High power adaptive mirror

Development of adaptive mirrors for intra-cavity laser applications

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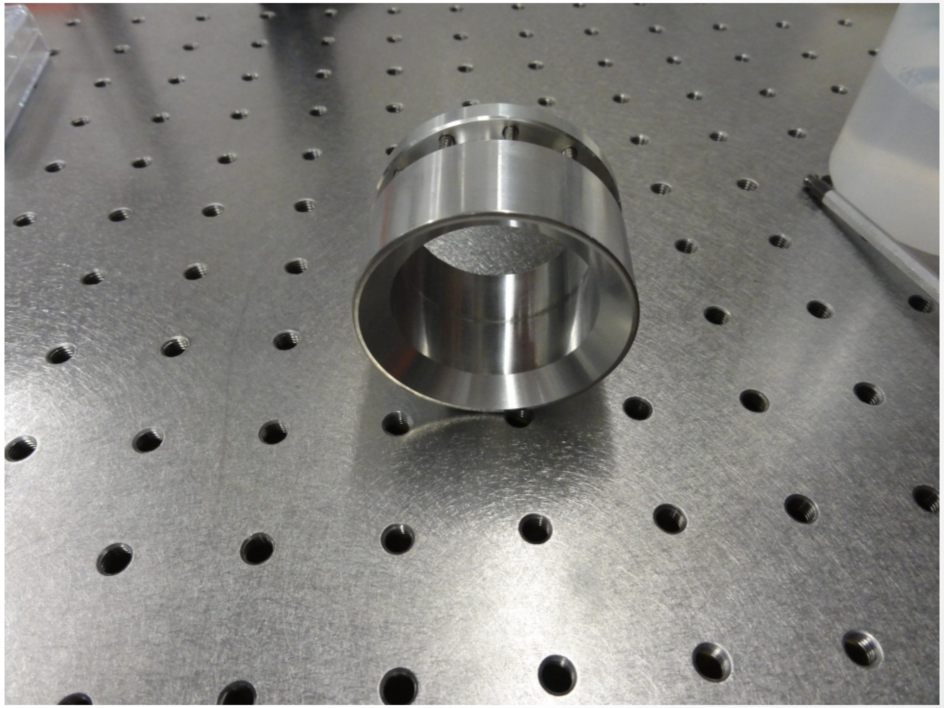
Overview

- Motivation (muonic hydrogen Lamb shift)
- Disk laser
- Thermal lens problem
- Adaptive glass mirror
- Results
- Outlook

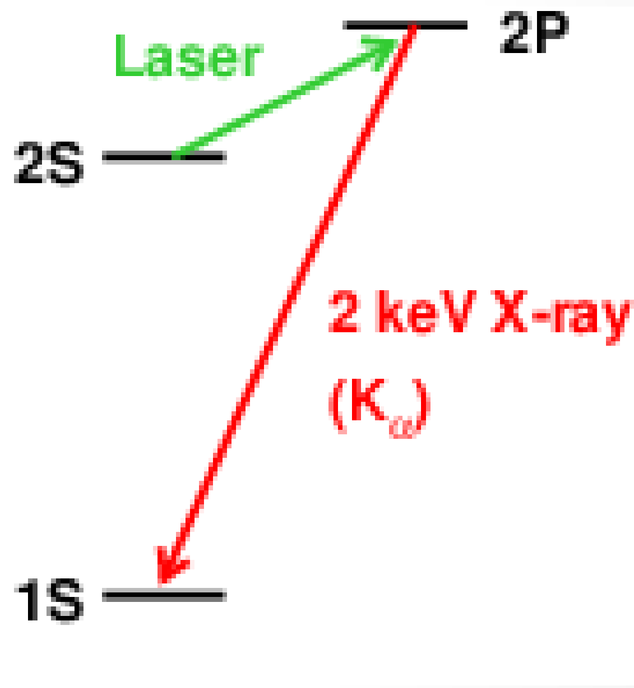


Proton radius puzzle

- Spectroscopy of μp
- 2S-2P transition frequency depends on the proton radius (R)
- CODATA: R=0.8775 (51) fm
- Our result:R=0.84184 (67) fm
- 7σ discrepancy

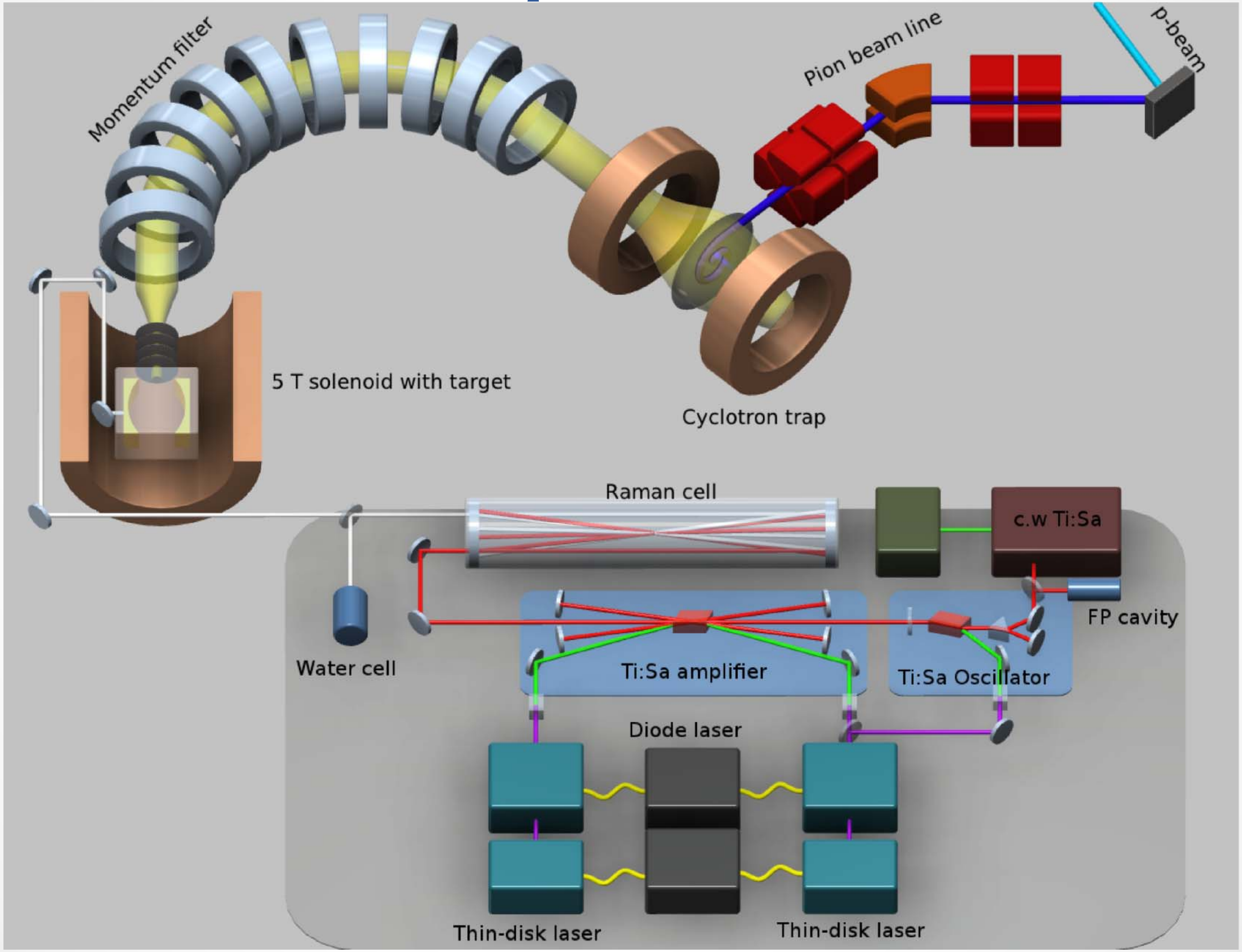
Laser spectroscopy of μp

- Measure $\Delta E^{exp}(2S\text{-}2P)$
- Compare with theoretical prediction:
  $$\Delta E^{th}(2S{-}2P) = 209.9779(49)$$
  $$+5.2262 \cdot R^2$$
  $$+0.0347 \cdot R^3$$
  - Units are in [meV] and [fm]



- Extract proton radius

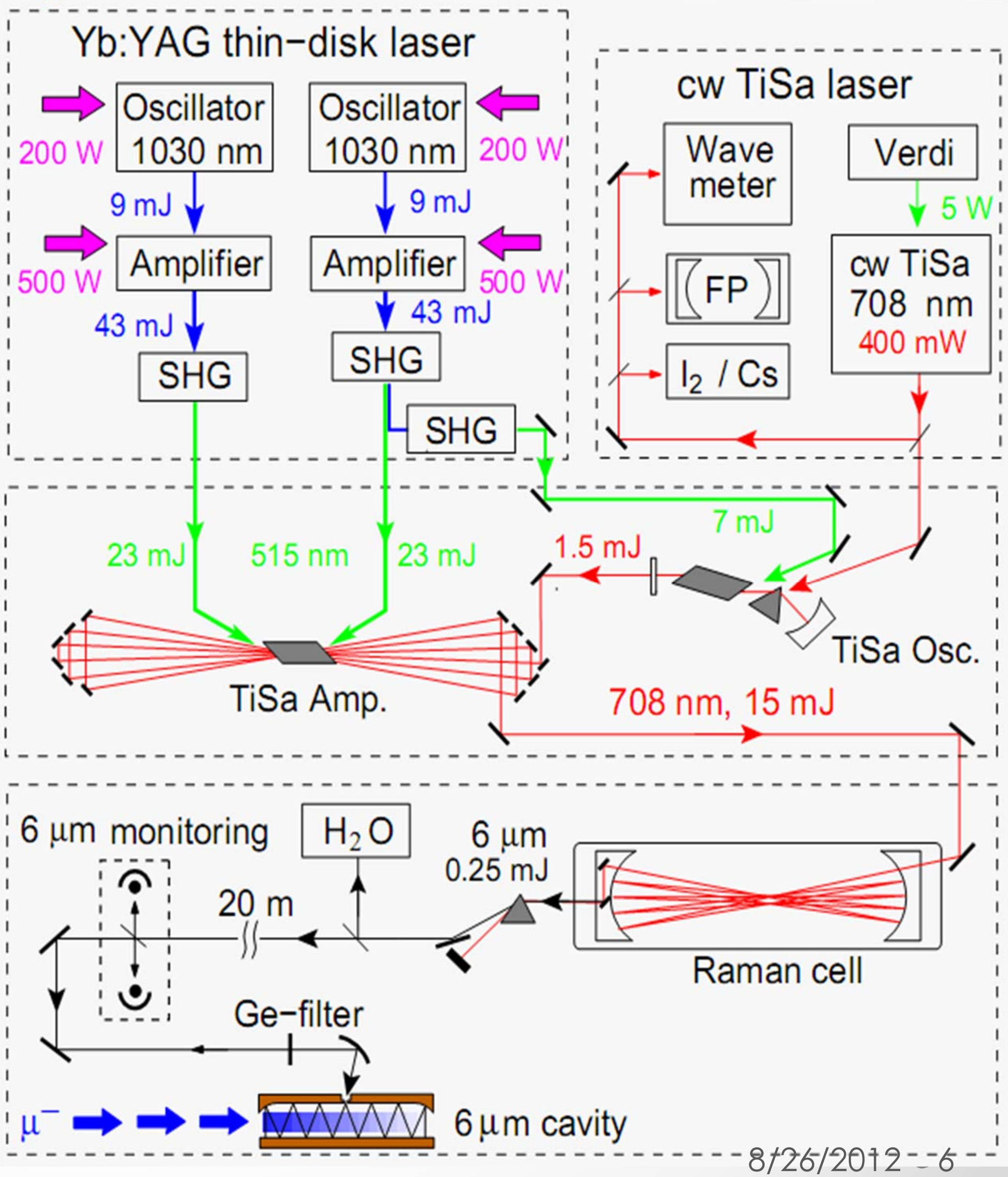
Setup at PSI



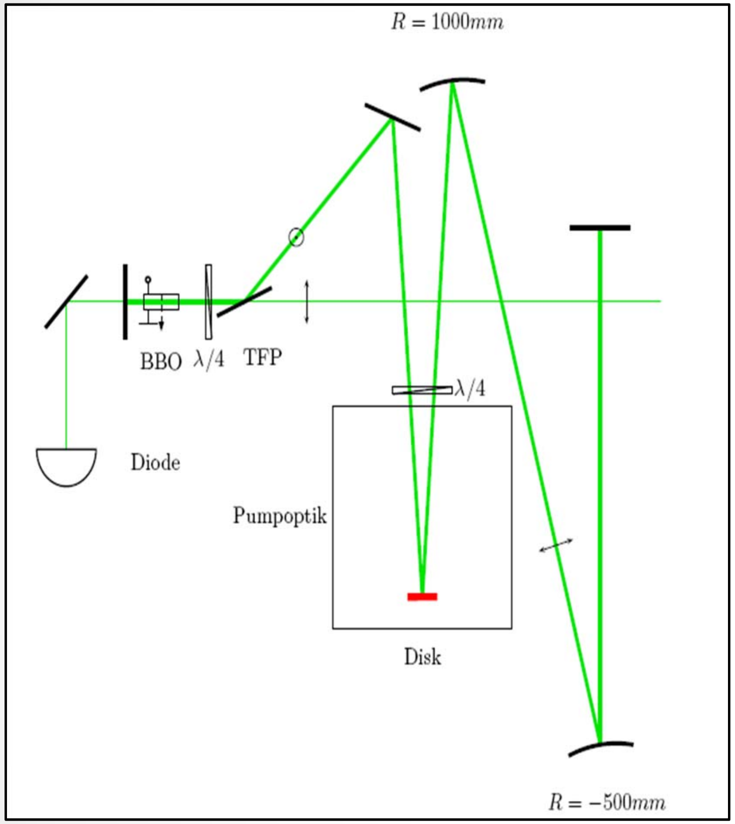
Momentum filter
Pion beam line
p-beam
5 T solenoid with target
Cyclotron trap
Raman cell
c.w Ti:Sa
FP cavity
Water cell
Ti:Sa amplifier
Ti:Sa Oscillator
Diode laser
Thin-disk laser
Thin-disk laser

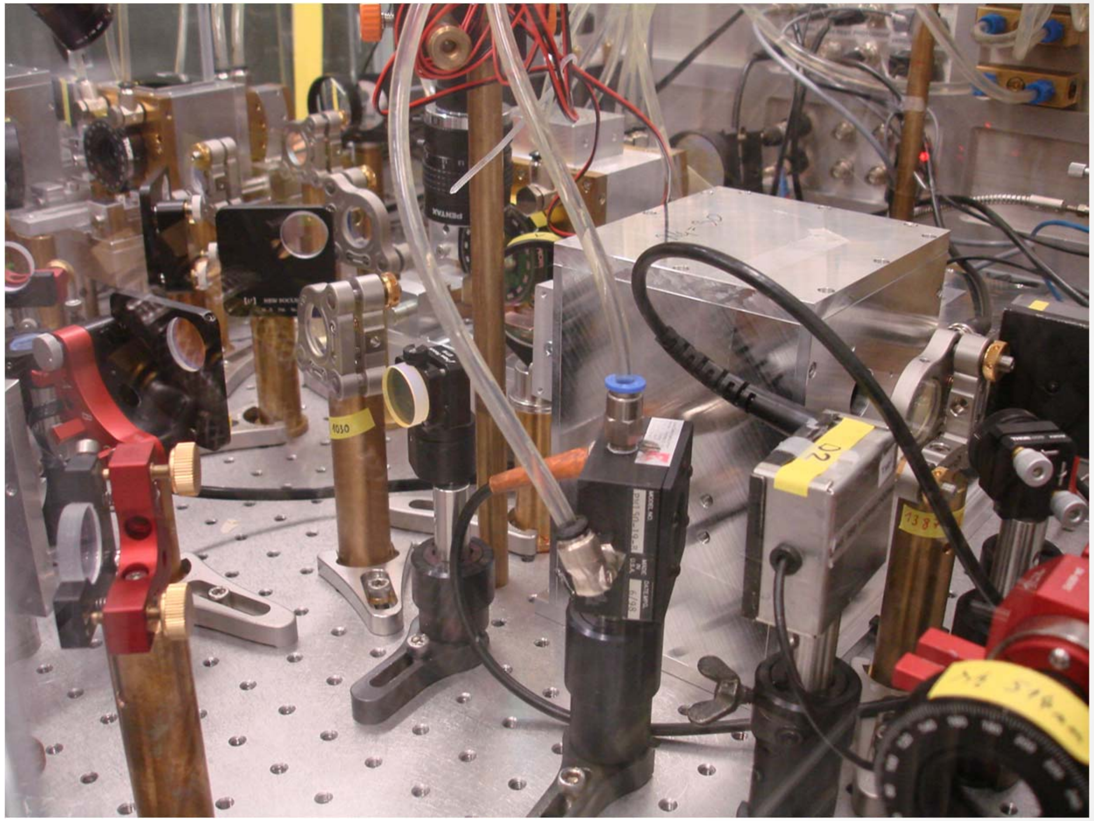
Laser for μp Lamb shift

- Stochastic trigger
- 0-1200 Hz rep. rate
- 400 ns latency
- 80 mJ @ 1030 nm



"Old" disk laser oscillator

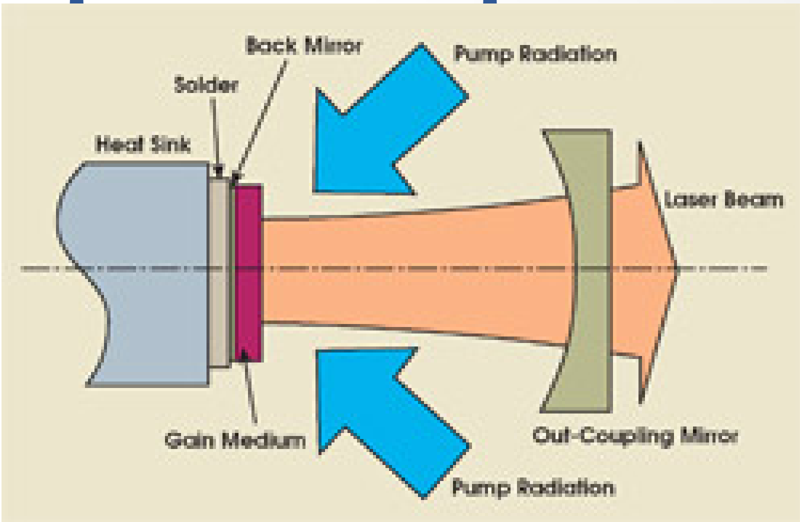




E_{max}=15 mJ
Latency=200 ns

Beside other Improvements we want to use the adaptive mirror to improve this setup.

Disk laser principle



- Crystal has the form of an extremely short rod
- Large surface
- Efficient cooling
- HR- and AR-coating

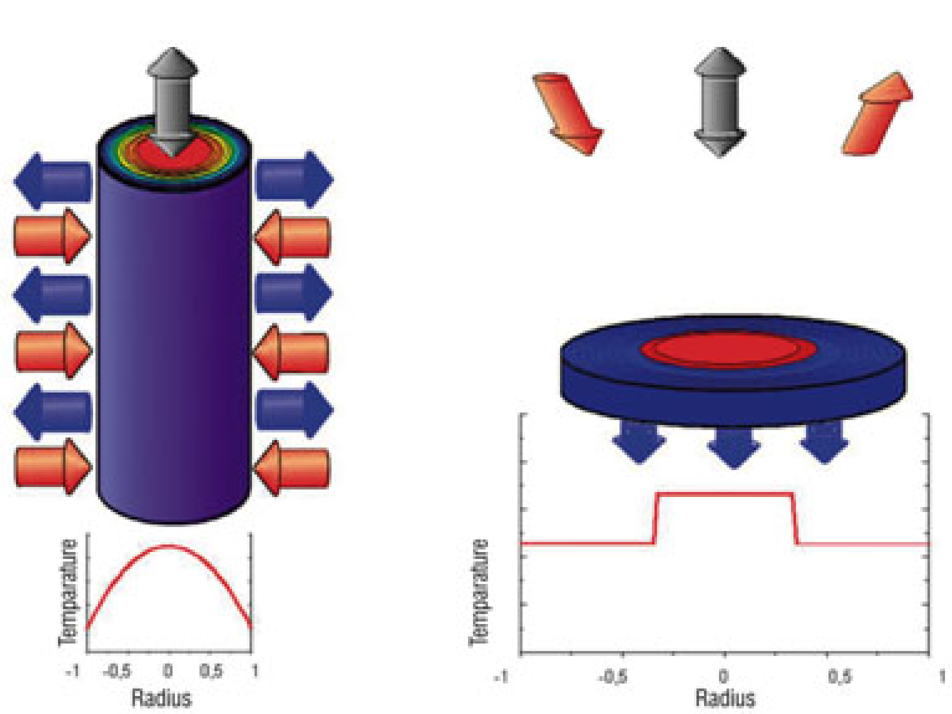
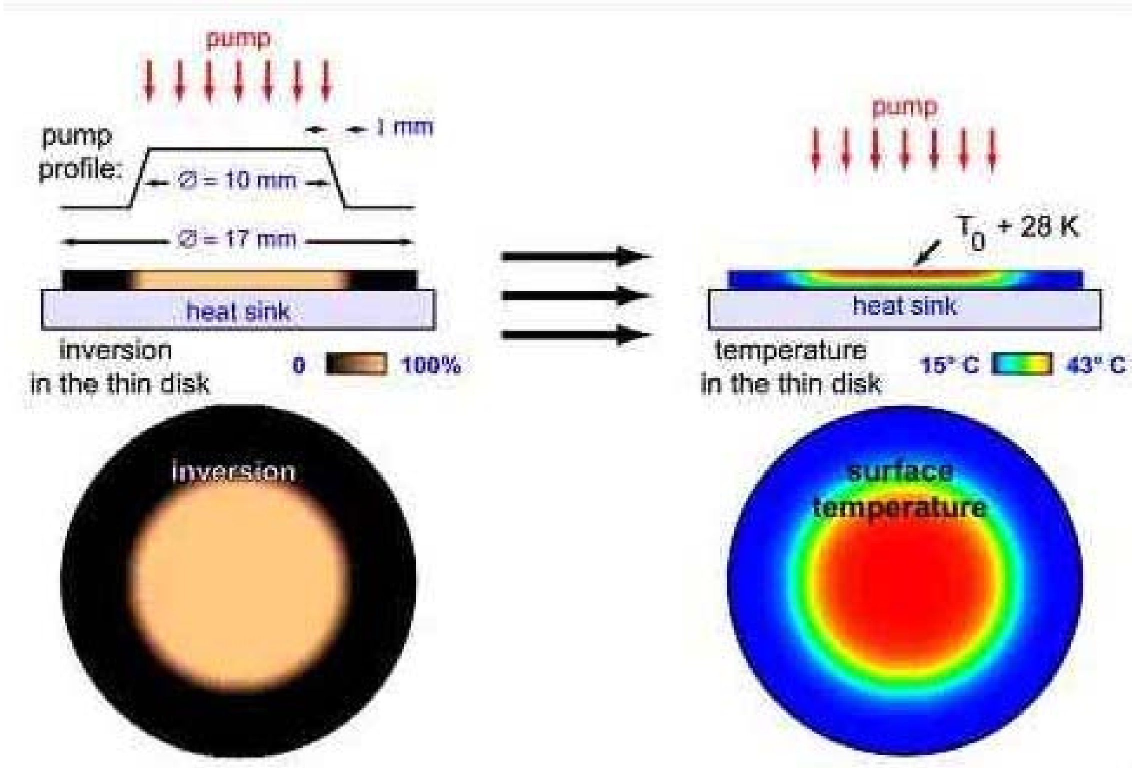
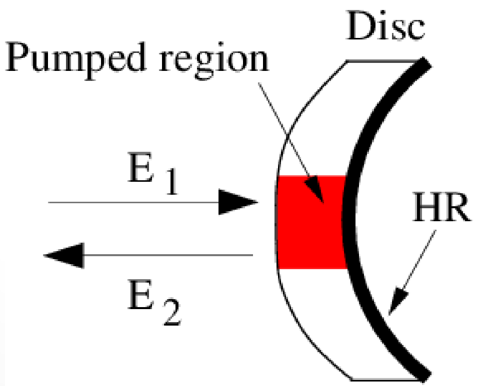


Figure 1

Thermal lens of disk

- Thermal expansion
- Thermal change of refractive index dn/dT
- Inversion dependent change of refractive index
- Bending of substrate

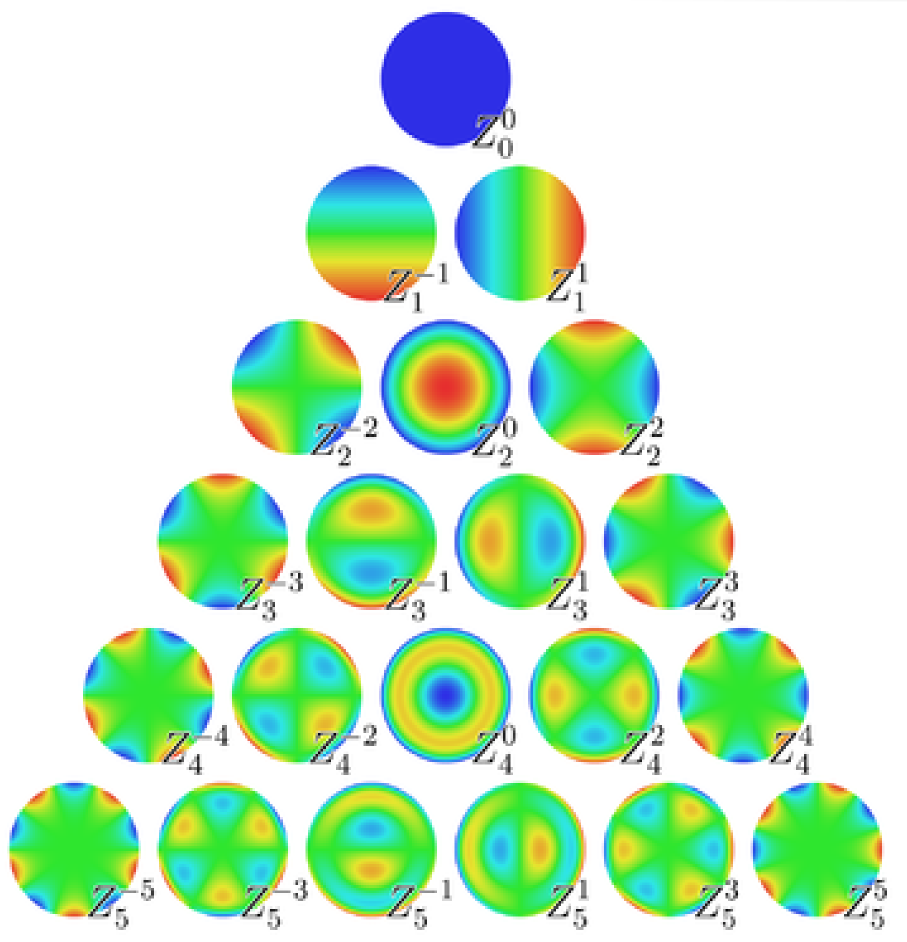




$$OPD(x, y) = d(x, y) * n(x, y)$$

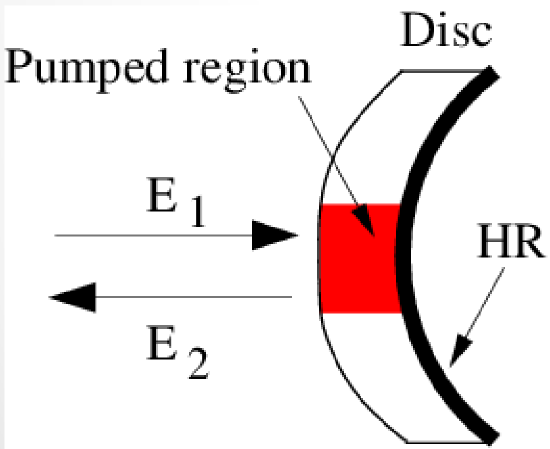
Description of thermal lenses

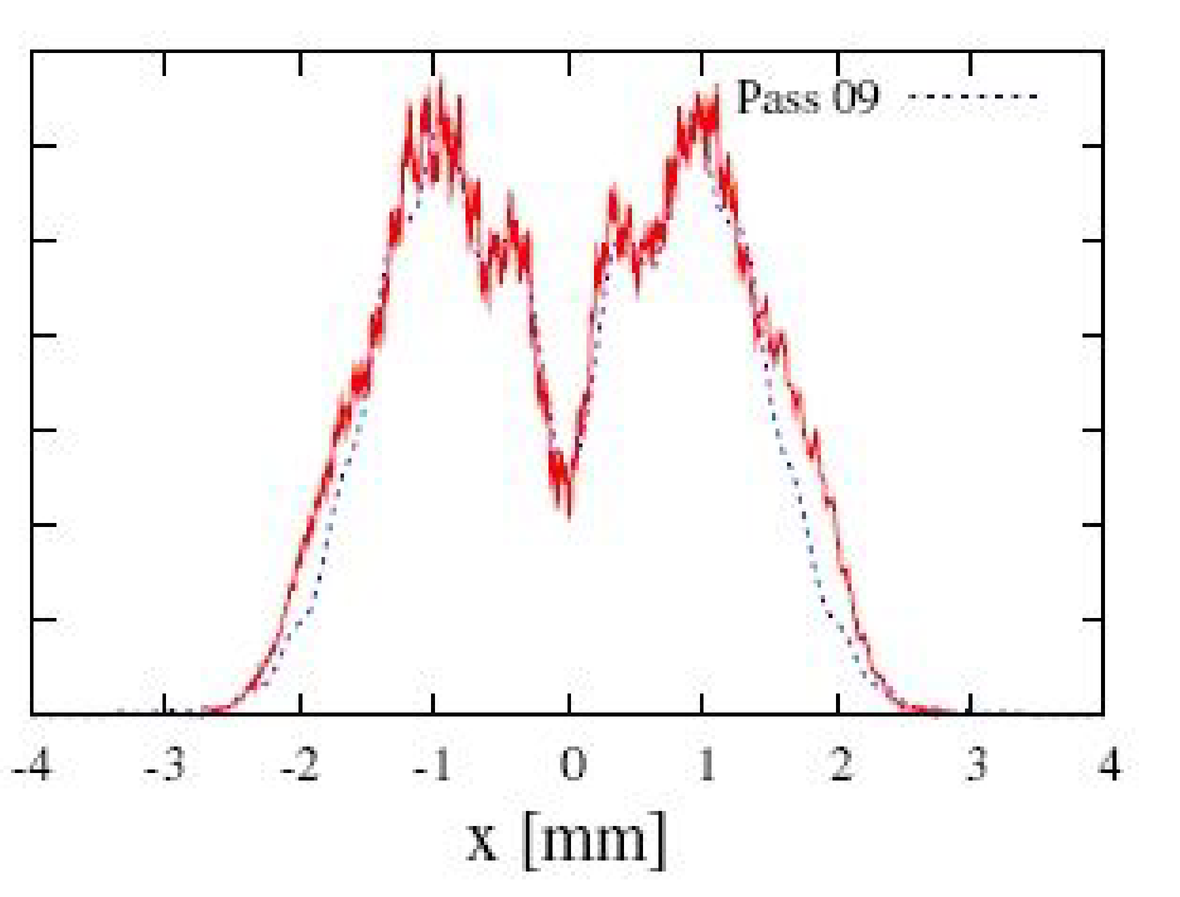
- The thermal lens is optical phase difference (OPD)
- It can be described using the Zernike polynomials
- For ideal alignment only symmetrical deformation occur
  - o Spherical deformation
  - o Higher order deformation



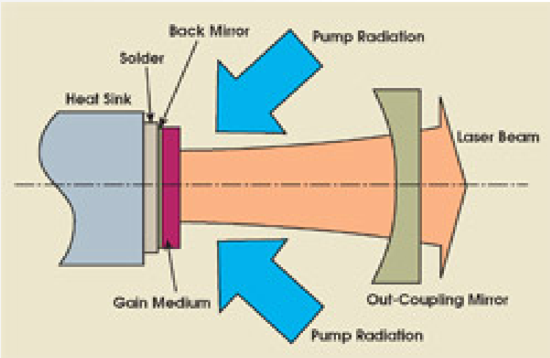
Aspherical deformation of disk

A Gaussian beam reflected on an aspherical disk acquires high order components





Resonator stability vs. waist (pulse energy)

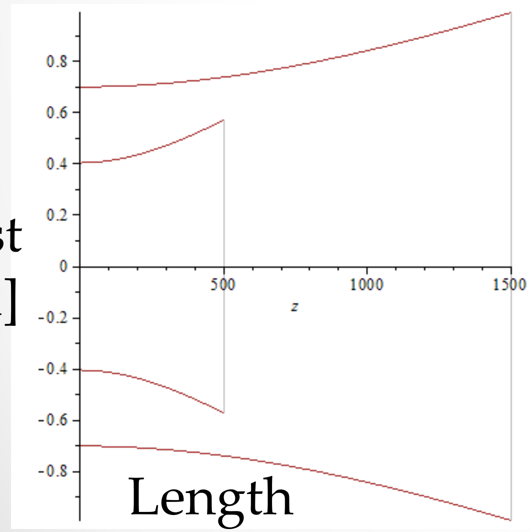


Comparison of two resonators with:
w=0.4 mm
w=0.7 mm

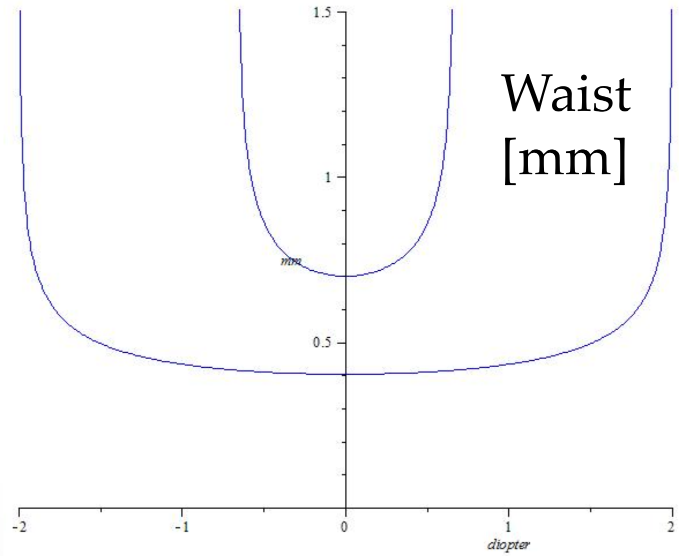
$$\Delta V \sim \frac{1}{w^2}$$

- The stability range ΔV can be shifted changing laser layout (mirror curvatures and distances).
- But the with of this range depends only on wavelength and waist.

Waist [mm]



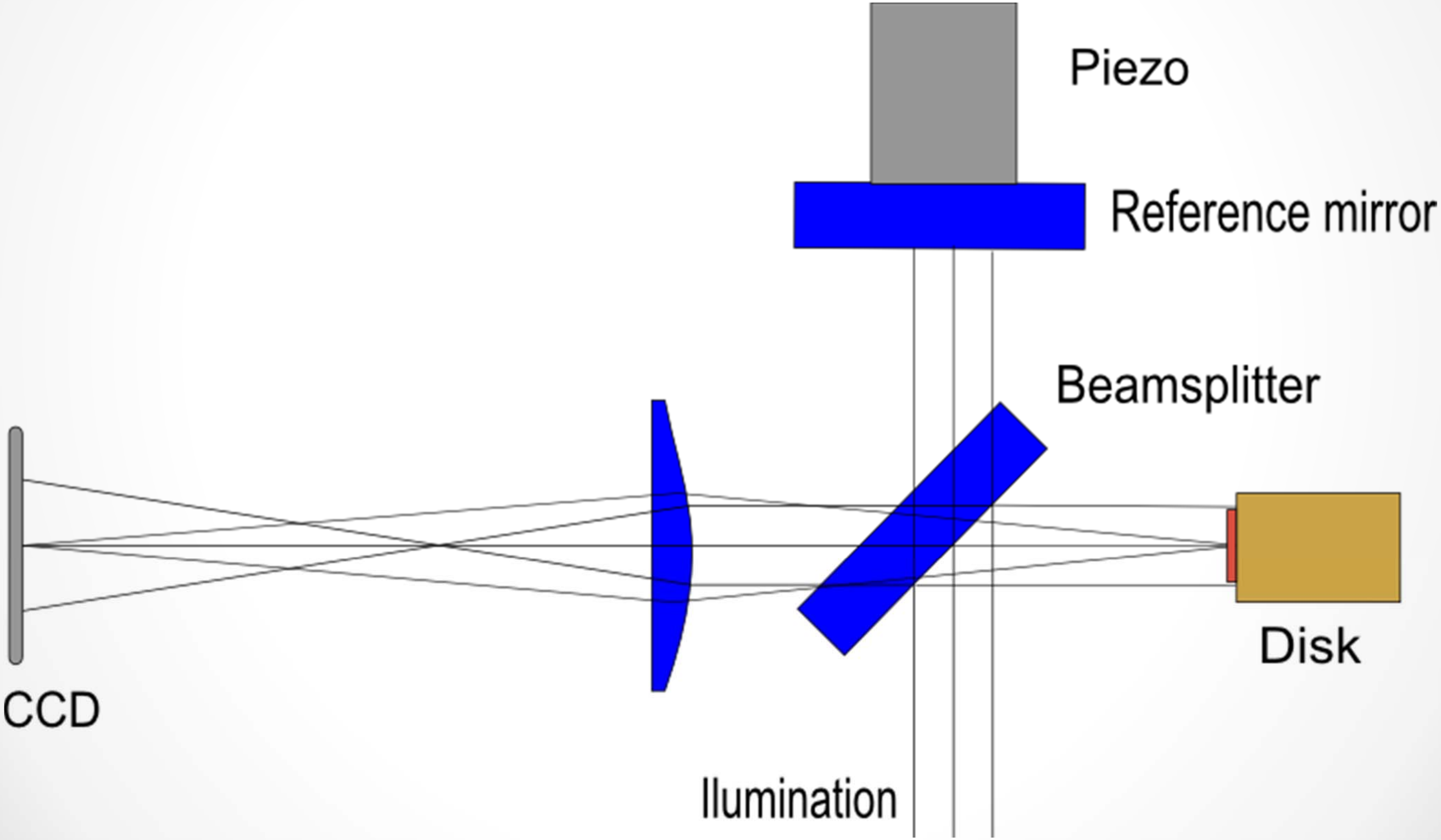
Length [mm]



Waist [mm]

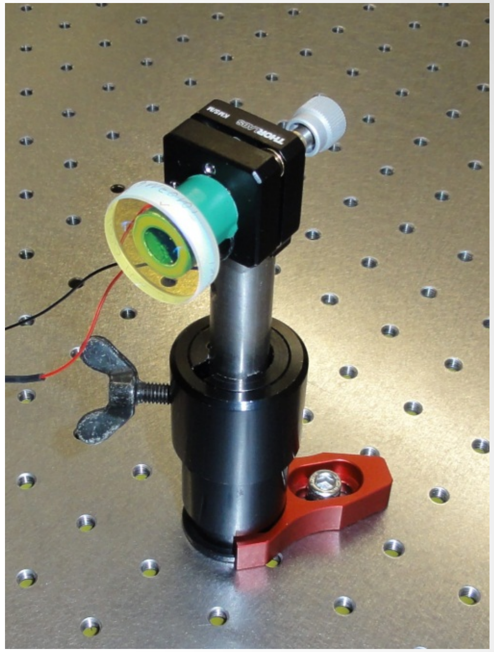
focal strength [1/m]

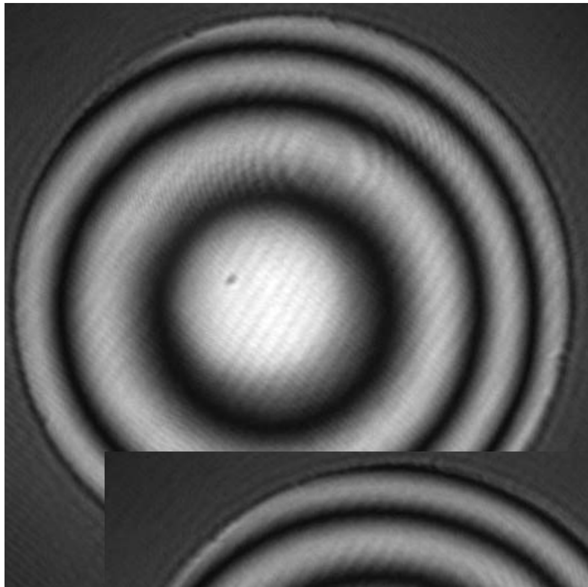
Interferometry

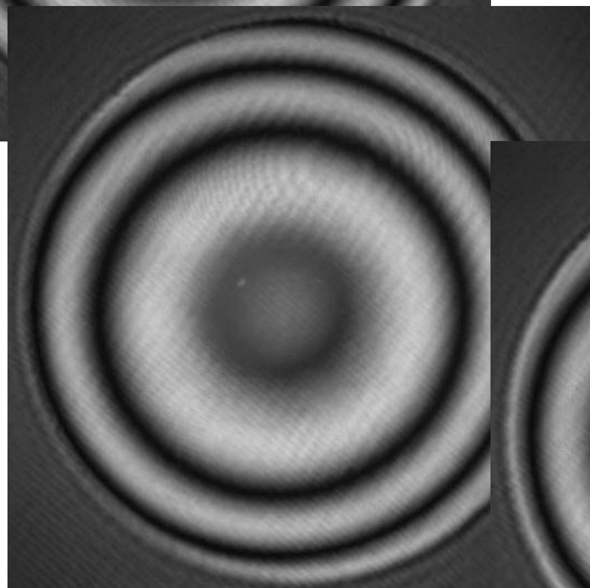


In situ measurement

- Measurement of optical phase deformation (OPD) of laser disk during operation
- We developed an interferometer for in situ measurements
- Record multiple pictures with shifted reference mirror (phase shift measurement)







Unfolded OPD

- We developed a software to evaluate interferograms
- Phase shift analysis of N pictures
- Phase unwrapping

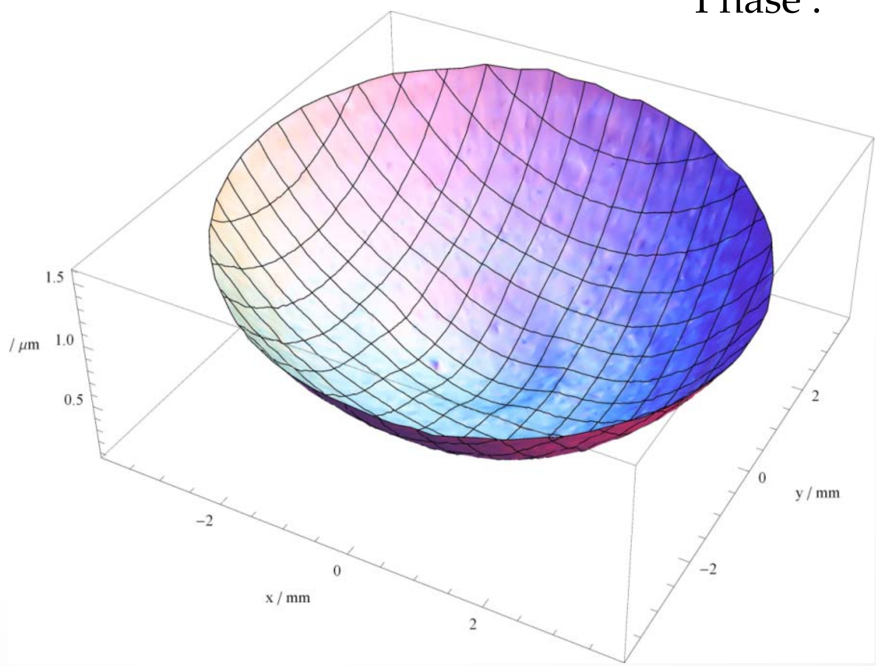
Example for N=3

$$Phase = \arctan\left(\frac{\begin{pmatrix}\sin(\alpha_1)\\ \sin(\alpha_2)\\ \sin(\alpha_3)\end{pmatrix}\times\begin{pmatrix}A_1\\ A_2\\ A_3\end{pmatrix}}{\begin{pmatrix}\cos(\alpha_1)\\ \cos(\alpha_2)\\ \cos(\alpha_3)\end{pmatrix}\times\begin{pmatrix}A_1\\ A_2\\ A_3\end{pmatrix}}\right)$$

$\alpha_{1..N}$: Global phases of the various pictures

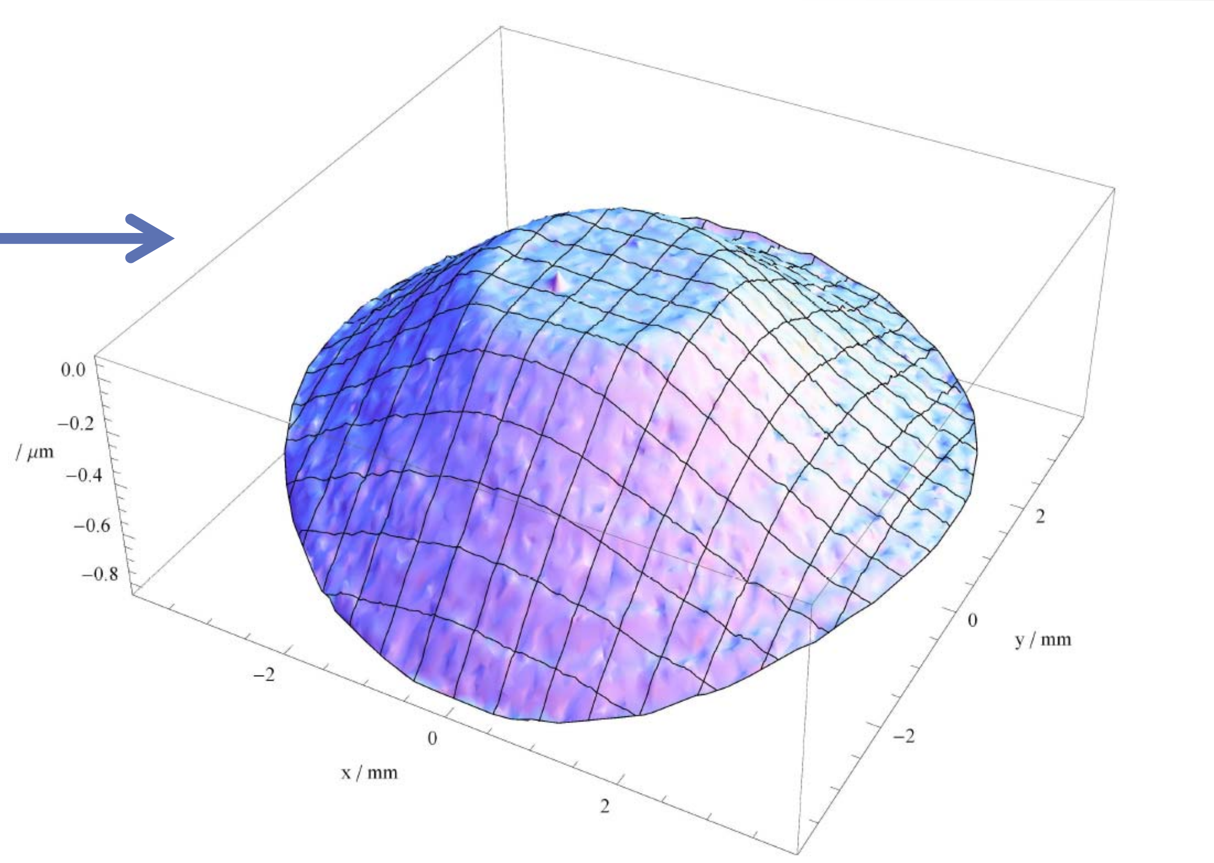
$A_{1..N}$: Intensity of a pixel of the various pictures

Phase : Phase of pixel



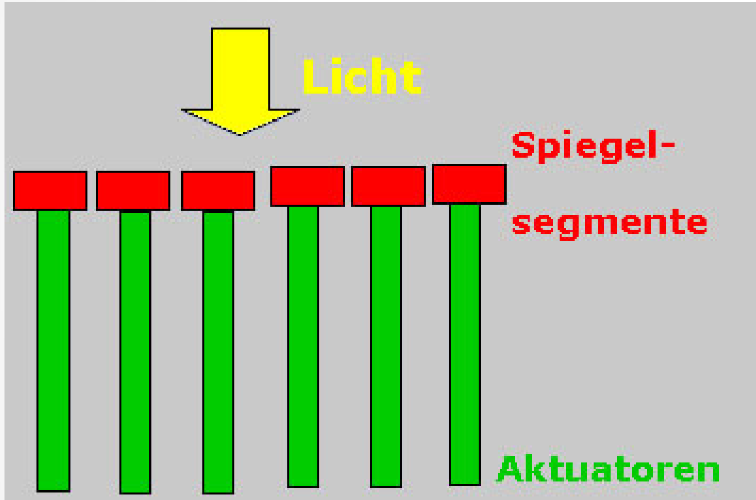
OPD with subtracted spherical lens

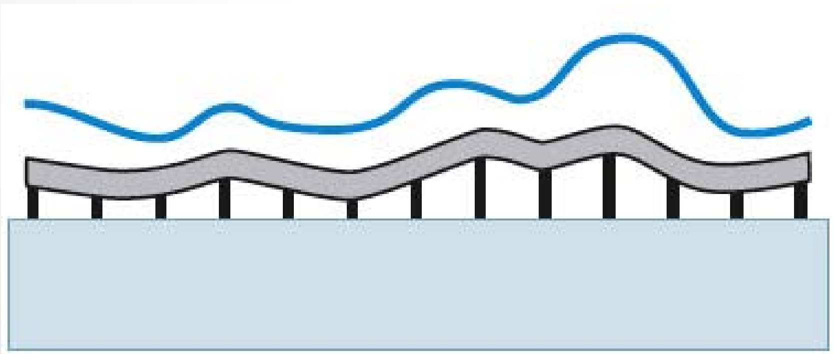
- Fit parabola to OPD within the pump spot
- Get the remnant →
- Mainly bending of substrate
- Within the pump spot the aspherical deformations are negligible



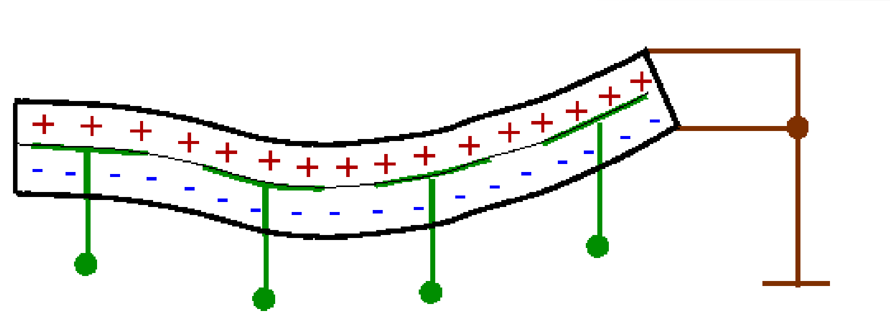
Bending mirrors in astronomy

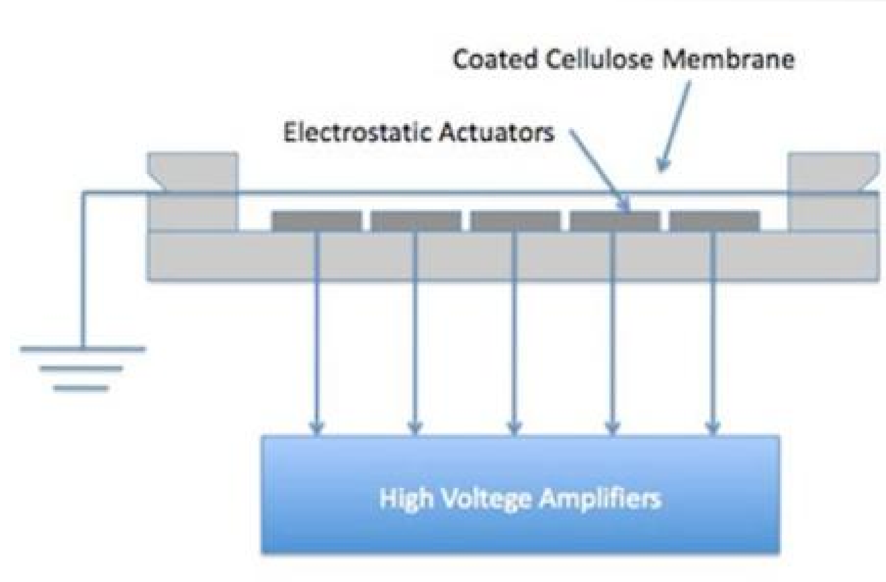
Mirror with discrete actuators





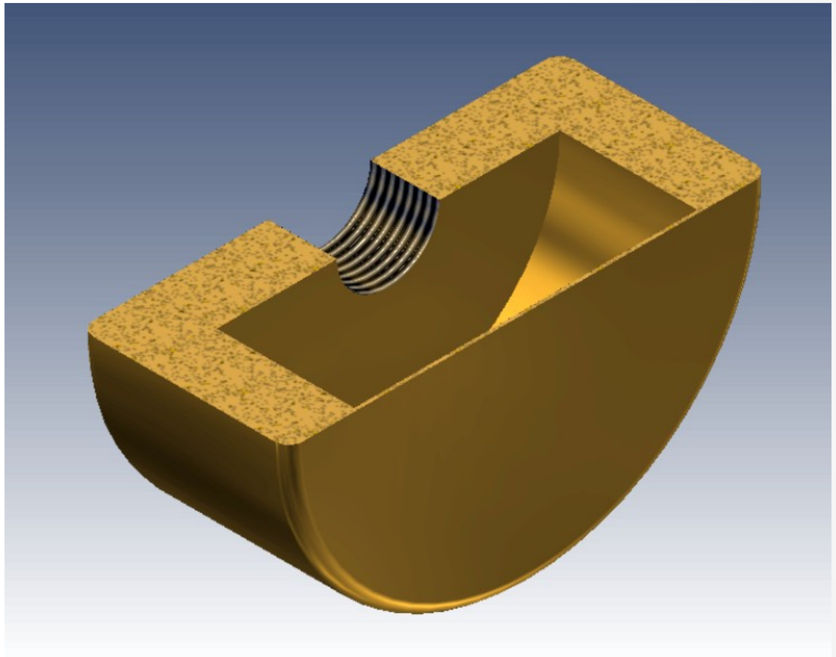
Full surface electrostatic adaptive mirrors

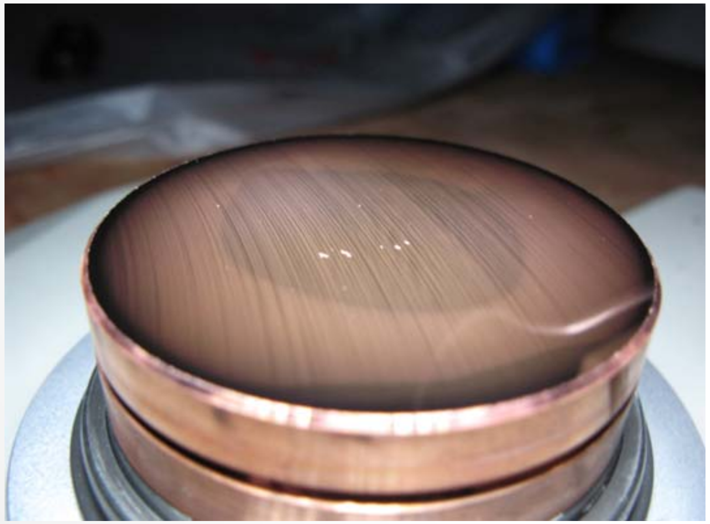




Pressure driven metallic membrane

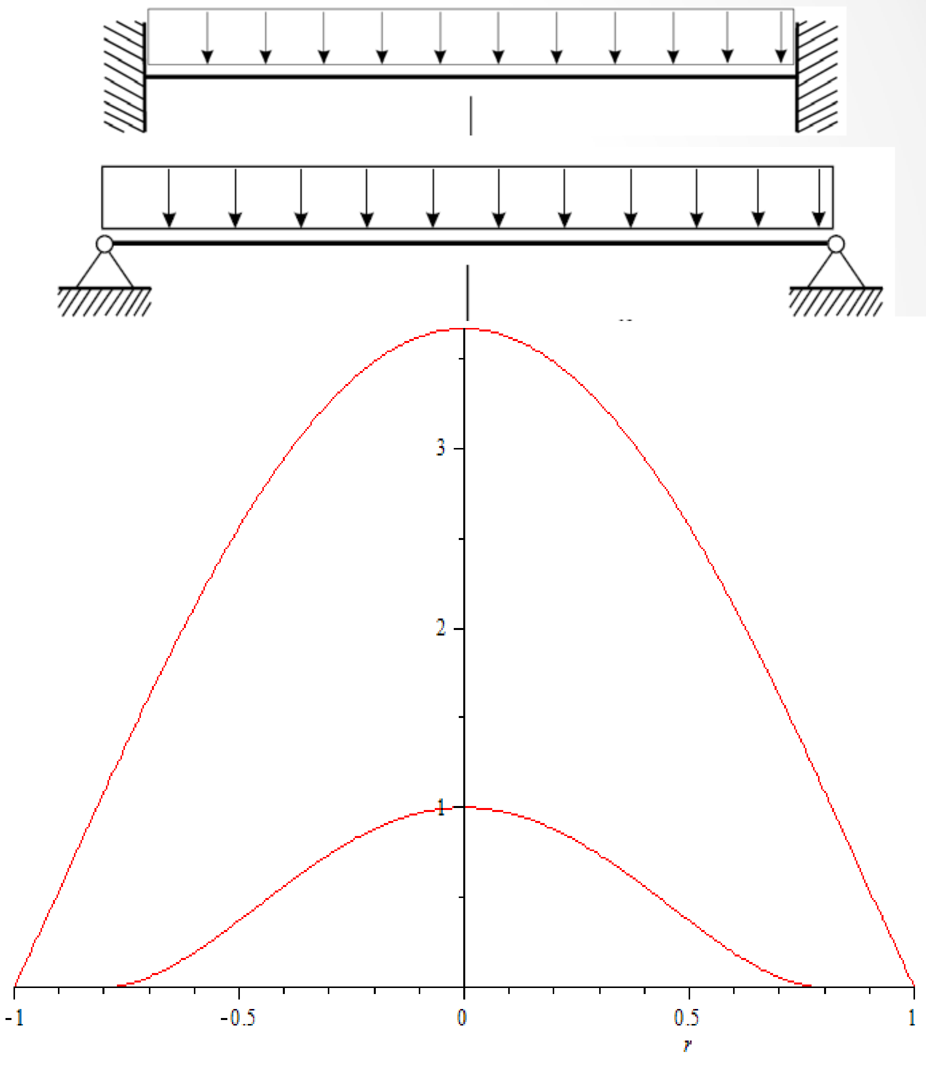
- 0.25 % scattering loss
- 80 kW/cm^2 damage threshold



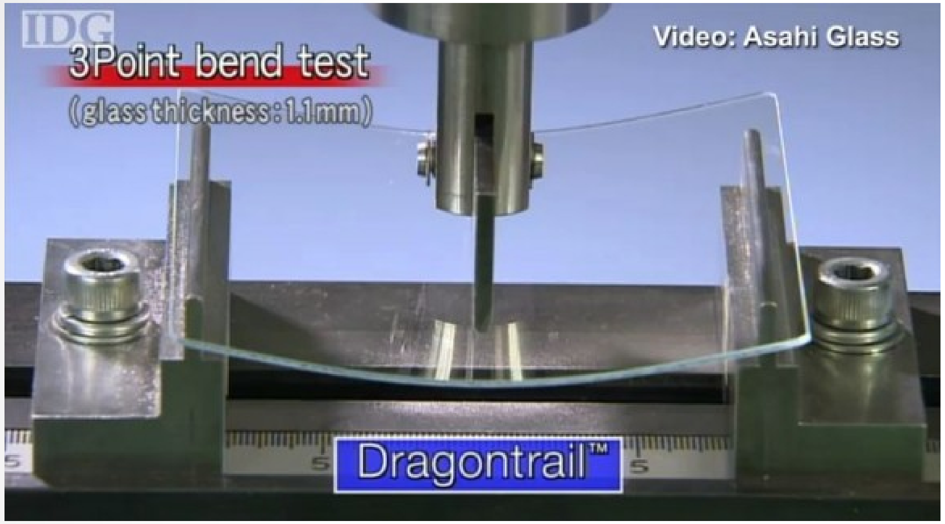


Deformation

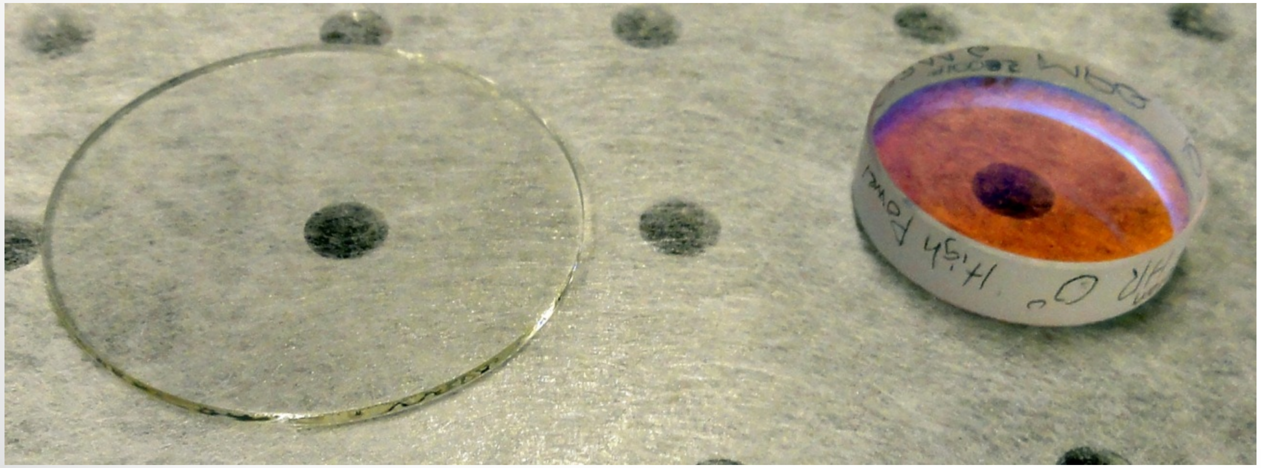
- Solutions of dgl. are well known
    - Clamped substrate
      $w \sim 1 - 2 \cdot r^2 + r^4$
    - Flexible mounting
      $w \sim 5 - 6 \cdot r^2 + r^4$
- Thick substrate with homogeneous properties
- Homogeneous pressure



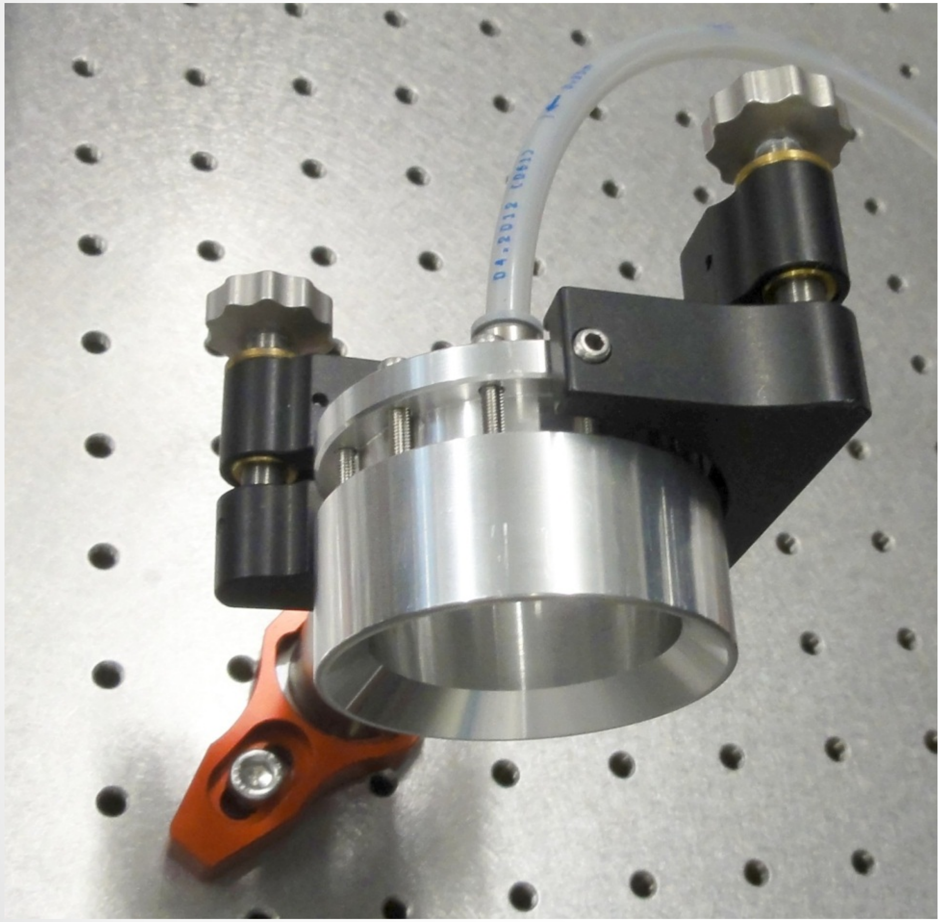
Benefit of glass membrane

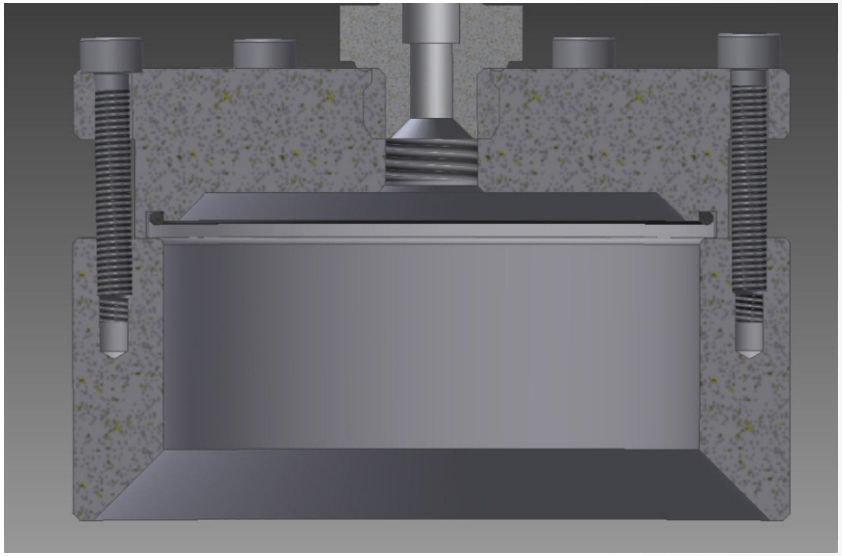


- Very low surface roughness
  (scattering loss ≤0,01 %)
- Damage thresholds up to 100 MW/cm^2
  (1000 times larger than on a metallic substrate)

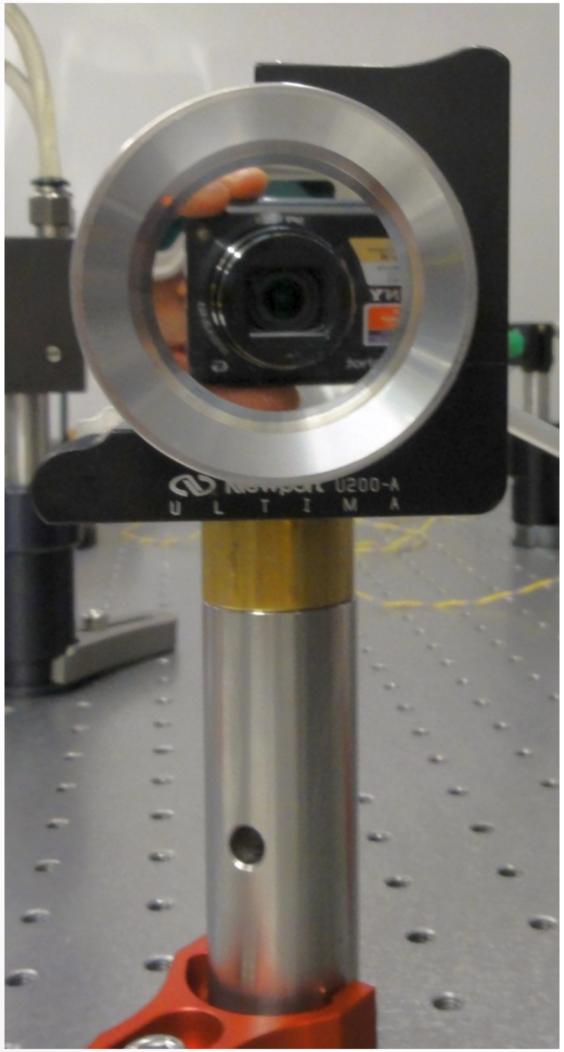
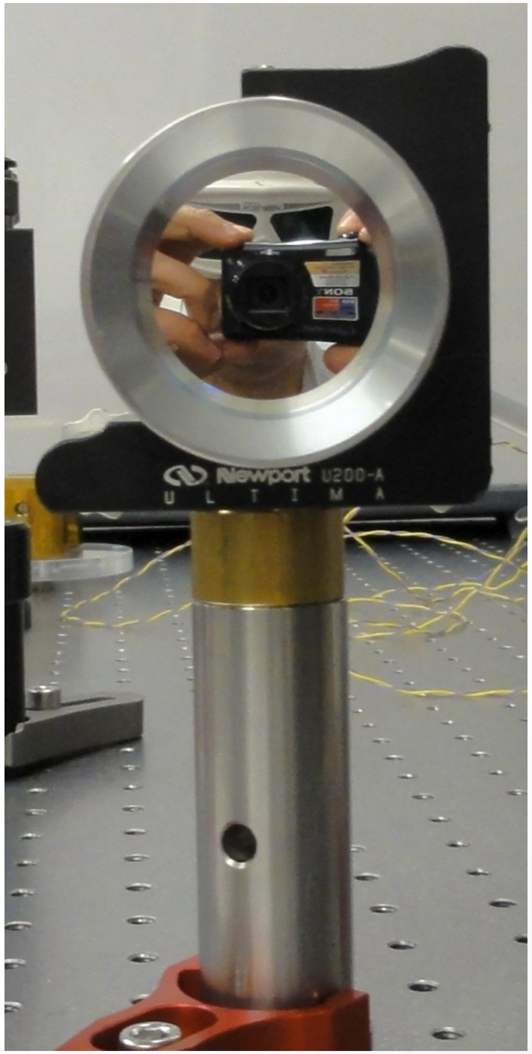


Our deformable mirror

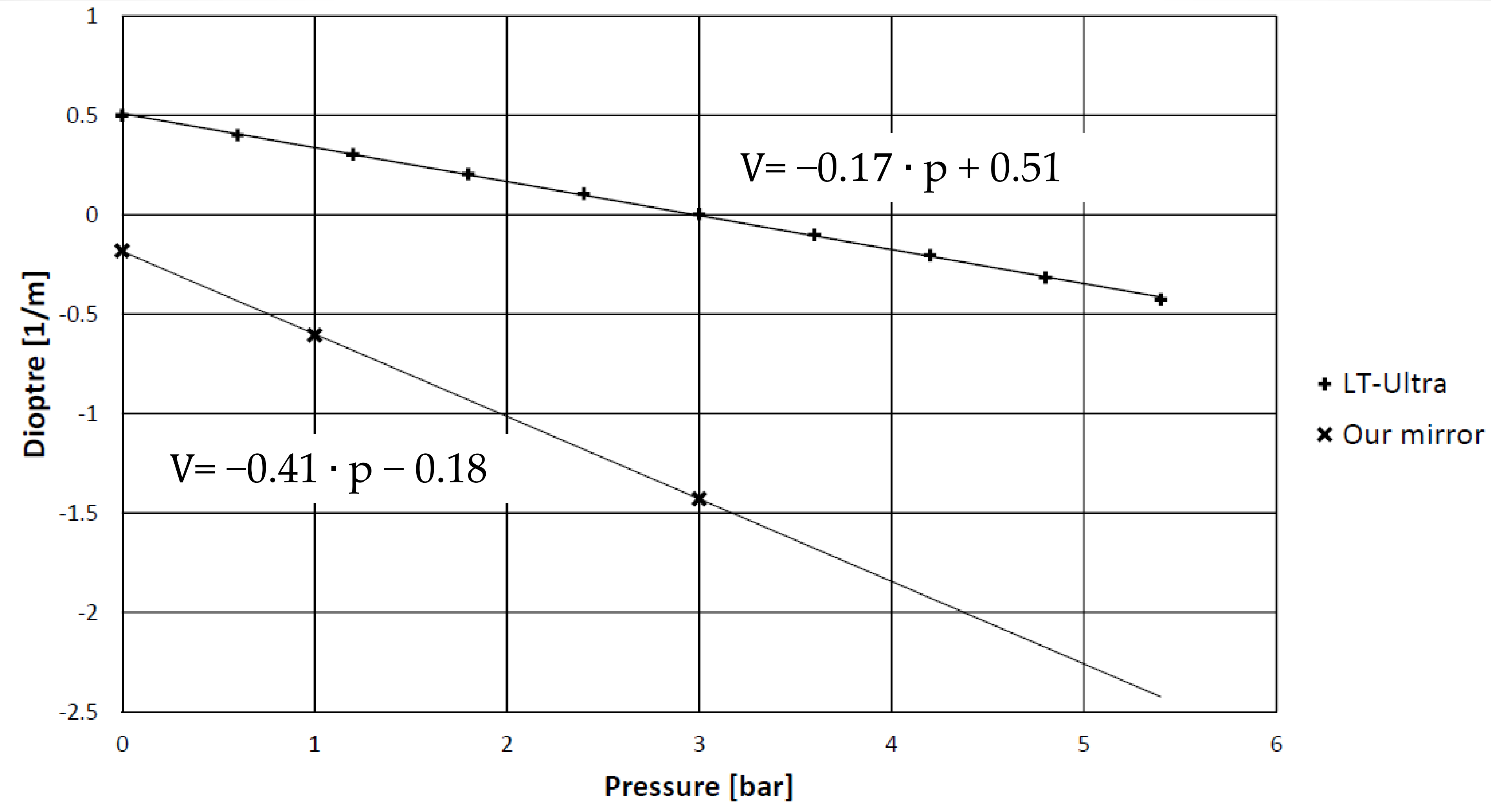




- Driven with pressurized air
- Glass substrate

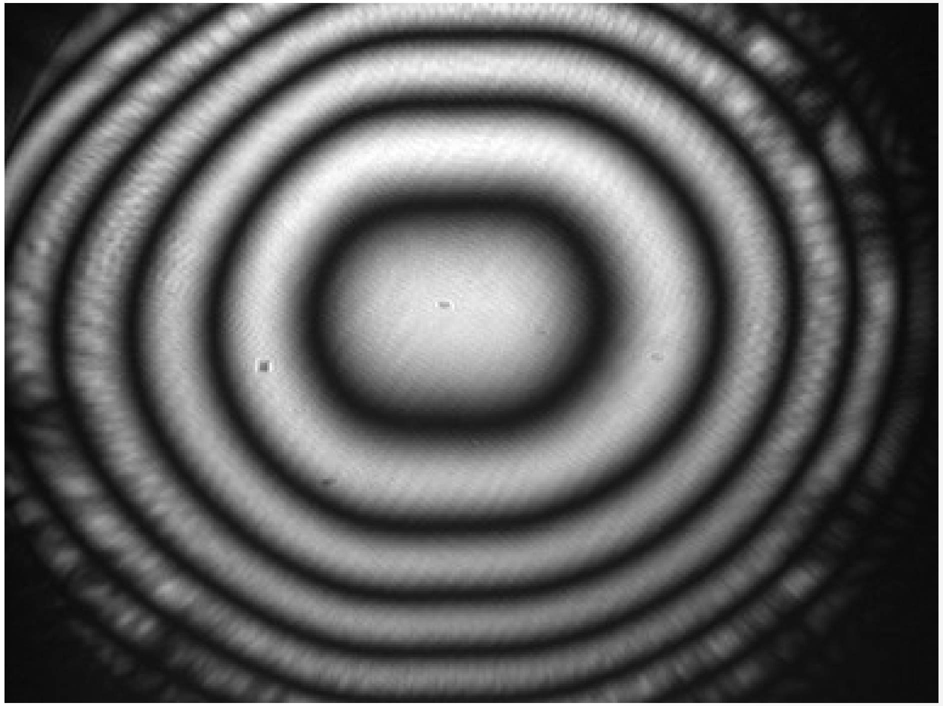
0 bar	6 bar
	

Measured adaptive range



Future improvements

- Improve surface quality
- Apply HR-coating
- Intra-cavity test
- Measurement of adaptive mirror OPD in laser operation



Outlook

- Implement adaptive mirror in disk laser oscillator for upcoming Lamb shift measurement in muonic helium ion.
- Improve laser stability.
- Increase pulse energy from a single oscillator to 100 mJ.

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