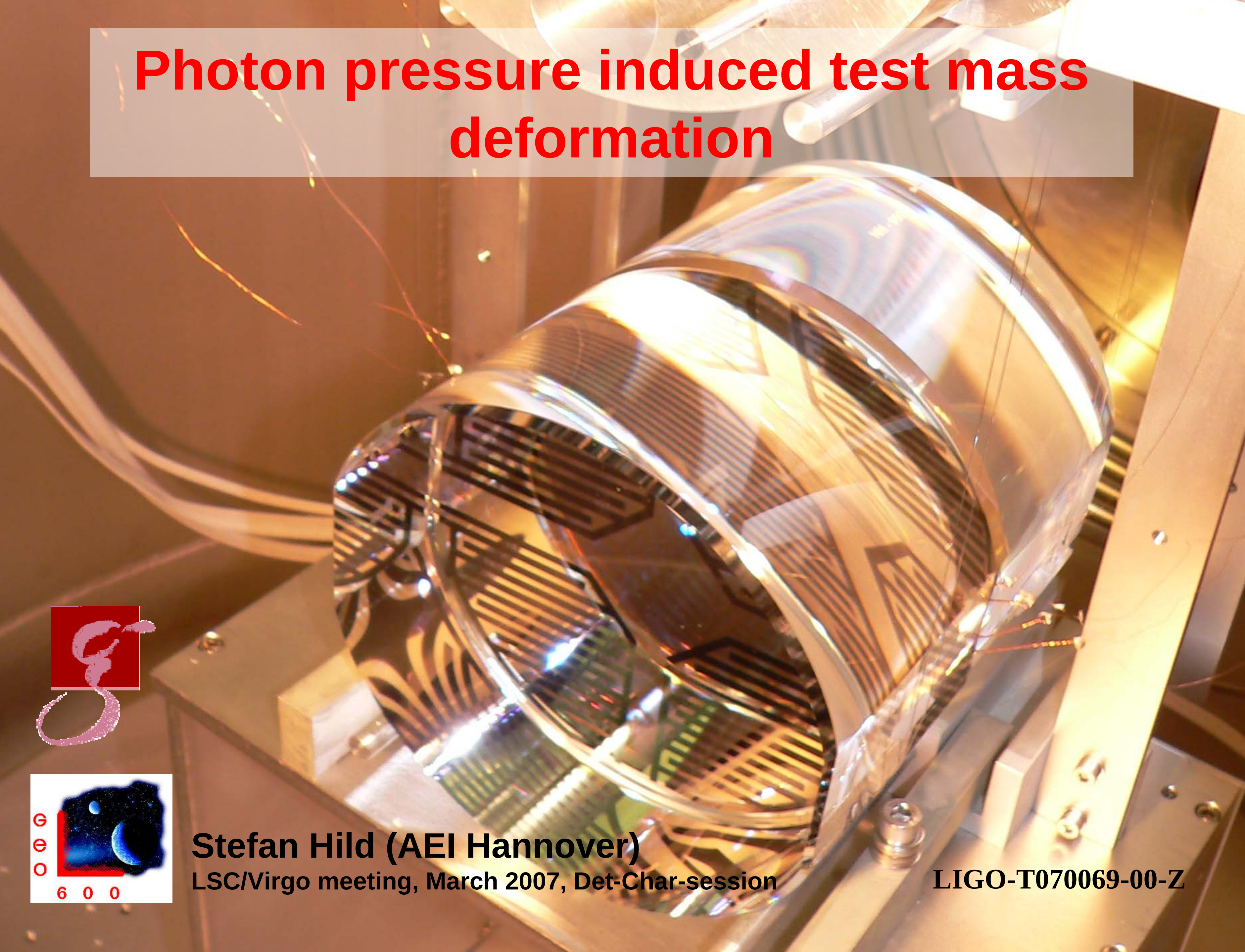
Photon pressure induced test mass deformation



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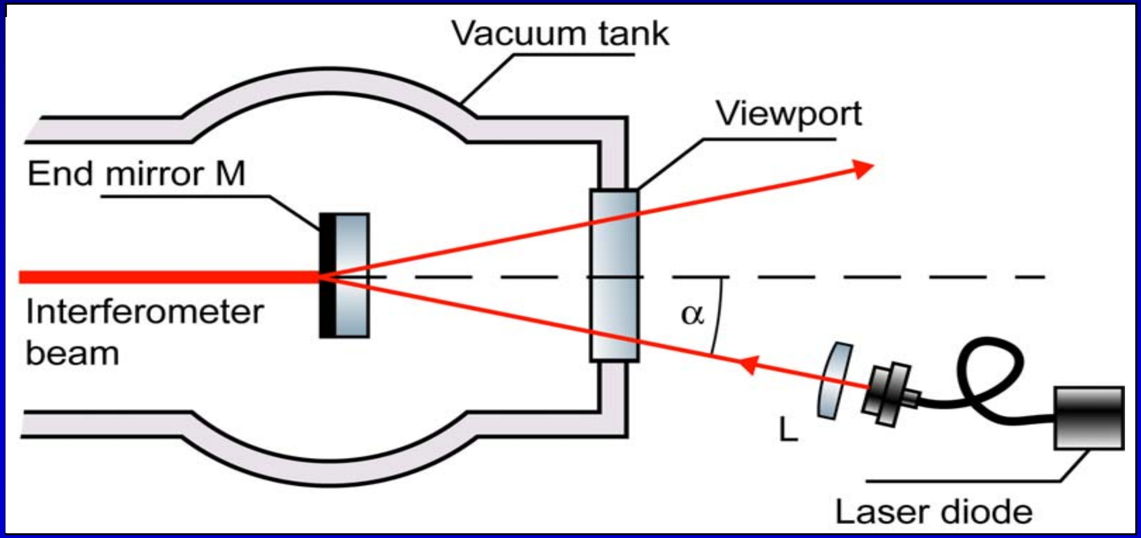
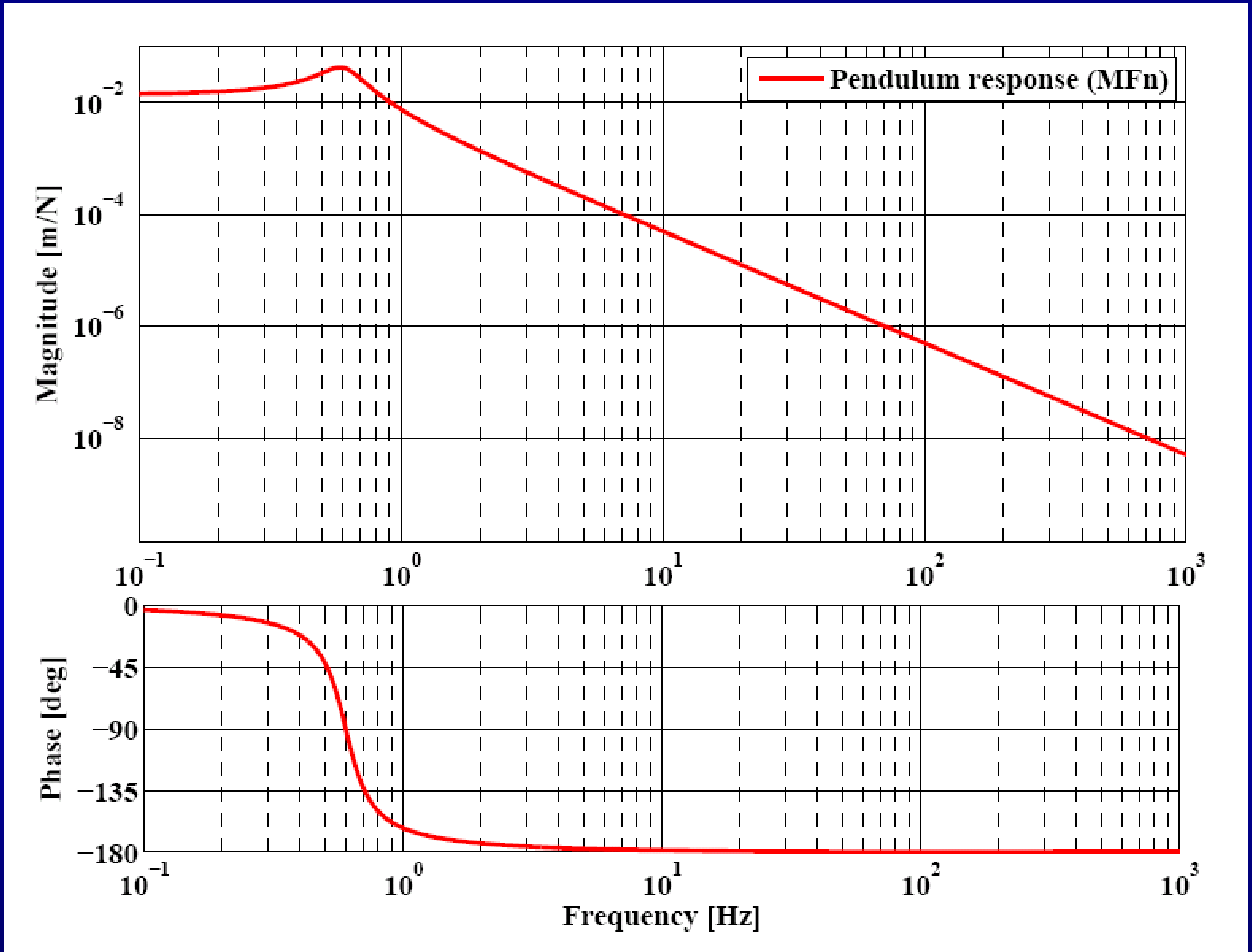
The GEO setup

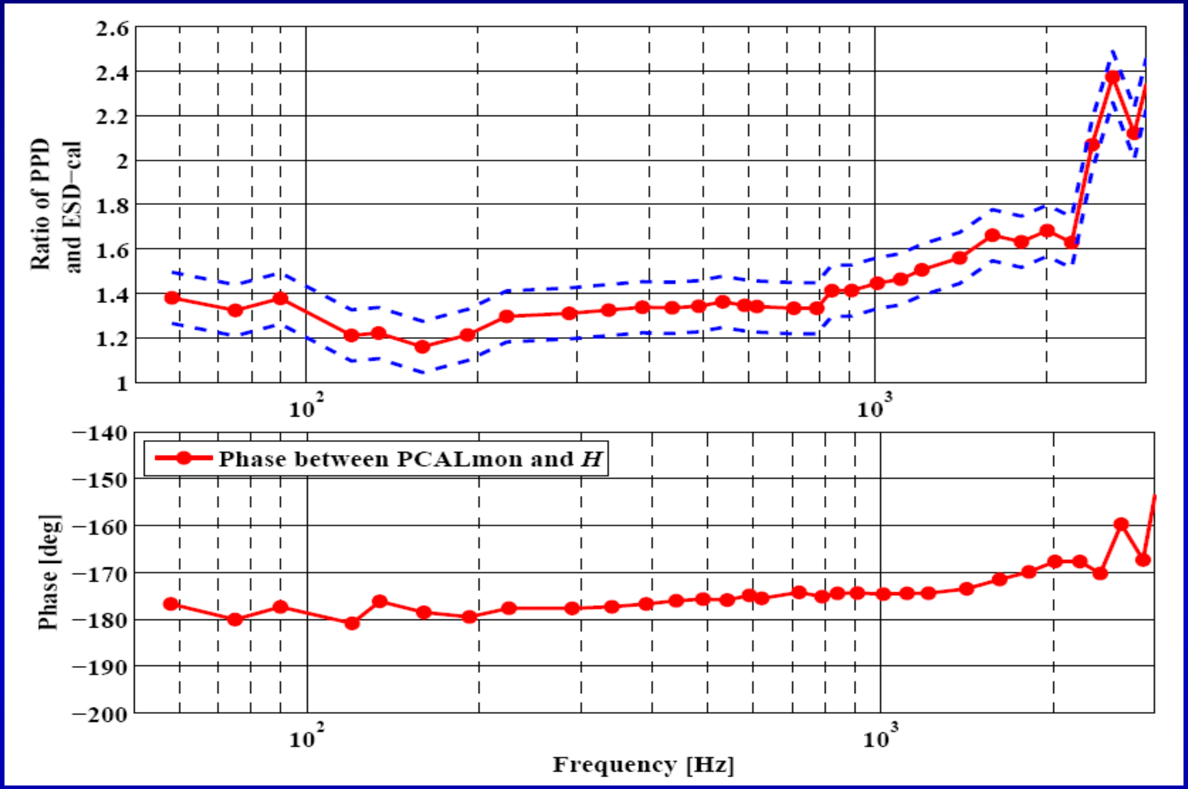


- Source: modulated Laser diode.
- Wavelength =1035 nm, DC power = 1 W, modulated power up to 800 mW.
- Power is monitored by an photodiode inside the Laser diode.
- Shining from back (through the substrate)
- Restricted geometrical setup: the reflected beam is clipped on the way out of the vacuum.
- PPD beam diameter at MFN = 5mm (main IFO beam = 50 mm)

Pure PCAL response (without test mass deformation)



Comparison of official and photon pressure calibration



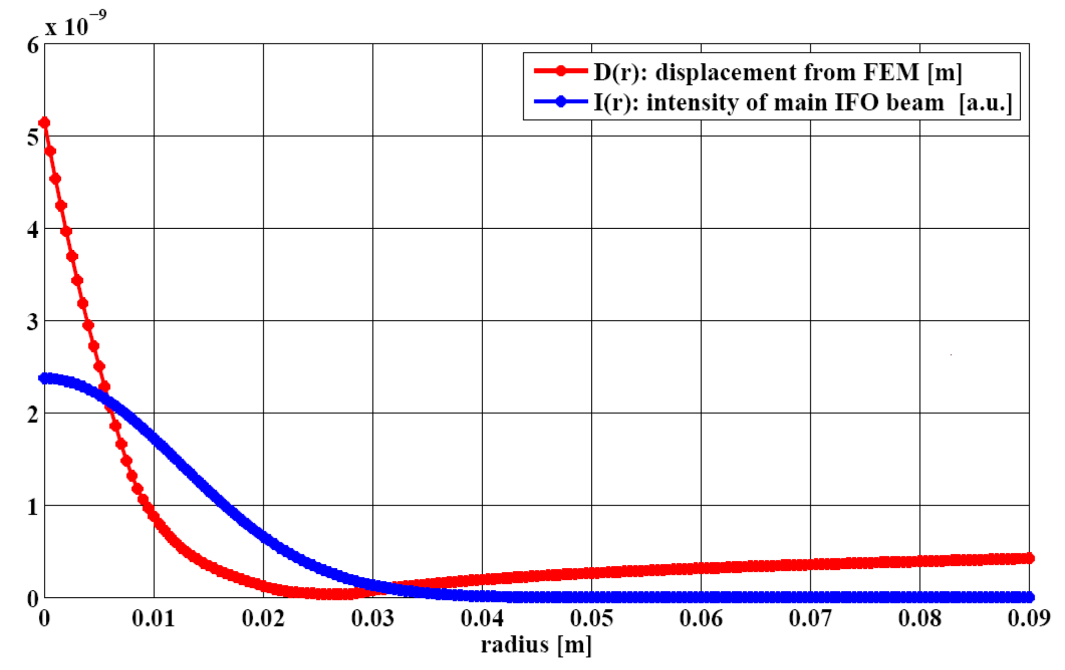
- Below 1kHz a systematic deviation of 30-40% is observed.
- Above 1kHz the deviation increases strongly
- In the following I will focus on the high frequency behaviour and explain it.

Finite element model

- Simulating the DC effect of radiation-pressure-induced test mass deformation.

(Simulation was provided by our colleagues from Glasgow: I. Martin, S. Reid, J. Hough)

Effective displacement caused by mirror deformation

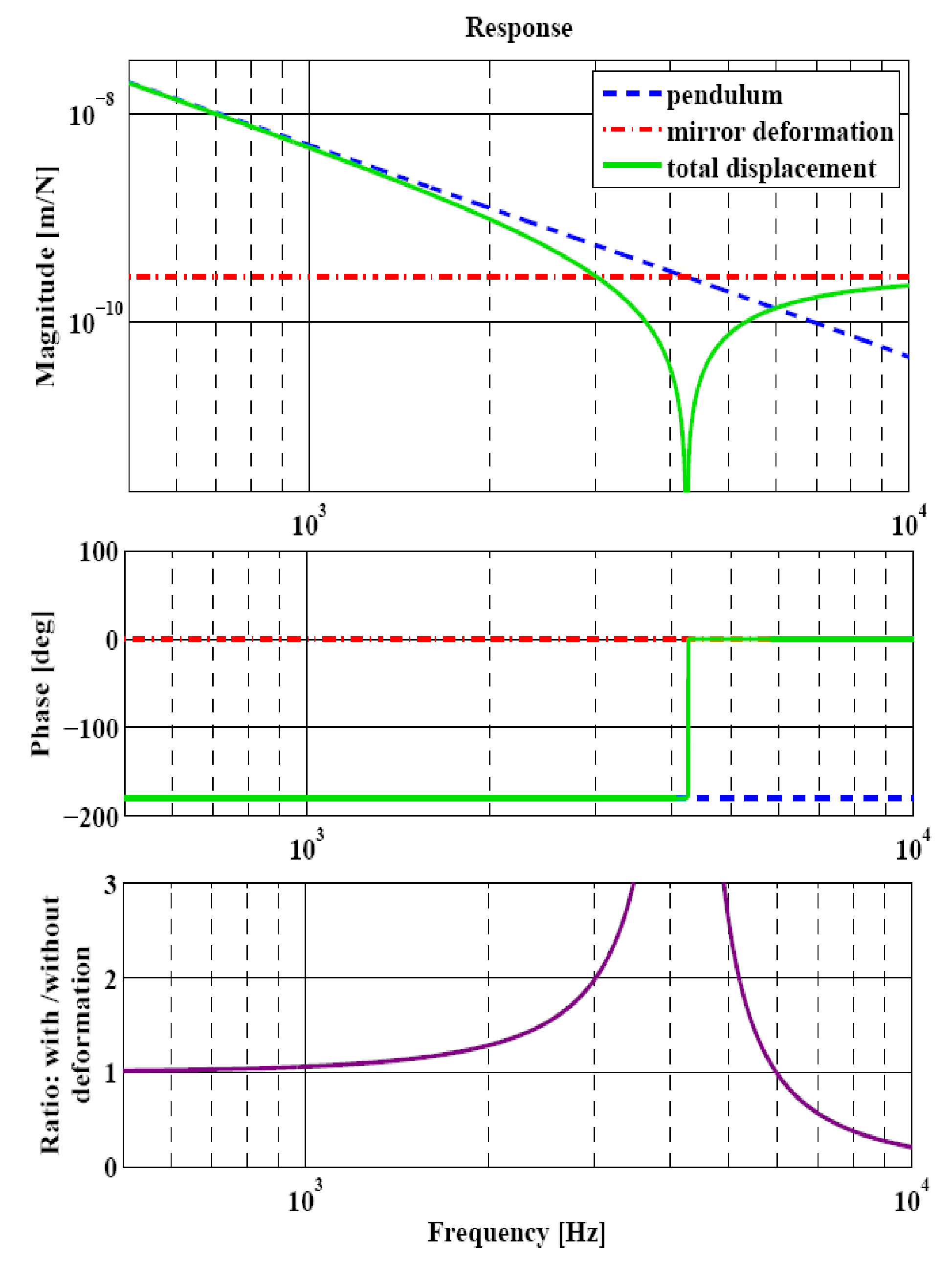


$$D_{\text{total}} = \int_0^{0.09\text{m}} \int_0^{2\pi} D_{\text{eff}} \cdot dr \cdot d\varphi = \int_0^{0.09\text{m}} 2\pi \cdot r \cdot k_I \cdot I(r) \cdot D(r) \cdot dr.$$

$$\int_0^{0.09\text{m}} 2\pi \cdot r \cdot k_I \cdot I(r) \cdot dr = 1.$$

- The effective mirror deformation amounts to 2.73×10^{-10} m / N

Simple model



Assumptions:

- Below the internal resonances (<10 kHz) the mirror deformation is flat in frequency.
- Below the internal resonances the mirror deformation is in phase with the modulated light.
- The pendulum response is 180 degrees out of phase.

Prediction:

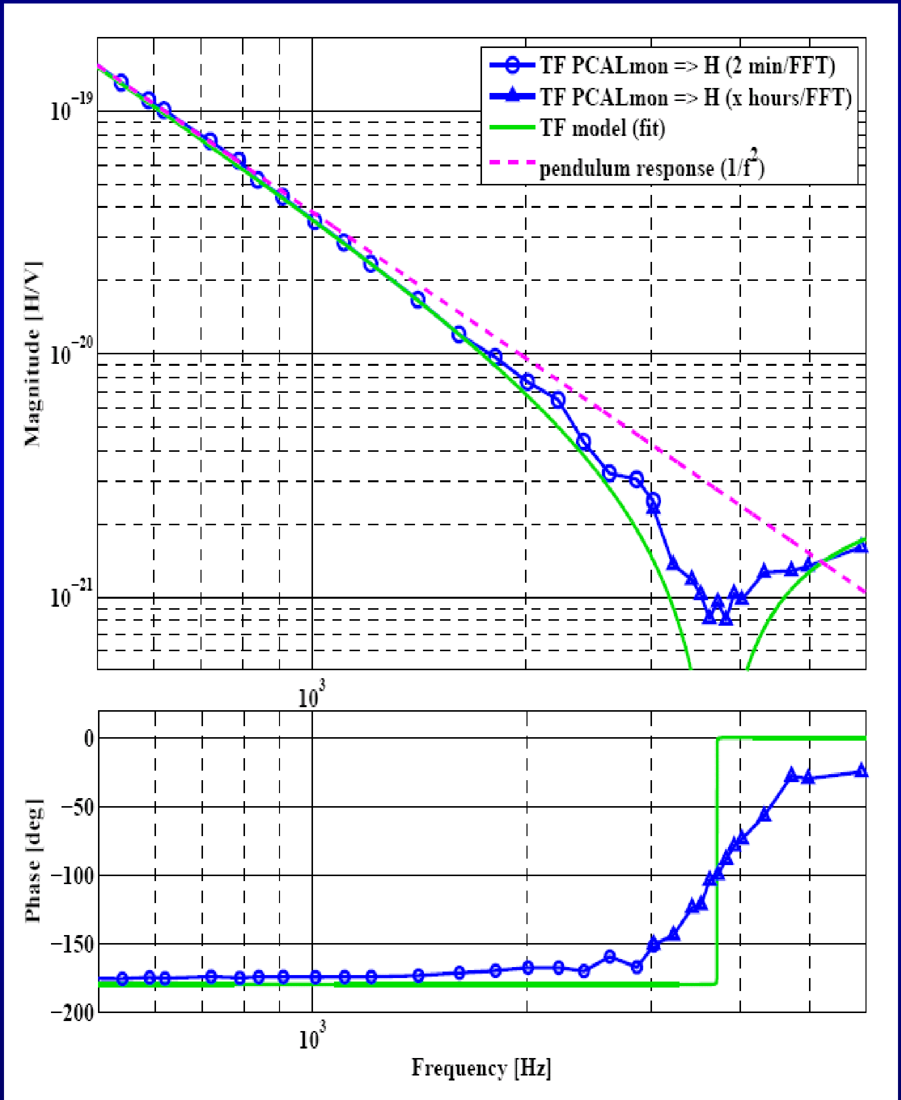
- Presence of a notch at the crossover of the responses from pendulum and mirror deformation.

Transfer function of modulated light to the GW-channel at high frequencies

- Long duration measurements have been carried out at frequencies between 3 and 6kHz.
- Using a heterodyne downsampling technique up to 10 hours of data are used for a single DFT.

$$E_{\text{sig}} \cdot sin(\omega_{\text{sig}} t) \cdot sin(\omega_{\text{het}} t) = \frac{1}{2} E_{\text{sig}} [cos(\omega_{\text{sig}} - \omega_{\text{het}})t - cos(\omega_{\text{sig}} + \omega_{\text{het}})t]$$

- Presence of the notch was confirmed.
- Notch structure seems to be smeared out.

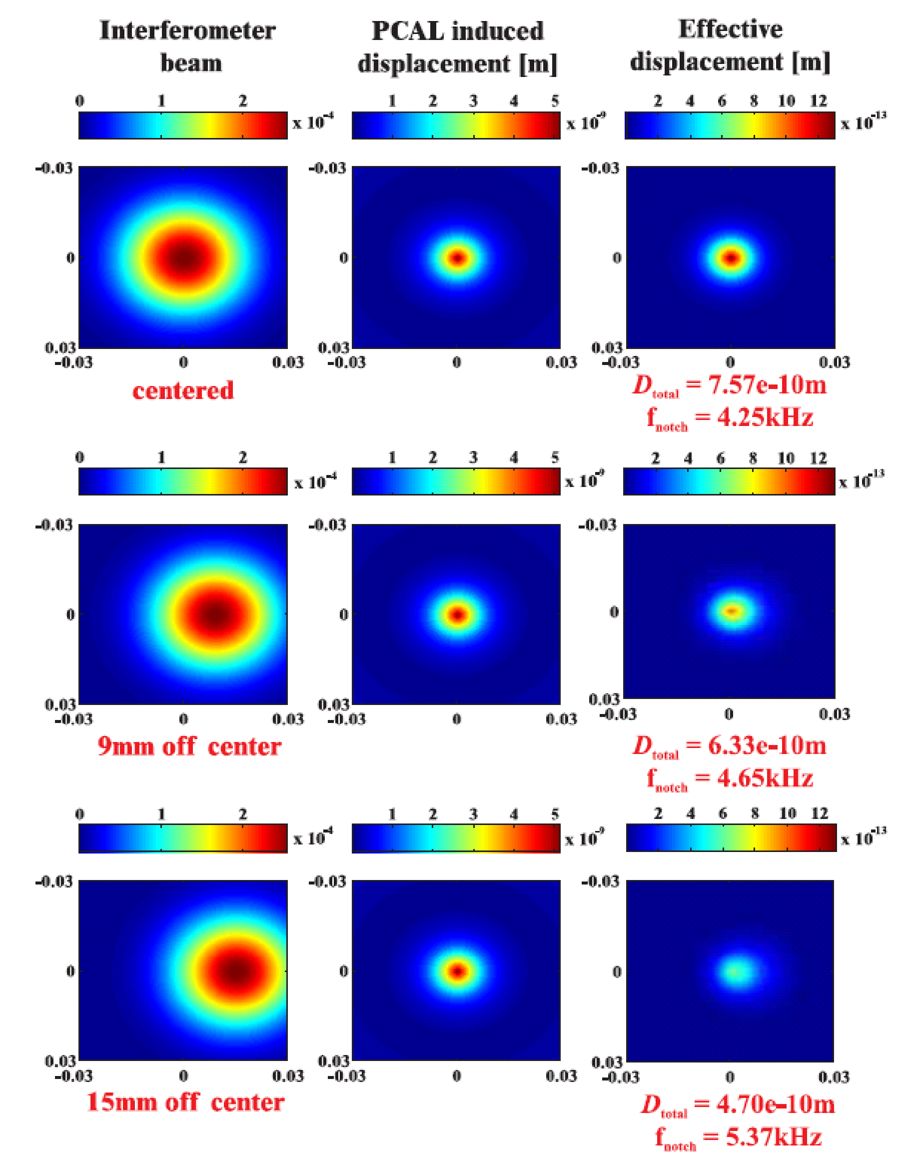


Explanation for the smearing-out of the notch: Jitter of the main IFO beam.

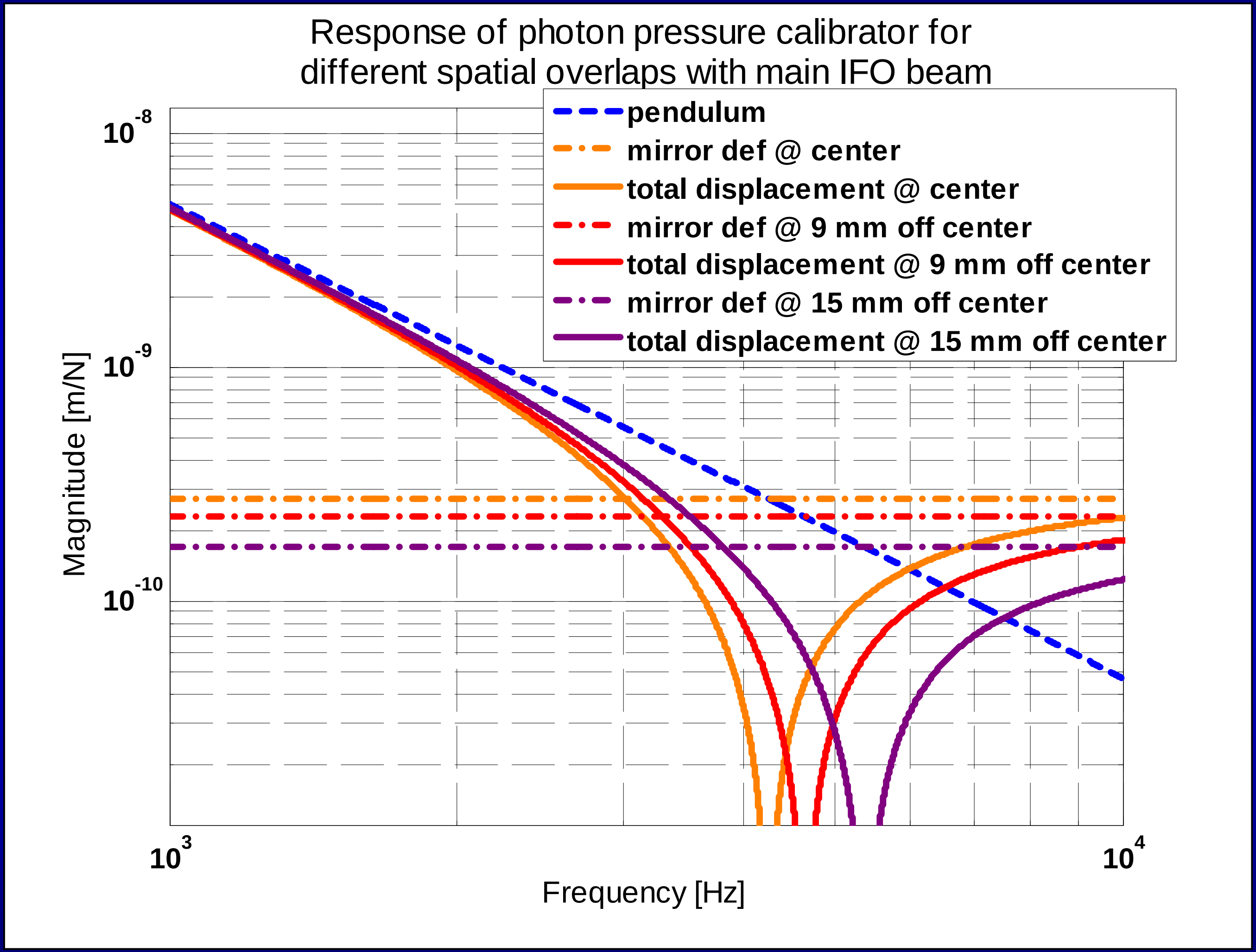
- Effective displacement seen by GEO600 depends on overlap of mirror deformation and main IFO beam:

$$D_{\text{total}} = k_I \int_0^{0.09\text{m}} \int_0^{360\,\text{deg}} \cdot I(r,\varphi) \cdot D(r,\varphi) \cdot dr \cdot d\varphi.$$

- The natural movement of the IFO beam can explain a shift of the notch frequency by several 100 Hz.
- The long duration measurements average over different notch frequencies.



Explanation for the smearing out of the notch: Jitter of the main IFO beam.



Summary of photon-pressure-induced testmass deformation

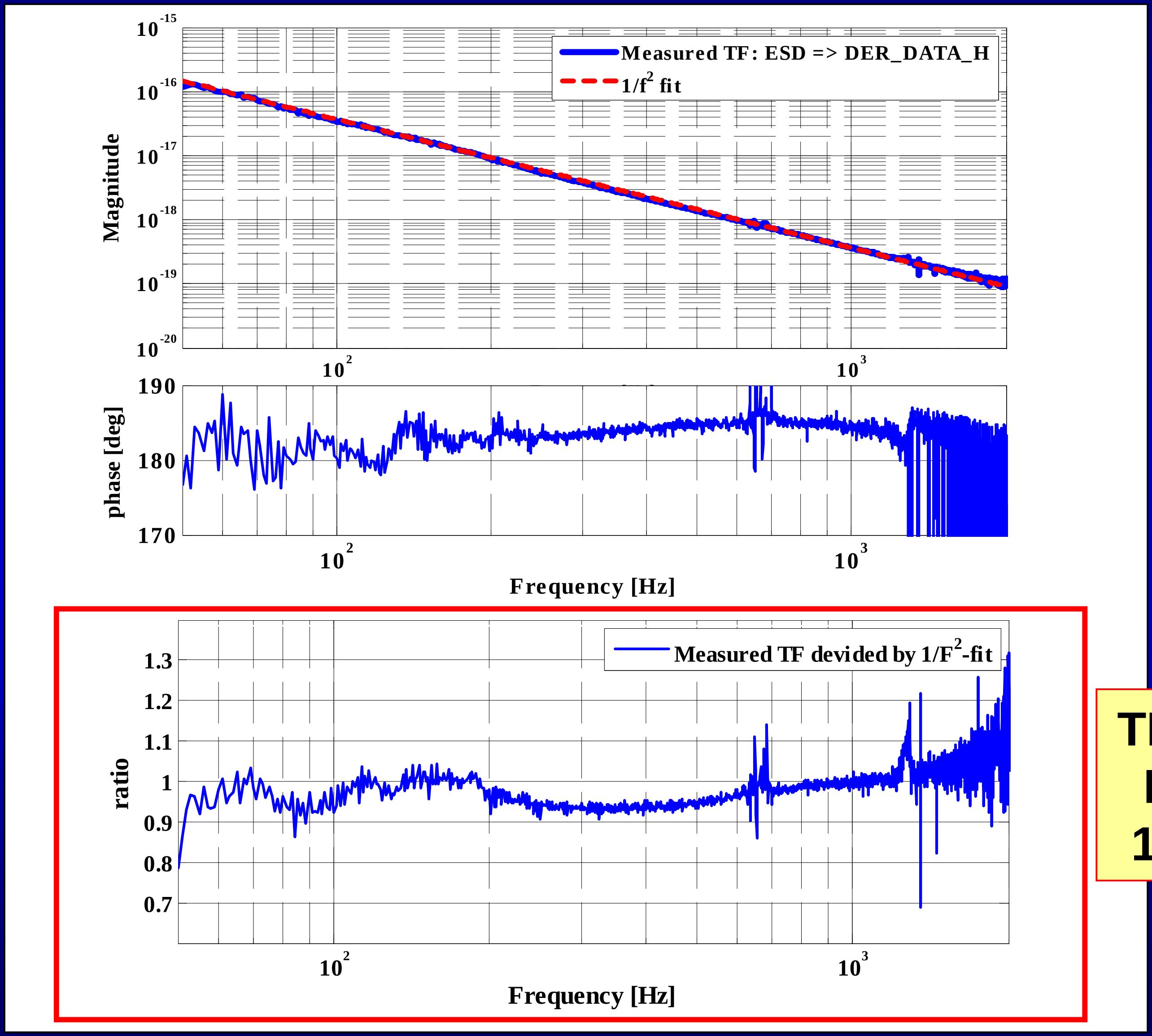
- Photon-pressure-induced mirror deformation limits the accuracy of the GEO photon pressure calibration above 1 kHz.
- Above 4 kHz this is the dominating effect.

- The test-masses are not rigid bodies !!

- Consequences:
  - At least at high frequencies the accuracy achievable with a photon pressure calibration is limited.
  - Coil/magnet actuators probably also cause a test mass deformation.
  - The mirror deformation might be reduced by applying a homogeneous actuation (for instance with an ESD).

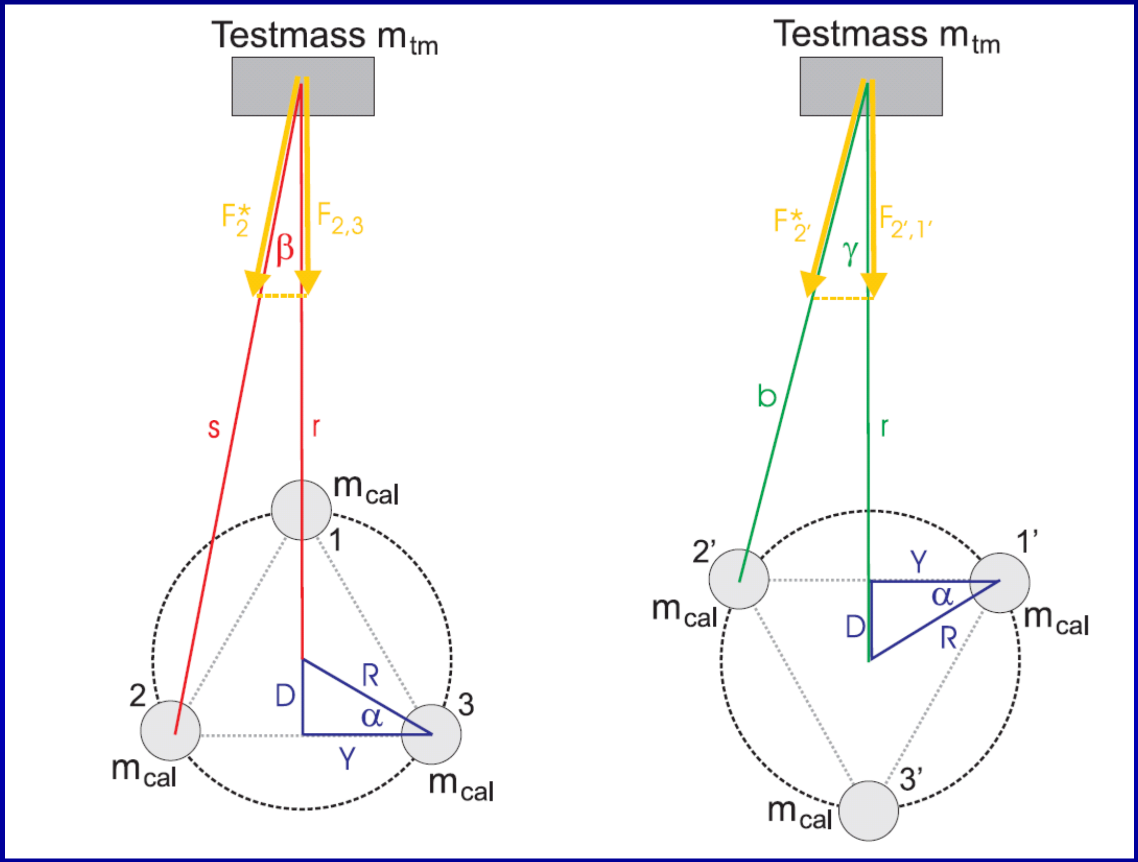
E N D

Ruling out any artefacts from calibration process: Checking the 1/f^2 of ESD vs official calibration.



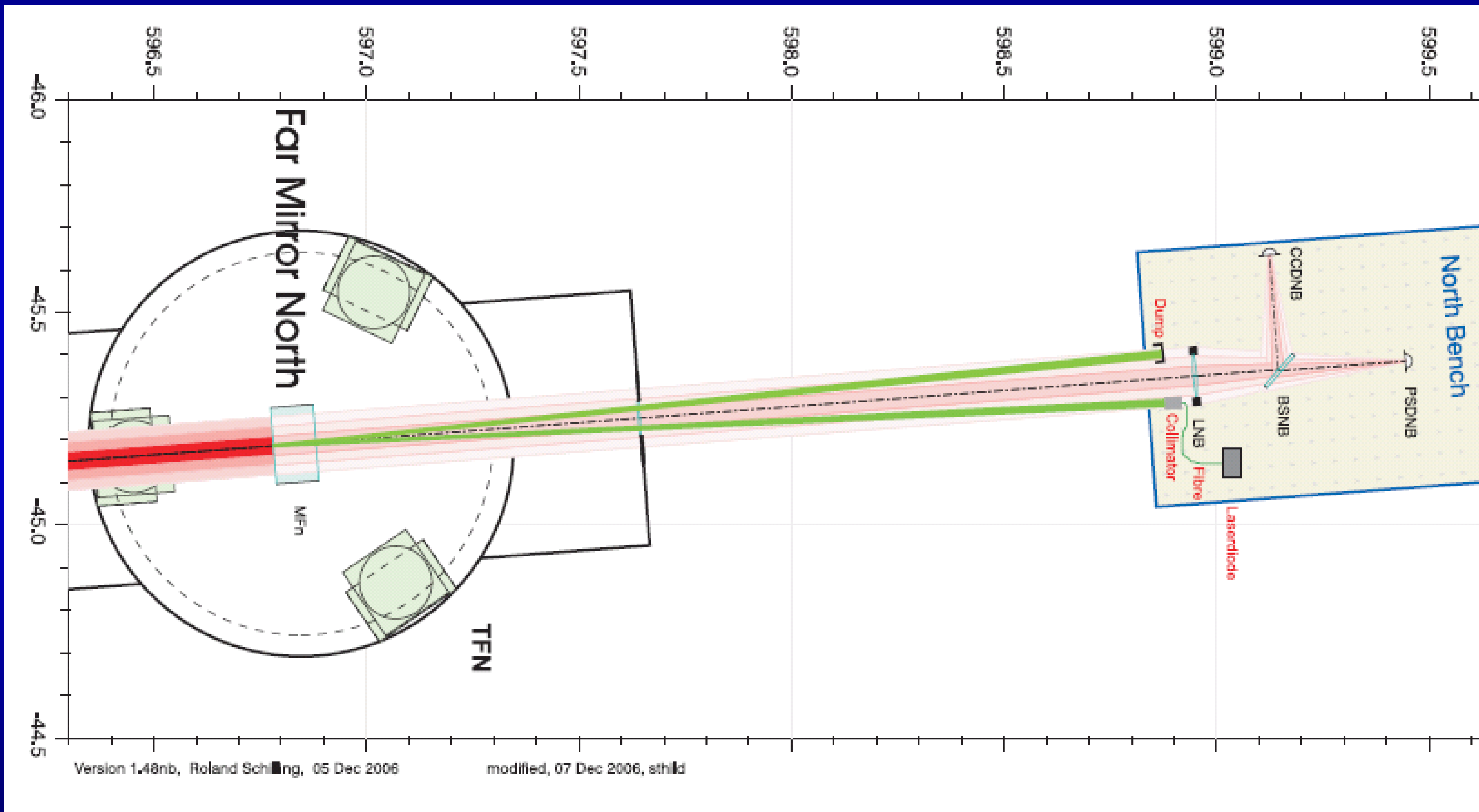
TF from ESD-FB to DER_DATA_H is 1/f^2 within +/-5%

Gravity calibrator



$$\Delta F = G \cdot m_{tm} \cdot m_{cal} \left[\frac{1}{(r+R)^2} + \frac{2\cos\beta}{r^2 - rR + R^2} - \frac{1}{(r-R)^2} - \frac{2\cos\gamma}{r^2 + rR + R^2} \right]$$

Optical layout of the photon pressure calibrator



Effect from off-center laser beams