The LIGO Advanced System Test Interferometer

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LLO LSC

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Mission

- Test LIGO components, systems at full mechanical scale
- Practice installation & commissioning
- Minimize delays & downtime for LIGO site upgrades

Adv LIGO specialization:

- Test Adv LIGO seismic isolation & suspension system and associated controls at full scale
- Develop detailed SEI/SUS installation & commissioning handbook
- Look for unforeseen interactions & excess displacement noise
- Target of opportunity: high-power tests of laser, mode cleaner
- Goal: complementarity to 40m, other performance demonstrations

Plan

- Set up and test the infrastructure: vacuum system, optical sensing system, and data handling
- Test seismic isolation systems 'stand-alone' using seismometers
- To measure relative displacement between the two seismic systems using interferometry
- To test the suspensions as stand-alone elements
- To assemble a Mode Cleaner suspension cavity between the two seismic isolation systems, perform tests of relative motion
- To form a short Test-Mass suspension cavity on the BSC isolation system, illuminated with mode-cleaned light, perform tests of relative motion
- Suspension tests to be done first for 'controls prototypes' of the suspensions; and then for final 'noise performance prototypes' of the suspensions.

Controls vs. Noise suspension prototypes

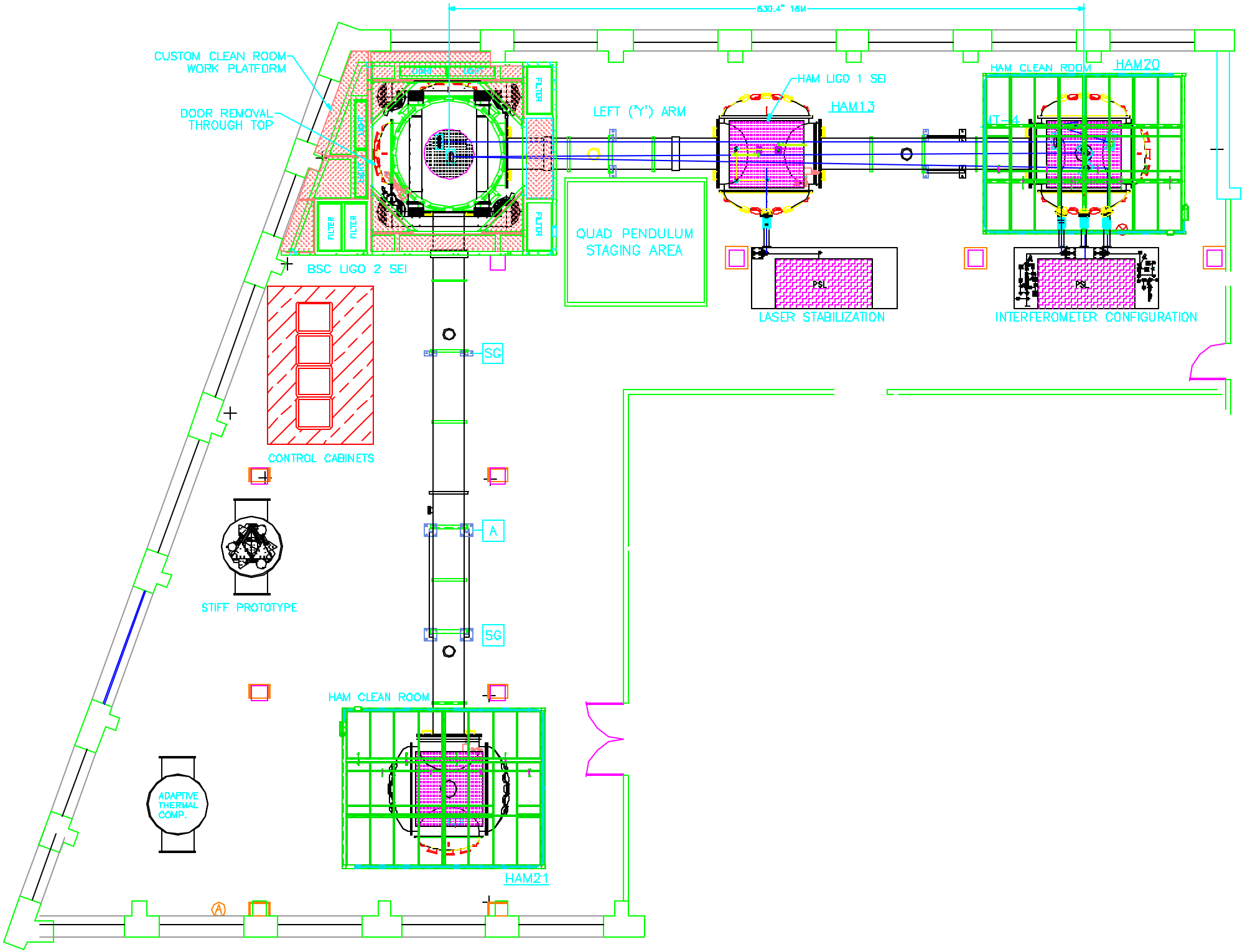
- Initial plan had fabrication of two complete sets of suspensions
- Expensive, and poor timing w.r.t. SEI delivery
- Present plan calls for fabrication of cage, sensors, actuators, upper masses and springs in ‘final design’
- Initial installation with dummy masses, steel wires
- Refit with final optics and silica fibers when ready
  - » Installation plan and practice
  - » Initial shakedown of suspension and controls
  - » Optics and fibers ready

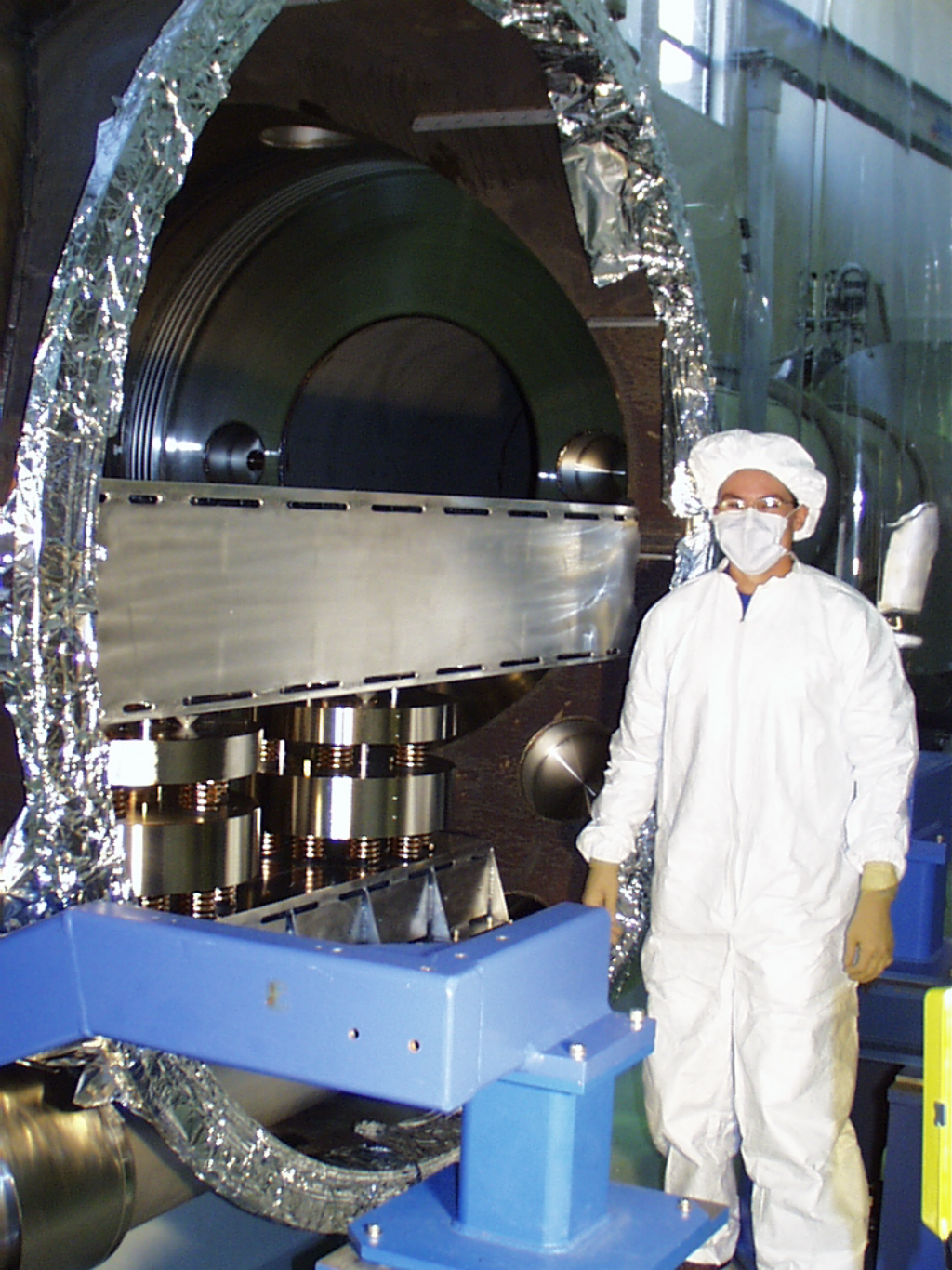
Design goals

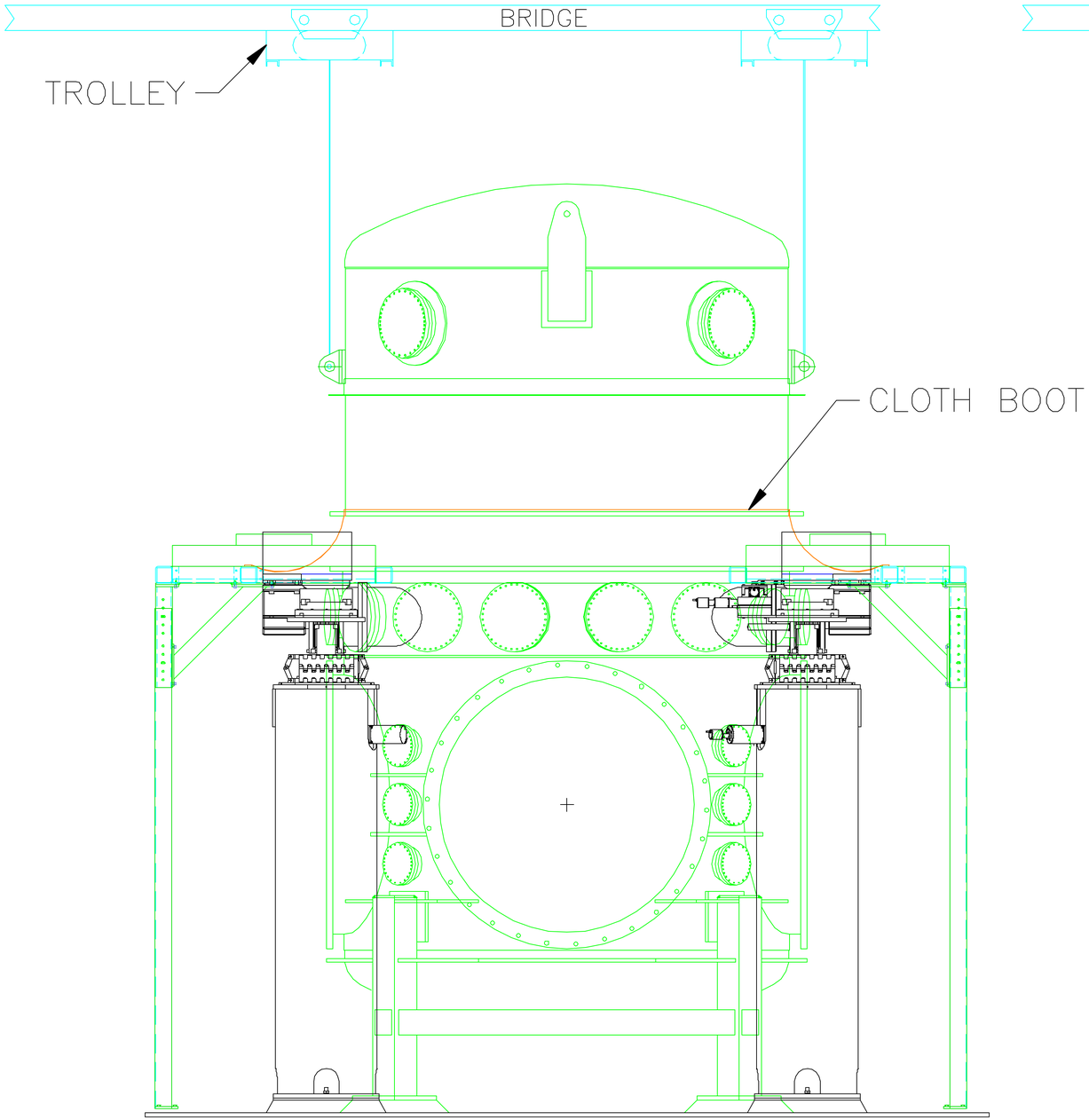
- Conceptual design and measurement goals consistent with the realistic aspirations for lab-scale tests of the mechanical system for the next generation LIGO
- Choosing a reasonable trade of sensitivity vs. heroism
- A system simple enough to succeed in the allotted time
- Be at a ‘sweet spot’ for the exploitation of the installation and the manpower
- Capable of being responsive to changes in the program due to (incremental) changes in suspension or isolation design, e.g., Sapphire/Silica

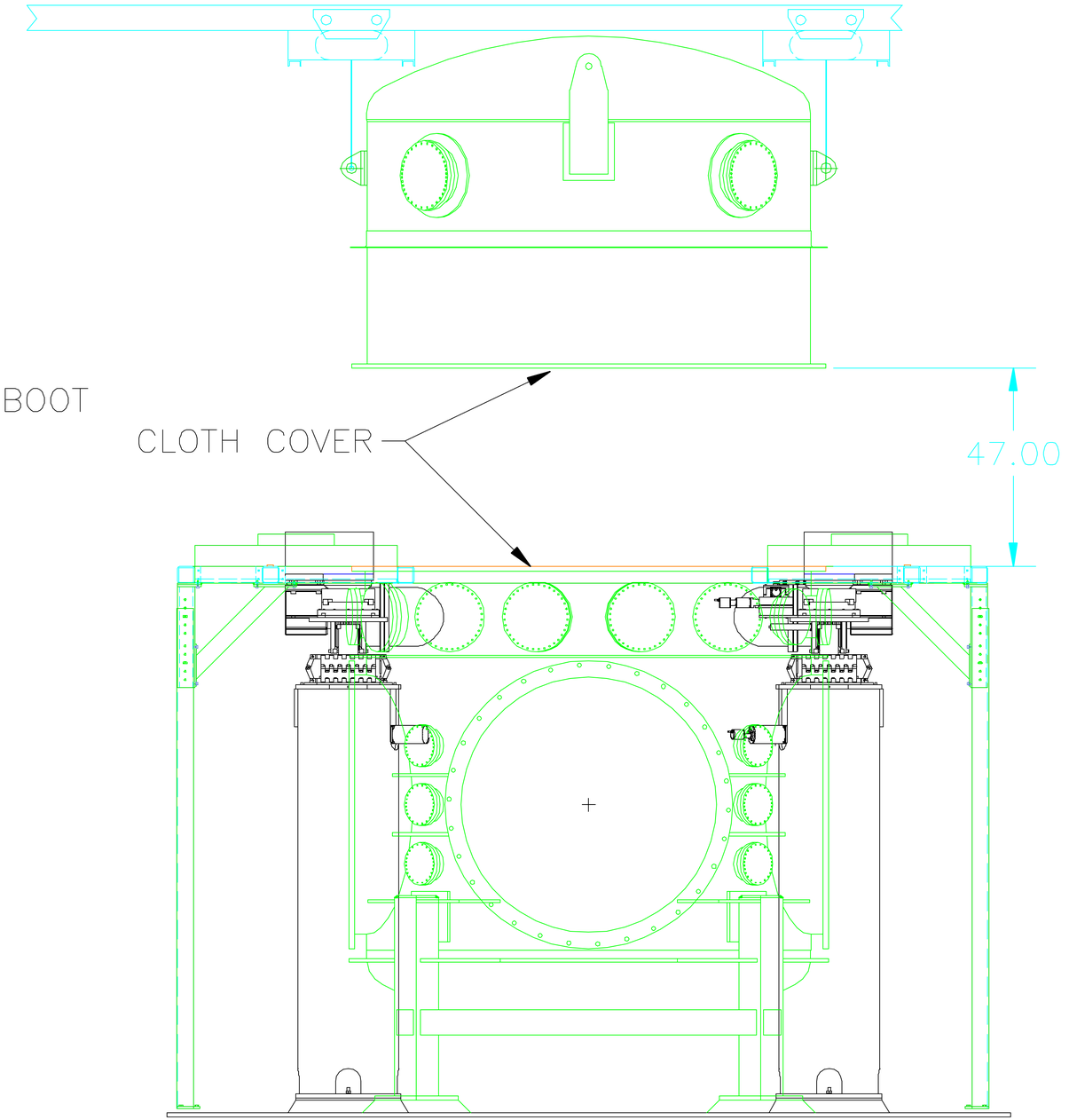
LASTI

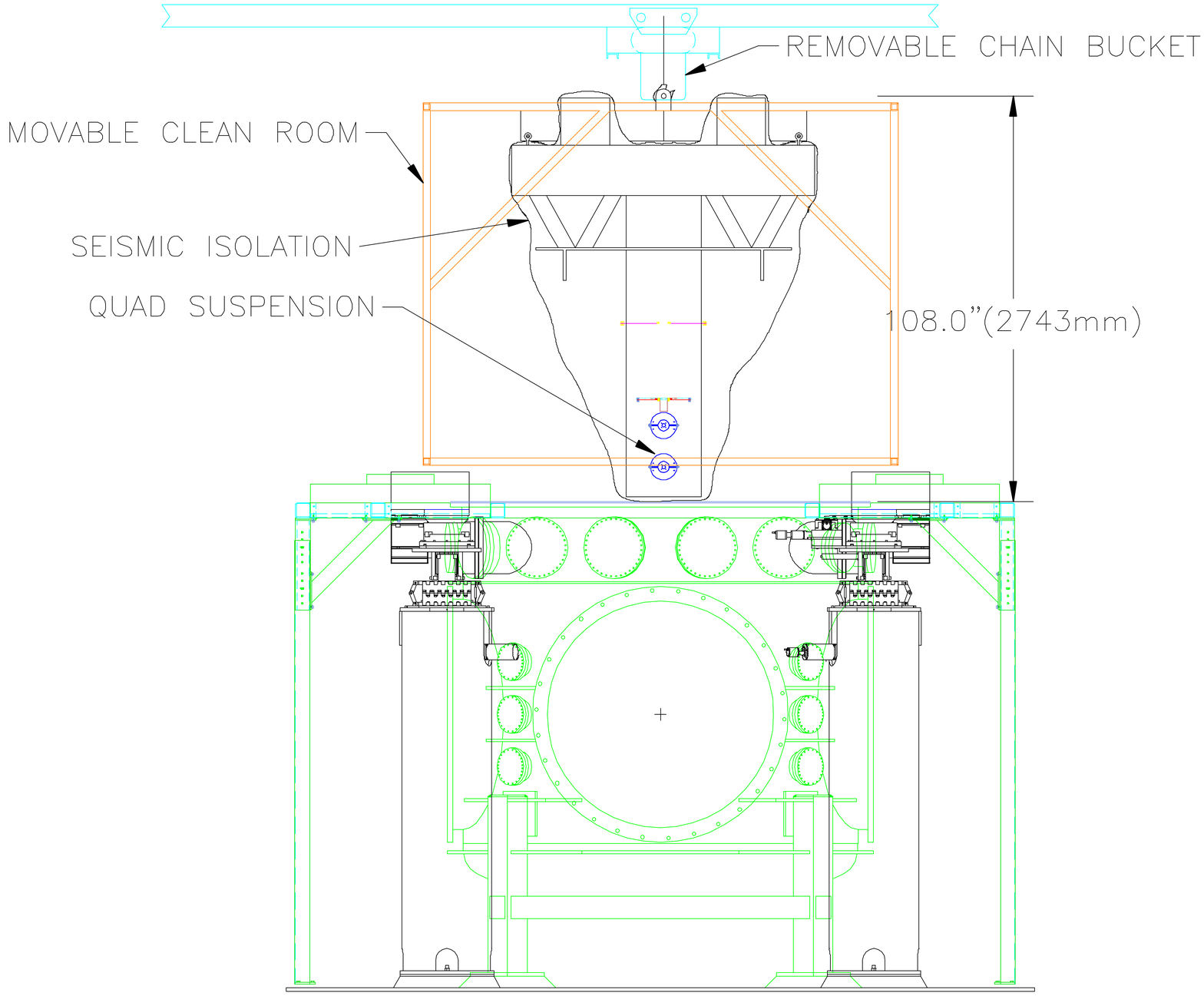
- LIGO Vacuum Chambers
- BSC, HAM
- ‘L’ arrangement
- 16 m baseline
- Clean High Bay
- Bridge Cranes
- Support Labs

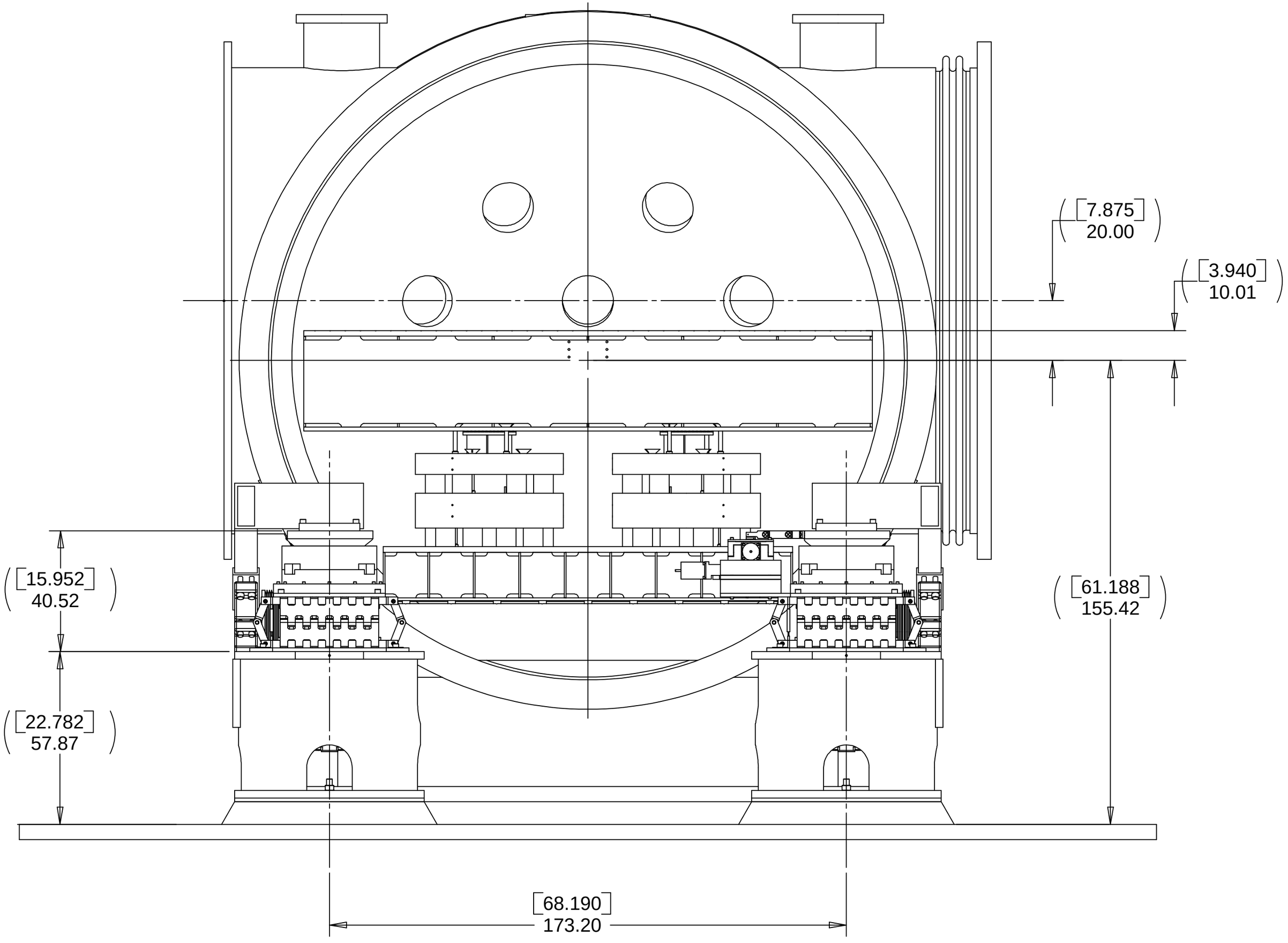

630.4" 16M
CUSTOM CLEAN ROOM WORK PLATFORM
DOOR REMOVAL THROUGH TOP
FILTER
FILTER
FILTER
FILTER
BSC LIGO 2 SEI
LEFT ('Y') ARM
HAM LIGO 1 SEI
HAM13
QUAD PENDULUM STAGING AREA
PSL
LASER STABILIZATION
HAM CLEAN ROOM
HAM20
PSL
INTERFEROMETER CONFIGURATION
CONTROL CABINETS
SG
A
SG
STIFF PROTOTYPE
HAM CLEAN ROOM
ADAPTIVE THERMAL COMP.
HAM21
A




BRIDGE
TROLLEY
CLOTH BOOT


CLOTH COVER
47.00


REMOVABLE CHAIN BUCKET
MOVABLE CLEAN ROOM
SEISMIC ISOLATION
QUAD SUSPENSION
108.0"(2743mm)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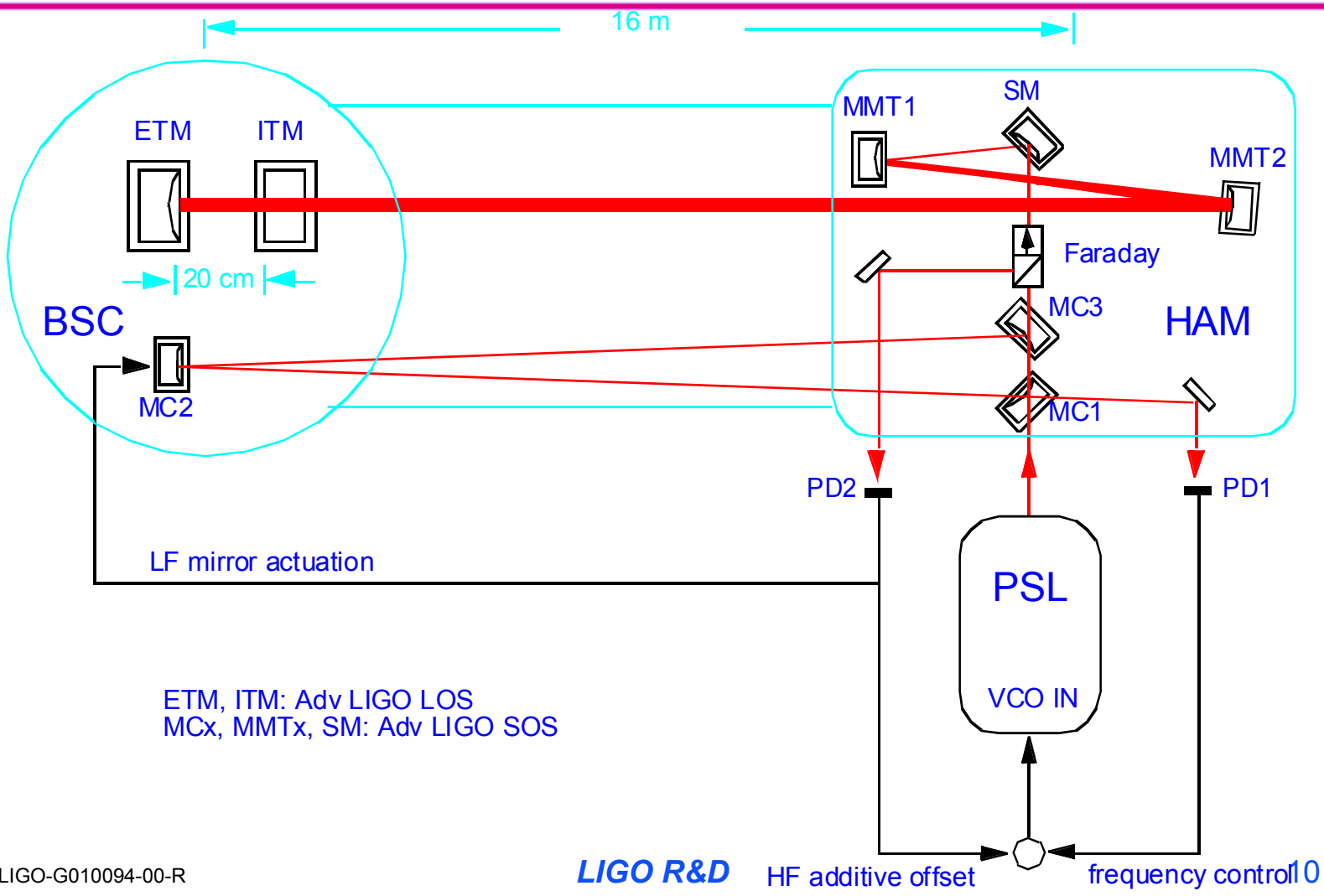
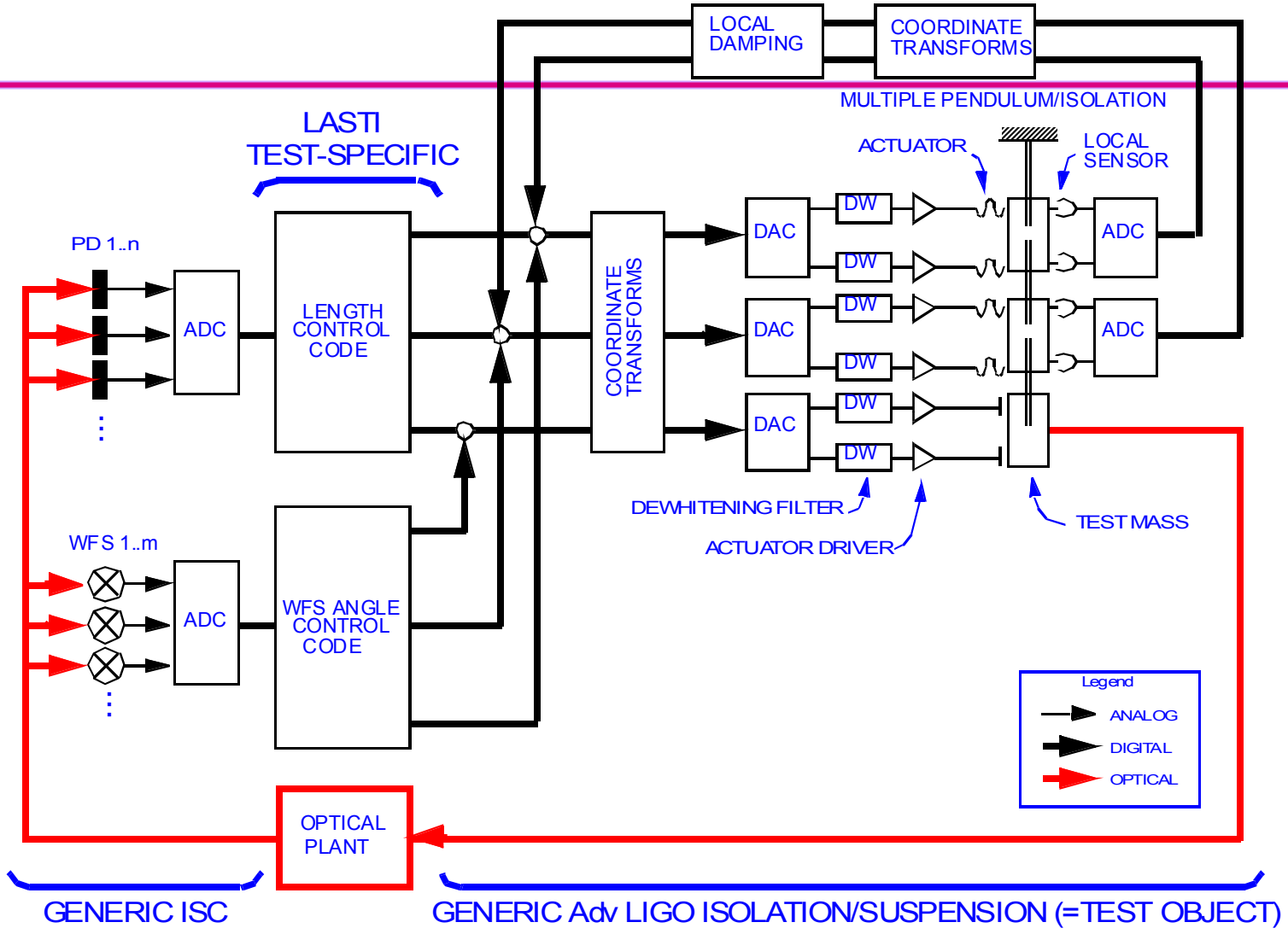
173.20

Baseline Optical Configuration



Controls Implementation



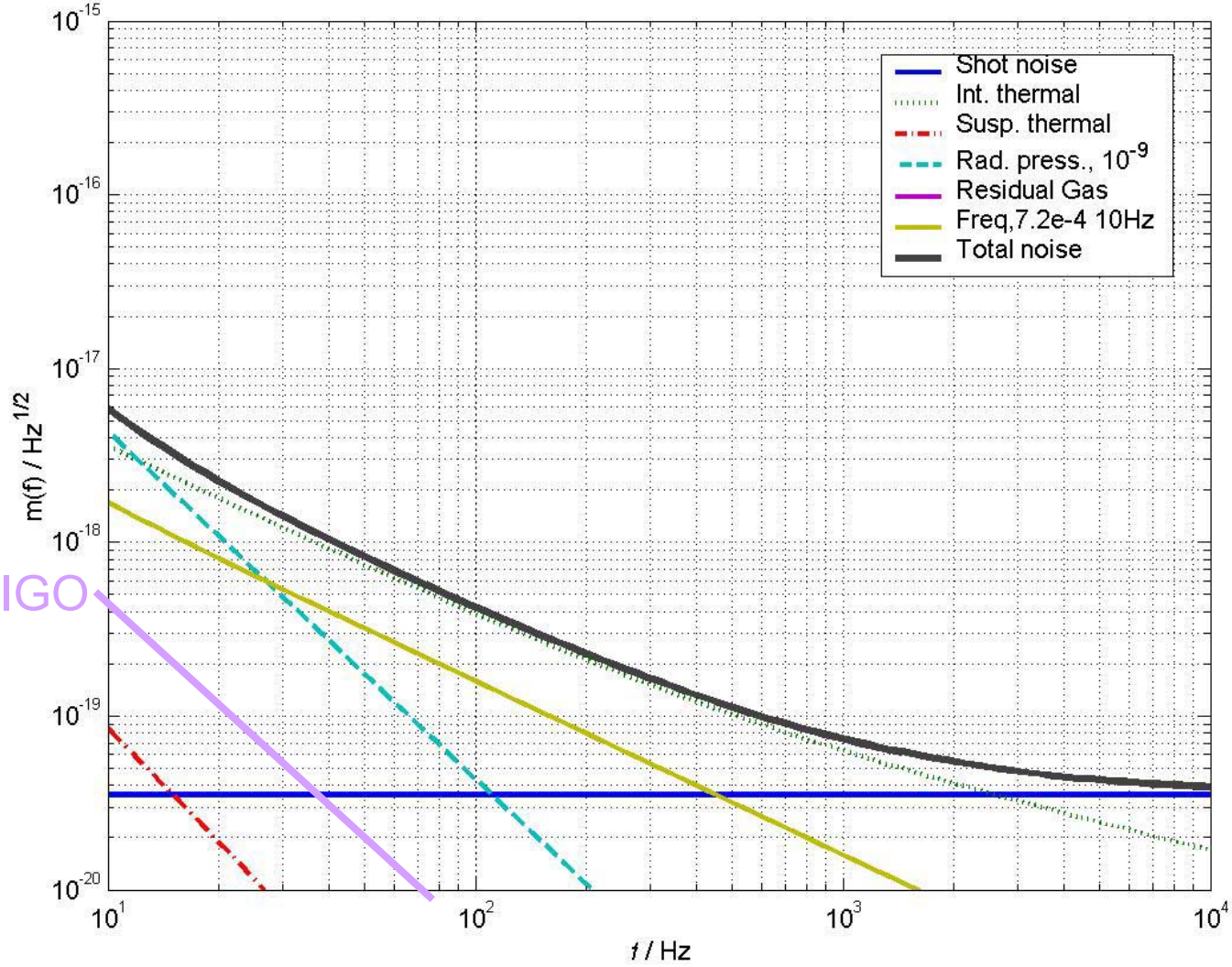
Things to discuss

- Thermal noise
- Seismic noise
- Sensing noises
- Pacing from subsystems
- Controls vs. noise testing
- Tests beyond seismic isolation and suspensions

Thermal Noise

- Internal thermal noise is anticipated dominate spectrum (sapphire or silica masses)
  - » could be frequency noise, esp. if silica test masses, of internal thermal noise of Mode Cleaner
- Beam spots smaller than LIGO
  - » leads to much greater internal thermal noise
  - » Manageable for fused silica (~5-50x greater than Adv LIGO)
  - » Awful for Sapphire in baseline design

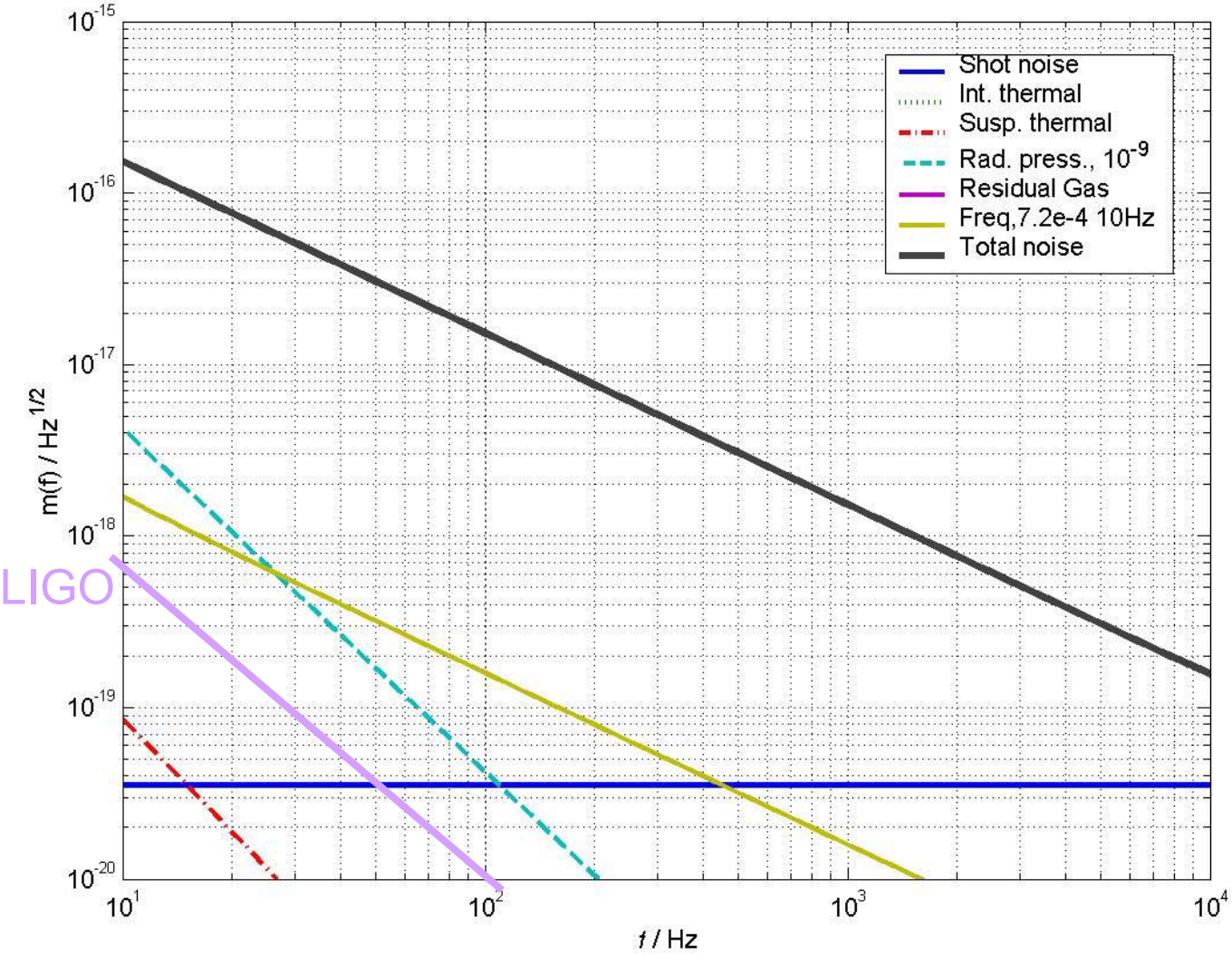
Fused Silica Test Mass Substrates



Adv LIGO

Sapphire Test Mass Substrates

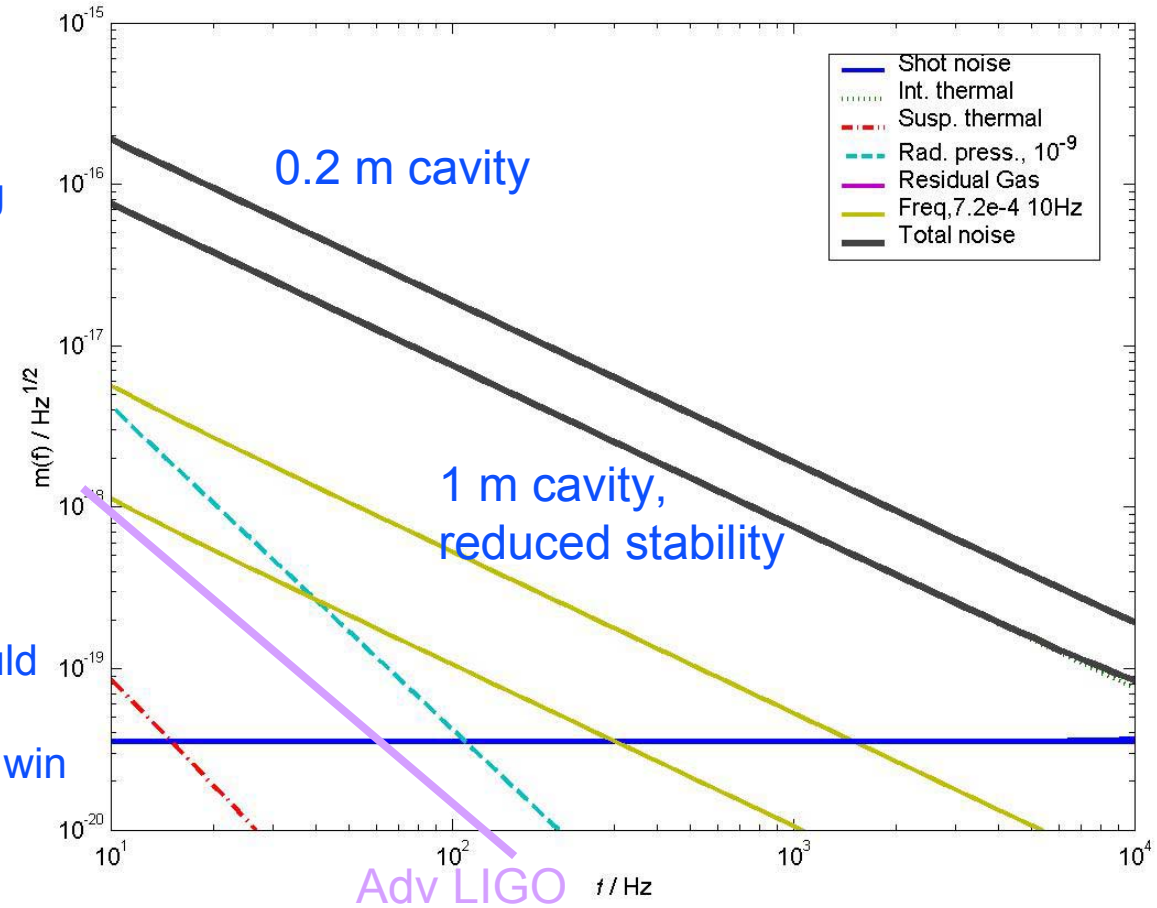
(g=1/3 cavity, sub-mm spots)



Adv LIGO

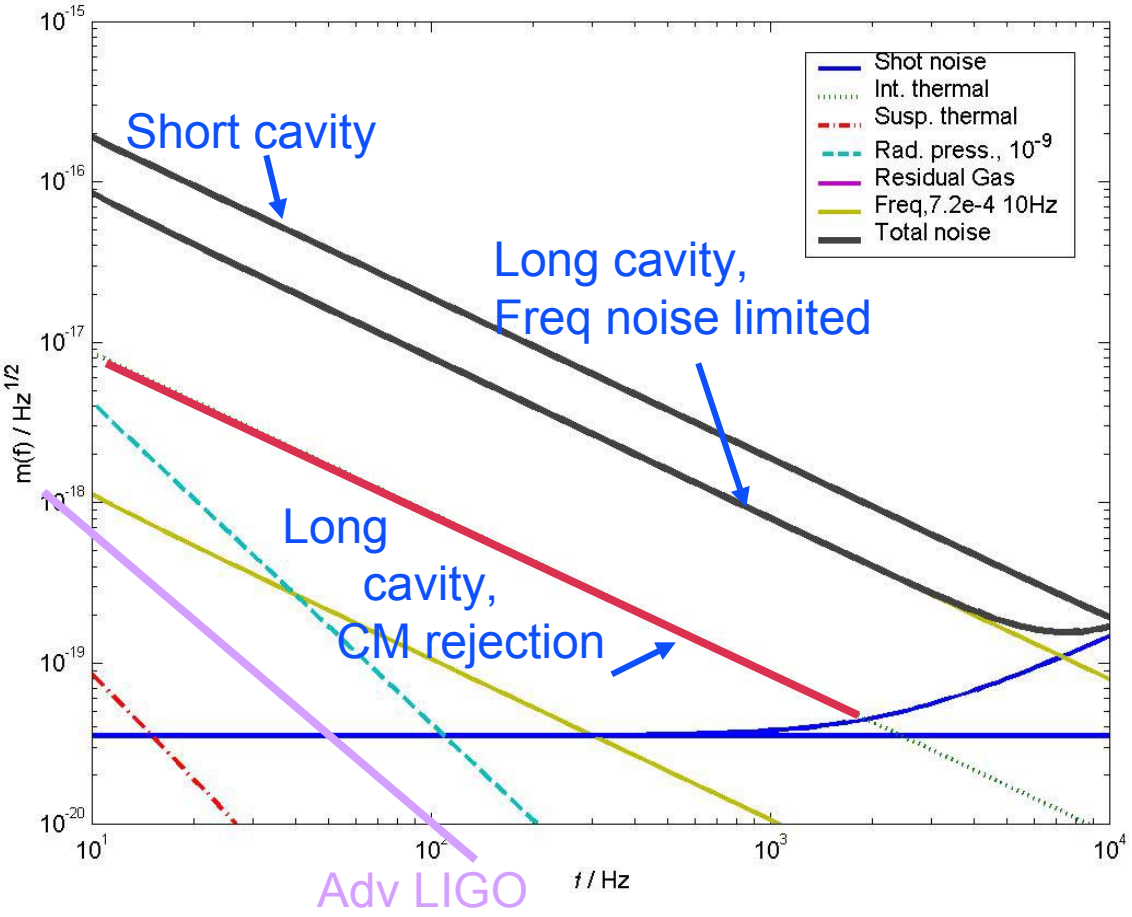
Sapphire thermal noise: Possibilities

- Marginally stable cavity for larger spots
  - » Factor 3 in spot size, ~5 reduction in noise – looks feasible, wavefront sensing signals still available
  - » TBD if larger is sensible: models and tabletop experiments planned.
  - » Alignment stability (and sensing) is the issue
- Slightly longer cavity
  - » BSC table is 1.5 M dia; could go from present model of 20cm to as much as 1 m – win with square root

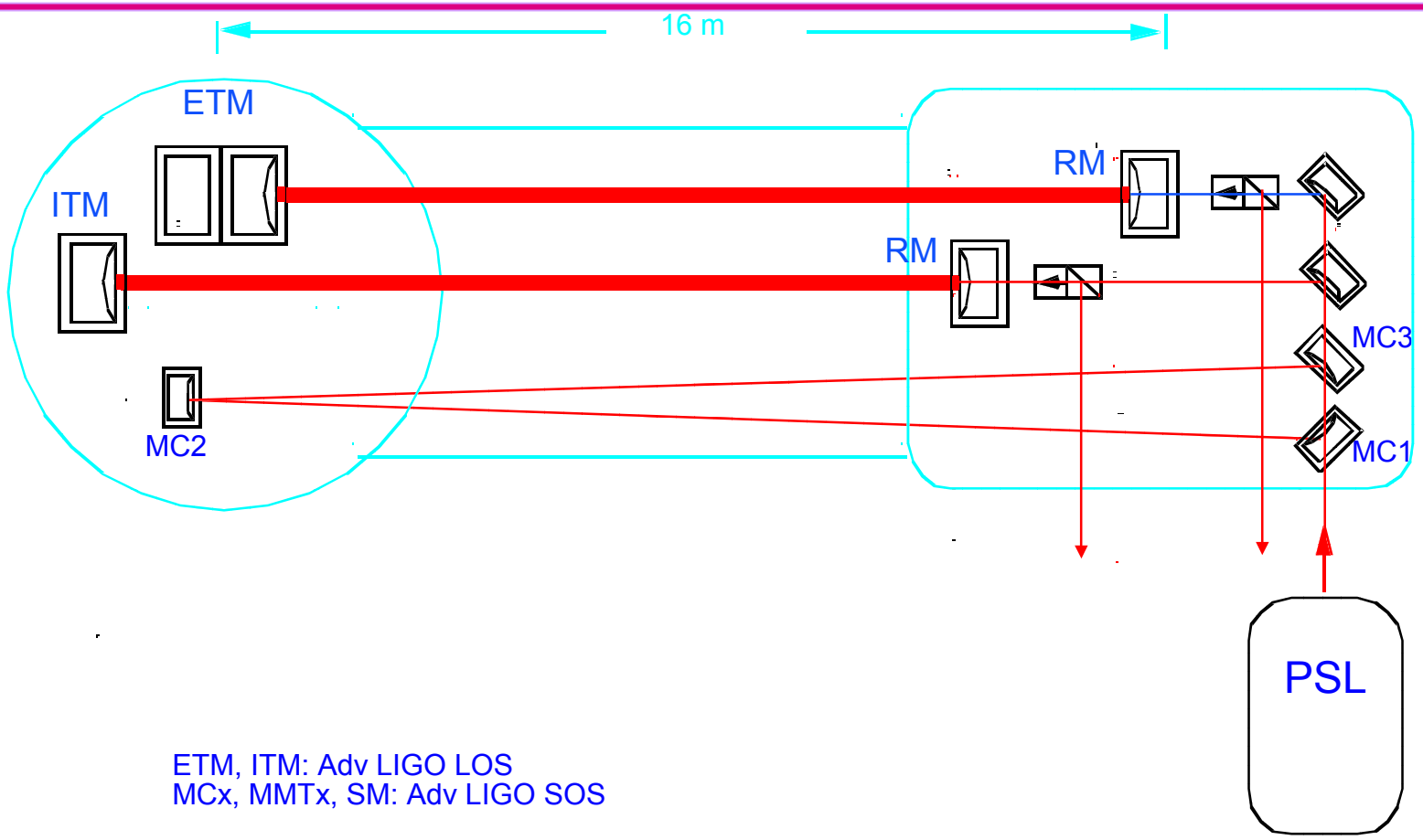


Sapphire thermal noise: Possibilities

- 15 m cavity, asymmetric
- Use TM – RM
- Significantly lower thermal noise, but frequency noise 'leverage' gone
- Can make two parallel cavities (sapphire-silica each), get CM rejection
- Could eke out yet a bit more with lower-stability cavities (larger spots)



Long Cavity Optical Configuration



ETM, ITM: Adv LIGO LOS
MCx, MMTx, SM: Adv LIGO SOS

Long cavity scheme

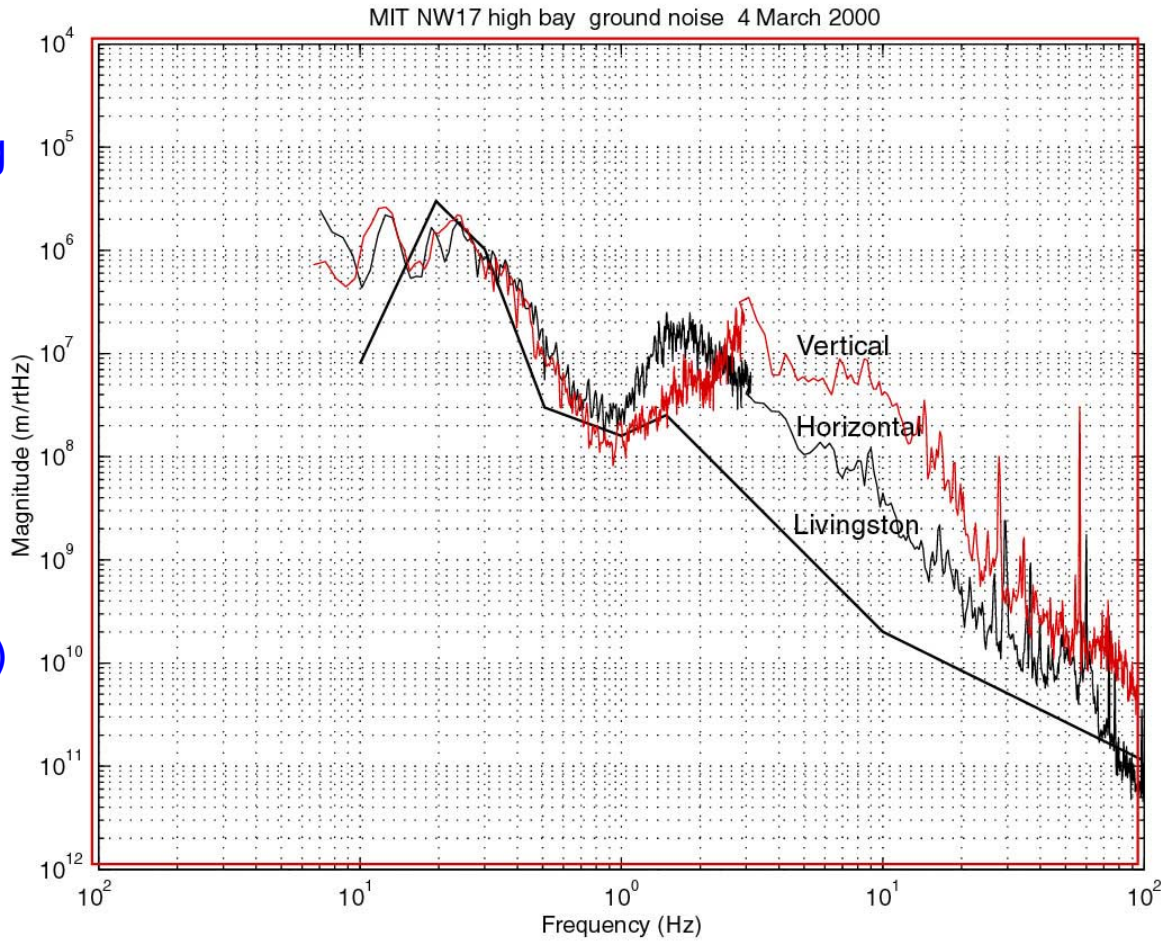
Reduces thermoelastic contribution such that we test to ~10x – 50x the Adv LIGO noise for sapphire

- Increase in interferometer optical complexity
  - » Add a second photodiode, wavefront sensing system, optical isolator; SOS-style beamsplitter and steering mirror
  - » (Identical to old 40m configuration that demonstrated initial LIGO displacement noise)
- Increase in demand on COC/SUS
  - » Add a second Recycling Mirror and suspension, both with short (~1000 m) ROC; can be repolished to be used as Production Items
  - » Both Test Masses can be 'ETM Production Items' in ROC and transmission
- Does it fit? It is too heroic?

Seismic noise

- Seismic noise at MIT Campus site greater than sites

- Stiff seismic isolation falling as ~$1/f^2$, so similar noise at 30 Hz to LIGO
- Suspension falling as $1/f^8$ (TM) or $1/f^6$ (MC); at LIGO noise by 15 Hz
- For masses on a common table, common mode motion to some level (10^2?)



Seismic noise

- MIT much noisier (and variable) than sites in controls band
- Also would like to have source of excitation for testing
- Plan to implement the SEI hydraulic actuators
  - » Feedforward and locally sensed feedback
- Start with one hydraulic system under LIGO I HAM stack
  - » Potential also as test of remedial retrofit for initial LIGO
  - » Schedule TBD, but LASTI installation is ready and available
    - – Would love to accomplish this during summer 2001

Optical sensing noise

Influence scales in ratio of length of TM cavity to MC cavity (typ. 1:50)

- Adv LIGO frequency noise requirement TBD (readout scheme…)
- Probable ~10^-3 Hz/rHz at 10 Hz, 10^-4 at 100 Hz
  - » limited by thermal noise of suspensions, substrates
- Used in models above – looks workable
- Shot Noise - want it well below thermal noise in broad frequency range; easy with LIGO I laser (~5-10 W), finesse of both cavities ~ 2000
- Radiation pressure noise - ditto on requirement; assume 10^-9 (Adv LIGO components but used at <1/10 power); no problem

Tests beyond Isolation and suspension

- Will study PSL, IO subsystem interface, controls, noise:
  - » Adv LIGO mode cleaner: same length, same optics, same controls, the same environment in a practical sense; compare with second 16m cavity. Start with ~10 W
  - » Pre-stabilized laser: install serial #1 Adv LIGO laser, test in hierarchical servo loop with mode cleaner and a test cavity
- High-power testing of mode cleaner
  - » At actual Advanced LIGO power levels, with correct suspensions and controls
  - » Locking, and operational, tests; independent cavity noise measurement
- High-power testing of test-mass suspensions
  - » realistic photon pressure, but smaller spots – can allay fears of some controls problems
- Propose to review these tests at August LSC meeting

Progress on instrument equipment

- PSL: thanks to LIGO I PSL team, parts largely complete
  - » To be delivered in April, including analog and digital electronics
  - » To be assembled by LASTI team for fun and profit
- Initial test cavity built with initial LIGO SOS: thanks to LIGO I SUS team, parts largely complete
  - » Most mechanical pieces delivered
  - » Will re-use PNI optics
  - » OSEMs/controllers in discussion – depends on initial LIGO and Burr-Brown
- DAQ/GDS: thanks to LIGO I CDS group, configured and ordered
  - » Racks and crates showing up
  - » Challenge will be to assemble, configure, understand, master
- Optical design: with some help from Nergis, getting going
  - » All detailed work to be done, and better get underway soon

Demands on Subsystems

- Dates are ‘old’ – look critically
- Seismic Isolation
  - one HAM in 1Q02 (parts and people arrive)
  - one BSC in 3Q02 (parts and people)
- Suspensions
  - (2 LIGO I SOS like suspensions/optics for start-up tests; probably 2-4 more in 1Q02)
  - one MC ‘controls’ prototype (dummy masses, steel fibers) ready to install in 1Q02 (parts and people)
  - one TM controls prototype in 3Q02
  - 3 (or maybe 4) MC ‘noise’ (fused silica fibers) in 2Q03
  - 1 ITM ‘noise’ prototype in 2Q03
  - 1 ETM ‘noise’ prototype in 2Q03
  - 1 (or 2 if long cavities) RM ‘noise’ prototypes in 2Q03

Demands on Subsystems

- Core Optics
  - (1" optics for 'controls' prototypes, 1Q02, 3Q02)
  - 3 MC real optics in 2Q03
  - 1ETM sapphire/silica optic in 2Q03 (can be e.g., a pathfinder)
  - 1 'custom' (short radius of curvature, only good in center) ITM sapphire/silica optic in 2Q03 (or a second 'stock' piece if long cavities)
  - 1 (or 2 if long cavities) RM optic, relatively short ROC (~1km)
- Laser
  - parts for 10 W LIGO I PSL in 1Q01
  - Adv LIGO PSL in 1Q04 (complete and installed – need to discuss installed)
- Input Optics support
  - Modulation, controls to complement Mode Cleaner by ~2Q03

Demands on Subsystems

- DAQ/GDS (by 4Q01)
  - » small-scale LIGO I system; like 40m
  - » just disk storage
- ISC (by 4Q02)
  - » 2 (or 3 if long cavities) LIGO I length photodiodes, demod
  - » 4 (or 6 if long cavities) quad alignment sensors, demod
  - » subset of LIGO I controls (2 copies of LIGO I MC controls)
  - » (controls for SUS and SEI delivered with them)
  - » (supervisory control either LIGO I or Adv LIGO derived)

Schedule

- 4Qq99: LASTI envelope commissioned DONE
  - » The vacuum envelope is installed and aligned; the vacuum pumping system is commissioned, and the system is pumped down for the first time.
- 1Q00: LASTI external structures installed mostly DONE
  - » The HAMs are installed; waiting on BSC until initial LIGO staff free
- 2Q00: LASTI infrastructure design review DONE
  - » covers noise sources; models for the performance of the system; estimates for the optical sensing system, control and data, mechanical interfaces to LASTI; and the experimental program.

Schedule – to be updated during this meeting

- 3Q01 ►4Q01: LASTI infrastructure complete
  - » sensing system, control and data, and a trial cavity test of the complete system function
- 1Q02: HAM pathfinder installation complete, standalone testing starts
- 2Q02: MC controls SUS installation complete, testing starts
- 3Q02: BSC pathfinder installation complete, standalone testing starts
- 4Q02: TM controls SUS installation complete, testing starts

Schedule – should not change

- 3Q03: LASTI controls test review
  - » An understanding of the controls performance of the seismic isolation systems and of the suspensions
- 2Q04: LASTI noise prototype installed
  - » The 'controls prototypes' for suspensions changed out and fused silica fiber, sapphire test mass Test Mass suspensions installed.
- 2Q05: LASTI SUS/SEI test review
  - » The status of tests to meet the noise performance verification.
- 3Q05: Adv LIGO PSL/MC tests start

People

- On board: Gregg Harry, Jamie Rollins, Rich Mittleman
- To arrive: Joshua Phinney, add'l PostDoc
- In bits and pieces: Ken Mason, Mike Zucker, David Shoemaker, add'l Electrical Engineer
- Indespensible: Myron MacInnis, add'l Technician
- You: the LSC

General Questions

- How hard to push on noise performance for sapphire test masses?
- Does the system provide the infrastructure, and carry the right program for testing the
  - » SUS
  - » SEI
  - » PSL
  - » IO

Random testing questions

- SUS/SEI
  - » External excitation
  - » Safety/robustness
  - » SEI table tilts
  - » Optical levers
- SUS
  - » Photon actuator (technically AOS)
  - » Thermal compensation (ditto)
  - » Violin mode monitor(s), damping
  - » Excitation/damping of internal mass modes
- SEI
  - » Seimisc displacements, tilts of the floor
  - » Magnetic field mapping