Flat-Top Beam Profile Cavity Prototype

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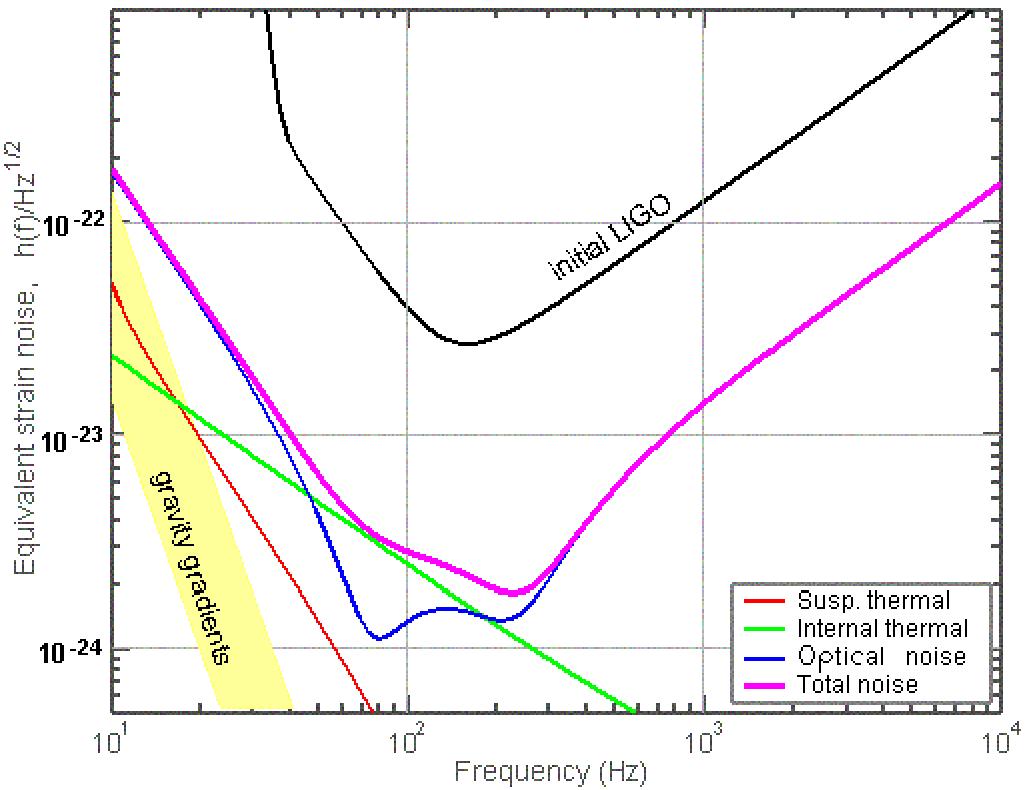
Motivations for a flat-top beam:



Advanced-Ligo sensitivity

(Sapphire Mirror Substrates)

Dominated by test-masses thermoelastic and coating thermal noises.

↓

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

Thermoelastic Noise:

Created by stochastic flow of heat within the test mass

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Fluctuating hot spots and cold spots inside the mirror

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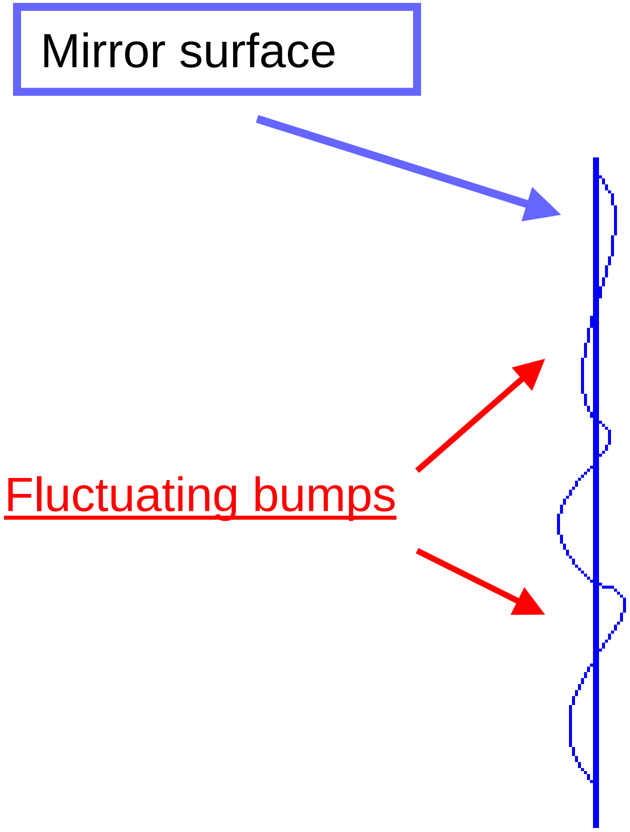
Expansion in the hot spots and contraction in the cold spots creating fluctuating bumps and valleys on the mirror's surface



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

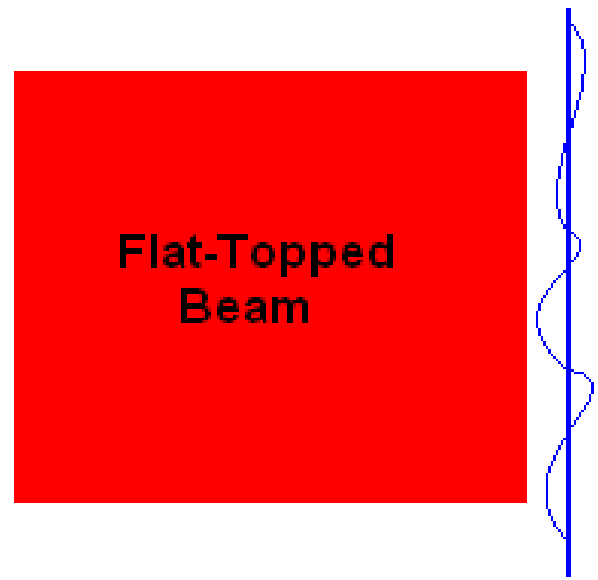
Gaussian beam

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

Mirror surface

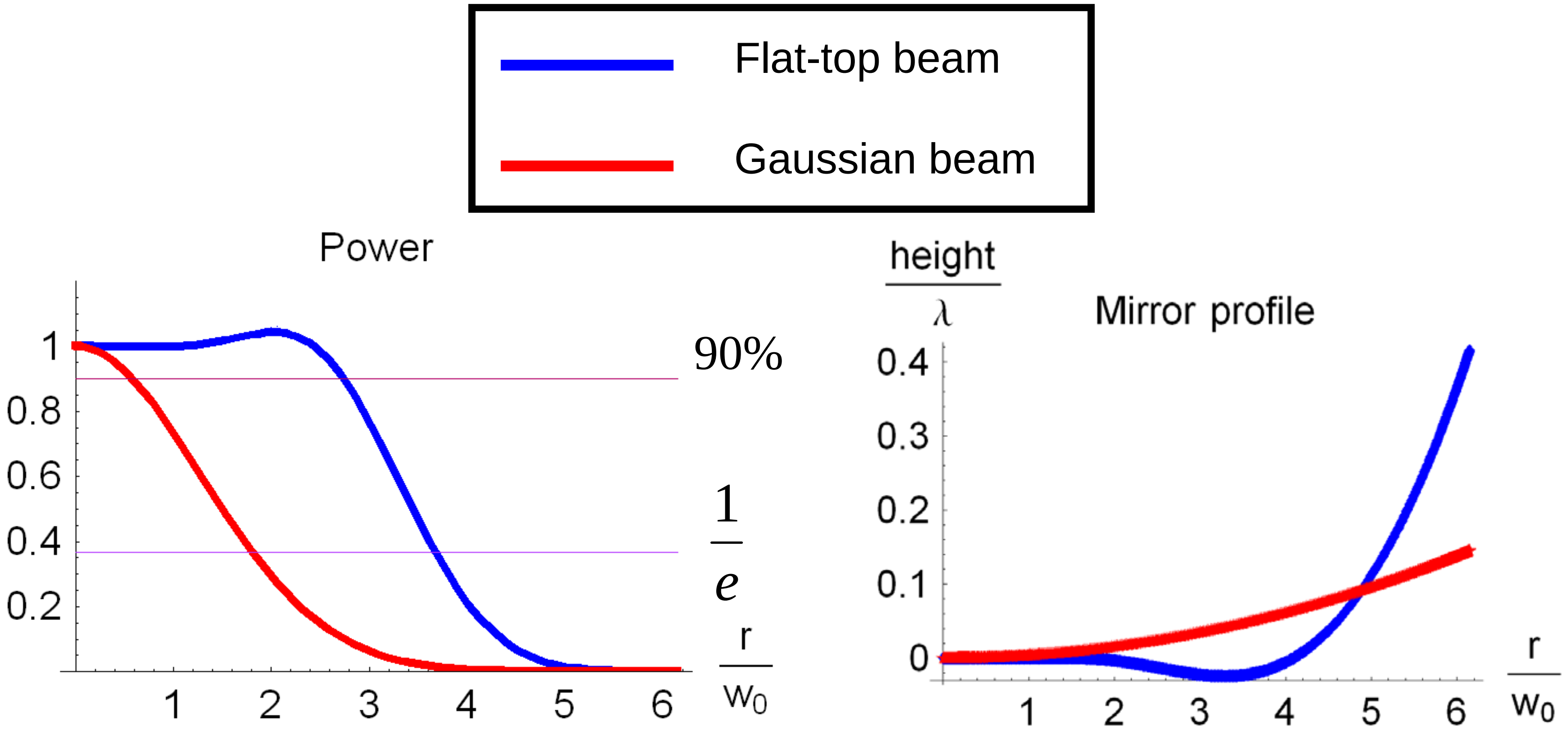
r_0 **As large as possible** (within diffraction loss constraint).

The sampling distribution changes rapidly following the beam power profile



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

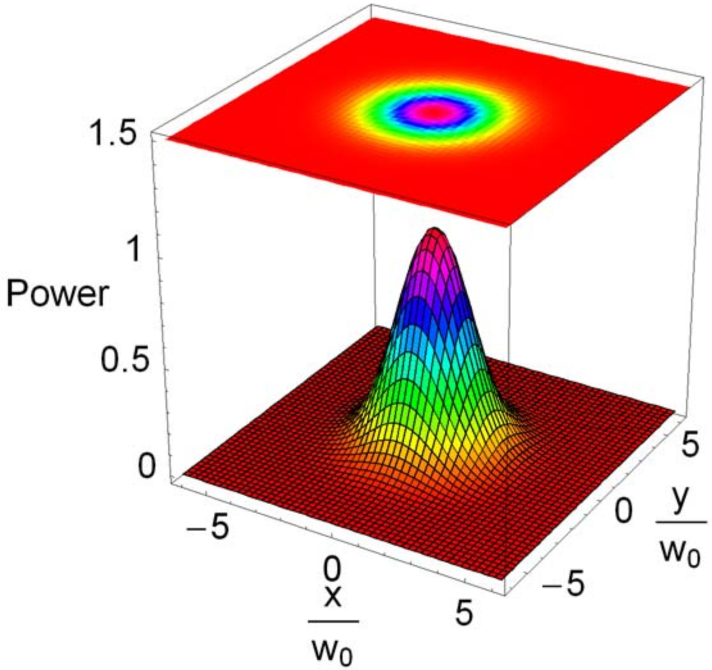
Diffraction prevents the creation of a beam with a rectangular power profile…but we can build a nearly optimal flat-top beam:

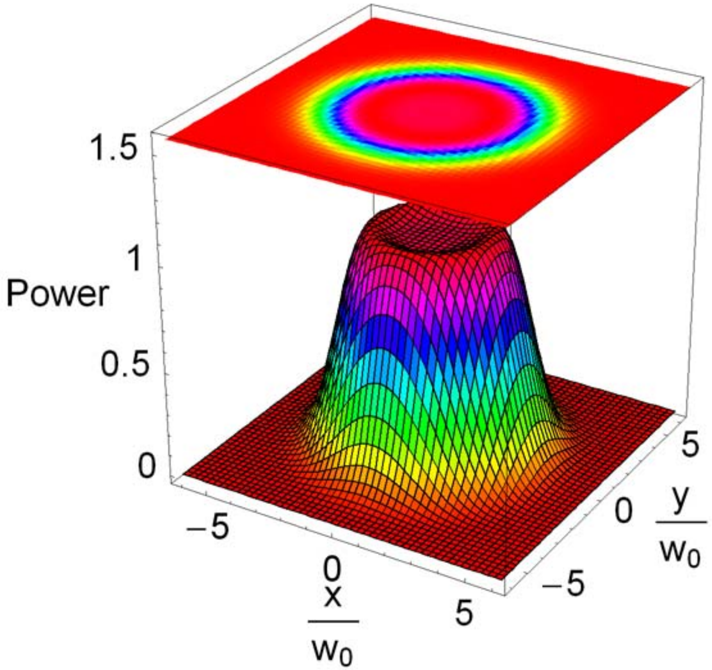


•The mirror shapes match the phase front of the beams.

Comparison between the two beams

(Same diffraction losses)





$$S(r_0) \approx 0.09 S_{mir}$$

$$S(r_{90\%}) \approx 0.01 S_{mir}$$

$$S(r_0) \approx 0.36 S_{mir} \qquad R = 4$$

$$S(r_{90\%}) \approx 0.20 S_{mir} \qquad R = 20$$

Indicative thermal noise suppression trends

$$S_h \propto \frac{1}{\sqrt{r_0^3}}$$

Substrate thermoelastic noise

$$S_h \propto \frac{1}{r_0}$$

Coating thermal noise

$$S_h \propto \frac{1}{\sqrt{r_0}}$$

Substrate thermal noise

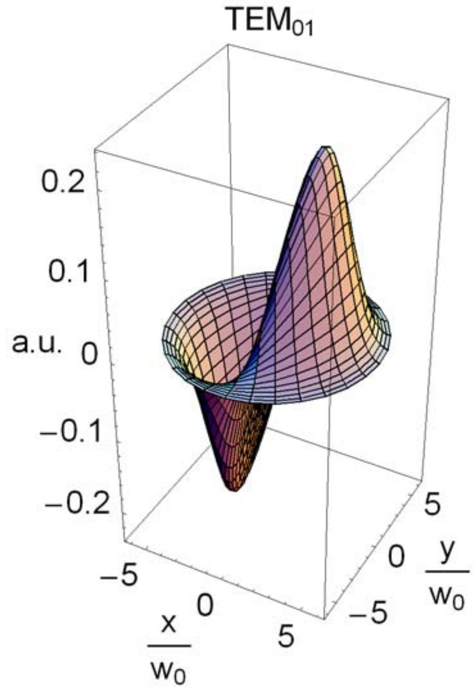
Exact results require accurate information on material properties (Q-factors)

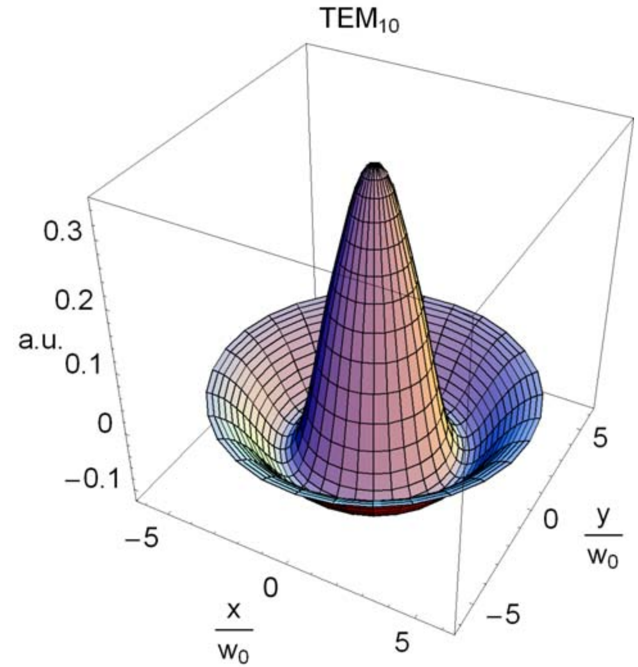
Expected gain in sensitivity ~ 3

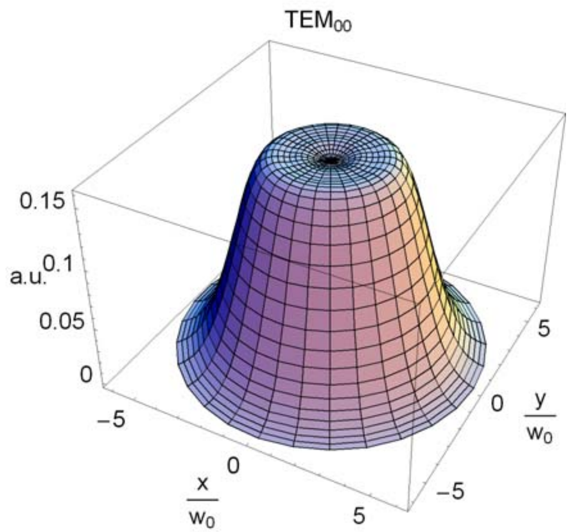
Goals of our project:

Build a small optical cavity to verify the behaviour of the flat top beams and gain experience in their generation and control.

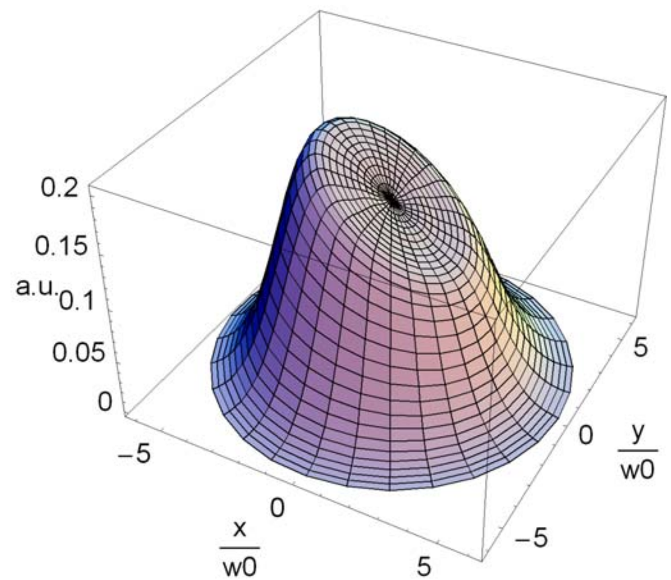
We will investigate the **modes structure** and characterize the **sensitivity to perturbations** when non Gaussian beams are supported inside the cavity.



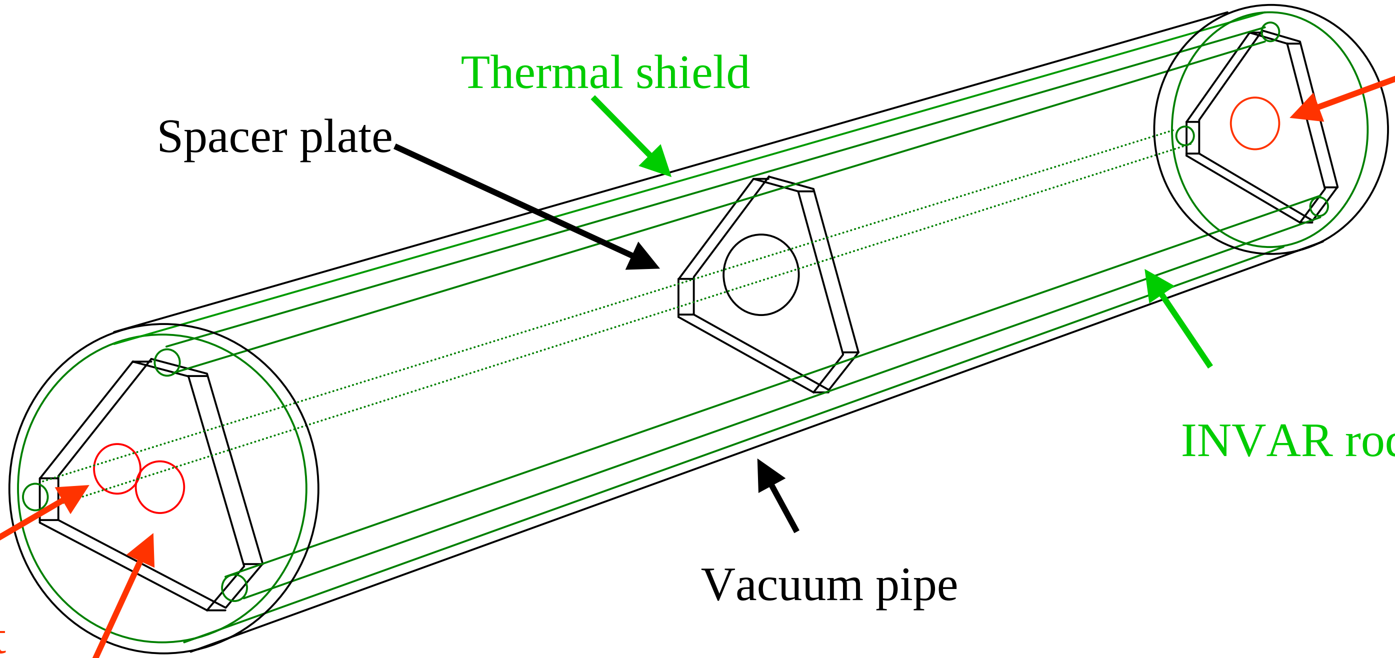




Misalignment produces coupling between modes



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:

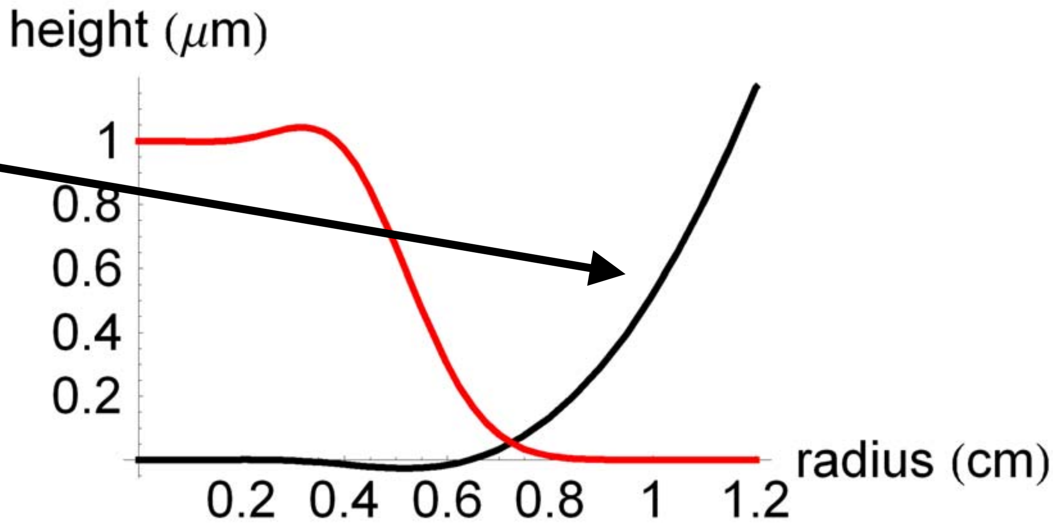
- Injection Gaussian beam designed to optimally couple to the cavity.
- Required finesse $\mathcal{F}$ = 100 to suppress Gaussian remnants in the cavity.

Length stability: ~ 5 nm

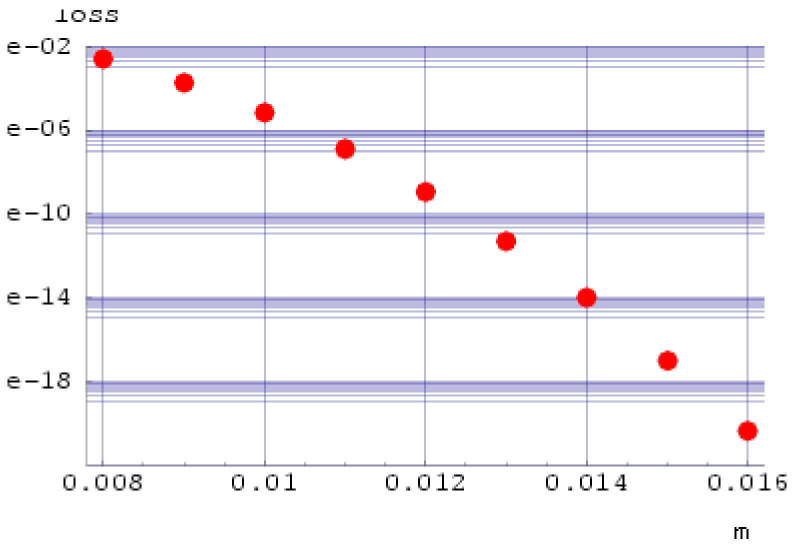
- INVAR rods (low thermal expansion coefficient).
- Stabilized temperature.
- Vacuum eliminates atmospheric fluctuations of optical length.
- Ground vibrations can excite resonance in our interferometer structure: suspension from wires and Geometrical-Anti-Spring blades.

Mirror's size constrained by beam shape and diffraction losses

Our Mexican Hat mirror:

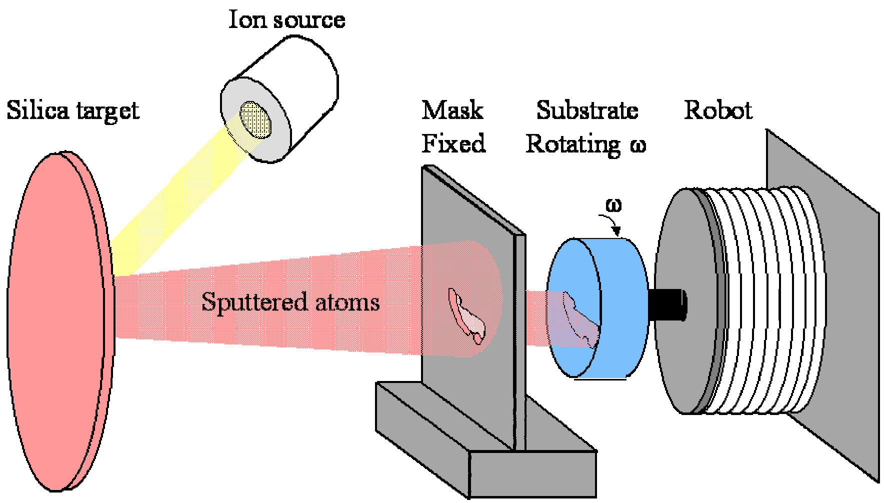


Diameter set by diffraction losses and technical difficulties…



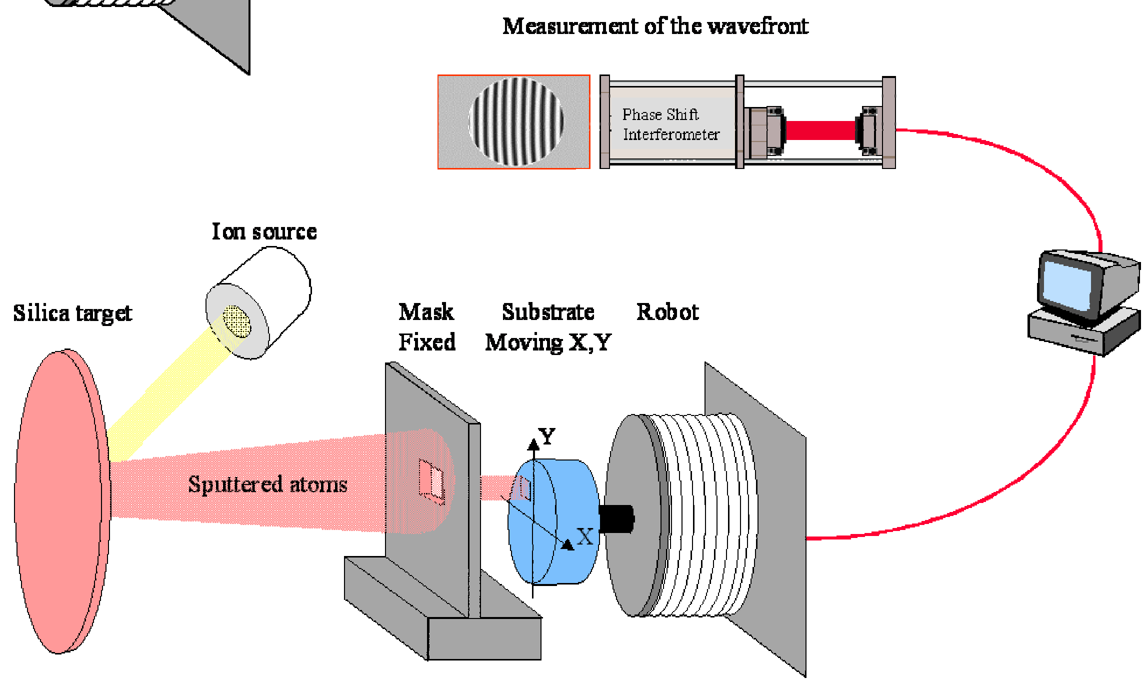
Diffraction losses of ~ 1ppm requires mirror's radius >1 cm.

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.**

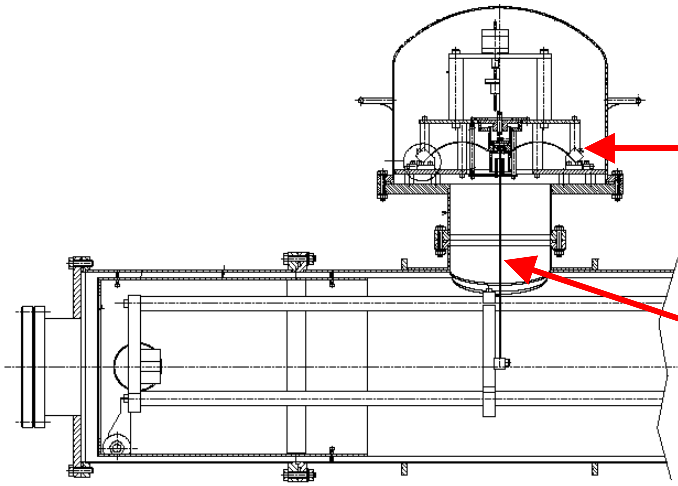


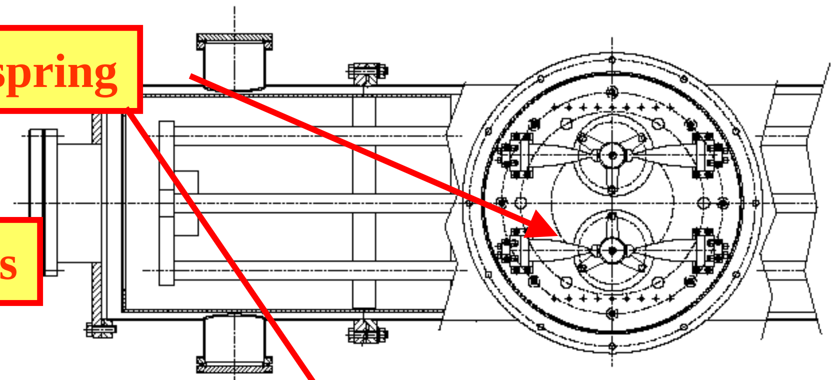
Maximum slope ~ 500nm/mm

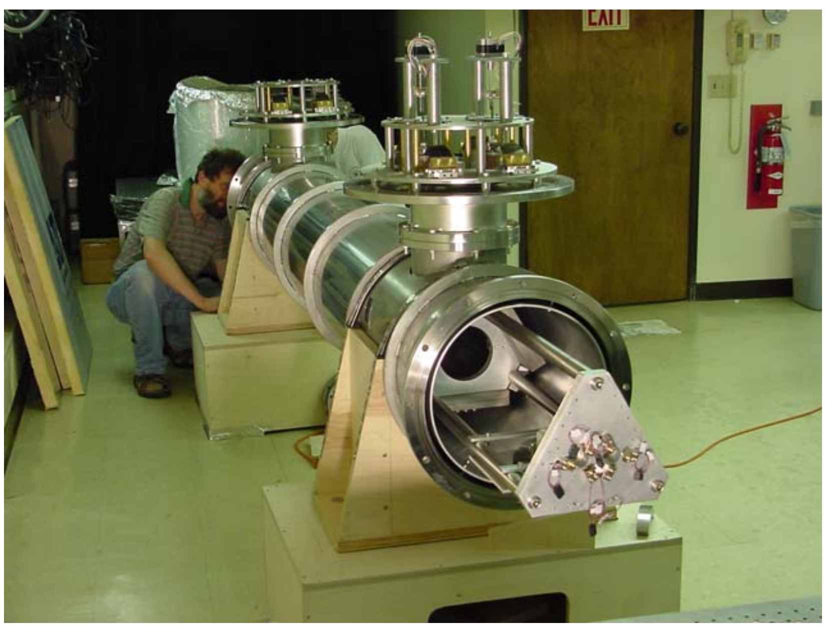
Cavity Suspensions

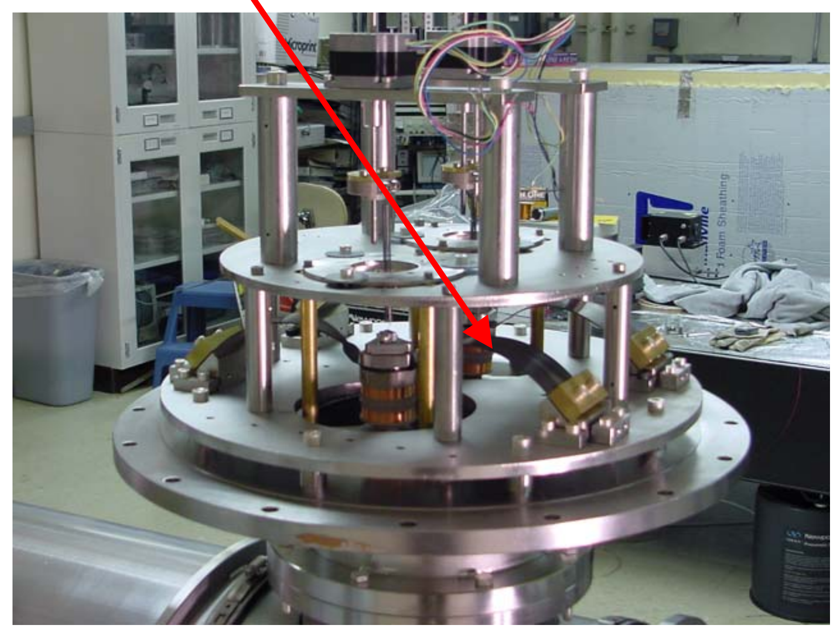
V~ 0.6 Hz

H ~ 1 Hz

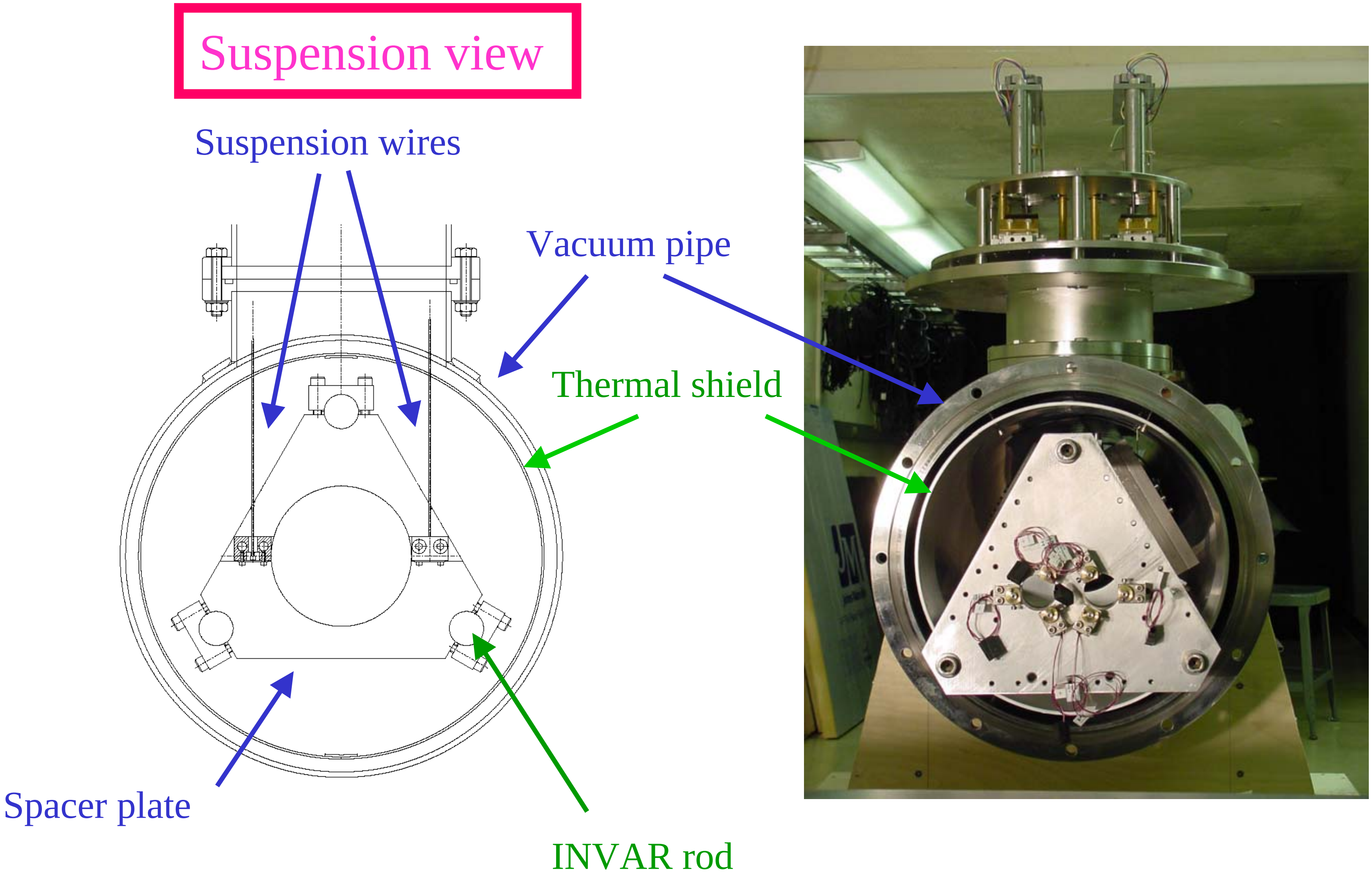








Cavity Vacuum & Thermal Shield



Suspension at work!

Schedule for the future

- Complete building the cavity including the optics and the electronics
- Lock the cavity with spherical mirror (test the apparatus)
- 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.