# HAM Seismic Attenuation System (SAS)

## System Fabrication, Assembly, Performance

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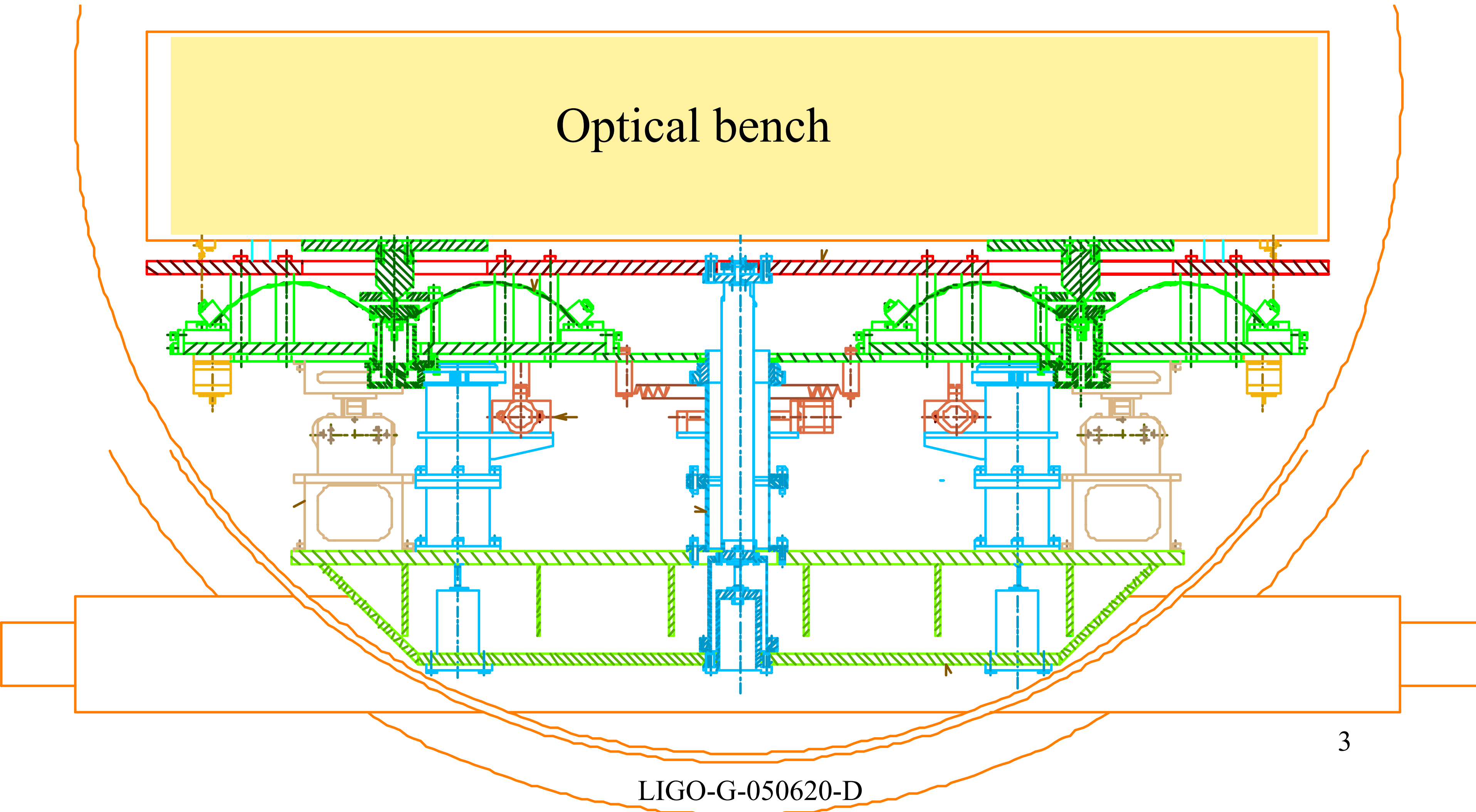
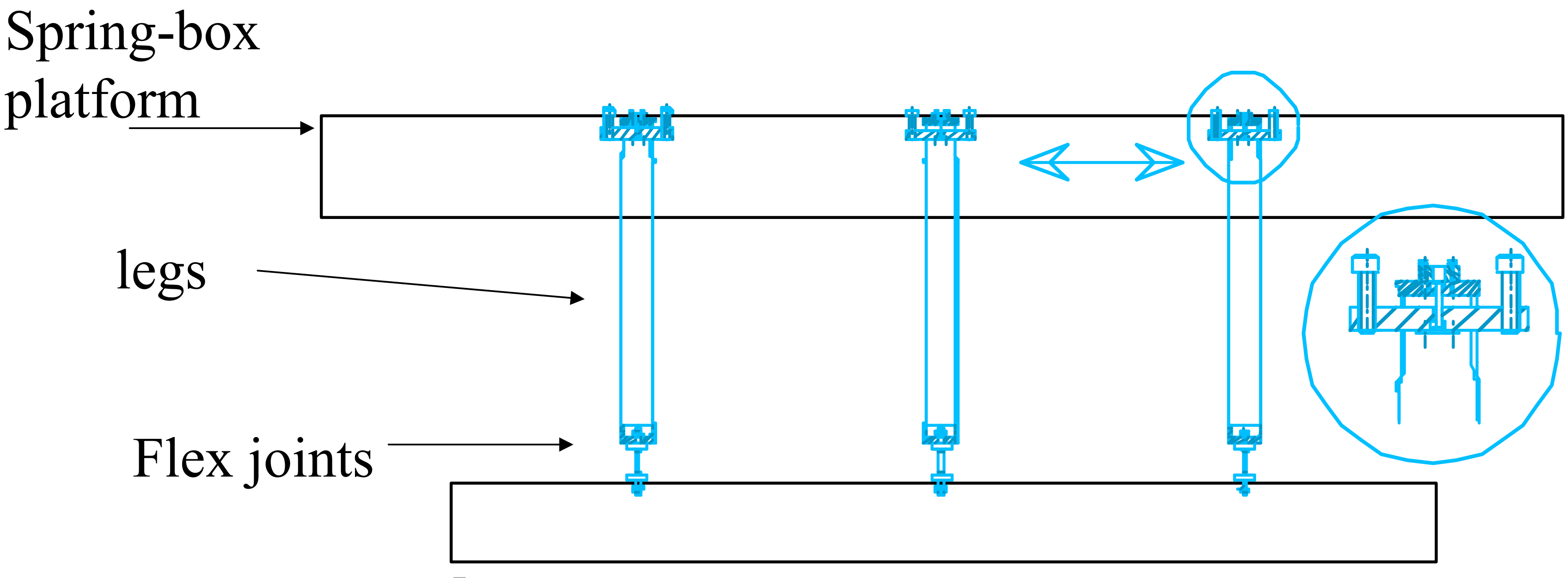
LIGO

- What are we building
- How are we putting it together
- Which tests to perform
- How do we implement it in the HAMs
- How much HAM-SAS costs

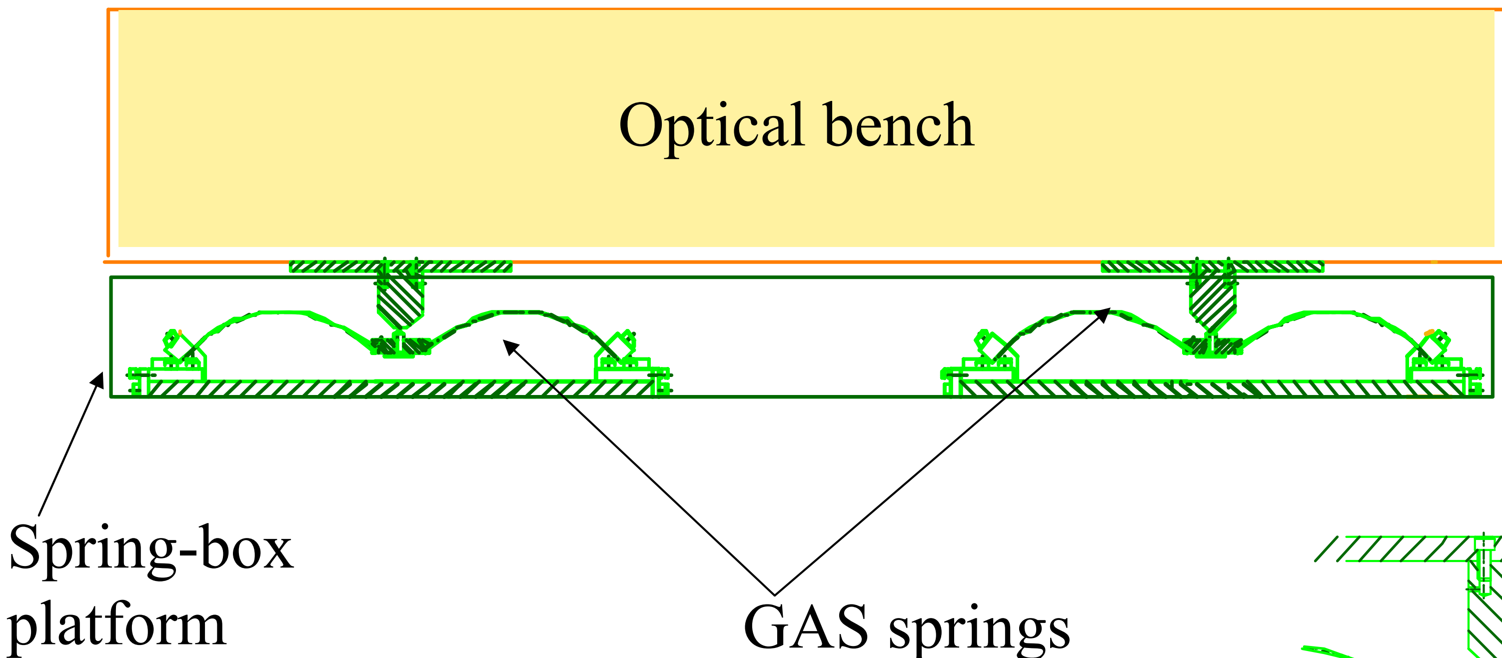
# A seismically attenuated optical bench for the HAM chambers

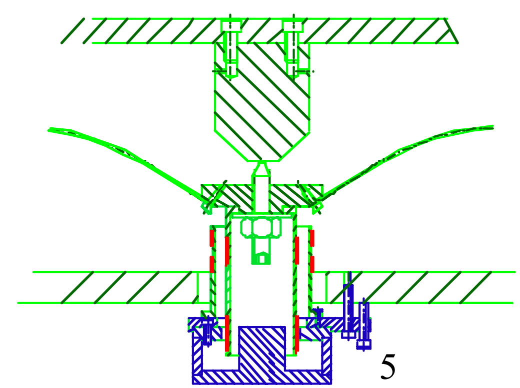


# Horizontal direction, x, y, φ the Inverted Pendula



# Attenuation in the vertical direction, the GAS springs



# Pedigree

- The present LIGO optical benches
- The Virgo passive Superattenuators
- The TAMA SAS filter and IP know how
- Further advances in Inverted Pendula (IP)
  - => 80 to 100 dB
- Further advances in Geometric Anti Spring filters (GAS)
  - => 60 to 80 dB

# Performances

- Deliver more than 60 dB attenuation at > 1 Hz
  - performance & design requirements per E990303 http://www.ligo.caltech.edu/docs/E/E990303-03.pdf
  - these requirements are being re-evaluated and likely reduced, though perhaps not in the total rms motion
- 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 few nm level
- No standing control forces
- Provide earthquake protection for up to ±12 mm movements
- Recycle existing optical benches where available

# Development status

- HAM SAS have been extensively tested at the component level,

  not yet as an integrated system

- Factory tests and/or LASTI tests

  will validate the system performances

# Controls

(see Virginio/Valerio presentations)

- The bulk of the performance will be passive
- The role of controls is minimized
- Controls provide positioning and pointing
- Modes are mostly low quality factors $Q \sim 1/f^2$

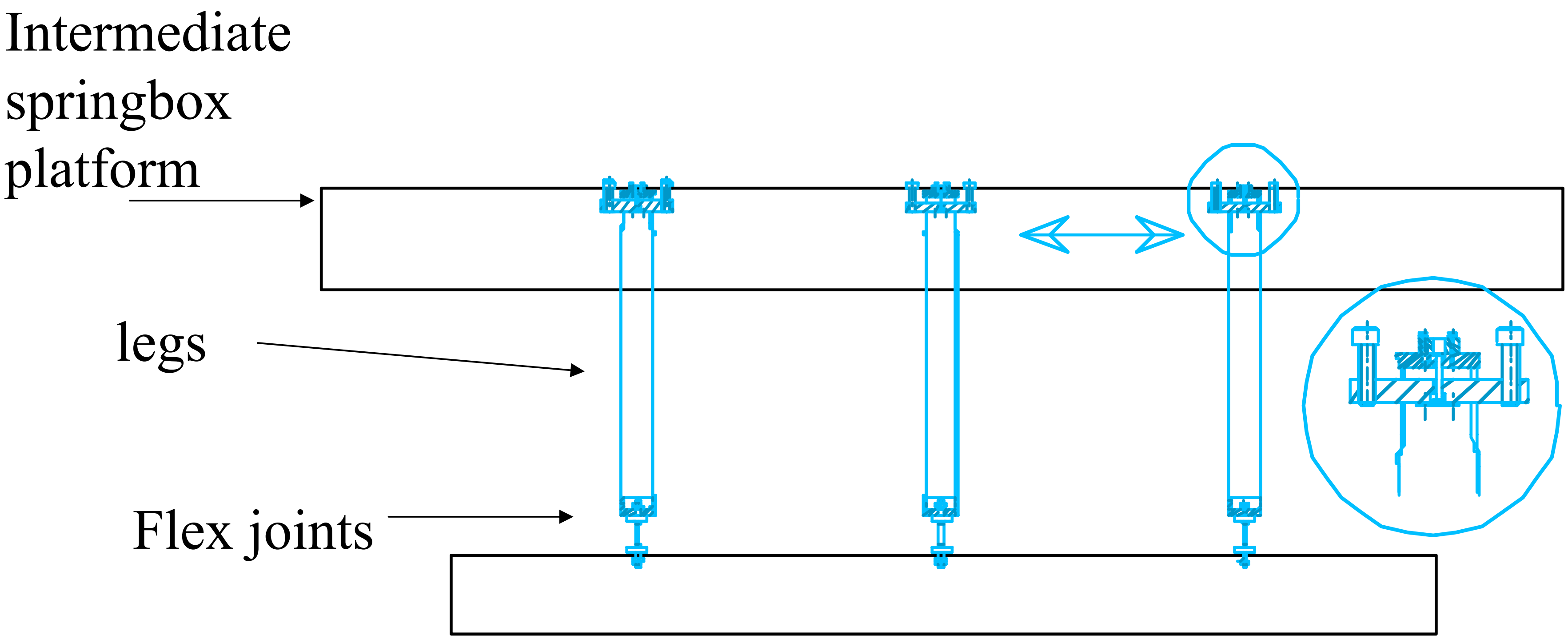
  Active controls may provide additional damping
- The specifications to be be met in passive mode, with only DC positioning controls

# Controls

(see Virginio/Valerio presentations)

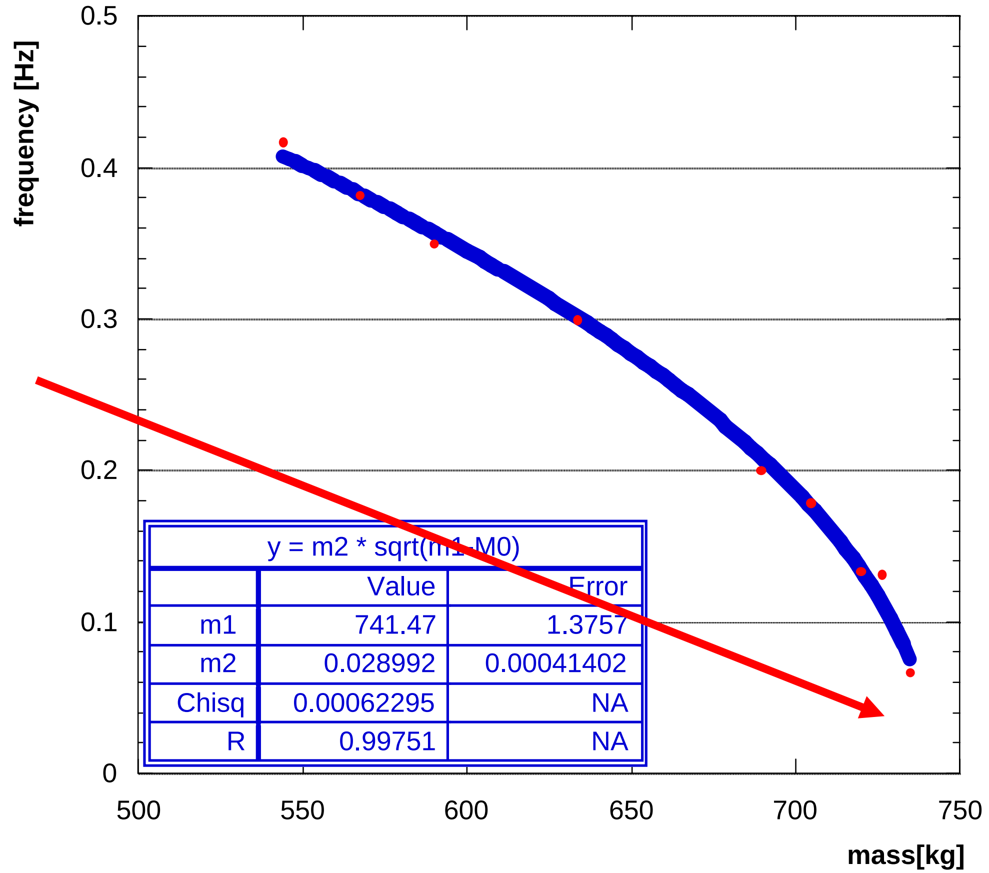
- The equipment for positioning and viscous damping are identical, viscous damping can be achieved with only software
- DC controls with or without viscous damping will be implemented
- Inertial damping and/or active attenuation will require the implementation of accelerometers
- Inertial damping and active attenuation, with increasing complexity levels, would provide a performance reserve or boosting
- Studies at LASTI will show the necessity and/or convenience of these improvements which are very likely not strictly necessary for the OMC

# Horizontal direction, x, y, φ the Inverted Pendula



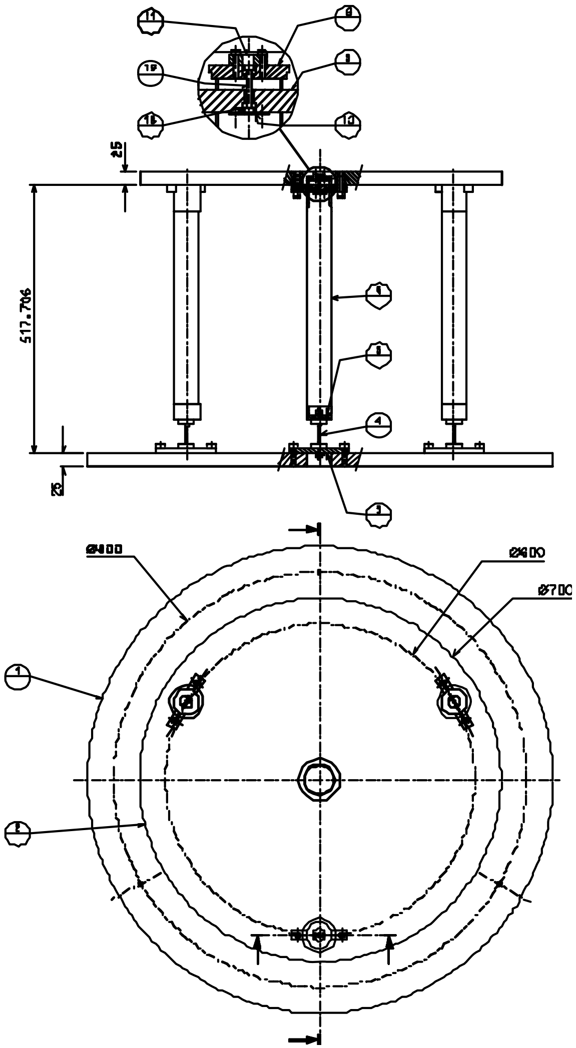
# IP Resonant Frequency

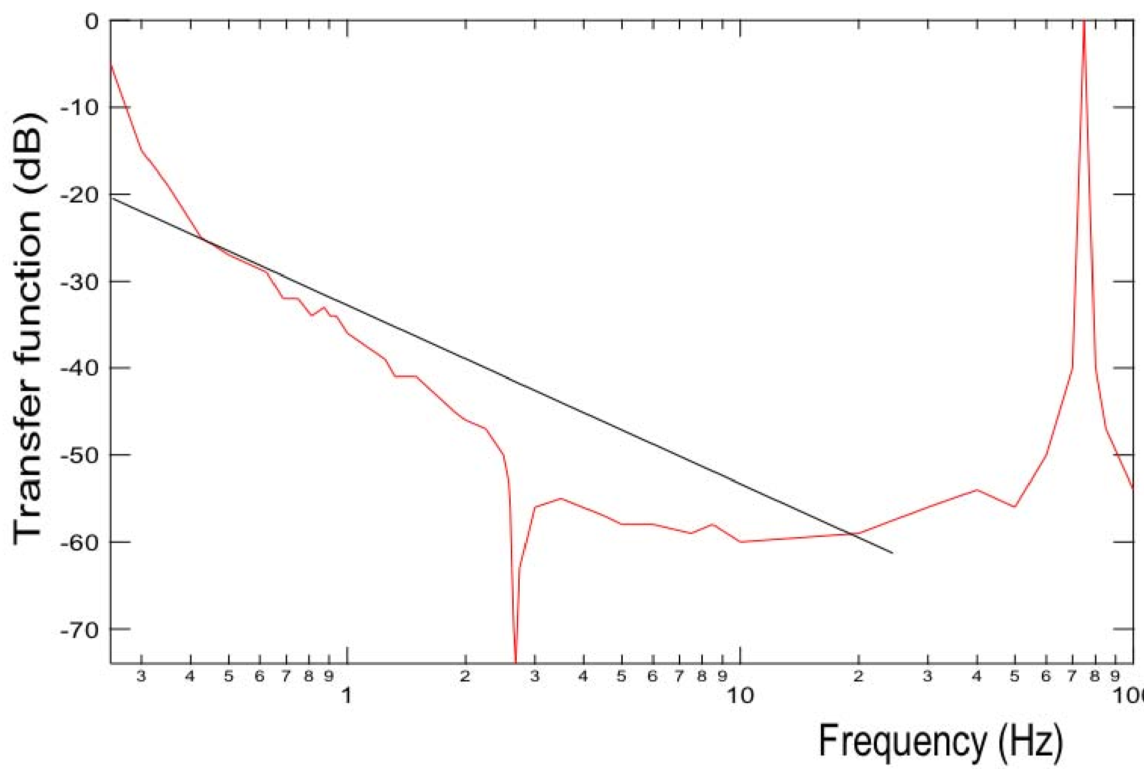
< 30 mHz
for LF attenuation



# Light legs no counterweights HAM IP first tests

- Preliminary test results
- 60 dB achieved without CW with 1/8 payload
- >70 dB expected with full payload
- >80 dB with CW





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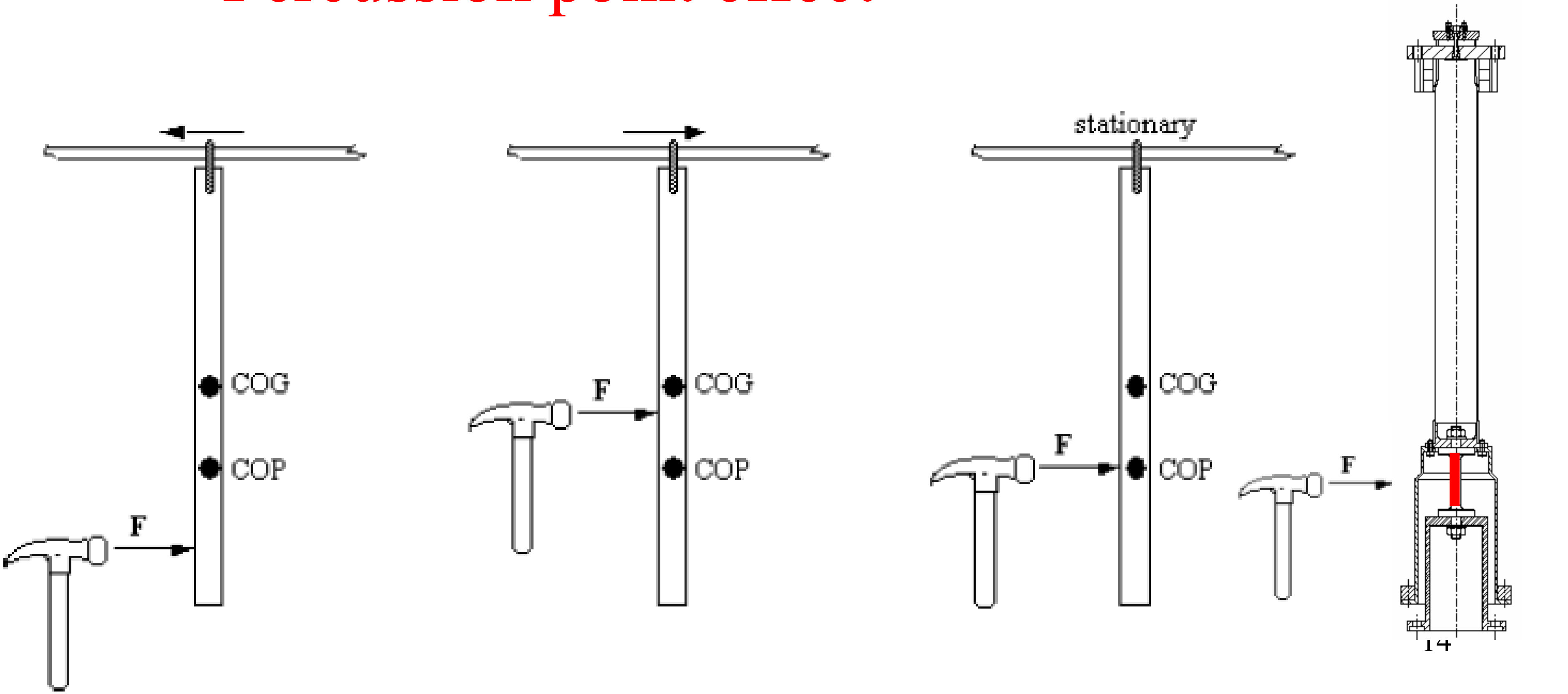
Seism Busters

# the C.O.P.
# attenuation saturation

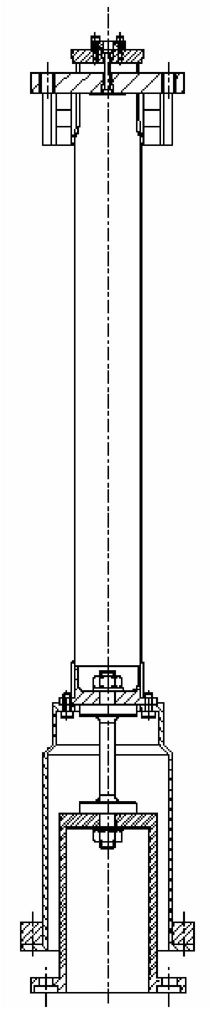
- Some shaking energy transmits due to the Percussion point effect

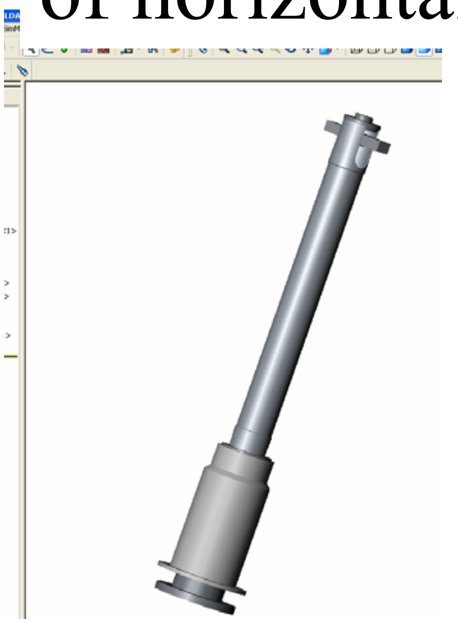


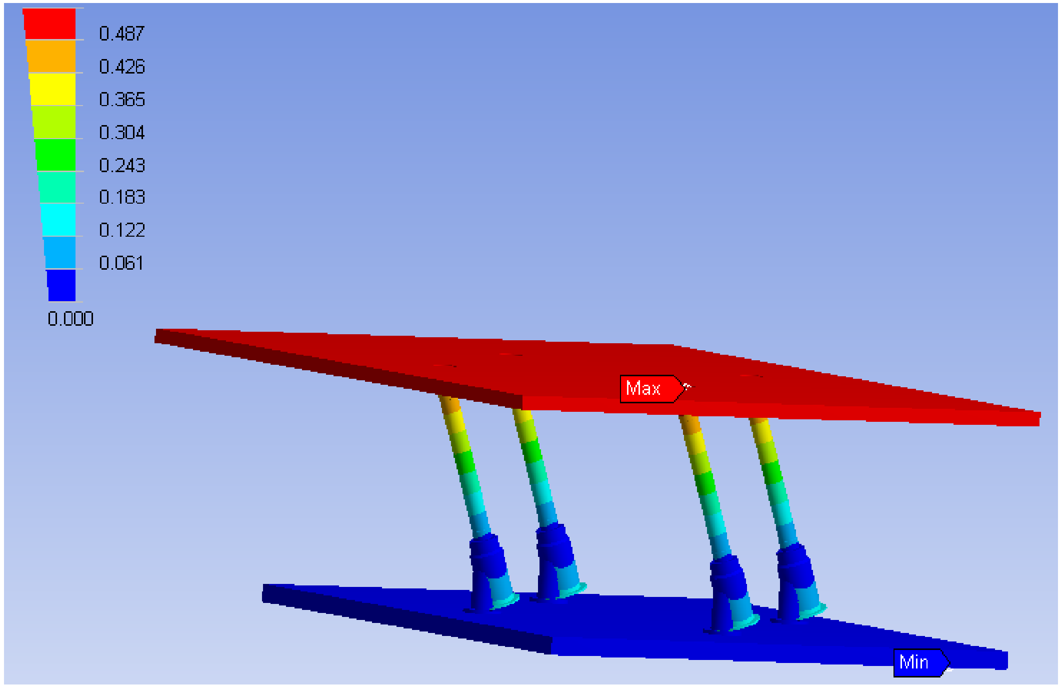
LIGO

# Introduction of counterweights

The CW will boost the performance from 70-80 dB to 100 dB of horizontal attenuation







# CW tuning

1. Dead reckoning using FEM ?
2. Component tuning ?
3. Full system tuning ?

- In the past full system tuning
- Light legs already yield good performance
- 10% precision is sufficient
- Probably step 1 or 2 would be sufficient

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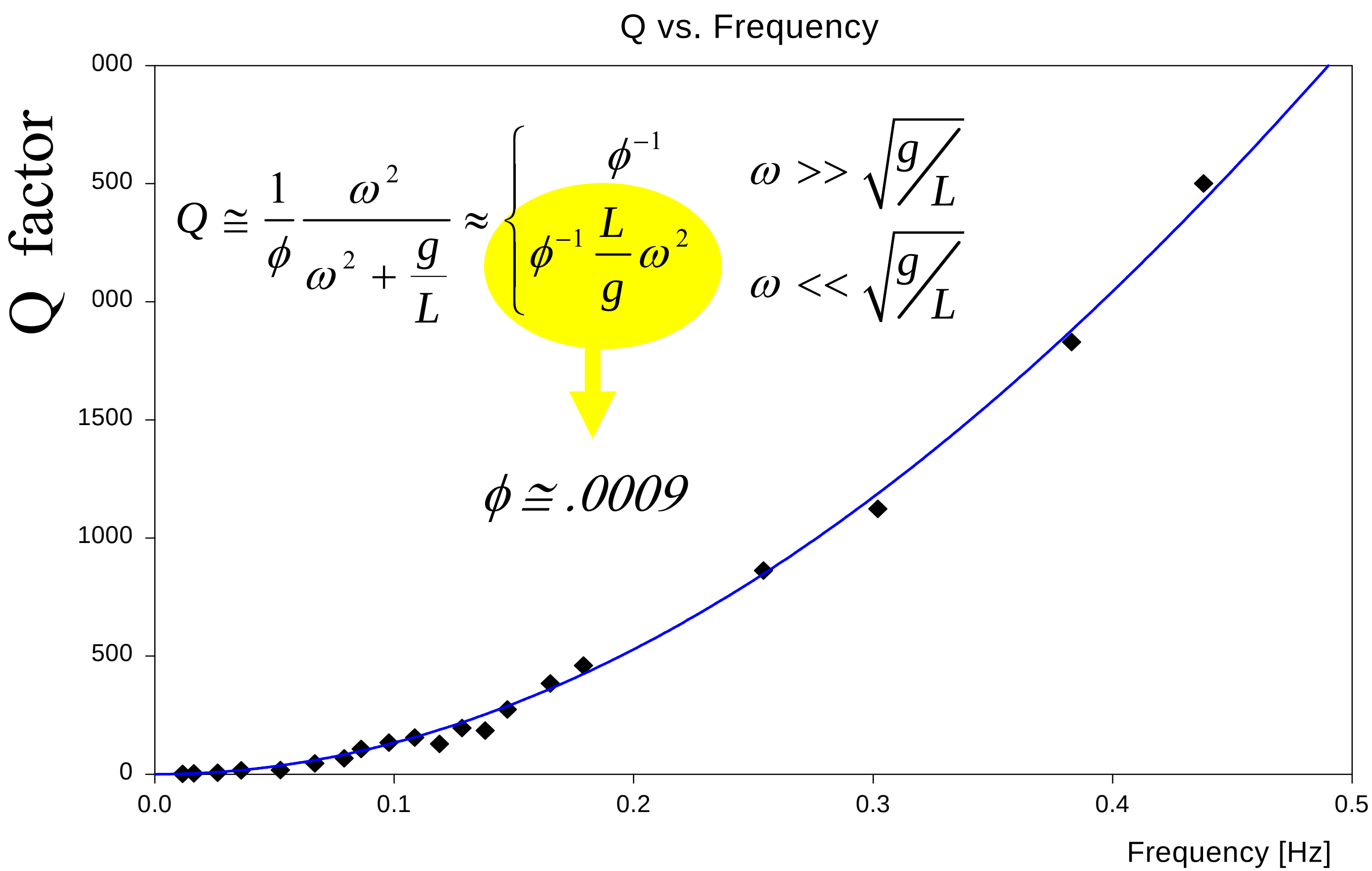
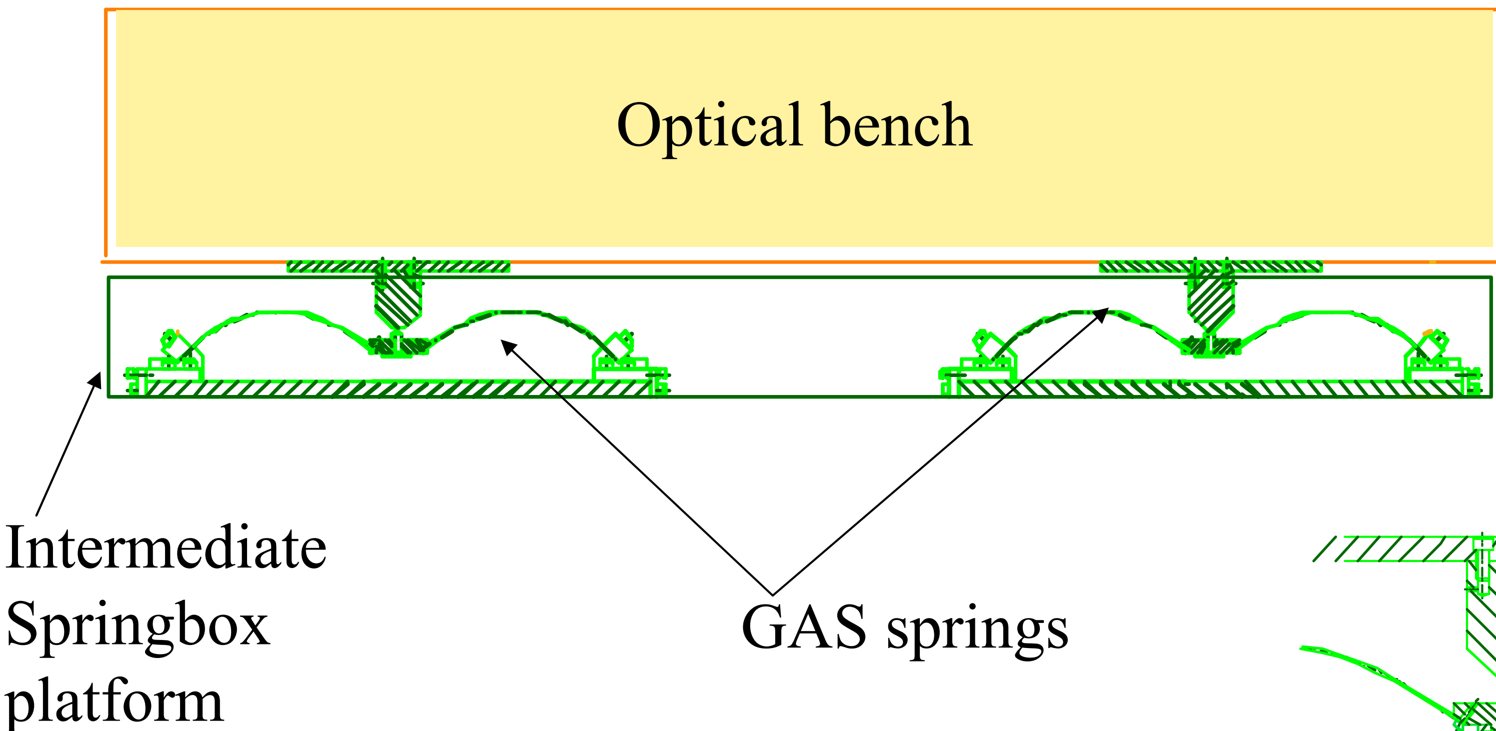
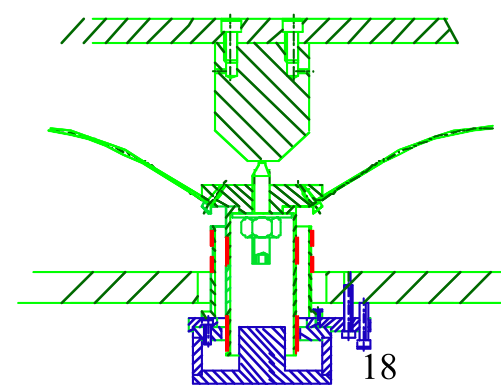
# Q-factor <10 at LF tune




Low Q means limited control damping requirements

# Attenuation in the vertical direction, the GAS springs

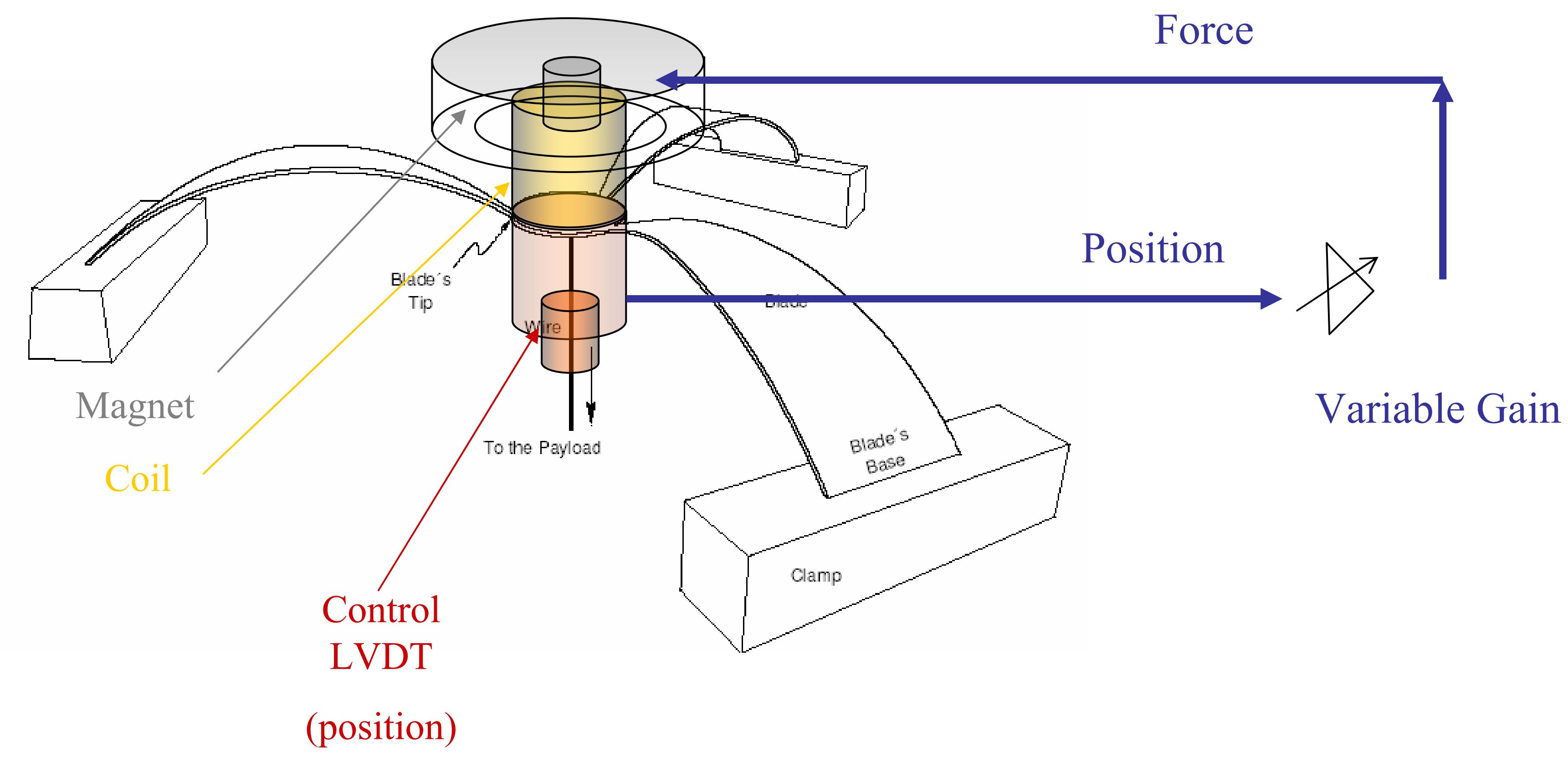


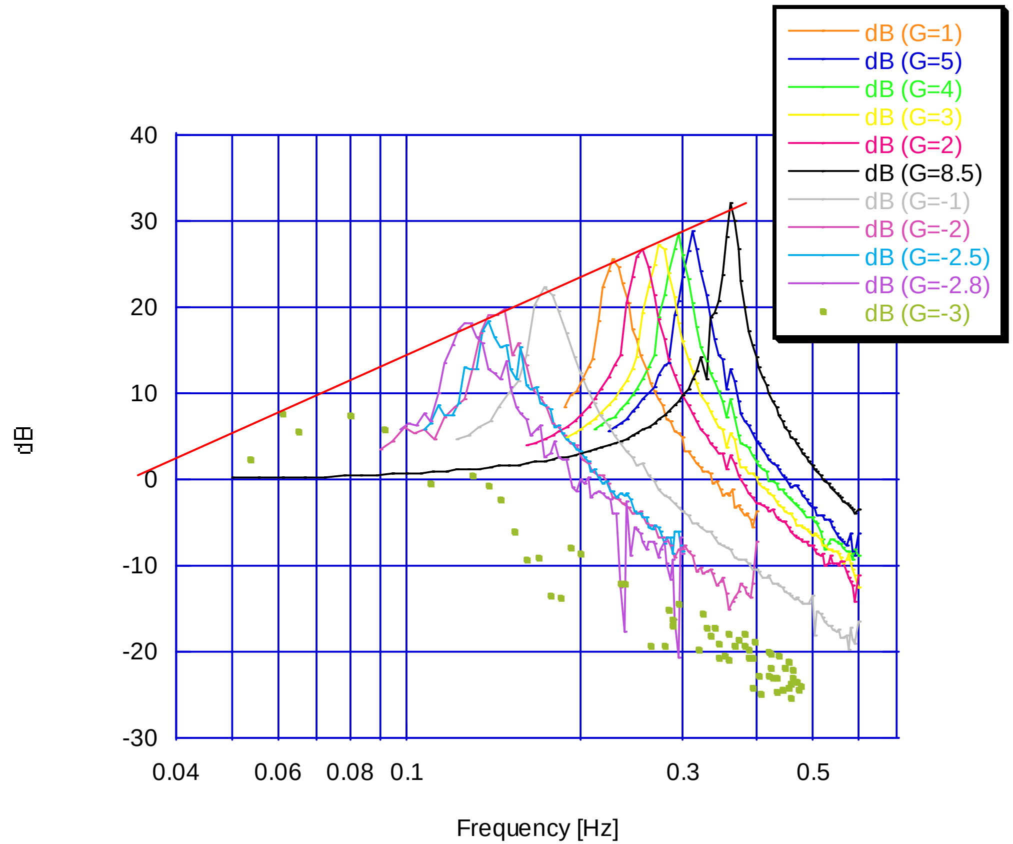
# Tuning GAS springs to 30 mHz

resonance frequency limited at >200 mHz

lowered < 100 mHz with E.M. springs



# Transfer Function with Different Gain values




## Lowering the system stiffness

As the Transfer Function is shifted to lower frequencies,

the Q factor decreases

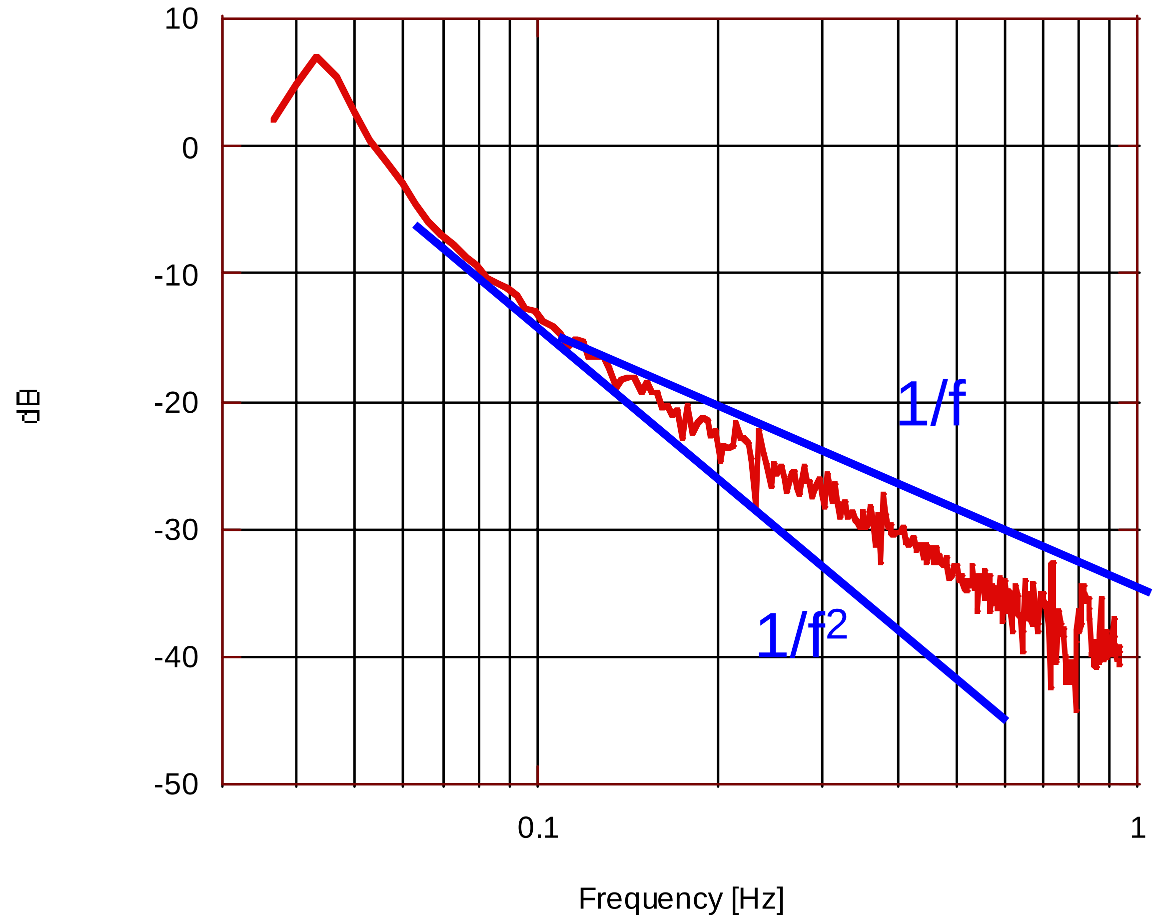
Lowering the resonant frequency
Provide LF seismic attenuation

- Vertical Passive attenuation limited to ~ 20 dB at the micro seismic peak


- (Obviously much more isolation available in the horizontal direction)

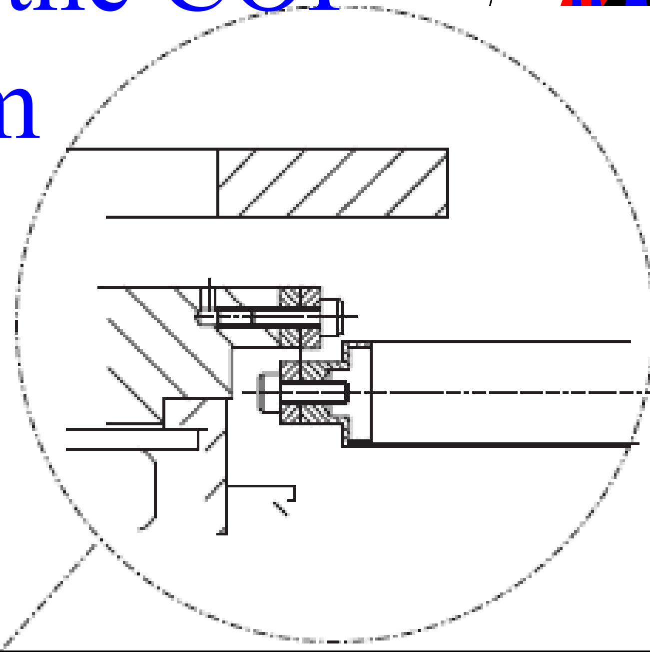
# The hysteresis limit?

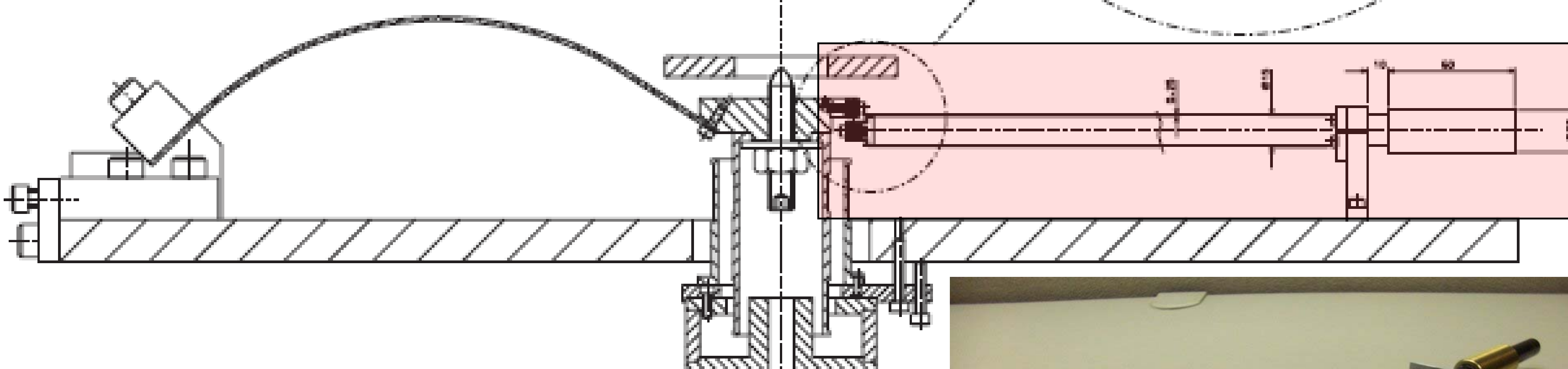
• because of hysteresis, below 120 mHz the $1/f^2$slope softens towards a 1/f slope



# Neutralizing the COP limit: the boom

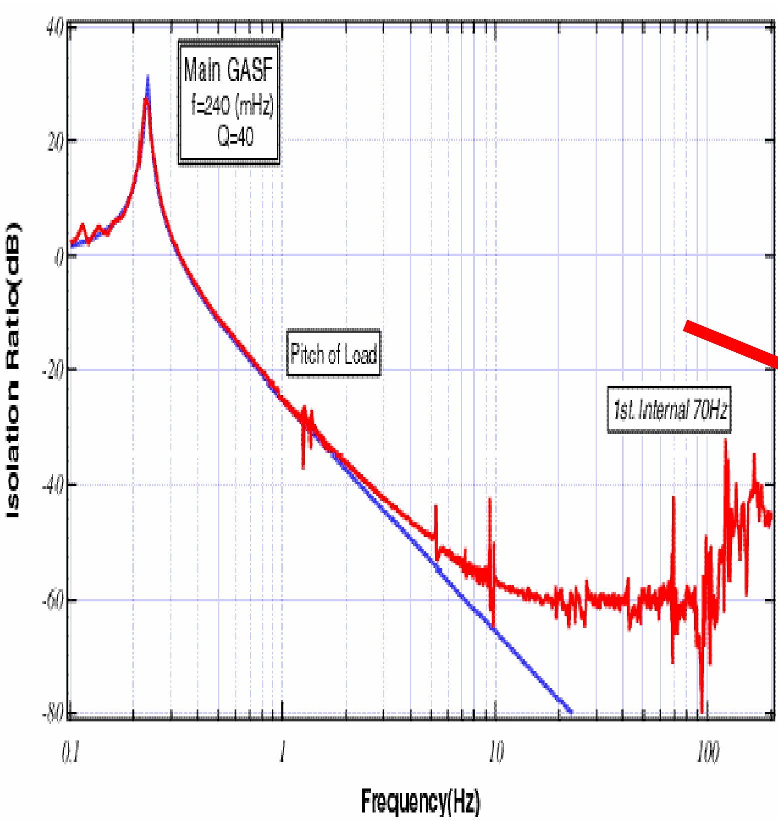
- 60 dB limit without counterweight rods
- Down to ~ 80 dB with C.O.P compensation

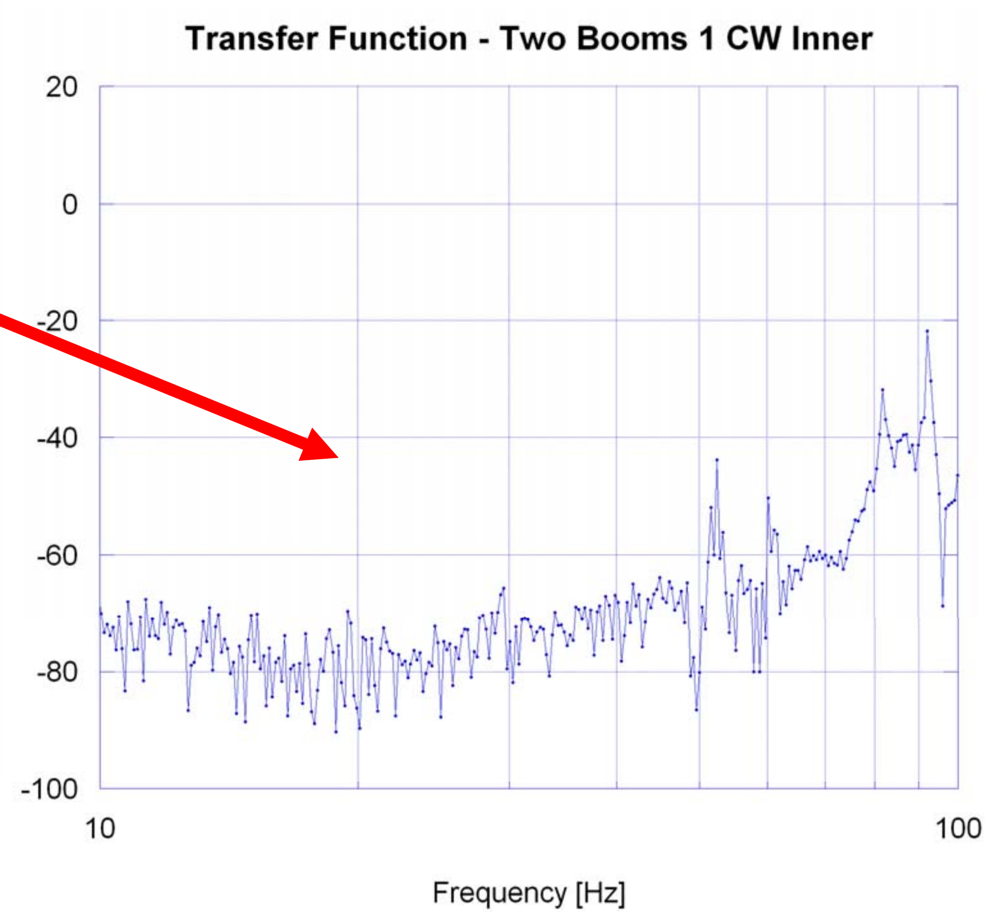




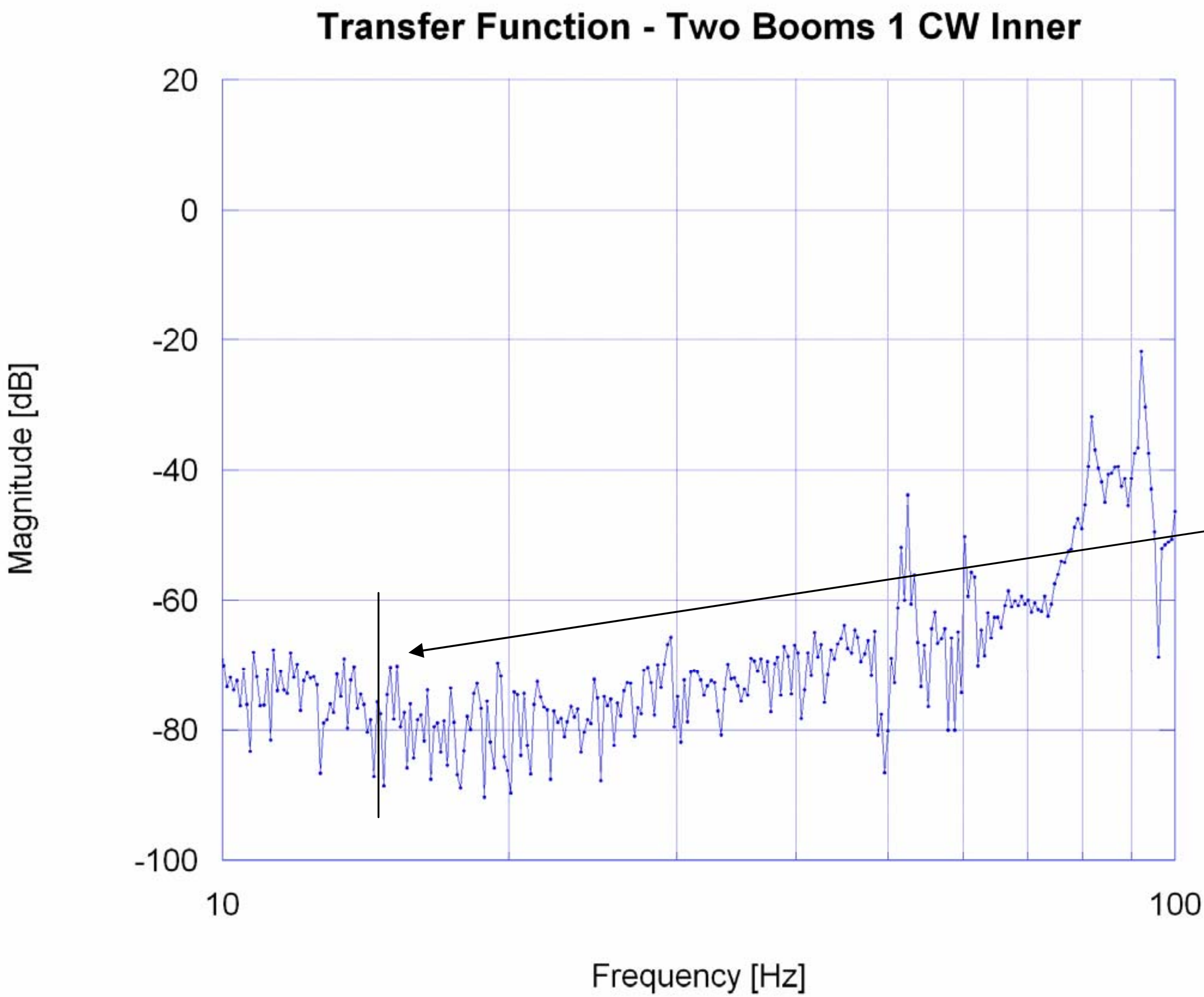
Seism Busters

# The effect



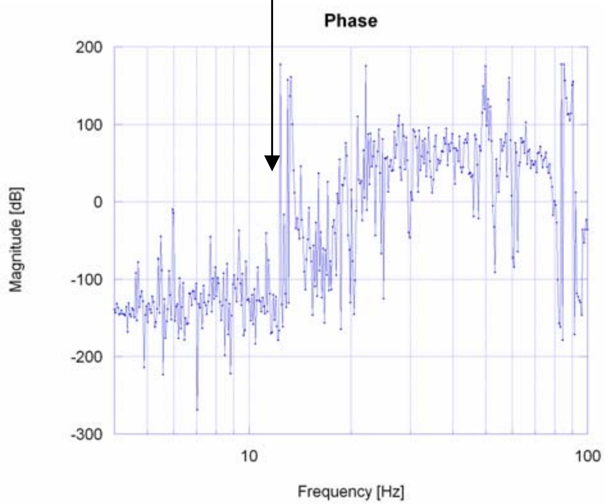



# The Boom effect



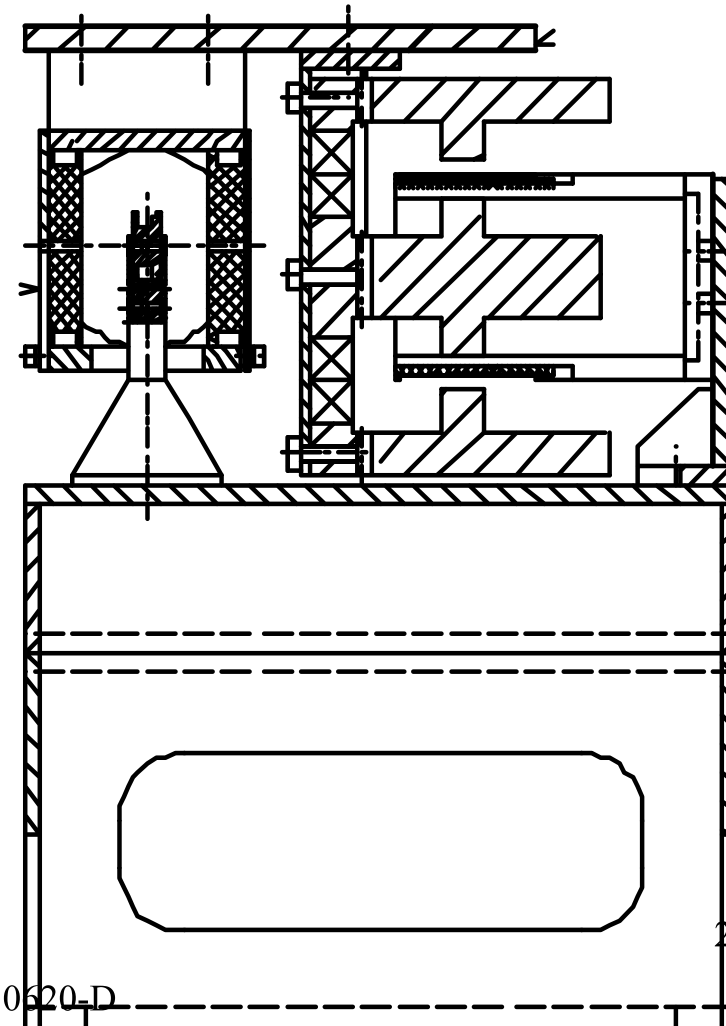

- 80 Db per filter (or better) is possible

overcompensation



# Sensors and coil actuators

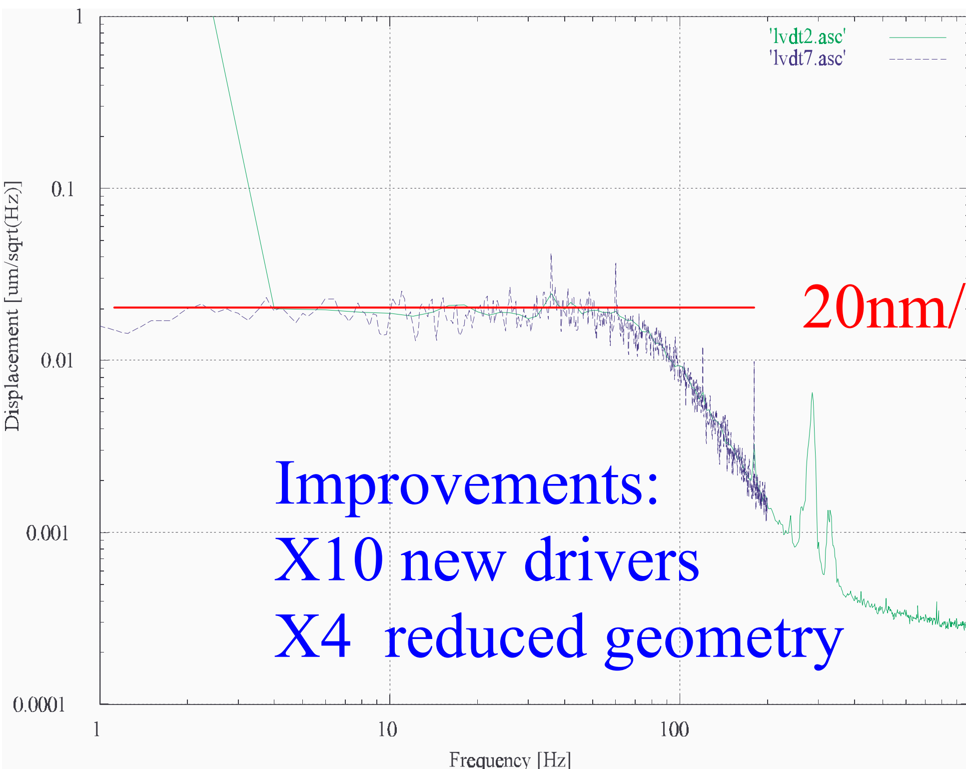
- produced with UHV compatible materials and procedures
  - TAMA resolution (nm/√Hz)



Static and dynamic control elementss

# MICRO POSITIONING AND POINTING

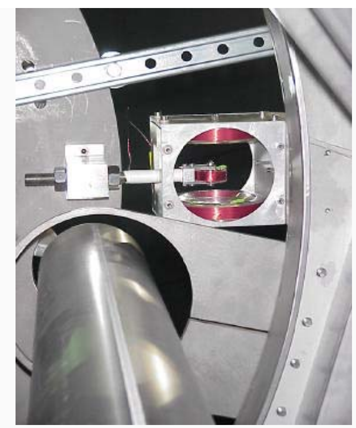
- LVDT for local nanometer positioning memory
- Voice coil actuator dynamic controls
- Position and alignment controls < 30 mHz

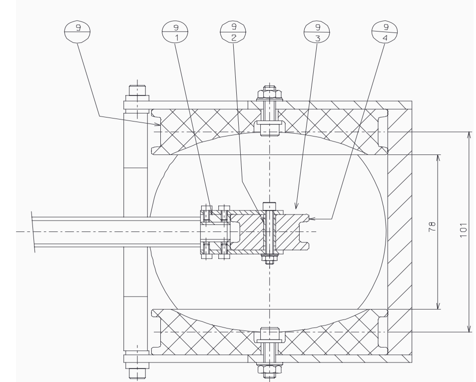



20nm/√Hz

Improvements:
X10 new drivers
X4 reduced geometry

D





- What are we building
- How are we putting it together
- Which tests to perform
- How do we implement it in the HAMs
- How much HAM-SAS costs

# Assembly philosophy

- Clean assembly and factory tuning maximized
  - Minimize expense of LIGO manpower
- Training fabricators to our procedures
- Shipping clean assembly
- Develop clean installation techniques atg factory

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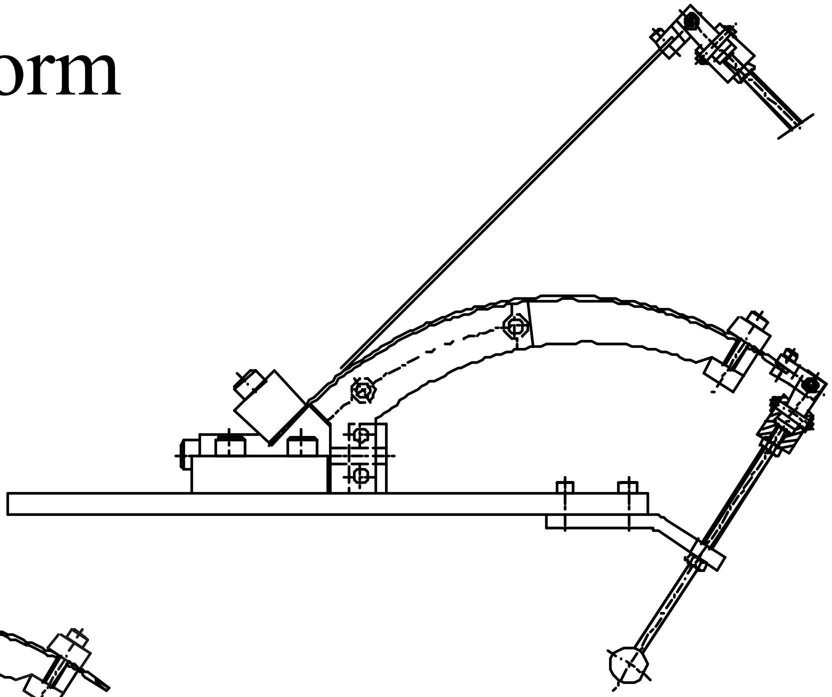
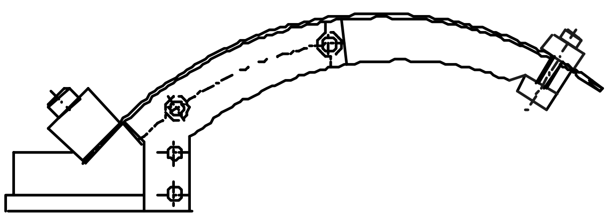
# Examples of safe HAM SAS assembly

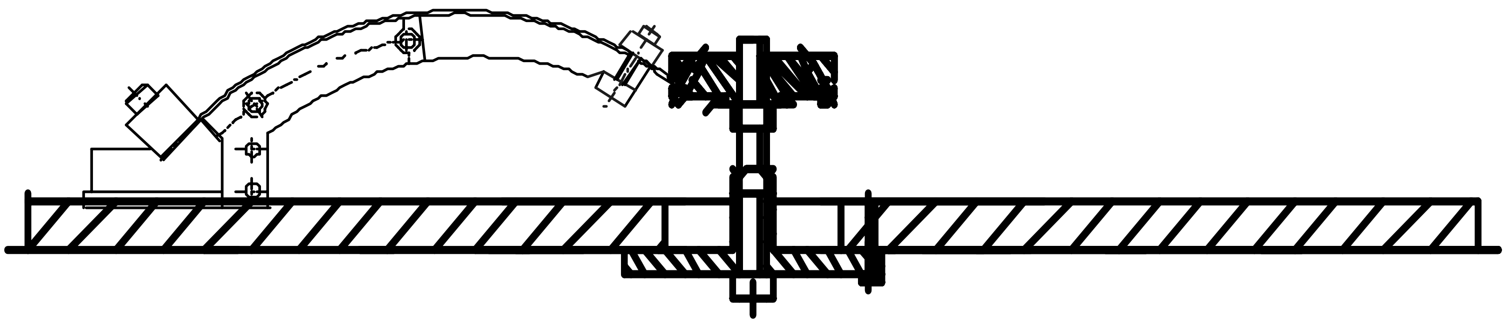
- Pull the blade over a form
- Clamp for transport



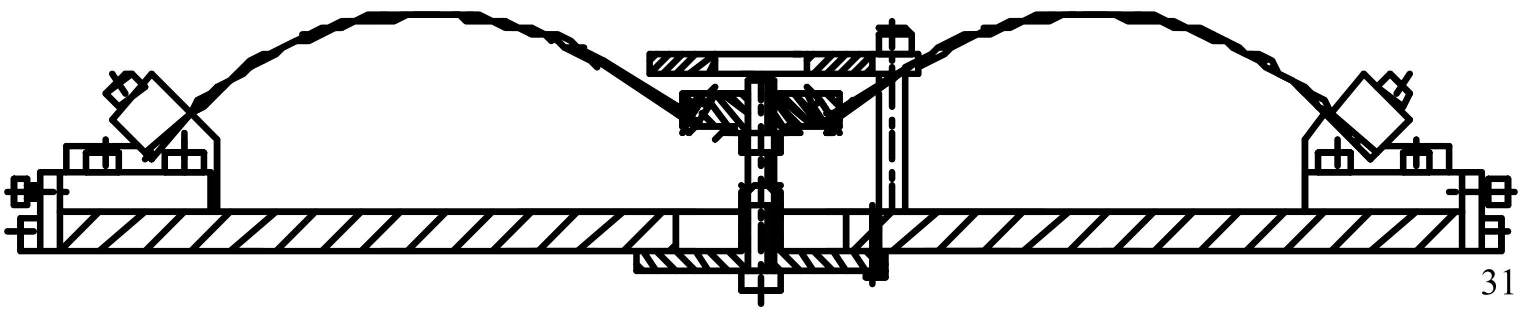


# Examples of safe HAM SAS assembly

- Mount on the base and against the keystone

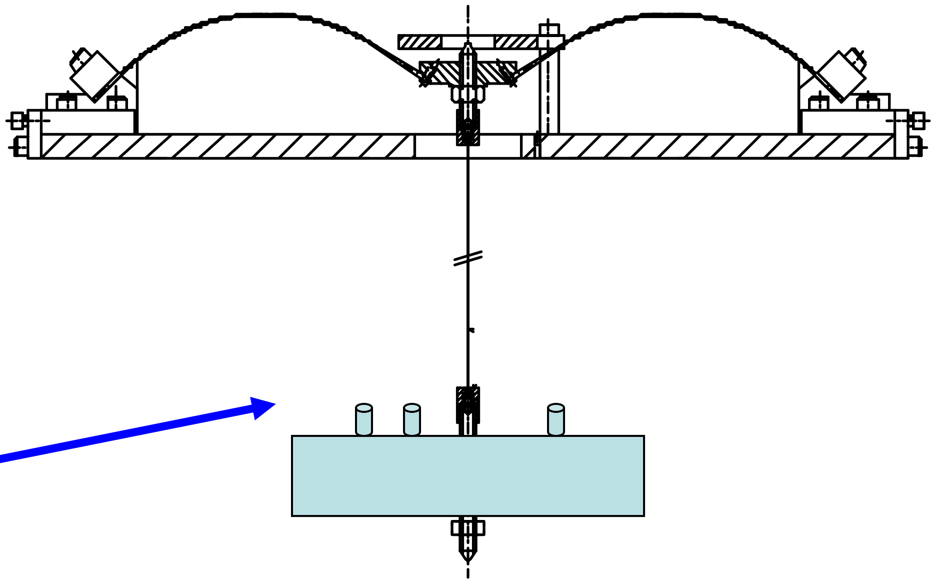


- Transfer the load and tune



# Tuning the GAS filter

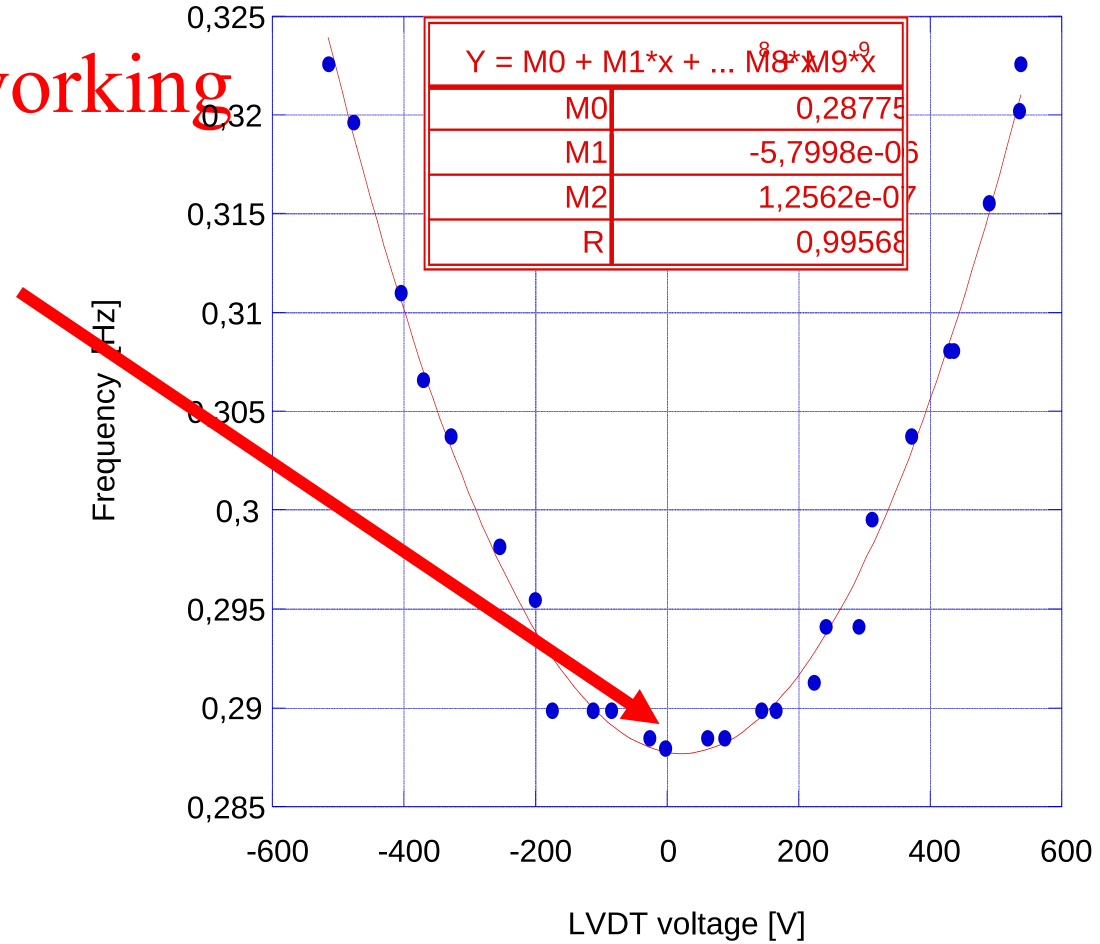
- Use screws for radial compression tuning



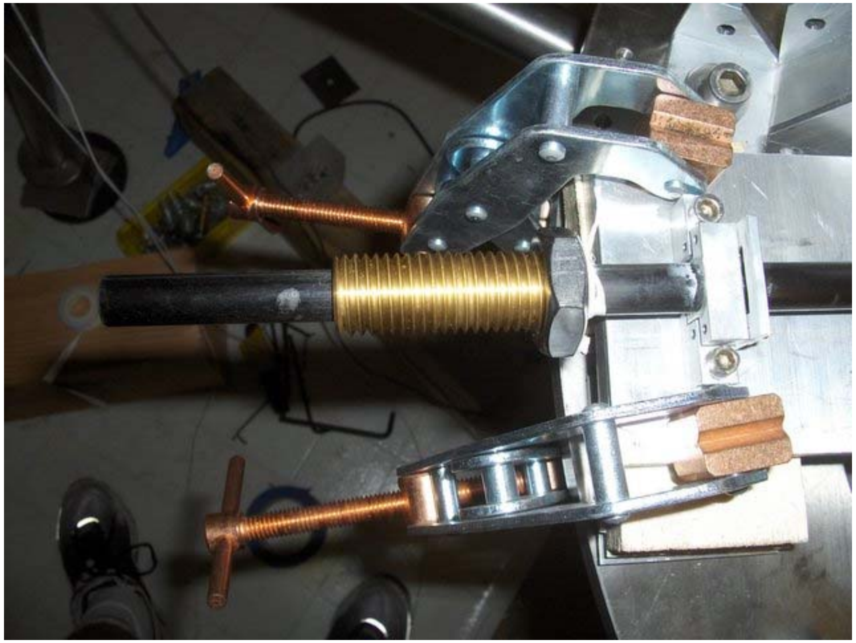
- Add mass to change working point

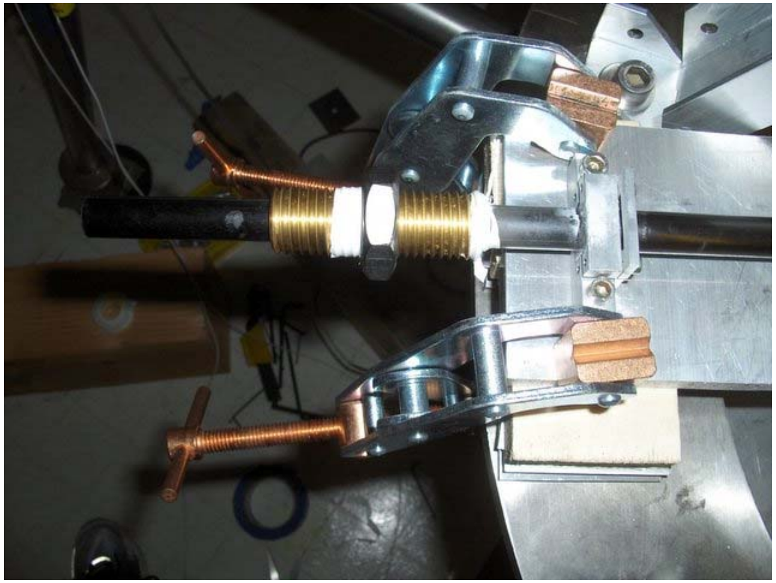
# Resonant frequency vs. load

- Best working point



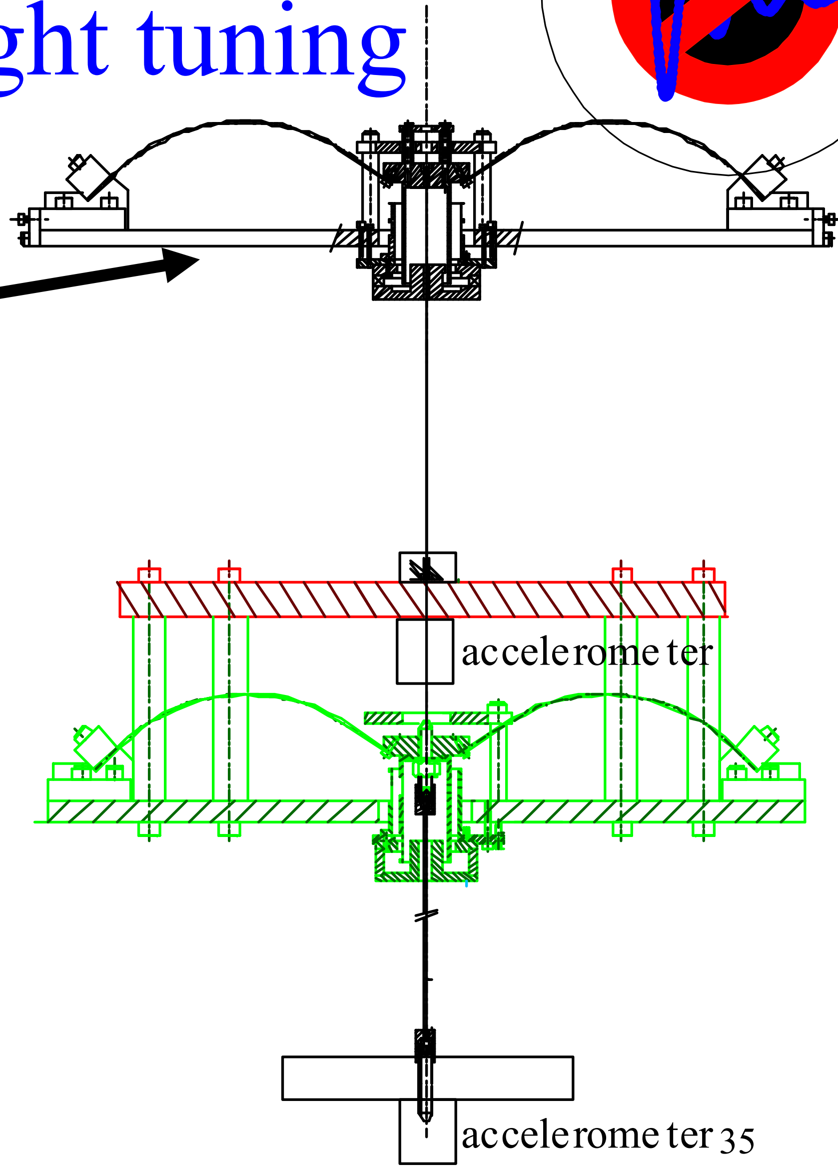
# Tuning of the Counterweight





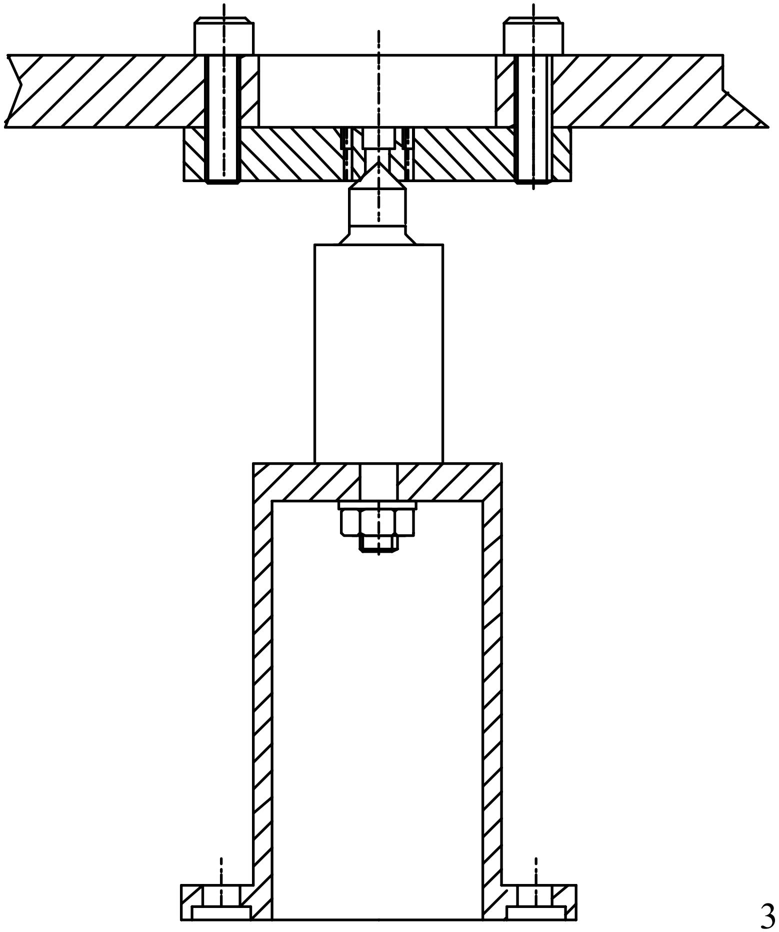
# Counter-Weight tuning

- Use a calibrator larger filter to excite a bench GAS filter
- Measure TF
- Mount and adjust counterweights to minimize the TF



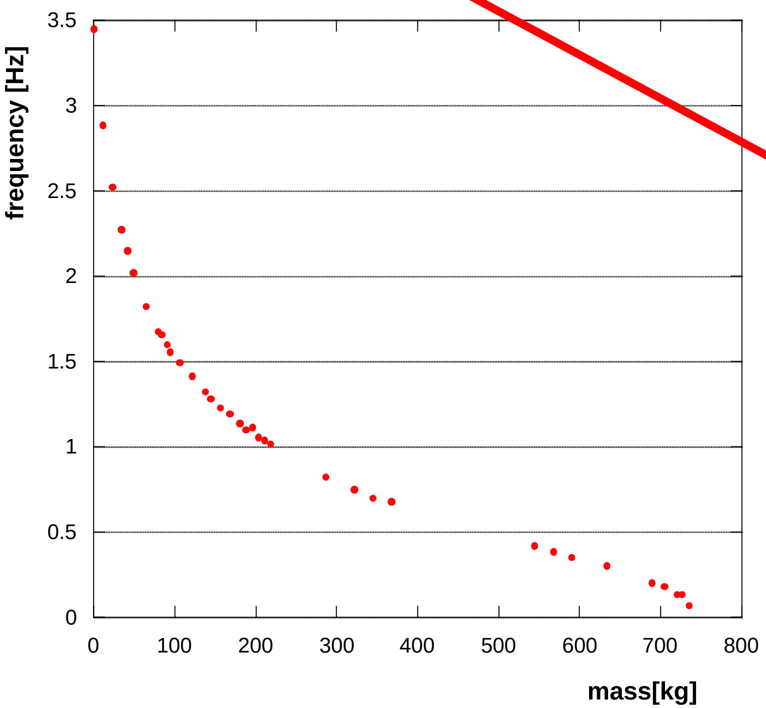
- Special procedure to align IP legs and avoid cradle effects

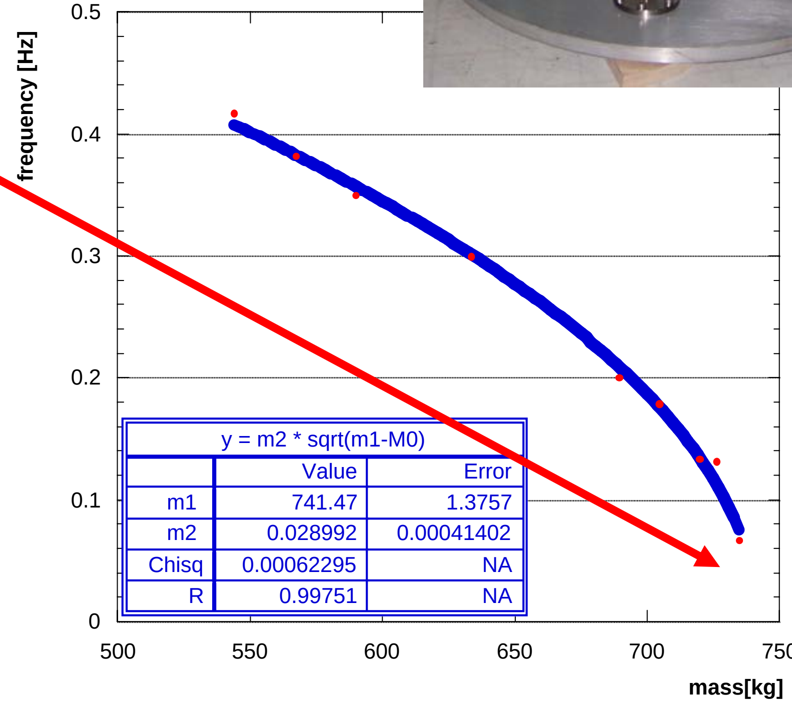
- Legs aligned to <1/4 mm



# IP tuning

< 30 mHz tune achieved with
~ 5 Kg  Tuning steps



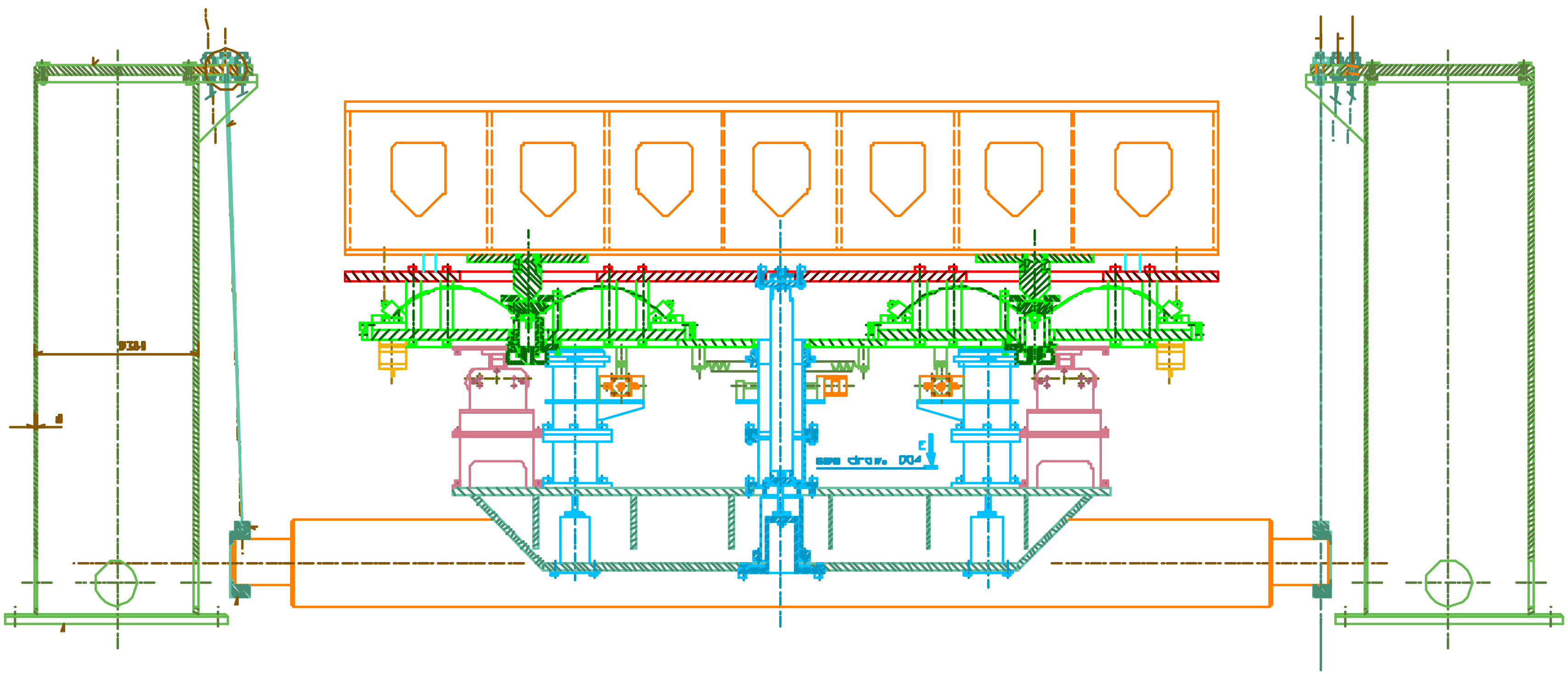



- What are we building
- How are we putting it together
- Which tests to perform
- How do we implement it in the HAMs
- How much HAM-SAS costs

# Factory Characterizing HAM SAS?

- Traditionally characterization of system is done in a scientific lab
- There is no time to move the system to Caltech for characterization and maintain the time-line for the OMC implementation
- We thought of performing the characterization at factory

# Calibrator tools



# Factory Characterizing HAM SAS?

- The calibrations would be performed using devices that allows shaking the entire attenuator and measure its performance
- Separate characterization (and tooling) in the horizontal and vertical direction
- Need to implement some level of controls
- Do the tuning in the dirty stage, then disassemble, clean and assembly

# Factory Characterizing HAM SAS?

- Do we need to make a full characterization or is it sufficient to characterize the HAM SAS performance at LASTI?
- We can (mostly) optimize the system performance with the calibration
- Can we afford to bypass the characterization step?

# Implementing the accelerometers?

- The HAM SAS passive performance will almost certainly be sufficient for OMC
- There is no need for inertial damping because the LIGO optical components are internally damped
- Accelerometers maybe necessary for characterization
- Accelerometers in LASTI allow development of performance boosting active attenuation controls

- What are we building
- How are we putting it together
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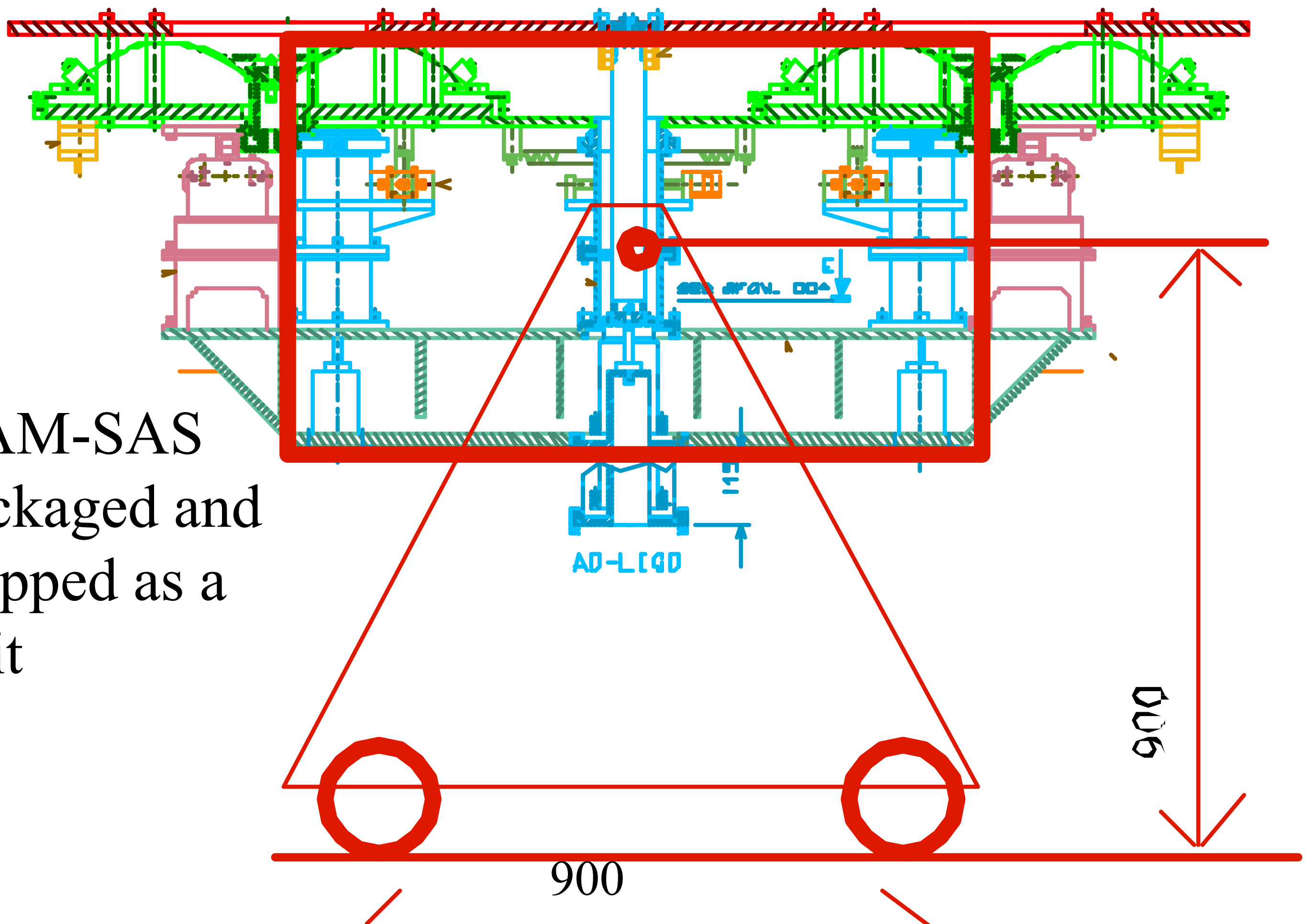
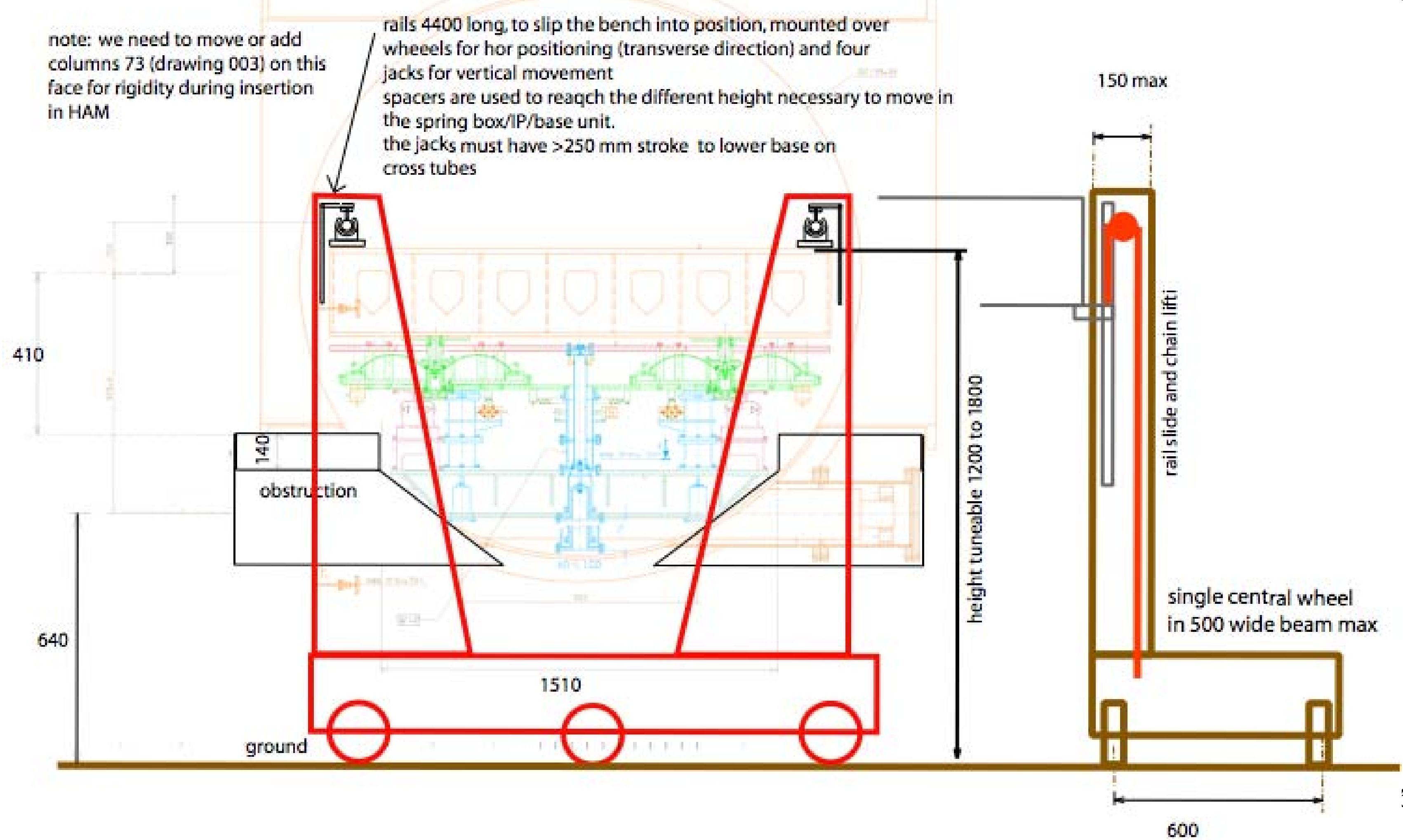
# Moving in at LASTI




HAM-SAS packaged and shipped as a unit

A special cart is used to rotate the assembly and move it from the loading dock to the HAM

# Sliding into the HAM



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Seism Busters

# Sliding into the HAM

- 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

- What are we building
- How are we putting it together
- Which tests to perform
- How do we implement it in the HAMs
- How much HAM-SAS costs

# Construction costs

| | |
|---|---|
| HAM SAS | 128,200 |
| Assembly | 41,100 |
| Cleaning/FTIR | 56,700 |
| Packaging shipment | 11,800 |
| Cleaning room | 20,400 |
| Calibration tools (filter only) | 15,000 |
| Total | 273,200 $ |

# Readout electronics cost

| | | |
|---|---|---|
| • Vacuum motors | 2,040*8$ | 16,300 |
| • Motor drivers | ? 5,000$? | 5,000 |
| • LVDT driver | 3*1,250 Eur | 4,500 |
| • Coil driver | 4*1,300 Eur | 6,200 |
| • UHV cables feed-through | | 13,500 |
| • NIM crates 2 (available?) | | |
| • Total readout electronics | | 45,500 $ |

# LASTI Installation carts costs

| | |
|---|---|
| • Lift-transfer cart | ?20,000? $ |
| • HAM-SAS cart | ?2,500? $ |
| • Optical bench cart | ?2,500? $ |
| • Total | ?25,000? $ |

Internal cost estimations

# Characterization costs

| | |
|---|---|
| • Bench and tube | 59,000 |
| • Ballast bench | 3,700 |
| • Characterization tools (complement to calibration costs) | 30,100 |
| • Total | 92,800 $ |

- Item 1 and 2 necessary and recycled in subsequent OMC HAM SAS

# Accelerometer cost

- Accelerometer 4*4,350 Eur 20,900
- Acceler. Driver 2*3,200 Eur 6,400
- Total accelerometers 27,300 $

# Additionals

- GAS balances 8*690 $ 5,500
- Eddy current Dampers
  (if necessary) 4*2,650 $ 10,600
- Total additionals 16,100 $

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# Costs summary (#)

| | | |
|---|---|---|
| • Construction, cleaning, ass.y | 273,200 $ | 273,200 |
| • Readout electronics | 45,500 $ | 318,700 |
| • Installation carts | ?25,000?$ | 343,700 |
| • GAS balance | 5,500 $ | 349,200 |
| • Accelerometers (+) | 27,300 $ | 376,500 |
| • Dampers (x) | 10,600 $ | 387,100 |
| • Characterization (*) | 92,800 $ | 479,900 |

* 63,000$ of which is for 1 set of bench and tubes for OMC

\# N.B.: Does not include travel costs for personnel to help with installation, commissioning and test of the HAM-SAS

\+ witness sensors and/or associated data channel costs may have to be added if the accelerometers are not implemented

x If needed