H1 Squeezer Experiment

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ANU, AEI, MIT, CIT and LHO
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G080436-00-D

Motivation

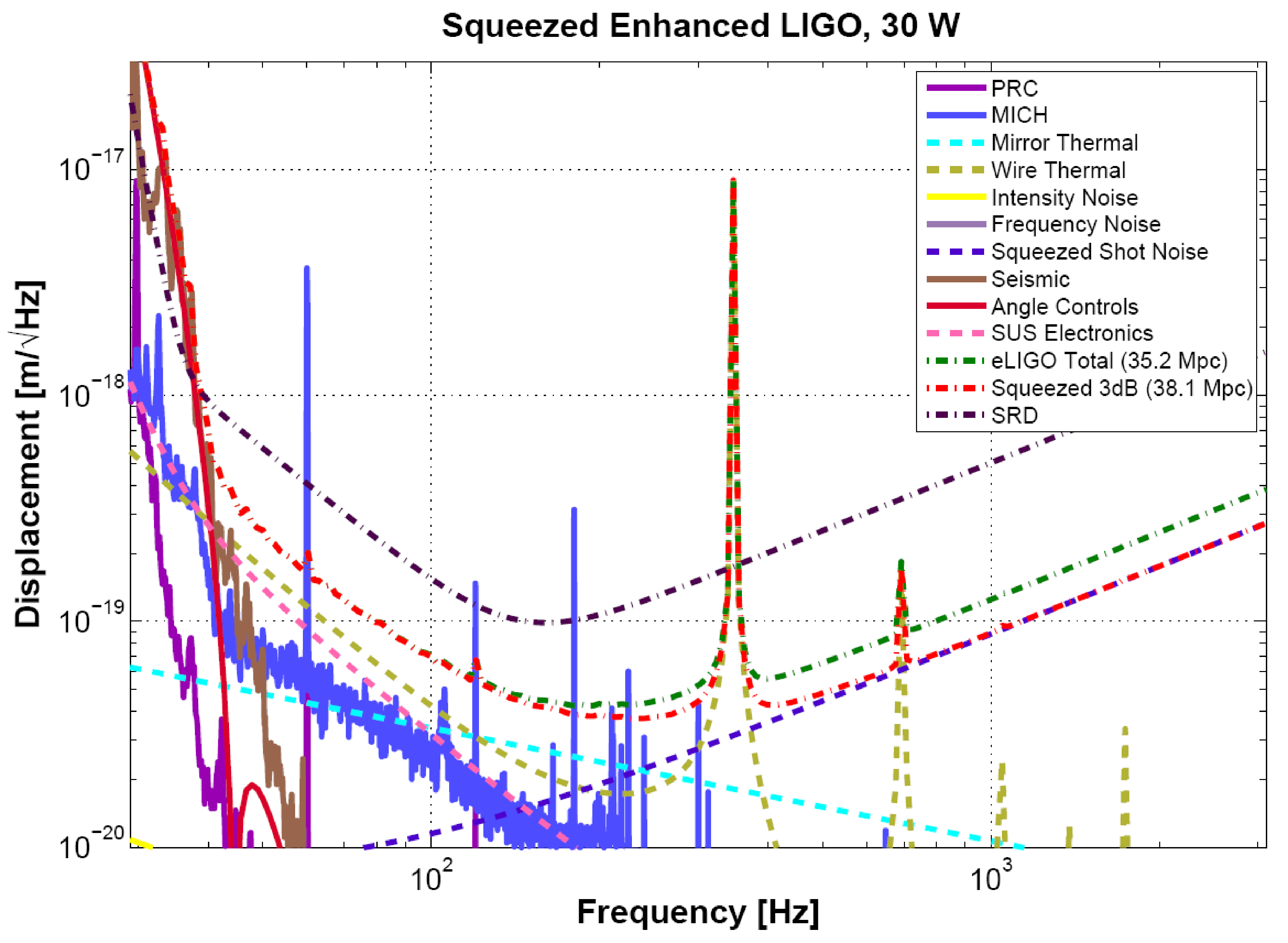
- High power operation in future detectors
  - Biggest remaining technical risk (after DC readout)
  - Squeezing allows for lower laser power
- Squeezer technology now ready
  - 7 dB of squeezing down to 10 Hz
  - Has been demonstrated on a bench and on interferometers (40M)

Missing: Low frequency noise demonstration

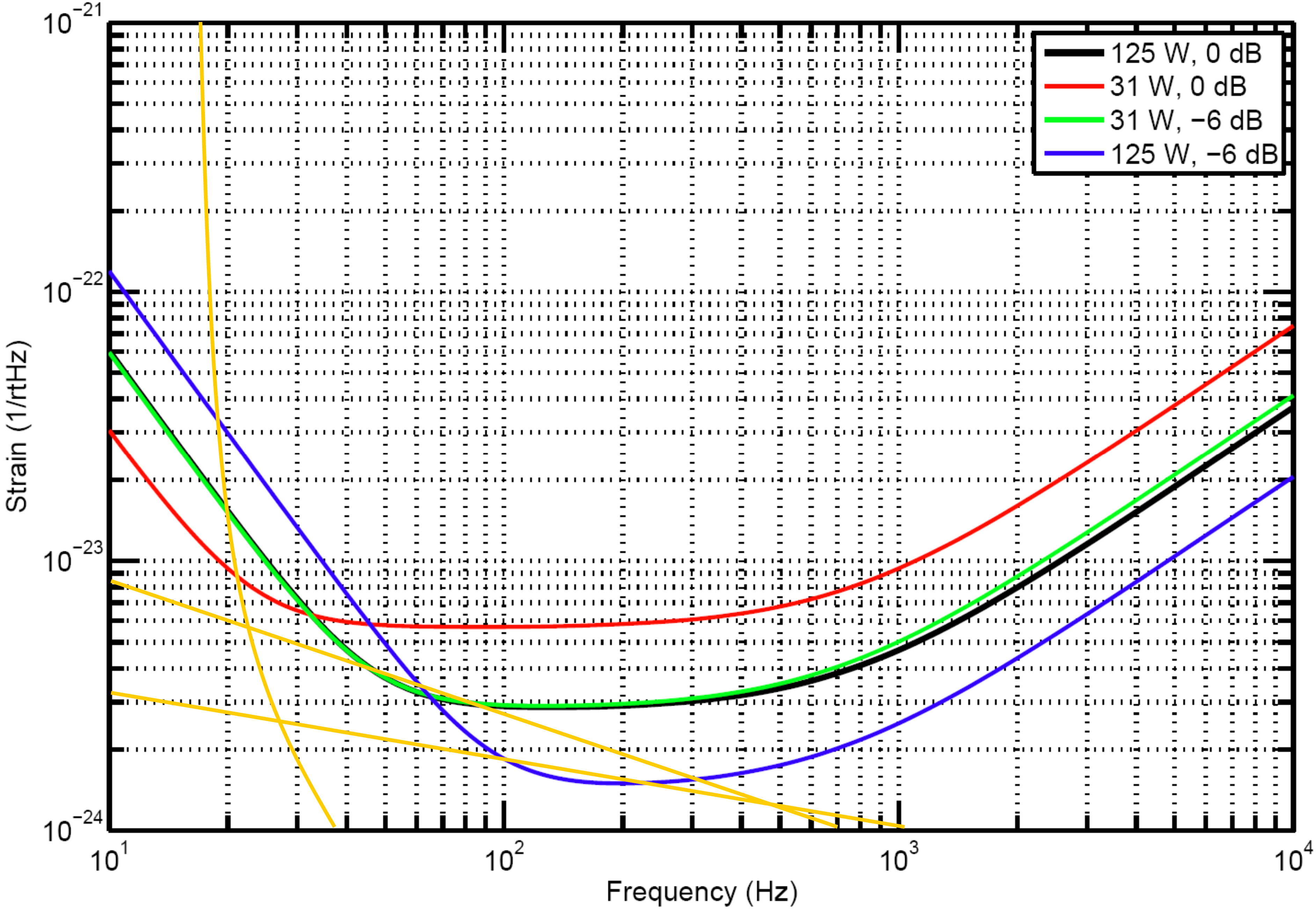
- Planned Experiments
  - GEO600: prototype for long baseline interferometers
  - Hanford H1: low noise at low frequency

Goal of the H1 Squeezer Experiment

- Demonstrate squeezing at low frequency with a high sensitive long baseline interferometer
  - Demonstrate 3 dB of squeezing at frequencies where we are shot noise limited
  - Do not introduce noise at other frequencies!
- Build a squeezer which could be readily turned into an advanced LIGO upgrade
  - Fully engineered optical breadboard
  - Use LIGO type electronics and controls
  - Prepare for long-term reliability investigations
- Be ready for a test on H1 after S6

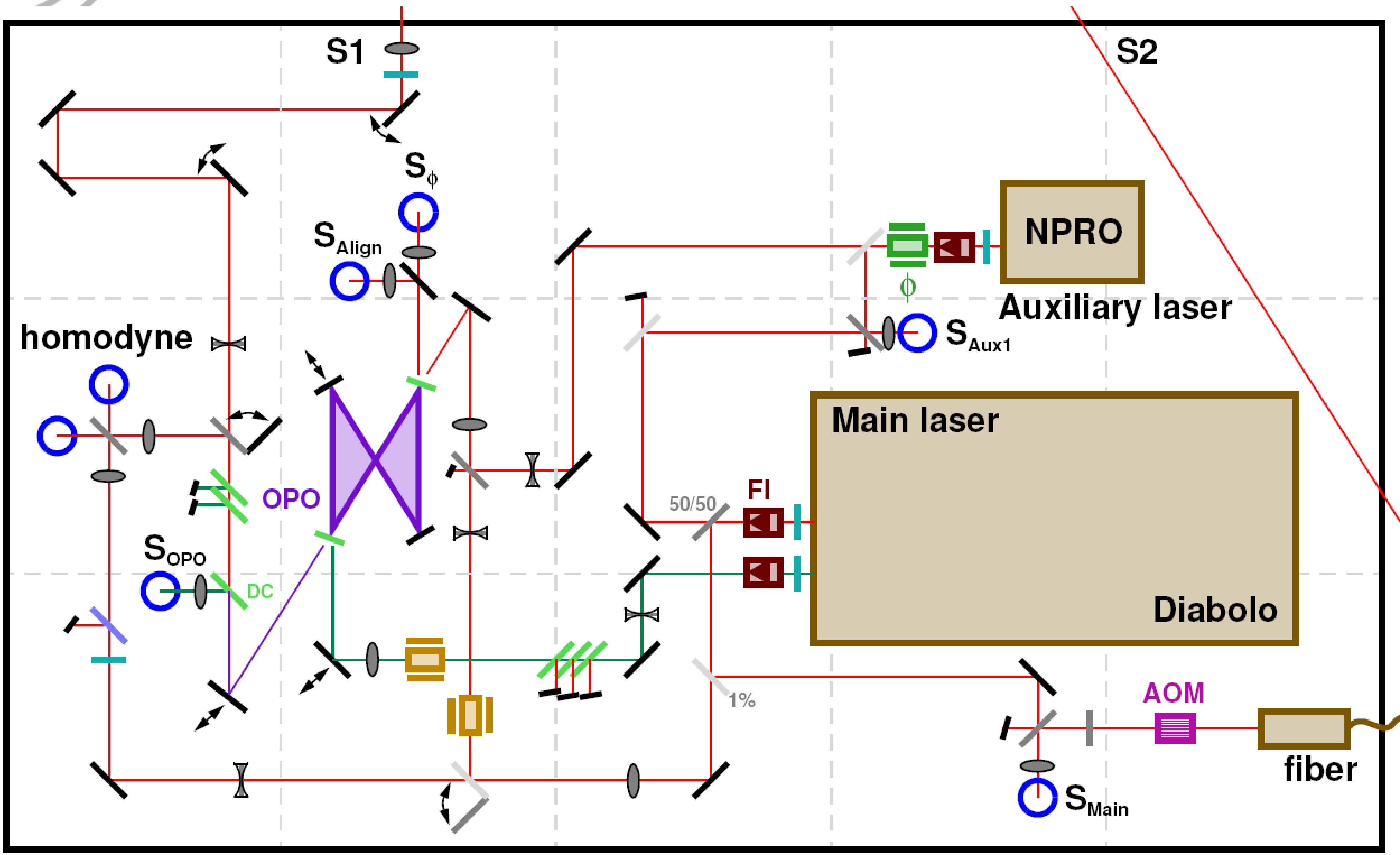


Squeezed Enhanced LIGO, 30 W
PRC
MICH
Mirror Thermal
Wire Thermal
Intensity Noise
Frequency Noise
Squeezed Shot Noise
Seismic
Angle Controls
SUS Electronics
eLIGO Total (35.2 Mpc)
Squeezed 3dB (38.1 Mpc)
SRD
10^{-17}
10^{-18}
10^{-19}
10^{-20}
Displacement [m/√Hz]
10^2
10^3
Frequency [Hz]


125 W, 0 dB
31 W, 0 dB
31 W, −6 dB
125 W, −6 dB
Strain (1/rtHz)
Frequency (Hz)
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{1}
10^{2}
10^{3}
10^{4}

Baseline Design

- Inject into HAM4
  - SQT4 opposite of ISCT4
  - New advanced LIGO Faraday design
- Optical breadboard 5’ x 3’
- 1W frequency double Nd:YAG laser
  - Locked to interferometer laser by fiber
- Auxiliary laser for frequency shifted subcarrier
- Optical parametric oscillator (OPO)
  - Doubly resonant
  - Bowtie configuration
  - Non-linear crystal: PPKTP

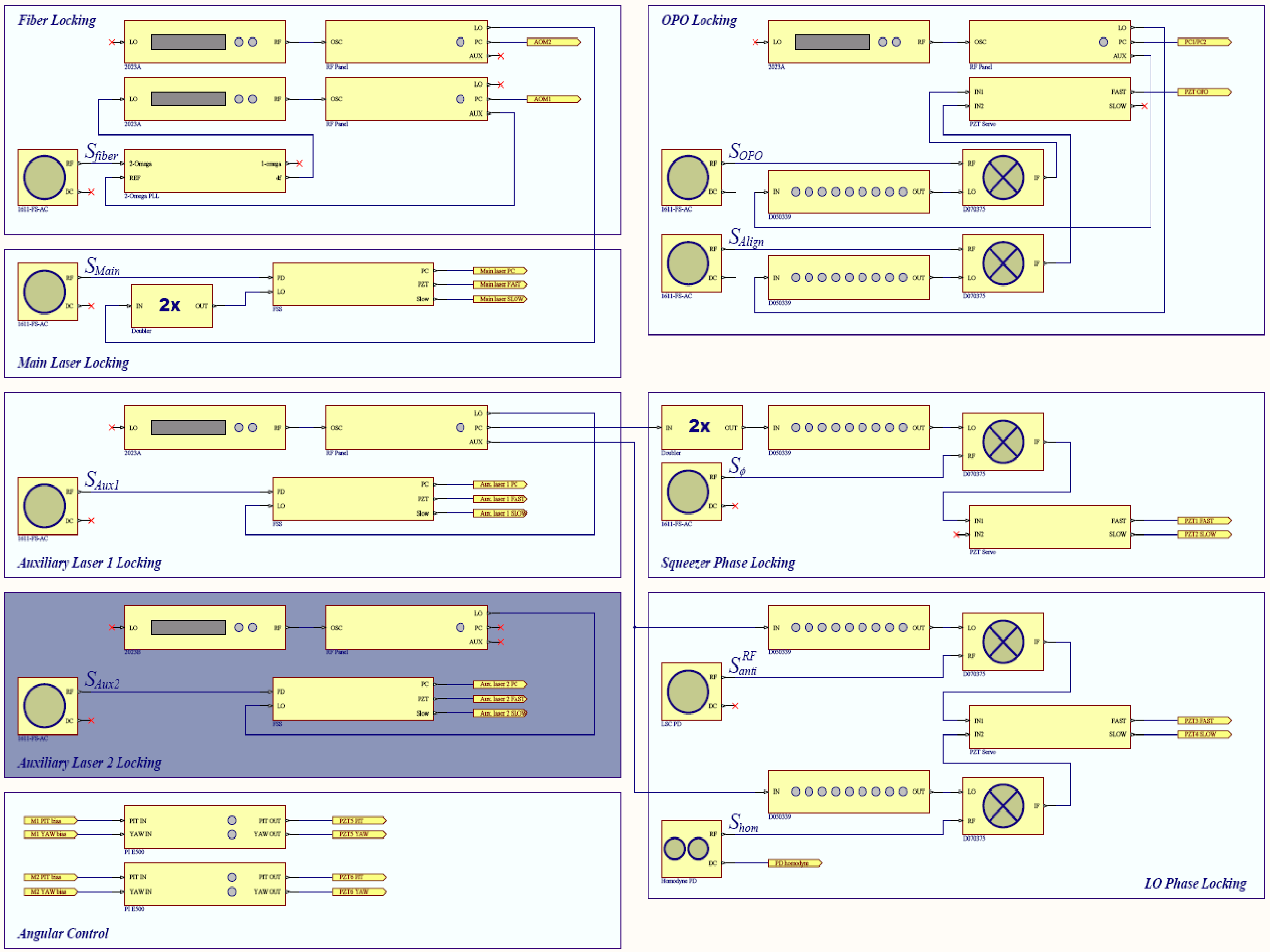

S1
S2
Sϕ
SAlign
NPRO
ϕ
Auxiliary laser
SAux1
homodyne
Main laser
OPO
FI
50/50
Diabolo
SOPO
DC
1%
AOM
fiber
SMain

Servos

- Fiber stabilization: Feed forward
- Main laser offset-locked to probe beam
  - Use initial LIGO FSS
  - Pockels cell & PZT & thermal actuator
- Auxiliary laser offset-locked to main laser
- OPO: PDH on green light
  - PDH on probe beam at carrier frequency for alignment
- Squeezer phase & LO phase
  - Subcarrier sensing
  - Feedback to PZT mirror in green and squeezed light paths
- Homodyne detector for verifying squeezing

Electronics Setup

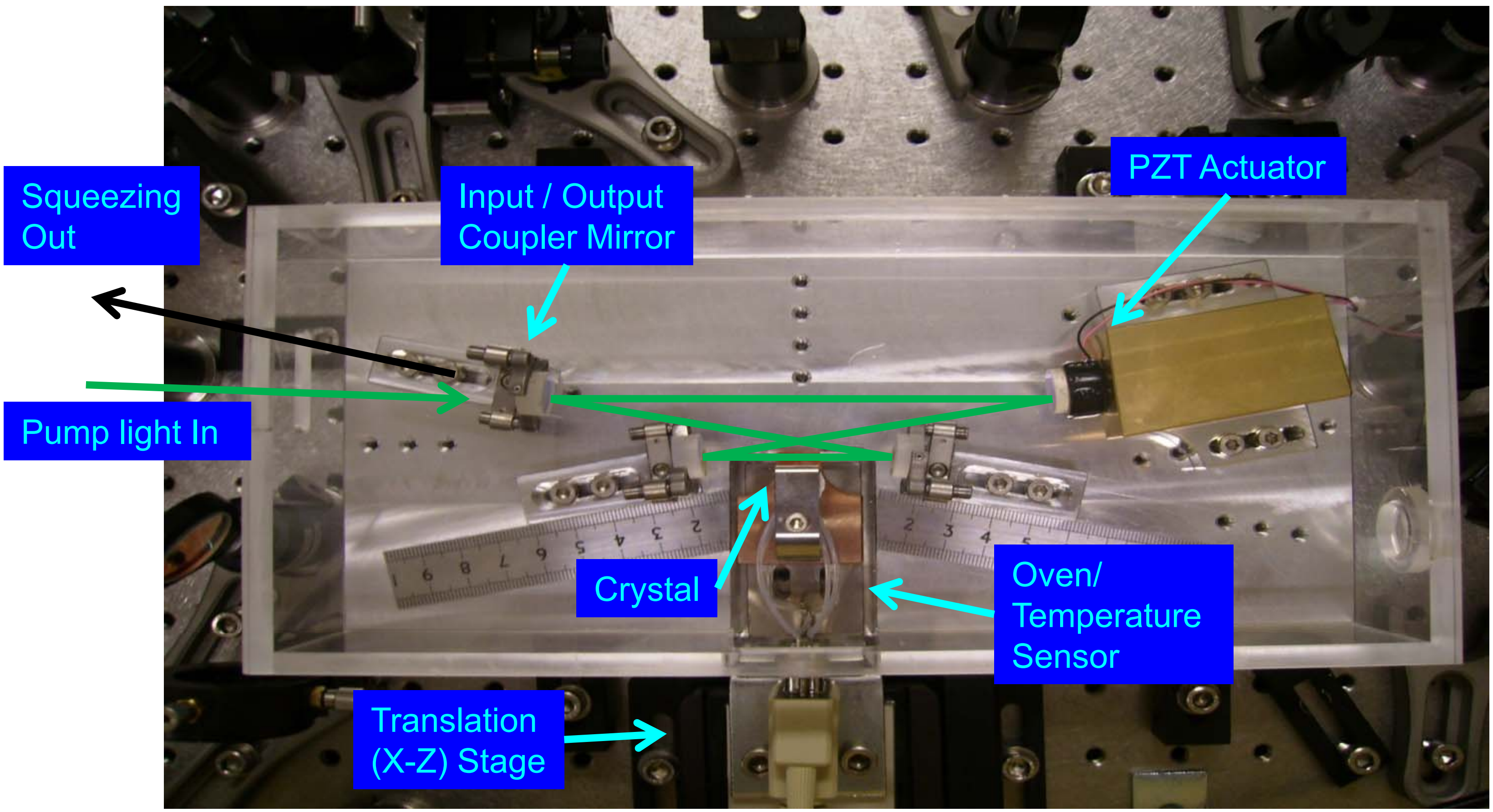
- Compensation networks too fast for digital servos
  - Look-and-feel of a PSL system
- Remote controls: EtherCat from Beckhoff
  - Same as in Advanced LIGO laser
  - EPICS interface through OPC server
  - Can be used stand-alone with a PC or control panel
- LIGO electronics wherever possible
  - FSS, CM/MC board, RF distribution, demodulator, phase shifter, …
  - PZT actuators from Physik Instrumente
  - No WFSs!



Fiber Locking
OPO Locking
Main Laser Locking
Auxiliary Laser 1 Locking
Squeezer Phase Locking
Auxiliary Laser 2 Locking
LO Phase Locking
Angular Control
S_fiber
S_OPO
S_Align
S_Main
S_Aux1
S_φ
S_Aux2
S_anti^RF
S_hom
2x
2023A
RF Panel
2-Omega PLL
1611-FS-AC
FSS
Doubler
PZT Servo
D050339
D070375
LSC PD
Homodyne PD
PI E500
AOM2
AOM1
PZT OPO
PD homodyne

OPO Design Summary

- **Configuration:** Doubly Resonant Bow-Tie Cavity
- **Crystal:** PPKTP [Flat-wedge geometry]
- **Finesses** ~ $\mathcal{F}$ = 50 for 1064nm, ~ $\mathcal{F}$ = 100 for 532nm
- **Temperature Control:** Oven and Newport Temperature Controller
- **Optical Path Length:** ~ 700mm
- **Physical Dimensions:** ~ 200 mm x 150mm



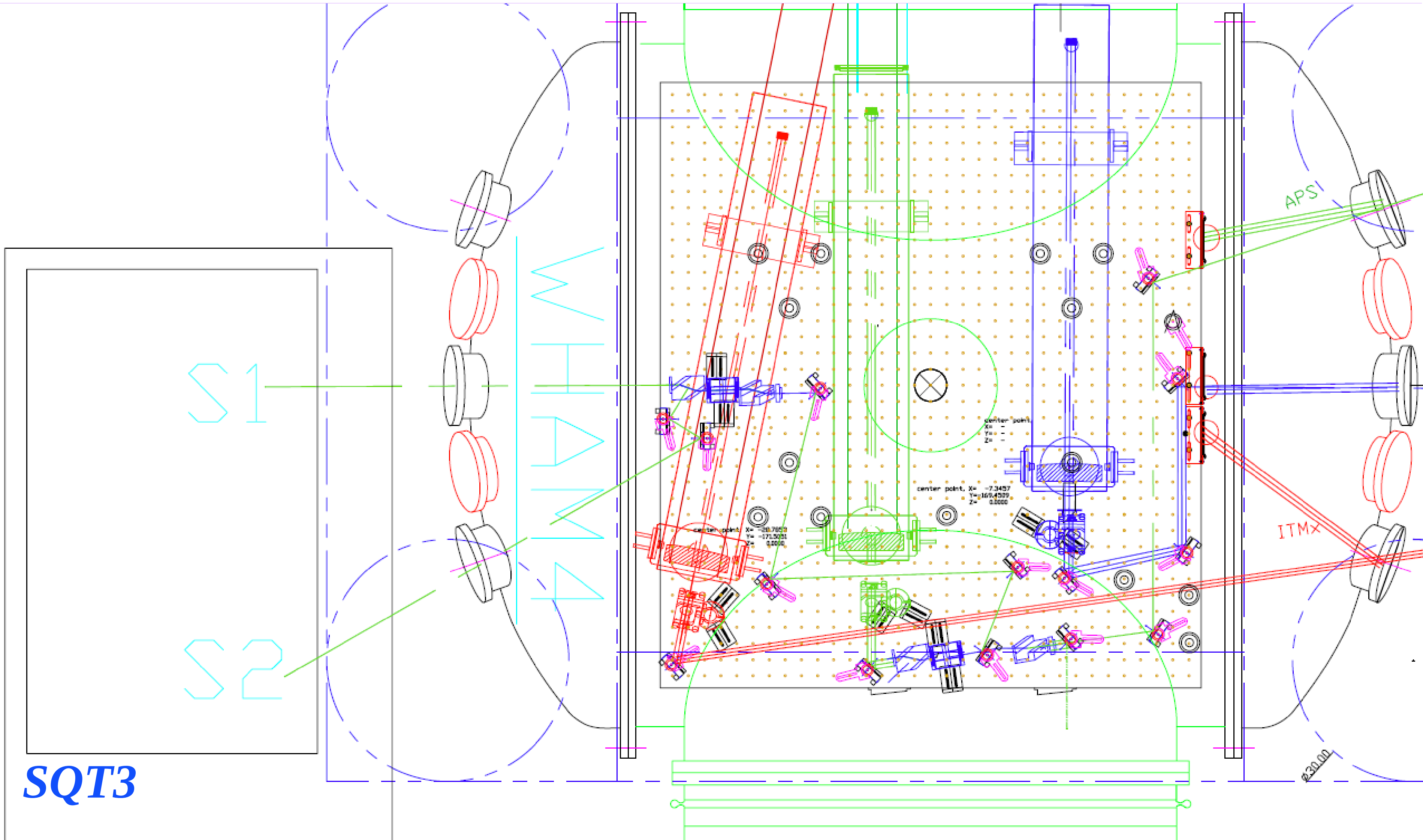
Technical Issues (1)

- OPO: see ANU slide
- SHG
  - Diabolo laser system comes with an integrated SHG
  - Need to address internal scattering issues
- Auxiliary lasers
  - Scattering of AOMs too much trouble
  - Freedom to choose subcarrier frequency
  - A singly-resonant cavity would require a 2^{nd} auxiliary laser to lock it
- Fiber stabilization
- In-vacuum AS-port Faraday isolator
  - Develop advanced LIGO unit

Technical Issues (2)

- Scattering paths
  - Inject opposite ISCT4
  - Second in-vacuum Faraday isolator in injection path
  - Baffling on the optical breadboard
- Long-term reliability
  - Squeezer will be available after H1 experiment
- SQT4
  - Reuse ISCT3
  - Mount table high to avoid a periscope
- Initial Alignment
  - Use rejected beam from Faraday in injection path as a fiducial

HAM4 Layout



H1 Squeezer Time Line

- Fixed start date for H1 experiment: 2/15/2011
- Fixed end date for H1 experiment: 10/3/2011

Better be ready!

Plan

- Setting up the lasers (MIT/LHO)
  - Critical path: building the electronics
  - Grad student from MIT
  - Electronics support from LHO
- Building and commissioning the OPO (ANU)
  - Grad student from ANU
  - Electronics support from LHO
- Characterization of the squeezer (ANU/LHO)
- Homodyne detector (AEI)
- Experiment at H1