Integration Planning

April 25, 2011

Valera Frolov, Daniel Sigg, Peter Fritschel

NSF Review, LLO

G1100445-v3

Challenges

- Nature of a new physics experiment
  - Not all requirements are known upfront
  - Past experience only goes so far
- Geographically distributed team
  - Caltech, MIT, AEI, Birmingham, ANU, LLO, LHO, LSC institutions
  - Designers become testers and installers, then commissioners

Major Remaining Technical Risk

- Complexity of seismic isolation and suspensions
  - Virgo experience: Commissioning a highly complex isolation system takes a long time
  - Limited experience with monolithic suspensions at low noise
- Core optics: coatings, thermal noise and absorption
- High power operations
- Controls
  - Number of control loops an order of magnitude larger than initial LIGO
  - Reliable and robust controls of interferometer

Approach

- Start from the front:
  Michelson test at LLO (L1)
  - Build laser, mode cleaner, vertex chambers and optics
  - Test PSL, HAM isolation, interferometer sensing and control
  - Should have decent phase sensitivity
- Start from the back:
  One arm cavity test at LHO (H2 Y-arm)
  - Build a single arm cavity and inject light from the end
  - Test BSC isolation, part of the locking scheme
  - Look at stability
- Beyond first year:
  - Get L1 interferometer up as fast as possible
  - H2 and H1 staggered by about half intervals behind L1

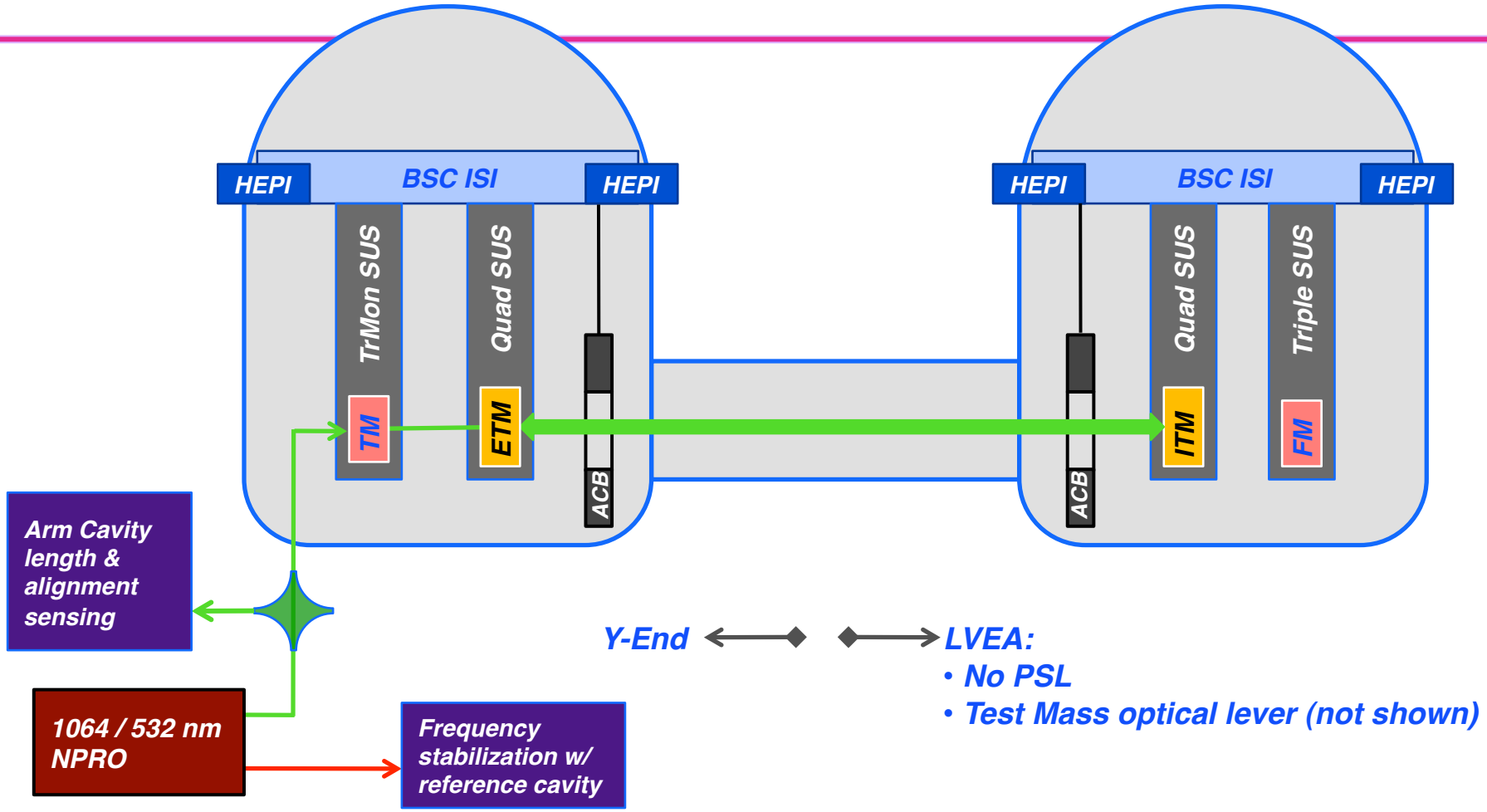
Advantages

- Reduce a lot of technical risk early
  - A lot of systems need to get installed at least once in the first year
  - All teams have to be on site
- Get some early feedback on our designs
  - Seismic isolation and suspension performance
    - Low frequency: One arm test
    - High frequency: Michelson test
  - Optics: Coating quality
  - Laser performance: Acoustic enclosure, high power
  - Sensing and control: new digital controls system

Interaction between Installation and Integration

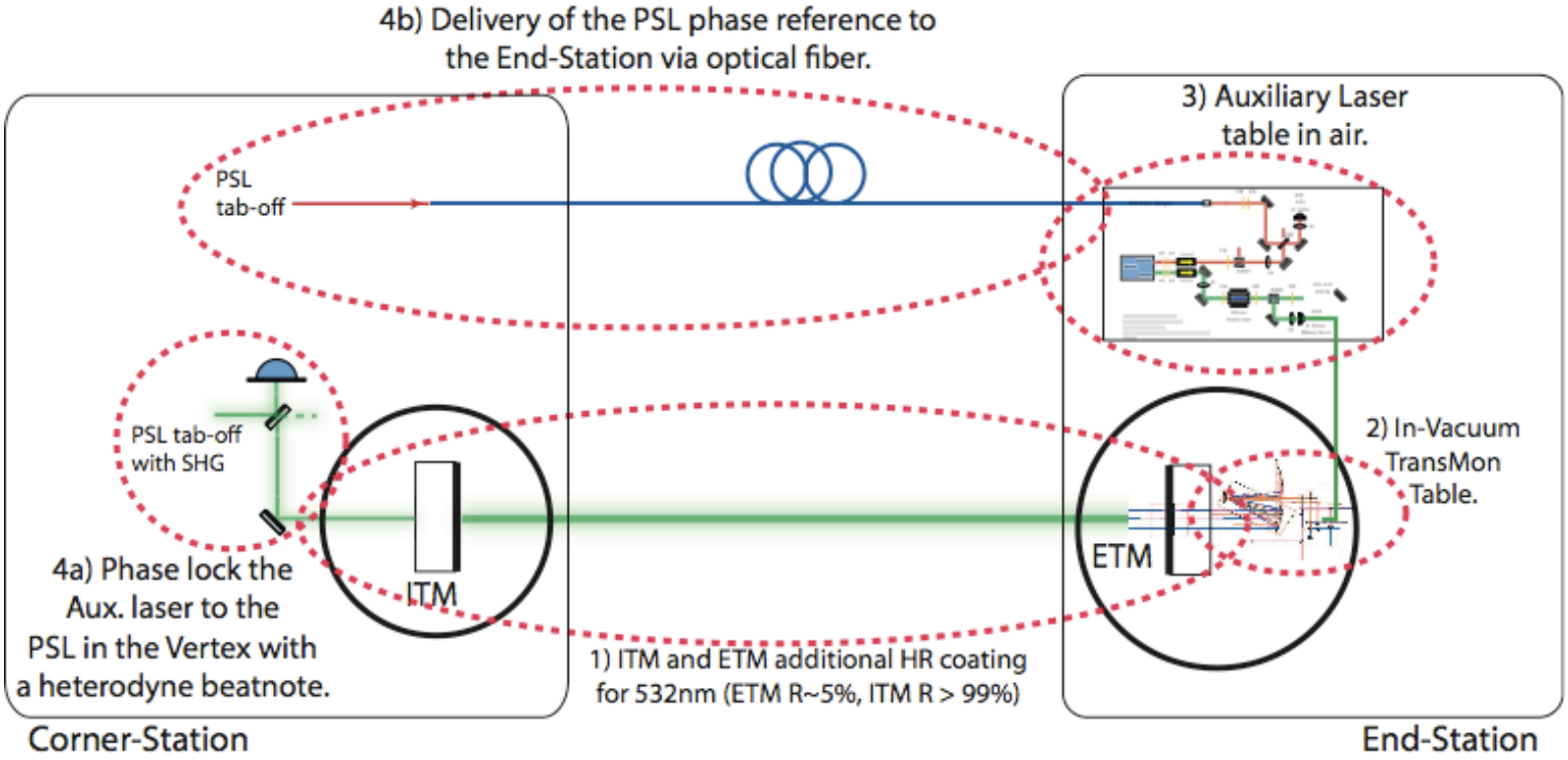
- Dedicated installation periods
  - Coordination between different installation teams
  - This is what we have right now
- Dedicated commissioning periods
  - Commissioning takes lead
  - Limited installation tasks relegated to mornings or of no impact
  - One arm test: October ‘11 to January ’12
- Shared installation/commissioning periods
  - Early shift: installation
  - Late shift and weekends: commissioning
  - Mid/Late 2010: Cooperation with H1 squeezer test

Overview of H2 One Arm Test



H2 One Arm Test

- New lock acquisition strategy developed for aLIGO
  - Arm Length Stabilization system controls each arm cavity, putting them off-resonance
  - The 3 vertex lengths are controlled using robust RF signals
  - Arm cavities are brought into resonance in a controlled fashion



Technical Objectives of H2 One Arm Testing Phase

- BSC seismic isolation, quad suspension & transmission monitor
  - Verification of the installation and alignment process
- Develop robust locking with the ALS laser
  - Wide-band feedback to the laser for easy locking; the low-frequency control (< 10 Hz) sent to the quad suspension to stabilize the arm length
  - Characterize alignment stability (cavity will be outfitted with wavefront sensors)
    - Active stabilization of ALS beam alignment required?

Technical Objectives of H2 One Arm Testing Phase

- Characterize and fine-tune low frequency performance of the ISI (seismic isolation)
  - First chance to look at what is really important: relative fluctuations over 4 km baseline
  - Trade-offs in the seismic isolation between very low frequencies (<~ 0.1 Hz) and mid-frequencies (1-few Hz) can be explored with the arm cavity
  - Implement adaptive feed-forward controls to further minimize the arm length fluctuations

Intermediate and Quantitative Goals of One Arm Test

- Initial alignment: Sustained flashes of optical resonances in the arm cavity.
- 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.
- SEI: Relative motion at the suspension point between the two SEI platforms below 250 nm rms (without global feedback).
- Cavity length control (SEI/SUS/ALS): Relative longitudinal motion between ITM and ETM below 10 nm rms for frequencies below 0.5 Hz.
- Cavity alignment fluctuations (SEI/SUS): Relative alignment fluctuations between the TIM and ETM below 100 nrad rms for frequencies above 0.1 Hz (without global feedback).

Intermediate and Quantitative Goals of One Arm Test (cont.)

- Controls (SUS): Decoupling of length-to-angle at the level of 0.05 rad/m or less, for frequencies below 0.5 Hz.
- Controls (ISC): Fully automated cavity locking sequence; long term cavity locking.
- TCS: Ring heater wavefront distortion, as measured by the Hartmann sensor, in agreement with the model at the 10 nm rms level.
- Optical levers: Optical lever long term drift below 1 urad.
- Calibration: ETM displacement calibration at the 20% level.
- ALS: Ability to control frequency offset between 1064 nm and 532 nm resonances at the 10 Hz level.
- ALS: Relative stability of the 1064 nm and 532 nm resonances at the 10 Hz level for frequencies below 0.5 Hz.

Personnel

- Adv. LIGO Management
  - Carol and David
- Installation leaders
  - Mike (LHO) and Brian (LLO)
- Commissioning leadership
  - System lead: Peter
  - LLO vertex test: Valera
  - LHO one arm test: Daniel
- Commissioning team
  - Current LHO Team: Bram Slagmolen (ANU visitor), Keita Kawabe, Dani Atkinson, Victor Bigea, students from WSU and Columbia
  - 8-9 people total dedicated from LIGO lab for one arm test

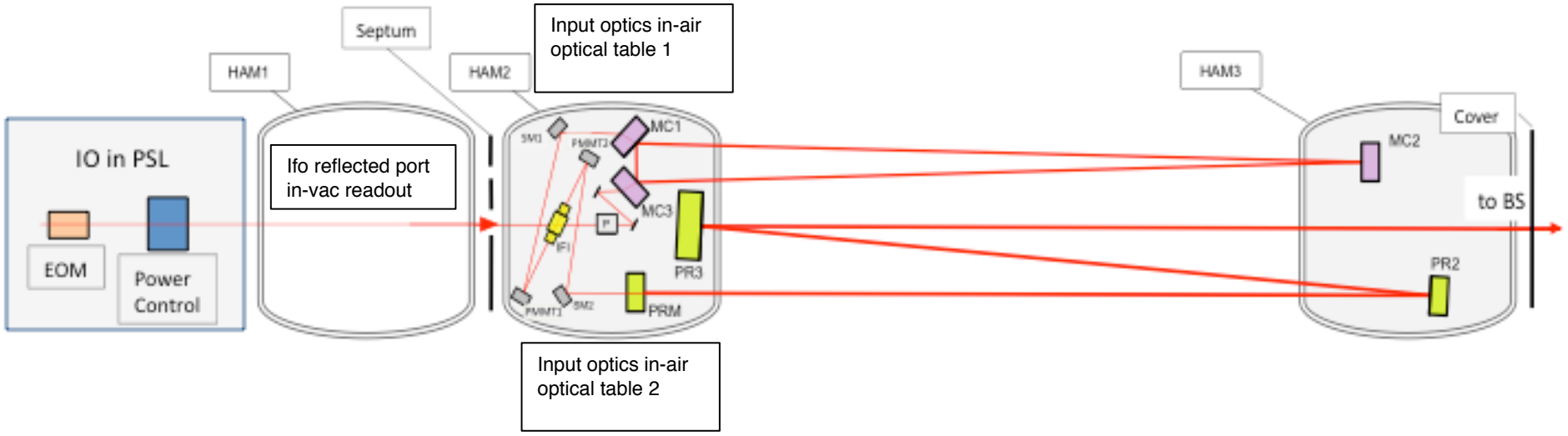
One Arm Cavity Test Schedule Installation Phase

- ITMY (Input Test Mass Y-arm)
  - February/March ’11: Install HEPI (Hydraulic External Pre-Isolator)
  - May-July ‘11: Install SEI and SUS (Seismic and Suspension)
  - August ‘11: Checkout
  - September/October `11: Acceptance
- ETMY (End Test Mass Y-arm)
  - March/April ’11: Install HEPI
  - June-August ‘11: Install SEI and SUS
  - August ‘11: Install AOS (Auxiliary Optics Support)
  - August ‘11: Install ISC (Interferometer Sensing and Controls)
  - September ‘11: Checkout
  - October/November `11: Acceptance

One Arm Cavity Test Schedule Integration Phase

- One Arm Cavity Test:
  - October ‘11 to January ’12: Dedicated commissioning time
  - February to May ’12: Shares installation and commissioning time
- Second half of ’11:
  - PSL (Pre-Stabilized laser), no impact
- Starting February ’12:
  - IMC (Input Mode Cleaner)

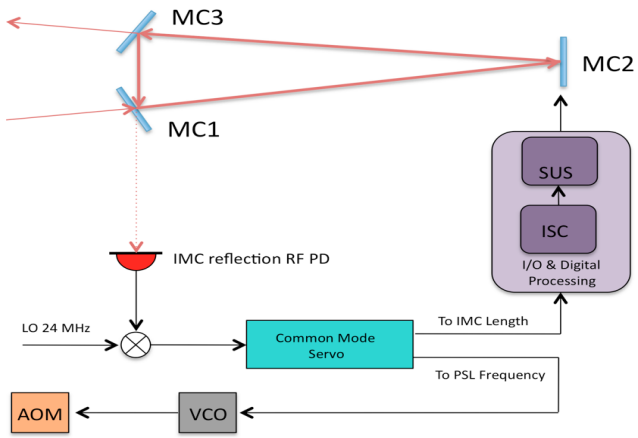
Overview of L1 Pre-Stabilized Laser, Input Mode Cleaner, and Input Optics Integrated Test

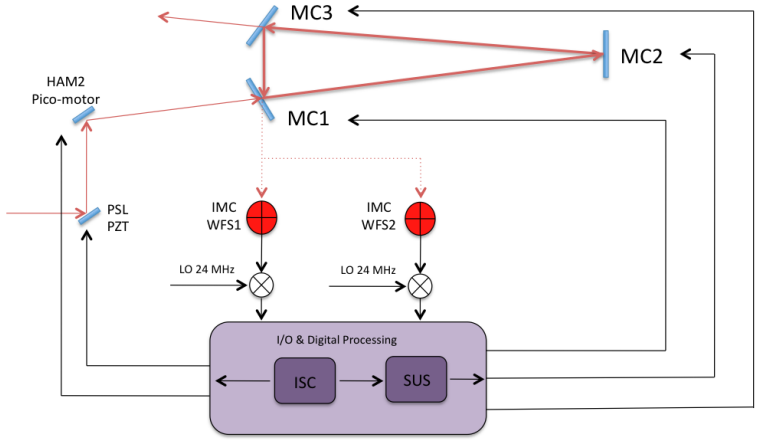


Components:

- PSL operational at maximum power of 165 W
- Input optics: phase modulator, power control, Faraday isolator
- Suspended Input Mode Cleaner, auxiliary optics, power recycling cavity optics
- Seismic isolation: HEPI and ISI for HAM2/3, HEPI and passive stack for HAM
- AOS: stray light baffles and optical levers

L1 PSL/IO/IMC Test





- Main function of the IMC is the spatial filtering of the PSL light
- The IMC also provides the frequency reference before the common arm signal is available
- The IMC control scheme is the same as in initial LIGO
- Much better isolation from the ground motion down to ~0.5 Hz

Technical Objectives of L1 PSL/IO/IMC Testing Phase

- Achieve robust operation of the IMC and noise performance sufficient to move to the next commissioning phase
  - In-air locking at low power for initial alignment of IMC, FI, and PR optics
  - In-vacuum locking at ~5 W to optimize the control loops: length, angular, local damping
- High power operation up to 165 W – look for problems
  - Evaluate the thermal effects in IMC and FI: transmission, isolation ratio, absorption, mode distortion, drift
  - First assessment of the outer loop laser amplitude stabilization

Technical Objectives of L1 PSL/IO/IMC Testing Phase

- Characterize the noise
  - PSL frequency noise
  - IMC angular motion
  - Power fluctuation on the IMC transmitted light
- Optimize low frequency performance of the seismic isolation
  - Use adaptive feed forward to minimize the relative motion of HAM2/3
  - Evaluate the necessary VCO range to minimize the phase noise out of the PSL

Intermediate and Quantitative Goals of L1 PSL/IO/IMC Test

- IMC availability >90% with mean lock duration of >4 hours
- Fully automated locking sequence
- PSL to PRM power transmission > 75%
- Longitudinal control bandwidth ~40 kHz
- Frequency/length feedback cross over frequency ~10 Hz
- Angular control bandwidth ~1 Hz
- IMC transmitted beam angular motion rms <1.6 urad (1/100 of the cavity angle)

Intermediate and Quantitative Goals of L1 PSL/IO/IMC Test (cont.)

- IMC transmitted light power fluctuation <1% rms
- IMC transmitted light RIN <1e-7/rtHz
- IMC visibility >95%
- FI isolation ratio at full power 30 dB

Personnel

- LLO Commissioning team
  - Commissioning leader: VF
  - Commissioning team: Joe Betzweizer, Suresh Doravari, Chris Guido, Keith Thorne (LLO CDS), David Feldbaum (UF), Matt Heintze (UF), Ryan de Rosa (LSU), Anamaria Effler (LSU)
  - 7-8 LIGO lab personnel including 2-3 visitors from CIT/MIT during the PSL/IO/IMC test

PSL/IO/IMC Test Schedule

- June/July `11: Install input/output vacuum tubes, septum plates
- HAM1
  - February/June `11: Install HEPI
  - July/August `11: Install passive stack
  - September `11: Install ISC
  - October/December `11: Acceptance
- HAM3
  - February/June `11: Modify HEPI
  - August `11: Install ISI
  - September `11: Install SUS
  - October/January `12: Acceptance

PSL/IO/IMC Test Schedule (cont.)

- HAM2
  - February/June `11: Modify HEPI
  - August/September `11: Install ISI
  - October/November `11: Install SUS and Optics
  - January/March `12: Acceptance
- September `11: AOS (stray light baffles)
- **January `12: Start of PSL/IO/IMC testing**
- **May `12: Start of corner Michelson testing**