The LIGO input optics

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1. IO for initial LIGO
2. IO for enhanced LIGO
3. IO for advanced LIGO

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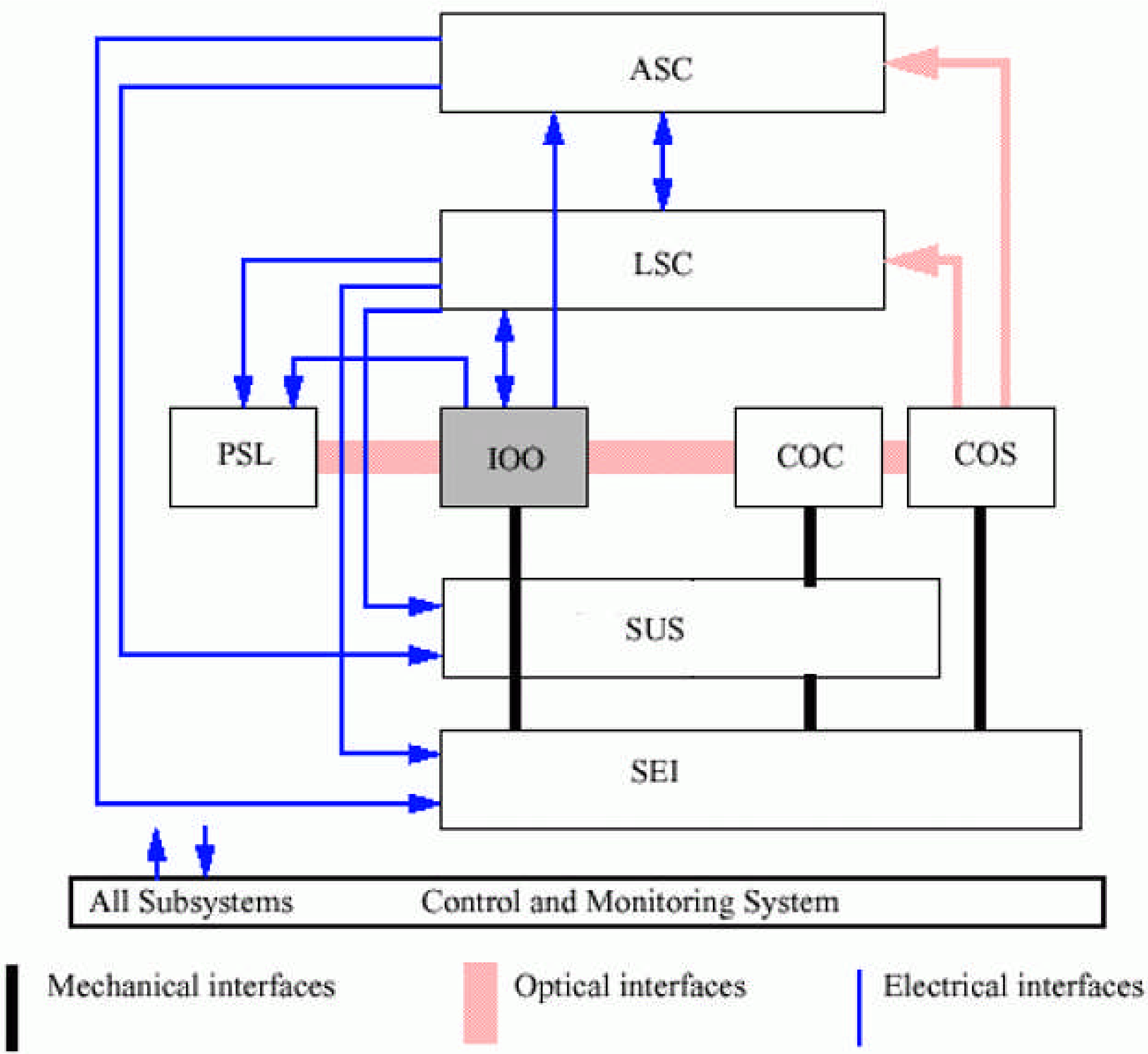
IOO = "input optics"



Adv LIGO Input Optics

- The Input Optics conditions the light from the pre-stabilized laser, sending it to the main interferometer

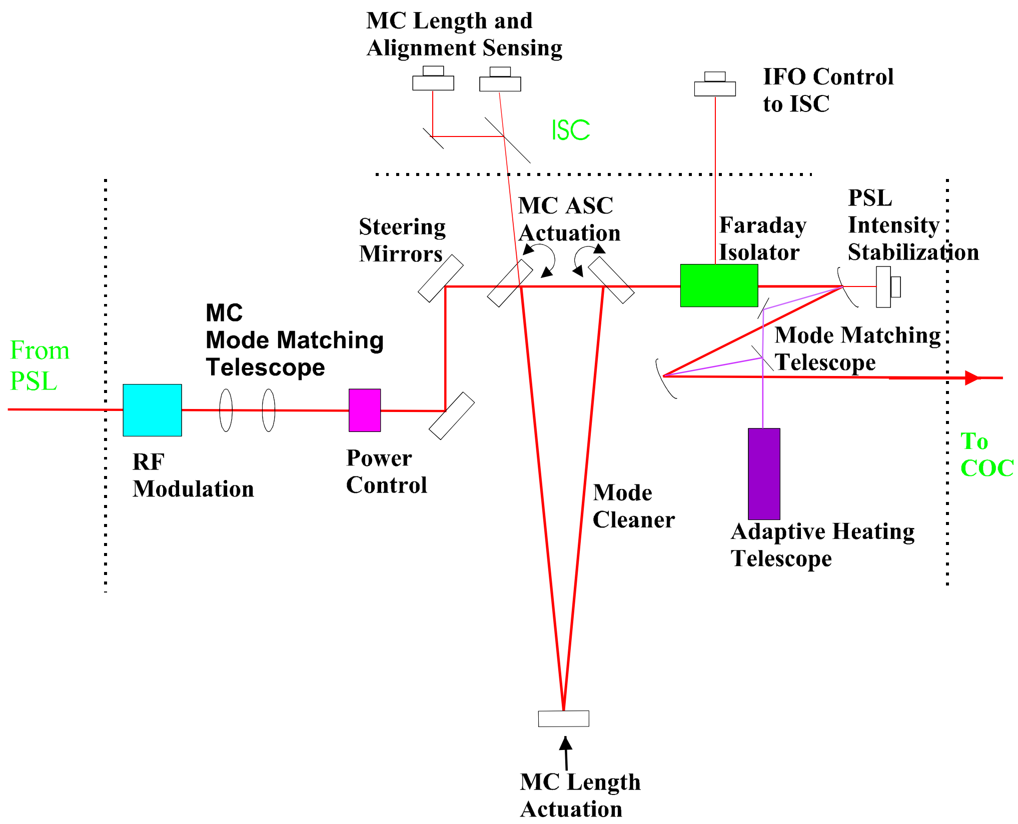
» Phase modulation
  – Electro-optic modulators

» Interferometer power control
  – Continuous variable attenuation

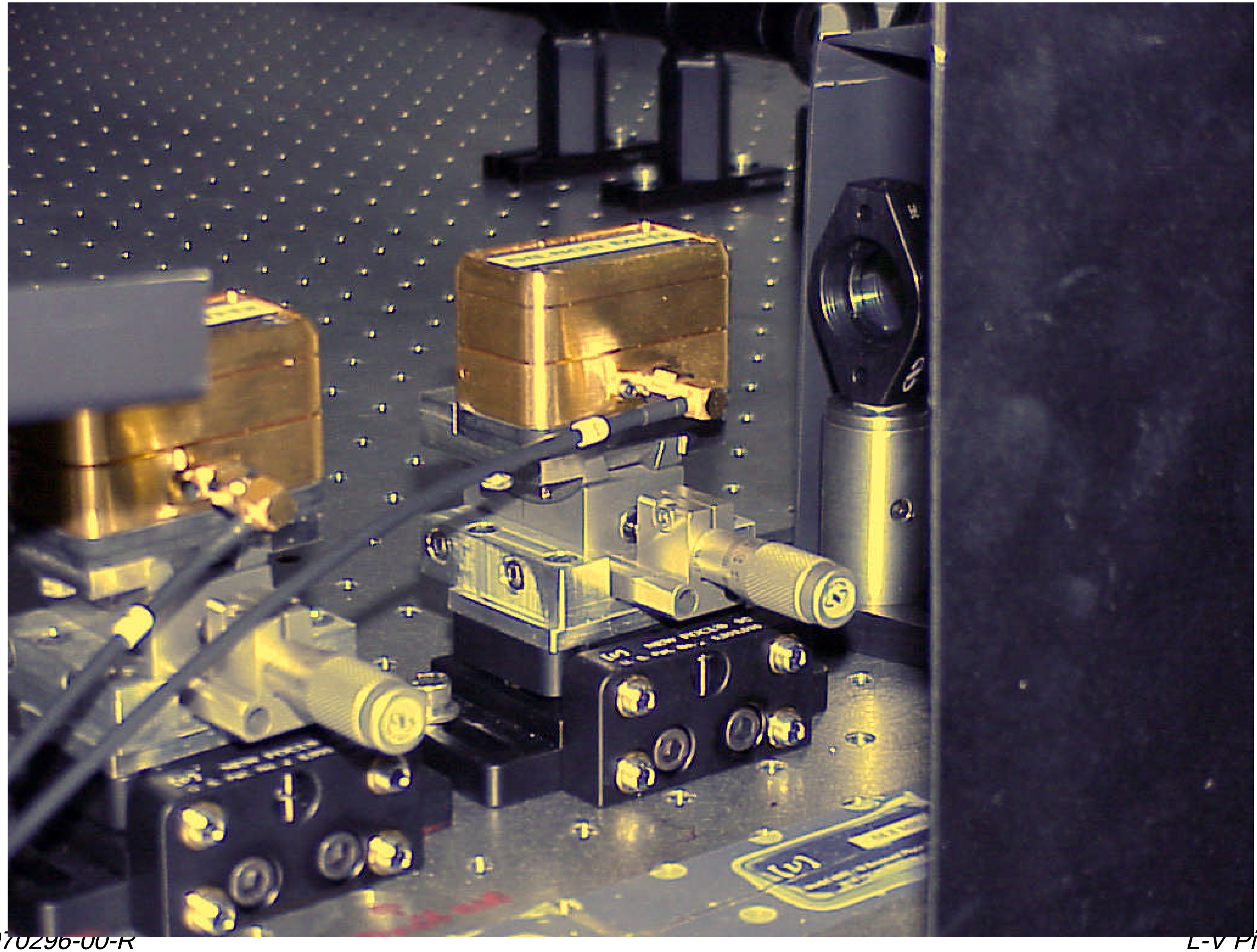
» Spatially and temporally filter the light
  – Mode cleaner

» Optical isolation + diagnostic signals
  – Faraday isolator

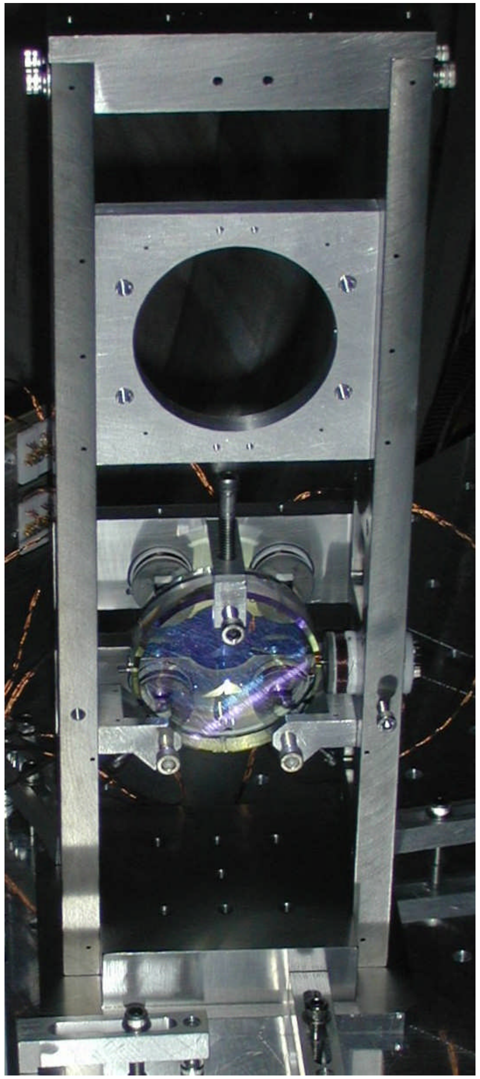
» Mode match into the interferometer
  – Adaptive beam-expanding telescope



RF modulators

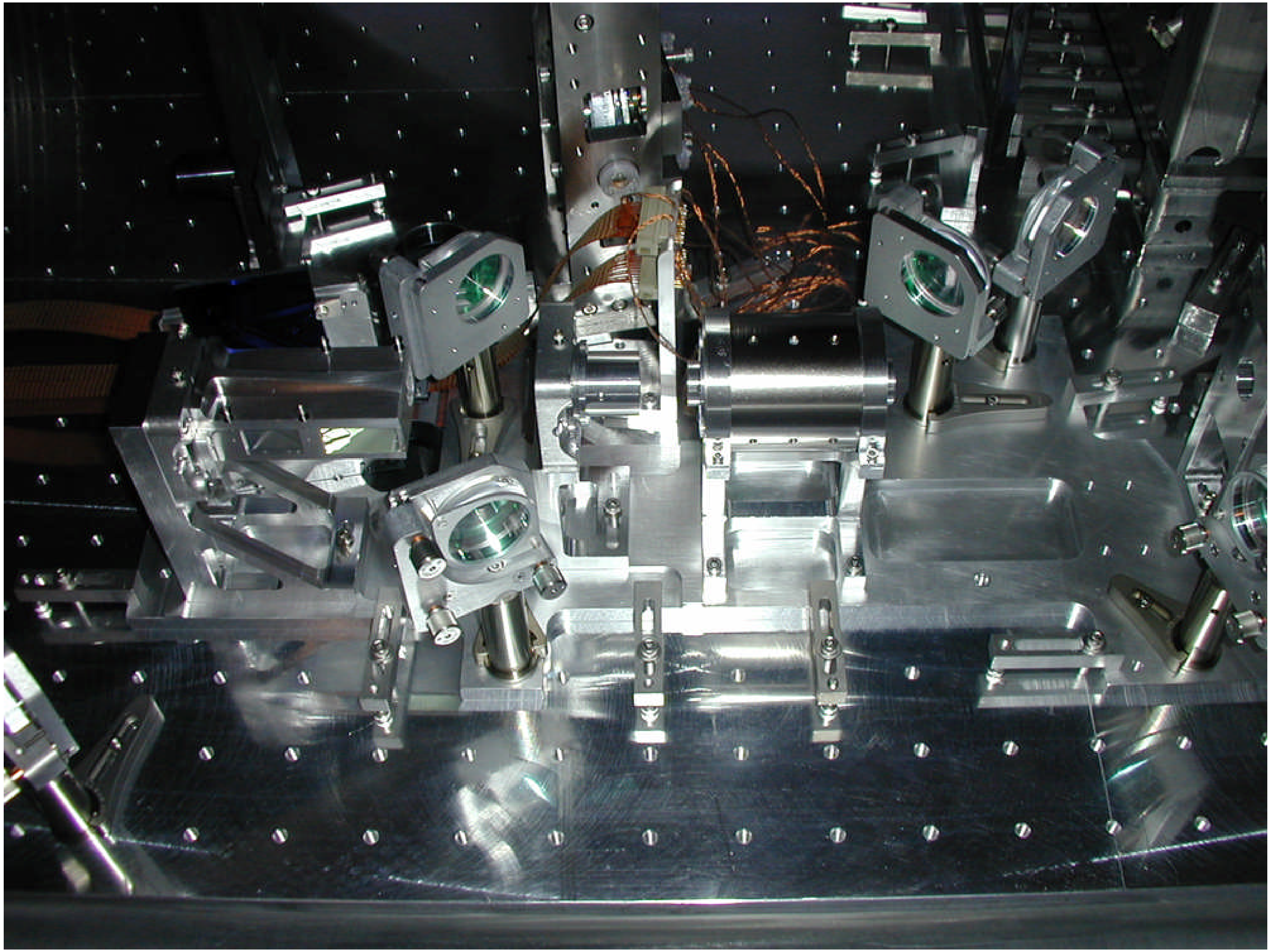


Mode cleaner: SOS



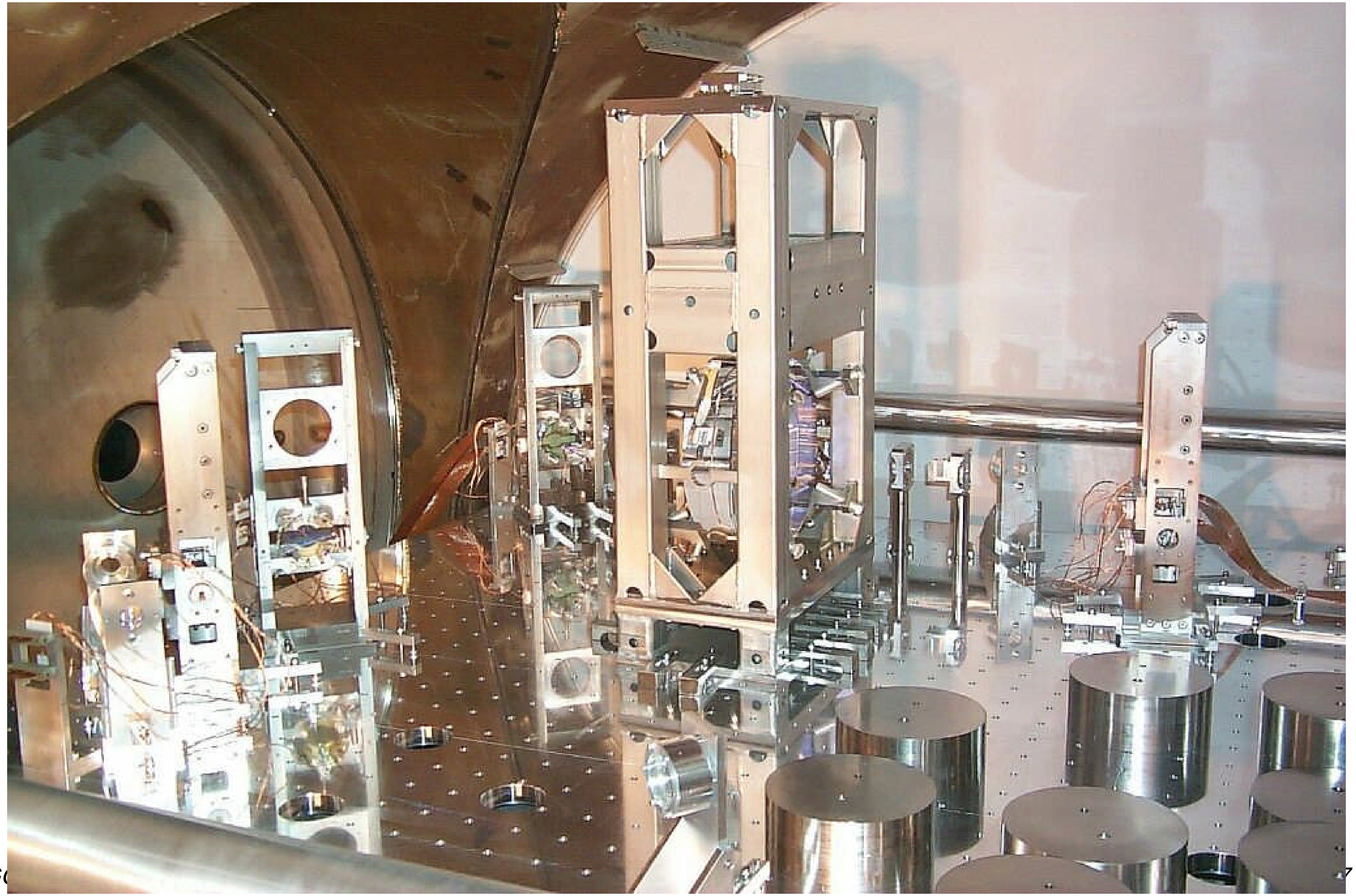
- SOS = small optics suspension.
- Mirrors are 3 inch diameter, 1 inch thick.
- Hung by a single loop of 0.0017 inch diameter steel wire.
- Mirrors have magnets glued to their backs
- Coils on frame can push, tip, tilt the mirrors.
- Safety stops all around to catch mirror if the wire breaks.
- Several did during the 2001 Olympia earthquake.

Faraday isolator



Parts installed in vacuum chambers with incredible precision

HAM 1



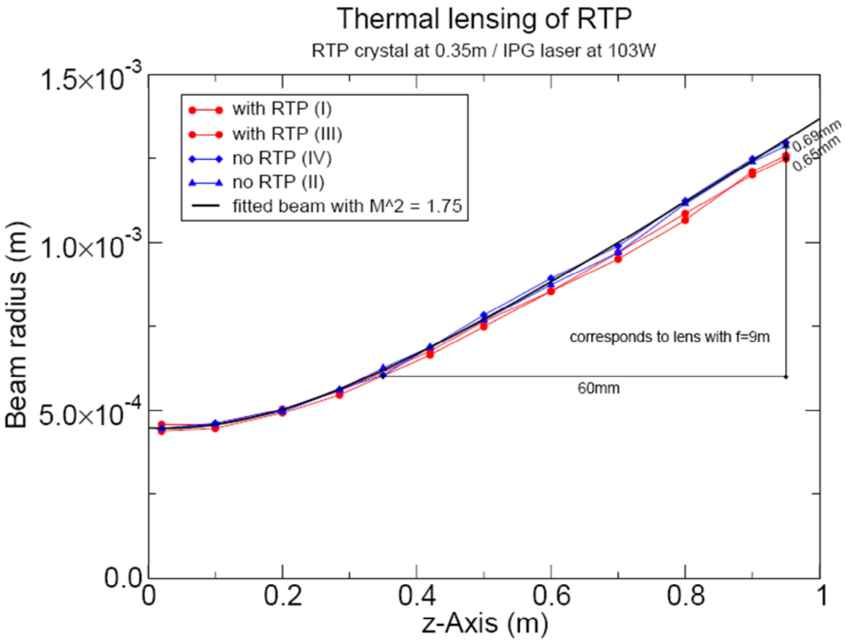
LIGO, eLIGO, Adv LIGO

	Laser Power (W)	EOM type	Freqs (MHz) H1/L1	Mod index (nom)	Configs	MC Suspensions	PRC	Faraday type
LIGO	8	νFocus $LiNbO_3$	24.5 61.2 33.3 (mc)	0.5 0.05 0.05	3x	SOS single	Marginal	EOT TGG
eLIGO	30	UF RTP	24.5 61.2 33.3 (mc)	0.5 0.05 0.05	1x, 3 electrodes	SOS single	Marginal	IAP TGG Qtz TGG
Adv LIGO	180	UF RTP	9 45/63/180 TBD	0.8! 0.8! TBD	Baseline: Mach Zehnder	MC Triple	TBD: Stable or marginal	IAP TGG Qtz TGG

RF Modulation

- Requirements:
  - » Amplitude and phase stability:
    - – Amplitude: differential radiation pressure noise due to arm cavity carrier imbalance

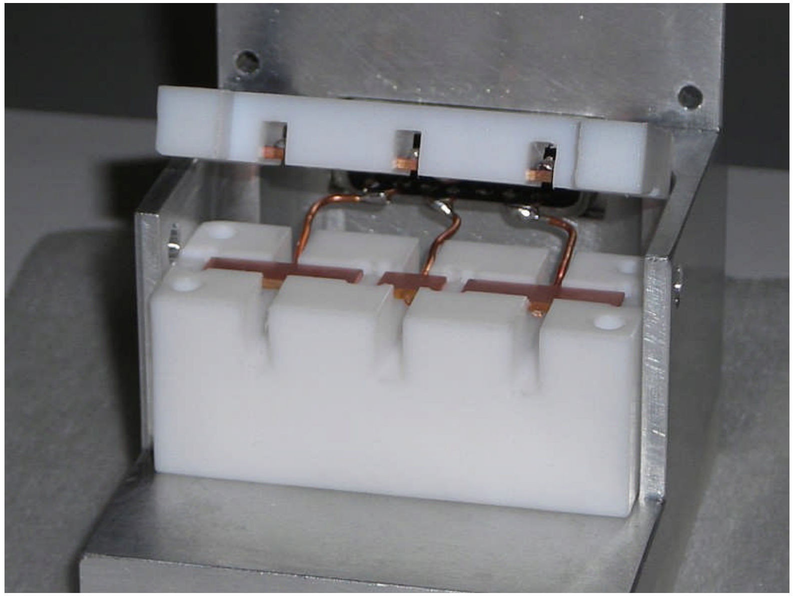
      $\Delta m < (10^{-9}/m)(f/10\ \mathrm{Hz})/\mathrm{rtHz}$
    - – Phase: no direct coupling for DC readout, but possible couplings through auxiliary loops
- Rubidium titanyl phosphate (RTP)
  - » Electro-optic response similar to $LiNbO_3$
  - » low absorption → low thermal lensing
- In-house design and build
  - » Matching circuit in separate housing
- Modified version for eLIGO upgrade

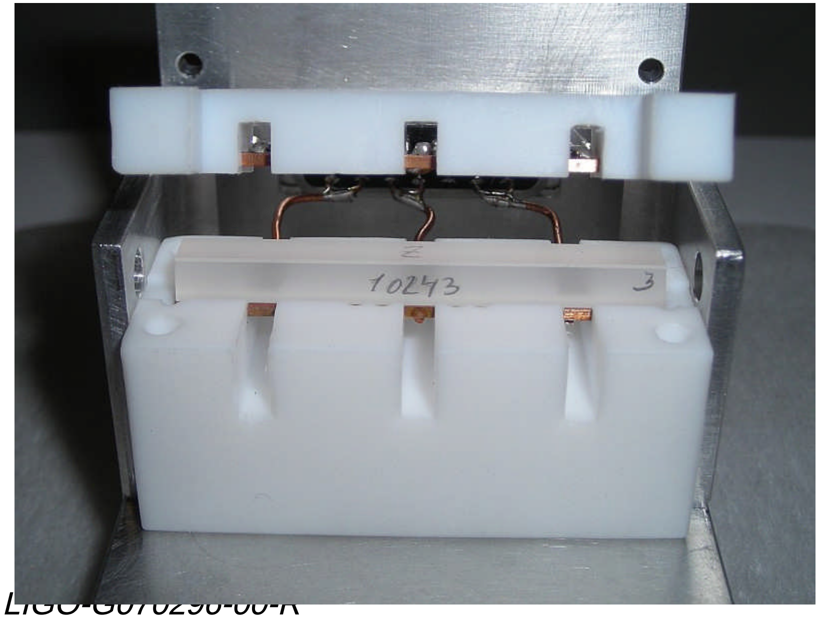


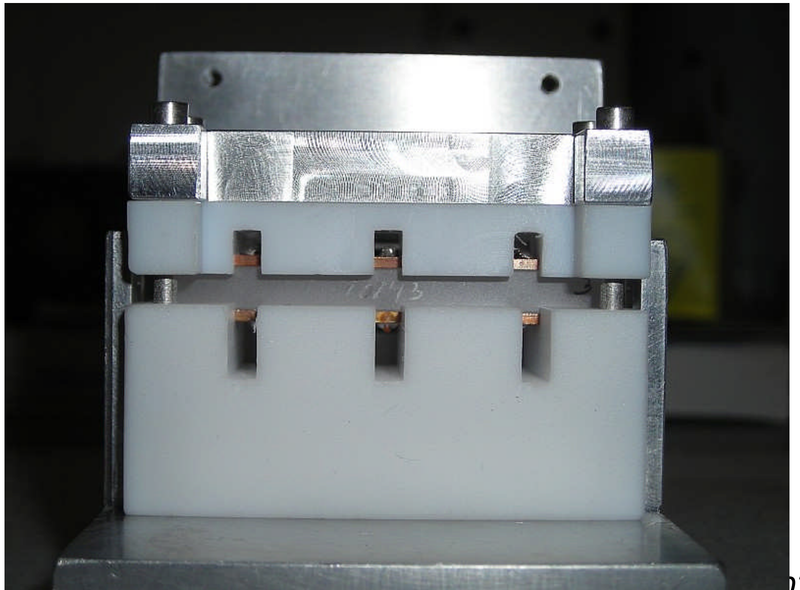
Mueller, LIGO T020022 (2002).
Mueller, et al., LIGO T020025 (2002).
UFGroup, LIGO E060003 (2006).

eLIGO: 3 frequencies / 1 crystal

- Use one crystal but three separate electrodes to apply three different modulation frequencies at once.

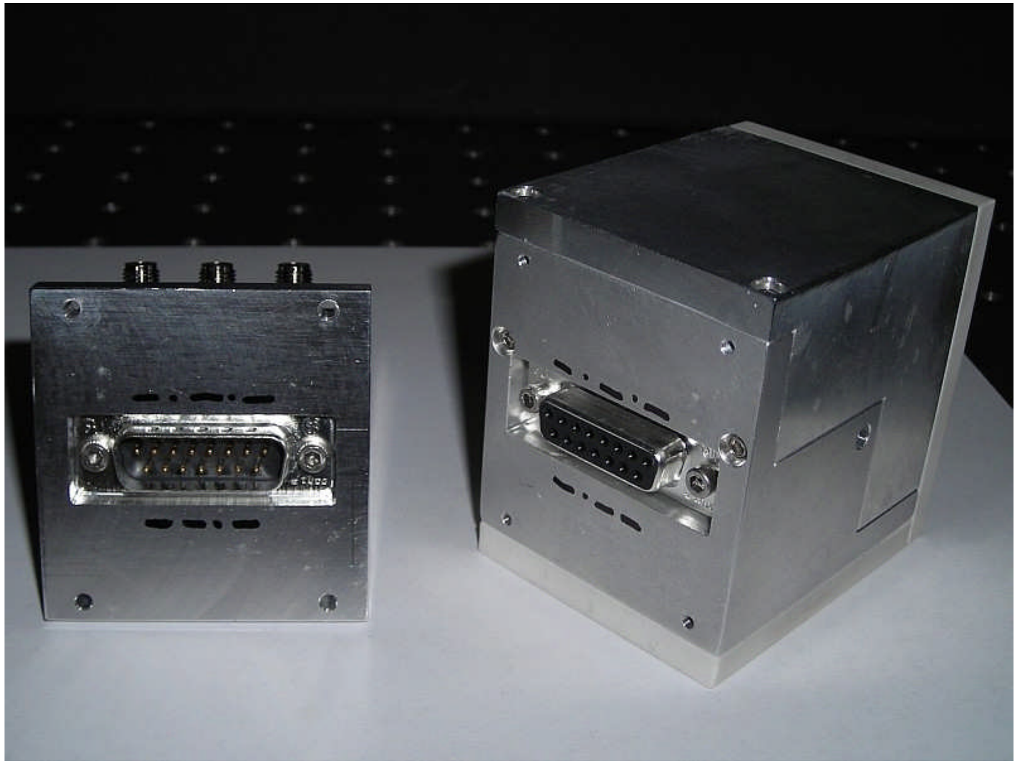


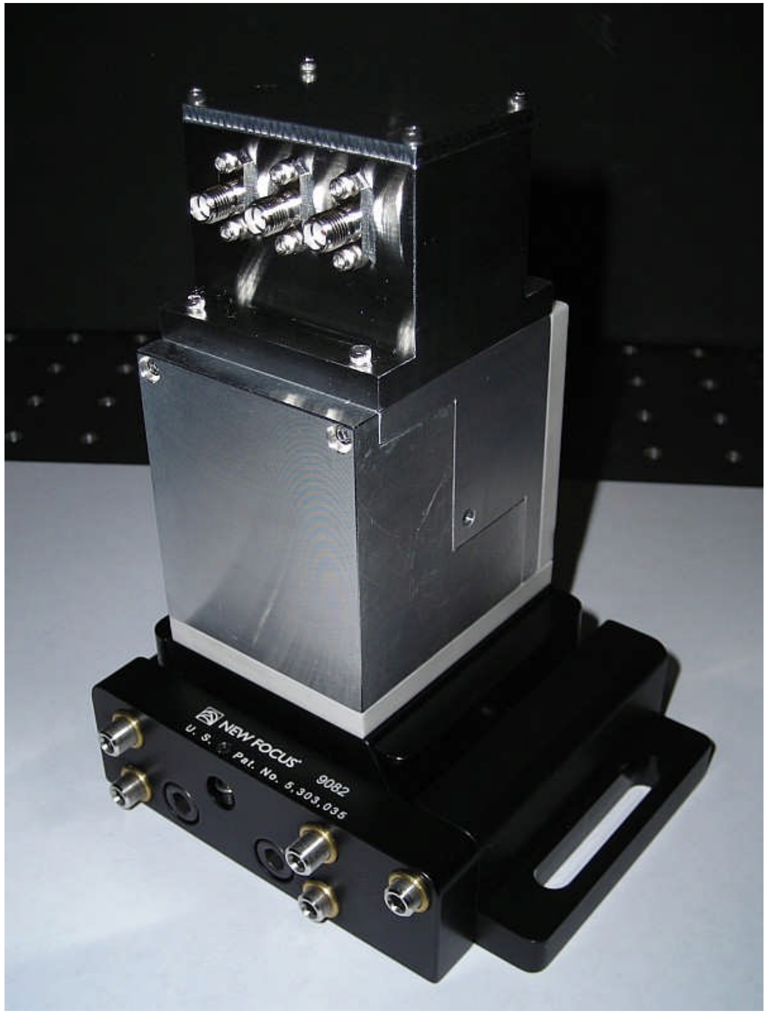




Assembled modulator

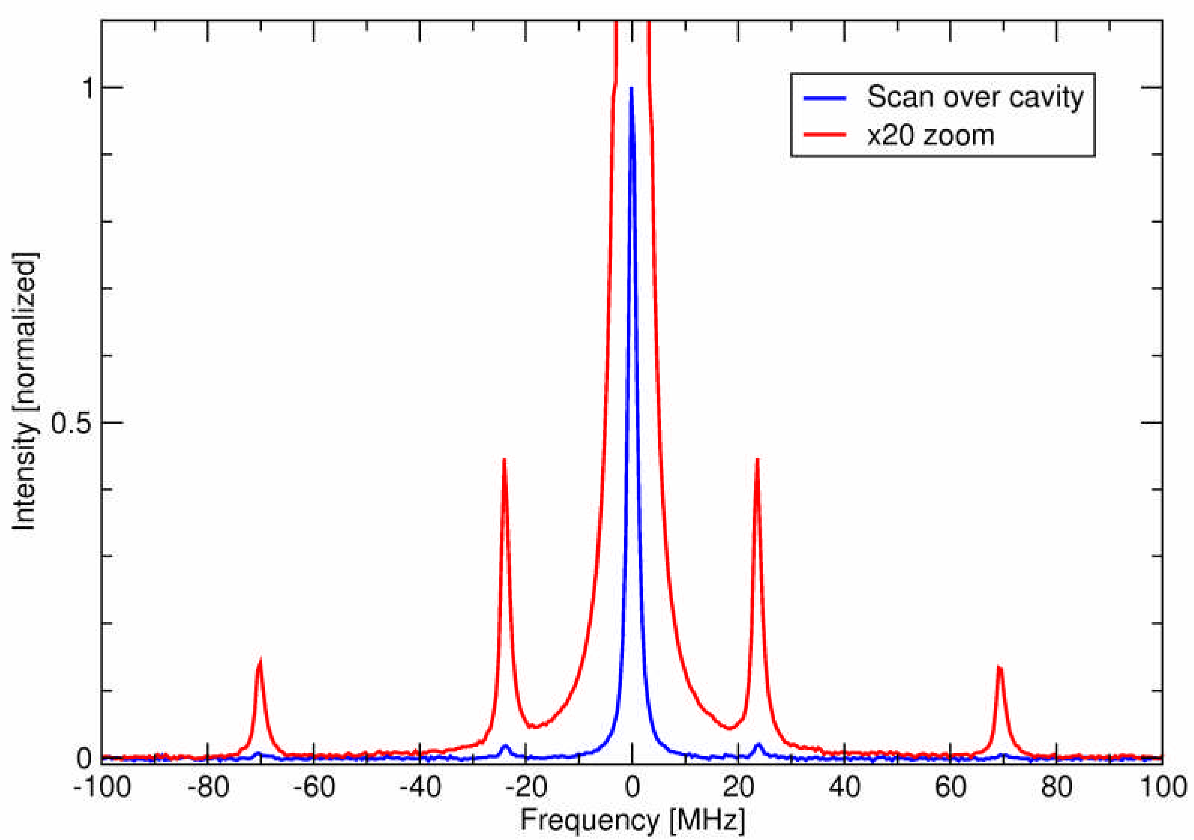
- Separate the crystal housing from the housing of the electronic circuits to maintain maximum flexibility.





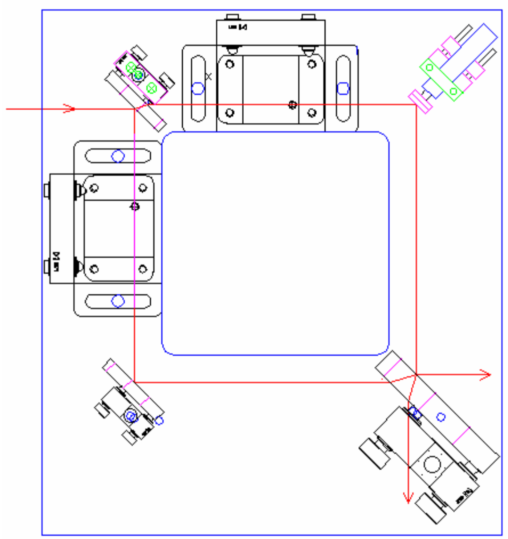
Modulation index

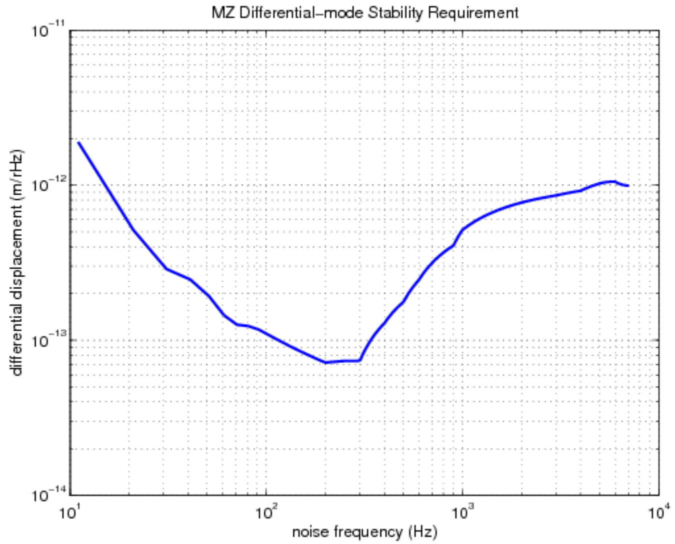
- Measure with 10 V_{pp} drive, 23.5 & 70 MHz.
  - » $m_{23.5} = 0.29$
  - » $m_{70} = 0.17$

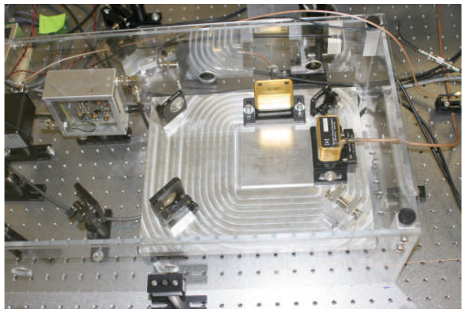


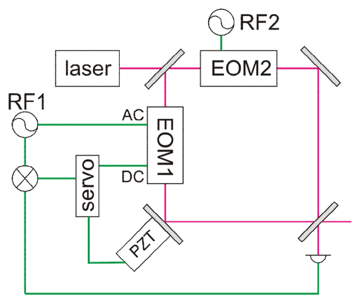
AdvLIGO: Mach-Zehnder

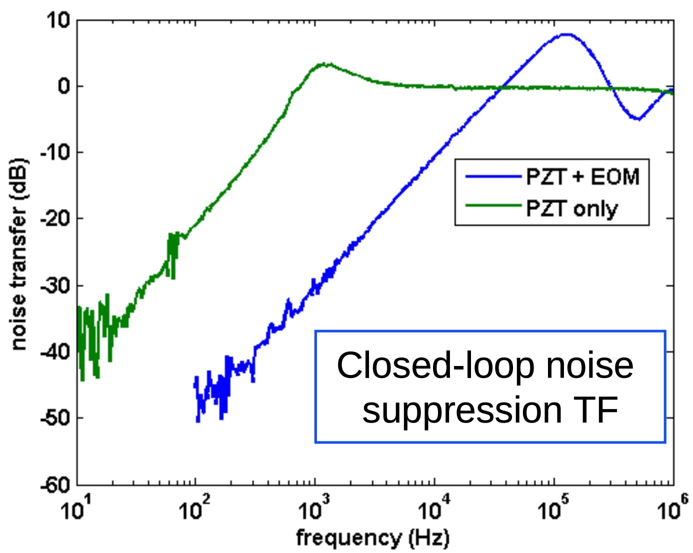
- Modulation architecture needed to eliminate cross products
  - » Mach-Zehnder architecture
    - – Requirement: differential arm motion → carrier-sideband phase noise → common mode frequency noise:
    - →$\Delta L \sim 7 \times 10^{-14}$ m/rHz in 20 – 80 Hz band
  - » Complex (AM/PM) modulation





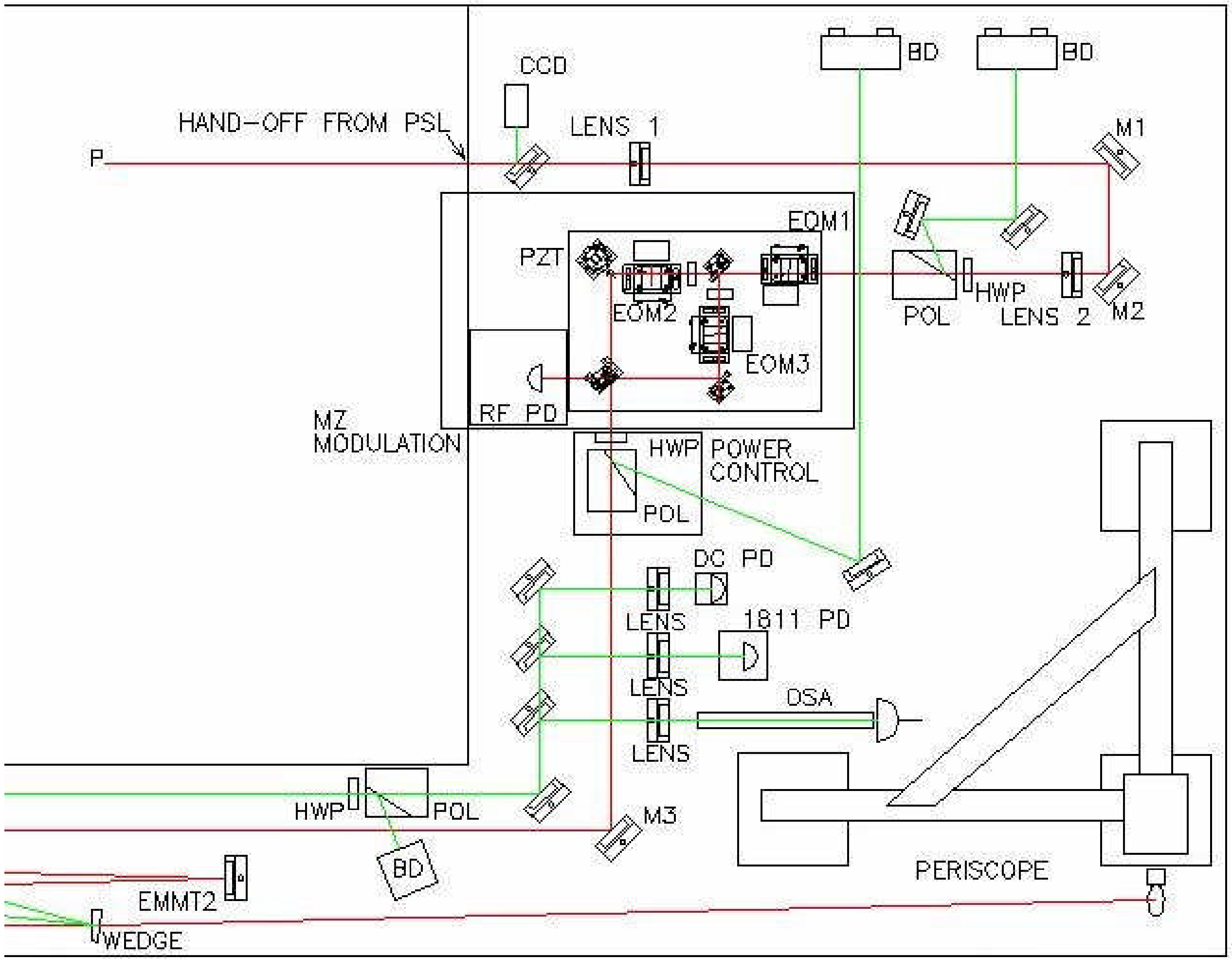






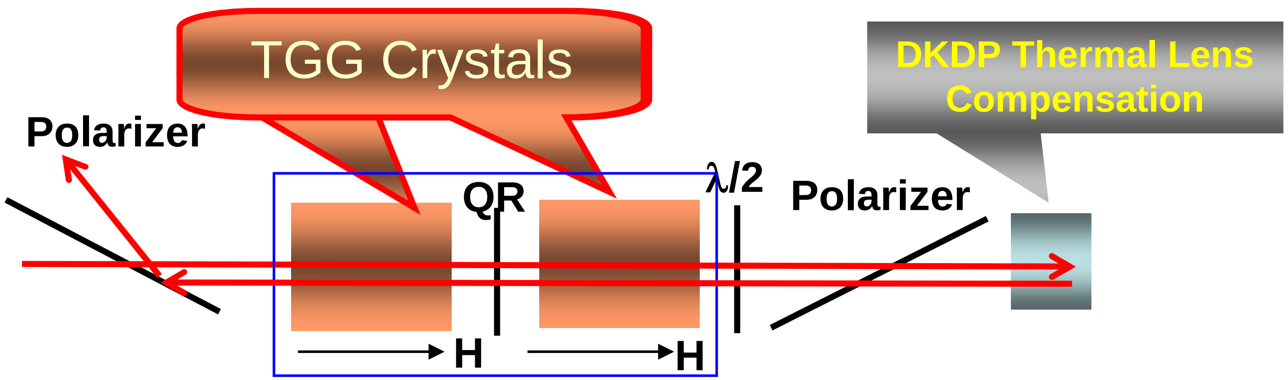
Adv LIGO layout

- MZ on the PSL/IO table



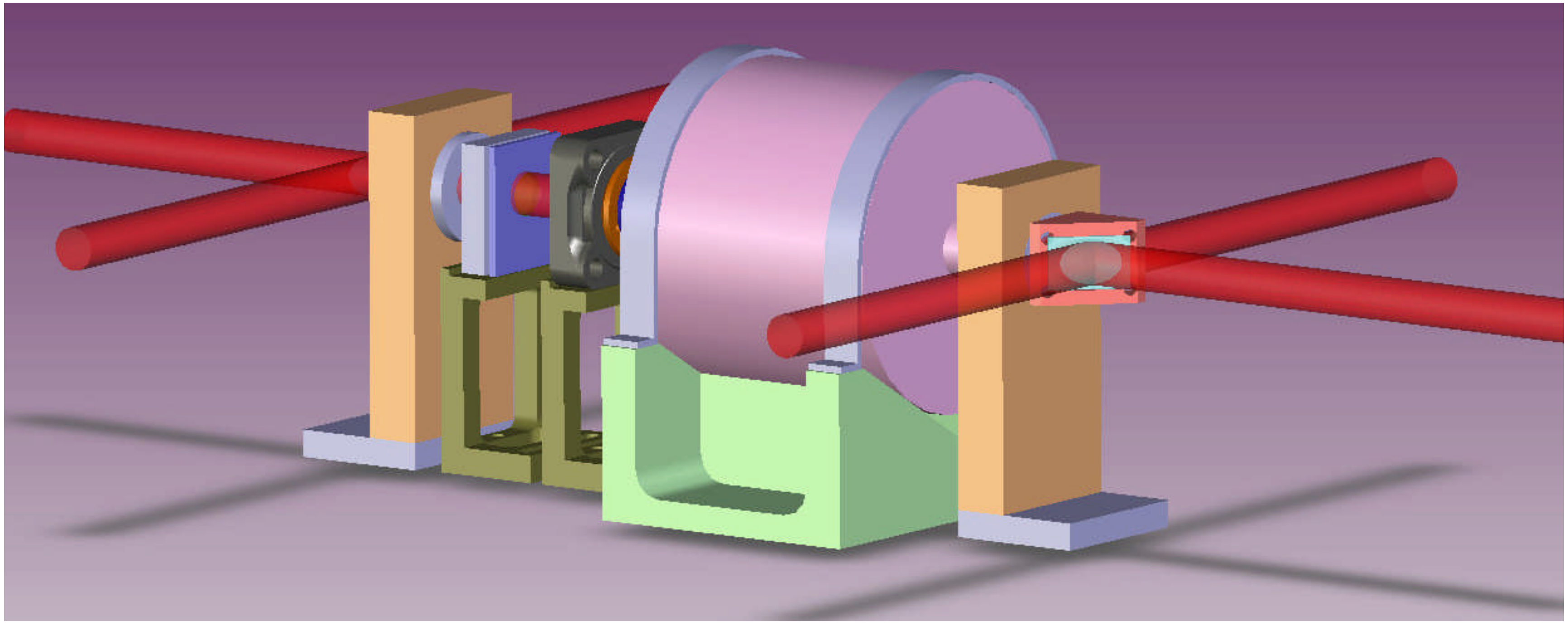
Faraday isolator

- Faraday rotator
  - » Two 22.5° TGG-based rotators with a reciprocal 67.5° quartz rotator between
  - » Polarization distortions from the first rotator compensated in the second.
  - » ½ waveplate to set output polarization.
  - » Thermal lens compensation: negative *dn/dT* material: deuterated potassium dihydrogen phosphate, KD_2PO_4, or 'DKDP').
- Calcite wedges or TFP polarizers
- Will be used in eLIGO upgrade

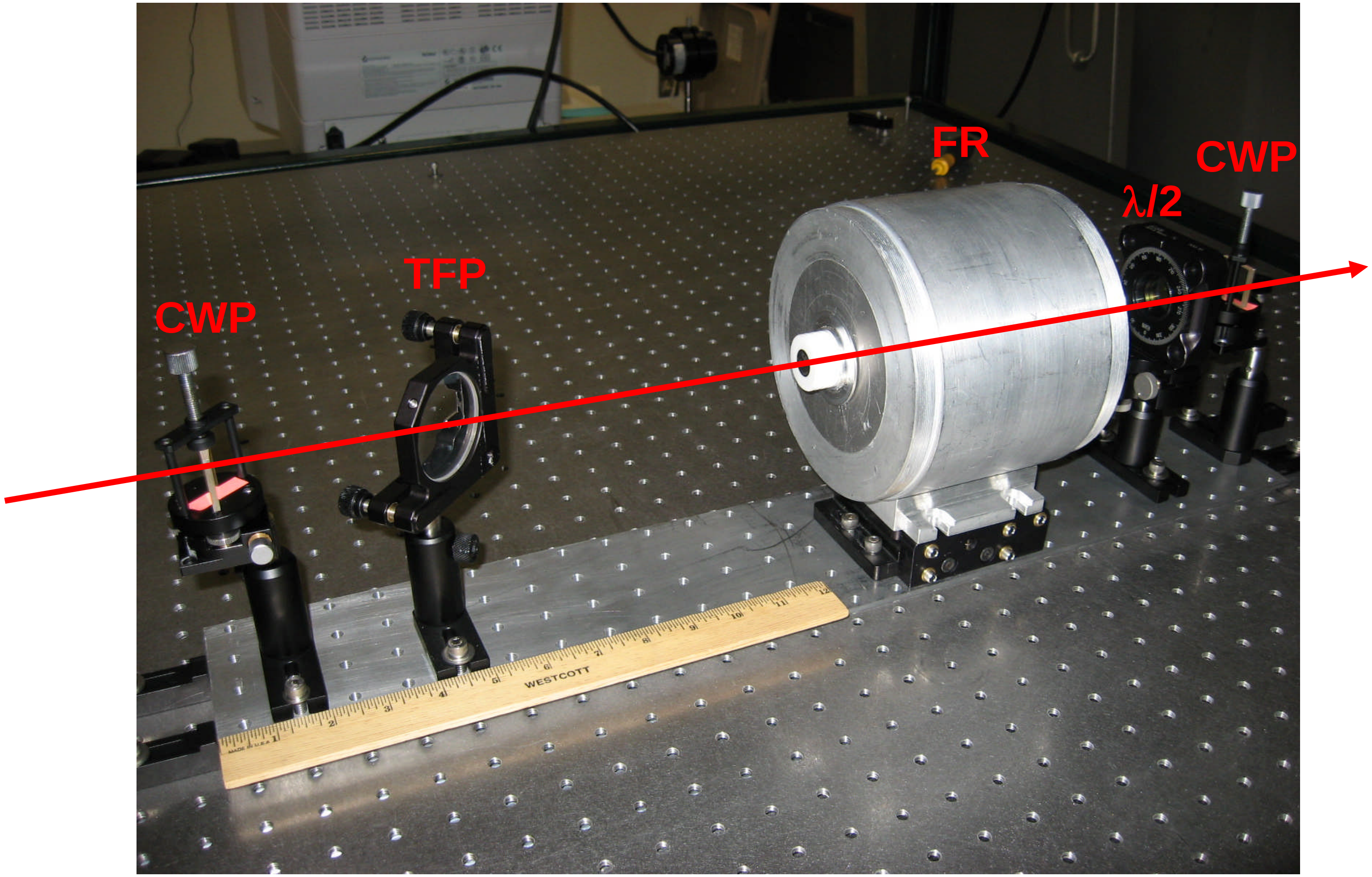


Mechanical design- TFP

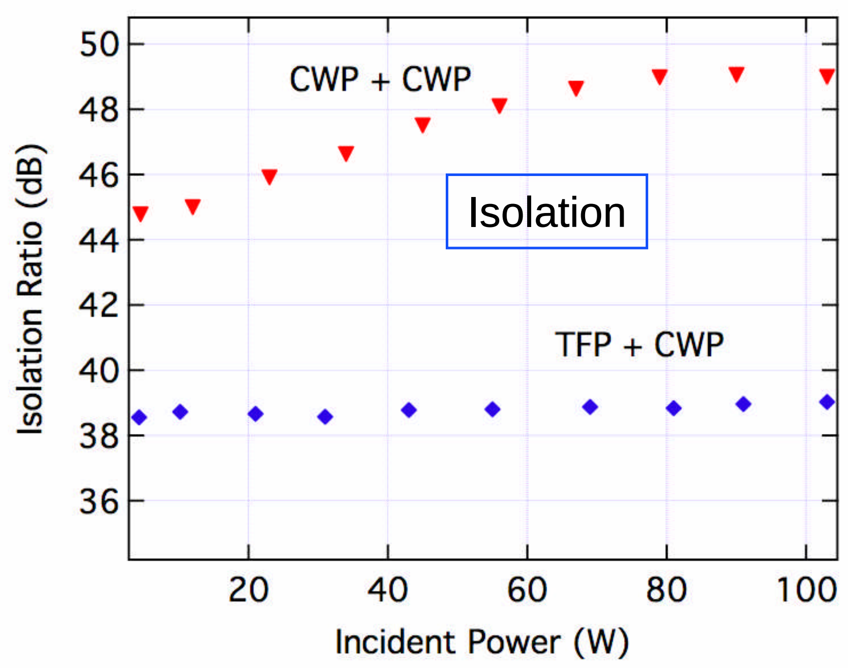
- TGG and quartz crystals all in large magnet housing
- TFP's on stands, orientation controlled by mechanical design
- DKDP compensator on fixed stand
- ½ wave plate on CVI vacuum-compatible rotator

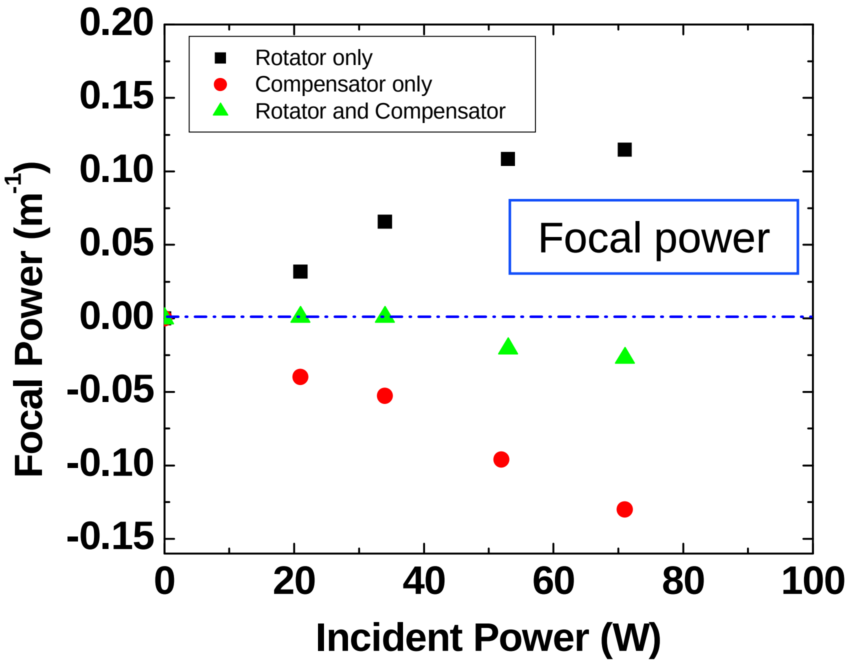


FI set up at LLO



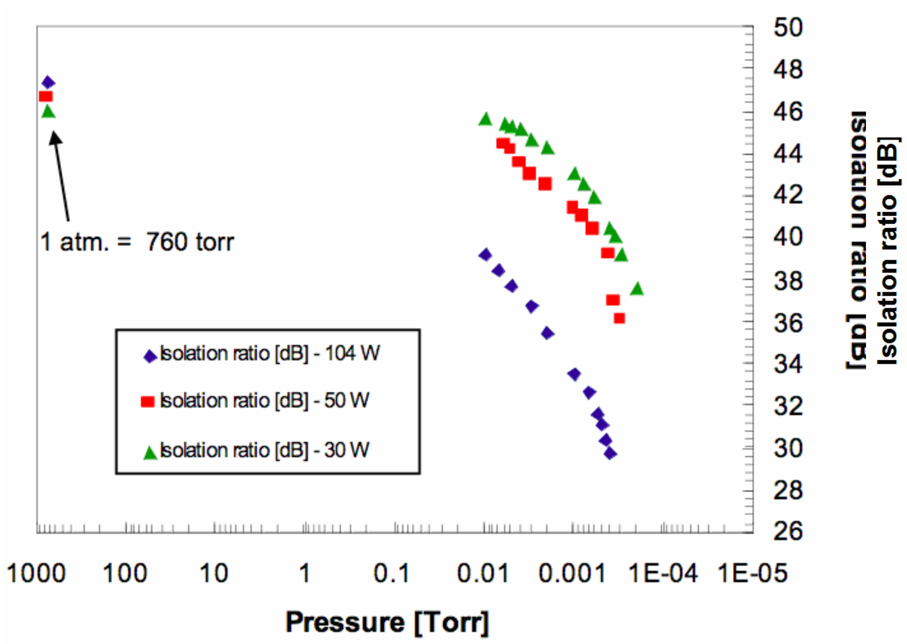
Faraday Isolator performance

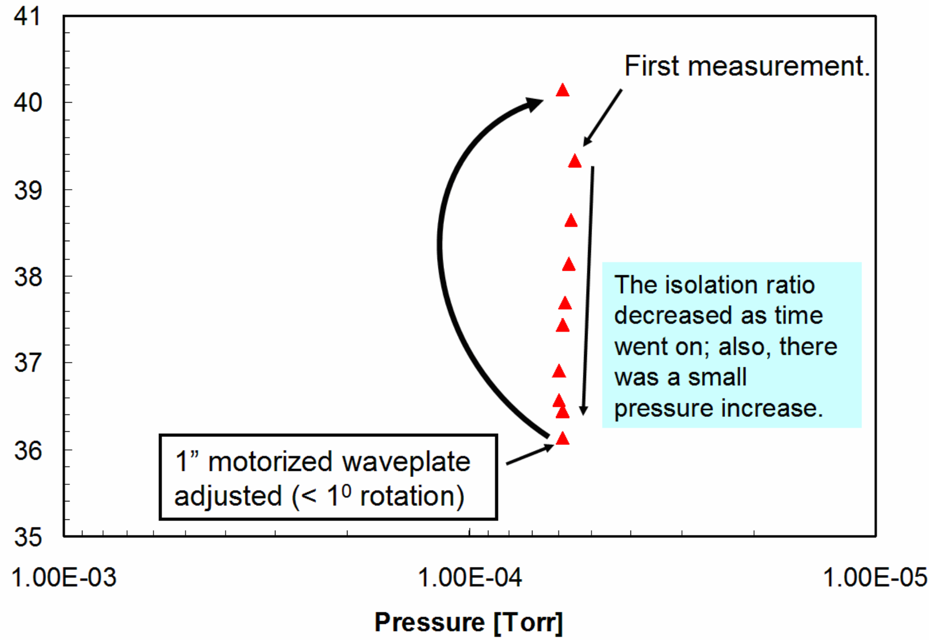




- Suppression is set by the polarizers.
- Calcite wedge polarizer superior to thin film Brewster's polarizer

Effect of vacuum





- Initial vacuum testing reveals drop in isolation ratio under vacuum
  - » from >47 dB to < 30 dB (@100 W)
- It’s all temperature
  - » Thermal contact of TGG and housing undergoing re-design
- Thermal time constant ~ 45 mins
- Isolation recovers with < 1^{o} rotation of waveplate

Thermal model

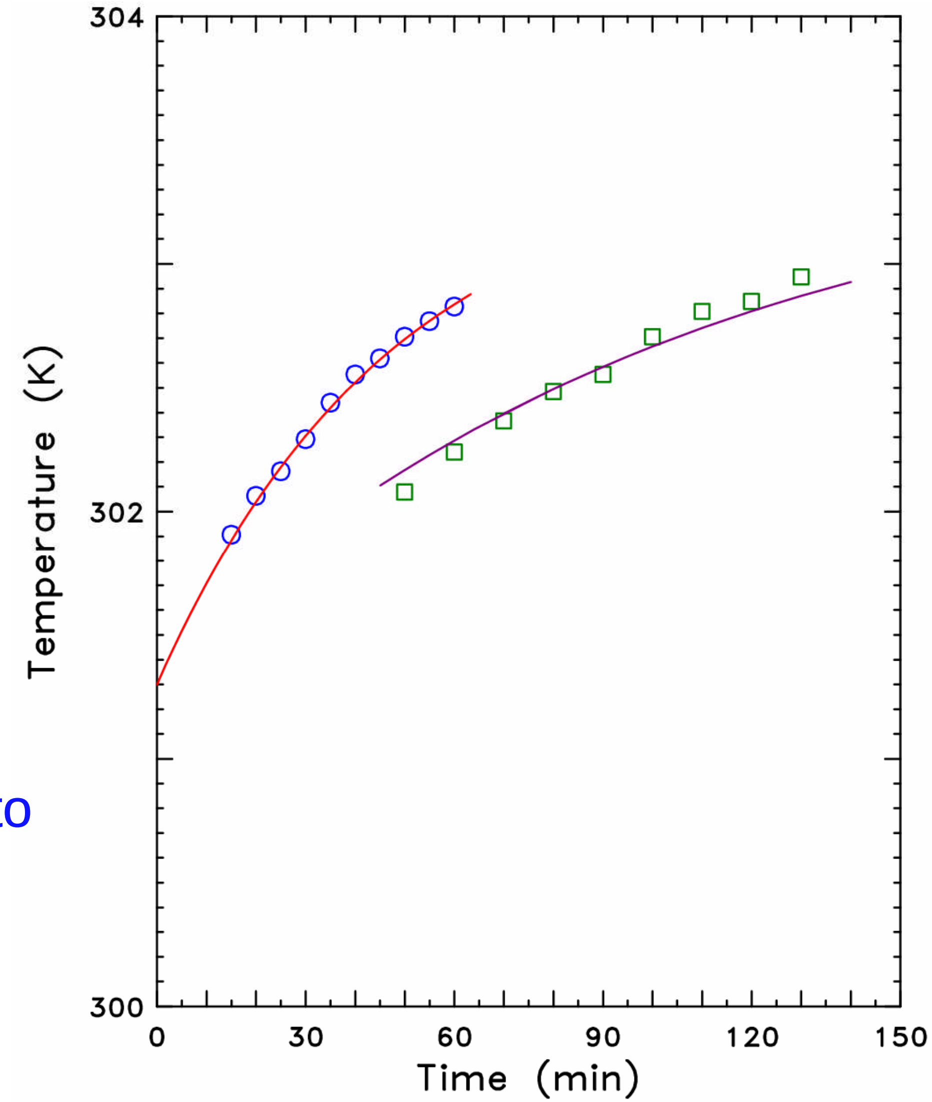
- Isolation ratio (dB)
- -> FI transmission $\mathscr{T}$
- -> Polarization angle, from

  $\mathscr{T} \sim \cos^2(\theta)$ around $\theta = 90^0$
- -> Verdet constant vs. time,

  from $V = \theta/(B*L)$
- -> Temperature from known

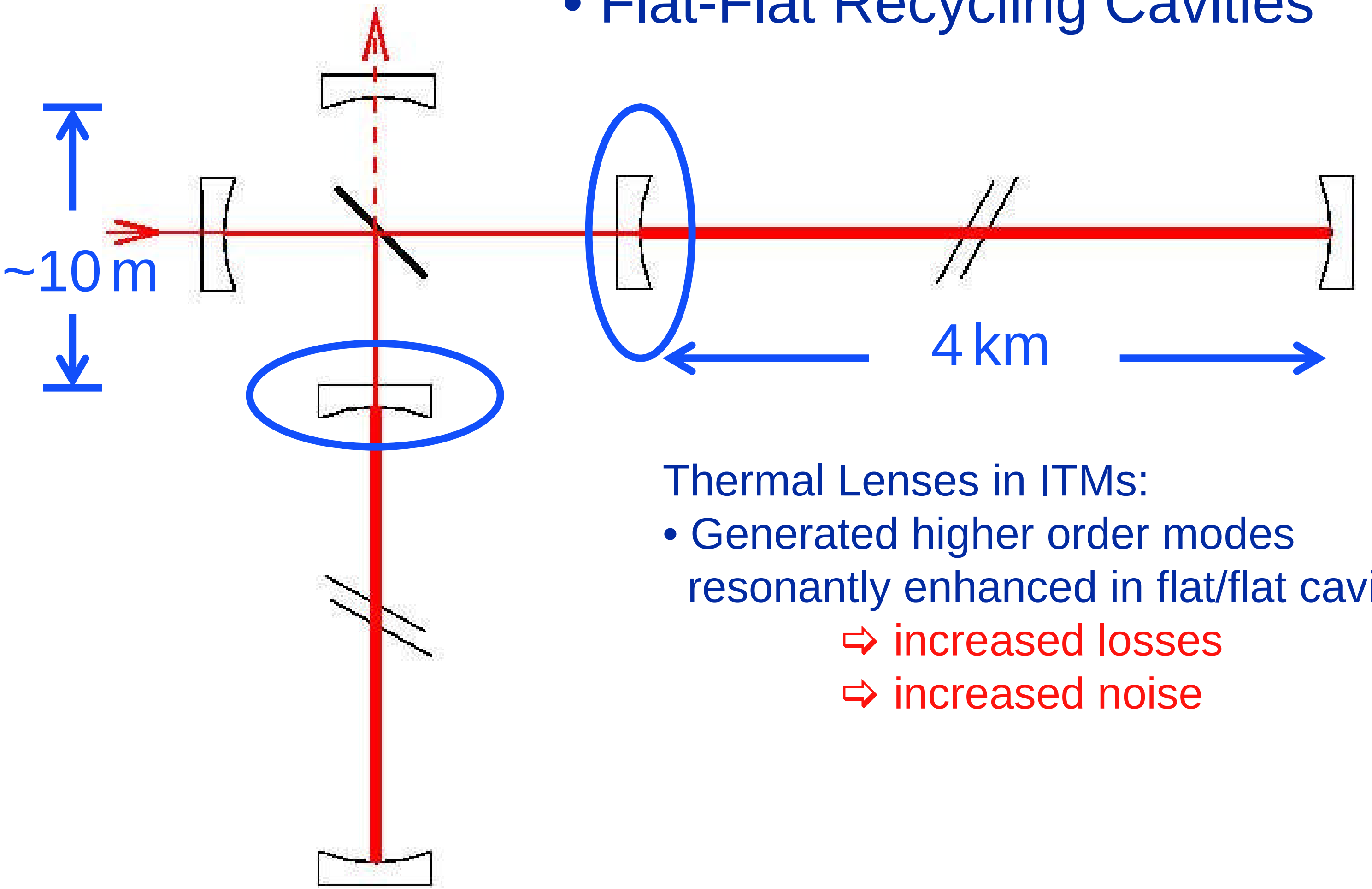
  dV/dT

- Then the time dependence fits to
  $T(t) = T_o + \Delta T * [1\text{-}\exp(-t/\tau)]$
- $\tau \sim$ 50-100 mins



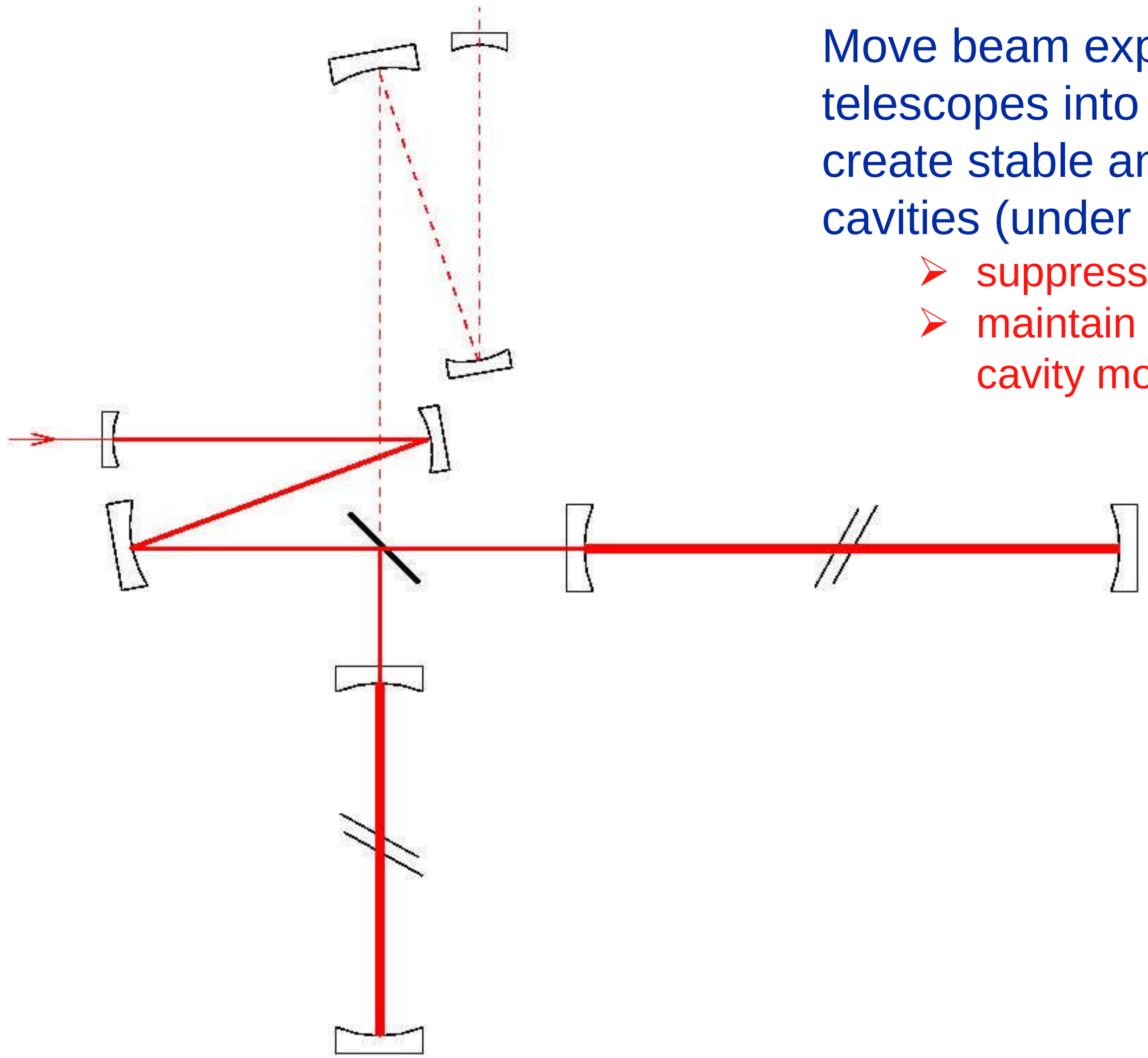
Marginal PRC

Baseline Design:
- Flat-Flat Recycling Cavities



Thermal Lenses in ITMs:
- Generated higher order modes resonantly enhanced in flat/flat cavity
  - ⇨ increased losses
  - ⇨ increased noise

Stable recycling cavities



Move beam expanding/reducing telescopes into recycling cavities to create stable and flexible recycling cavities (under LSC review)

- suppress higher order modes
- maintain mode matching between arm cavity mode and recycling cavities

Stable PRC layout

- Power recycling cavity:

  $f_{prc} = (k + 1/2)c/2L_{prc}$ (k = 0,1,2, ...)

- Factor of 1/2 occurs because the carrier is resonant in the arms; sidebands are not

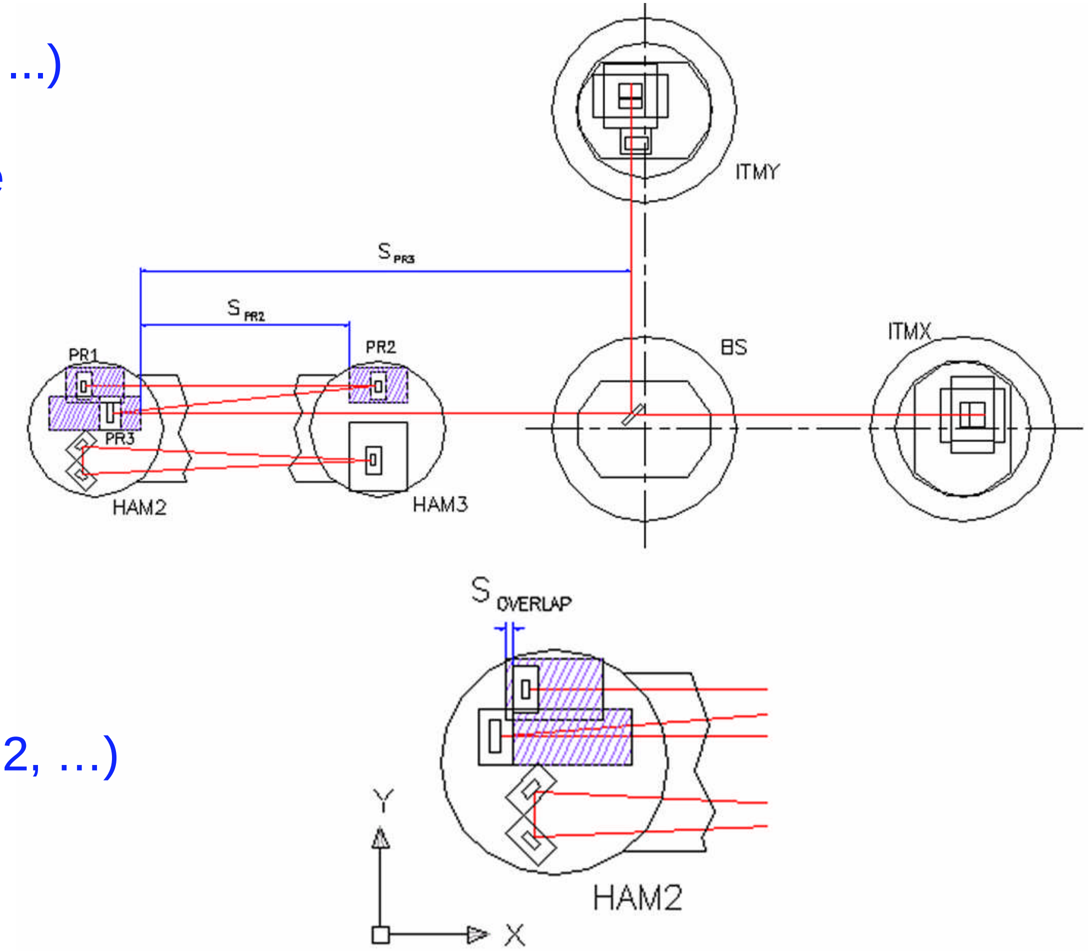
- Input mode cleaner

  $f_{imc} = nc\,/2L_{imc}$ (n = 1,2,3, …)

- Signal recyling cavity

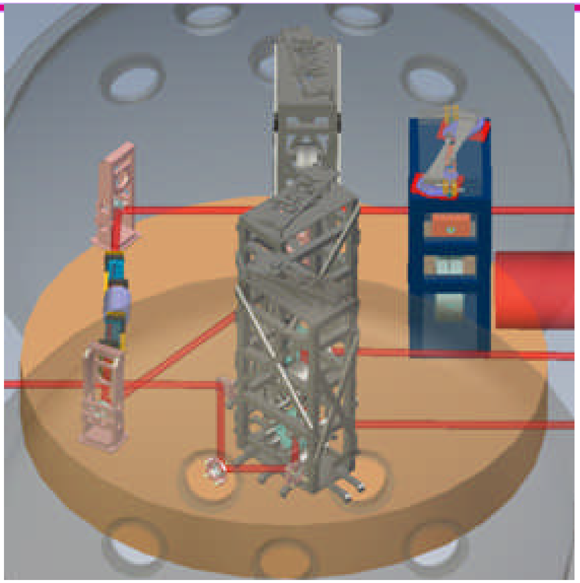
  $f_{src} = (p + d\phi/2\pi)c/2\,L_{src}$ (p = 1, 2, …)

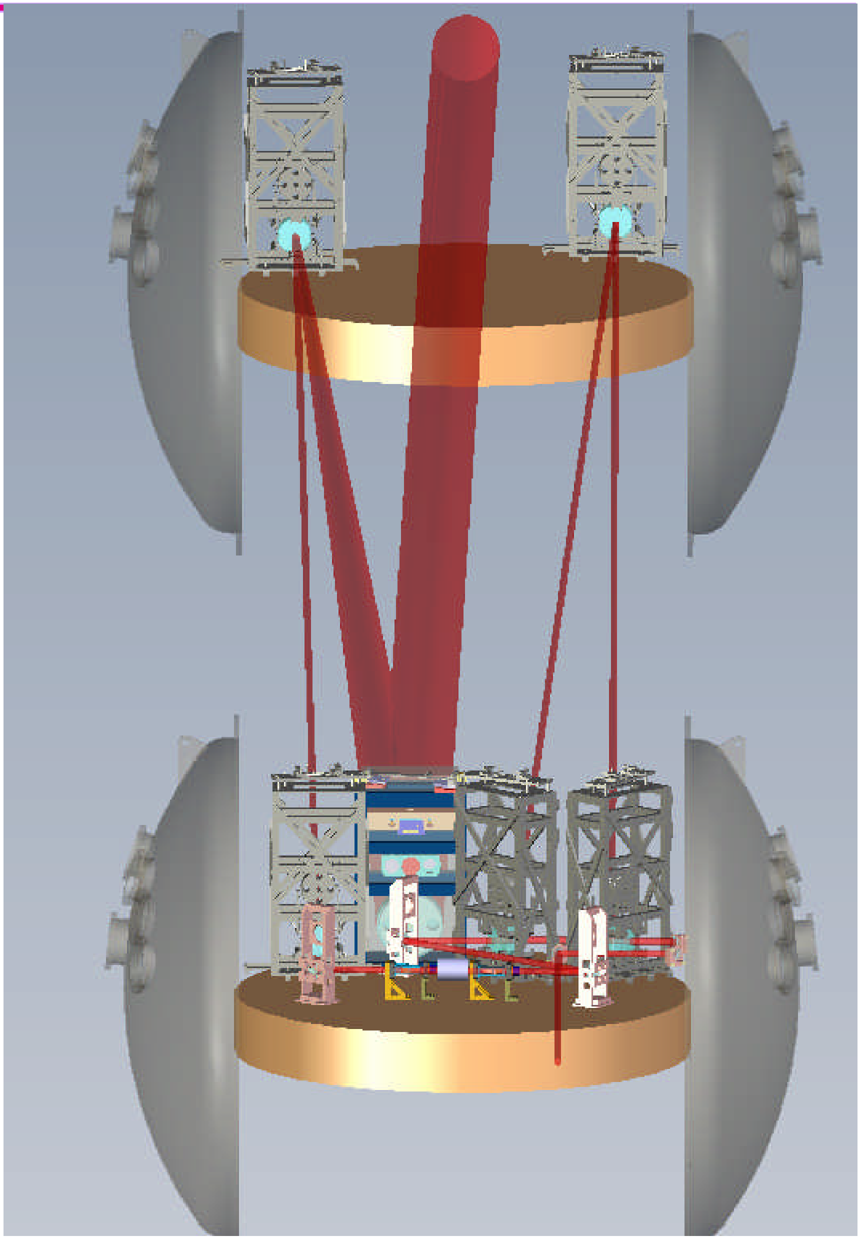
- Allows 9.3996 & 46.9979 MHz



See “Optical Layout for Advanced LIGO,” D. Coyne, LIGO-T010076-010D (7/1/2001)

HAMs 2 and 3, with SPRC





- It does all fit, though HAM 2 will be full
- Beam injection TBD

- IO for eLIGO:
  - » Under construction
- IO for adv LIGO:
  - » PDR underway