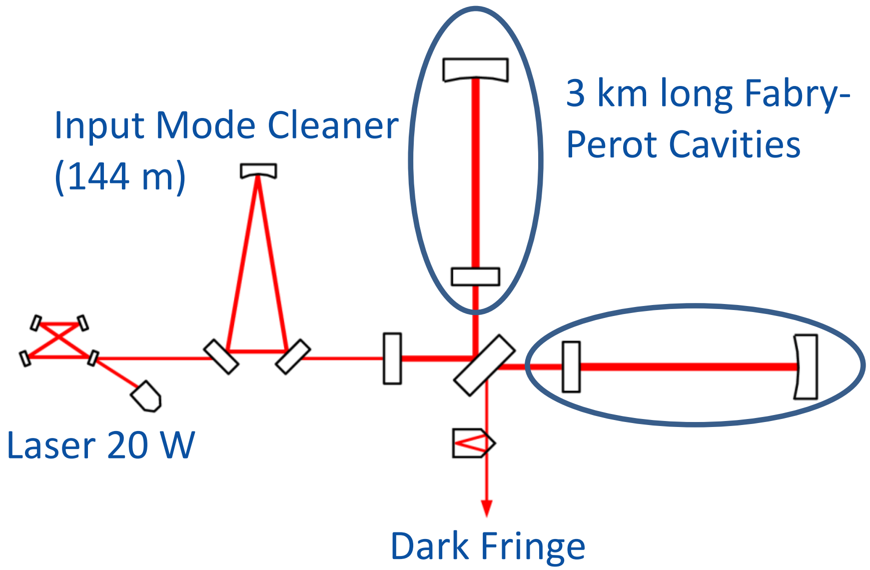
External Injection Bench Seismic Attenuation System of the Advanced Virgo gravitational wave detector

Mathieu Blom, on behalf of the Virgo collaboration

12th Pisa Meeting on Advanced Detectors,
La Biodola, Isola d'Elba, 25th of May 2012

The Virgo gravitational wave detector

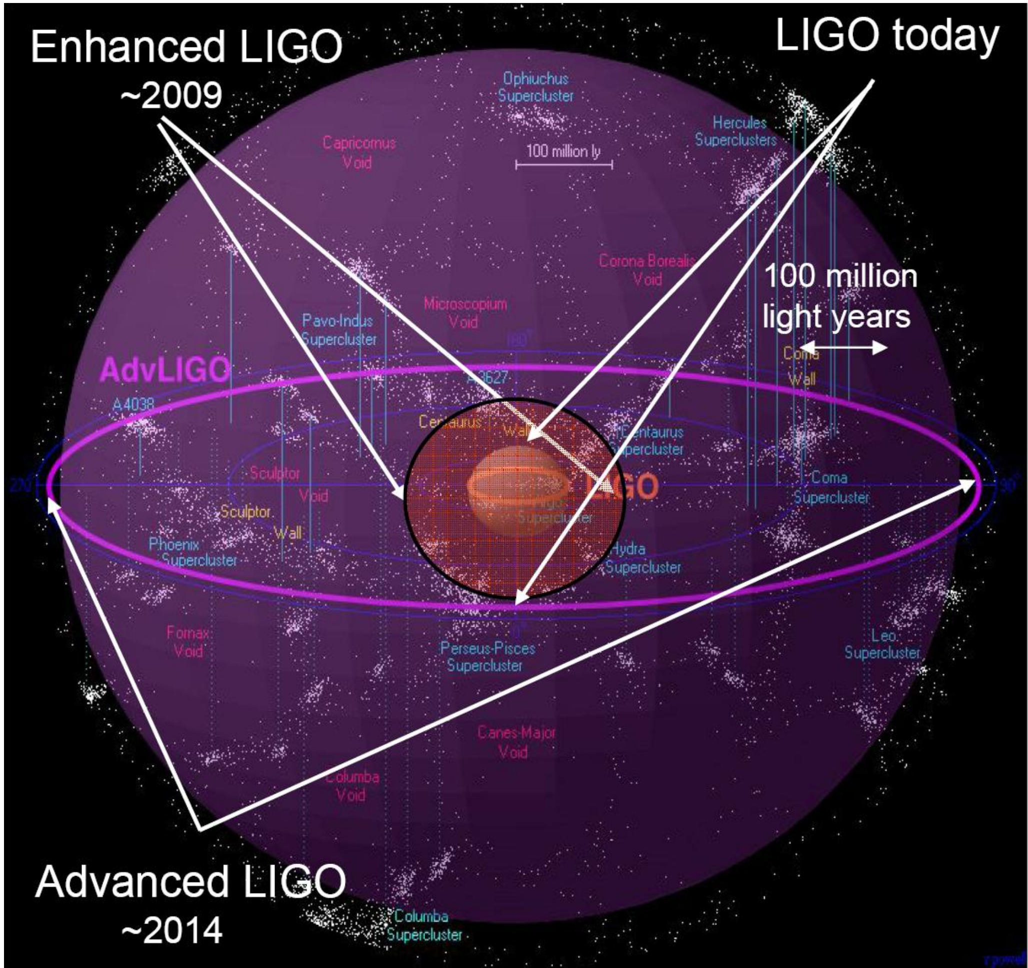


A world-wide network of gravitational wave detectors

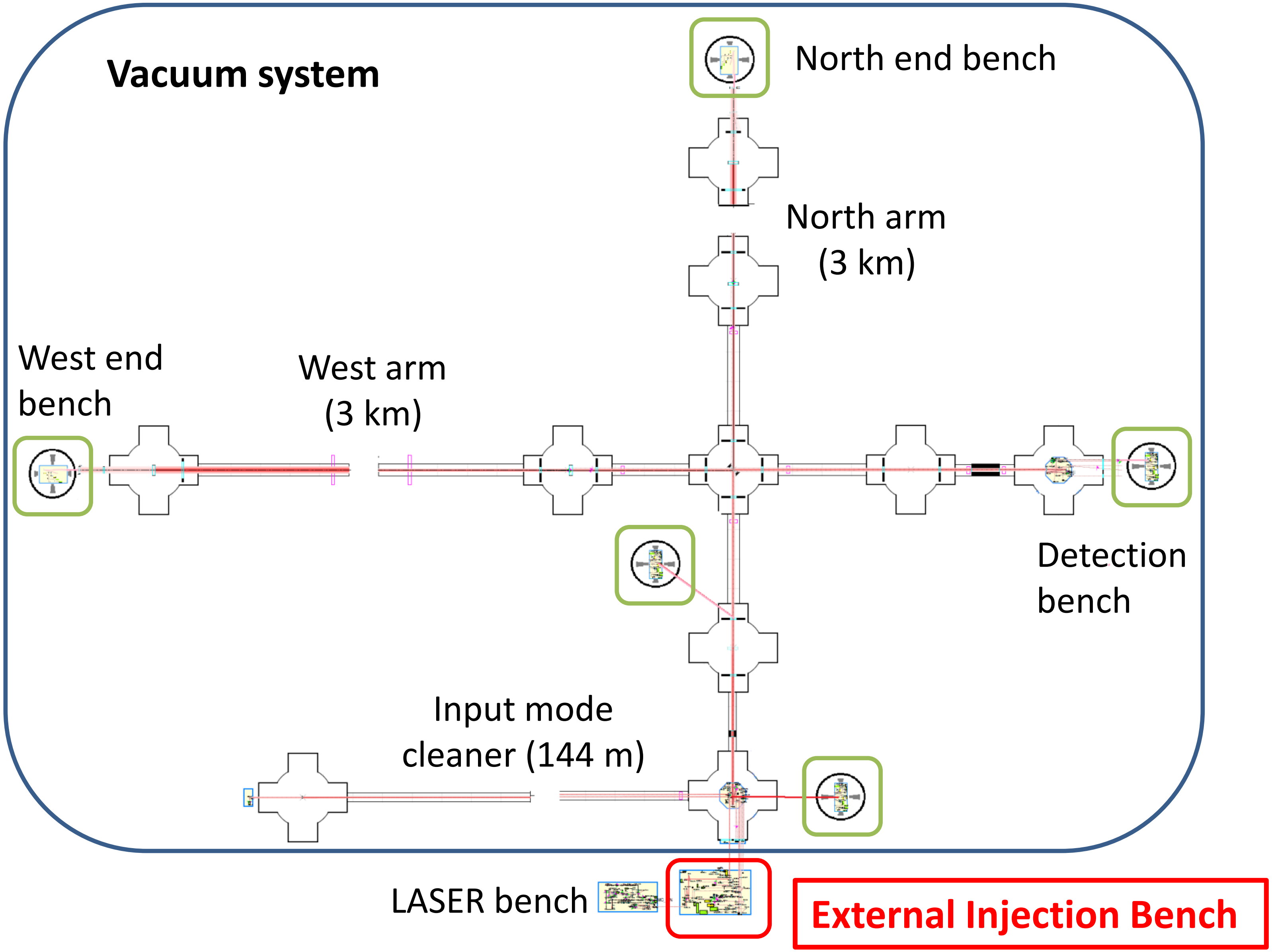
2nd generation: Advanced Virgo

- Upgrades **of LIGO (USA) and Virgo (Italy)** are being carried out
- Advanced Virgo:
  - Improved sensitivity/horizon by factor 10
  - and **event rate by 10^3**
  - 1 event per day – week expected

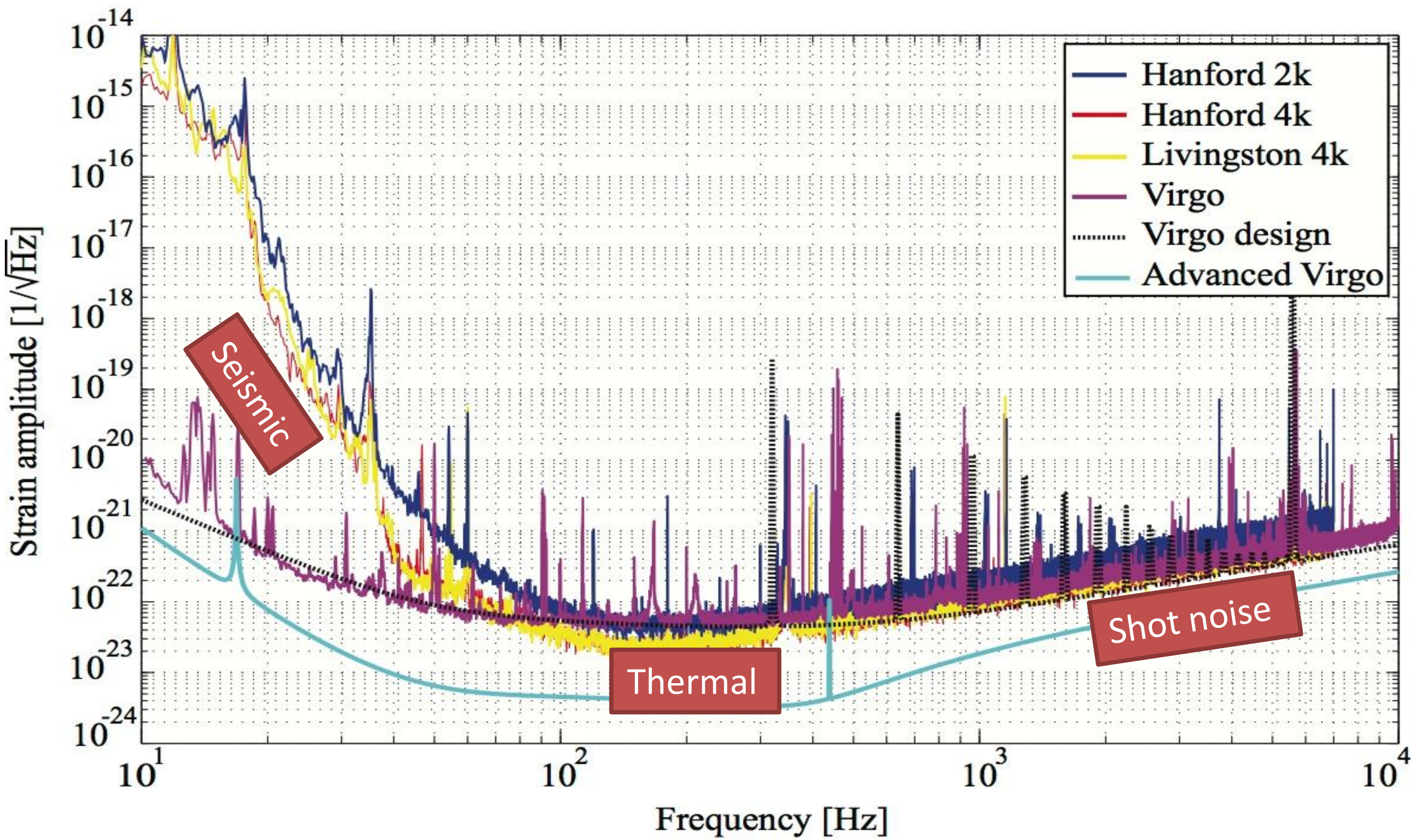
Start of gravitational astrophysics!



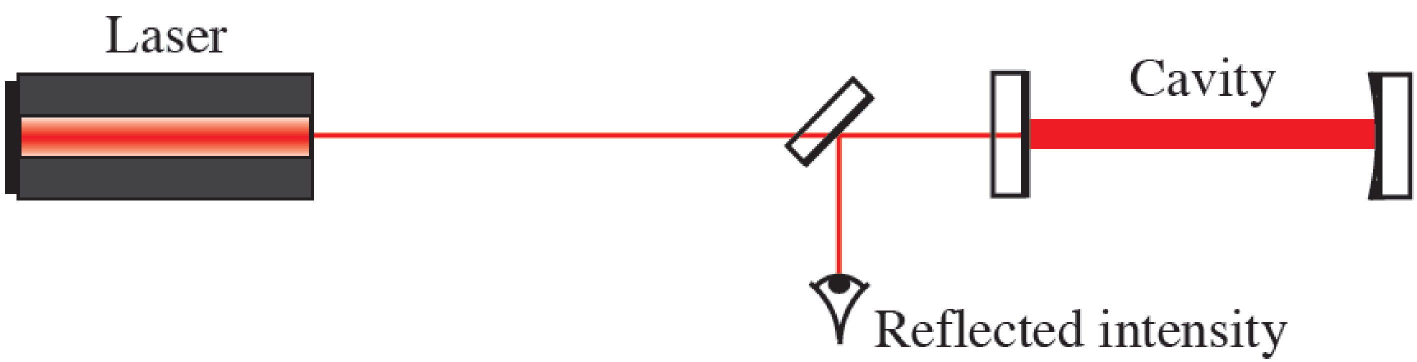
Advanced Virgo optical layout

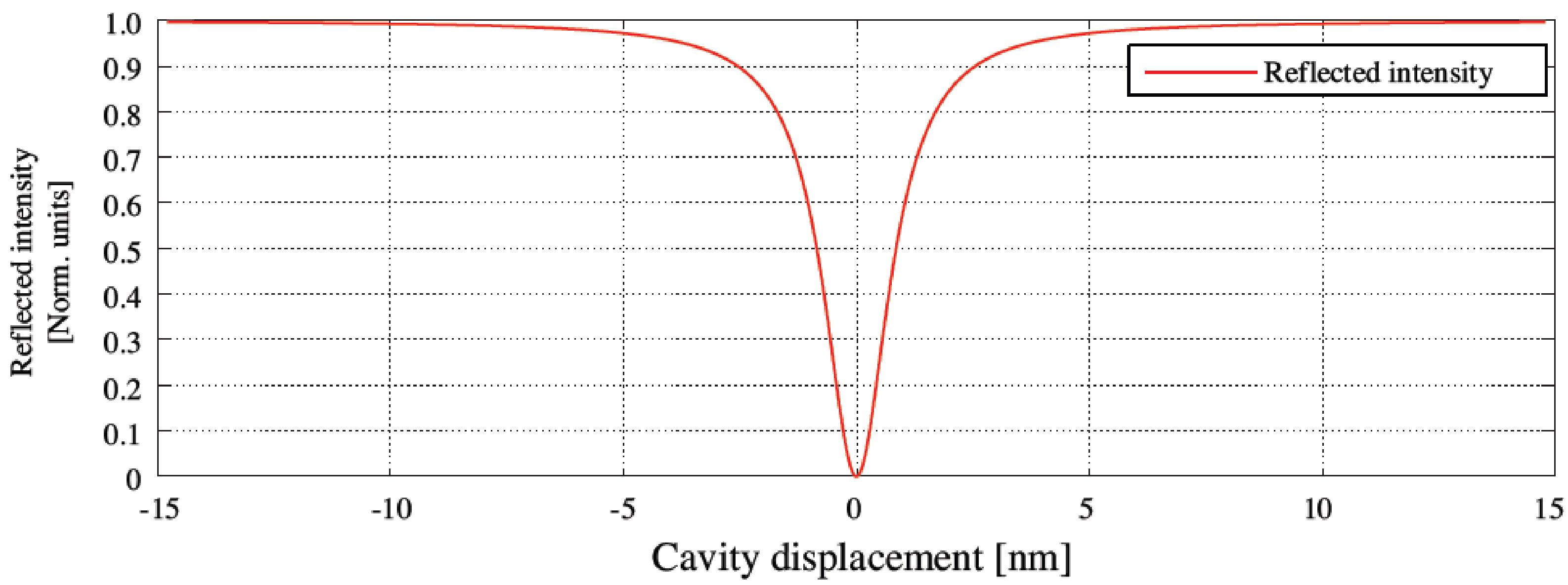


Detector sensitivity given in strain: *ΔL/L*

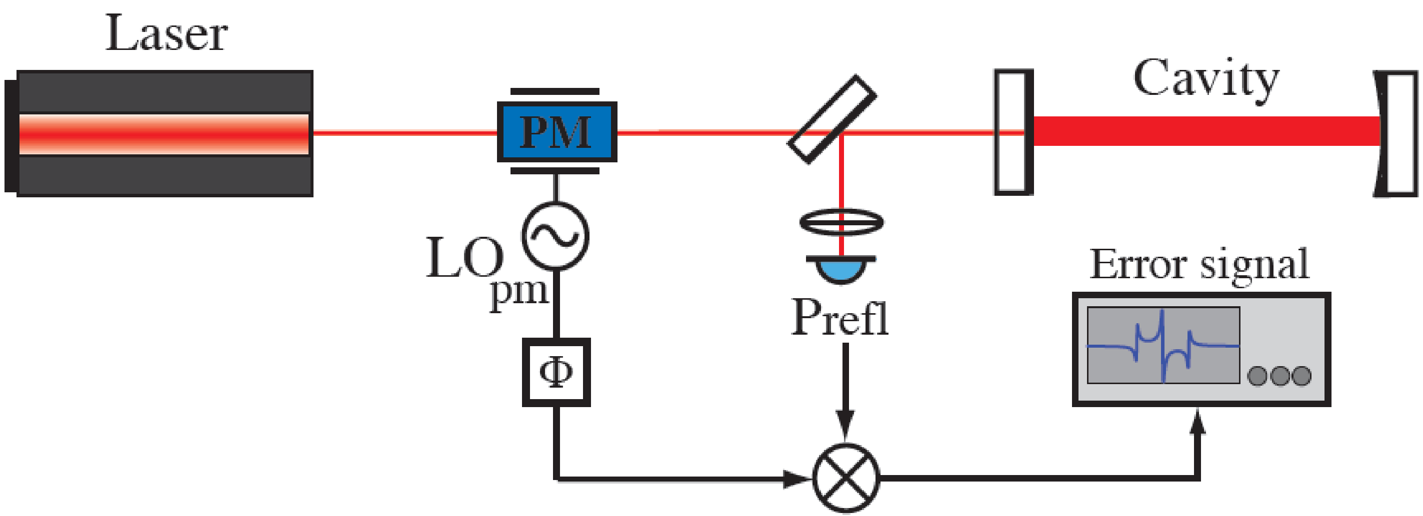


Controlling the cavity length

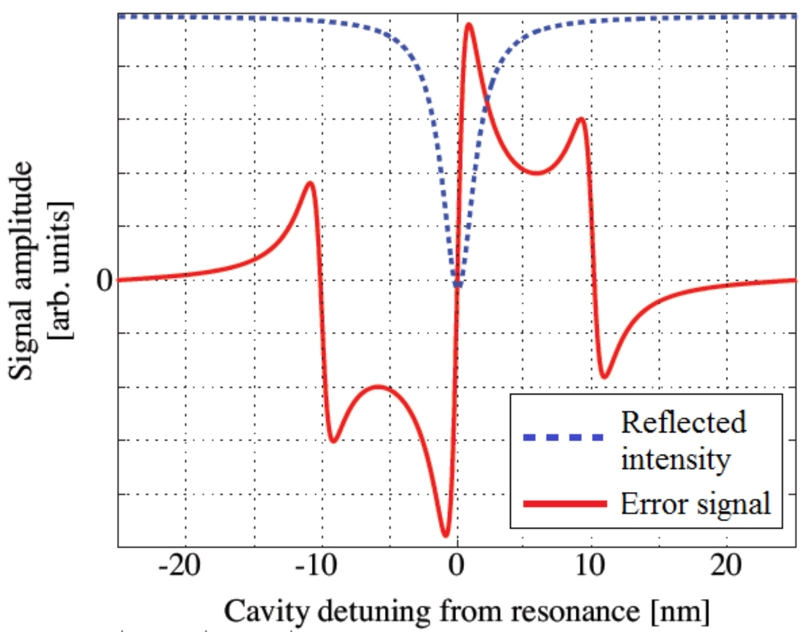




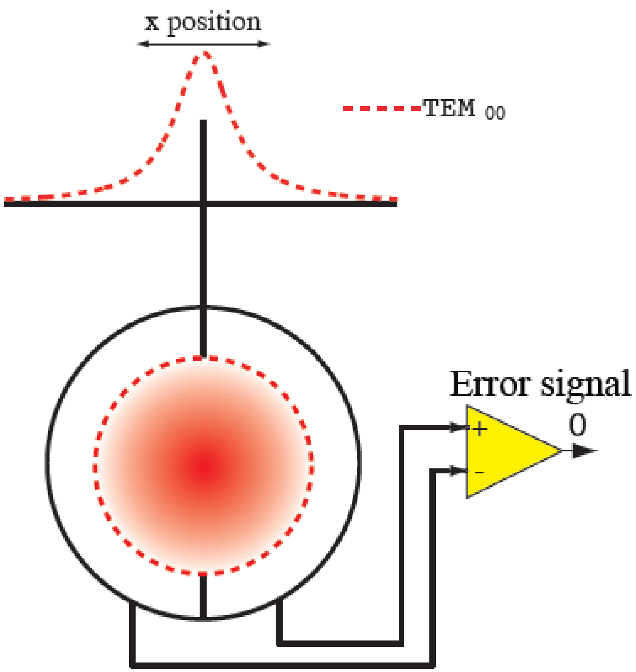
Length sensing with Pound-Drever-Hall signal



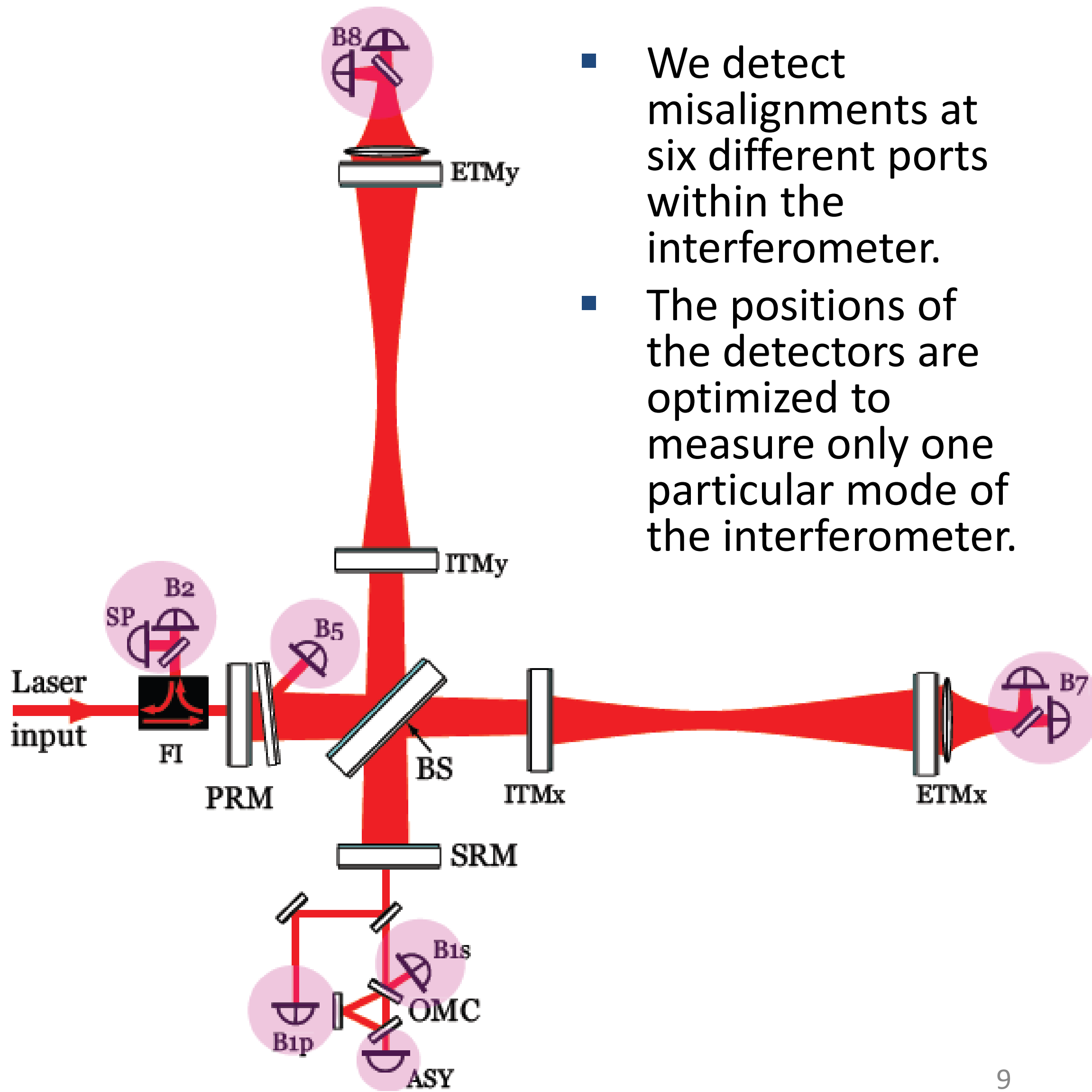
- Inject some laser light modulated at a frequency Ω and modulation amplitude Γ
- Take reflected beam of cavity
- The detected photo-current is then multiplied (mixed) with the original modulation signal to recover the PDH error signal:
- This signal is highly sensitive and proportional to deviation from resonance!



The detection of interferometer misalignments

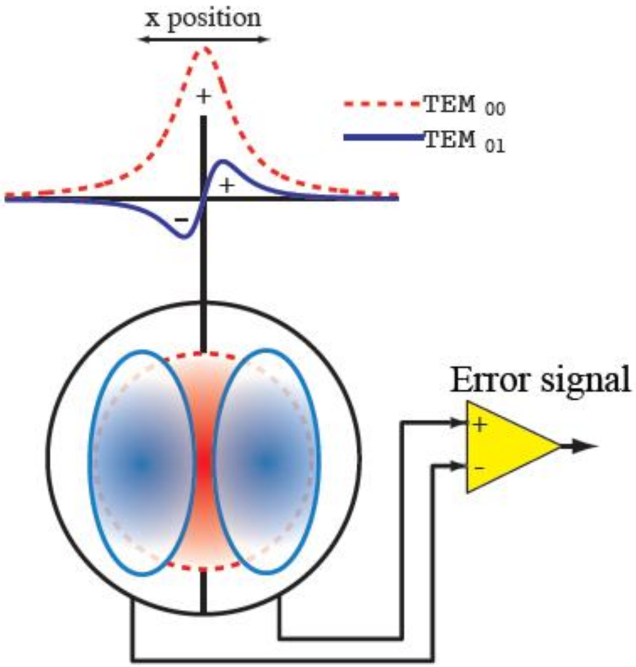


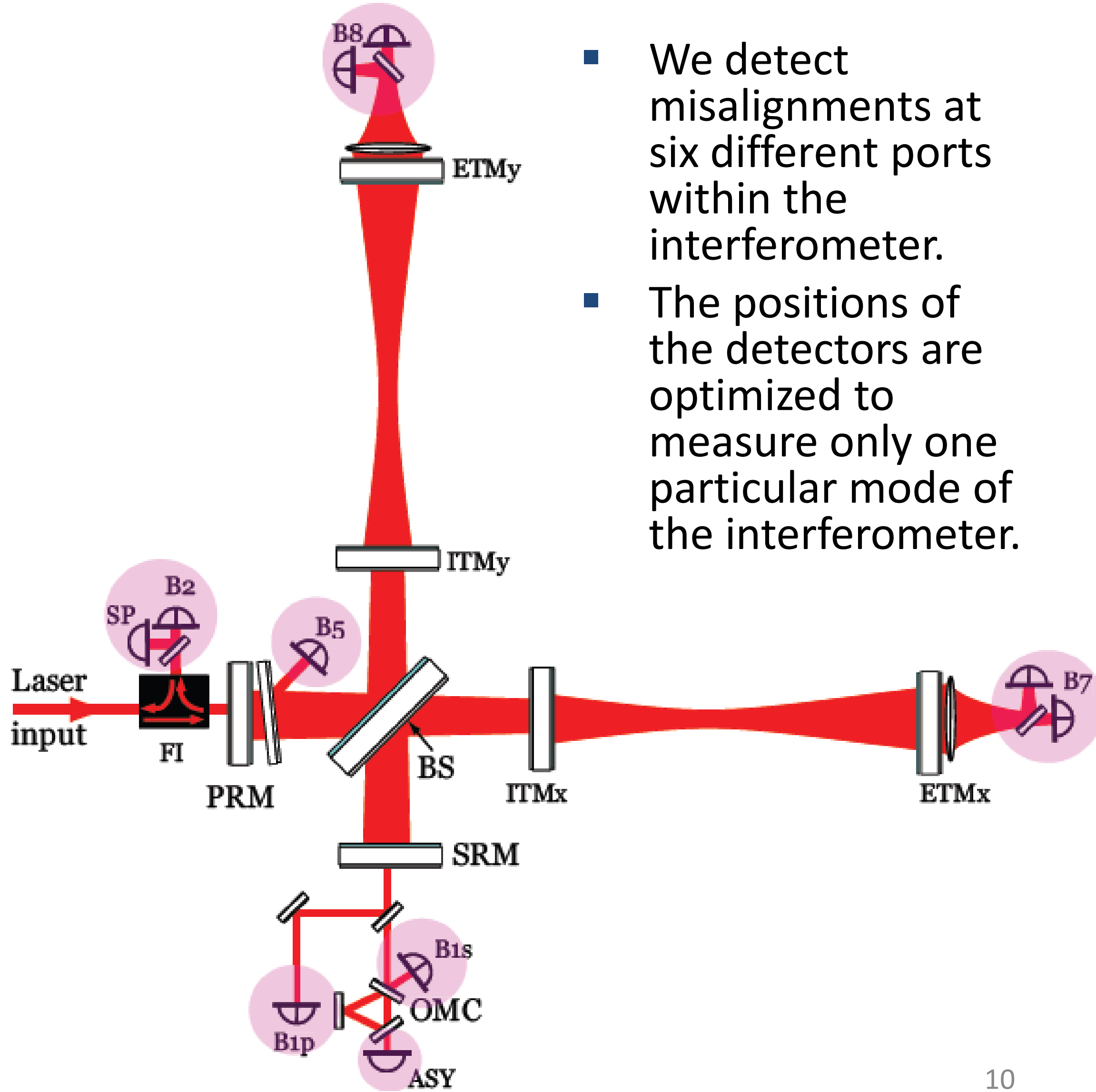
Use split-quadrant photodiodes to obtain the spatial equivalent PDH sensing signals



- We detect misalignments at six different ports within the interferometer.
- The positions of the detectors are optimized to measure only one particular mode of the interferometer.

The detection of interferometer misalignments

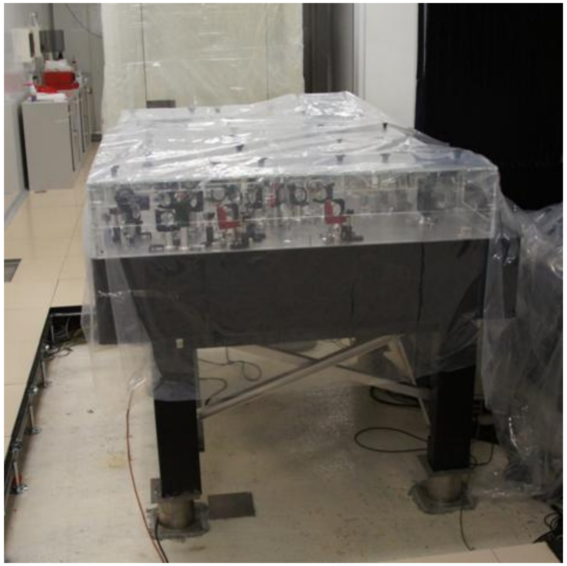


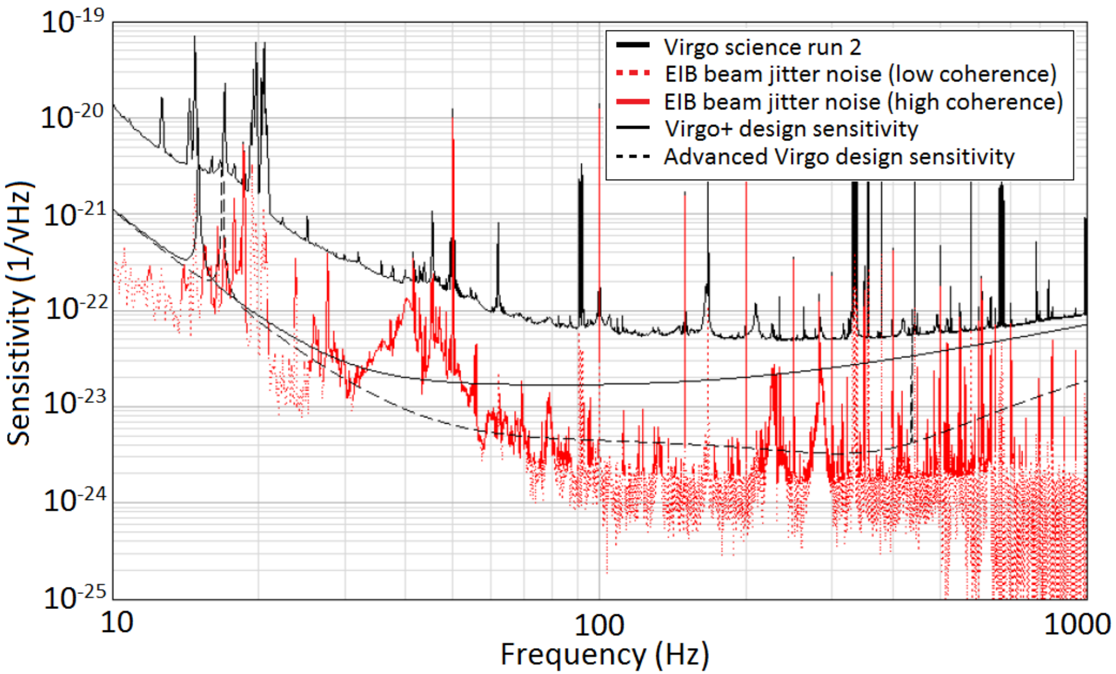


- We detect misalignments at six different ports within the interferometer.
- The positions of the detectors are optimized to measure only one particular mode of the interferometer.

Use split-quadrant photodiodes to obtain the spatial equivalent PDH sensing signals

External Injection Bench – beam jitter

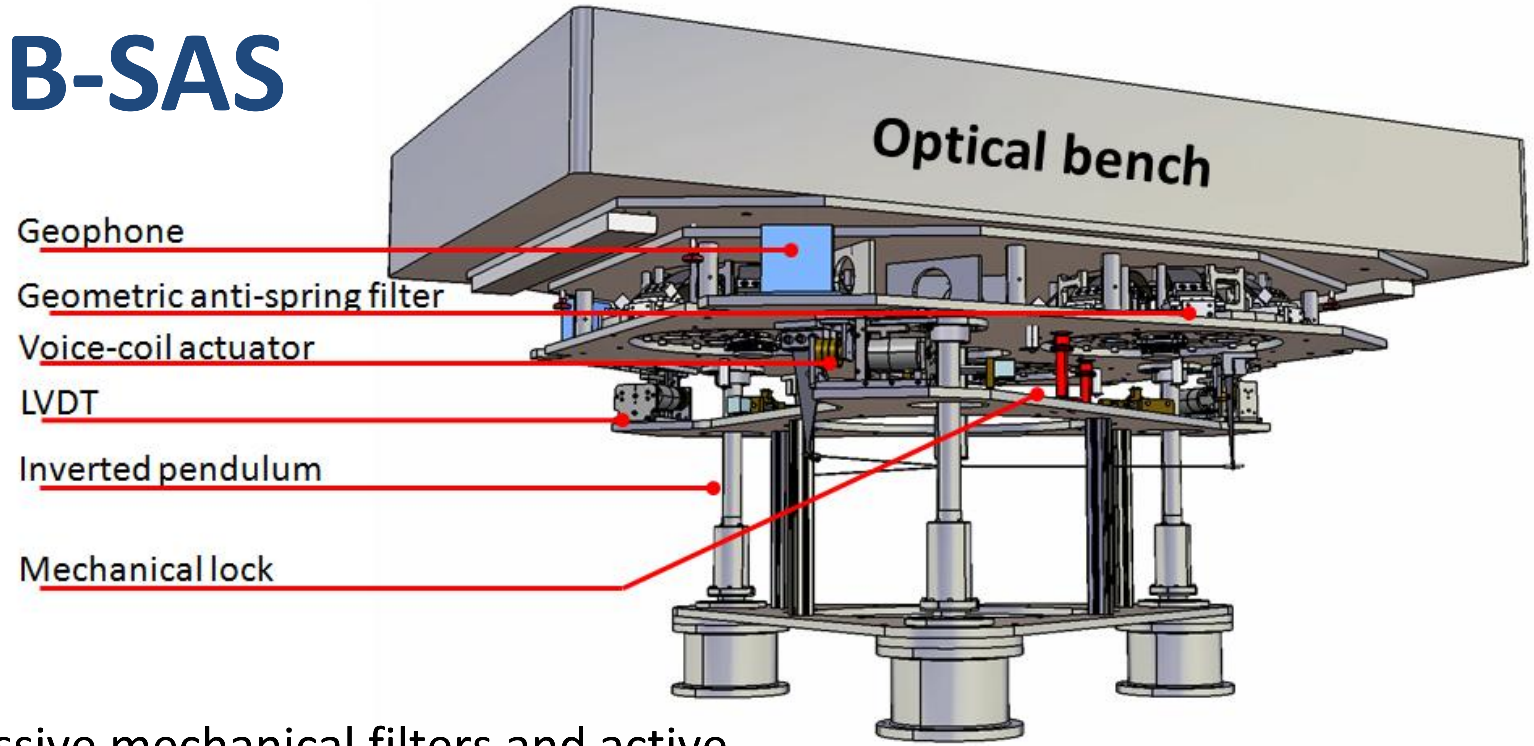




- External Injection Bench moves due to seismic ground motion
- Produces beam jitter noise @
  - ~20 Hz
  - 30 – 60 Hz (legs)
  - 200 – 300 Hz (optical mounts)
- Must be minimized for AdV

Need better seismic isolation of external injection bench

EIB-SAS



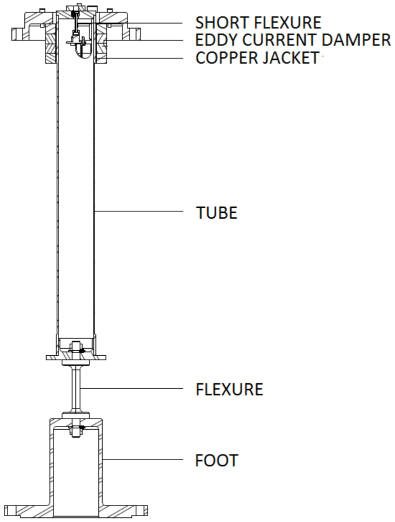
- Passive mechanical filters and active feedback to attenuate horizontal and vertical motion
  - 3 Geometric anti-spring (GAS) filters
  - 3 Inverted Pendulum (IP) legs
  - Real-time digital control system
    - 800 kHz 18 bit ADCs
    - 6 x LVDTs (displacement sensor)
    - 6 x geophones (motion sensor)
    - 6 x voice coil actuator

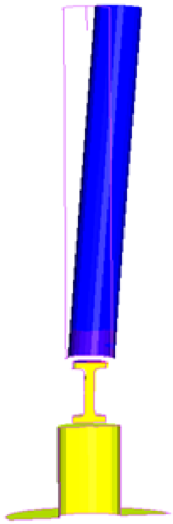
Inverted pendulum

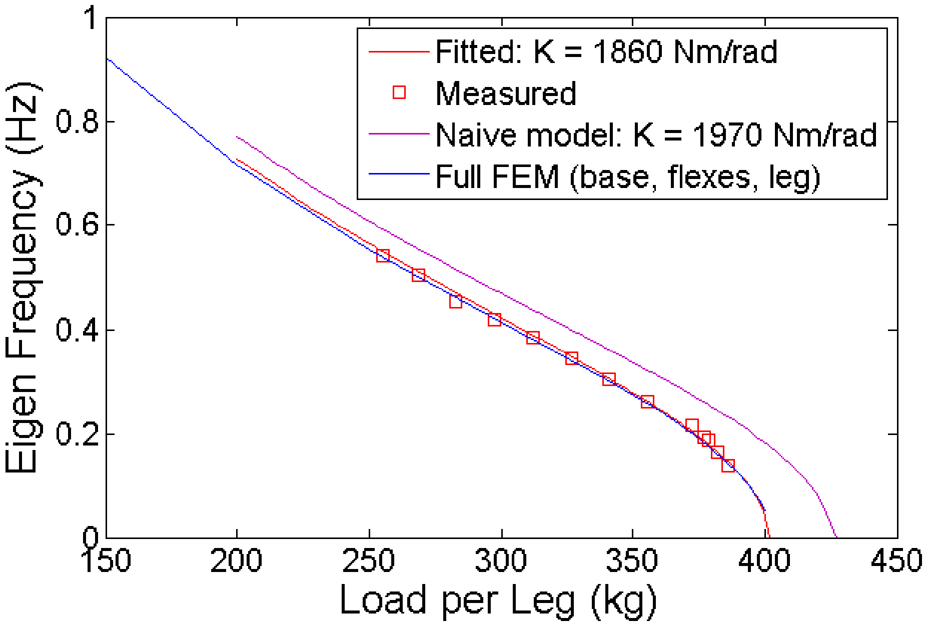
- Pendulum is 2^{nd} order low pass filter
- Transfer function:
    - = 1 @ below resonance frequency
    - > 1 @ resonance frequency
    - ~ $1/f^2$ above resonance frequency
- Inverted pendulum can be tuned to low frequencies (< 1 Hz) and still be compact (~ 1m)
- Gravity acts as anti-spring:

$$\omega_0 = \sqrt{\frac{g}{l}} \rightarrow \sqrt{\frac{k}{M} - \frac{g}{l}}$$

- Tuning done by adjusting the supported mass
    - for EIB-SAS f_0 = ~200 mHz







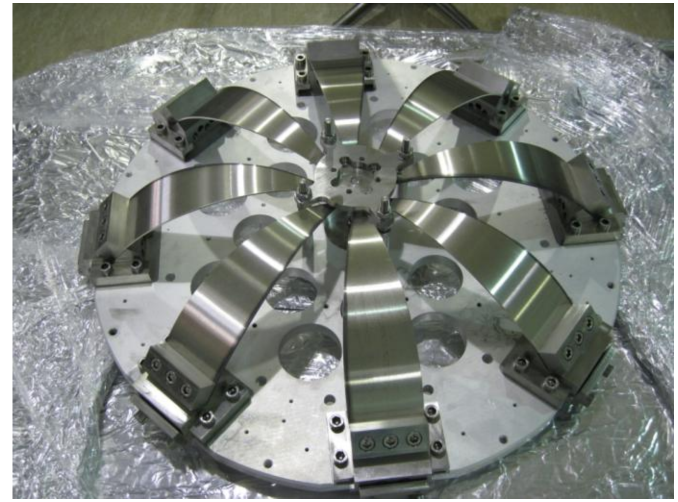
Geometric Anti-Spring filter

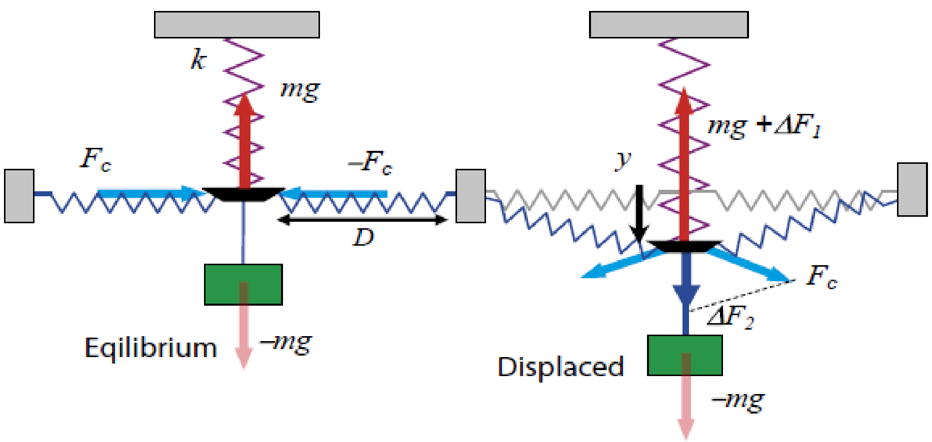
- 8 maraging steel (hard, no creep) blades in pairs
- Opposite blades push against each other:
  - High pressure in radial direction
  - Compound vertical spring low stiffness in equilibrium position

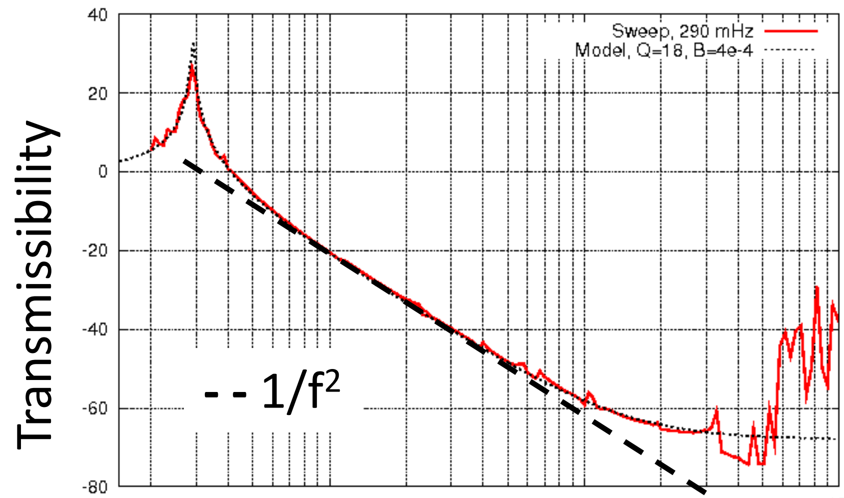
    ⟶ supports ∼320 kg

⟶ low eigenfrequency: ∼400 mHz

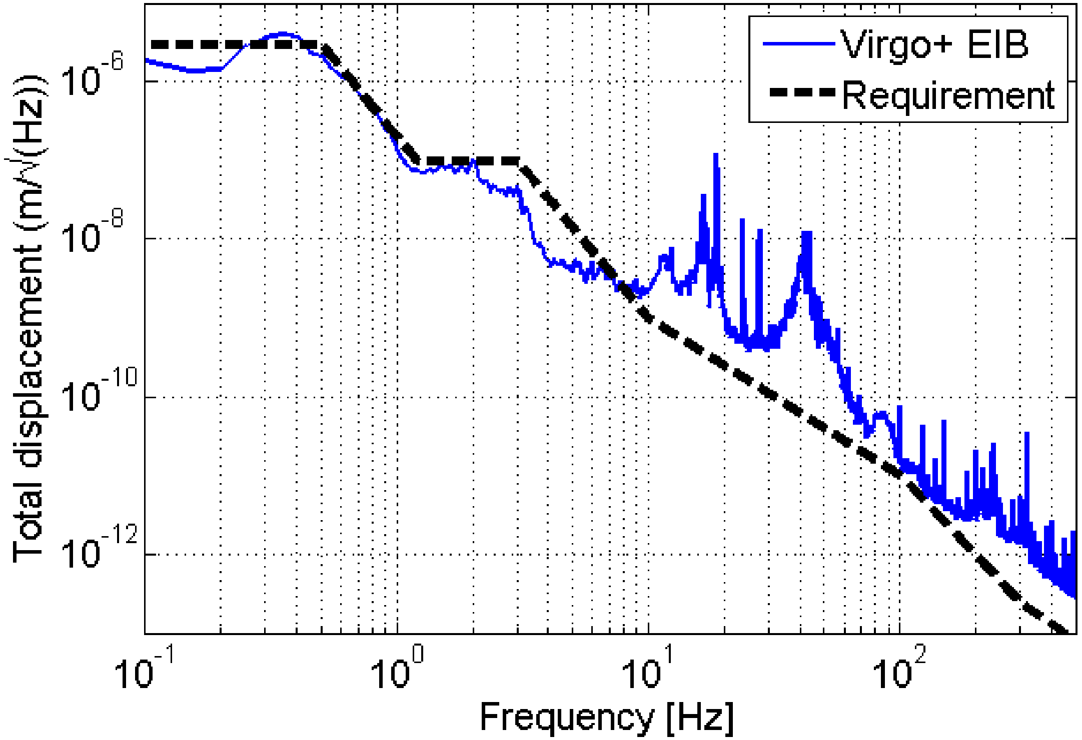
⟶ strong filtering > 10 Hz





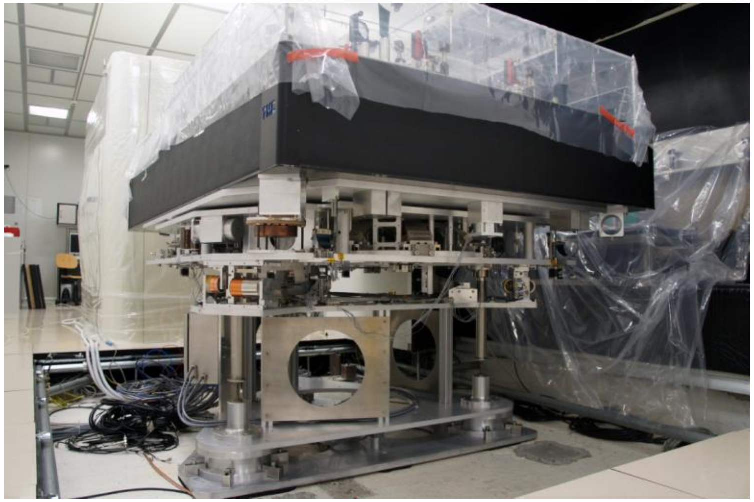


Requirements



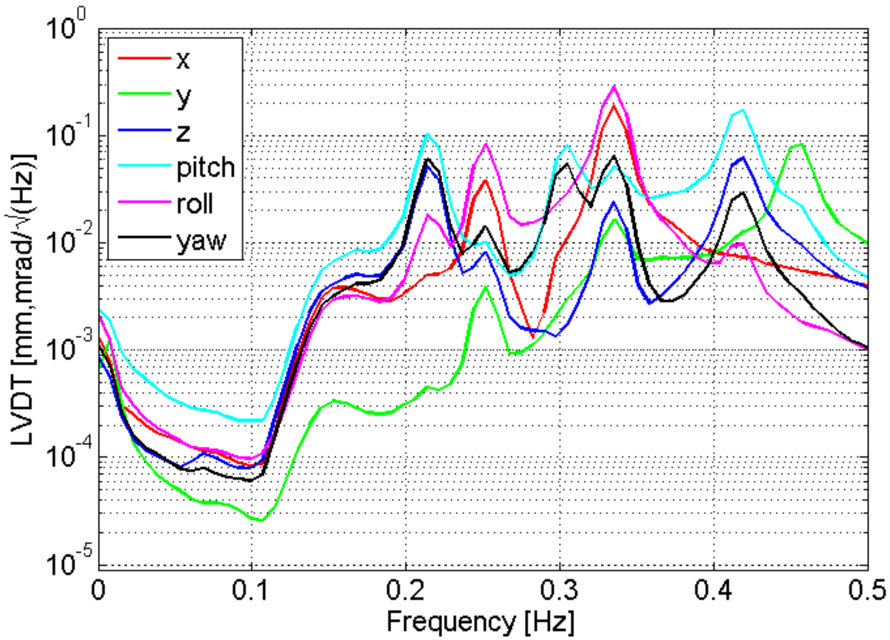
- Comply with seismic attenuation request
- long-term stability and DC control
  - 1 week
  - $x_{ref} \pm 20$ μm
  - $\theta_{ref} \pm 10$ μrad
- Stable w.r.t. temperature variations of $\pm$ 1 °C
- Characterize mechanical modes

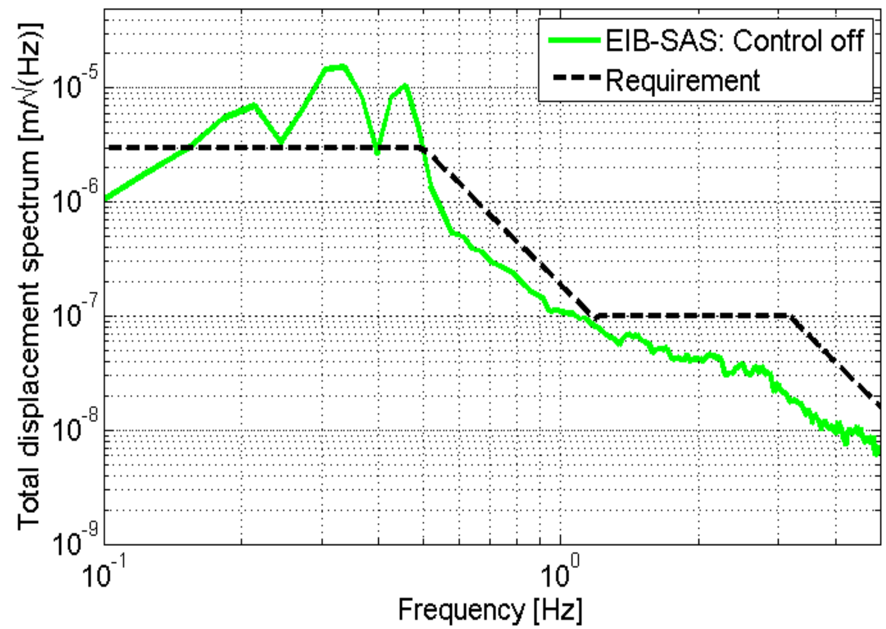
EIB-SAS Installed in February 2012



First major installation for Advanced Virgo

Low frequency resonances





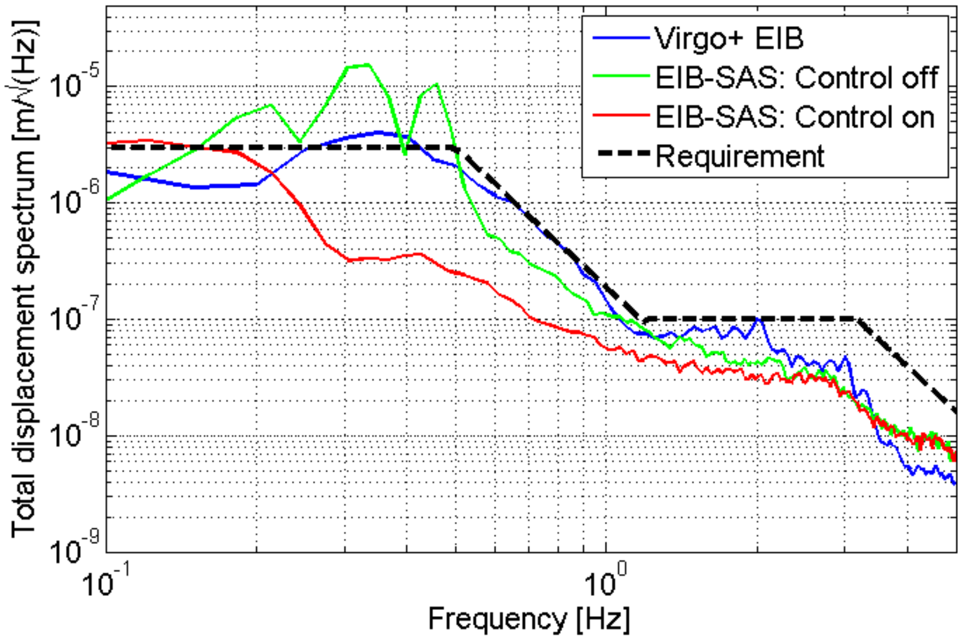
- f_0 GAS filters 390 mHz
- f_0 IP legs 200 mHz
- $200 < f_0 < 500$ mHz for all 6 d.o.f.

Need active feedback to meet requirements < 1 Hz

Controls: low frequency resonances

Use a mix of LVDT and geophone signals (blending) for the control of the d.o.f. along the optical coordinates:

$$signal = lvdt \times \frac{s_0^{\ 5} + 5s_0^4 s + 10 s_0^3 s^2}{(s+s_0)^5} + geophone \times \frac{s^4 + 5s_0 s^3 + 10 s_0^2 s^2}{(s+s_0)^5}$$

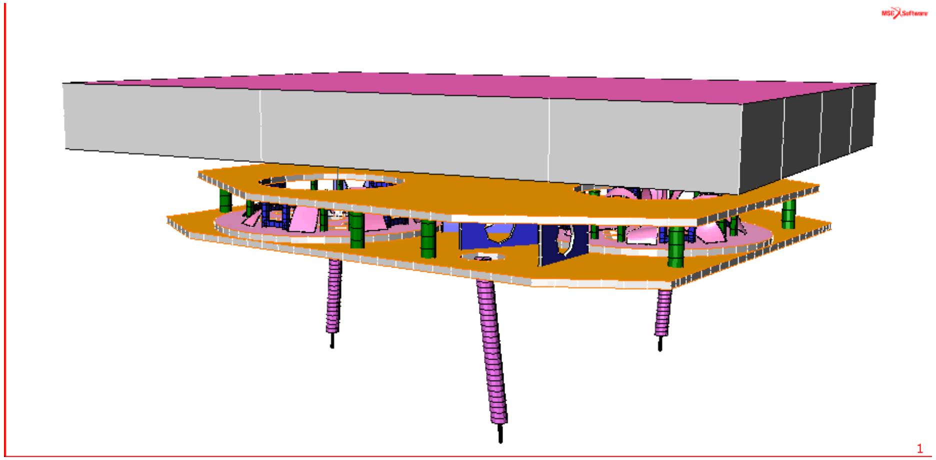


Low frequency resonances damped;

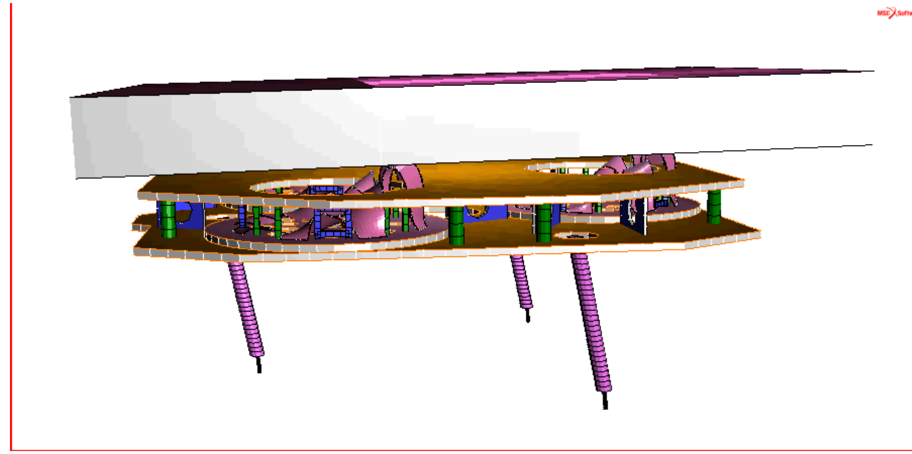
controls perform within requirements

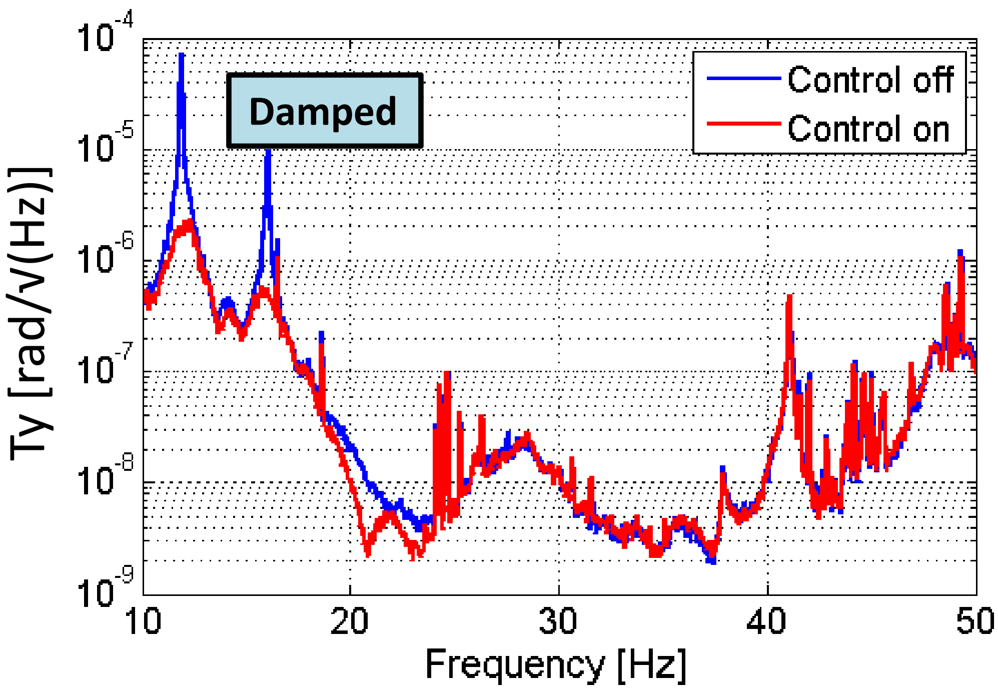
Controls: mechanical modes < 20 Hz

12 Hz

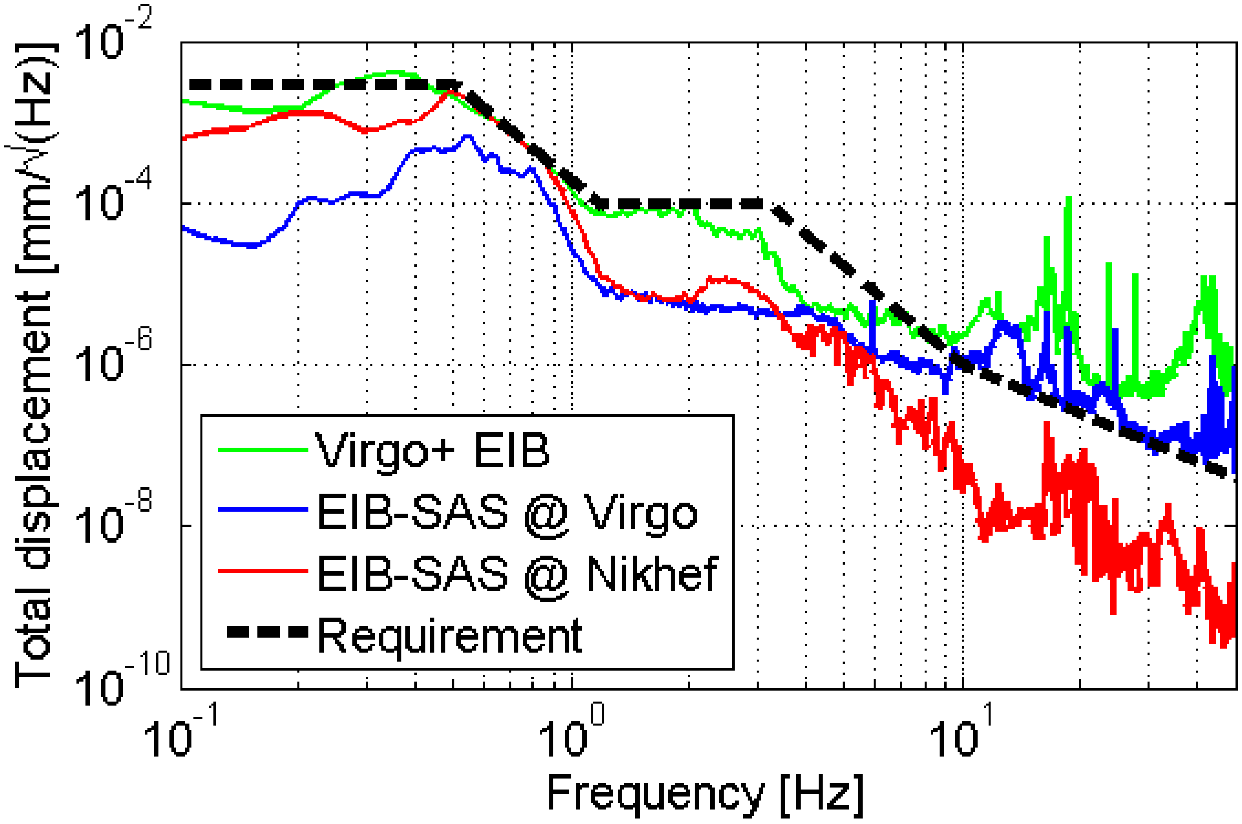


16 Hz





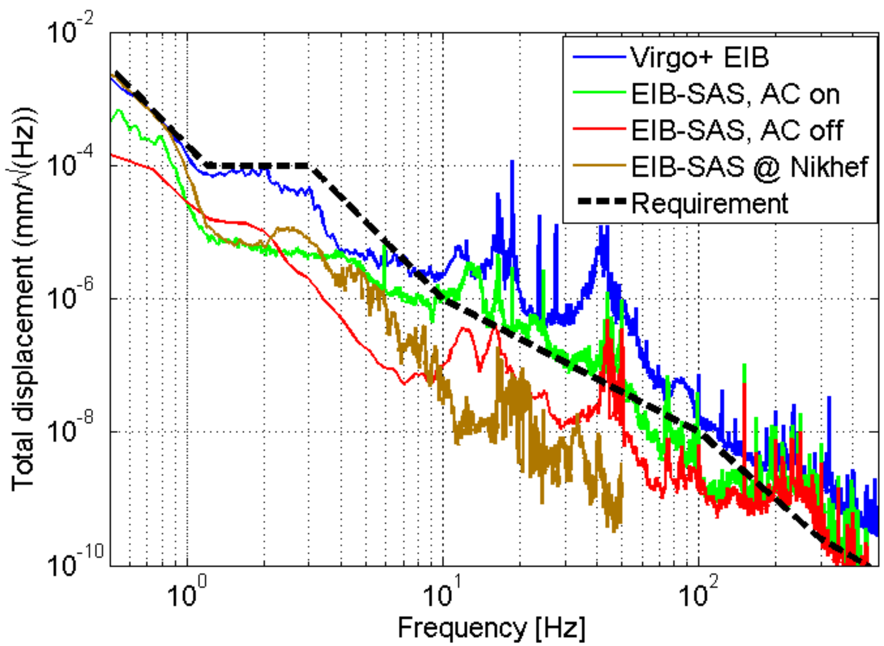
EIB-SAS stand alone

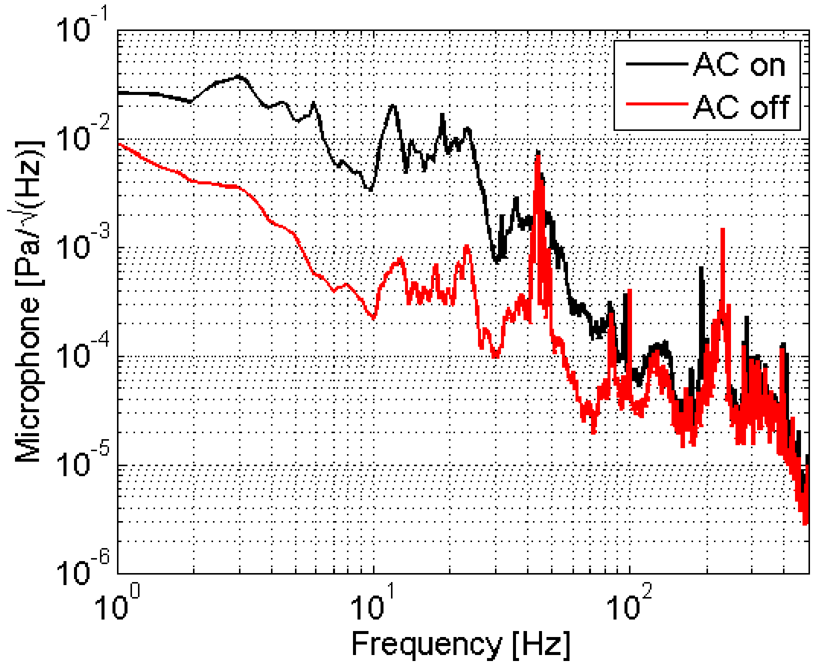


Above 10 Hz performance @ Virgo not as good as @ Nikhef

Why?

Effect of acoustic noise air-conditioning on EIB motion

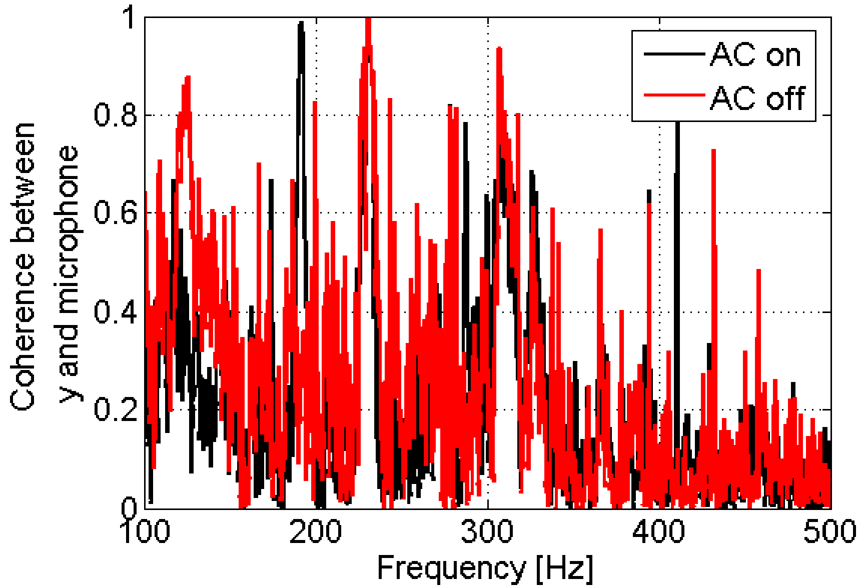


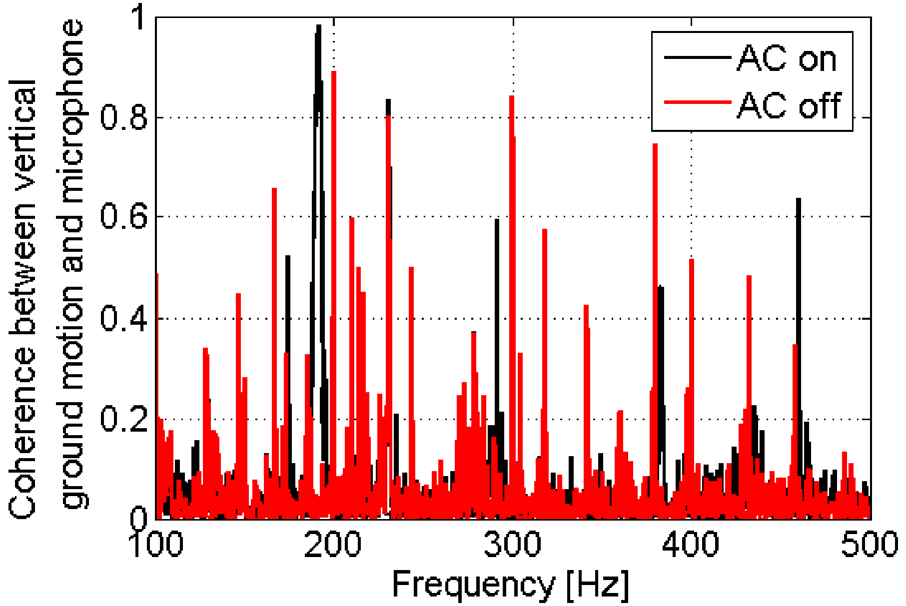


The AC systems in the central building create a lot of acoustic noise in the laser lab

- Between 1 – 100 Hz bench movement is caused by acoustic noise of the central building AC's
- Between 40 and 50 Hz a second noise source is present

Effect airconditioning on EIB motion



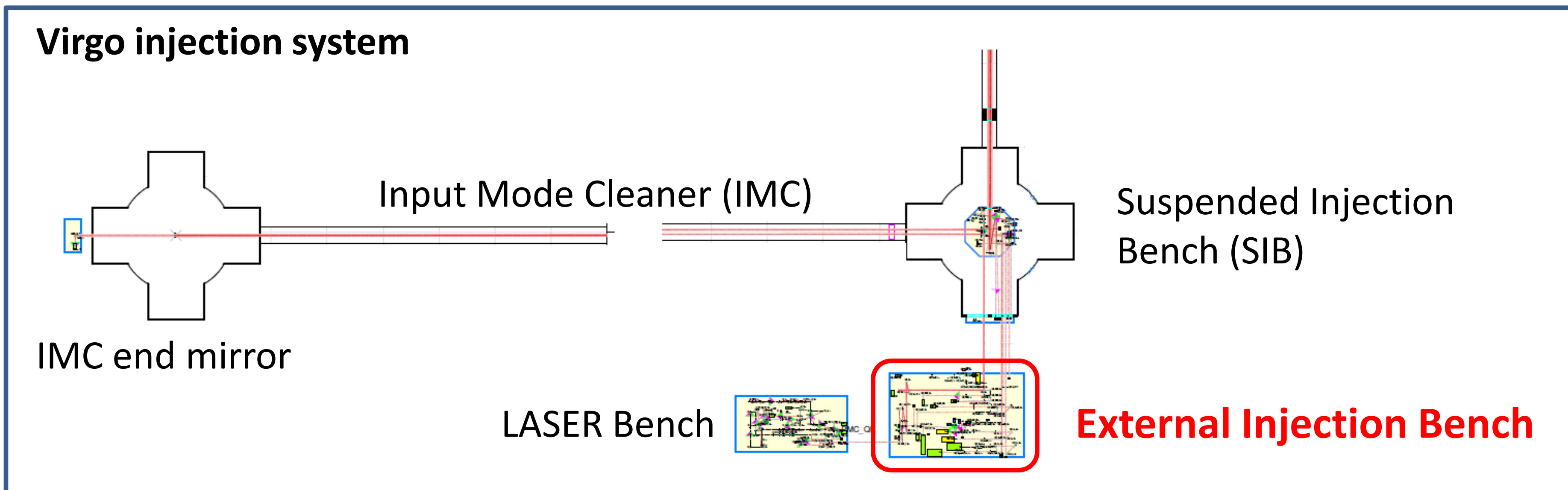


Above 100 Hz:

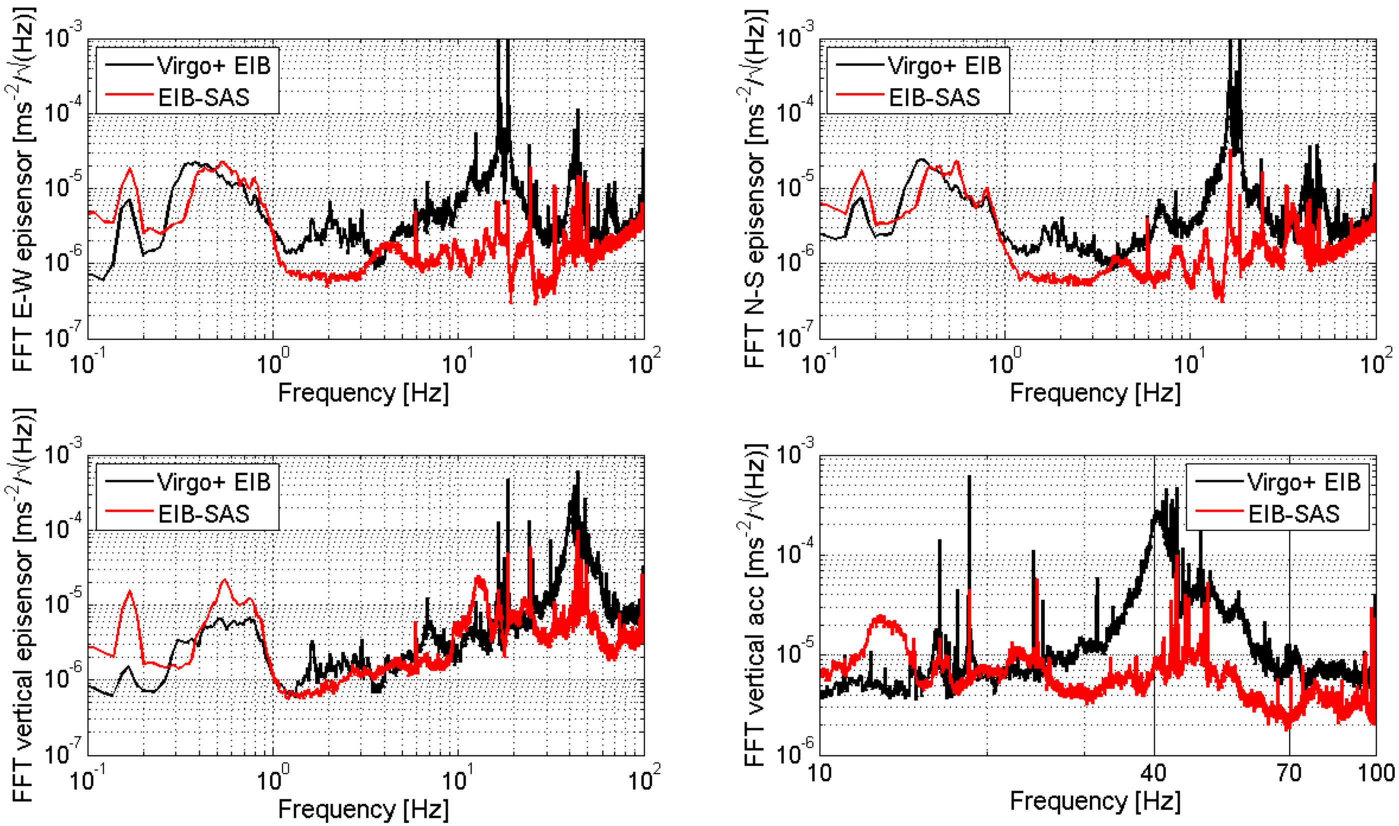
- No coherence with ground motion sensor
- Coherence with microphone, but source is not the AC system

Compare EIB-SAS to old support system

- The external injection bench contains:
  - 3-axis geophone
  - Vertical accelerometer
  - Quadrant photo diodes for SIB alignment
    - Look at reflection of SIB
- SIB follows the laser beam exiting the external injection bench
- Use SIB control signals and motion sensor data to compare EIB-SAS and Virgo EIB support



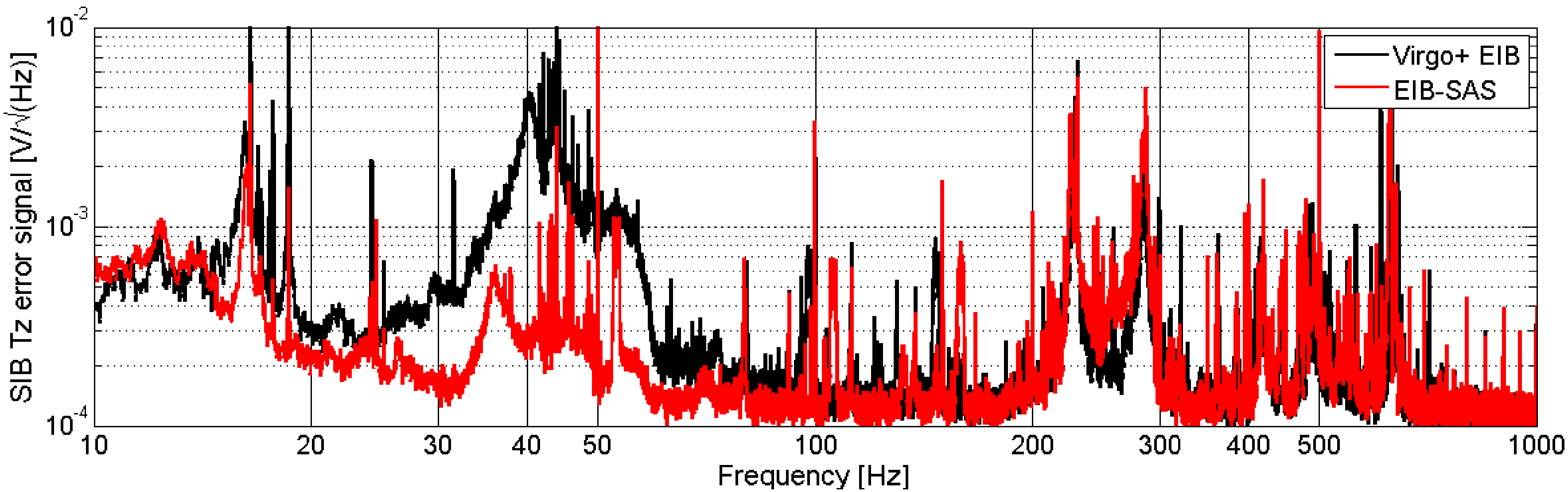
EIB-SAS vs. Virgo EIB

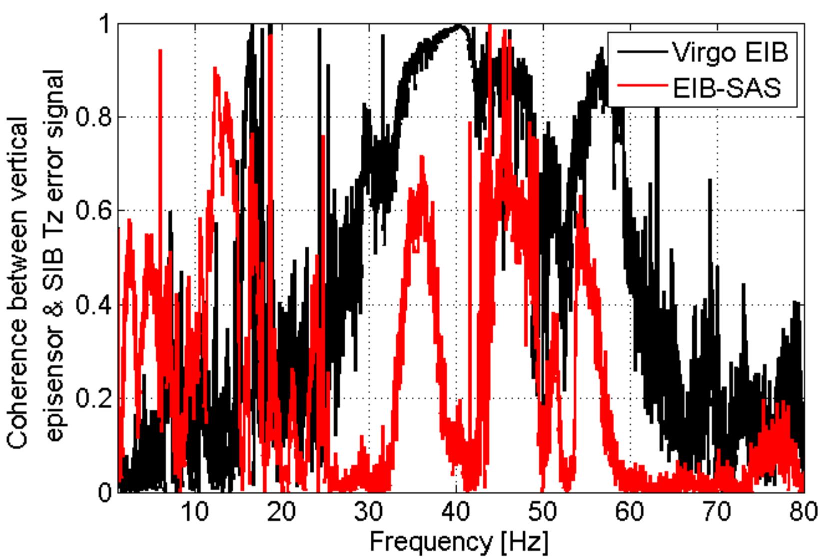


Compare 3-axial geophone and accelerometer spectrum Virgo+ EIB and EIB-SAS

- Structures at 20 and 40 – 60 Hz gone
- Below 1 Hz, small increase due to increased ground motion
  ⟶ SAS is locked to the ground by the controls
- Acoustic coupling at 45 – 50 Hz

Performance: IMC error signals

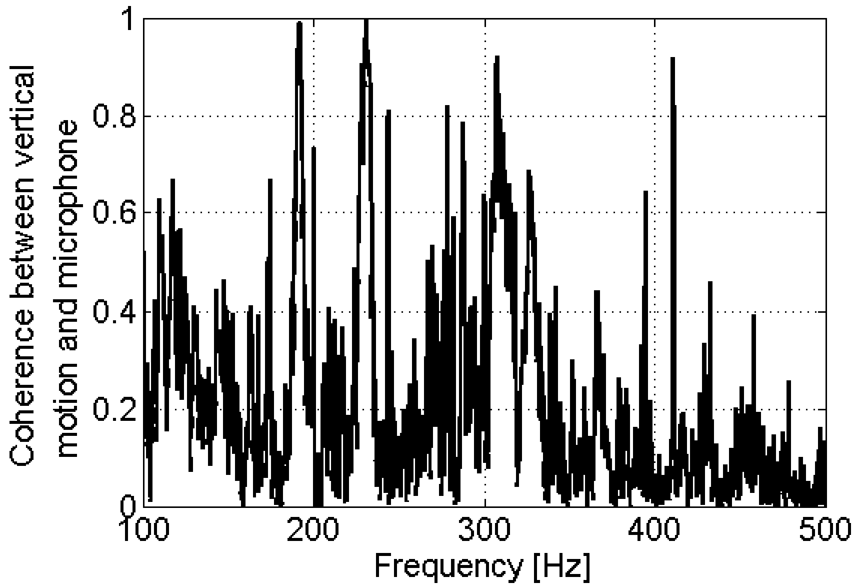


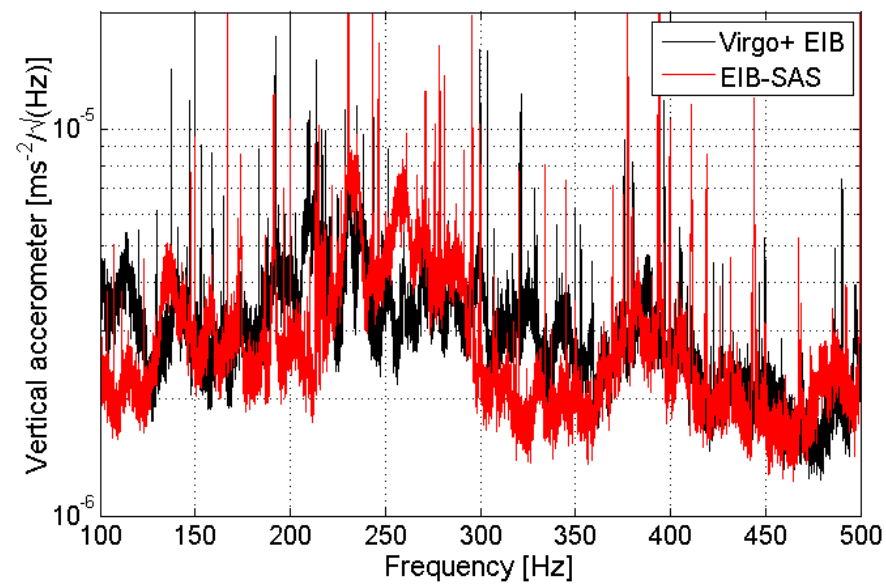


Spectrum of IMC Tz (pitch) error signal:

- Structures < 100 Hz belonging to Virgo+ EIB support are gone
- Structures between 200 – 300 (optical mounts) remain

EIB-SAS vs. Virgo EIB @ high frequencies





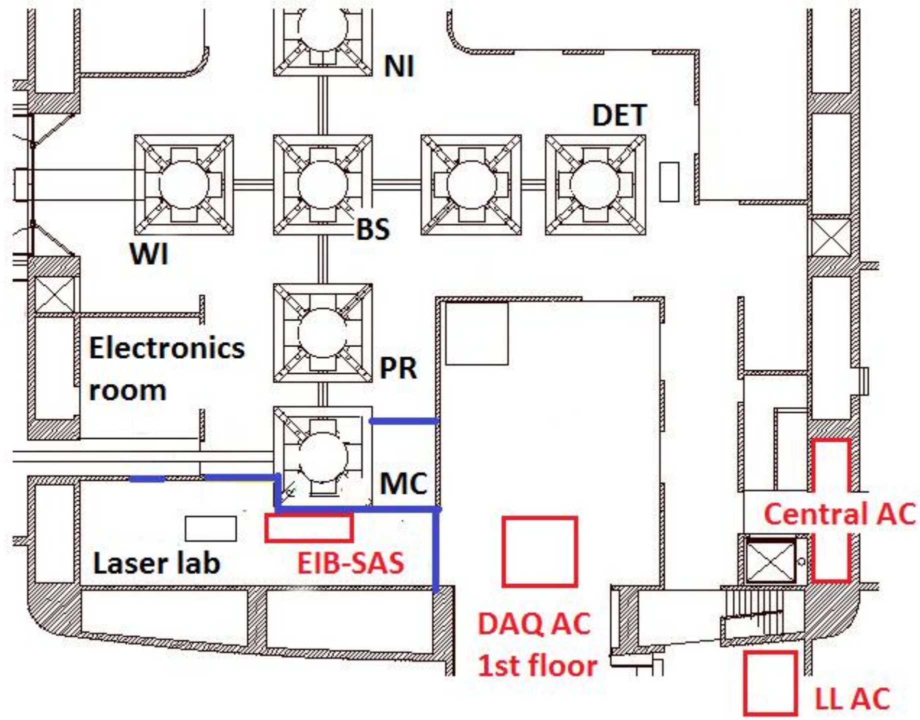
- @ 200 – 300 Hz (bandwidth resonance optical mounts)
  no improvement
- Above 100 Hz coherence with micro-phone

Optical mount resonances are probably excited acoustically, not seismically

Acoustic isolation for Advanced Virgo

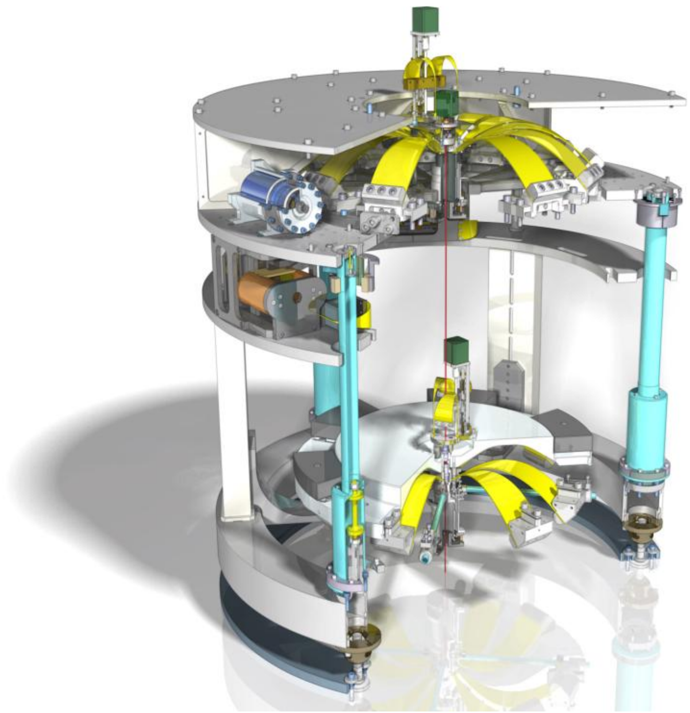
- Commissioning EIB-SAS has shown the prominent role of acoustic noise above 100 Hz
- The walls between the central hall and the laser lab (—) are cleanroom walls → they do not shield from acoustic noise

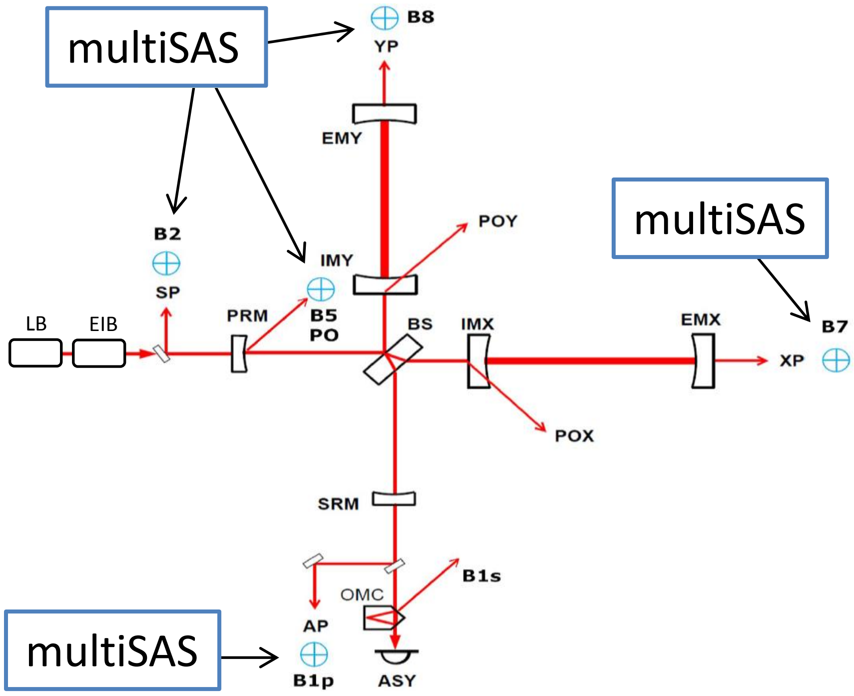
For AdV laser lab walls will be replaced by concrete walls



Latest activities: Multistage Seismic Attenuation System

- MultiSAS features
- Compact design
  - Antispring technology
    - Inverted pendulums
    - Geometric antisprings
    - Consistent with 10^{-15} m (rad)/√Hz (6 dof)
- UHV compatible

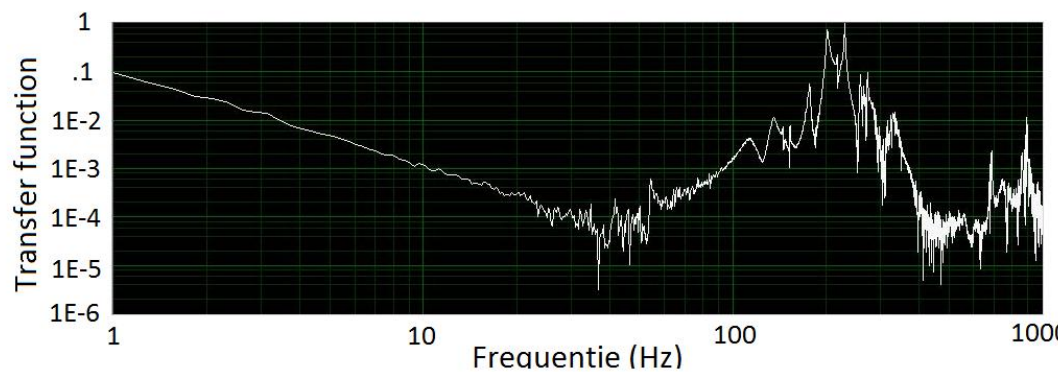


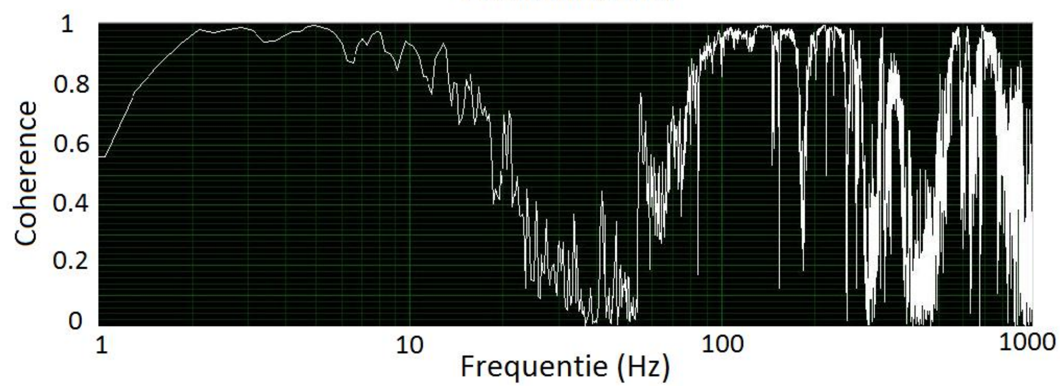


MultiSAS: First results

- The top filter has been tuned to 110 mHz
- Intermediate filter to 280 Hz
- 80 dB attenuation from intermediate filter alone

- Prototype assembled
- Dummy bench design completed
- Tests ongoing
- In-air till Sep 2012
- Final design by December
- Production from Jan 2013

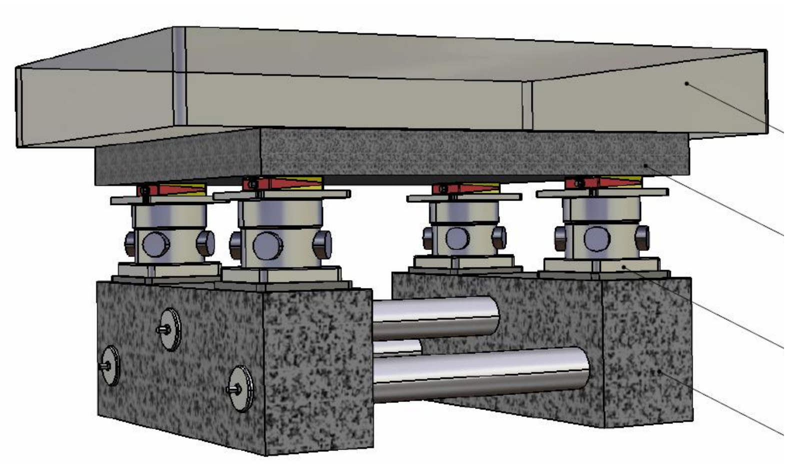




Summary

- New External Injection Bench Seismic Attenuation System (EIB-SAS) for Advanced Virgo performs well
- EIB-SAS has been installed and commissioned without major problems
- **Beam jitter is significantly reduced**
- **Acoustic noise** affects the EIB-SAS
  - 1 – 100 Hz acoustic noise from AC systems
  - Above 100 Hz coherence with microphone – source unknown
- For Advanced Virgo shielding against acoustic noise will be improved
- Multistage seismic attenuation systems with better performance and UHV compatible have been designed for 5 other benches
  - Prototype has been built
  - Tests are ongoing

Active seismic isolation



- **Commercial system: Stacis**
- Good isolation < 200 Hz
- >200 Hz: injects acoustic noise and shakes floor
- **Can not be used**

use passive isolation