First Results from the Mesa Beam Profile Cavity Prototype

Marco Tarallo
(Universita` di Pisa)

In collaboration with **J.Agresti, E.D'Ambrosio, R. DeSalvo, D.Forest(*), B.Lagrange(*), J.M. Mackowsky(*), C. Michel(*), J.L. Montorio(*), N.Morgado(*), L.Pinard(*), A.Remilleux(*), B.Simoni, P.Willems**

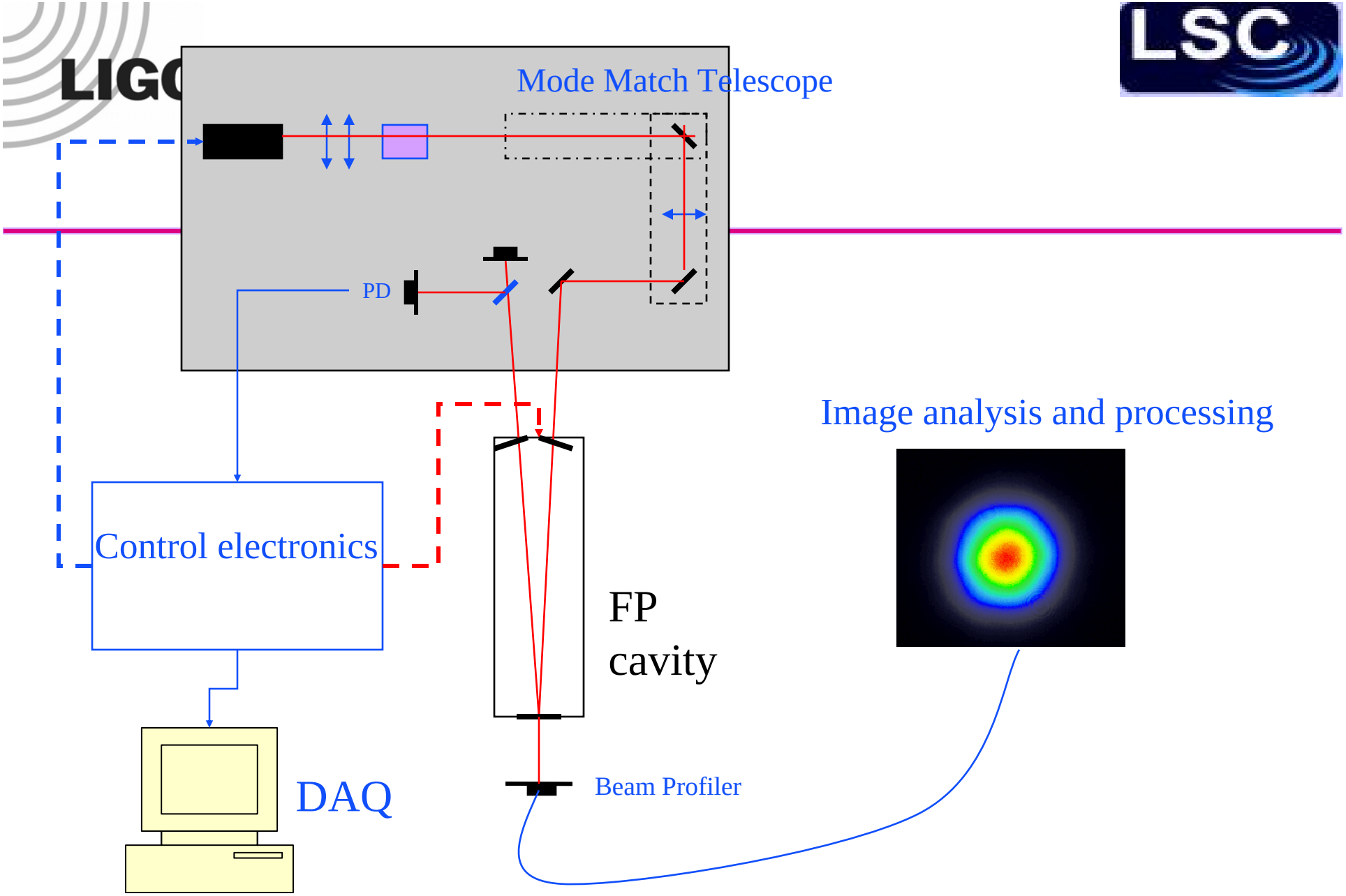
(*) = LMA Laboratory Collaborators

Contents

- Environment setup: description and first tests with spherical optics
- MH mirrors: their shape and expected resonant beams
- Sample C05008: profiles analysis and simulations
- Systematic and next steps

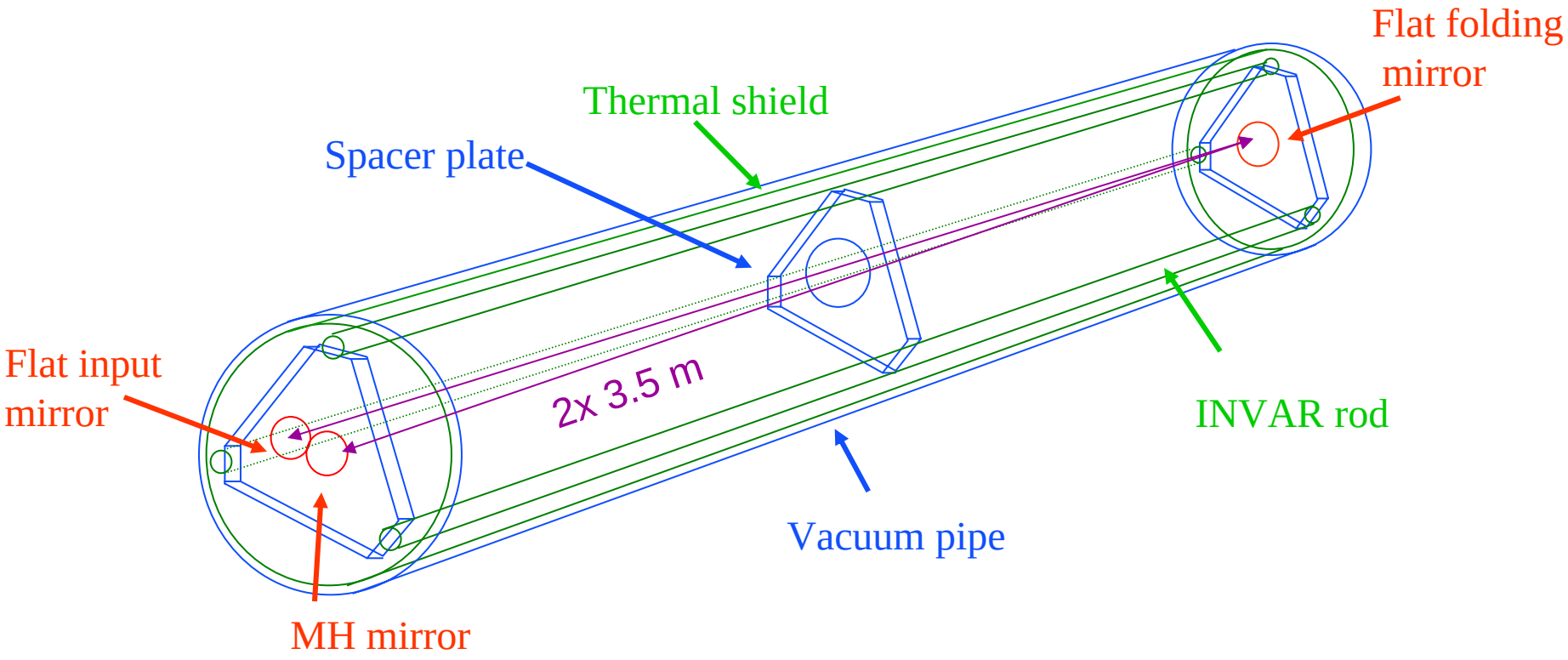
Environment setup

- Input/output optics bench:
  - Nd:YAG Mephisto laser
  - Mode match telescope
  - Fast photodiode for transmitted power readout
  - CCD camera to control the locked TEM
- Suspended FP cavity
- Profile readout bench (CCD camera, high resolution)
- Feedback control electronics & cavity mirrors DC driving


Mode Match Telescope
PD
Control electronics
FP
cavity
Image analysis and processing
DAQ
Beam Profiler

Environment setup

Fabry-Perot cavity structure in detail



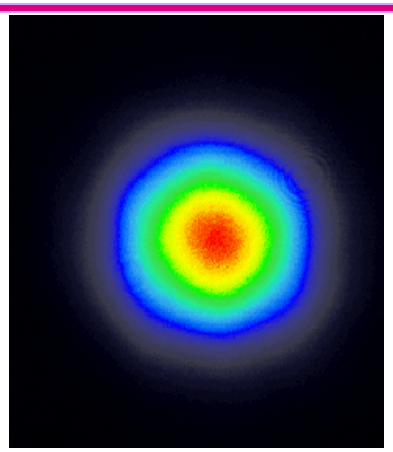
Cavity Lock Acquisition

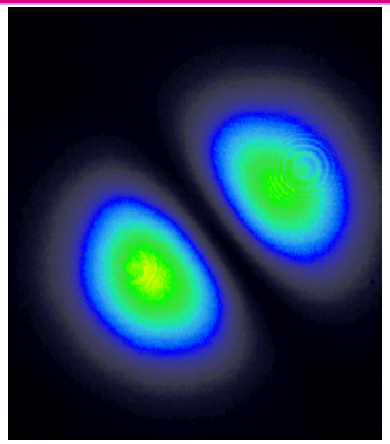
- Tested with a R=800cm roc spherical mirror
- Two techniques:
  - Side locking: control on the injection current -> easier
  - Dither locking: modulation of the cavity length -> possibility to measure coupling with input beam but more sensitive to noise
- Results:
  - TEM patterns characterization
  - Environment capability to keep a lock

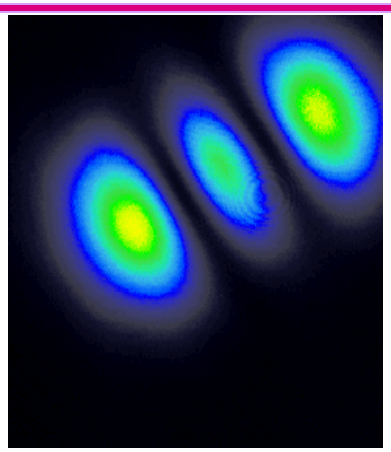
TEMs with spherical end mirrors

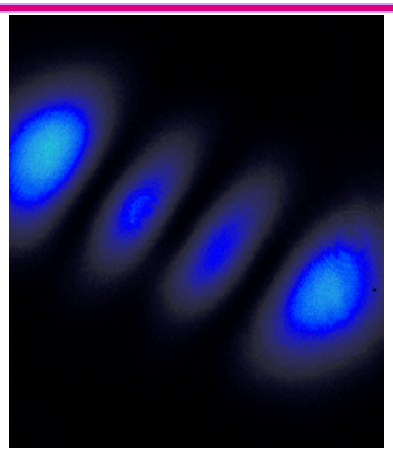
Resonant beams: experimental data

Hermite-Gauss TEM set


TEM00

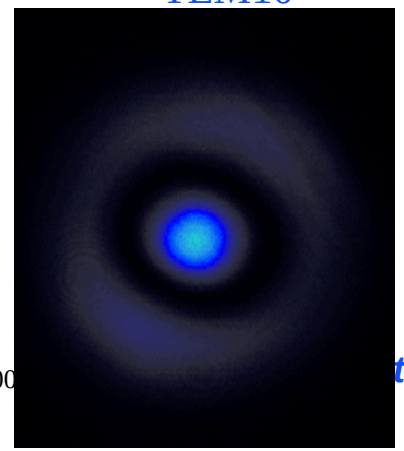

TEM10


TEM20

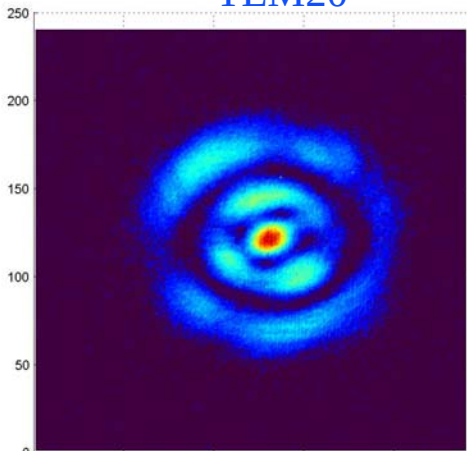

TEM30

Laguerre-Gauss TEM set

TEM10

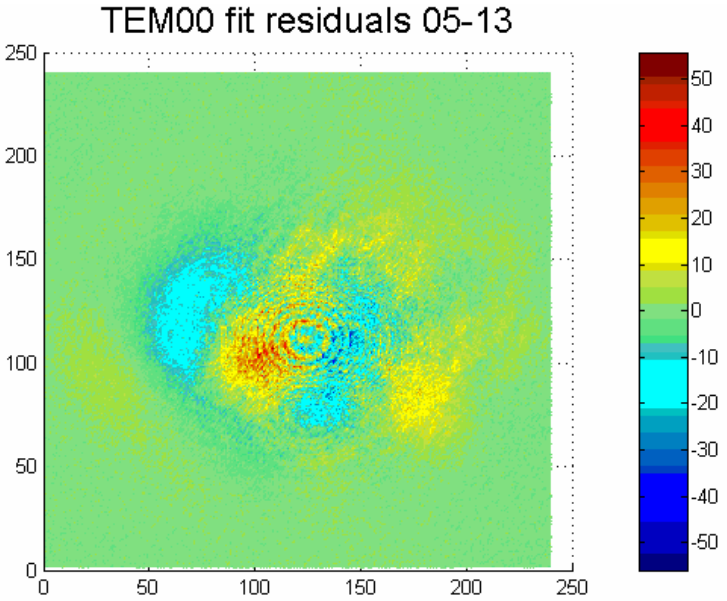


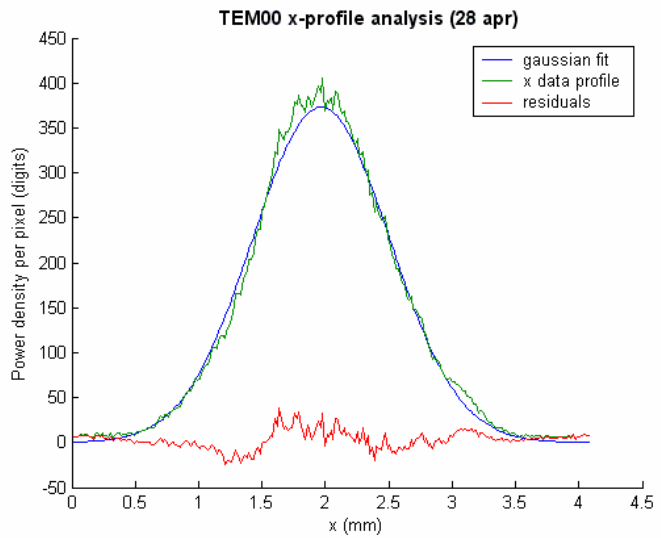
TEM20



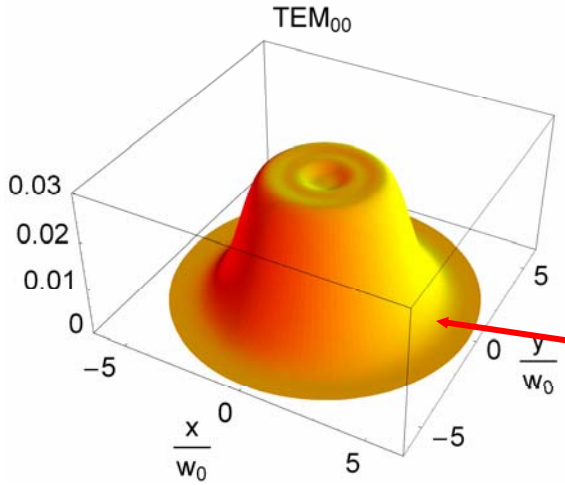
TEMs with spherical end mirrors

- Qualitative analysis:
- Cylindrical symmetry gradually lost
- Difference between theoretical Hermite-Gauss and actual TEMs beam profiles (structure in the residual map)
- Marked unbalance between the two TEM10 peaks: not avoided with fine PZTs adjustments



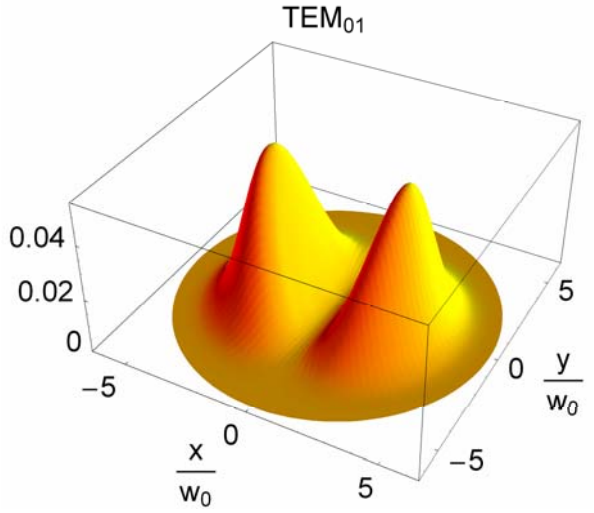


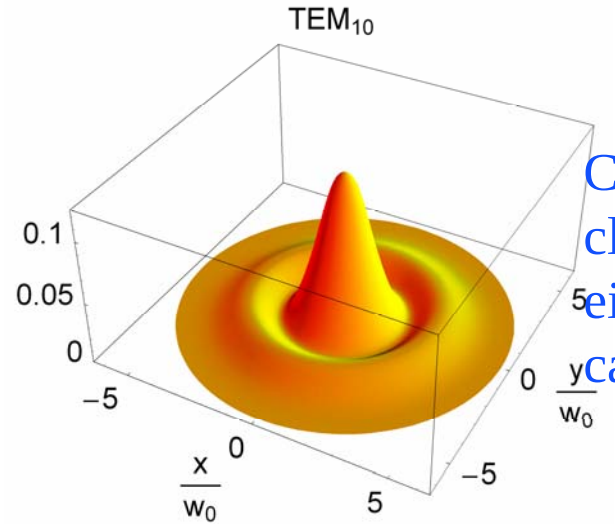
“Mexican hat” mirrors



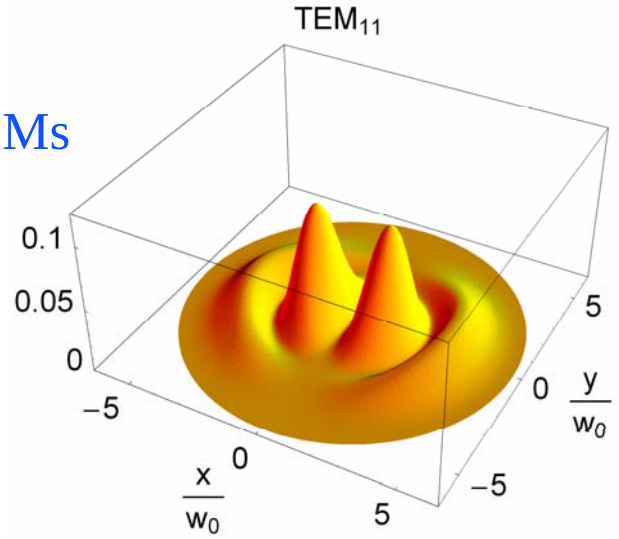
Numerical eigenmodes for a ideal MH Fabry-Perot interferometer:

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



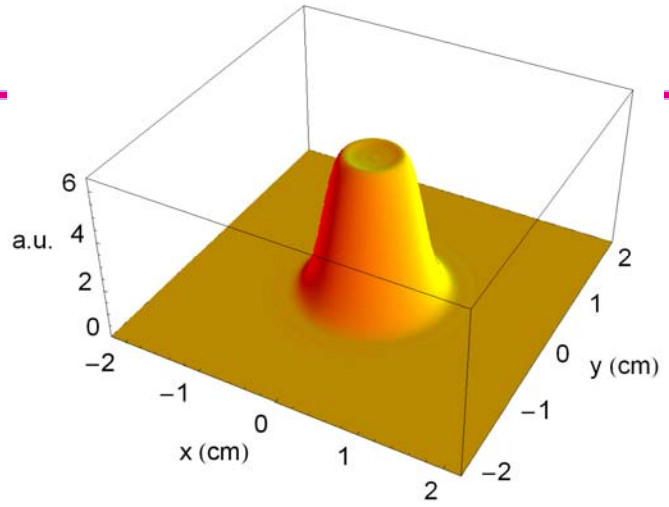
“Mexican hat” mirrors

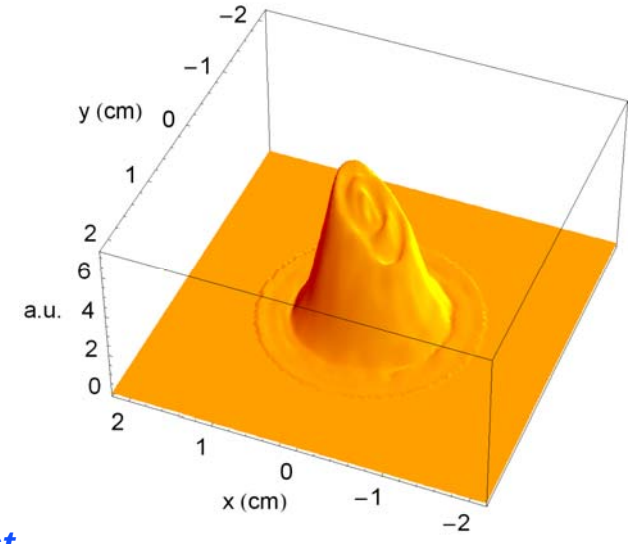
- LMA laboratories provided three mirror samples
- C05004 (test run):
  - Thin substrate (20 mm)
  - large offset on the central bump
- C05008 & C05009:
  - Thick substrate (30 mm)
  - Both affected with a not negligible slope on the central bump

➡ We can characterize how mirrors imperfections affects the resonant beam in such a interferometer

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

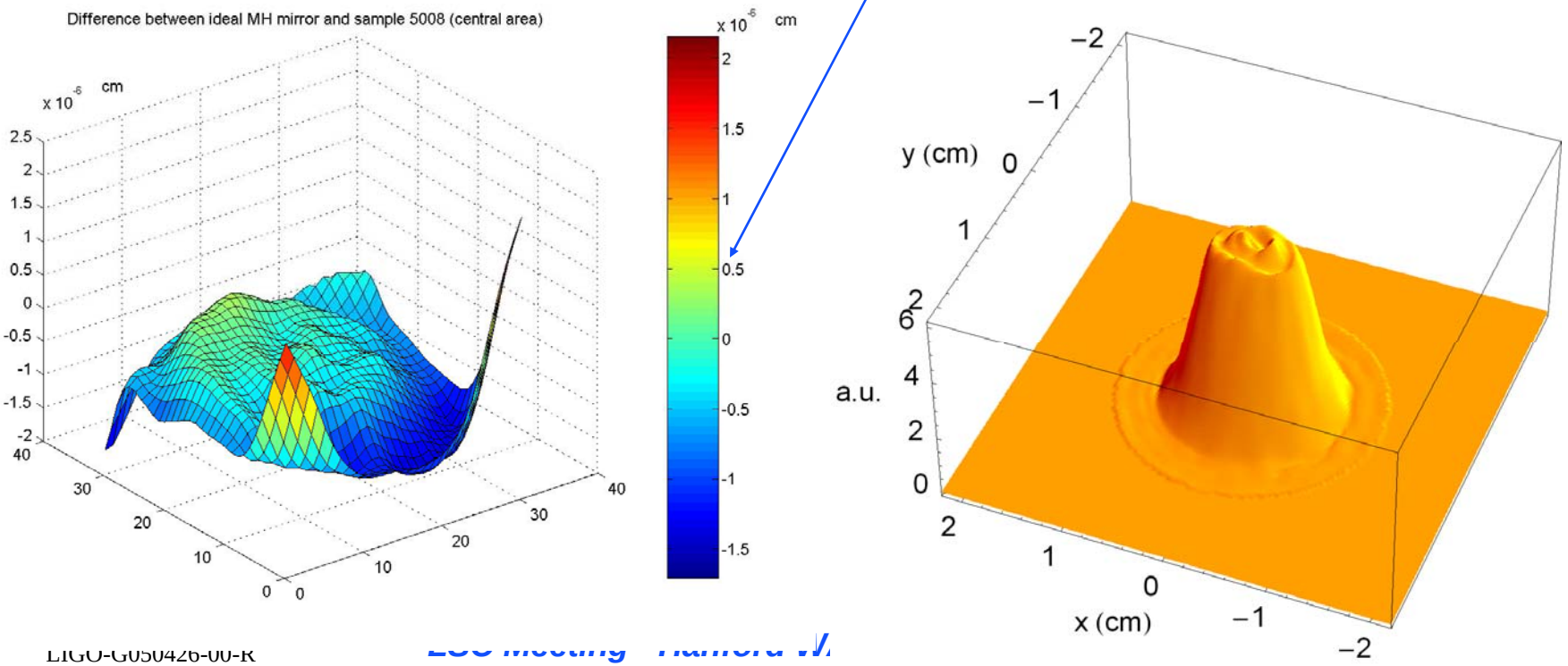




FFT simulations

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

≈5 nm error central area



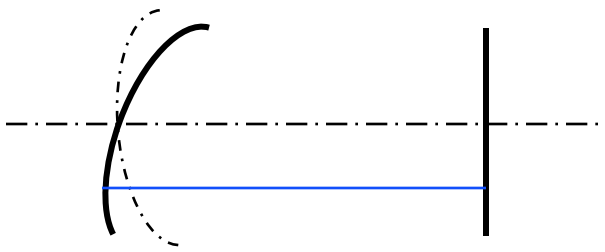
MH Cavity Alignment

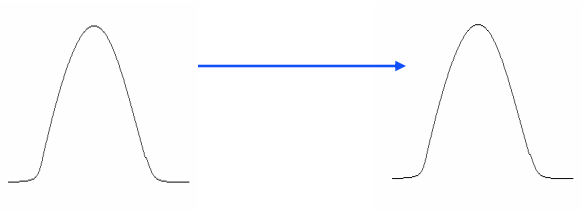
- Spherical optics: tilt is translated in a change of the optical axis
- MH mirrors: only cylindrical symmetry

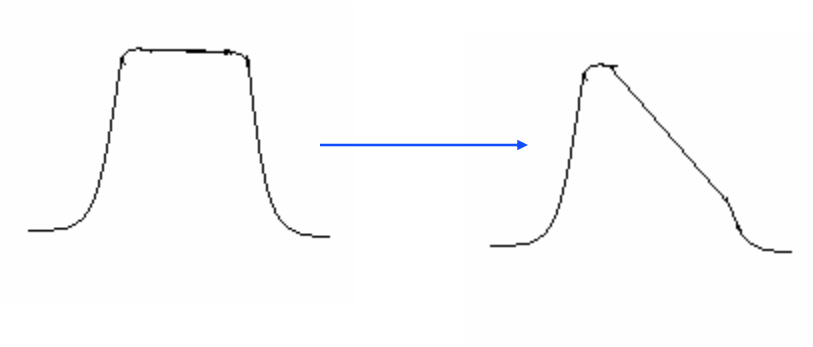
-> resonant beam phase front change with the alignment

- Folded cavity: no preferential plane for mirrors alignment

-> very difficult align within ❍rad precision

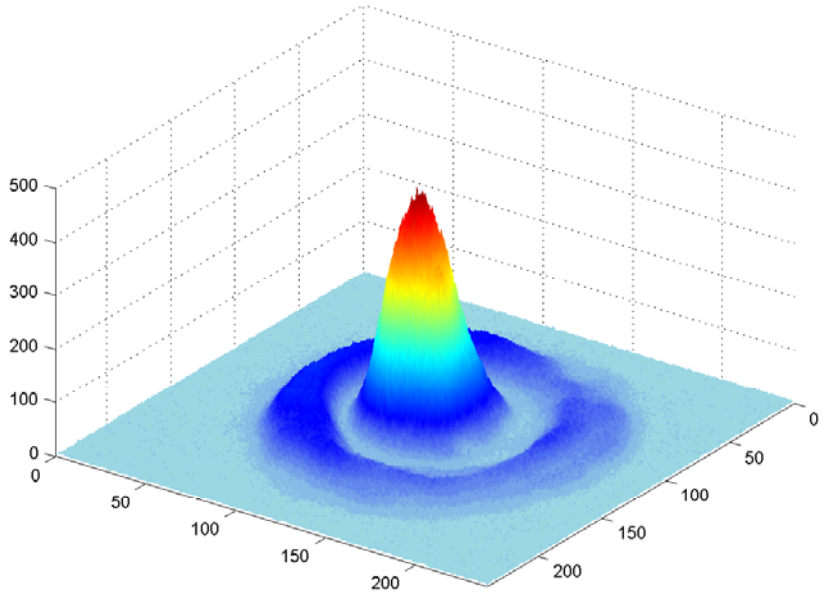


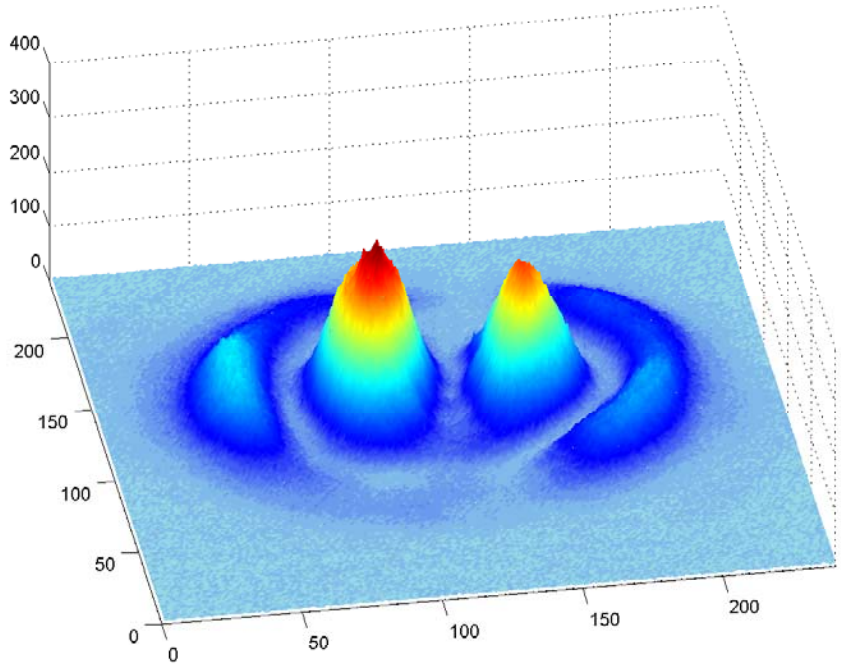




Experimental Results

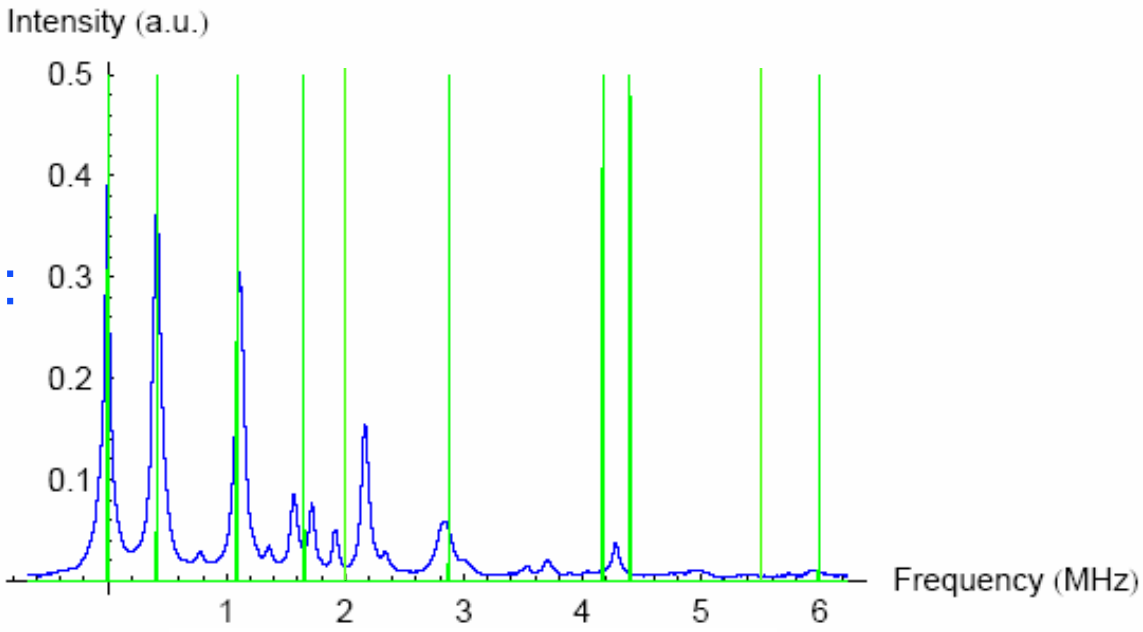
- No stable Mesa beam profile has been acquired yet
- Higher order modes were found very easily





Experimental Results

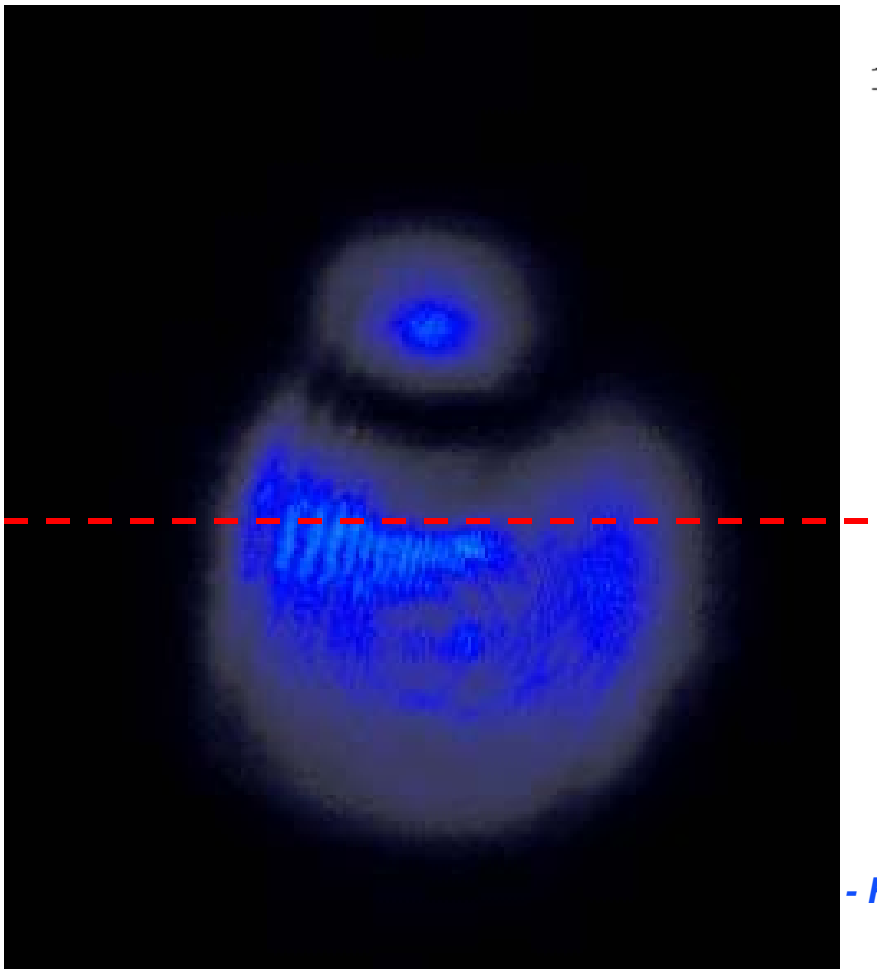
- FP spectrum analysis:
- TEMs identification and coupling analysis
- Non-symmetric spacing: as expected
- More peaks than we should see?

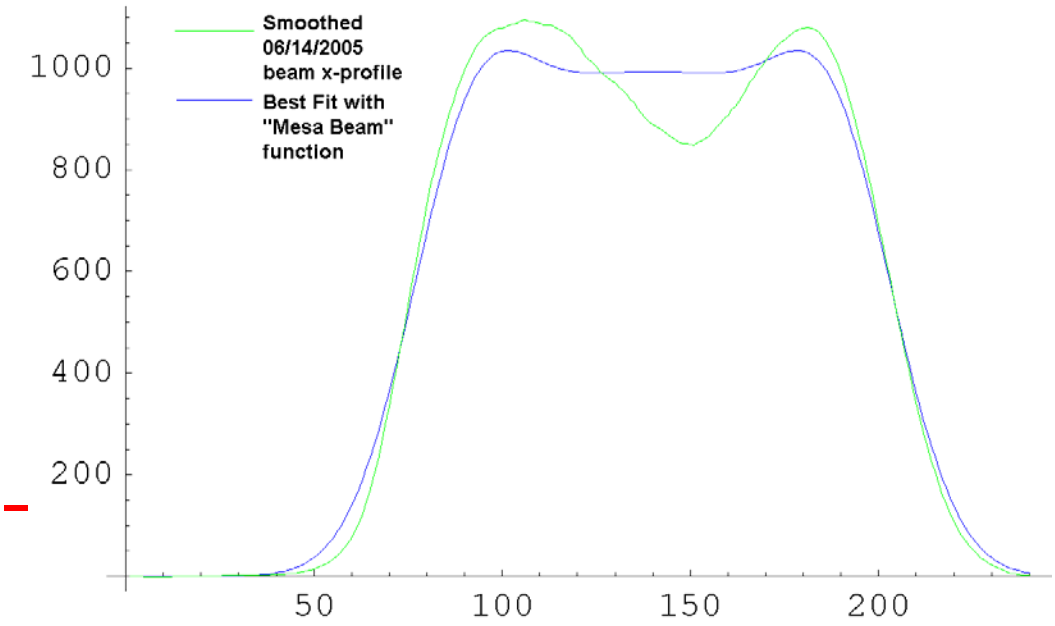


$$\Delta\nu_{FSR} = 20.5 \text{ MHz}$$

Experimental Results

- Other resonant TEMs:



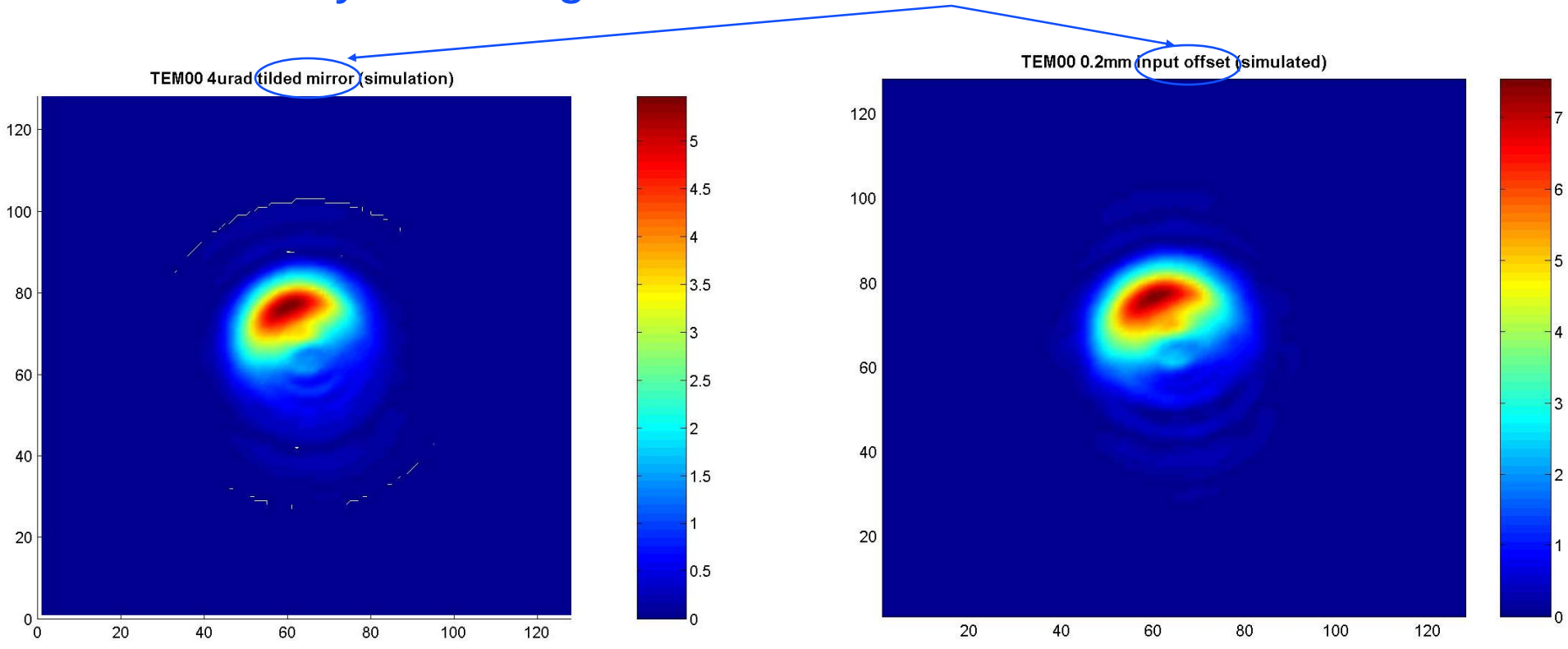


2-dimensional nonlinear regression:

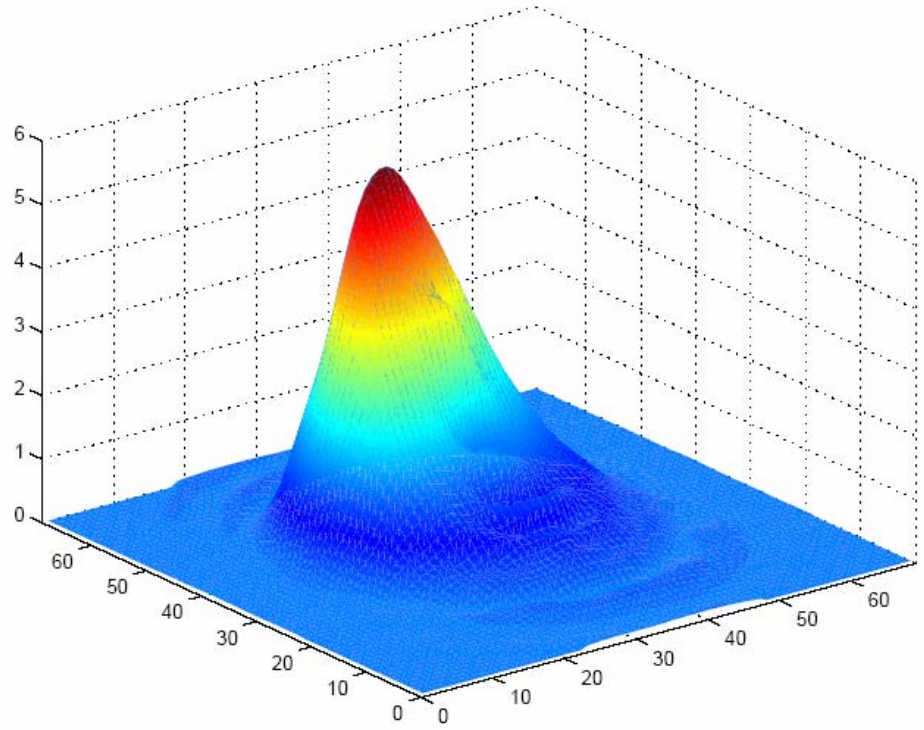
Definitively not gaussian

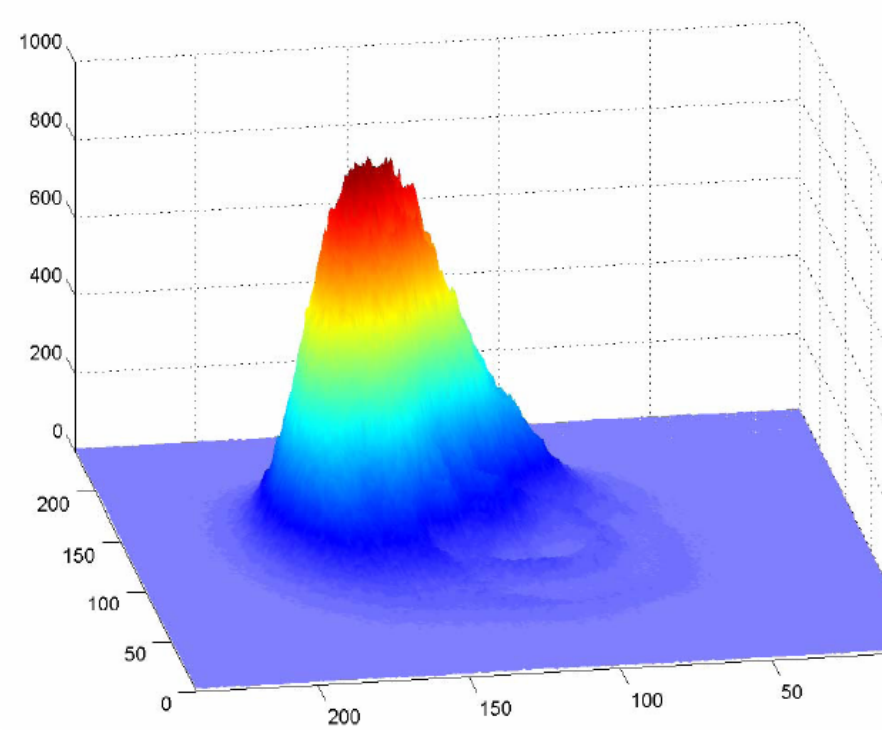
Experimental Results

- Misalignments and mismatching effects has been modeled to recognize “strange” resonant modes
- No way to distinguish between them



Experimental Results

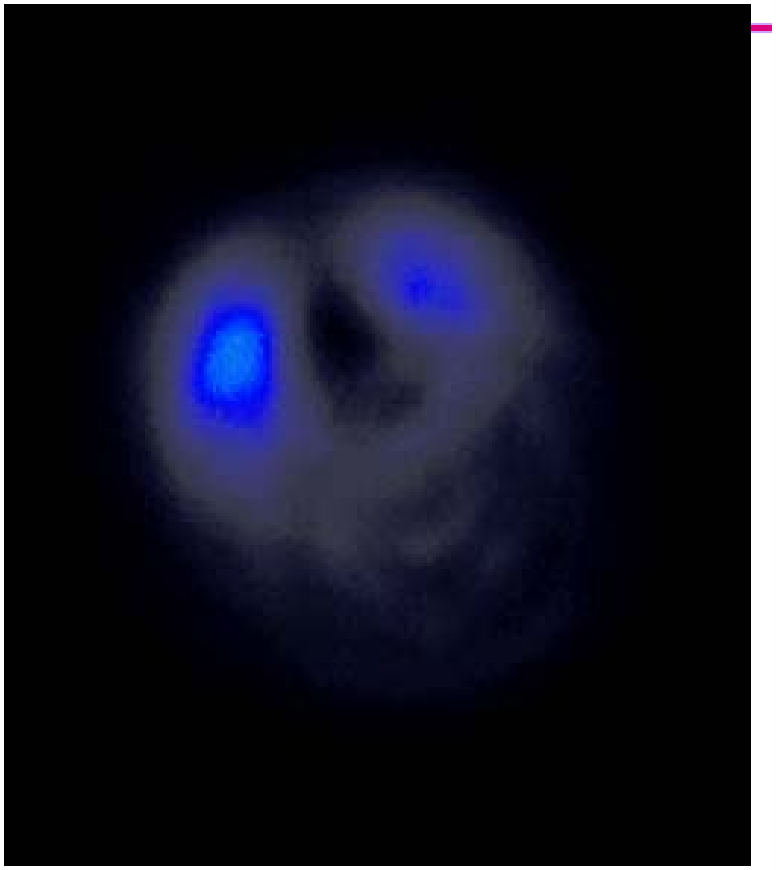


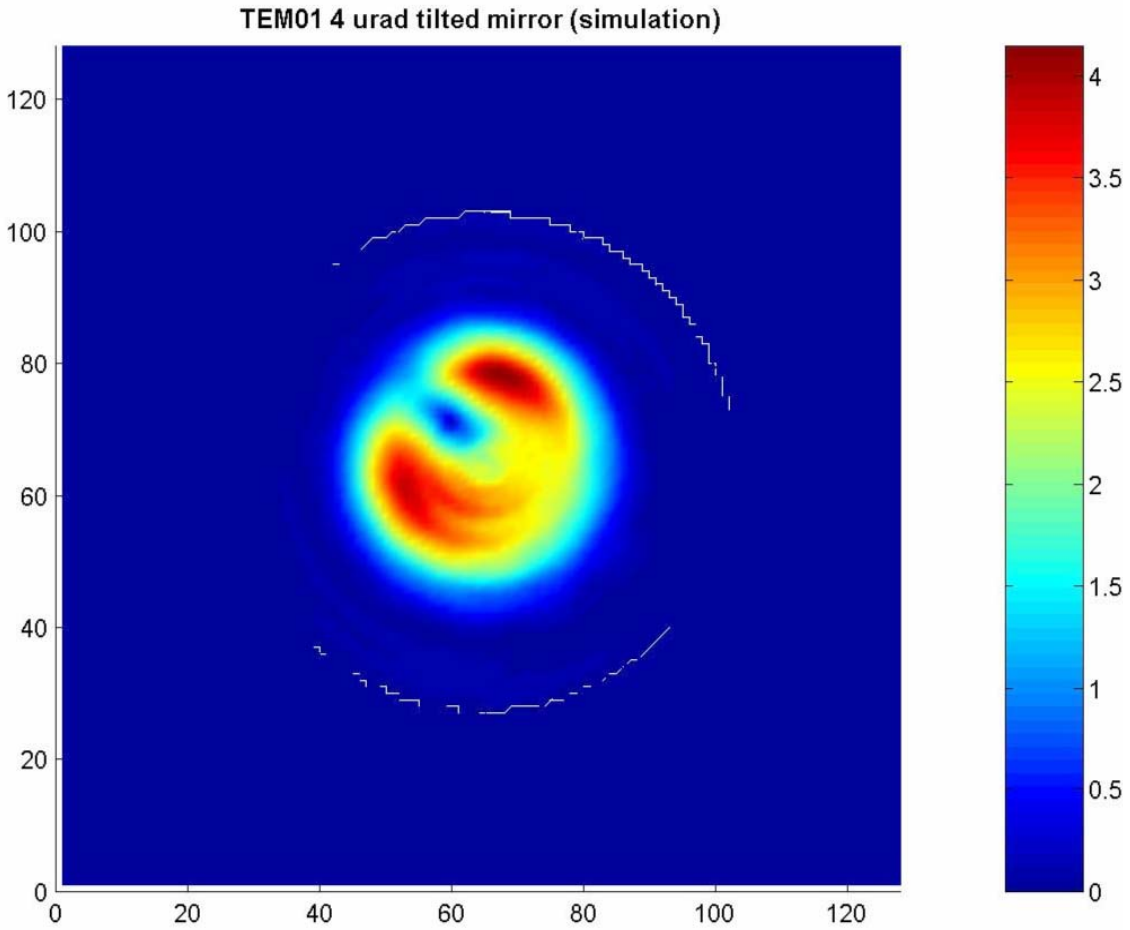


- TEM00 tilt simulation

TEM00 data

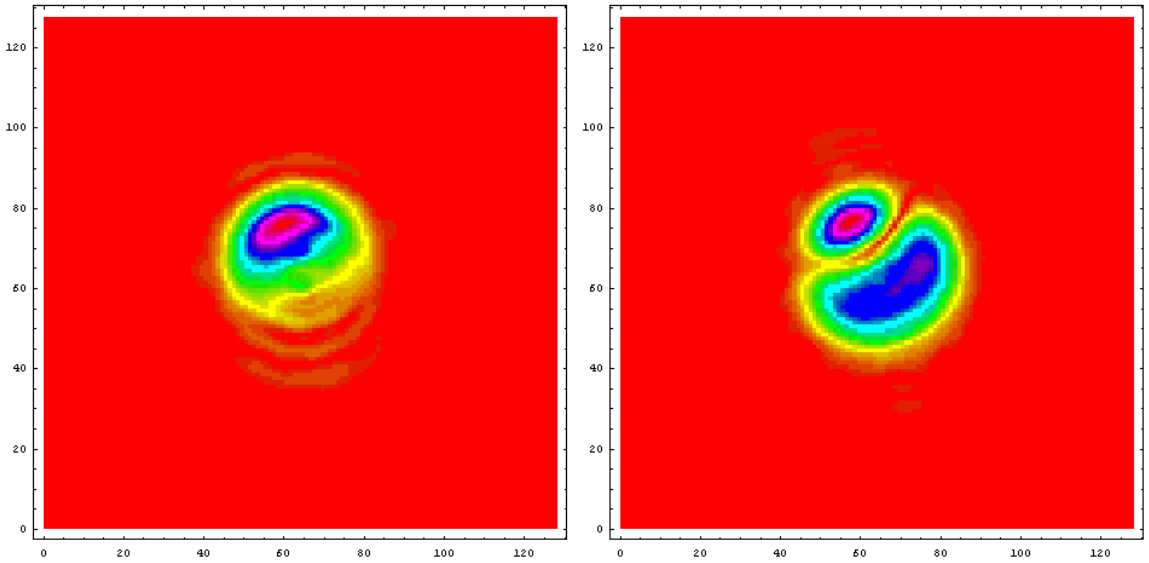
Experimental Results





Systematic and next steps

- Any attempt to “drive” the beam in a centered configuration failed
- FFT: even cylindrical symmetry is definitely lost
- FP spectrum analysis: peaks are separated enough -> we are observing the actual cavity modes

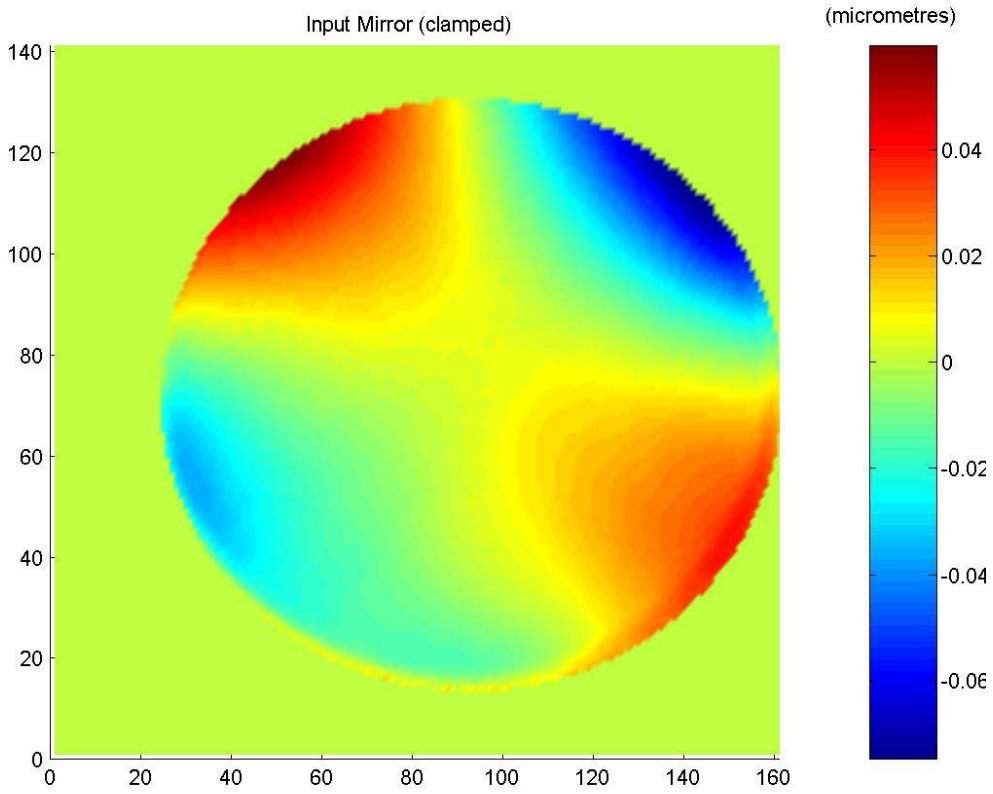


Systematic and next steps

- Coupling efficiency measurements:
- Since TEM10 seemed very stable, we investigated about the actual coupling coefficients and modes finesse
- Strange evidence: every time we tried to align the cavity, mode shapes became worse and worse (as with spherical end mirror) -> coupling measurements are not concluded yet
- 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



Systematic and next steps

- Next steps:
- Change mirrors mounts (done!) and test new cavity behavior
- Model folder mirror effects on the resonant modes
- Automatic alignment, vacuum operations…
- Noise characterization: dithering possible only at low frequencies (~10 kHz) -> maybe error signal too noisy (work in progress)