Recent LIGO I simulation results

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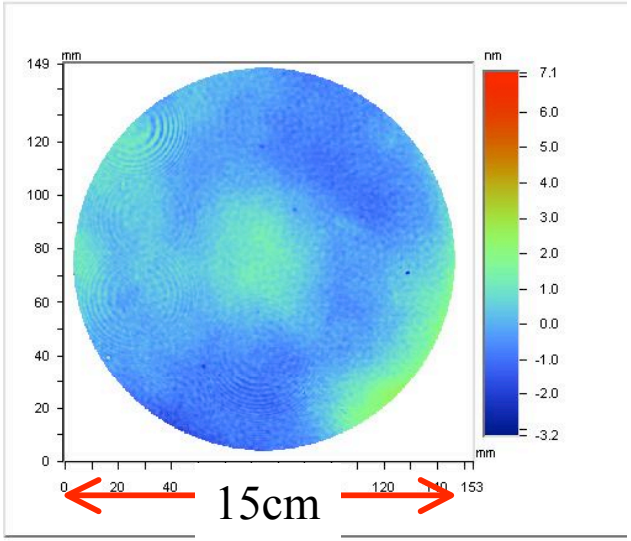
- As-built LIGO I performance and the path to it
- FFT run with as-built HR phase map
  - » Contrast defect
  - » Shot noise limited sensitivity
  - » R.Dodda(SLU), B.Bhawal, H.Yamamoto, B.Kells, E.D'Ambrosio
- SimLIGO
  - » Status
  - » Noise hunting
  - » M.Evans, H.Yamamoto, X.Xu (Caltech)
- Radiation pressure effects
  - » Simple FP stability
  - » Effects on LIGO I COC
  - » X.Xu, H.Yamamoto, J.Agresti (U.Pisa)

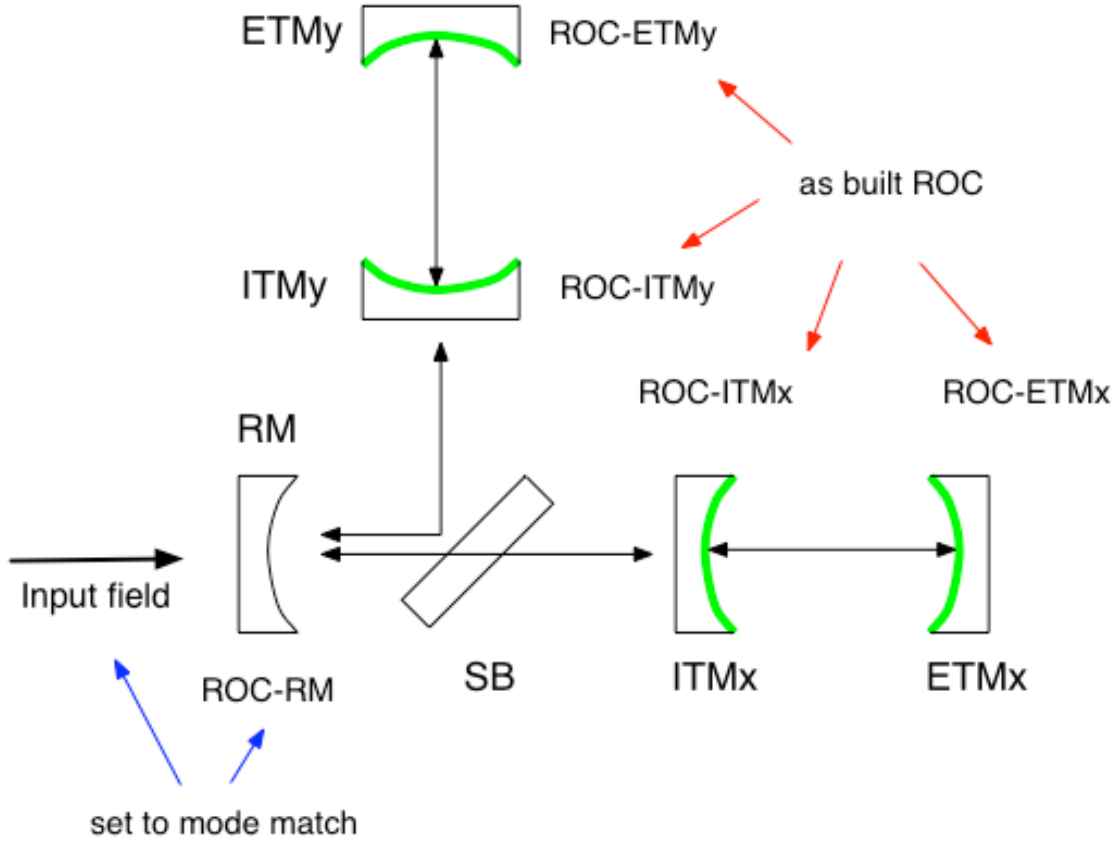
FFT run with as-built HR phase map

effect of the aberration of test mass surfaces

http://www.ligo.caltech.edu/~gari/COCAsBuilt.htm

WA4K-Y ITM





FFT analysis
technical details

- FFT program
  - » Developed by B.Bochner of MIT (1998 PhD)
  - » Static LIGO field simulation which can include details of optics, including the mirror phase map, reflection and transmission
- Measured data
  - » Central region (15cm diameter, 0.2668x0.3114mm)
  - » Extrapolate to full mirror (24cm diameter, 2.73x2.73mm)
    - – Systematic uncertainty of this extrapolation ~ 5%
- Tilt removal
  - » FFT has a simple length control, but no alignment control
  - » Phase map is modified to remove “tile” seen by a gaussian field.

FFT run result

recycling gain and contrast defect

	LHO4k	LHO2k	LLO4k
Symmetric (ROCx = ROCy)	47 5.5e-7	44 3.6e-7	46 1.3e-7
As-Built ROC	47 3.7e-5	44 8.5e-6	46 1.5e-7
As-Built ROC w/ phase map	43 1.6e-4	41 1.7e-4	42 1.2e-4 ?
Data	6e-4		3e-5

The HR loss (I.e. "base loss") values used for these simulations are not at all consistent with what we know about the fabricated mirror surface smoothness (micro-roughness). This is the main problem for prediction of advanced LIGO performance. (Bill Kells)

FFT result

shot noise limited sensitivity : Is this real ?

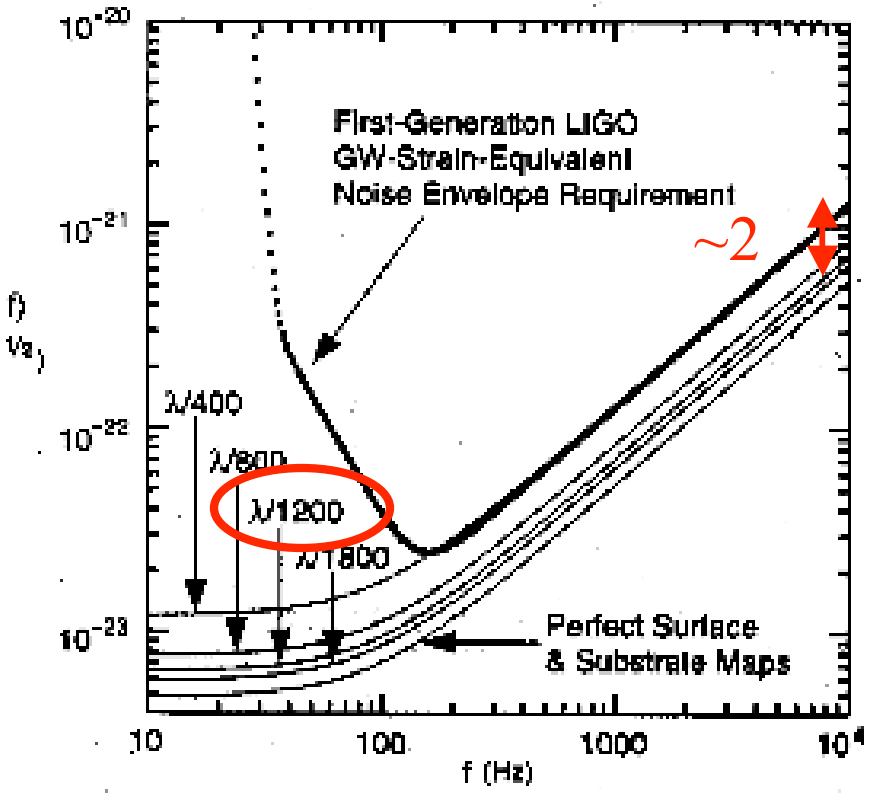
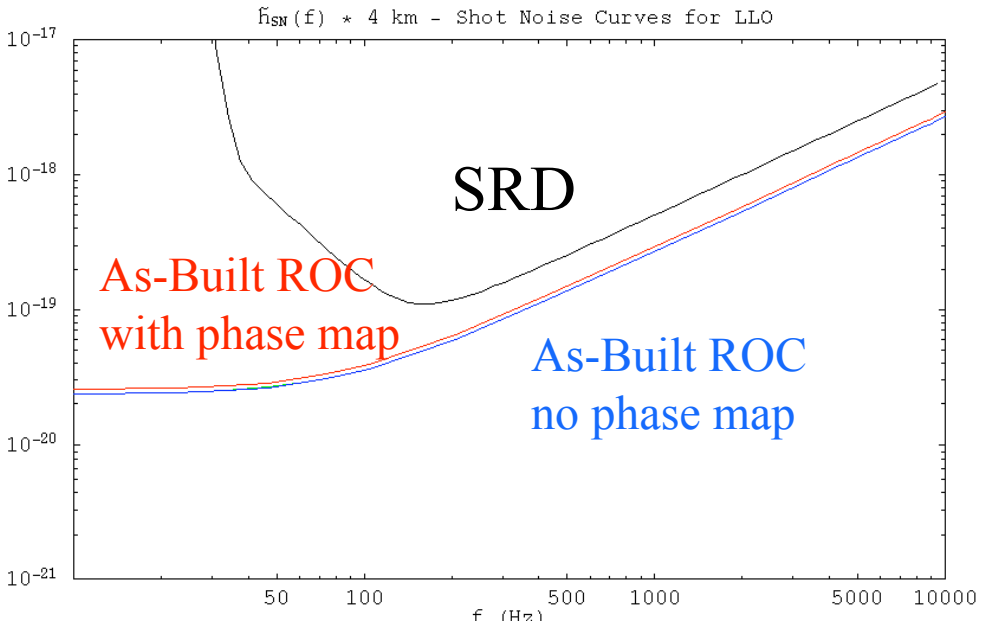


Fig.3.3 in B.Bachner's thesis



LLO : 2003 SURF calculation
LHO4k and LHO2k are same

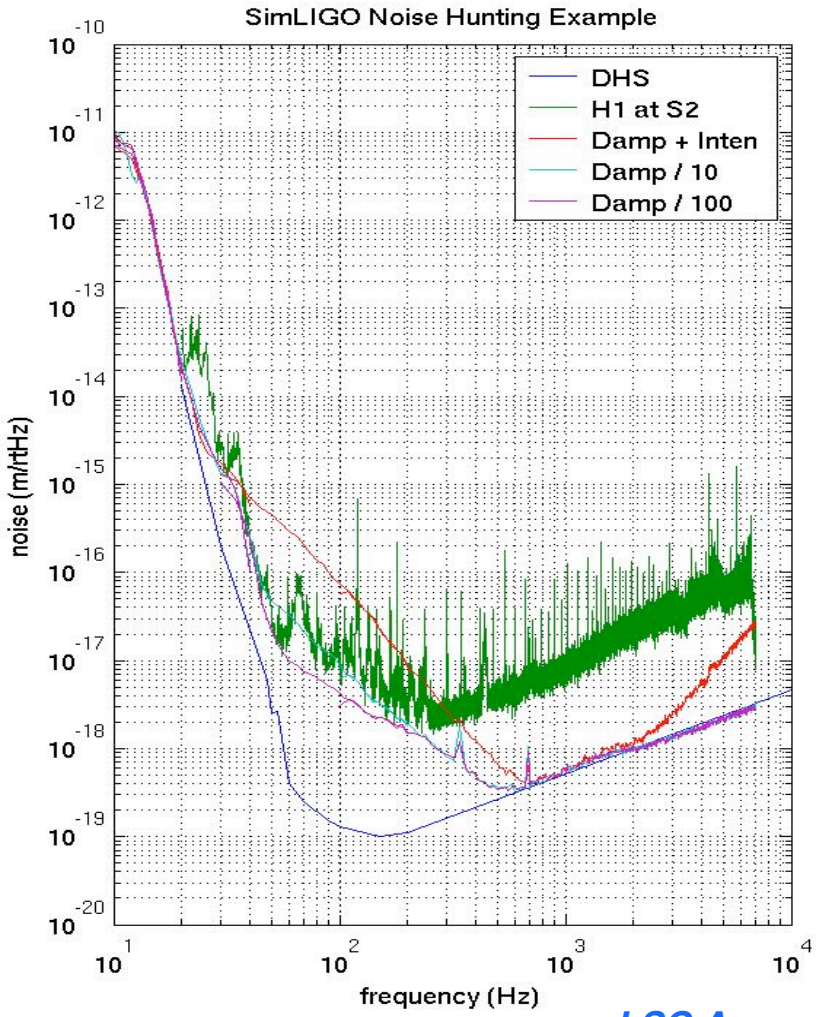
SimLIGO
status

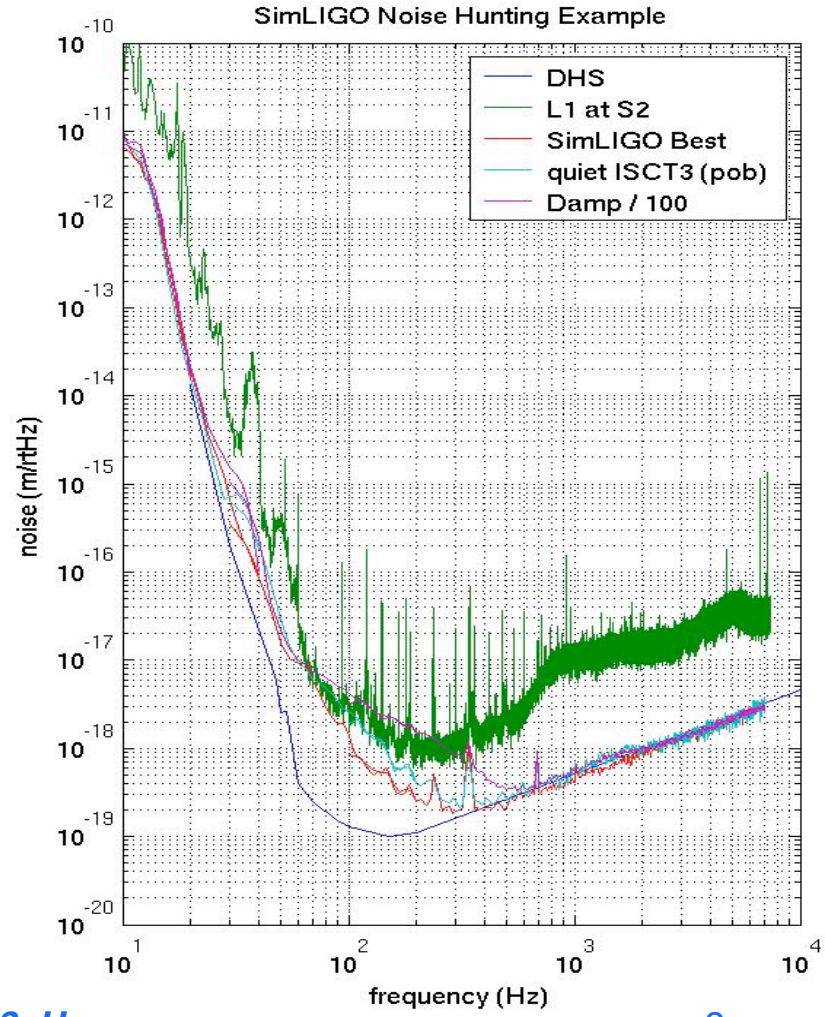
- SimLIGO
  - » Realistic LIGO I simulation
  - » LSC / ASC / DSC / major noise sources / Optical Lever included
  - » thermal lensing simulated - good near hot state
  - » radiation pressure included
- Stones in the Road : Matt Evans talk on June 16, G030419-00-E
  - » things to watch out for, and some potentially useful tools, as we work toward a better LIGO1 detector

SimLIGO
application

- Robust lock acquisition - from cold to hot
  - » beam profile (original one used scalar model)
  - » thermal lensing effect
  - » signal reliability - mode matching not necessarily good
  - » 4k Schupp asymmetry problem detected
- Robust alignment control - in a realistic condition
  - » ASC is a problem of linear system, but
    - – noisy and gain varying system
  - » SimLIGO can provide qualitatively similar nice play ground
  - » Robust algorithm with reliable signal

SimLIGO
Noise Hunting





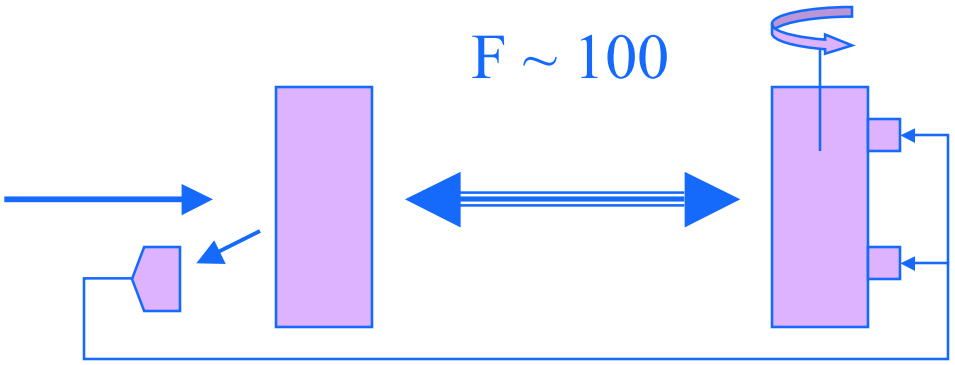
Radiation pressure

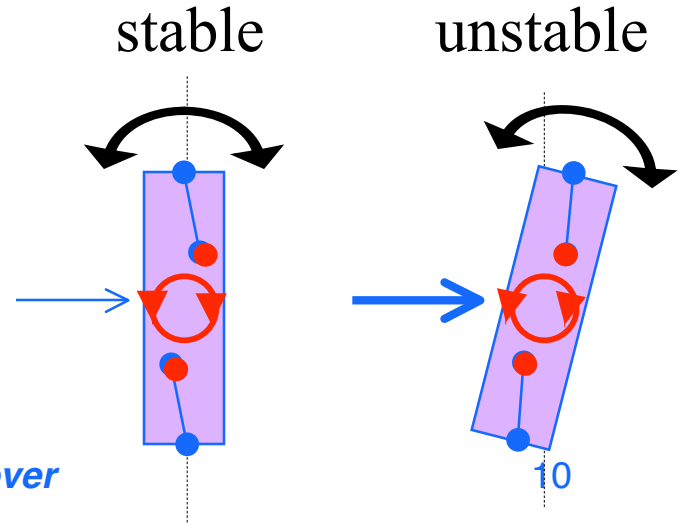
- Notes by D.Sigg and B.Kells about radiation pressure
- End to End model with radiation pressure
  - no mathematics or no approximation
  - yaw - pitch - length dof
  - field dynamics included
  - implication of stability - instability
  - role of control systems
- Alignment control makes system more stable
- Even for LIGO I COC, the radiation pressure will affect the control design.

Radiation pressure
(not so) simple FP YAW motion

$$\ddot{\phi} = -\omega_0^2 \cdot (\phi - \phi_{sus}) + B \cdot \phi \cdot F_{RP} + C \cdot \dot{\phi}$$

- LIGO I 4k arm FP cavity
- Only yaw dof is active (torsion pendulum, a.la.Danniel)
- Local dumping by small Q
- Only ETM moves by radiation pressure and ASC
- Reflected signal is used to control yaw
- ETM suspension point moves as 1e-7 rad / (s+2 π)^2

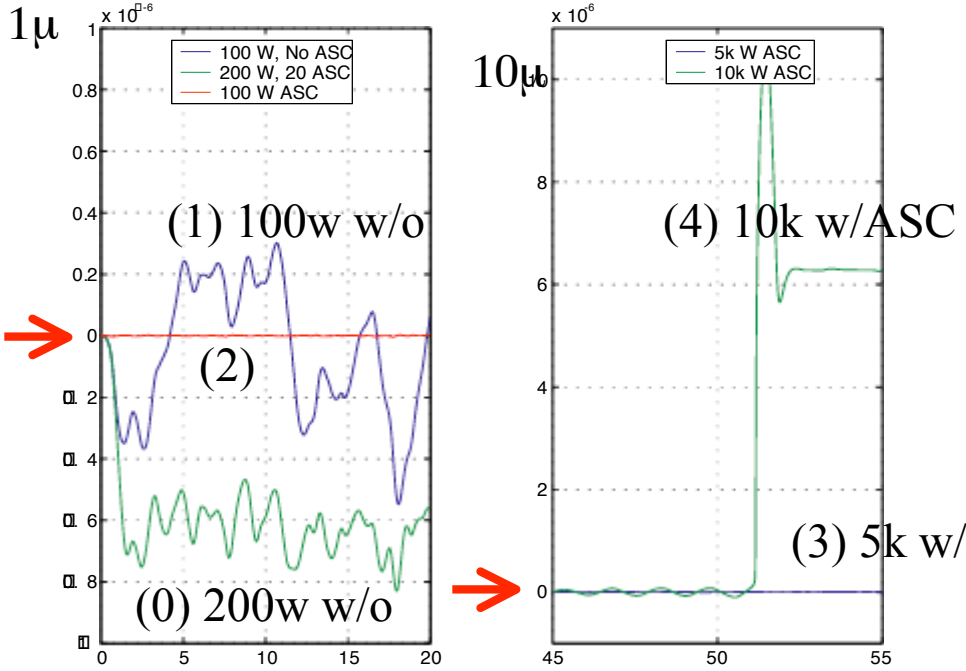


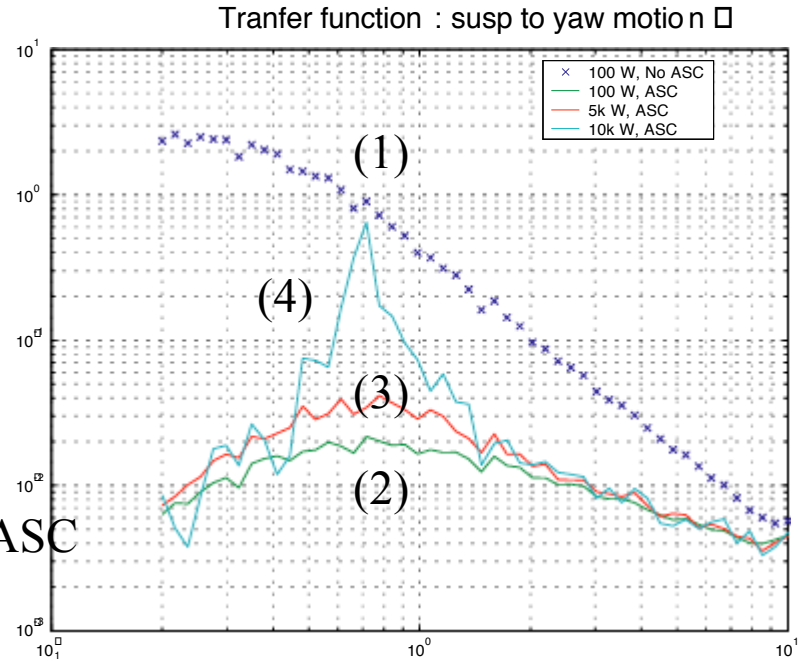


FP with radiation pressure

Stable and unstable examples

YAW motion : torsion pendulum + optical spring, no ISC





Radiation Pressure in LIGO I

analysis using SimLIGO with full ASC/LSC

	Radiation pressure effect included	No radiation pressure effect
Full Alignment control	lock stable	lock stable
Partial alignment control	unstable	lock stable

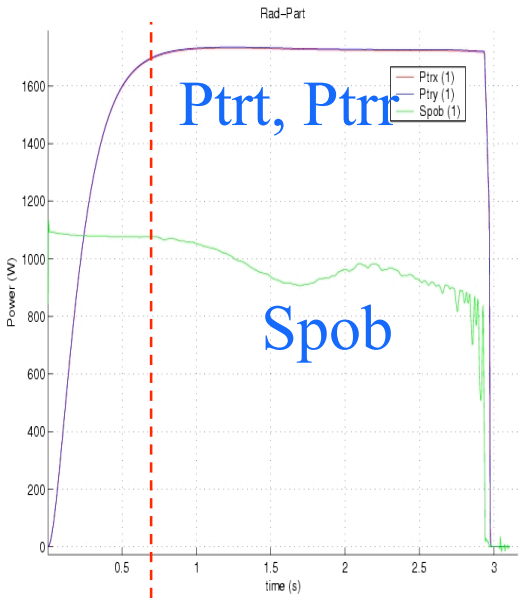
* The difference between Full Alignment Control and Partial is that in Full, the beam axis is fixed at the mechanical center of the ETMs. In other words,
Full: QPDx – QPDy = 0 and QPDx + QPDy = 0
Partial: QPDx – QPDy = 0 but QPDx + QPDy is not constrained to be 0.

Radiation Pressure on the Pitch dof

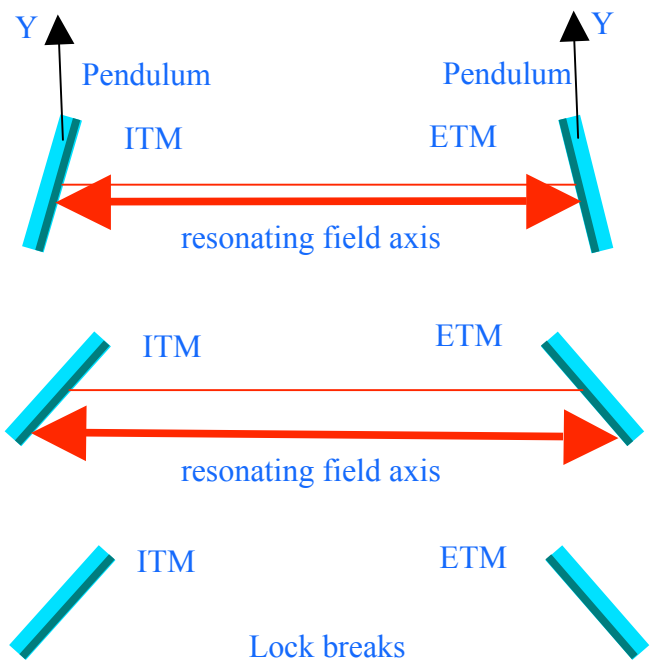
ASC design is sensitive to rad.press.

Current SimLIGO ASC design does not take rad.press. into account

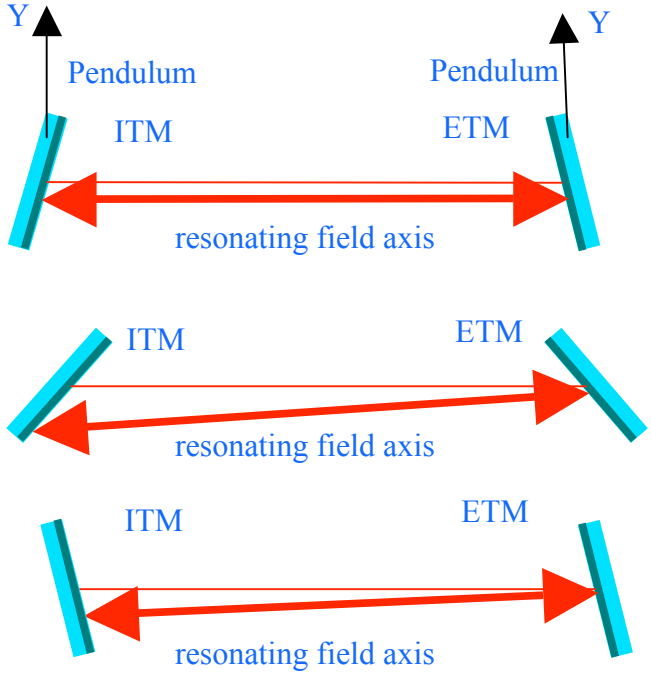
CR and SB power evolution toward the lock loss



Partial ASC



Full ASC (QPDx+QPDy=0)



How to address radiation pressure issue

- Danniel
  - » Some of the results observed are not the same as actual LIGO
  - » Needs to make it more realistic and it could provide useful input for the ASC design
- Missing piece - simulation and real LIGO ASC
  - » Transfer function of pendulum response with optical spring
  - » Run simulation of 6 suspended optics mutually connected by optical springs with length control on
- Radiation pressure in SimLIGO
  - » ASC design with radiation pressure activated
- Full LIGO simulation with realistic ASC/LSC and radiation pressure