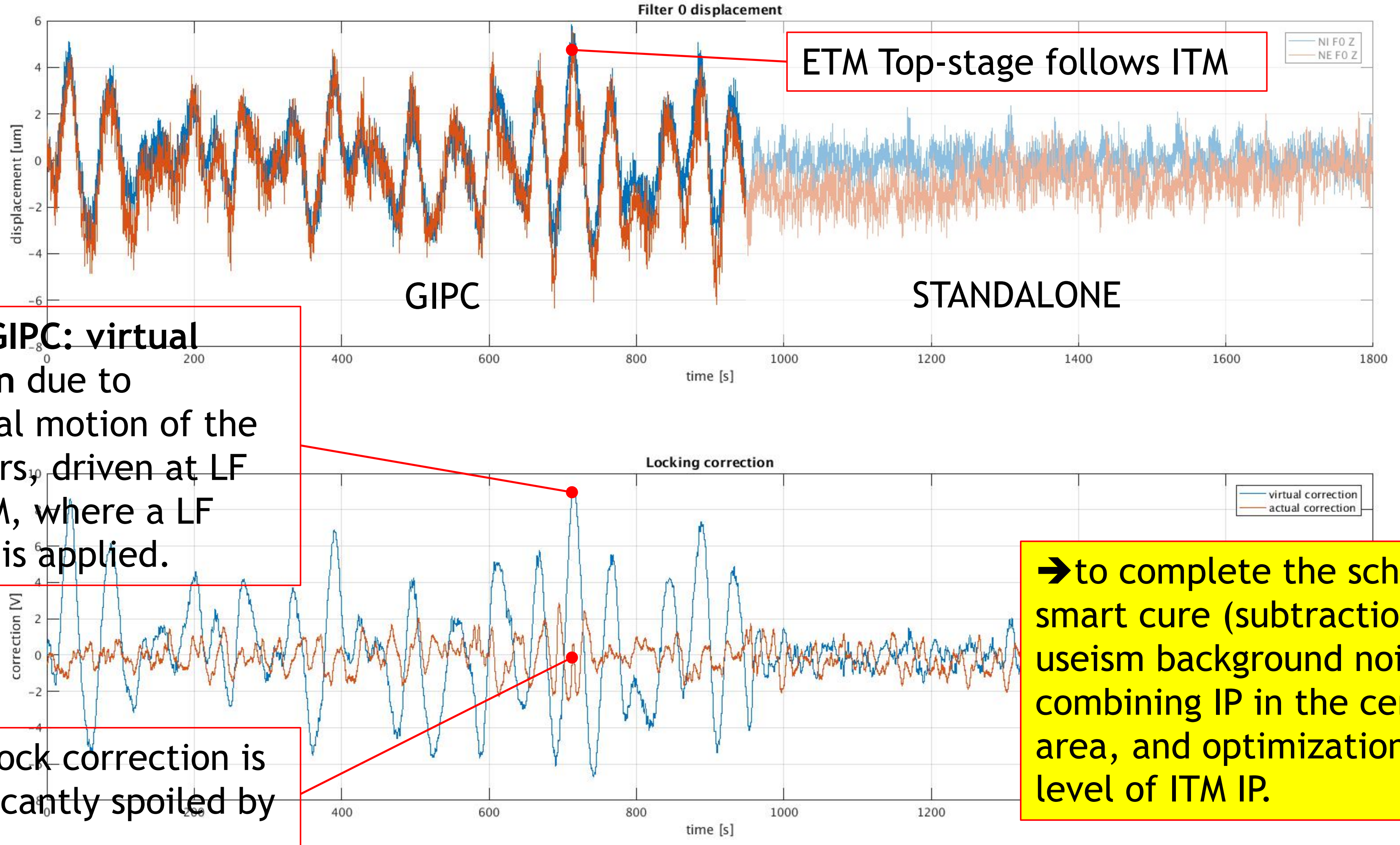
$$\ddot{z}_{BS}^{\mu SF} = \ddot{z}_{BS} - \frac{1}{\sqrt{2}}(\ddot{z}_{NI} + \ddot{z}_{WI})$$

PINNING ITMs
DIFF on ETM
COMM on ITM



The 4th recombination to be studied (just tested)

Preparatory tests ongoing: recombined FP lock, single arm



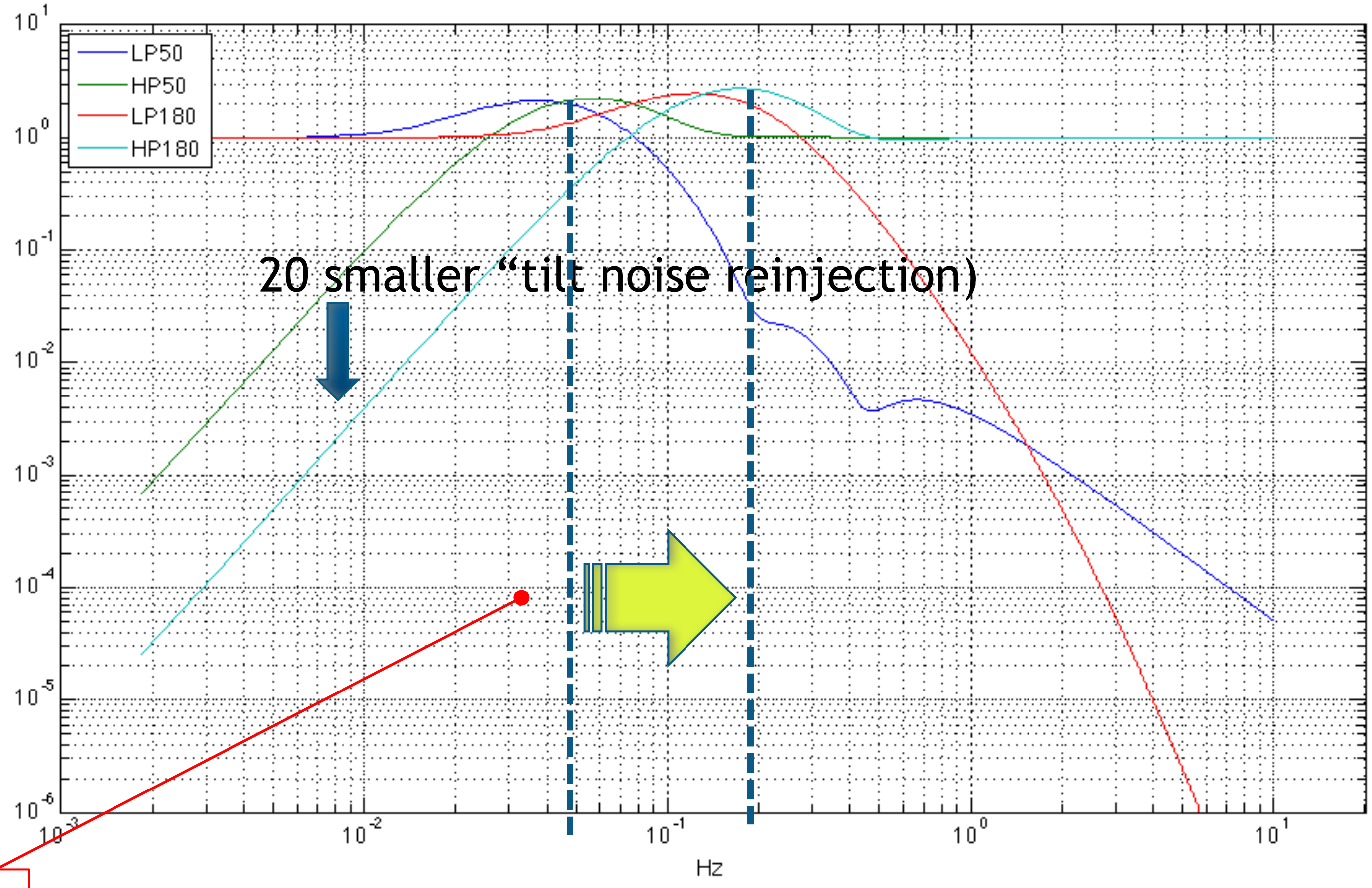
Without GIPC: virtual correction due to differential motion of the two mirrors, driven at LF by the ITM, where a LF crossover is applied.

The real lock correction is not significantly spoiled by tilt noise

➔to complete the scheme: smart cure (subtraction) of useism background noise, by combining IP in the central area, and optimization at the level of ITM IP.

Preparatory tests ongoing: recombined FP lock, single arm

Is it possible (and meaningful) to further increase the blending blending frequency ?



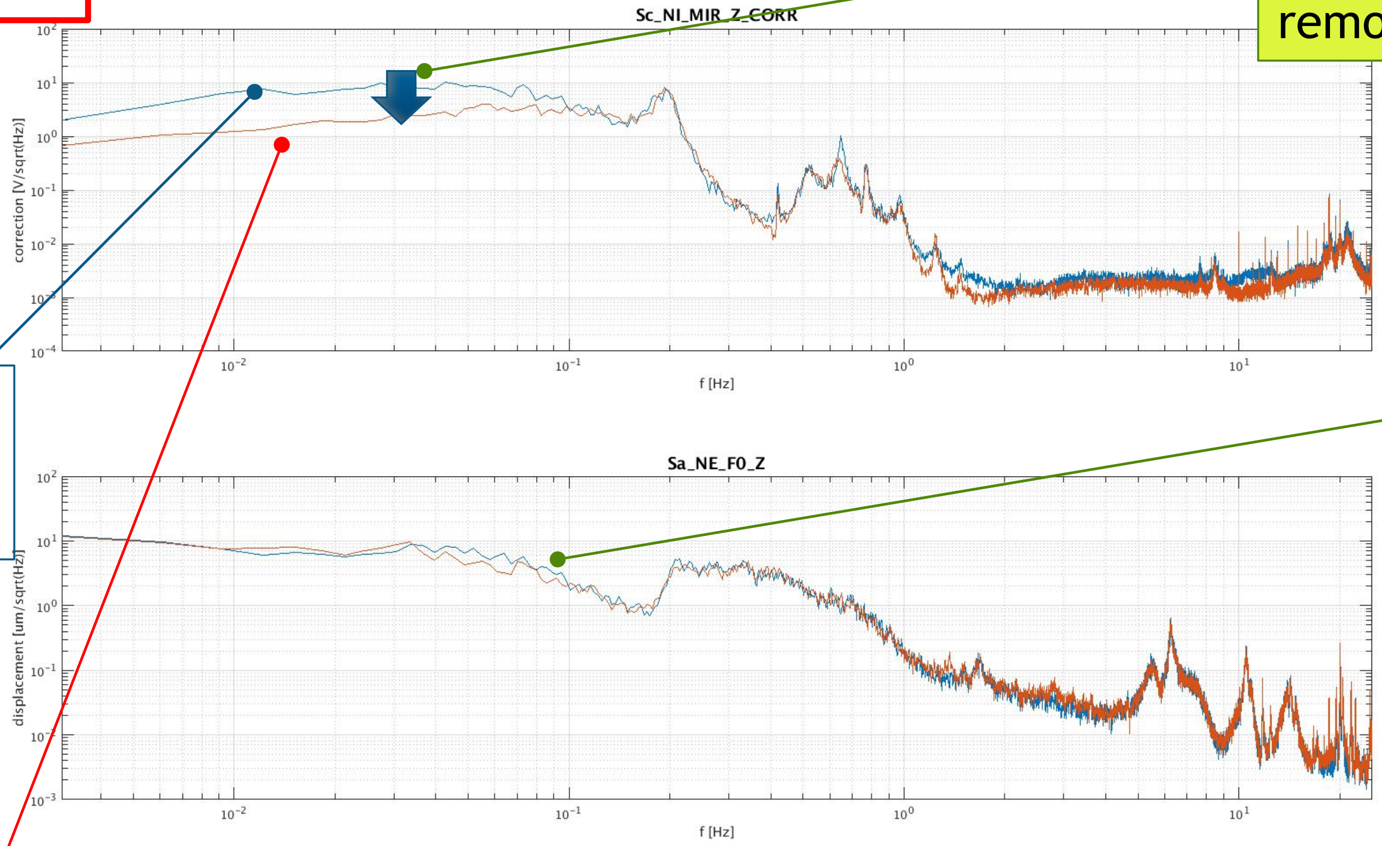
standalone control of IP with such high crossover would be meaningless !

AdV:BLENDING TESTED UP TO 180 mHz !
(in V+ achieved 110-120 mHz)

Preparatory tests ongoing: recombined FP lock, single arm

Wind speed: 42-45 km/h (ave)
April 28 2017

Lock correction reduced : i.e. ETM tilt background removed.



Blending cavity Length/Acc at medium-high frequency (GIPC crossover 120 mHz)

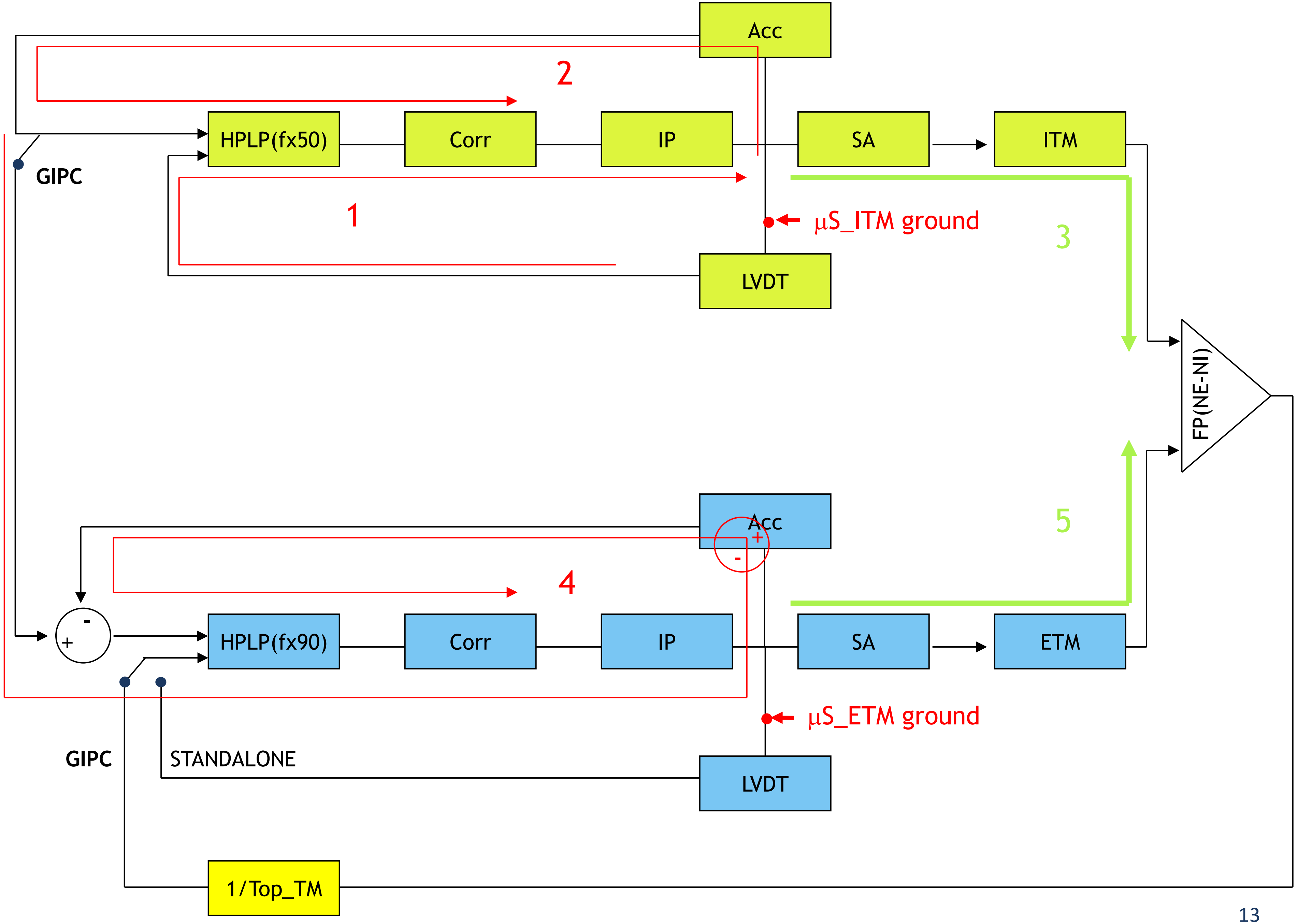
displacement RMS unchanged

ETM: Blending cavity Length/Acc at high frequency (GIPC at 180 mHz)

AdV:BLENDING TESTED UP TO 180 mHz !
(in V+ achieved 110-120 mHz)

HPLP(fx50) = Sensor blending
~50 mHz

HPLP(fx90) = Sensor blending
~90 mHz



µSeism evasion strategy: an example

Pics from the past: potentially with AdV we can do even better

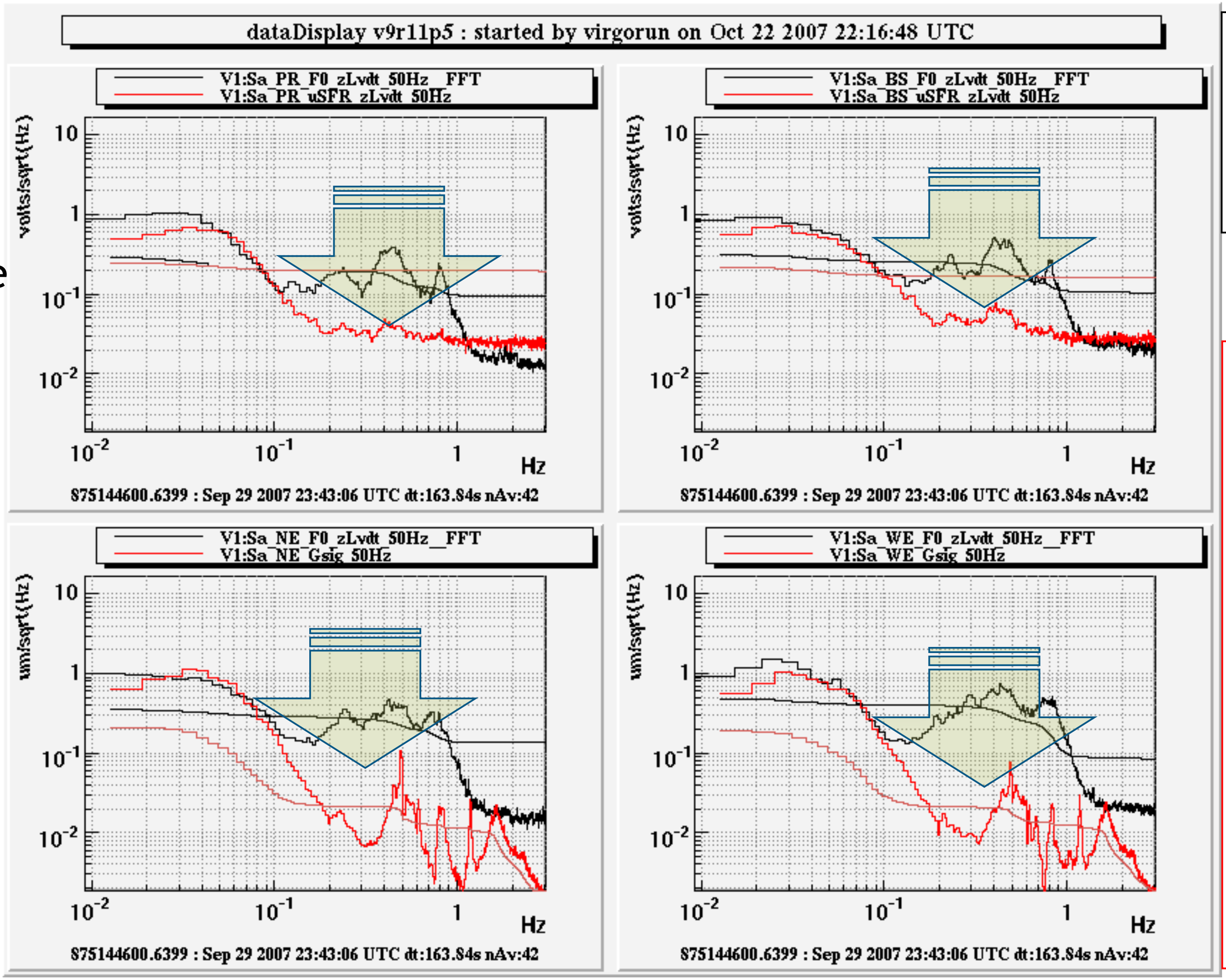
- Better payloads,
- Optimized study

quiet

INPUT mirror suspensions used as drift controlled reference

Central area
ITM as reference

ETM



local LVDTs, used in-loop sense and re-inject µseismic noise

Combined channels: **µSFR** (µSeism-Free Reconstruction, the noise is coherent because central area suspensions are close each other)
+
GIPC (Global-Inverted-Pendulum Control, for 3-km-separated susp.)

Pics from the past: potentially with AdV we can do even better

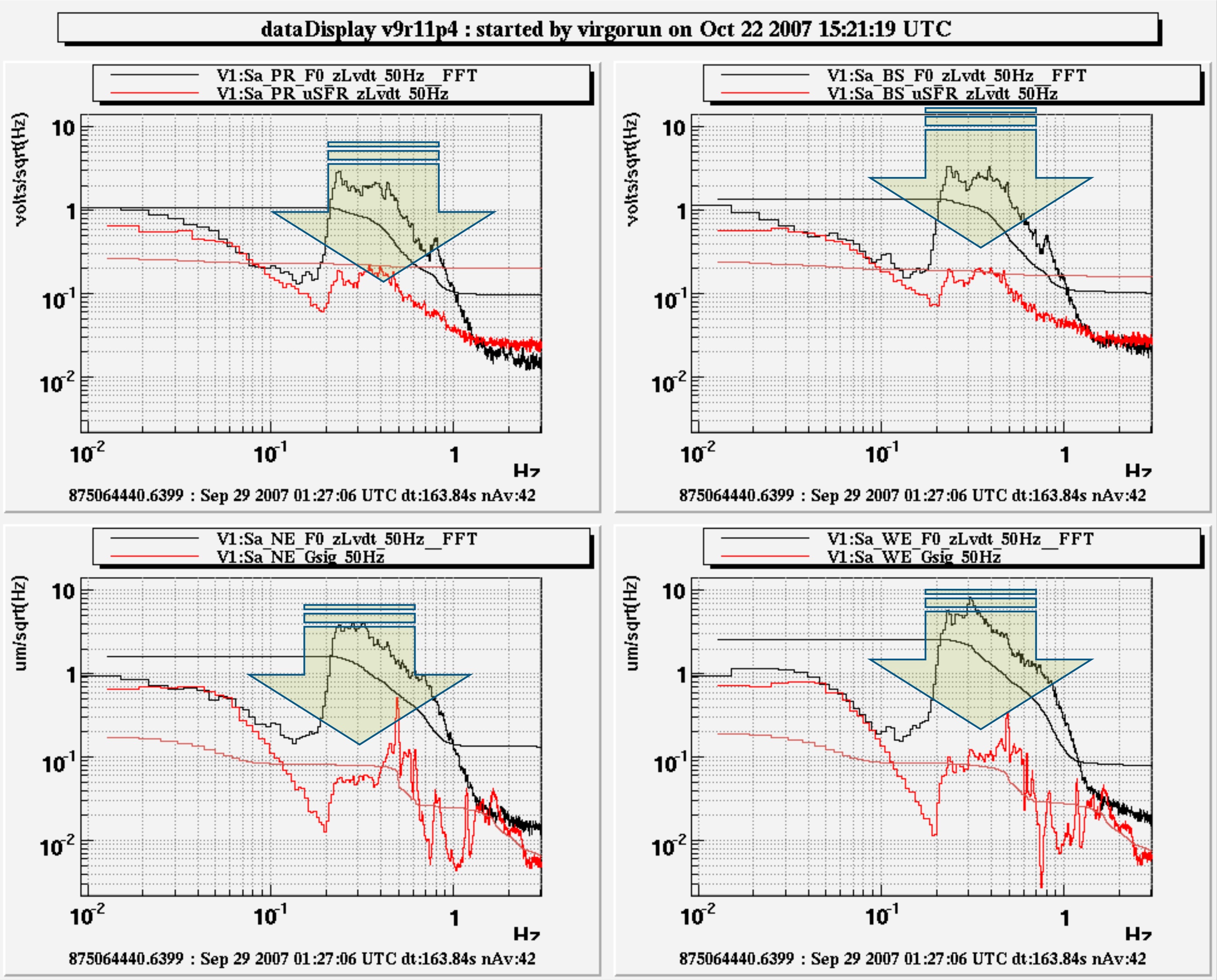
- **Better payloads,**
- **Optimized study**

µseism: rejection VSR1start-VSR1stop

INPUT mirror suspensions used as drift controlled reference

Central area
ITM as reference

ETM



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Pics from the past: potentially with AdV we can do even better

- **Better payloads,**
- **Optimized study**

MSC VS robustness : earthquakes/stable GIPC

A “lucky” occurrence !*

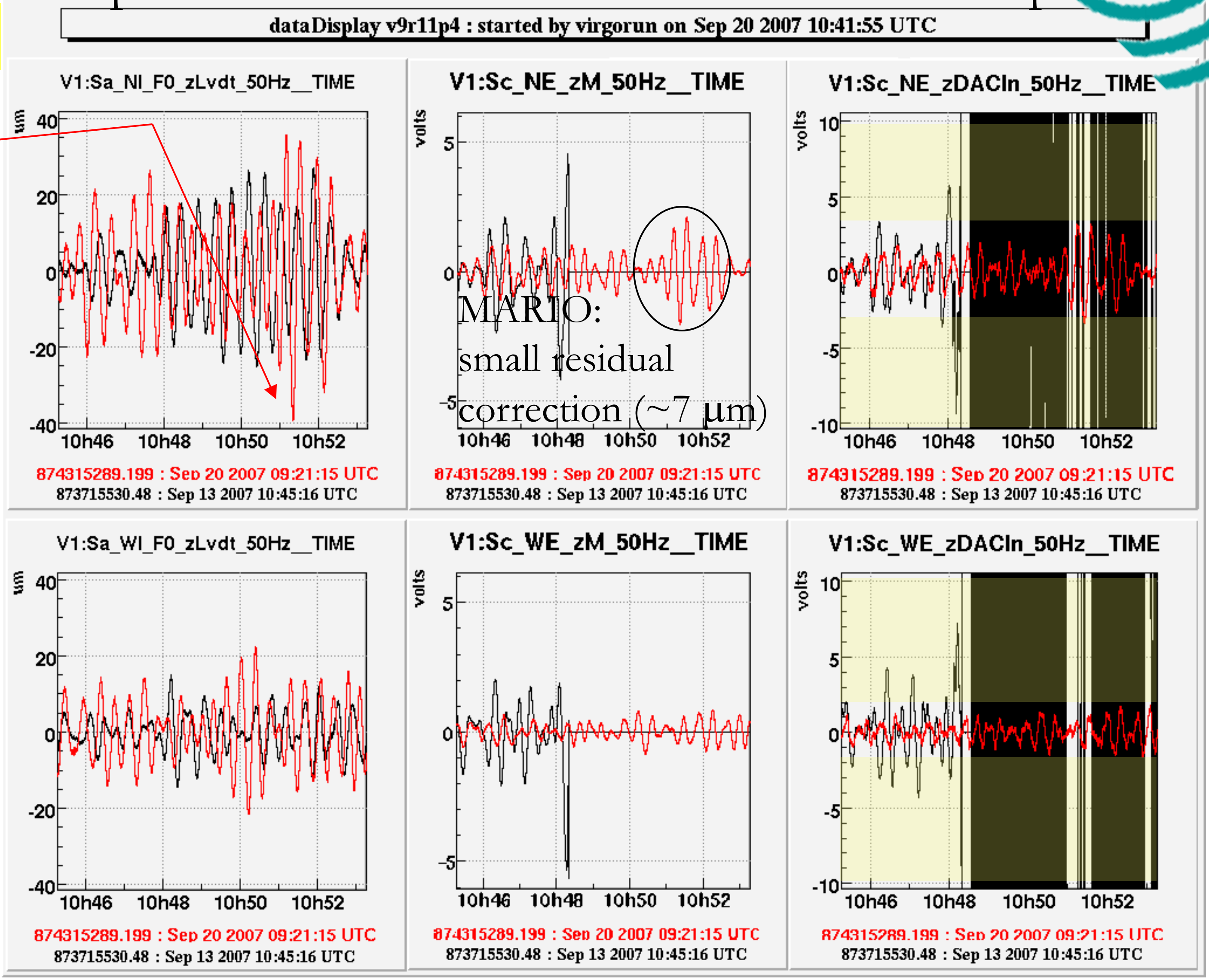
Comparison of two events with similar local amplitude

40 μm peak

Previously we had saturation as the amplitude was less than **20 μm**

The system is much more robust .

Correction dynamics more than doubled.



Conclusions

Global Inverted pendulum control is a way to evade indirect microseism contamination due to the sensors (both Pos and Acc) used in top stage SuperAttenuator control.

The blending at the ETM should be at higher frequency with respect to the standalone
➔ no accelerometer "wind noise" contamination there

In absence of Tiltmeter, "wind noise" remains, but it is quite reduced, in case of HQ the lock is more robust.

The scheme was used intensively in Virgo.

AdV news:

- Better payloads (pitch/roll very LF, even below 50 mHz, reduced the impact of microseism on residual tilt.)
- Higher frequency Pos/Acc-blending for ETM SuperAttenuators (up to 180 mHz !!) tested.
- Common mode reallocation at ITM top-stages, just tested: the advantage of full diagonalization isn't clear yet.
- In case of background noise with different properties along the two arms, the blending at the ITMs can be specified using an optimized strategy that exploits direct measurement of seismic noise (P. Ruggi, L. Trozzo).