Recent LIGO I simulation results

Hiro Yamamoto / Caltech - LIGO Lab

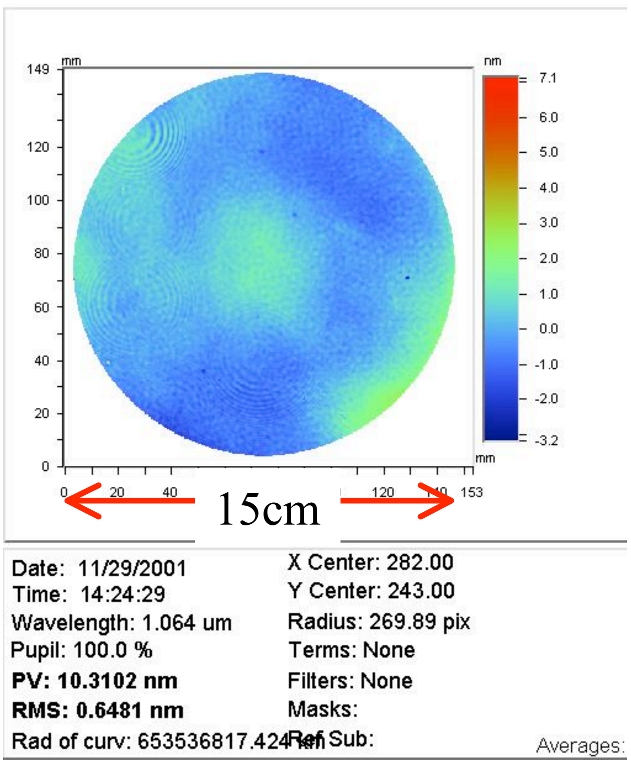
- FFT run with as-built HR phase map
  - Contrast defect
  - Shot noise limited sensitivity
  - R.Dodda(SLU), B.Bhawal, H.Yamamoto, B.Kells, E.D'Ambrosio
- SimLIGO
  - Status
  - Noise hunting
  - M.Evans, H.Yamamoto, X.Xu (Caltech)
- Radiation pressure effects
  - Simple FP stability
  - Effects on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

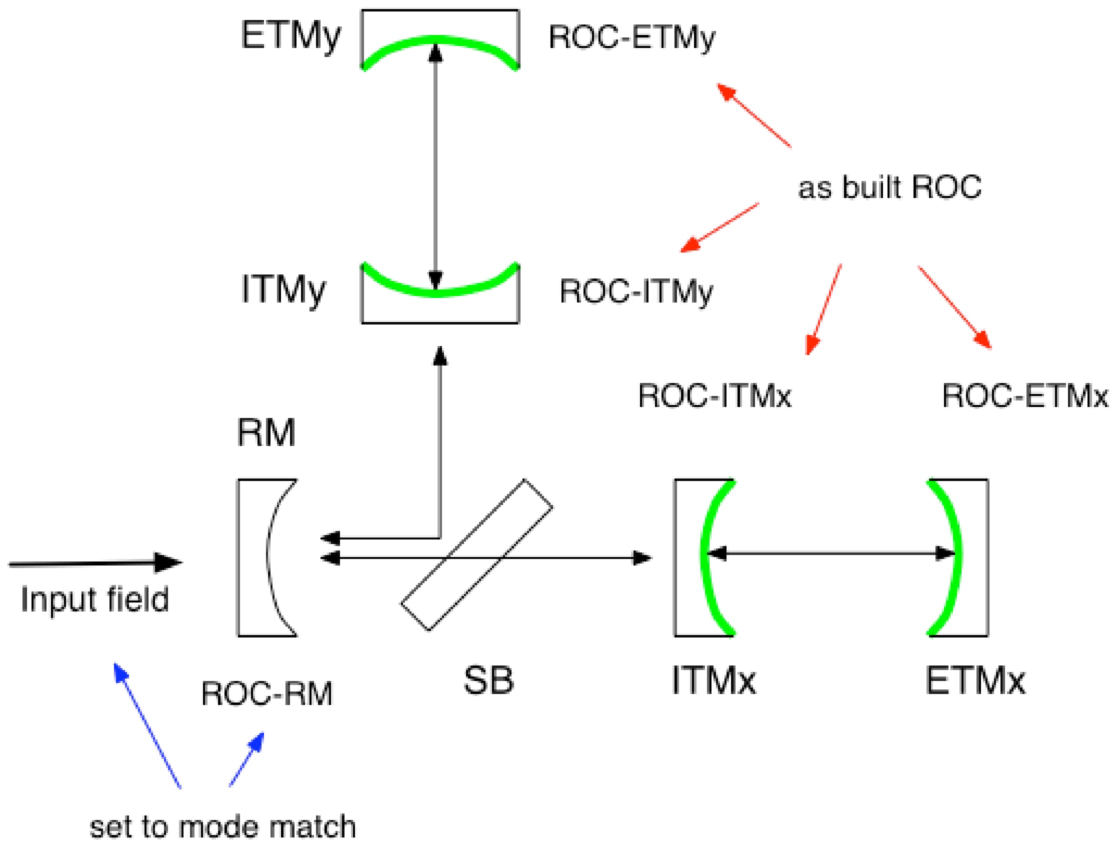
FFT run with as-built HR phase map

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 ?

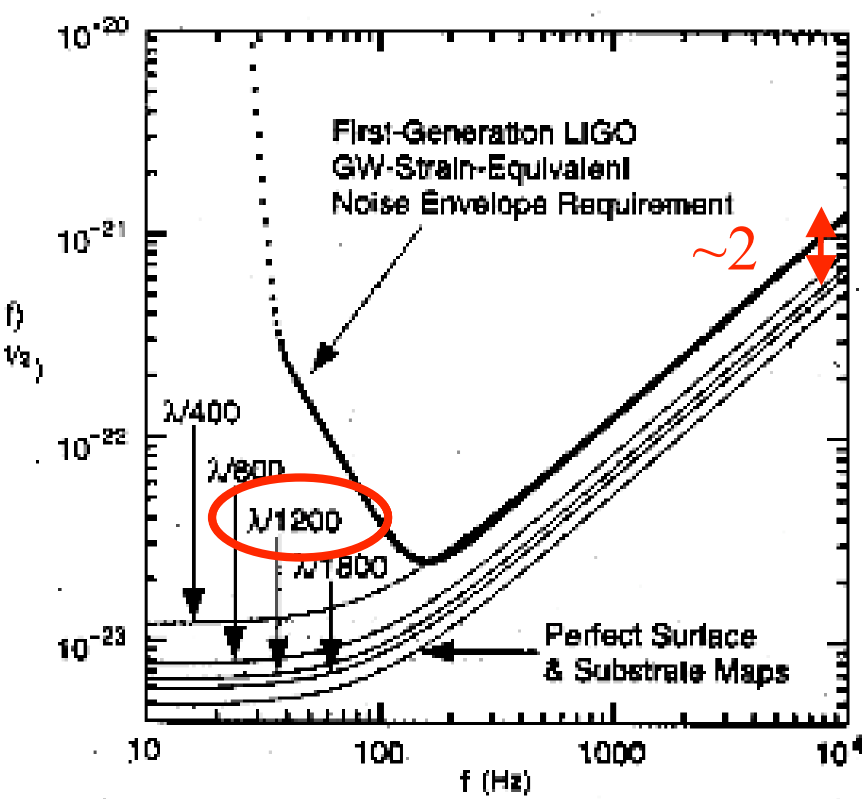
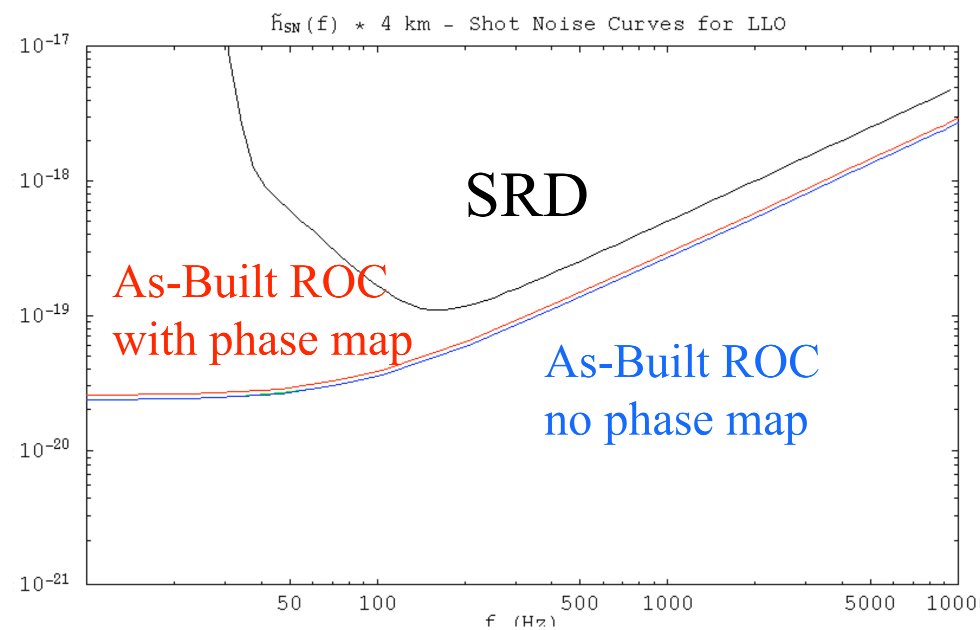


Fig.3.3 in B.Bachner's thesis



LLO : 2003 SURF calculation
LHO4k and LHO2k are same

SimLIGO
status

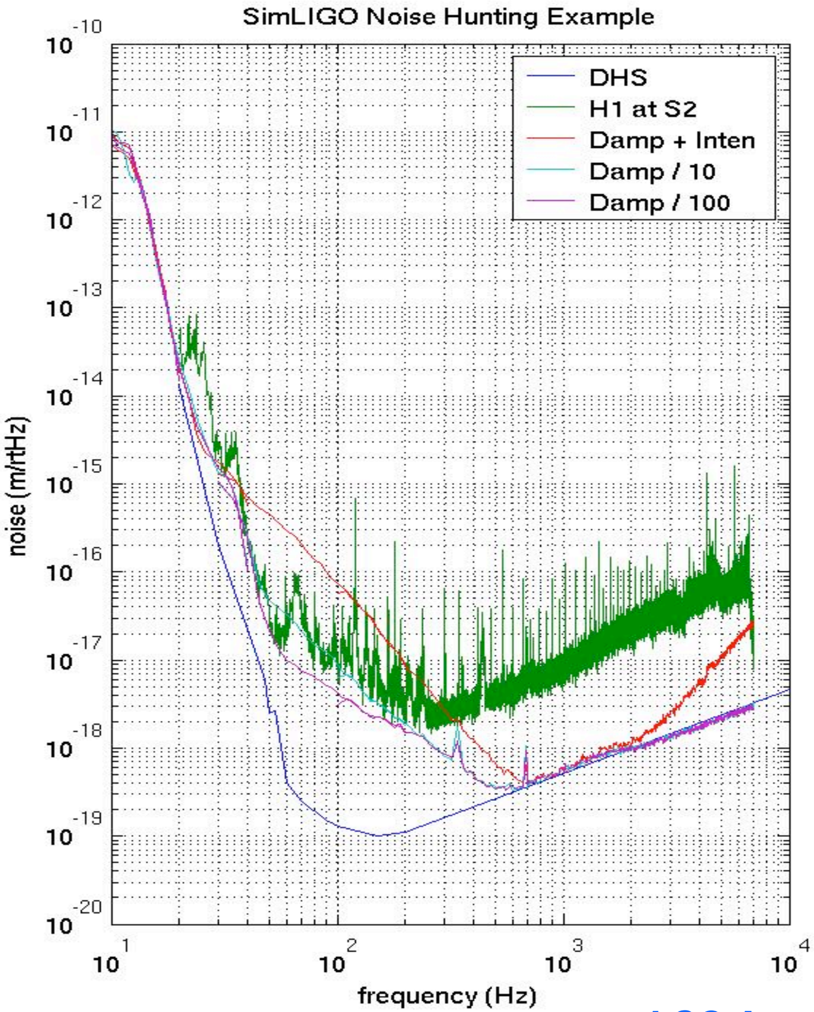
- SimLIGO
  - Realistic LIGO I simulation
  - LSC / ASC / DSC / major noise sources / Optical Lever included
  - thermal lensing simulated - good near hot state
  - radiation pressure included
- Stones in the Road : Matt Evans talk on June 16, G030419-00-E
  - things to watch out for, and some potentially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

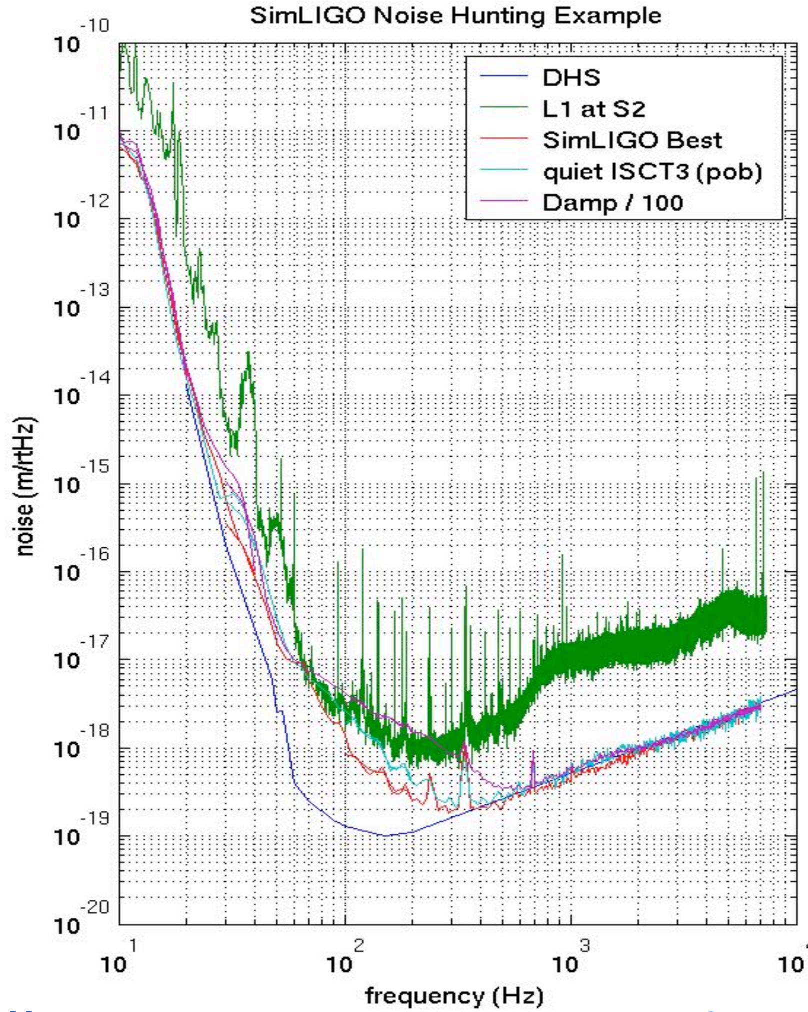
SimLIGO
application

- 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

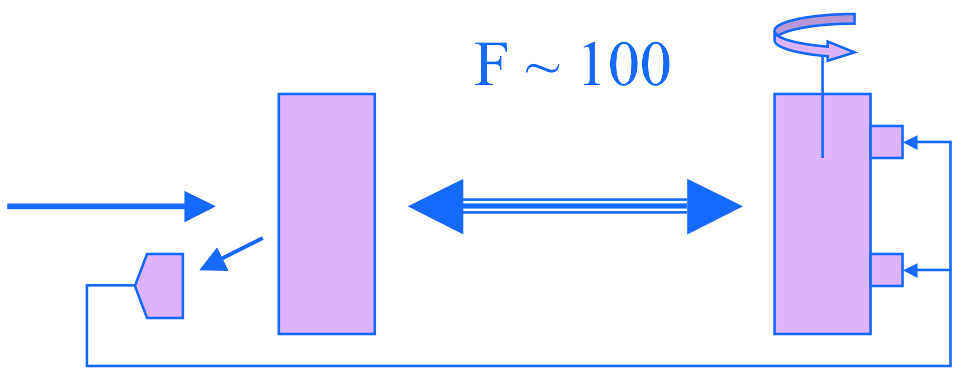
- Notes by D.Sigg and B.Kells about radiation pressure
- End to End model with radiation pressure
  - » no mathematics or no approximation
  - » yaw - pitch - length dof
  - » field dynamics included
  - » implication of stability - instability
  - » role of control systems
- Alignment control makes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

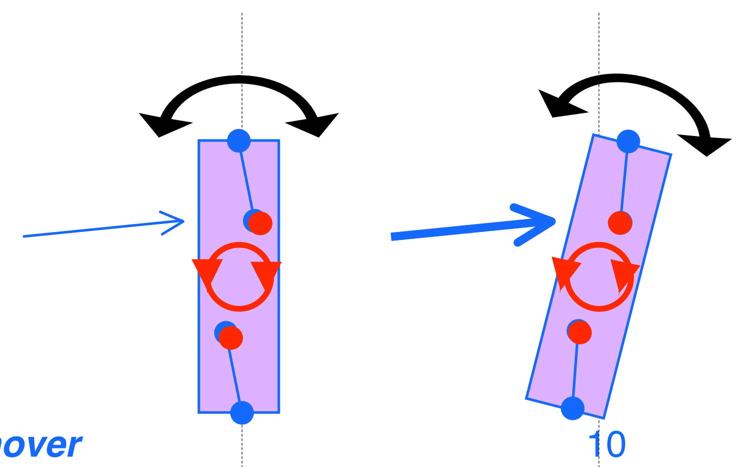
Radiation pressure

(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

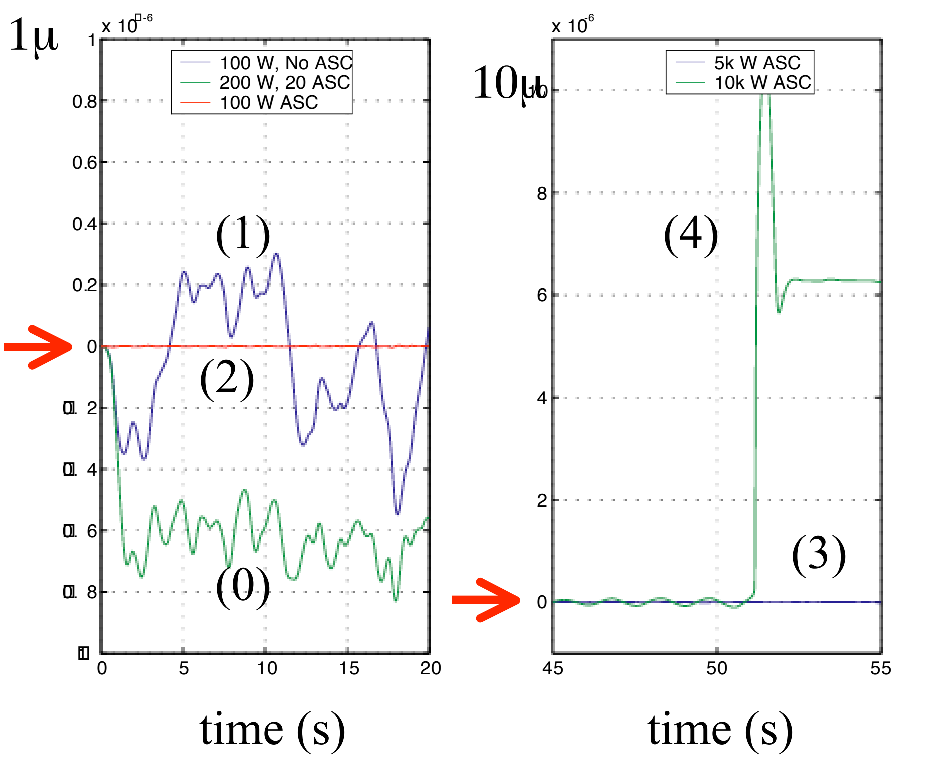


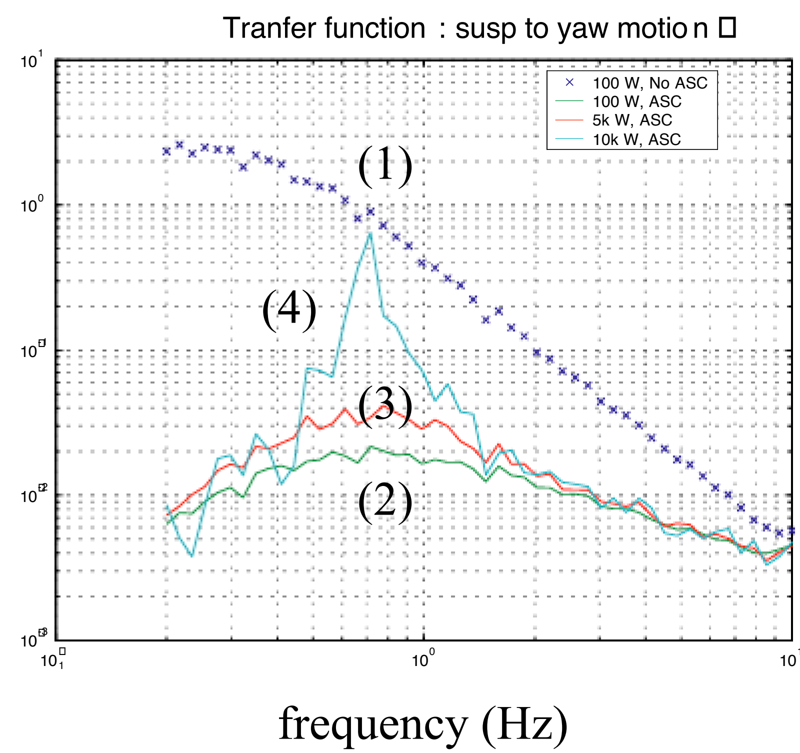


FP with radiation pressure

Stable and unstable examples

yaw motion





low power w/o ASC
100-200 W input

high power w/ ASC
5k-10k w input

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

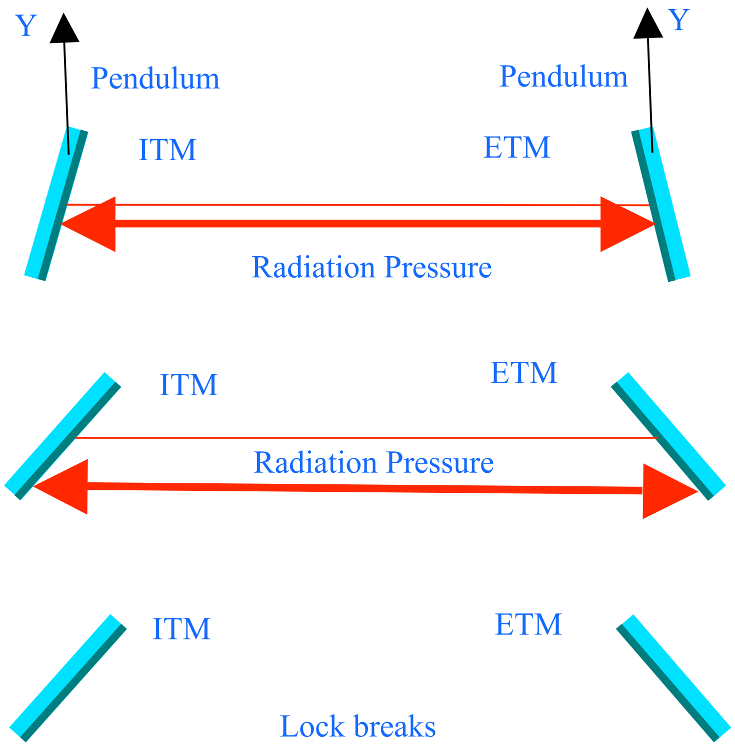
* The difference between Full Alignment Control and Partial is that in Full, the beam axis is fixed at the mechanical center of the ETMs. In other words,

Full: QPDx – QPDy = 0 and QPDx + QPDy = 0

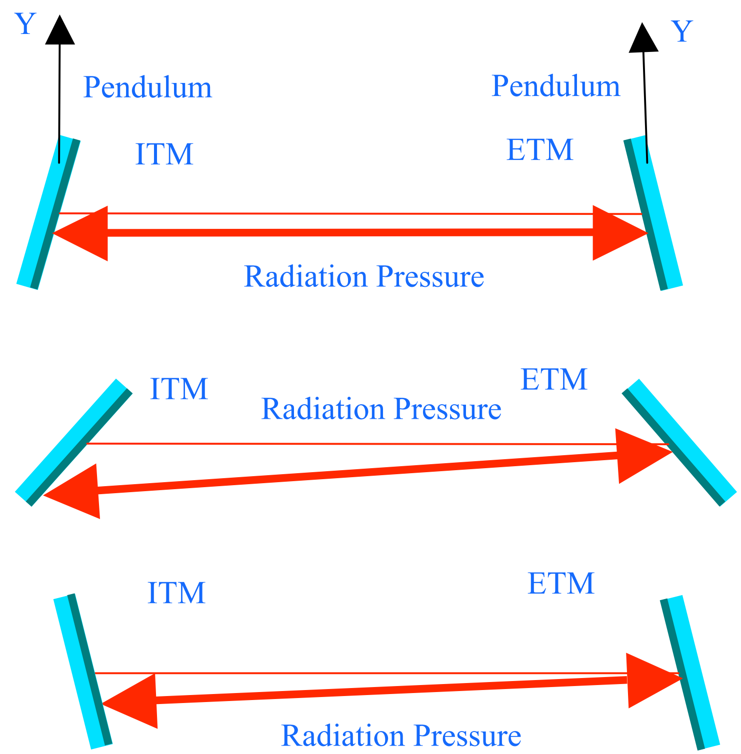
Partial: QPDx – QPDy = 0 but QPDx + QPDy is not constrained to be 0.

Radiation Pressure on the Pitch Angle

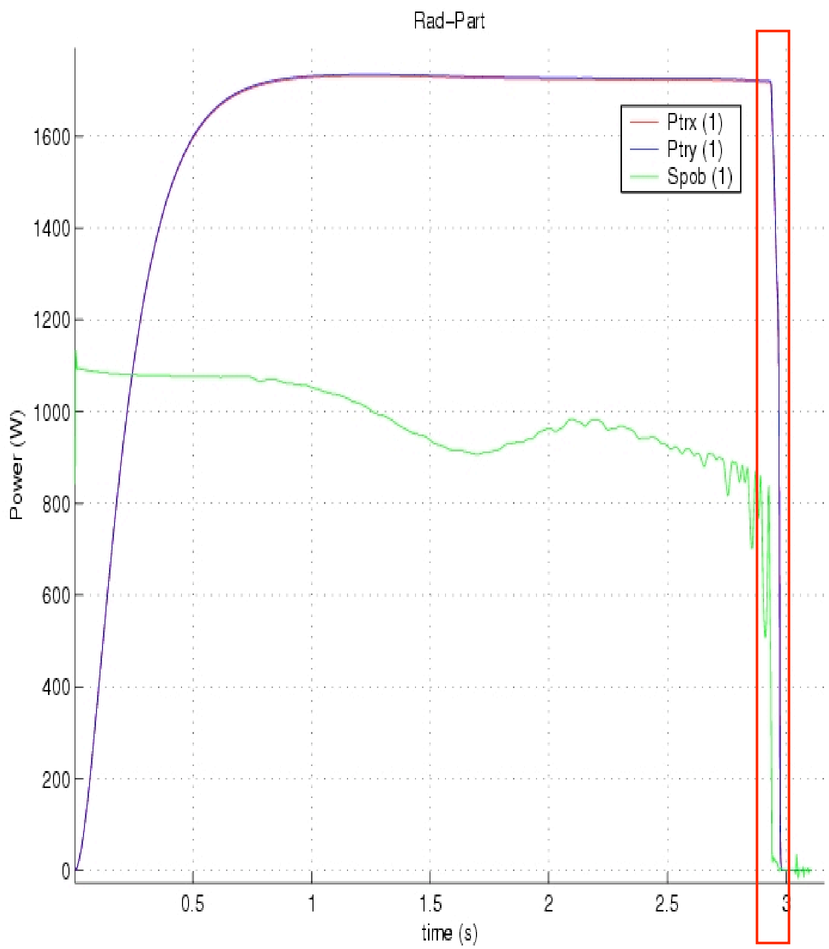
Partial ASC



Full ASC



Instability scenario



How to address radiation pressure issue

- Danniel
  - » Some of the results observed are not the same as real
- Missing piece
  - » Transfer function of pendulum response with optical spring
  - » Run simulation with length control on
- Radiation pressure in SimLIGO
  - » ASC design with radiation pressure activated
- Full LIGO simulation with realistic ASC/LSC and radiation pressure