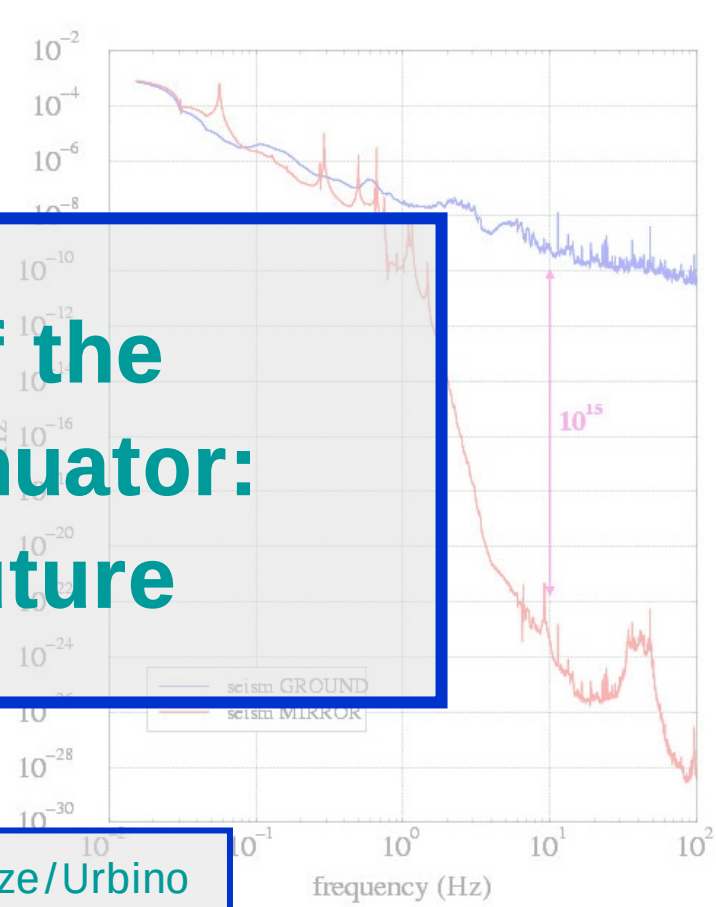
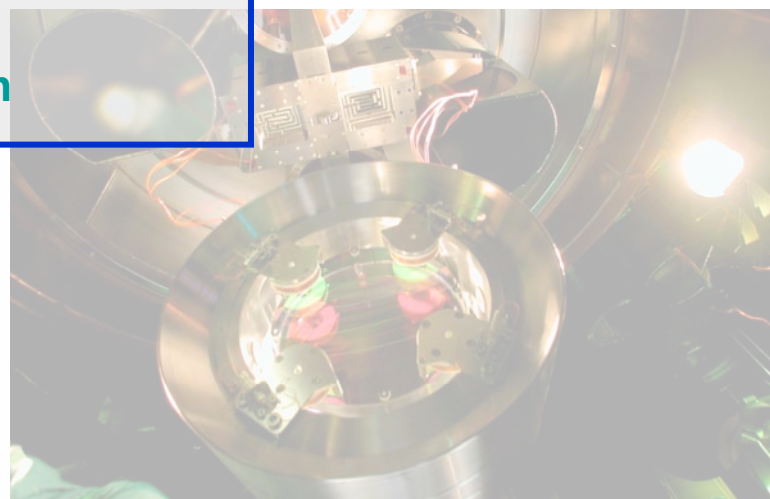
The control of the Virgo Superattenuator: present and future

Giovanni Losurdo - INFN Firenze/Urbino

on behalf of the

Virgo Collaboration





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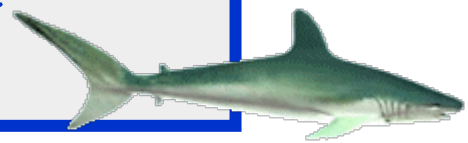
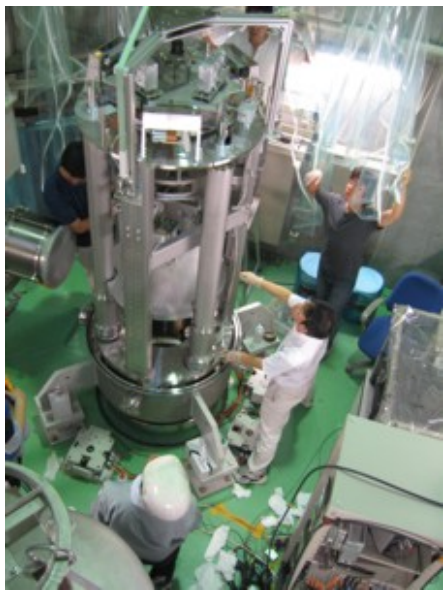
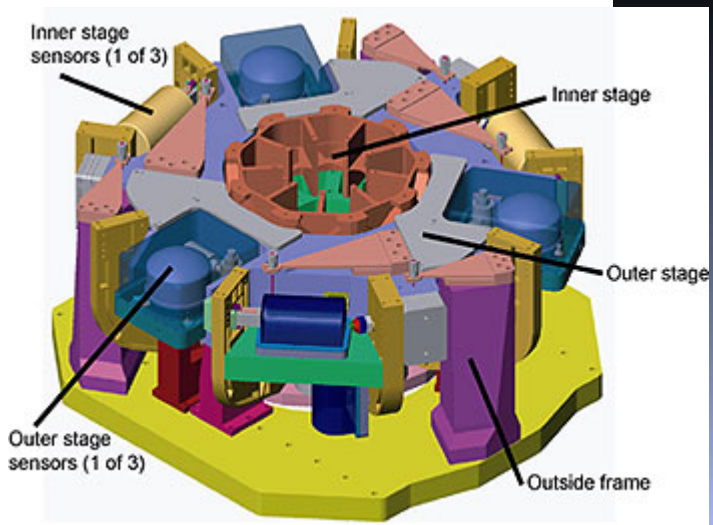
or…

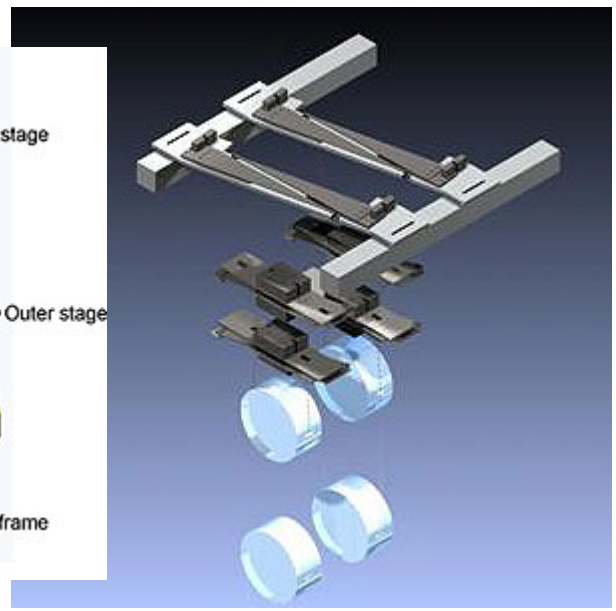
The way towards the design sensitivity @ 10 Hz

catch the Grishchuk's shark!









WARNING

Some of the issues treated in this talk are a bit technical

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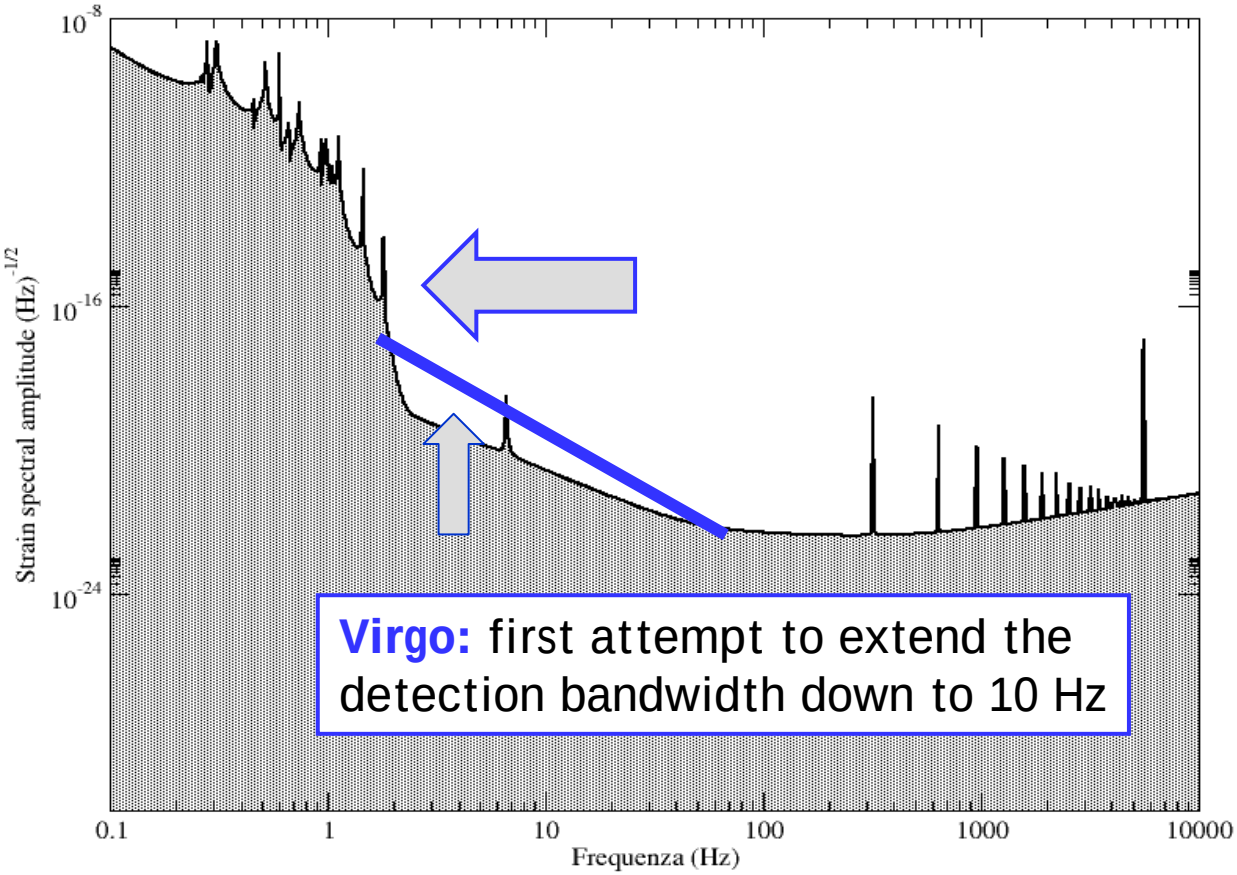
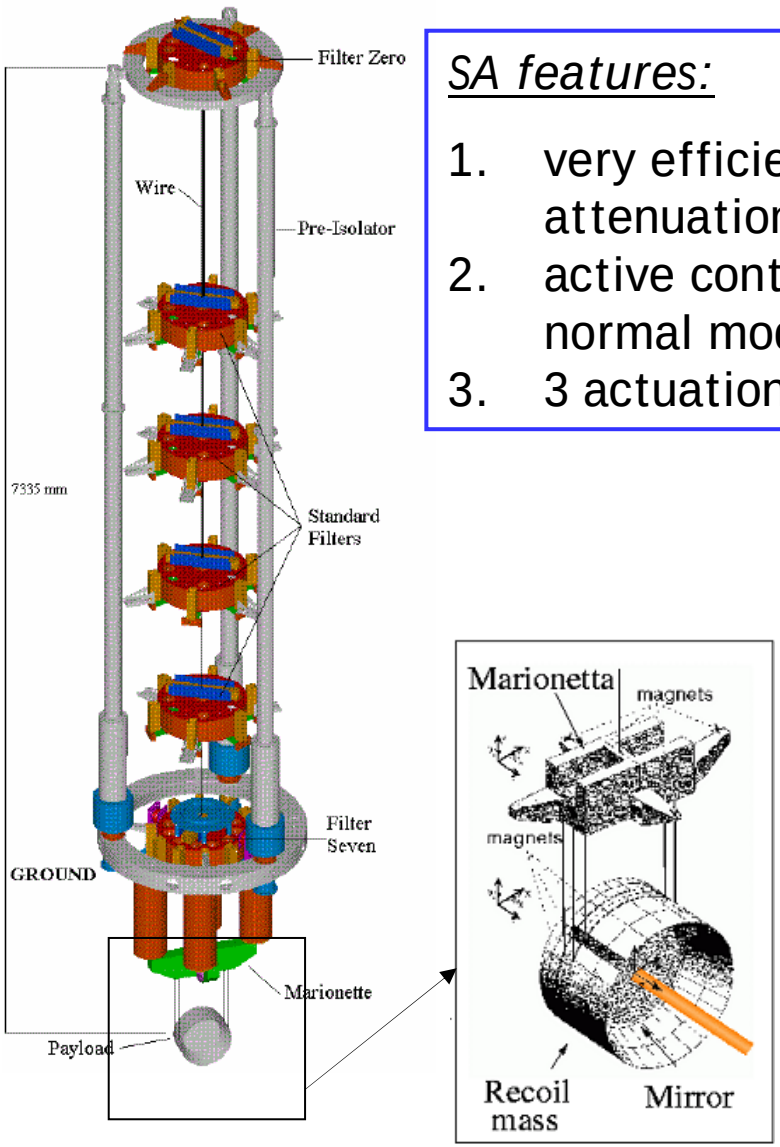
then you can check your email…

Low frequency noise



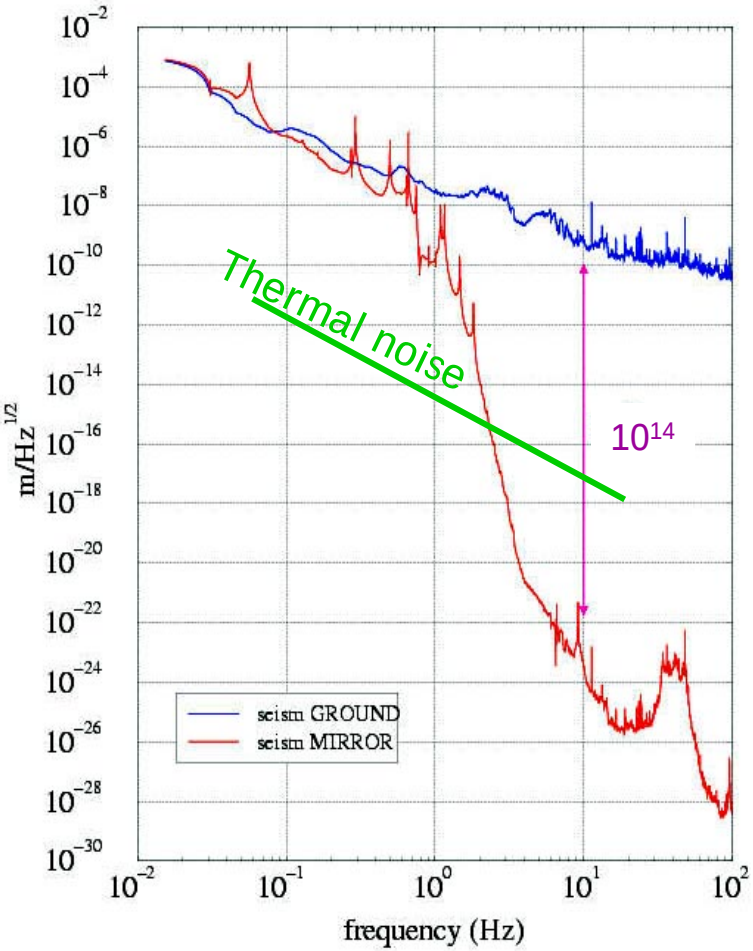
Low frequency sensitivity can be spoiled by **control noise**

Superattenuator



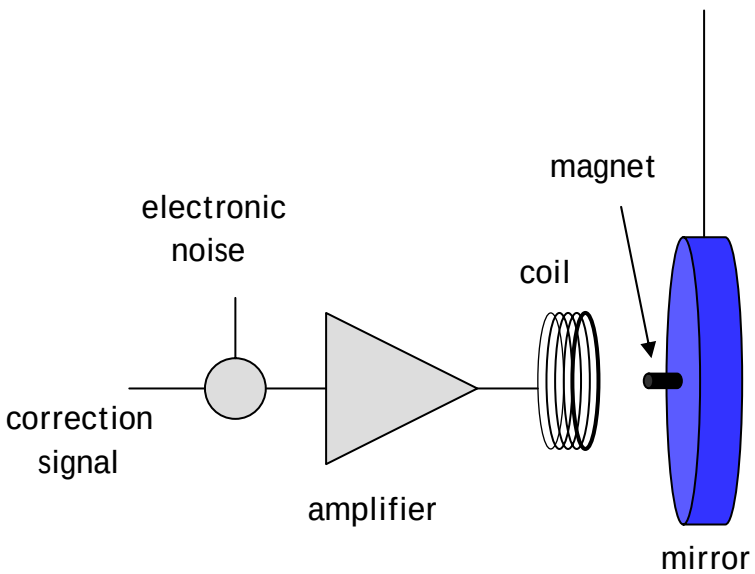
SA features:

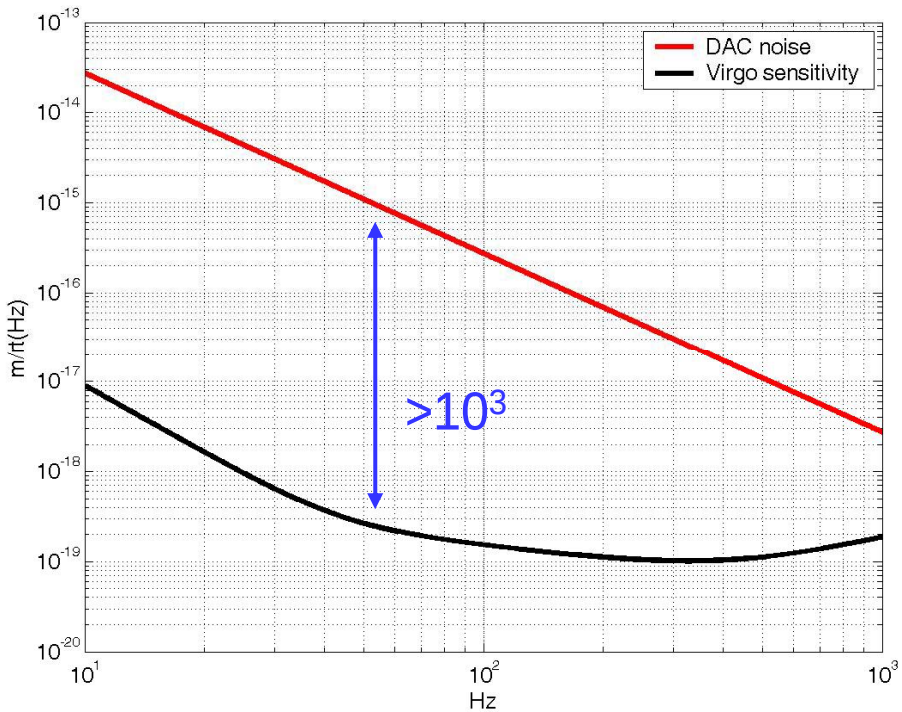
1. very efficient passive attenuation
2. active controls for normal mode damping
3. 3 actuation points



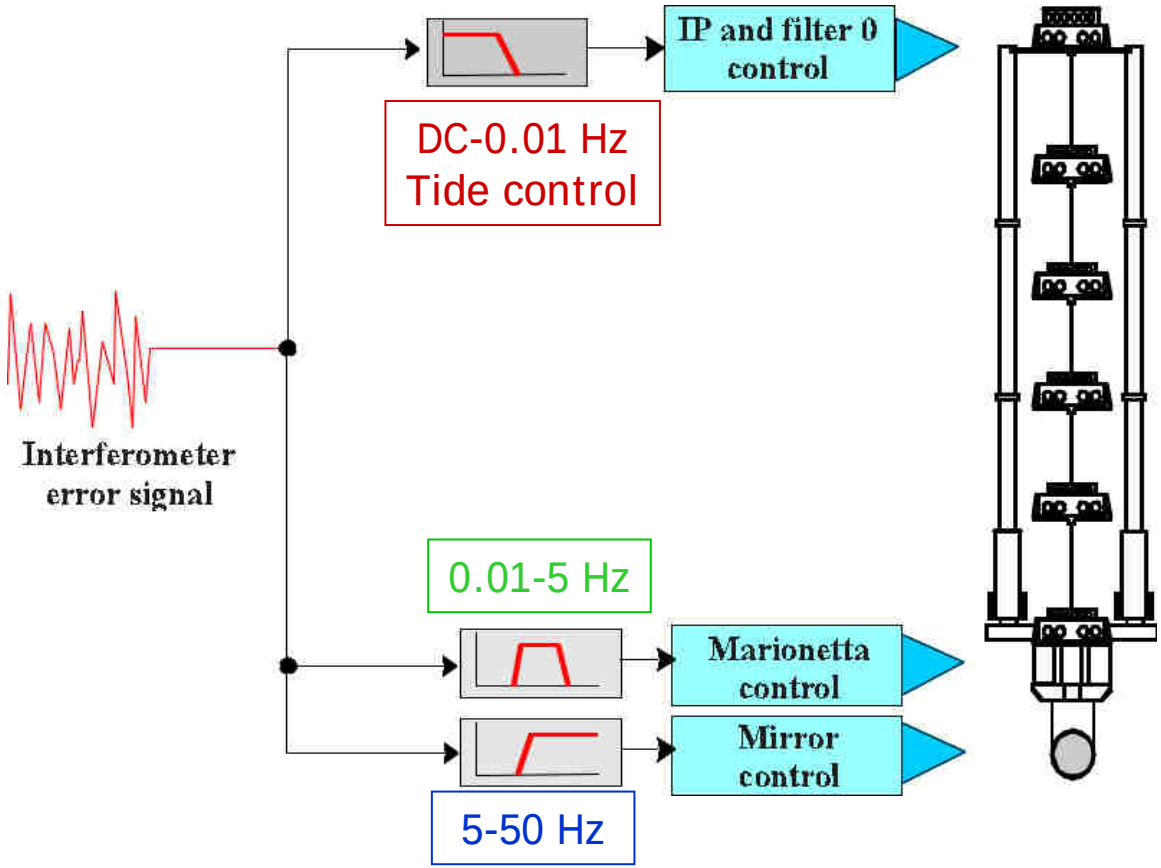
Control noise sources: mirror actuation

- The force needed to acquire the lock is much larger than that needed to keep it
- "Stronger actuation" means larger electronic noise





Solution: HIERARCHICAL CONTROL

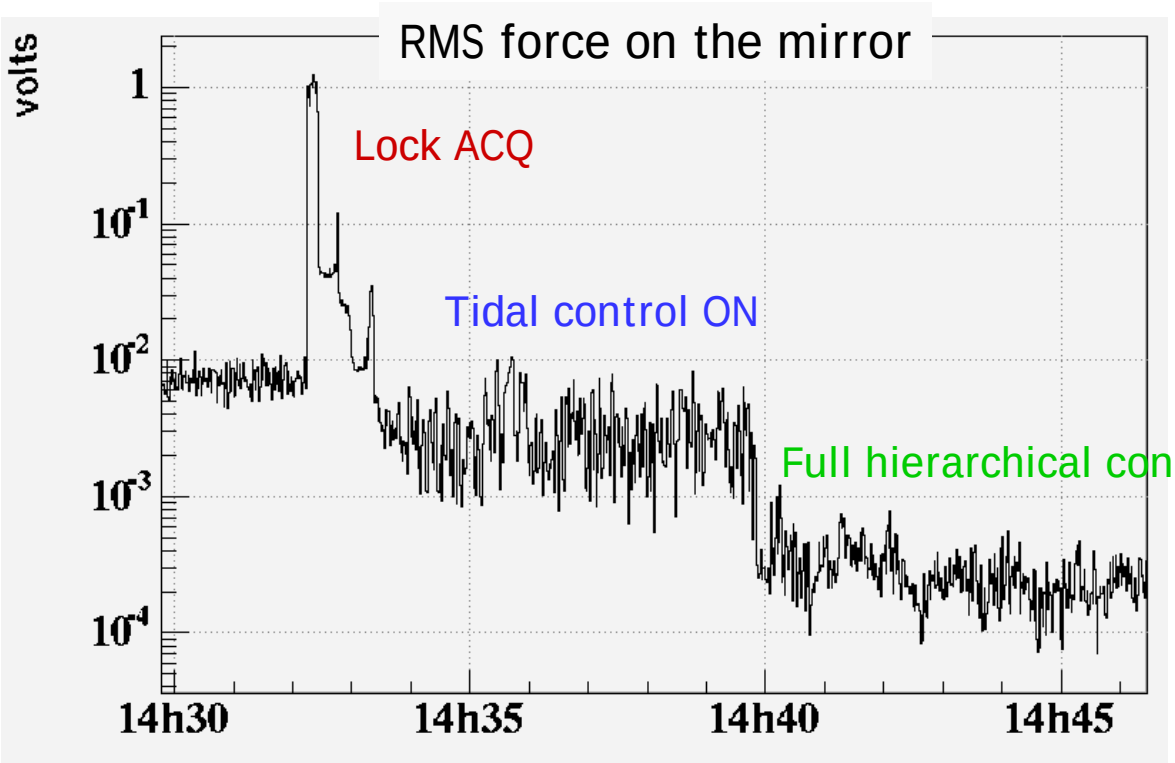


1. Force reallocation over three actuation stages.
Allows strong reduction of the force exerted on the mirror
2. After reallocation, reduce the actuators gain

Hierarchical control

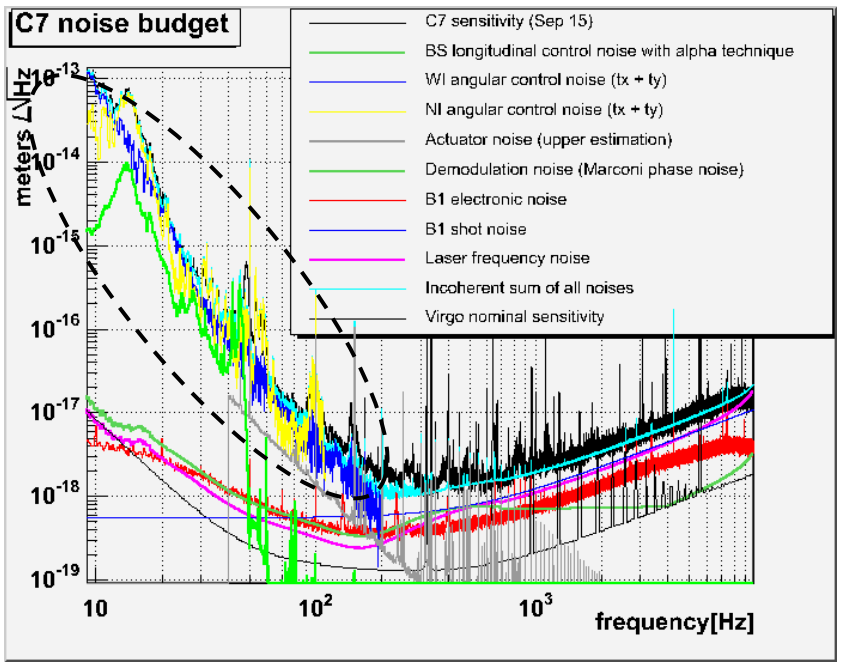
Hierarchical control allows to reduce the needed force (and thus the electronic noise) by almost 4 orders of magnitude

~ 10^4



Control noise sources: ALIGNMENT NOISE

- Low frequency sensitivity is dominated by ALIGNMENT noise (coupled with longitudinal d.o.f. via bad beam-mirror centering)
- The larger the excitation of the payload angular modes the larger the force needed to keep the mirror alignment
- Again, larger force (wider bandwidth) → larger control noise

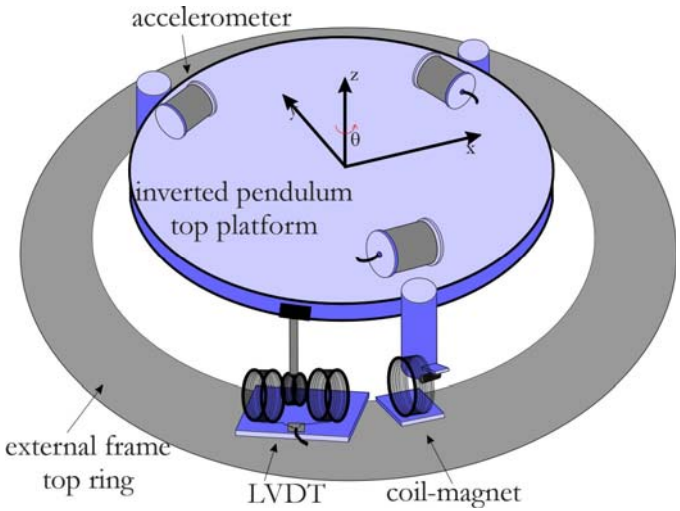


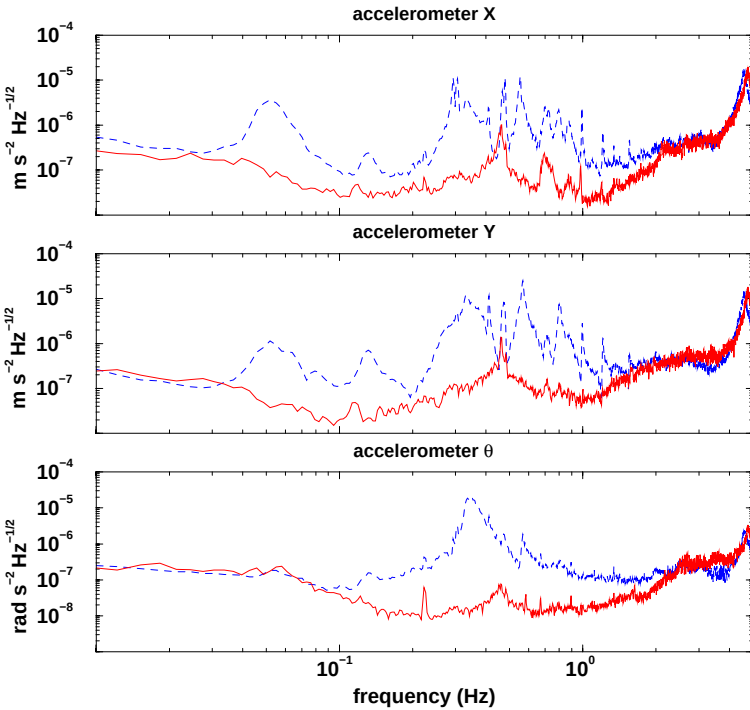
SOLUTIONS:

1. better centering of the beam on the mirrors
2. **reduce the angular modes excitation**

Inertial damping

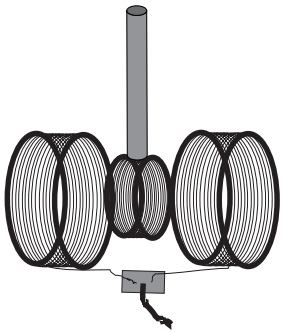
- Active damping of the SA modes, actuation on top stage, 3 d.o.f., DC-5 Hz
- Error signal from inertial sensors but…
- Position sensors (LVDT) needed for "DC control": **source of seismic noise reinjection**



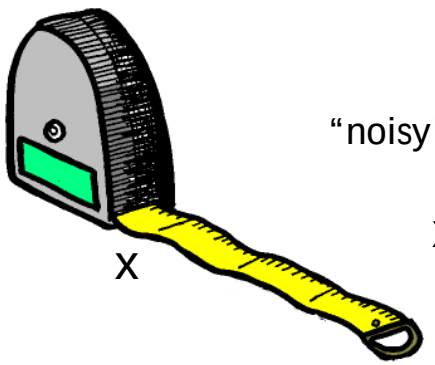


Sensors

Position sensor



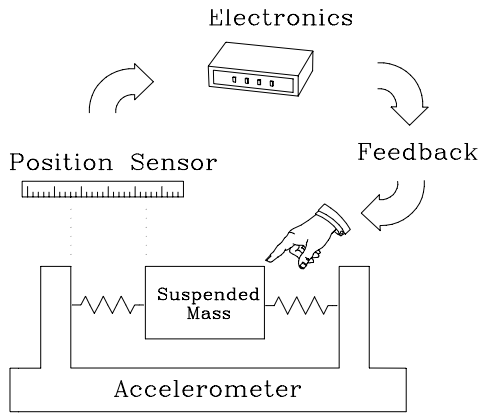
$$\text{signal} \propto x - x_0$$



"noisy" reference

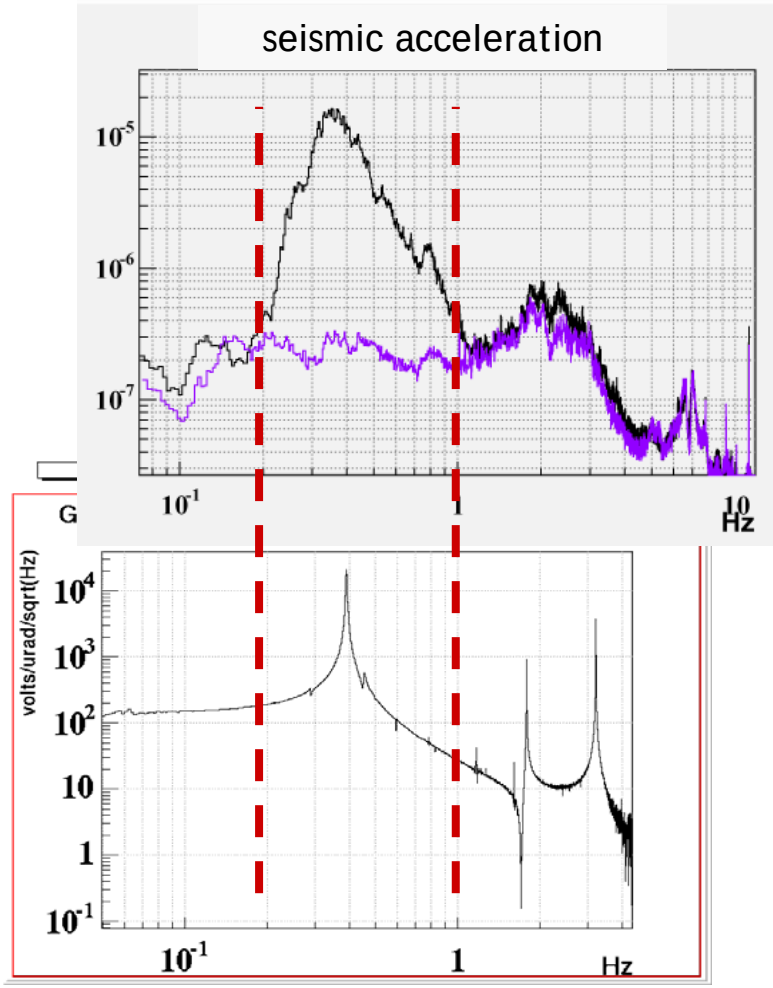
x_0

Inertial sensor



$$\text{signal} \propto \ddot{x}$$

Seismic noise vs interferometer



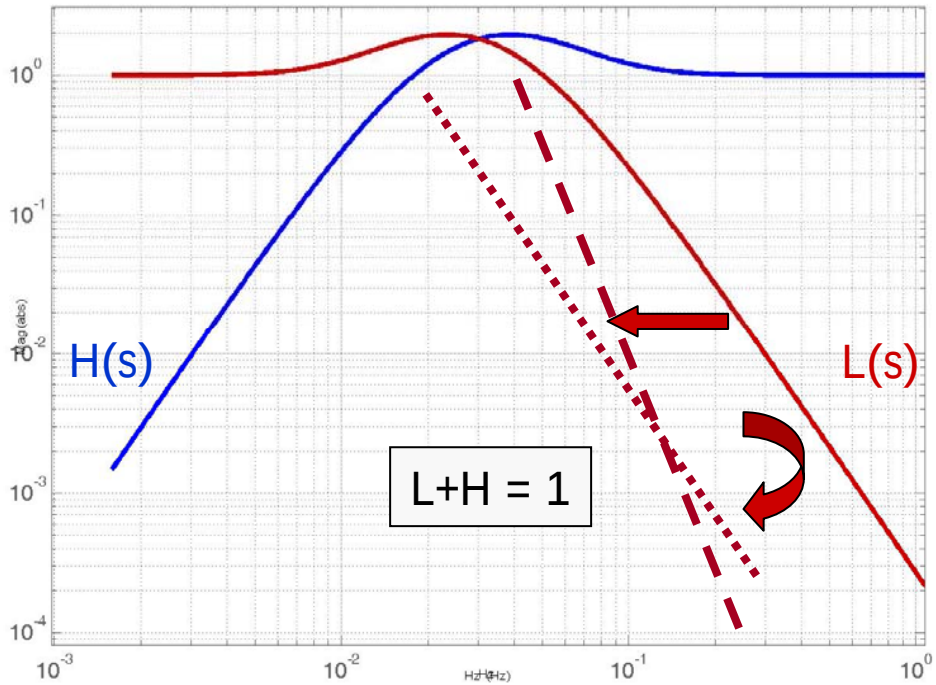
- The microseismic peak falls in the same as the main angular modes of the payload
- If it leaks to the mirror it makes angular control more difficult and the detector less stable

The amplitude of the microseismic depends strongly on the weather

Blending the sensors

$$\text{error signal} = \frac{a}{s^2}\cdot H + l\cdot L = x - L\cdot x_0$$

seismic noise reinjection



- ACC and LVDT are blended using two complementary filters
- The fraction of reinjected seismic noise depends on *L(s)*
- To reduce seismic noise:
  - steeper rolloff
  - **lower blending frequency**

Moving the crossover from 70 to 30 mHz means reducing the reinjected seismic noise by 10 @ microseismic peak

MAKE IT AS LOW AS POSSIBLE!

The cradle effect

The possibility to reduce the crossover is limited since…

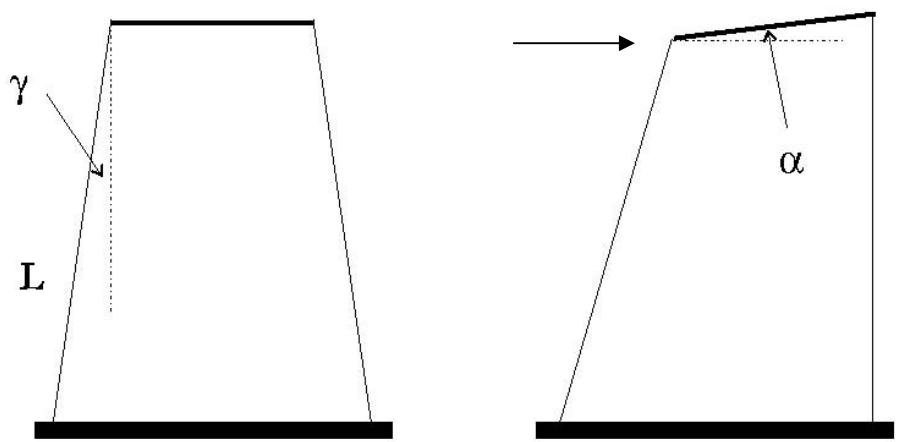
An accelerometer cannot distinguish a translation from a gravitational field

In presence of tilt α, accelerometer response:

$$a = \ddot{x} + g\alpha$$

Cradle effect:

due to mechanical imperfections top table tilts as it translates



Cradle effect subtraction

Model:
tilt depends on displacement only

Use displacement sensors to measure and SUBTRACT the cradle effect:

$$\begin{pmatrix} a_x \\ a_z \end{pmatrix} = \begin{pmatrix} s^2 x \\ s^2 z \end{pmatrix} + \mathbf{T} \cdot \begin{pmatrix} l_x \\ l_z \end{pmatrix}$$

Before subtraction: $|t_{ij}| < 0.02$

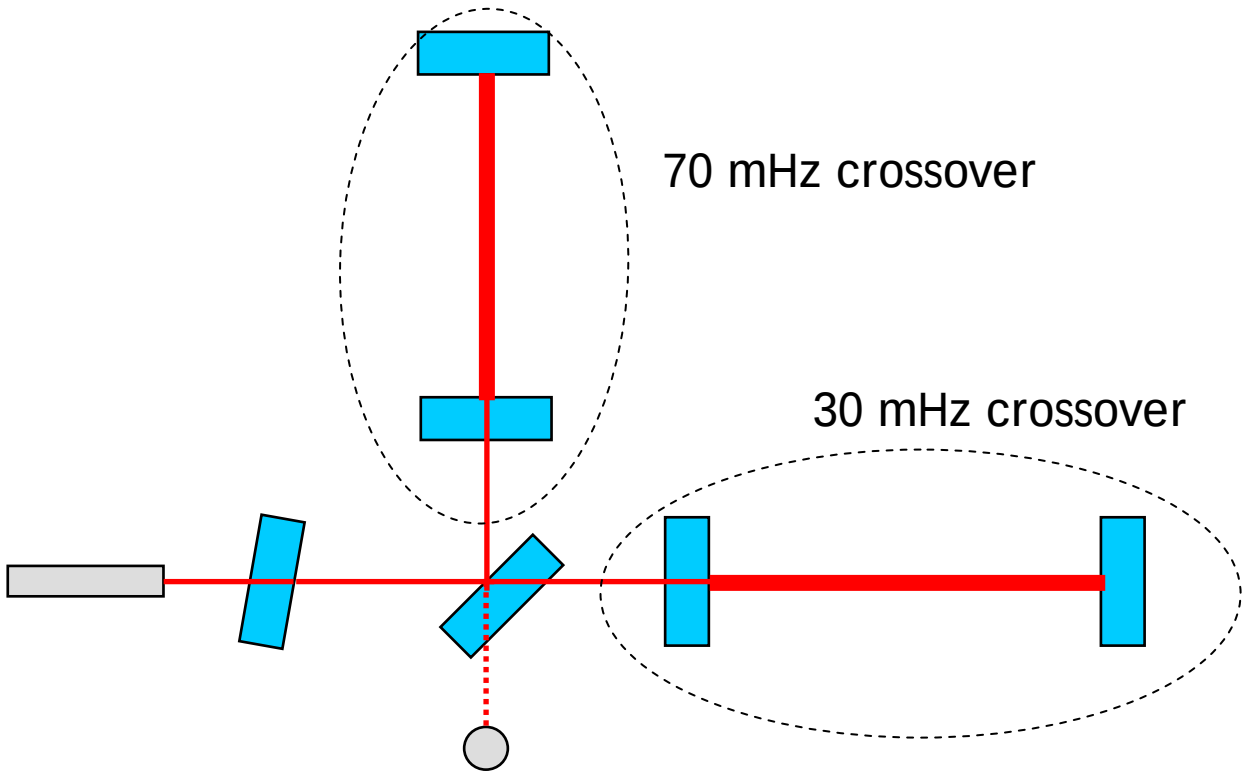
After subtraction: $|t_{ij}| < 10^{-3}$

After subtraction it was possible to reduce crossover form 70 to 30 mHz gain **10x** @ microseismic peak

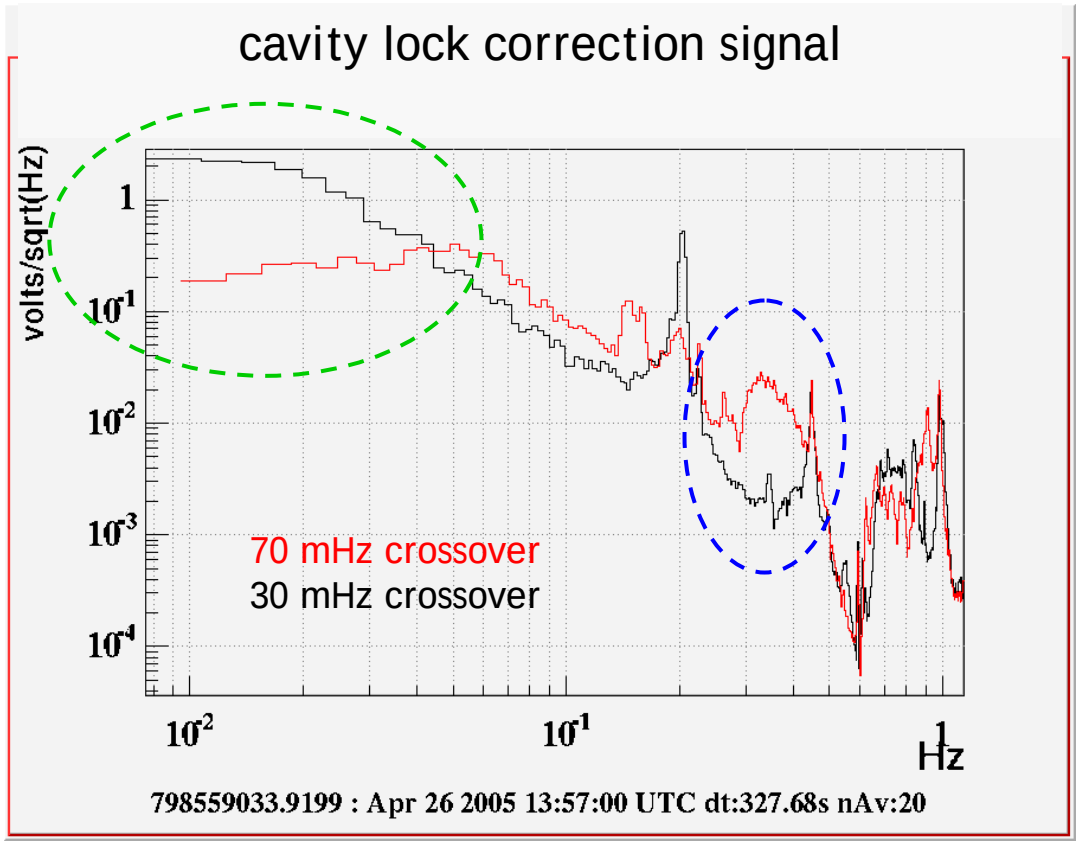
Test

Comparing the performance of different crossover in same noise conditions:

- Cavities locked independently, 70 mHz crossover on WEST cavity, 30 mHz on NORTH cavity
- Compare the correction signals to measure the motion of the mirrors



Results

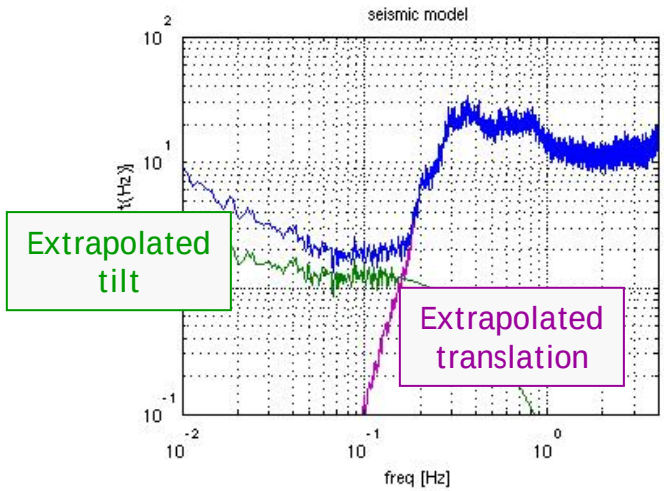


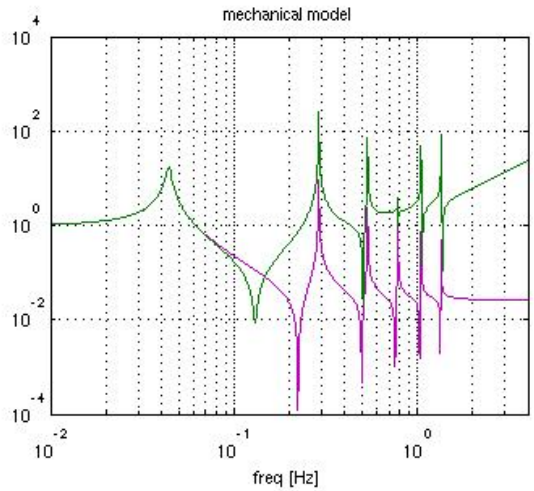
Reducing the position sensors control bandwidth:

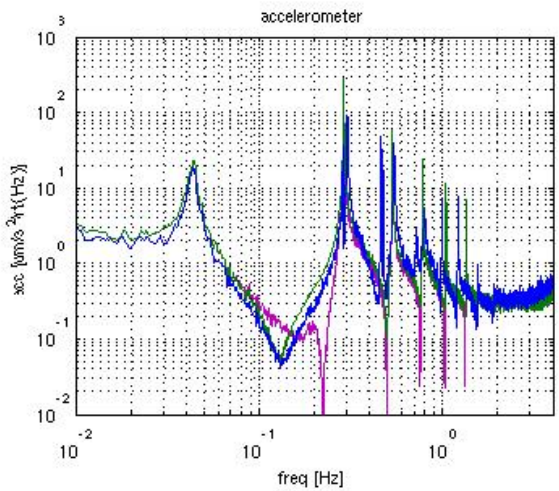
~**10x** less noise
@ microseismic peak
AS EXPECTED

excess noise
below 50 mHz:
WHY?

The role of seismic tilt

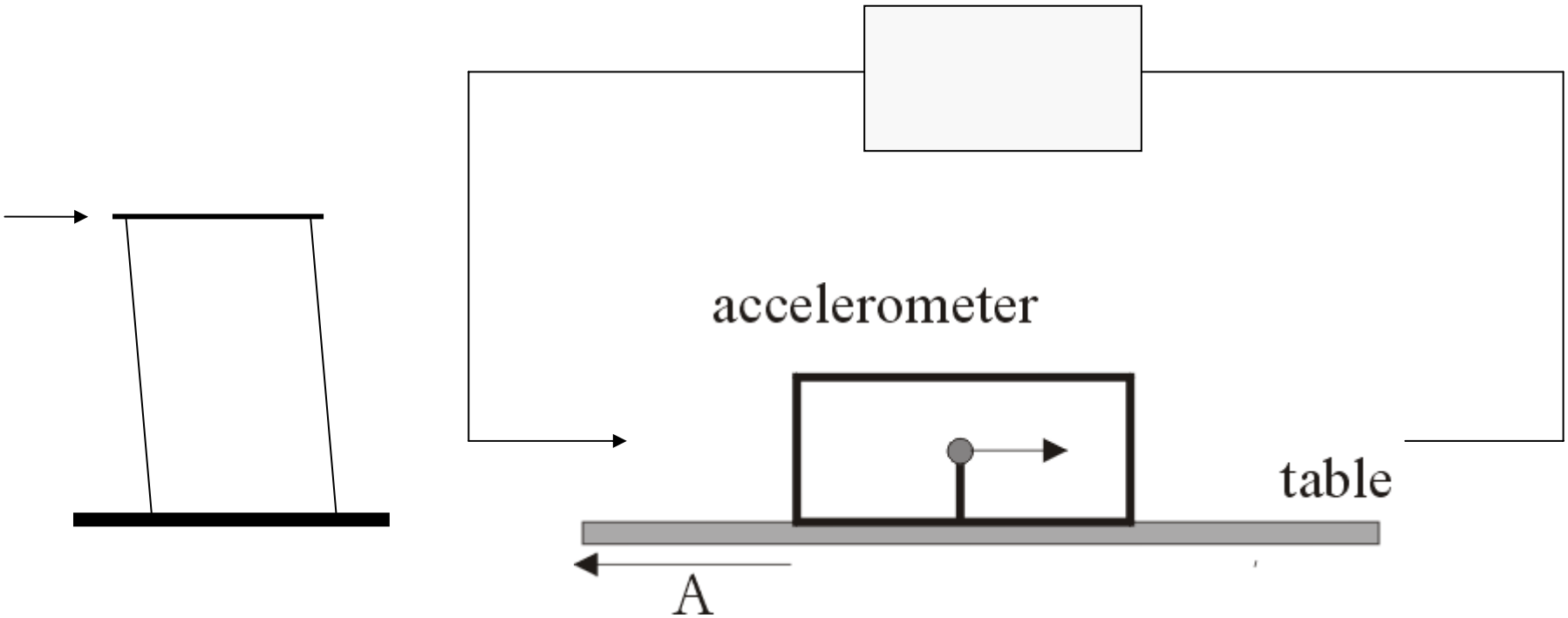






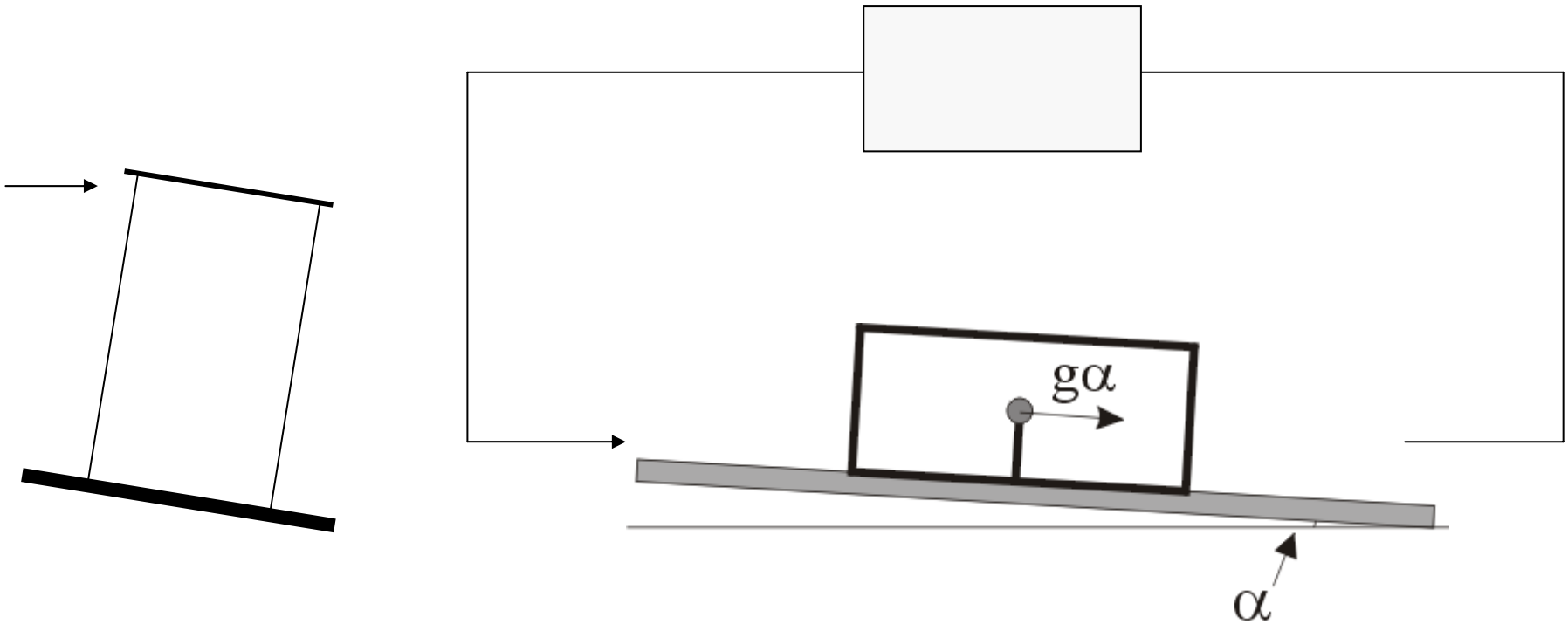
The response of the ACC on the IP can be fully explained only if the seismic noise is tilt-dominated below 100 mHz

Effects of tilt on the control strategy



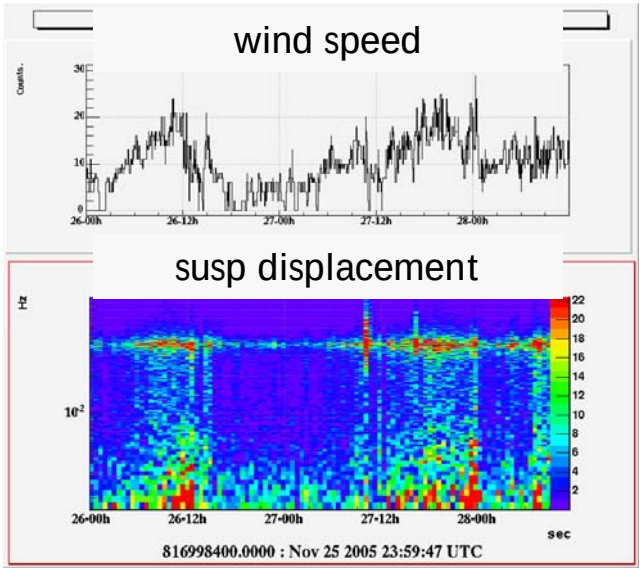
Effects of tilt on the control strategy

The feedback will push the table in the wrong direction!

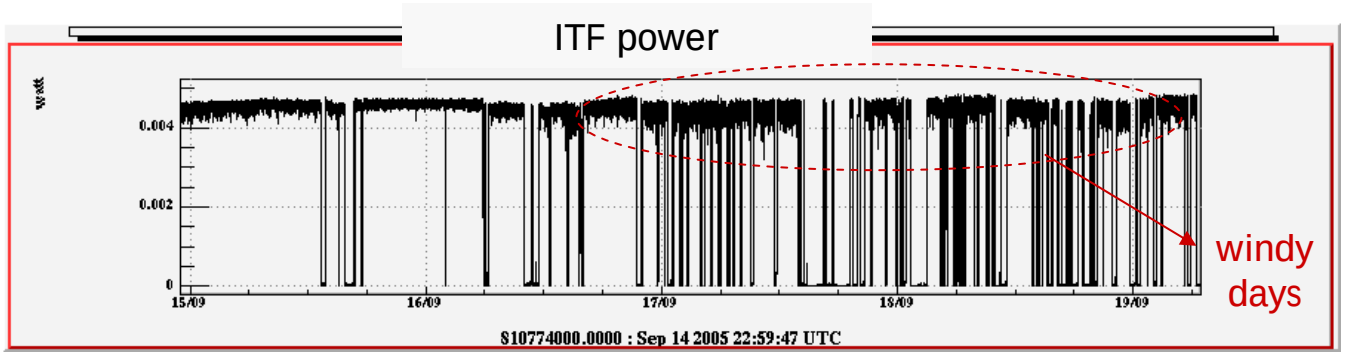


If the seism is tilt-dominated at low frequency we are using the wrong control strategy!

Wind vs interferometer

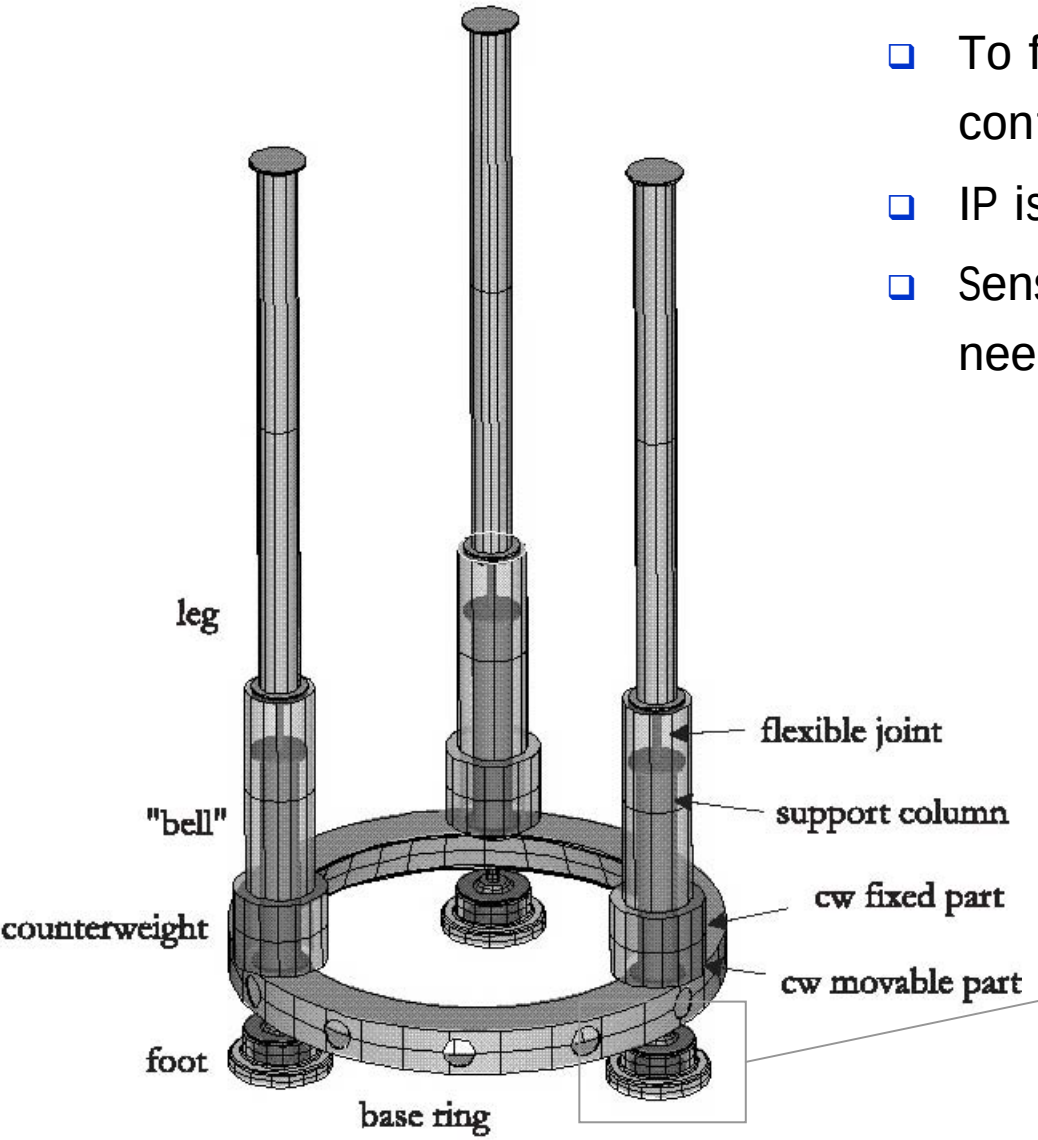


The **low frequency motion** of the suspension is strongly correlated with the wind speed

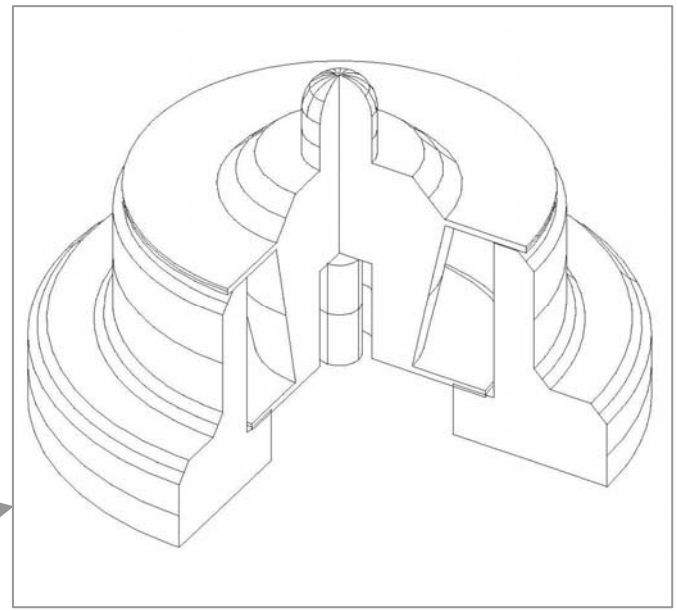


The detector **duty cycle** is affected by the wind

Control of tilt

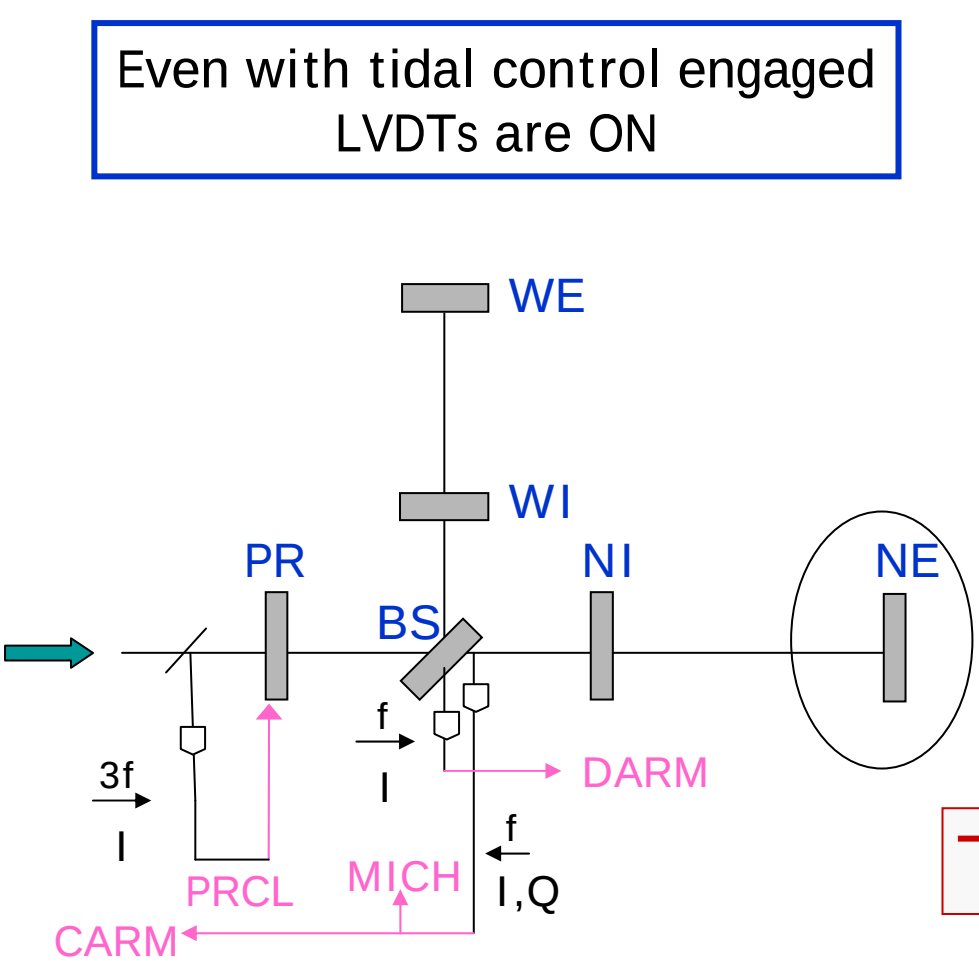


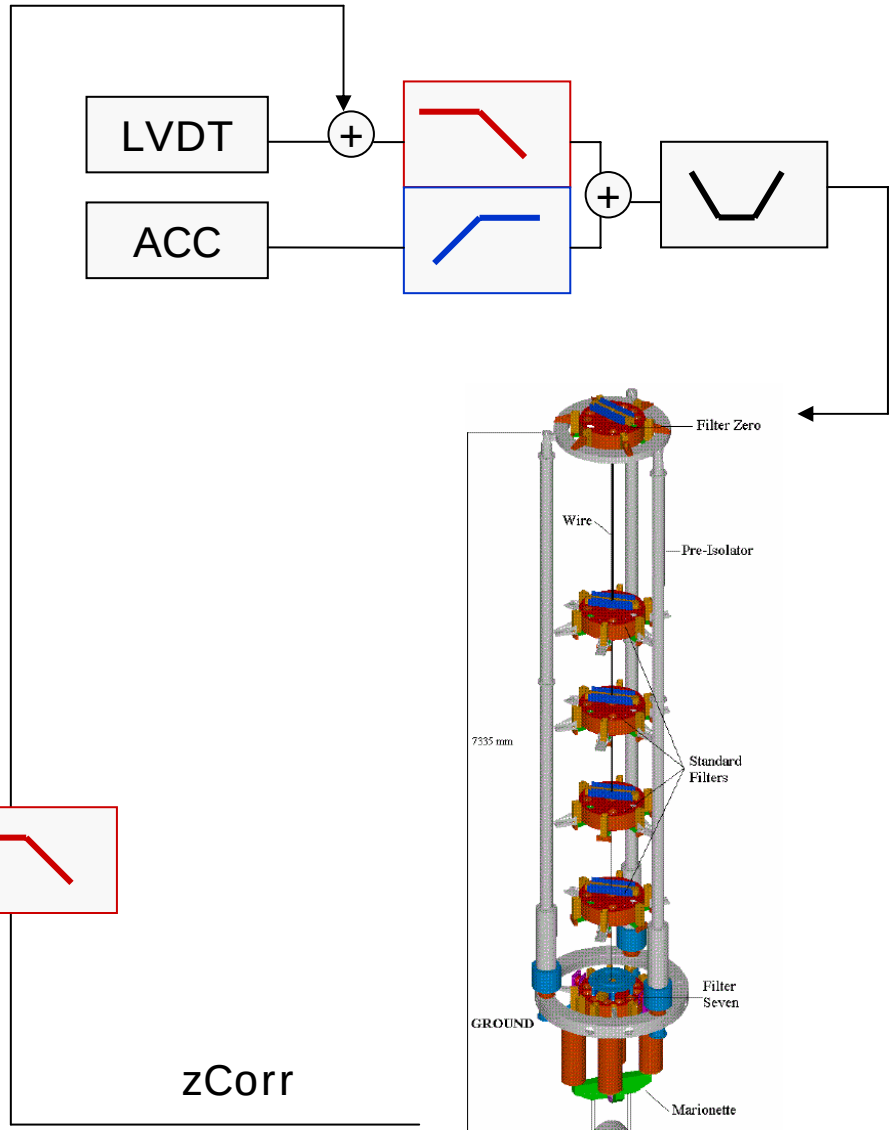
- To further improve the inertial control we need to get rid of tilt
- IP is designed for tilt control
- Sensing: an angular accelerometer is needed, decoupled form translations



What can be done more now?

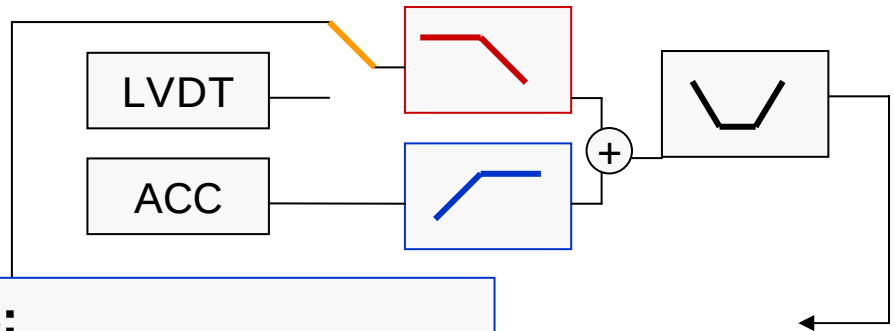
Even with tidal control engaged
LVDTs are ON





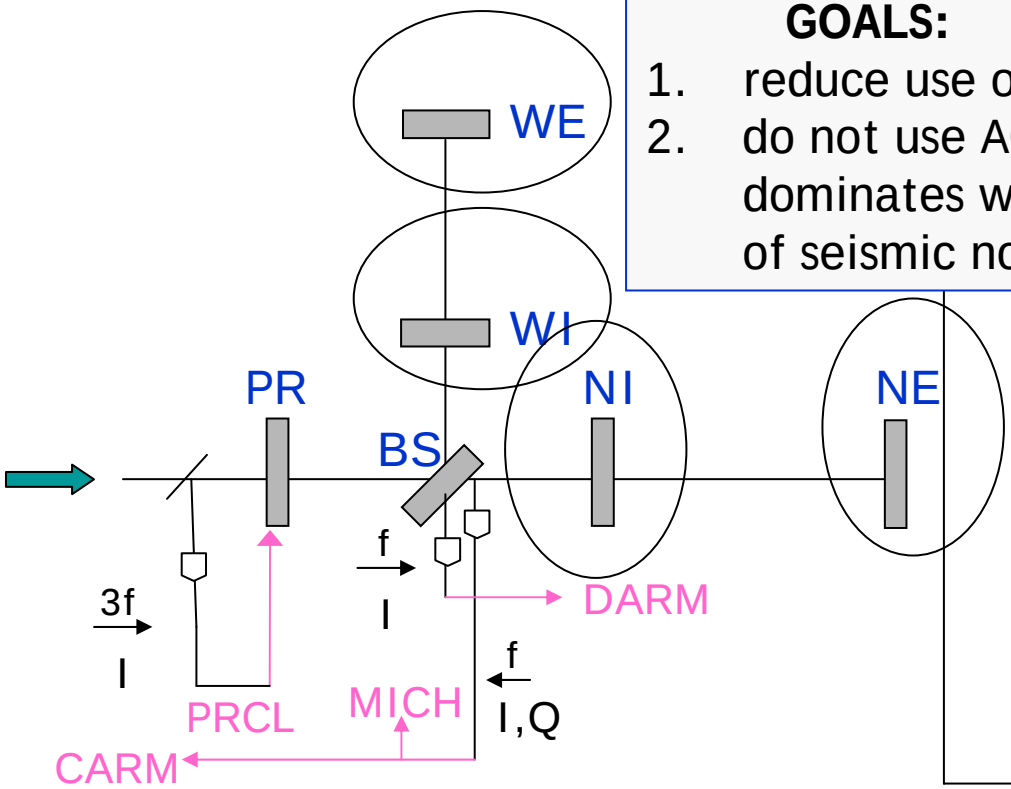
“Removing” local signals

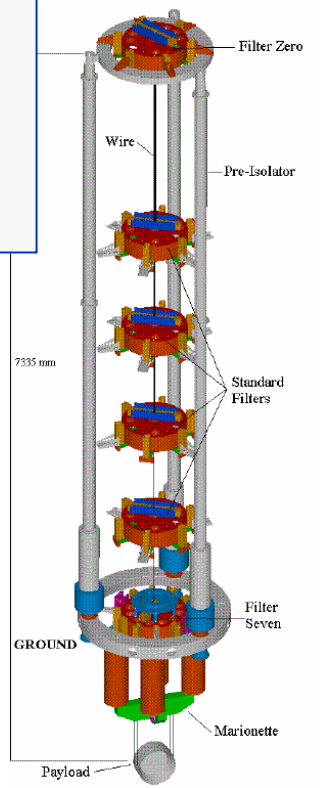
Use 4 locking signals for the position control of 4 mirrors in the beam direction



GOALS:

1. reduce use of noisy sensors
2. do not use ACC where tilt dominates with no reinjection of seismic noise





Summary

Extending the detection bandwidth down to 10 Hz is a hard job

Control noise reduction is a crucial issue

- Reduce as much as possible the use of local position sensors to reduce the dependence on seismic noise variability:
  - **smarter filtering**
  - use of **interferometric signals for position control**

- Seismic tilt may mess up the control strategy. **Active control of tilt** can be important for further improvements

For more details see:
http://wwwcascina.virgo.infn.it/suspcon/MSCdocs/notes/tilt.pdf