
# Initial LIGO Seismic Isolation System Upgrade

Dennis Coyne

LIGO Seminar

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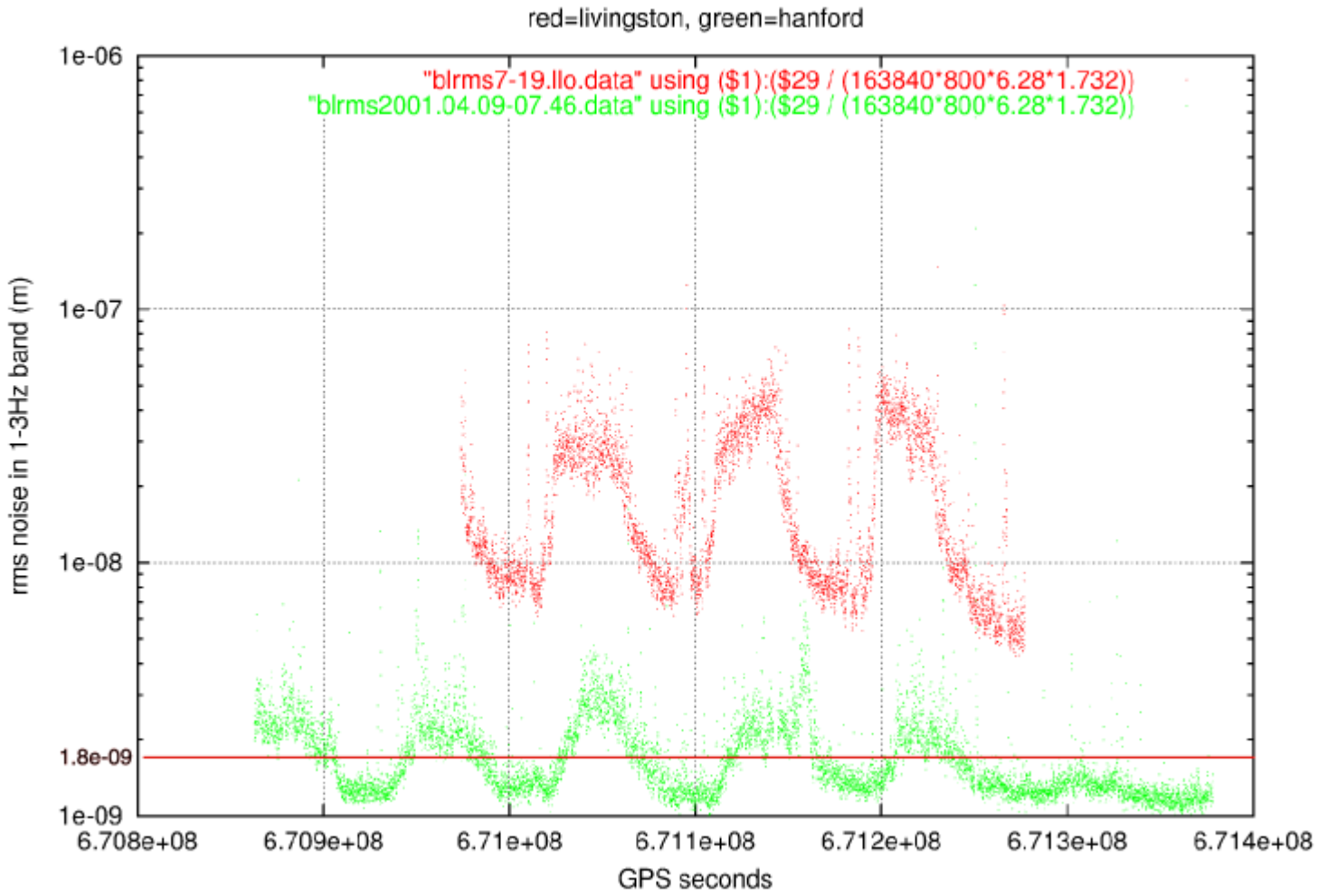
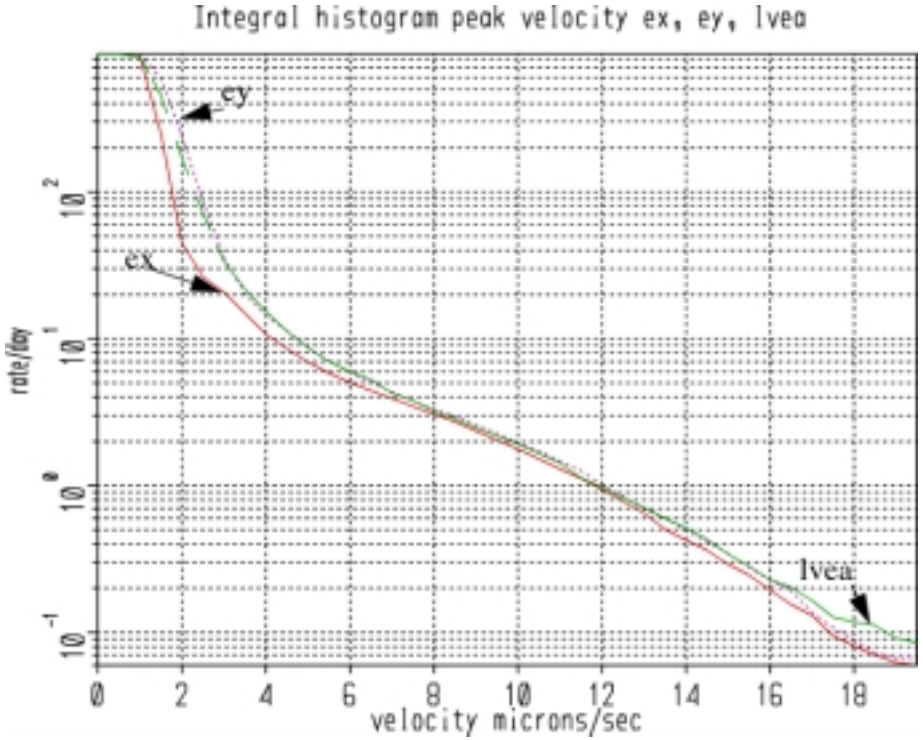
# Problem

- Ground motion at LLO with the initial LIGO seismic isolation system makes it impossible to hold the interferometers locked reliably during the day
  - » Steady-state ambient noise is higher due to anthropomorphic sources
  - » Transients, particularly from logging
- Wind induced seismic noise at LHO:
  - » exceeds locking threshold at ~25 mph, or 4% of the time
  - » Expect up-conversion is a problem at significantly lower wind speeds & a large fraction of the time
- Upgrade is required to allow both reliable locking and to allow better noise performance while locked
  - » Need 90% duty cycle & lock durations > 40 hours
  - » Need to reduce noise in the control band (< 40 Hz) to permit a smaller suspension actuator authority & lower noise
  - » Suppression in the 1-3 Hz band is most important due to excitation of the lower stack modes (Q ~ 30)

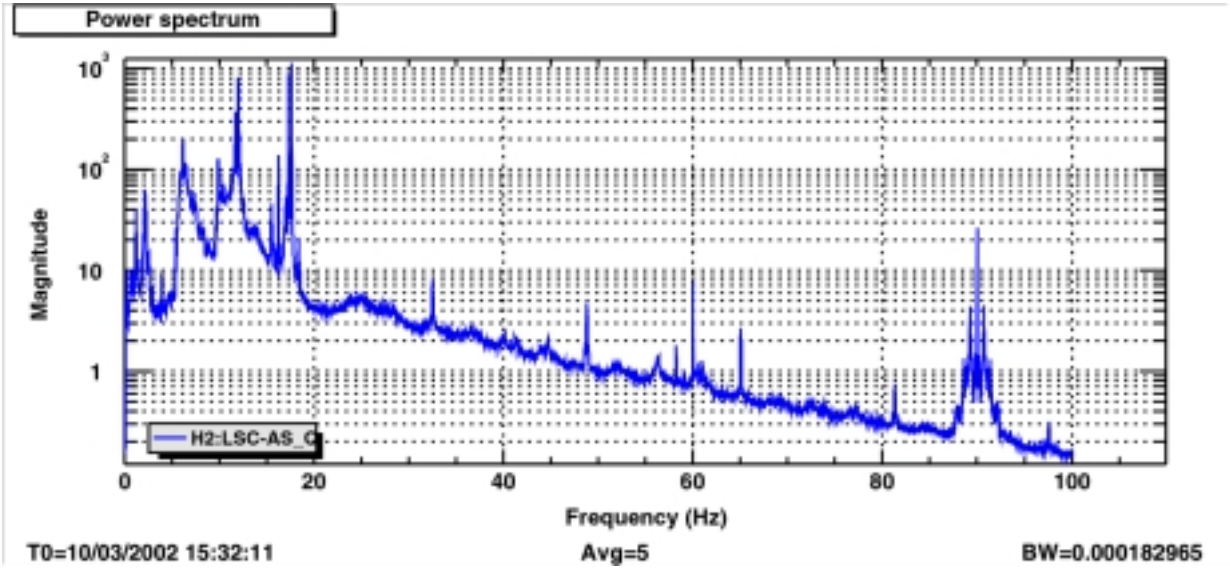
# Typical Day/Night Seismic Noise Levels in the 1-3 Hz Band



# Integral Histogram of the Peak Ground Velocity



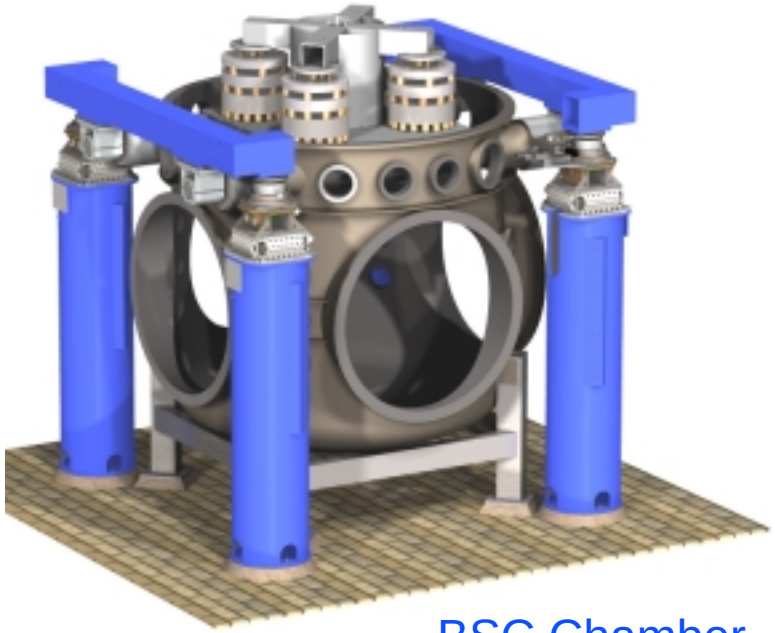
# Up-conversion Example



# Initial Vibration Isolation Systems

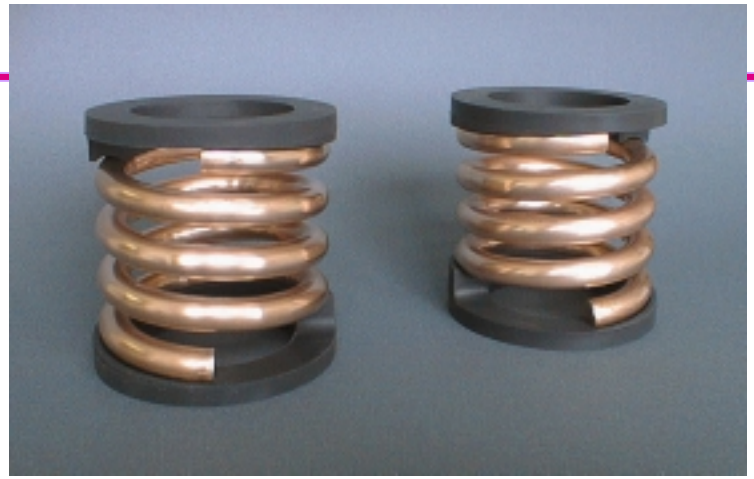
- Reduce in-band seismic motion by 4 - 6 orders of magnitude
- Little or no attenuation below 10Hz; amplification at stack mode resonances
- Large range actuation for initial alignment and drift compensation
- Quiet actuation to correct for Earth tides and microseism at 0.15 Hz during observation

HAM Chamber

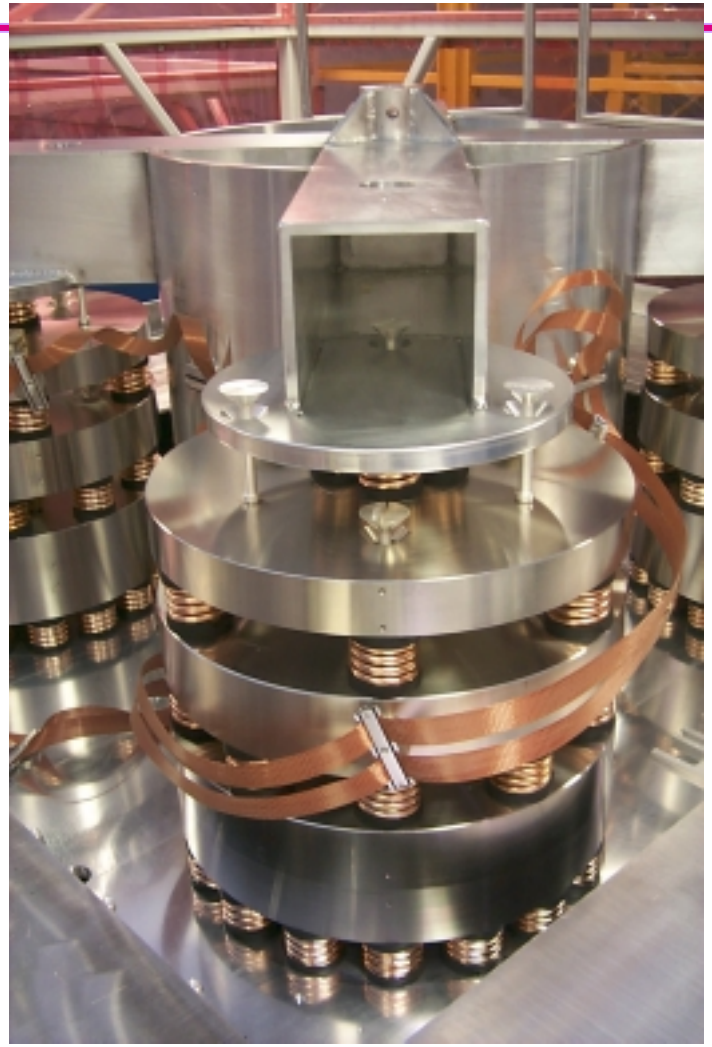


BSC Chamber

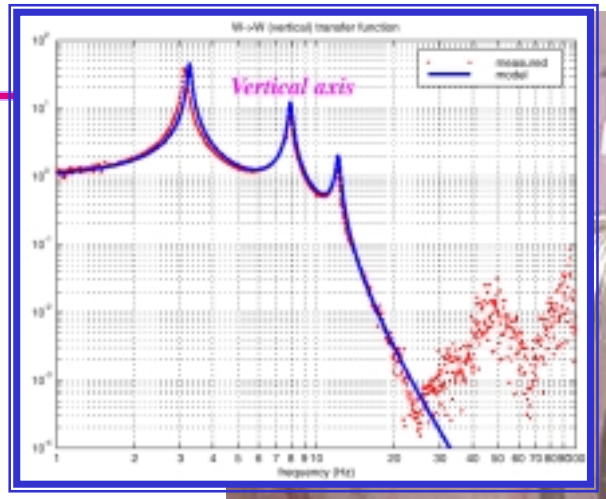
# Seismic Isolation – Springs and Masses



damped spring
cross section



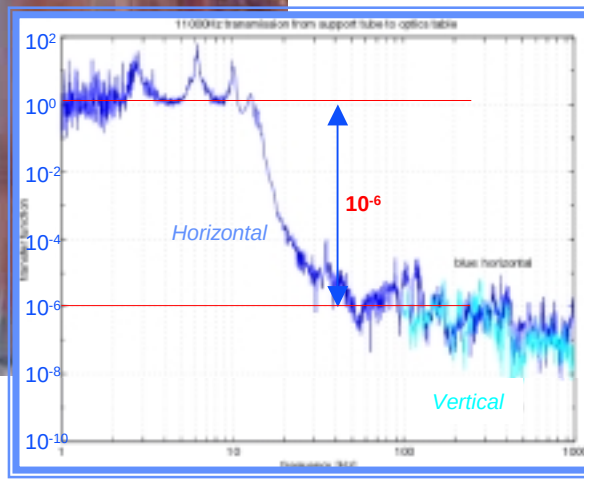
# Seismic System Performance



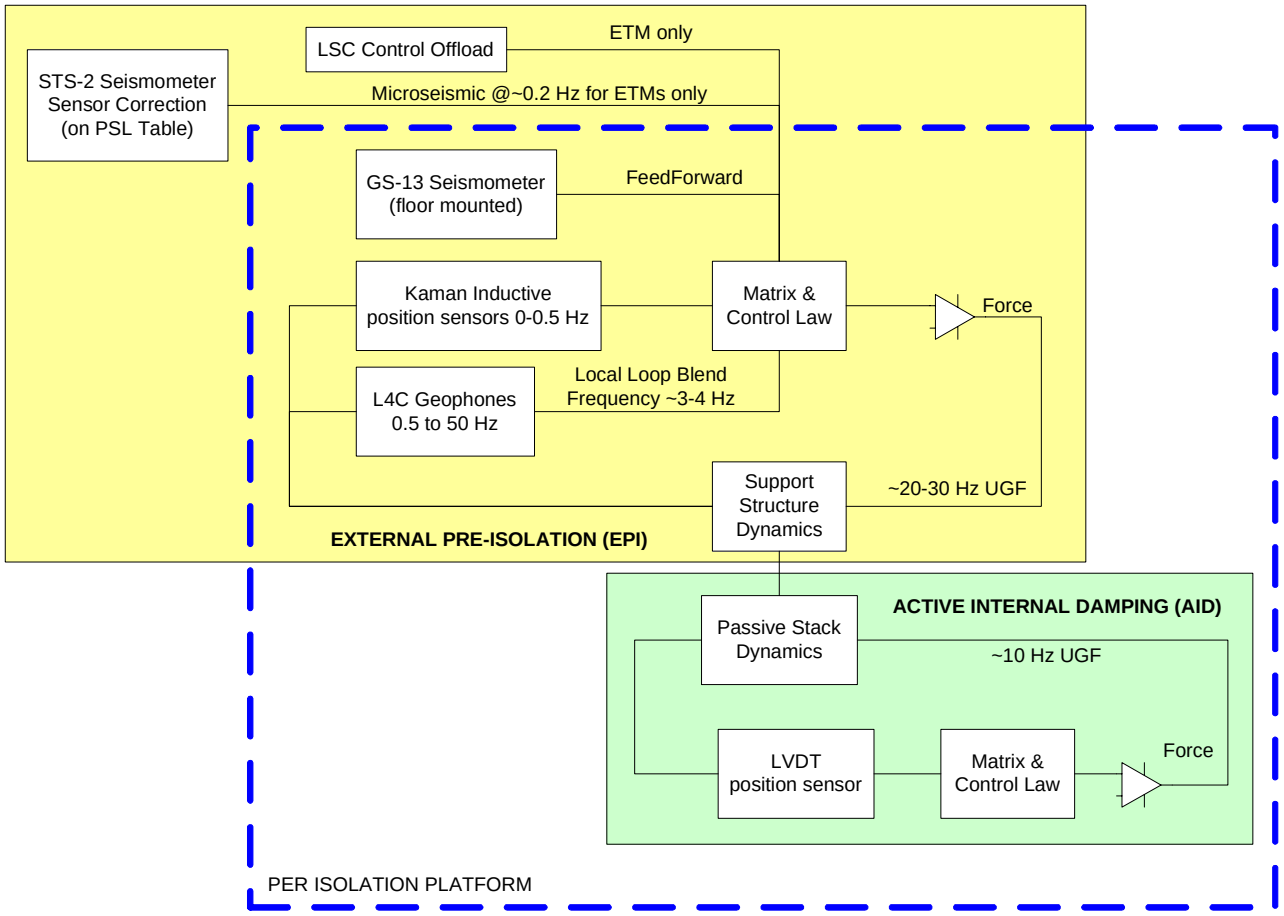

HAM stack
in air



BSC stack
in vacuum



# Active External Pre-Isolation (EPI) & Active Internal Damping (AID)



# Alternate Approaches

| Approach | Description/comments | Options | Isolation | Stack Damping |
|---|---|---|---|---|
| External pre-isolation | 6 DOF isolation with co-located sensing & actuation at the base of the passive stack; feedback & feedforward control to be explored including use of OSEM sensing | Hydraulic actuator | Y | ? |
| | | EM actuator | Y | ? |
| Internal active damping | Co-located sensing and actuation on the internal optics table (e.g. LVDT and voice coil) to sense & damp from support structure to optics table. The addition of inertial sensing on the optics table may permit isolation. | Voice Coil or EM linear motor<br>LVDT or geophone | ? | Y |
| Existing fine actuators | Longitudinal & yaw velocity feedback with co-located geophones. Being pursued as an interim measure. | | Y | N |
| COTS isolation systems | Piezo isolation systems like Stacis; minus-k compact low frequency spring, etc. which can perform the external pre-isolation task. | Various | Y | unlikely |
| SAS-like Implementation | A hybrid passive/active “soft” alternative approach to the stiff external pre-isolation approach. | | Y | N |
| Tuned Mass Dampers | With existing payload mass limits the optimum reduction in stack mode resonance is ~4. This does not meet requirements and requires in-vacuum hardware | Viscous fluid, eletro-restrictive or eddy current | N | Y |
| Multiple pendulum or longer period suspensions | Too invasive, too large a schedule & cost impact; not clearly a solution either | | Y | N |
| Cooled suspension coil drive electronics with larger dynamic range | Does not preclude increased noise due to bi-linear coupling mechanisms & large amplitude of real motion; might be a last ditch effort after other measures are taken | | Y | N |
| Short across 1 layer of the HAM Stack | Compromise the better-than-needed high freq. HAM isolation performance; shift stack modes; not clear this works; seems wrong to compromise performance | | N | Y |
| Replace some or all springs with lower Q springs | Too invasive & marginal improvement in Q without complete replacement | | N | Y |
| Add eddy current damping between stages | Too invasive & marginal improvement in Q without the addition of many components | | | |


# EPI Requirements

- Net Noise at the base of the stack:
  - » Maintain present drift stability: 1 month, 10 microns pk-pk
  - » Alignment precision for lock: 100 seconds, 1 micron pk-pk
  - » Microseismic peak: 0.16 Hz, 4e-7 m/√Hz
  - » Integrated rms level similar to Hanford at night & consistent with the technology:
    - 1 Hz 1e-9 m/√Hz
    - 10 Hz 4e-10 m/√Hz
  - » Suspension vertical bounce mode: 15 Hz, 2e-10 m/√Hz
  - » No degradation in current in-band isolation:
    - 30 Hz 6e-11 m/√Hz
    - > 50 Hz 2e-11 m/√Hz
- Dynamic Range: 10mm p-p static alignment, 300 microns p-p

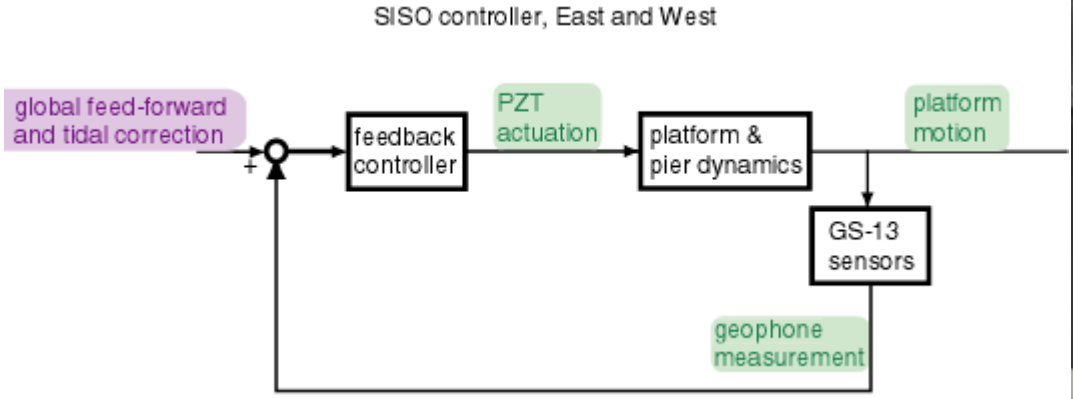

# AID Requirements

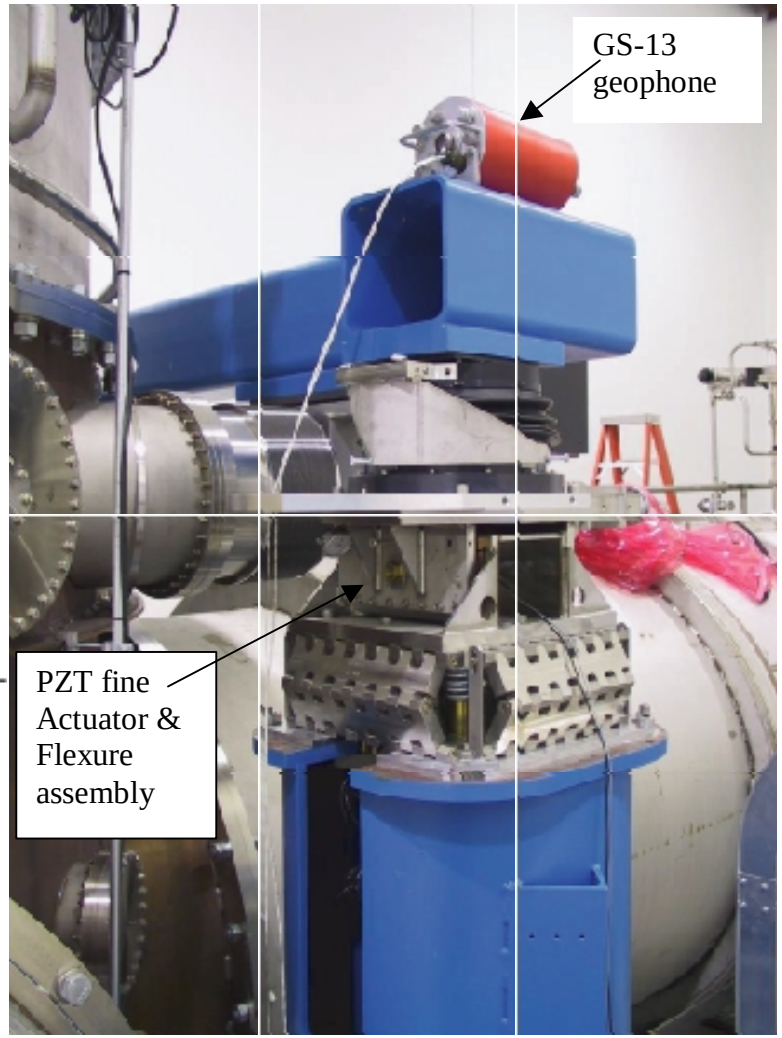
- Noise contribution in the GW band must be < 1/10 of the Science Requirements Document (SRD), or at the optics table:
  - » BSC:
    - Horizontal: 1.2e-13 m/√Hz at 20 Hz, 2.5e-17 m/√Hz at > 50 Hz
    - Vertical: 5e-13 m/√Hz at 20 Hz, 1e-16 m/√Hz at > 50 Hz
  - » HAM:
    - Horizontal: 4e-12 m/√Hz at 20 Hz, 2.5e-16 m/√Hz at > 50 Hz
    - Vertical: 2e-11 m/√Hz at 20 Hz, 1e-15 m/√Hz at > 50 Hz
- Damping to Q~3 on at least the 1.2 and 2.1 Hz BSC modes, with no ‘spillover’ in excess of 1.5 x total rms

# LIGO 2 DOF Pre-Isolation with the existing Fine Actuation System (FAS)

- Proof-of-principle test for external seismic isolation layer.
- Existing fine actuators in end (and mid)station,driven in pairs,can move stack base in beam direction and in yaw.
- GS-13 seismometers placed on crossbeams above FAS
- Provide inertial error signals for 2,1-DOF SISO servos.
- dSpace signal processing board and software in PC allows rapid controller/compensation development and provides GUI control panel
- Resonant gain added at two troublesome stack modes (1.2 and 2.1 Hz), allowing factor of a few more gain there without destabilizing overall servo.
- This resulted in about a factor of 7 decrease in motion seen by the test mass at the stack modes.

# LIGO 2 DOF Pre-Isolation with the existing Fine Actuation System (FAS)



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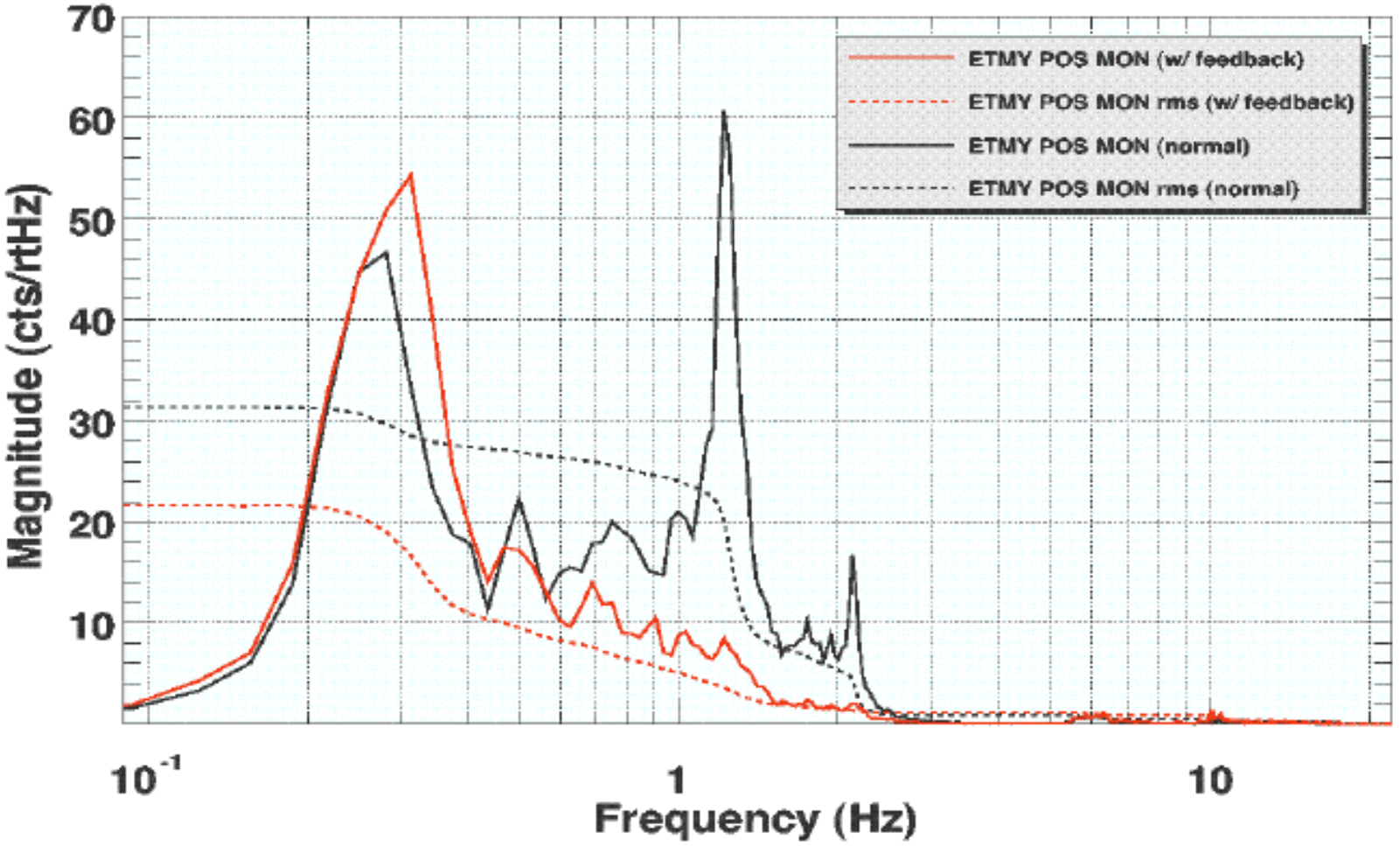

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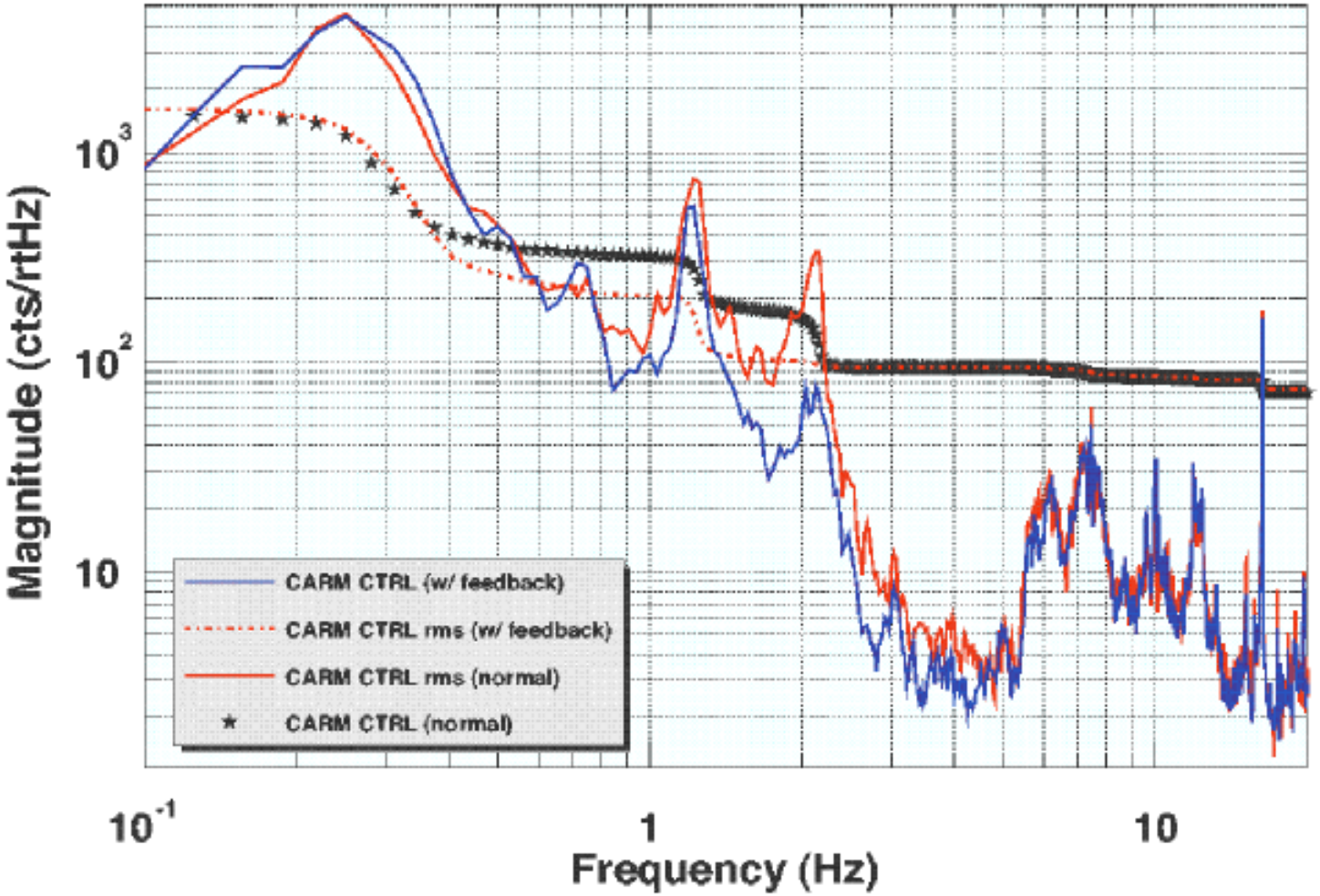
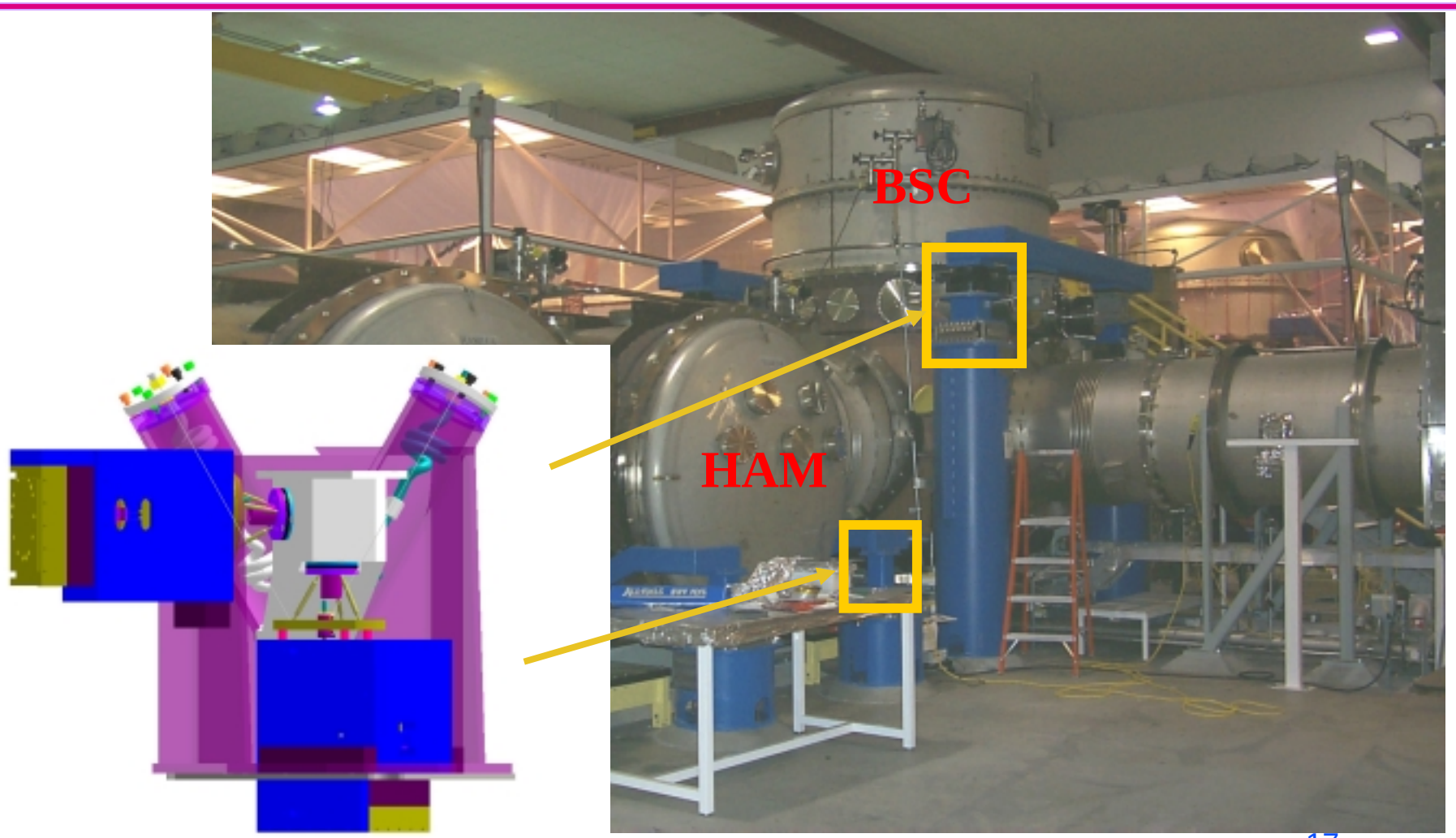
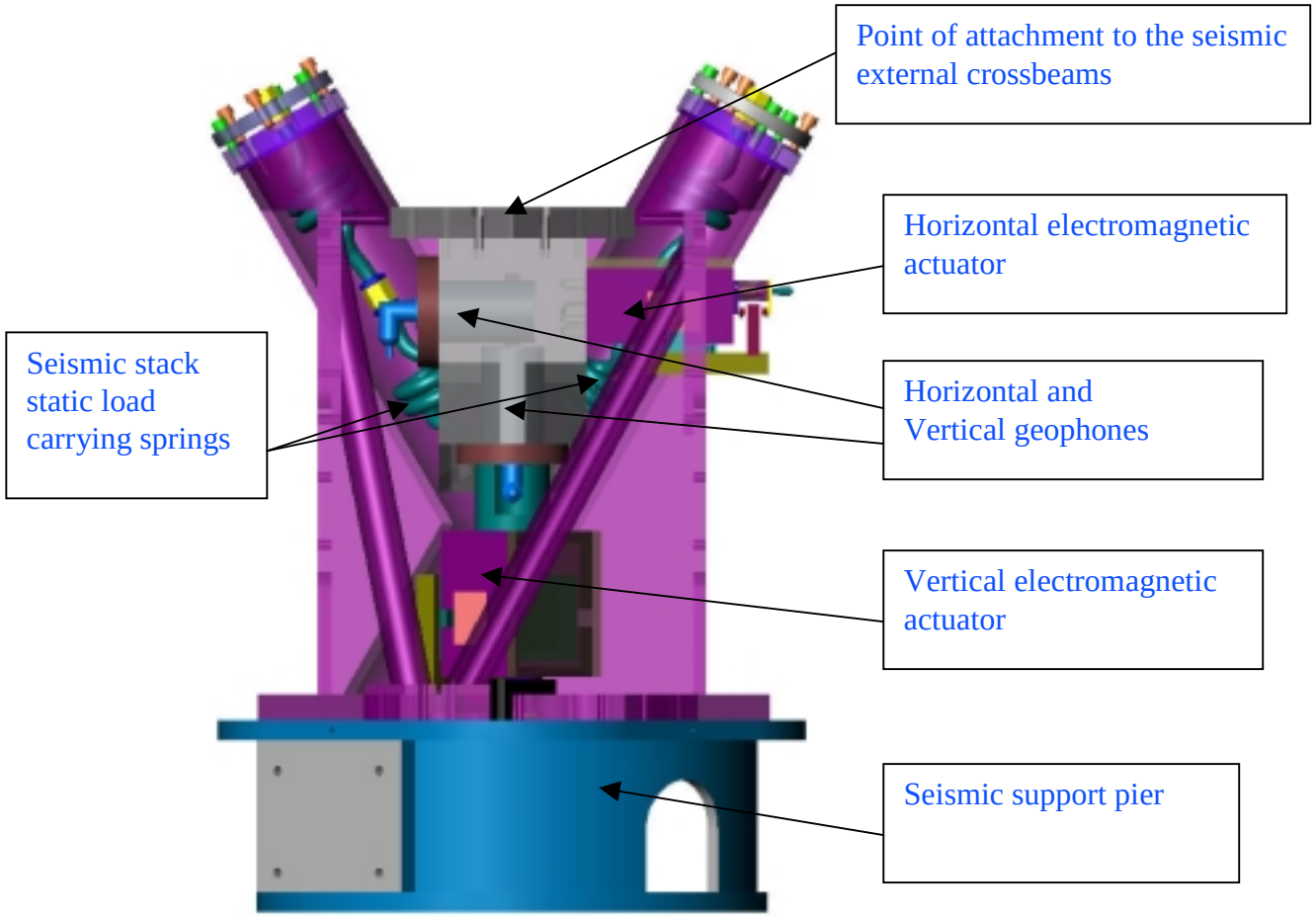


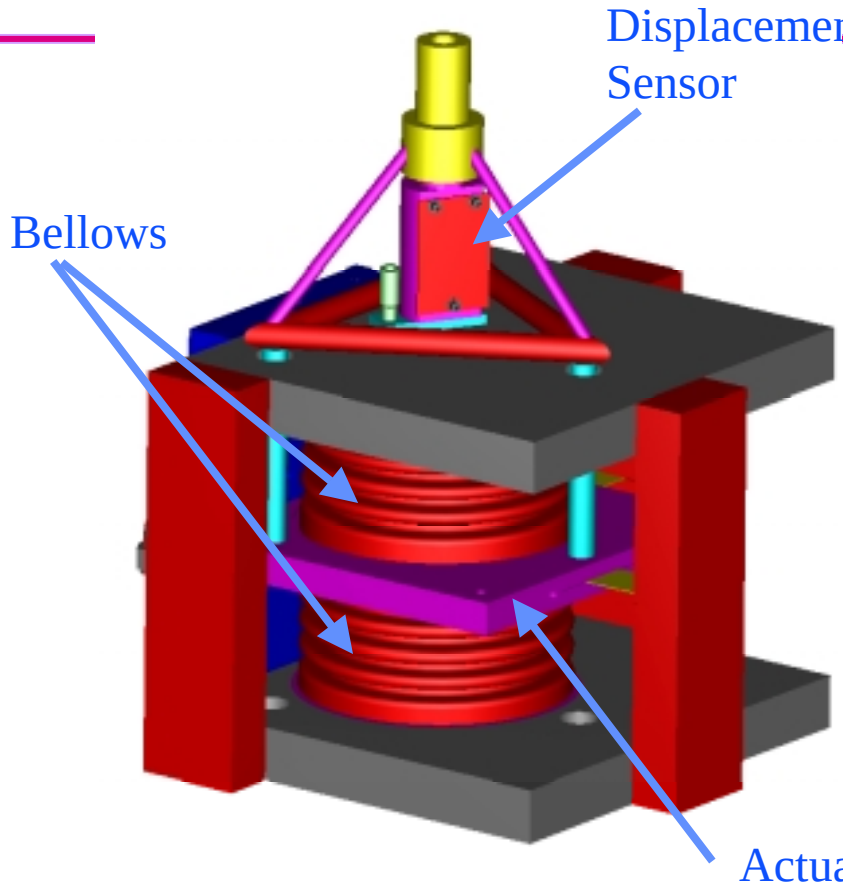
# Planned Initial Detector Modifications



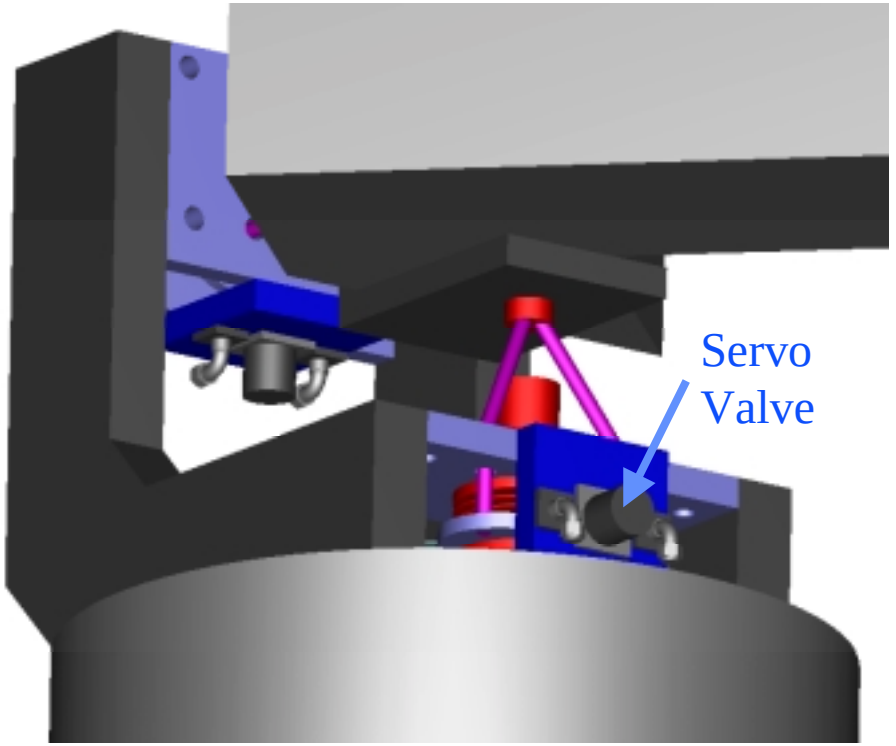
# Spring/Actuator Assembly with the Electro-Magnetic Actuator



# The Quiet Hydraulic Actuator




**Current Design**




**Current Design Implemented On LIGO Pier**

# Differential Bellows for Quiet Actuator

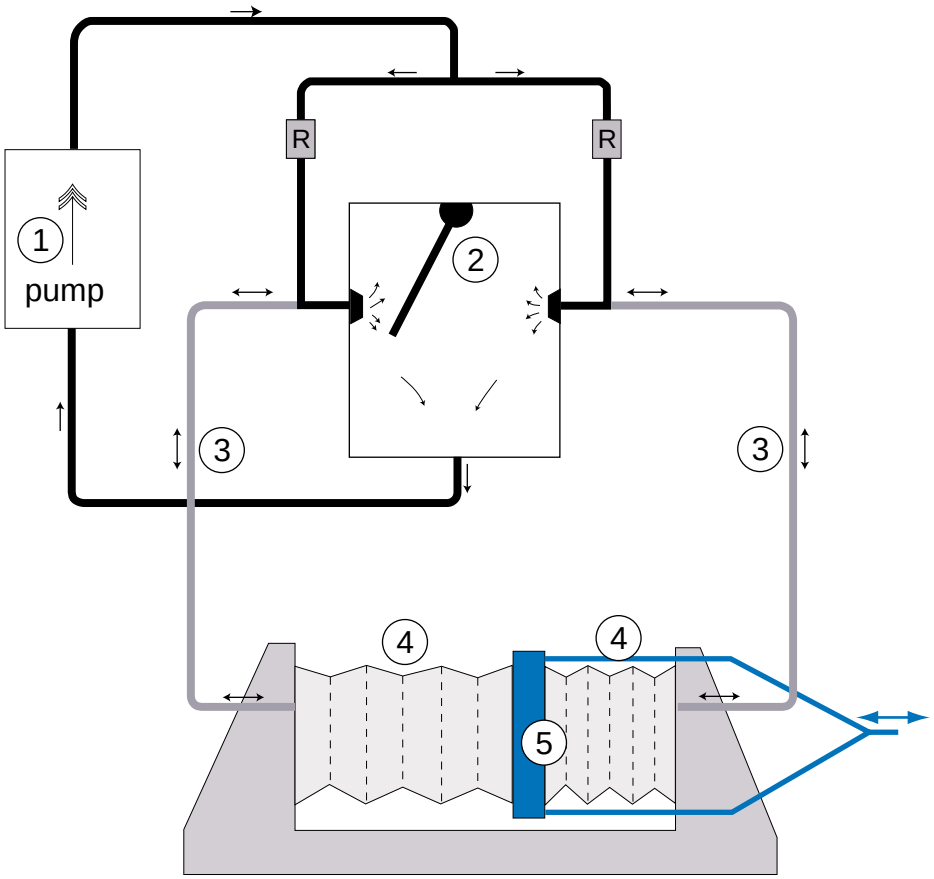
1) Pump

2) Differential Flapper Valve

3) Bellows Supply

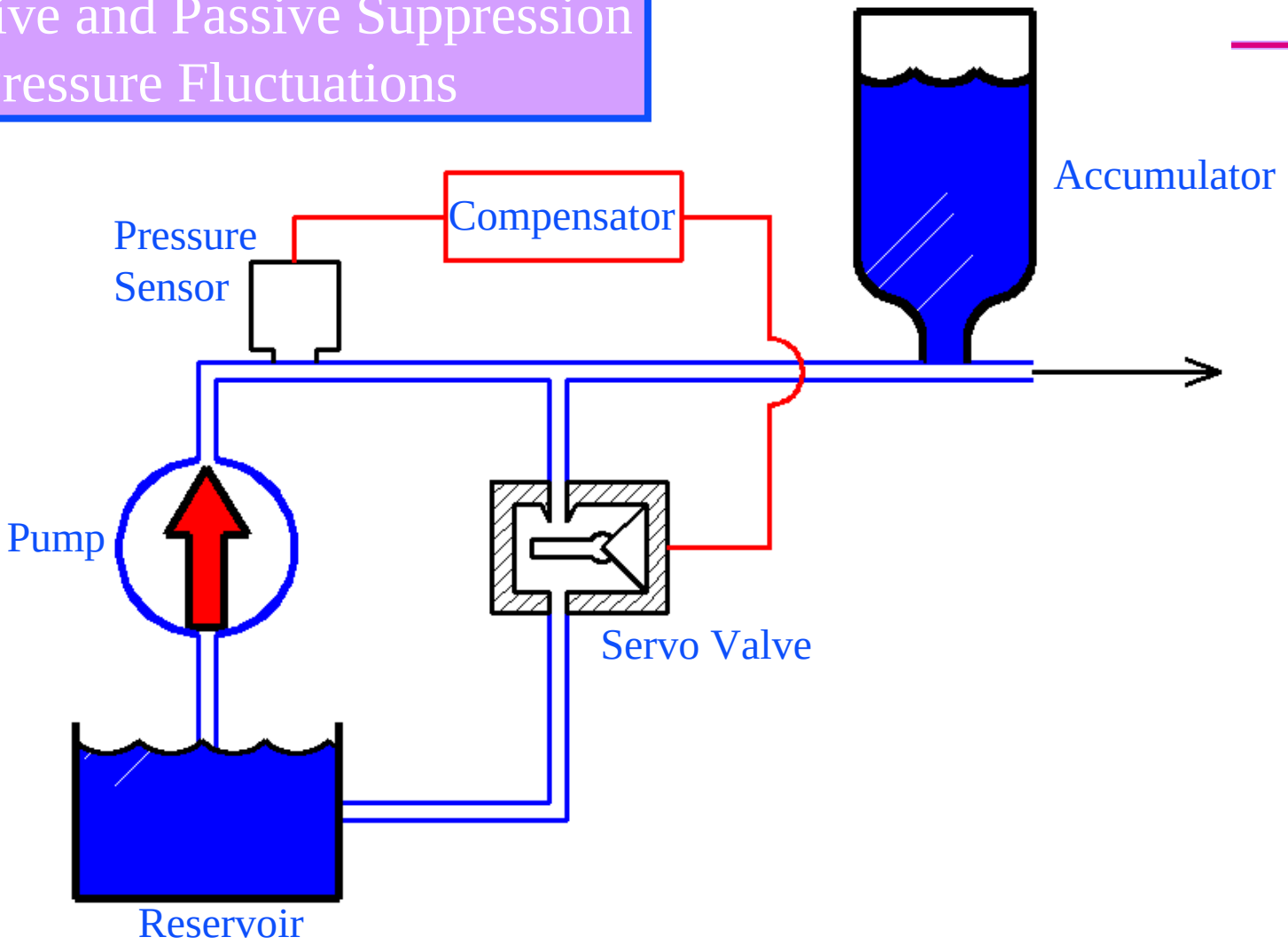
4) Differential Bellows

5) Actuation Plate

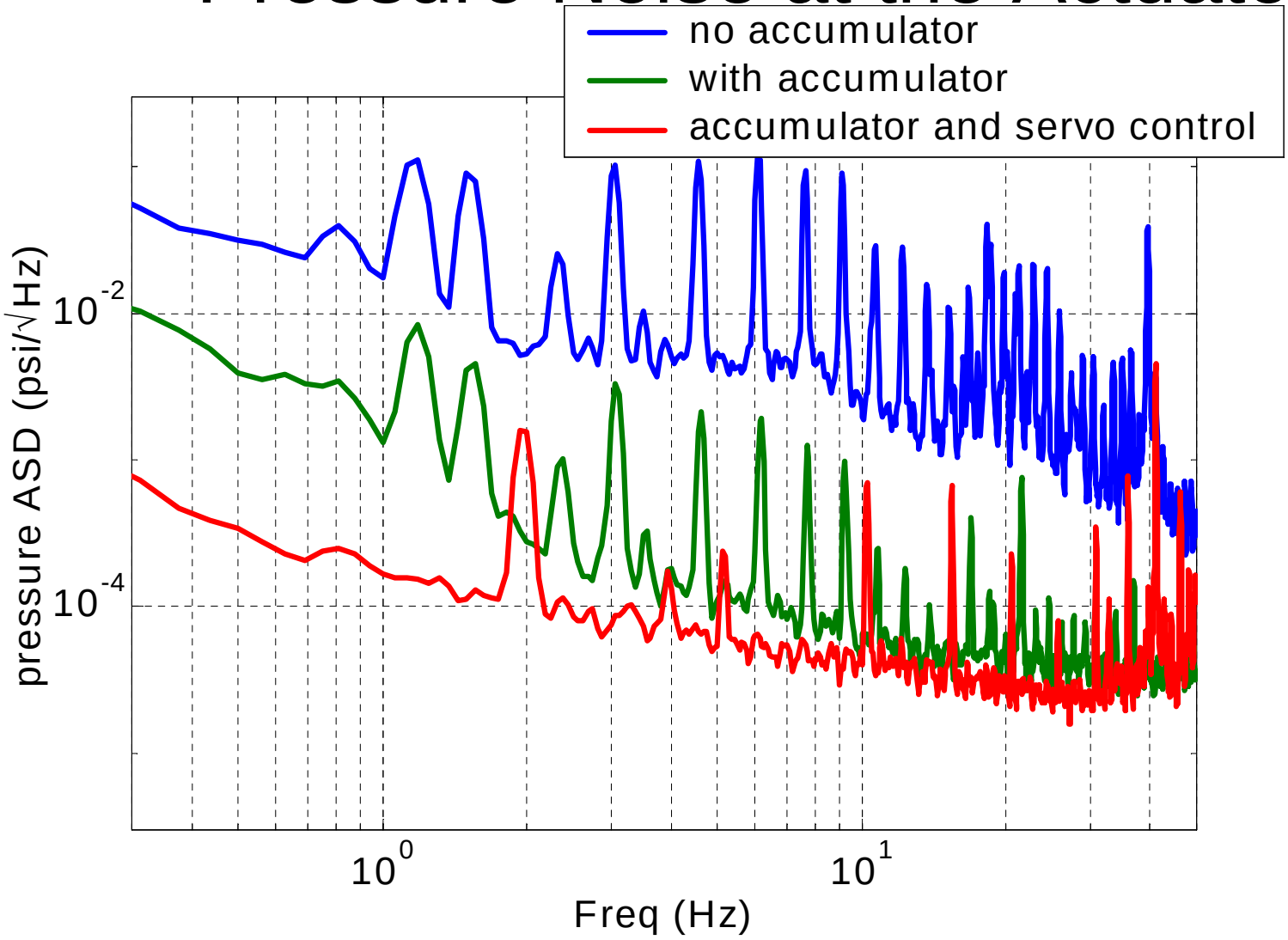


# Conditioning a Pressure Source

## Active and Passive Suppression of Pressure Fluctuations

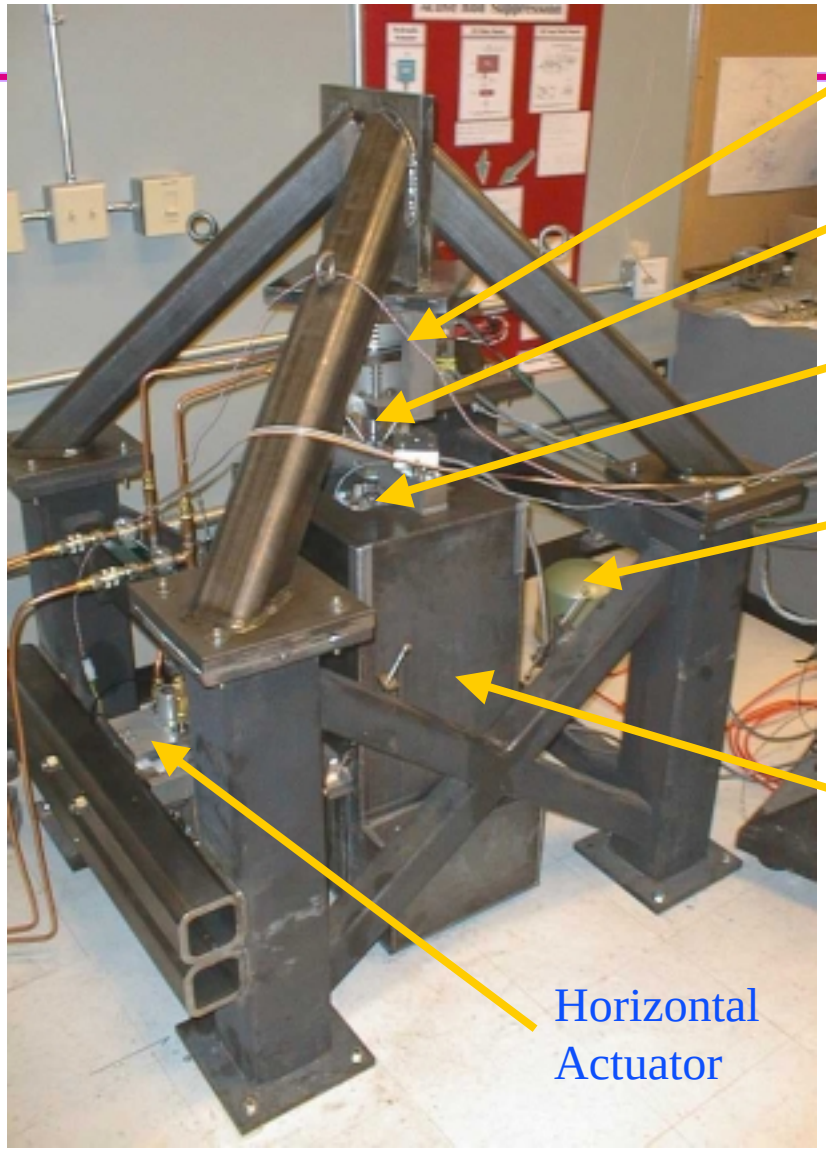


# Pressure Noise at the Actuator

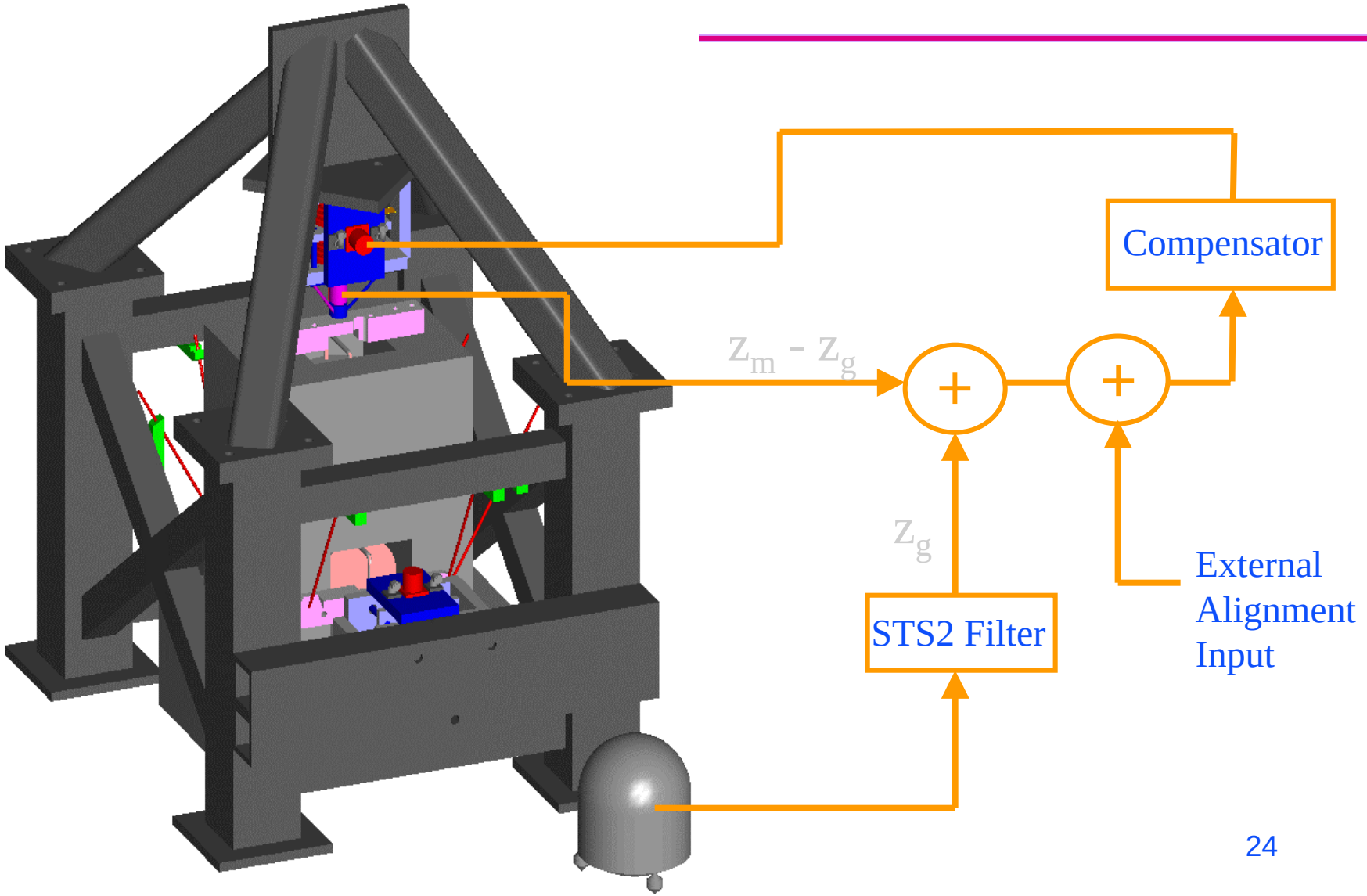


# The Test Platform at Stanford

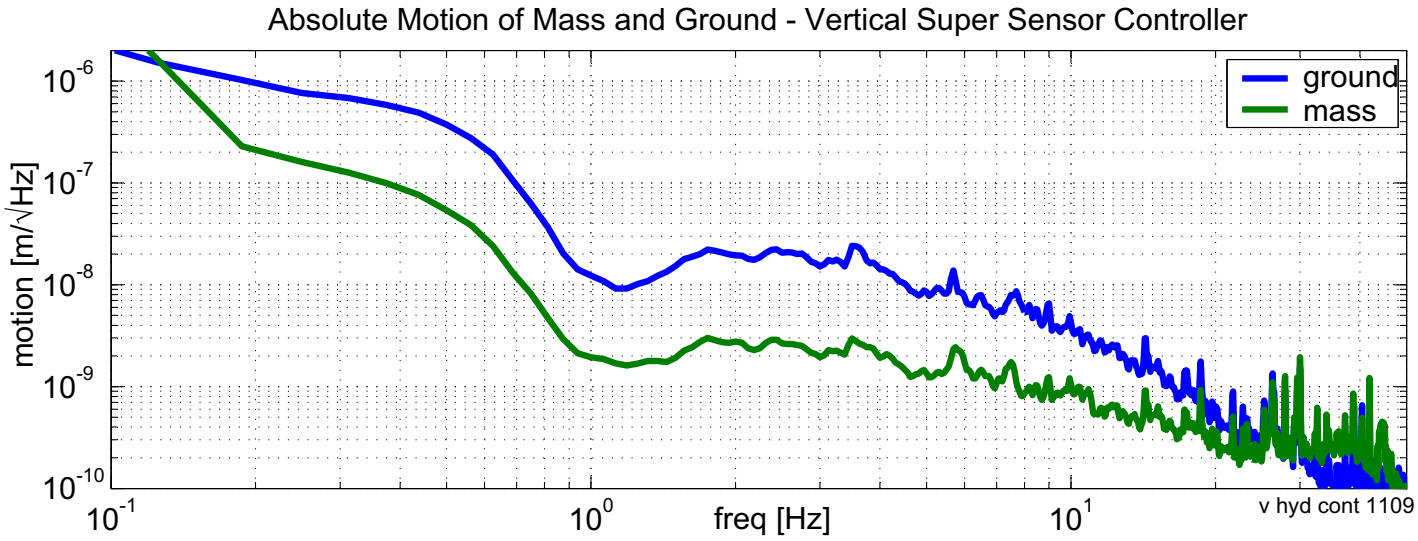
Vertical Actuator

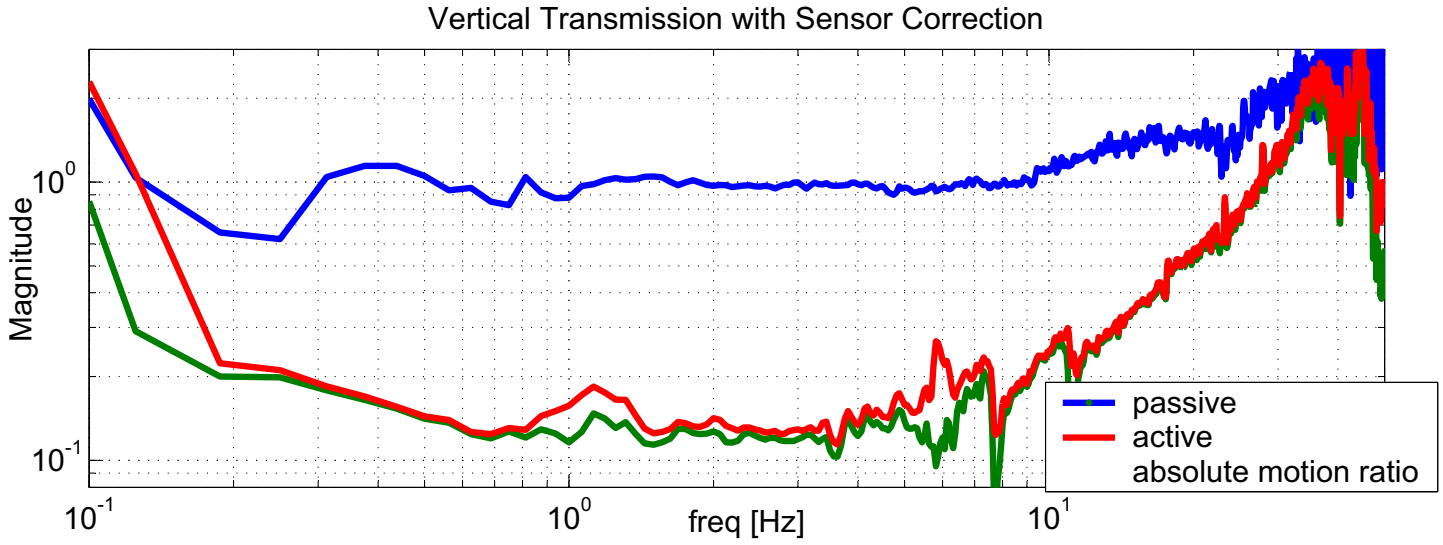


# Sensor Correction

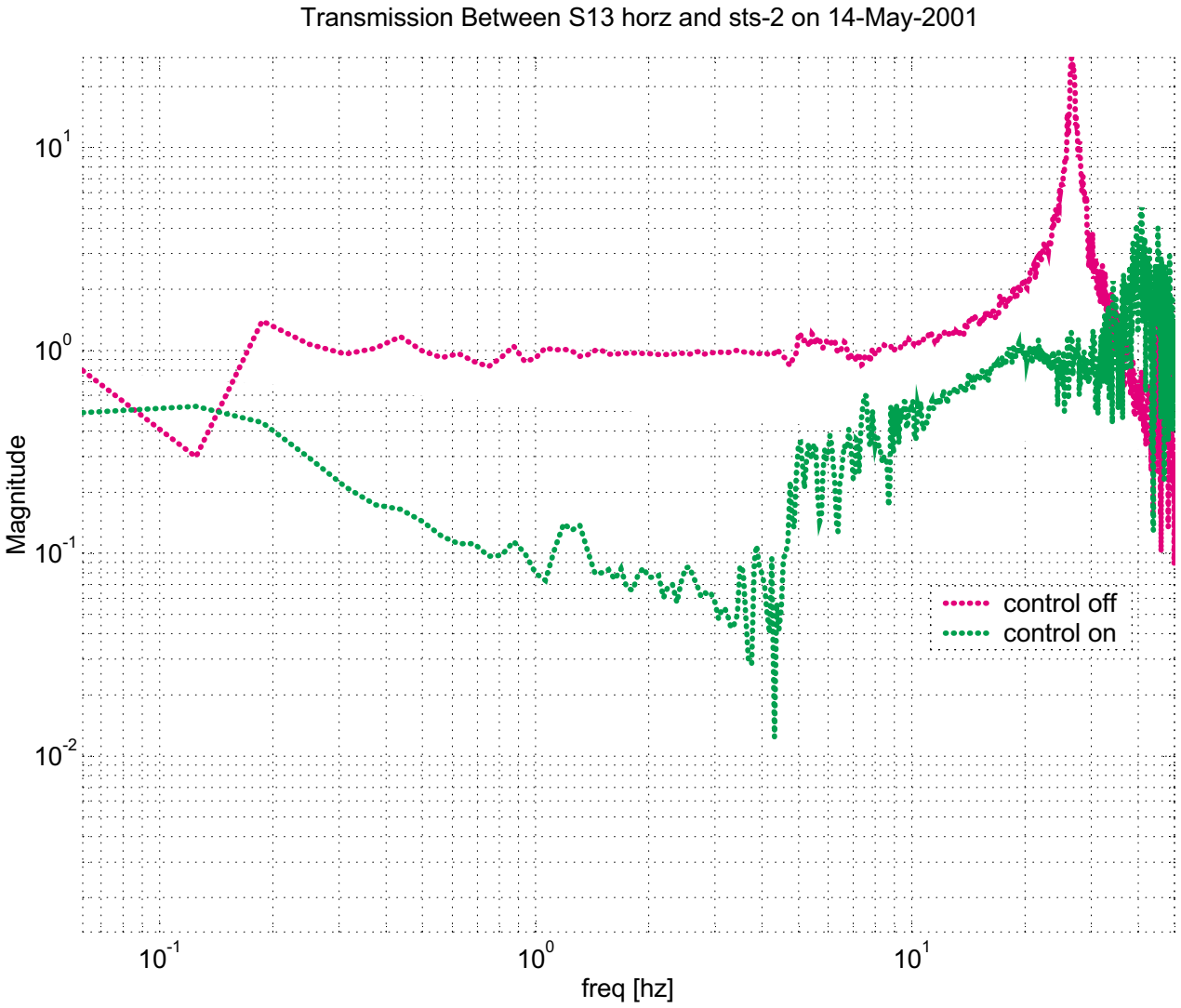


# Vertical Isolation

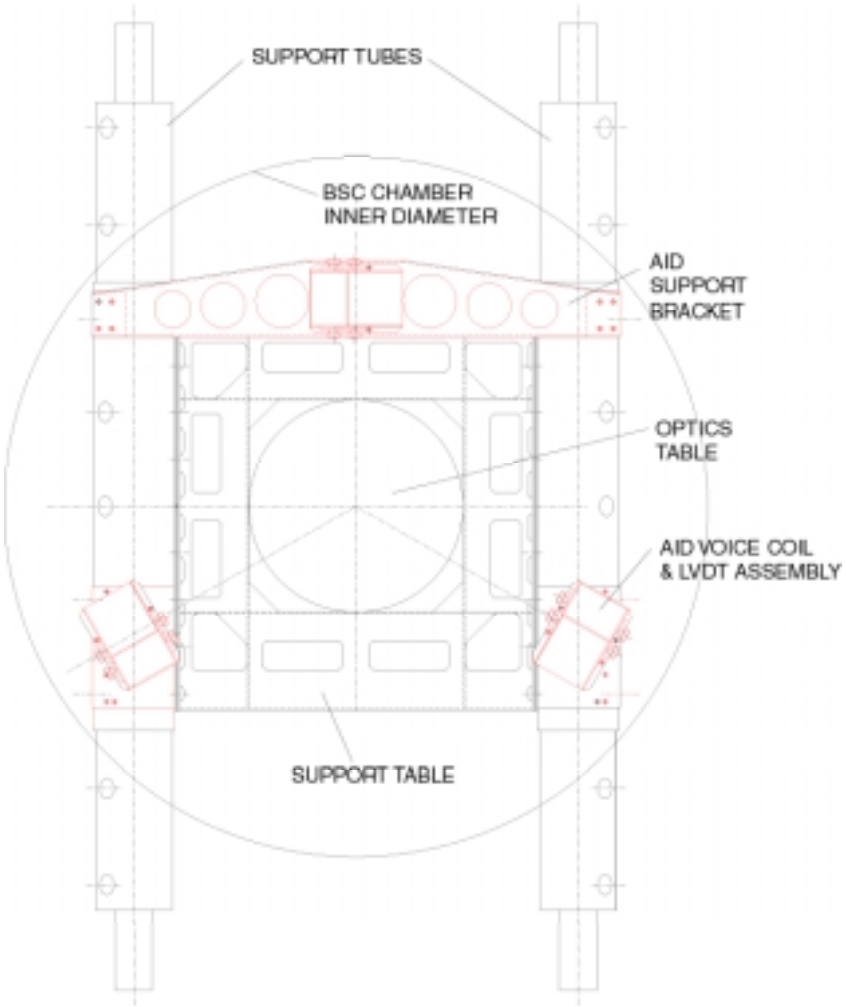


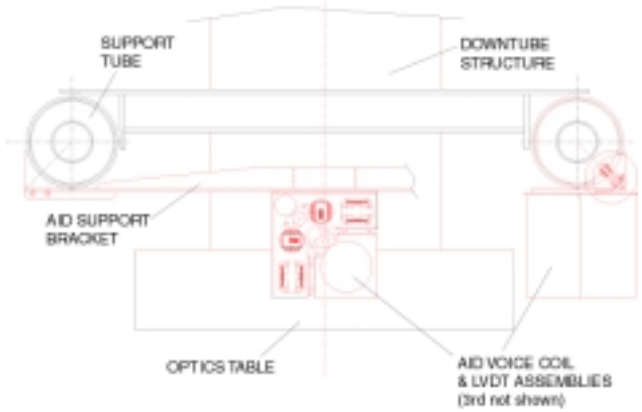



# Horizontal Isolation



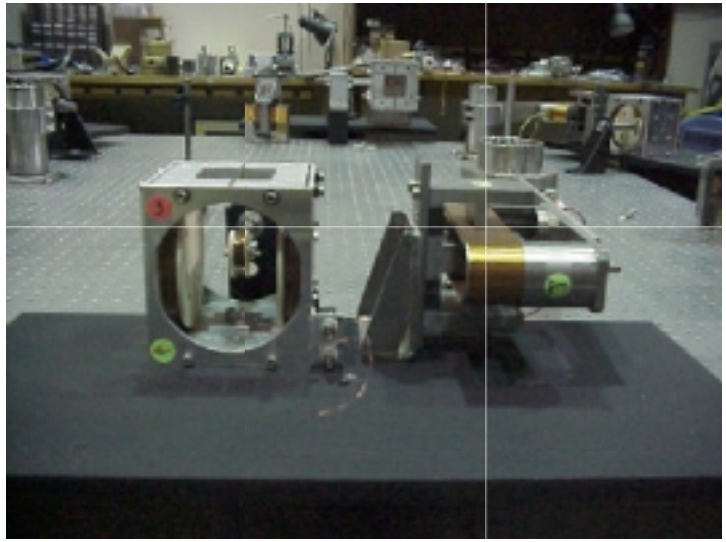
# Active Internal Damping System Layout



# Active Internal Damping (AID) Prototyping

LVDT (left) &
Constant force
Actuator horizontal
doublet



HAM Prototype


# LASTI Full Scale Prototype Testing

- Stand-alone subsystem testing is underway for each subsystem
- The AID & HEPI subsystems will be tested on a BSC isolation stack/chamber at the LASTI facility (MIT) starting in June/July
- The MEPI subsystem will be tested at the same time on a LASTI HAM stack/chamber
- Initially all controls will be performed with D-Space controllers before integrating the systems into the LIGO Epics Supervisory Control & DAQ systems


# Summary

- Testing and analyses to date all look promising
- An interim solution which should enable LLO to lock reliably between the Science 1 and Science 2 runs is being installed (2 DOF pre-isolation with the fine actuation system)
- Seismic retrofit with an active pre-isolation system and an active internal damping system is planned for after the Science 2 run, in Jan 2003
- A Design Review will be held in 2 weeks
  - » April 12, 9:00 am PT
  - » Documentation is nearly ready for release