Initial LIGO upgrade to 30 W: Implication for the Input Optics

UFLIGO Group

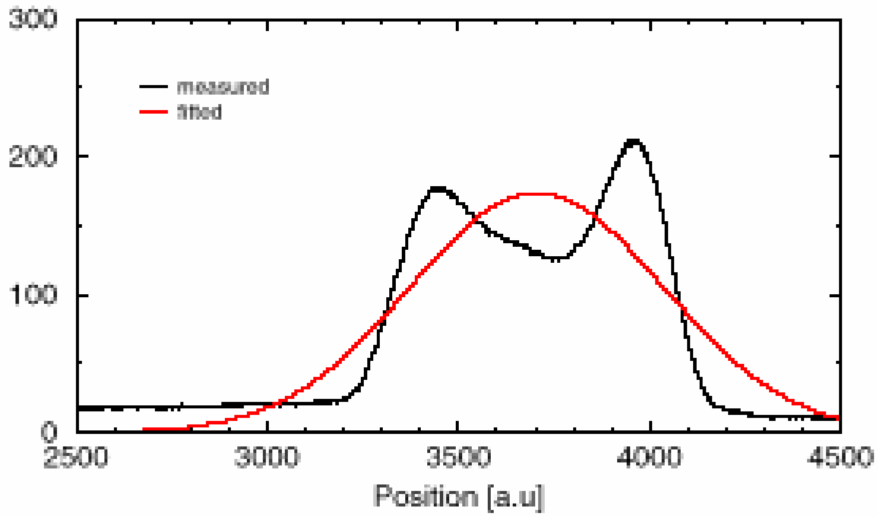
Major IO components and concerns at 30 W

- Electro-optic modulators
  - » Thermal lensing
  - » Degraded noise performance
  - » Long term damage?
- Mode cleaner
  - » Thermal lensing due to coating absorption
    - – MC_REFL beam → MC WFS
      - How much of a problem?
    - – Coating hot spots?
- Faraday isolator
  - » Degraded isolation
  - » Thermal lensing → power dependent mode change into IFO
- Mode-matching telescope
  - » Probably no major concerns

Modulators I

- Current EOMs:
  - » New Focus $LiNbO_3$
  - » 2 x 2 mm aperture
- Thermal lensing at 30W in $LiNbO_3$
  - » Absorption ~ 0.1-0.5%
  - » dn_x/dT 🕒 dn_y/dT
- Need new EOMs!

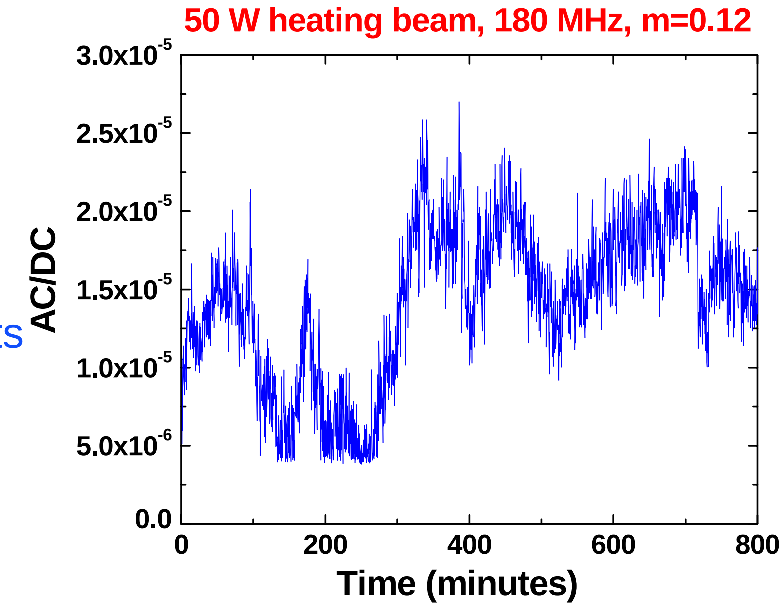
$LiNbO_3$ at 30W:



10 x 10 x 20 mm $LiNbO_3$ EOM - thermal lensing is:
i) severe
ii) position dependent

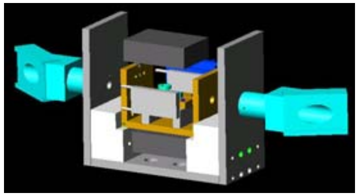
Modulators II

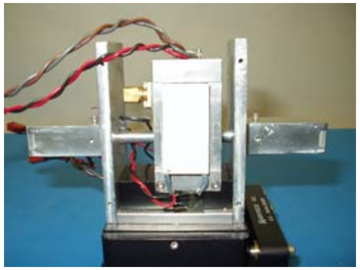
- Advanced LIGO EOM development
  - » Nonlinear crystal: RTP and RTA
    - – 4 x 4 mm^2 aperture
  - » Currently look at two EOM designs
    - – Hybrid UF/New Focus
    - – Home-made
- Summary of performance to date
  - » Bare crystals handle 95 W in 300 μm spots
    - – 400 hours of continuous testing
    - – Negligible thermal lensing
  - » RFAM reasonably good
    - – No worse than LIGO 1
    - – Piezo-electric resonances in the 100s kHz regime
    - – Fluctuations correlate with pump power

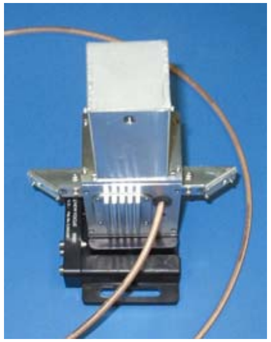


Modulators II

- Hybrid UF/New Focus RTP ‘plug and play’
  - » Pricy - $5500/EOM, but could negotiate bulk discount
- Home-made
  - » Materials are cheap, but manpower needed to assemble and test EOMs and spares costs $
  - » Better temperature stability
  - » Not as well characterized, but should be within the next year

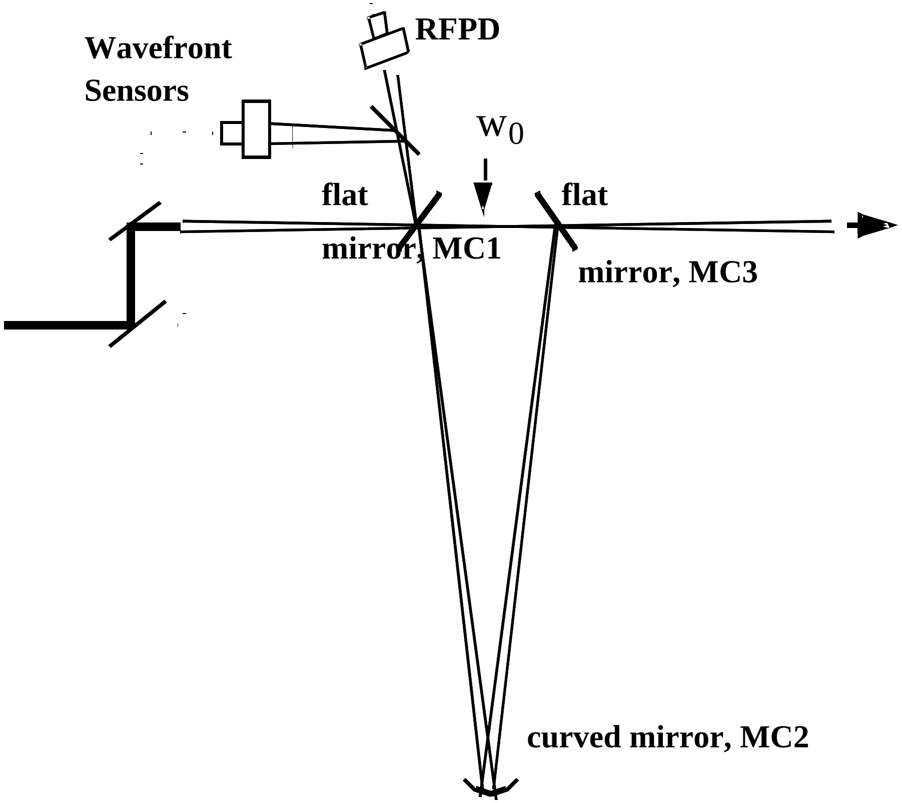






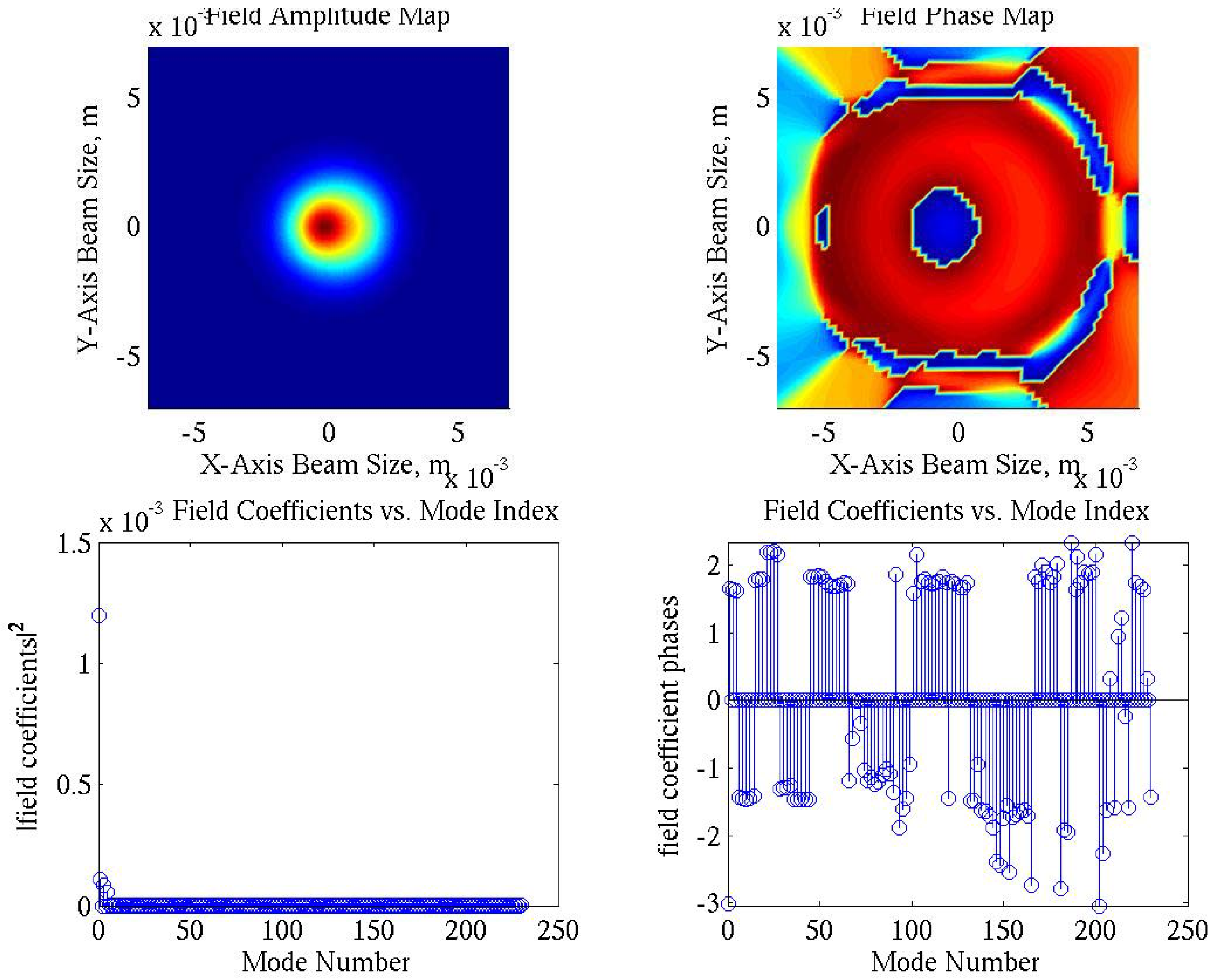
Mode Cleaner

- Main issues
  - » Coating absorption
    - – Affects MC_REFL mode
    - – Impact on MC WFS
  - » 10X increase in intracavity power → 10X increase in MC frequency noise
    - – Limiting noise source?
    - – Assumes current PSL RIN
  - » 10X increase in intracavity power → 1.2 x 10^5 W/cm^2 on each mirror
  - » Throughput
    - – Plagues current MCs

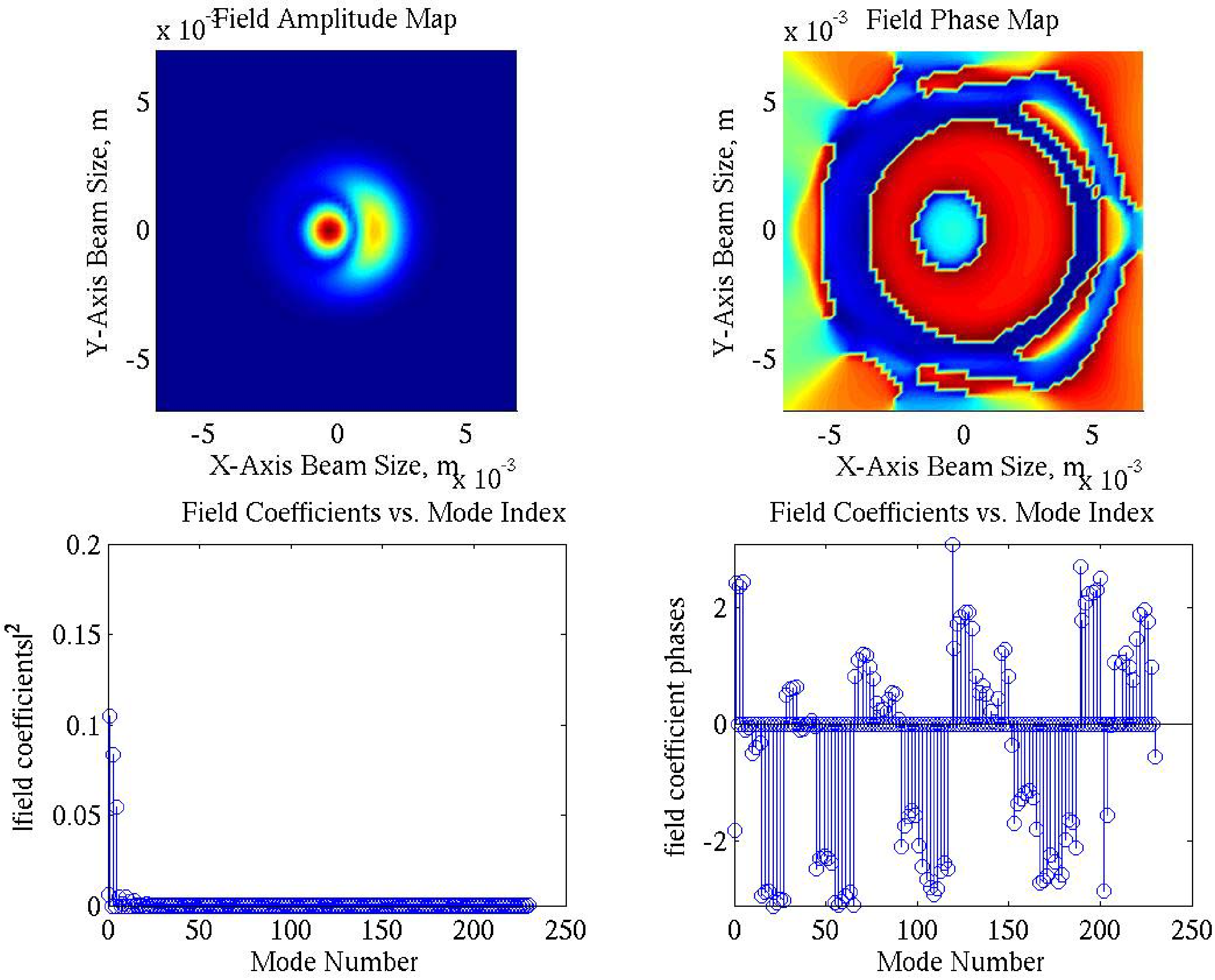


MELODY MODEL

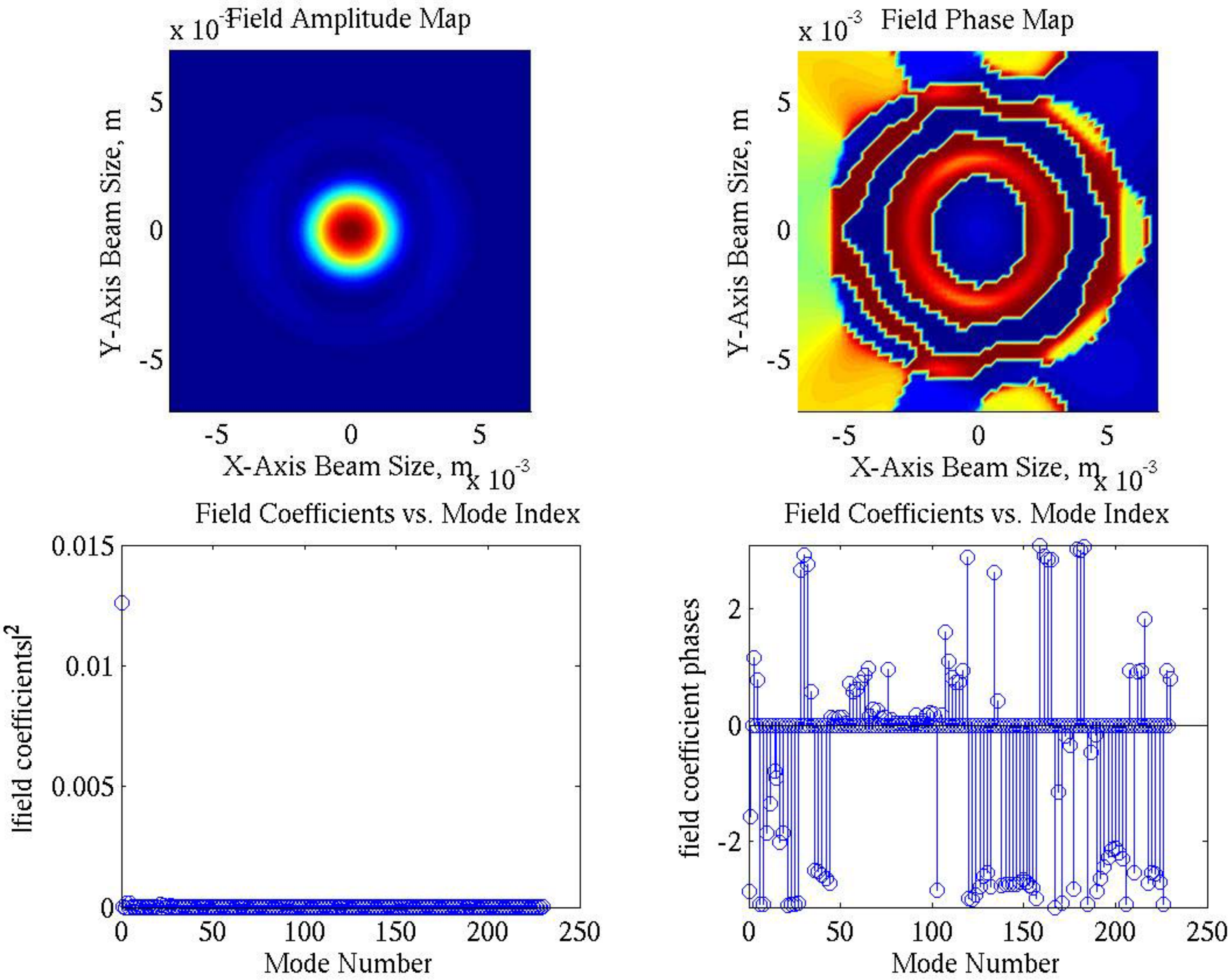
3 W input, MC1 injection, 1.8 ppm coating loss



30 W input, MC1 injection, 1.8 ppm coating loss



30 W input, MC1 injection, no thermal lensing



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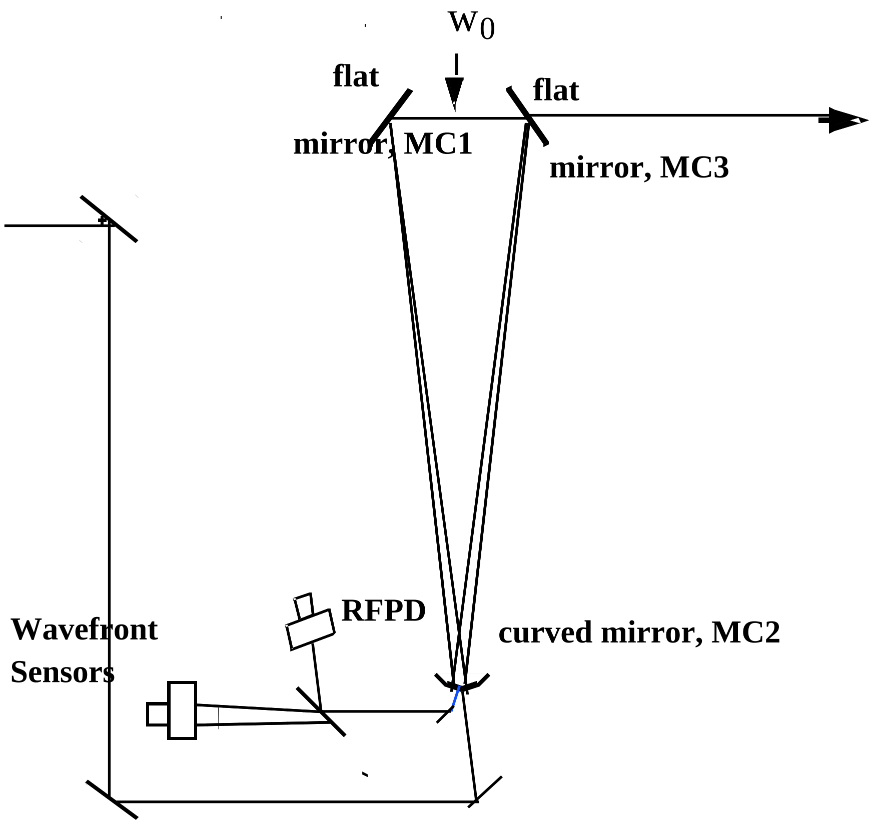
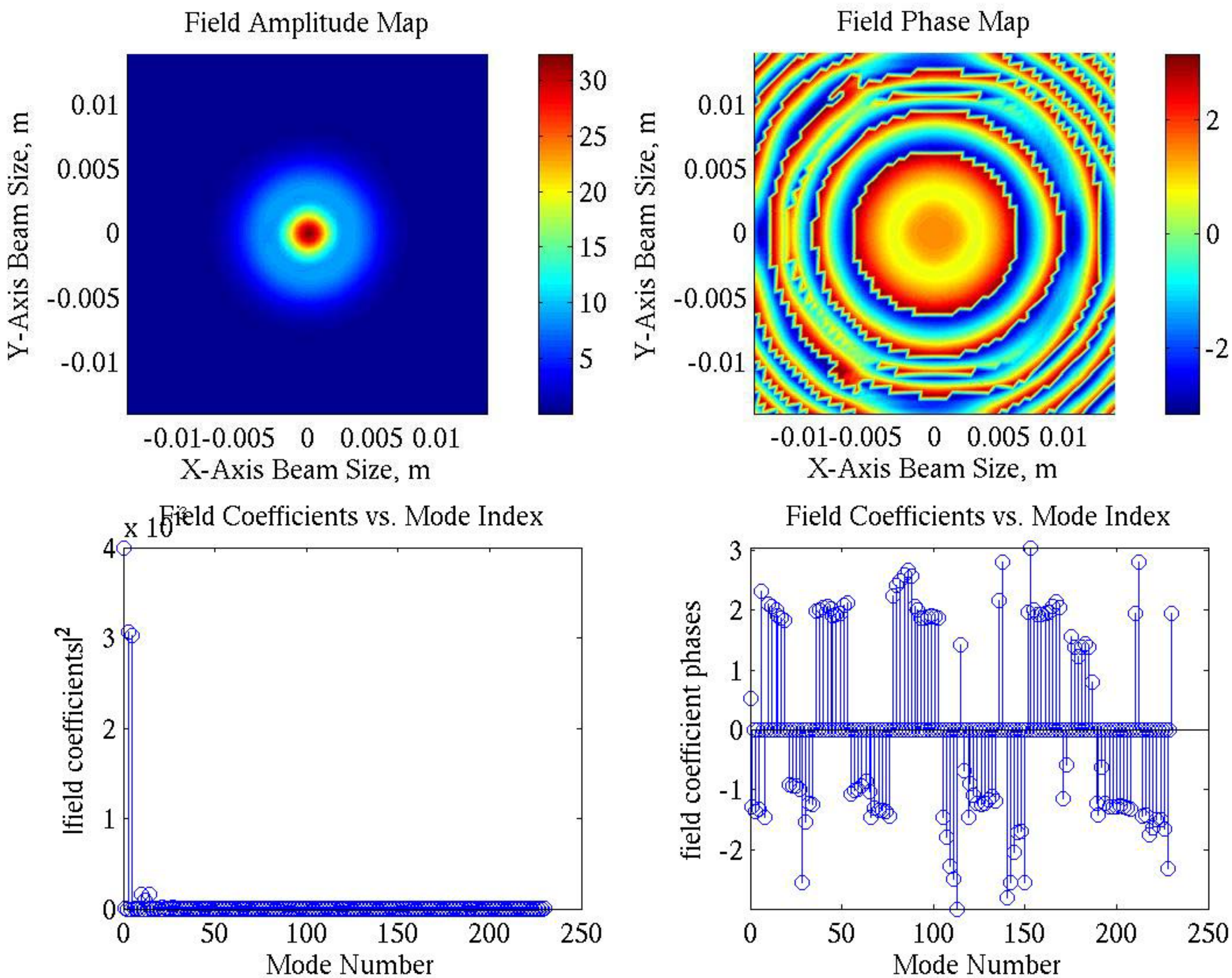
Alternate MC geometry

- Inject beam into MC2
  - » Lower AOI
- Requires some re-routing of beams in HAMs
  - » IOT table moves to HAM2



30 W input, MC2 injection, 1.8 ppm coating loss



Mode Cleaner II

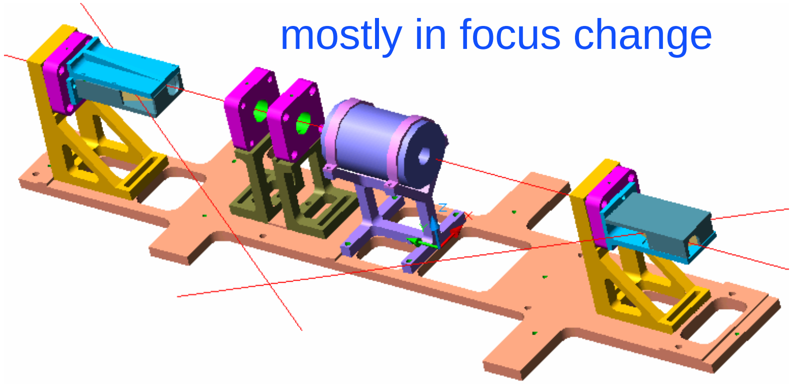
- 10X increase in input power → 10X increase in MC frequency noise
  - » Limiting noise source?
  - » If so, is intensity stabilization able to handle this? 10X more power to PD
  - » Possible to live with higher δf and reallocate problem to controls or elsewhere?
- Long term performance at higher power
  - » Are the MCs getting worse with time?
    - – Contamination?
  - » 10X increase in power → 10X speed up in degradation? 100X?
- Current H1 MC has low throughput (65%)
  - » Scatterer on MC mirror?
    - – Serious negative implications for high power operation
  - » Change MC mirrors!

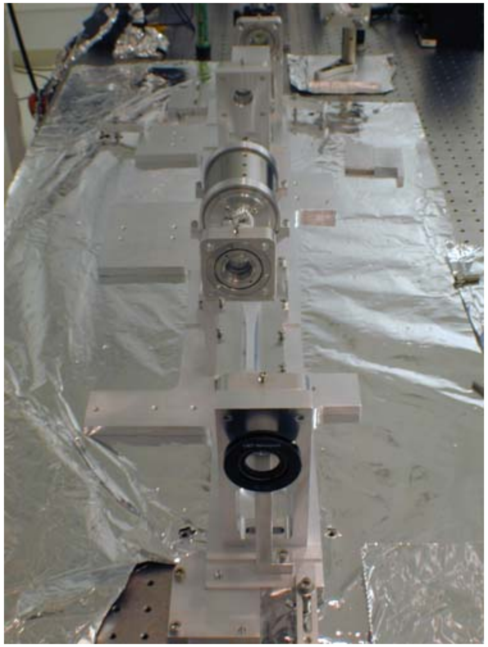
Faraday Isolator I

- FIs currently different in (H1, L1) and H2
  - » H1, L1 → initial FI, 10 mm aperture, 90% throughput, thermal beam drift on lock and unlock at low (2W) powers
  - » H2 → new FI design, 20 mm aperture, low absorption TGG, 98% throughput, no beam drift, bench tested to 6W
- Advanced LIGO FI prototype tested
  - » Compensation of thermal birefringence and thermal lensing
  - » Predicted performance isolation > 40 dB at 100 W based on depolarization measurements
  - » Imperfect but reasonable thermal lensing compensation at 100 W
    - – Should be fine for 30W

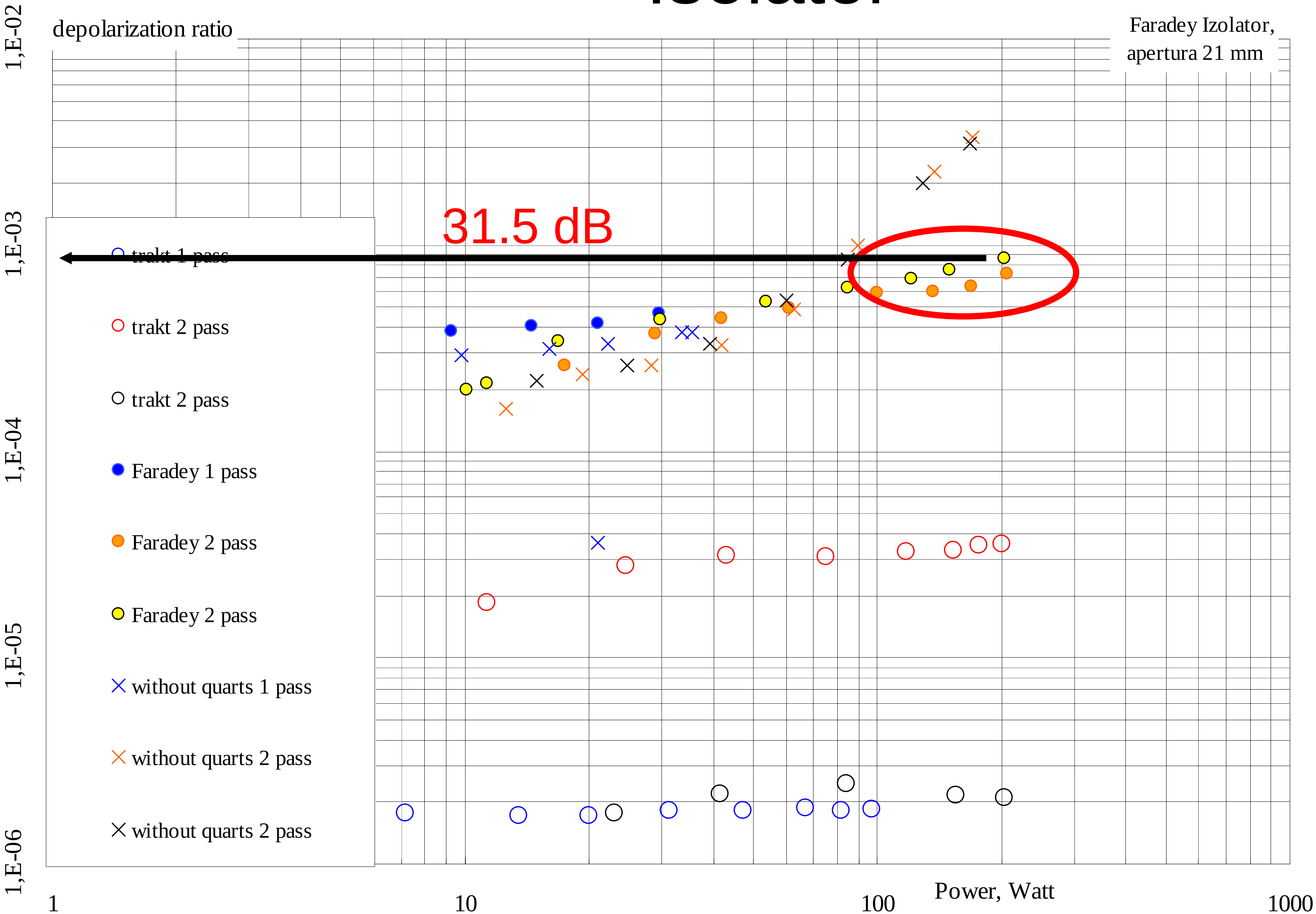
Faraday Isolator II

- Current H2 FI
  - » Isolation at 30 W would be reduced relative to current performance
    - – How much??
    - – Need to measure…
  - » Thermal lensing at 6 W negligible
    - – Evidence that calcite Brewster polarizers might lens at 30 W
      - Worst case 25% loss of TEM00, mostly in focus change





Status of AdvLIGO Faraday Isolator



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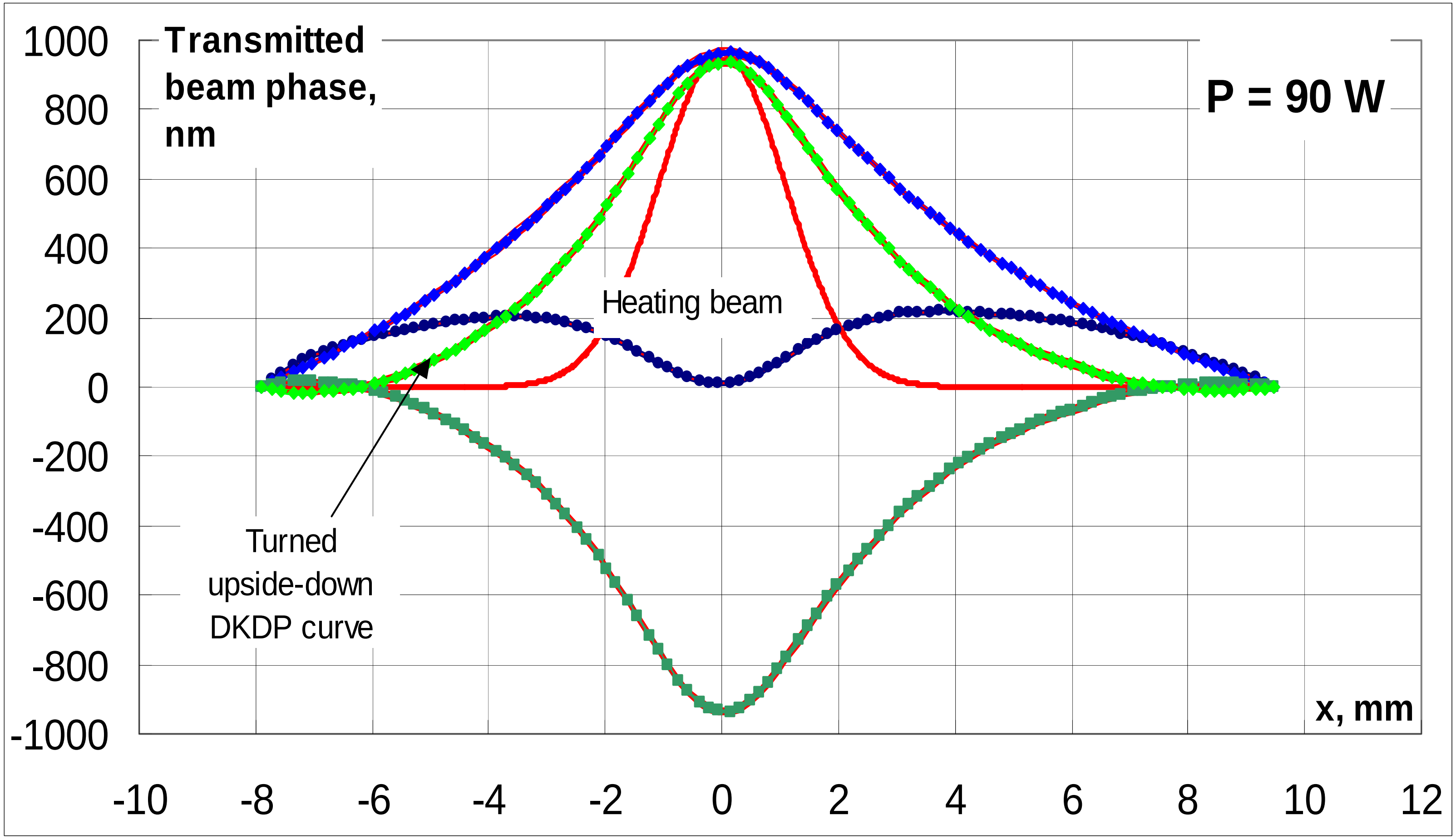

Status of AdvLIGO Faraday Isolator

- FR: Dual TGG crystal design + quartz compensator
- Thermal lens compensation
  - » KD*P –dn/dT material
- Isolation performance
  - » 31.5 dB
- Thermal Lens performance
  - ≈ λ/10 OPD across beam waist at 90 W single pass
  - ≈ λ/30 OPD expected at 30 W
    - – Negligible thermal lensing

Recommendations I

- EOMs
  - » Need to be changed
    - – Impact mode matching into MC
  - » Simplest solution is to replace current EOMs with New Focus RTP version
  - » Could have a homemade one ready on a year time scale
- Mode cleaner
  - » High power operation problematic for REFL beam
    - – But is it really a problem?
      - Need some investigations
  - » Solution is to inject through MC2
    - – Major surgery, requires getting new mirrors and swapping

Recommendations II

- Faraday Isolator
  - » Current H2 design *may* work
    - – Need to build another one and test it at 30 W
  - » AdvLIGO design prototype will work

- Costs:
  - » $50-60K for EOMs and spares
  - » $40K – 50K for FIs and spares
  - » $75K for new MC mirrors (do we need to do this?)