SYSTEM FOR CHARACTERISING VIRGO/ADVANCED VIRGO TEST MASS QS

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on behalf of the Virgo Collaboration

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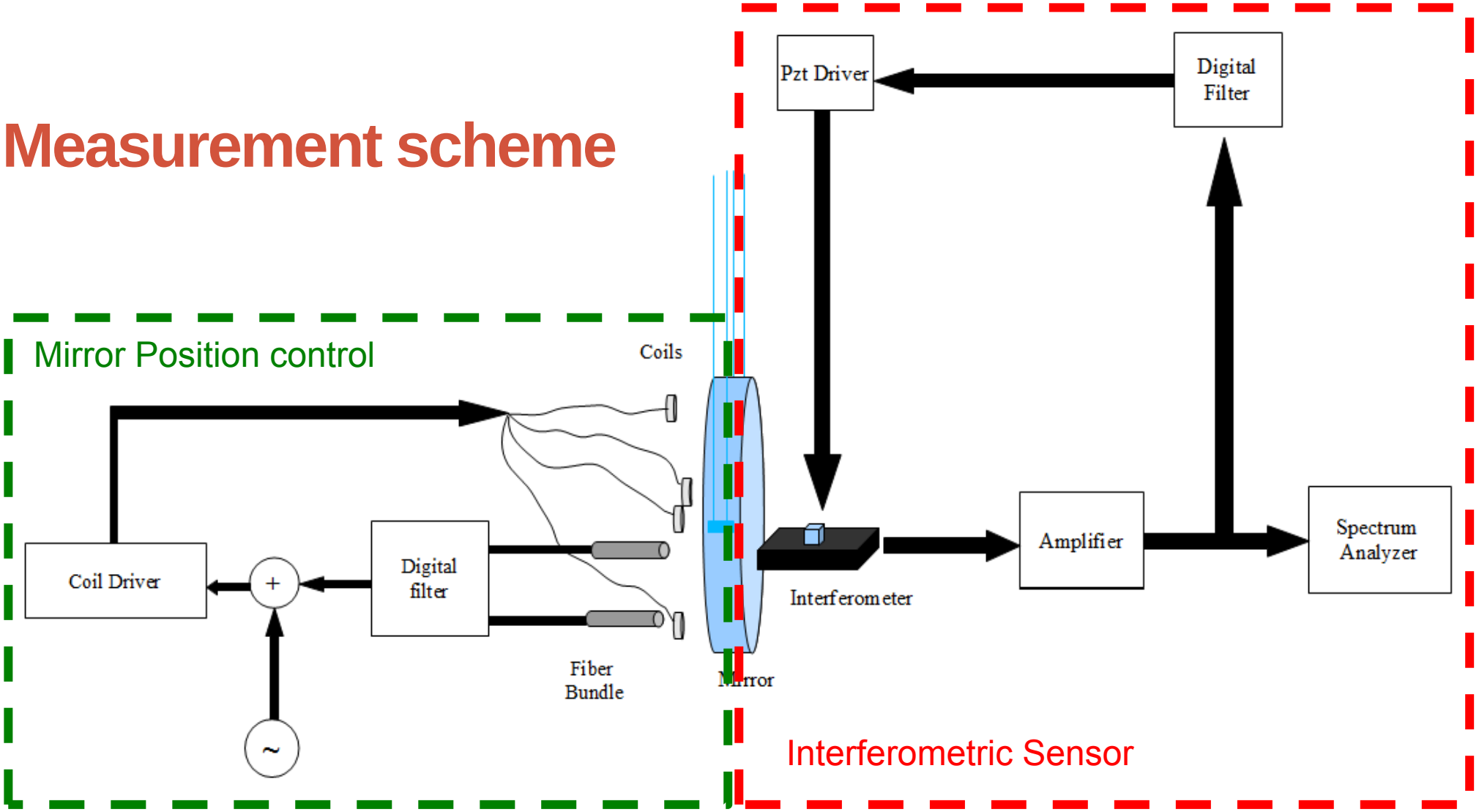
Experiment goal

- Characterization of the mirror losses once installed in the last stage suspension system before the integration in the tower.

Sensitivity Requirements

- Q to be measured of the order 10^5-10^7 (decay times 10-1000 s for the mirror internal modes)
  - Expected amplitude for drum mode (5.7 kHz) with Q=10^6 (τ = 50 s) with excitation force of about 10^{-5} N (about 1 A on the coil): 2x10^{-10} m.
  - Max Peak Amplitudes 10^{-9} – 10^{-10} m
  - Observe up to 10 decay times → integration times (100s-1000s), bandwidths (1-10Hz);
  - Noise floor 10^{-12} m/sqrt(Hz)
  - Measurement Frequency Range : 2-10 kHz

Measurement scheme

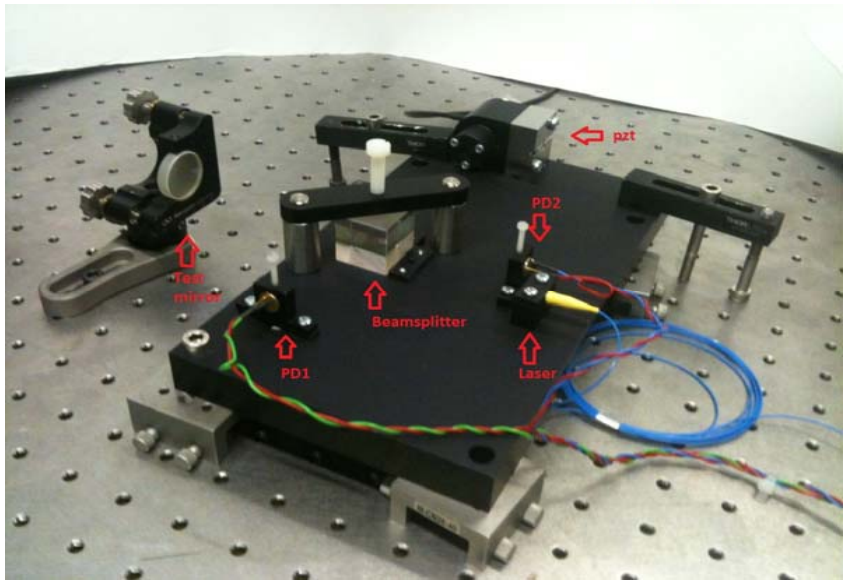


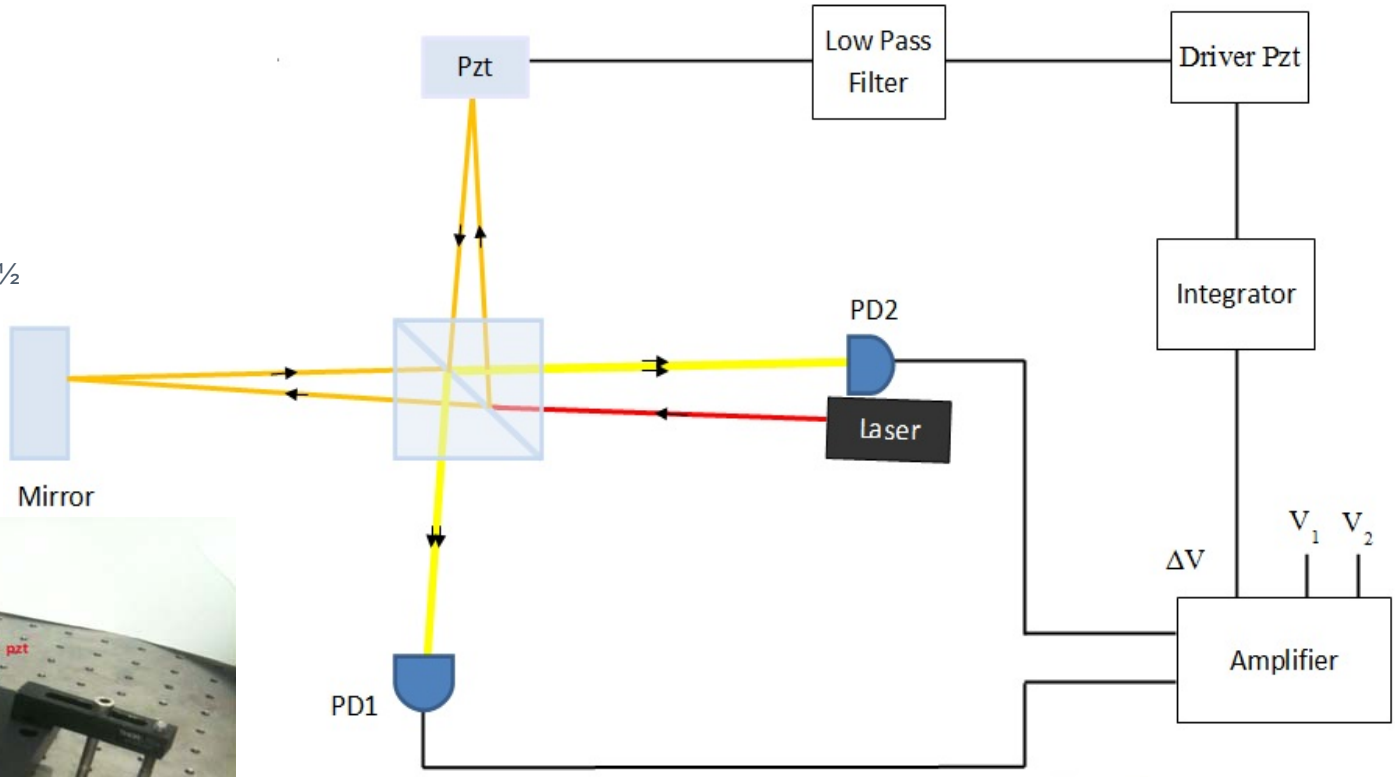
Interferometer Scheme

(assembled and tested in Naples Virgo Laboratory)

Specifications on the optical table:

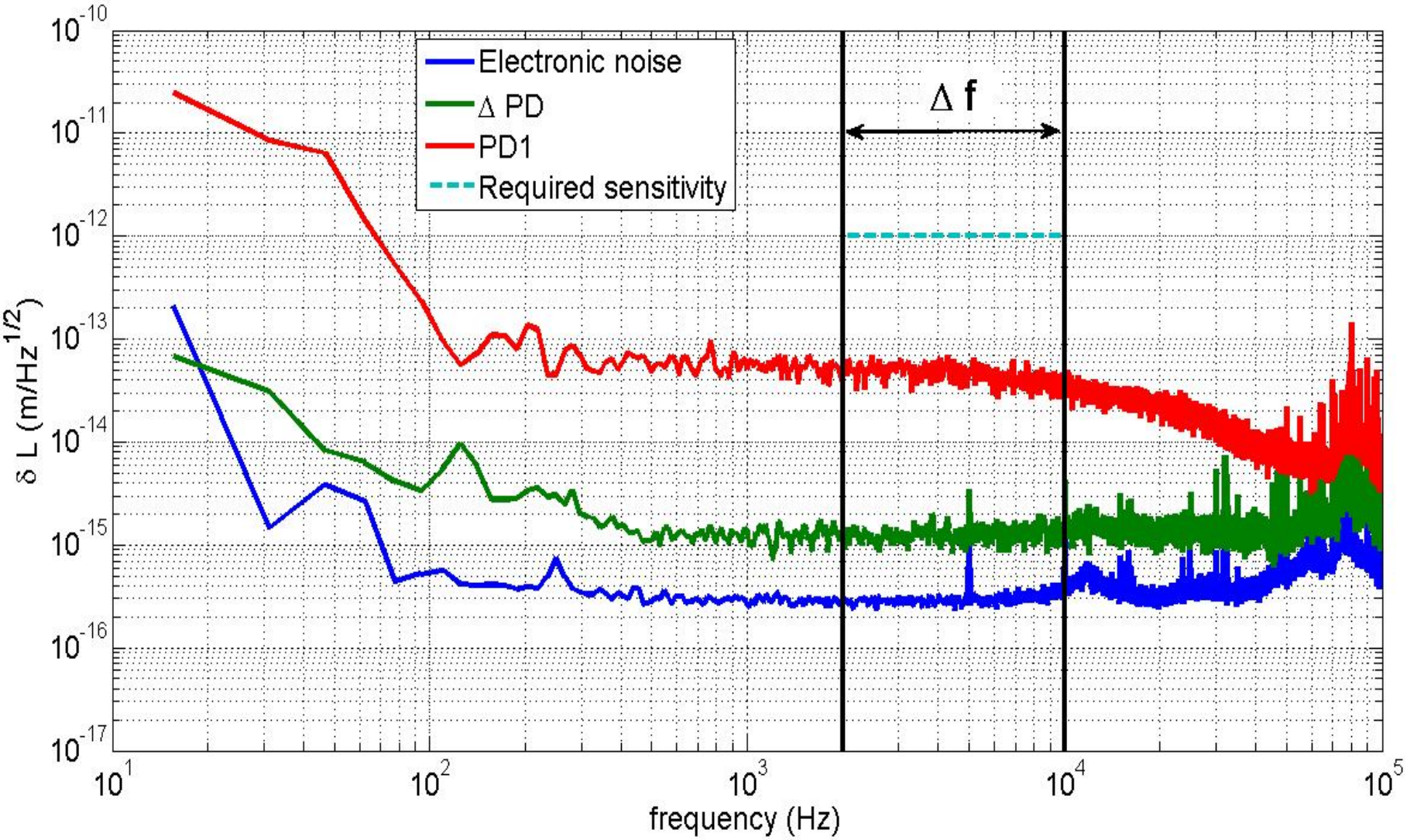
- Laser wavelength : 1064 nm
- Input Power : 10.4 mW
- Arm length : 10 cm
- Shot noise: $\sigma_{\delta L} = 5.5 \times 10^{-16}$ m/Hz$^{1/2}$
- Contrast: C = 0.63





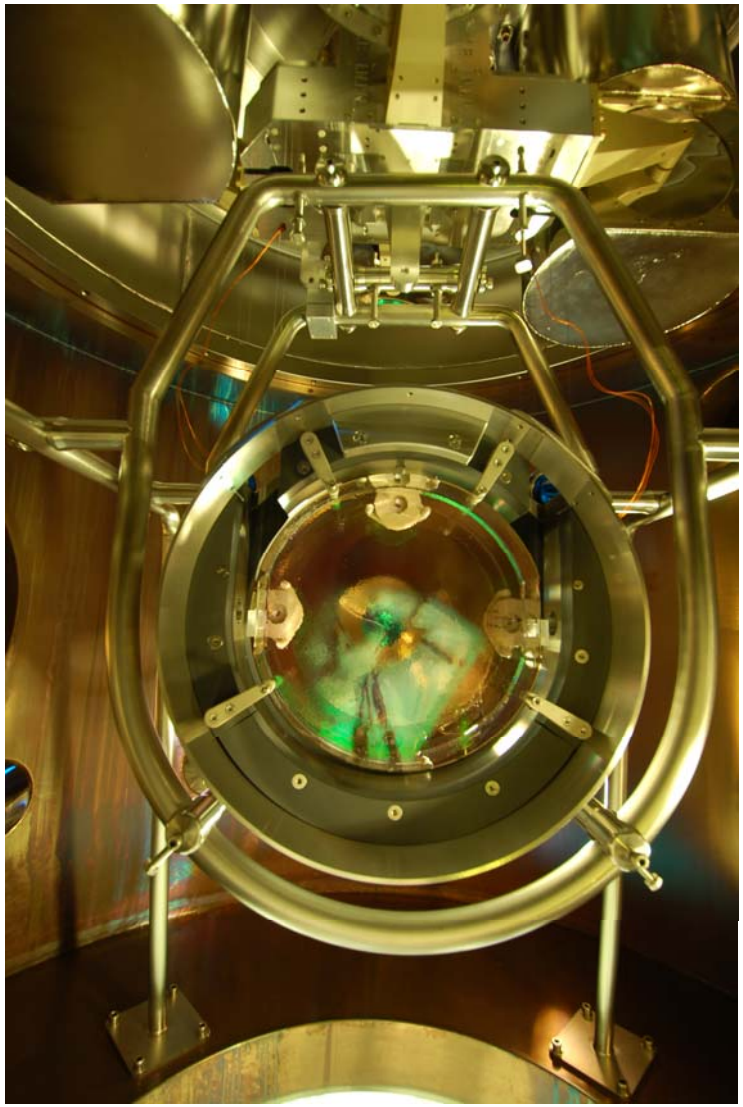
Convenience of photodiodes signals difference:

signal measured with one arm obscured



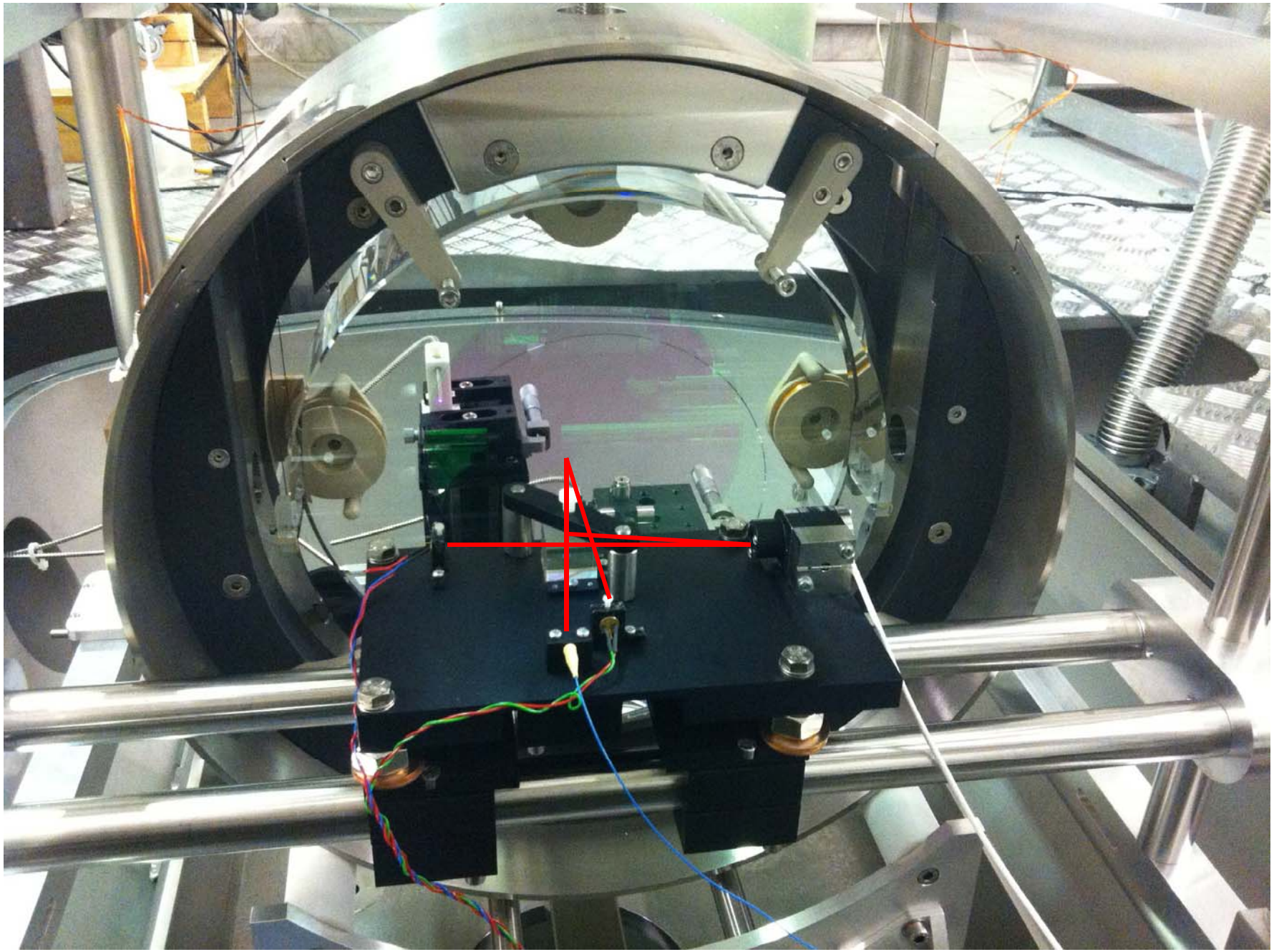
Virgo+ Mirrors

Monolithic suspension in Virgo+

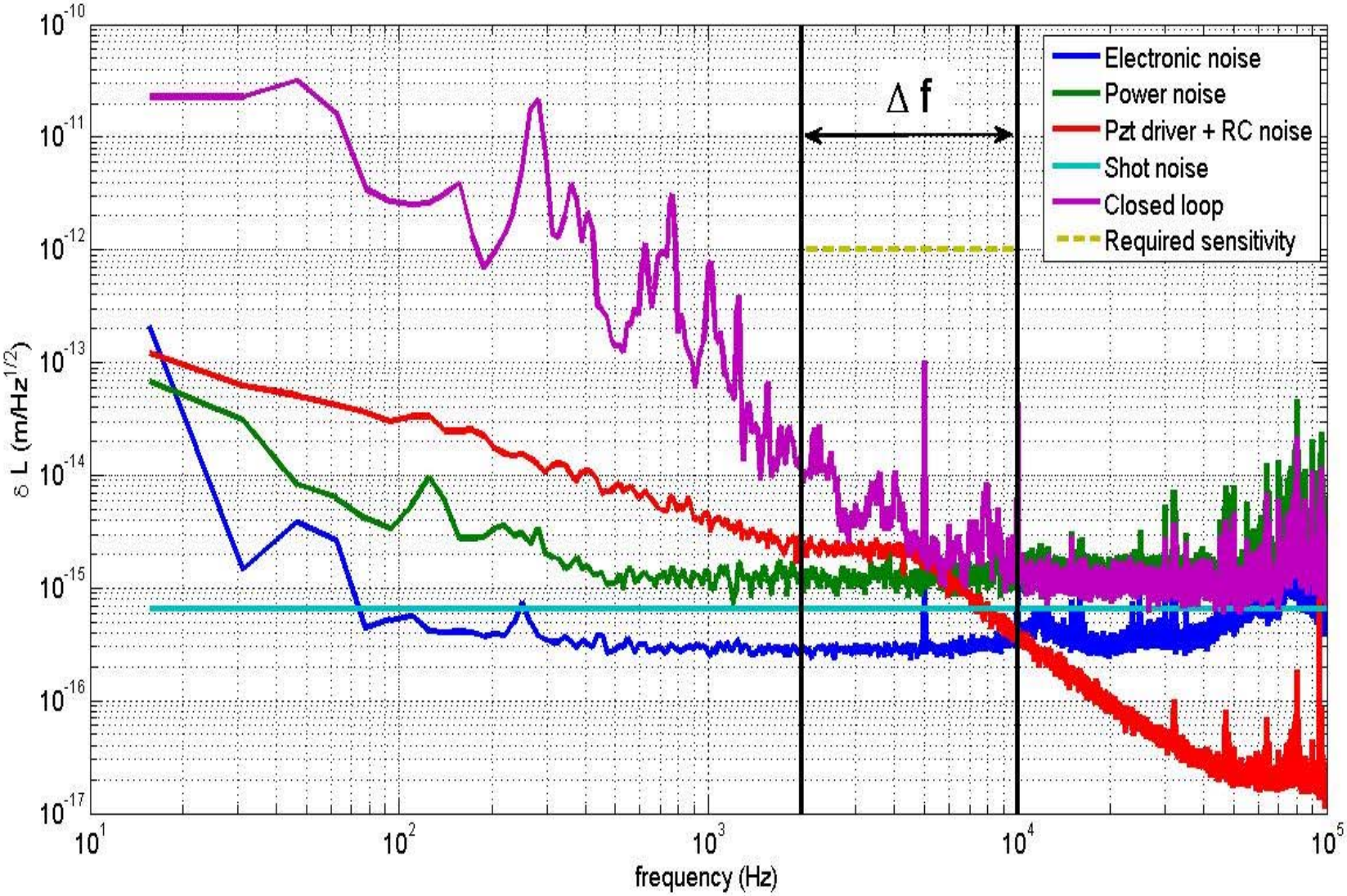


Payload in the tower (Virgo+)

Setup in Rome Virgo Laboratory: the Interferometer

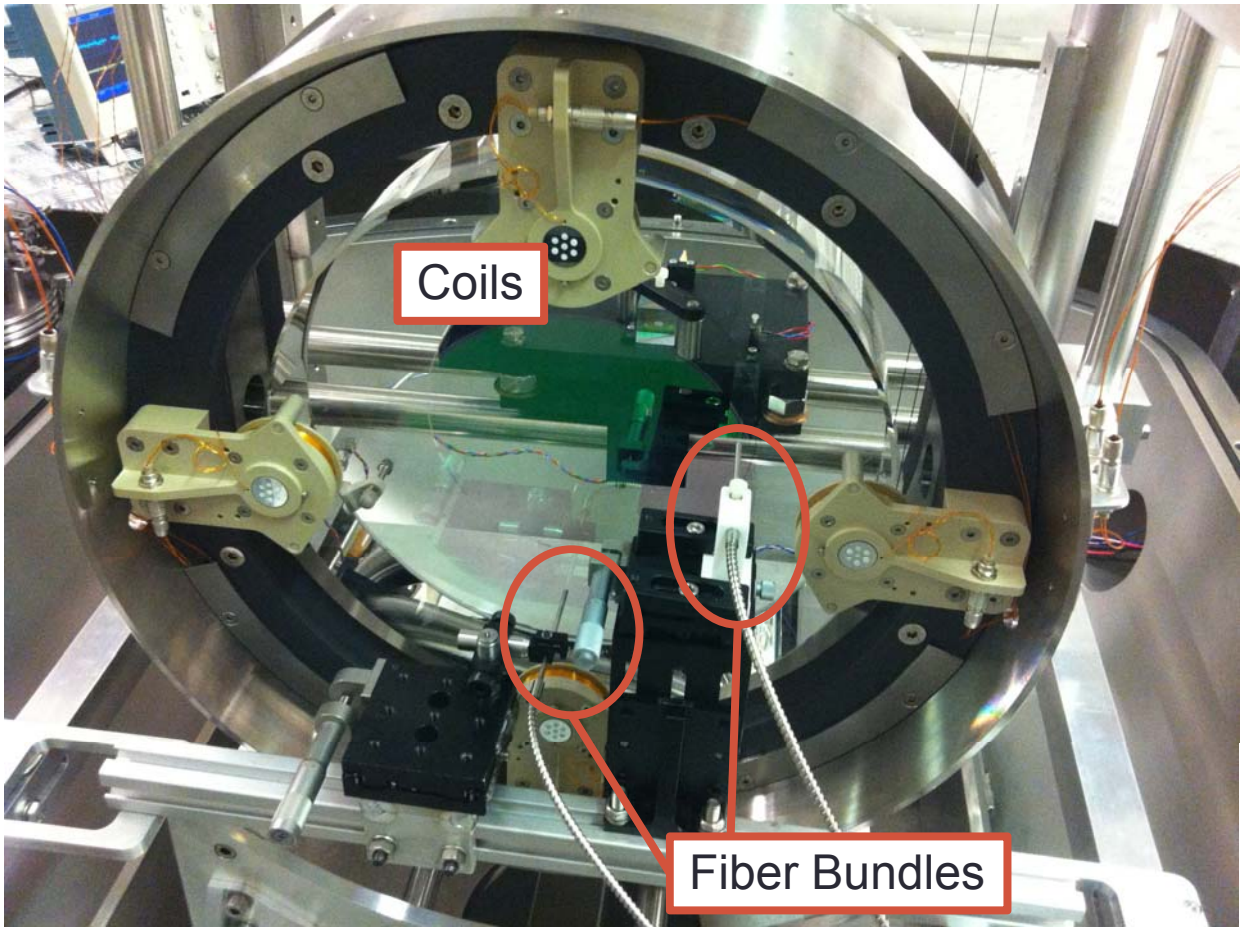


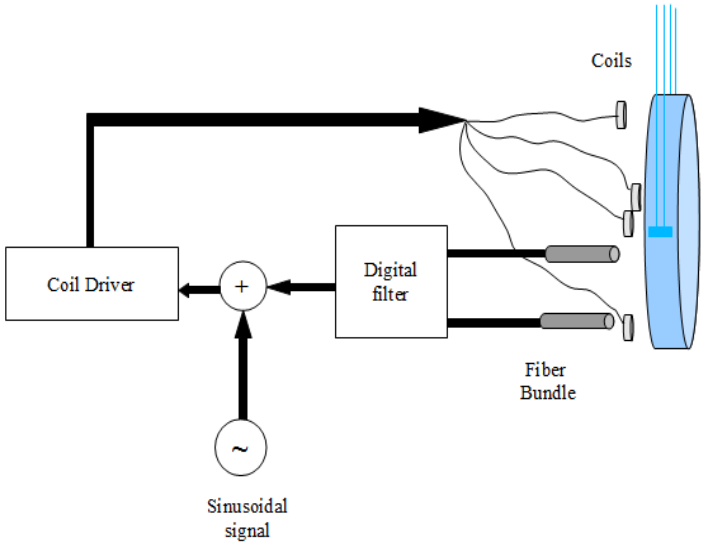
Noises


Electronic noise
Power noise
Pzt driver + RC noise
Shot noise
Closed loop
Required sensitivity
Δ f
δ L (m/Hz^1/2)
frequency (Hz)
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^-17
10^1
10^2
10^3
10^4
10^5

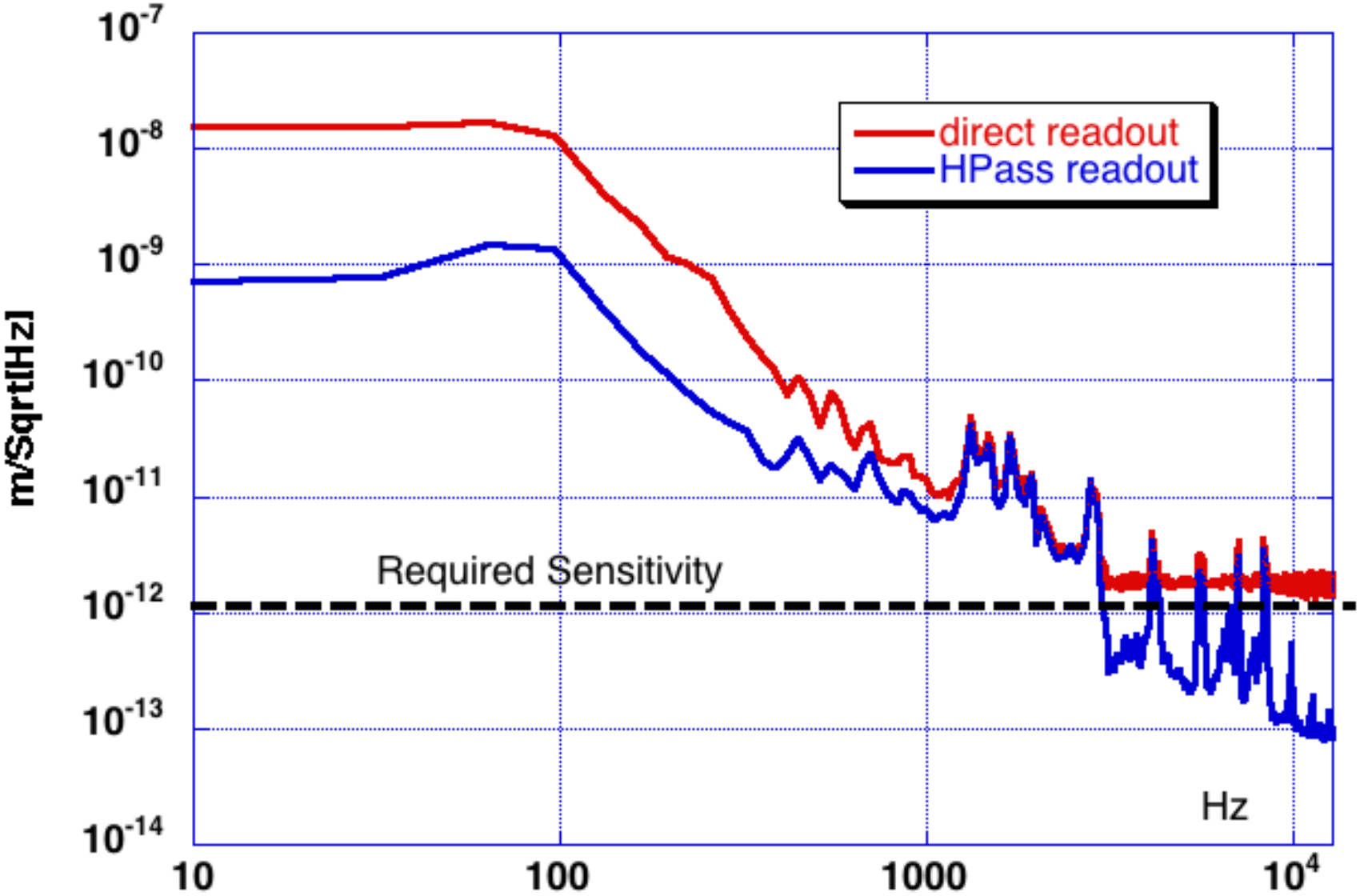
Setup in Rome Virgo Laboratory: the position control

- The fiber bundles are used to reconstruct the angular and z displacements of the mirror;
- The mirror position correction signal is sent to 3 of the 4 coils of the reaction mass;
- We use one coil to excite the resonance frequencies





Sensitivity of the interferometer in Rome



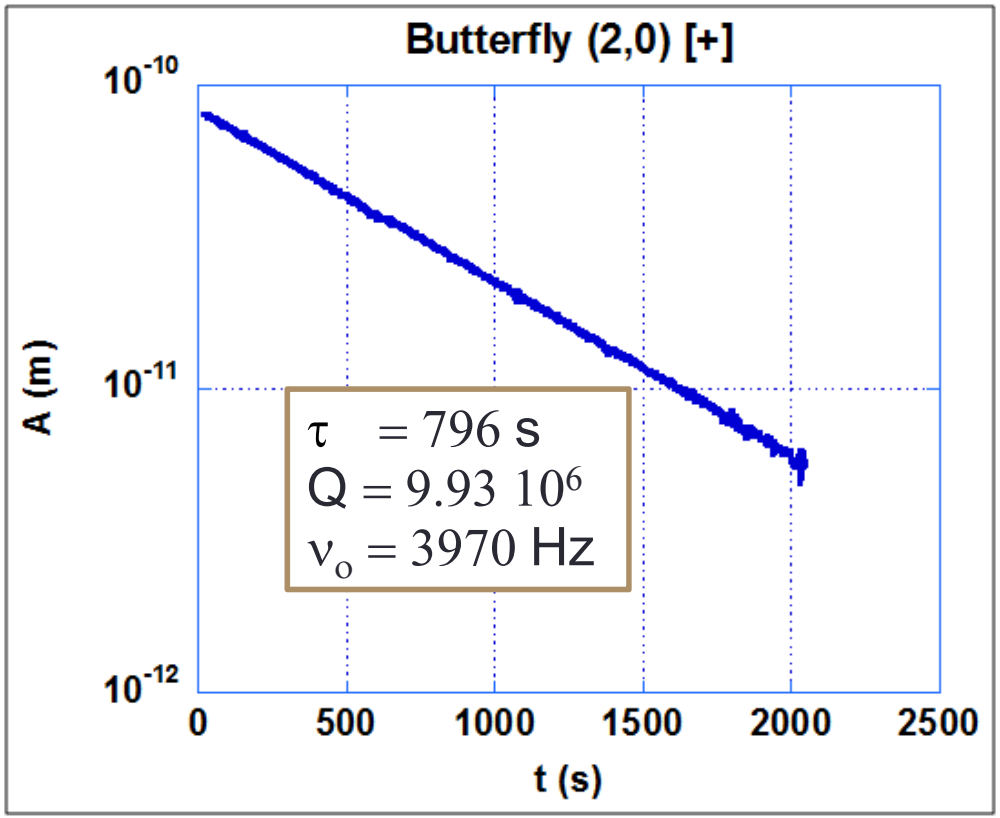
The coefficient of Calibration is $2 \cdot 10^{-8}$ m/V.

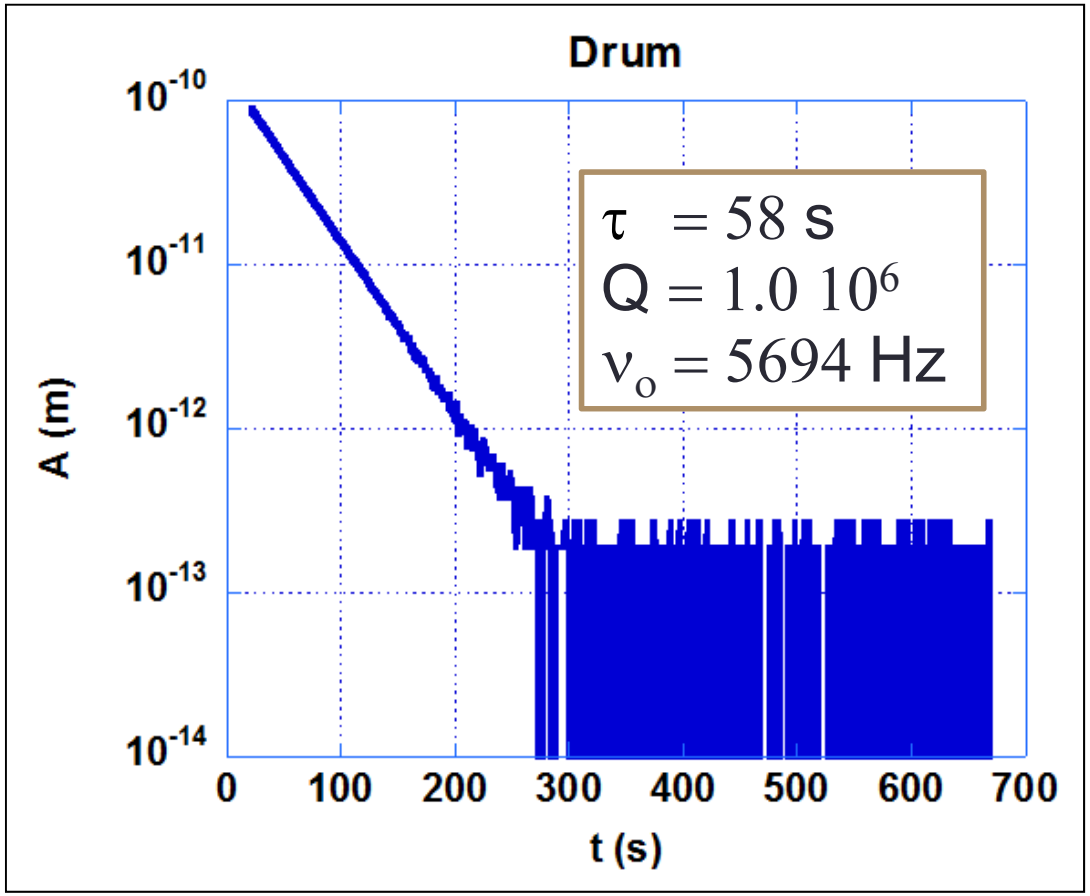
Results on Virgo+ mirrors

Ring-down measurements:mirror resonant modes are excited and the free decay is demodulated at ν_o.

$$Y(t) = Ae^{-\frac{t}{\tau}}$$

$$Q = \pi \nu_0 \tau$$





The excited amplitudes are much higher than in Virgo+

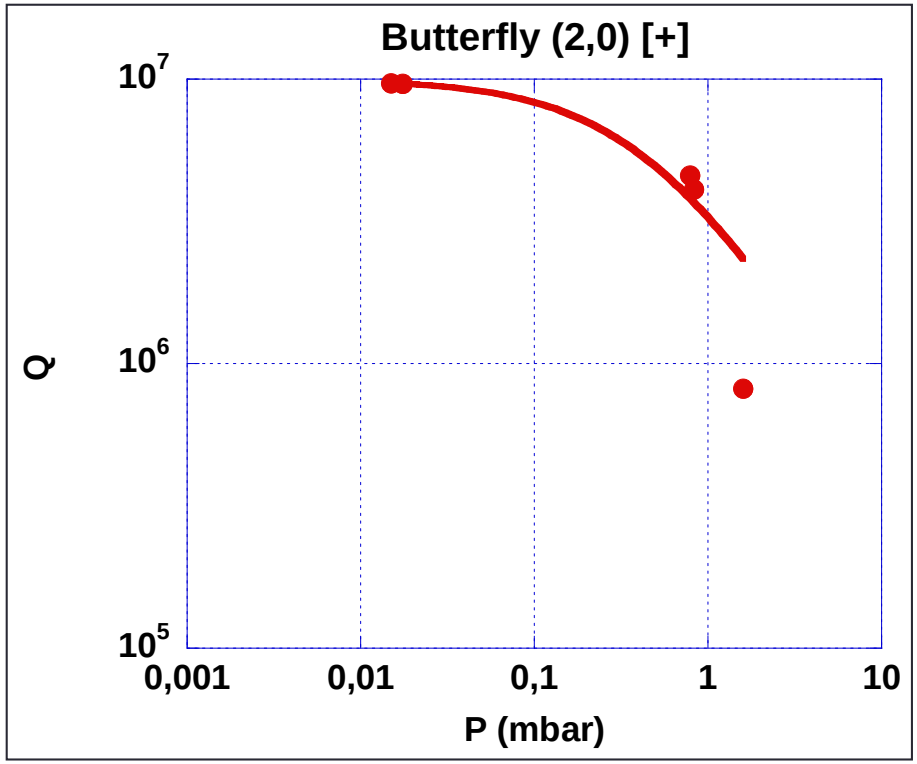
- Virgo+: A_{max} of order of 10^{-12} m
- Rome Lab of order of : 10^{-9}-10^{-10} m

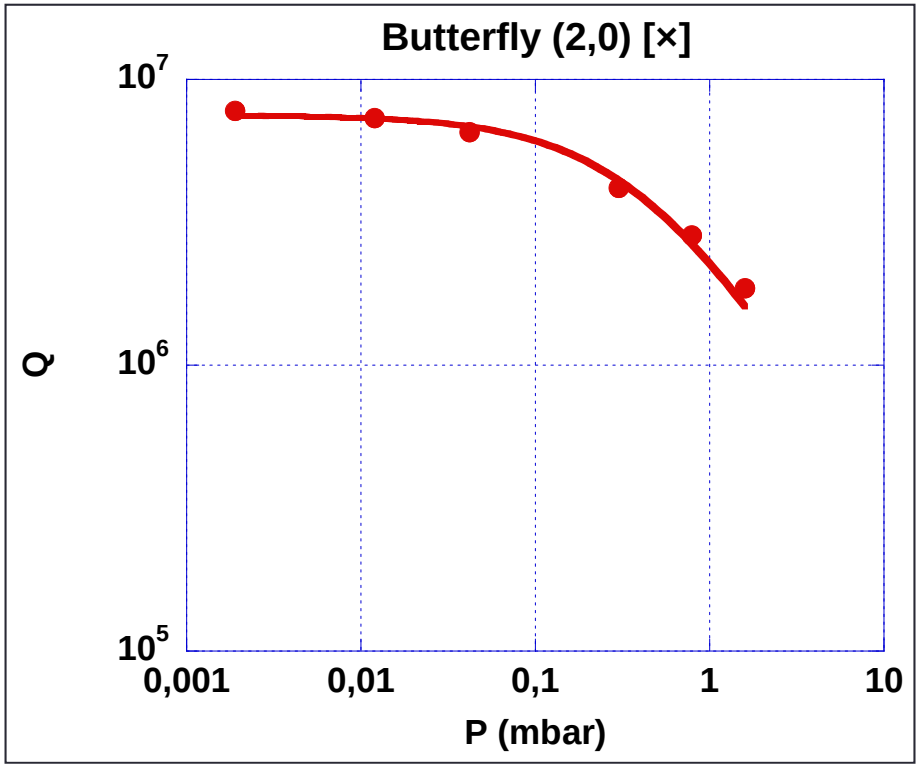
Quality Factor versus Pressure

- Vibration damper was added on the pumping chain so that the pumps can be kept turned on while measuring the Q;

- The viscous damping effect due to the residual molecules of gas sets a limit to the quality factors of mirror internal modes.

$$Q_{tot} = \left(\frac{1}{Q_{intr}} + \frac{1}{Q_{gas}} \right)^{-1} \qquad Q_{gas} \propto \frac{1}{P}$$

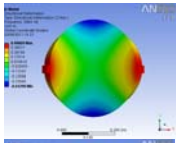
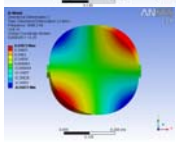
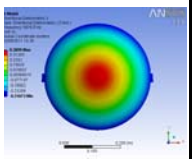
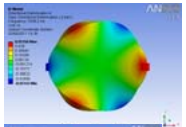
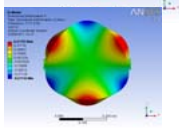




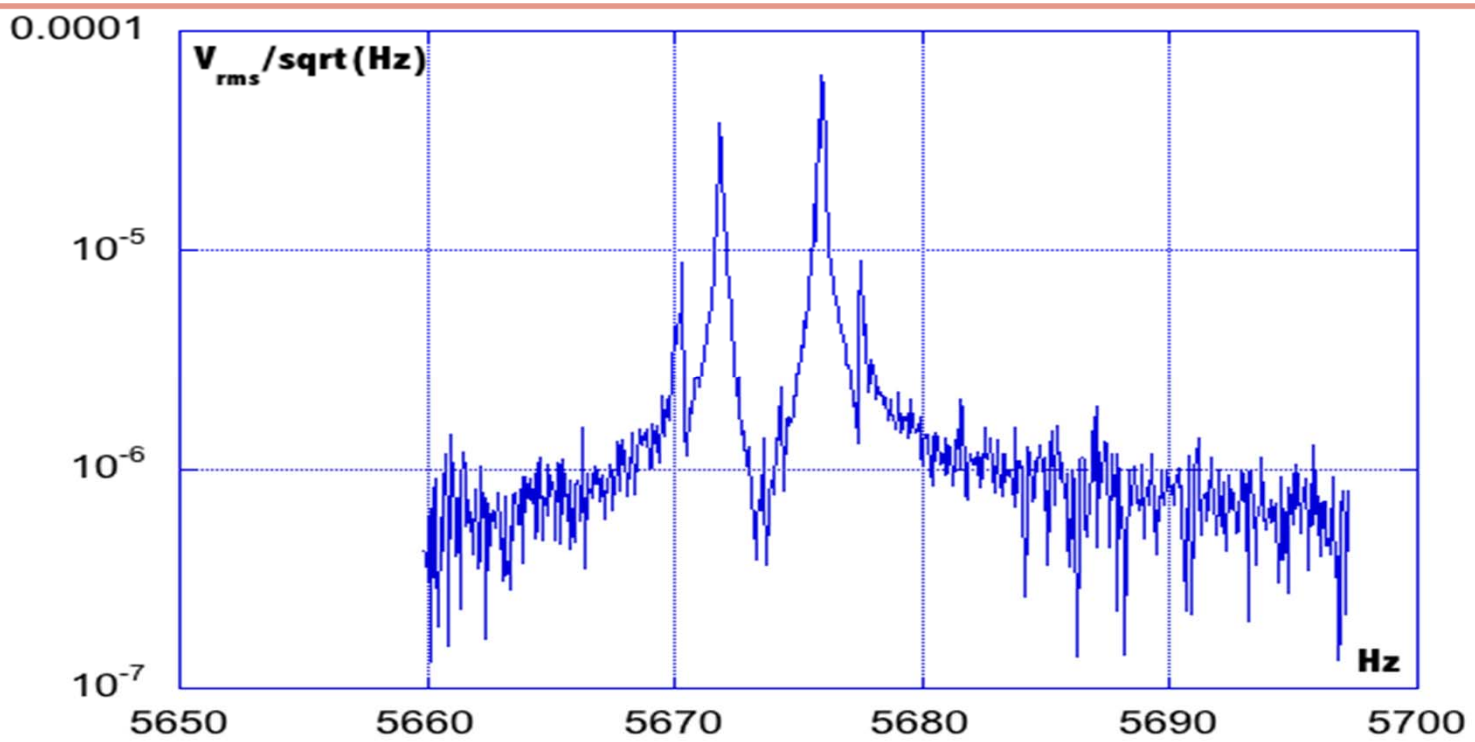
Above 10^{-3} mbar, the gas damping is not negligible.
In order to measure the mirror mechanical losses, it is necessary to work at pressures lower than **10^{-3} mbar**.

North Input Mirror modes

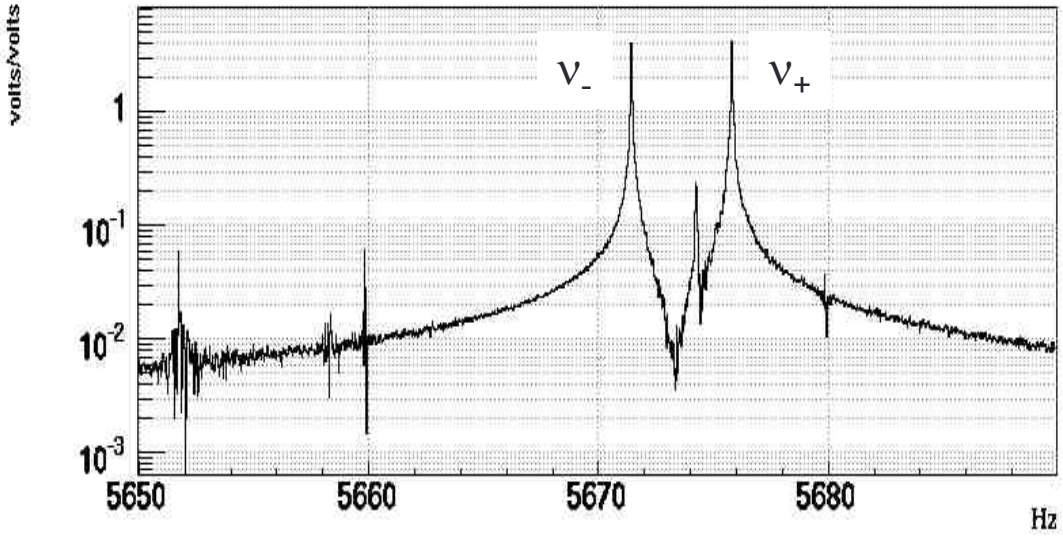
- **The frequency values are in good agreement with the ones measured in Virgo+;**
- **Agreement in the measured Qs.**

	Virgo+		Rome Lab	
	Frequency (Hz)	*Q (10^6)*	*Frequency (Hz)*	*Q (10^6)*
 **Butterfly (2,0) (X)**	3964.30	(0.58 ± 0.1)	3964.12	(3.6 ± 0.4)
 **Butterfly (2,0) (+)**	3996.67	(12.7±0.6)	3997.00	(10.25 ± 0.01)
 **Drum**	5671.6 5676.0	(0.34±0.01) (0.34±0.03)	5672.1 5674.6	(0.343 ± 0.001) (0.261 ± 0.001)
 **Butterfly (3,0) (|)**	7641.5	(0.552±0.03)	7643.56	(0.59 ± 0.01)
 **Butterfly (3,0) (-)**	7710.5	(5.4±0.3)	7710.0	(8.17 ± 0.04)

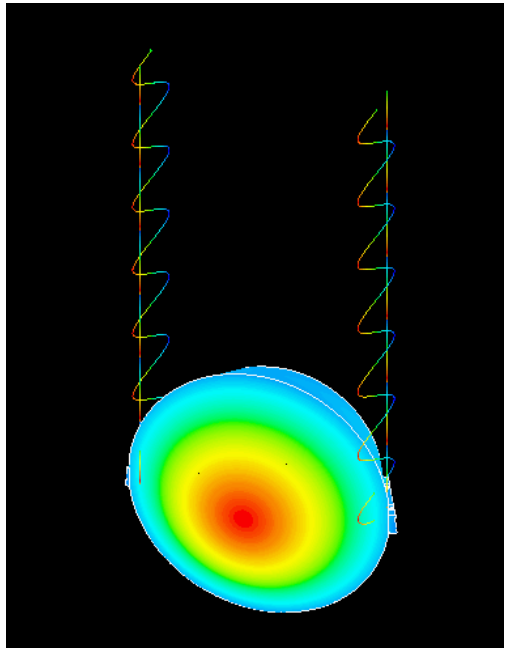
Drum Mode degeneracy with the XIII violin

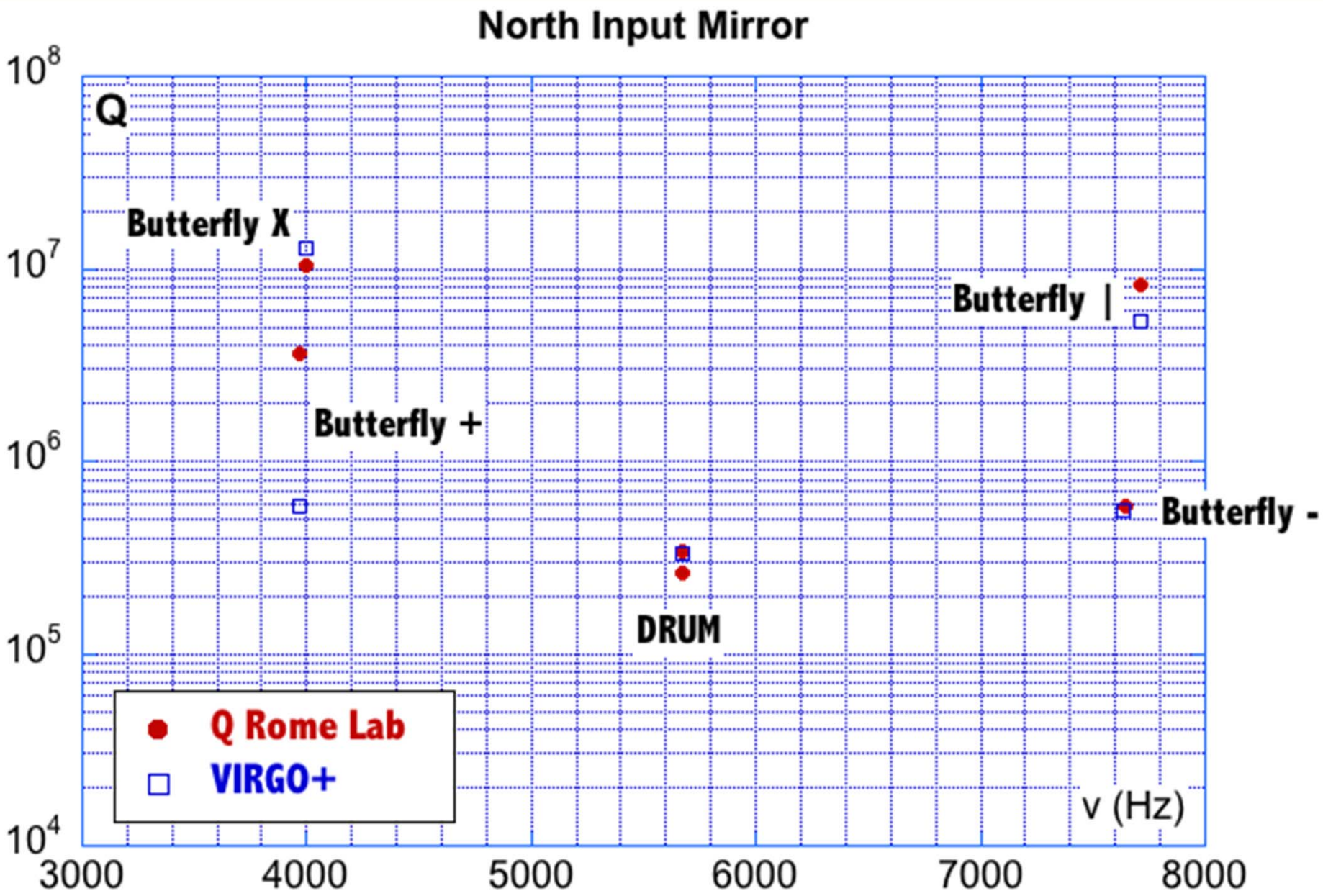


Rome Laboratory



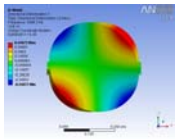
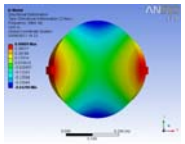
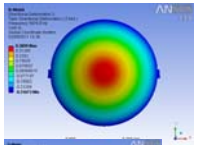
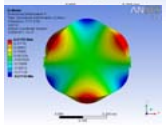
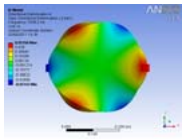
Virgo+

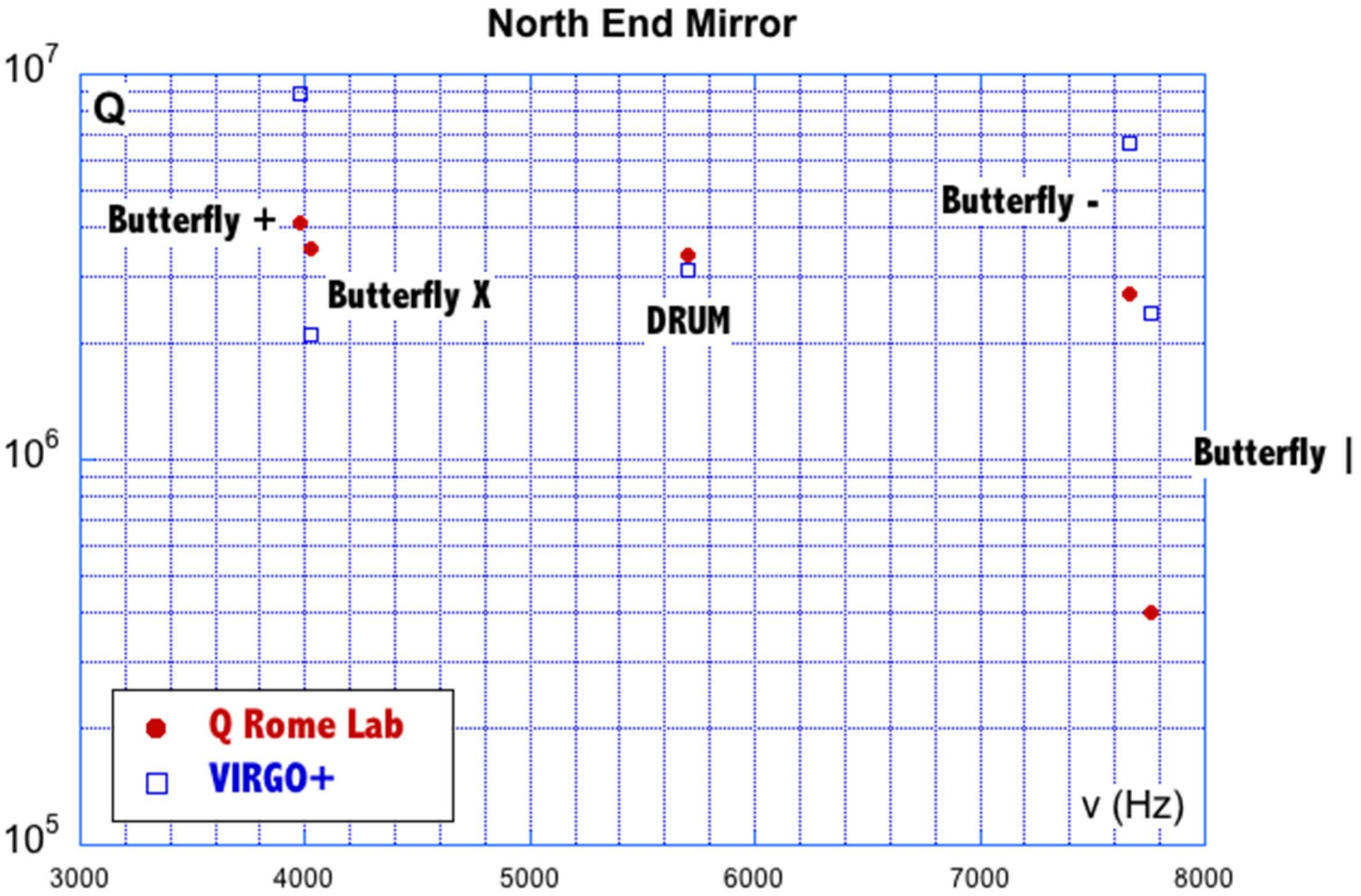



North Input Mirror
Q
Butterfly X
Butterfly +
Butterfly |
Butterfly -
DRUM
Q Rome Lab
VIRGO+
ν (Hz)
10^8
10^7
10^6
10^5
10^4
3000
4000
5000
6000
7000
8000

North End Mirror modes

- One of the anchors detached during the mirror transportation to Virgo Rome Lab;
- The Qs are similar to the ones in Virgo+ with some exceptions;
- The frequencies are the same as in Virgo+;
- *Measurements still in progress;*

	Virgo+		Rome Lab	
	Frequency (Hz)	*Q (10^6)*	*Frequency (Hz)*	*Q (10^6)*
 **Butterfly (2,0) (+)**	3980.0	(8.9 ± 0.3)	3980.5	(4.1 ± 0.2)
 **Butterfly (2,0) (X)**	4025.0	(2.1 ± 0.3)	4026.0	(3.6 ± 0.2)
 **Drum**	5706.9	(3.08 ± 0.05)	5707.0	(3.39±0.06)
 **Butterfly (3,0) (-)**	7667.5	(6.6 ± 0.4)	7667.9	(2.7±0.2)
 **Butterfly (3,0) (|)**	7761.2	(2.36 ± 0.02)	7761.5	(0.40±0.01)

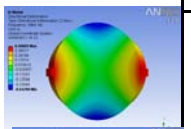
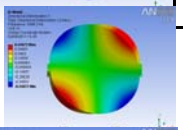
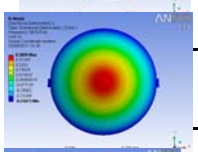
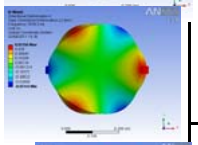
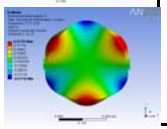

North End Mirror
Q
10^7
10^6
10^5
Butterfly +
Butterfly X
DRUM
Butterfly -
Butterfly |
Q Rome Lab
VIRGO+
ν (Hz)
3000
4000
5000
6000
7000
8000

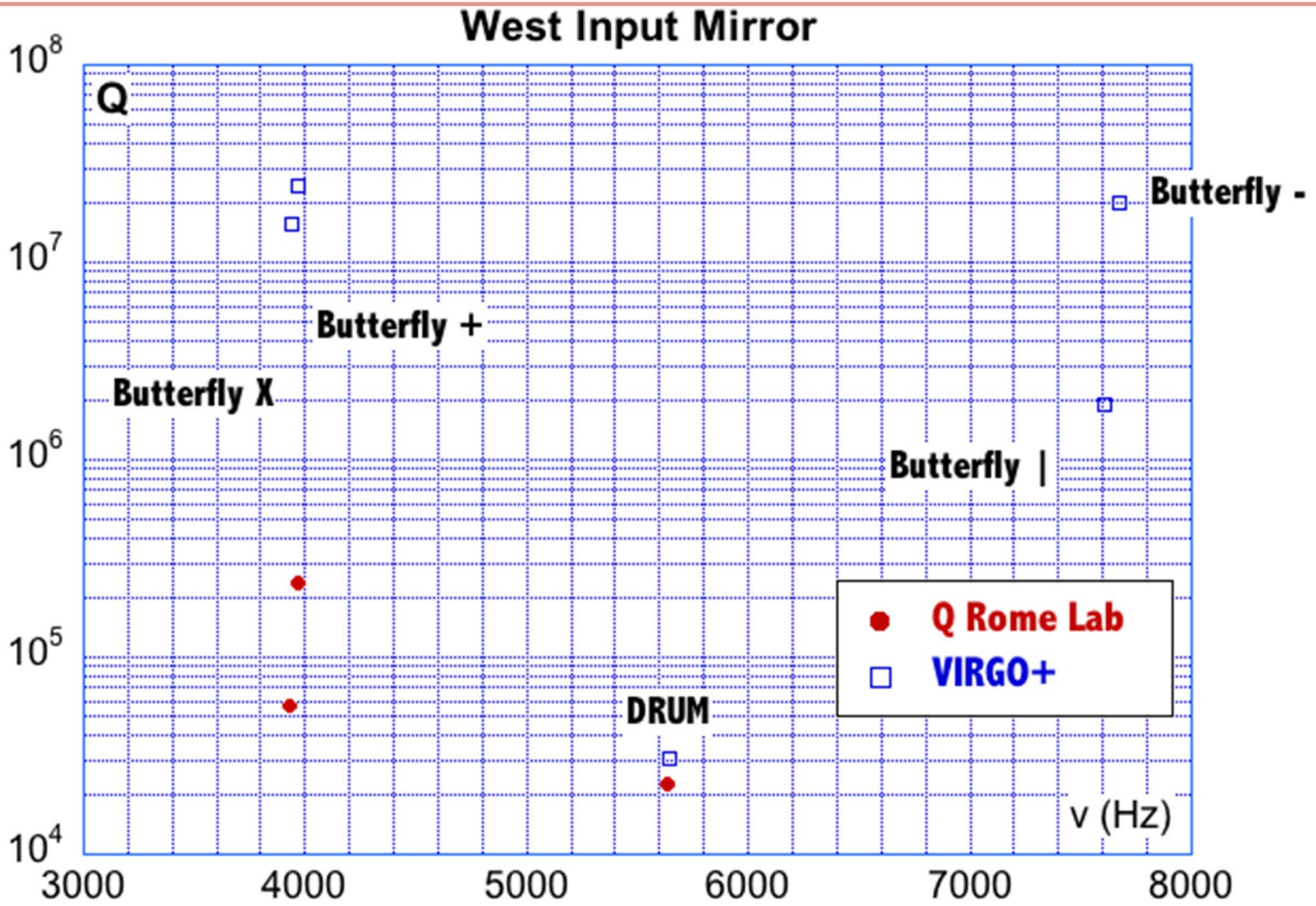
West Input Mirror modes

- The FS wires were broken, so we measured the internal Qs on the mirror hung to steel wires with anchors in aluminum alloy, not glued to the ears;
- As expected the Qs are lower than the ones in Virgo+;
- The frequencies are lower than the ones in Virgo+,

this is also an effect of the loose anchors;

- This measurement was useful to understand the effect of the detached anchors;

	Virgo+		Rome Lab	
	Frequency (Hz)	*Q (10^6)*	*Frequency (Hz)*	*Q (10^6)*
 **Butterfly (2,0) (X)**	3939.5	(16.0 ± 0.4)	3929	(0.057±0.010)
 **Butterfly (2,0) (+)**	3971.5	(24.5 ± 0.4)	3971	(0.238±0.070)
 **Drum**	5642.0	(0.030 ± 0.003)	5632	(0.023±0.01)
 **Butterfly (3,0) (|)**	7605	(1.9 ± 0.1)	-	-
 **Butterfly (3,0) (-)**	7673	(24.6 ± 1)	7677	-


West Input Mirror
Q
Butterfly -
Butterfly +
Butterfly X
Butterfly |
DRUM
Q Rome Lab
VIRGO+
ν (Hz)
10^8
10^7
10^6
10^5
10^4
3000
4000
5000
6000
7000
8000

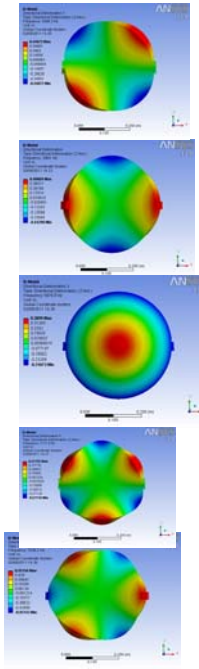
Comments on the WI mirrors measurements

- The dummy anchors are not attached to the ears so recoil is present with several effects:
  - changing the frequencies (decrease in average);
  - decreasing ALL the Qs because of the friction effect;
  - in particular the greater is the anchors recoils the higher is the effect on the Q's, so some modes are more affected than others;
  - Butterfly X
    - frequency 3939 Hz →3929 Hz
    - Q 16 milions → 60000
  - Butterfly +
    - frequency 3971 Hz → 3971 Hz
    - Q 25 milions → 238000
  - Drum
    - frequency 5642 Hz → 5632 Hz
    - Q 30000 → 20000

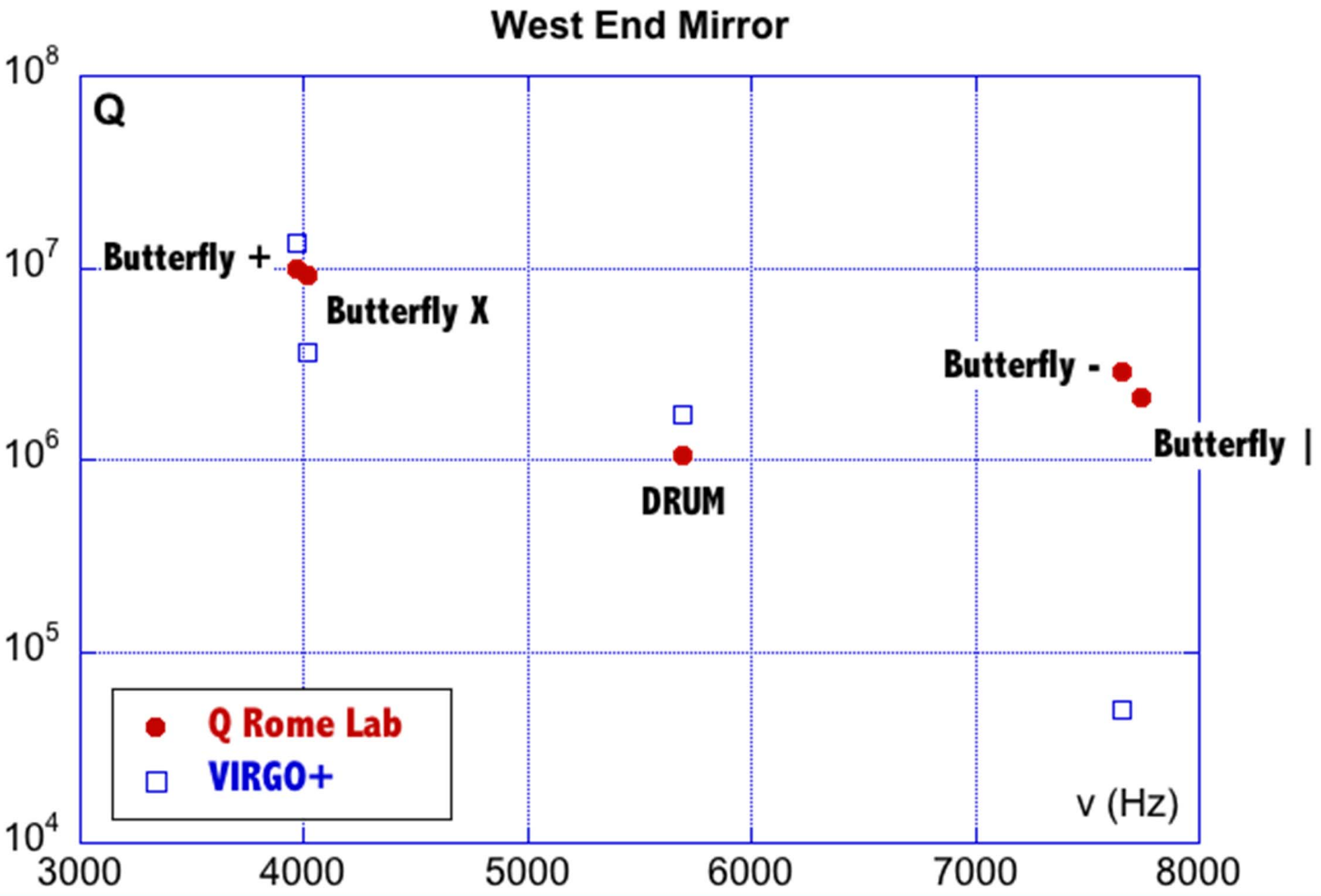
The loose anchors lower both the modes frequencies and Qs

West End Mirror modes

- The frequency values are in agreement with the ones measured in Virgo+
- The Qs agree with the measurements in Virgo+ with some differences.



	Virgo+		Rome Lab	
	Frequency (Hz)	*Q (10^6)*	*Frequency (Hz)*	*Q (10^6)*
Butterfly (2,0) (+)	3969.00	(13.5 ± 0.1)	3969.00	(9.9 ± 0.1)
Butterfly (2,0) (X)	4015.00	(4.0 ± 0.2)	4014.00	(8.2 ± 0.4)
Drum	5695.00	(1.7 ± 0.2)	5693.00	(1.1 ± 0.1)
Butterfly (3,0) (-)	7654.00	(0.05 ± 0.005)	7653.00	(2.9 ± 0.2)
Butterfly (3,0) (|)	7746.00	-	7745.00	(2.09 ± 0.04)


West End Mirror
Q
10^8
10^7
10^6
10^5
10^4
Butterfly +
Butterfly X
DRUM
Butterfly -
Butterfly |
Q Rome Lab
VIRGO+
ν (Hz)
3000
4000
5000
6000
7000
8000

Conclusions

- In spite of the different amplitude regions and the different boundary condition on the marionette, the measured Q are at the same level of the ones measured in Virgo+;
- The measurements are reproducible;
- The developed interferometer can be a good and reliable sensor for measuring the Q of the mirrors before installing them in AdVirgo;