NEWS

NEw WindowS on the universe and technological advancements from trilateral EU-US-Japan collaboration

In-Situ Laser Mode Spectroscopy for Mirror Phase Mapping

Annalisa Allocca

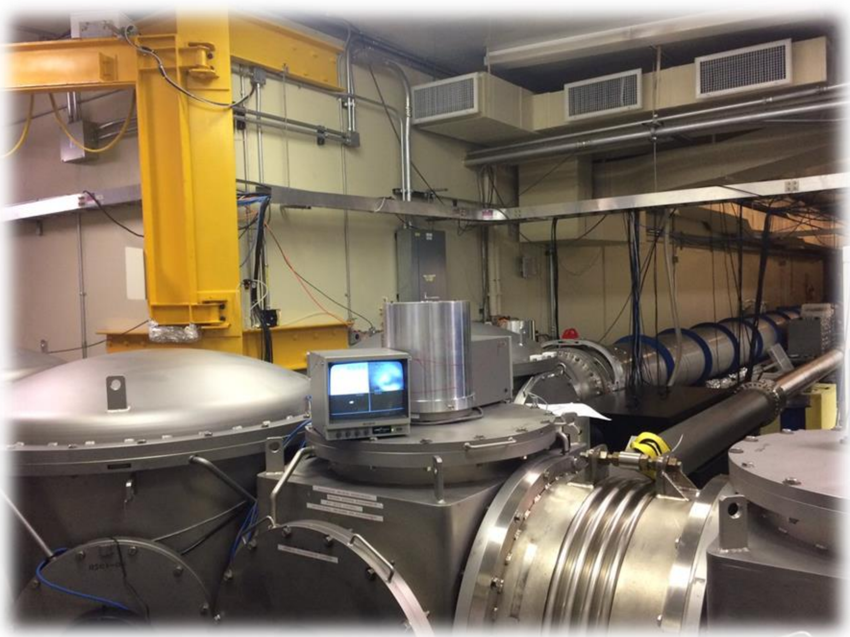
MidTerm Review, Pisa, March 4-5, 2019

Web site: risenews.df.unipi.it

European Commission

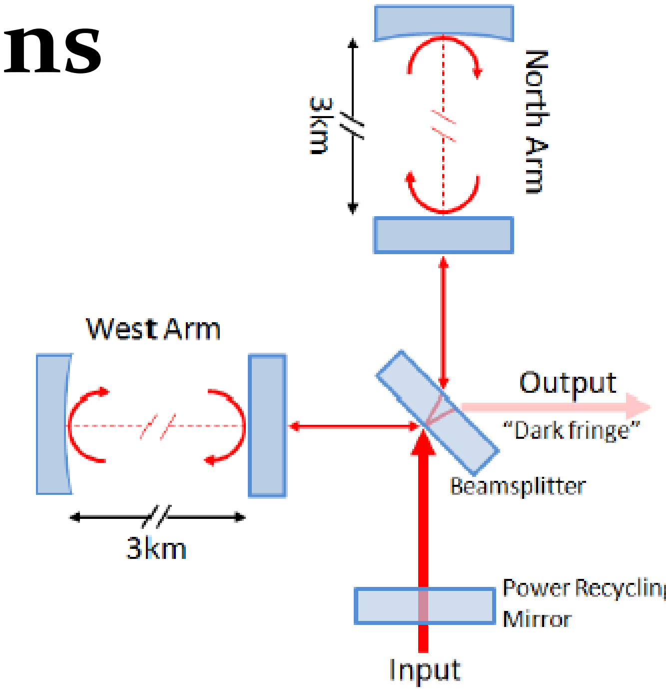
The collaboration

Project carried out at the LIGO 40m prototype at Caltech in collaboration with Prof. Rana Adhikari [(1)], Gautam Venugopalan [(1)], Koji Arai [(1)], Hiroaki Yamamoto [(1)], Terra Hardwick [(2)]

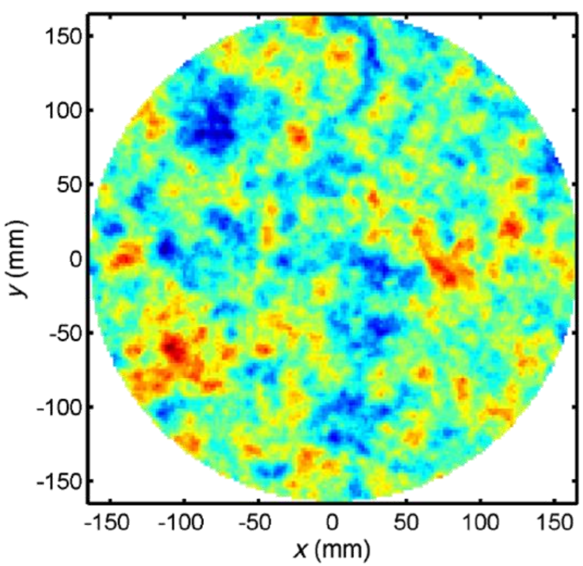


(1) California Institute of Technology
(2) LIGO Lab – University of Louisiana

Motivations



Mirrors surface residual roughness can spoil the quality of the beams reflected by the arm cavities, and consequently the near perfect destructive interference at the dark port.



State-of-the-art techniques have been used in order to ensure the highest quality surface possible and fulfill the expected RMS roughness for Advanced Virgo mirrors, which is of **0.5 nm** over a region 150mm diameter.

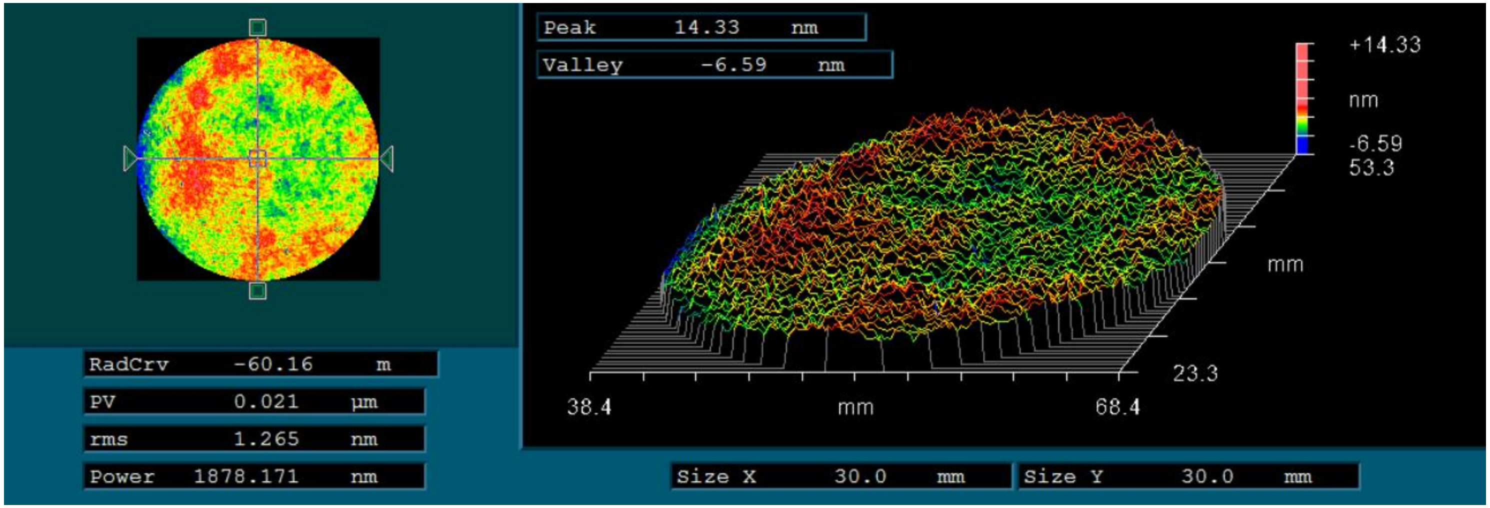
However, the fundamental limitation lies in the *on-site* metrology

Mirror figure error measurements

Mirror figure error are **currently measured off-site**, through phase measurements.

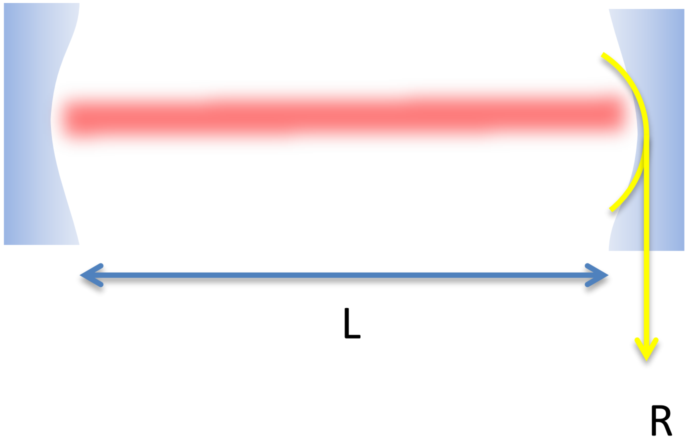
However, this measurement doesn't account for the geometry of the mirror mount and the environmental conditions, which can affect the final measurement. In addition the mirror will deform when suspended in the interferometer.

Ultimately the final validation of such a process will be the *in-situ* measurements



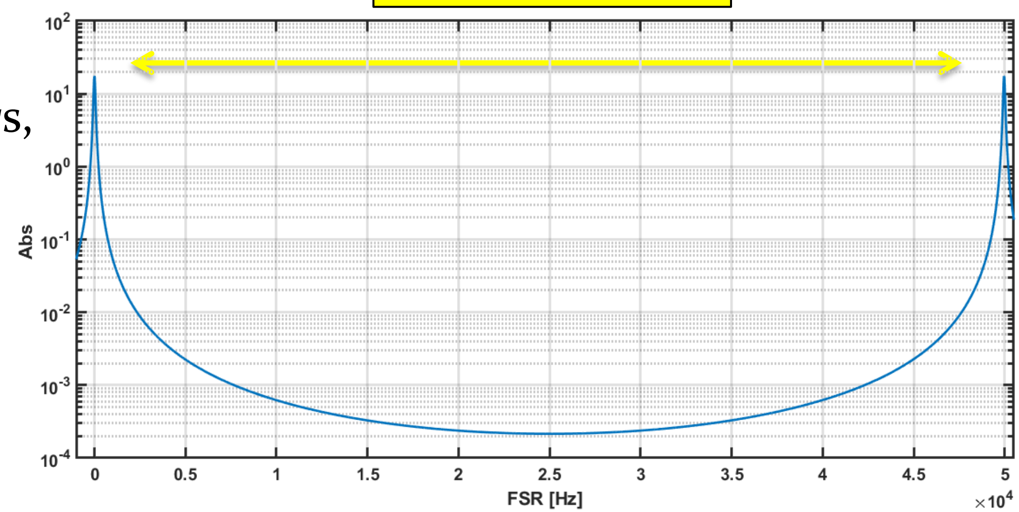
To know about the mirrors, ask the cavity!

Fabry-Perot optical resonator



Beams actually circulating into the resonators are the solution of the Maxwell equation in paraxial approximation.

$$FSR = \frac{c}{2L}$$

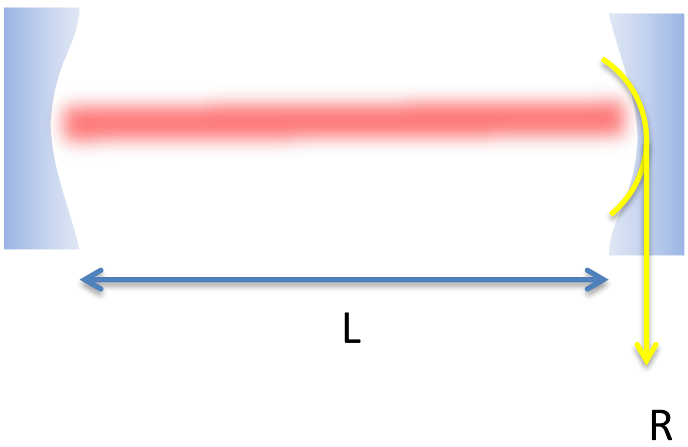


The resonance condition of the modes is related to the main cavity parameters, i.e. the **length** and the **radius of curvature**

The **length** defines the Free Spectral Range, which is the distance between the resonance of two fundamental modes

To know about the mirrors, ask the cavity!

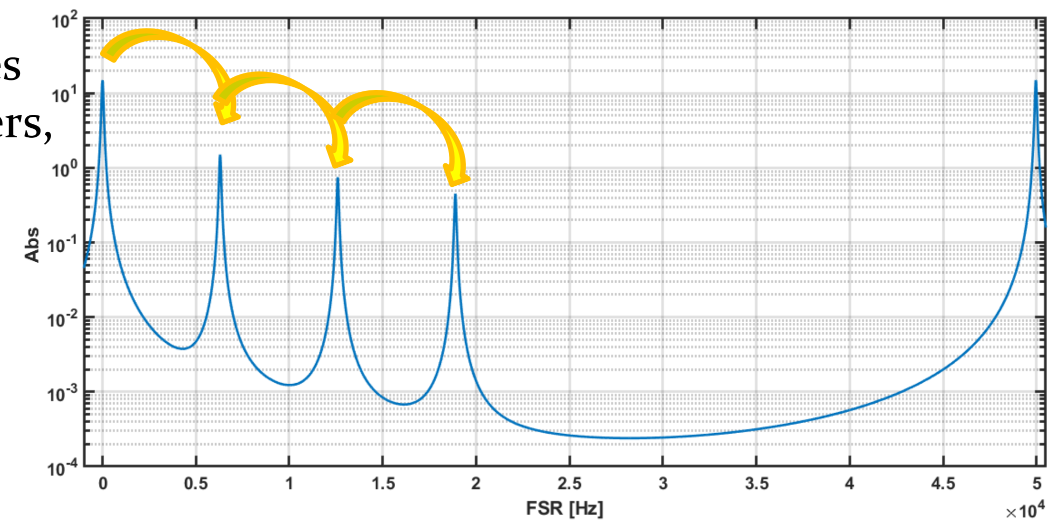
Fabry-Perot optical resonator



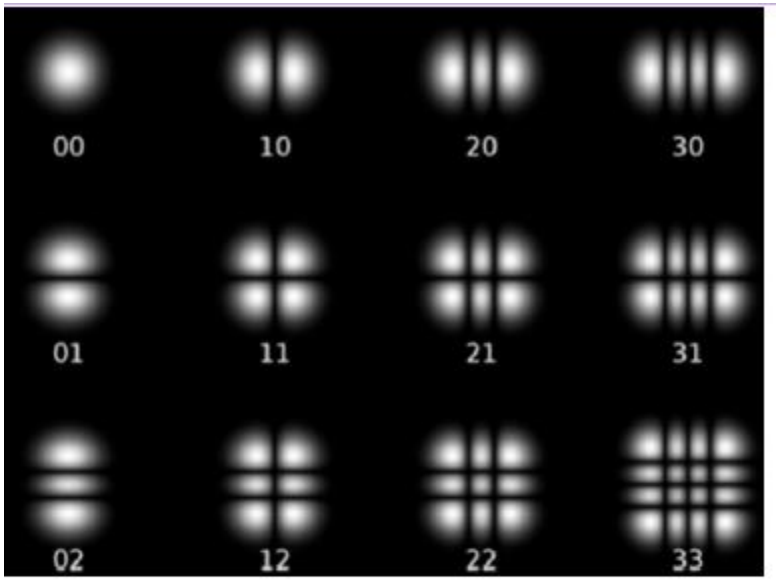
Beams actually circulating into the resonators are the solution of the Maxwell equation in paraxial approximation.

The resonance condition of the modes is related to the main cavity parameters, i.e. the **length** and the **radius of curvature**

The **radius of curvature** is embedded in the definition of the Gouy phase, which is the distance between two adjacent high order modes



The radius of curvature as “seen” by different high order modes

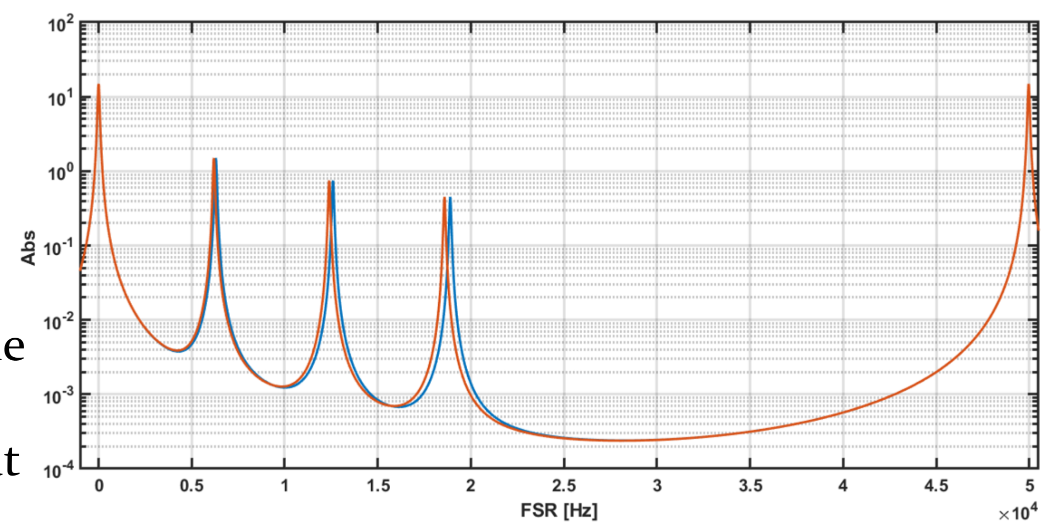


Hermite-Gauss modes (which are a possible basis for the resonator’s modes) have different spatial extension and shape, therefore they imping on a different region of the mirror.

If the mirror is not perfectly spherical over the whole surface, they can see a different average radius of curvature

This manifests itself with a resonance condition slightly different for the different modes.

Reverting the problem, starting from the measurement of their resonance condition, we can infer something about the mirror shape



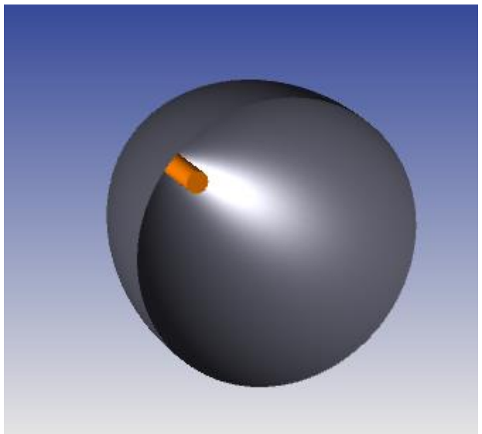
Allocca's secondment

In order to test the sensitivity of the auxiliary laser system, I installed a setup able to induce a "known" deformation (a heater) and try to match prediction to the measurements.

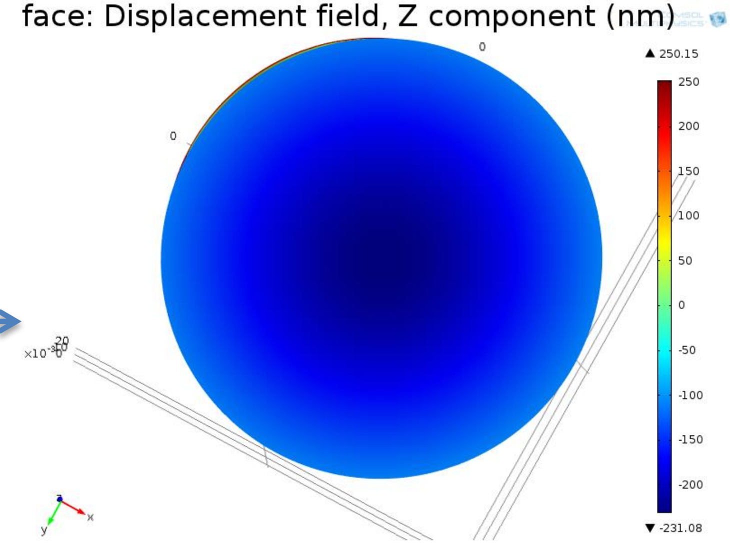
- Design a thermal setup to induce a known deformation on the mirror (first secondment)
- Install the thermal setup in the vacuum chambers (second secondment)
- Tune the setup to perform high precision measurement injecting an auxiliary laser in the interferometer

Heater setup

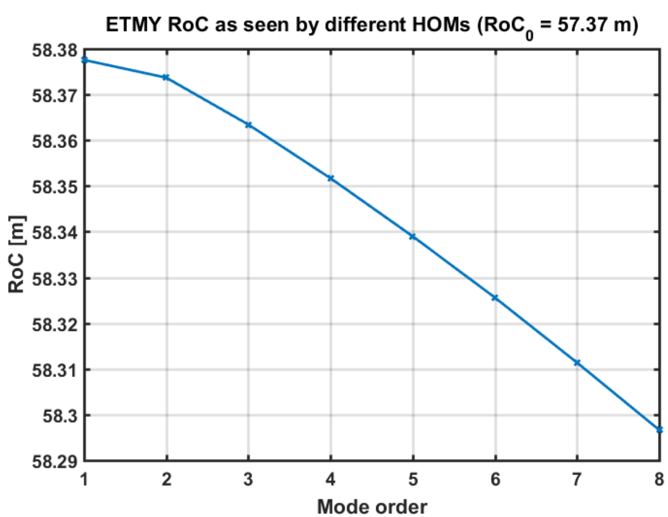
Ellipsoidal reflector with heating element in one of the focus

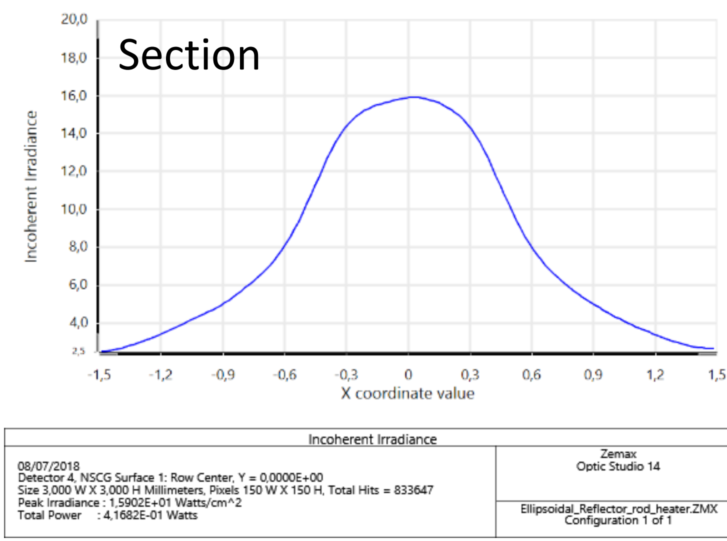


Induced deformation on the mirror

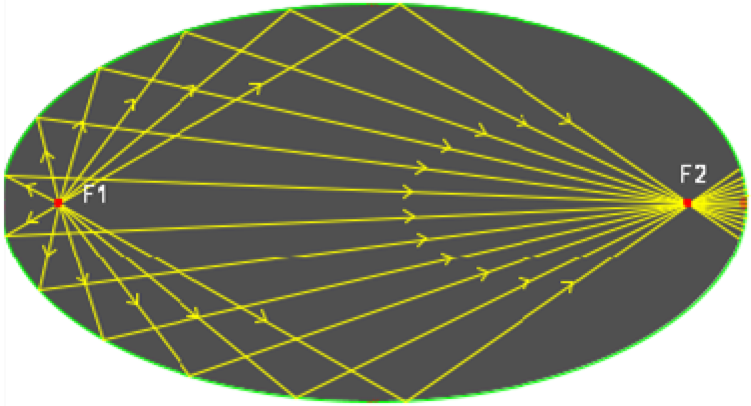


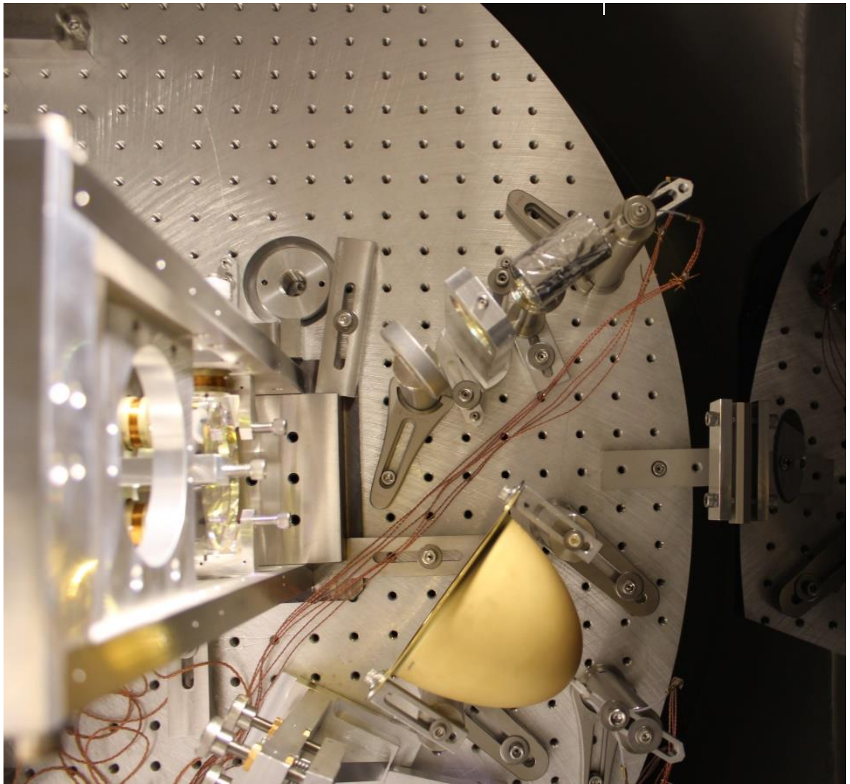
Mirror radius of curvature as seen by the different HOMs

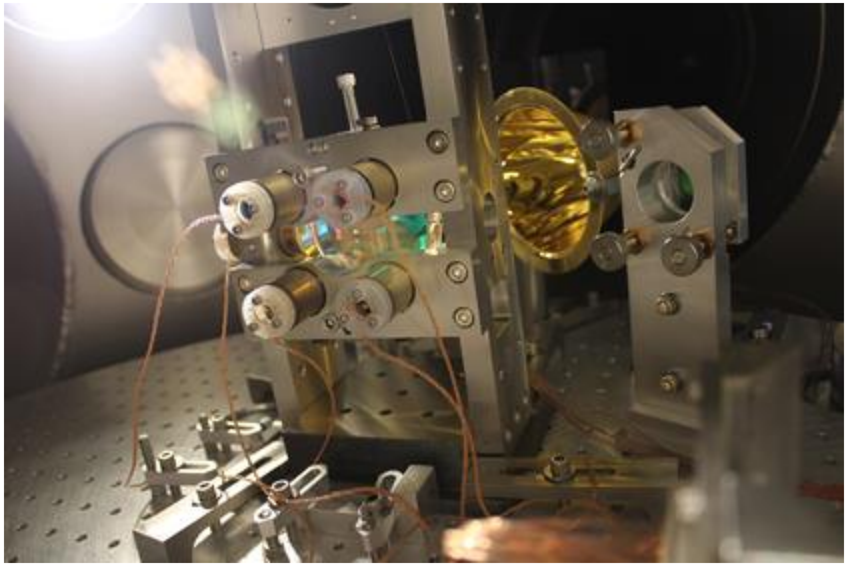




Heater setup

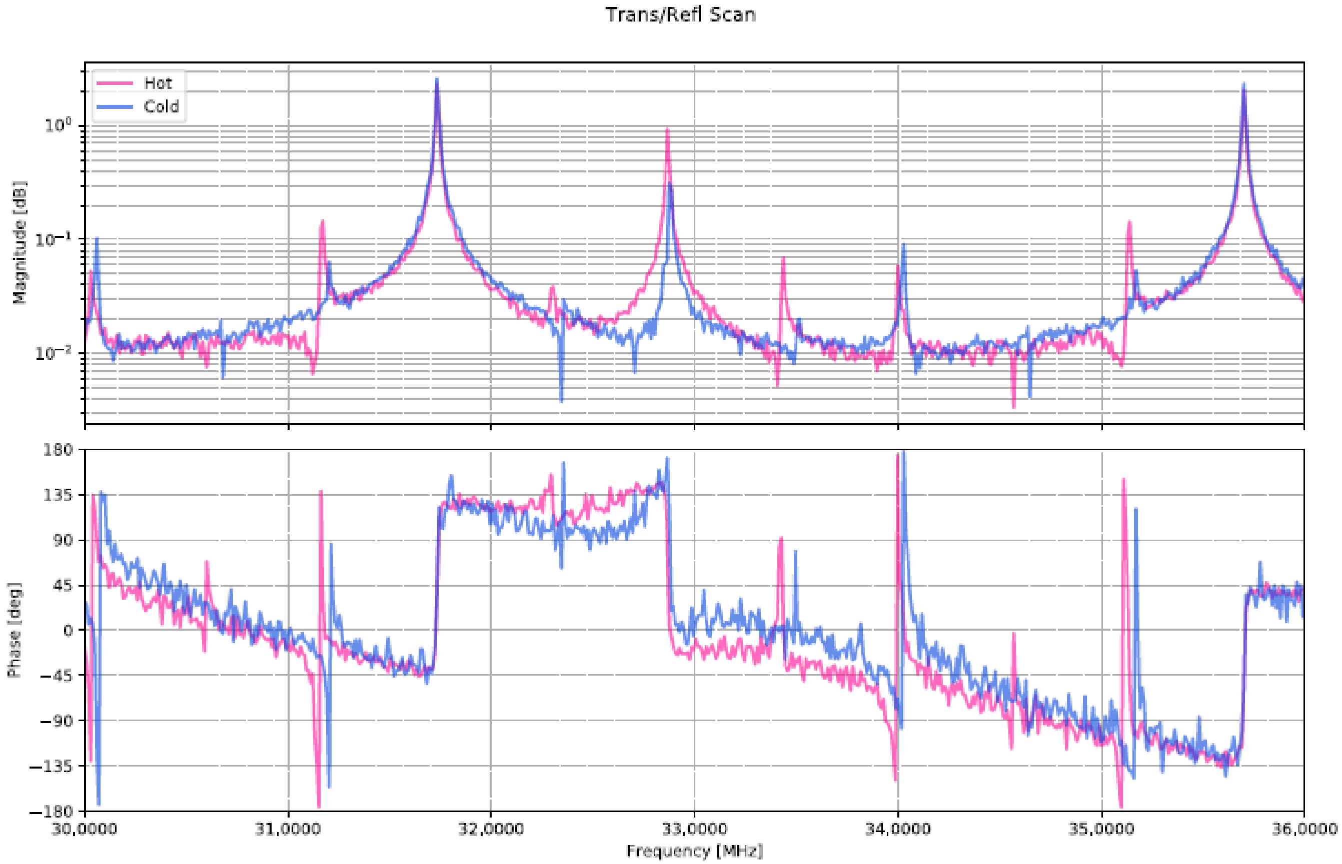






The measurements

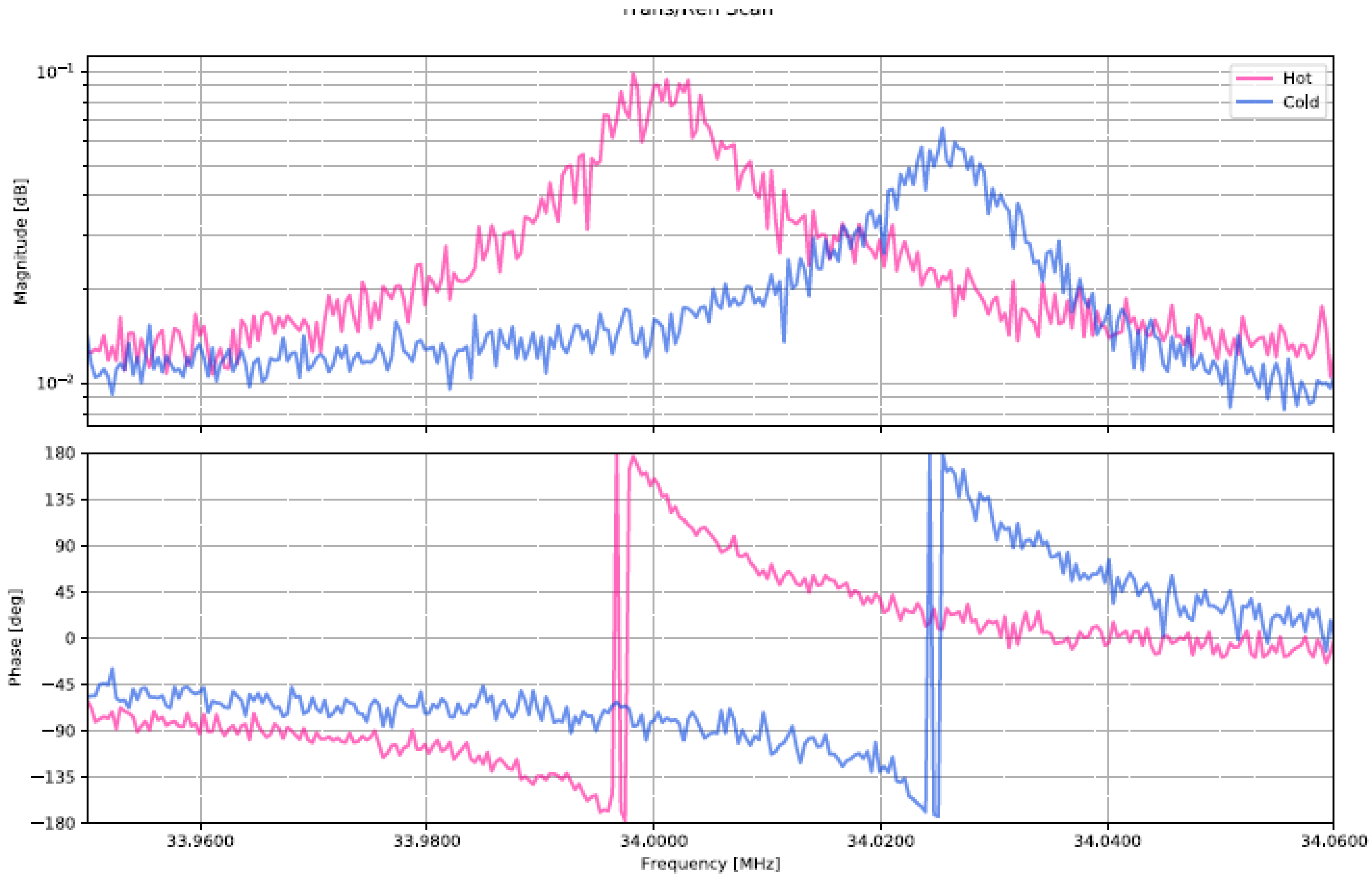
Experiment performed on 40m prototype by injecting an auxiliary (AUX) laser from antisymmetric dark port, which allows for extremely precise measurements.



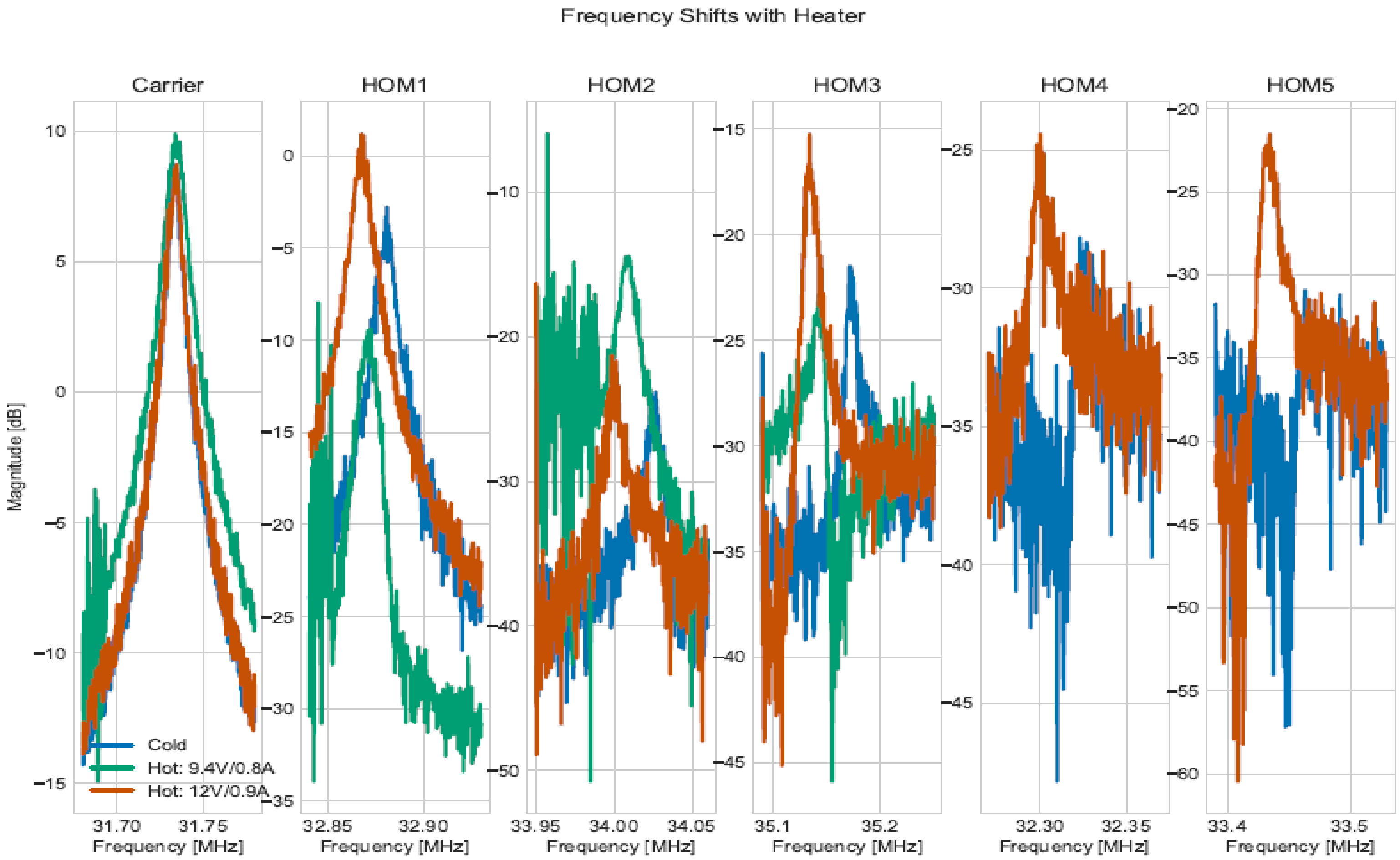
Measuring the ***transfer function*** between transmitted and reflected beams, it is possible to retrieve the **phase information**, therefore performing a much more precise measurement (~Hz or even lower).

The measured shift

Order 2 mode



The measured shift



Different HOMs see a different shift but there's still work to do to characterize the system and perform valuable measurements

Conclusions and future perspectives

- The work represents a first proof of concept, showing that it is possible to perform measurements with very high precision and induce a precise deformation which can be seen differently from the different high order modes
- Statistical (Bayesian inference), simulation and analytical tools have to be extensively used to perform a map reconstruction starting from the high order modes resonance

WORK IN PROGRESS!