Current Work on Advanced LIGO Seismic Isolation

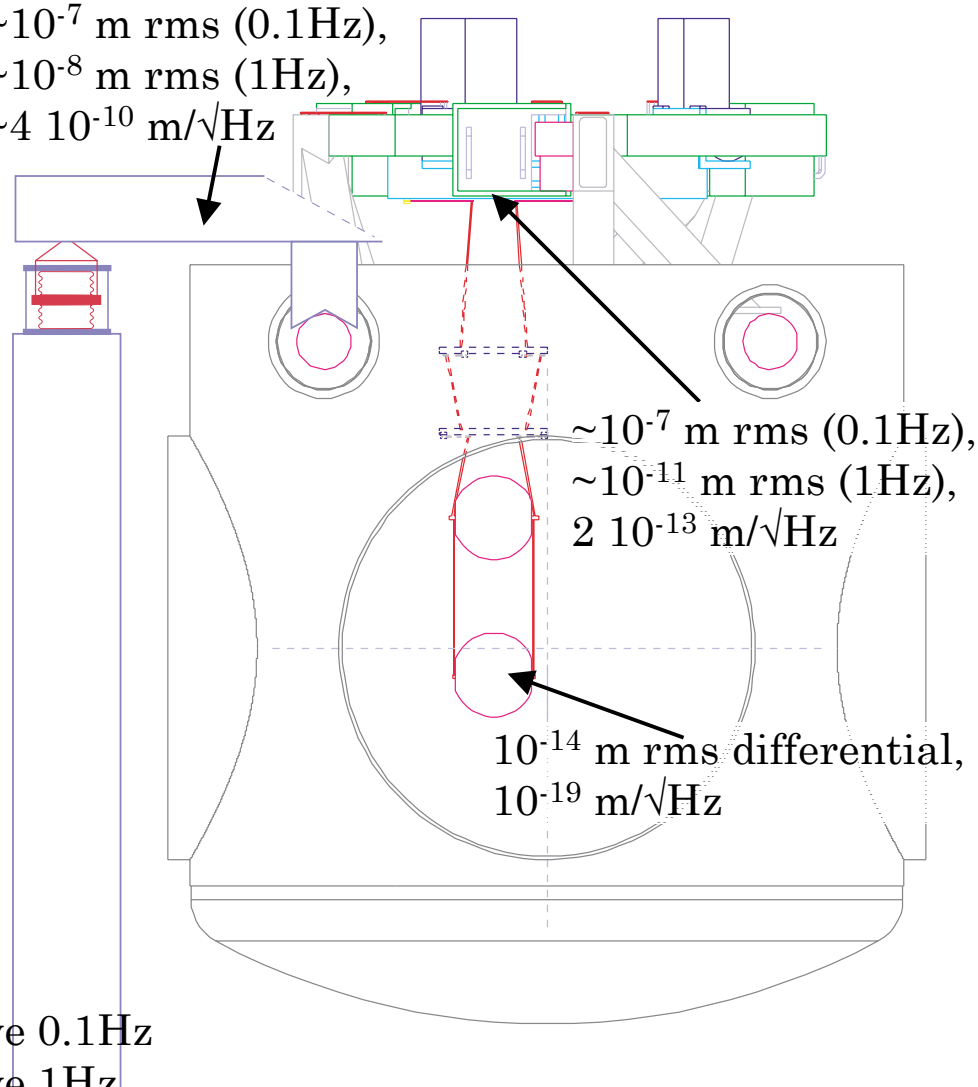
JILA, LLO, LSU, MIT, Stanford

Rich Abbott, Graham Allen, Daniel DeBra, Joe Giaime, Giles Hammond, Marcel Hammond, Corwin Hardham, Jonathan How, Wensheng Hua, Brian Lantz, Ken Mason, Rich Mittleman, Jamie Nichol, Joshua Phinney, Gerry Stapfer

LIGO-G010318-00-Z

Functional Description of the System

LIGO-I Subsystem	LIGO-II Subsystem
Single-pendulum test mass suspension	Quad-pendulum test mass suspension
Minimize thermal noise, passively isolate test mass	
Mass-spring four-layer isolation stack	Two-layer active noise reduction platform
GW band isolation, (LIGO-II: RMS motion reduction)	
1-DOF, 5 Hz BW Fine actuation system	6-DOF, 2 Hz BW Hydraulic fine actuation system 6-DOF, 0 Hz BW coarse actuation adjustment in hydraulic system
6-DOF, 0 Hz BW coarse actuation system	
Feedback/ feedforward compensation of earthtides and microseismic motion	Coarse alignment during installation and occasional drift correction



Currently, Work is Proceeding along Several Directions

- External Hydraulics
- Continuing Studies of Existing Prototypes
- Design of the new ETF Technology Demonstration Prototype

Differential Bellows for Quiet Actuator

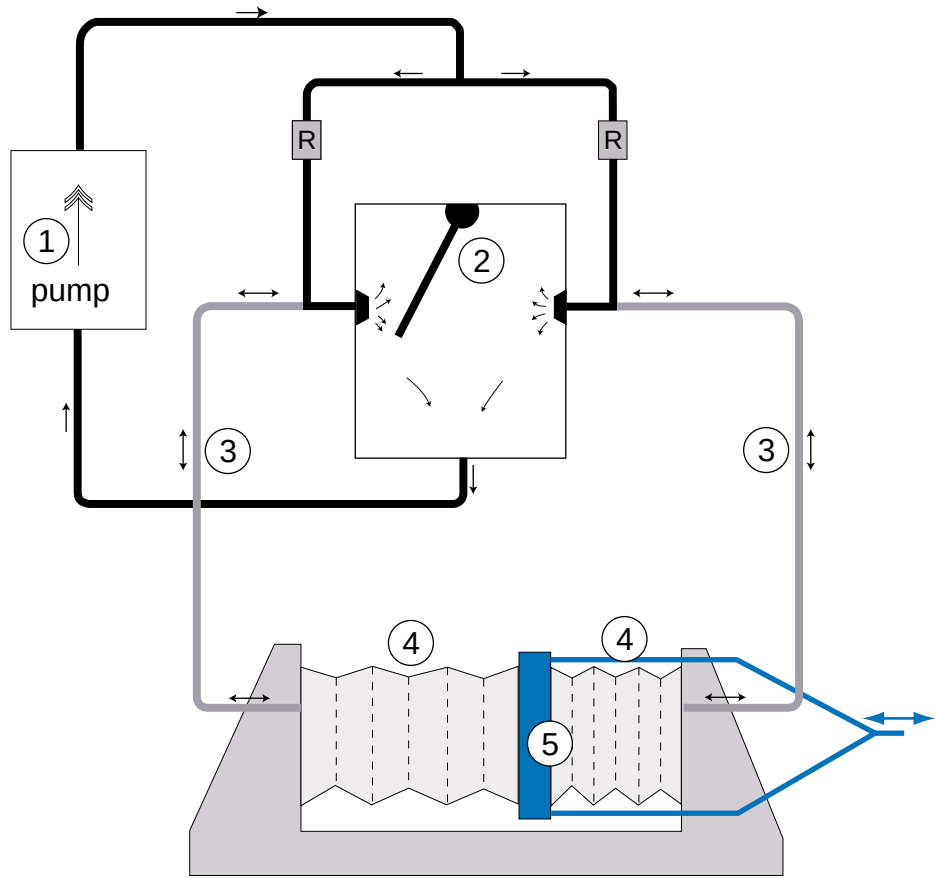
1) Pump

2) Differential Flapper Valve

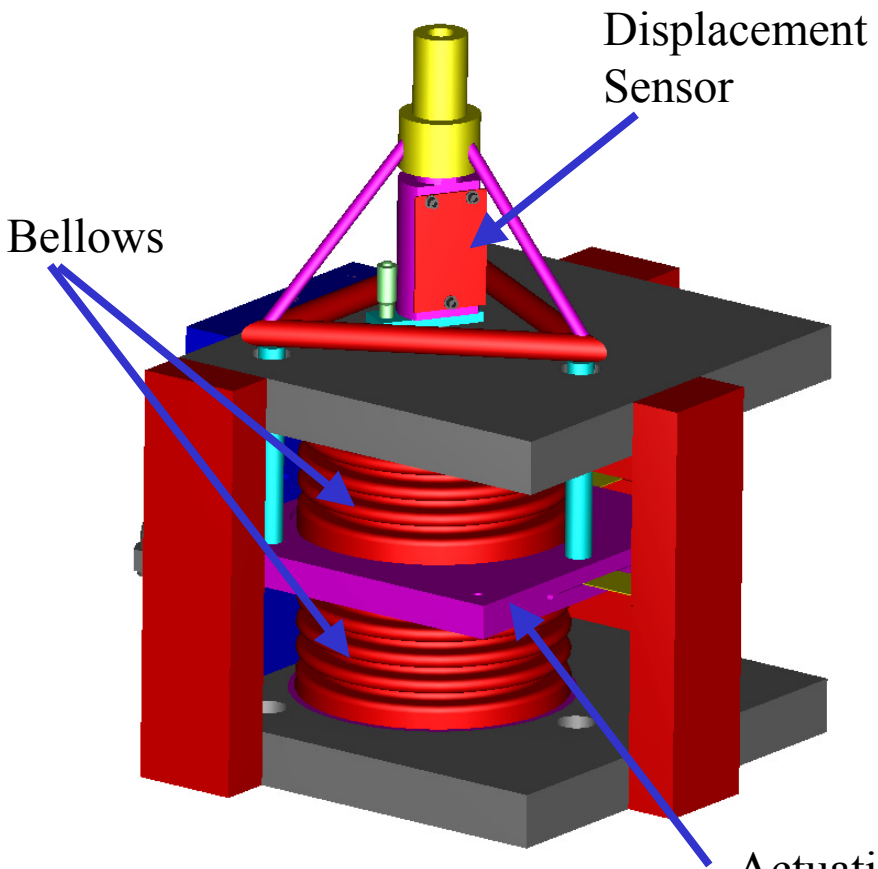
3) Bellows Supply

4) Differential Bellows

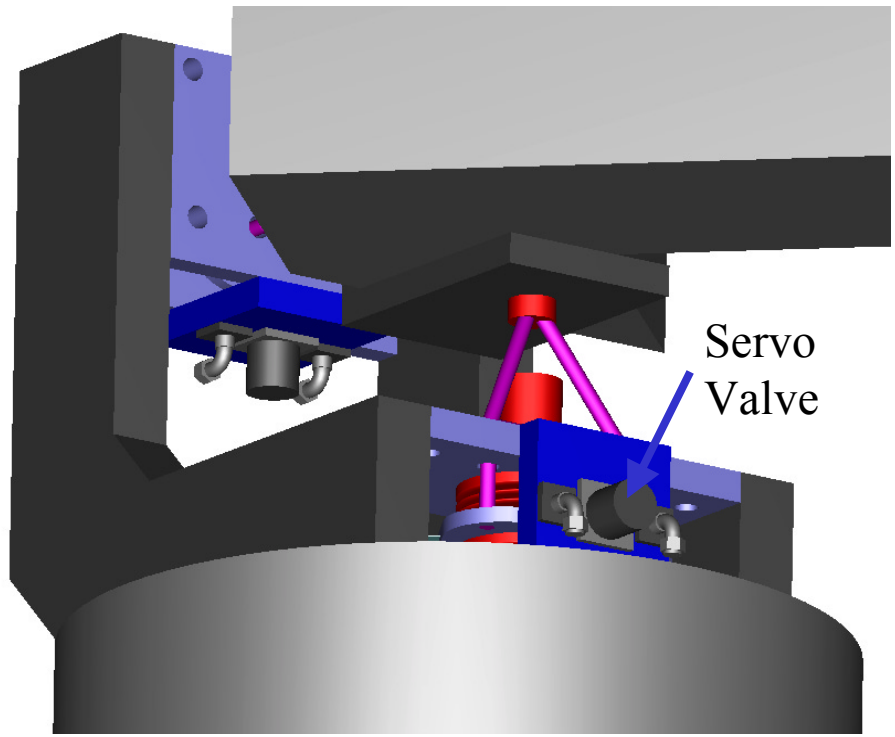
5) Actuation Plate



The Quiet Hydraulic Actuator



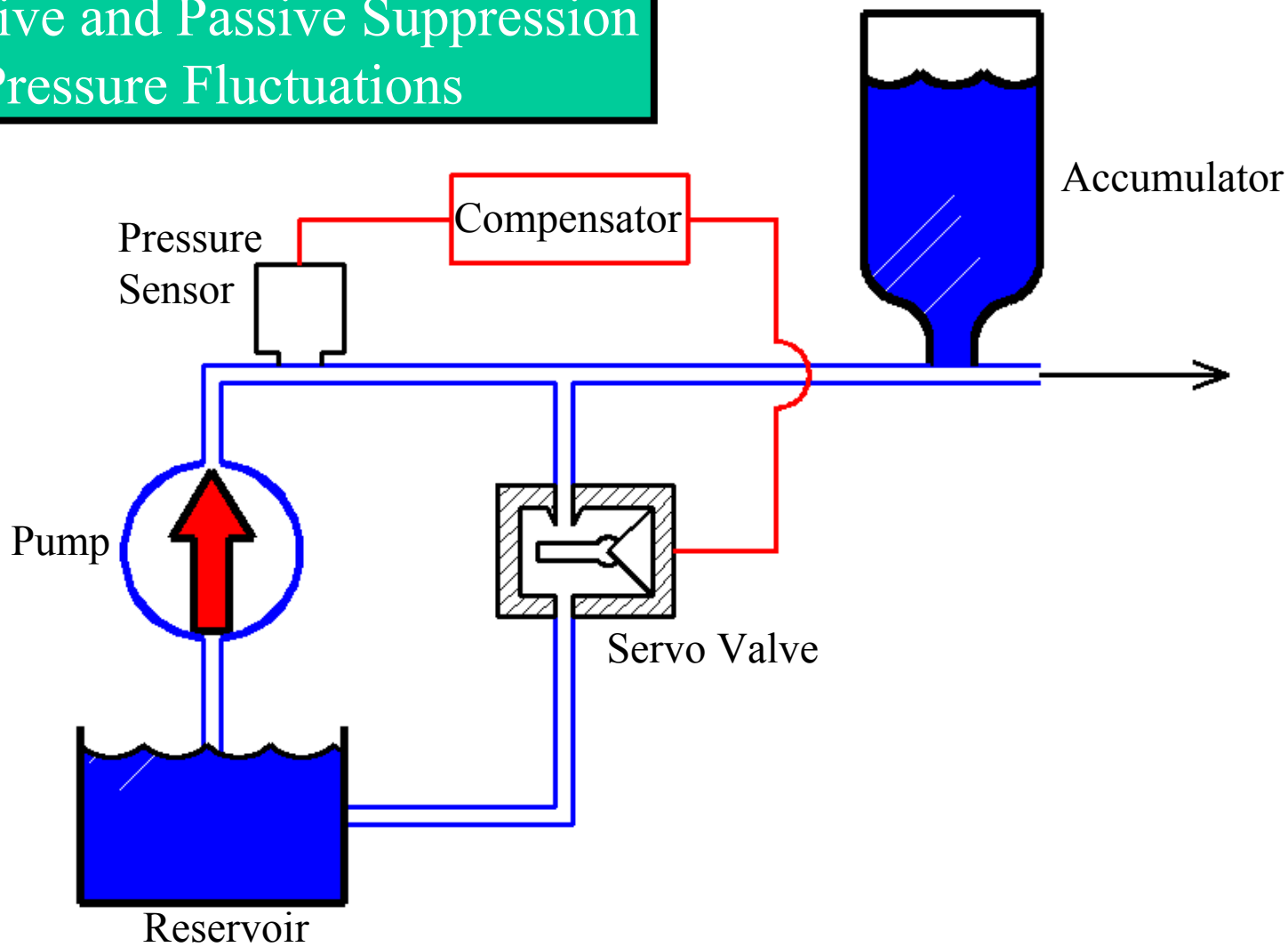
Current Design



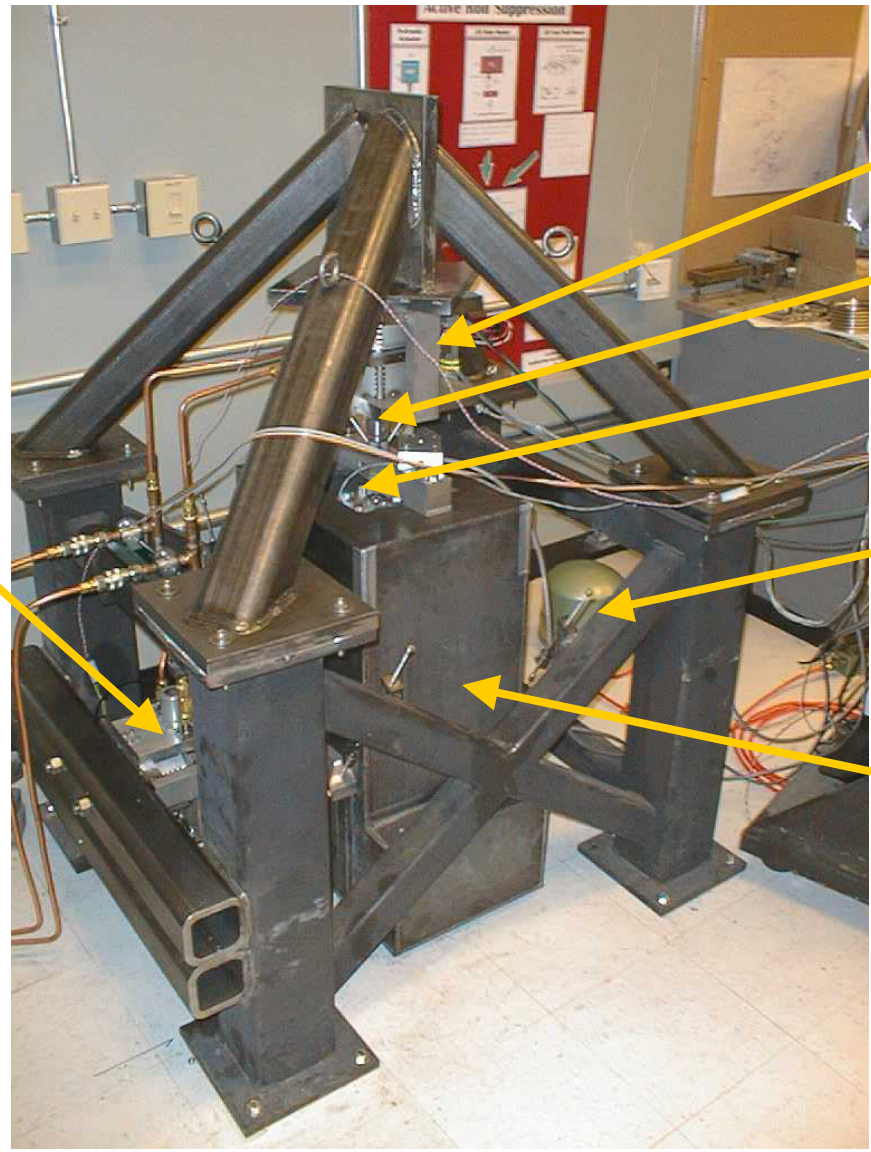
Current Design Implemented On LIGO Pier

Conditioning a Pressure Source

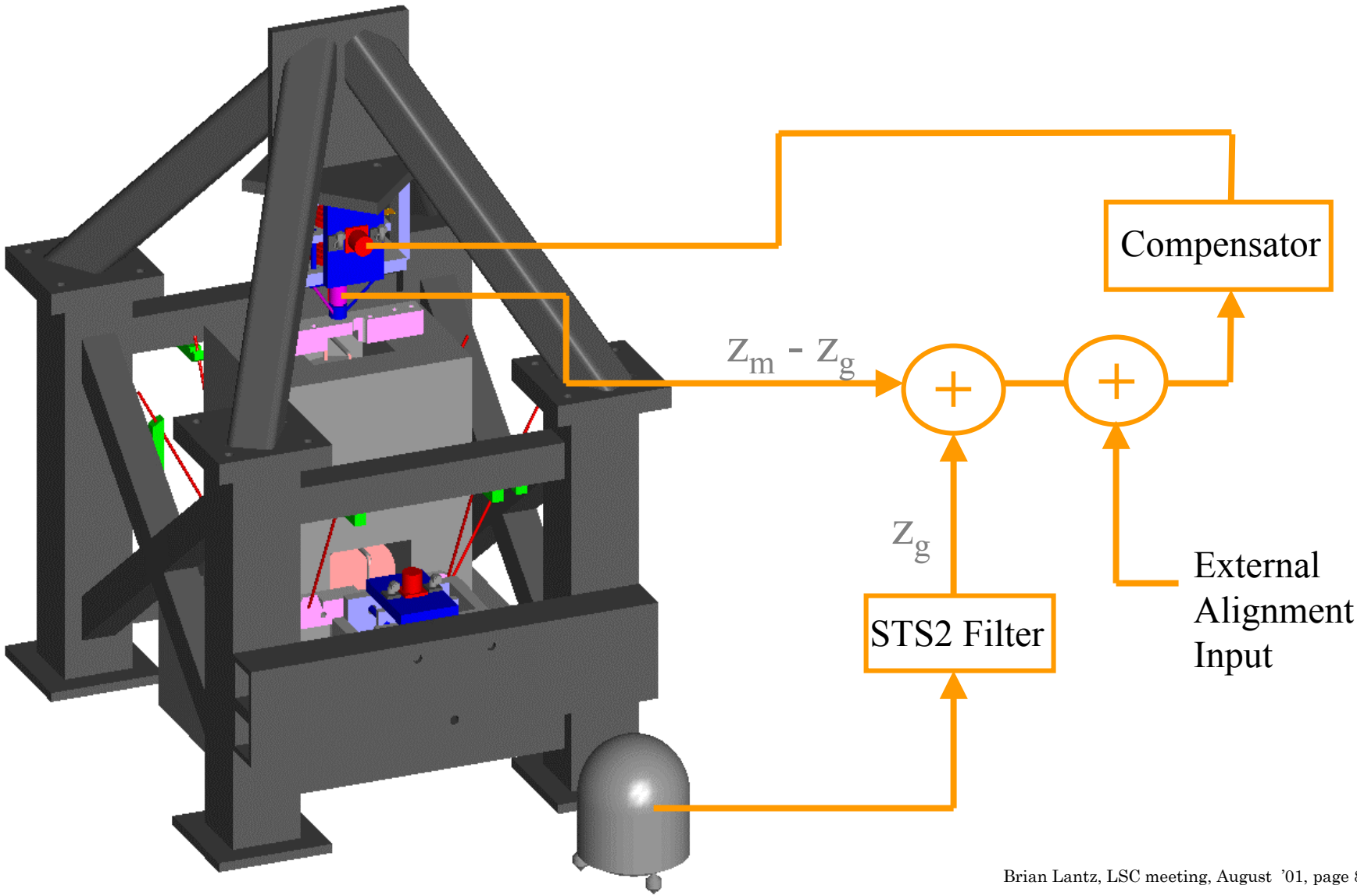
Active and Passive Suppression of Pressure Fluctuations



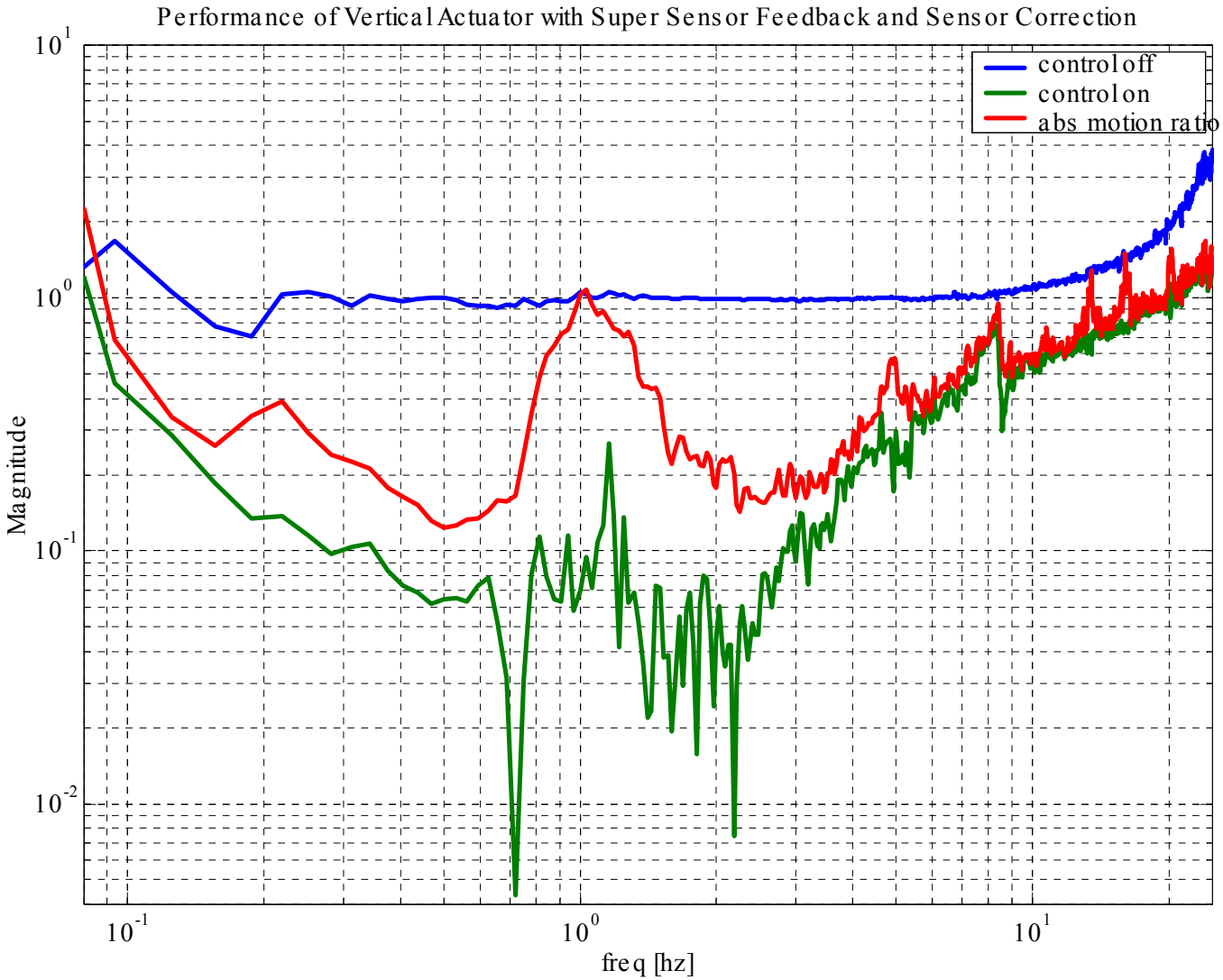
The Test Platform at Stanford



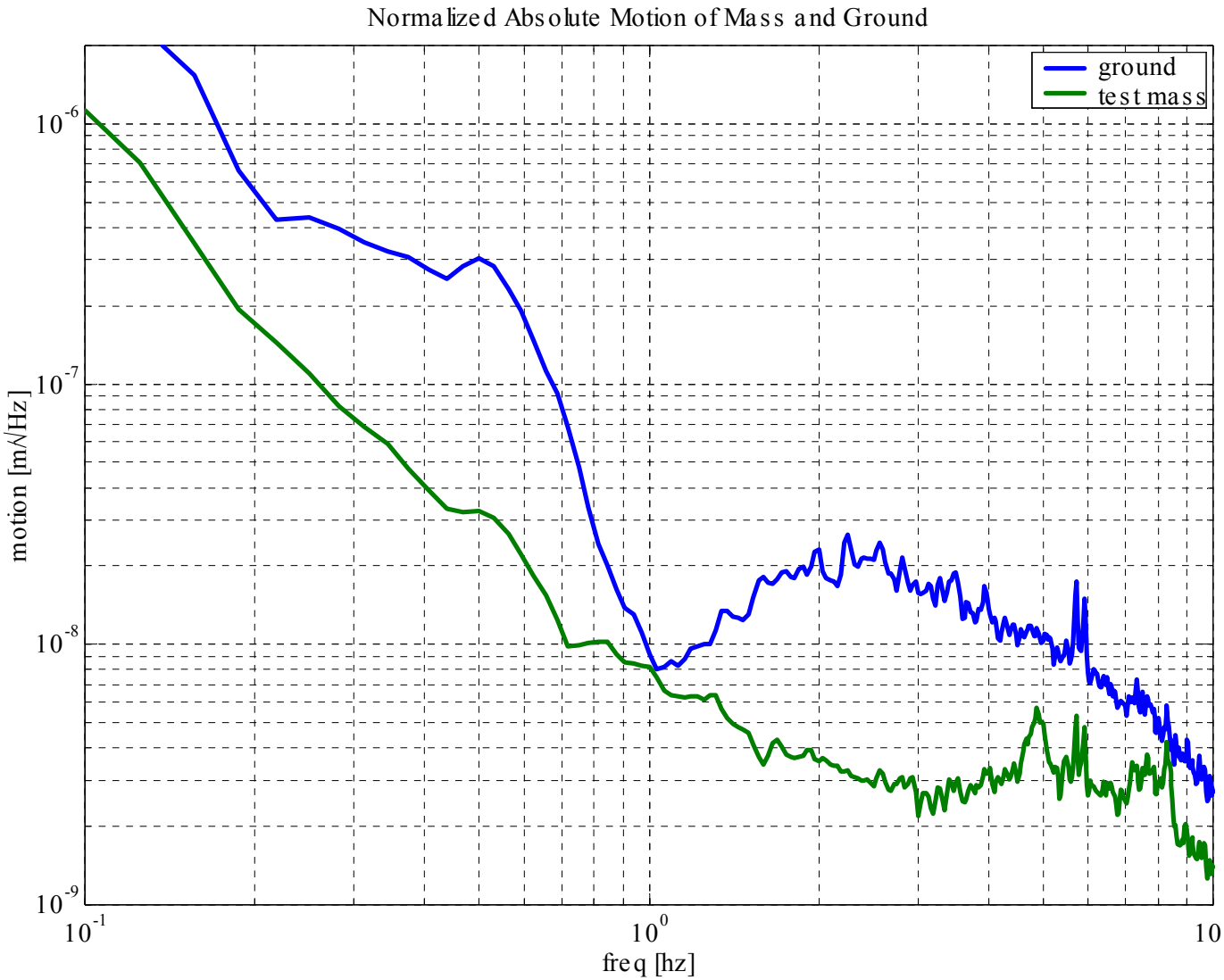
Sensor Correction



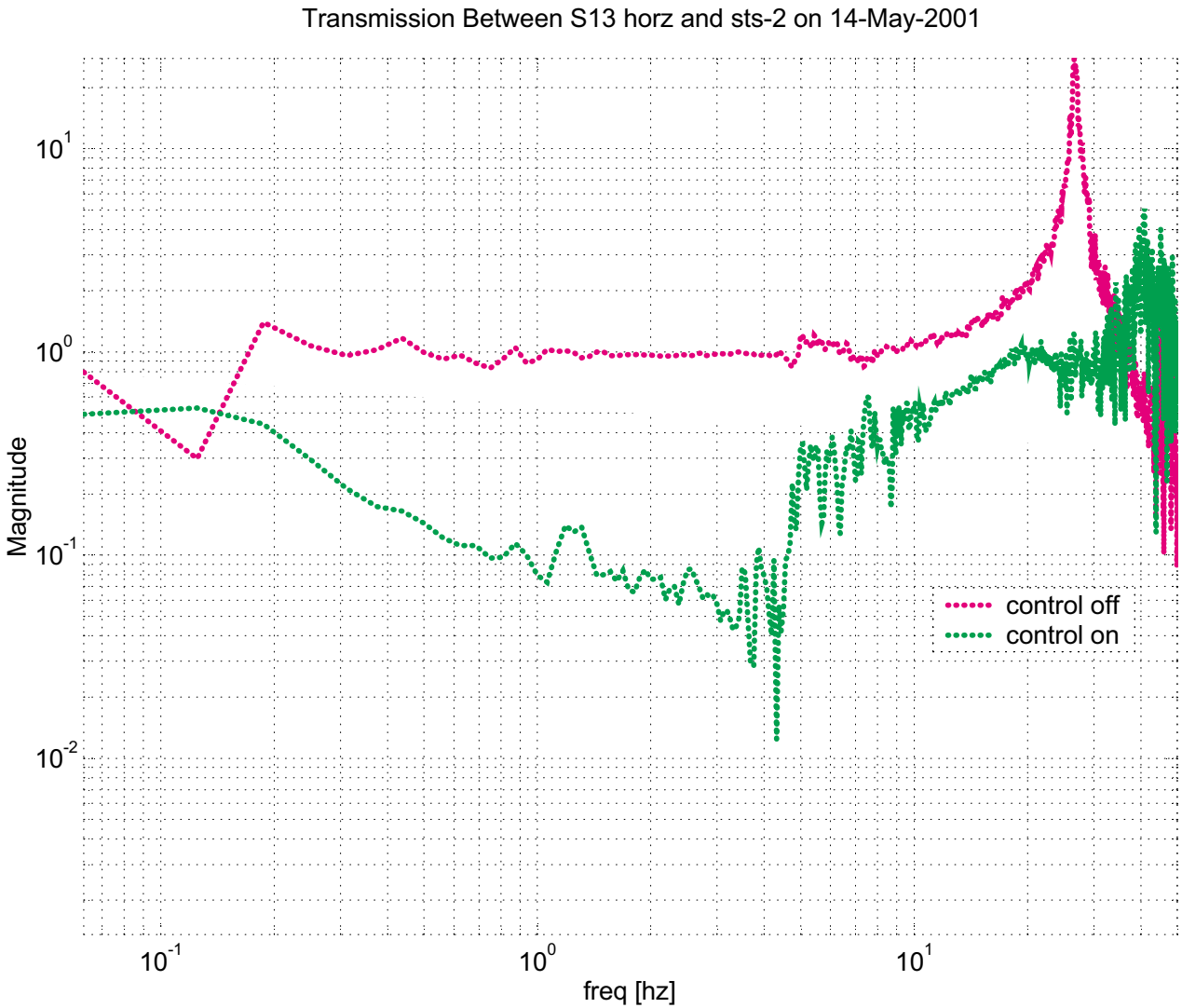
Vertical Isolation



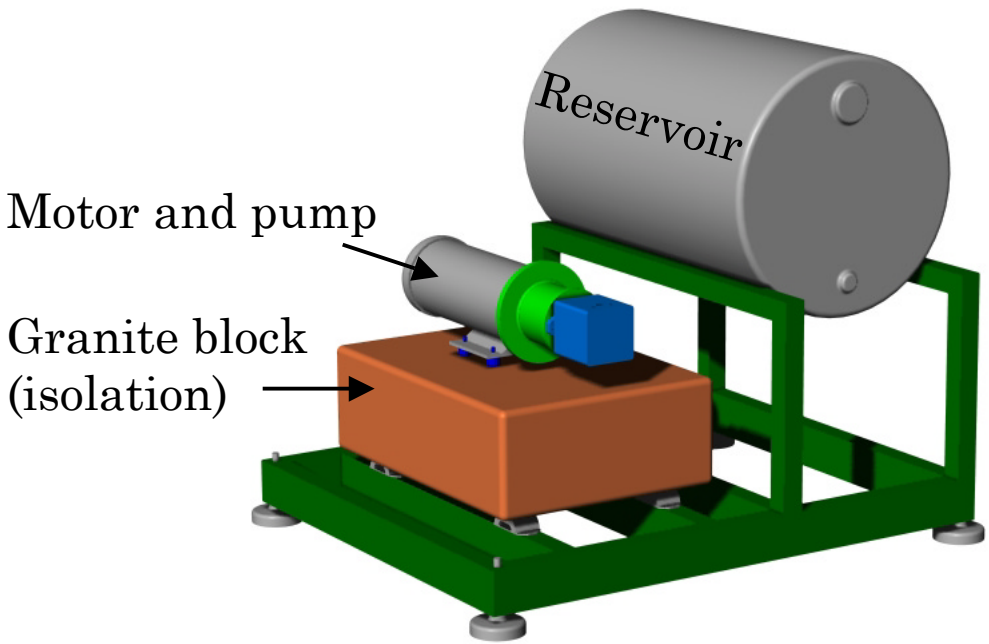
Vertical Motion



Horizontal Isolation

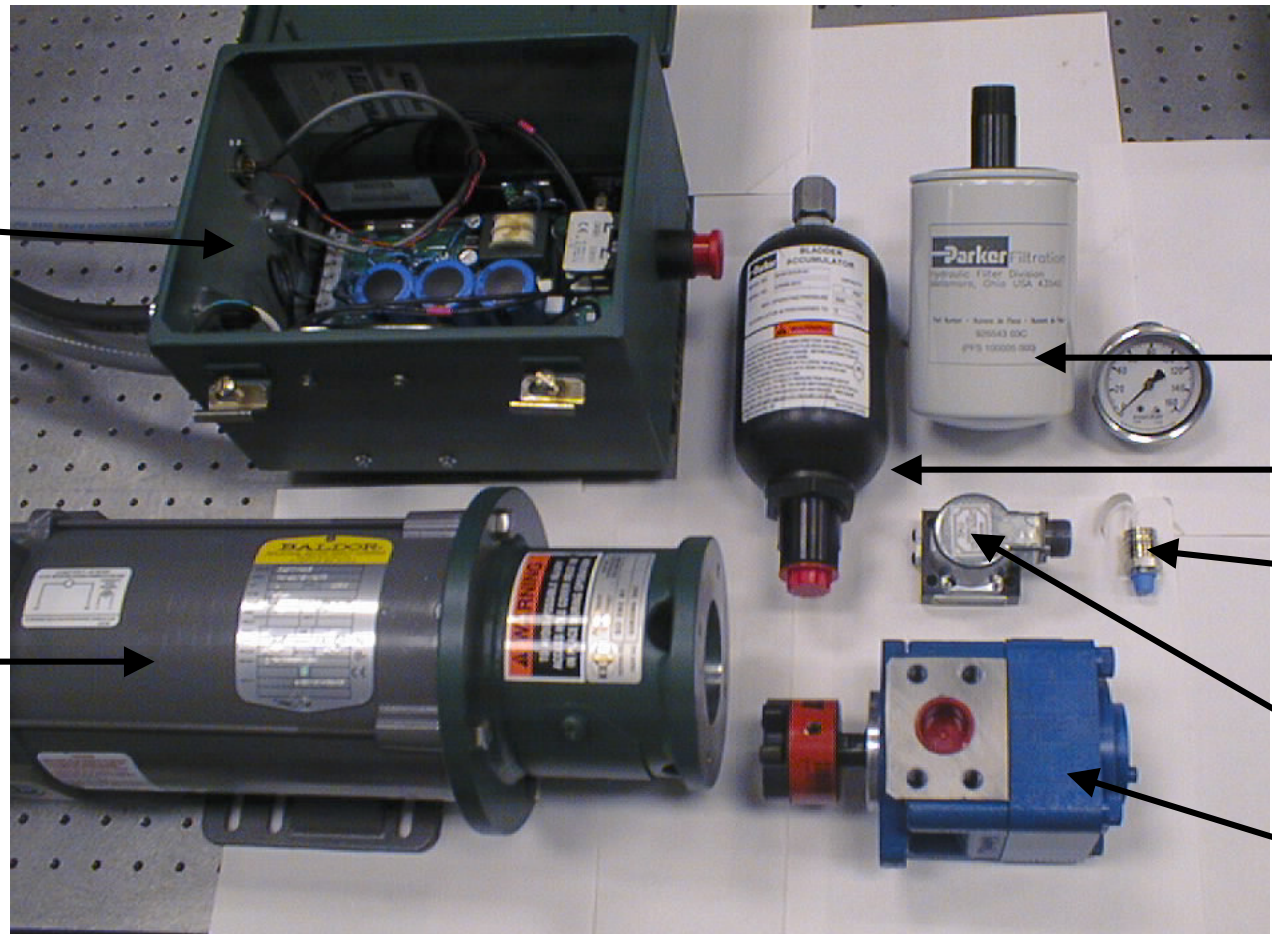


New Pumping Stand



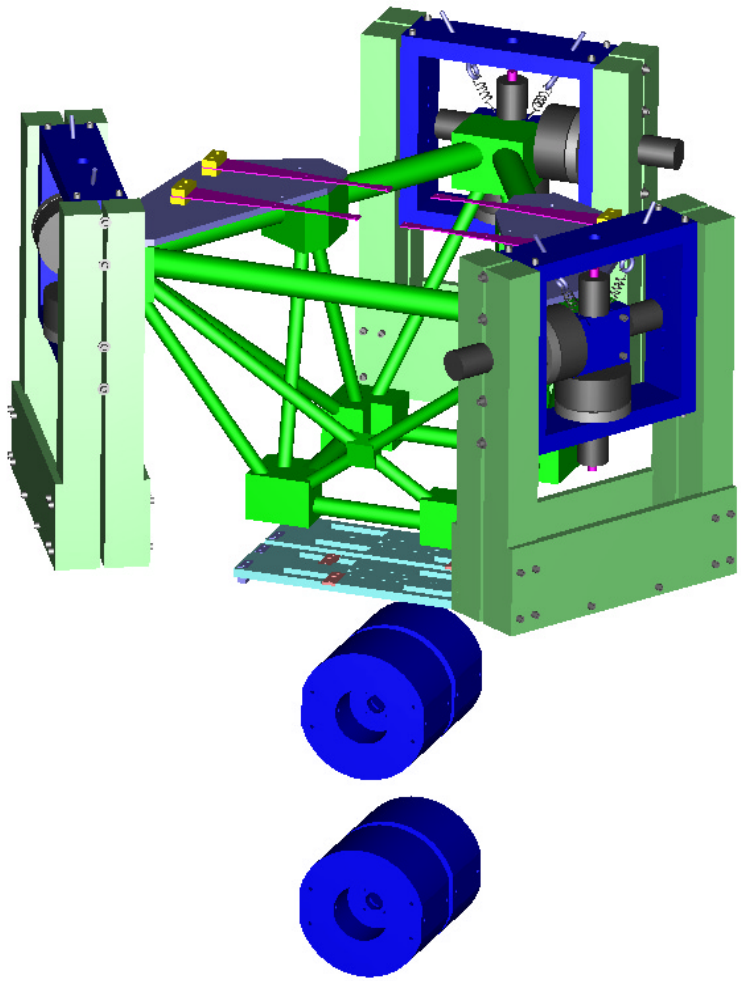
- Build new system with improved low freq range, and capacity to drive 8 actuators.
- Allow Stanford and LASTI to order identical stations (easier debugging).
- Assembled and instrumented by end of October.

New Pump Station is Progressing

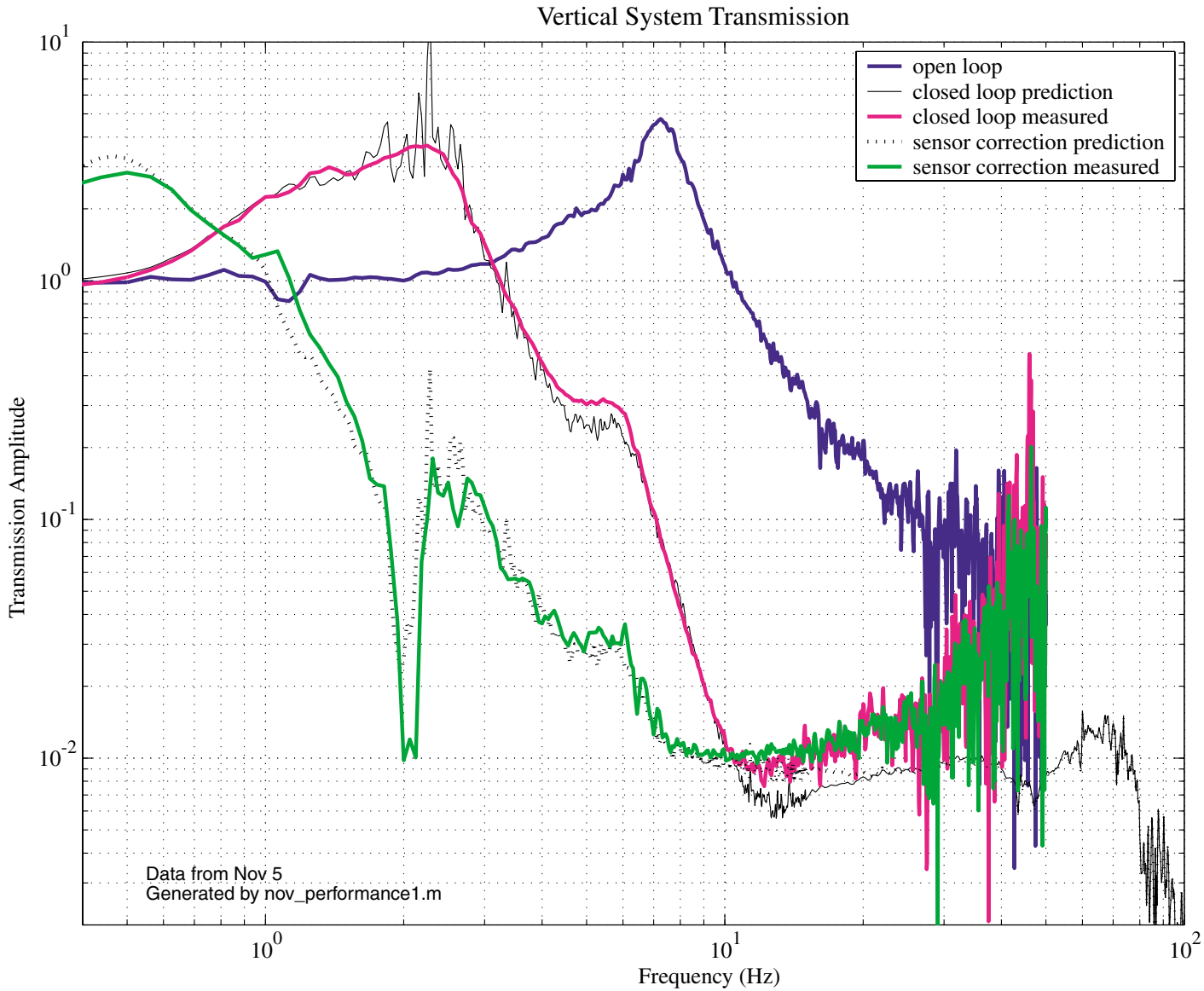


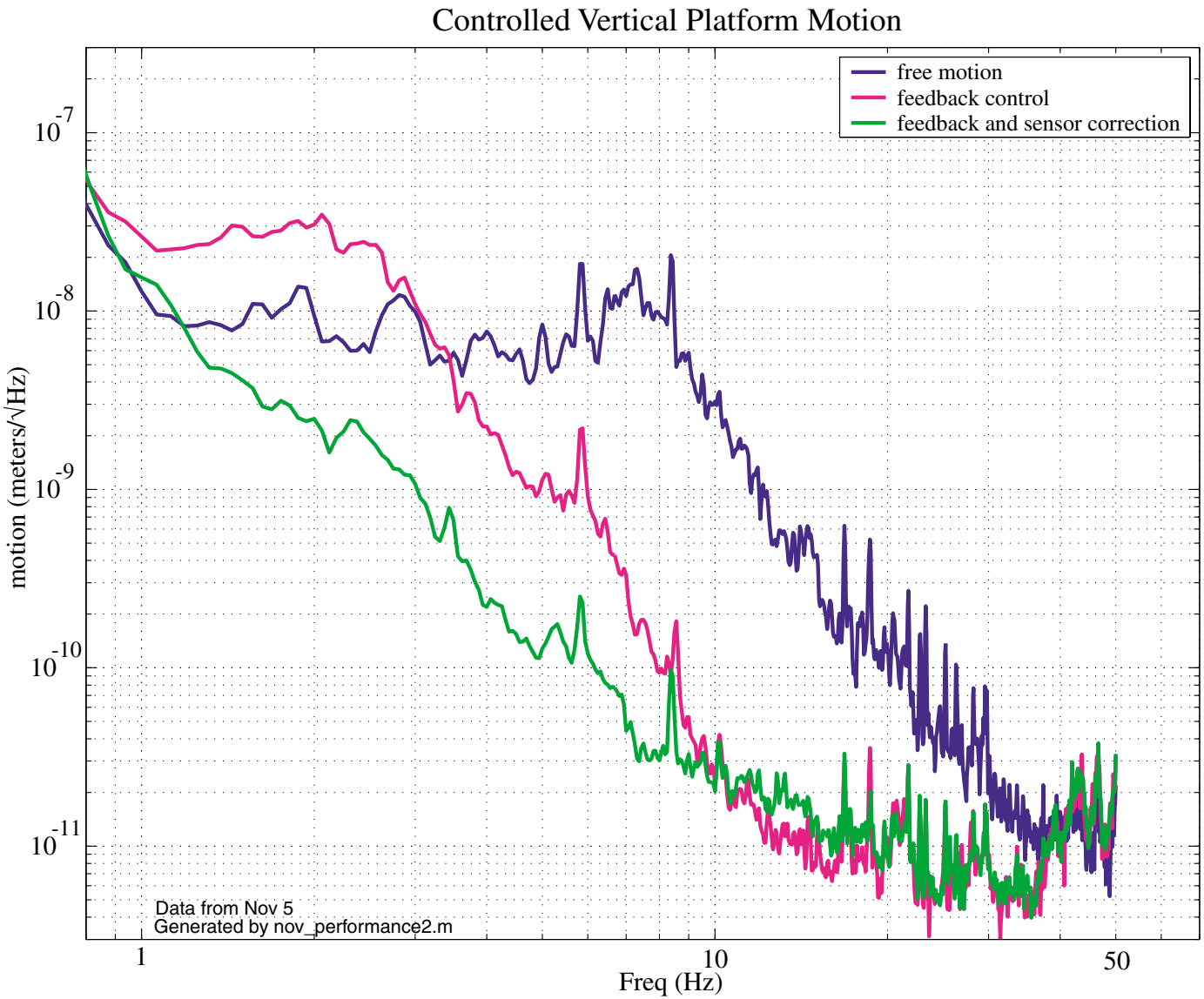
Single Layer Platform with Pendulums

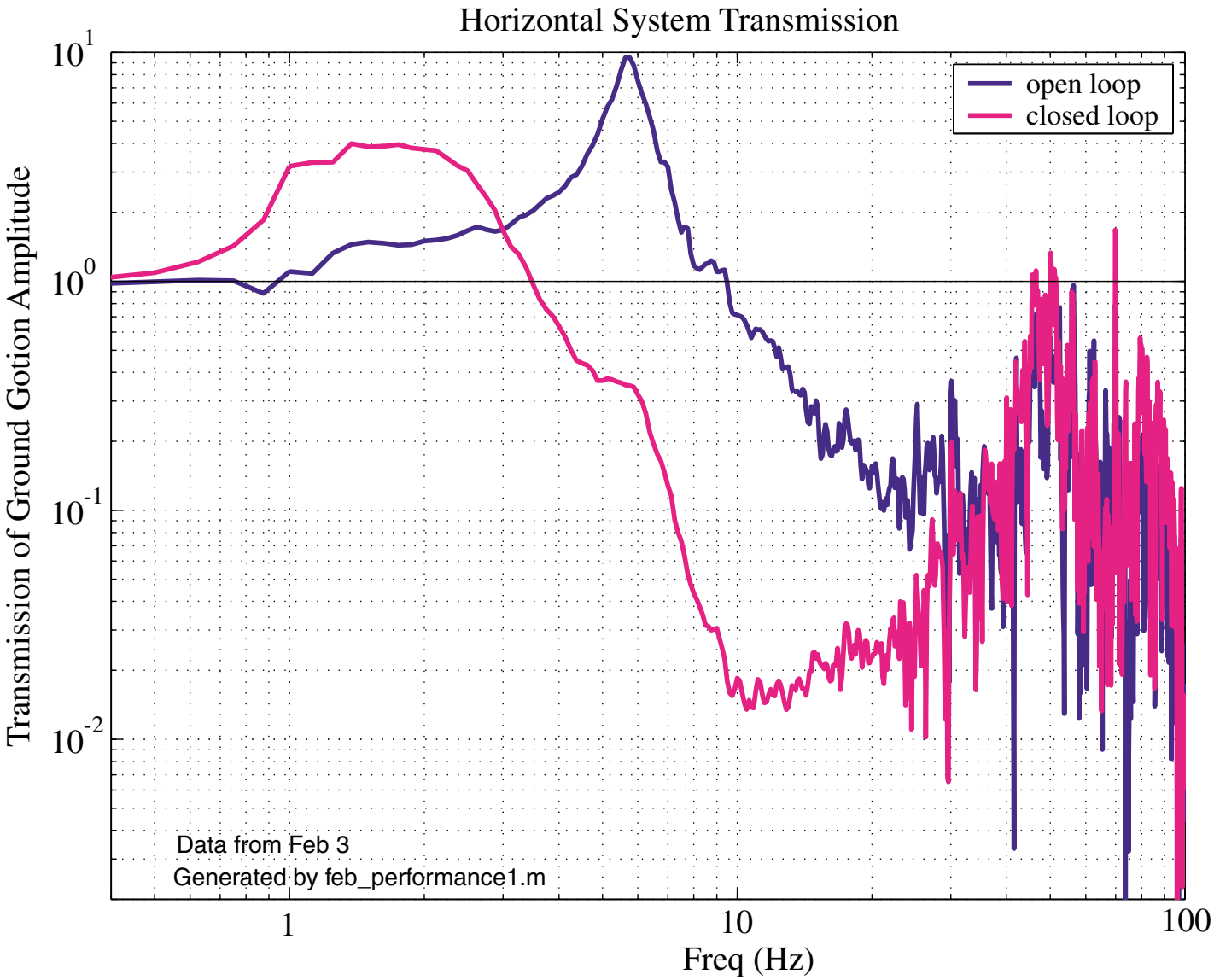
- Demonstrate 6 DOF active platform with collocated sensors and actuators.
- Demonstrate sensor blending.
- Validate computer model used to design LIGO system.
- Demonstrate sensor correction to reduce ground motion.
- Demonstrate reliable operation of stiff platform and pendulum working together.

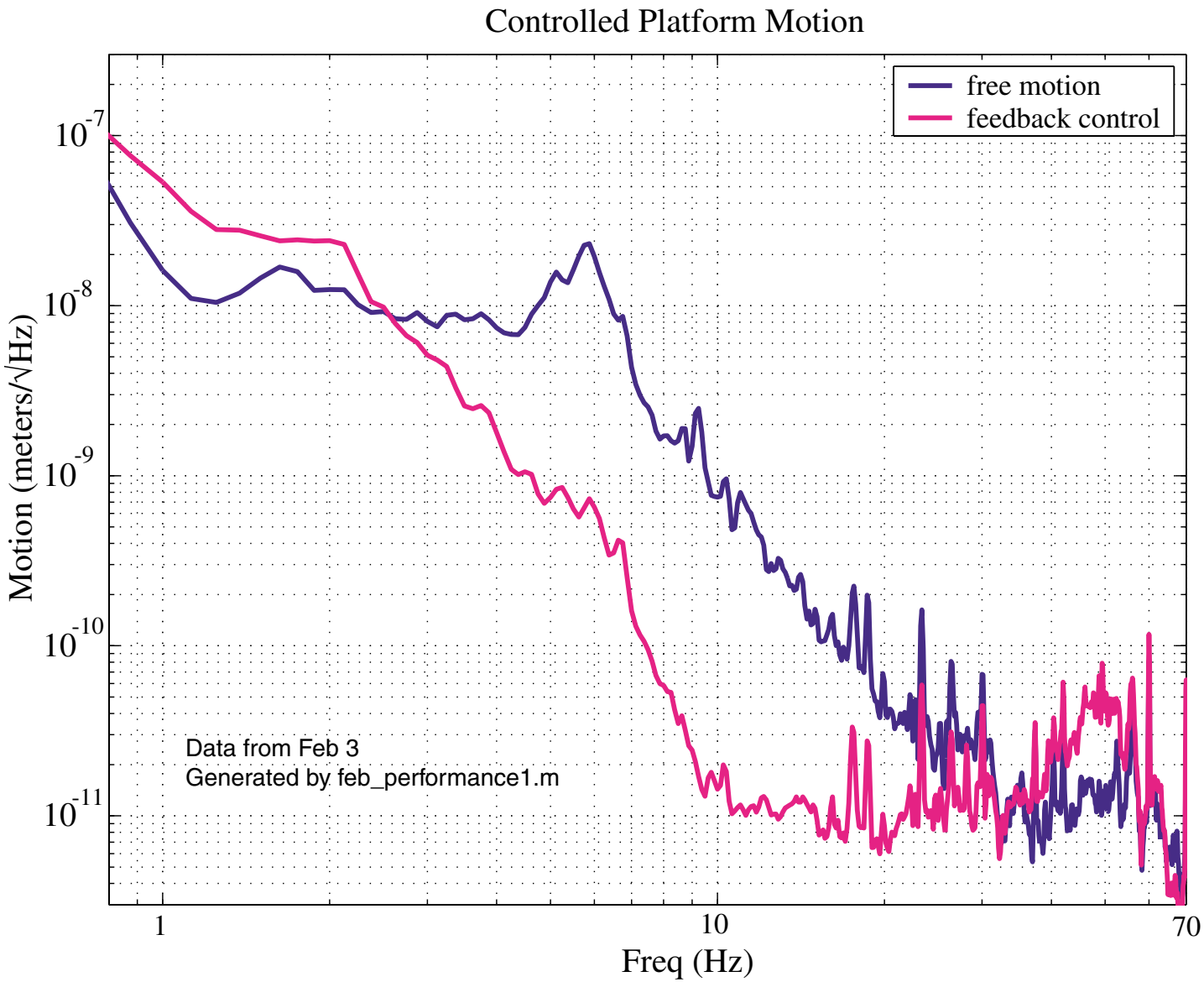


Results from Single Layer Platform

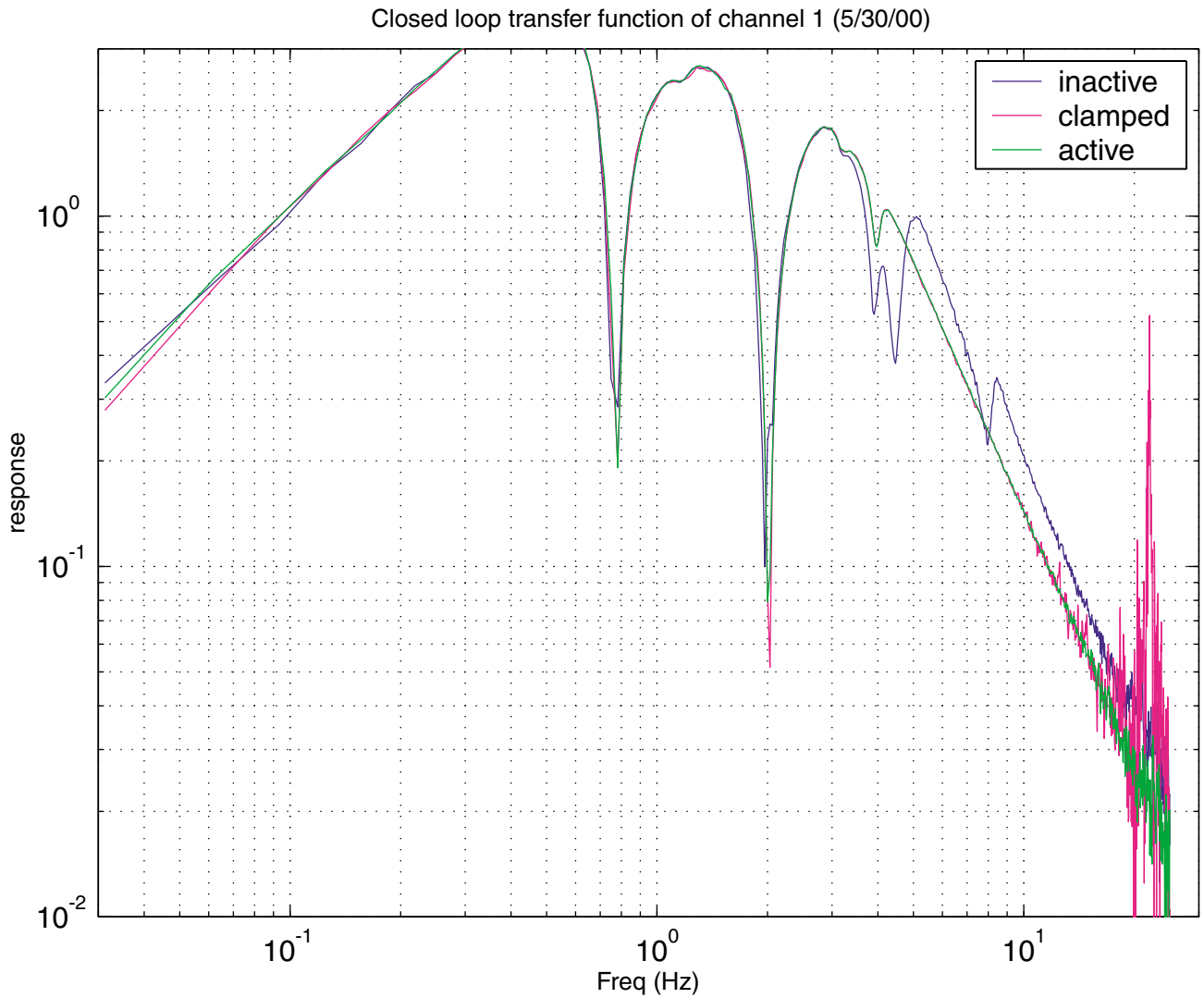



Controlled Vertical Platform Motion
free motion
feedback control
feedback and sensor correction
motion (meters/√Hz)
10^-7
10^-8
10^-9
10^-10
10^-11
Data from Nov 5
Generated by nov_performance2.m
1
10
50
Freq (Hz)

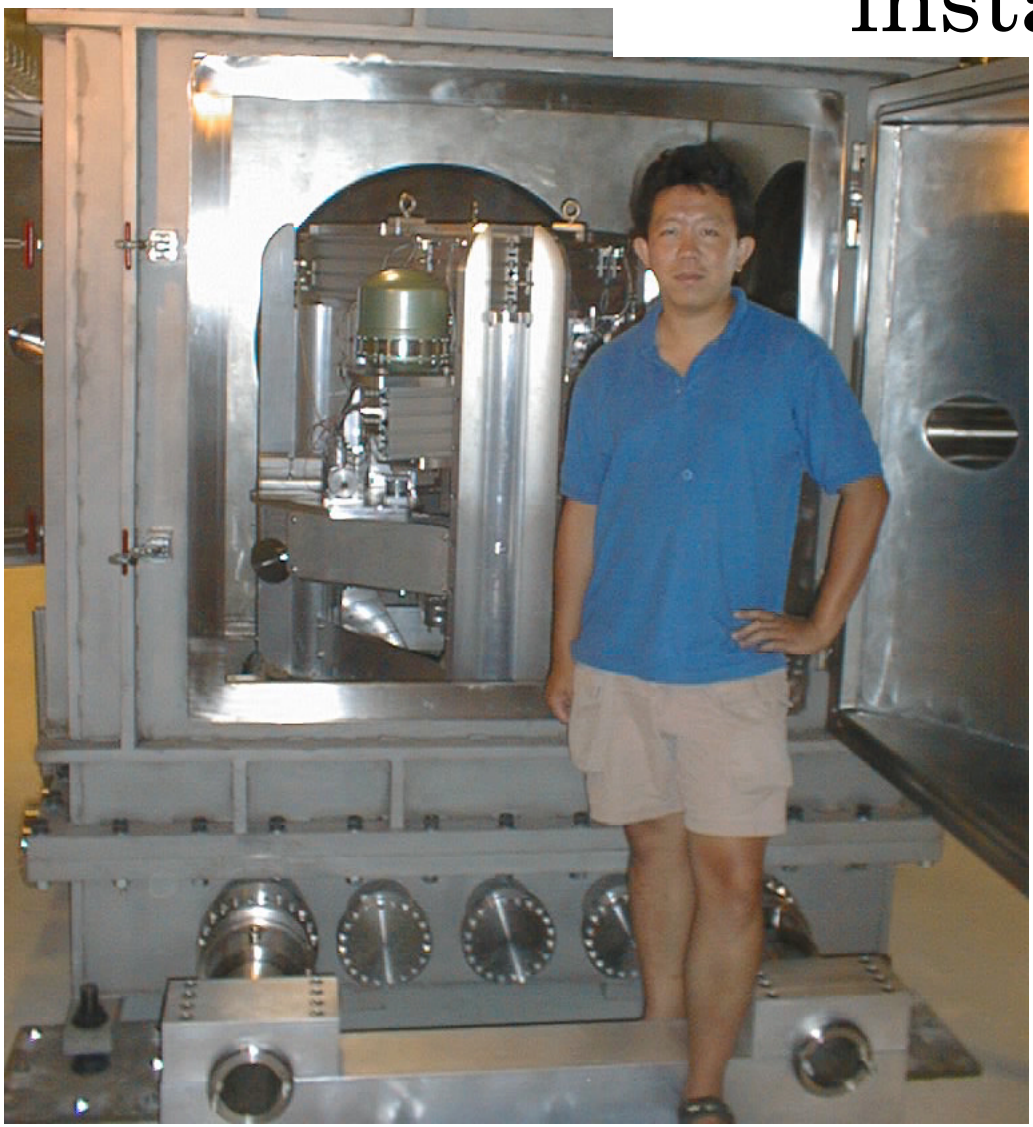

Horizontal System Transmission
Transmission of Ground Gotion Amplitude
10^{1}
10^{0}
10^{-1}
10^{-2}
open loop
closed loop
Data from Feb 3
Generated by feb_performance1.m
1
10
100
Freq (Hz)


Controlled Platform Motion
free motion
feedback control
Motion (meters/√Hz)
10^-7
10^-8
10^-9
10^-10
10^-11
Data from Feb 3
Generated by feb_performance1.m
1
10
70
Freq (Hz)

Pendulum Interactions



Rapid Prototype (mostly) installed in ETF



Improve performance

New flexures to reduce T/H coupling

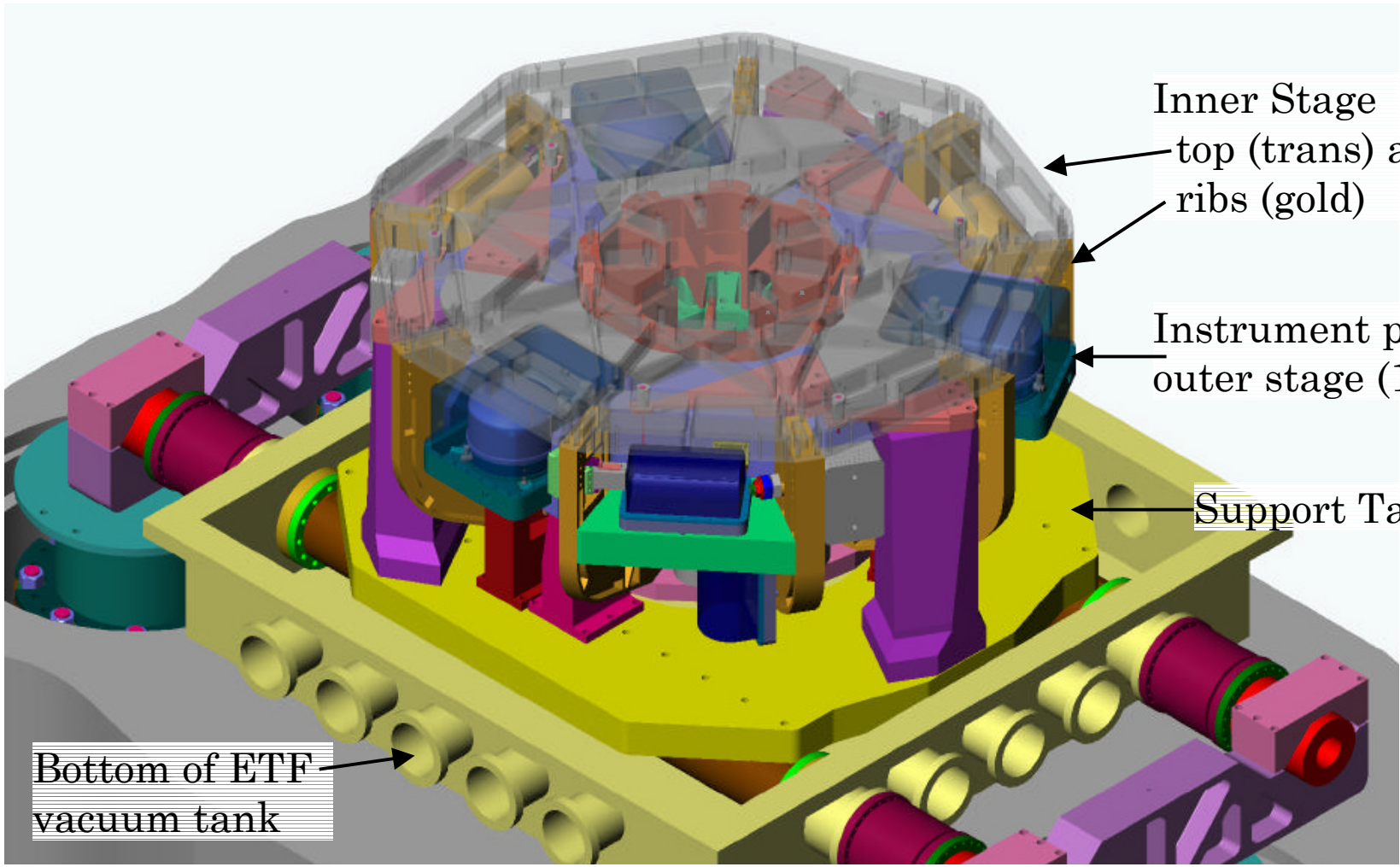
Study ways to combat tilt

Improved System ID

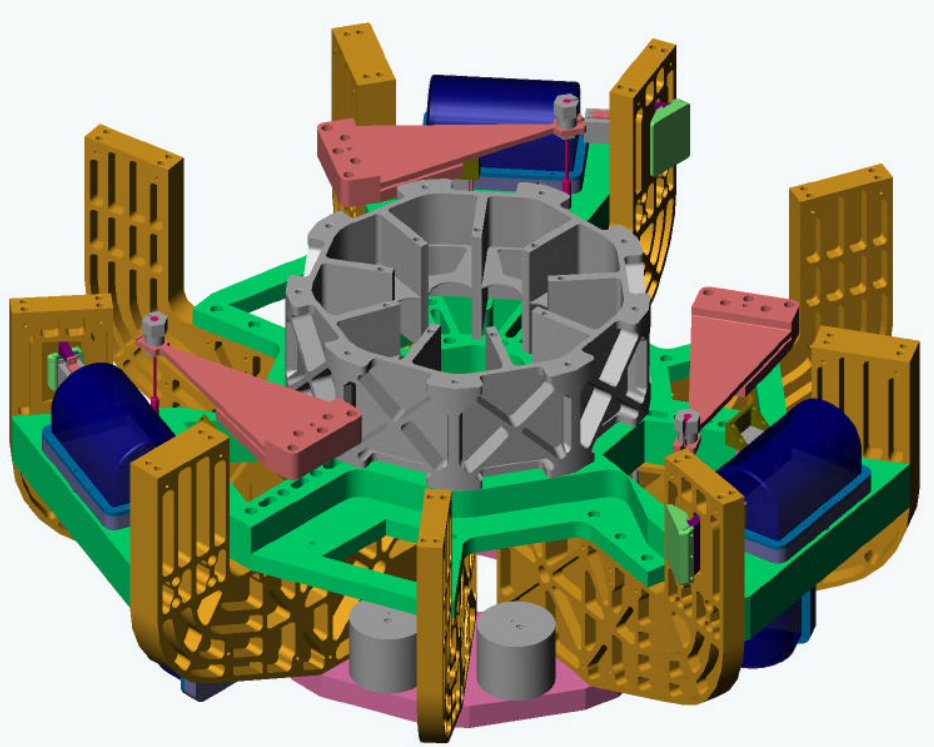
Next Step: Two Stage Prototype for Advanced LIGO

- Prototype for the HAM chamber system, to be installed in vacuum at the Stanford ETF.
- Same sensors, similar actuators as the Advanced LIGO system.
- Same dynamics as the Advanced LIGO system.
- Centers of mass of two stages at the same location.
- Sensors and actuators well aligned.
- How well does it work? Feed design information to the Pathfinder design at LASTI.

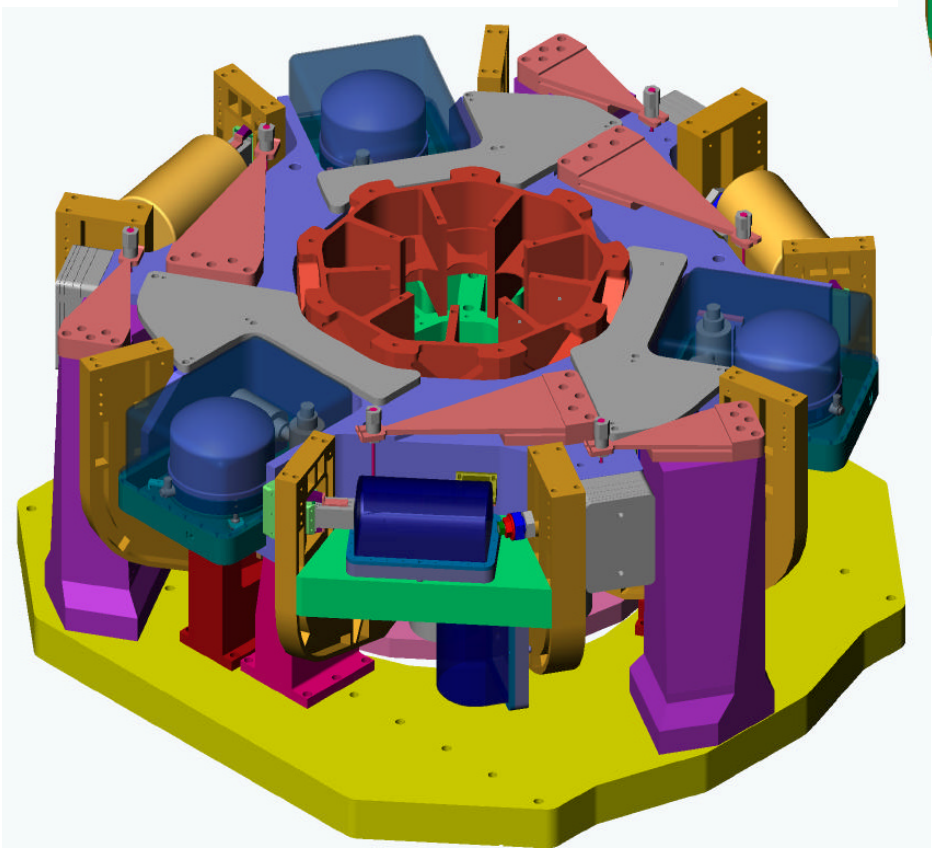
HPD Design for the New Prototype



Views of the Prototype Design

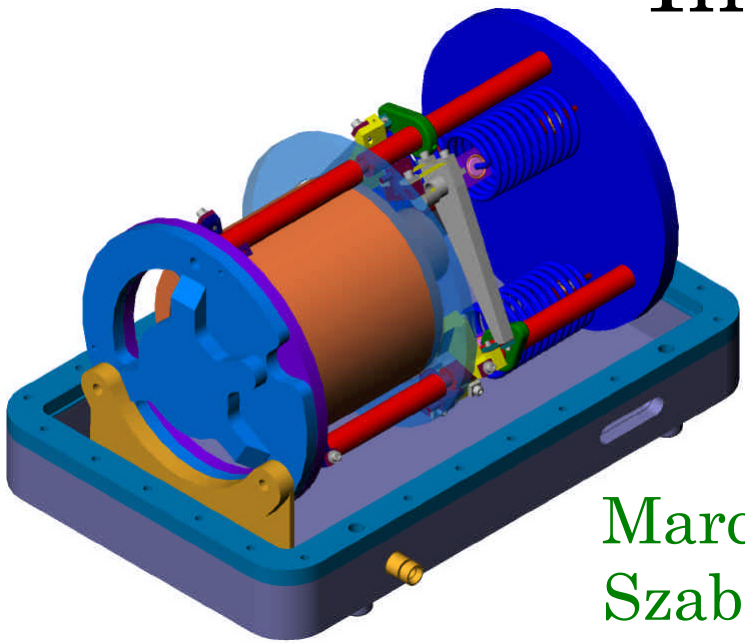


Inner Stage
w/o table top



Both stages and
support table

In the Labs…



Marcel Hammond and Szabi Marka adapt instruments to vacuum

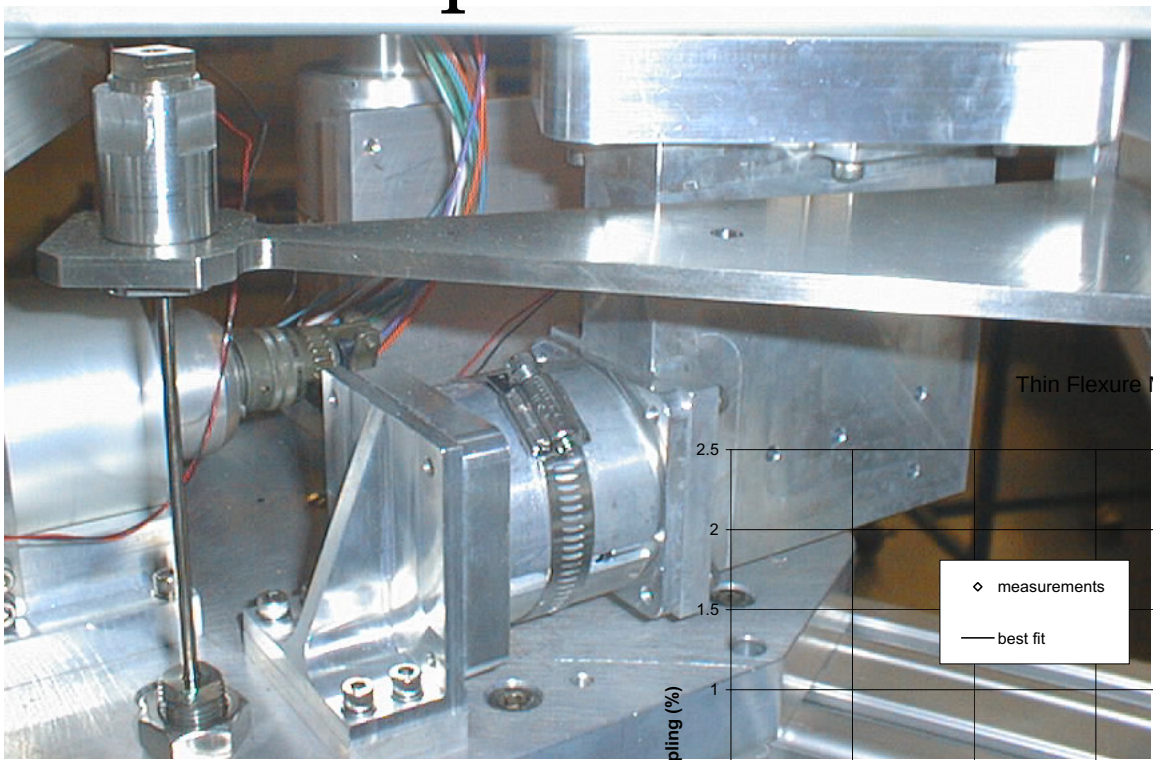
Model: 3800 version one

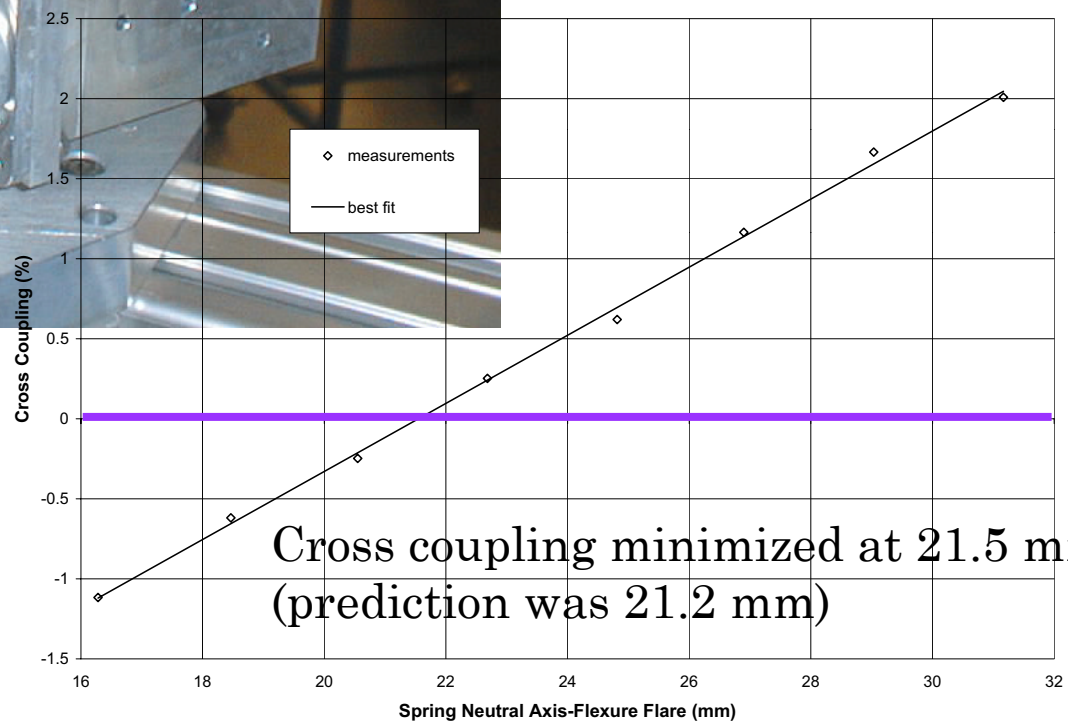
Rich Abbott qualifies capacitive sensors

Sensor Gain - 1V/100um
Sensor dynamic range - +/- 500um about a 1000um mean yields 0 to 10 volts
Observed frequency range for noise analysis - 0 to 100 Hz
Output when attached to standard target supplied by manufacturer - 5.39 VDC
Magnitude of observed power spectral density of sensor - 2.5e-6 V/rtHz

Equivalent displacement noise - 2.5e-10 m/rtHz

Improved Flexure Design





Cross coupling minimized at 21.5 mm, (prediction was 21.2 mm)

Magnetic coupling of Actuator / Geophone - Giles

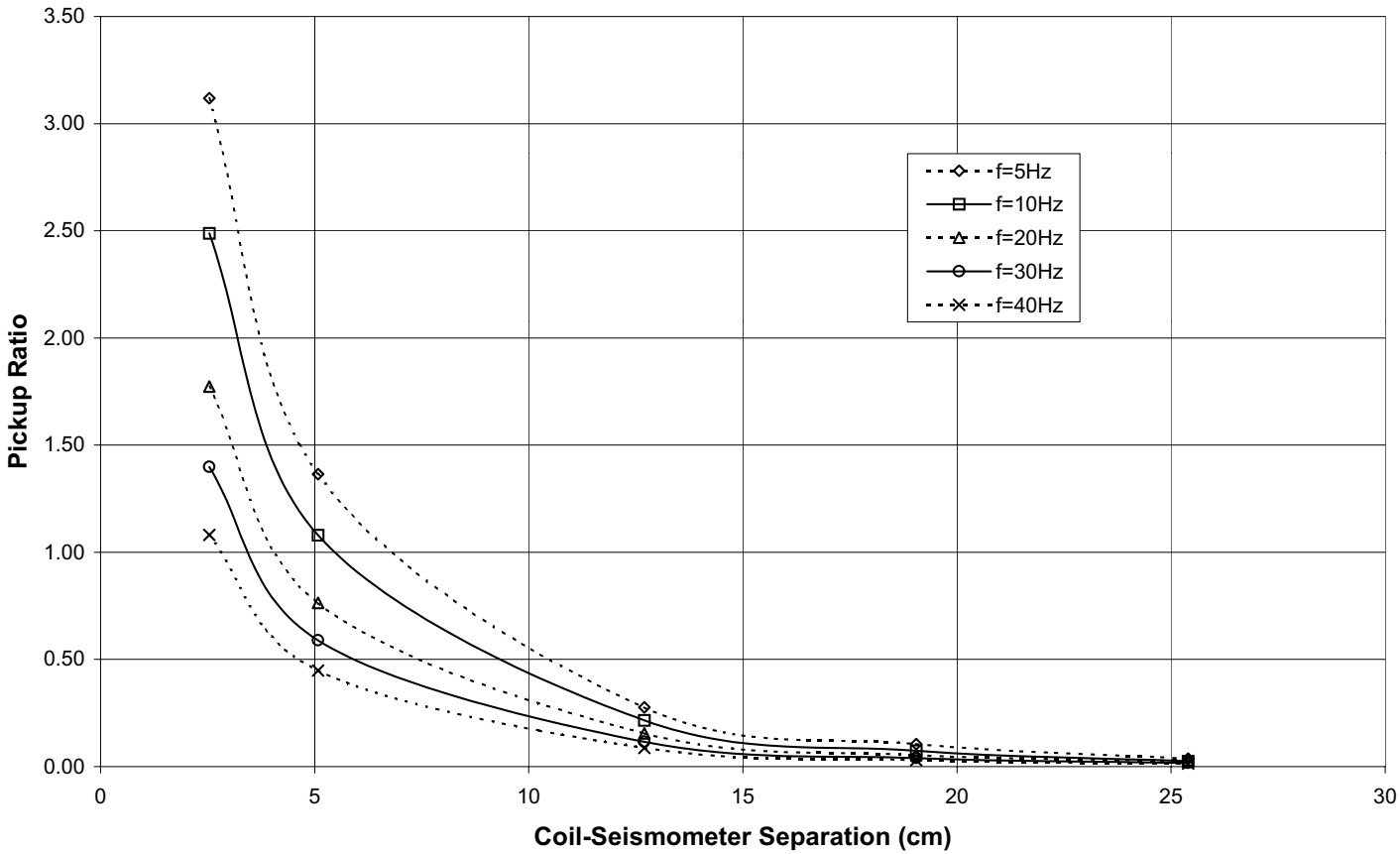


Figure 2. Pickup ratio versus coil-seismometer separation

Summary

Hydraulics work well – working to install the next version in LASTI.

Learned much from the prototypes – hardest problem is tilt/ horizontal coupling.

New prototype is underway, due for delivery in November!

Candidate Actuators

	Force	Velocity	Stiffness	Displacement	Stiction	Hysteresis	Mechanical Noise
Hydraulic	High	Low	Med	Med	Low	Low	Low
Ball Screw	High	Low	High	High	High	Low	High
Linear Motor	High	High	Low	High	Low	Low	Low
Piezo or Magnetostriction	High	High	High	Low	Low	High	Low