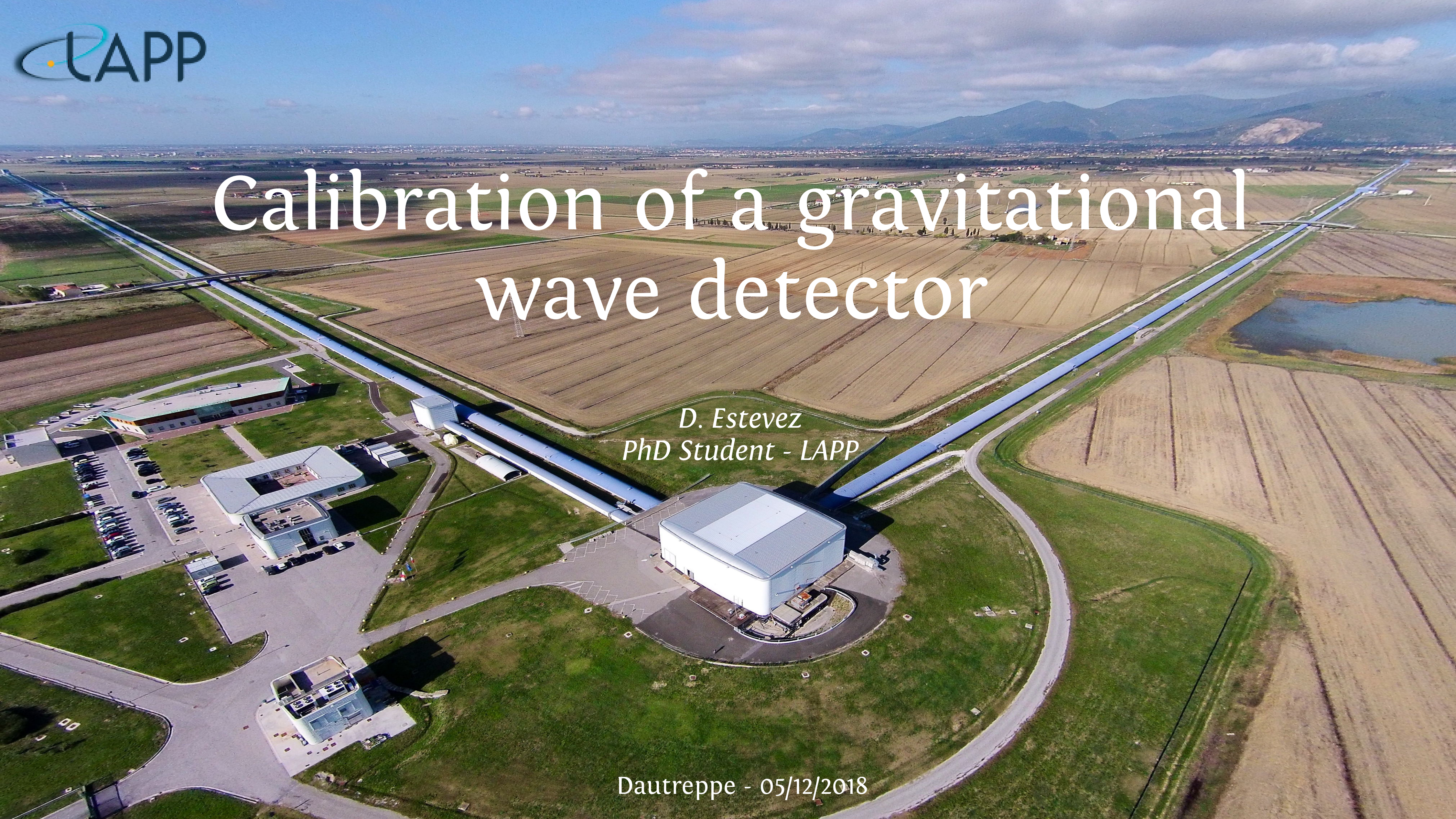


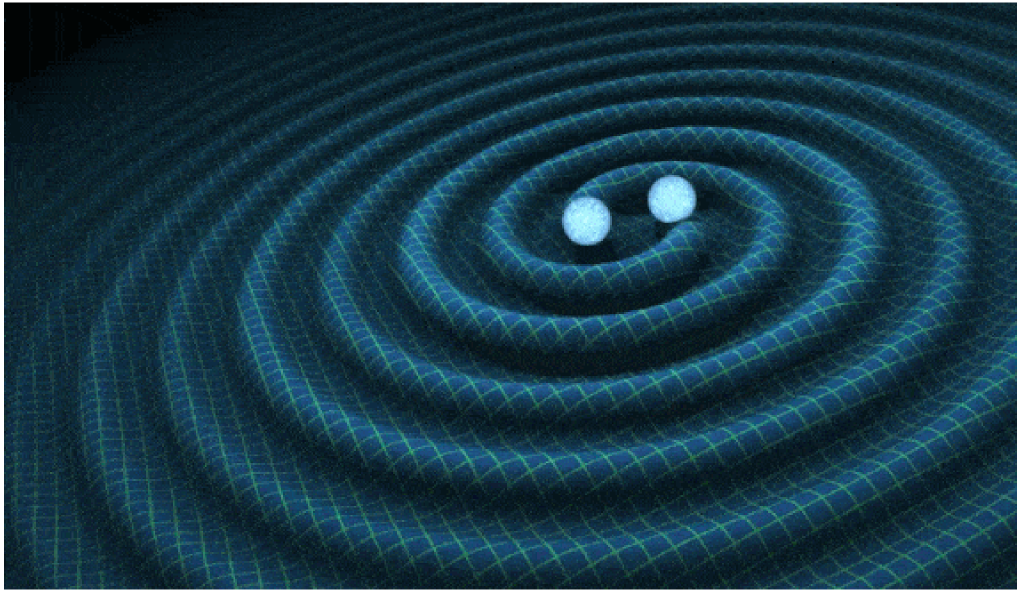
Calibration of a gravitational wave detector

D. Estevez
PhD Student - LAPP

Dautreppe - 05/12/2018

Effect of gravitational waves

Gravitational waves

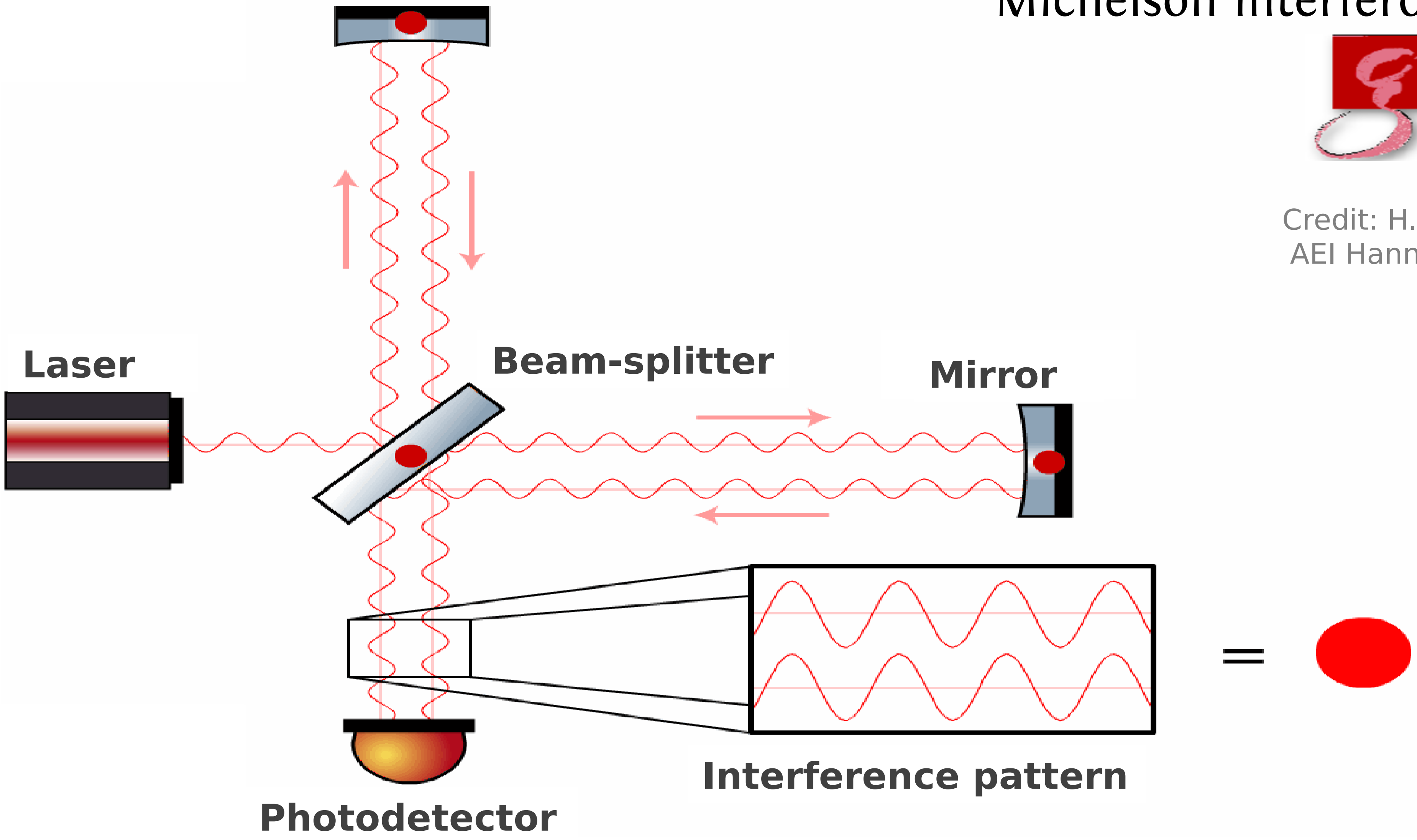


Perturbations of the metric : h(t)

Ponctual test masses

Stretch and squeeze spacetime between particles with respect to the wave polarization

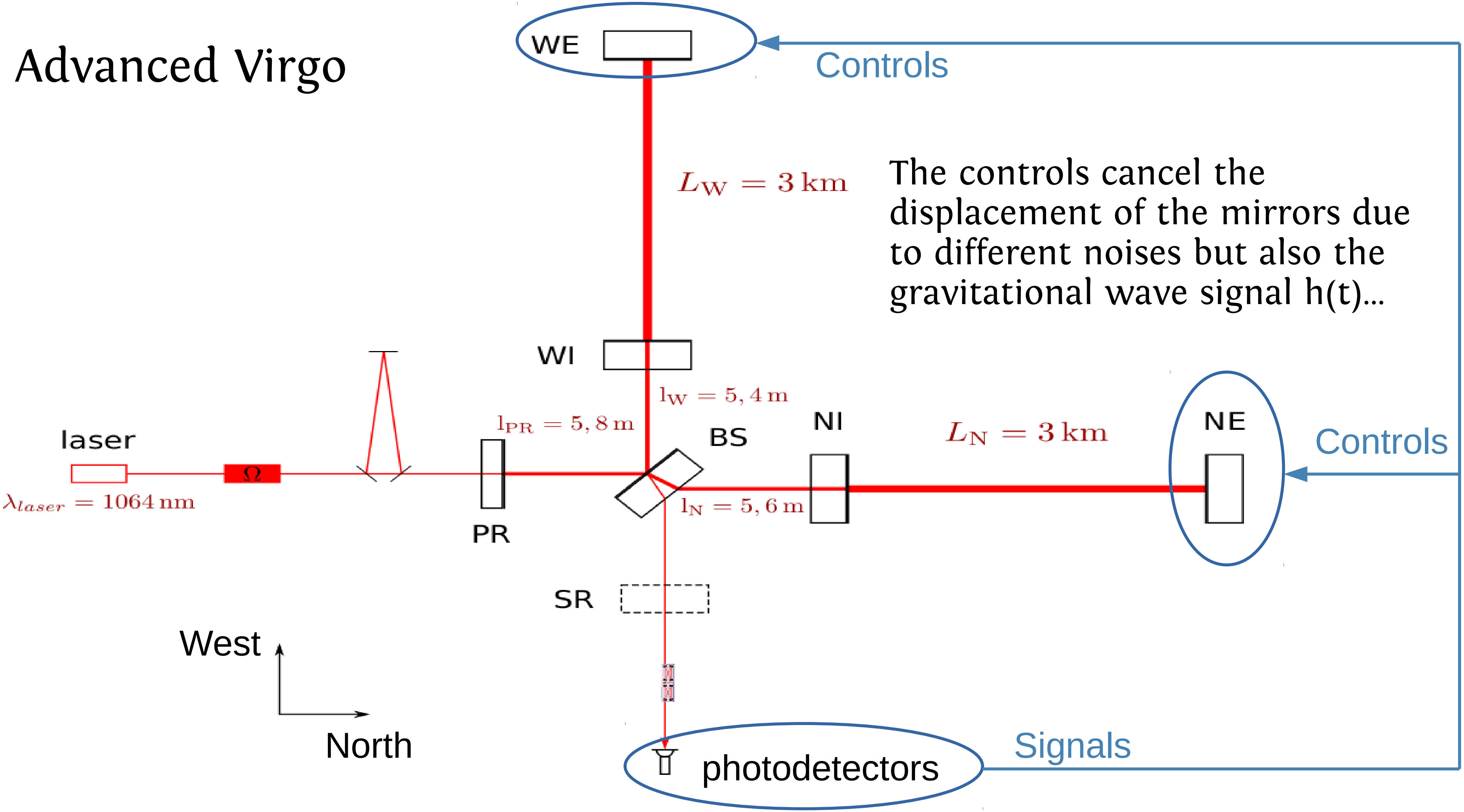
Michelson interferometer



Credit: H. Lück
AEI Hannover

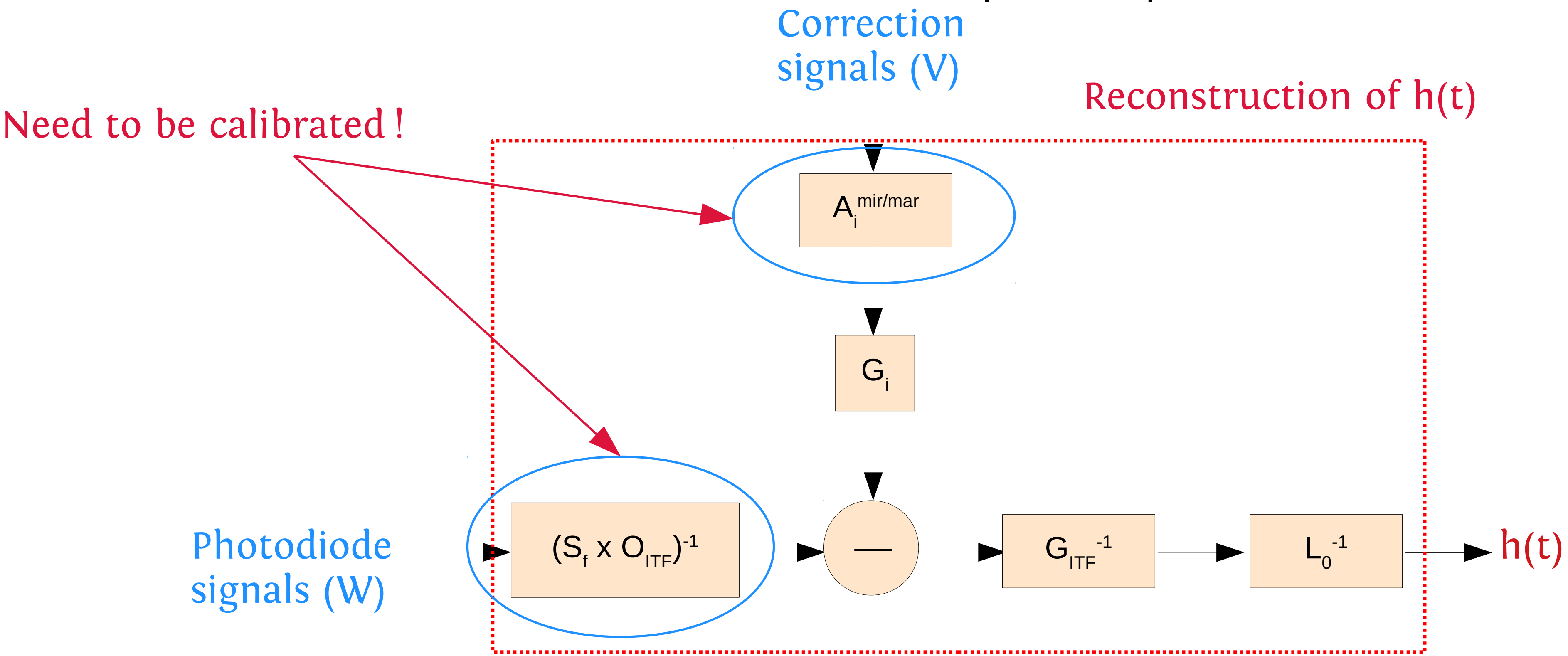
Advanced Virgo

The controls cancel the displacement of the mirrors due to different noises but also the gravitational wave signal h(t)…



Reconstruction of h(t)

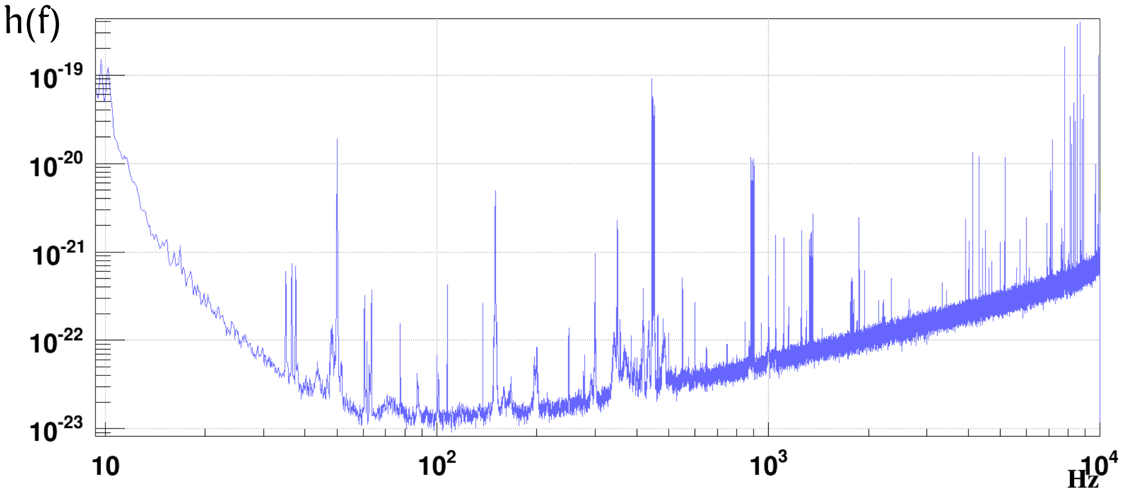
- Subtract control signals from dark fringe signal
- Correct for the interferometer optical response



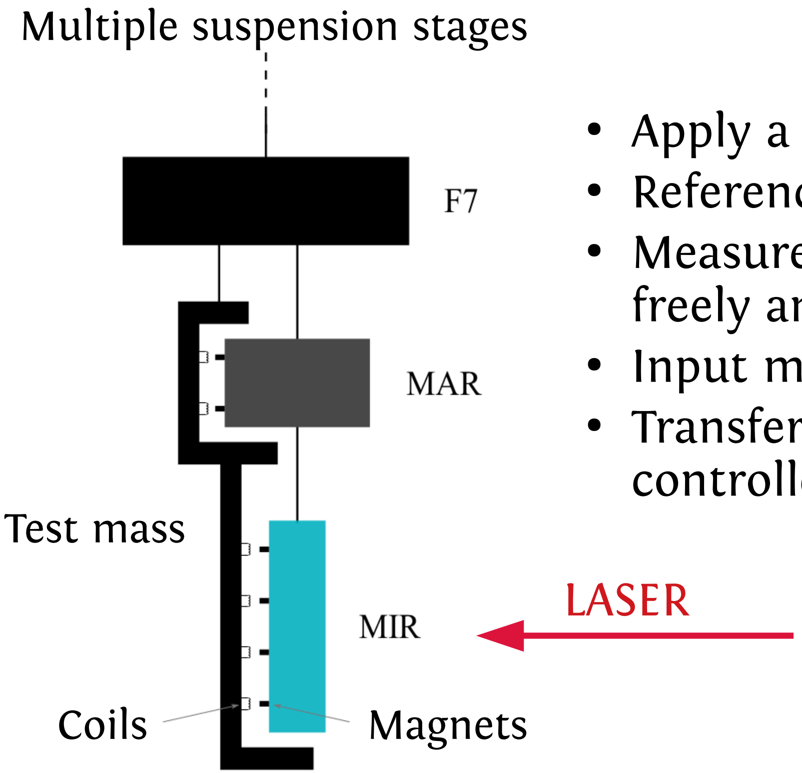
What is calibration ?

- Need to understand the detector response when an external signal changes the **differential arm length** $\Delta L = L_N - L_W$
  and extract the **external perturbation** $h_{ext} = \frac{\Delta L}{L_0}, L_0 = 3\,km$
- Measure the detector sensitivity h(f)
- Reconstruct in real time the evolution of the amplitude signal h(t)
- Simulate gravitational wave signals by moving the mirrors

Advanced Virgo current sensitivity



Electromagnetic actuators

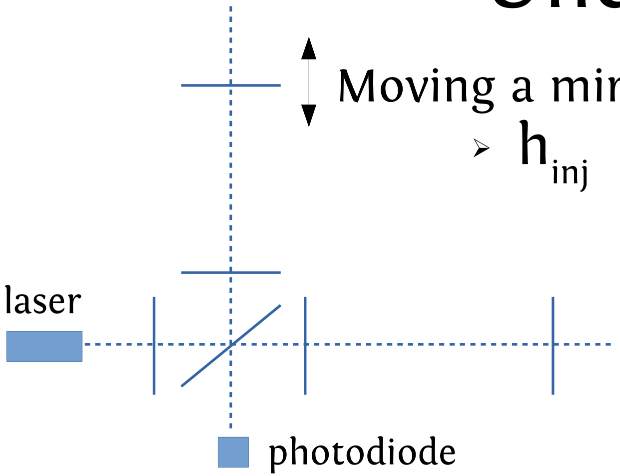


- Apply a voltage on the coils (V) ---› Moves the mirrors (m)
- Reference is the wavelength of the ITF : 1064nm
- Measure the optical signal when the input mirrors move freely and reconstruct ΔL_{free}
- Input mirrors and beamsplitter are then calibrated
- Transfer procedures to calibrate the other mirrors when controlled

During the observation run O2
(August 2017 for Virgo)
Systematic uncertainties were:

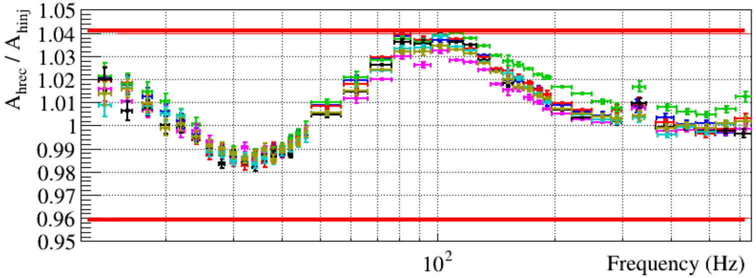
- 1,1 % in amplitude (m/V)
- 5 mrad on phase

Uncertainty on h(t)



Moving a mirror
- h_{inj}

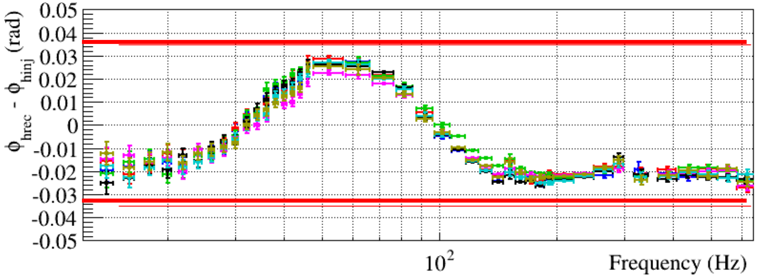
Reconstruction of this displacement using the whole interferometer
- h_{rec}
- Compute h_{rec} / h_{inj}



±4% amplitude

σ_{hrec} = ±5.1% amplitude

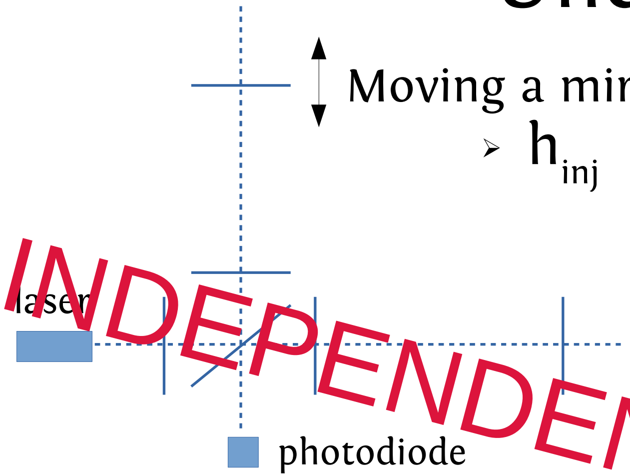
Class.Quant.Grav. 35 (2018) no.20, 205004



±35 mrad phase

σ_{hrec} = ±(40 mrad + 2πfτ) où τ = 20 μs

Uncertainty on h(t)



Moving a mirror

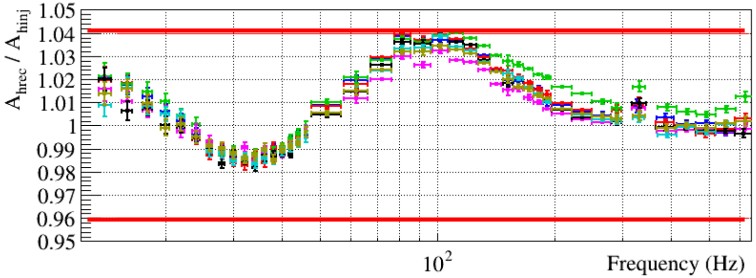
- h_{inj}

Reconstruction of this displacement using the whole interferometer

- h_{rec}

- Compute h_{rec} / h_{inj}

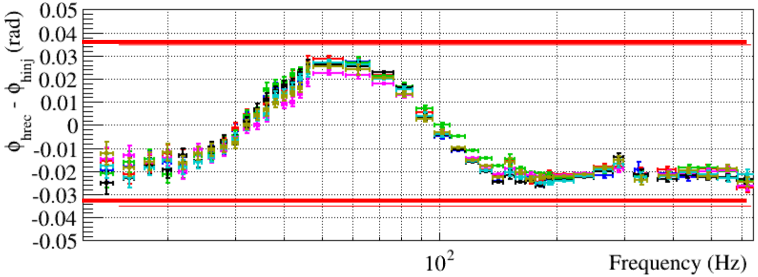
INDEPENDENT METHODS NEEDED



±4% amplitude

σ_{hrec} = ±5.1% amplitude

Class.Quant.Grav. 35 (2018) no.20, 205004



±35 mrad phase

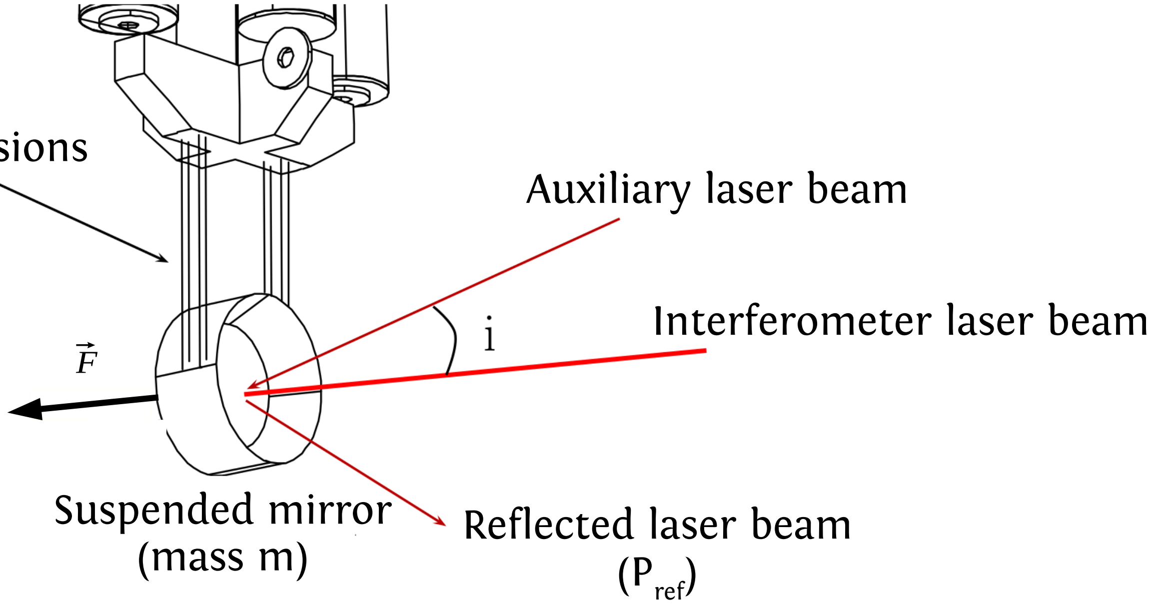
σ_{hrec} = ±(40 mrad + 2πfτ) où τ = 20 µs

Photon calibrator (Pcal)

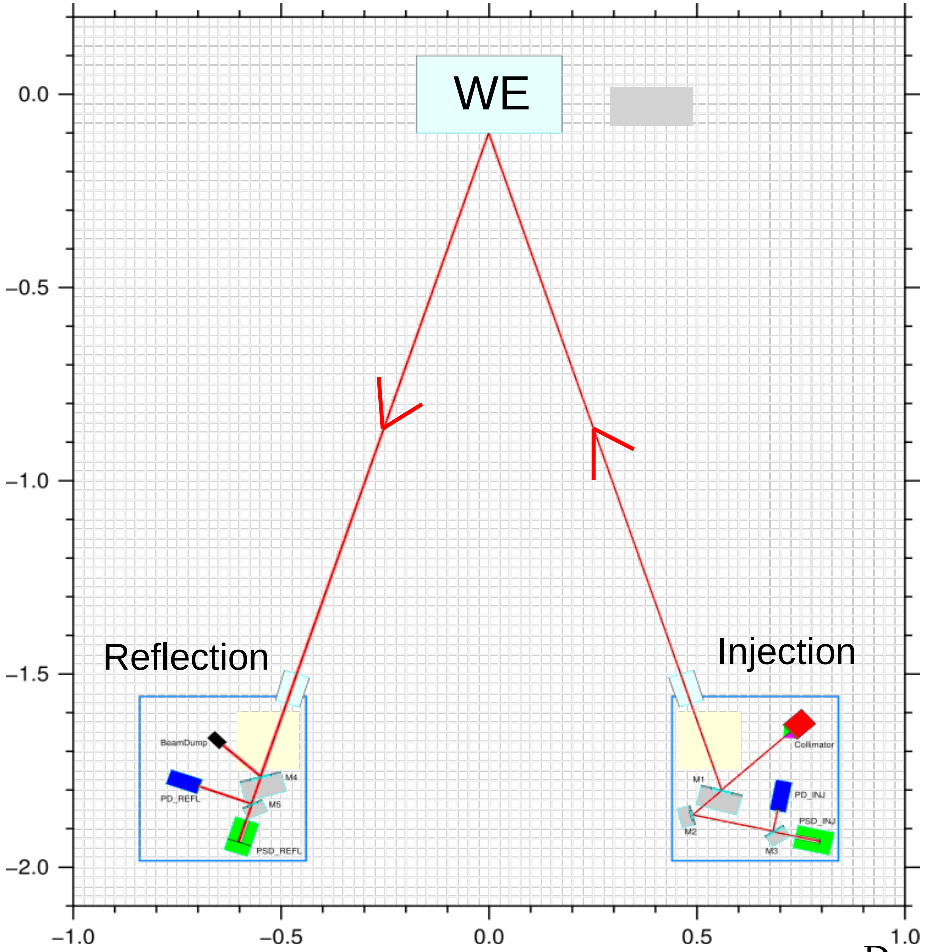
Moving the mirrors by radiation pressure:

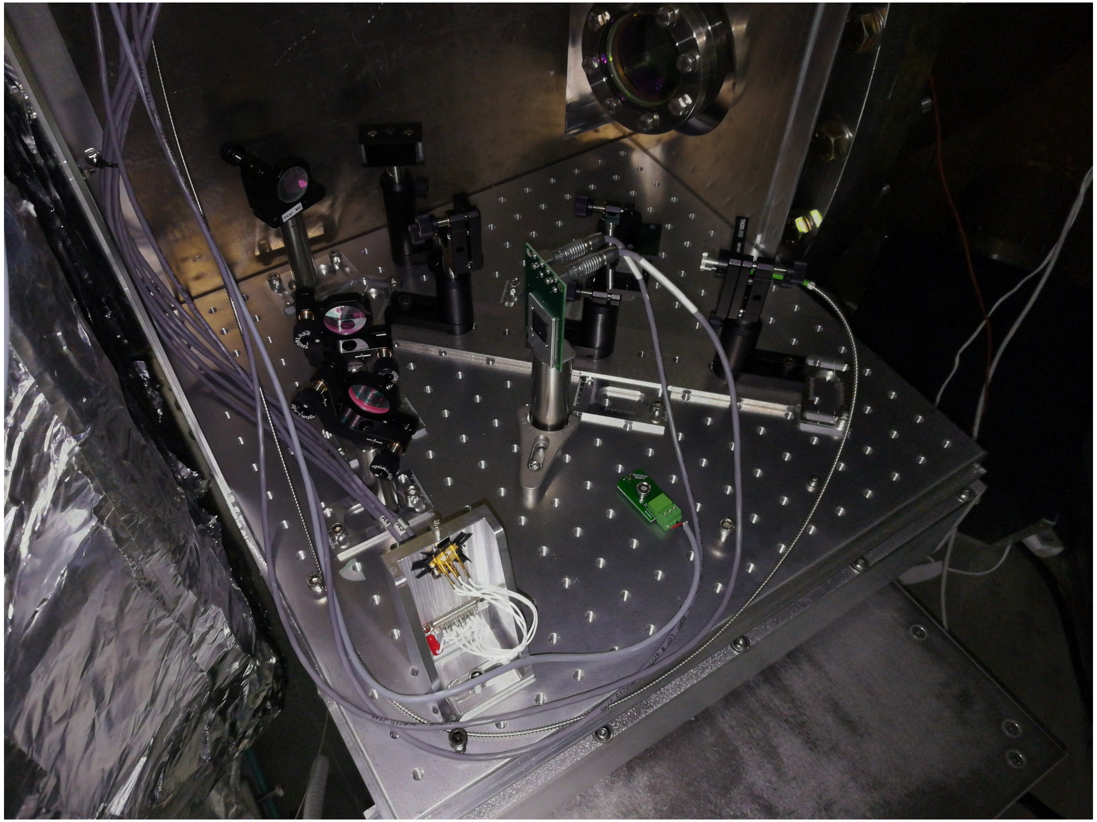
$$F(t) = \frac{2\cos(i)}{c} P_{ref}(t)$$

$$x(t) = -\frac{1}{m} \frac{F(t)}{(2\pi f)^2}$$

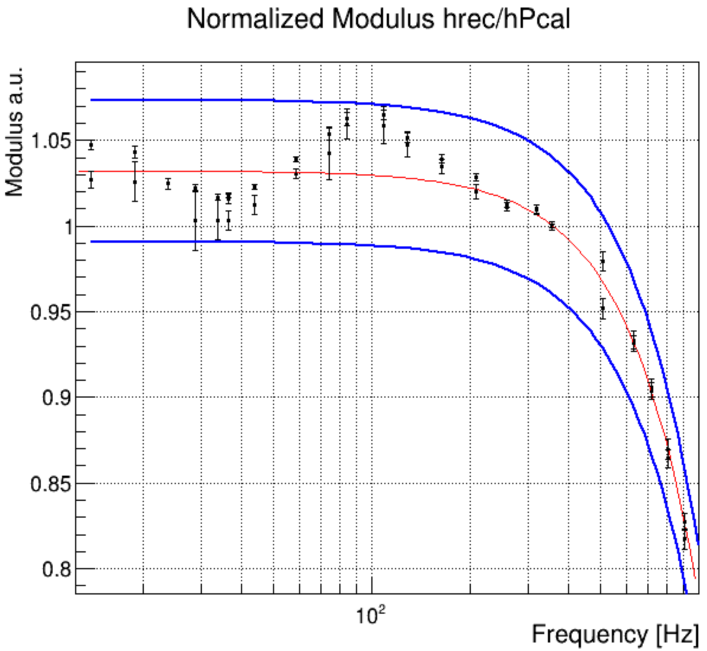


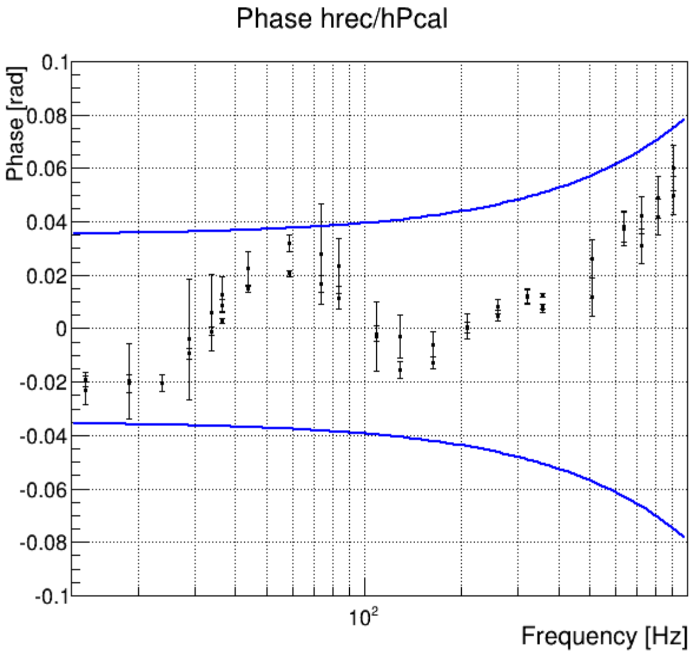
Pcal set-up on Advanced Virgo





Checking h(t) with the Pcal





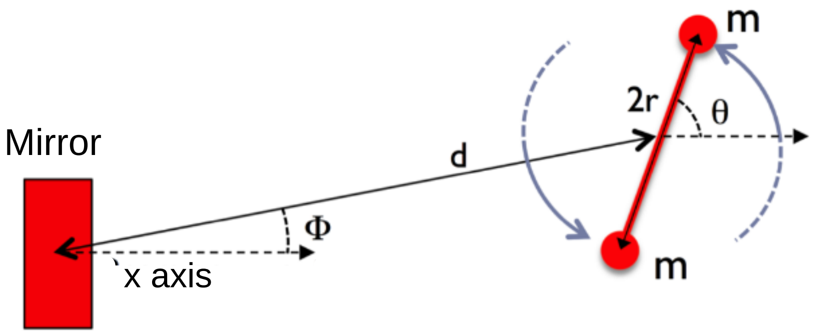
Amplitude : ± 4 %

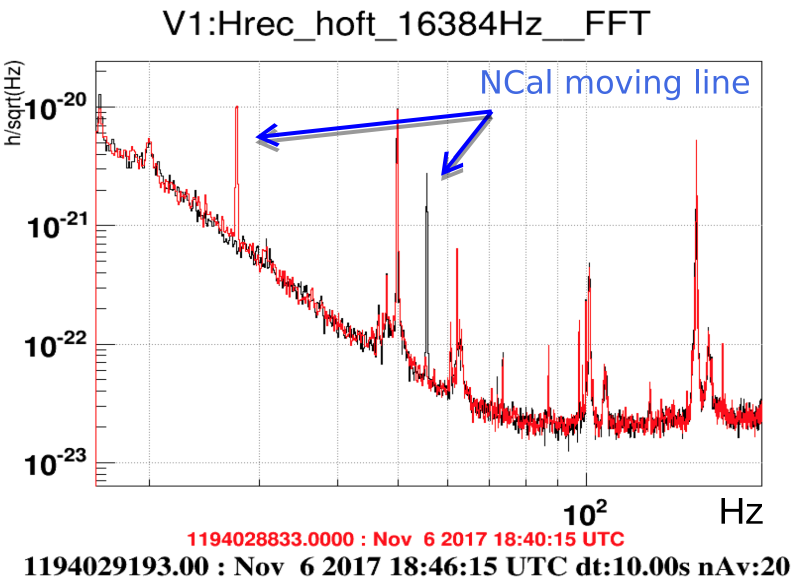
Phase : ± (35 mrad + 2πfτ) with τ = 7 μs

Class.Quant.Grav. 35 (2018) no.20, 205004

- Consistent with the uncertainties given for h(t) reconstruction during the observation run O2 with the electromagnetic actuators

Newtonian calibrator (Ncal)

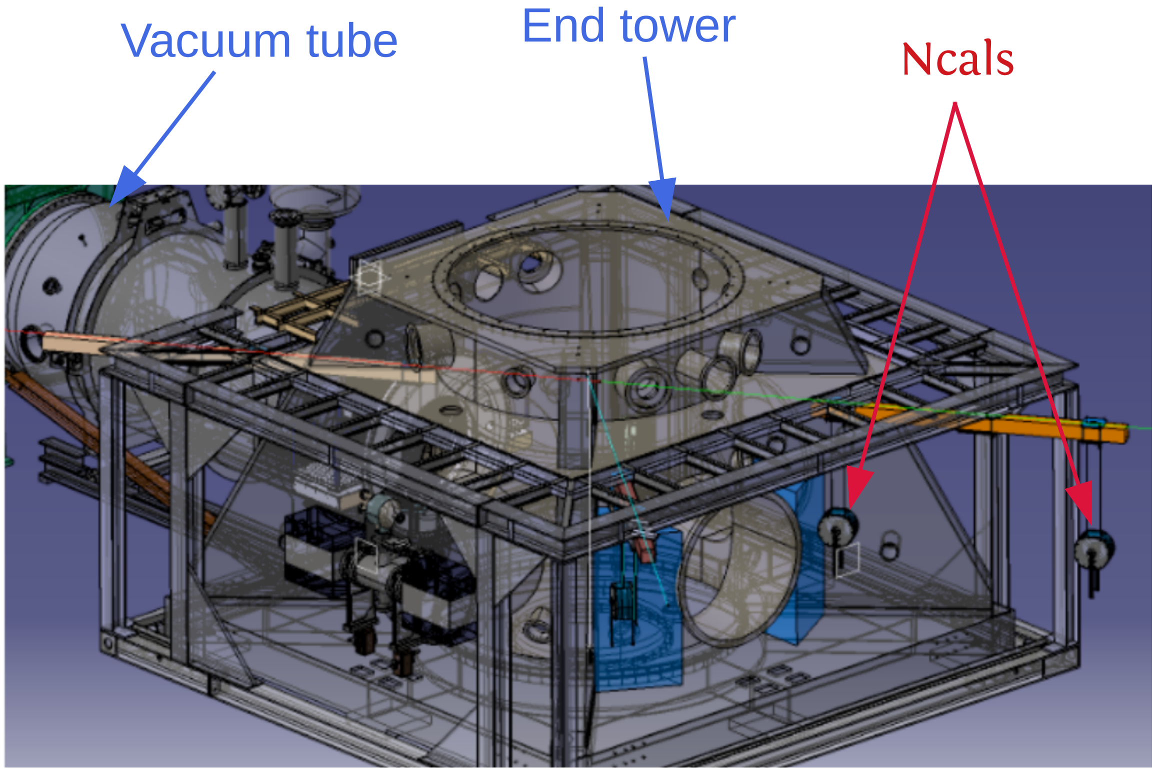


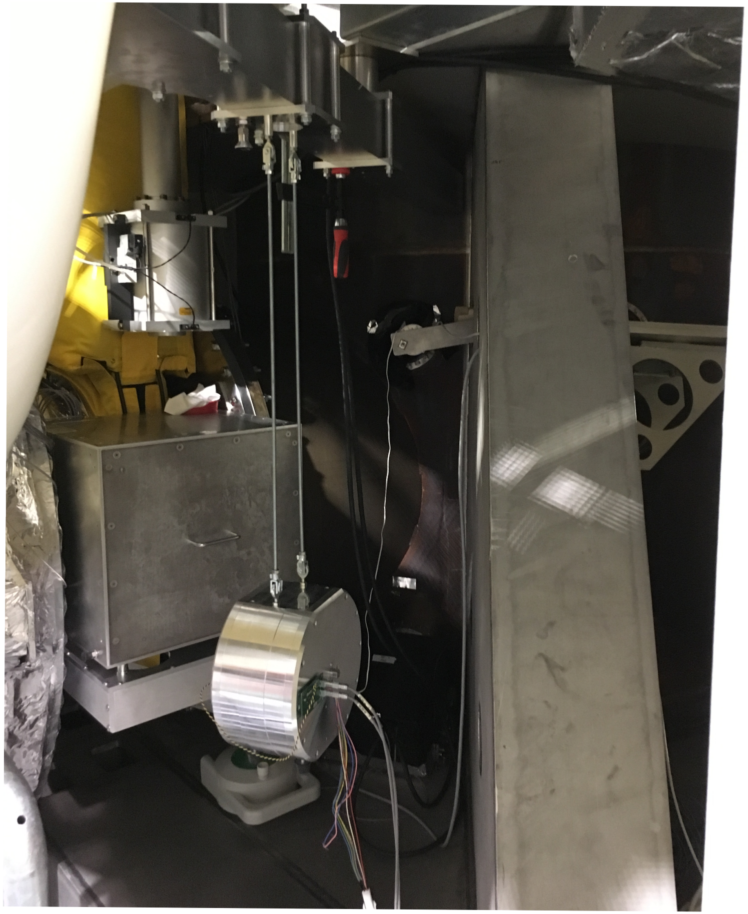


- Rotor made of two masses
- Non-linear Newtonian force generates the signal
- Signal at twice the frequency of the rotor
- $1/d^4$ effect

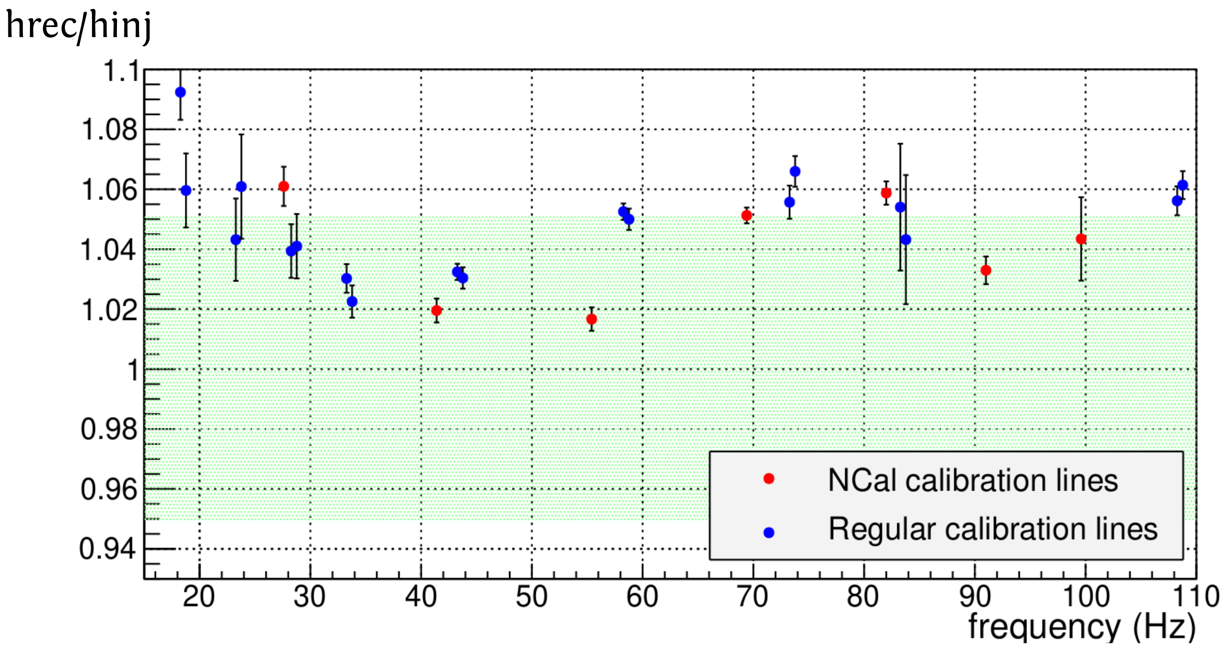
- Still in development
- Promising results for future calibration

Ncal set-up on Advanced Virgo





Checking h(t) with the Ncal



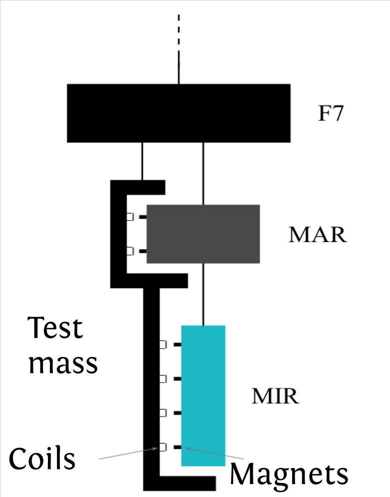
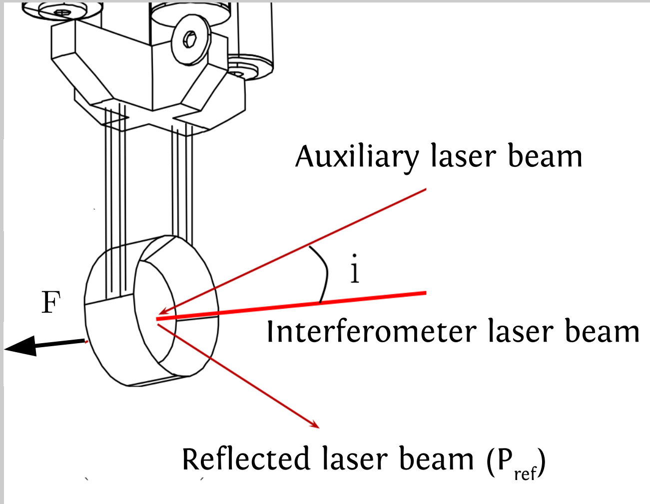
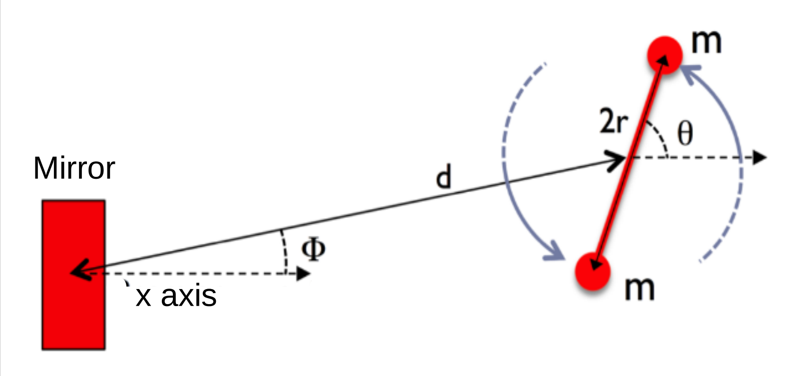
Class.Quant.Grav. 35 (2018) no.23, 235009

→ Measured/expected NCal lines amplitude are consistent with the coils injections measurements.

→ Better control of the systematic uncertainties (mass, distance...)

→ Absolute calibration below 1% seems possible.

Summary of calibration

EM	Pcal	Ncal
		

EM

- Calibration of MIR/MAR actuators
- Check hrec up to 1kHz but with the same model

Pcal

- Calibration of MIR/MAR actuators
- Independent check hrec from a few Hz to a few kHz
- Systematic uncertainties not easy to control (power...)

Ncal

- Calibration of MIR/MAR actuators
- Independent check hrec up to a few hundreds of Hz
- Better control of systematic uncertainties (mass, distance...)

Thank you !

Any questions ?