Compact, in-vacuum seismic isolation systems for Advanced Virgo

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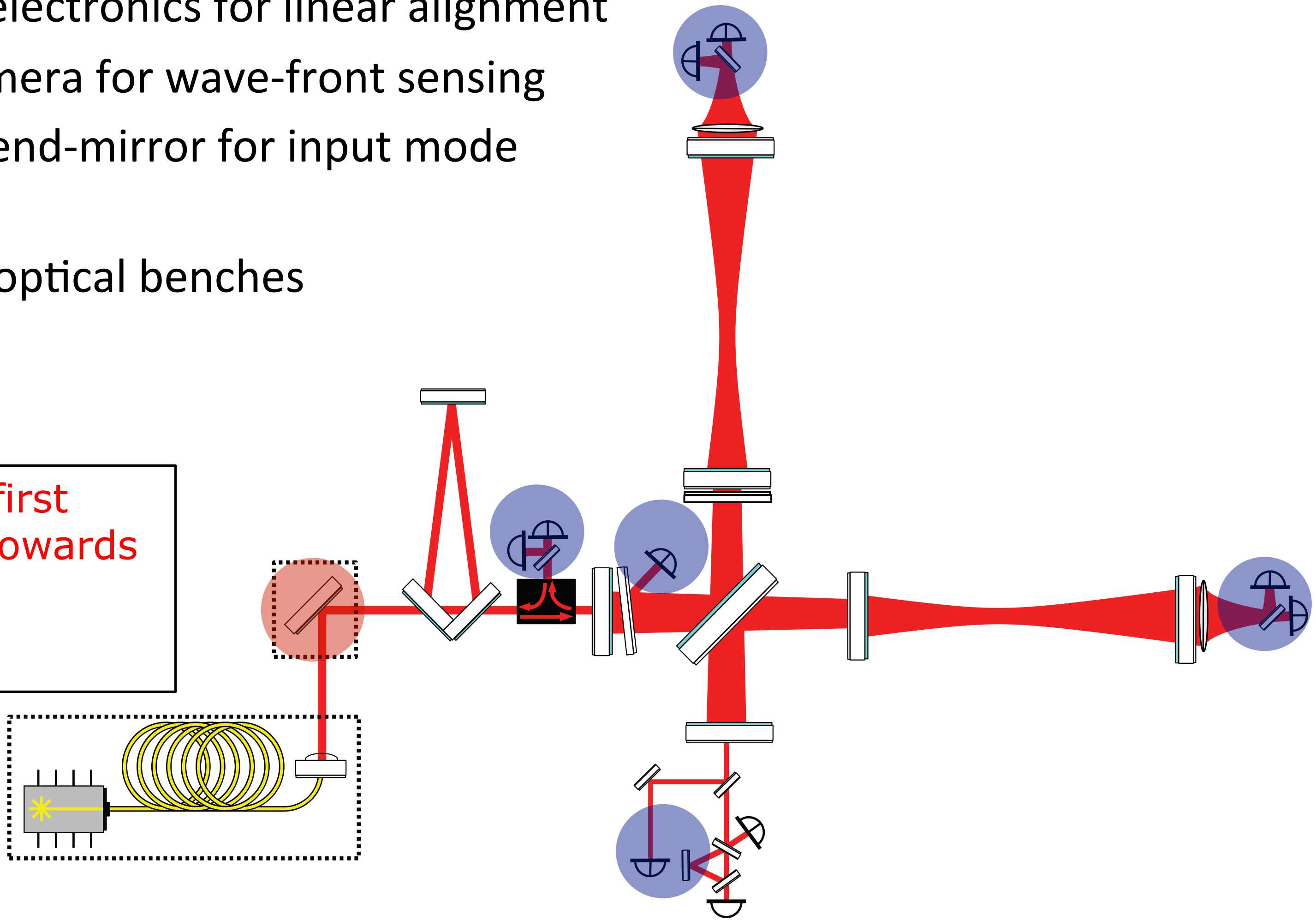
Nikhef is responsible for a number of Advanced Virgo upgrades

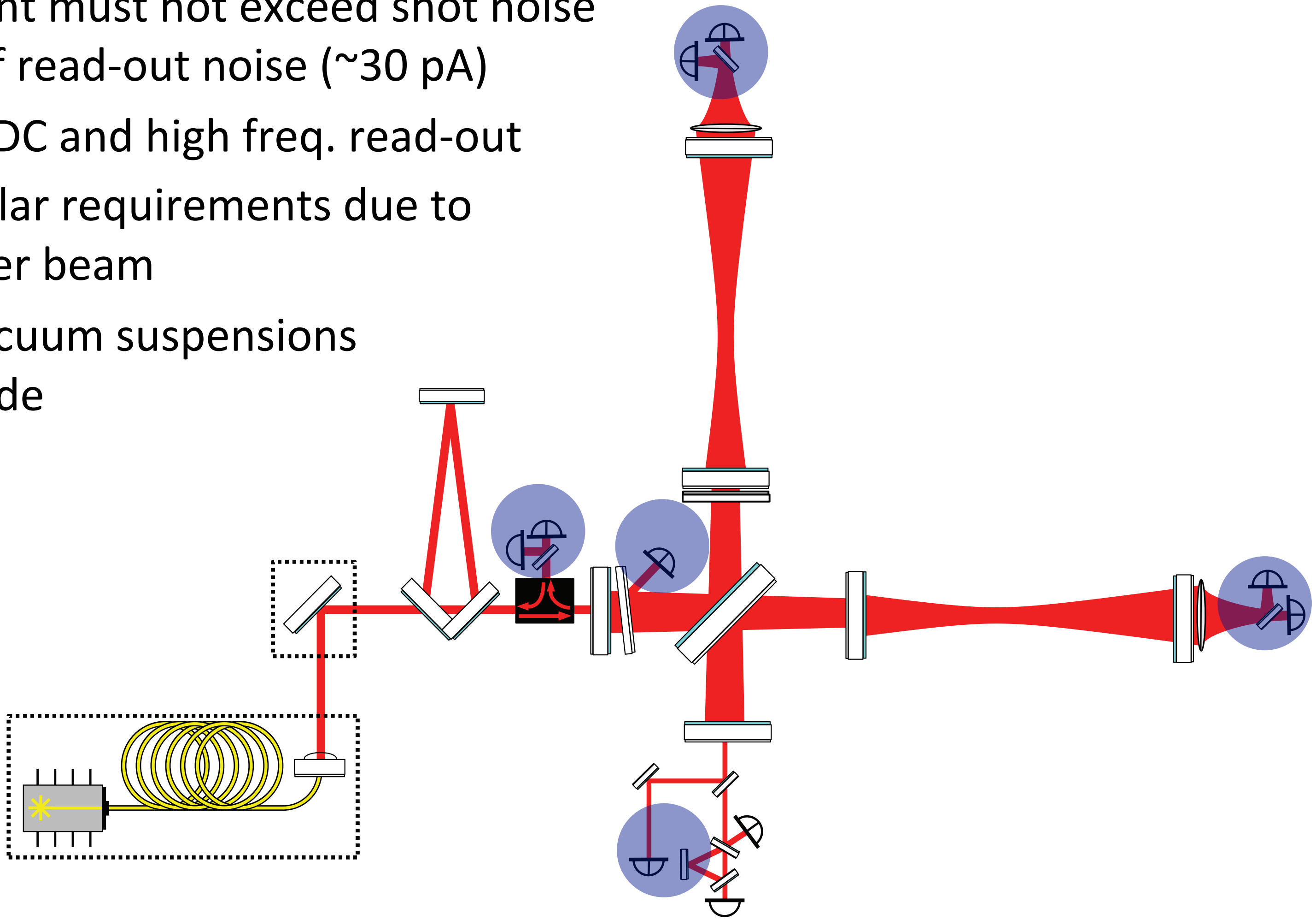
- Read-out and electronics for linear alignment
- New phase camera for wave-front sensing
- Dihedron and end-mirror for input mode cleaner
- Suspension of optical benches
  - 5 in vacuum
  - 1 external

EIB suspension first major upgrade towards Advanced Virgo (Previous talk)



End benches and other ITF alignment optics need to be seismically isolated as well

- Their movement must not exceed shot noise contribution of read-out noise (~30 pA)
- Optimized for DC and high freq. read-out
- Stringent angular requirements due to focusing of laser beam
- In total 5 in-vacuum suspensions need to be made
    - → MultiSAS

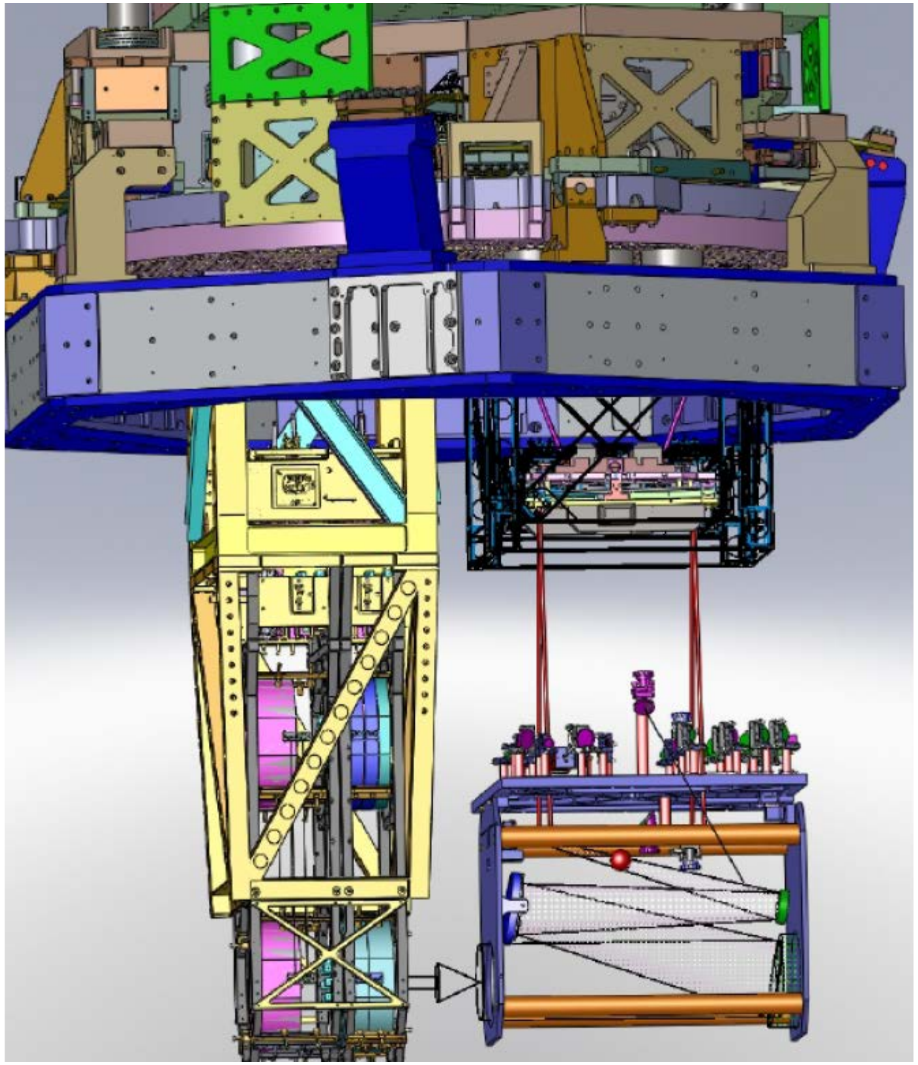


Stringent angular MultiSAS requirements (Similar to AdvLIGO TMS)

	MultiSAS Requirements **M. Mantovani, VIR-0101A-12**
δx	$2 \cdot 10^{-12}$ m/√Hz @ 10 Hz
$\delta\theta$	$3.3 \cdot 10^{-15}$ rad/√Hz @ 10 Hz
x_{rms}	$24 \cdot 10^{-6}$ m
θ_{rms}	$0.033 \cdot 10^{-6}$ rad

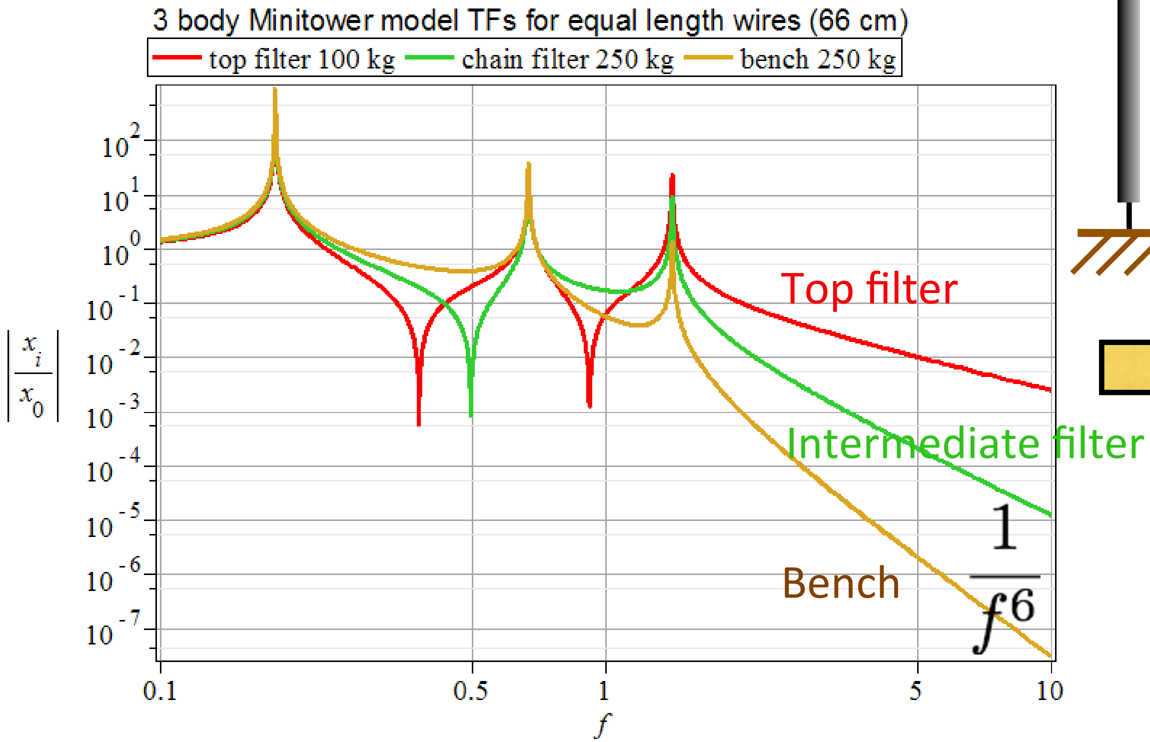
The requirements are still evolving yet look very challenging in terms of angular motion.

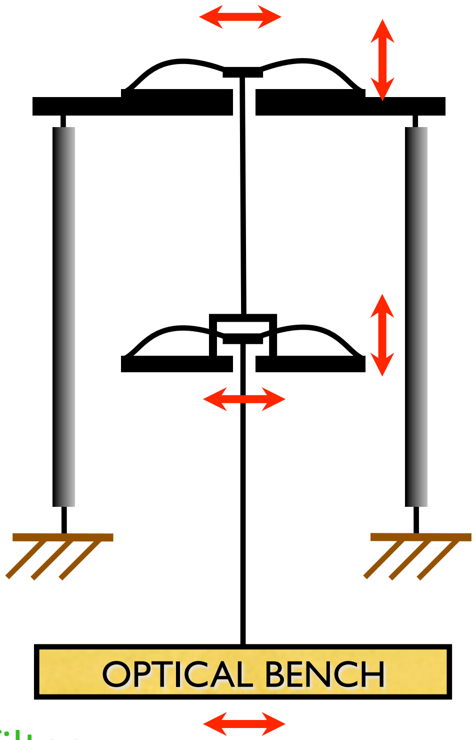
Similar specs have been produced for the AdvLIGO transmission monitor telescope suspension, hanging from ETM dual stage active isolator.



MultiSAS is a hybrid isolator is which bulk attenuation is provided passively

- Each stage provides an extra $1/f^2$ attenuation
- Horizontal most important for angular motion





1x horizontal
1x vertical

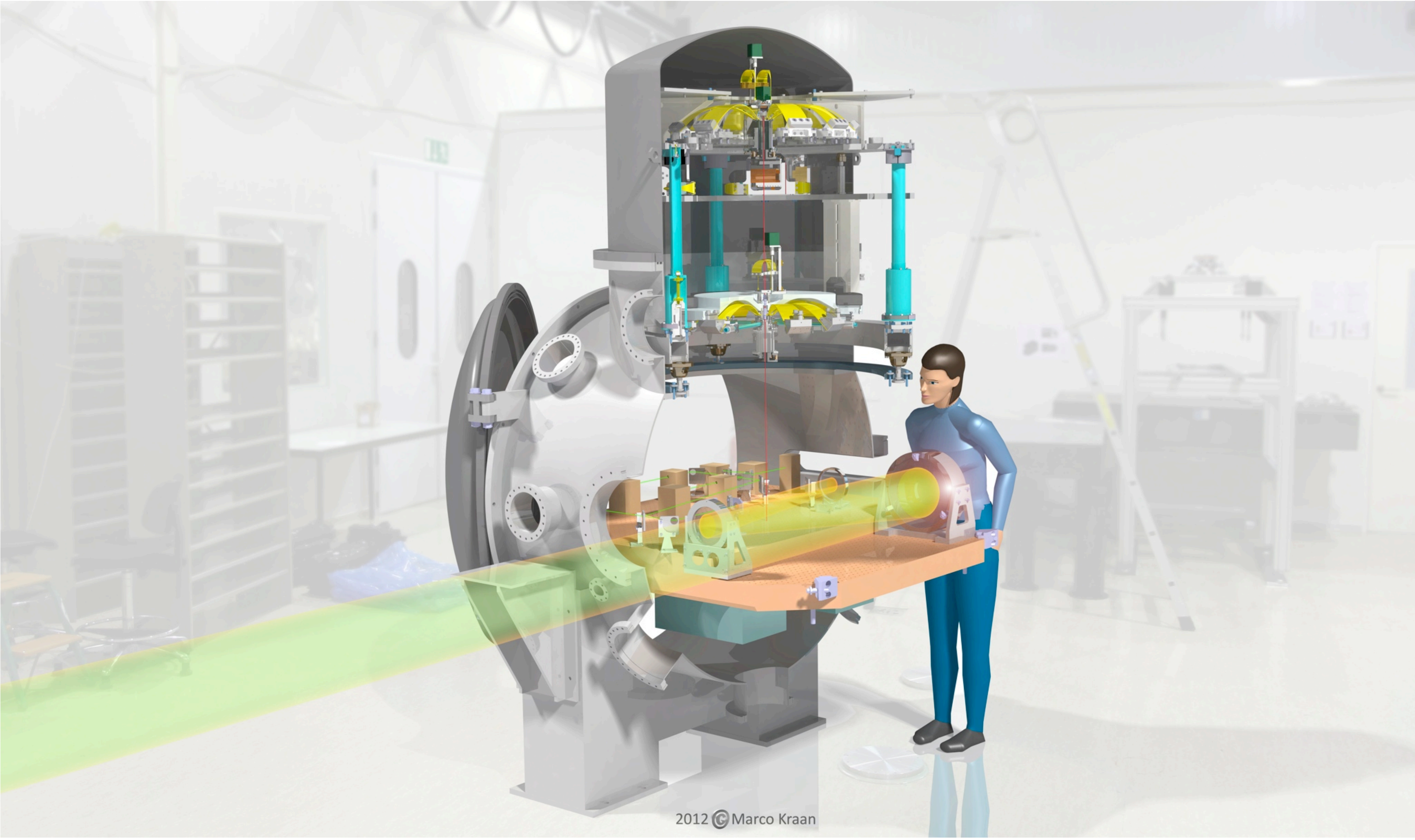
+

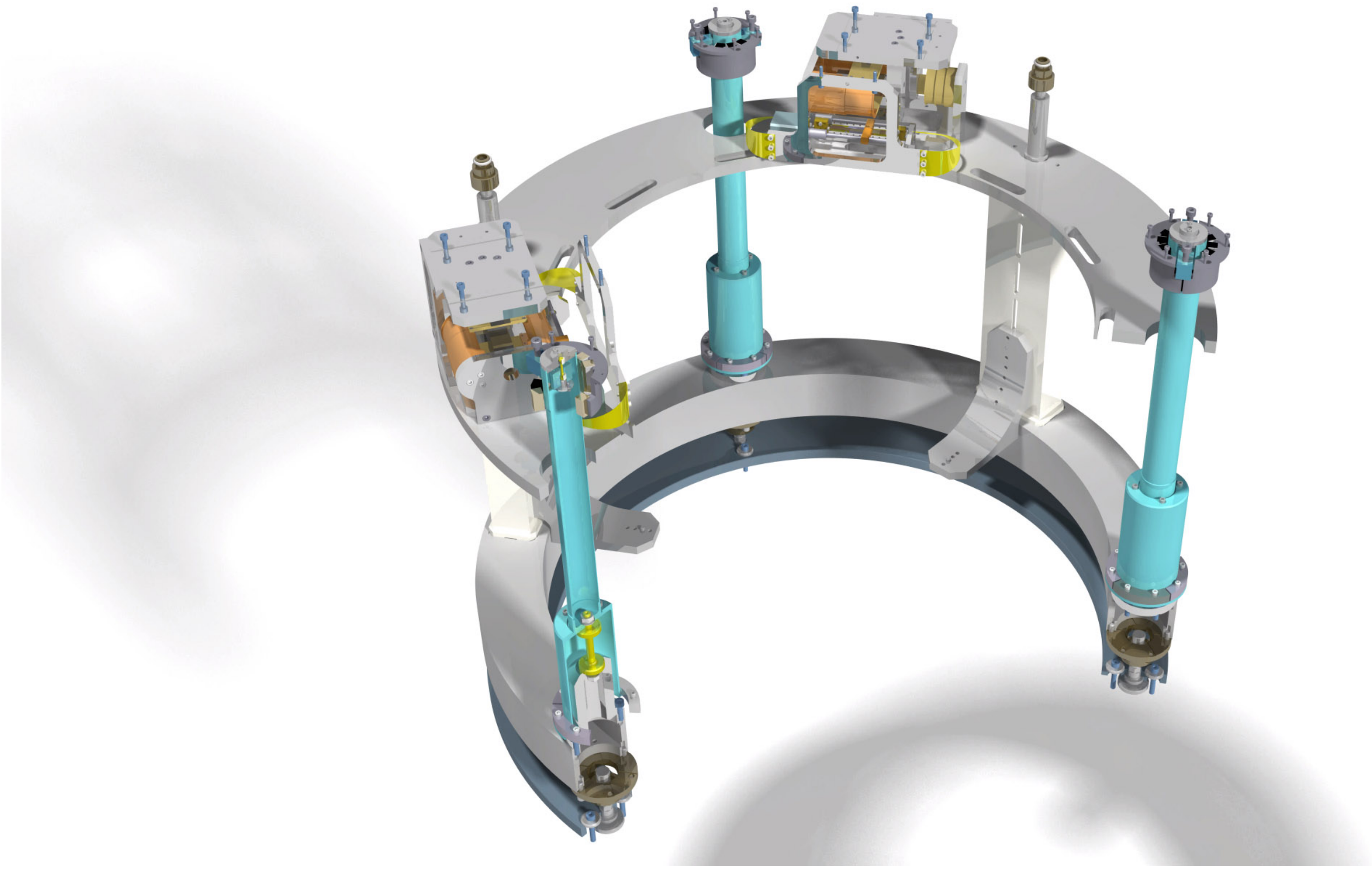
1x horizontal
1x vertical

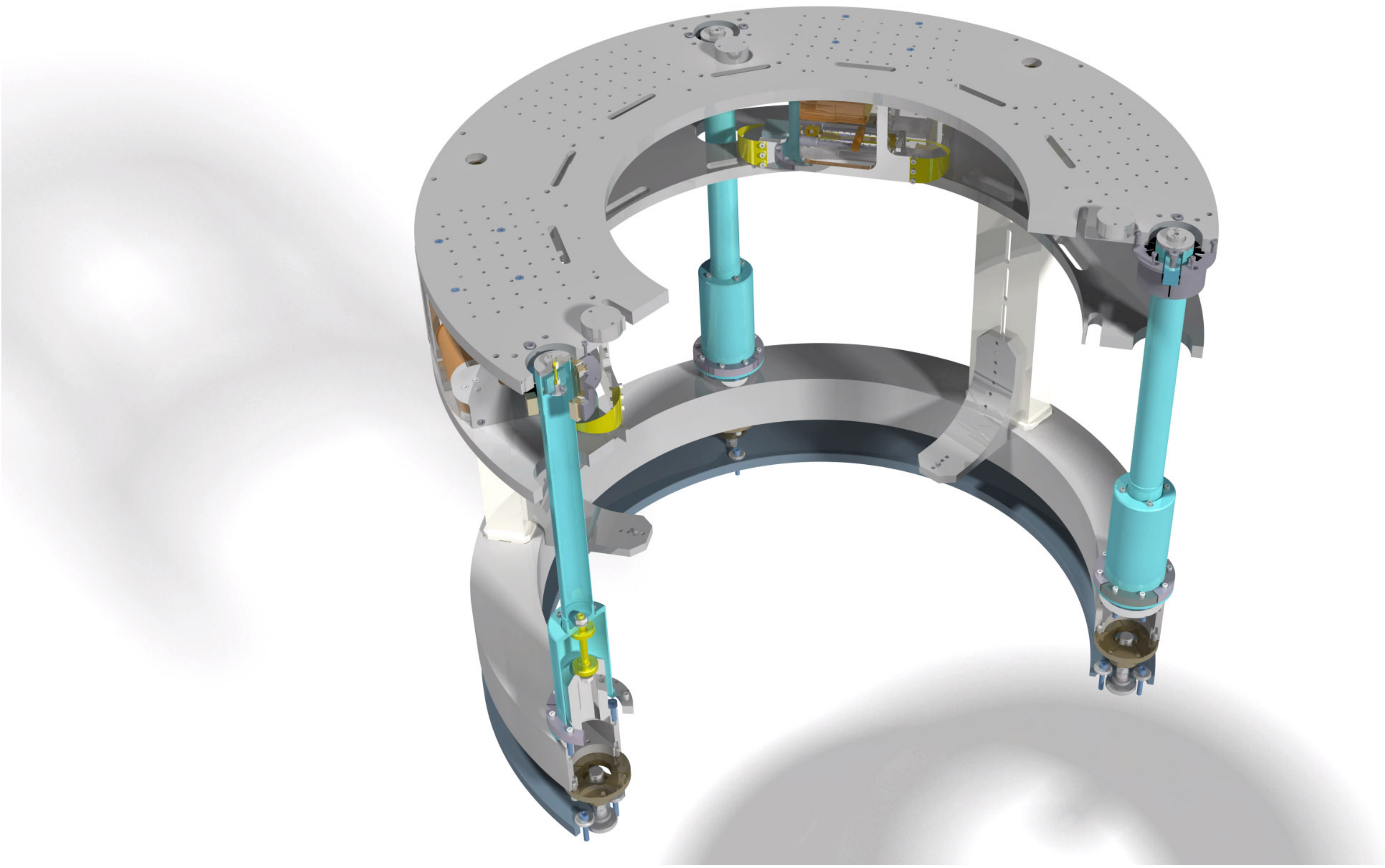
+

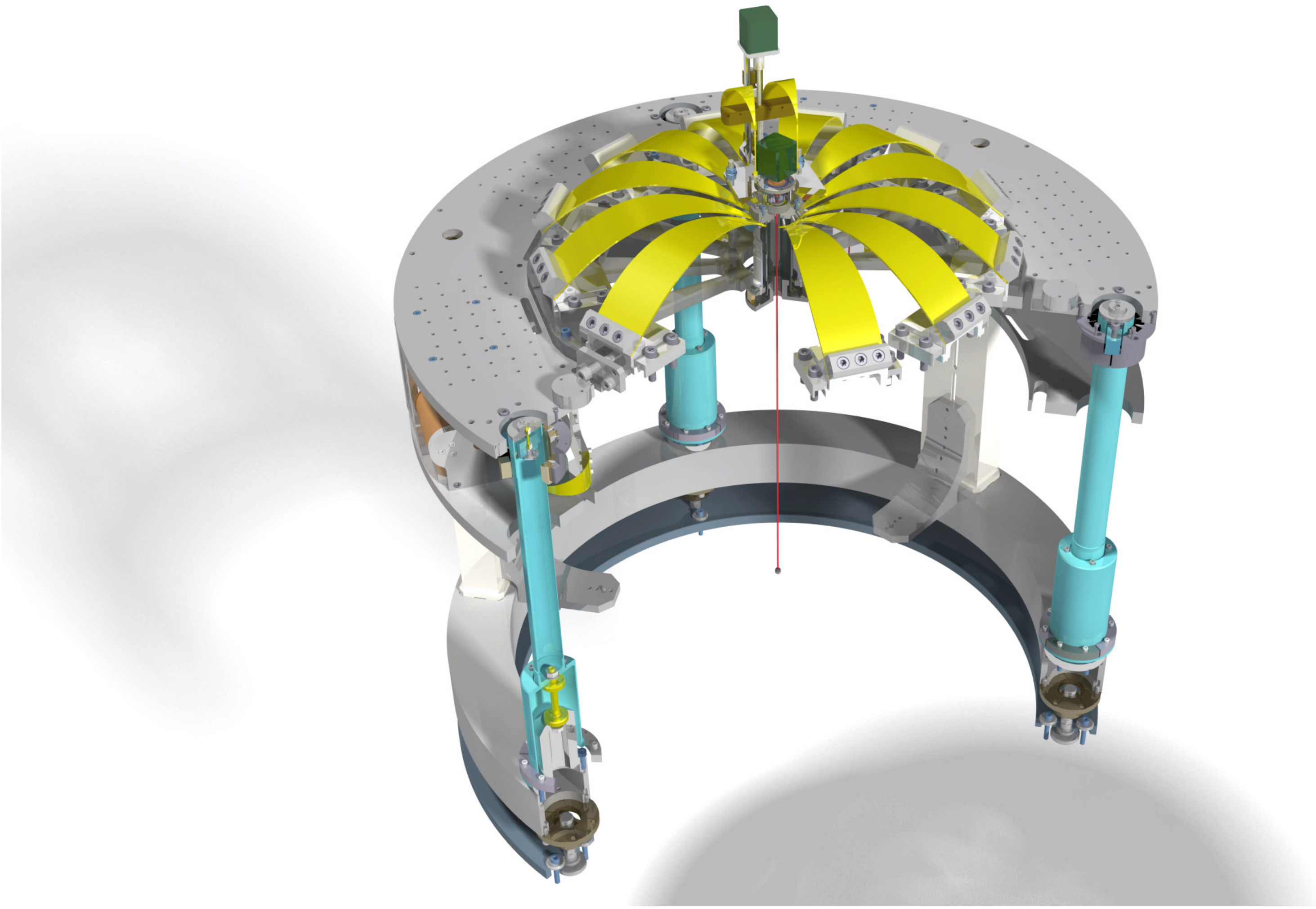
1x horizontal

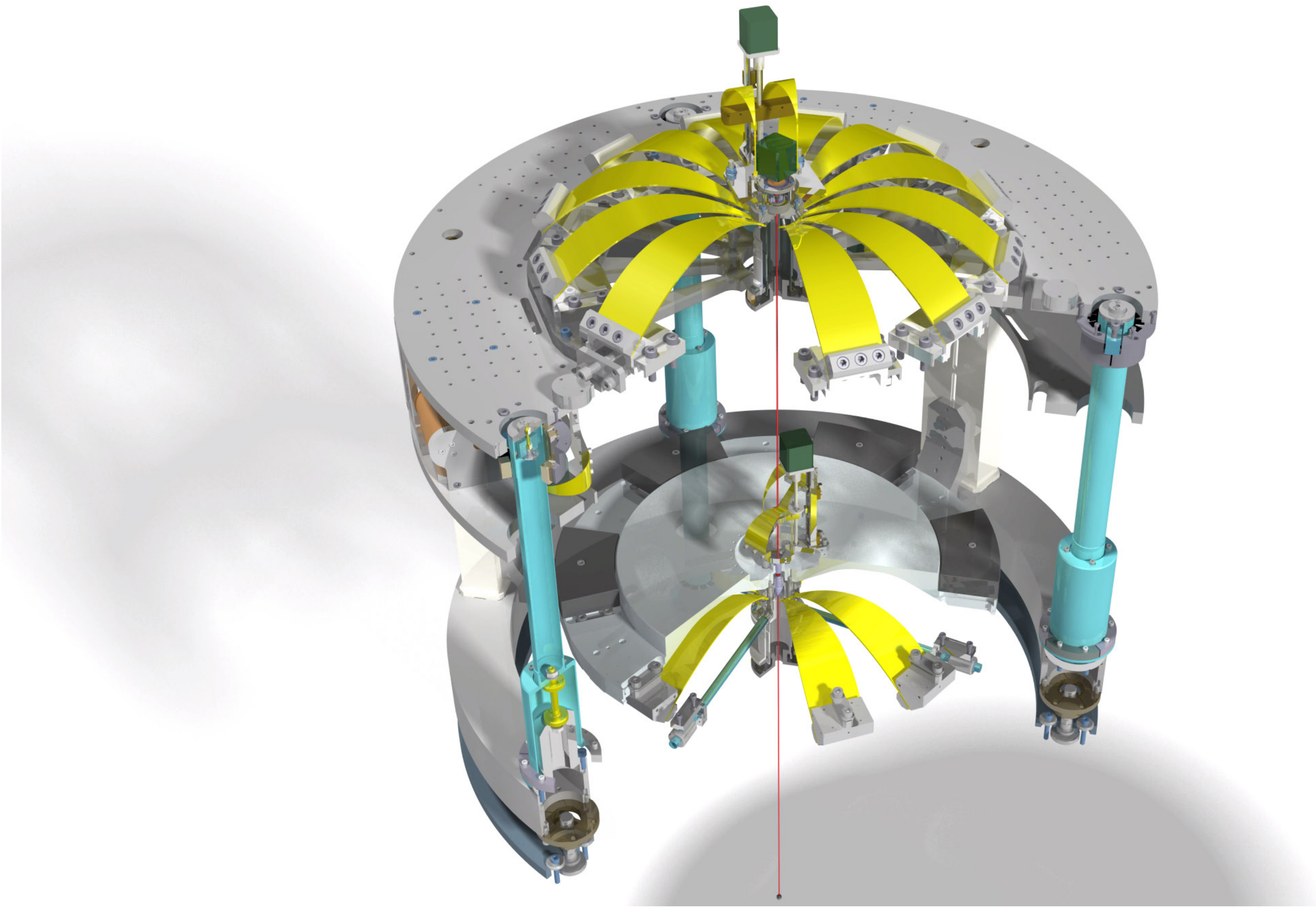
3x horizontal
2x vertical

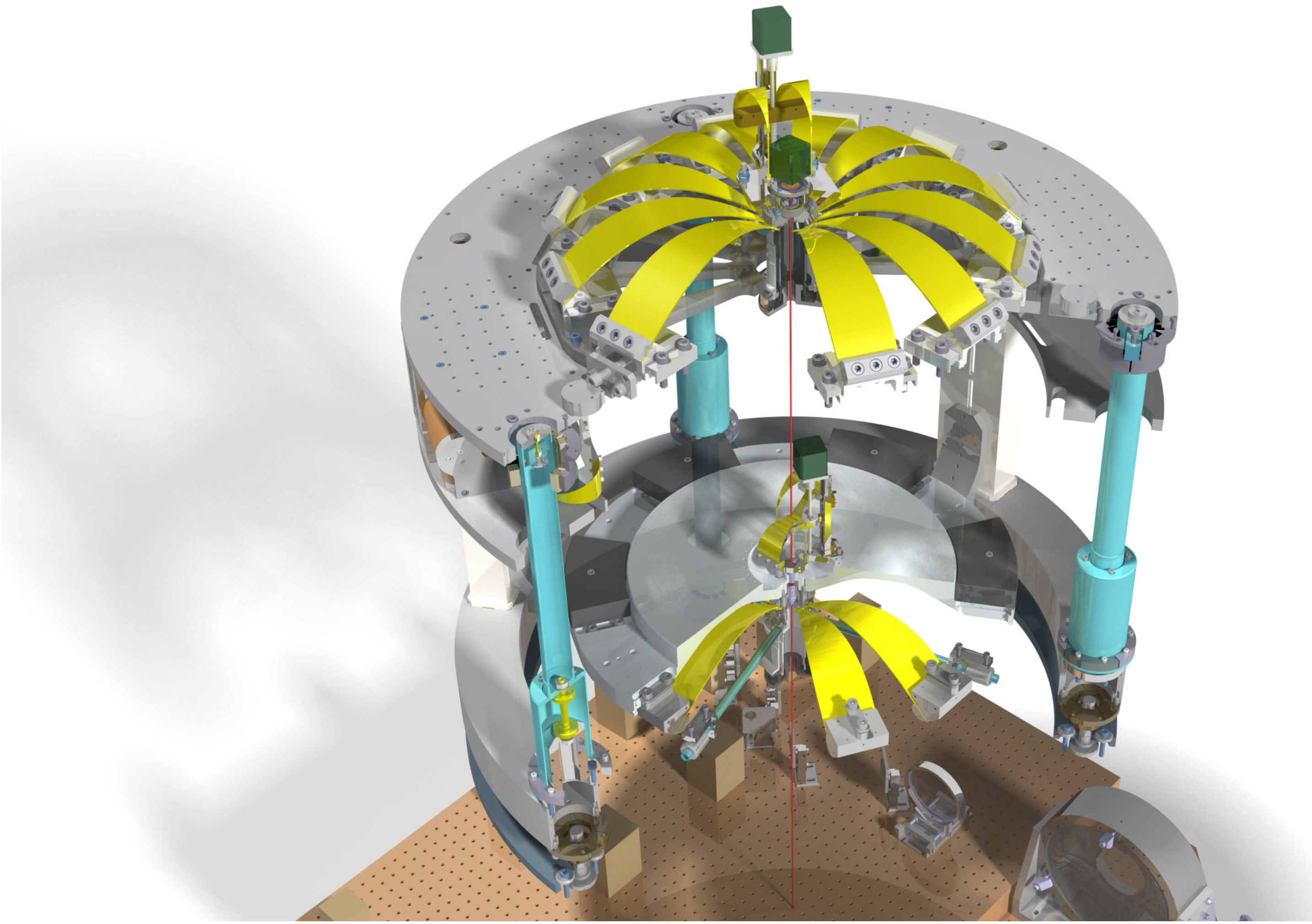

2012 © Marco Kraan

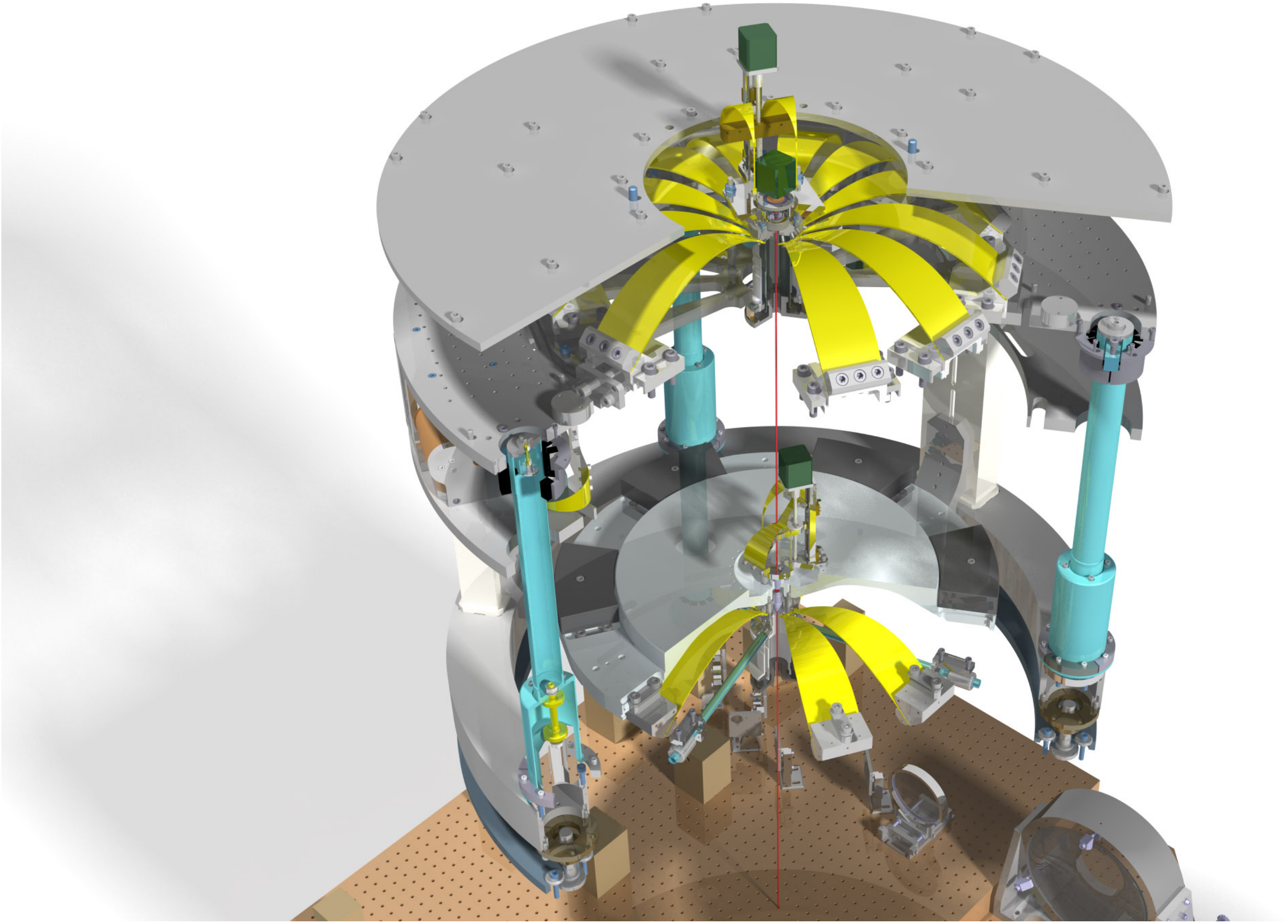


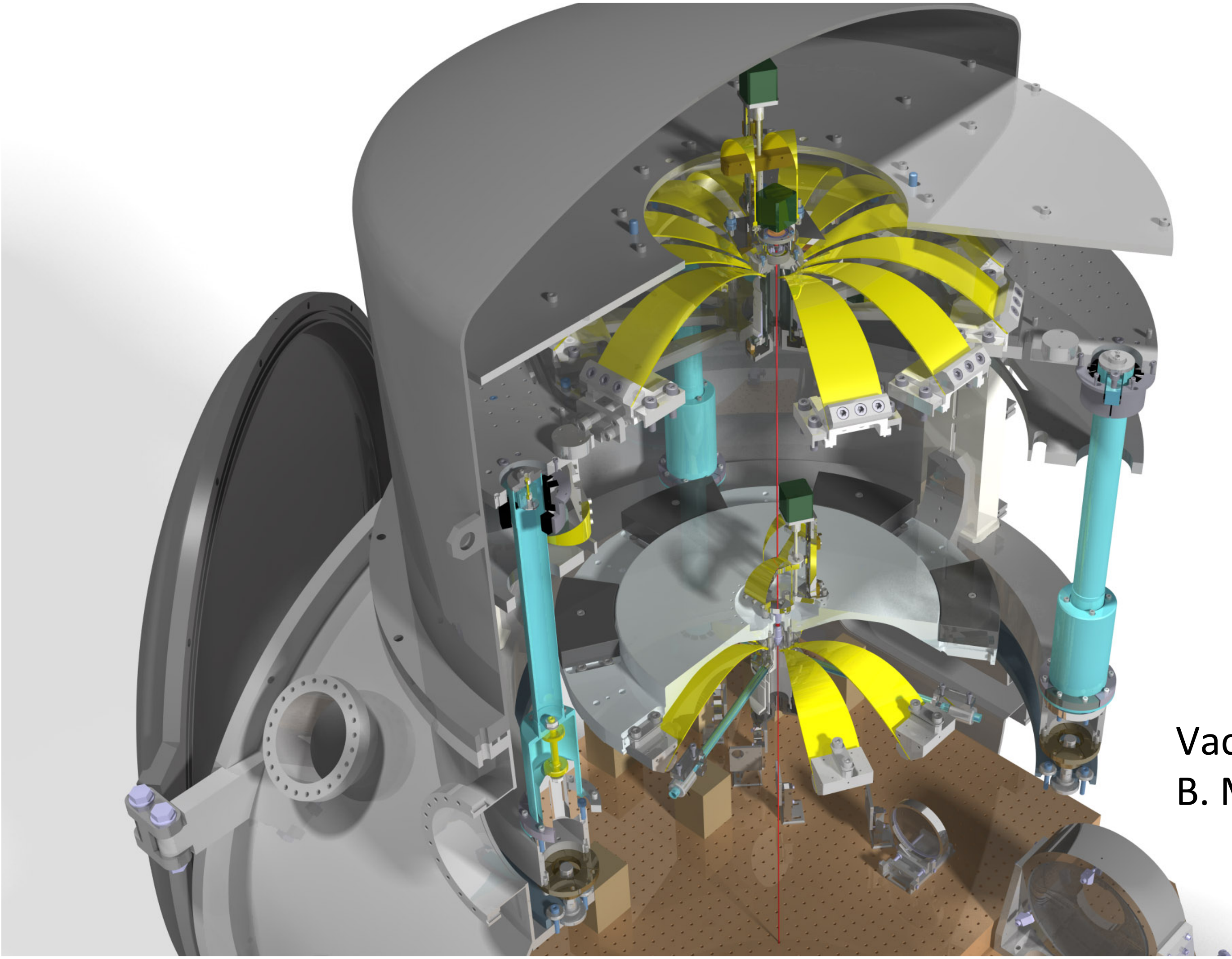








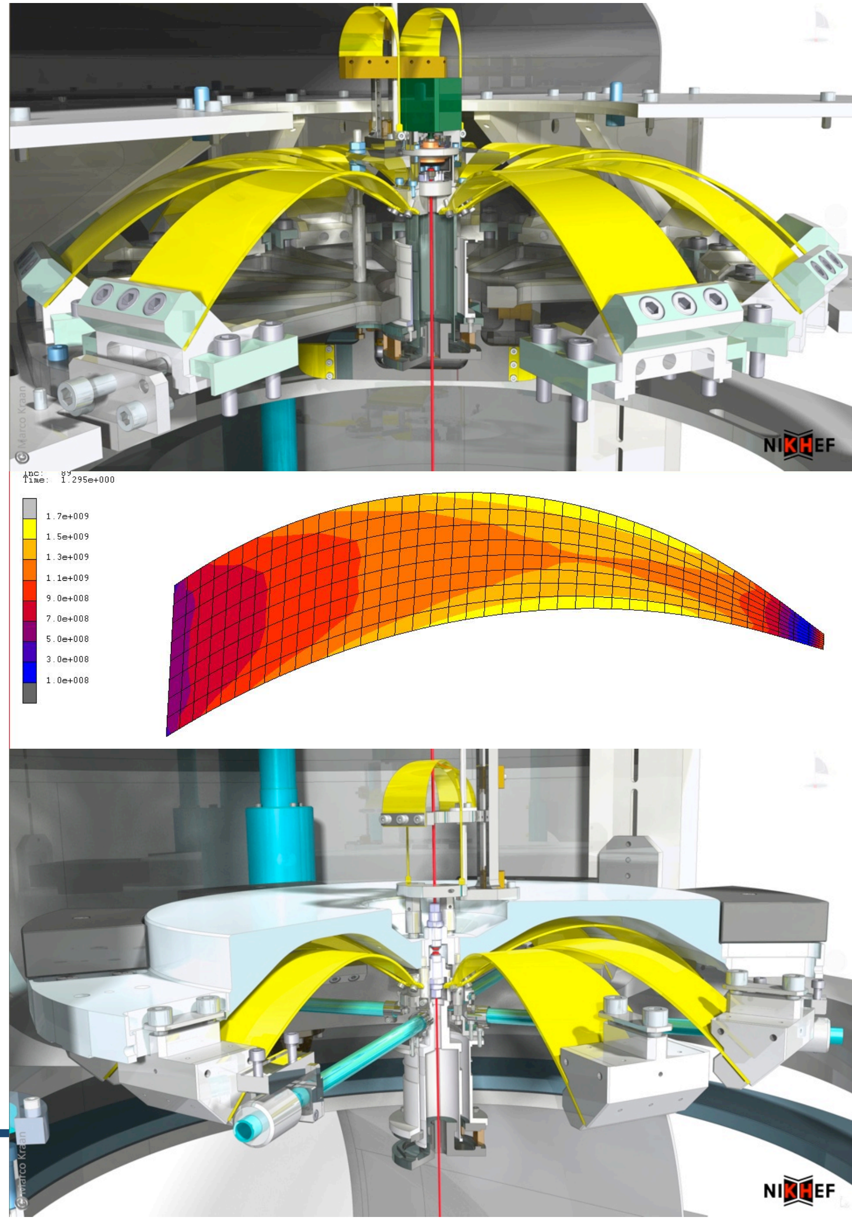




Vacuum chamber:
B. Mours / LAPP

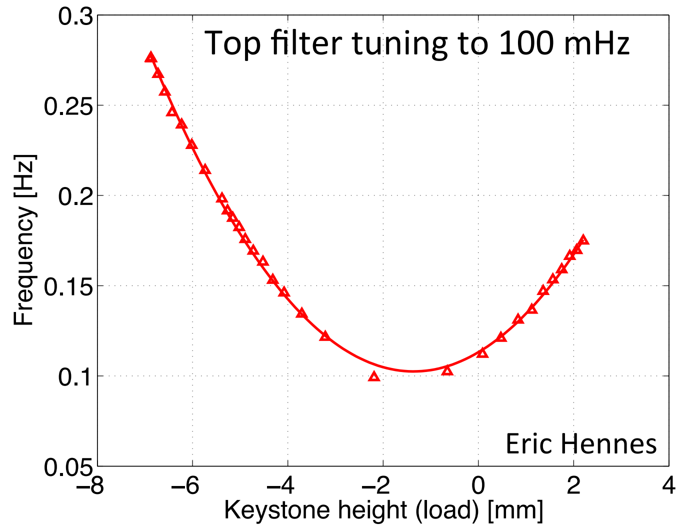
Vertical filters implement anti-springs and "magic wands"

- Top filter
  - Up to 12 blades for max load of 600 kg
  - Vertical DC position controlled by dual blade fishing rods
  - θy rotation controlled by harmonic drive
- FEA: Max von Mises stress: 1.7 GPa
- Bottom filter
  - "Inverted" design to better place wire bending point at COM
  - Magic wands used to lower saturation point

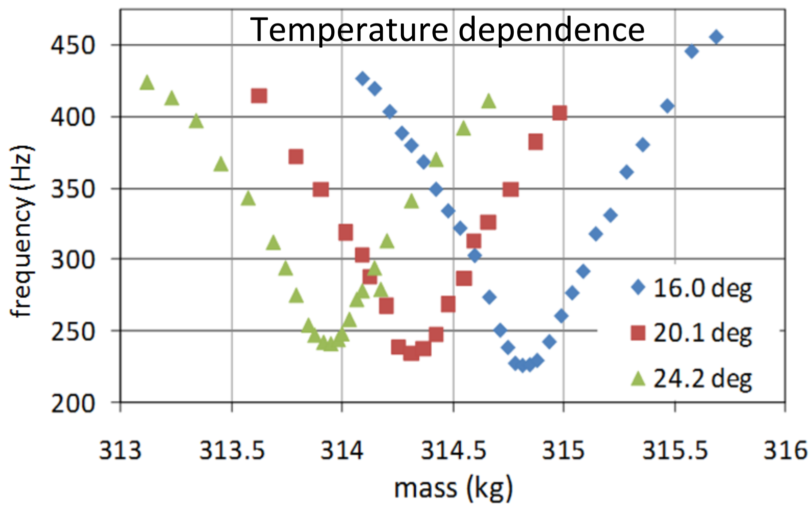


Tuning of vertical filter stages

- Top filter has been tuned below 100 mHz
  - (will be 200 mHz)
  - Bottom filter: 400 mHz



- Temperature dependence
  - Change in thermal elasticity
    - (and thermal expansion)
  - Top filter: -1.44 mm/K
  - Bottom filter: -0.35 mm/K
  - Need to be able to provide long-term DC positioning

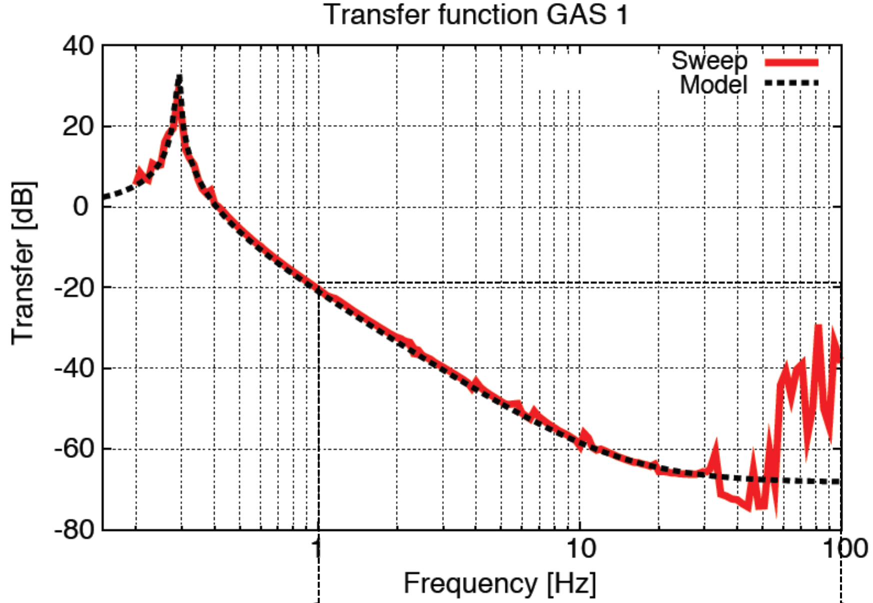


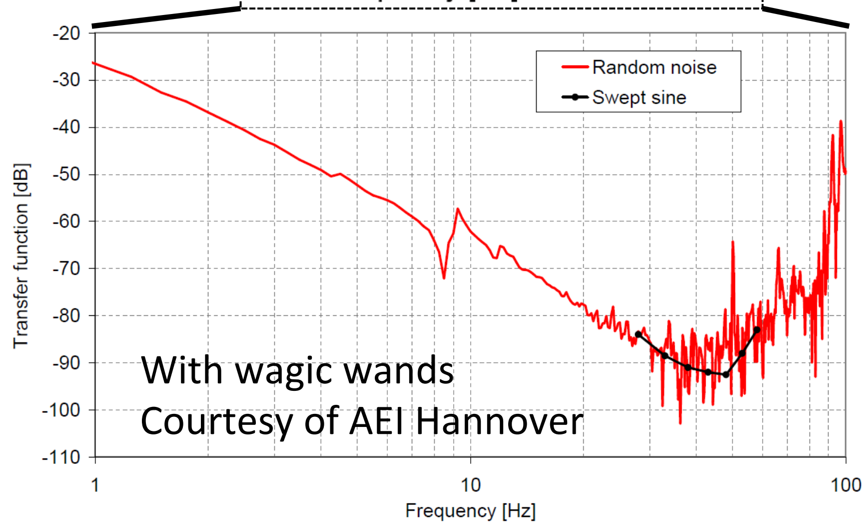
Magic wands decrease GAS saturation level to < 80 dB

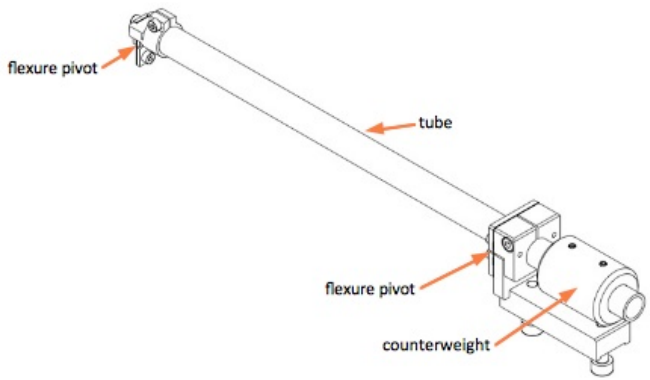
- Mass and moment of inertial not negligible wrt pay-load
- Results in saturation of transfer function

$$\frac{x_1(\omega)}{x_0(\omega)} = \frac{\omega_0^2 + \beta\omega^2 + i\alpha(\omega)}{\omega_0^2 - \omega^2 + i\alpha(\omega)}$$

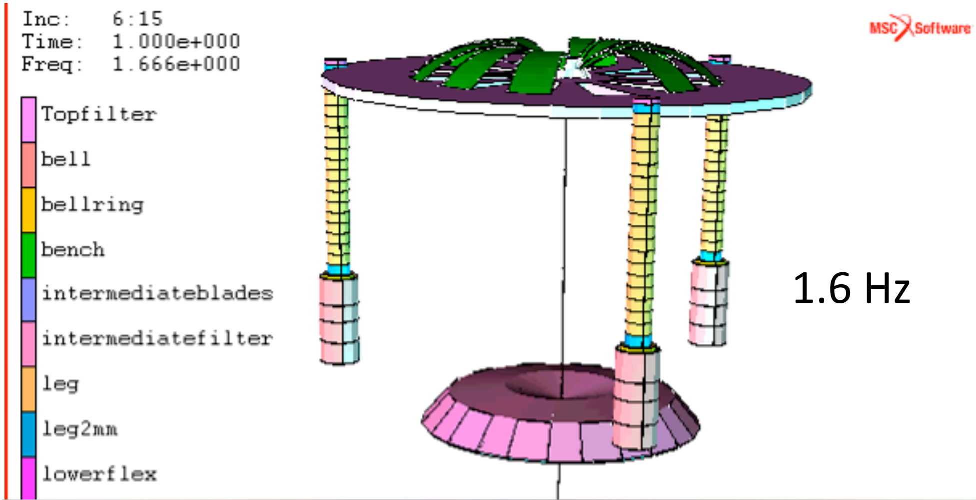
- Magic wands allow tuning of moment of inertia (and β)
- Lowers saturation level to < 80 dB

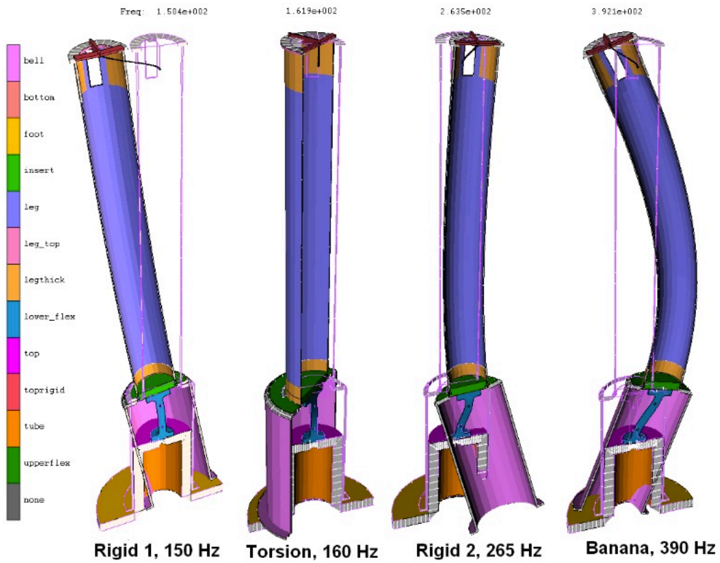




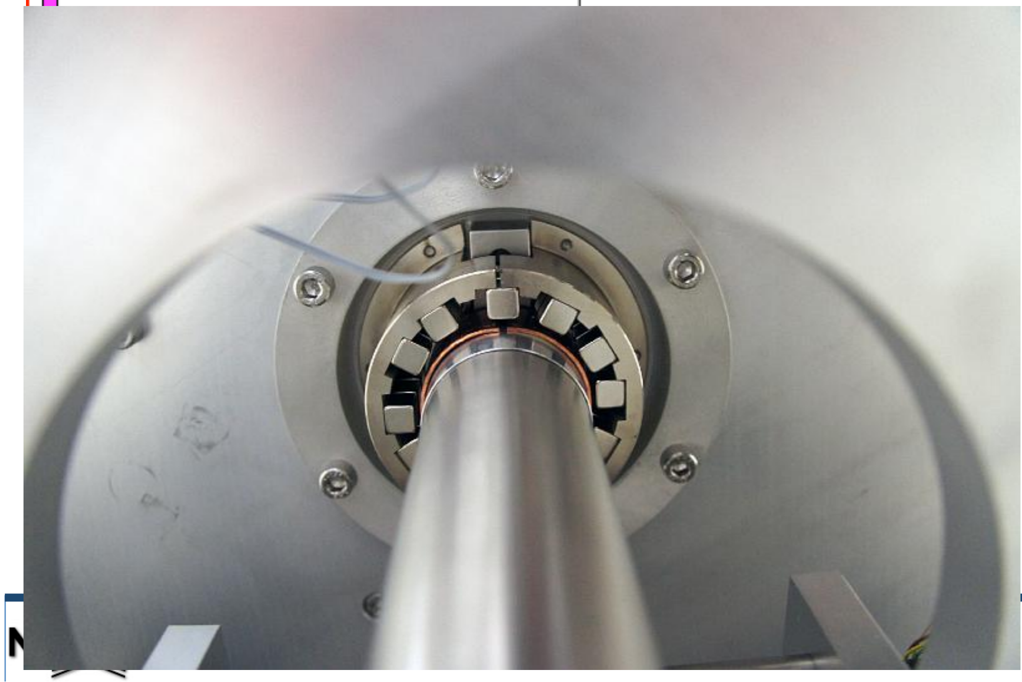


Finite element models used to identify all modes of the system



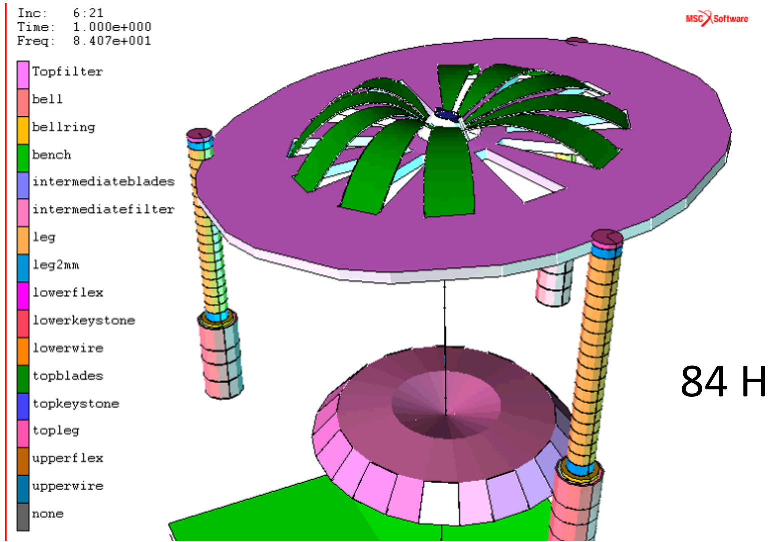


IP leg modes



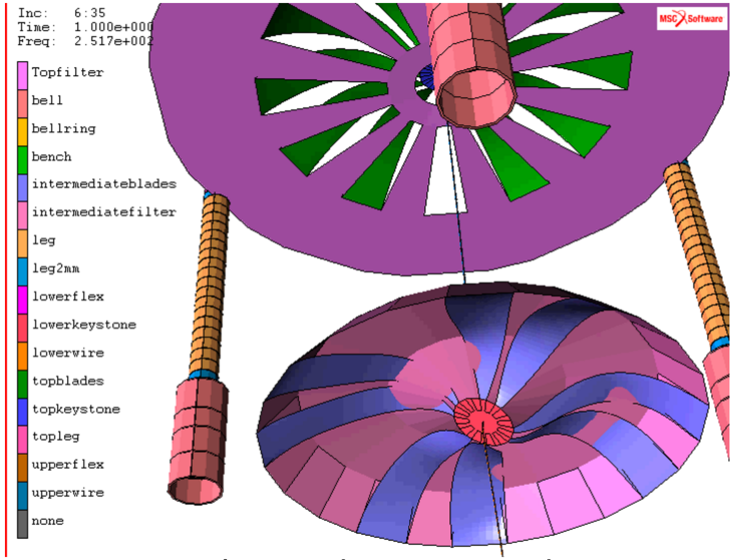
Where needed passive eddy current dampers can be used to lower Q-factor of higher order resonances

Finite element model: Higher order modes



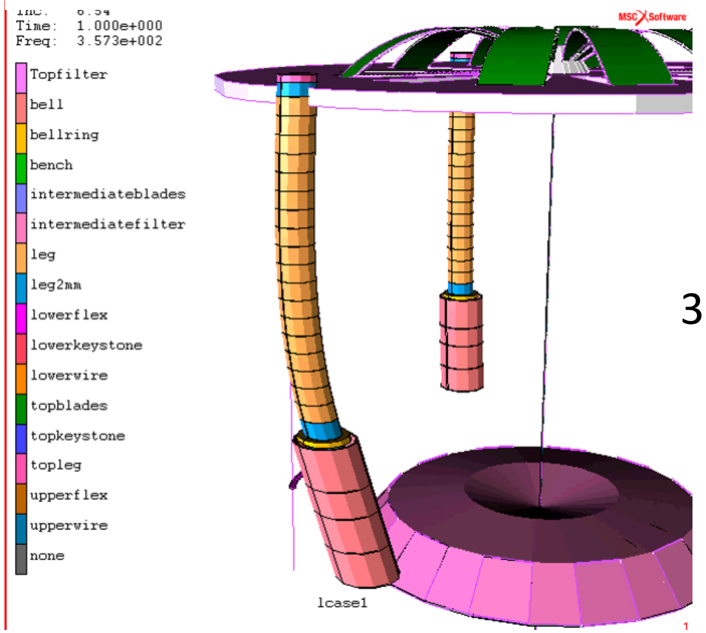
84 Hz

252 Hz



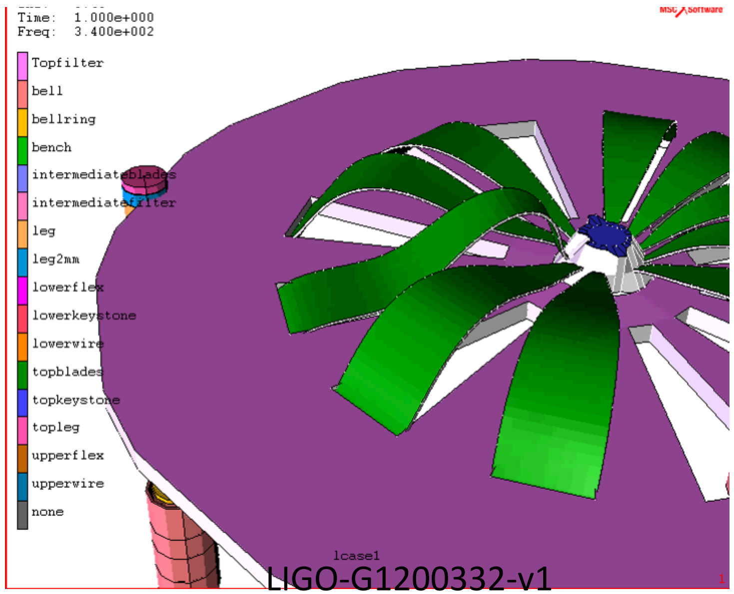
Non-rigid leg modes

Higher order GAS modes

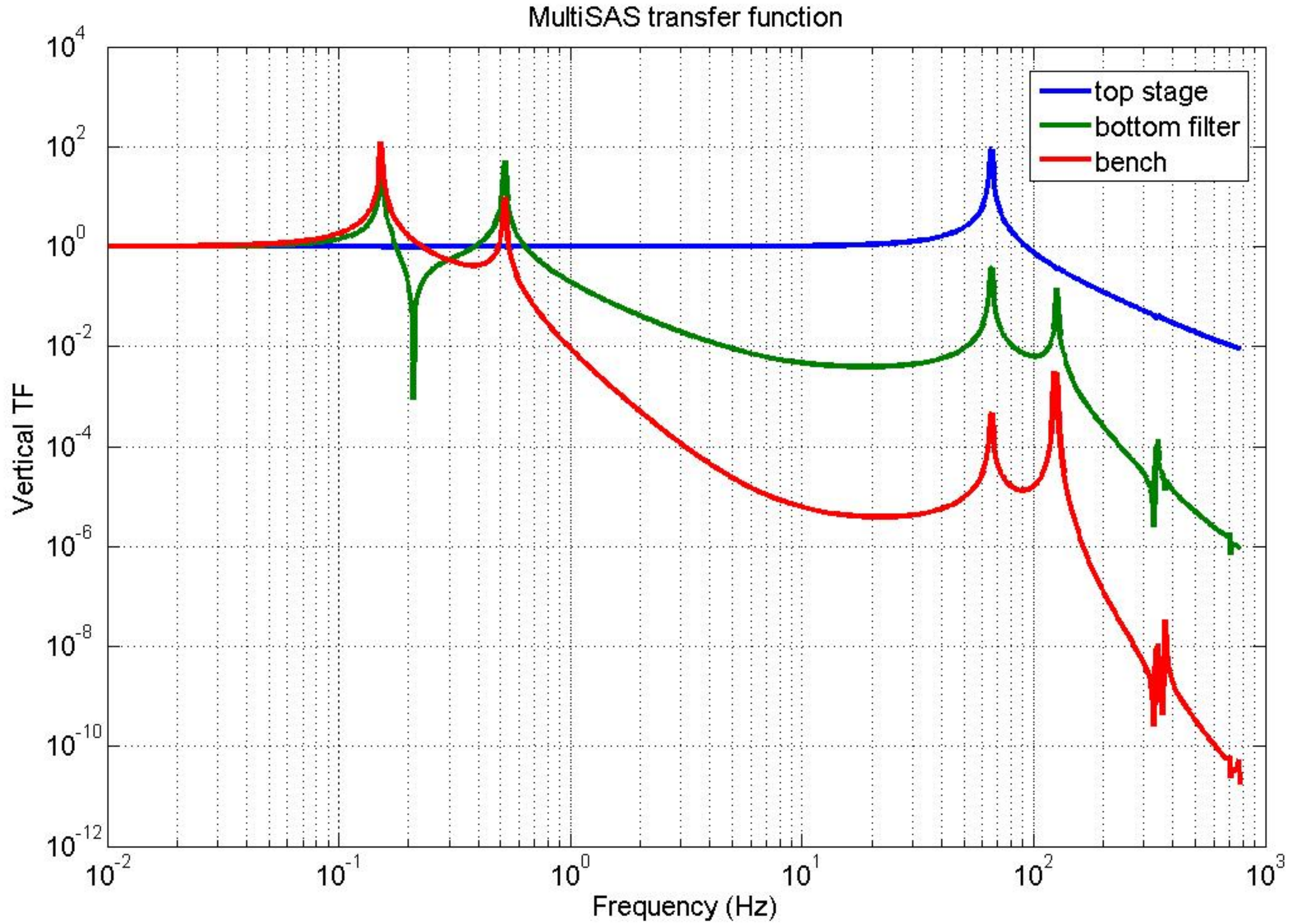


357 Hz

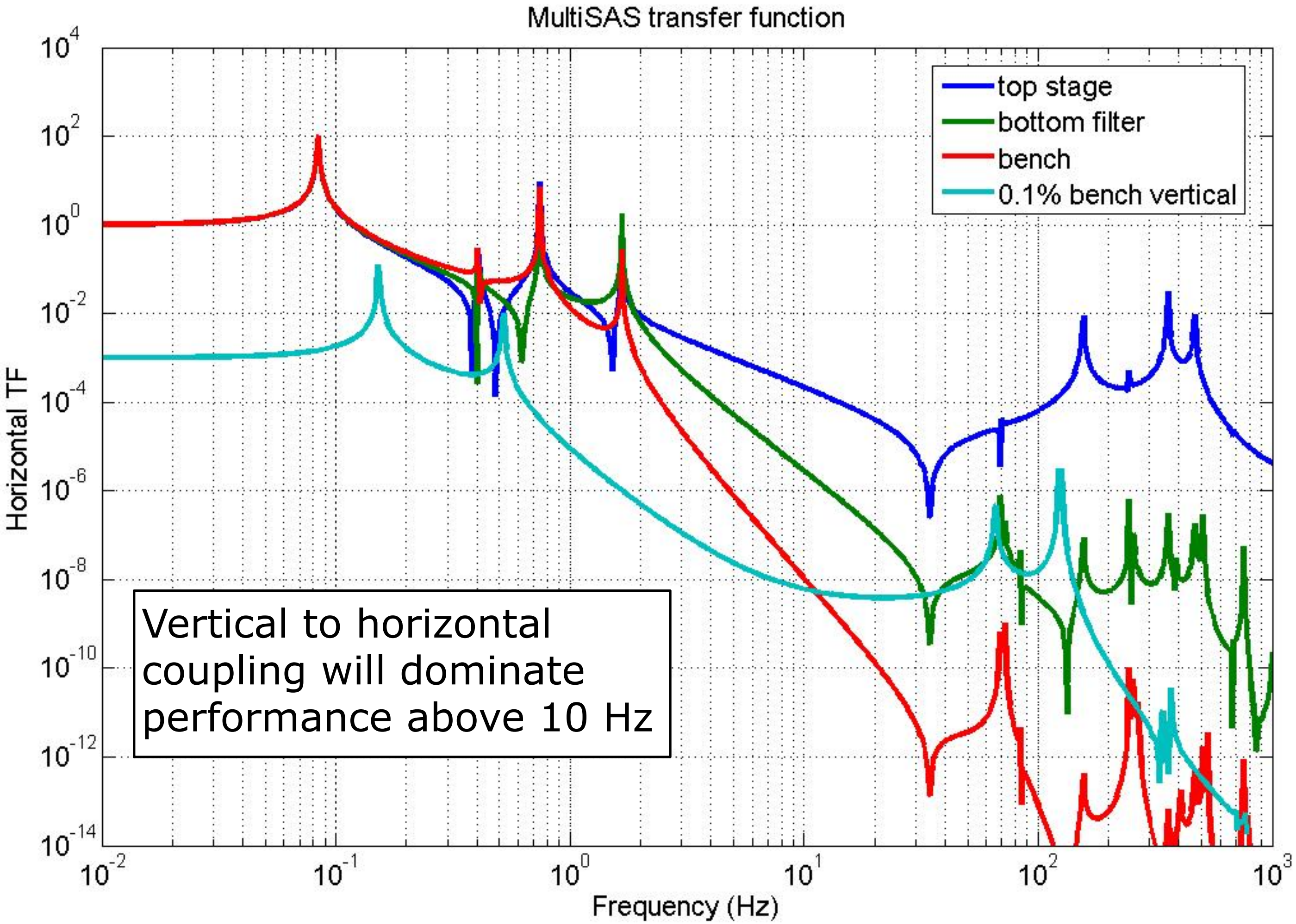
340 Hz



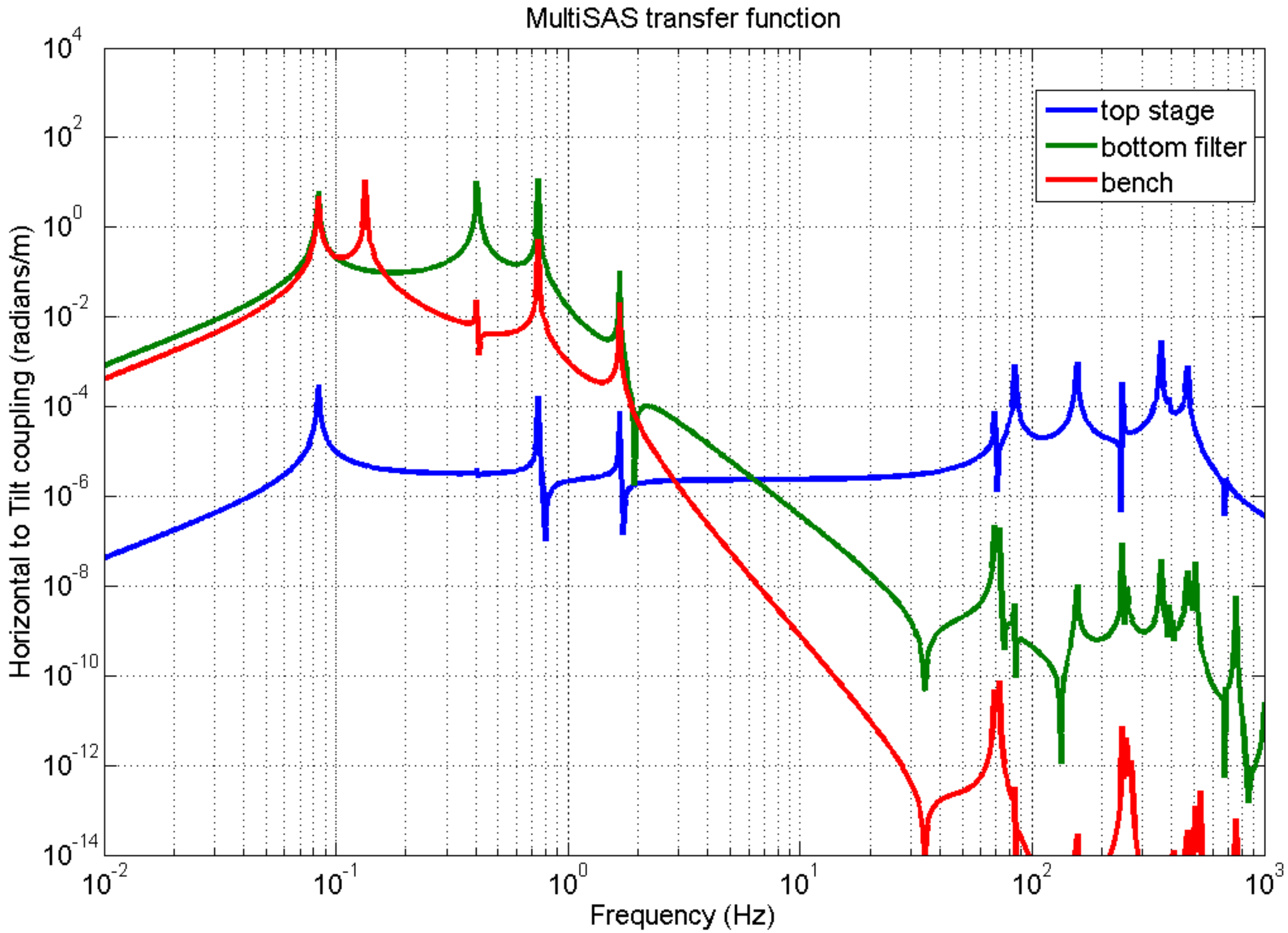
Simulated performance
Vertical transfer function



Simulated performance
Horizontal transfer function

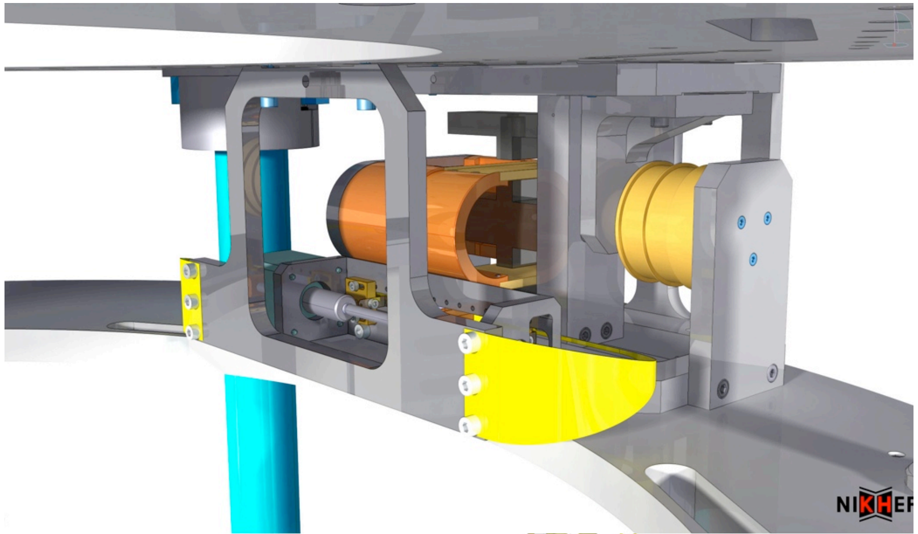


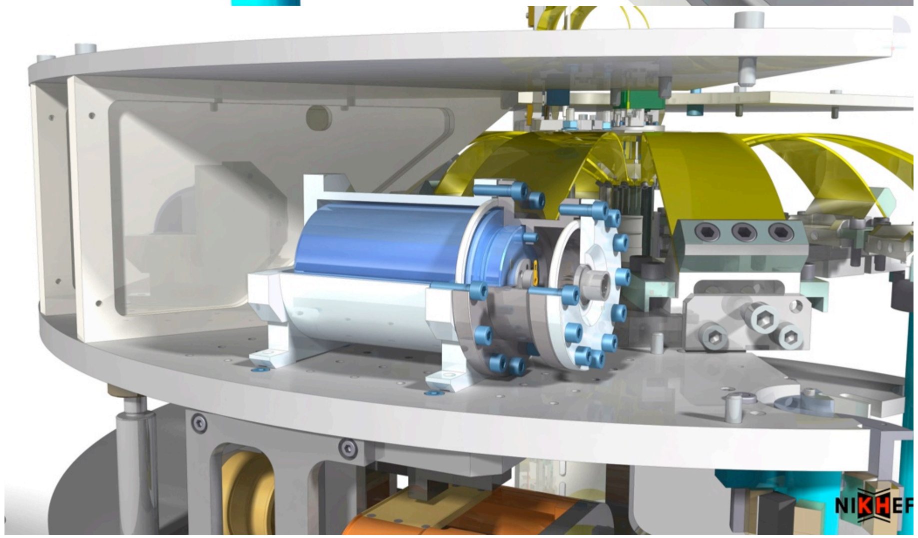
Simulated performance
Horizontal to tilt coupling



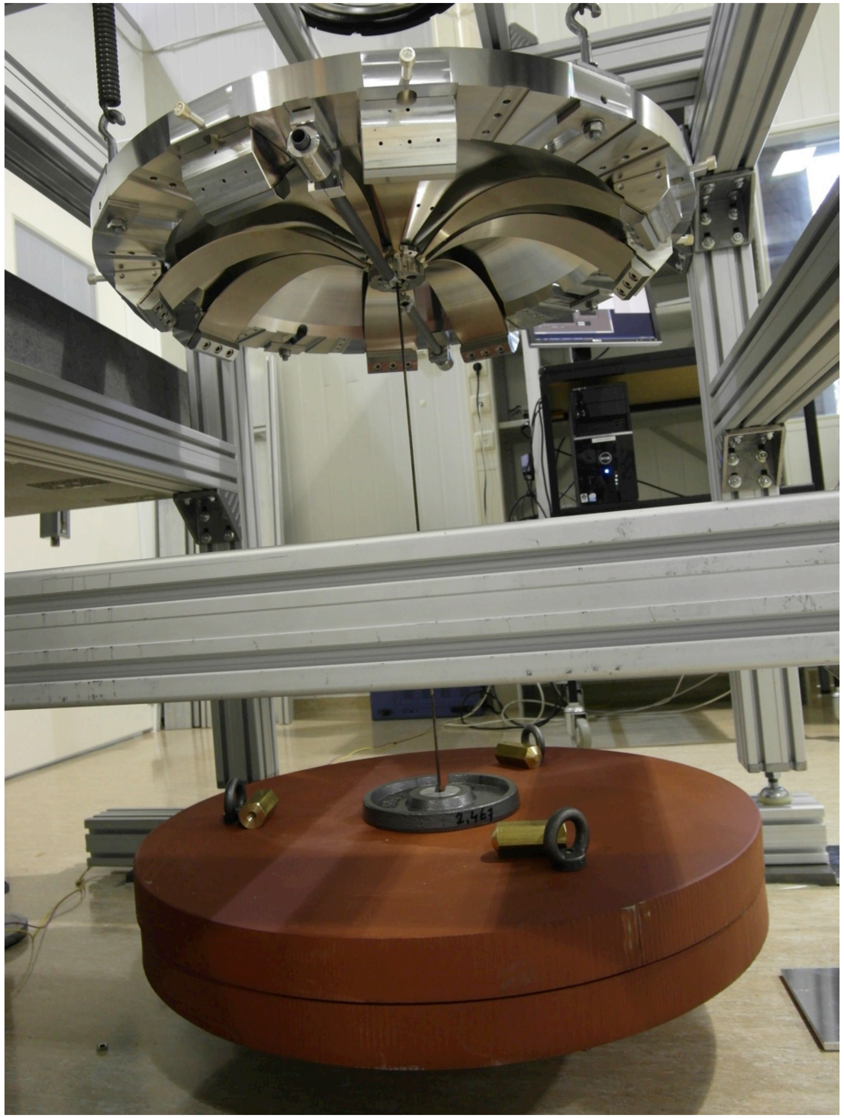
Control systems for DC positioning and resonance frequency damping

- Static positioning
  - Eight stepper motors for bench movement in 6 DOF
  - Used for long-term temperature effects
  - Tilt correction of optical bench
- Dynamic controls
  - 3 horizontal LVDTs
  - 3 horizontal L4-C geophone
  - 1 vertical LVDT is each filter
  - 3 horizontal and 1 vertical co-located voice-coil actuators
- Angular modes of bench controlled via direct feedback on bench itself



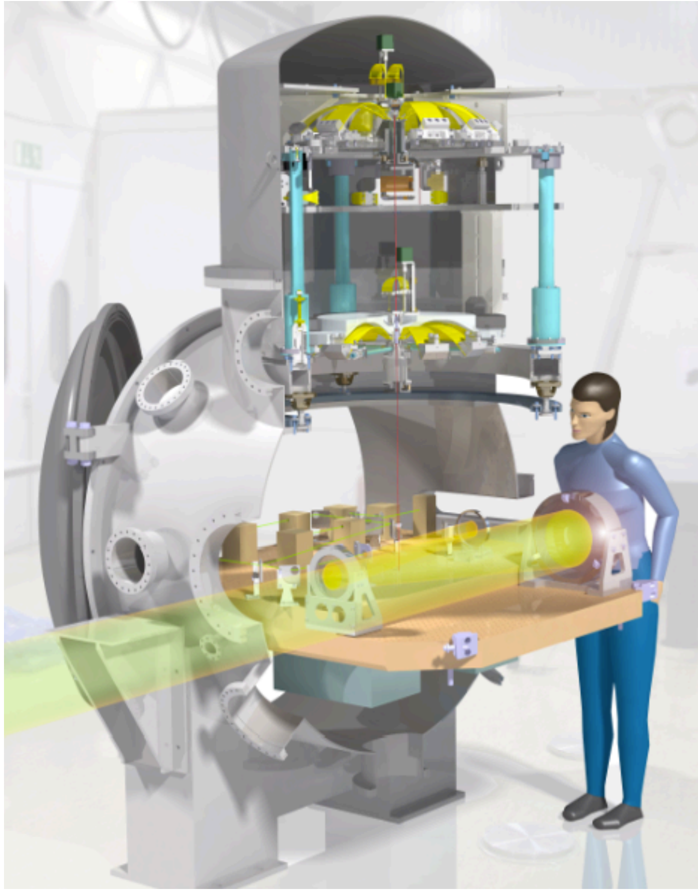


Construction has started, first prototype will be completed by summer 2012



Summary

- Five suspension systems for Virgo's end benches and alignment optics
- MultiSAS is a hybrid isolation system in which bulk attenuation is provided passively
- (Inverted) pendulums and anti-spring vertical filters
- Stringent requirements
  - Angular requirements are most challenging
- Current design performance
  - Vertical: 90 dB @ 10 Hz
  - Horizontal: 160 dB @ 10 Hz, limited by vertical -> horiz. coupling > 10 Hz
  - Rotational: 160 dB @ Hz, horiz. -> tilt coupling
- First prototype ready this summer



Thank you for your attention