Flat-Top Beam Profile Cavity Prototype: design and preliminary tests

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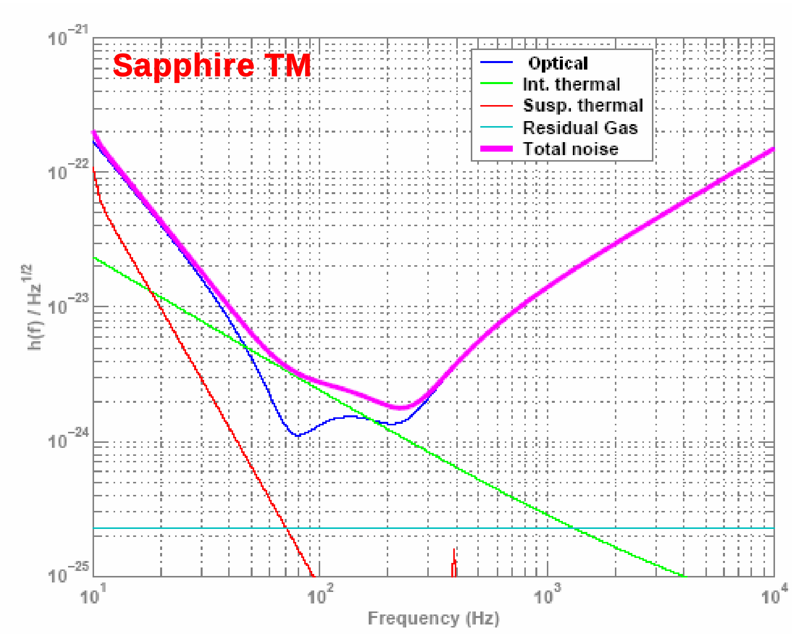
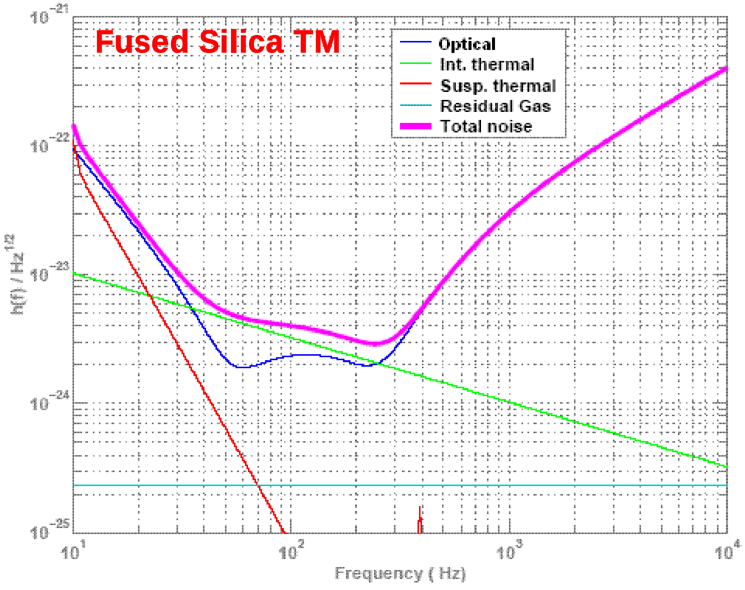
Motivations for a flat-top beam:





Advanced-Ligo sensitivity

Dominated by test-masses thermoelastic or coating thermal noises.

Can we reduce the influence of thermal noise on the sensitivity of the interferometer?

Mirror Thermal Noise:

Thermoelastic noise

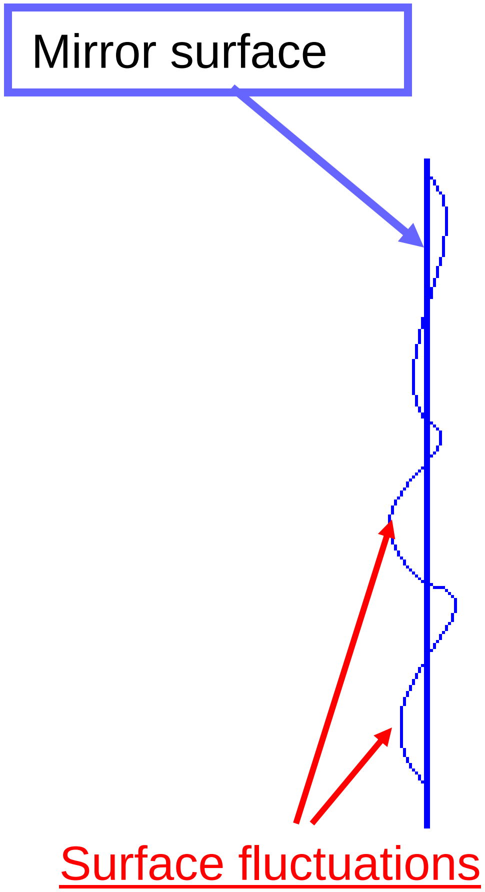
Created by stochastic flow of heat within the test mass

↓

Fluctuating hot spots and cold spots inside the mirror

↓

Expansion in the hot spots and contraction in the cold spots creating fluctuating bumps and valleys on the mirror's surface



Brownian noise

Due to all forms of background dissipations within a material (impurities, dislocations of atoms, etc..)

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

Indicative thermal noise trends

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

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

Exact results require accurate information on material properties and finite size effects must be taken in account.

Mirror surface averaging

Gaussian beam

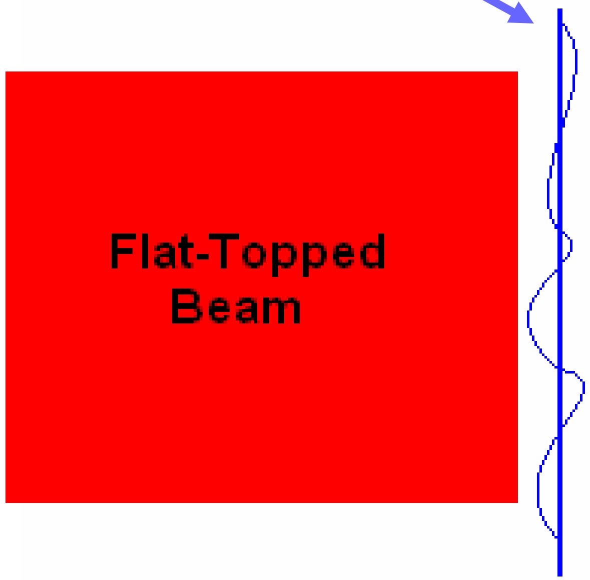
r_0 **As large as possible** (within diffraction loss constraint).

The sampling distribution changes rapidly following the beam power profile

Flat Top beam

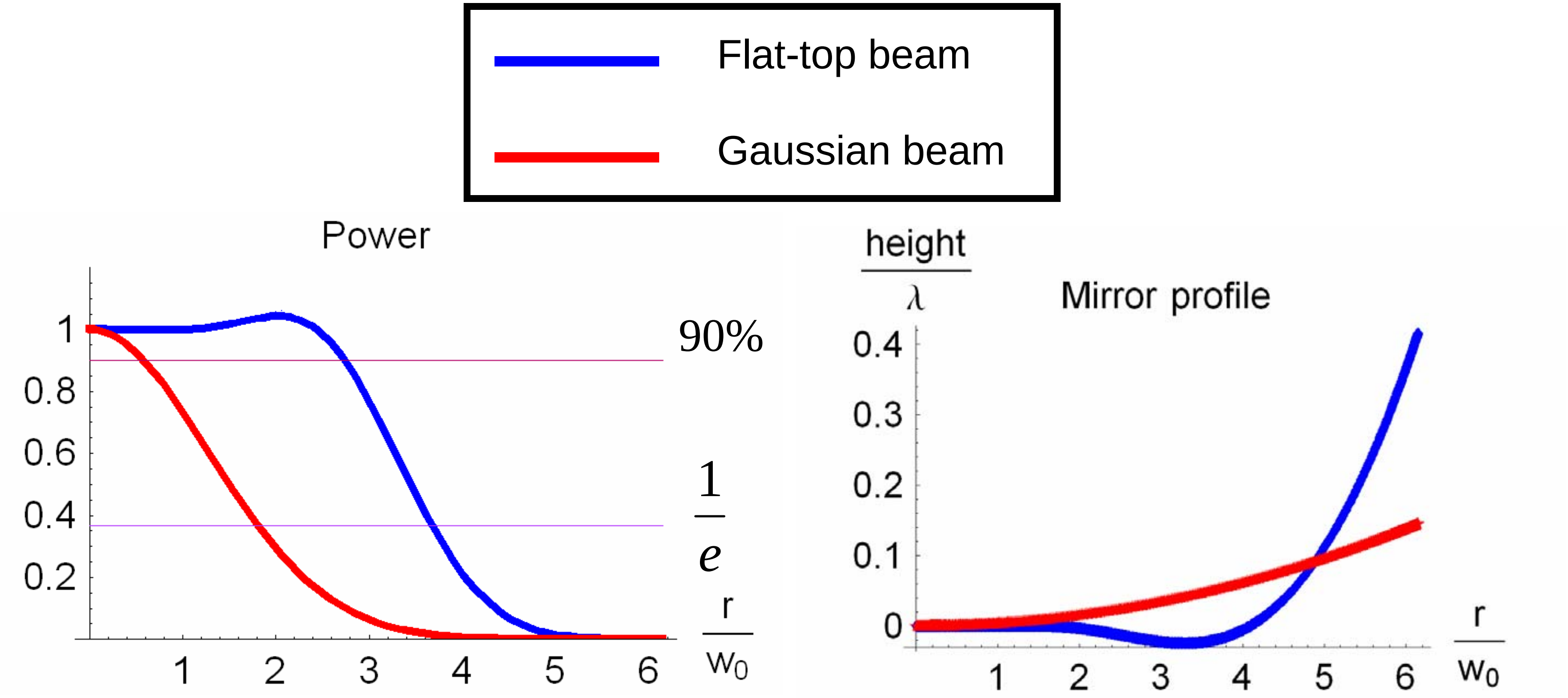
Larger-radius, flat-top beam will better average over the mirror surface.

Mirror surface fluctuations



Expected gain in sensitivity ~ 2 🕑 3

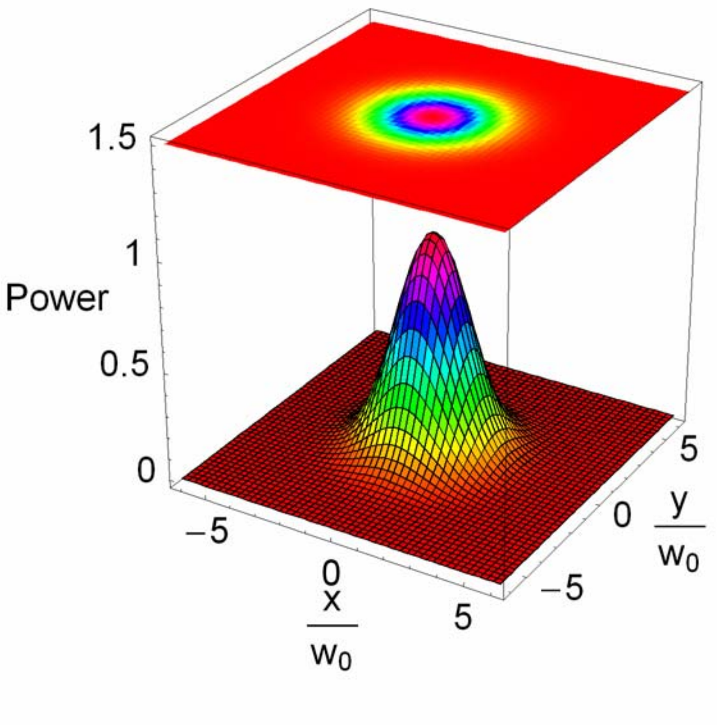
Diffraction prevents the creation of a beam with a rectangular power profile…but we can build a nearly optimal flat-top beam:

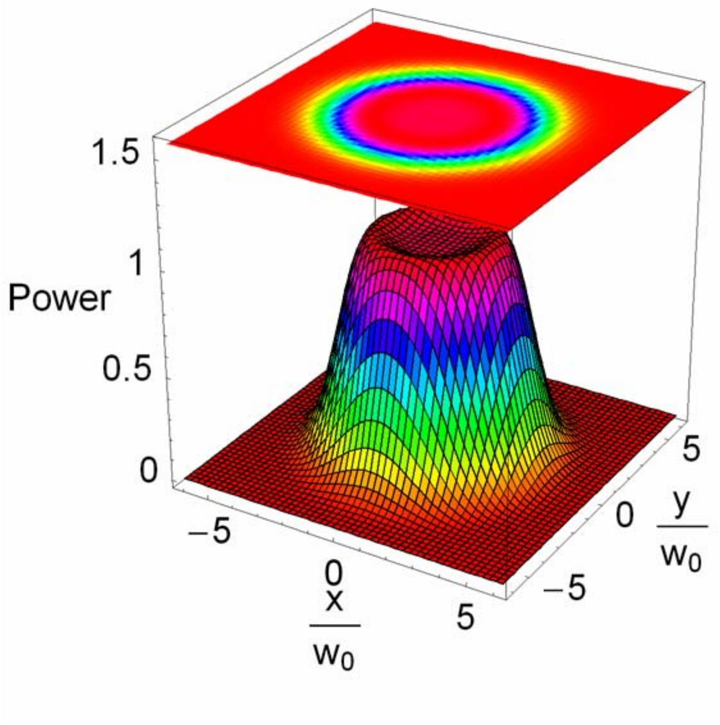


- The mirror shapes match the phase front of the beams.

Sampling ability comparison between the two beams

(same diffraction losses, Adv-LIGO mirror size)





Sampled area	**Advantage Ratio**	**Sampled area**
$S\left(r_0\right) \approx 0.09 S_{mir}$	$R_{Flat-top/Gaussian} = 4$	$S\left(r_0\right) \approx 0.36 S_{mir}$
$S\left(r_{90\%}\right) \approx 0.01 S_{mir}$	$R_{Flat-top/Gaussian} = 20$	$S\left(r_{90\%}\right) \approx 0.20 S_{mir}$

Flat top beam FP cavity prototype

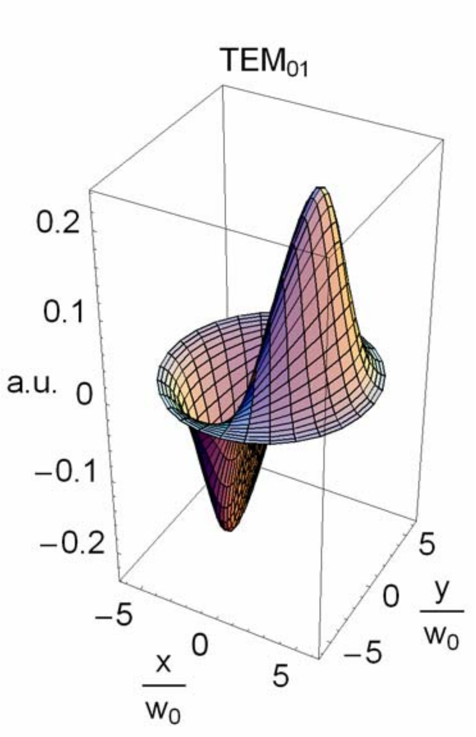
- Necessity to verify the behavior of the flat top beams and study their generation and control before its possible application to GW interferometers

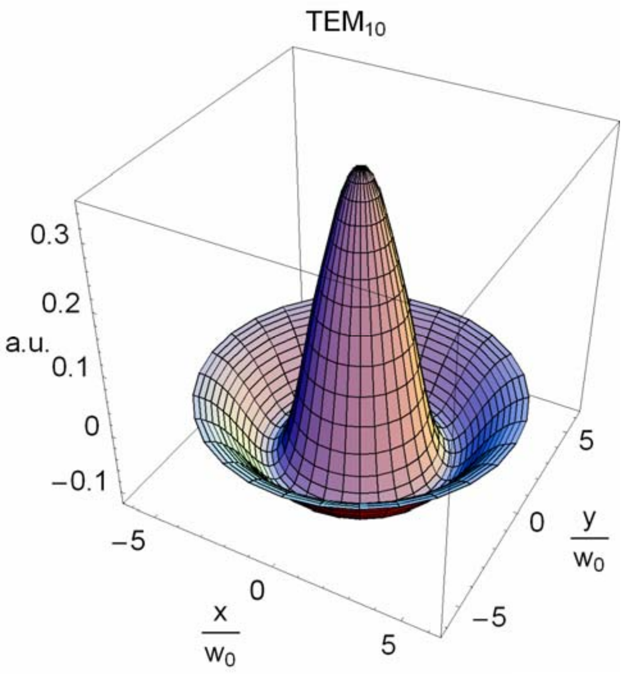
We have built a small FP cavity: a scaled version of *Advanced LIGO* which could contain gaussian and non-gaussian beams

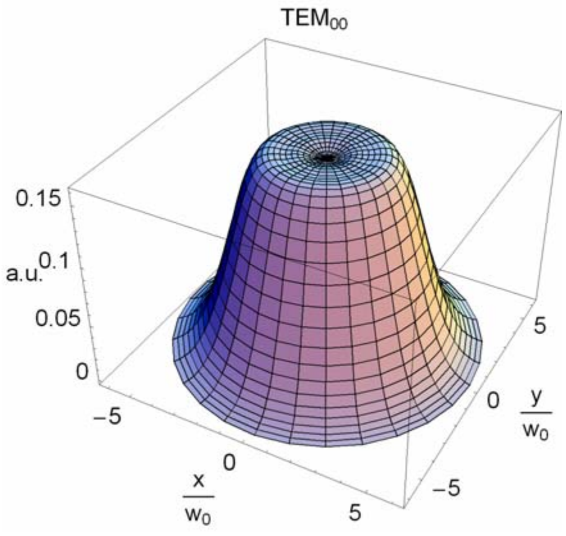
Mirror size constrain →

$$d_{FT} \approx d_{AdL} \sqrt{\frac{2L_{FT}}{L_{AdL}}}$$

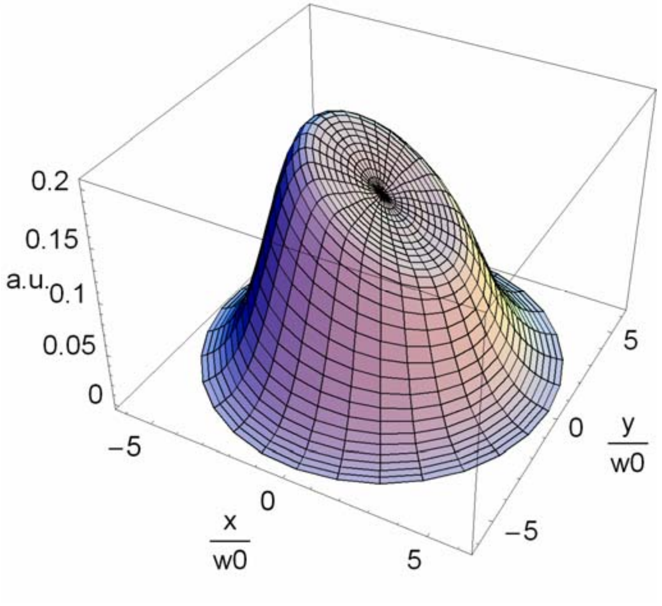
We will investigate the **modes structure** and characterize the **sensitivity to perturbations** when non Gaussian beams are supported inside the cavity.



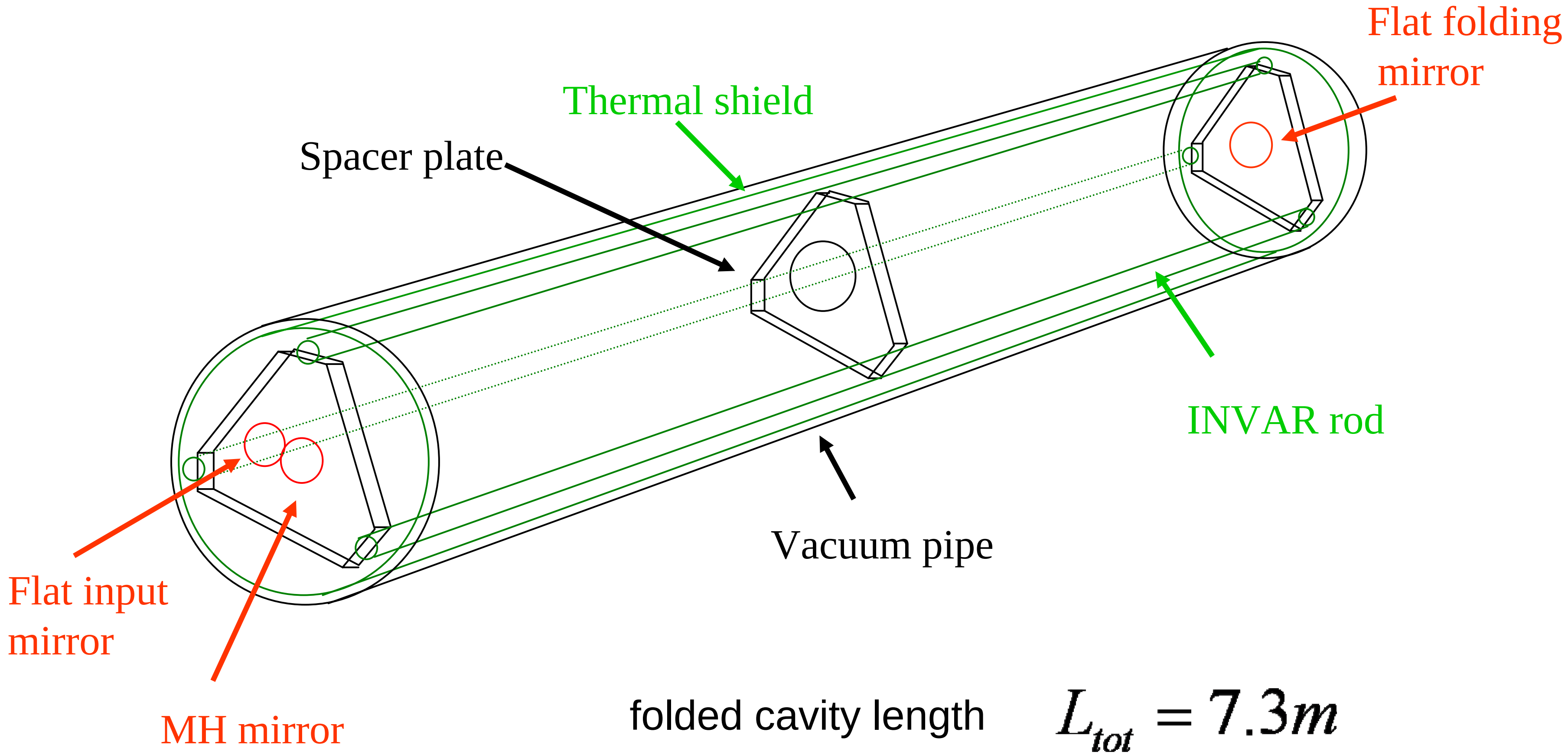




Misalignment produces coupling between modes



Design of the test cavity : Rigid cavity suspended under vacuum



folded cavity length $L_{tot} = 7.3m$

$W_{tot} \approx 87Kg$

Optical and mechanical design:

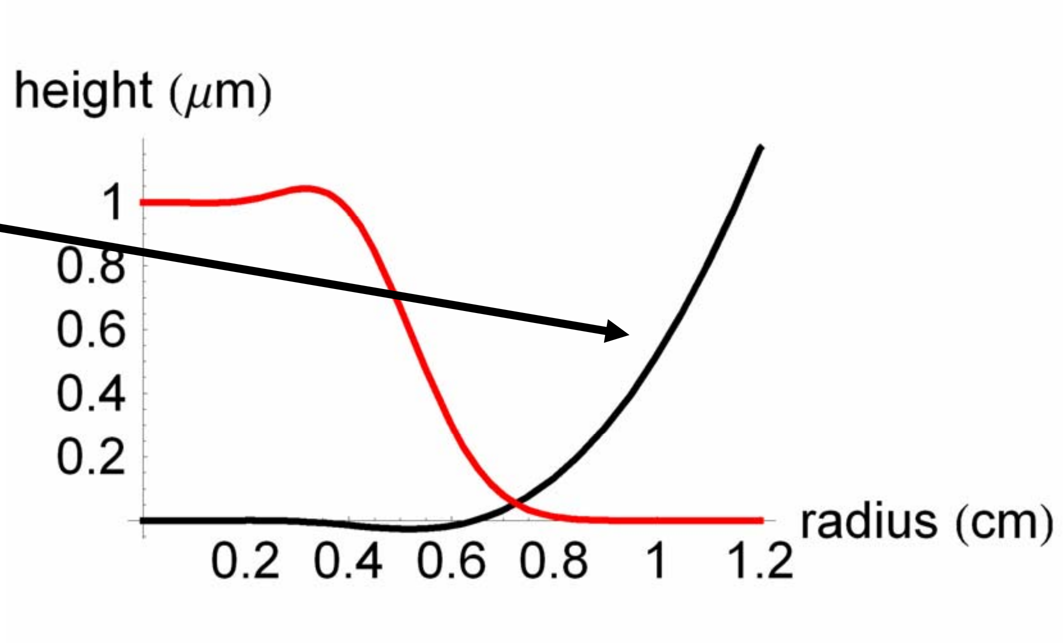
- Injection Gaussian beam designed to optimally couple to the cavity.
- Required finesse $\mathcal{F} = 100$ to suppress Gaussian remnants in the cavity.

Length stability: ~ 5 nm

- INVAR rods (low thermal expansion coefficient).
- Stabilized temperature.
- Vacuum eliminates atmospheric fluctuations of optical length.
- Ground vibrations can excite resonance in our interferometer structure: suspension from wires and Geometrical-Anti-Spring blades.

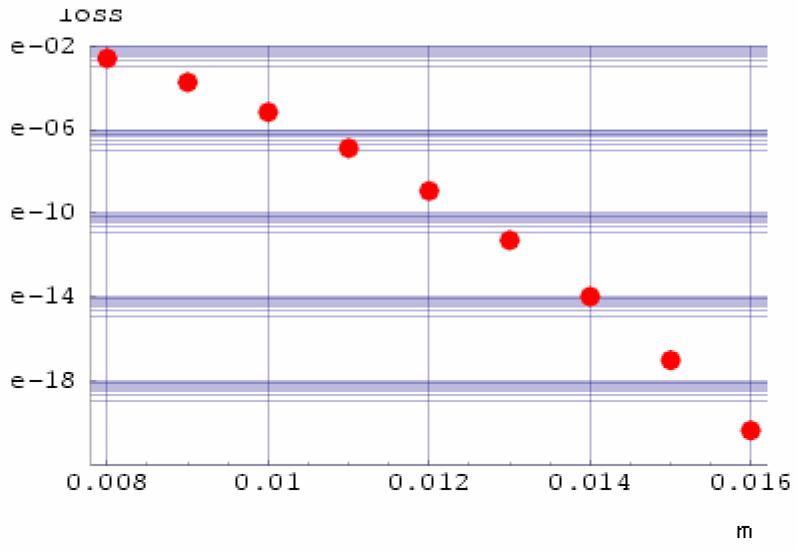
Mirror’s size constrained by beam shape and diffraction losses

Our Mexican Hat mirror:

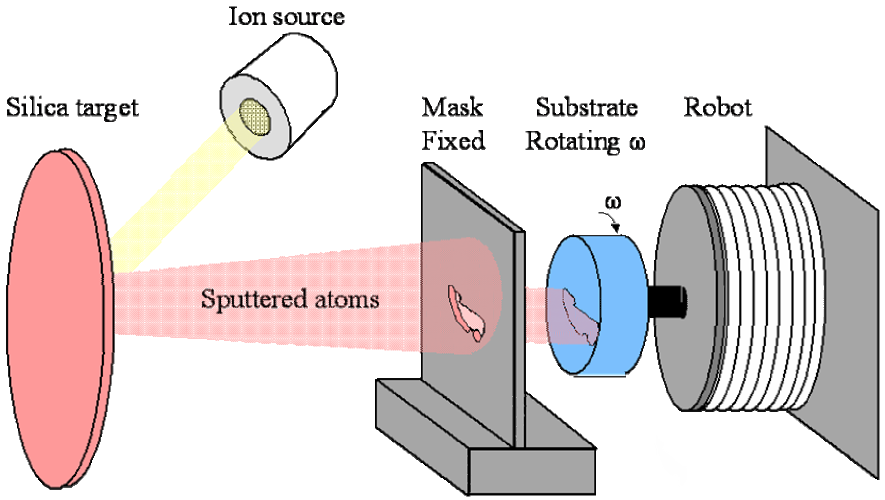


Diameter set by diffraction losses and technical difficulties…

Diffraction losses of ~ 1ppm requires mirror’s radius >1 cm.



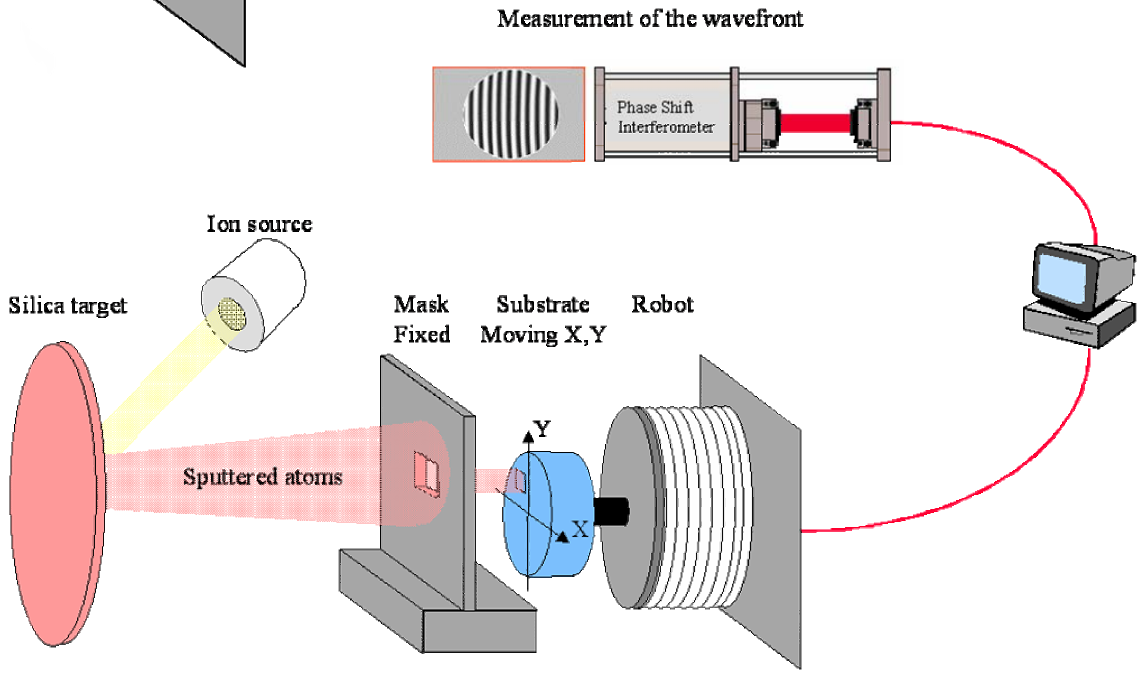
LMA’s Technique to build Mexican Hat mirrors



- Rough Shape Deposition:
  - **Coating the desired Mexican Hat profile using a pre-shaped mask**
  - **Achievable precision ~60nm Peak to Valley**

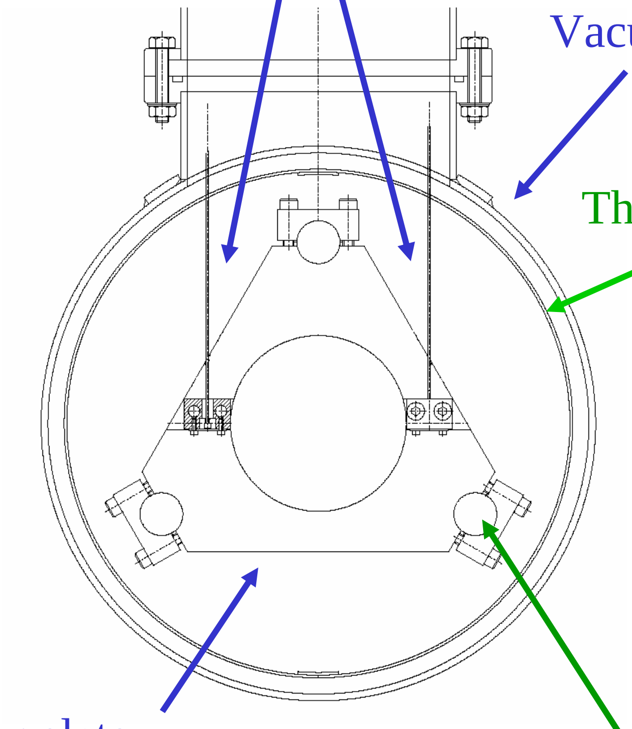
- Corrective coating:
  - **Measurement of the achieved shape**
  - **Coating thickness controlled with a precision <10 nm.**

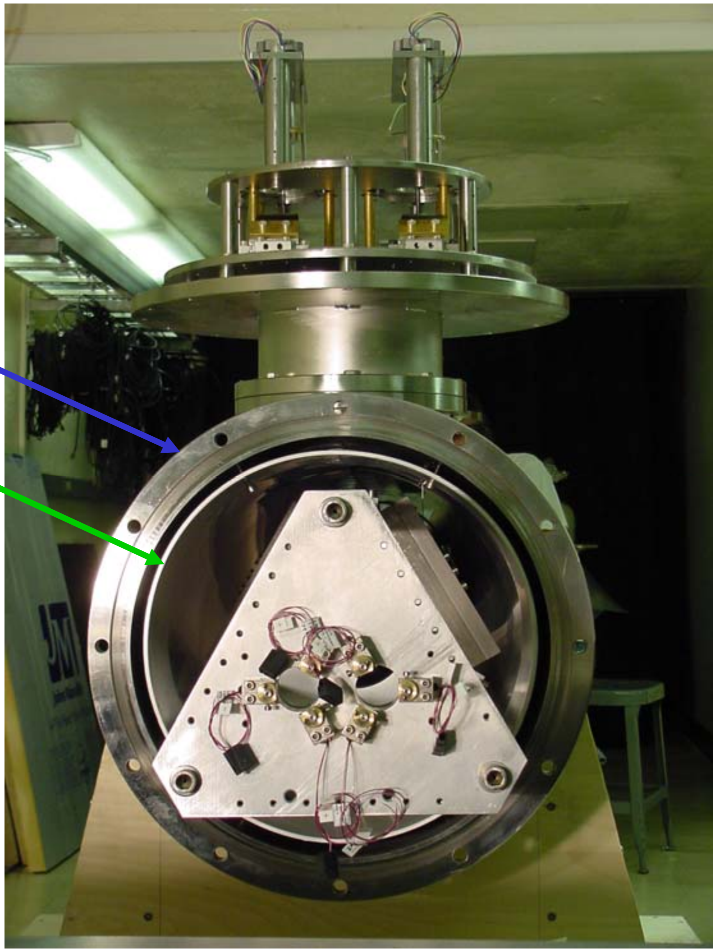
Maximum slope ~ 500nm/mm



Cavity Vacuum & Thermal Shield

Suspension view





Suspension wires

Vacuum pipe

Thermal shield

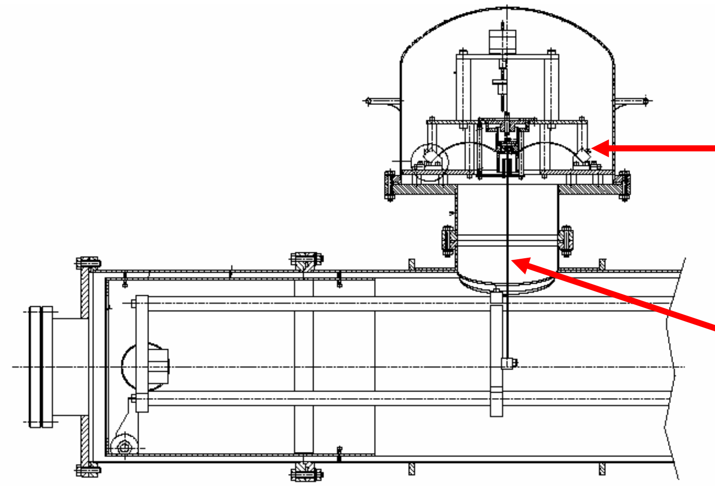
Spacer plate

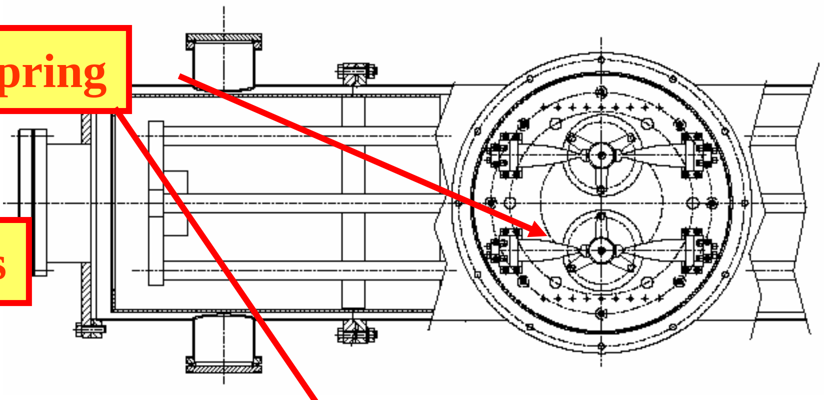
INVAR rod

Cavity Suspensions

V~ 0.6 Hz

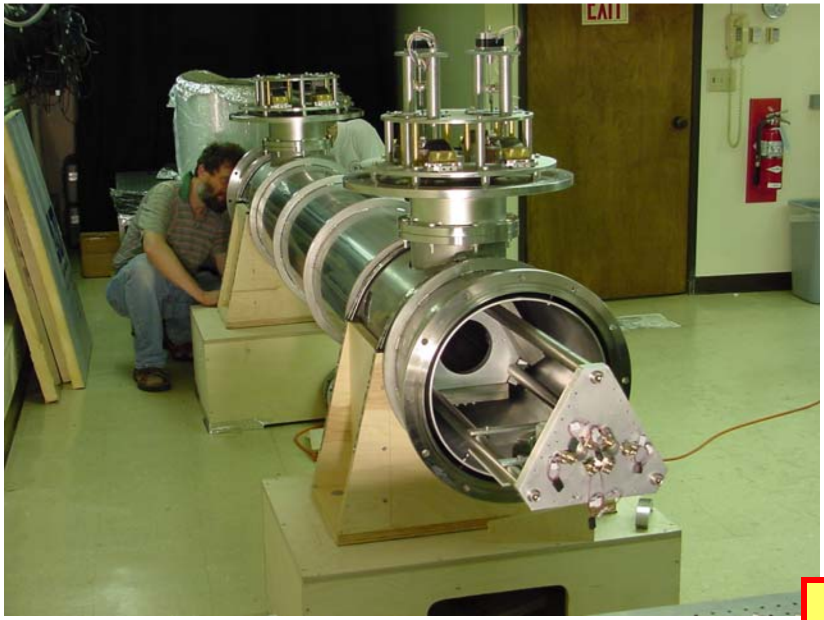
H ~ 1 Hz

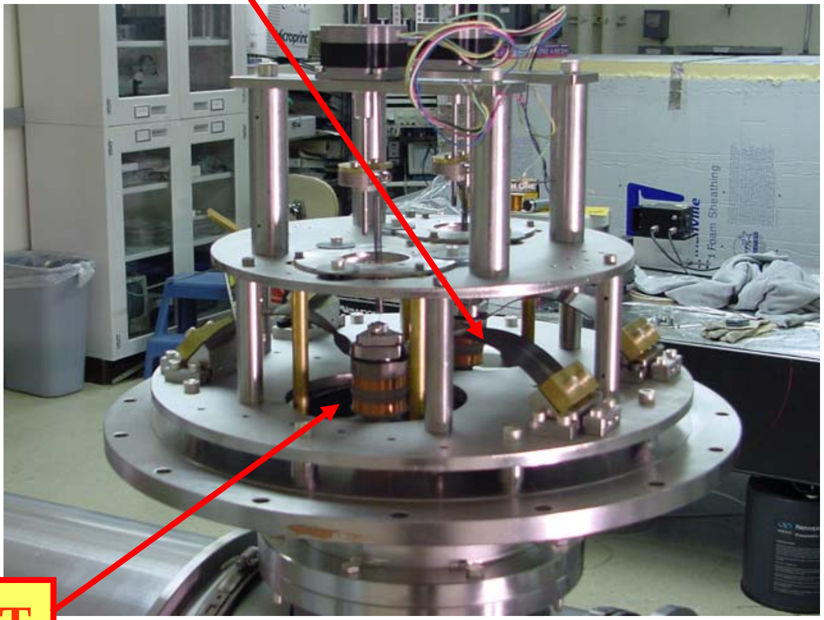




GAS spring

wires

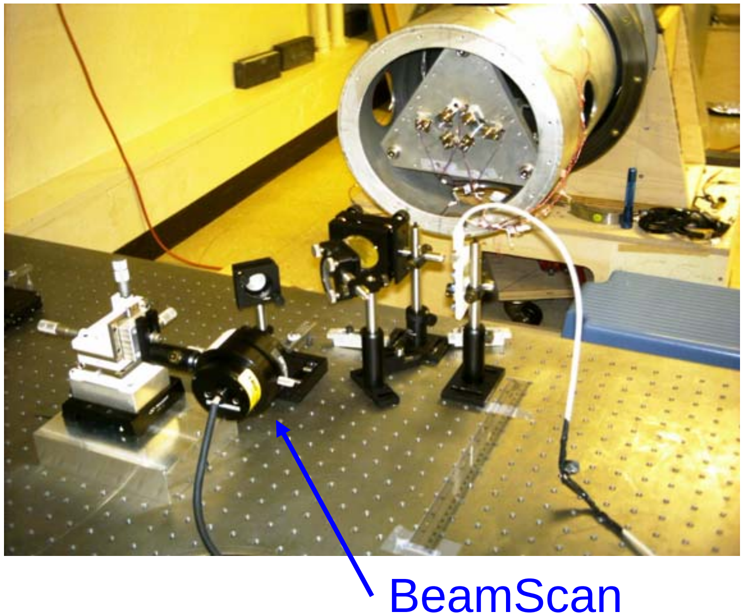




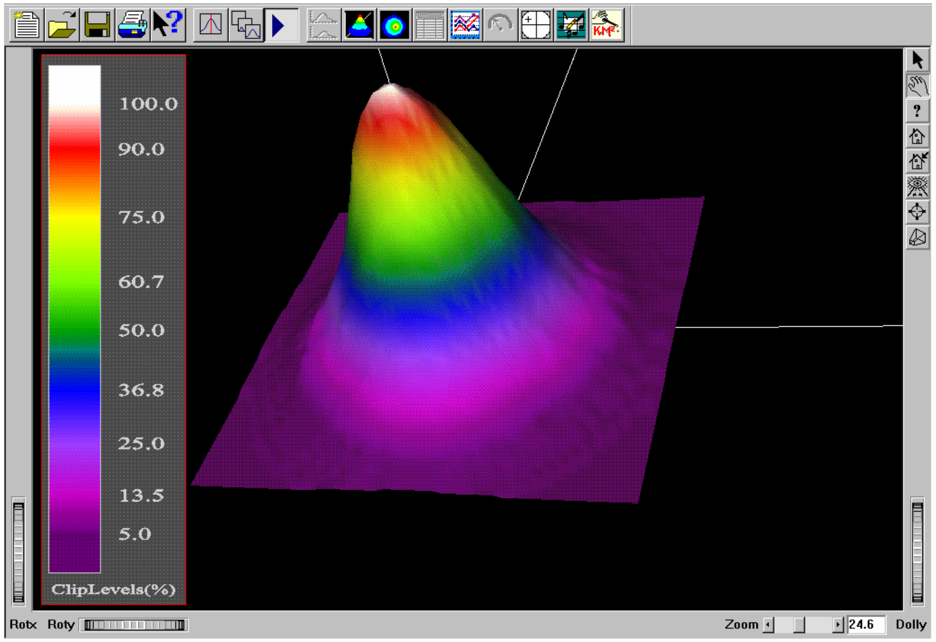
LVDT

First tests

- Output power feedback setting up
- First cavity lock with spherical end mirror
- High order modes characterization
- Upgrading suspension design and PZTs drivers for angular corrections and control



BeamScan



Output beam profile

Next Steps

- Vacuum operations and tests with the spherical end mirror
- Servo loop implementation (compensation and angular control)
- Turn on the “One Hertz Seismic Attenuation System” for the vertical suspensions
- Switch to Mexican-Hat mirror as soon as available
- Characterization of Flat-top beam modes and misalignment effects

Next possible developments

Flat topped beam inside a nearly-concentric cavity: same power distribution over the mirrors but less sensitive to misalignment.

Overcome the technical limitation on the slope of the coating… not impossible.