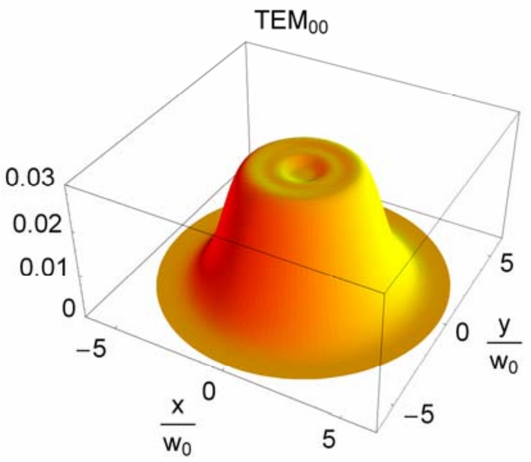
Depressing Thermal Noise via Non-Gaussian Beams

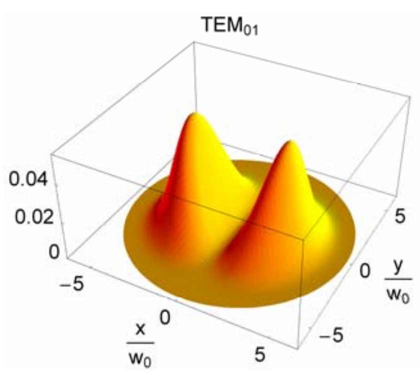
John Miller

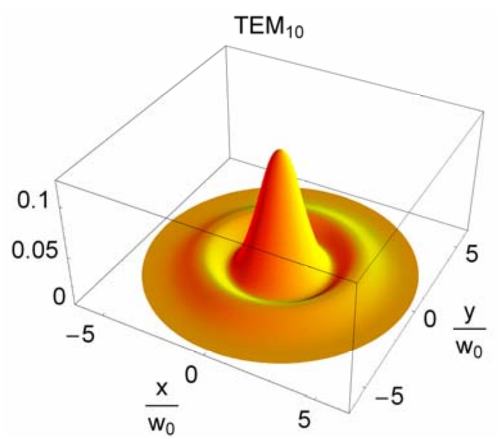
University of Glasgow, U.K.

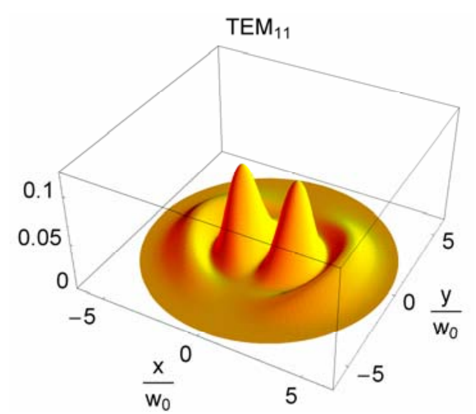
Introduction

- Motivation for non-Gaussian beams
- Mesa beams
- Prototype cavity
- Initial Results





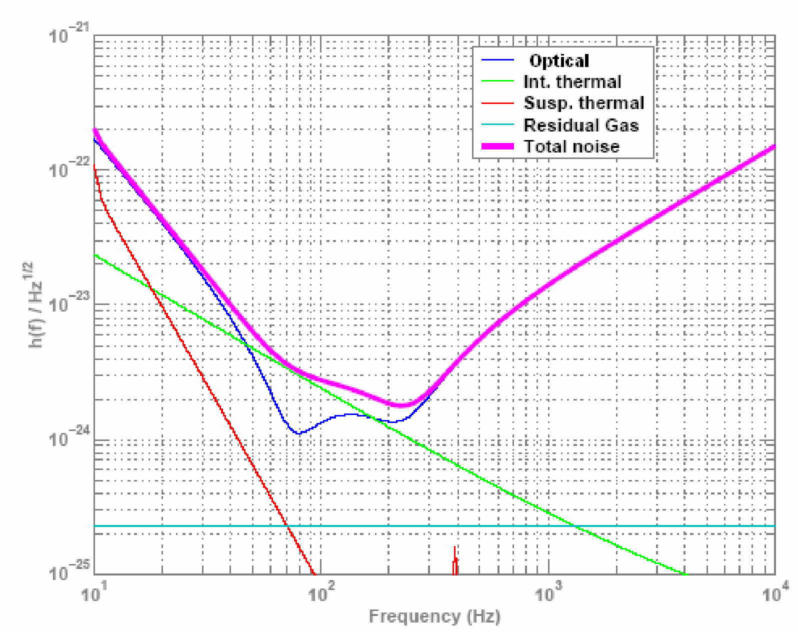




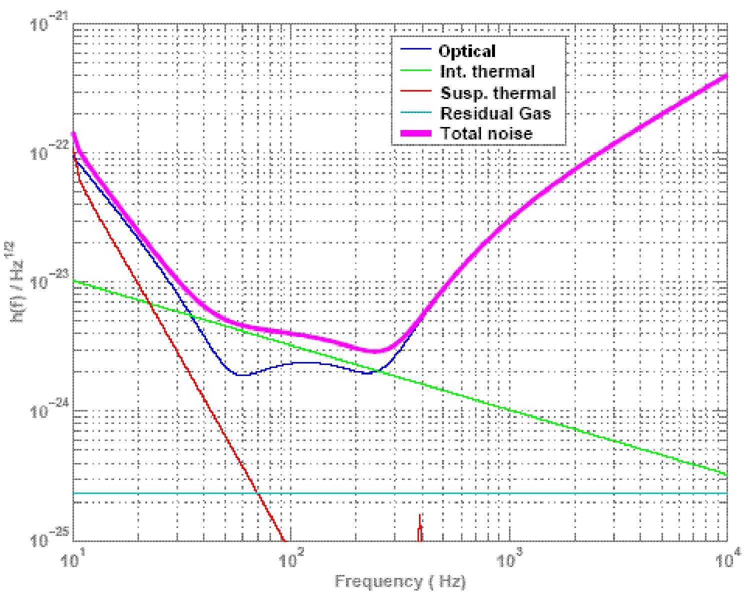
Thermal Noise

- Future detectors will be limited by thermal noise

Sapphire



Fused Silica



Dependence on size

$$S_h^{TE-s} \propto \frac{1}{r_0^3}$$ Substrate thermoelastic noise

$$S_h^{TE-c} \propto \frac{1}{r_0^2}$$ Coating thermoelastic noise

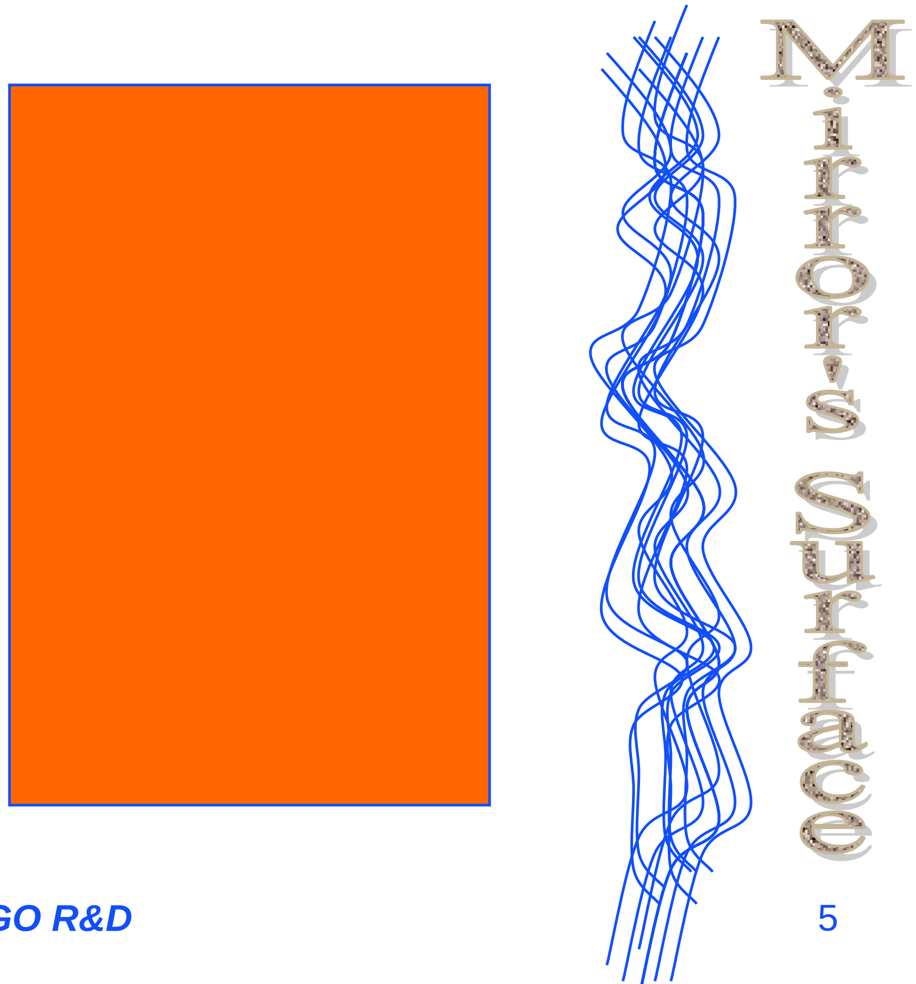
$$S_h^{B-s} \propto \frac{1}{r_0}$$ Substrate Brownian noise

$$S_h^{B-c} \propto \frac{1}{r_0^2}$$ Coating Brownian noise

- Larger beams reduce thermal noise
- Diffraction losses limit size of Gaussian beam

Dependence on profile

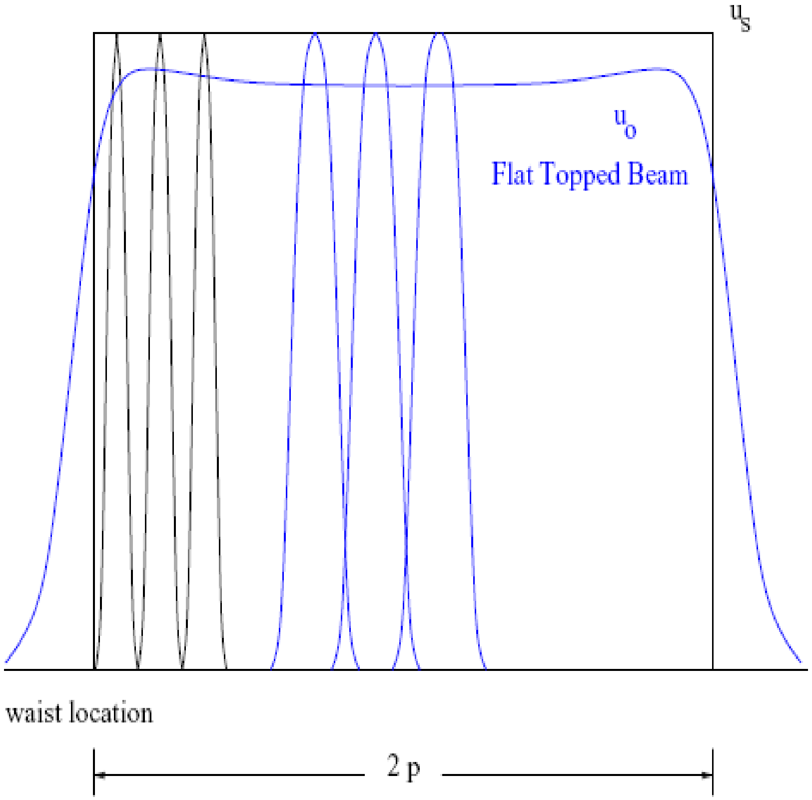
- Gaussian beams sample only a small portion of mirror’s surface
- Poor average
- Rectangular profile is optimal



Gaussian vs. Mesa

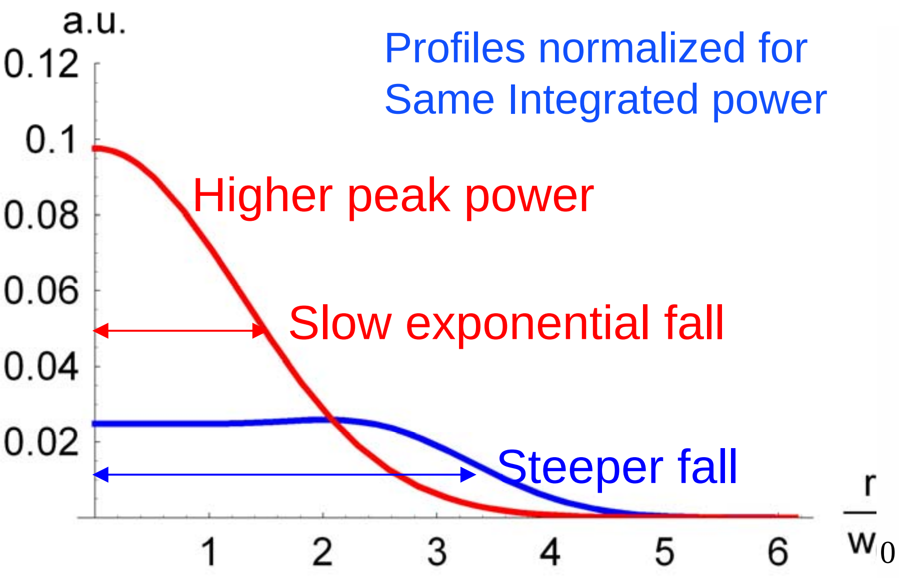
- Solution is the mesa beam
- Mesa beam field

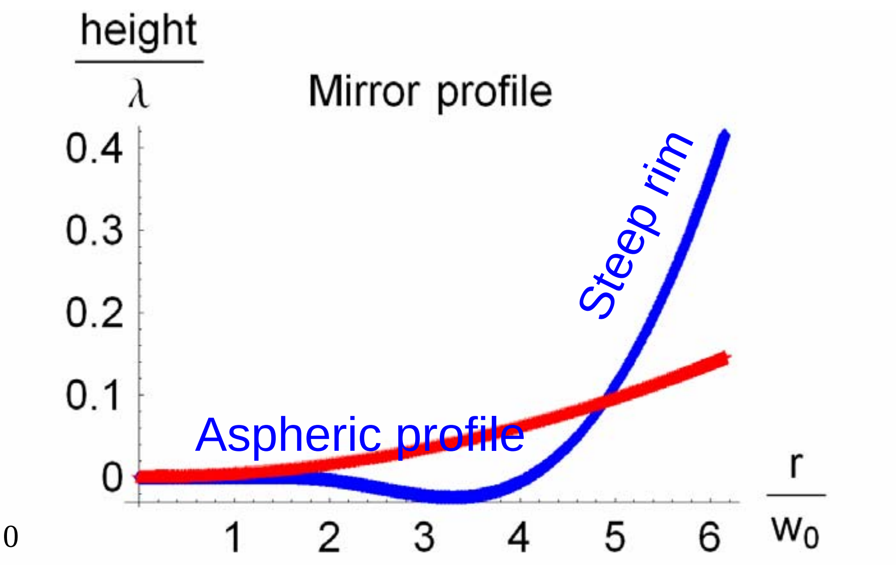
$$U(D,r) = \int_{C_D} \exp\left[\frac{-[(x-x_0)^2+(y-y_0)^2][1+i]}{2b}\right] dx_0 dy_0$$



Profiles

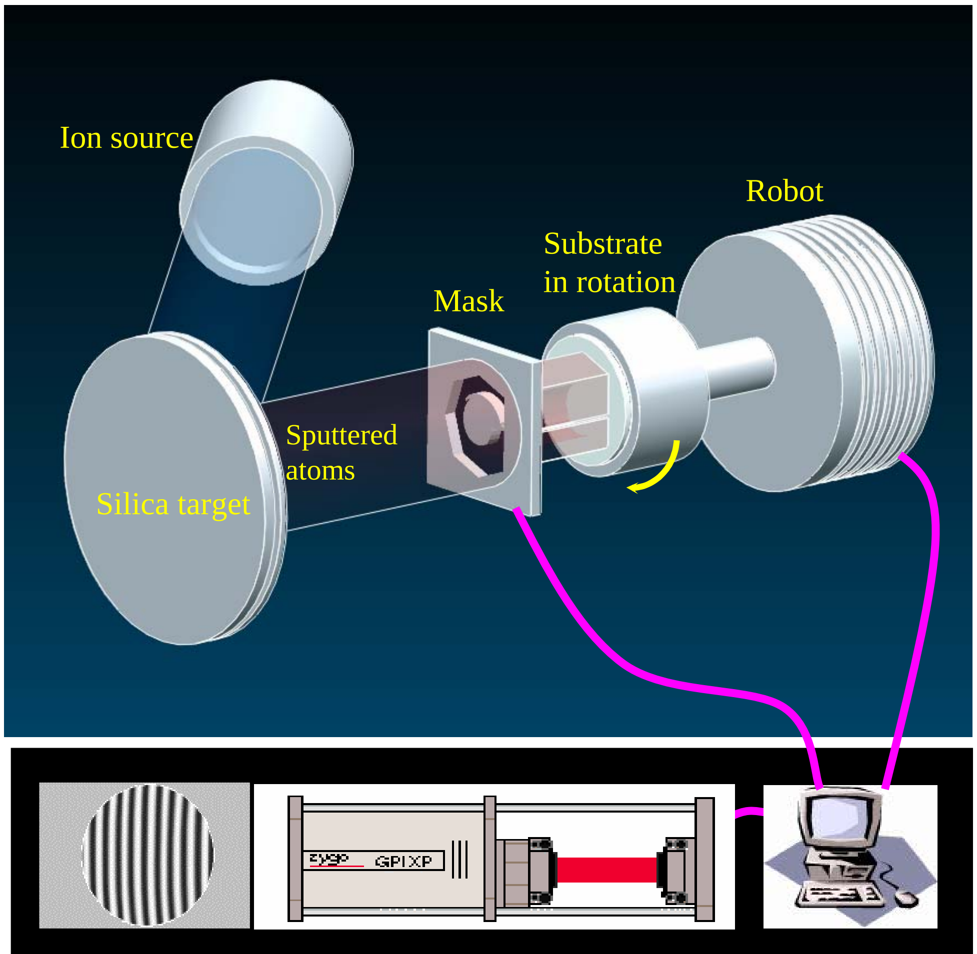
Profiles normalized for
Same Integrated power





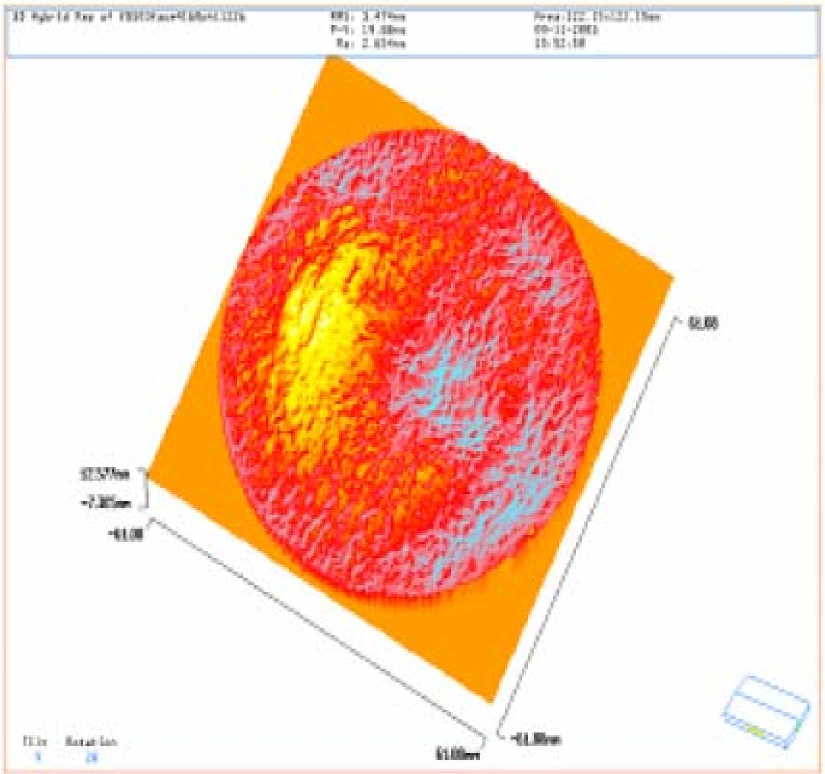
Same diffraction losses

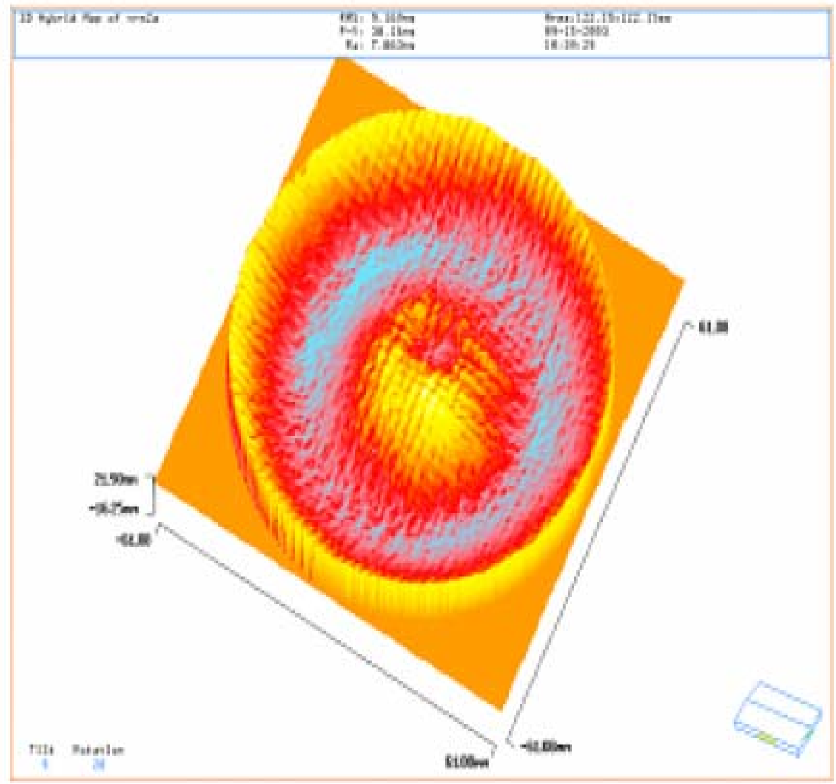
Mirrors



- Two step process
- 500 nm/mm
- Larger mirrors easier

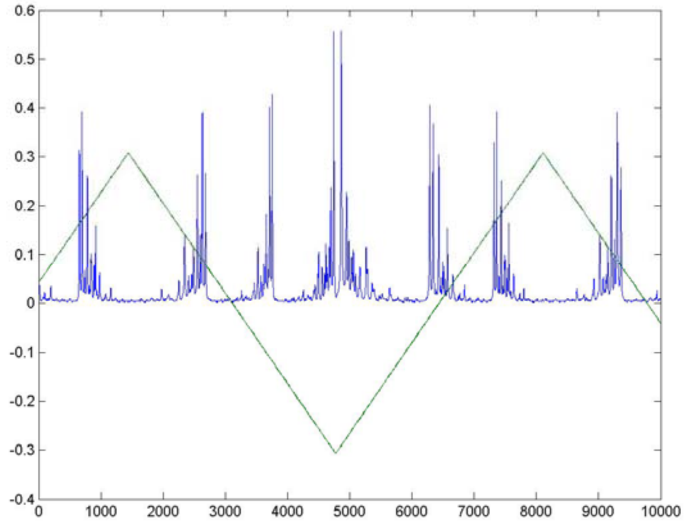
Corrective Coating

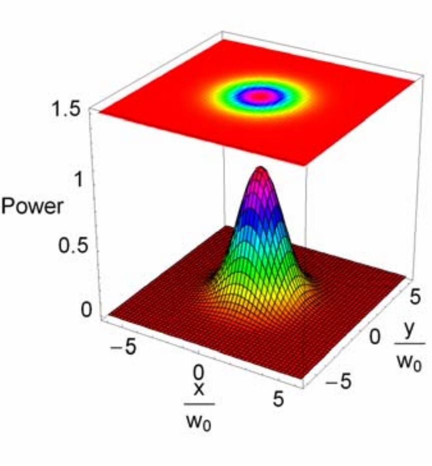


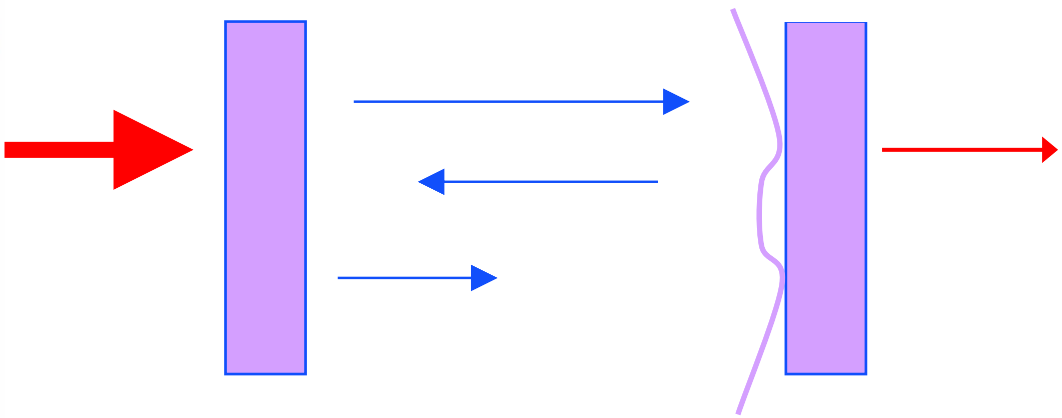


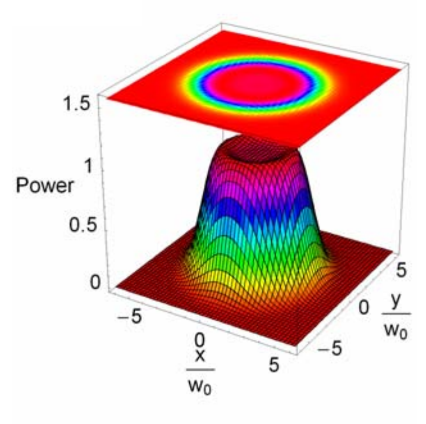
Fabry-Perot Cavity

- Flat cavity
- Two mirrors
- Interference



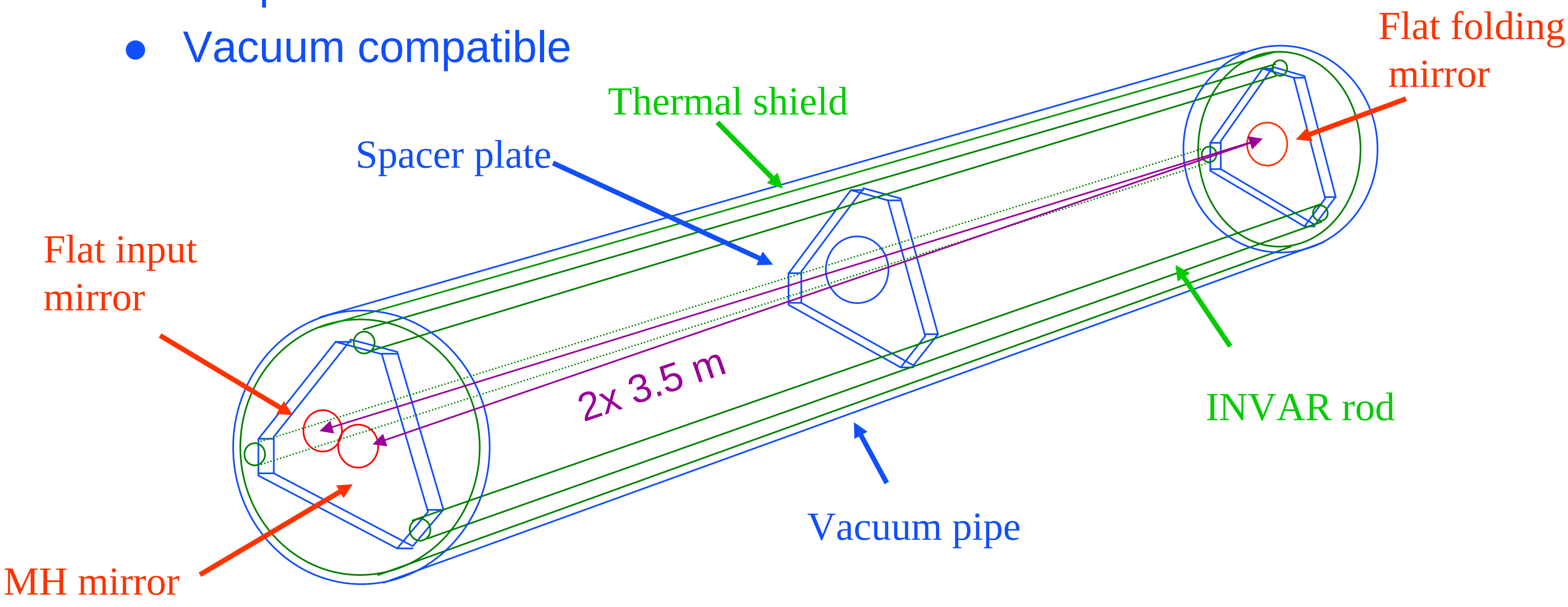




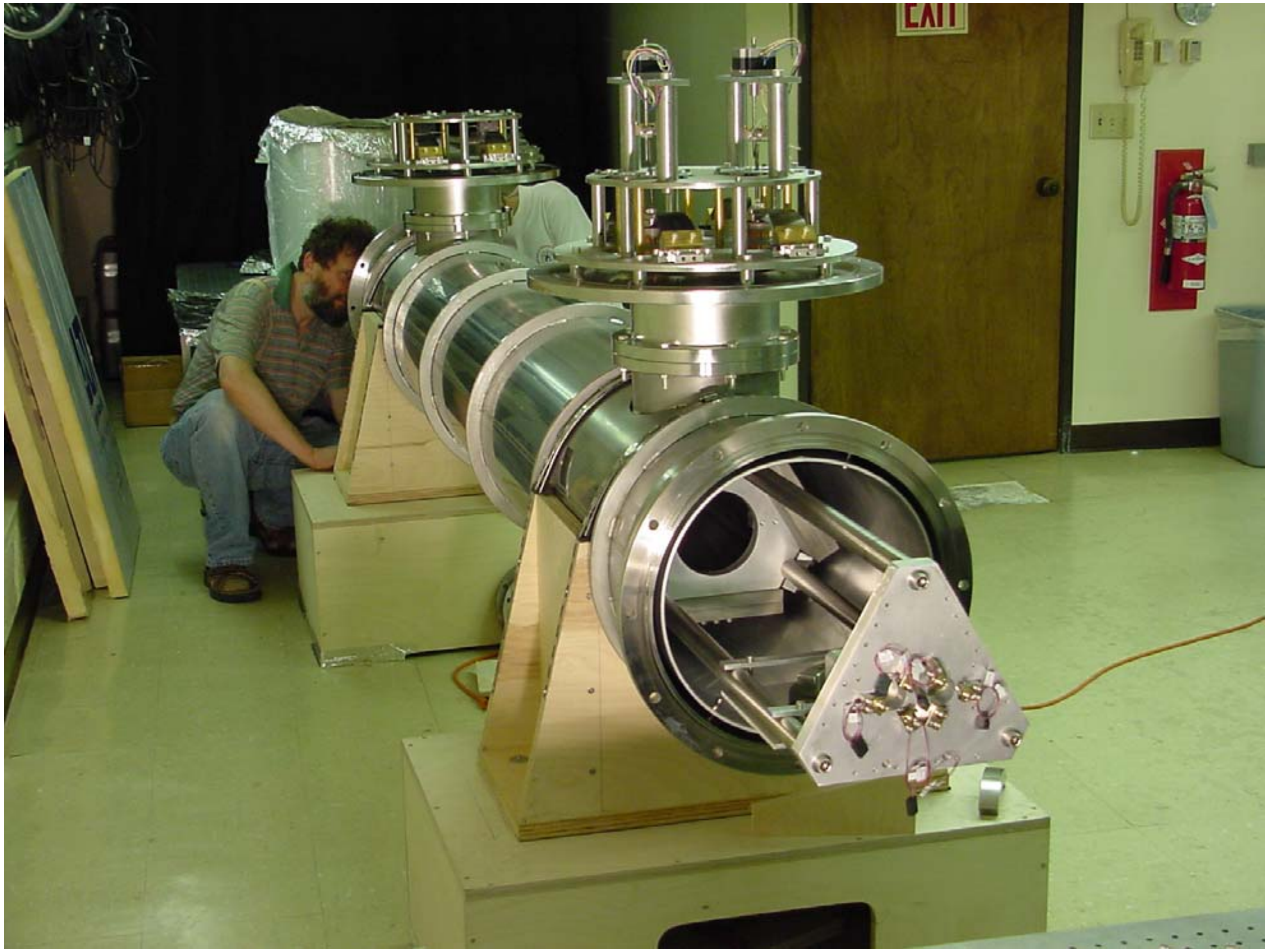


Our Cavity

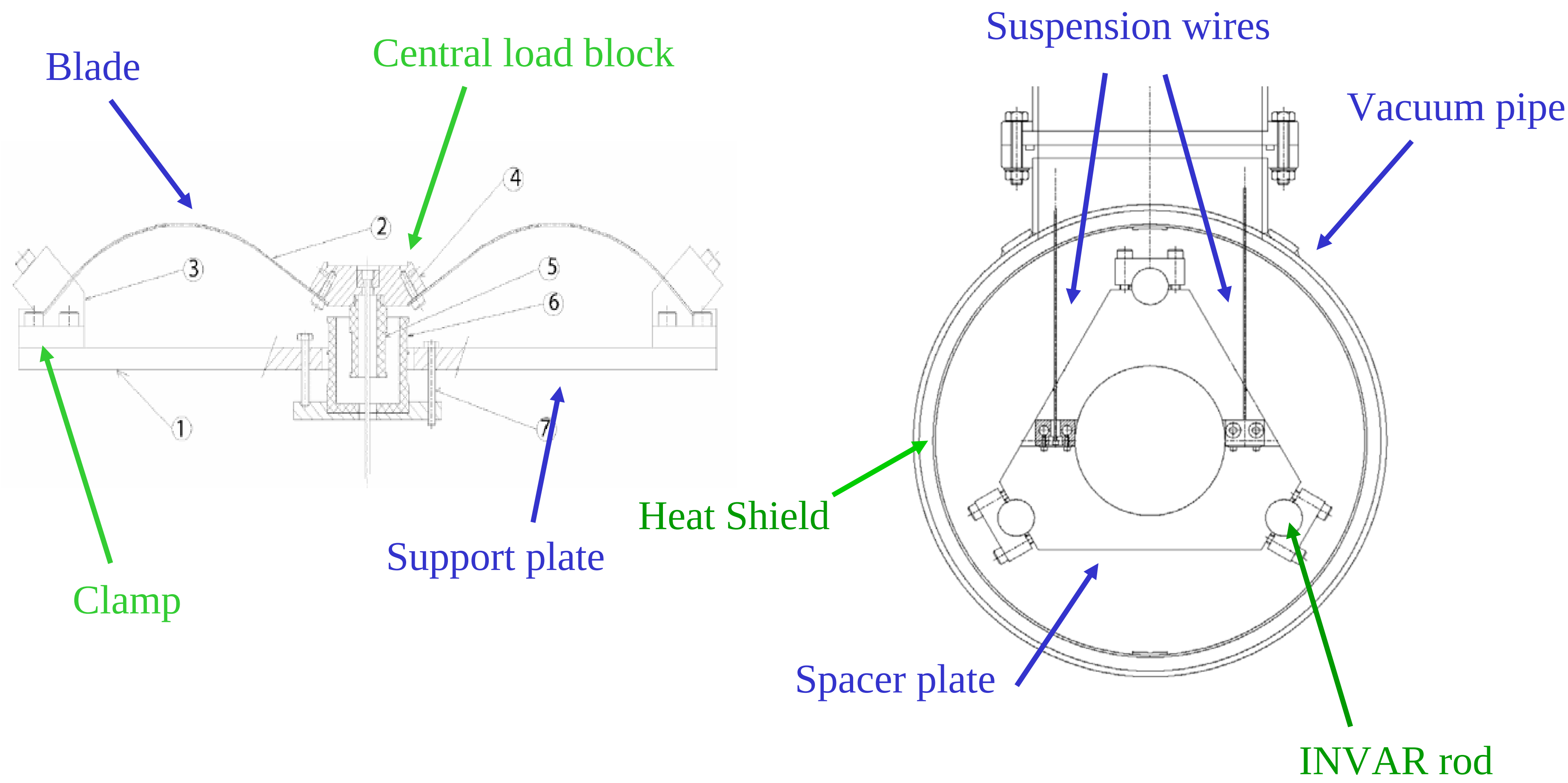
- 7.32 m folded cavity
- Suspended
- Vacuum compatible



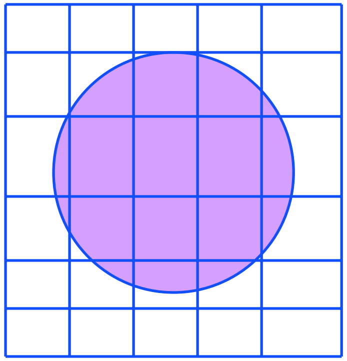
Our Cavity



Our Cavity


Blade
Central load block
Suspension wires
Vacuum pipe
4
2
3
5
6
1
7
Heat Shield
Support plate
Clamp
Spacer plate
INVAR rod

FFT Simulations



- MH theory is well understood – D'ambrosio, Thorne, O'shaughnessy etc
- Simulate results using FFT algorithm
- Change hard integrals into simple multiplication

$$\psi_2(x_2, y_2) = \int_{grid} G(x_1, y_1, x_2, y_2)\psi_1(x_2, y_2)dS$$

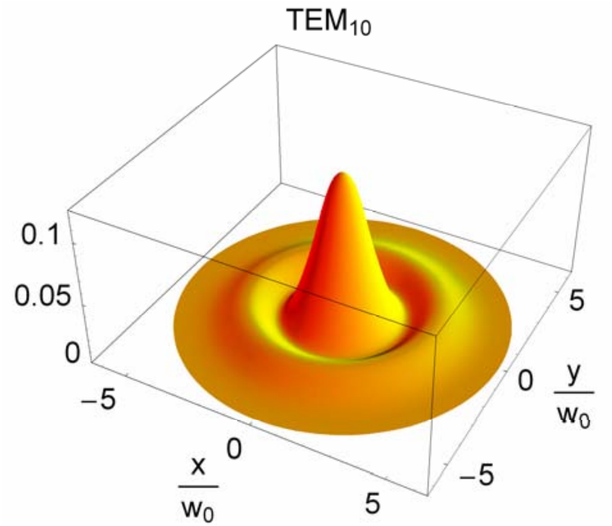
$$\psi_2' = G' \cdot \psi_1'$$

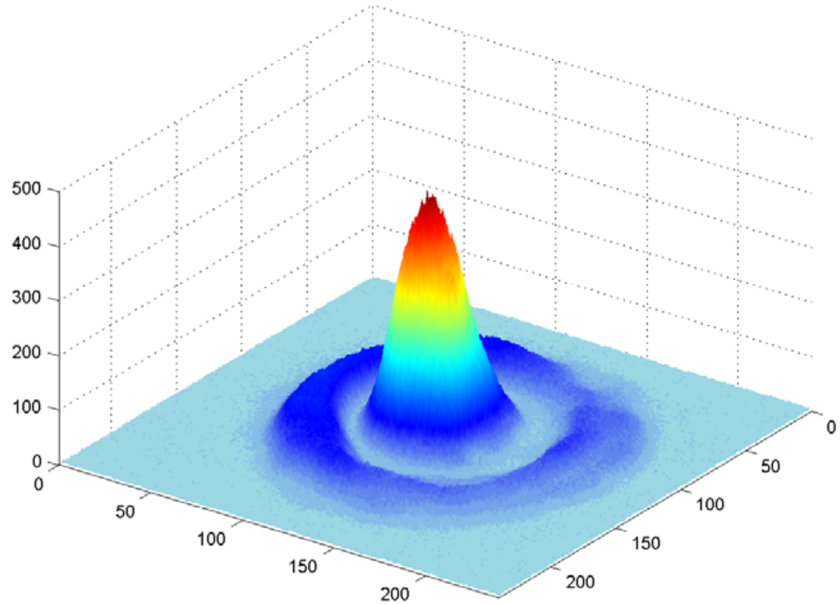
$$G = -\frac{i}{\lambda \Delta z}\exp\left(-i\frac{k(x^2 + y^2)}{2\Delta z}\right)$$

Results

TEM$_{10}$

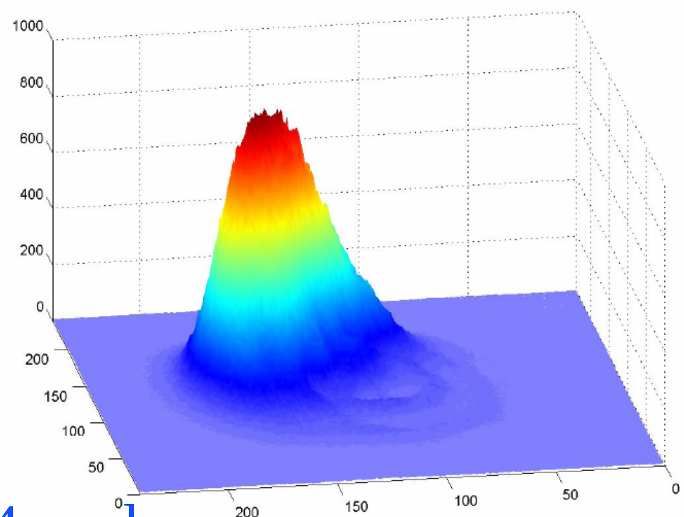
- 'Easily' locked to higher order modes
- Good agreement



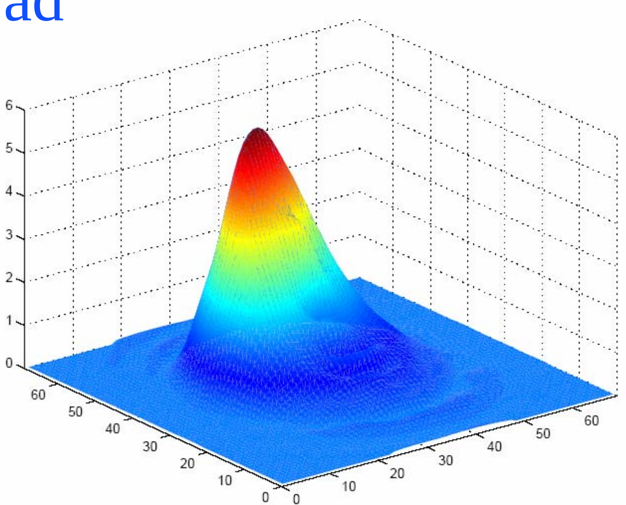


The Fundamental?

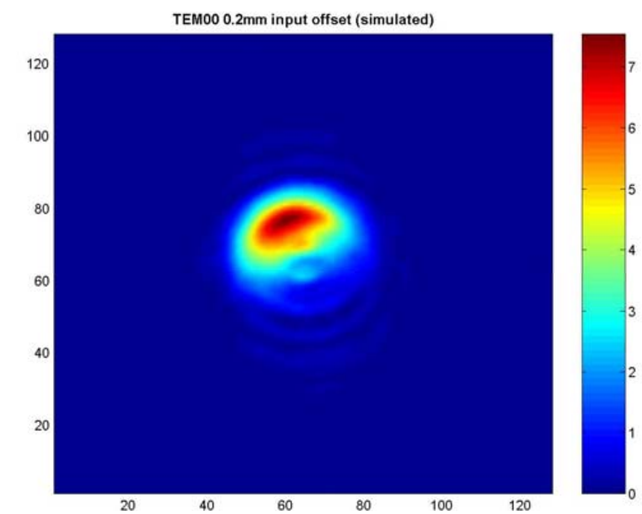
- Unable to produce stable TEM_{00}

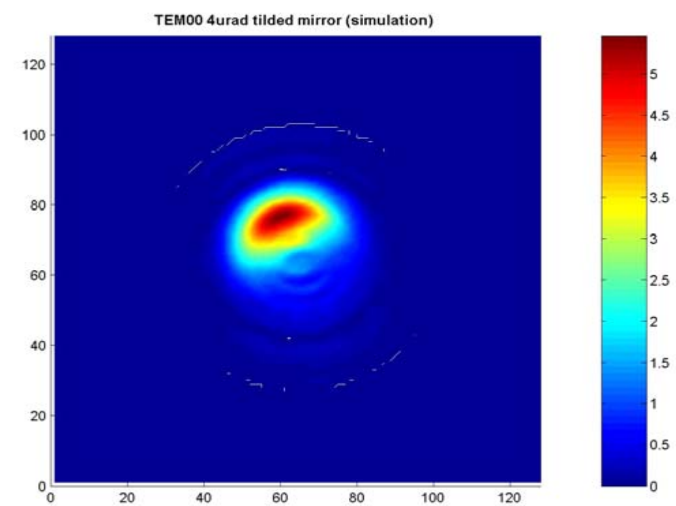


4μrad tilt



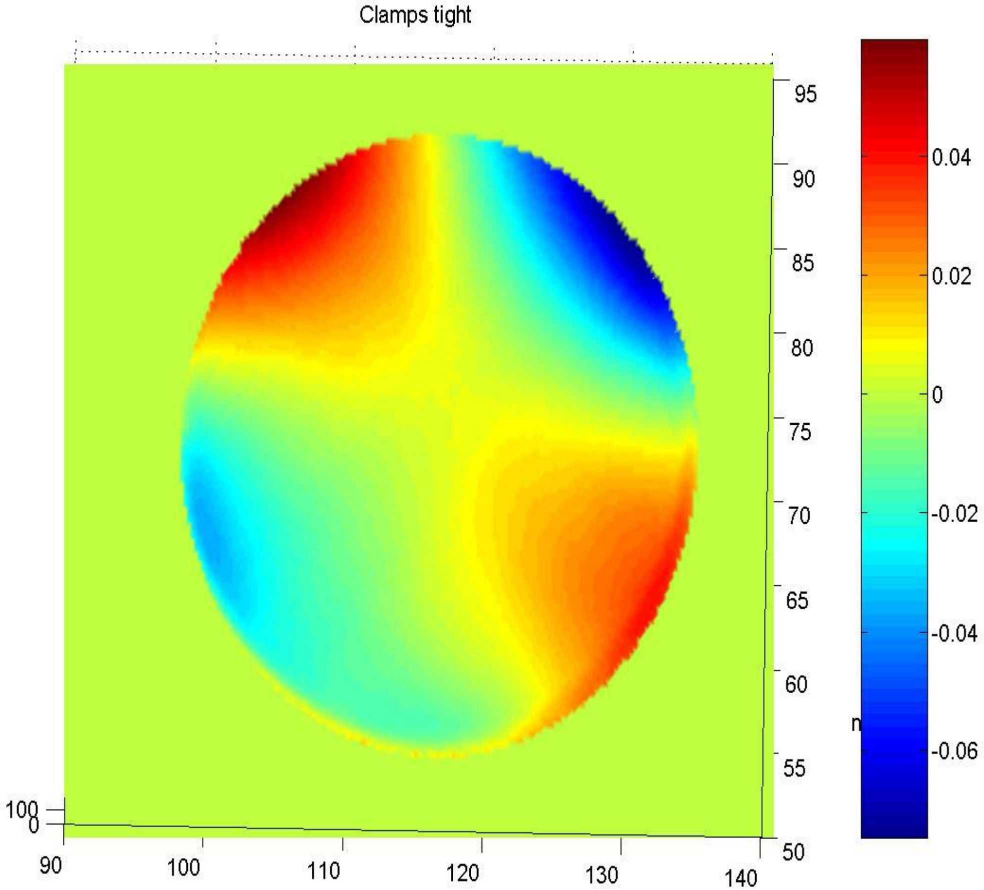
Tilt vs Offset



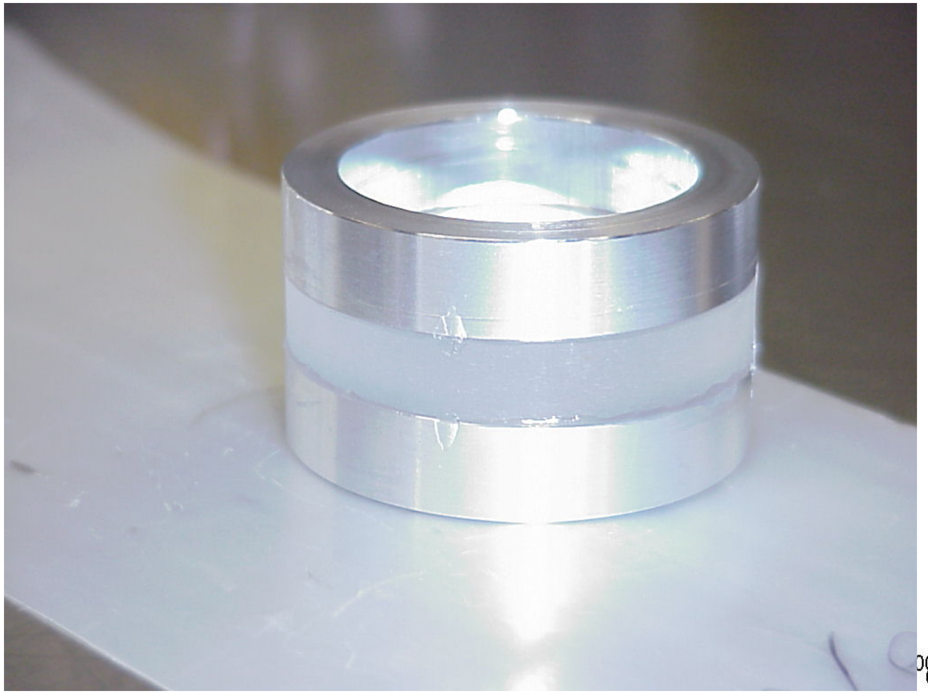


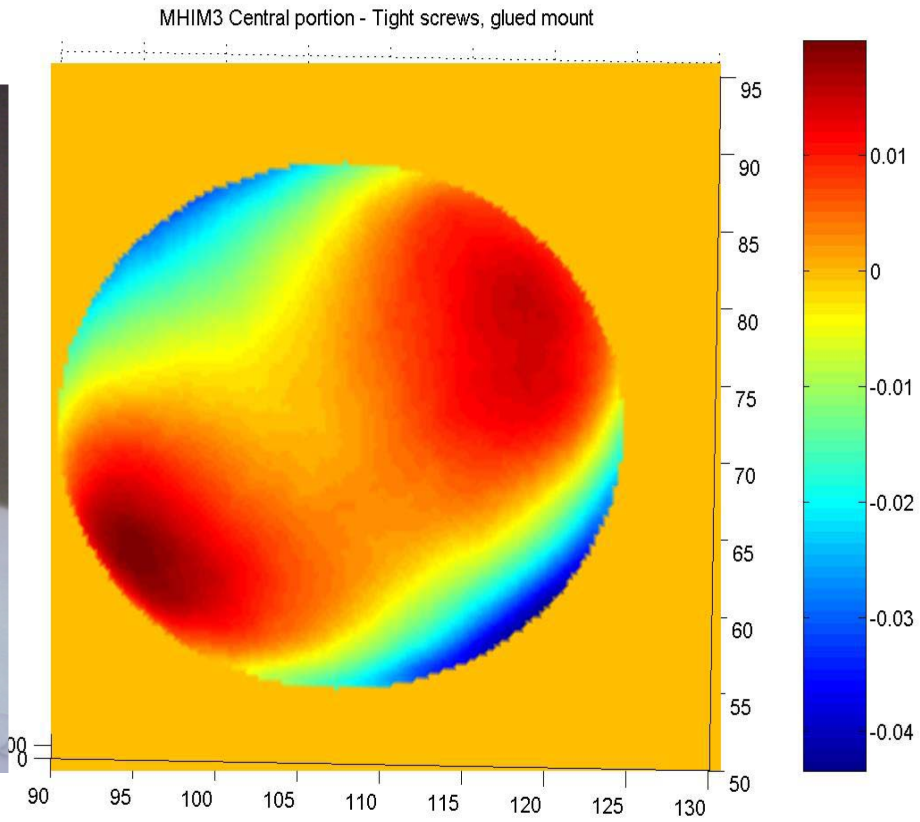
Mirrors

- Our mirrors are warped
- Fizeau Interferometer



Mirrors




MHIM3 Central portion - Tight screws, glued mount
95
90
85
80
75
70
65
60
55
50
90
95
100
105
110
115
120
125
130
0.01
0
-0.01
-0.02
-0.03
-0.04

Current Work

- Theory
  - » Extend FFT simulation to folded cavity
  - » Use real mirror maps for all three optics
  - » Is mesa beam possible with current apparatus?
  - » How flat must mirrors be?

- Experiment
  - » Characterise warped mirrors
  - » Order new mirrors – try again
  - » Test 3 MH optics

The Future

- Spherical MH cavity
- TNI interferometer – Naples
- TAMA/AIGO

Summary

- Thermal noise will be principal problem for GW detectors
- Mesa beams reduce thermal noise
- Predicted that mesa beams shall not be significantly more difficult to manage than Gaussian
- Continue until end of September. Replaced by new student

Thanks

- American Tax Payers
- Ken Libbrecht
- Riccardo DeSalvo
- Marco Tarallo
- Juri Agresti
- Mike Smith
- Phil Willems
- GariLynn Billingsley