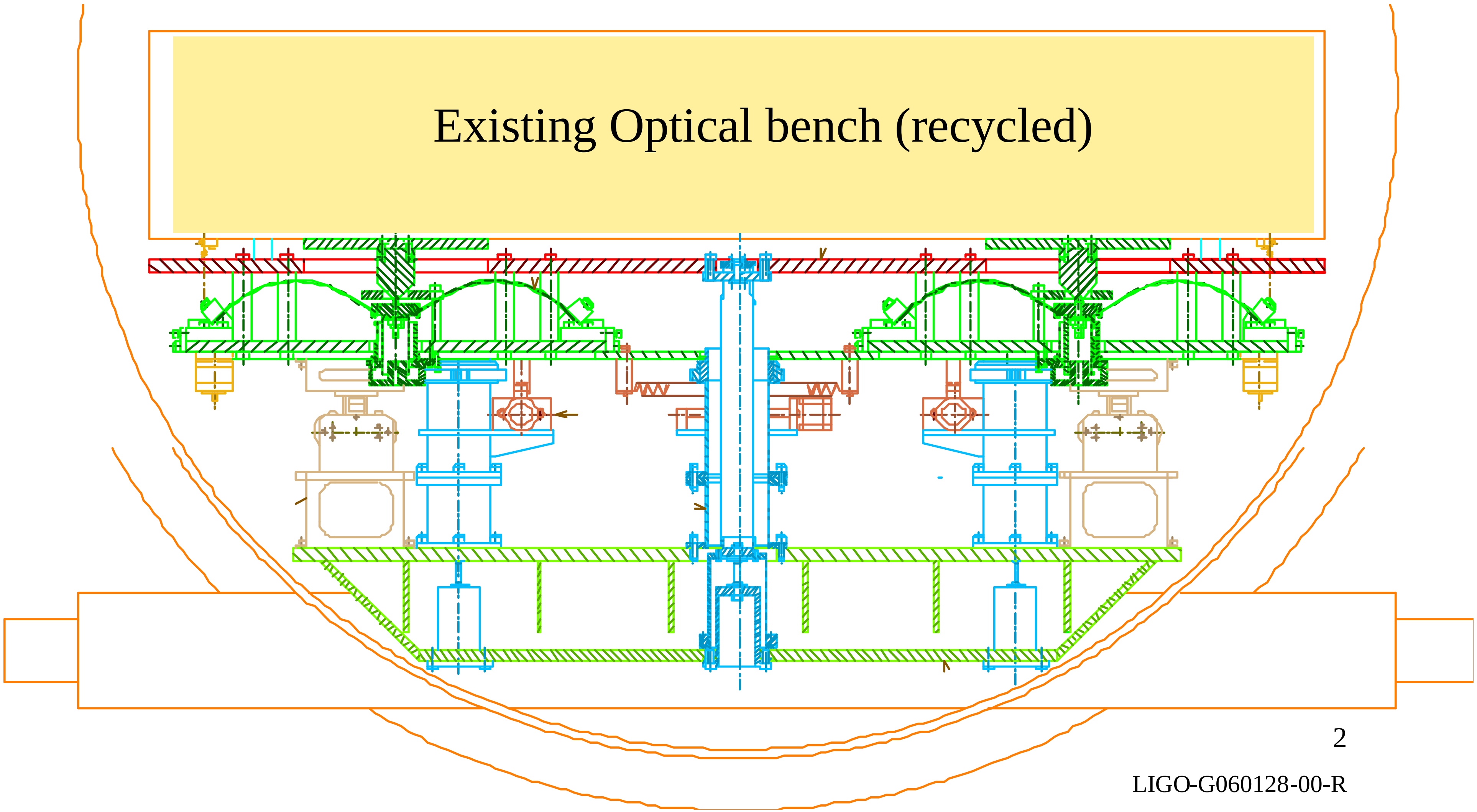
HAM Passive Seismic Attenuation System (SAS)

System Performance, Fabrication, Assembly , Installation

Riccardo DeSalvo, Valerio Boschi, Dennis Coyne, Yumei Huang, Virginio Sannnibale
LIGO Gravitational Wave Observatories
California Institute of Technology

LIGO-G060128-00-R

A seismically attenuated optical bench for the HAM chambers



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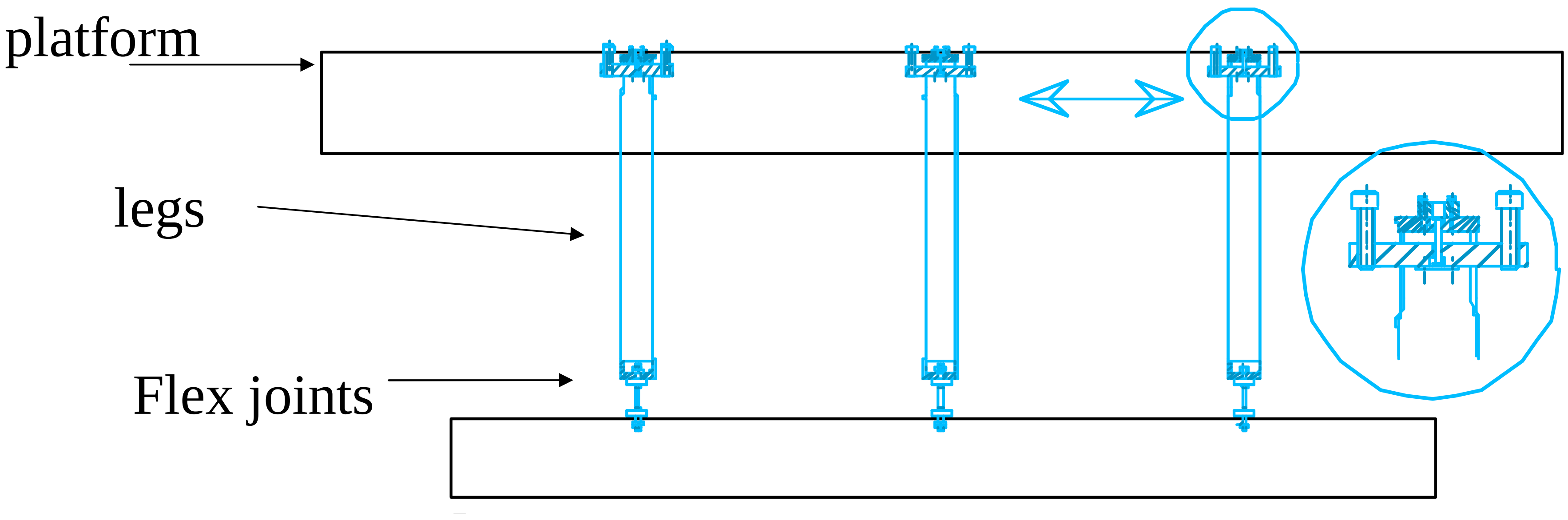
Horizontal direction, x, y, φ the Inverted Pendula



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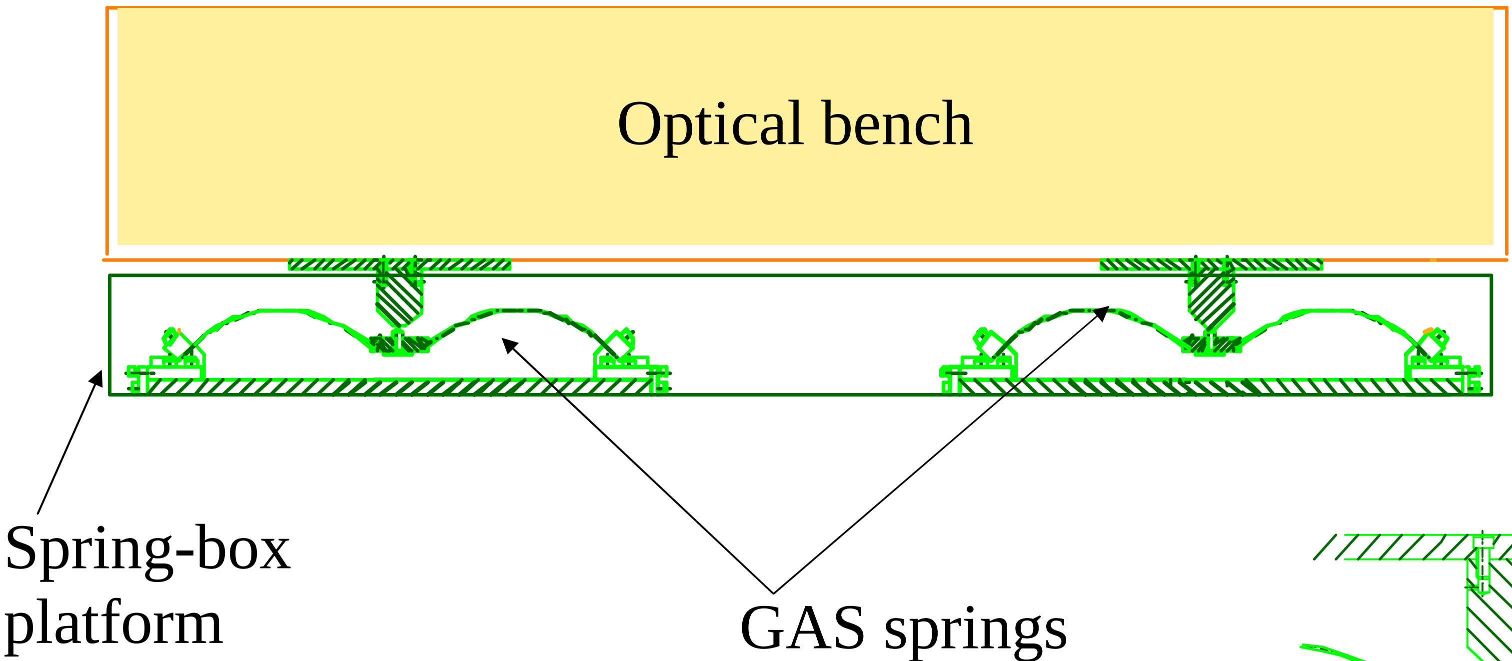
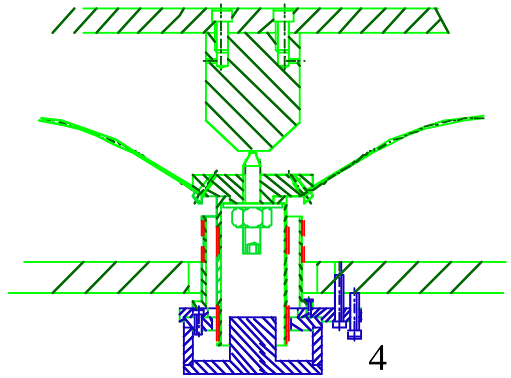
Attenuation in the vertical direction, the GAS springs





Performances

- Deliver more than 60 dB attenuation at > 1 Hz
- Single, passive layer attenuation to satisfy requirements and minimize complexity
- Significant attenuation at the micro seismic peak
- Internal damping for minimized control burden
- Tidal control with pointing accuracy at ~ nm level
- No standing control forces
- Earthquake protection for up to ±12 mm shakes

Performances

- **Reliability ! ! !**

1. No active components in vacuum
   - Only coils in vacuum
     - No electronics failures in vacuum ! ! !
     - No power dissipation under vacuum ! ! !
2. No sealed gas volumes in vacuum
   - No chance of crippling virtual leaks ! ! !
3. Four actuator/sensor groups for each three d.o.f.
   - functions unimpeded by one sensor/actuator failure
4. Functionality unimpeded by power losses
   - (earthquake protection)

Difficulties

- Careful tuning and weight watching required.

Assembly philosophy

- Clean assembly and factory tuning
  - Minimize expense of LIGO manpower
  - Training fabricators to our procedures
- Shipping clean assembly
  - Develop clean installation techniques in HAMs
  - Install populated optical bench

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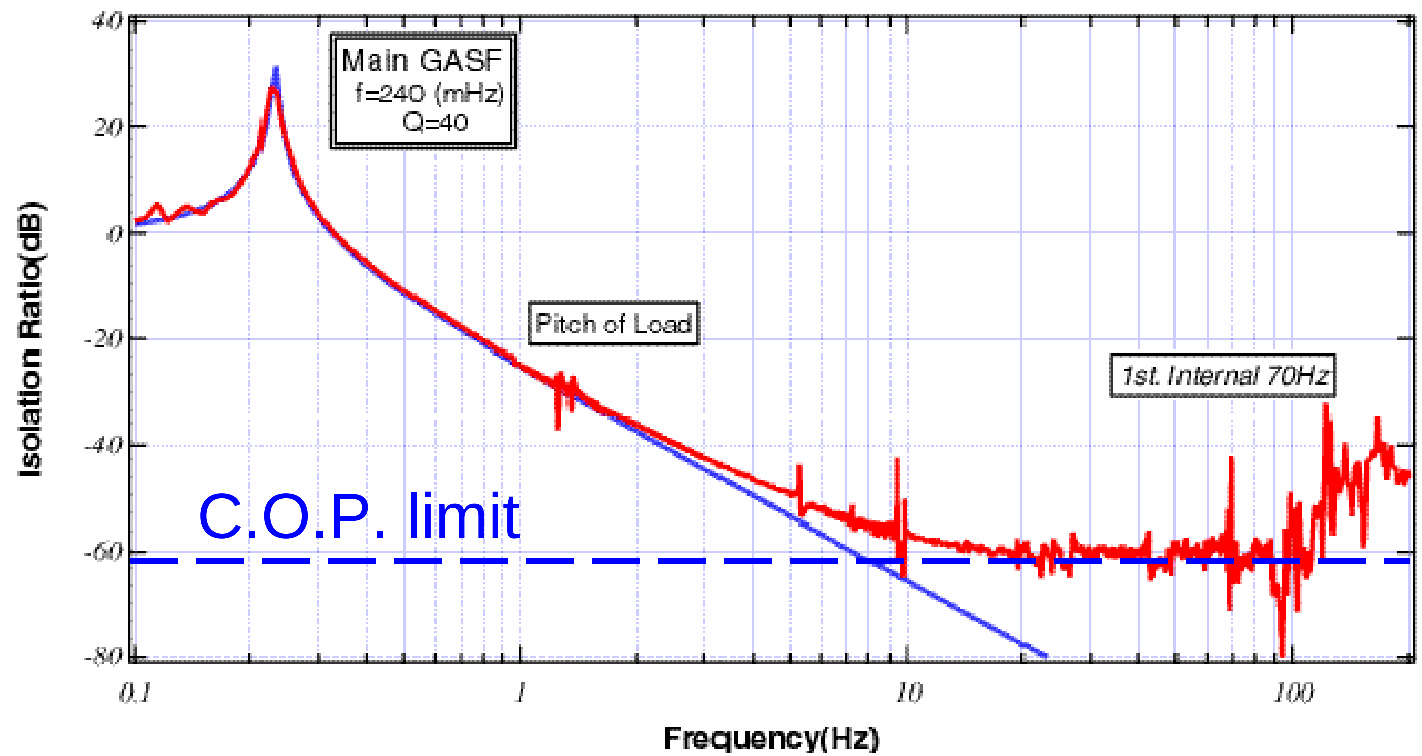
Illustration of vertical attenuation

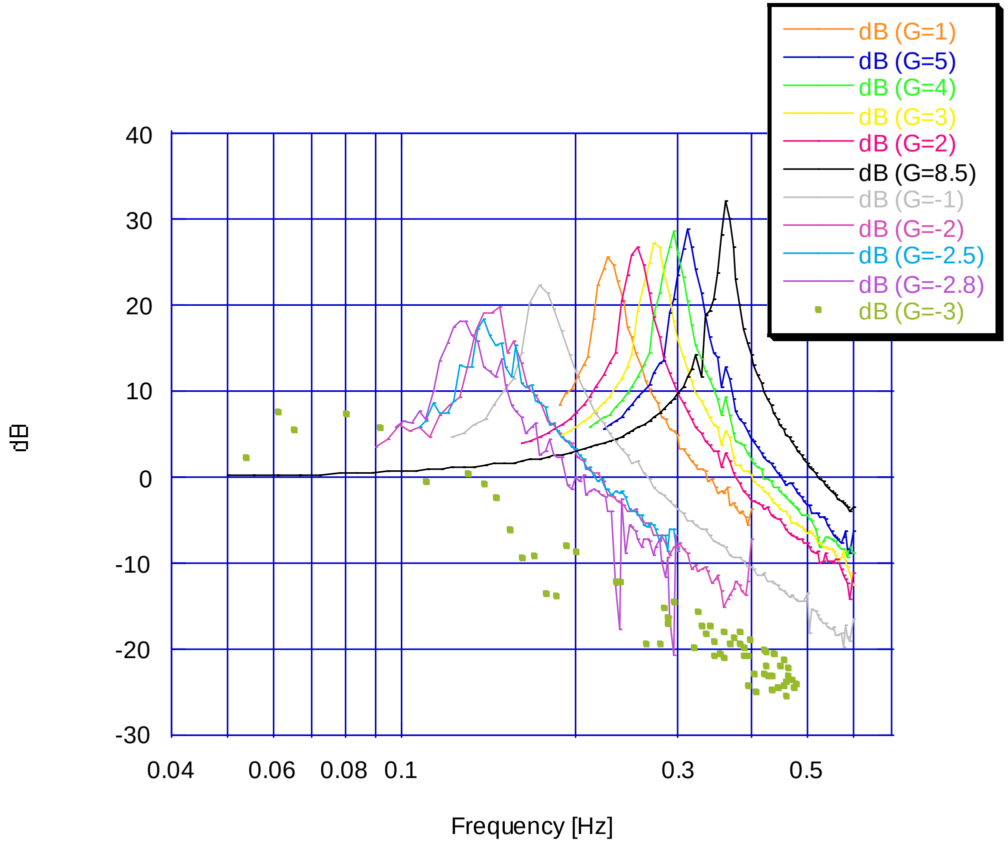
QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Typical GAS performance

- LF tune sets the attenuation startup
  - Can tune to 30 mHz
- 60 dB c.o.p. attenuation limit
  - Can exceed with CW.



Transfer Function with Different Gain values



Lowering the system stiffness to 30 mHz

The Transfer Function shifts to lower frequencies,

The Q factor decreases

Origin of Q-factor decrease advantage

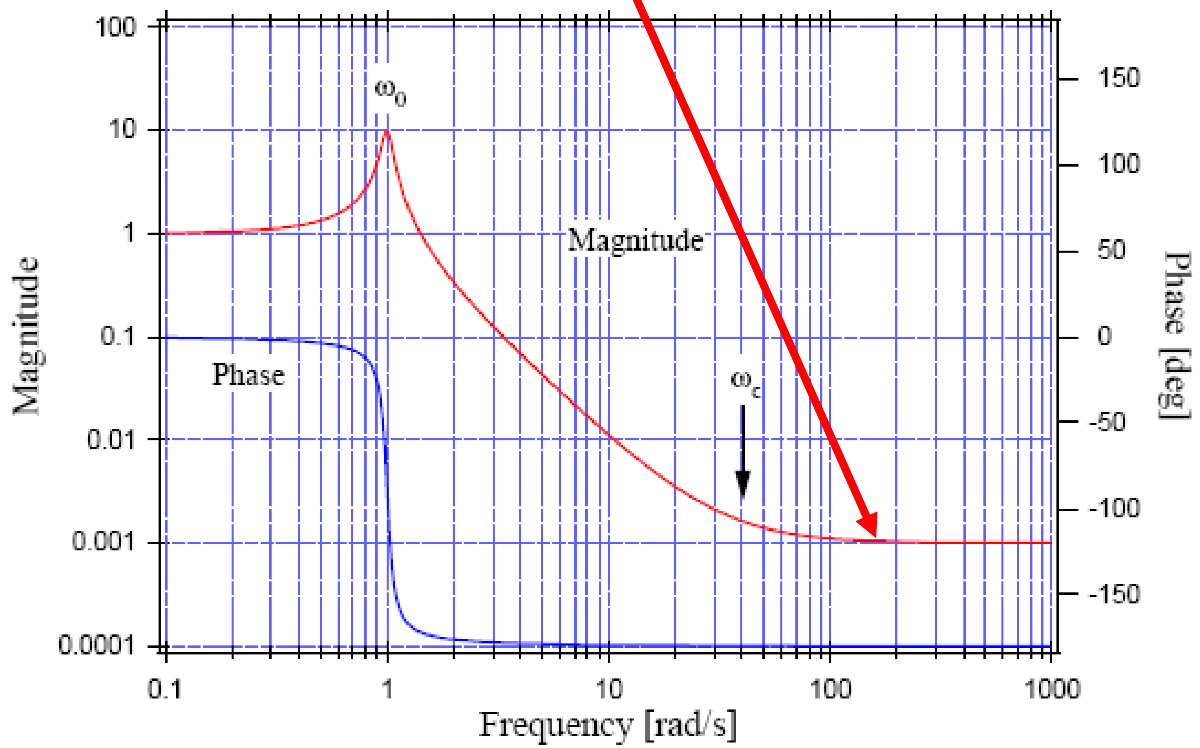
- The GAS process cancels the return forces
- Reduces the oscillation frequency ω
- Not the dissipation processed
- Energy dissipation(per cycle) δE = constant
- Kynetic Energy $E_k \sim \omega^2$
- $Q = E_k / \delta E$ => $Q \dashrightarrow 0 \sim 1/\omega^2$

<u>No damping required !</u>

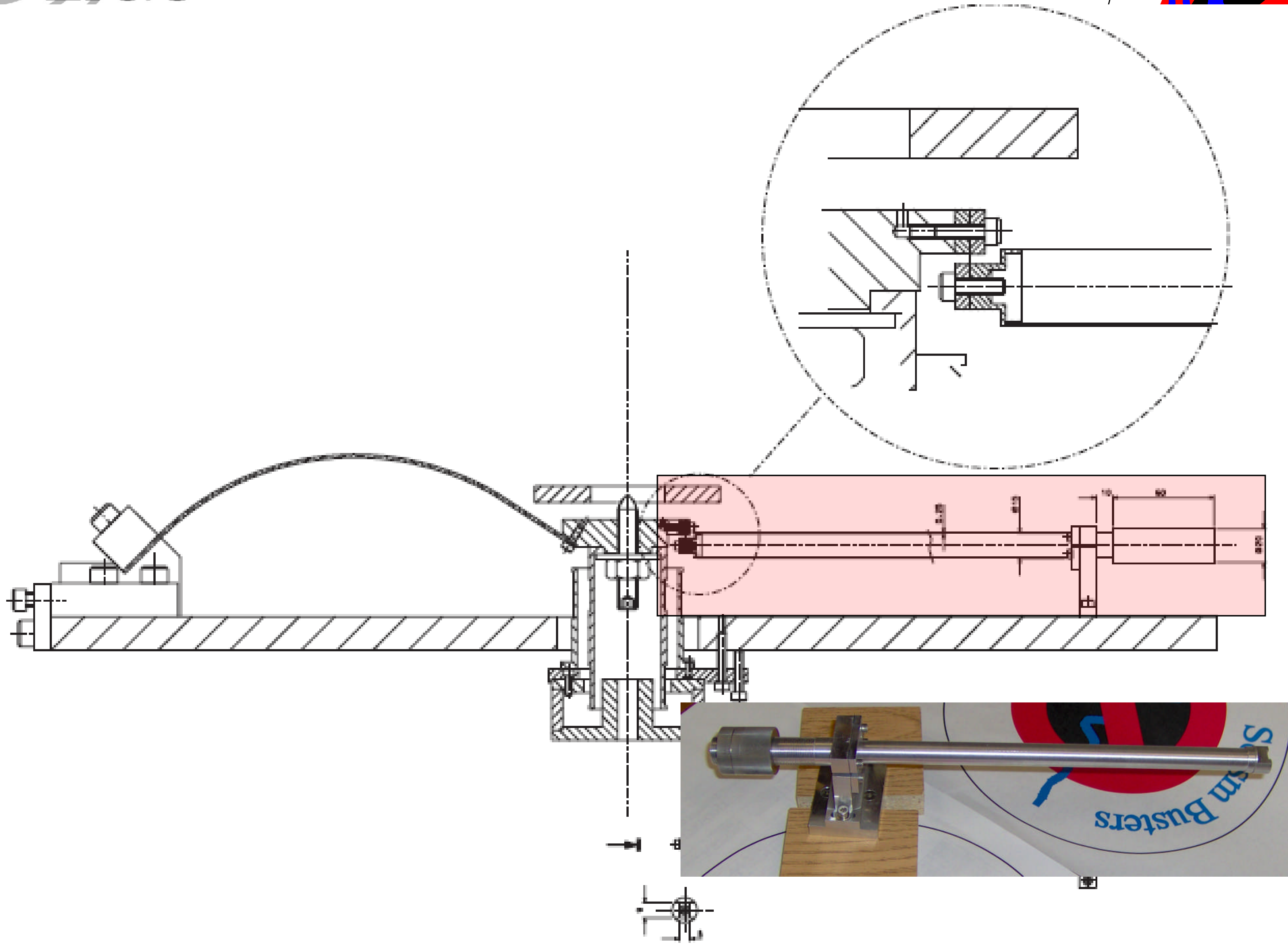
Center Of Percussion effect

$$H_x \equiv \frac{\omega_0^2(1+i\phi)+\frac{M}{m}\omega^2}{\omega_0^2(1+i\phi)-\omega^2+i\frac{\gamma}{m}\omega}$$

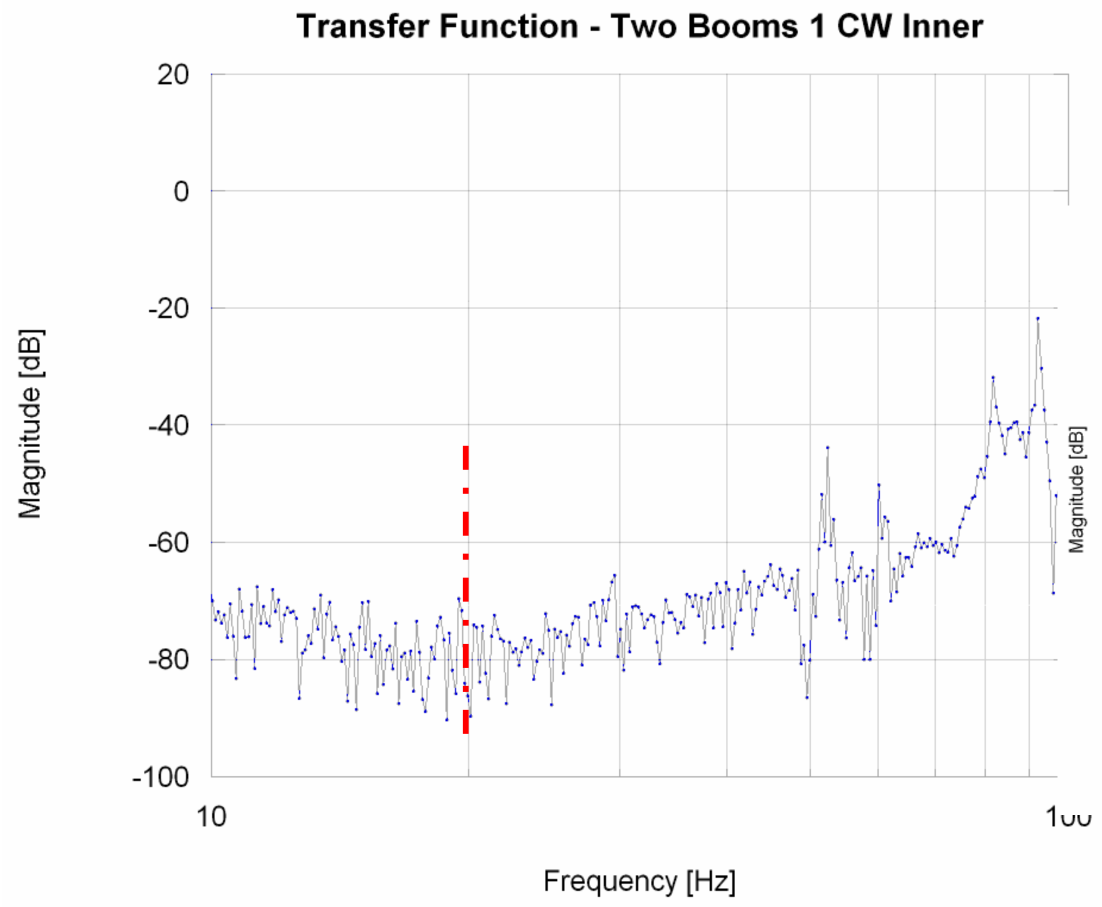
- Mass term limiting the attenuation performance



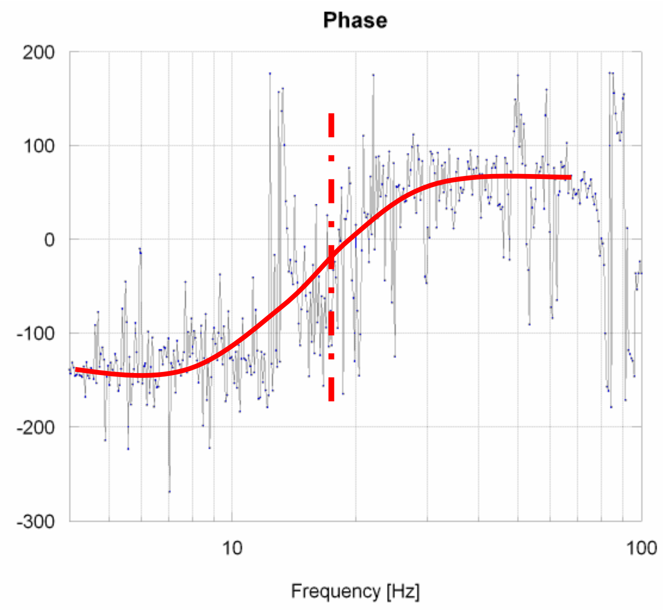
Magic Wand Implementation



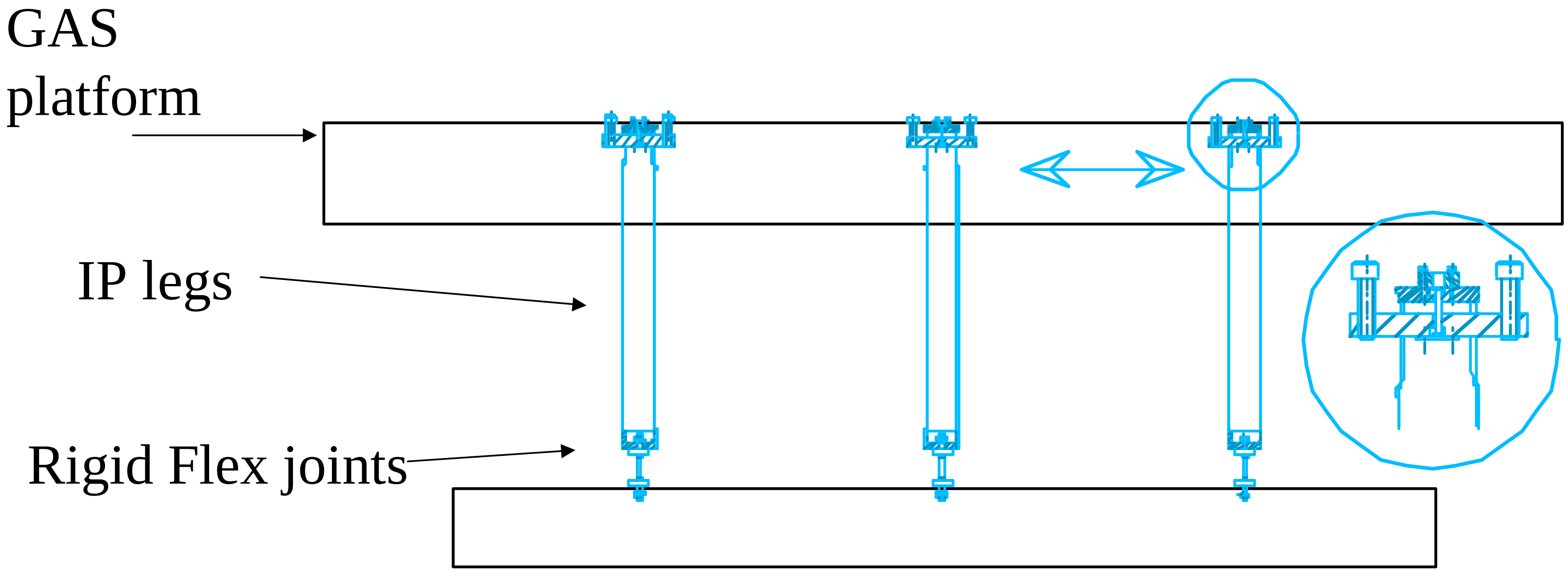
Magic wand tuning
80 dB GAS springs
vertical isolation



- (Still overcompensated)



Horizontal direction, x, y, phi
the Inverted Pendula



QuickTime™ and a
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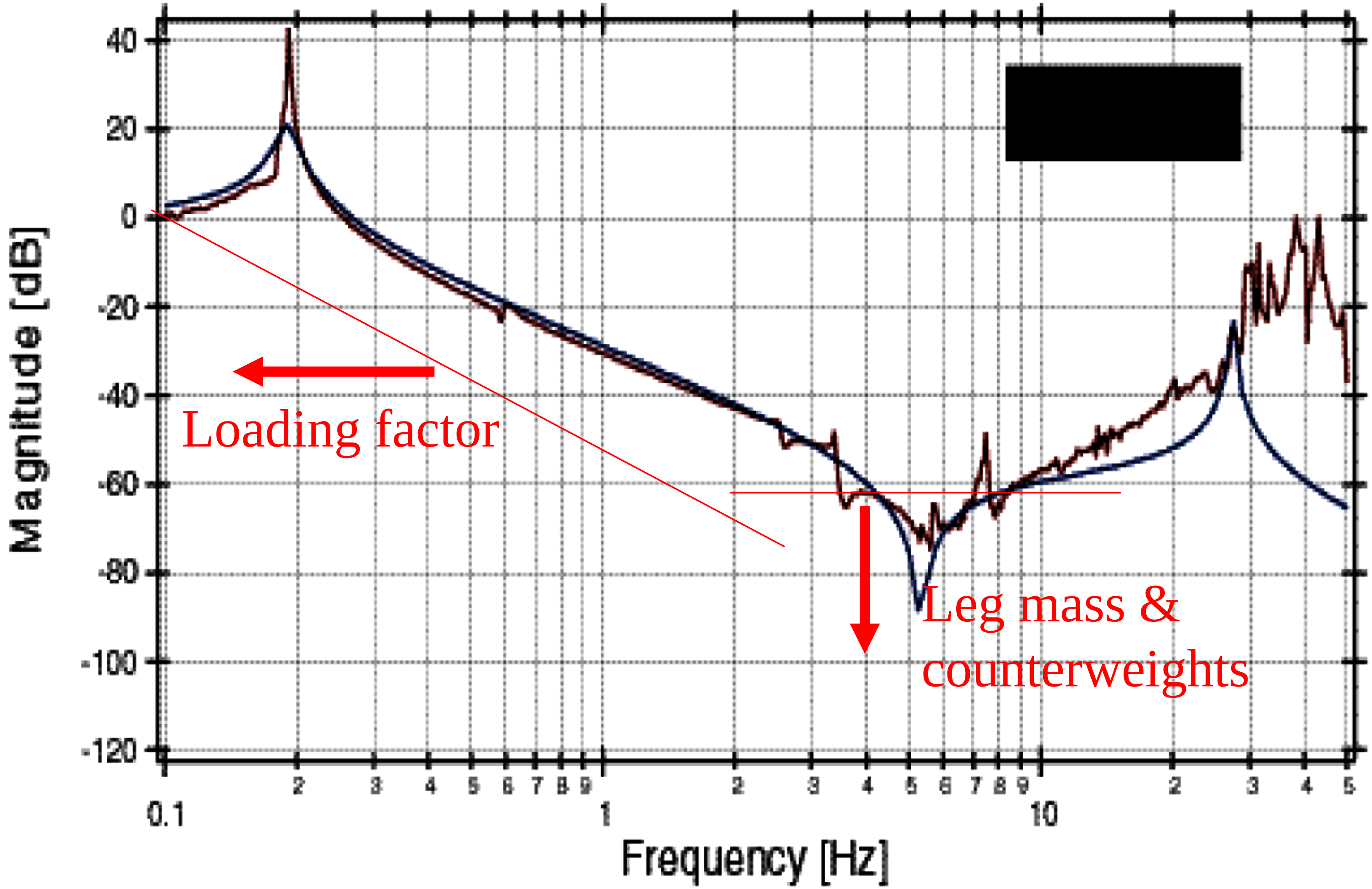
Typical IP Horizontal performance



IP performance and improvements

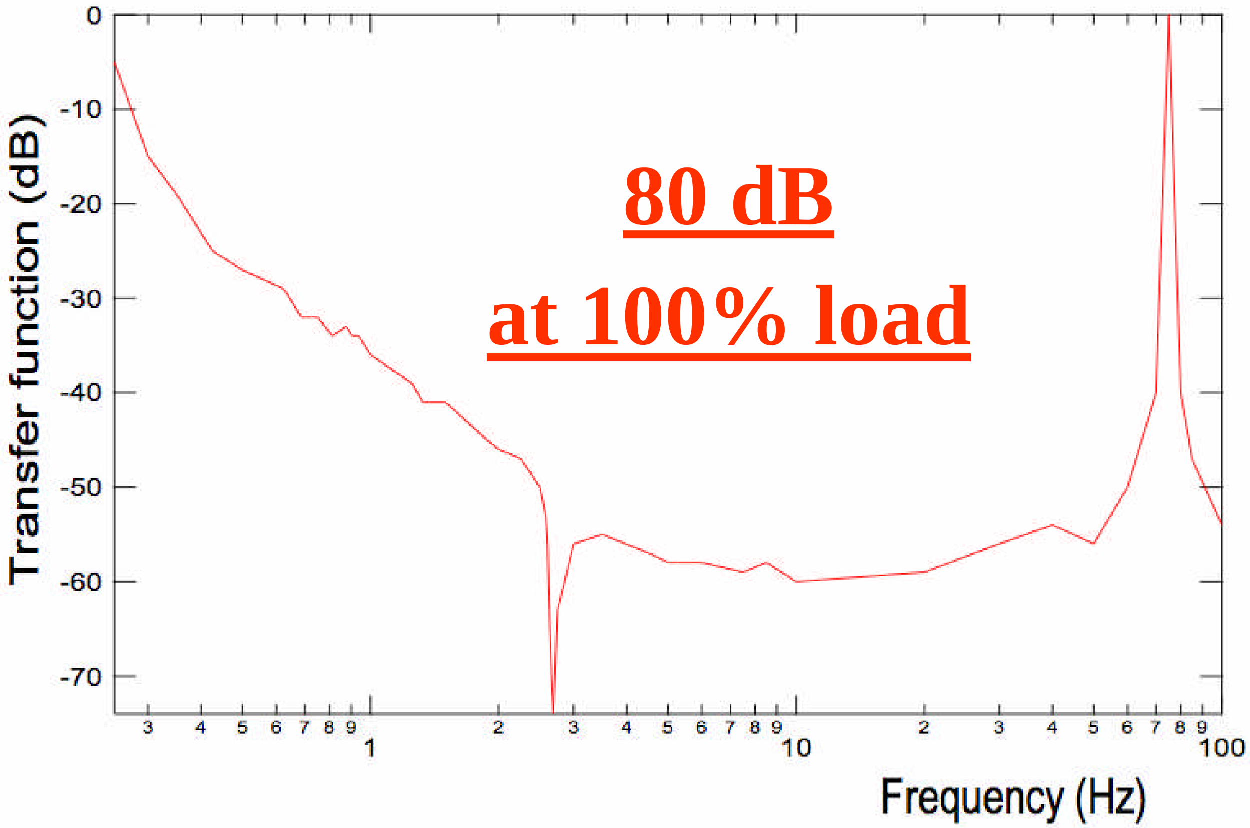
- Minimize the mass of the legs
  - => up to 80 dB attenuation

- Add counterweights to null the COP effect
  - => beyond 80 dB attenuation

Attenuation performance

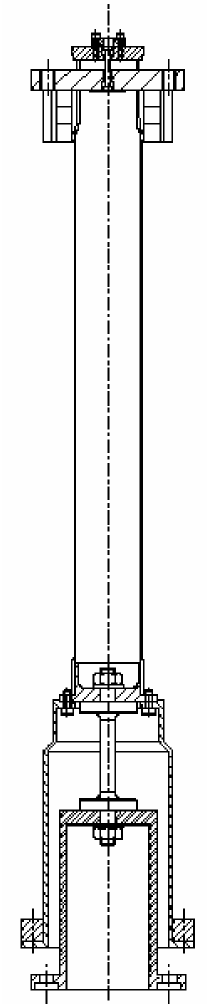
10% payload

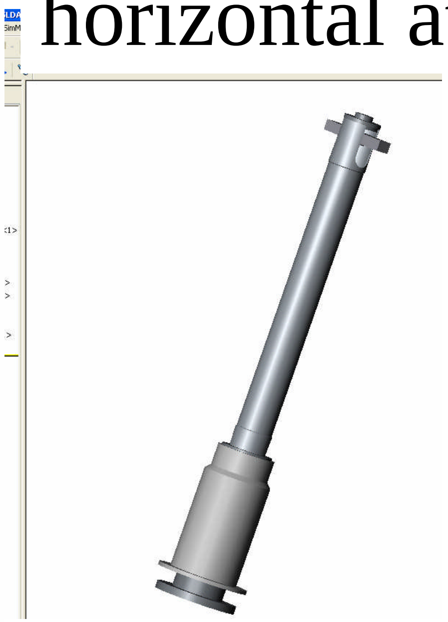
No counterweights

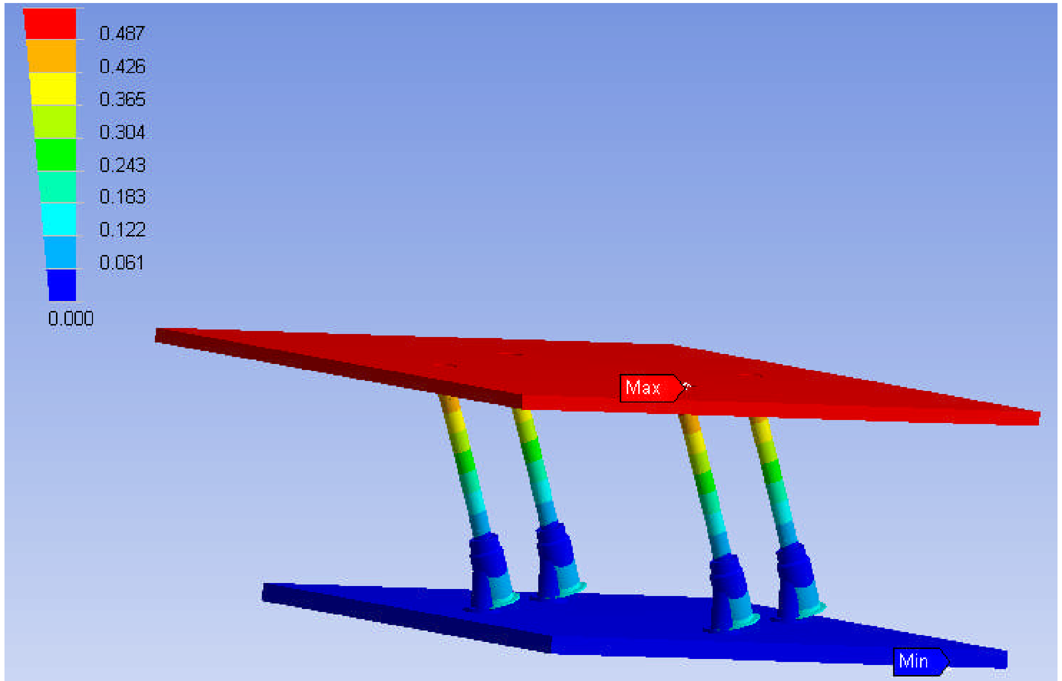


Introducing counterweights

from 80 dB to 100 dB
horizontal attenuation





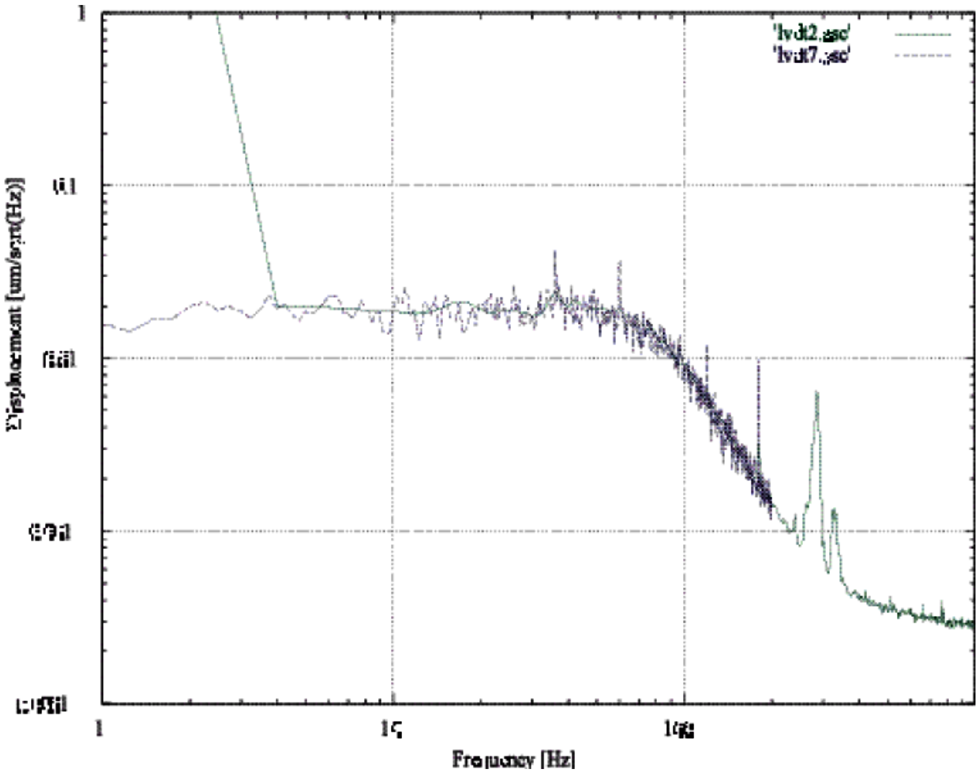


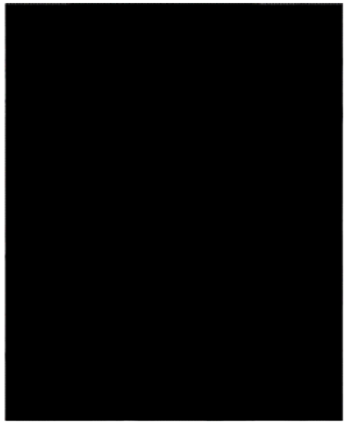
- 10% CW tuning precision => x 10 perf.

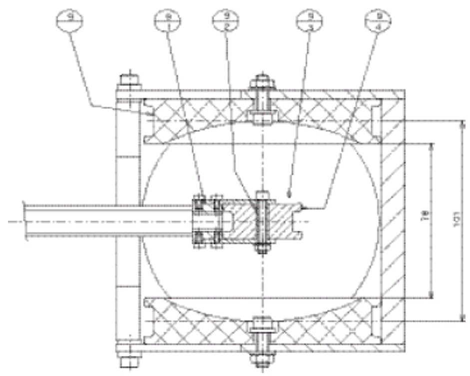
Static and dynamic controls

MICRO POSITIONING AND POINTING

- LVDT for local nanometer positioning memory
- Voice coil actuator dynamic controls
- Position and alignment controls < 30 mHz

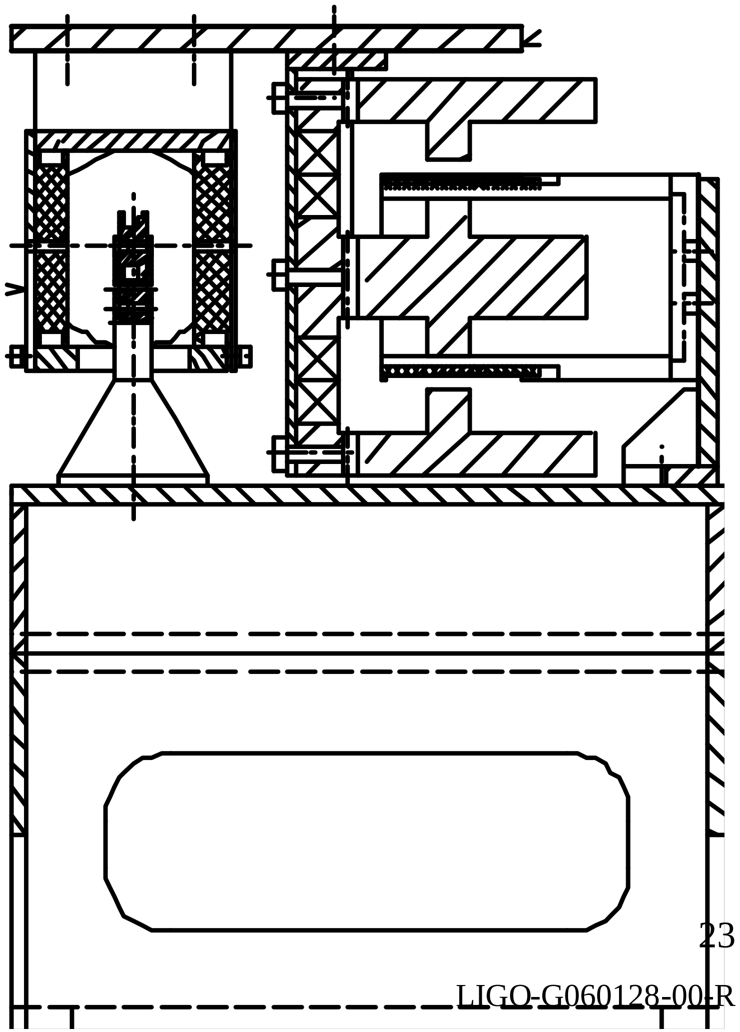






Sensors and coil actuators

- produced with UHV compatible materials and procedures
  - TAMA resolution (nm/√Hz)

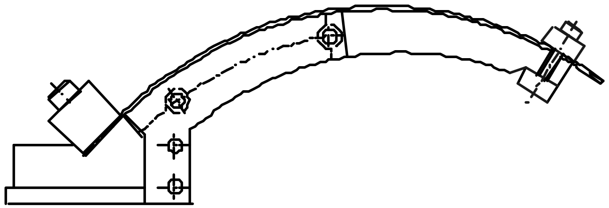


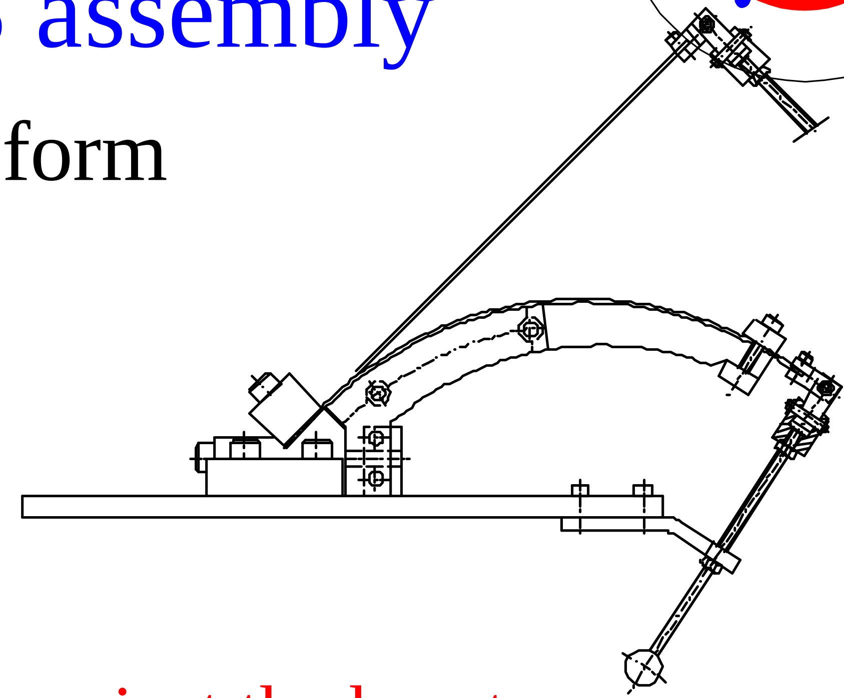
Assemblying a real attenuator system

- What are we building
- How are we putting it together

HAM SAS assembly

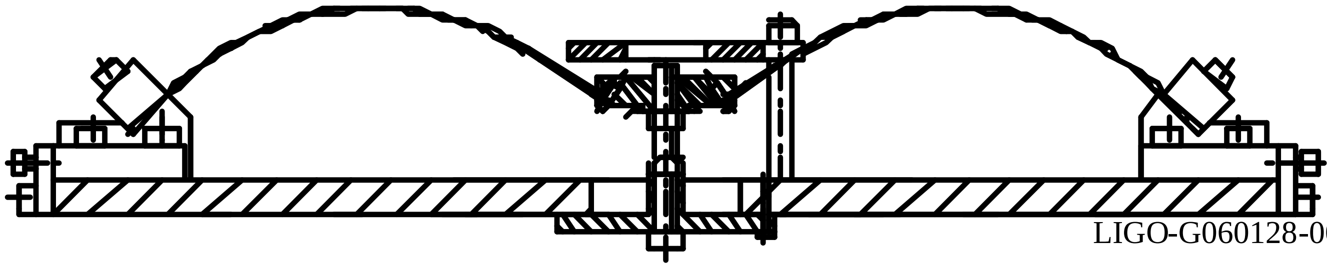
- Pull the blade over a form
- Clamp for transport





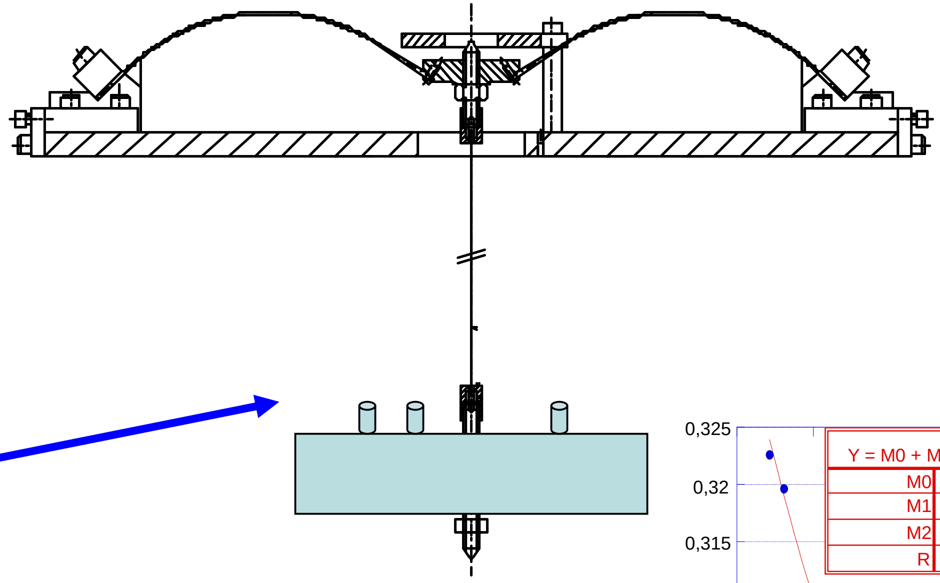
•Mount on the base and against the keystone

•Transfer the load and tune



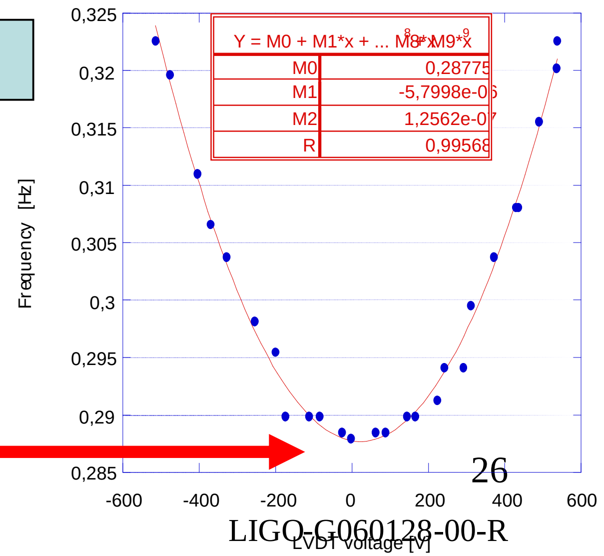
Tuning the GAS filter

- Use screws for radial compression tuning



- Add mass to change working point

- Best mechanical working point



Horizontal direction,
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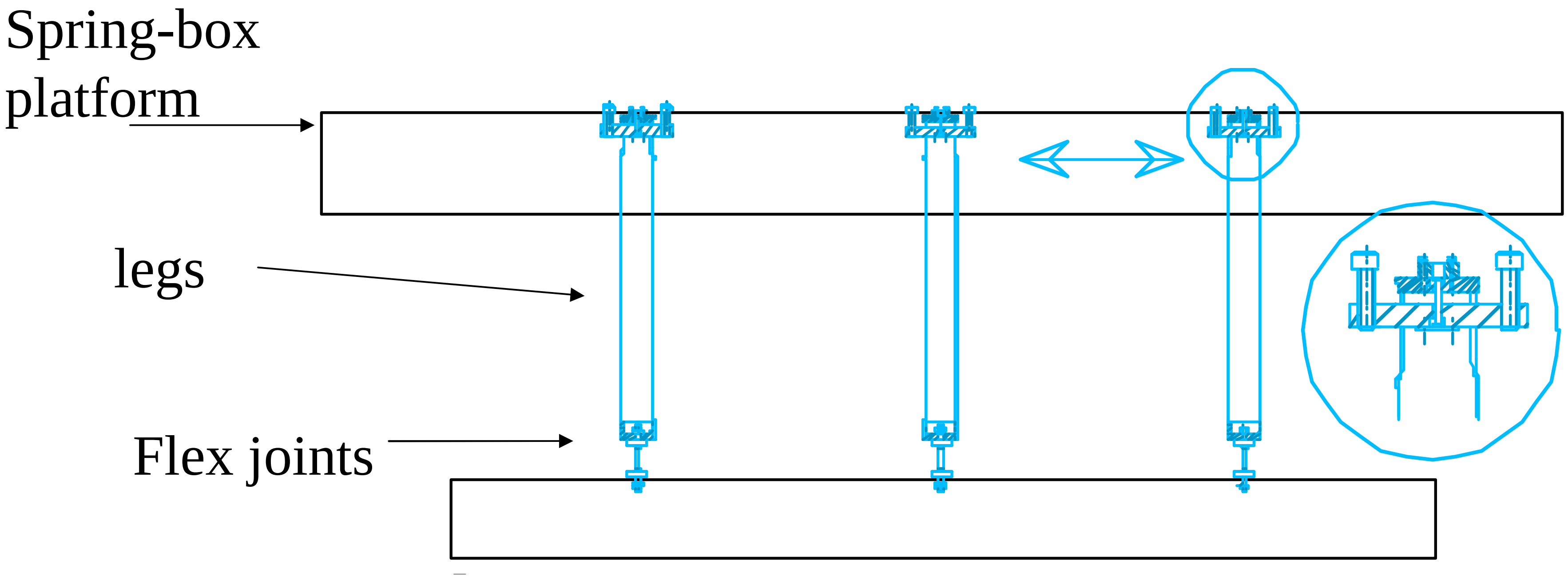
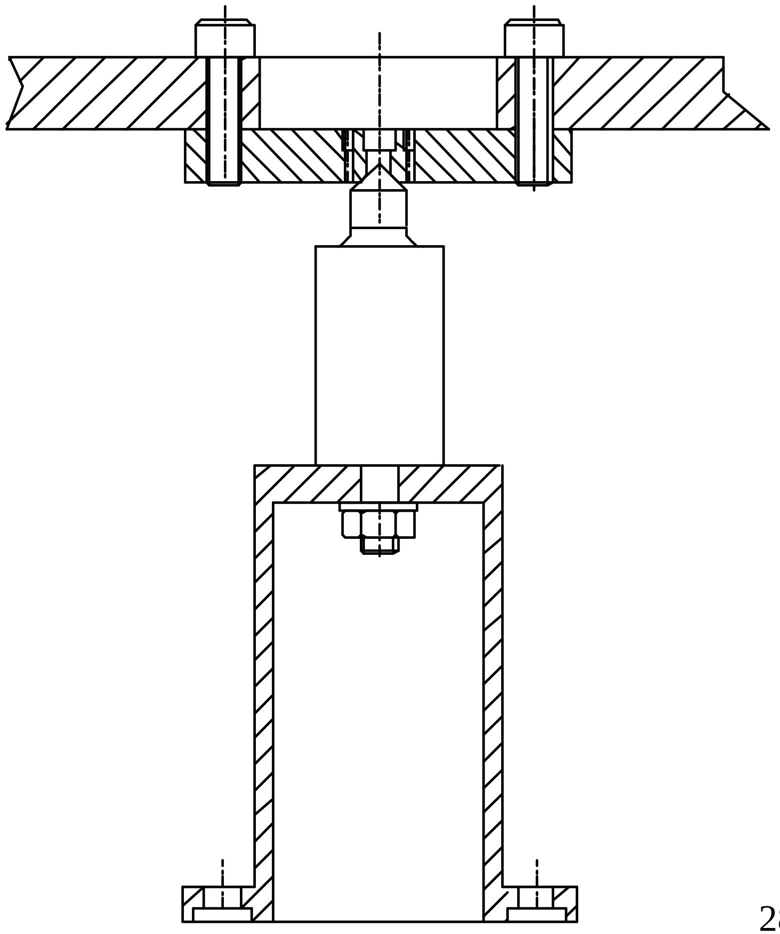


Leg alignment procedure: avoid cradle effect

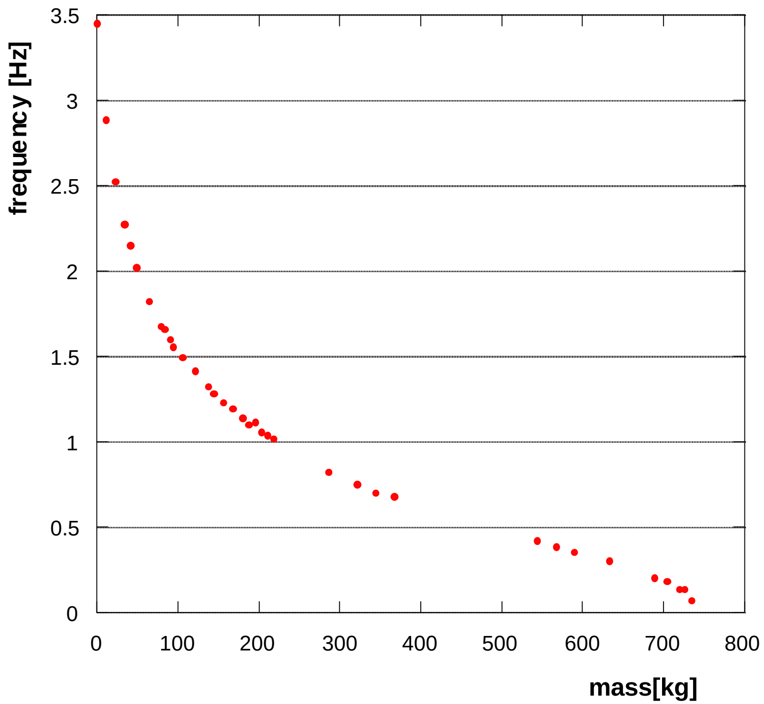
- Legs aligned

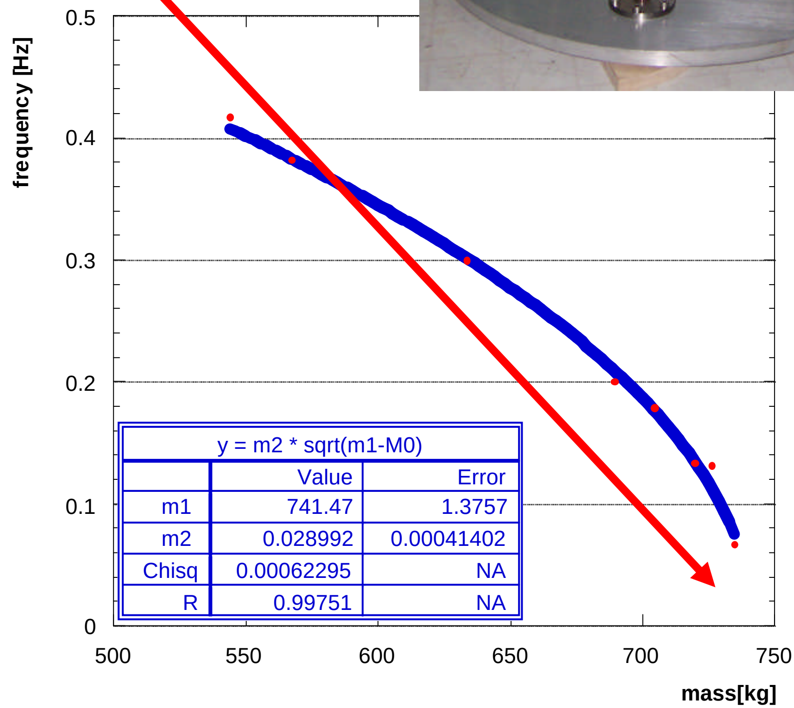
(cradle effect depressed) to 2.5 10^{-4} m/m



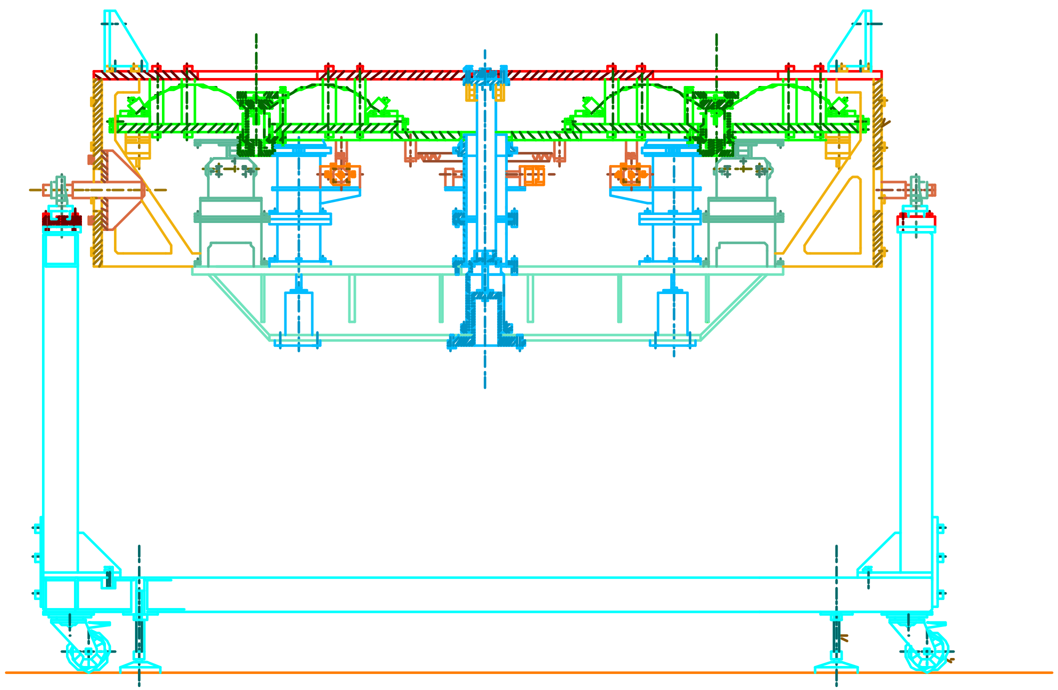
Frequency/Load tuning

<30 mHz tune on stable ground





Installing SAS in the HAMs



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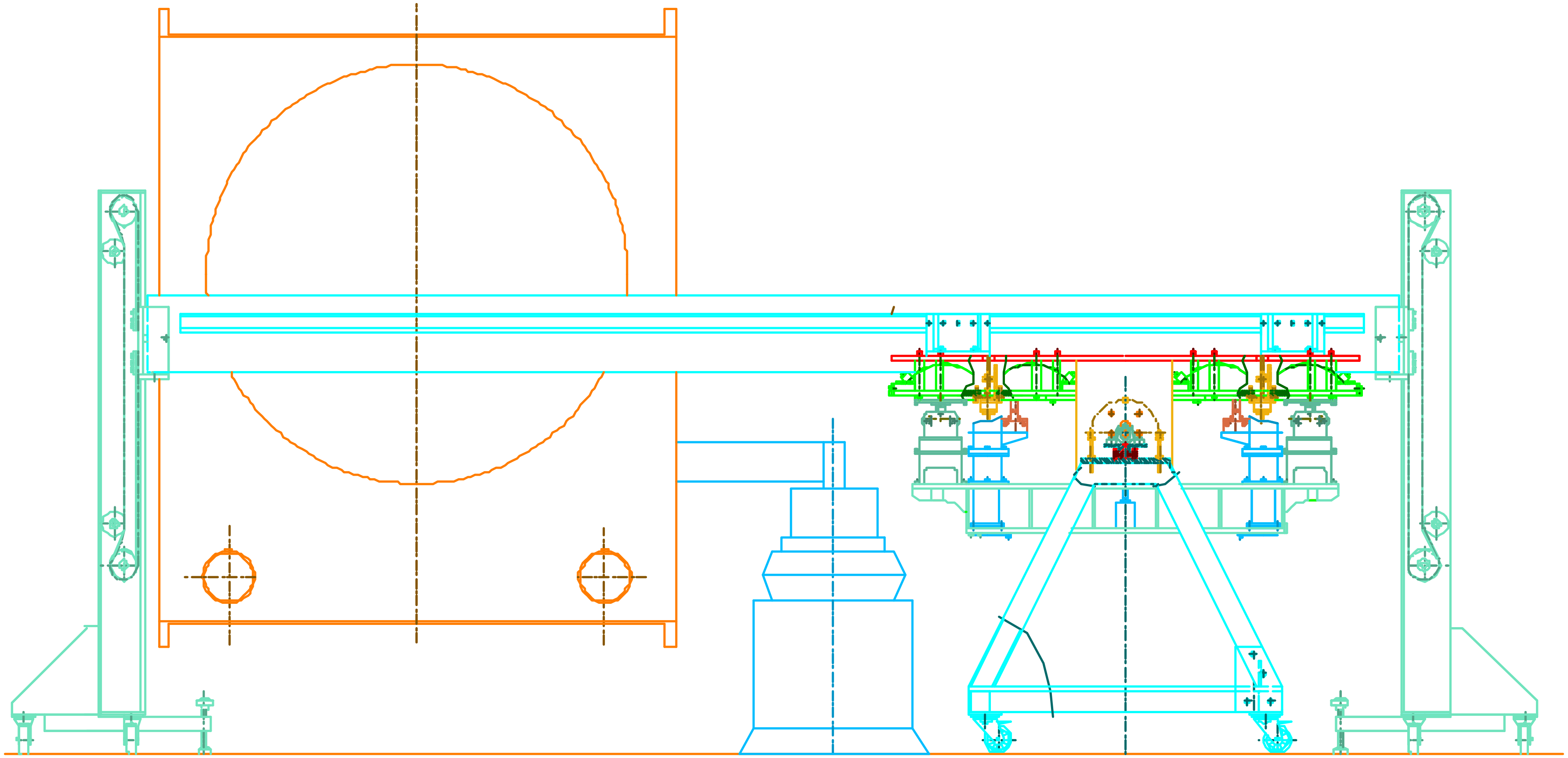

Installing SAS in the HAMs

- Two long rails are installed across the HAM doors extending two meter outside the chamber, resting on synchronous jacks on installation carts
- The rails are lowered to extract the optical bench from the chamber
- The optical bench slides off the HAM chamber and is lowered on a cart

- The rails descend to pick HAM-SAS from its cart
- The rails are raised to slide HAM-SAS inside the HAM
- The rails are lowered to position HAM-SAS on cross tubes

- The operation is repeated to pick-up the optical bench and lower it over HAM-SAS. The optical bench can be installed with most pre-assembled optics

HAM-SAS
primary seismic attenuation for Advanced LIGO