Thermal compensation simulation

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Based on work by:
M. Punturo
A. Rocchi
V. Fafone
J-Y Vinet

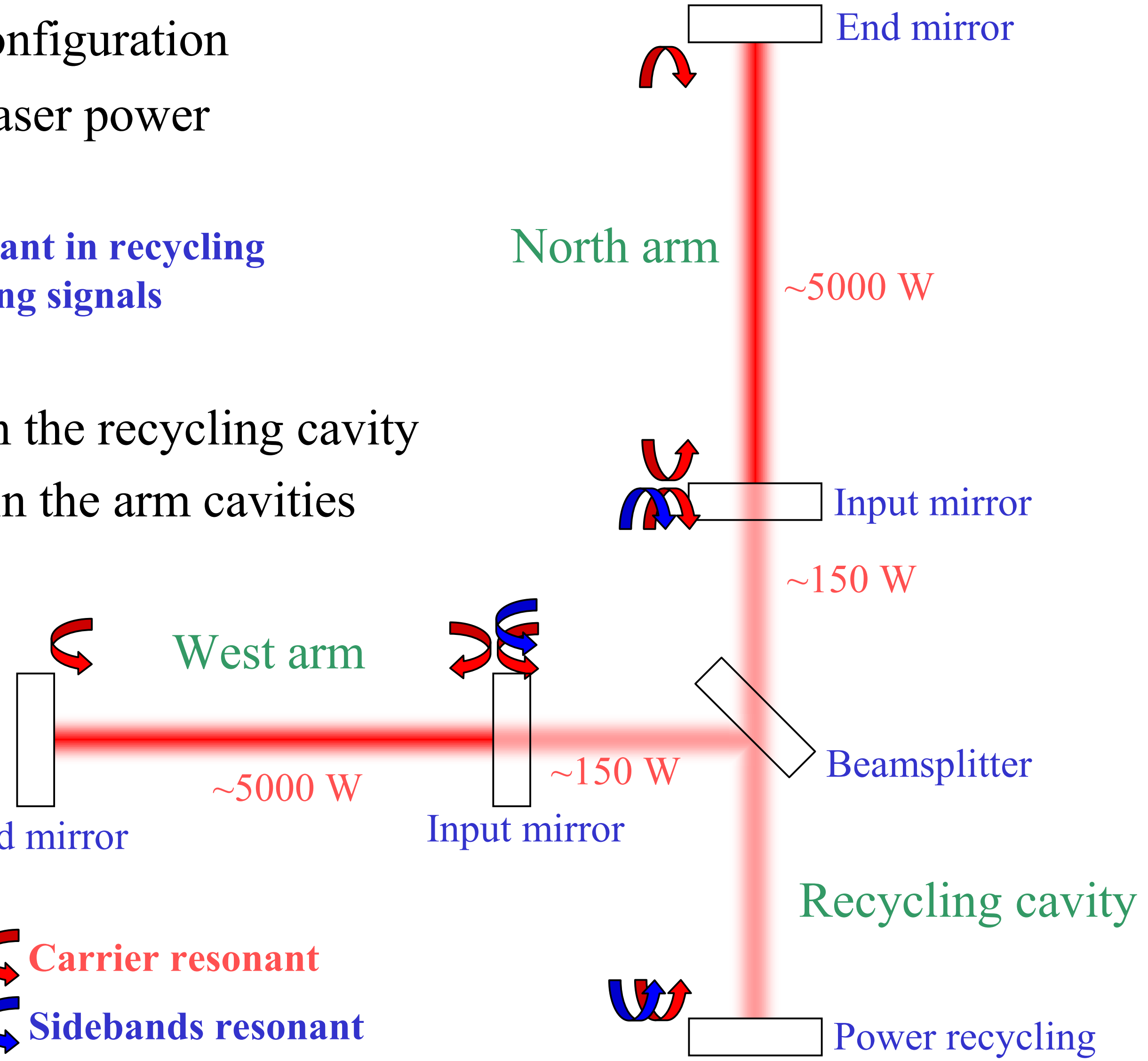
- Thermal Effects – Problem, Solution
- Simulation chain
- Optical Simulation (**Zemax)**
- Thermal simulation (**Matlab)** – Validation & preliminary results
- Interferometer simulation (**Darkf)** – Preliminary results
- Conclusions and further work.

Problem

Current virgo configuration
with 7W input laser power

Sidebands resonant in recycling cavity give locking signals

A lot of power in the recycling cavity
A huge amount in the arm cavities

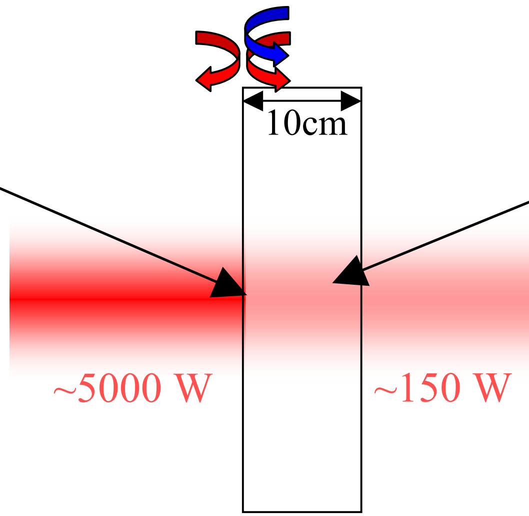


Carrier resonant
Sidebands resonant

Problem

Coating losses:

- ~2.3 ppm for NI
  → ~12 mW absorbed
- ~7.7 ppm for WI
  → ~39 mW absorbed



Input mirror

Substrate losses in Fused silica → 0.7 ppm/cm
→ ~2 mW absorbed

Determined experimentally.
See presentation by A. Rocchi
http://wwwcascina.virgo.infn.it/collmeetings/presentations/2007/2007-05/DetectorMeeting/Alessio%20Rocchi_Rocchi%20LSC-Virgo%20TCS.ppt

Problem

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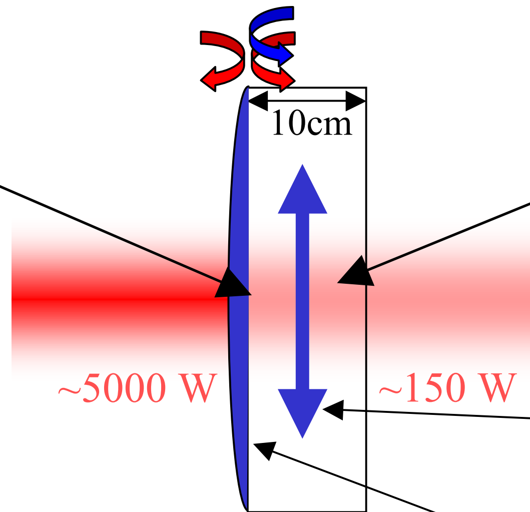


Input mirror

Substrate losses in
Fused silica → 0.7 ppm/cm
→ ~2 mW absorbed

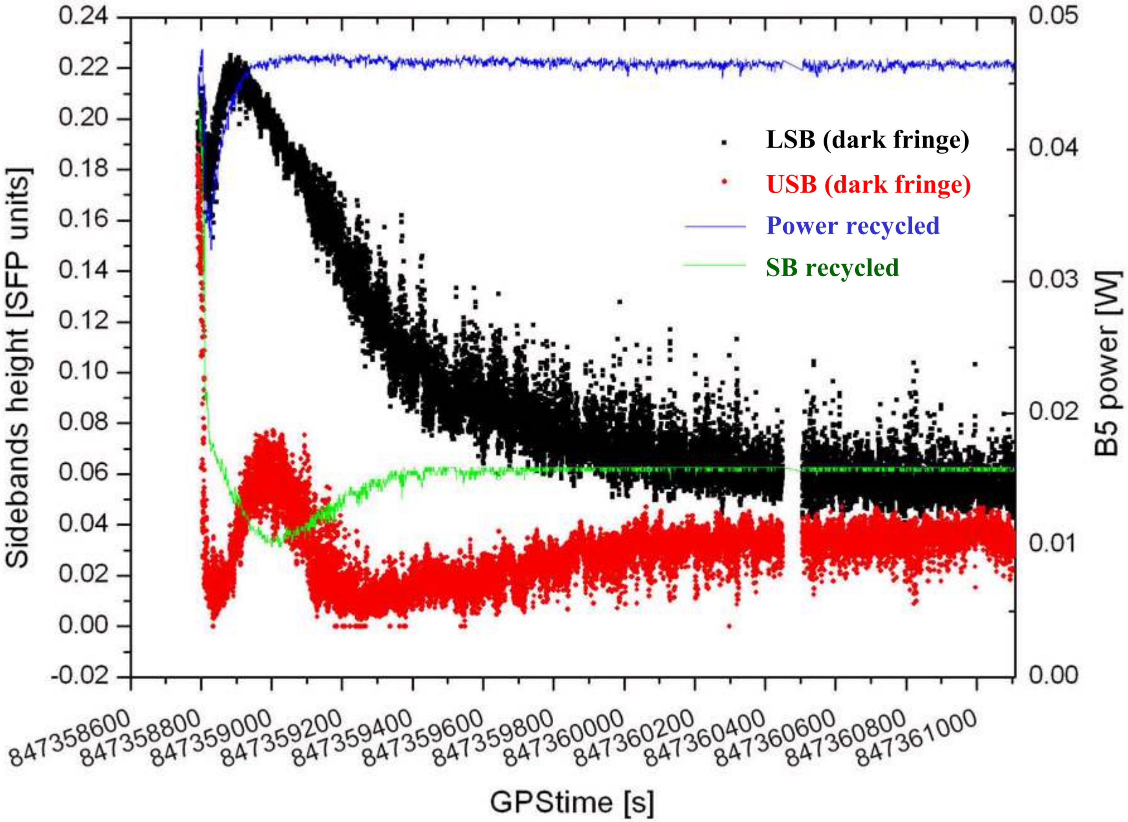
Thermal lensing
Inside substrate

Curving of surface
Due to thermal expansion

Effect on carrier in arm cavities small… For now!

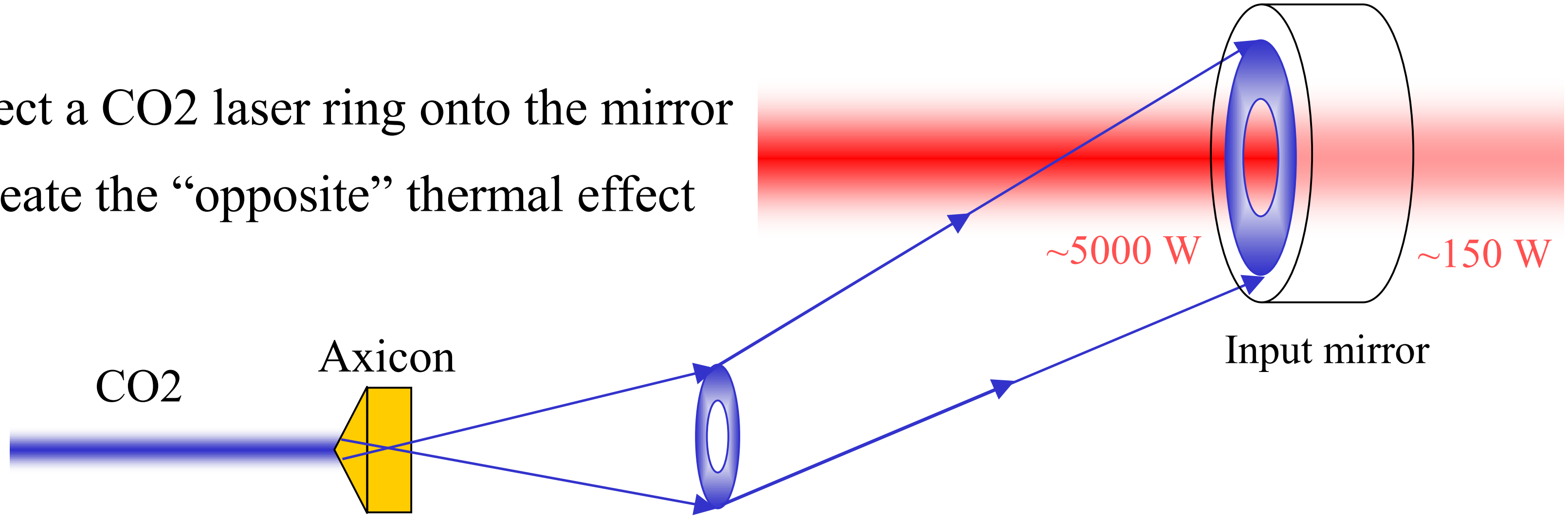
However situation is critical for sidebands in recycling cavity

Problem



- One hour of thermal transient can be seen in the signals
- Sideband signals become perilously low making locking extremely difficult

Project a CO2 laser ring onto the mirror to create the "opposite" thermal effect



However, not as easy as it sounds.

- First attempts on full interferometer have shown that optimization not easy
- Many Ring parameters to adjust:
  Power, **Alignment**, **Thickness**, **Diameter**, **Symmetry…**
- **Transient effects not well understood**

·Simulation of complete chain will give us a better understanding.

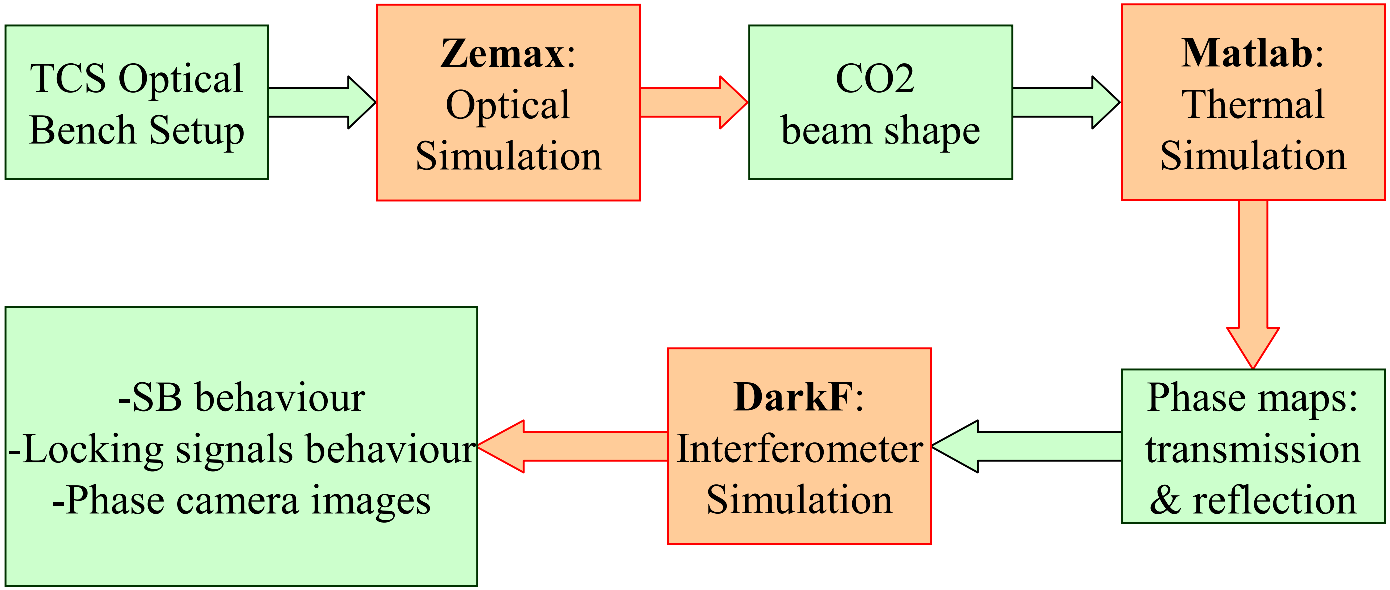
·This will help a lot during commissioning of the TCS.

·Extensive work already carried out on simulation chains:

Ansys: Maurizio Di Paolo Emilio (Tor-Vergata)

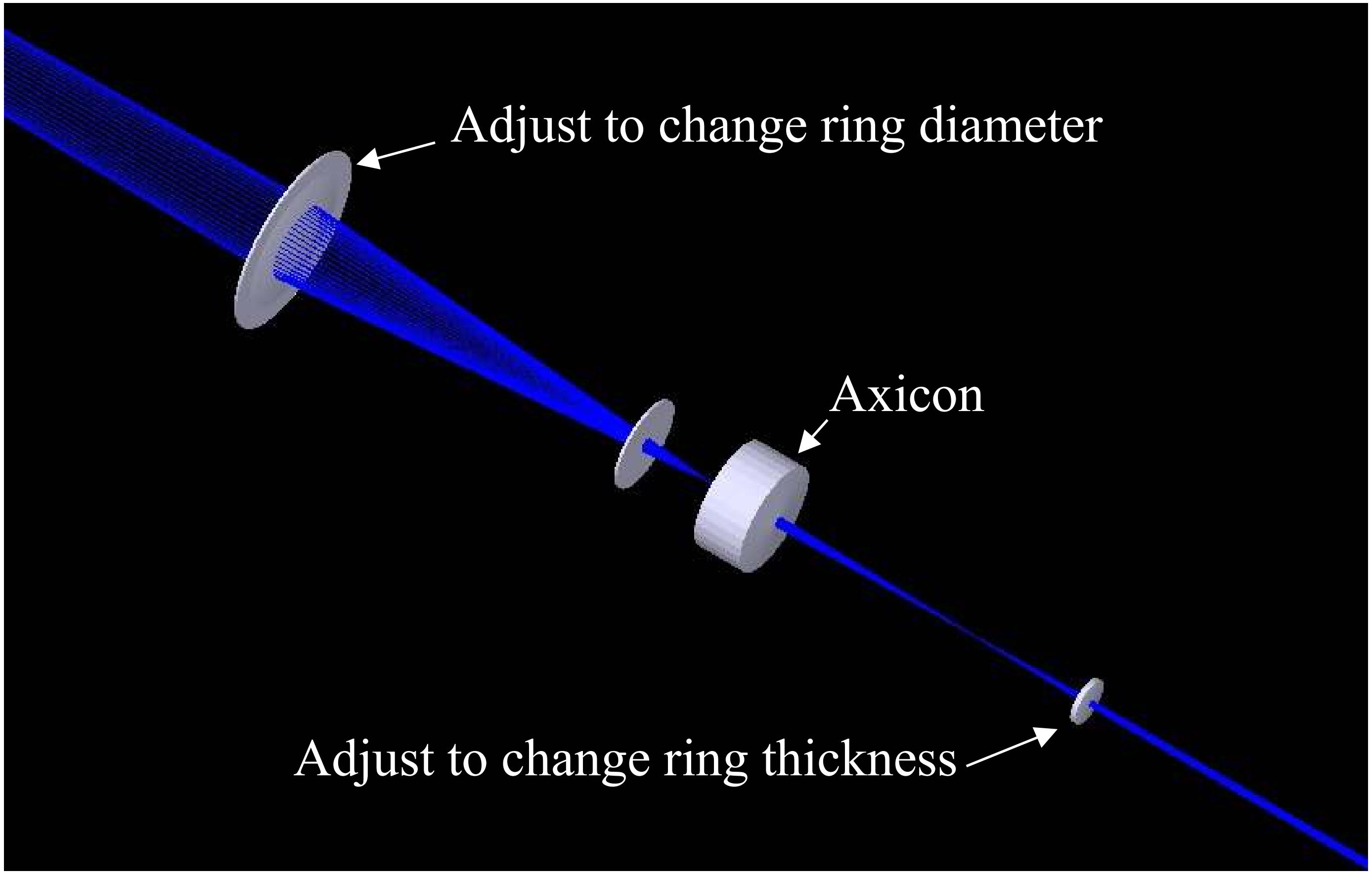
Analytical: Jean-Yves Vinet (ARTEMIS)

Developed simulation chain

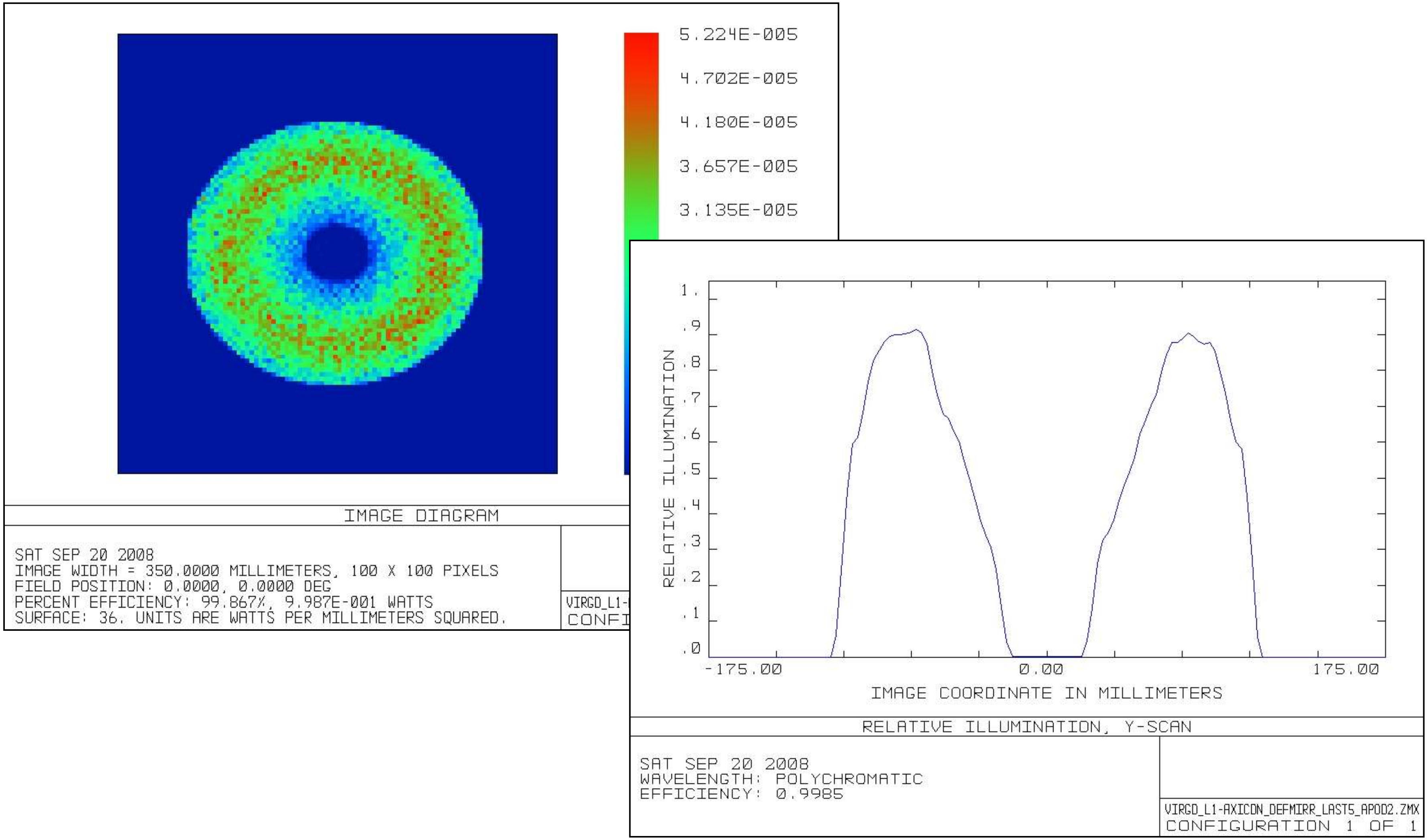


Zemax: optical simulation

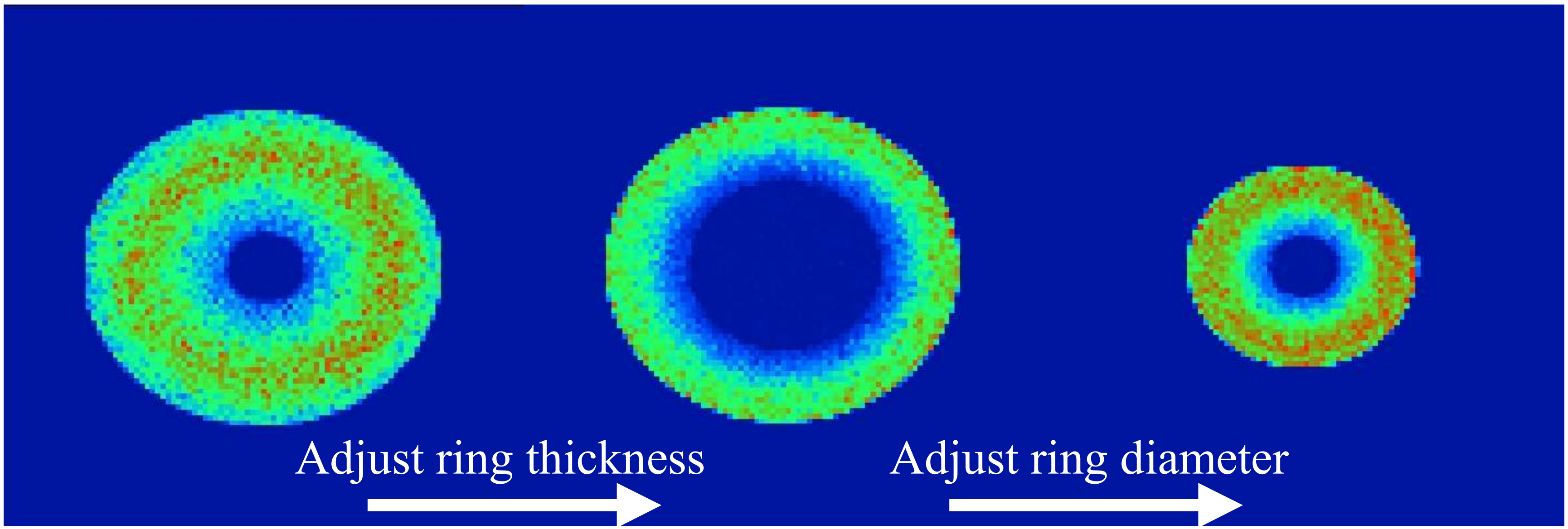
- Well known ray tracing software for optical design.
- Construct optical layout surface by surface
- Optical setup developed by Tor-Vergata & EGO



Zemax can produce intensity images and profiles



· By adjusting two lenses in system we tailor ring shape to our needs



· Using Matlab toolbox we move lenses and export data

· Automation important for optimizing ring shape.

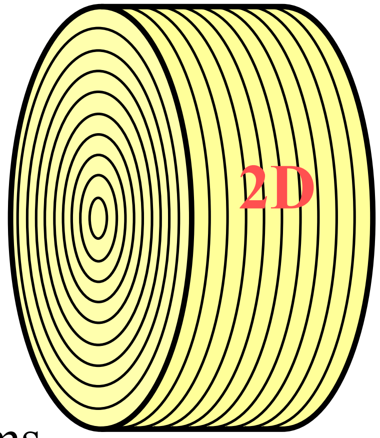
A lot of work already done with direct application to thermal compensation:

- Analytical solution by P. Hello / J-Y Vinet
- Comsol simulations by NIKHEF
- ANSYS simulations by Tor-Vergata
- A lot of work at LIGO (FEMLAB, see thesis R. Lawrence)
- 2-D simulation in Matlab by M. Punturo (slices and rings)

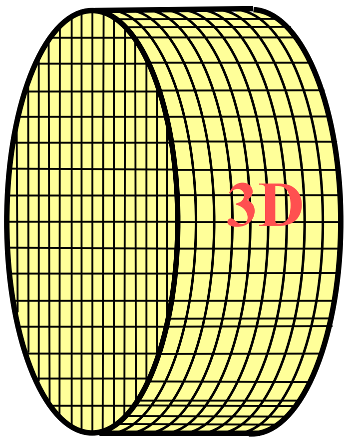
We chose to base our simulation on work done by M. Punturo

Two types of Matlab simulations were developed:

2D simulation: M. Punturo
· 3D problem reduced to 2D
· Assumes cylindrical symmetry
· 24 hrs in ~6 sec



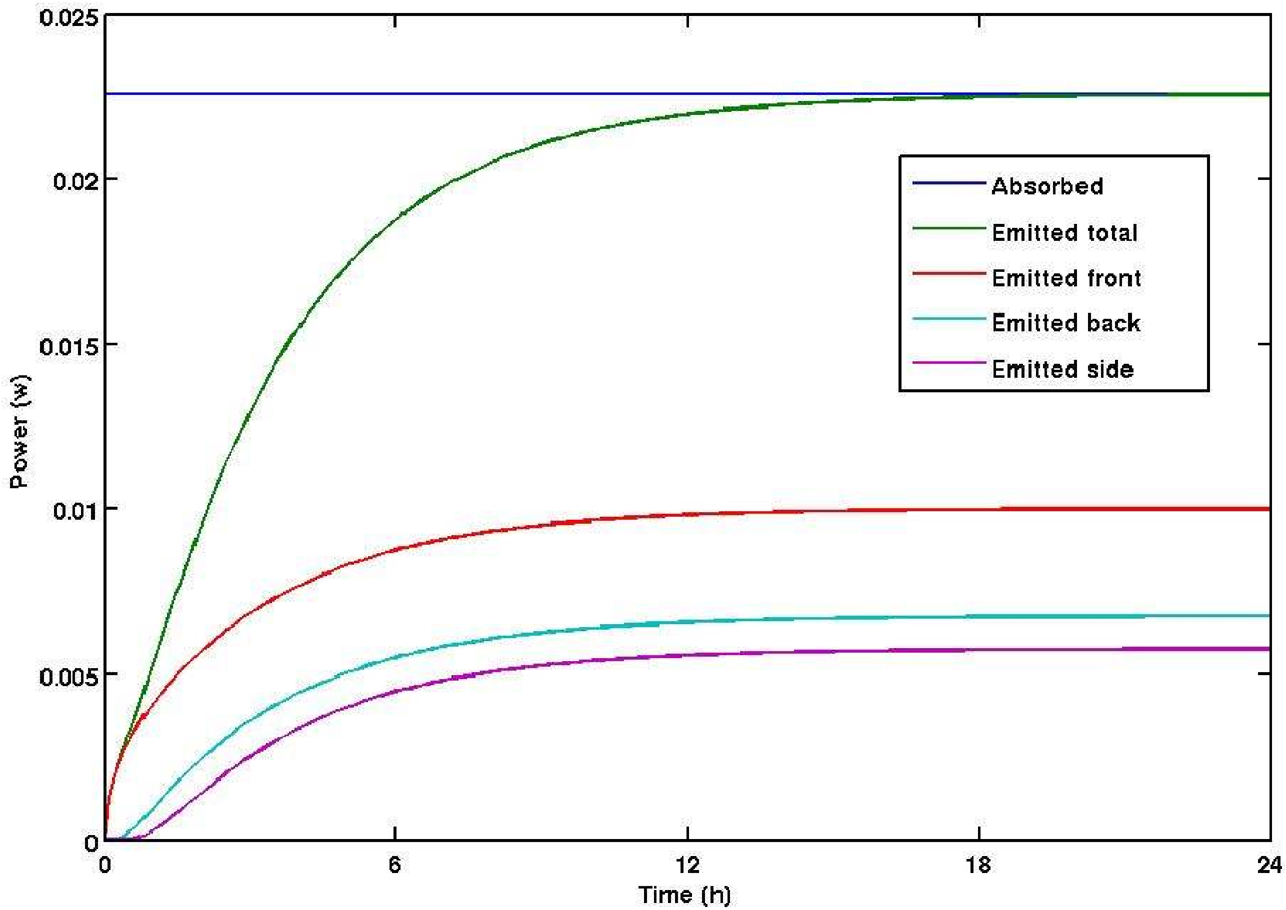
3D simulation: B. Swinkels
· Necessary for simulating decentred and asymmetrical beams
· 24 hrs in ~200 sec



Power transfer:
· YAG Power absorbed in coating and in substrate.
· CO2 power absorbed in coating using profiles from **Zemax**
· Power emitted by radiation from surfaces of mirror

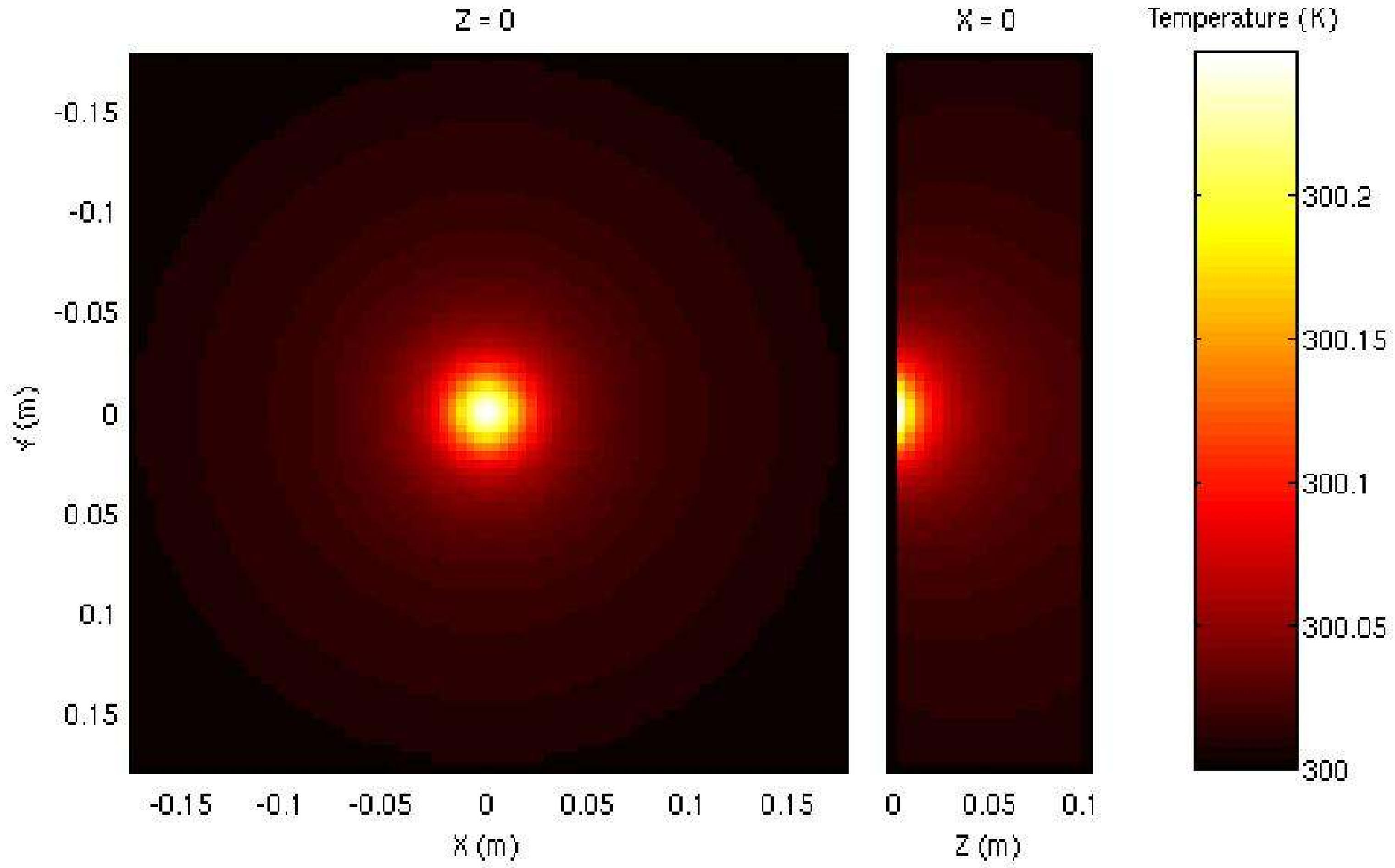
· Both measure time evolution of temperature in mirror

Switch on YAG beam

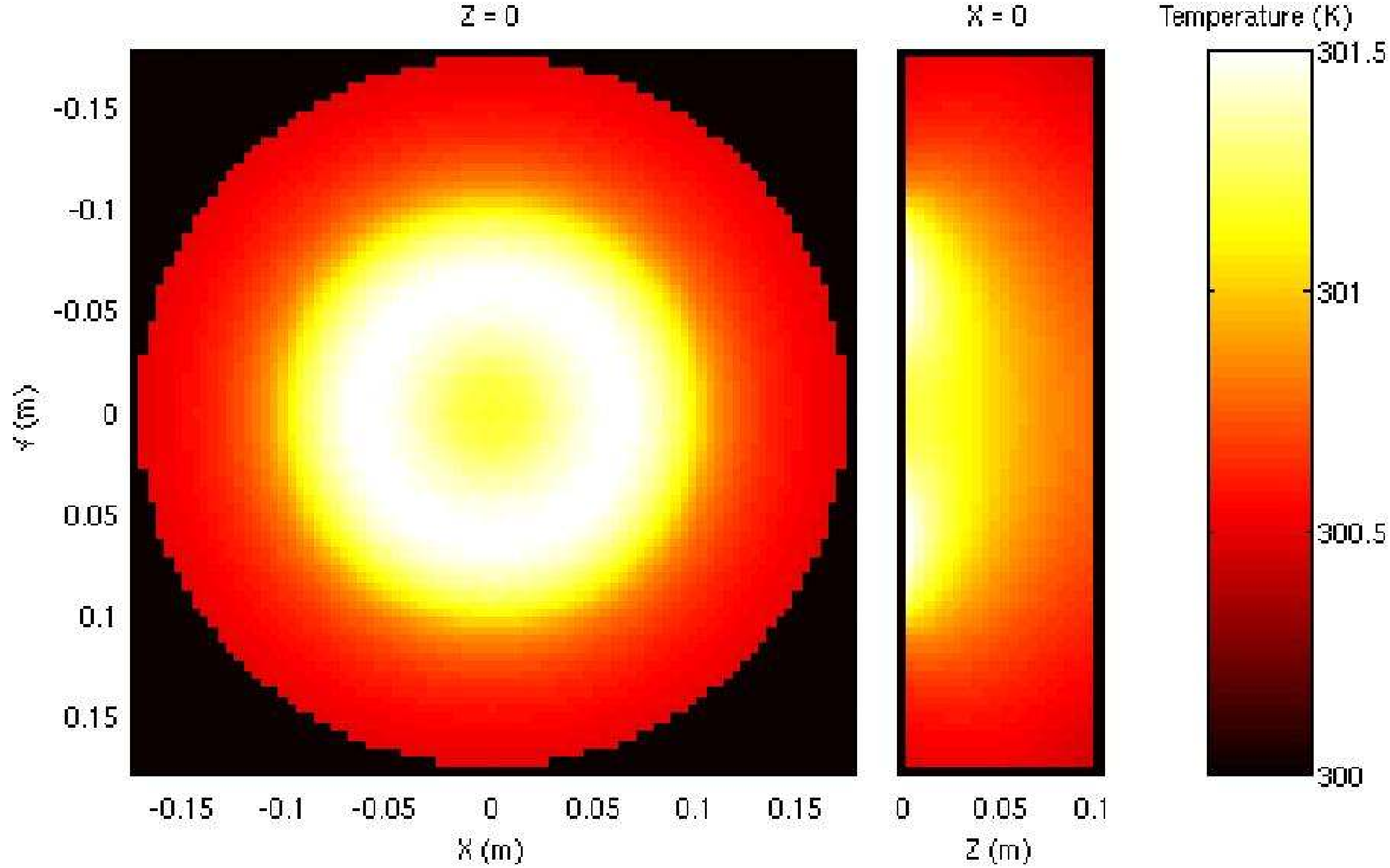


Thermal equilibrium reached when Power in = Power out

Time constant of ~ 5 hours



Temperature distribution after 12 hours of YAG heating



Temperature distribution after 12 hours of CO_2 ring beam heating (1W)

Three effects on optical path length due to mirror heating:

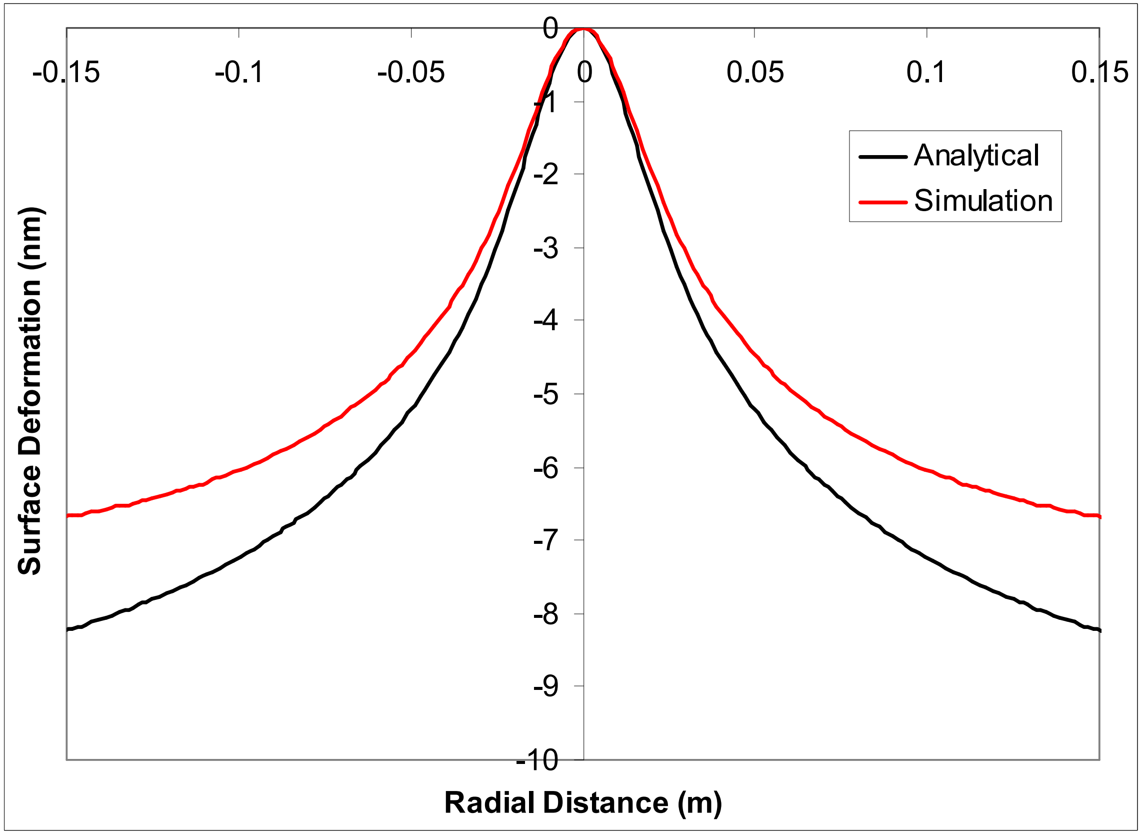
1. Thermooptic Effect (thermal lensing)
   - Change in refractive index with temperature.
   - Taken into account.
2. Thermoelastic Deformation
   - Curving of surface due to thermal expansion.
   - Partially taken into account.
     → Assume that all displacement occurs on absorbing surface.
3. Elastooptic Effect
   - Change in refractive index with thermal expansion induced strain.
   - Not taken into account.

- For Fused Silica these assumptions should give sufficiently accurate results.

(see thesis R. Lawrence)

Comparison with analytical solution (Hello & Vinet)

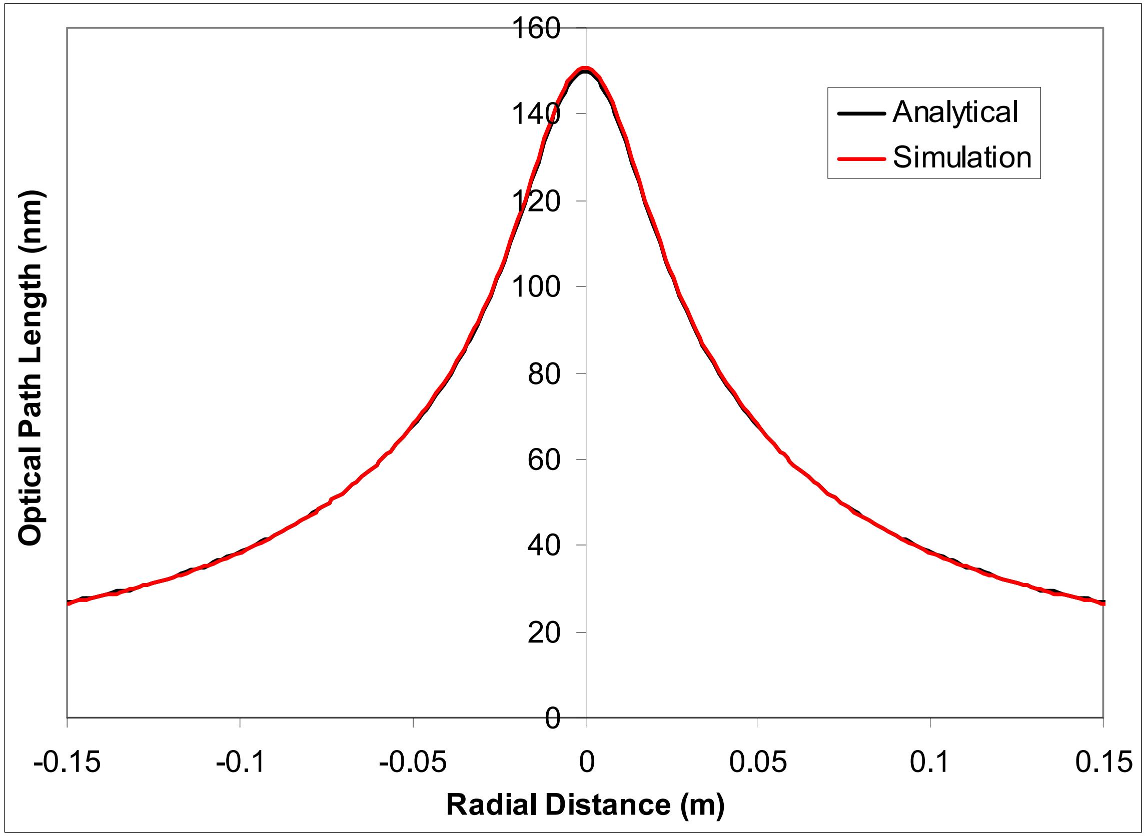
Thermoelastic Deformation



- Total deformation of ~ 7 nm
- Difference due to assumptions made for thermoelastic deformation
- Agreement to < 1nm in region of interest

Comparison with analytical solution (Hello & Vinet)

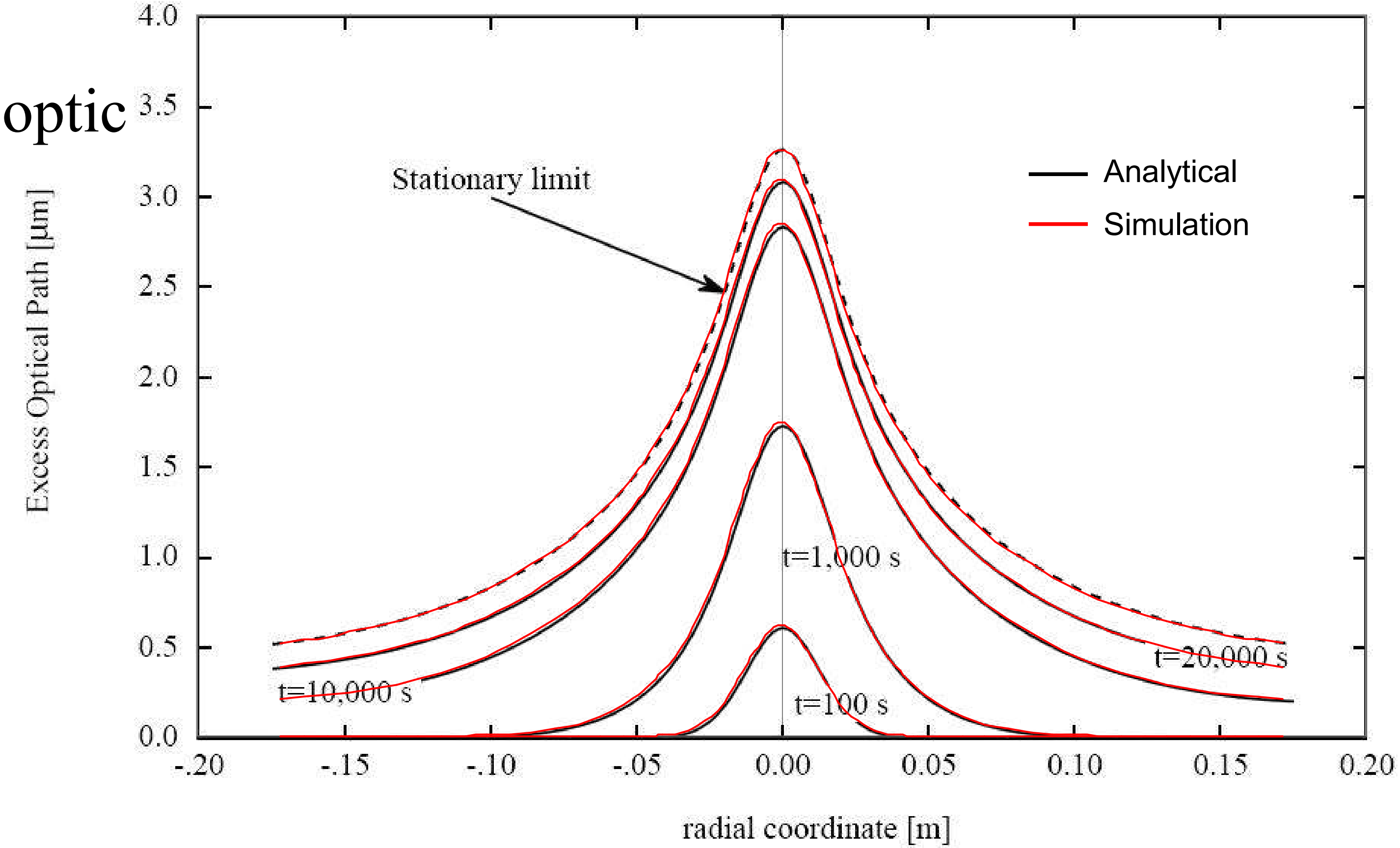
Thermooptic Effect



- Total optical path length change of ~ 150 nm
- Extremely good agreement with analytical solution
- **This effect (thermal lensing) is the most important for sidebands**

Comparison with analytical solution (Hello & Vinet)

Thermooptic Effect

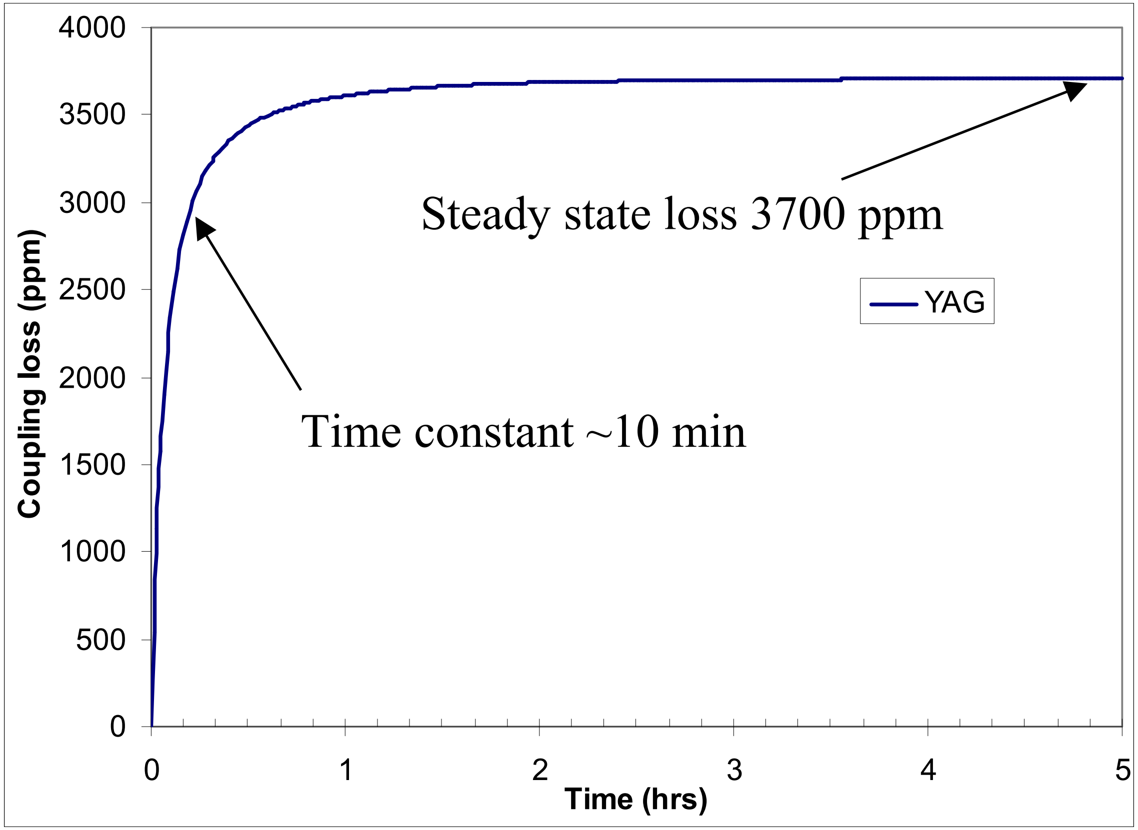


- Transient effects also agree well with analytical solution
- **We will see that transient effects are important for our application**

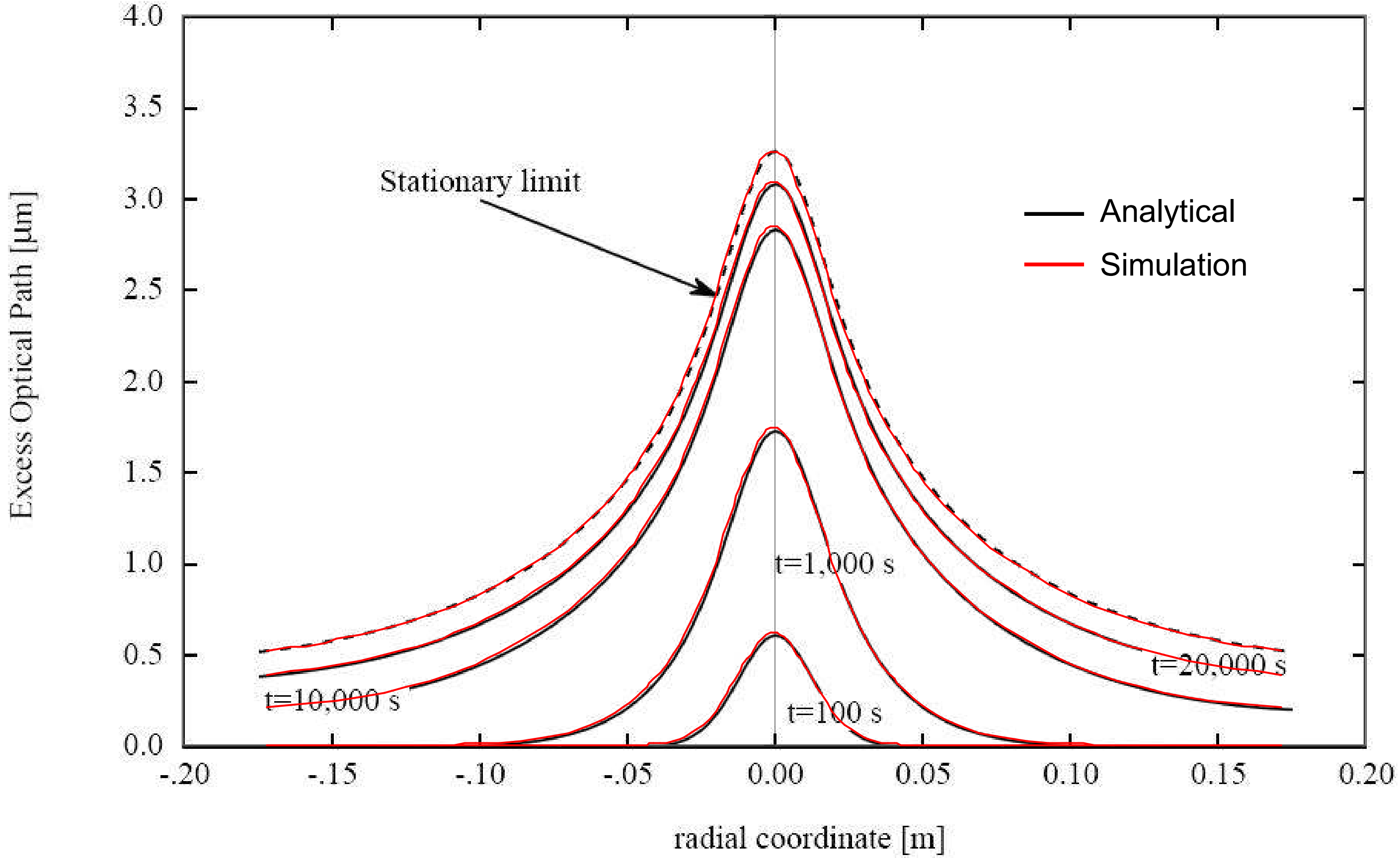
We are interested in distortion of YAG beam

→ Compare distorted & undistorted wave front → **Coupling Loss** (ppm)

Lock interferometer

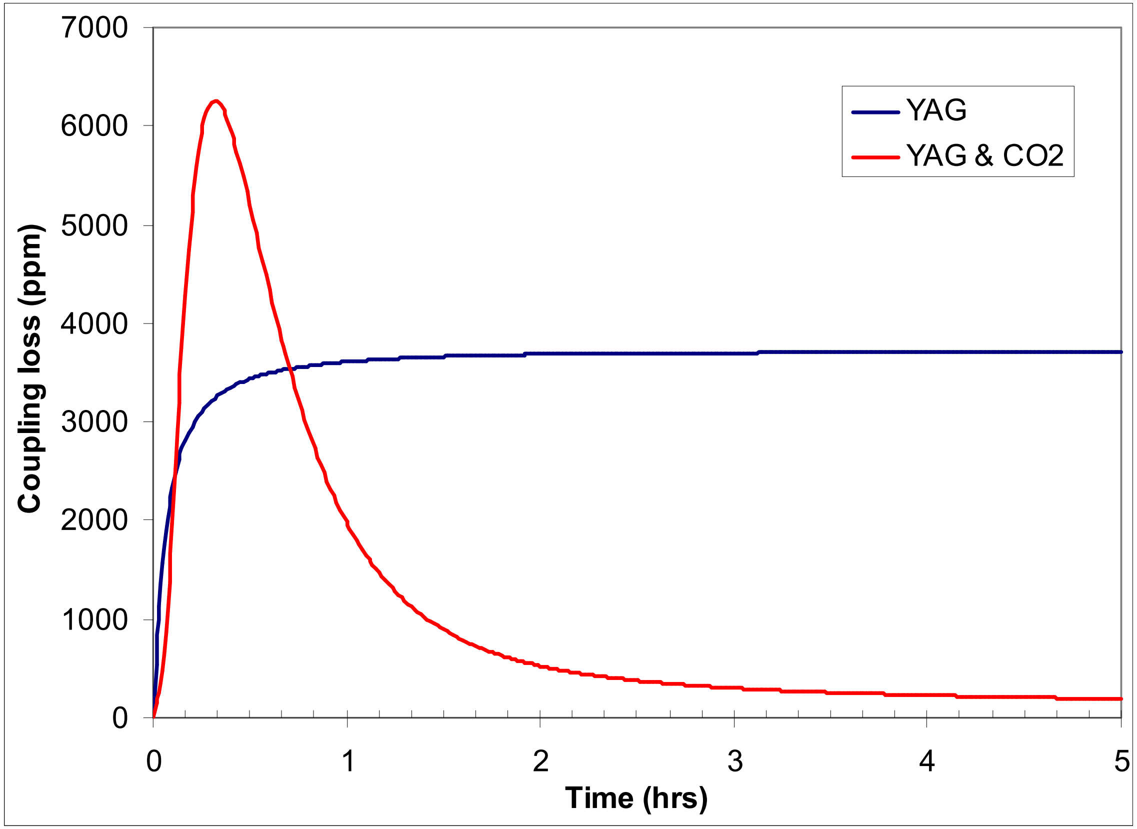


Remember that time constant of mirror temperature was 5 hours!



- Central “bump” forms very quickly
- Afterwards everything rises at the same rate

What happens if we switch on TCS when interferometer locks?



- TCS works but things get worse before they get better !!
- 2 hours before things settle down.
- **We're going to have fun trying to lock with things like this!**

But there is a solution:

- Never switch off the CO_2 laser ring
- When interferometer not locked heat the centre with CO_2 laser beam

In this way the mirror will never see a change

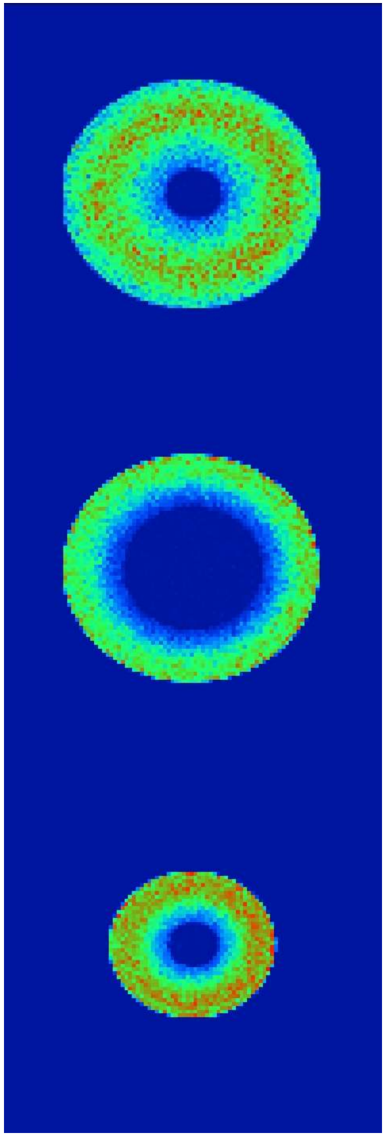
Installation of central heating beam planned before end 2008
by Tor-Vergata group with participation from EGO

Many parameters for CO_2 ring beam:

- Ring Thickness
- Ring Diameter
- Ring Power

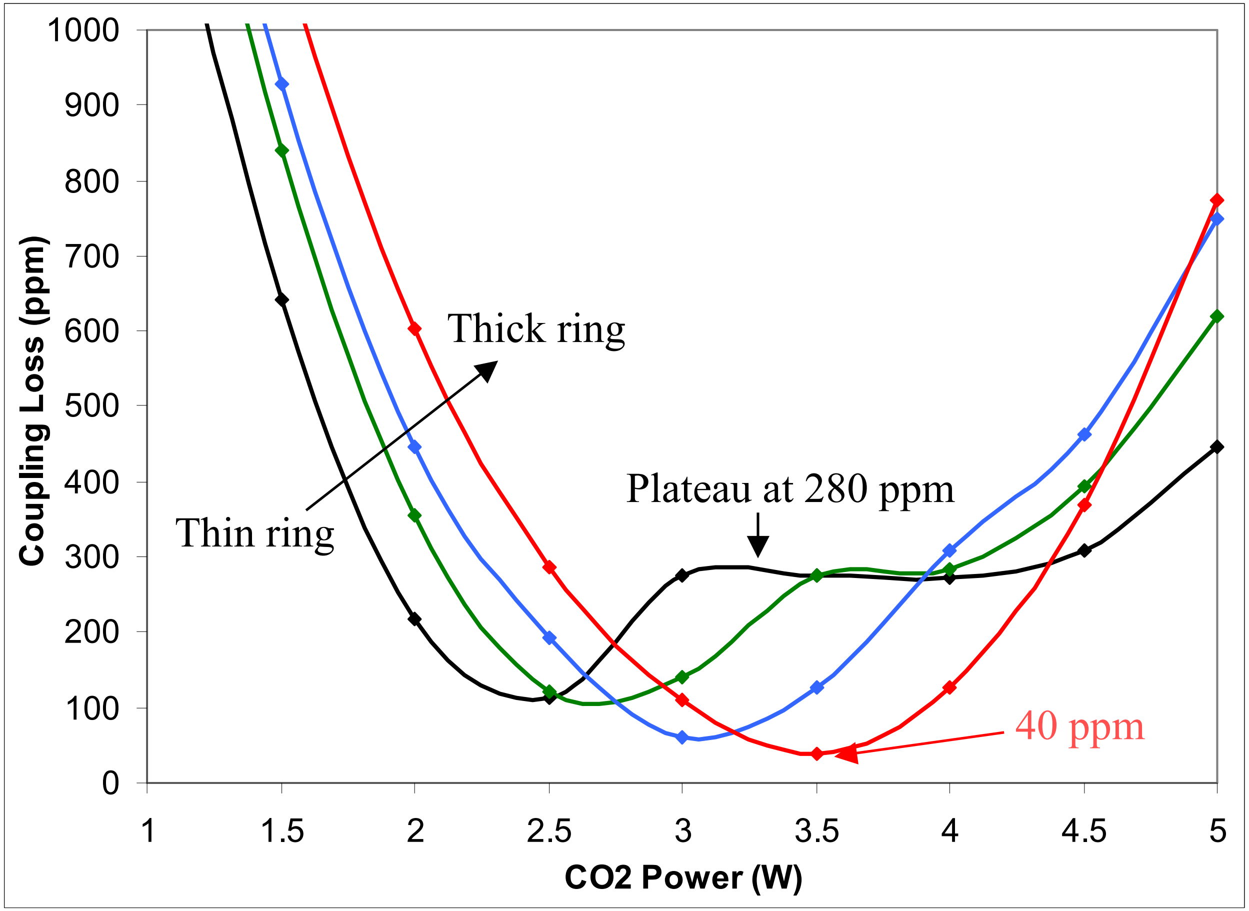
Use optical & thermal simulation to try all combinations.

Use coupling loss as measure of performance



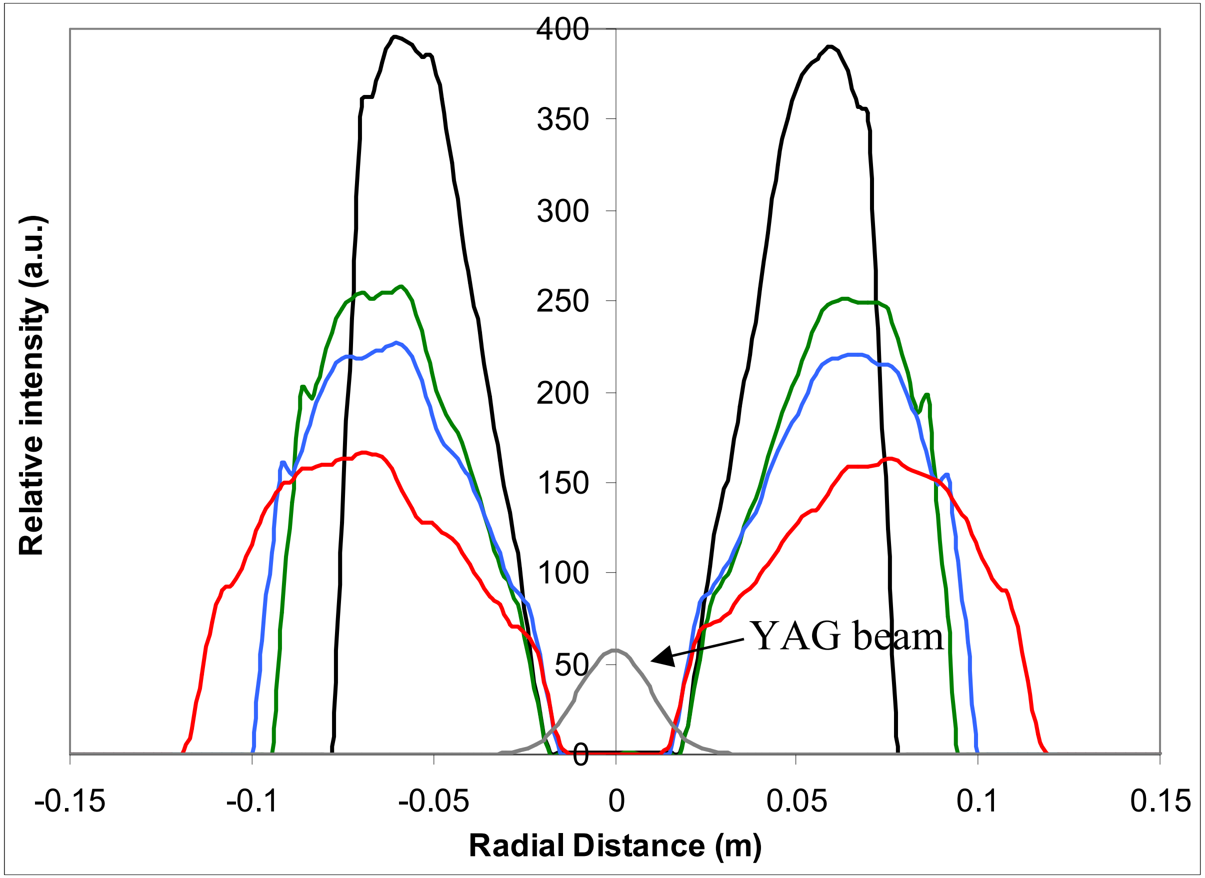
The perfect ring

For every ring thickness and at every power find best ring diameter



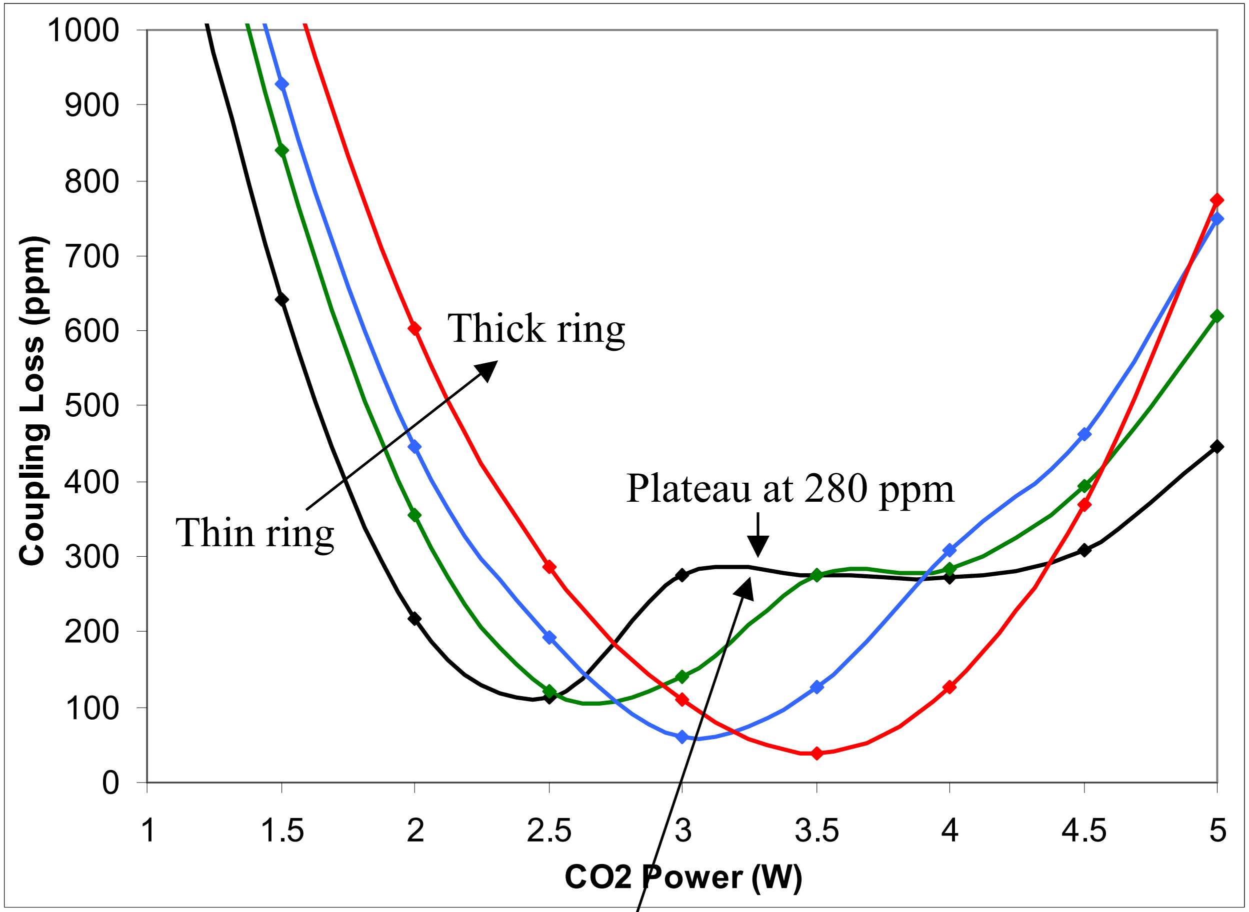
· Thin rings better at low power.
· Thick rings better overall

Lowest coupling loss for each ring thickness



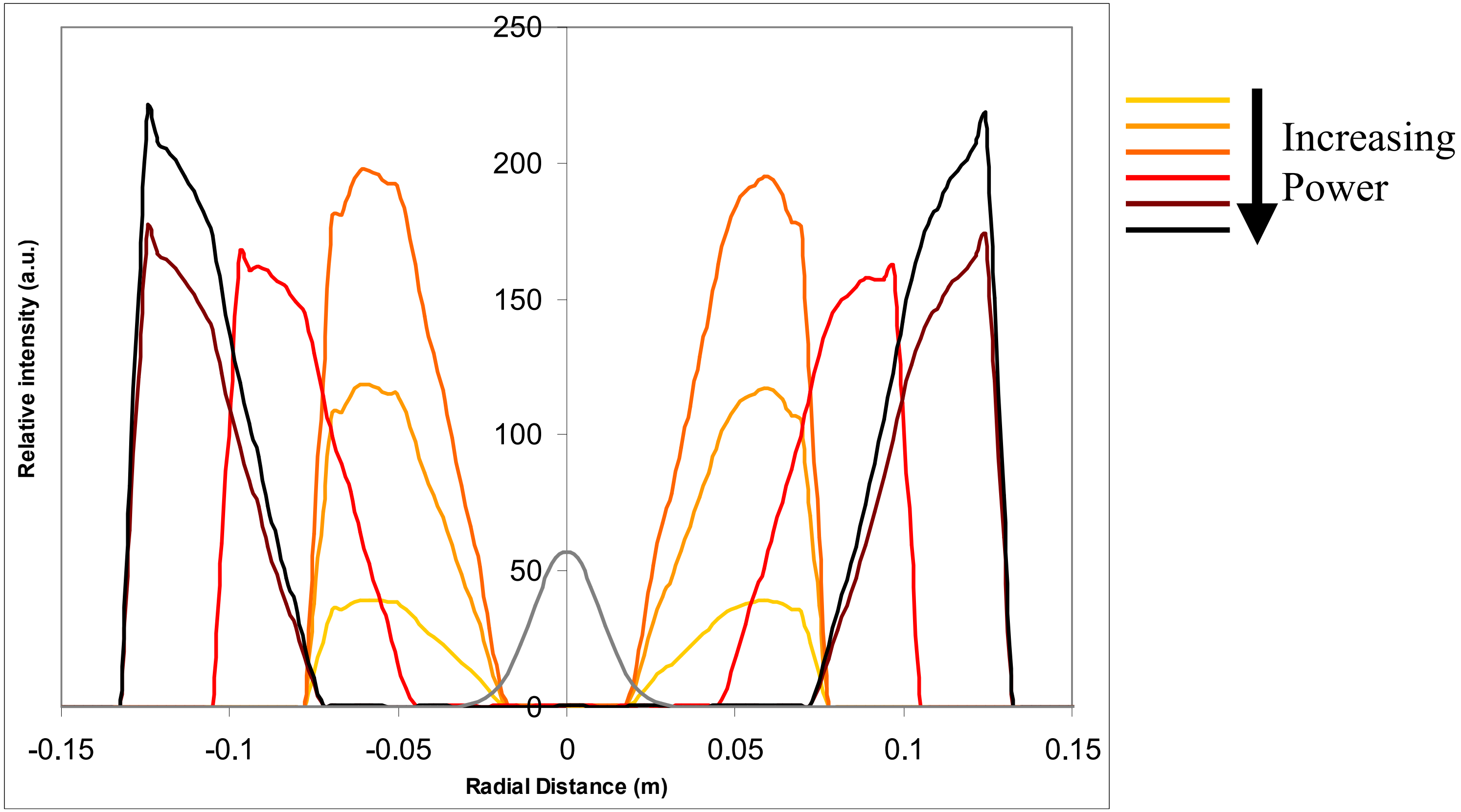
· The rings giving lowest coupling "hug" the YAG beam.

The perfect ring



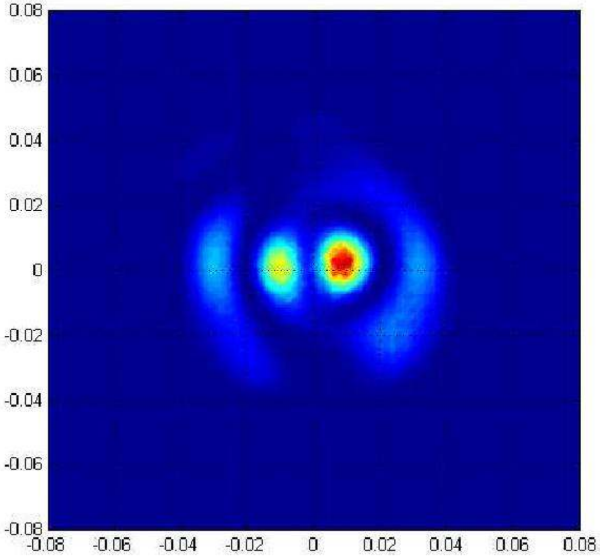
Where does this plateau come from?

Just look at thinnest ring. Find best diameter for each power.



Optimal heating of 280 ppm when ring is far from center

Not as good as 40 ppm but much less sensitive to alignment (3D simulations)



Created by
Mikael Laval & Jean-Yves Vinet

Mikhael Pichot continues work

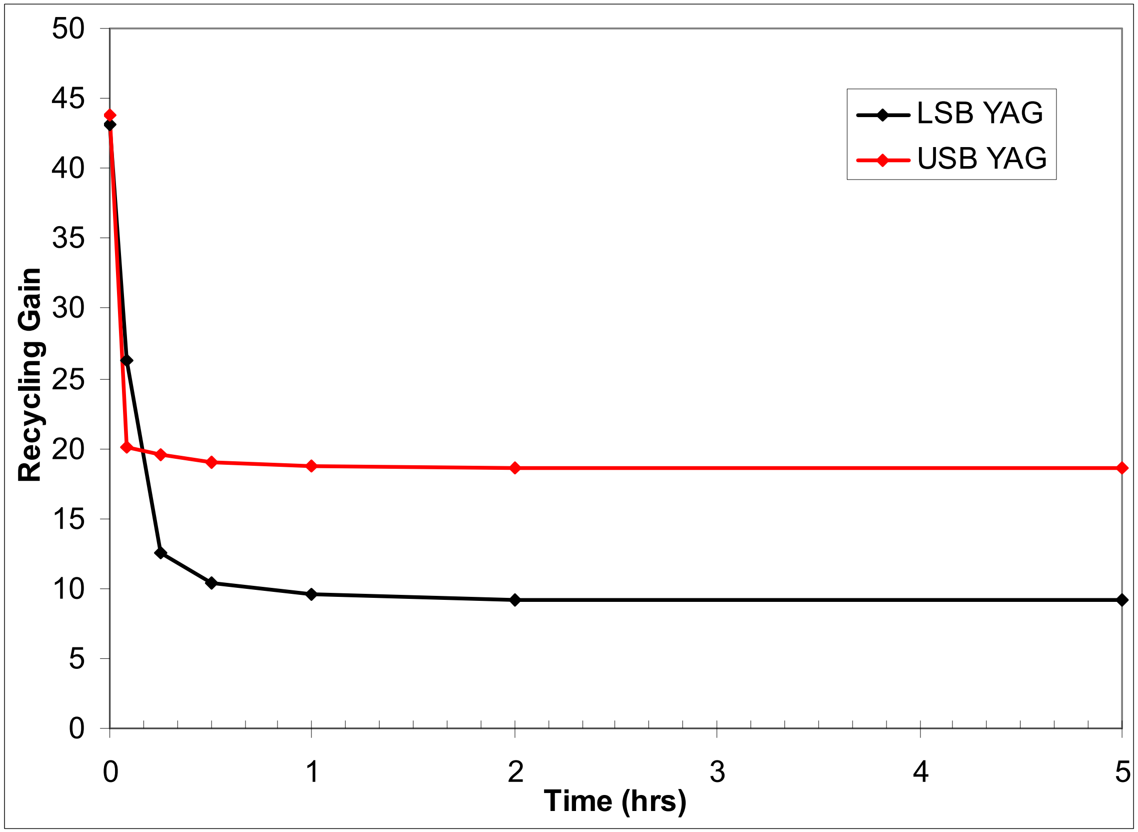
Optical simulation code in FORTRAN 90
Uses plane wave decomposition to propagate the wavefronts

We can insert phase maps from thermal simulations

Simulate entire Virgo interferometer to see thermal effects

Preliminary results

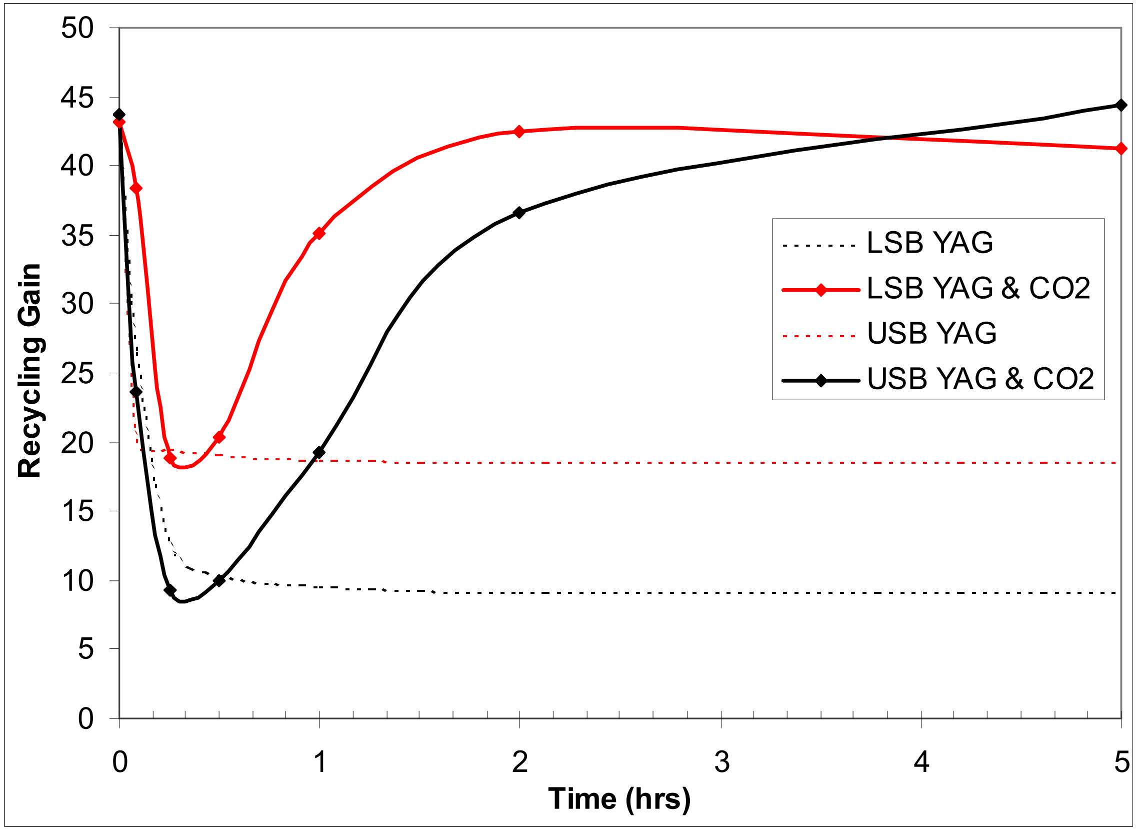
Lock interferometer



· Fast reduction in sidebands gain with time constant ~ 10 min

Preliminary results

Switch on TCS when interferometer locks



· Sidebands only get back to a stable state after about 2 hours

Conclusion

- Assembled complete simulation chain of Thermal compensation for Virgo.
- Better understanding of temporal evolution.
- Tools to choose best ring and calculate alignment tolerances.
- First results of simulated interferometer with thermal effects.

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Further work

- Add central heating spot to simulation.
- Use of finesse interferometer simulation: comparison DarkF.
- Compare interferometer simulations with experimental data.
- **Use experience gathered from simulations to help with installation and commissioning of Thermal Compensation System.**