First Lessons from the Advanced LIGO Integration Testing

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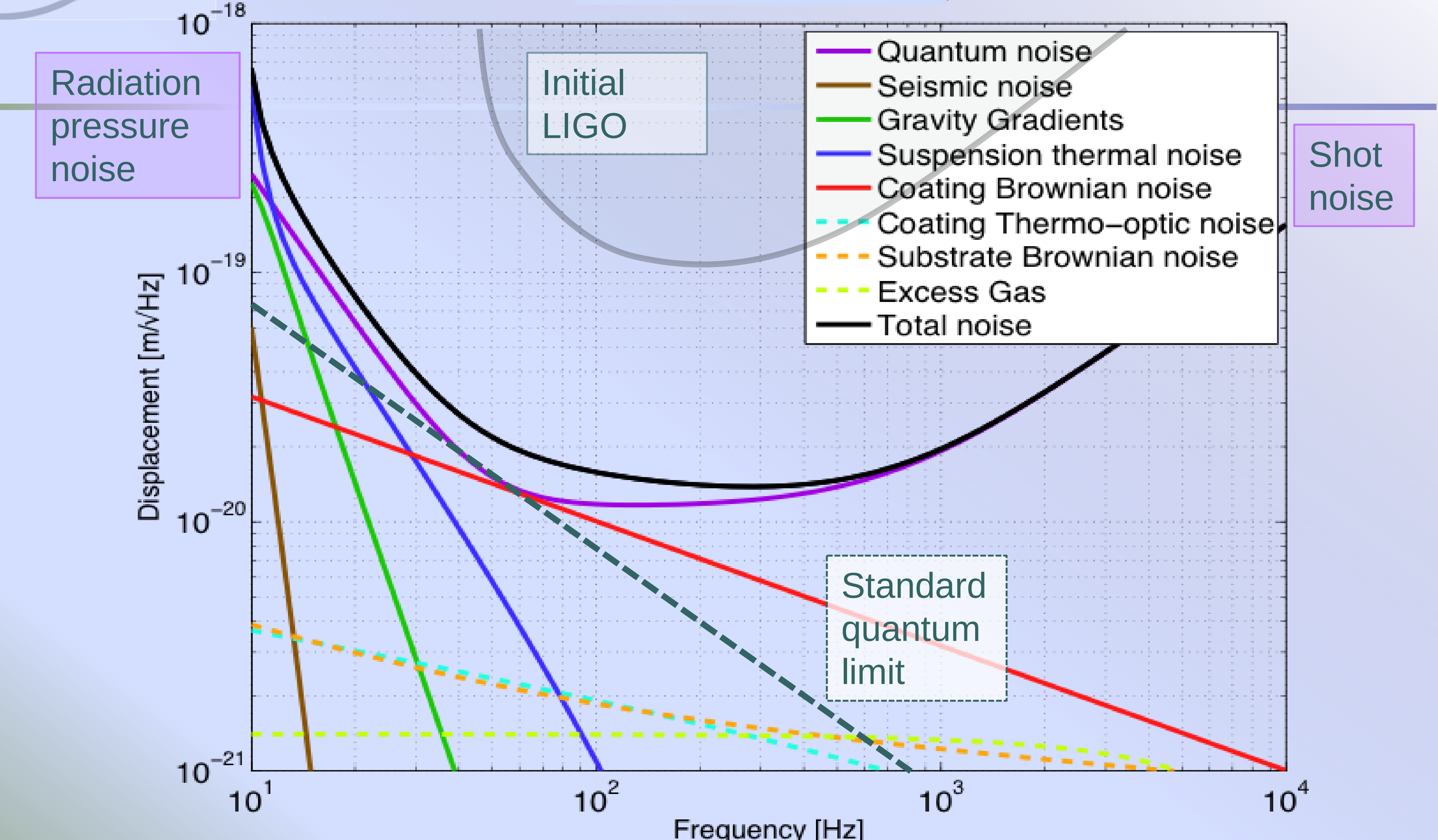
Daniel Sigg

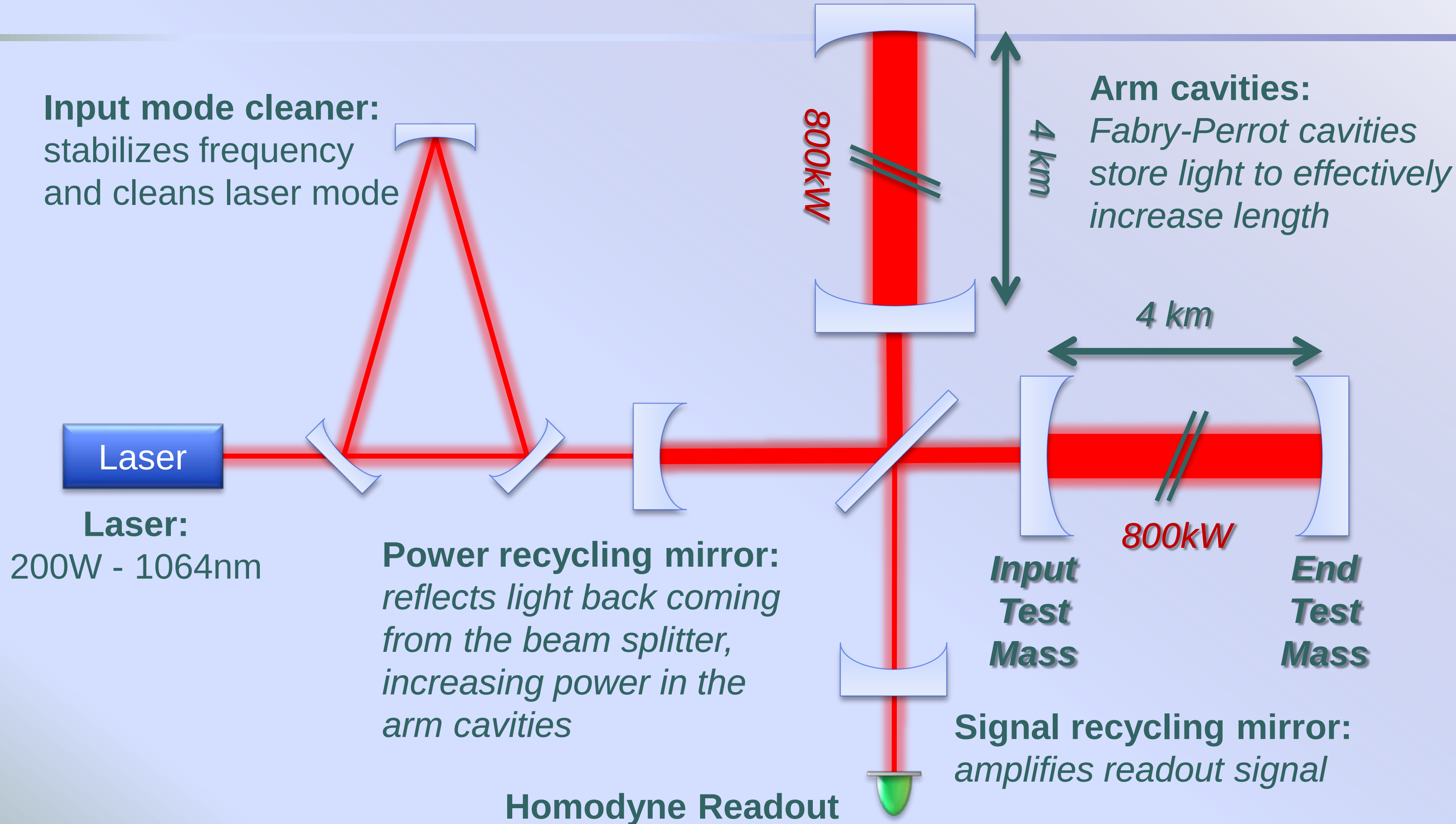
LIGO Hanford Observatory

GWDAW, Elba, 2013

Advanced LIGO Sensitivity



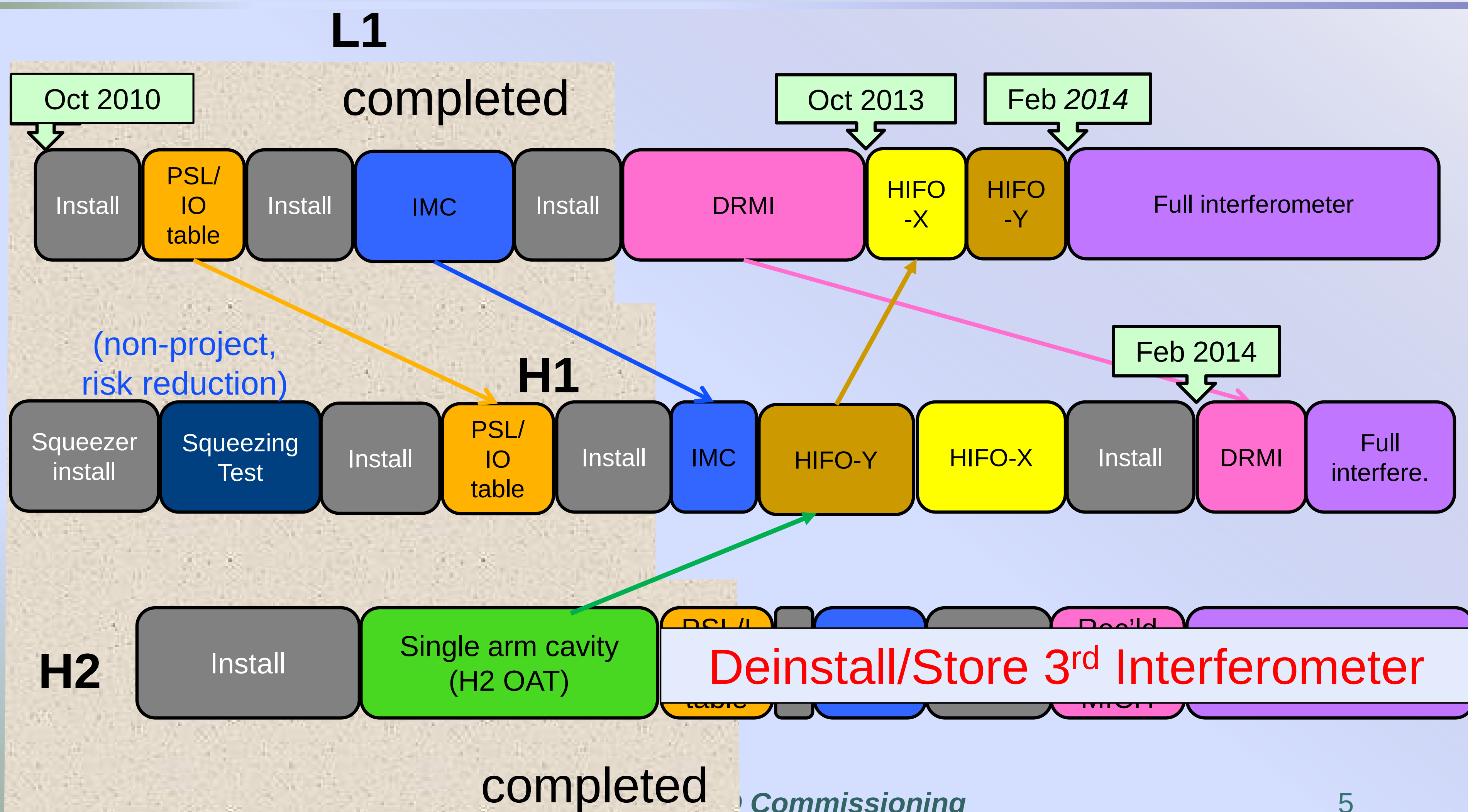
The Advanced LIGO Detector



Global Timeline

- October 2010: Hand-off of Observatories to Advanced LIGO for installation
- February 2012: Both Observatories have decommissioned initial LIGO detectors, started in-vacuum Installation and subsystem Integration
- April 2012: Recommendation to the NSF to place one interferometer in India
- Aug 2014: LLO ‘L1’ Interferometer accepted (internal plan date)
- Sep 2014 LHO ‘H1’ interferometer accepted (internal plan date)
- LHO ‘H2’ detector was on schedule to be accepted in March 2014, but instead will go to India pending NSF Approval
- Mar 2015: Data Analysis computer system completed, planned Project end

Sequence of Installation and Integration Testing



Subsystem Testing

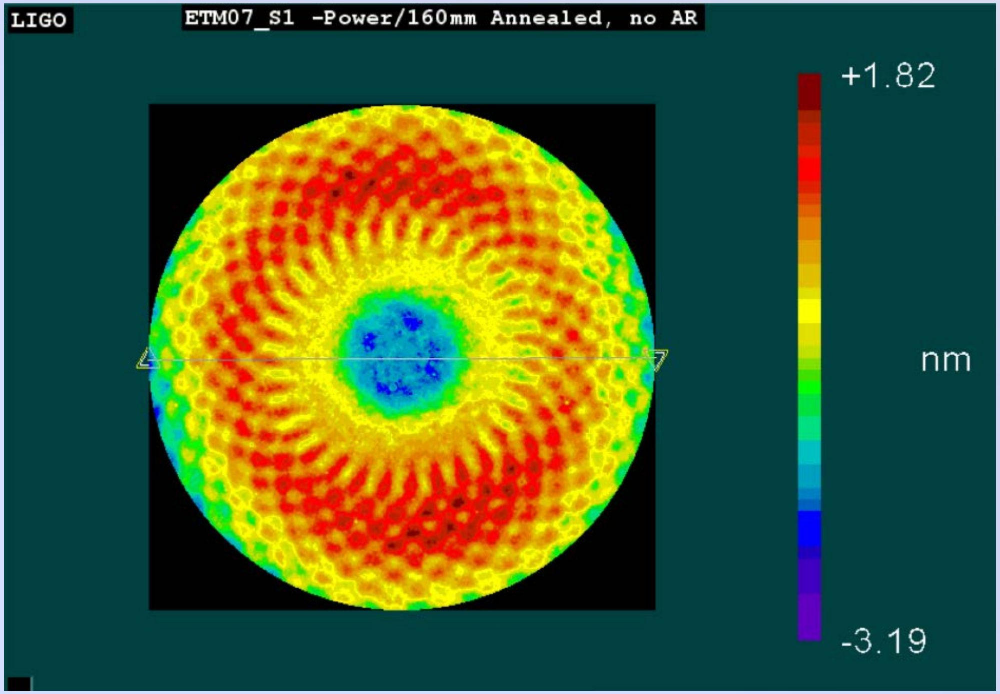
- Subsystem testing
  - All components are tested before installation
  - All subsystems have a test and verification phase before commissioning

  Paid off big time: Much faster startup of commissioning

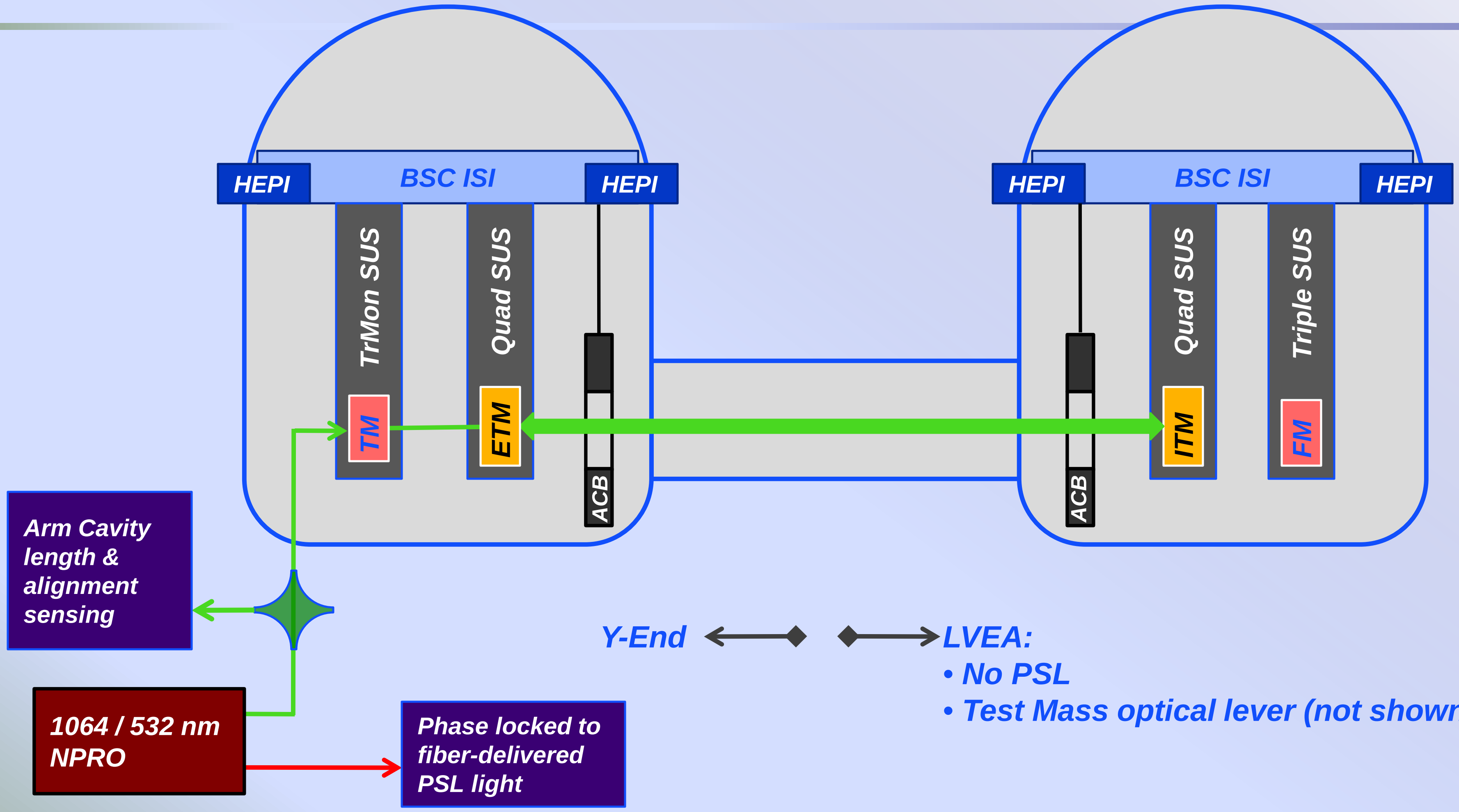
- PSL: Accepted and working
  - Lasers delivers stable 180W, currently running at 35W
  - Excess frequency, intensity and jitter noise due to water cooling flow (avoid 90 degree turns)
  - Lifetime of laser diodes factor 2 below specs of manufacturer
  - Unknown contamination reduced AR coating performance of PMC tank windows, windows could be cleaned, since tank is open no accumulation of stuff anymore

Core Optics Coatings

- ETM spiral pattern generates scattered ring
  - Back scatter from beam tube baffles can effect <30Hz sensitivity
- Spherical aberration acceptable (two ETMs are nearly identical)
- Arm Cavity Loss is within budget (50 ppm achieved vs. <75 ppm spec)



One Arm Test Components



Y-End LVEA:
- No PSL
- Test Mass optical lever (not shown)

One Arm Test
Summary and Actions

- Verified the basic functionality of many subsystems:
  - Two-stage active seismic isolation system (BSC ISI)
  - Quadruple suspension
  - Initial Alignment system/procedure
  - Thermal compensation ring heater
  - Green beam cavity locking
- Actions:
  - ALS wavefront sensors eliminated from design: alignment sufficiently stable
  - PZT steering control of ALS beam incorporated into design
  - Additional hardware was identified to support automation
  - Usability of various systems needs to be improved to be accessible to non-experts

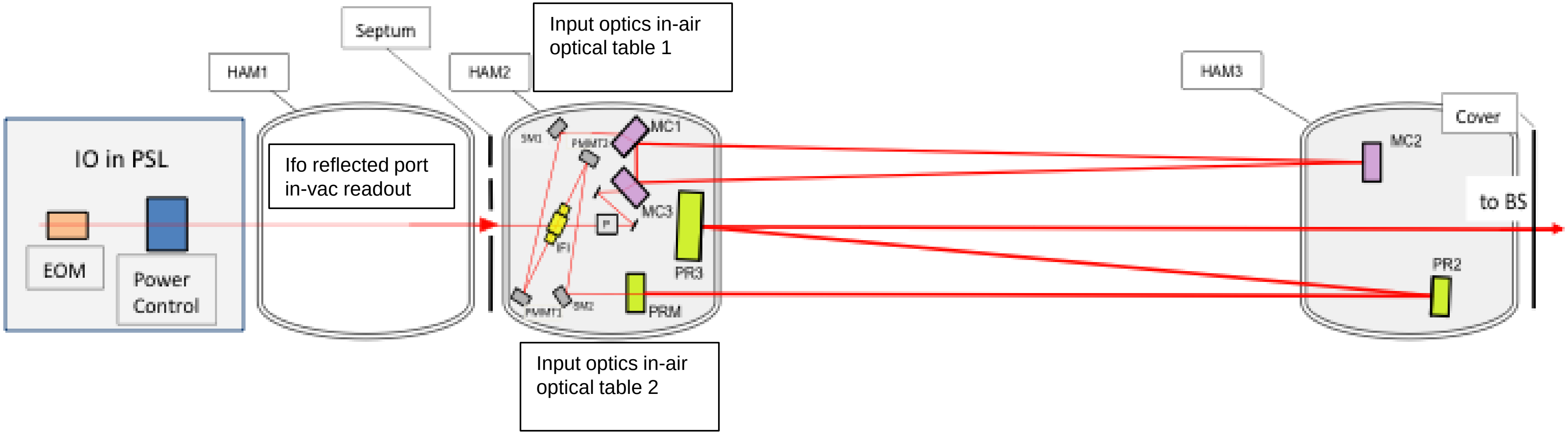
Intermediate and Quantitative Goals of the One Arm Test

Initial alignment: Sustained flashes of optical resonance in the arm cavity	*Achieved, within one week of operation*
Cavity locking/ISC: Green laser locked to cavity for 10 minutes or more	
TransMon/ALS: Active beam pointing error on the TransMon table below 1 urad rms in angle and below 100 um rms in transverse motion	*Achieved*
Calibration: ETM displacement calibration at the 20% level	*Achieved*
Thermal Compensation: Ring heater wavefront distortion, measured by Hartmann sensor, in agreement with model at the 10 nm rms level	*Achieved*
Optical levers: Long term drift below 1 urad	*Diurnal motion about twice this level, possibly actual test mass motion*

Intermediate and Quantitative Goals of the One Arm Test

Controls/SUS: Decoupling of length-to-angle drive of the quad suspension	*Achieved for TOP stage*
Seismic isolation: Relative motion between two SEI platforms below 250 nm rms (w/o global feedback)	*Achieved*
Cavity alignment fluctuations: Relative alignment fluctuations below 100 nrad rms	*Achieved*
Controls/ISC: Long term cavity locking; fully automated locking sequence	*Long term locking achieved; automation was rudimentary*
Cavity length control: Relative test mass longitudinal motion below 10 nm rms	*Not possible to assess with OAT. These have become objectives for the HIFO-Y test.*
ALS: Ability to control frequency offset between 1064 nm and 532 nm resonances at the 10 Hz level	
ALS: Relative stability of the 1064/532 nm resonances at the 10 Hz level	

IMC Test


Septum
Input optics in-air optical table 1
HAM1
HAM2
HAM3
IO in PSL
Ifo reflected port in-vac readout
MC1
MC3
MC2
Cover
to BS
IFI
PR3
PR2
PRM
EOM
Power Control
Input optics in-air optical table 2

IMC Test
Summary and Actions

- Locking was as easy and reliable as expected
  - Seismic isolation controls for HAM ISI are straightforward
  - Angular stability quite good; wavefront sensor alignment control only for long term drifts
  - New design for low-noise Voltage-Controlled Oscillator validated
  - No major problems with high power operation
- Issues and actions
  - Excess laser noise (frequency, amplitude, beam pointing). No show stoppers, but room for improvement (some already made)
  - PSL Intensity servo (outer stage) found to need re-engineering
  - Absorption in IMC mirrors. Two of the three mirrors found to absorb 2 ppm, vs 0.6-0.7 ppm nominal – relevant to contamination control

Intermediate and Quantitative Goals of the IMC Test

IMC availability: Locked duty cycle of >90%	*Achieved, would remain locked indefinitely*
Mean lock duration: > 4 hours	*Achieved*
Optical efficiency: Transmission from PSL output to Interferometer input (O-PRM), > 75%	*Achieved, 86%*
IMC visibility: > 95% (include mode-matching)	*Achieved, 97-98%*
IMC length/frequency control bandwidth: Goal of 40 kHz or higher	*Achieved, 60 kHz*
IMC frequency/length crossover: ~10 Hz	*Achieved*
IMC transmitted power stability: relative rms fluctuations of 1% or less	*Achieved, 0.5% RIN*
Pointing stability: angular motion of transmitted beam, < 1.6 urad rms	*Achieved, 0.4 urad*
Intensity noise: transmitted light RIN <10^{-7}/$Hz^{1/2}$	*Not achieved*
Faraday isolation: > 30 dB at full power	*Not measured in-situ*

So far so good!