Passive seismic attenuation for the LIGO Output mode cleaner; HAM-SAS

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Introduction

- A SAS configuration (HAM-SAS) have been designed for the seismic attenuations of the Output Mode Cleaner optical benches

- The resulting design of HAM-SAS has expected attenuation capabilities matching the Adv LIGO specs for any HAM (the cumulative performance of the three active SEI stages)

Introduction

- HAM-SAS is upgradeable beyond Adv-LIGO requirements
- The HAM-SAS, although designed for the Output Mode Cleaner,

  could be considered for use on all HAMs

- some preliminary considerations needed

Some perspective view

- LIGO
  - 4 stacks x-y-z $1/f^8$ starting @ 1-3 Hz
  - 1 pendulum x $1/f^2$ starting @ ~1 Hz
- Virgo
  - 1 IP x-y $1/f^2$ starting @ 30 mHz
  - 5+2 pendula x-y $1/f^{14}$ starting @ 0.5 Hz
  - 6 Vert-springs z $1/f^{12}$ starting @ 0.4 Hz

Some perspective view

				saturation
• Advanced LIGO				
– 3 active	x-y-z	$1/f^x$	starting @ 0.1 Hz	60 dB
– 4 pendula	x-y	$1/f^8$	starting @ 1 Hz	
– 3 Vert-springs	z	$1/f^6$	starting @ 1 Hz	120 dB
• Virgo				
– 1 IP	x-y	$1/f^2$	starting @ 30 mHz	60 dB
– 5+2 pendula	x-y	$1/f^{14}$	starting @ 0.5 Hz	
– 6 Vert-springs	z	$1/f^{12}$	starting @ 0.4 Hz	240 dB

Some perspective view

- Advanced LIGO

				saturation
– 3 active	x-y-z	$1/f^x$	starting @ 0.1 Hz	60 dB
– 4 pendula	x-y	$1/f^8$	starting @ 1 Hz	
– 3 Vert-springs	z	$1/f^6$	starting @ 1 Hz	120 dB*

- LIGO-SAS

– 1 IP	x-y	$1/f^2$	starting @ 30 mHz	60 dB
– 3+2 pendula	x-y	$1/f^{10}$	starting @ 0.5 Hz	
– 3 Vert-springs	z	$1/f^6$	starting @ 0.3 Hz	180 dB*

*difference due to different stress levels and Virgo blade design

Some perspective view

- Advanced LIGO

				saturation
– 3 active	x-y-z	$1/f^x$	starting @ 0.1 Hz	60 dB
– 4 pendula	x-y	$1/f^8$	starting @ 1 Hz	
– 3 Vert-springs	z	$1/f^6$	starting @ 1 Hz	120 dB *

- TAMA

– 1 IP	x-y	$1/f^2$	starting @ 30 mHz	60 dB
– 2+2 pendula	x-y	$1/f^8$	starting @ 0.5 Hz	
– 3 Vert-springs	z	$1/f^6$	starting @ 0.3 Hz	180 dB *

*difference due to different stress levels and Virgo blade design

Some perspective view

- Advanced LIGO HAMs (recycling mirrors)

				saturation
– 3 active	x-y-z	$1/f^x$	starting @ 0.1 Hz	60 dB
– 3 pendula	x-y	$1/f^6$	starting @ 1 Hz	
– 2 Vert-springs	z	$1/f^4$	starting @ 1 Hz	80 dB

- Advanced LIGO BSCs

				saturation
– 3 active	x-y-z	$1/f^x$	starting @ 0.1 Hz	60 dB
– 4 pendula	x-y	$1/f^8$	starting @ 1 Hz	
– 3 Vert-springs	z	$1/f^6$	starting @ 1 Hz	120 dB

Initial Considerations

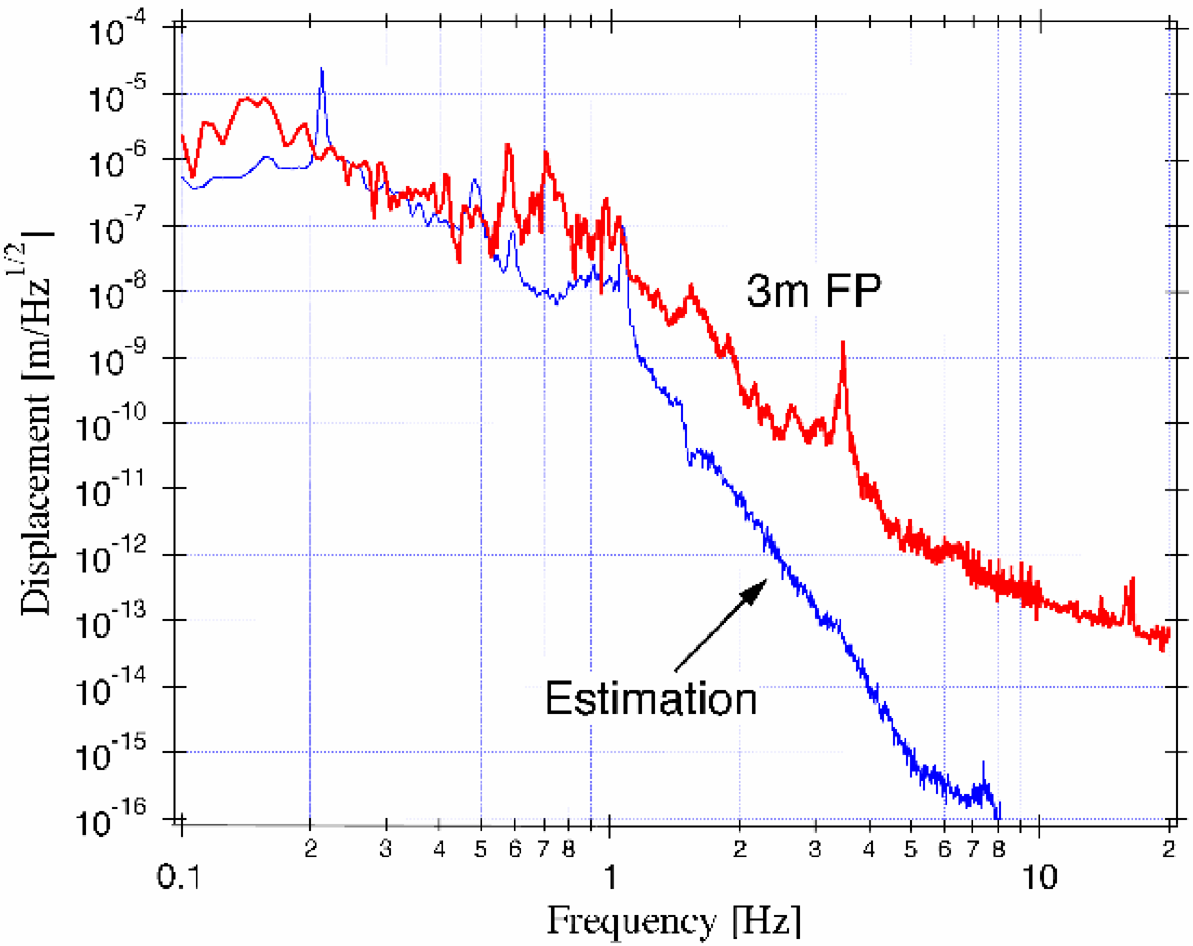
- The SEI of Advanced LIGO is roughly equivalent to the Virgo and SAS Inverted Pendula pre-isolators
- In all systems, including Advanced LIGO, the bulk of seismic isolation comes from passive mechanical oscillators
- The pre-isolation is the “easy” task!

Initial Considerations

- The pre-attenuator success in Virgo and TAMA indicate that HAM SAS can be potentially used for all HAMs

- Virgo has a large overkill
- The lower 4 stages of TAMA show a degradation of performance,
  - still satisfying,
  - but overkill is a good thing to have

Performance Measured in the 3 m Hongo experiment



This is not necessarily the case of triple and quads.

My Worries

- The recycling mirrors have less seismic attenuation requirements than the Fabry Perot mirrors but one less stage of attenuation
- The SEI of the HAMs have similar, but possibly tighter requirements than the SEI of the BSCs
- It is desirable to have a simple system which satisfy the requirements, but must be easily upgradeable to higher attenuation performance if needed

The components of HAM-SAS

- Inverted pendula
- GAS springs

- LVDT and actuators

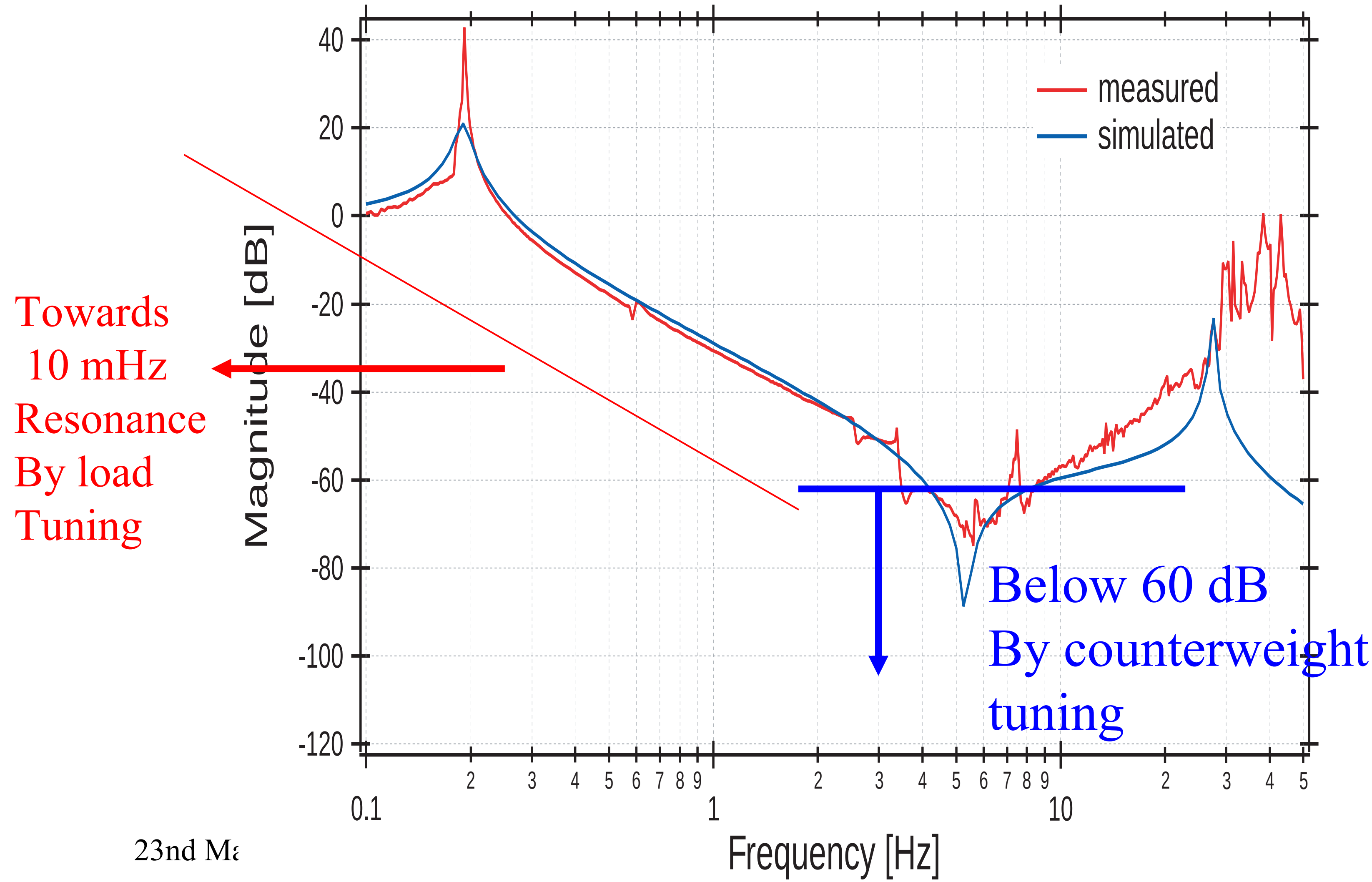
Illustrating
An IP performance

Earthquake generator shaking tower

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Typical IP performance



Typical IP performance

- The $1/f^2$ roll off starts at <50 mHz
- A saturation level typically of 60 dB is present because of the IP momentum of inertia
- The saturation can be pushed down, well below 60 dB, by means of counterweights.

GAS spring working principle

- The two cantilevers support the payload and, individually would have high resonant frequency.
- The frequency is lowered by radially compressing the two bent springs one against the other, the two compressed arches form an antispring that neutralize the cantilever springiness and the resonant frequency can be tuned at will

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Illustrating a GAS spring performance

exciting the payload
(hanging from the wire with the black flag)

Load support
Disk

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Suspension
Wire

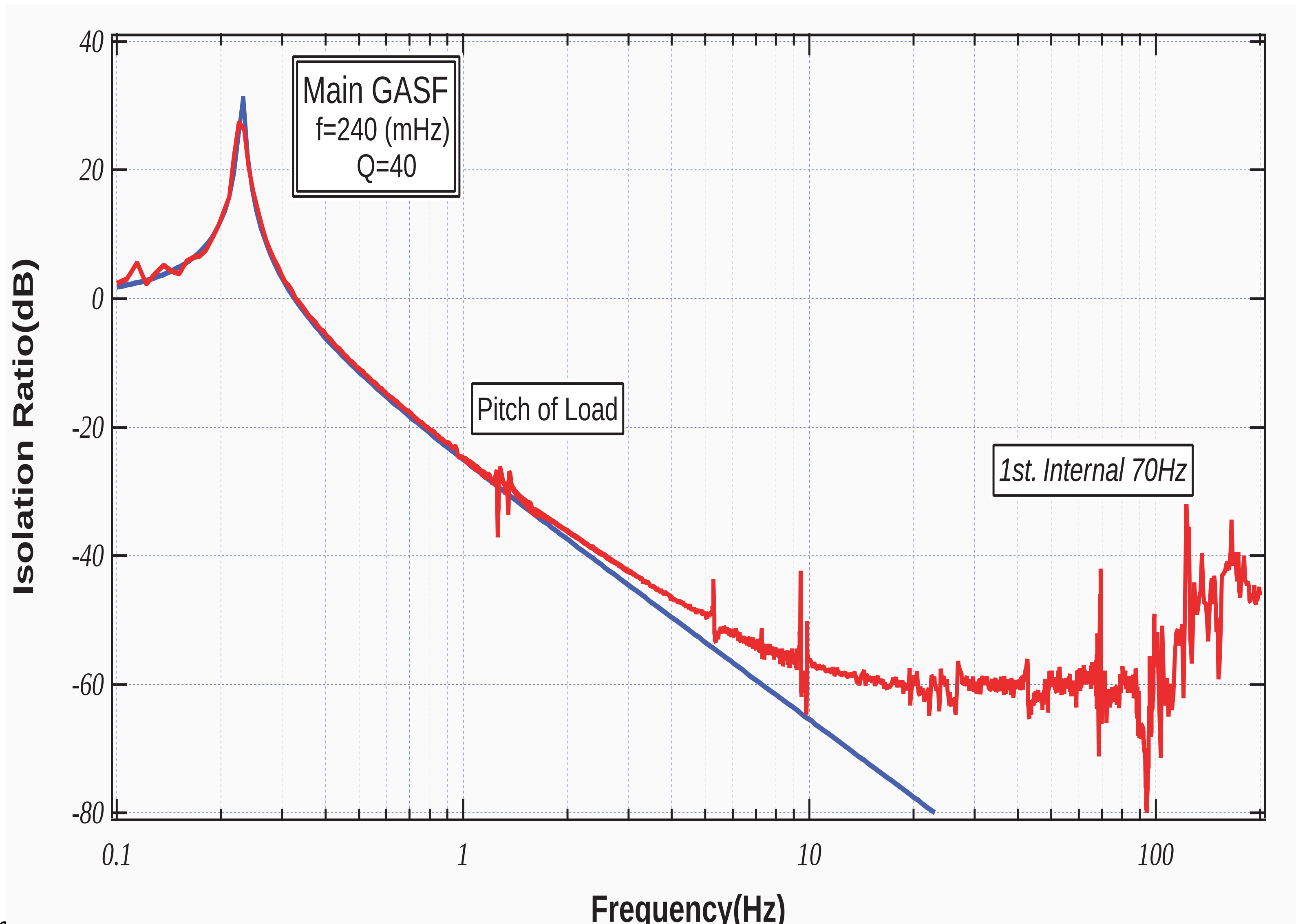
Payload
50 Kg

Now exciting the filter body

- If the filter is an attenuator the payload, black flag, should not move much.

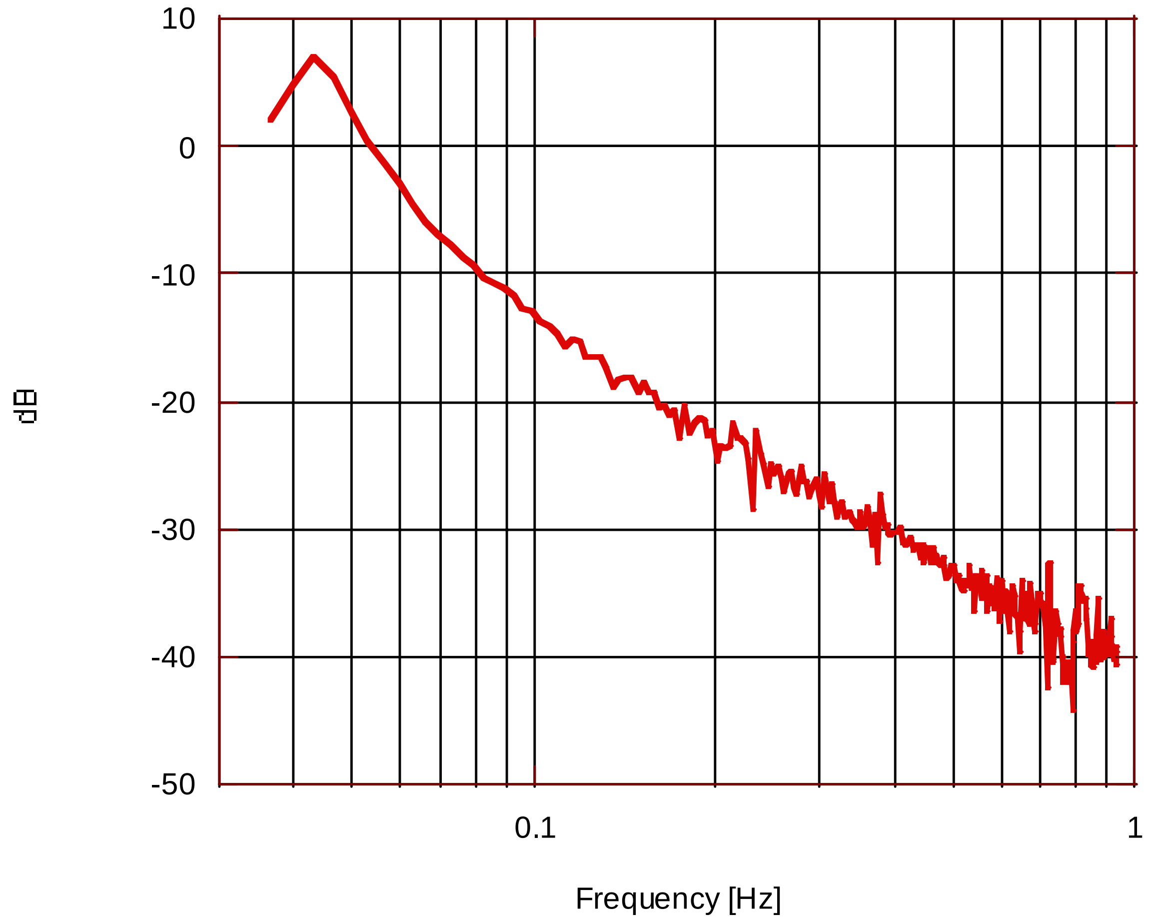
QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Typical GAS Passive vertical attenuation performance



Low frequency, in air, performance

- attenuation factors 60 dB above 3 Hertz for LF-GW-ID
- Sizeable attenuation at the micro seismic peak at 150 mHz



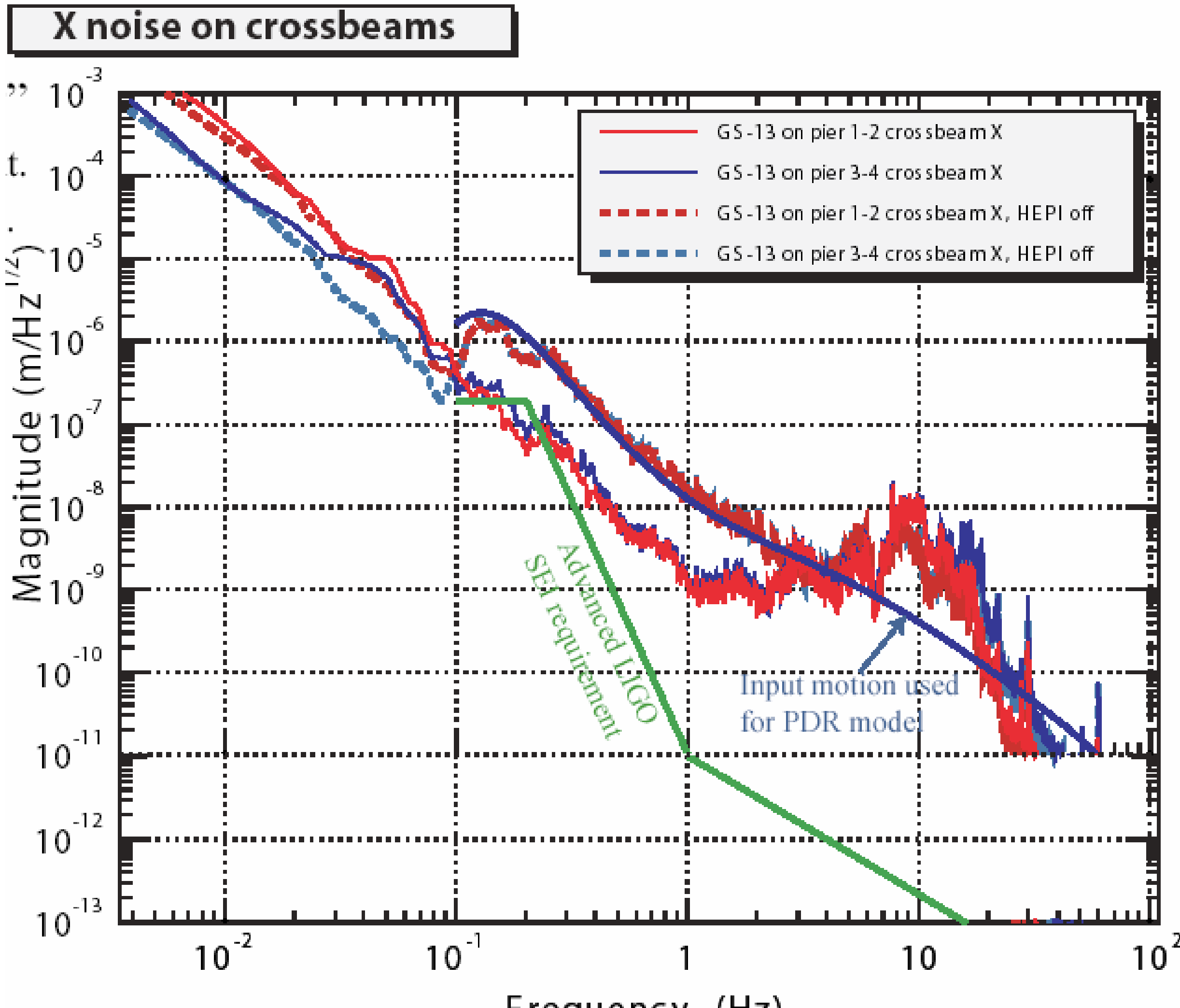
Typical GAS Passive vertical attenuation performance

- The $1/f^2$ roll off starts at <300 mHz
- A saturation level typically of 60 dB is present because of the blades' mass
- With e.m. correctors, roll off starts @<30 mHz

- Two ongoing summer projects to improve the saturation below 60 dB
  - Technology not available yet

Preliminary conclusions

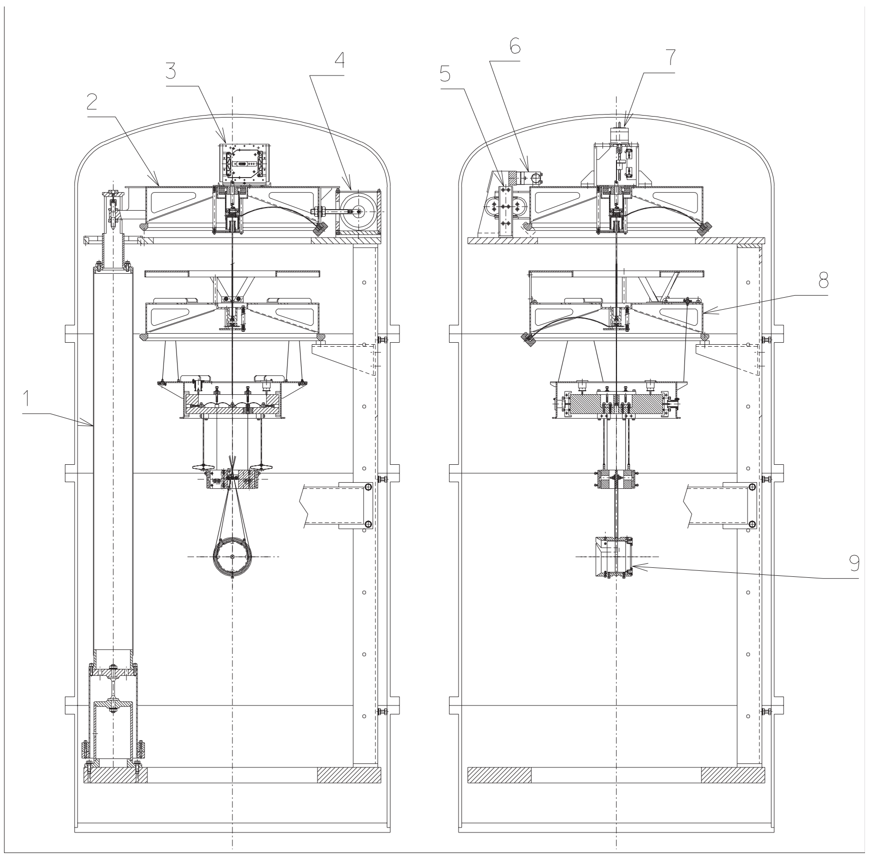
- Tests of IP and GAS filters show passive performance satisfying the Adv-LIGO seismic attenuation requirements



modified diagram from J. Giaime

Some historical points
how did we get to the HAM-SAS design

- TAMA-SAS



Some historical points

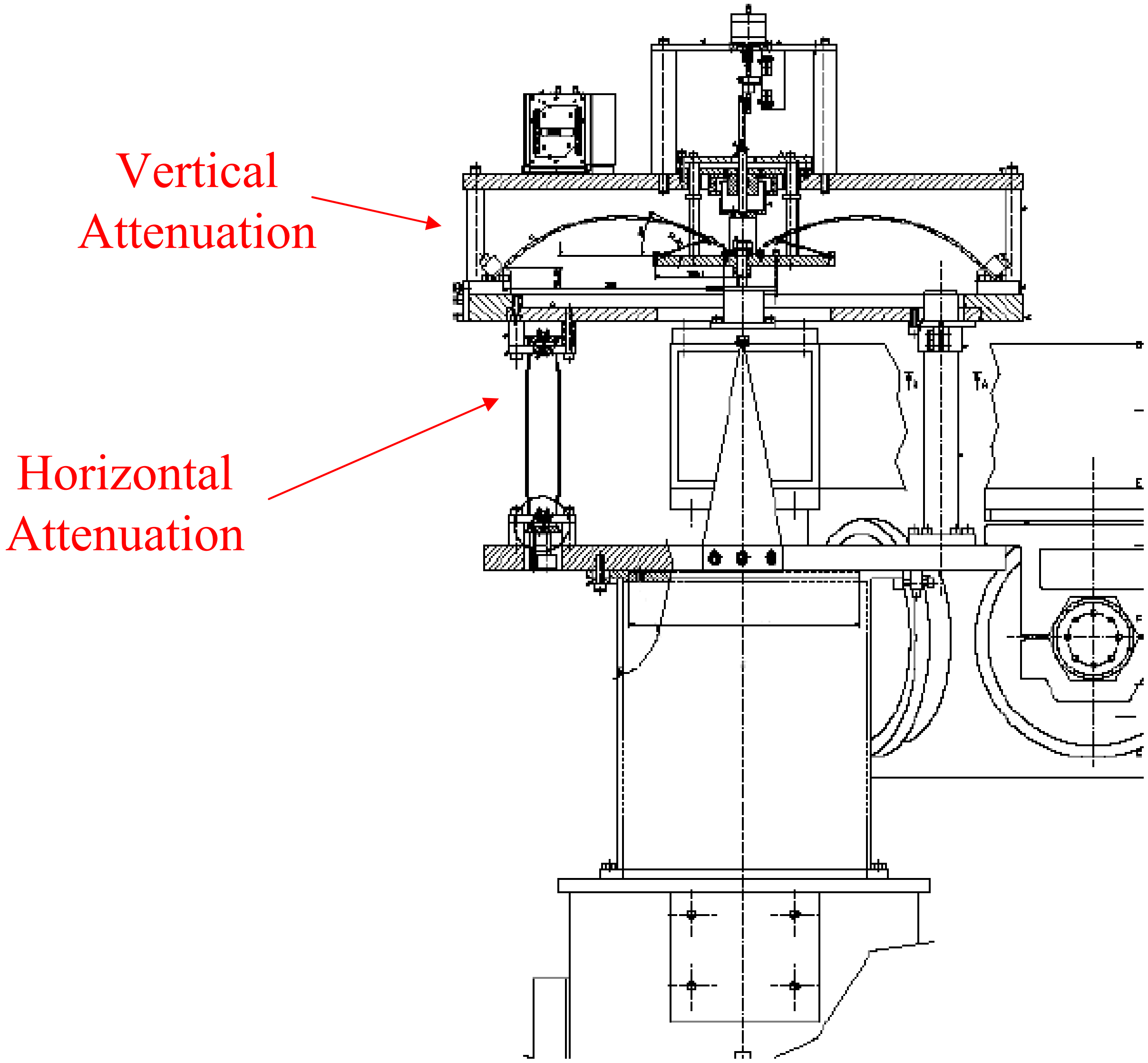
how did we get to the HAM-SAS design

- LIGO-DFBS
- Precursor of HAM SAS (and possible complement)
- Designed to provide pre-isolation just after S2, while waiting for HEPI design and implementation

- Negative stiffness designed into GAS springs and IP to offload the LIGO weight on the piers and neutralize the bellow stiffness with negative K

- Much tougher problem than HAM-SAS

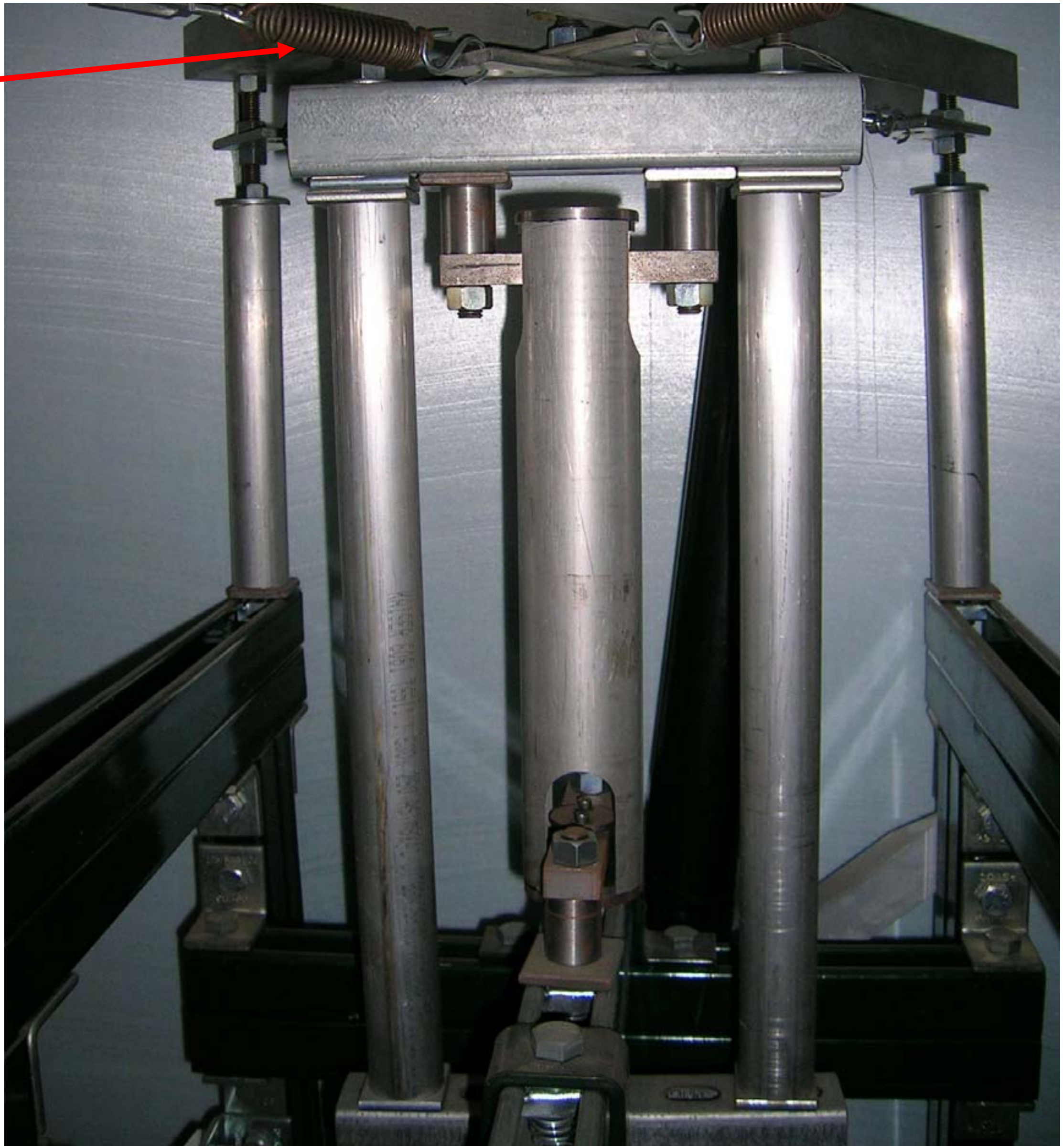
The DFBS pre-isolator design



the LIGO Deep Fall Back solution prototype for on-pier pre-attenuator

A DFBS IP leg (horizontal)

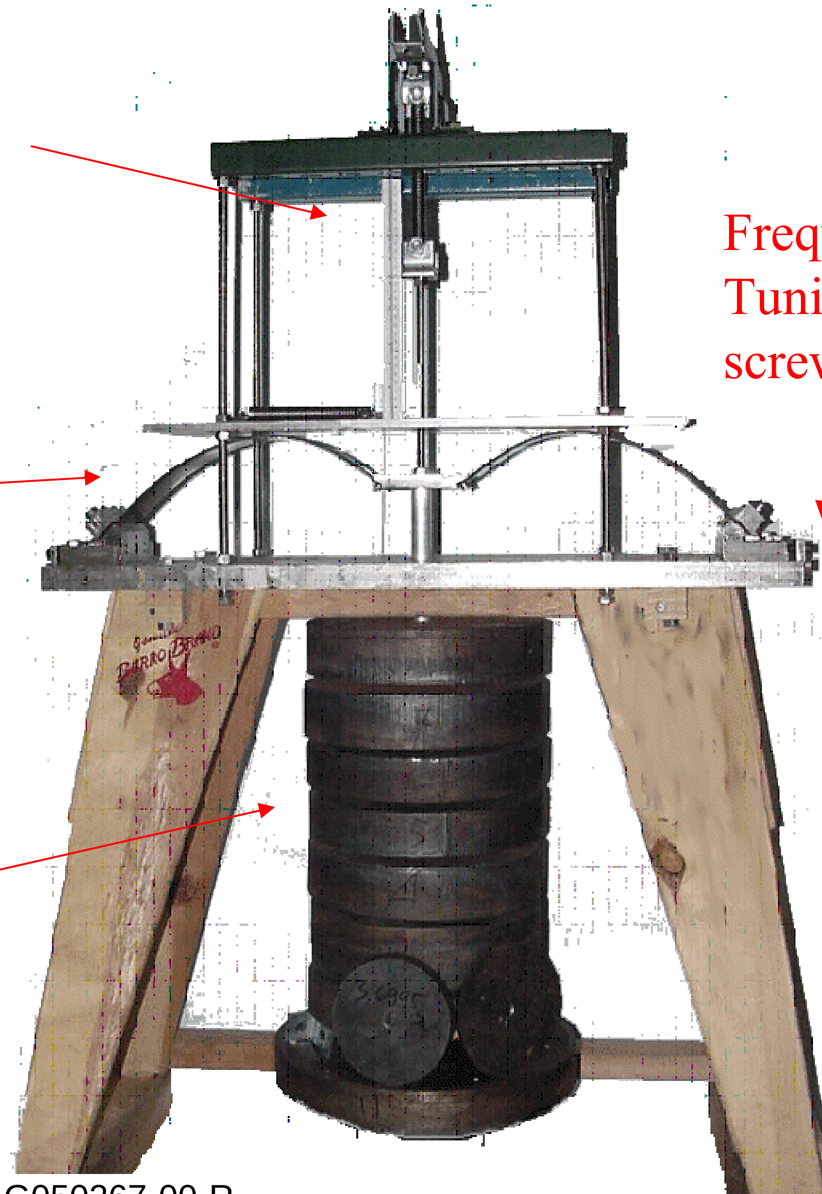
Springs simulating the stiffness of the bellows

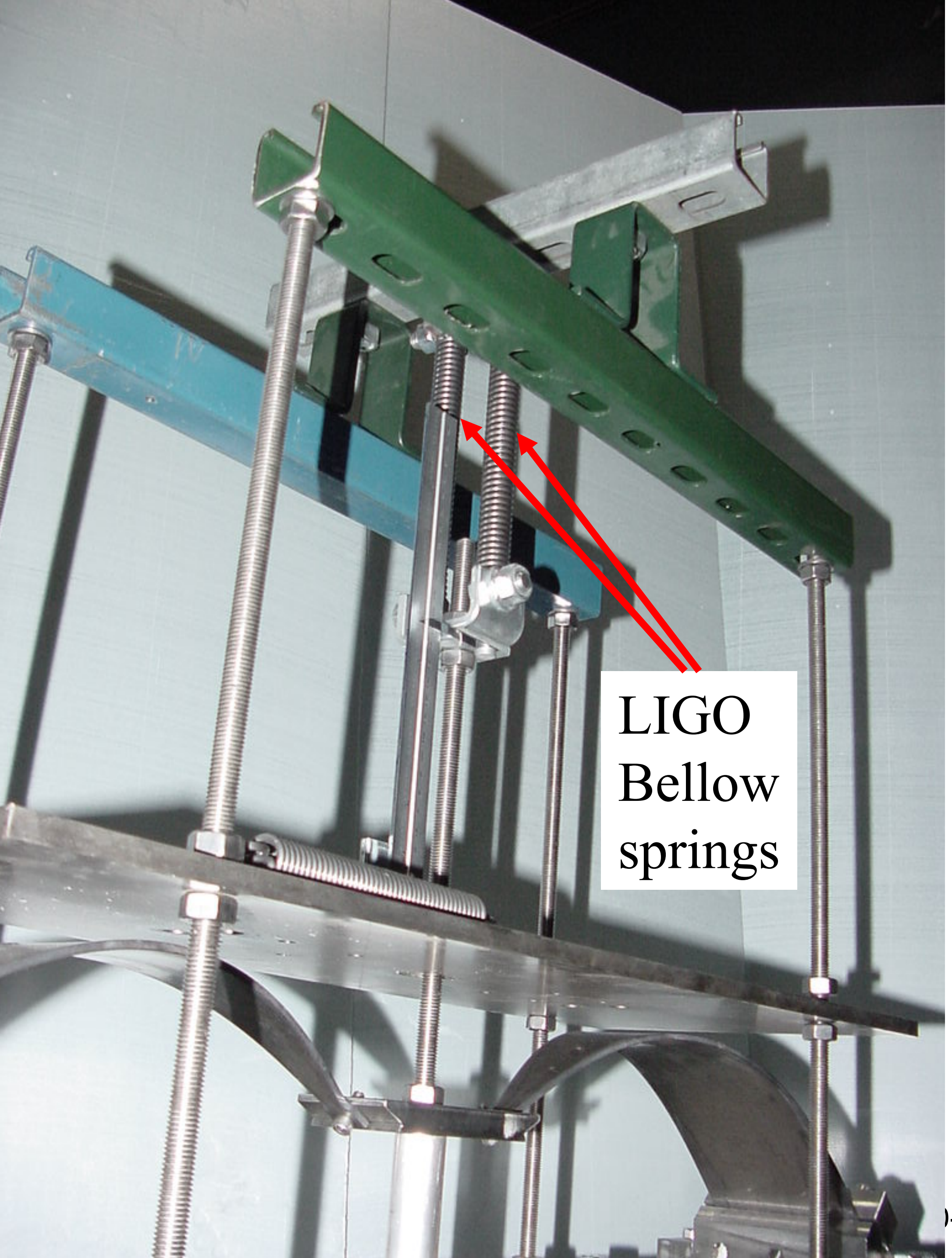


- This leg has roughly the length that will be required in the HAM-SAS
- designed to carry many times the load of a HAM-SAS
- designed to generate attenuation while neutralizing the bellow’s stiffness

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

DFBS vertical prototype working principle





-R

300 mHz tune

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

200 mHz tune

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

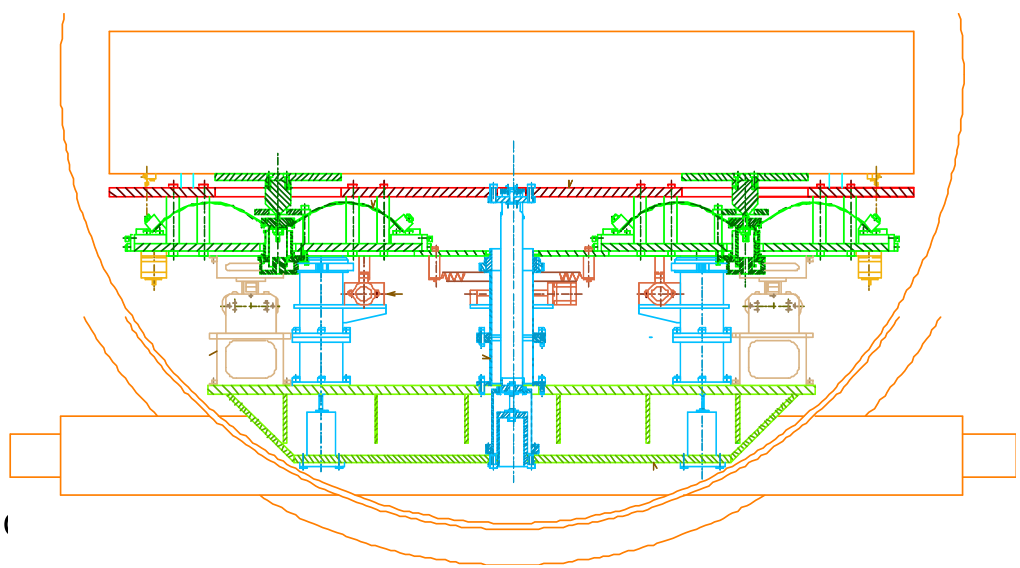
- The HAM SAS design is based on a rich field experience

HAM-SAS Design considerations

- Simplest possible seismic attenuation system.
  - One single stage of passive attenuation
  - Fully UHV compatible
  - Suitable for all conceivable options of OMC
  - Satisfying LIGO and Adv-LIGO requirements for all HAMS
  - Broadband attenuation performance 50~60 dB
  - Tidal correction and < μrad alignment incorporated
  - Earthquake protection incorporated
  - Upgradeable to active attenuation as reserve of att. power
  - As inexpensive as possible
    - Can replace stacks even without replacing optical tables

Design Results

- Expected passive performance comparable to the cumulative performance of all three layers of ad-LIGO active attenuation
- Single layer (~1/3 active SEI cost and complexity)
- Upgradeable (two level of upgrades)
- Less control complexity than a single layer (if passive)
  –

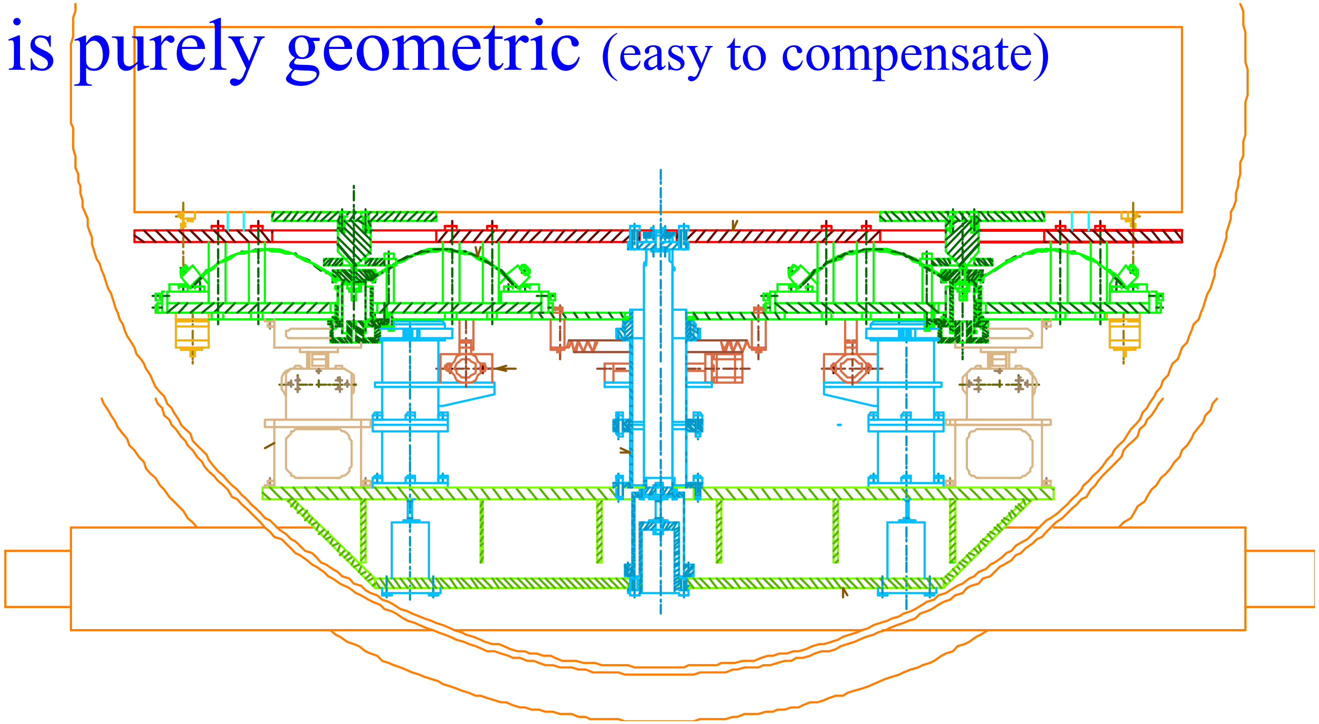


- Suitable to instrument any HAM for any load

www.LIGO.caltech.edu/~desalvo/HAM-SAS

Notable characteristic

- Horizontal and vertical degree of freedom are decoupled
- Minimized tilt/horizontal-acceleration coupling
- Coupling is purely geometric (easy to compensate)



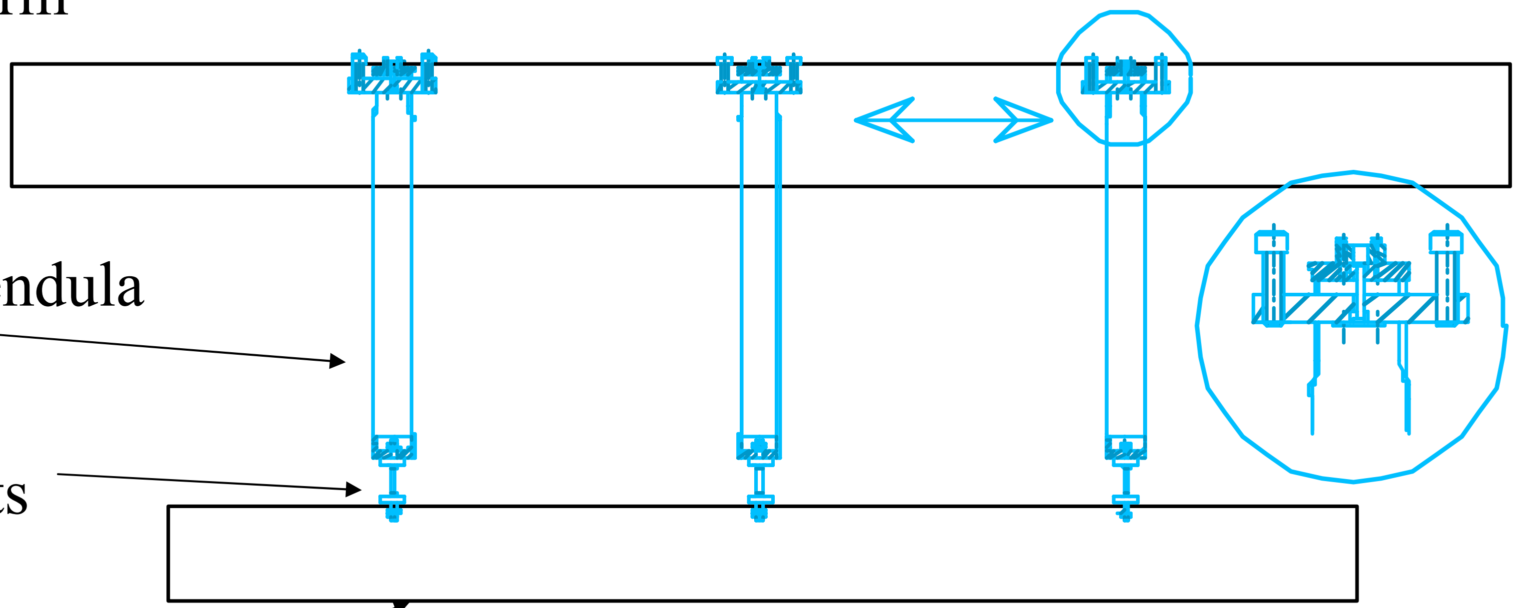
Horizontal attenuation

Intermediate (GAS) platform

Inverted Pendula

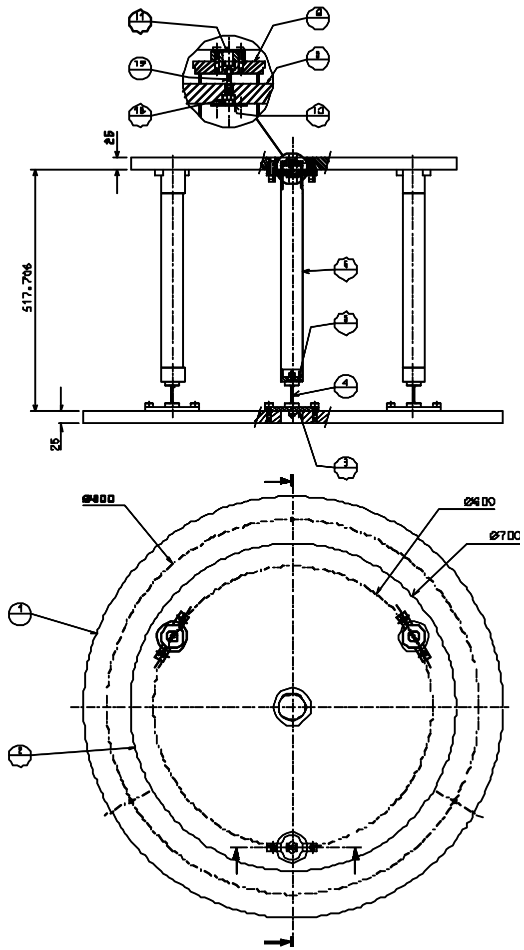
Flex joints

Base platform



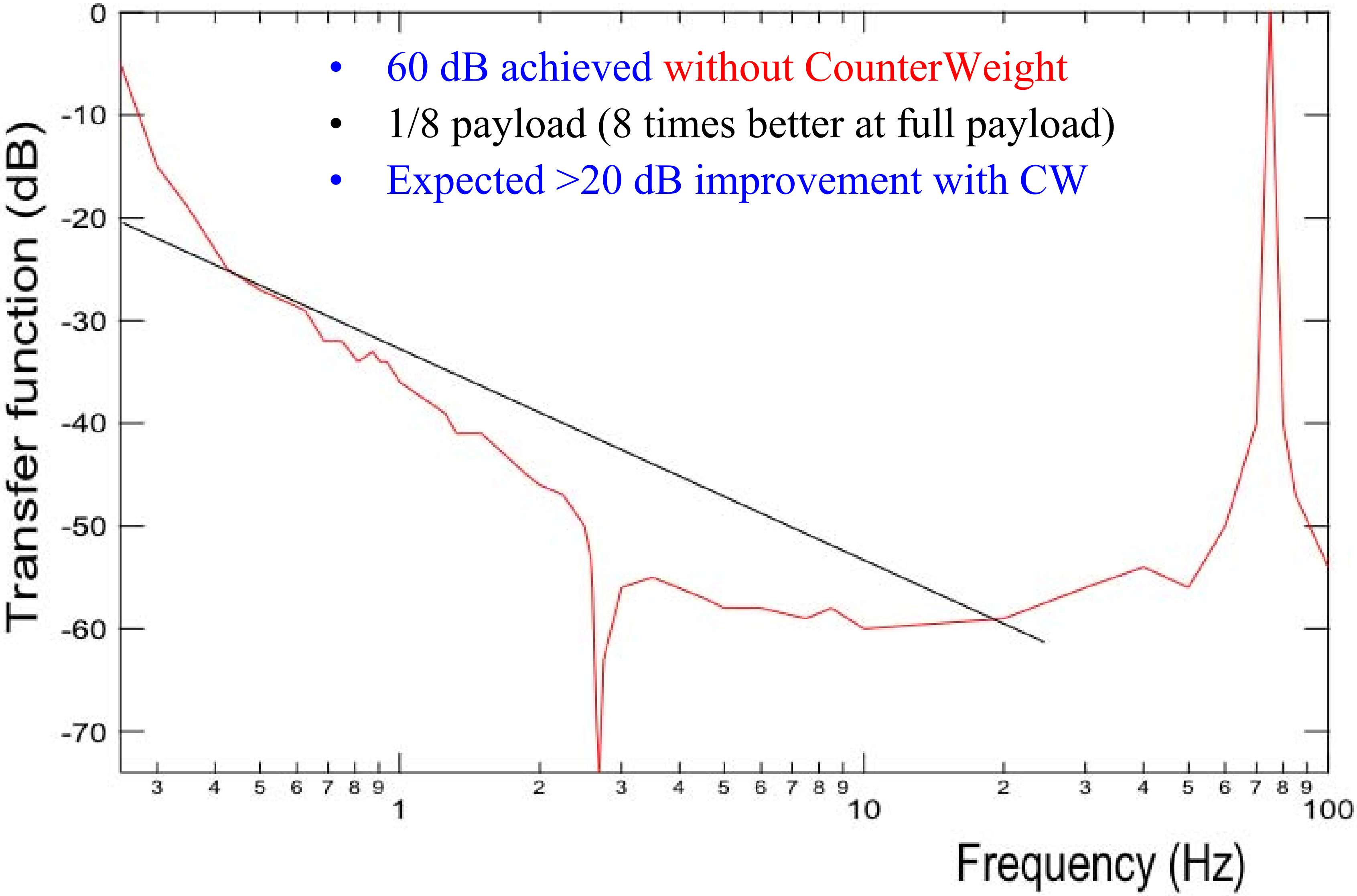
X Y ϕ

The HAM-SAS IP prototype



The HAM-SAS IP prototype tests measured attenuation properties

- 60 dB achieved without CounterWeight
- 1/8 payload (8 times better at full payload)
- Expected >20 dB improvement with CW

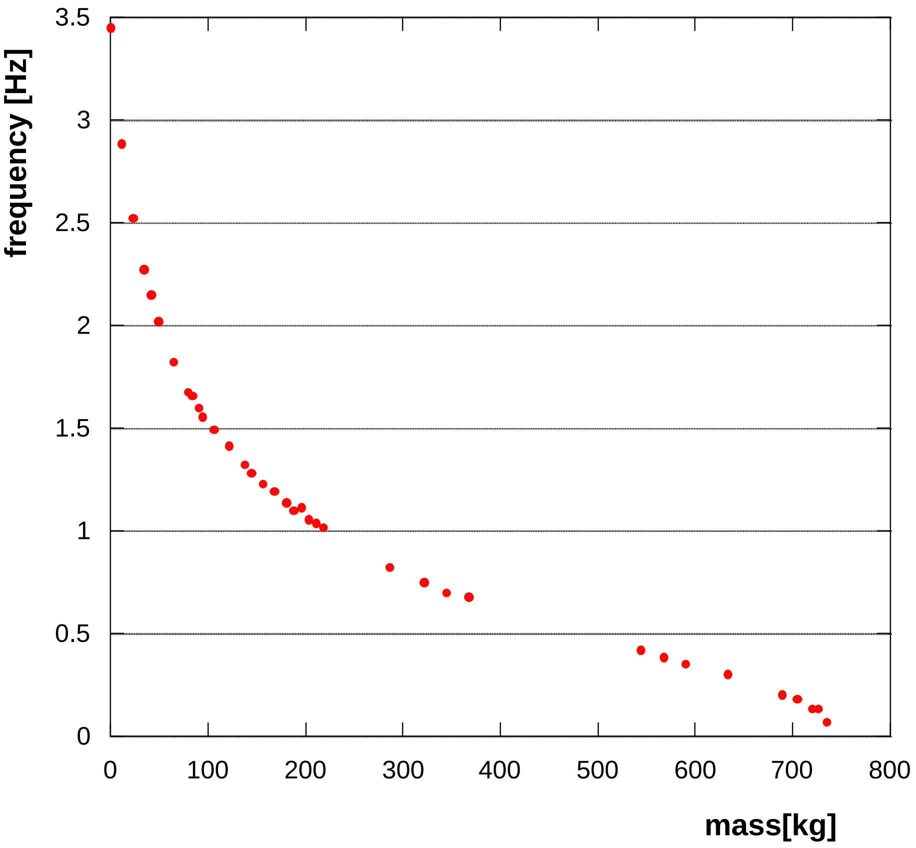


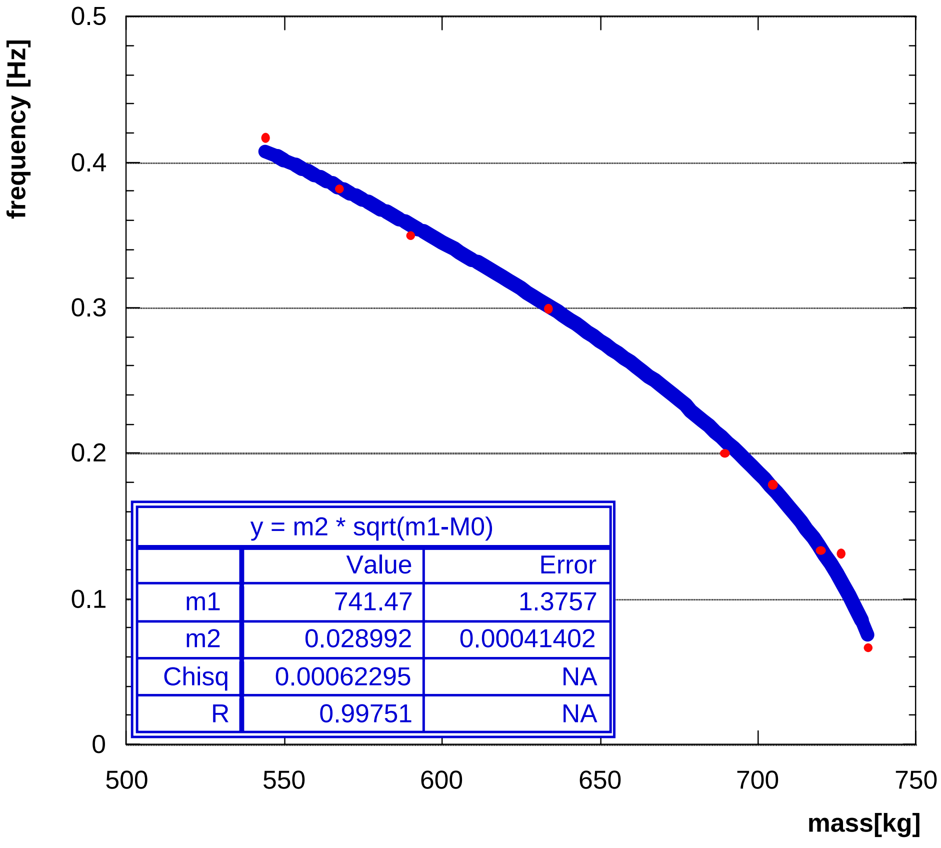
The HAM-SAS IP prototype tests measured attenuation properties

- Full size load tests performed
- TF impossible to measure because of testing facility limitations
- Compatible with 80 dB

- The 80 Hz resonance moved above 100 Hz

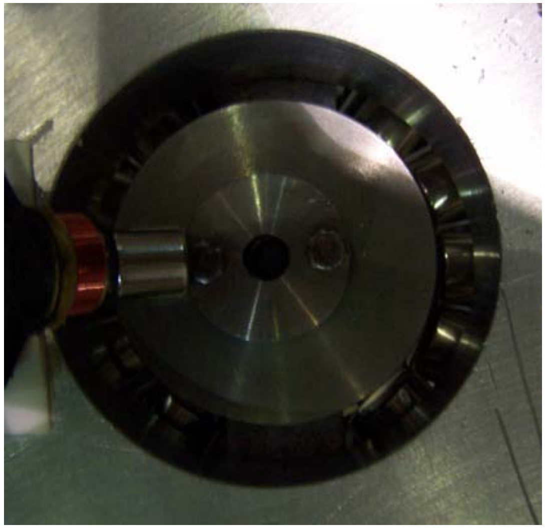
The HAM-SAS IP prototype tests
load versus frequency tuning



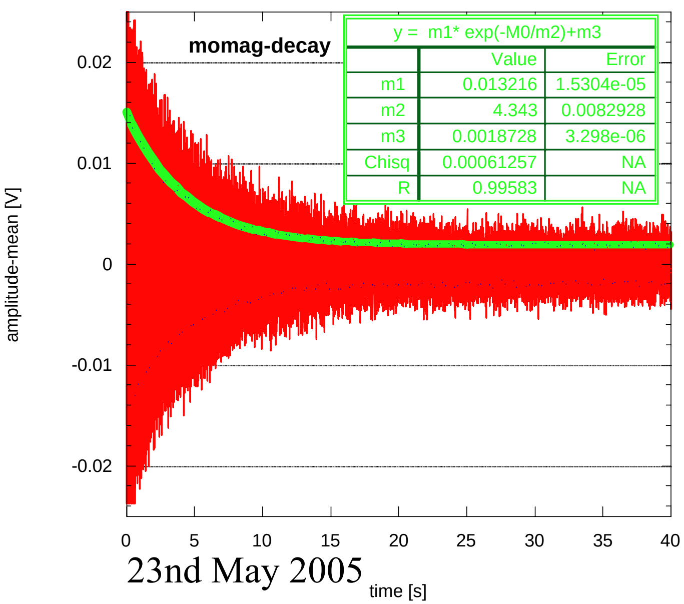


	Value	Error
m1	741.47	1.3757
m2	0.028992	0.00041402
Chisq	0.00062295	NA
R	0.99751	NA

100 Hz resonance neutralization

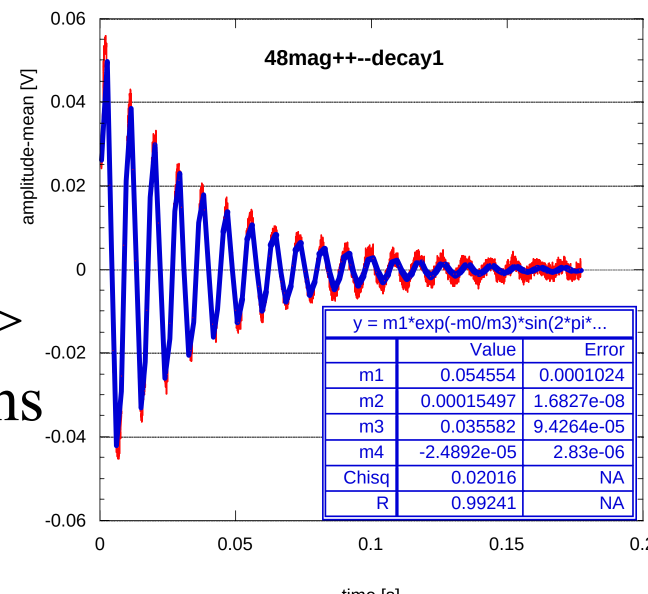


Eddy current
Damper view



<--Before
τ= 4.3 s

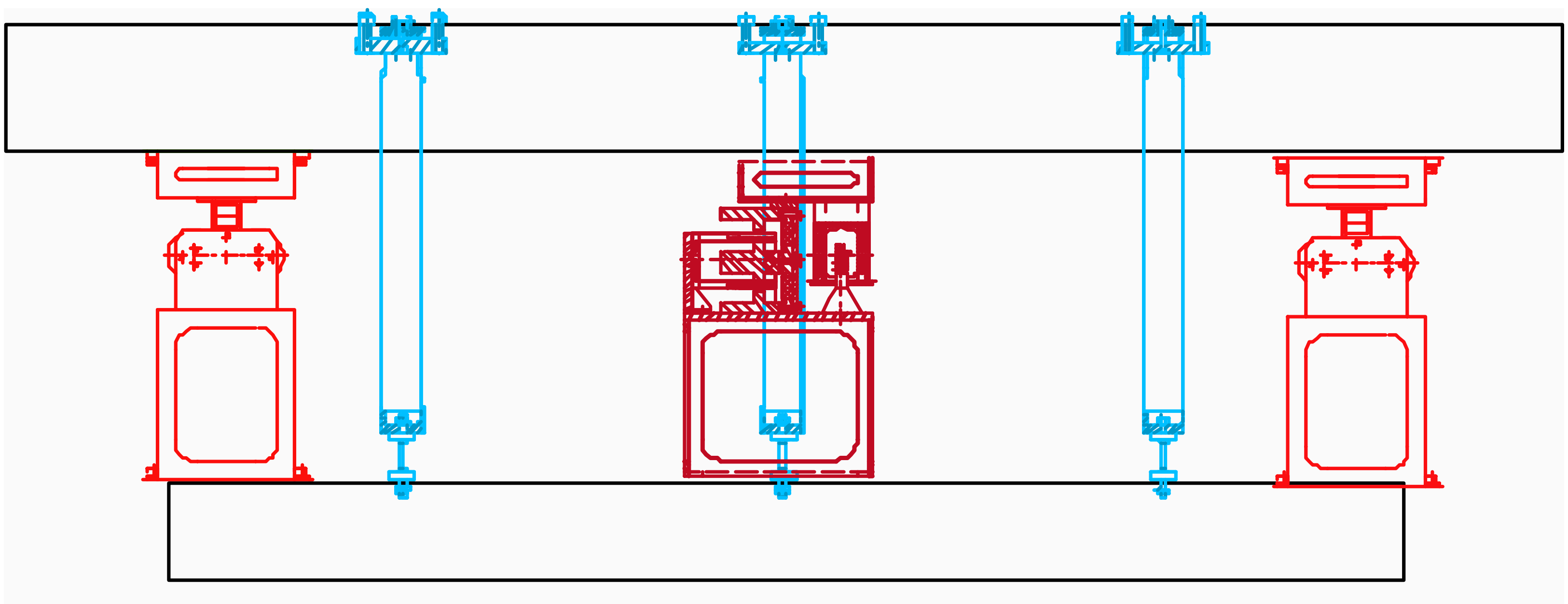
After -->
τ = 35 ms



23nd May 2005

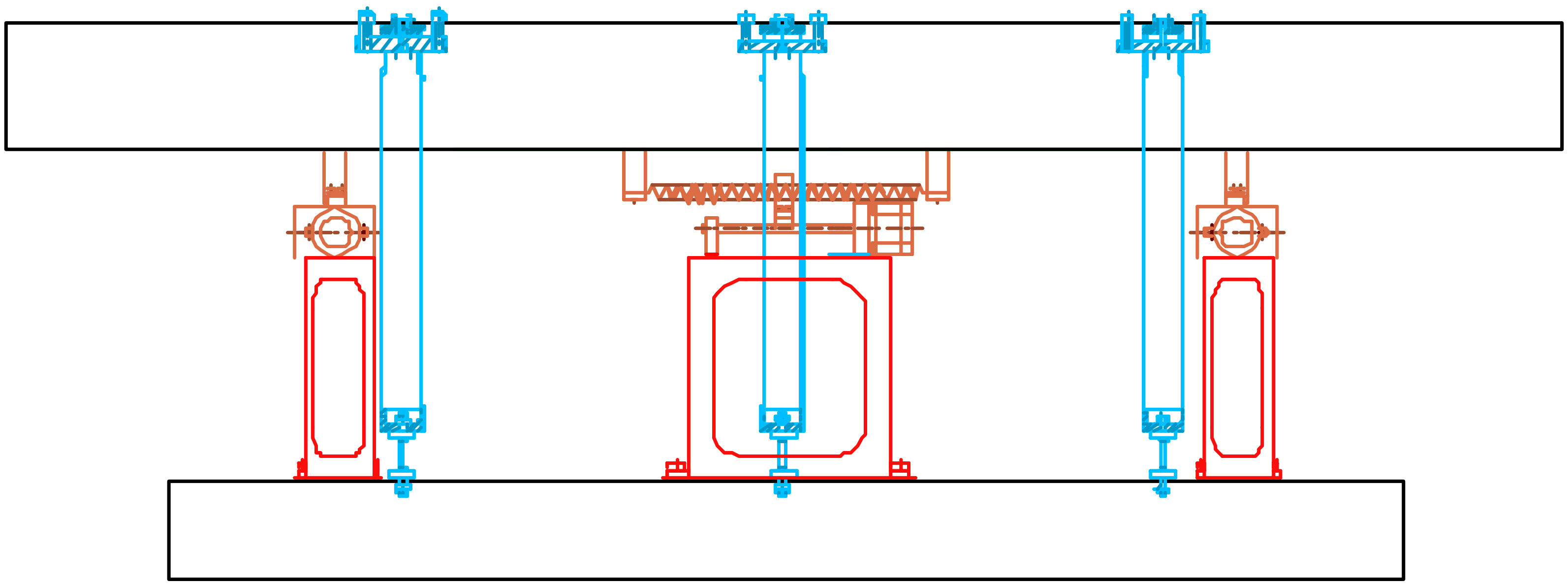
Dynamic micro-positioning

- LVDT for local nanometer positioning memory
- Tidal correction signal from global controls
- Voice coil actuator dynamic controls
- Micro/milli Watt in-vacuum power dissipation



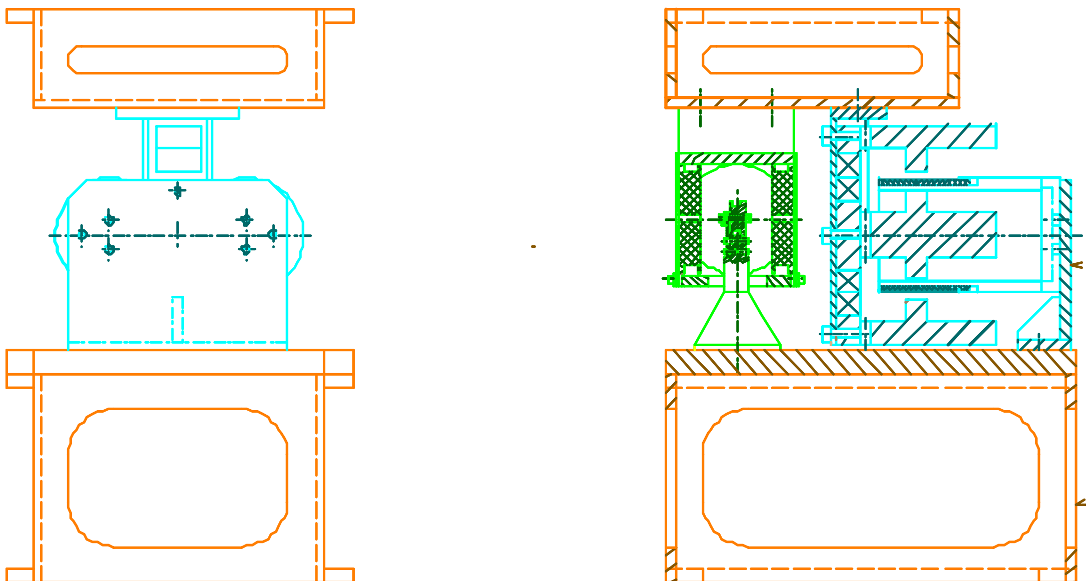
Static micro-positioning

- Remotely actuated springs in all d.o.f.
  - No standing currents in actuators

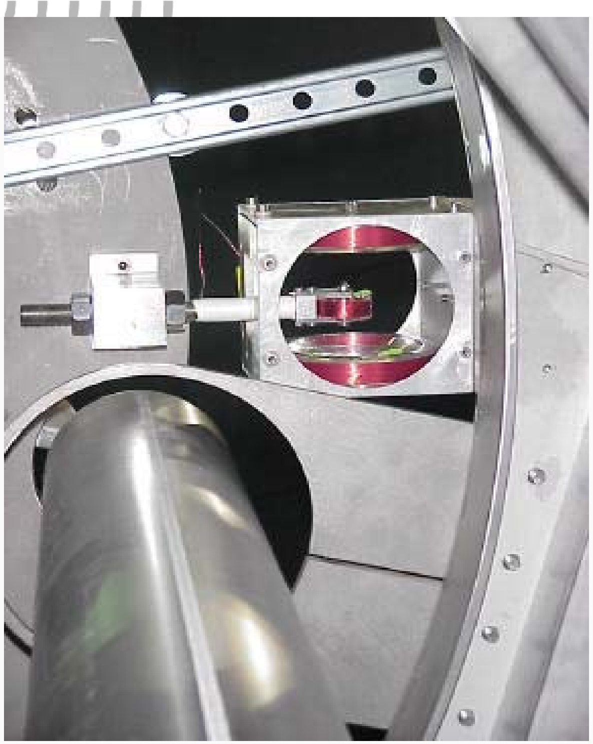


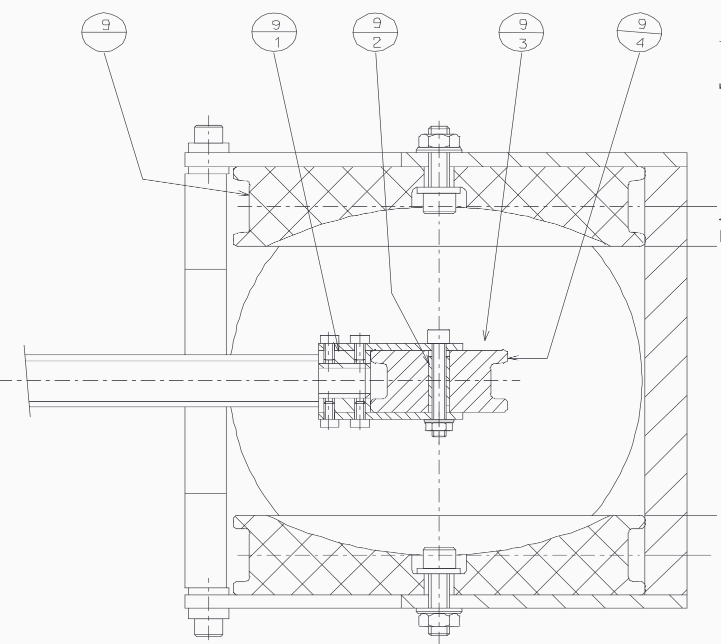
Dynamic micro-positioning

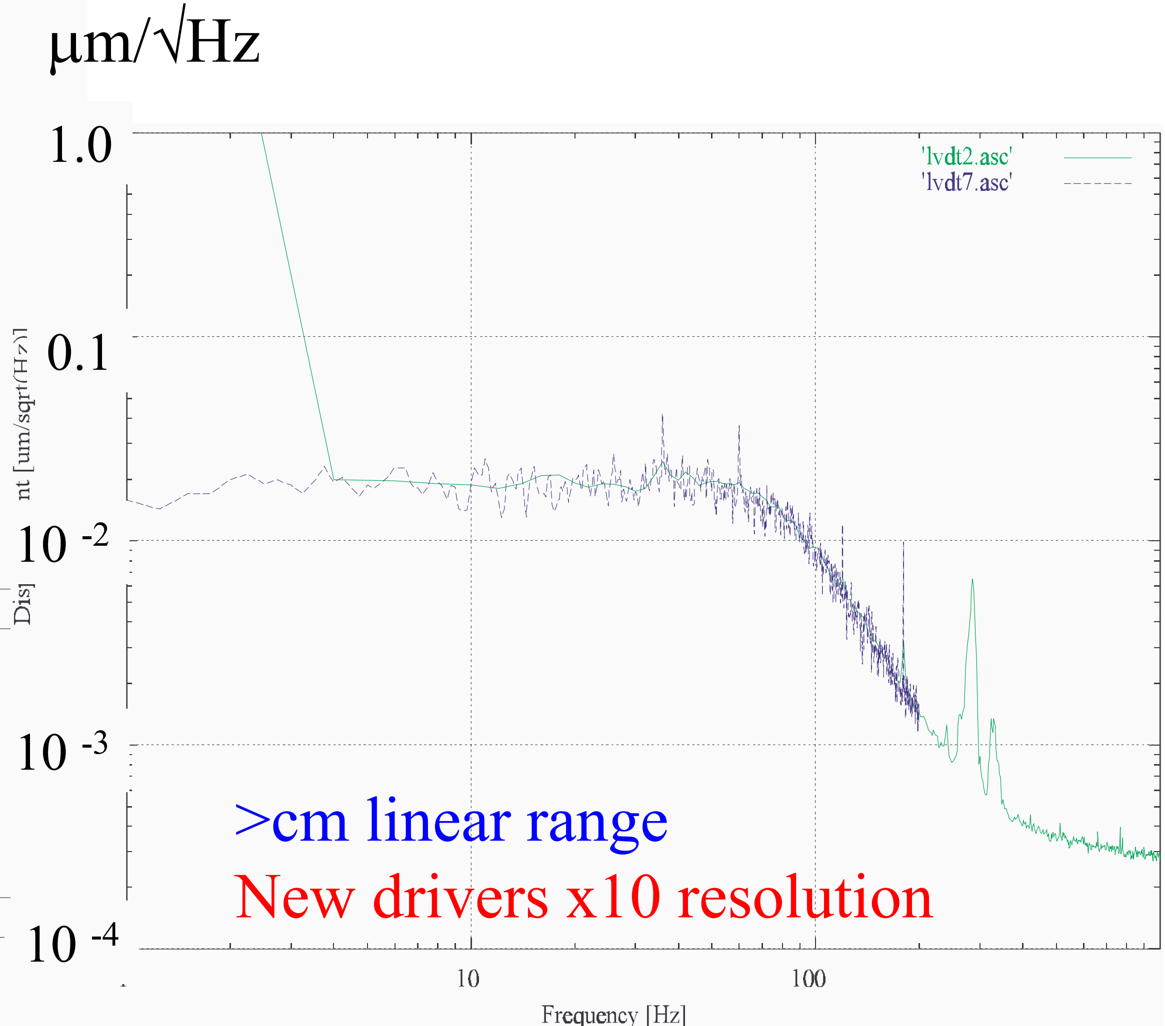
- Co-located LVDT actuator units



LVDT positioning performance



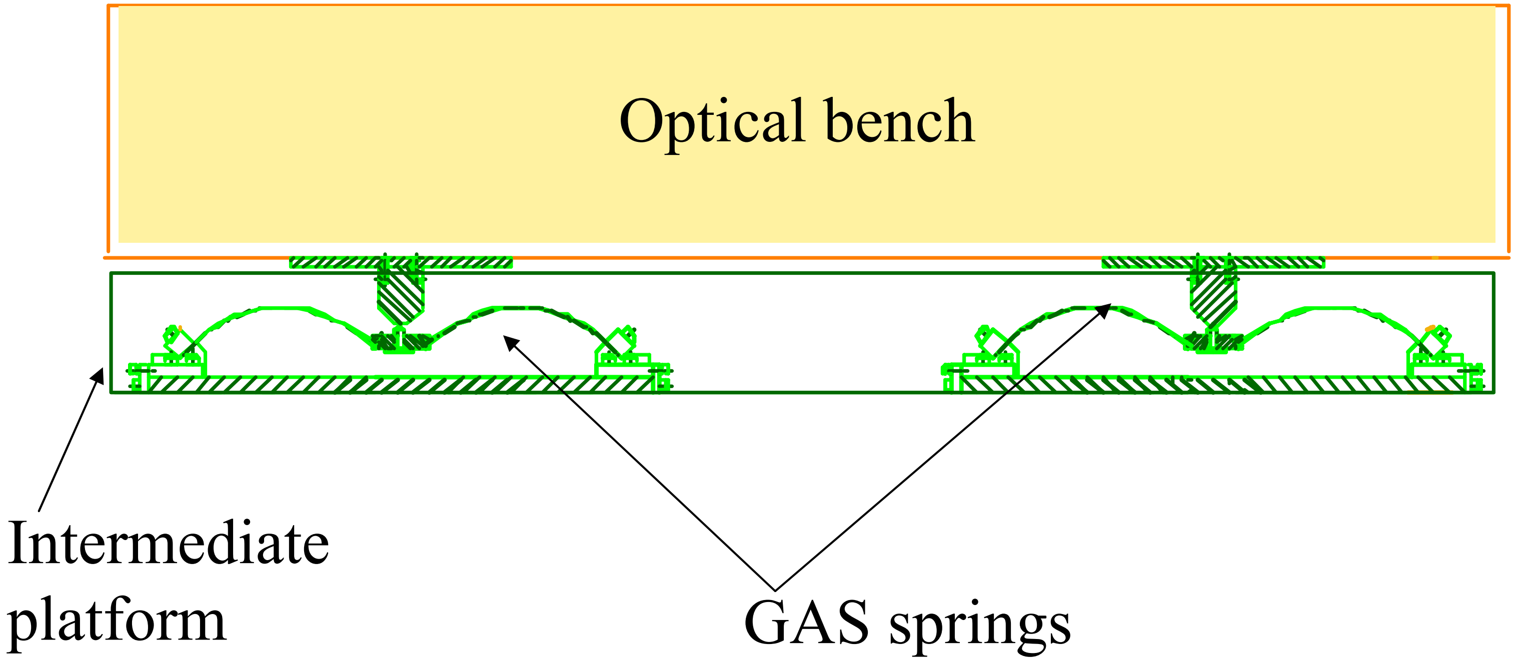




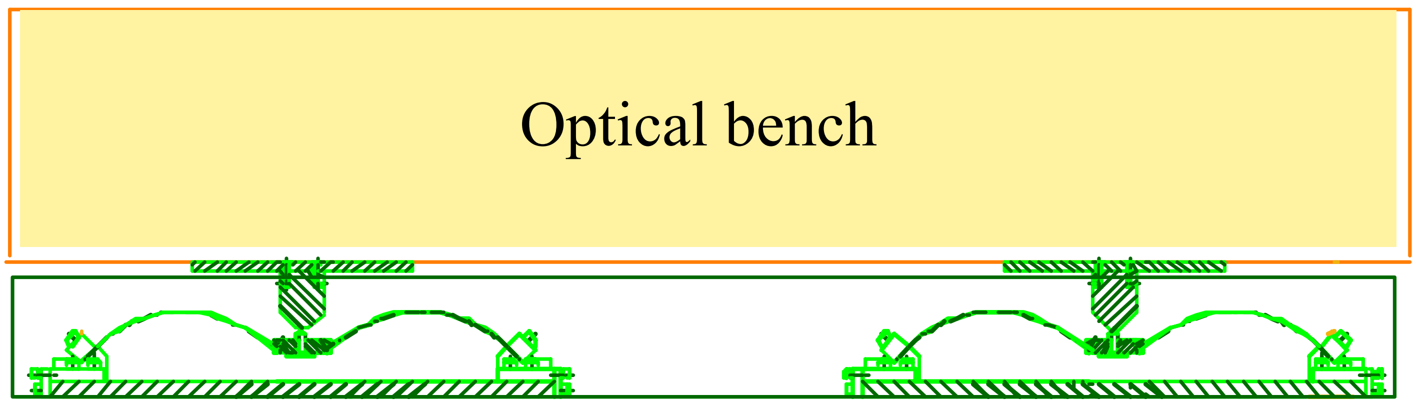
LVDT positioning performance

- This resolution, coupled to the soft suspension and the low power actuators, is what generates the positioning and pointing capabilities for the HAM optical benches

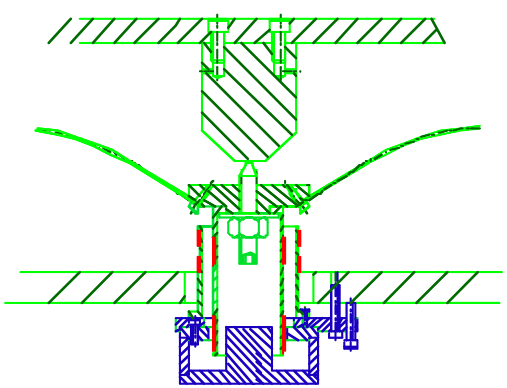
Vertical direction, the GAS springs



Vertical direction, the GAS springs



Equivalent LVDT/actuator unit implemented

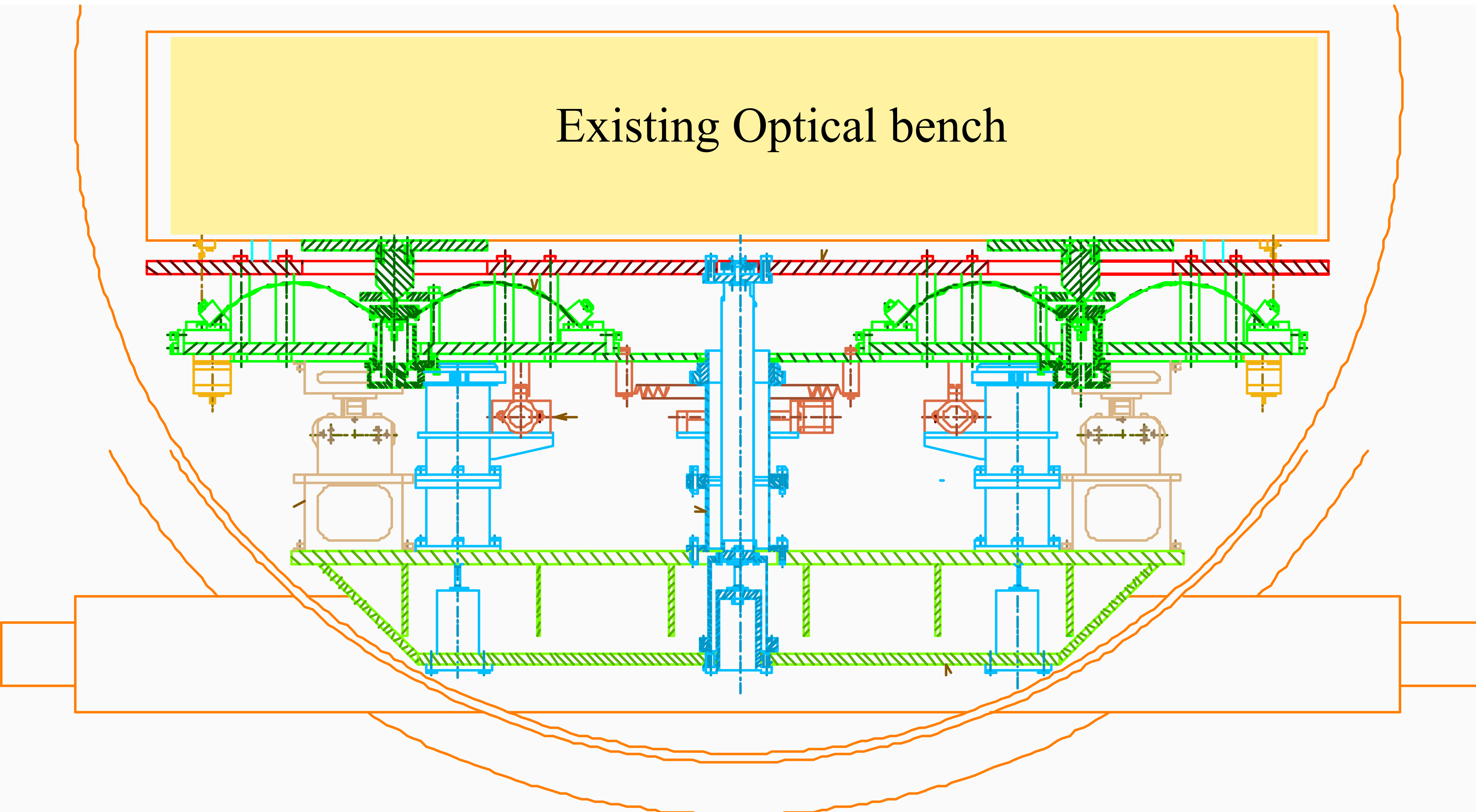


Positioning requirements/procedures

- To restore the bench alignment after interventions
- The LVDT sensors will read the changes of position and either suggest changes of ballast to restore the previous balance, or use the static actuators to return to the original table alignment

- Low power, UHV compatible voice coil actuators deal with tidal and thermal position changes
- These sensors and actuators are available for active attenuation upgrades

Complete SAS design for HAMs

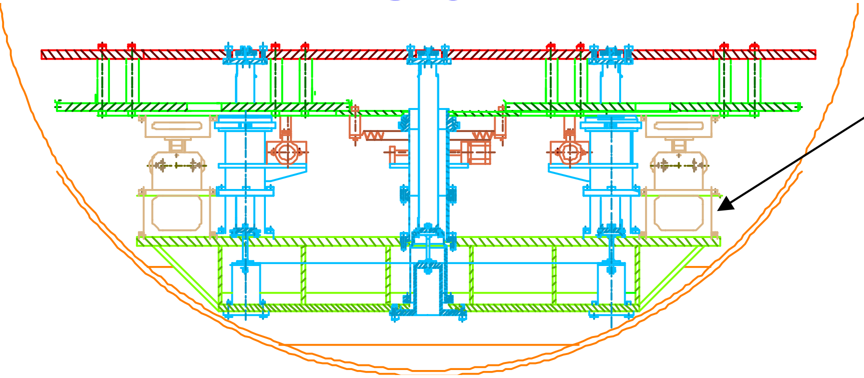


Transition from LIGO-I to Adv-LIGO

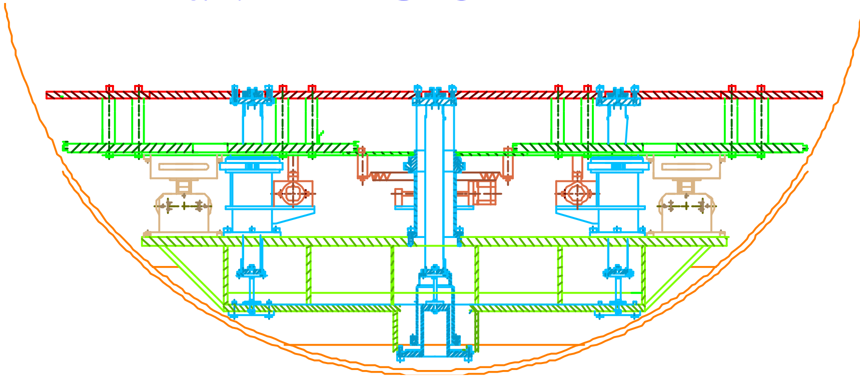
- To be performed by

simply eliminating a number of spacers

LIGO



Adv-LIGO



HAM SAS features

- SAS is a viable and relatively inexpensive in-vacuum seismic attenuation candidate for Adv-LIGO (60 dB broadband)
- One passive layer can potentially replace all three stages of stiff SEI
- Upgradeable to active attenuation as a <u>reserve of attenuation power</u>
- Fully compatible with the SUS system

Further upgradability

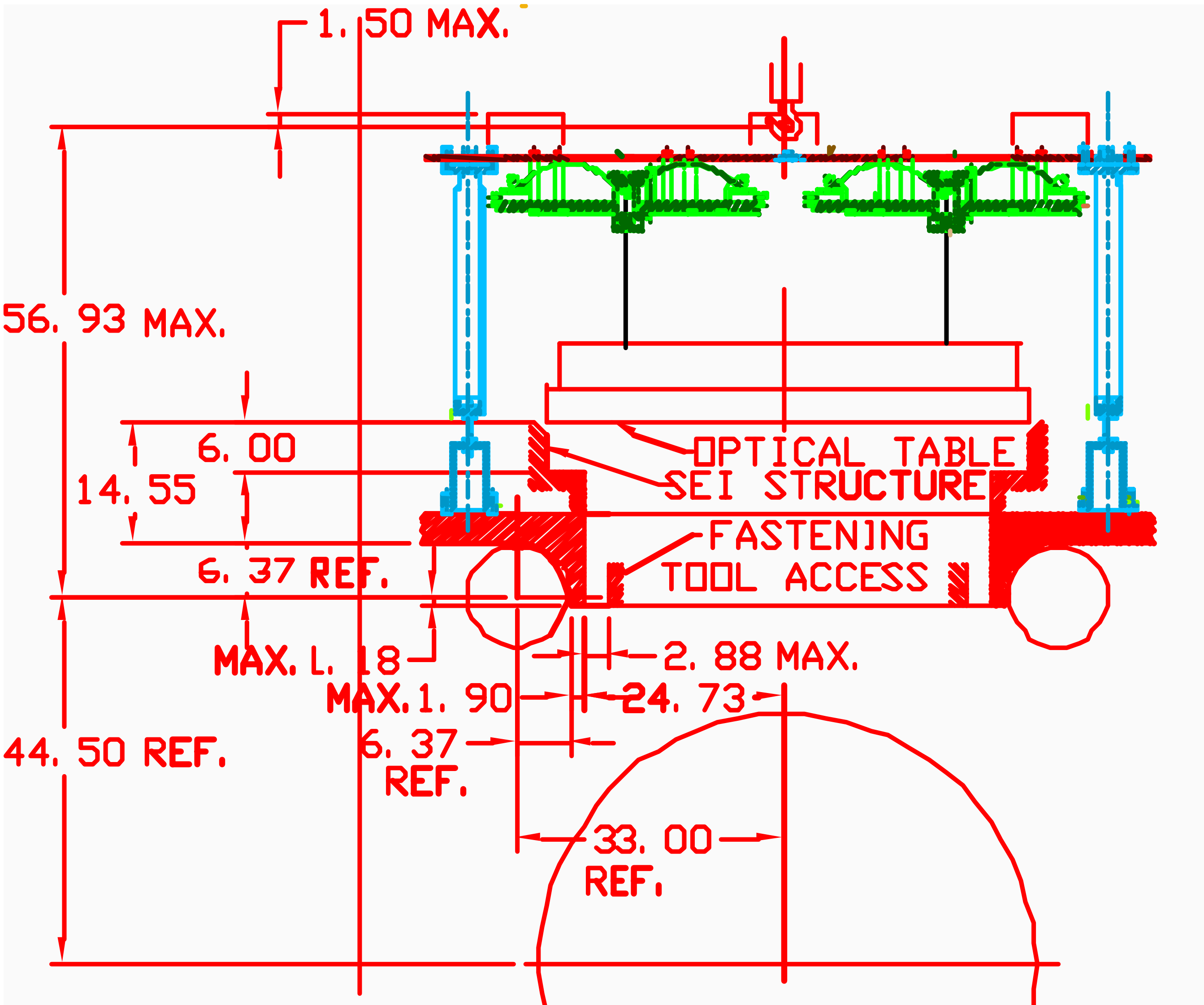
- If later Adv-LIGO evolutions needed upgraded seismic attenuation,

  DFBS can be installed upstream of HAM-SAS

  and boost seismic attenuation by an additional 40 dB

Is HAM-SAS applicable to BSCs?

SAS design for BSCs



BSC SAS

- The HAM-SAS design fits in the BSC and is scalable to offload the entire weight
- An additional pendulum stage is needed to reach down to the (lower) level of the quad suspensions,
  - gives a redundant safety factor in horizontal isolation
  - this added bonus is effective in the frequency range to naturally neutralize the excess seismic motion found on the pier tops.

Conclusions

- HAM SAS design is ready for production
  http://www.ligo.caltech.edu/~desalvo/HAM-SAS and http://www.ligo.caltech.edu/~desalvo/HAM-SAS.doc
- The design attenuation performance satisfy the Adv-LIGO requirements
- The cost (including the active upgrade) is comparable with one layer of active SEI
- Prototyping in LASTI are needed to validate the design
- Scaling of the design for use in BSC is possible
- Upgrading for higher attenuation performance is possible