LIGO ADVANCED SYSTEM TEST INTERFEROMETER

Conceptual Design Review

LIGO Science Collaboration Meeting

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G000203-00-R

Mission

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

LIGO II specialization:

- Test LIGO II seismic isolation & suspension system and associated controls at full scale
- Develop detailed SEI/SUS installation & commissioning handbook
- Look for unforeseen interactions & excess displacement noise
- Goal: complementarity to 40m, other performance demonstrations

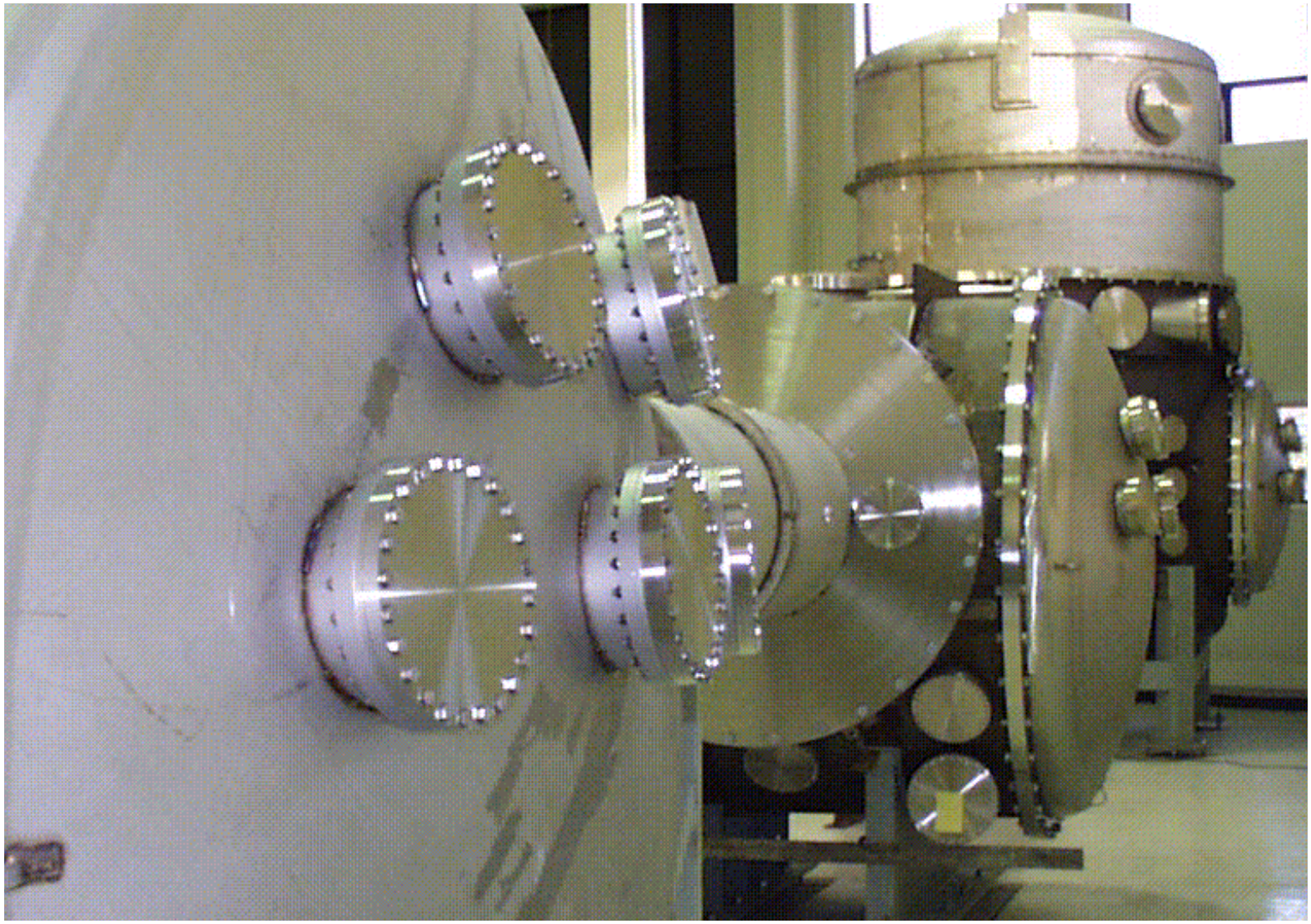
Plan

- 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.

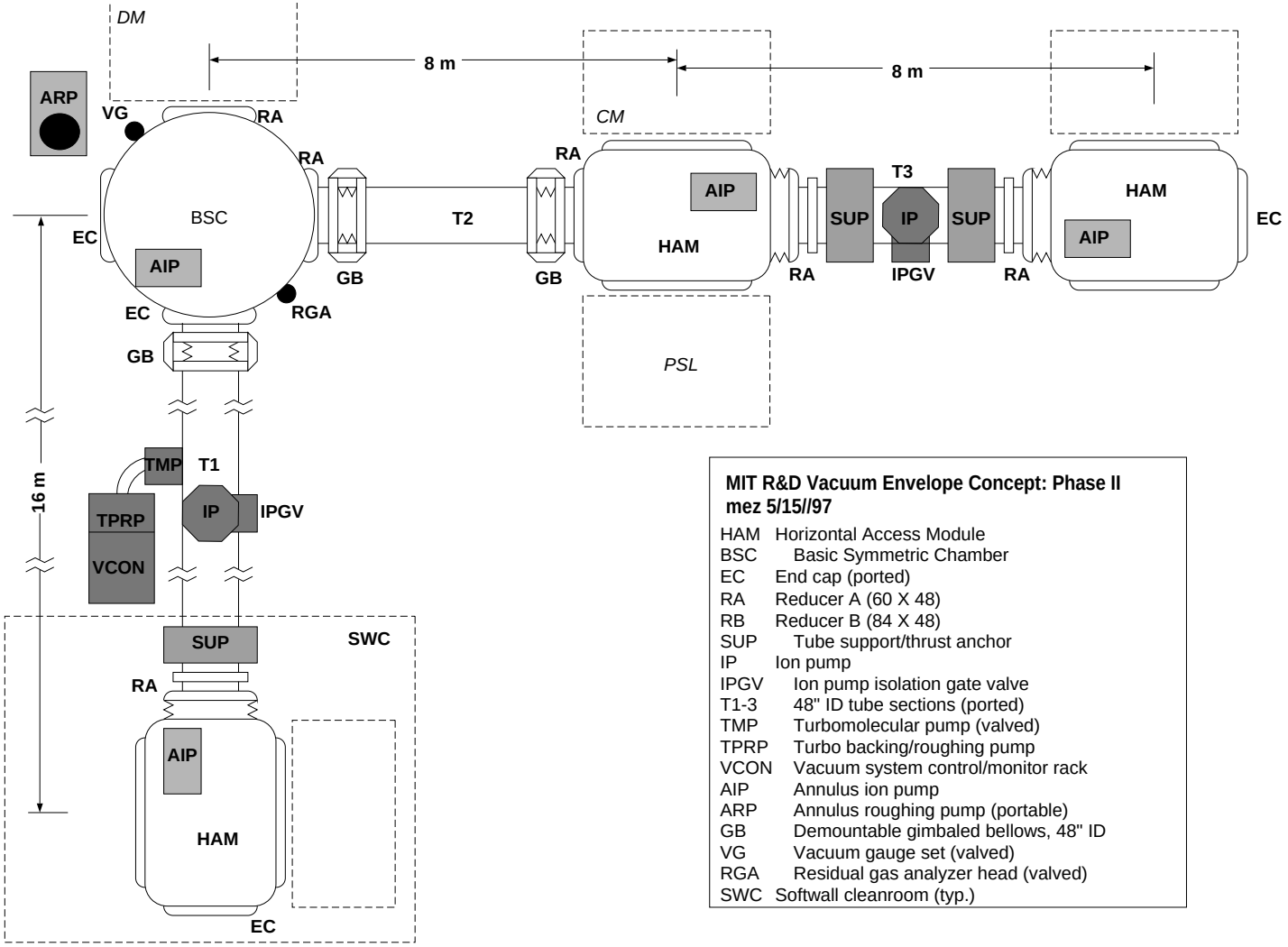
Goals, Questions for this review

- Conceptual Design Review
  - want to proceed with design, acquisition of equipment
  - are our conceptual design and measurement goals consistent with the realistic aspirations for lab-scale tests of the mechanical system for the next generation LIGO
- Key questions:
  - Are we choosing a reasonable trade of sensivitiy vs. heroism?
  - Is the system simple enough to succeed in the allotted time?
  - Are we at some kind of sweet spot for the exploitation of the installation and the manpower?
  - Can it respond to changes in the program due to (incremental) changes in suspension or isolation design, e.g., Sapphire/Silica?
  - additions of tasks (tests of the Mode Cleaner and possibly Laser)?
  - Is there a sense of the response to a different schedule for the next generation LIGO?

Vacuum envelope, left (S) arm



General vacuum equipment arrangement plan



MIT R&D Vacuum Envelope Concept: Phase II
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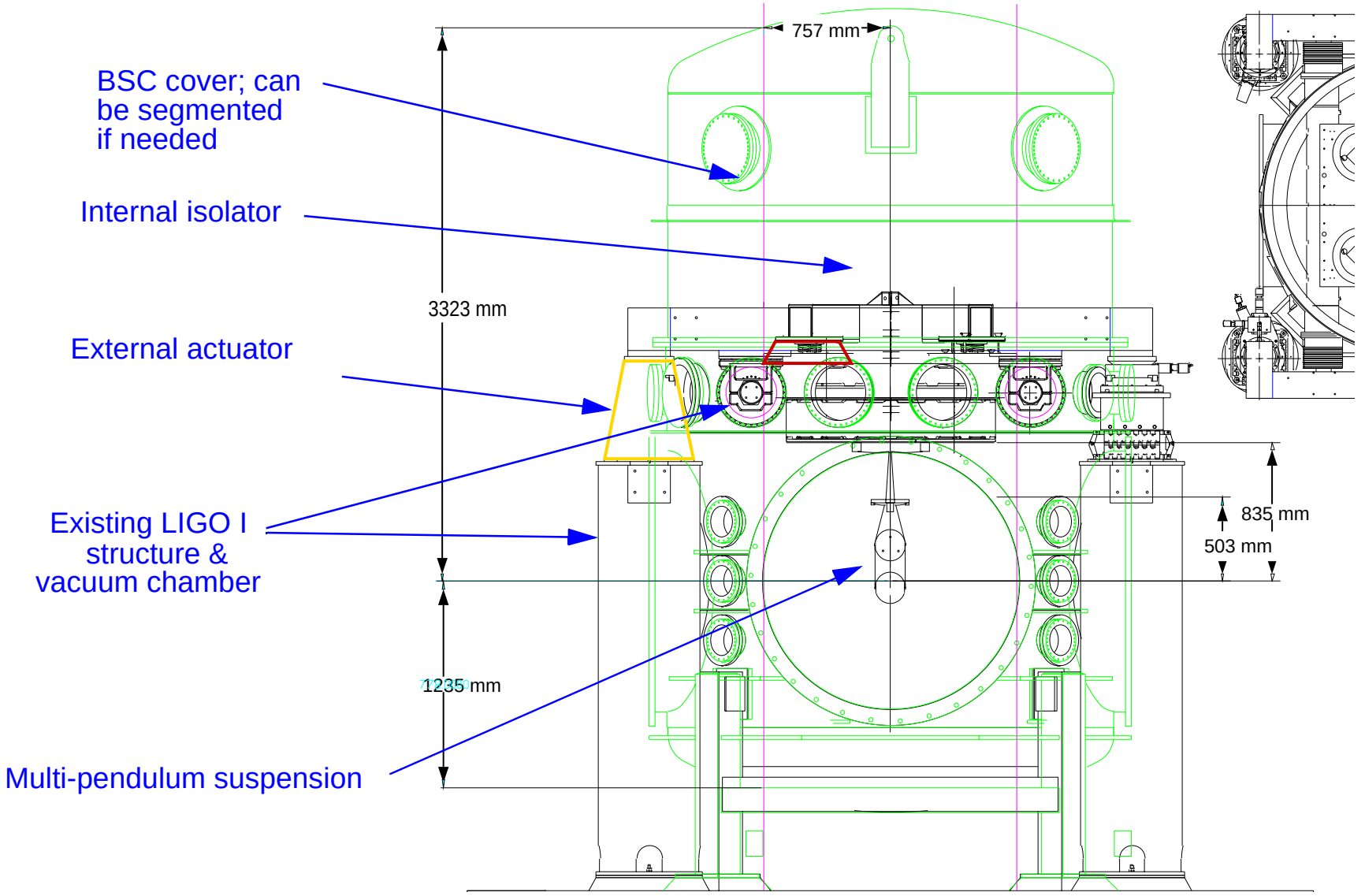
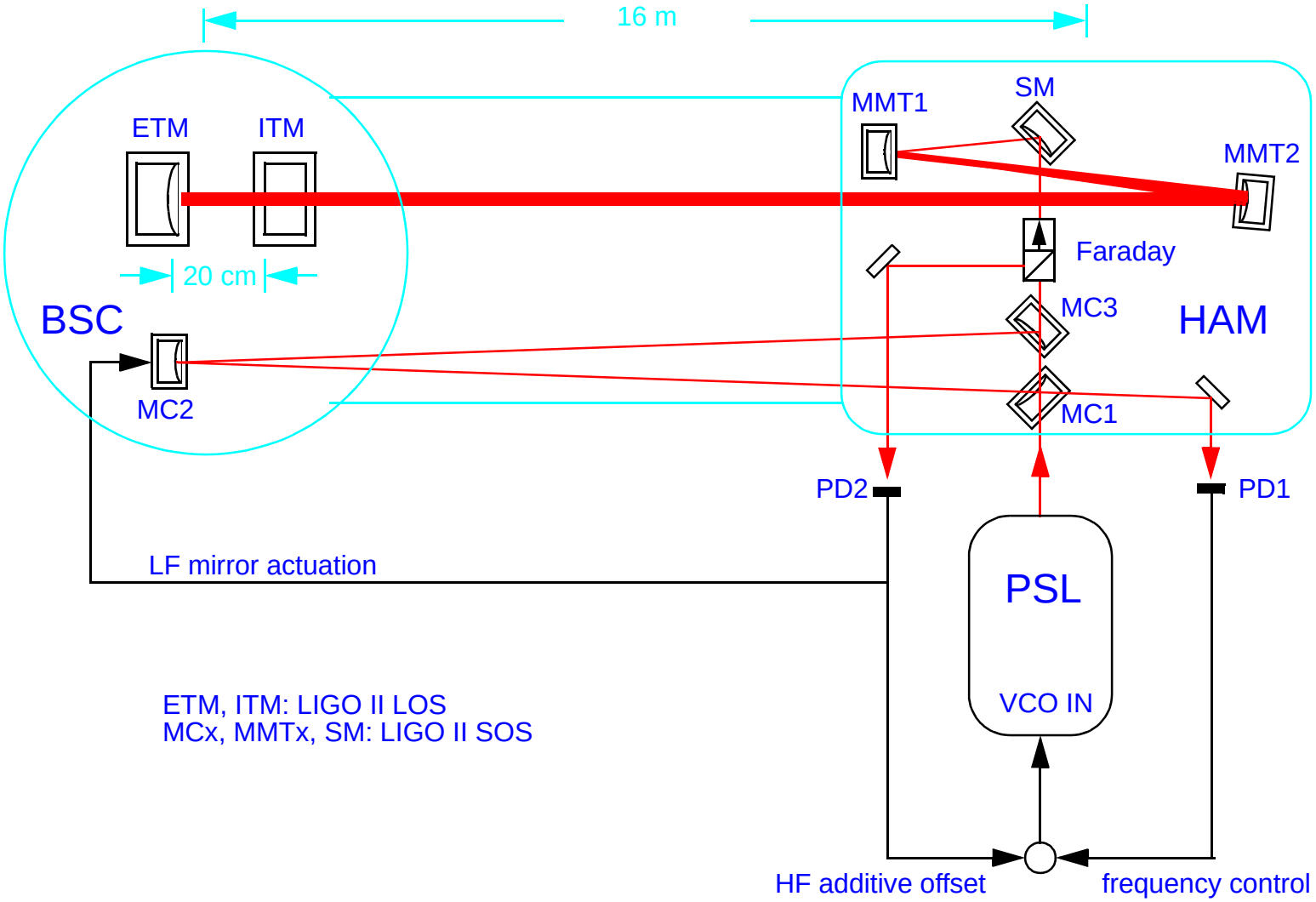
HAM	Horizontal Access Module
BSC	Basic Symmetric Chamber
EC	End cap (ported)
RA	Reducer A (60 X 48)
RB	Reducer B (84 X 48)
SUP	Tube support/thrust anchor
IP	Ion pump
IPGV	Ion pump isolation gate valve
T1-3	48" ID tube sections (ported)
TMP	Turbomolecular pump (valved)
TPRP	Turbo backing/roughing pump
VCON	Vacuum system control/monitor rack
AIP	Annulus ion pump
ARP	Annulus roughing pump (portable)
GB	Demountable gimbaled bellows, 48" ID
VG	Vacuum gauge set (valved)
RGA	Residual gas analyzer head (valved)
SWC	Softwall cleanroom (typ.)

Test target


BSC cover; can be segmented if needed
Internal isolator
External actuator
Existing LIGO I structure & vacuum chamber
Multi-pendulum suspension
757 mm
3323 mm
835 mm
503 mm
1235 mm

Proposed optical configuration



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

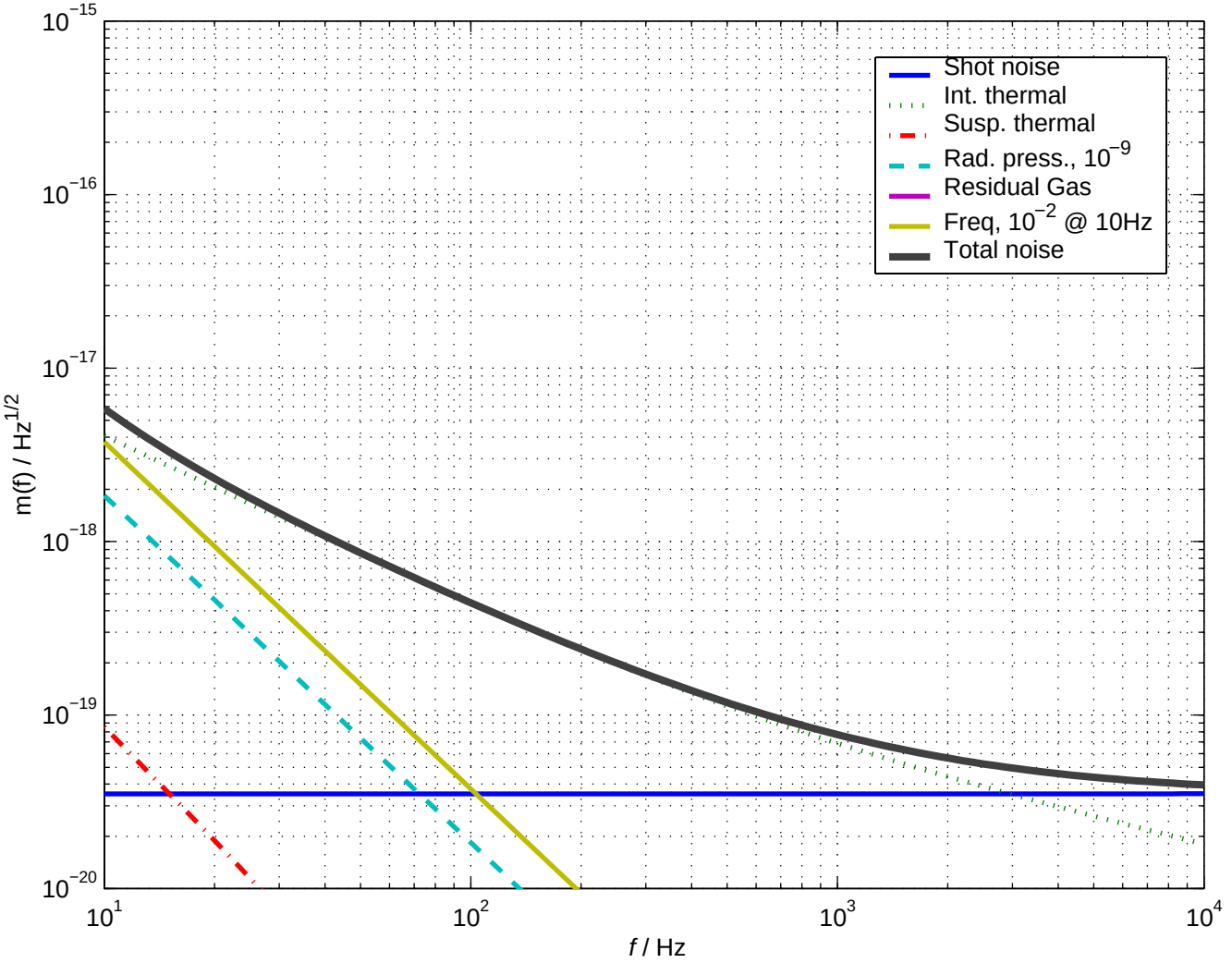
Measurement challenges and foci

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

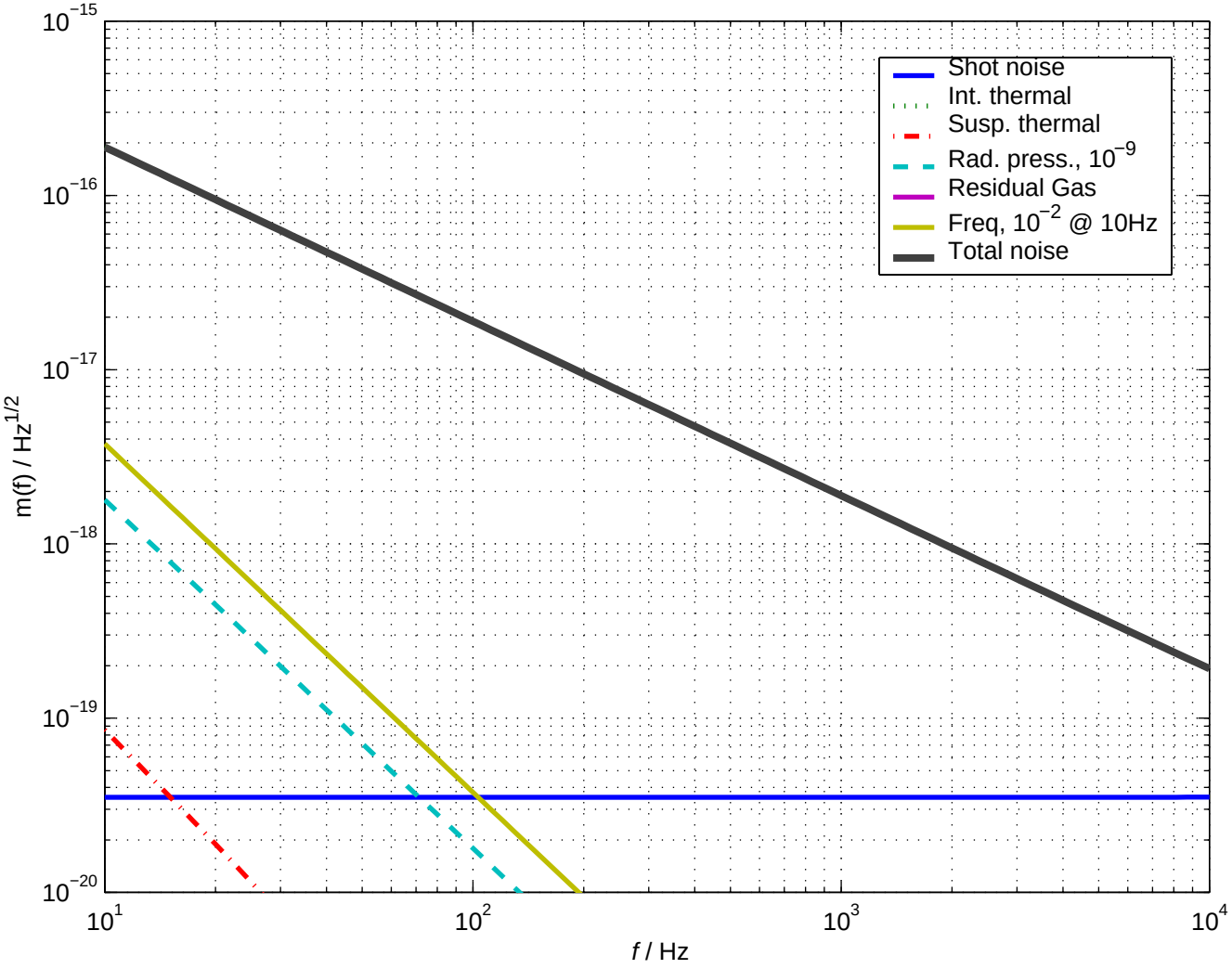
Thermal noise

- Internal thermal noise will probably dominate spectrum (sapphire or silica masses)
  - could be frequency noise, esp. if silica test masses
- Beam spots smaller than LIGO
  - needs some theoretical work for small spots - maybe quieter?
- short cavity (0.1-1m): spot size w~0.5 mm
- high-finesse and well-aligned nearly unstable cavity: w~5 mm?
- long cavity (~16 m)
  - formed of one TM and one MC suspension
  - MC suspension noise critical; if fused silica fibers, probably ok
  - spot size ~5 mm if g=1/3, could possibly force a larger beam

Silica TM substrates



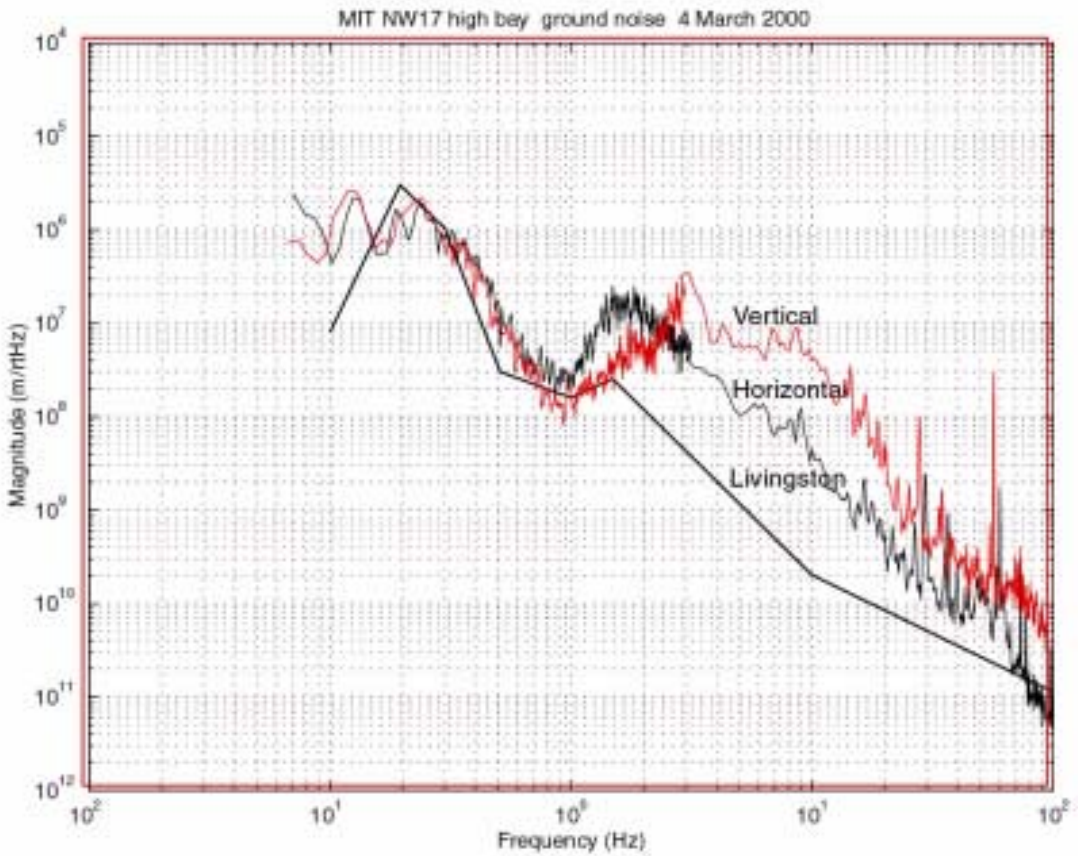
Sapphire TM substrates



Seismic noise

- Seismic noise at MIT Campus site greater than sites
  - similar RMS (dynamic ranges ok, performance test realistic)larger at e.g., 10 Hz by 10x to 100x
  - makes only small change in test start frequency

- 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?)



Frequency Noise

- minimum LIGO II MC requirement: 10^-2 at 10 Hz, 10^-3 at 100 Hz
- corresponds to 3e-16 m/rHz for all three mirrors
- influence scales in ratio of length of TM cavity to MC cavity (typ. 1:50)
- more probable requirement ~10^-3 at 10 Hz, 10^-4 at 100 Hz

- 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 (LIGO II components but used at <1/10 power)

Schedule constraints

- Interleaved availability of critical prototype hardware for nominal dates:
- HAM Seismic isolation pathfinder: available 3Q01
  - 2 months to assemble/install, 6 months of test
- 'Controls' suspension prototypes: 3Q01
  - 3 months to assemble, test in air
  - install as soon as the HAM isolation system is 'safe', 3 months test
- BSC Seismic isolation pathfinder: available 1Q02
  - 3Q01, 2 months to assemble/install, 6 months of test
- TM Controls suspension prototype - ready back in 3Q01?
  - install as soon as the BSC isolation system is 'safe', 3 months test
- Controls testing: a TM/BSC and MC/HAM cavity testbed, or.....
- 'Noise' suspension prototypes available 2Q03 - maybe jump over cavity testing with 'Controls' suspensions?

Controls vs Noise testing

- Cannot reasonably test at LIGO II displacement noise levels due to thermal noise
- All other infrastructure requirements become stiffer if strive ‘heroically’
- Controls testing is necessary, and possible,
  and a precursor to noise testing
- Propose to perform initial controls testing with just two suspensions: one TM, one MC, forming simple linear cavity
  - limits number of crude prototypes to be made
  - controls work can, nay, must continue with ‘noise’ suspensions
- PROBLEM: noise testing of actual LIGO II components will wait until actual installation, after commitment to designs and fabrication.
- Best solution involves clearly some noise testing.
  More time available, more testing.

Tests beyond suspension and isolation

- Can study many other controls problems perfectly, in particular
  - LIGO II mode cleaner: same length, same optics, same controls, the same environment in a practical sense
  - pre-stabilized laser: could install serial #1 LIGO II laser, test in hierarchical servo loop with mode cleaner and a test cavity
- First 6 months of LIGO II (I) commissioning could be (could have been) performed at LASTI.

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Demands on subsystems

- Seismic Isolation
  - one HAM in 3Q01 (parts and people arrive)
  - one BSC in 1Q02 (parts and people)
  - may need external attenuator (agressive hydraulic system)
- Suspensions
  - (2 LIGO I SOS like suspensions/optics for start-up tests)
  - 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

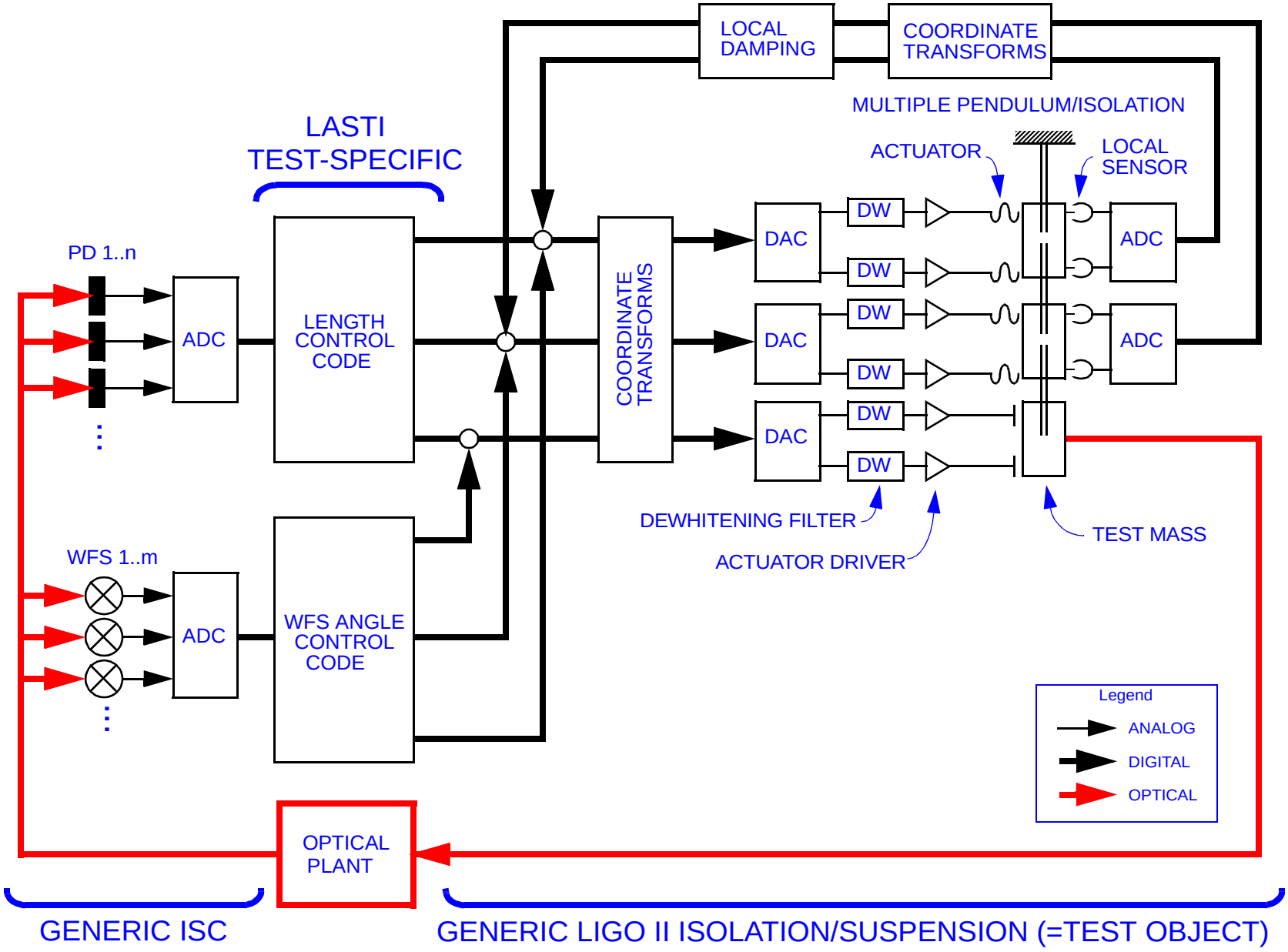
Demands on subsystems

- Core Optics
  - (1” optics for ‘controls’ prototypes, 1Q02, 3Q02)
  - 3 (or maybe 4) 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
- Laser
  - 10 W LIGO I PSL in 4Q00
  - if pursued, LIGO II PSL in 1Q04 (complete and installed)
- Input Optics support
  - if MC testing pursued, modulation, controls to complement Mode Cleaner by ~2Q03

Demands on subsystems

- DAQ/GDS (by 4Q02)
  - small-scale LIGO I system; like 40m
  - just disk storage
- ISC (by 4Q02)
  - 2 LIGO I length photodiodes, demod
  - 4 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 LIGO II derived)

Proposed controls implementation (mostly 'generic LIGO II')



Schedule

- Dates as per White Paper; needs review/revision for near-term
- 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 SEPT !5
  - The seismic piers are erected around the HAMs and BSC. We wish to delay this milestone until a firmer baseline for the seismic isolation is established to avoid any backtracking.
- 2Q00: LASTI infrastructure design review HERE AND NOW
  - 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.

- 3Q01: 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
- 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 final test review
  - This milestone should indicate the status of tests to meet the noise performance verification.

Schedule

- 3Q05: (maybe) LIGO II PSL/MC tests start, or
- 3Q05 LASTI first article installation starts
  - using the planned installation jigs and procedures, for seismic isolation and suspensions.

Personpower

- The success of this endeavor will require significant contributions from LSC members in and out of the Lab for success.
- presently a technician and bits and pieces of Zucker, Mason, and Shoemaker working on the vacuum system and experimental design.
- will ramp up this year to perform the design, procure and install the infrastructure; principally in-Lab personnel (at both MIT and Caltech, the latter for fabrication of PSL and CDS components).
- roughly 5-6 FTEs in the MIT Lab for the latter stages: 1 technician, 1 net FTE engineer, 2 students, 1-2 postdocs/scientists.
- need roughly again as many LSC Folk in moderate-term visits to MIT or thinking hard about the data and making frequent visits
- These manpower guesses do not include the staff associated with specific subsystems; there will clearly be constructive overlap in manpower.

The Last Slide (once again)

- clear that a significant test of the LIGO mechanical system can be performed
  - controls
  - performance - possible reduction in thermoelastic estimate TBD
- schedule workable, coordinated
- personpower requires strong collaborative effort, as for all of LIGO II