LIGO II Photodetectors and Adaptive Thermal Lensing Compensation for Core Optics

LIGO PAC Meeting

1 May, 2000

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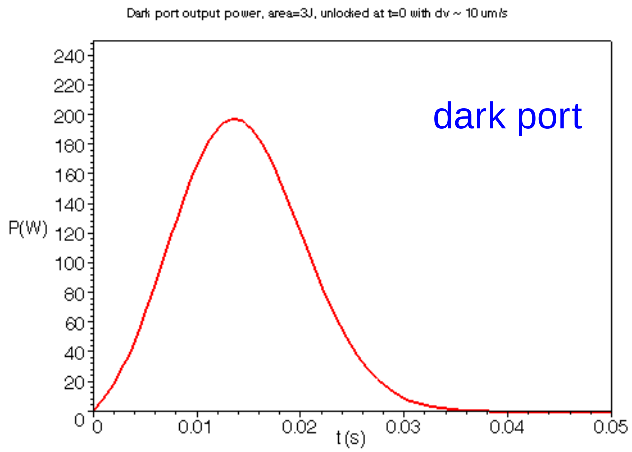
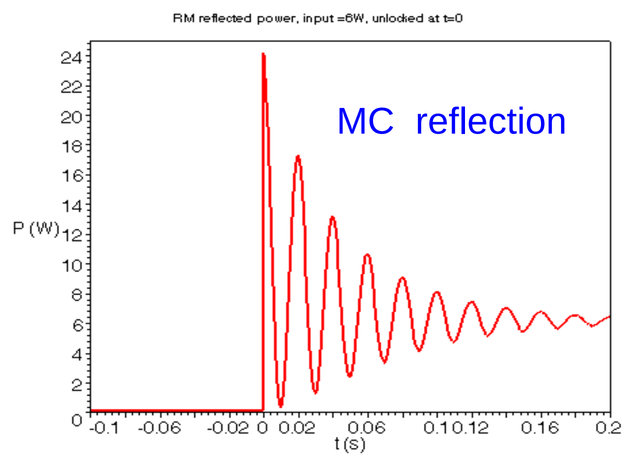
Photodetector optical & thermal requirements

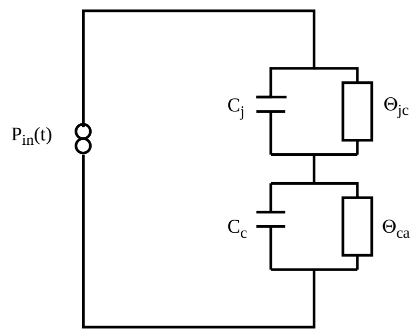
- CW power handling
  - "Dark" port with/without active thermal compensation: 1W? 10W?
- Transient power handling
  - reflection from PRC, MC ; full incident power, spike to 4x incident on unlock
- quantum efficiency
  - shoot for 90% (trades w/laser power, but poorly)
- backscatter
  - need 10-100 X improvement over LIGO I diodes (assuming Faraday isolator)

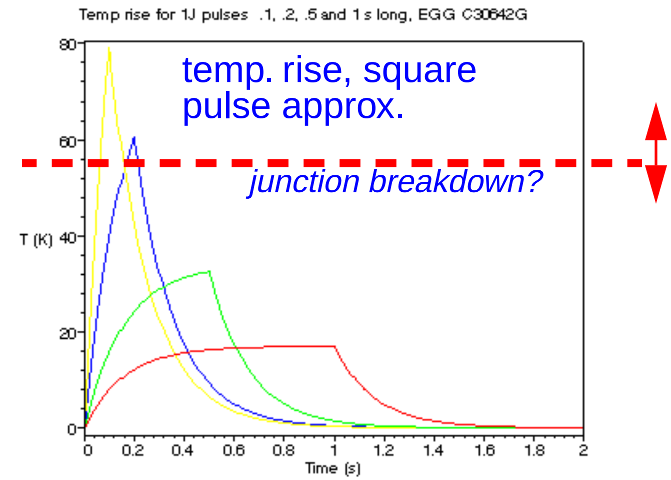
PD power transients (conceptual)

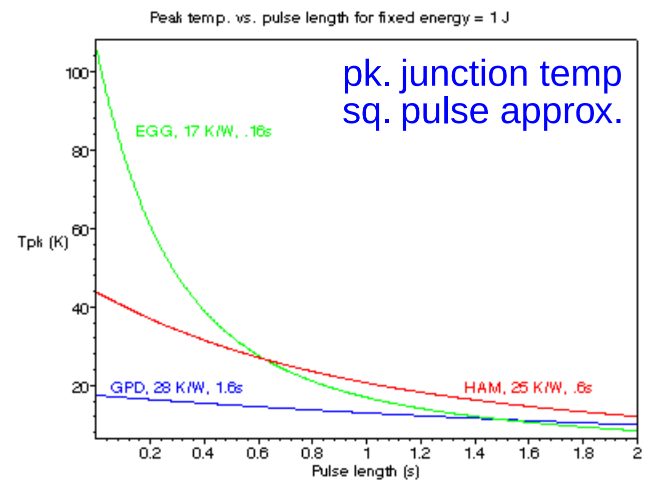




thermal device model



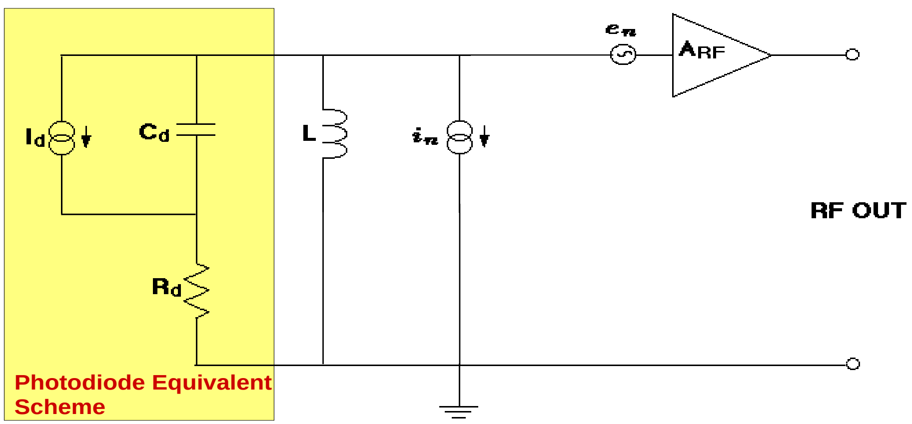




Electrical & signal requirements

- RF frequency
  - To provide flexibility for LIGO II modulation schemes => $f_{RF} \approx$ 100 MHz
- SNR (i.e., 'shot:electronic noise ratio')
  - $\frac{e_{elec}^2}{e_{shot}^2} = \frac{1}{2eI_{DC}K_{mod}}\left(\frac{4k_BT}{Z_D} + \frac{e_n^2}{Z_D^2} + i_n^2\right)$

$$Z_D(\omega_0) = \frac{1}{R_D\omega_0^2C_D^2}$$



  - damage -> lower I_{DC}
  - SNR -> raise I_{DC}
  - e.g., 1.2 W, 1 nV/√Hz, *N*=10 diodes => $|Z_D(\omega_0)| > 150\Omega$
  - EGG G30642G, 100 MHz: $|Z_D(100\text{MHz})| \approx 54\Omega$ (OK @29 MHZ)

LIGO II Photodetectors: Status & Plan

- Requirements definition & simulation
  - First-cut Requirements draft circulated for discussion at LSC 3/00
  - additional Melody & FFT simulations required to bound steady-state power
  - additional E2E simulations required to bound transient power
  - selection of modulation/readout configuration will determine frequencies
- Device fabrication
  - High power custom devices now being fabricated by D. Jackrel at Stanford
- Testing
  - MIT PD test rigs upgraded to f > 125 MHz, P > 0.5 W /diode, B < 10^{-6} sr^{-}

Current Best Guess: PD Specs for LIGO II Power and Sensitivity

Parameter	*LIGO I*	*LIGO II guess*
Steady-state power	0.6 W	3 W[a] ?
Transient damage	3 J / 10 ms	100 J / 10 ms ?
Signal/Noise	1.4×10^{10} $Hz^{1/2}$	3.1×10^{10} $Hz^{1/2}$
Quantum efficiency	80%	90%
Spatial uniformity	1% RMS	0.1% RMS ?
Surface backscatter	10^{-4} /sr	10^{-6} /sr[b]

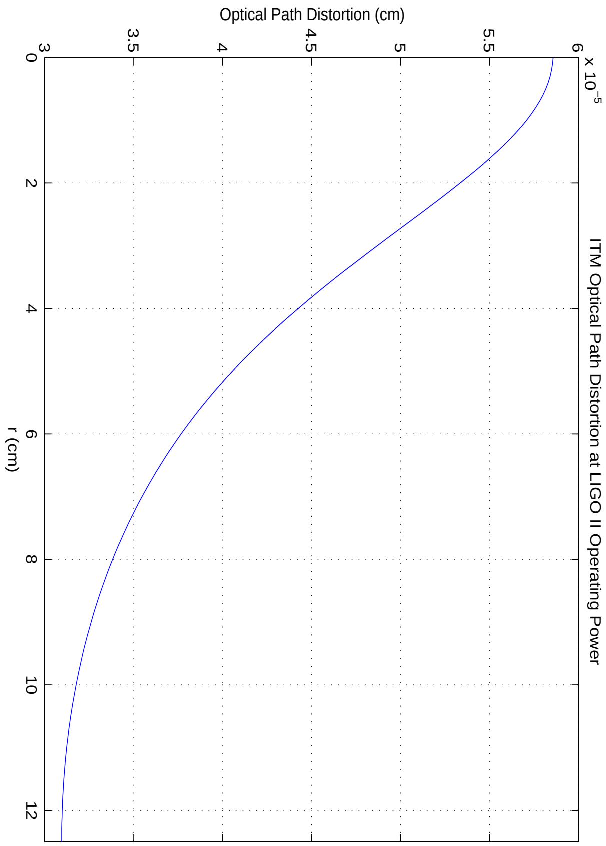
a. Assumes significant improvement in contrast defect & cancellation of thermal lensing

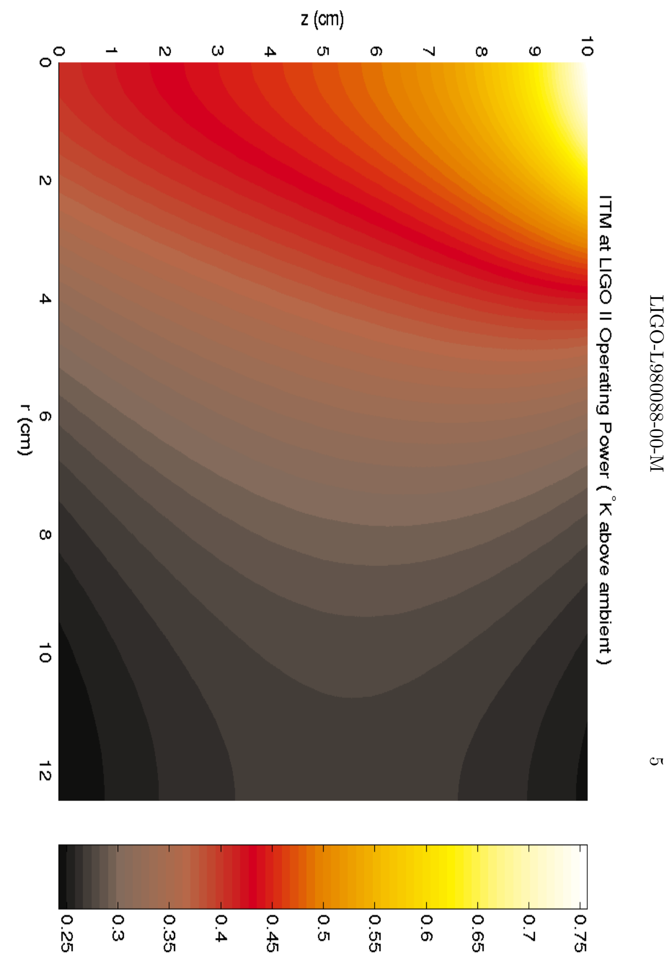
b. Assumes Faraday isolator and seismic isolation of detector

Adaptive Compensation of Thermal Lensing in LIGO II Core Optics

- In LIGO I, thermal lensing requires polishing curvature bias into core optics to achieve adequate performance at operating temperature
- LIGO II will have 30X greater laser power
  - lensing more severe
  - net figure requirements tighter (e.g., to reduce dark port power)
  - higher order (nonspherical) distortions significant; prepolished bias, refocusing not adequate to recover performance
  - possible bootstrap problem on cold start
- Test mass material change not adequate
  - SiO_2 has low k_{th}, but low bulk absorption
  - Al_2O_3 has higher k_{th} , but higher bulk absorption compensates (so far)

FEA model: uncorrected SiO_2 ITM

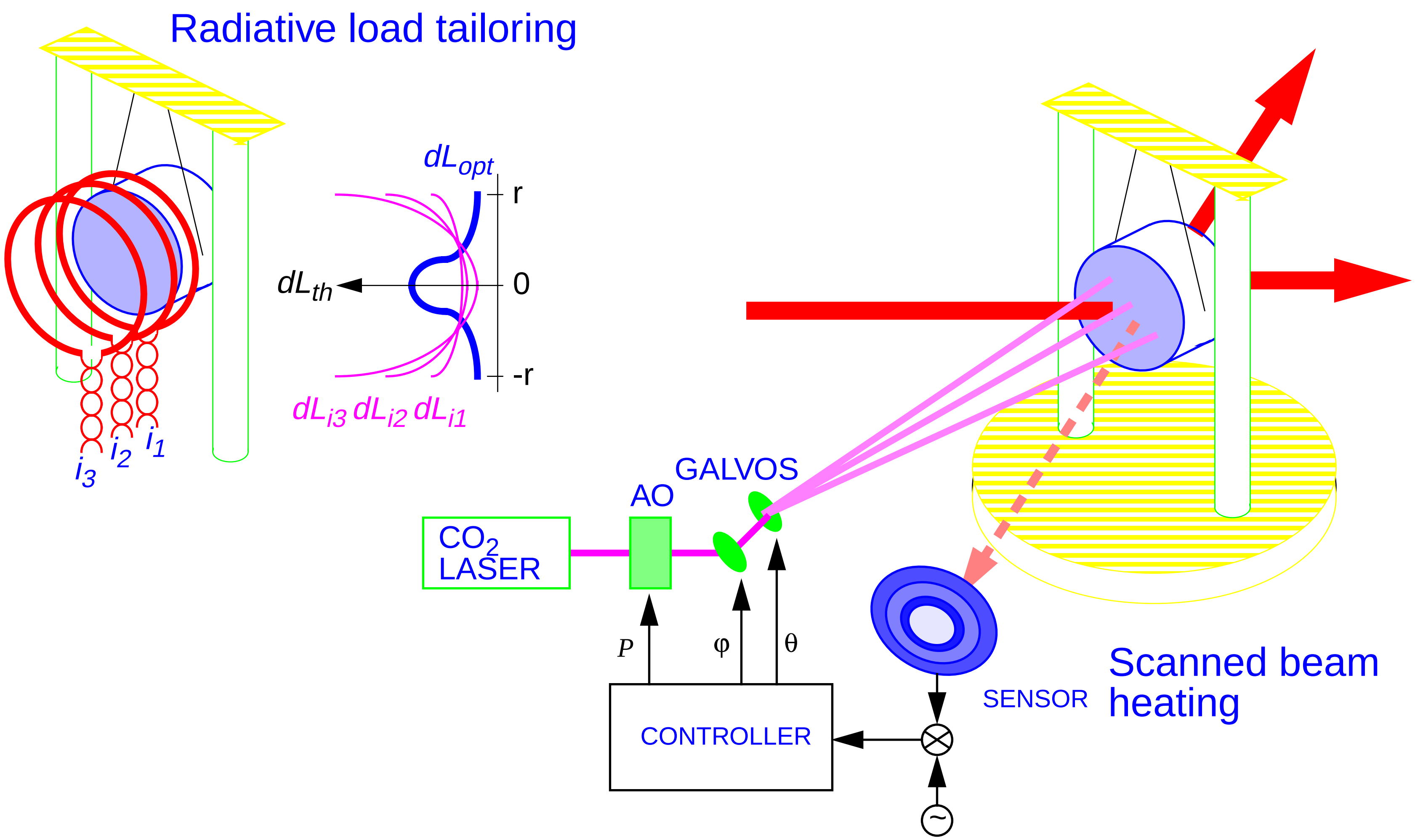




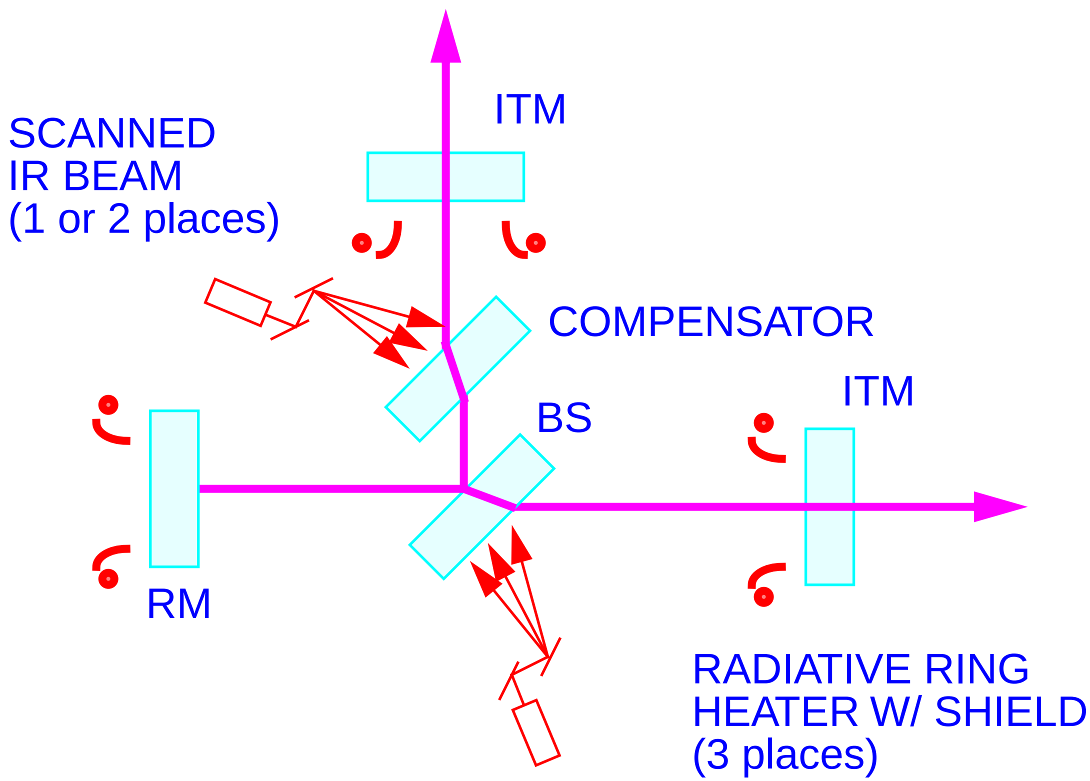
Sensing & Actuation

- Extension of LIGO I “Wavefront Sensing” technology to spatially decompose interferometric phase errors
  - scanning “Phase Camera” (Adhikari, MIT)
  - staring “Bullseye WFS” (Mueller, UF)
- Numerical inversion of errors into actuation basis
- Thermal actuation on core optics
  - Noncontact actuator with minimal spurious phase noise
  - Time constants matched to disturbance timescales
- Two actuators considered (possibly in combination)
  - Passive radiative ring heater
  - Scanned directed beam

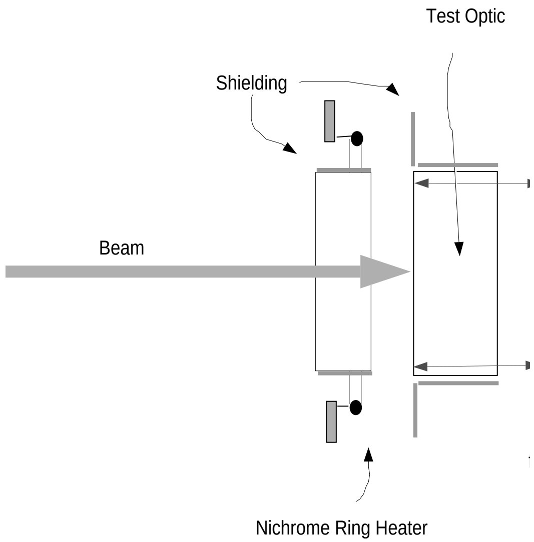
Thermal Actuation Methods

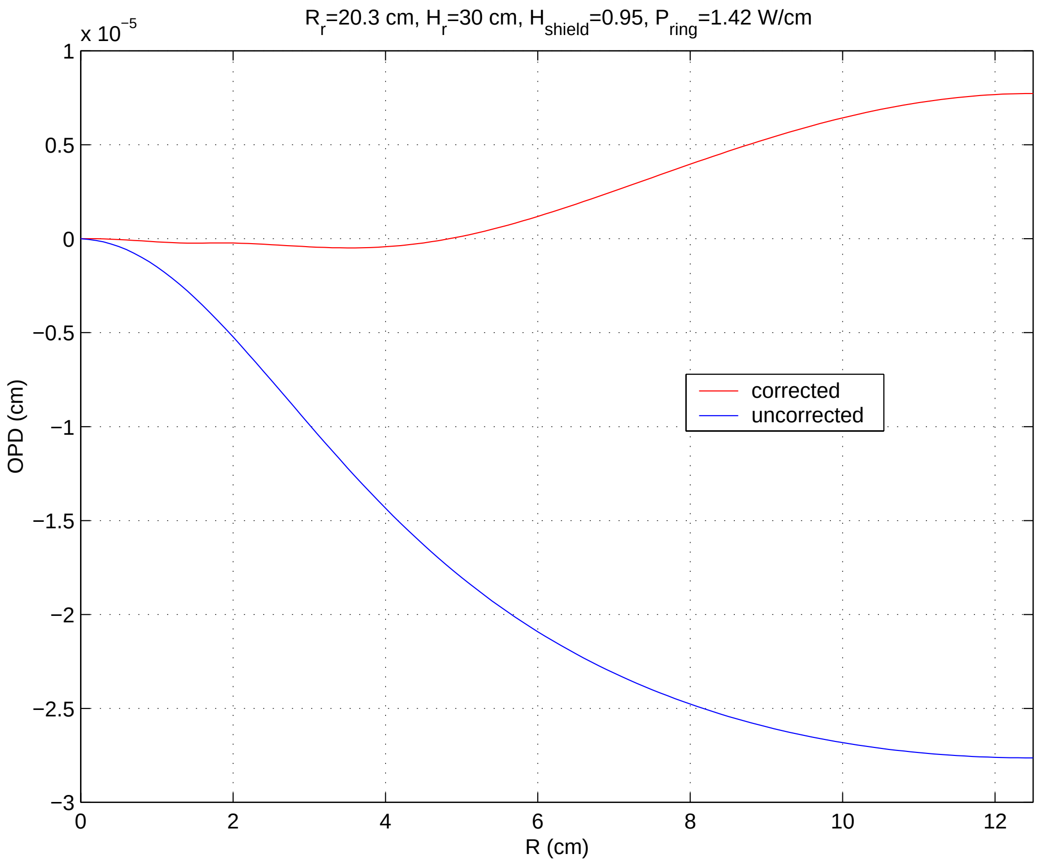


Possible implementation

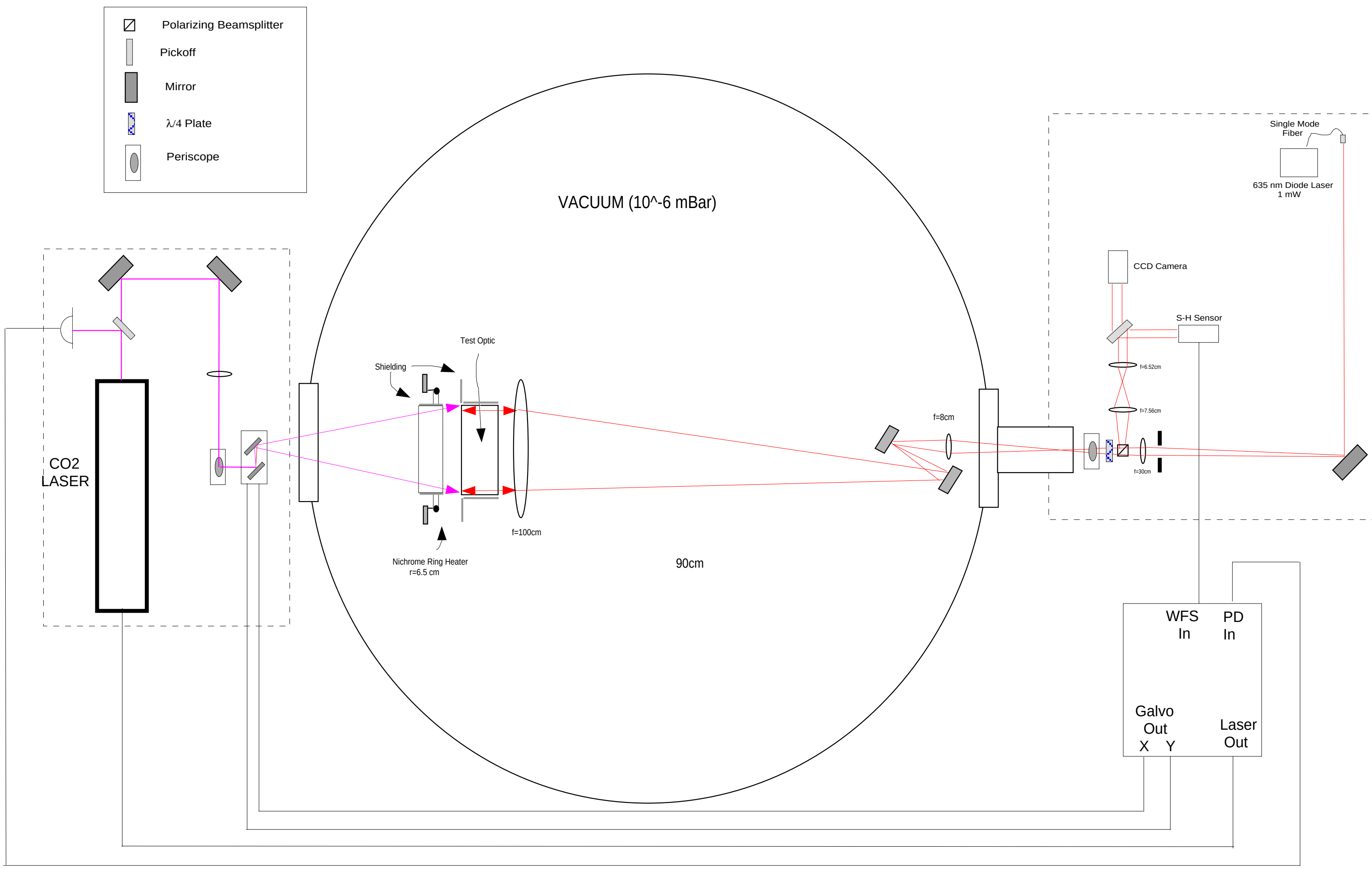


FEA model w/correction: ring heater + cylindrical radiation shield

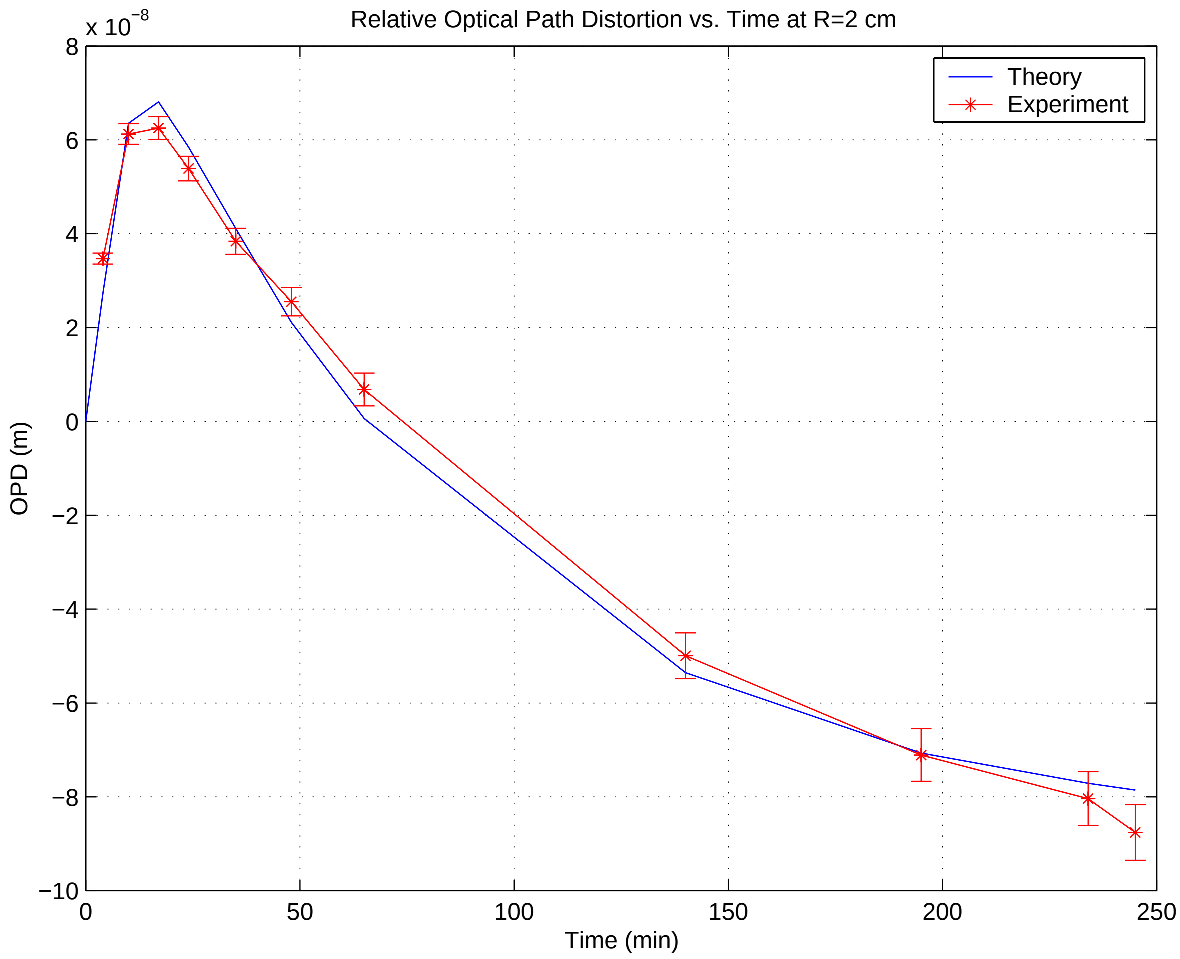




Test Experiment at MIT



Measured OPD vs. time, ring heater w/SiO_2 test optic



Thermal Compensation: Status & Plans

- Bullseye PD and scanning phase camera under test at UF, MIT and LHO (G. Muller, R. Adhikari)
- Experiment phase I complete, phase II underway (R. Lawrence):
  - Generate static Gaussian lens w/ CO_2 beam & correct with radiative ring
- Experiment phase III to begin by summer
  - “actuation basis” kernel for scanned beam under development (R. Bennett)
  - scanners, galvos & laser already installed & operational (R. Lawrence)
- New initiative for 3-d + t finite element model to treat noise/ thermal expansion interactions (R. Lawrence, R. Beausoleil)