Flat top beam profile cavity prototype

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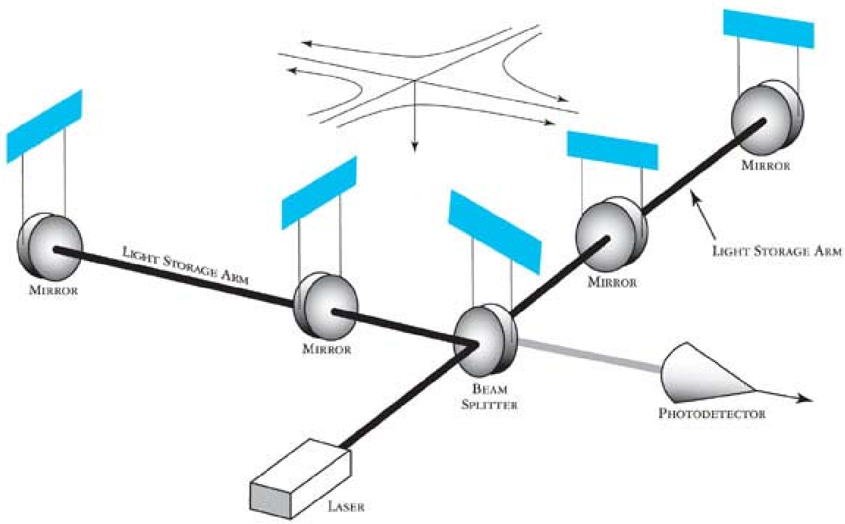
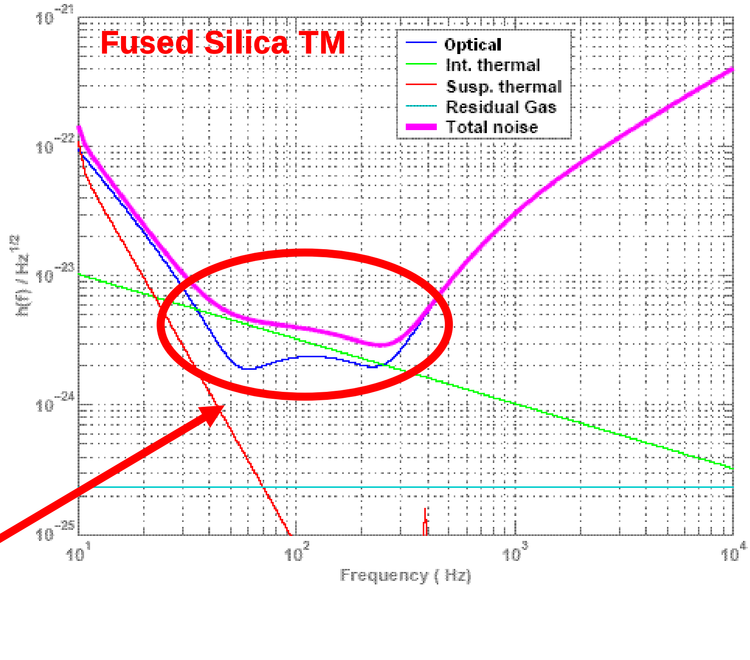
LIGO G050329-00-R

Motivation for non-Gaussian beams:

Mirror Thermal Noise in GW interferometers





Future detectors will be limited by mirror thermal noise

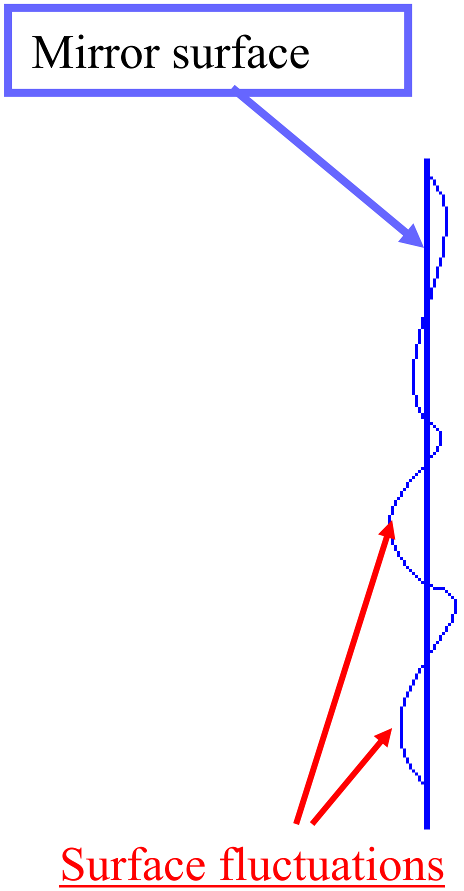
in the frequency band of higher sensitivity

Mirror Thermal Noise:

T≠0

Energy exchange with thermal bath

FDT→ relationship between the fluctuations of generalized coordinates and dissipation of the system



Interferometer output: proportional to the test mass average surface position, sampled by to the beam's intensity profile.

Mirror surface averaged

Gaussian beam

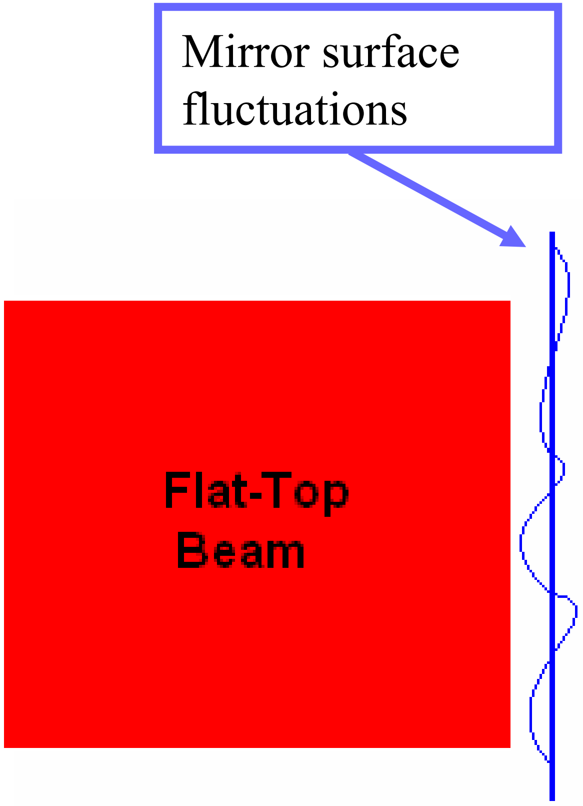
Thermal noise PSD $\propto \dfrac{1}{w^n}$

large beam radius

- Diffraction loss constraint
- The sampling distribution changes rapidly following the beam power profile

Flat Top beam

Larger-radius, flat-top beam will better average over the mirror surface.



Diffraction prevents the creation of a beam with a rectangular power profile…but we can build a nearly optimal flat-top beam

Flat "mesa" beam profiles require rimmed "Mexican Hat" mirror profiles

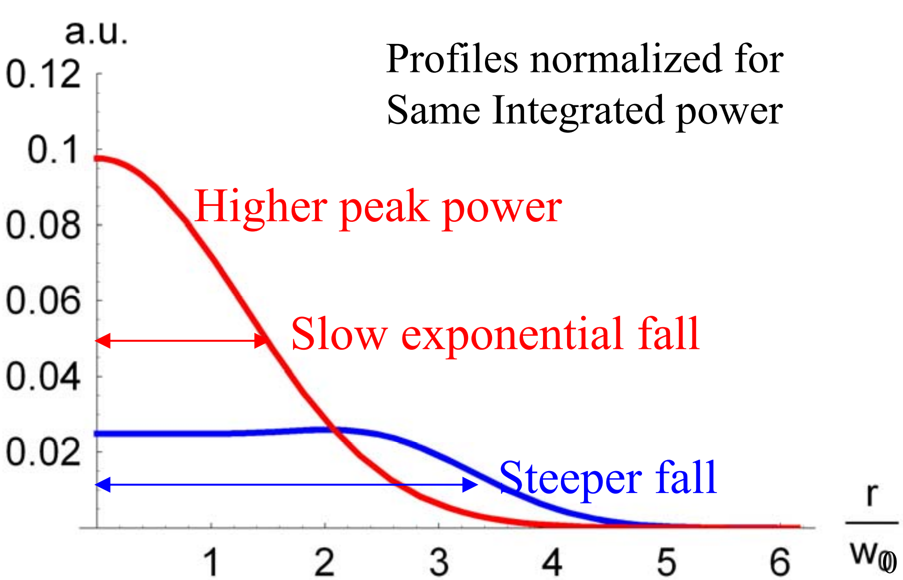
- Mesa beam (blue)
- Gaussian beam (red)

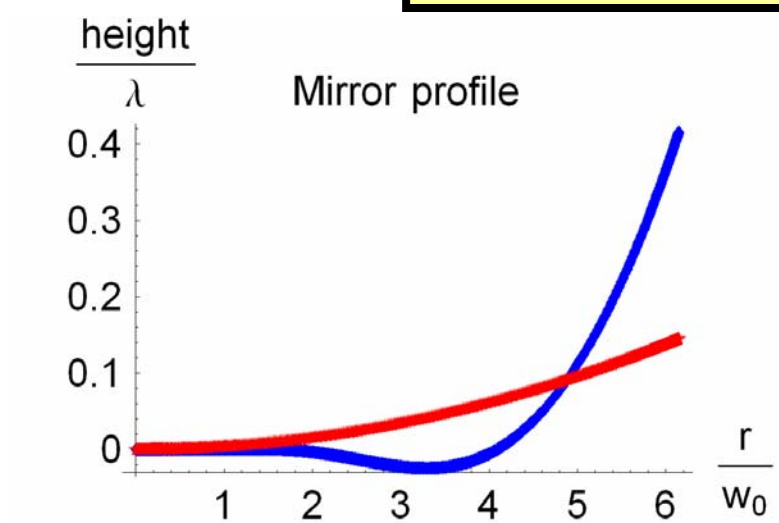
$$u_{FT}(r) \propto \int_{r' \leq D} d^2\vec{r}'\, e^{-\frac{(\vec{r}-\vec{r}')^2 (1-i)}{2 w_0^2}}$$

$$w_0 = \sqrt{\frac{L}{k}}$$

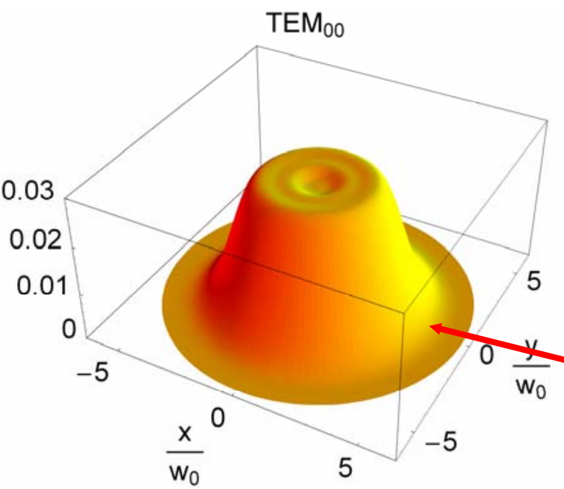
$$u_G(r) \propto e^{-\frac{r^2}{w^2}}$$

The mirror shapes match the phase front of the beams.

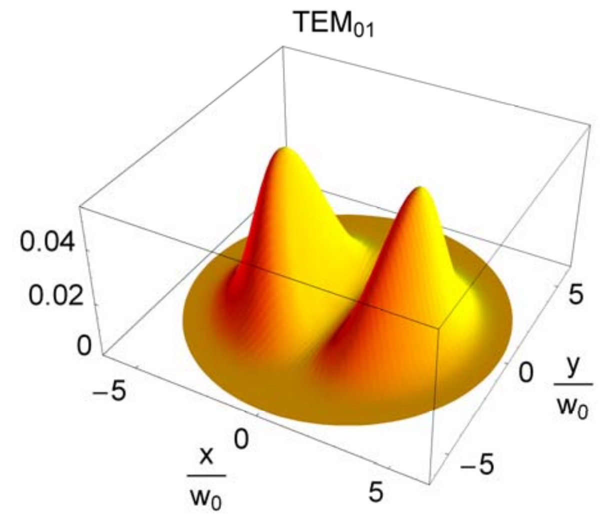




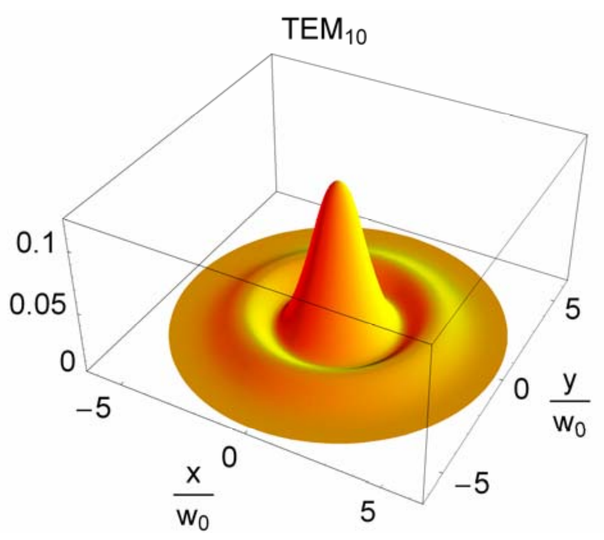
Optical cavity with Mexican Hat mirrors



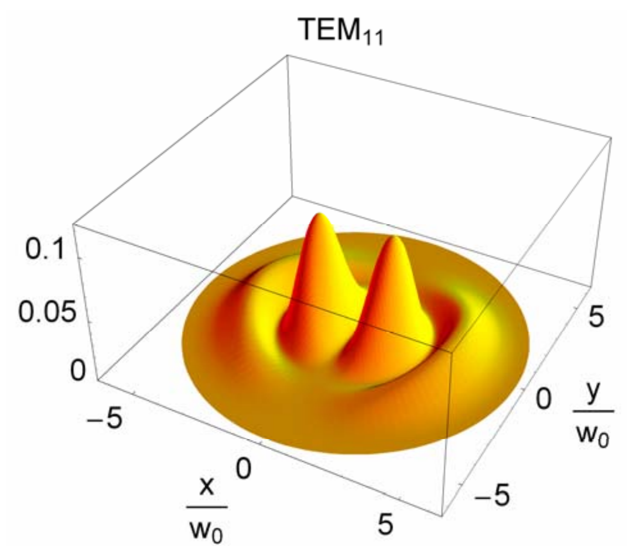
Numerical eigenmodes for a ideal MH Fabry-Perot interferometer:



The fundamental mode is the so-called “Mesa Beam”, wider and flatter than a gaussian power distribution



Cylindrical symmetry yields TEMs close to the Laguerre-Gauss eigenmodes set for spherical cavities



Flat top beam FP cavity prototype

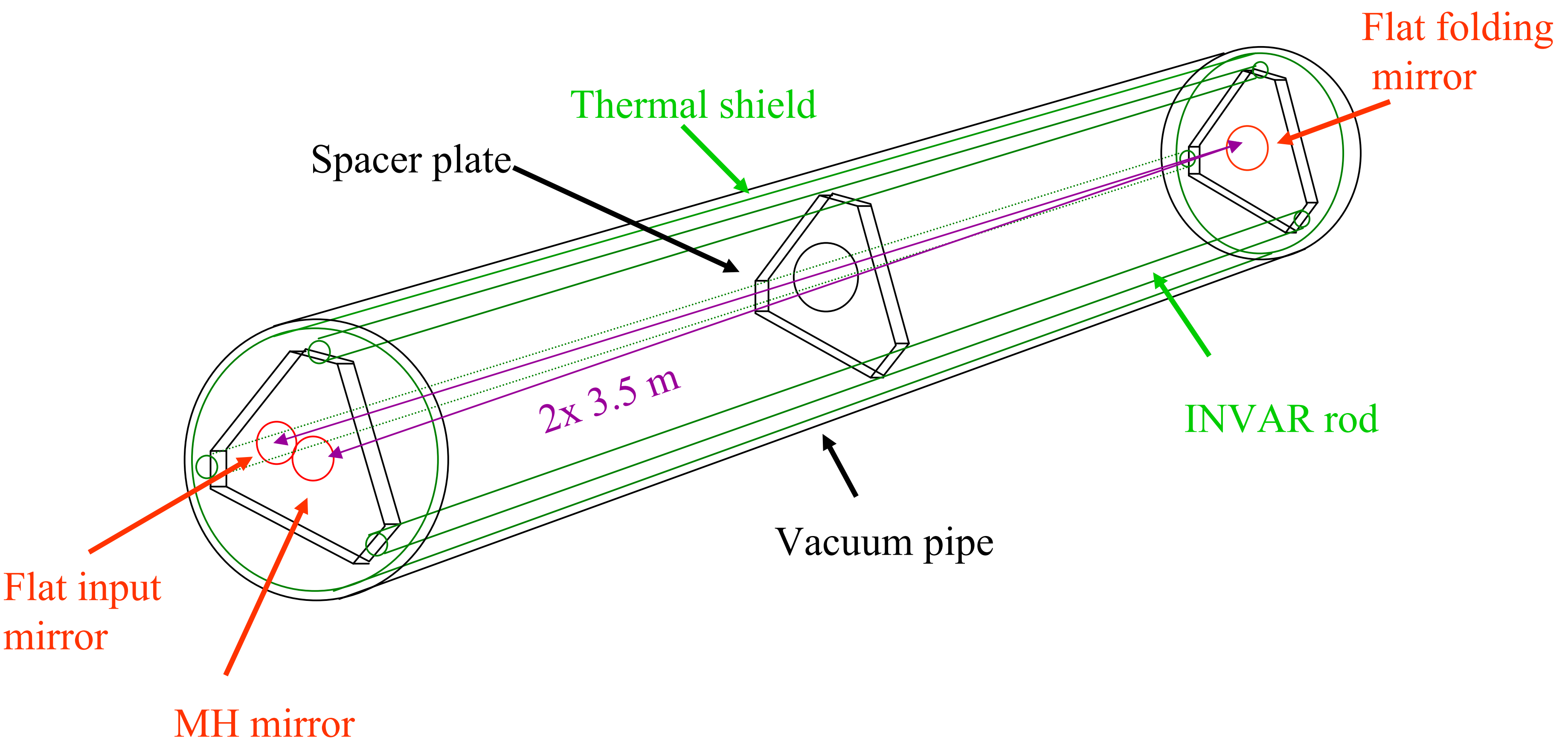
- Necessity to verify the behavior of the mesa beam and study its generation and control before its possible application to GW interferometers

We built a MH mirror FP cavity to investigate the **modes structure** and characterize the **sensitivity to perturbations**

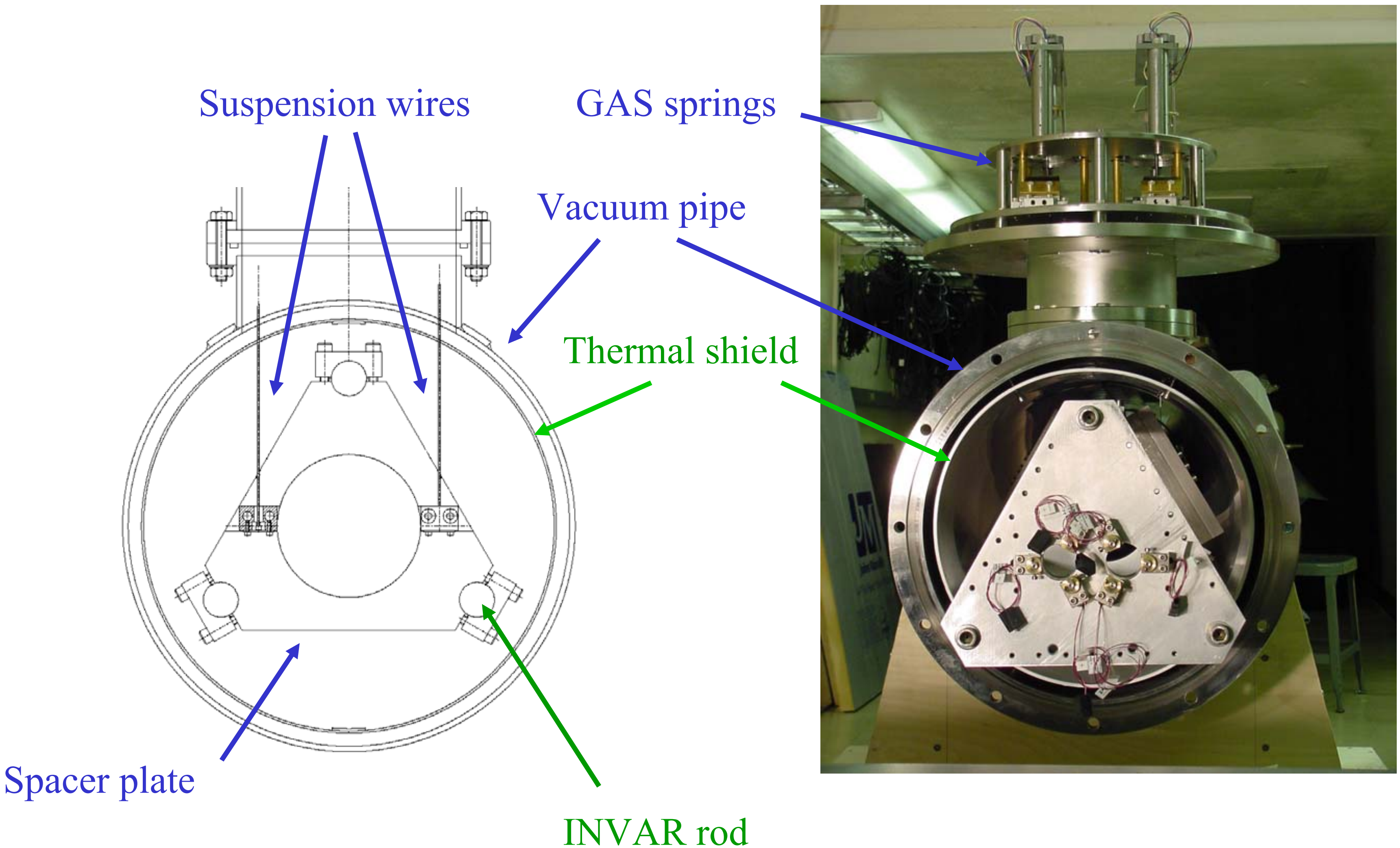
- **mirrors imperfections**
- **misalignments**

The test setup:

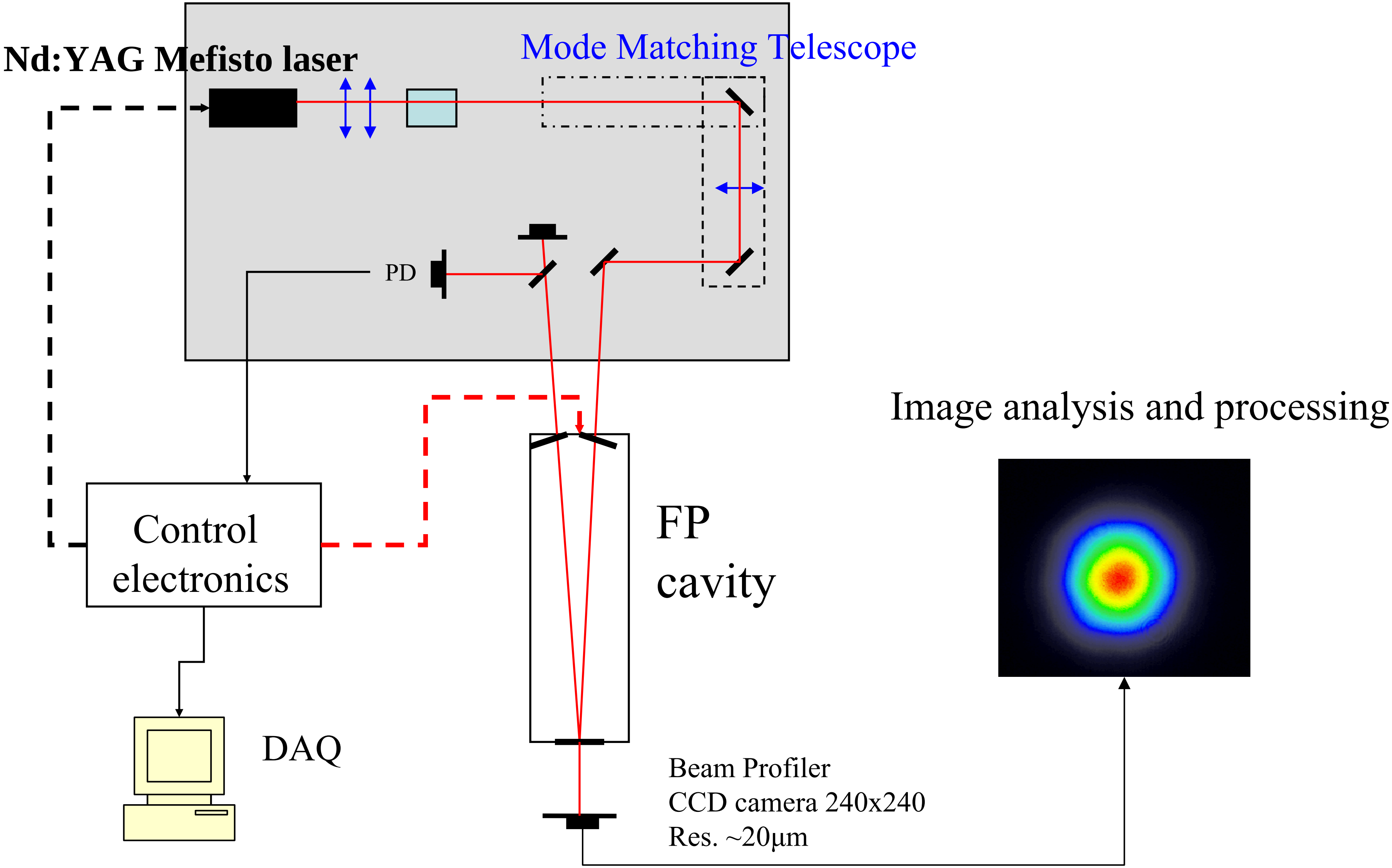
- A rigid, folded, suspended Fabry Perot Cavity



Mechanical setup



Environment setup



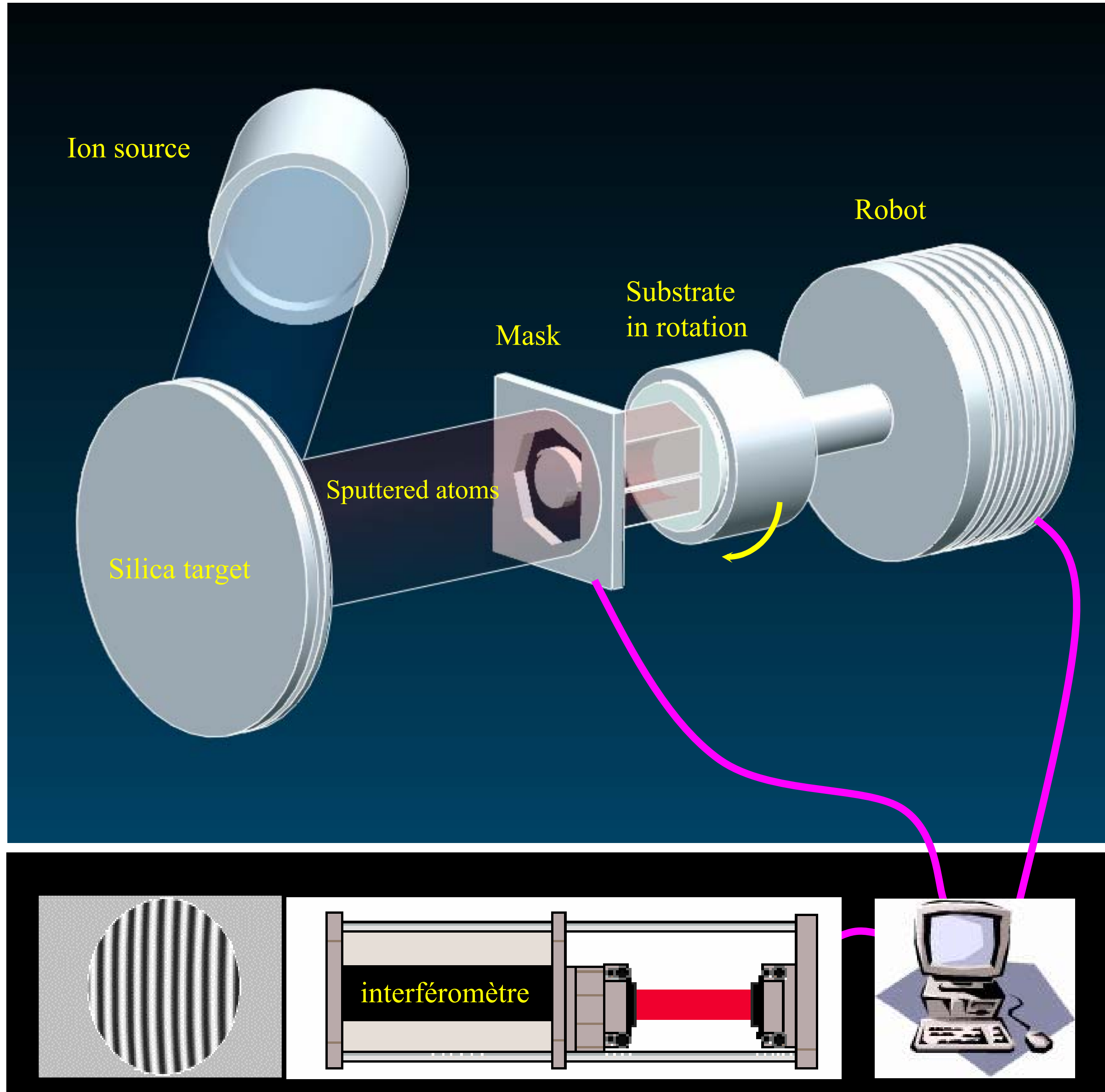
Mexican Hat mirror construction 1

Start from a flat substrate:

FIRST STEP

A carefully profiled mask between the SiO_2 ion source and the rotating substrate, calculated to deposit the required thickness where needed

•Achievable precision ~60nm Peak to Valley



Mexican Hat mirror construction 2

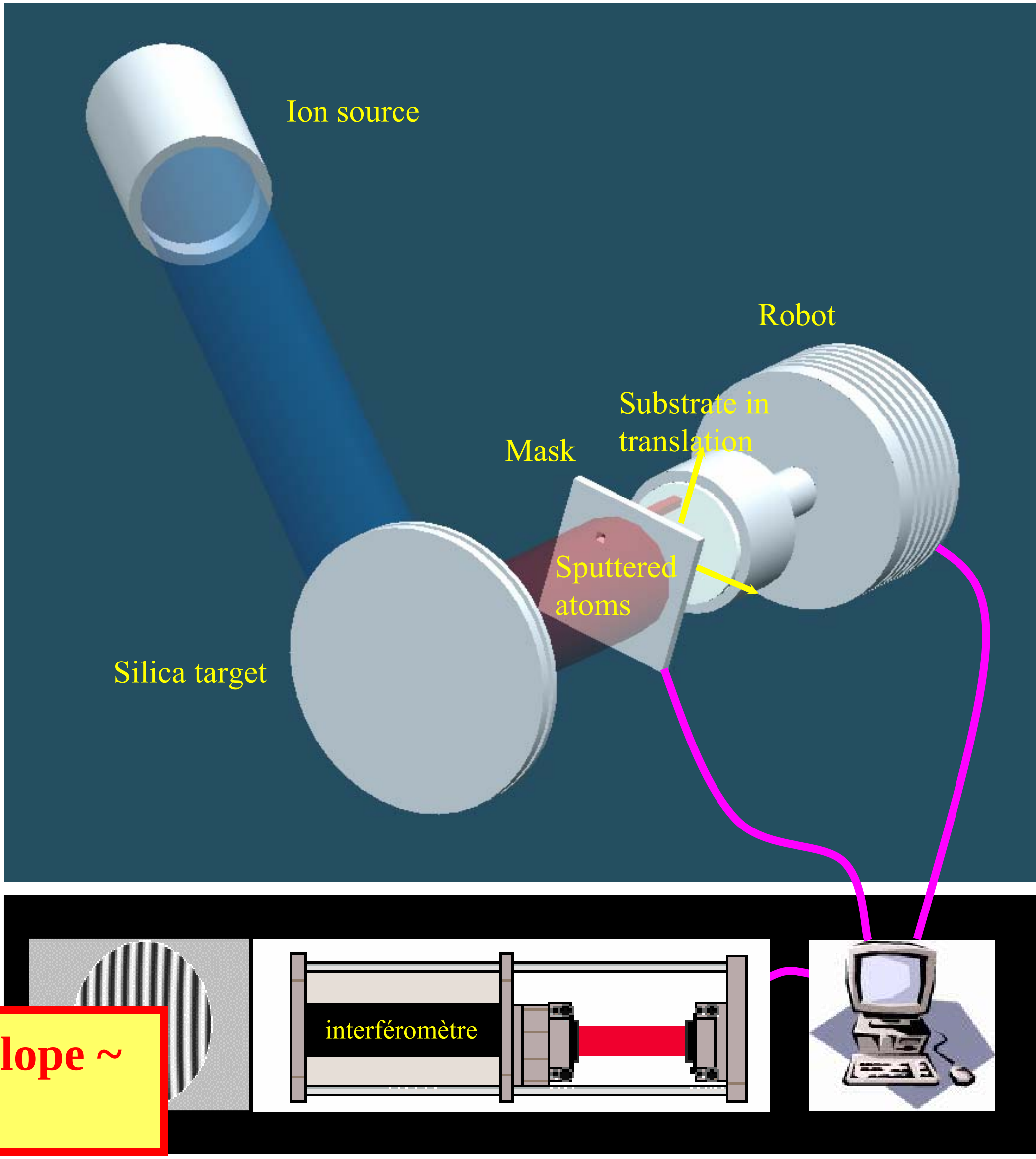
SECOND STEP

The mirror profile generated by the first step is interferometrically measured

A map of its deviation from the ideal profile is generated

The deviations are corrected under numerical control with a SiO_2 molecular beam pencil

- **Coating thickness controlled with a precision <10 nm.**



Maximum slope ~ 500nm/mm

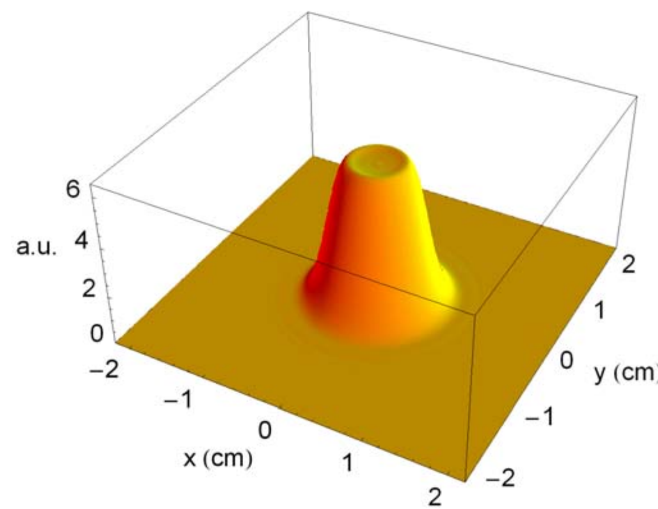
What beams can we expect from the new mirrors

- The mirrors built are at the lowest limit of manufacturable dimensions (Ø 5.08 cm)
- Larger mirrors much easier!!
- The test Mex-hat test mirrors are not perfect

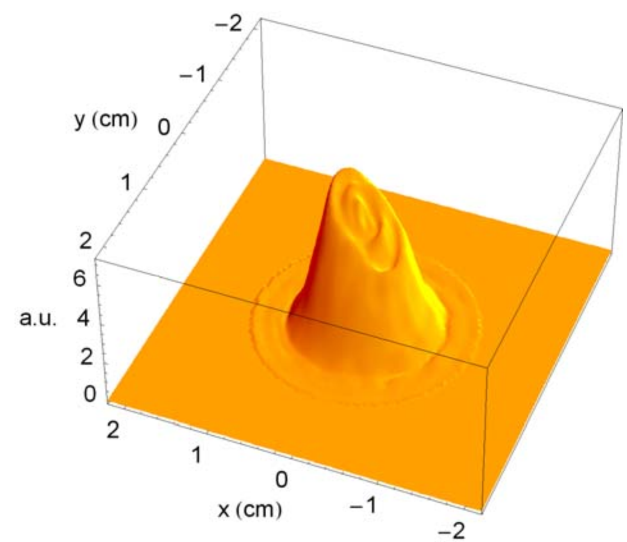
- The maps of the actual test mirrors have been used to calculate the expected best beam profile

FFT simulations

- Using paraxial approximation, FFT codes can simulate the propagation of actual TEM patterns on optical cavities



- A Mathematica FFT routine has been dedicated to simulate our cavity beam behavior: it gave us the best tool to choose the best MH: C05008

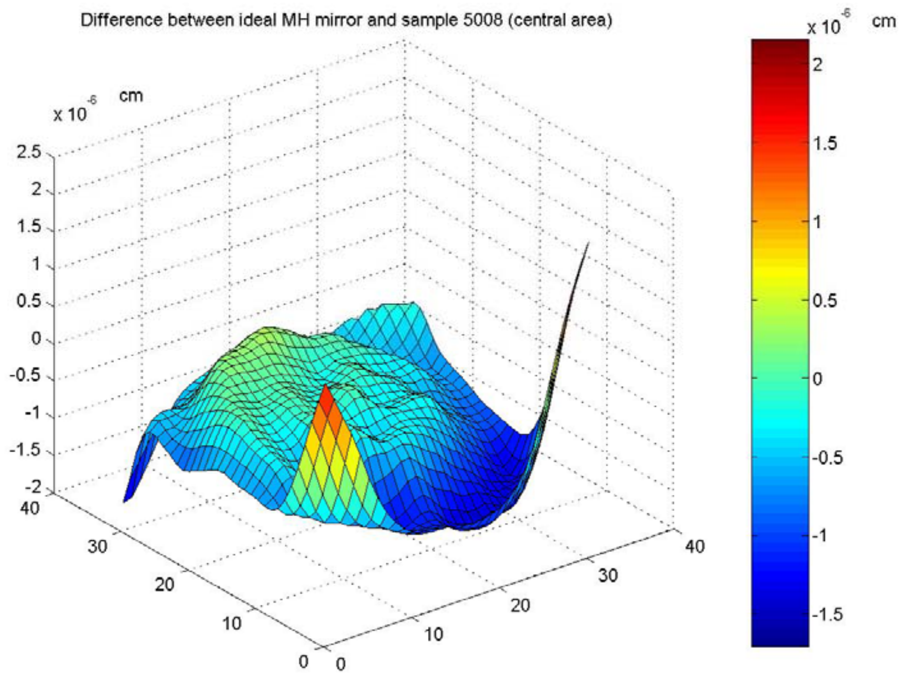


Simulation (as mapped)

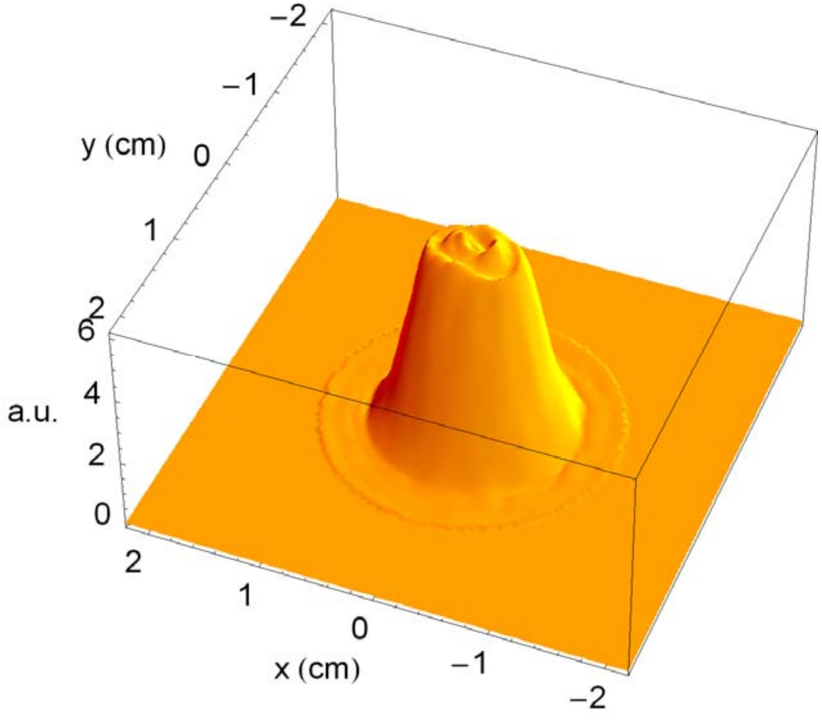
FFT simulations

- The slope on the central bump can be corrected applying the right mirror tilt

Deviation from ideal mirror profile



Beam simulated after ~1µrad tilt



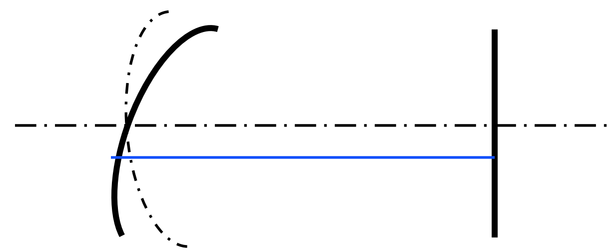
MH Cavity Alignment

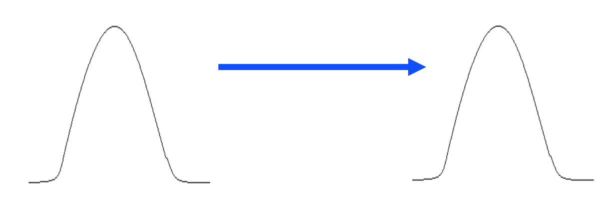
- Spherical optics: tilt is translated in a change of the optical axis
- MH mirrors: only cylindrical symmetry

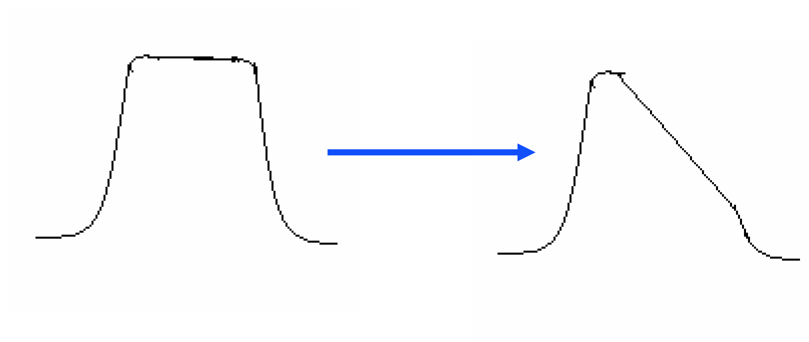
→ resonant beam phase front change with the alignment

- Folded cavity: no preferential plane for mirrors alignment

→ very difficult align within ❍m precision



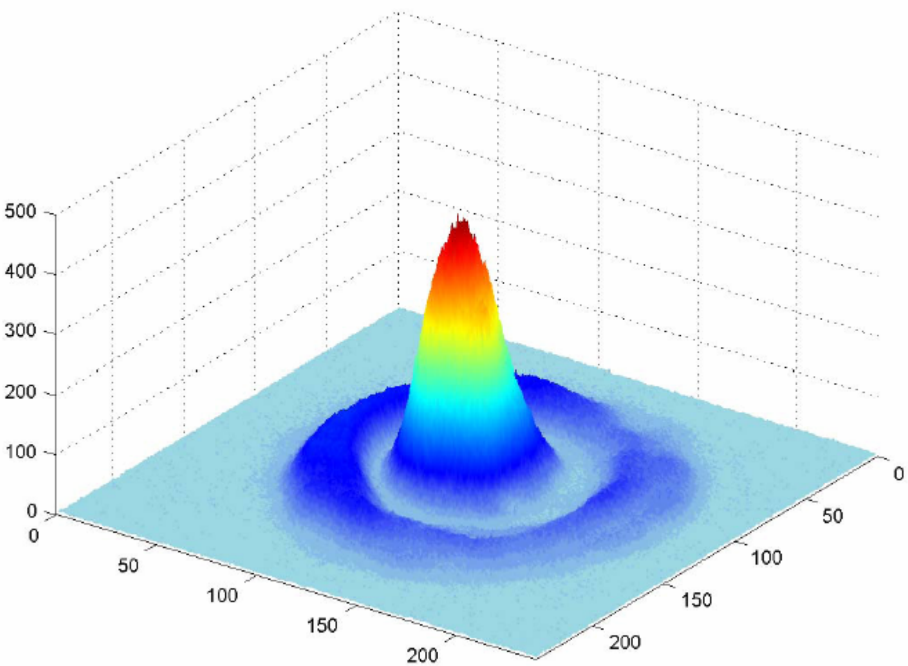




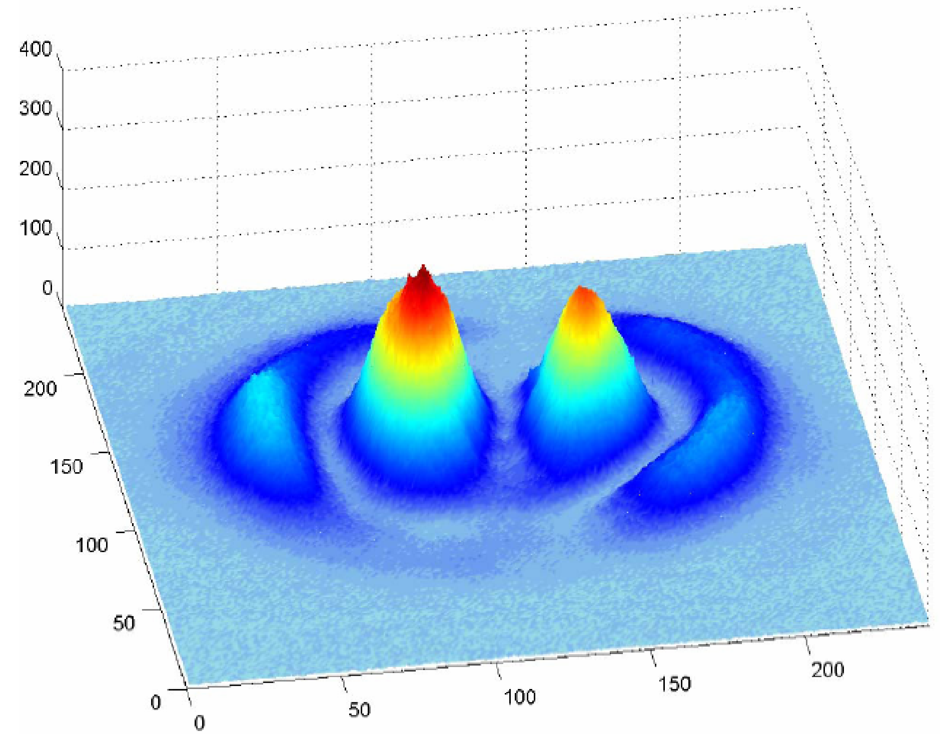
Experimental Results

- No stable Mesa beam profile has been acquired yet
- Higher order modes were found very easily

TEM_{10}

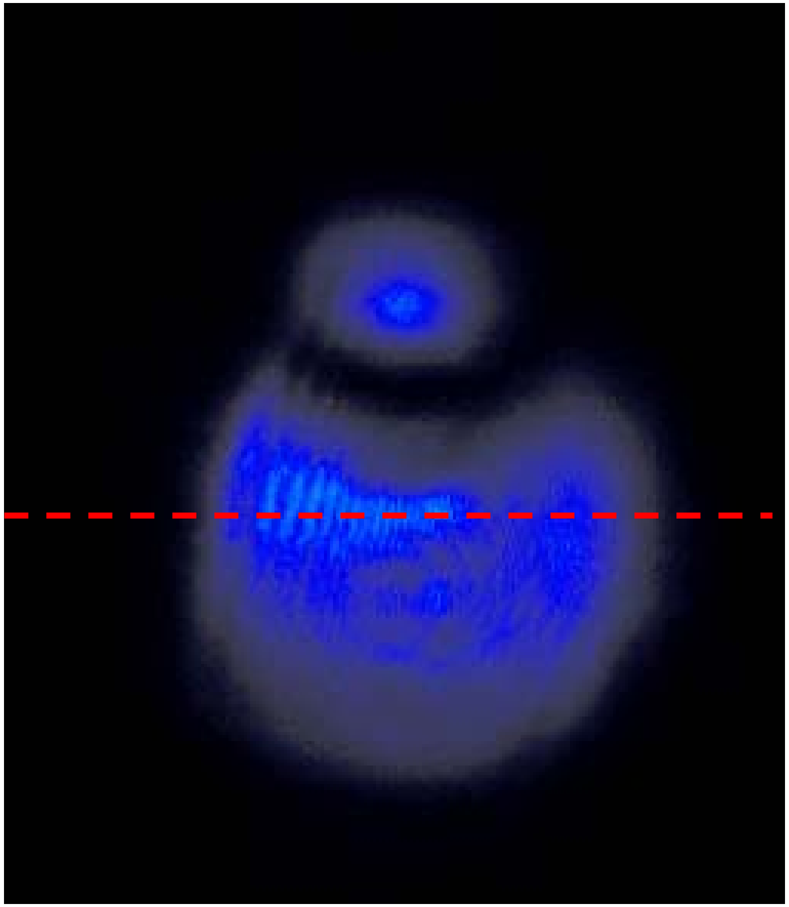


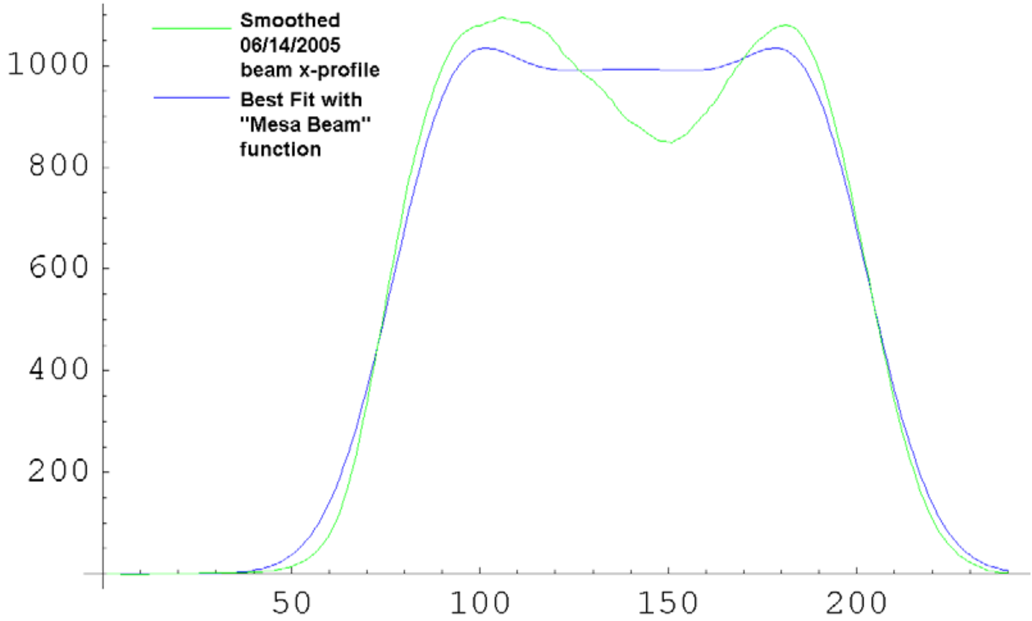
TEM_{11}



Experimental Results

- Other resonant TEMs:



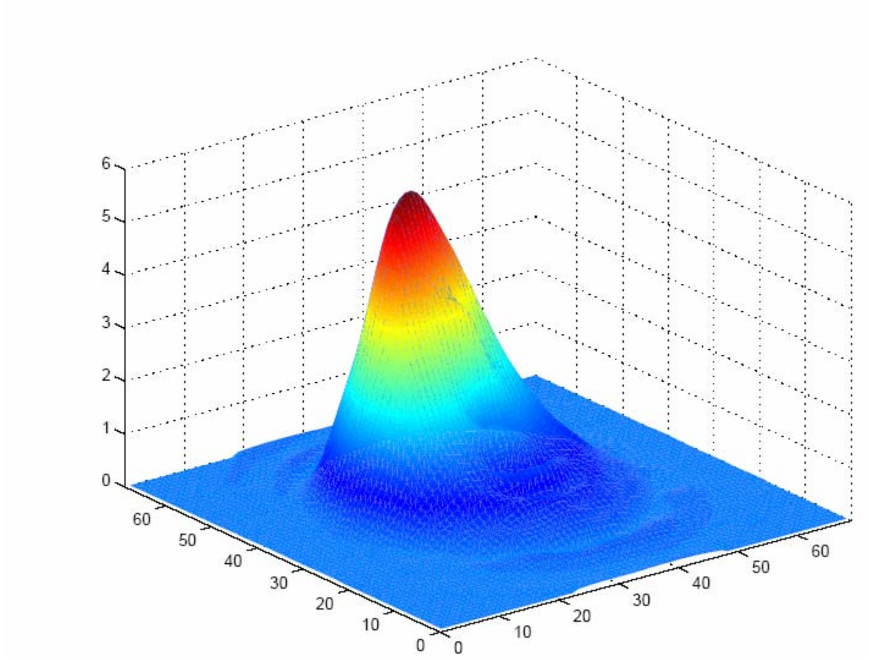


2-dimensional nonlinear regression:

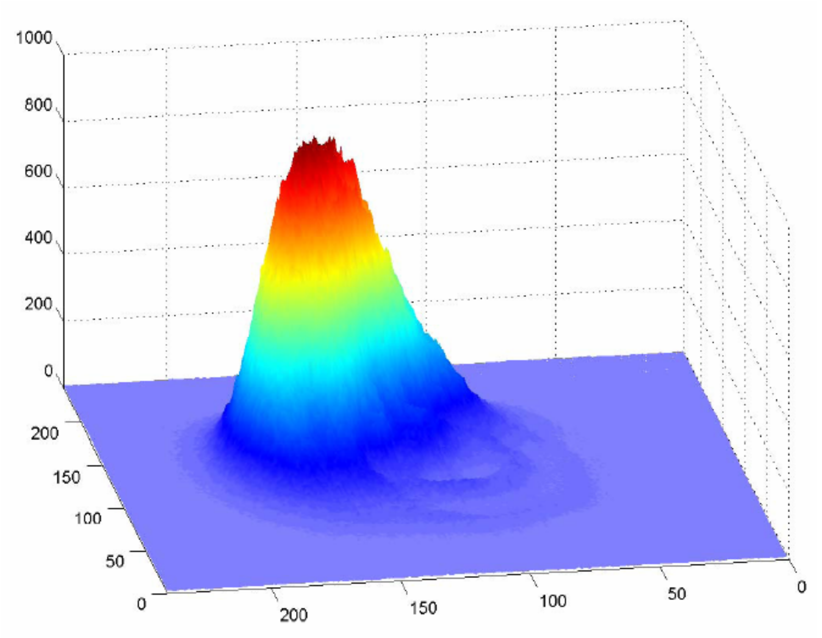
Definitively not gaussian

Experimental Results

Misalignment and mismatch effects have been modeled to recognize “strange” resonant modes

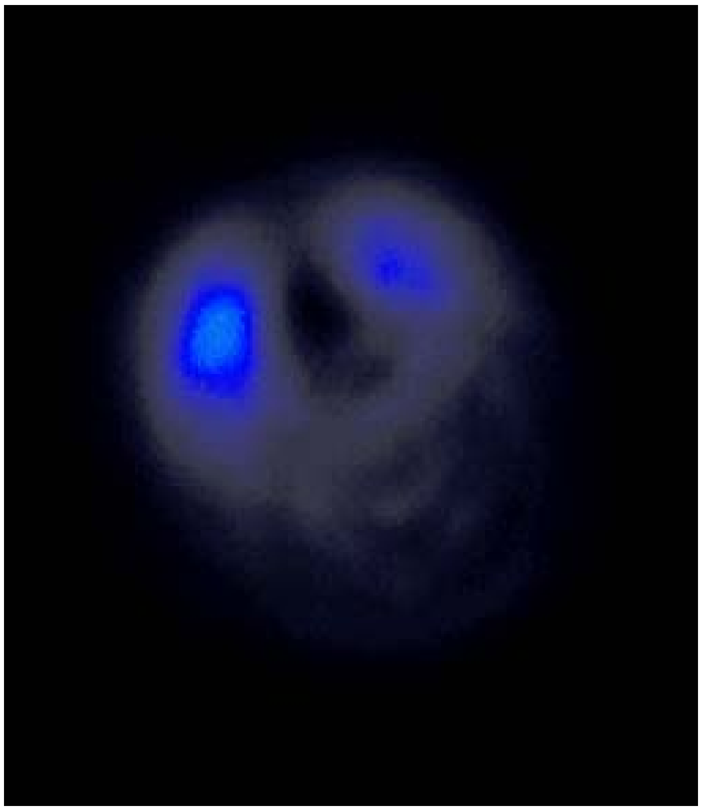


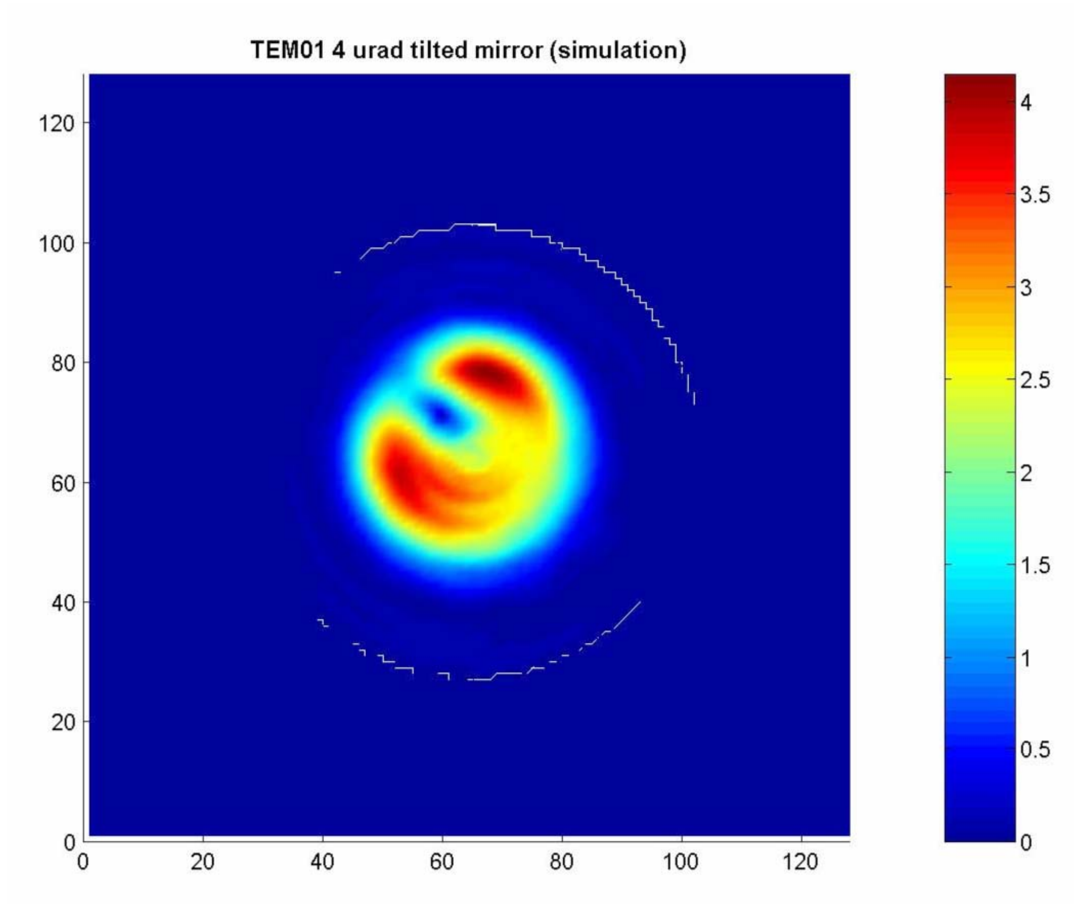
TEM00 simulated with 5μrad tilt of the MH mirror



TEM00 data

Experimental Results





Considerations and next steps

Any attempt to "drive" the beam in a centered configuration failed

FP spectrum analysis: peaks are separated enough → we are observing the actual cavity modes

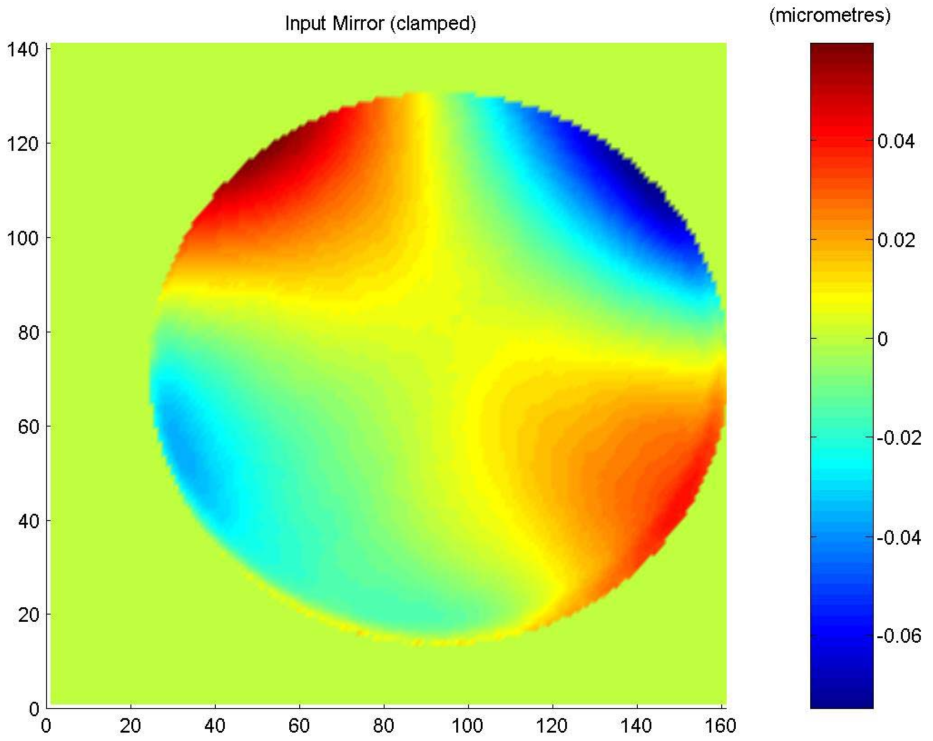
Manual alignment seems insufficient: simulations set a constraint on angular control better than few μrad

Evidence: mode shape degradation as we tried to align the cavity using the full range of PZT actuators

Central part of the cavity seems "unstable": maybe the problem is not the MH but the other two mirrors…

Systematic and next steps

- Mechanical clumping, PZTs and screws stress yields deformations on the folder and input mirrors
- ~ 60 nm deformation -> three times the height of the MH central bump
- Marked astigmatism is induced
- FFT simulation with actual IM profile in progress



Next…next steps

- Change mirrors mounts and test new cavity behavior
- Model folder mirror effects on the resonant modes
- Automatic alignment, vacuum operations…