Suspension design: impact on Vacuum and Cryogenics

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Purpose of ET suspension system

Suspension in vacuum of:

- Test masses (main mirrors) that have to follow their geodesic
- Other optical elements that generate, transport and detect main and auxiliary light beams

Function

- Avoid spurious motion resulting in position noise, decoupling light and masses from environment
- Control position and angle to bring and keep the interferometer on its working point

Main difficulty: very high attenuation and dynamic range required:

- 300 μm due to tides
- 10^{-8} m rms at 1 Hz underground
- Position noise 10^{-21} m $Hz^{-1/2}$
- Vacuum/cleanliness and cryogenics

Size of the task

For each of the six interferometers:

- maximum isolation must be provided for eleven mirrors
  - 4 Fabry-Perot cavity mirrors,
  - 1 Beam splitter,
  - 1 Signal Recycling mirror
  - 1 Power Recycling mirror
  - 4 folded telescope mirrors

for a total of **66 high performance suspensions**.

- Other optical elements amount to about 10:
- folding mirrors
- optical benches
- filtering cavity mirrors

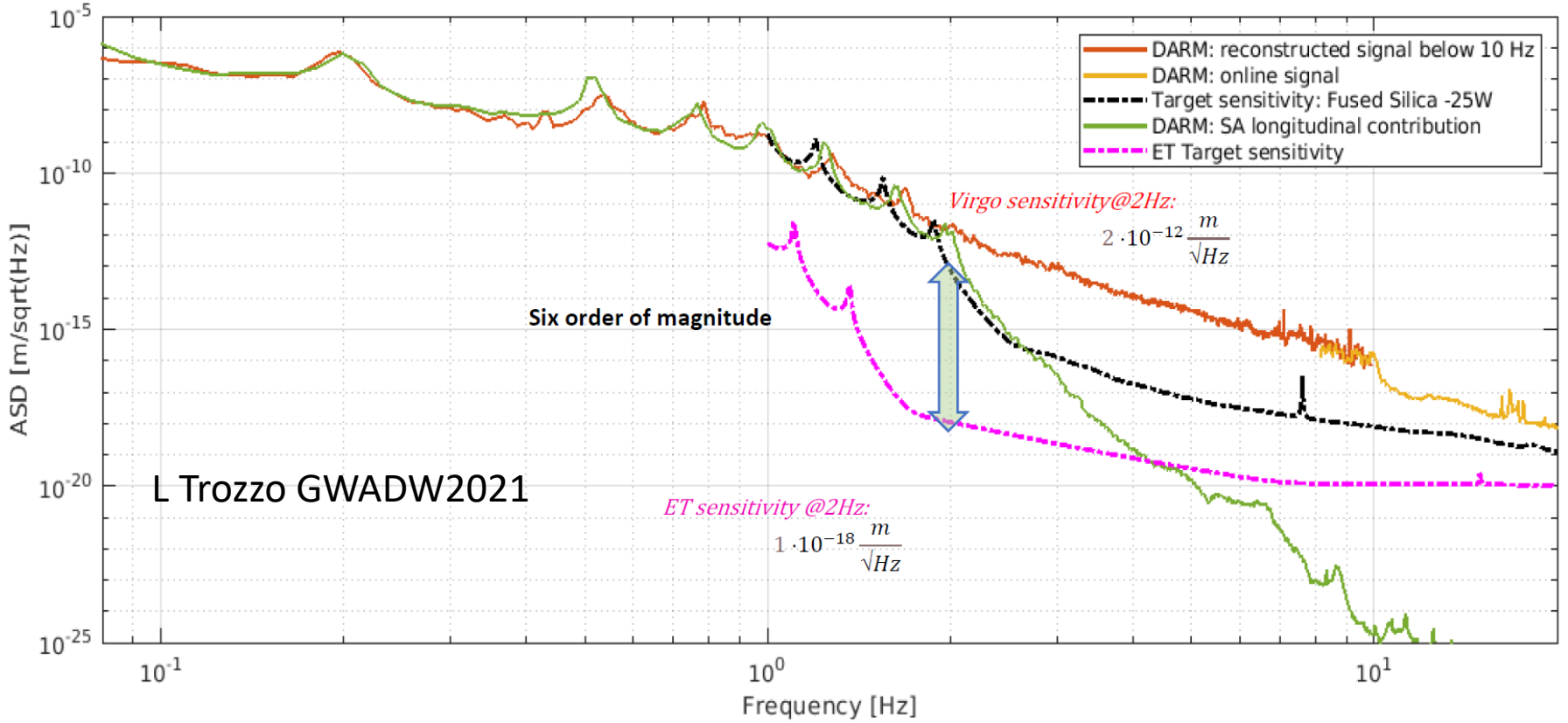
Which amount to **60 auxiliary optics suspensions**.

The exact number will be defined with the detailed design of the warm and cold optical schemes.

Frequency band involved

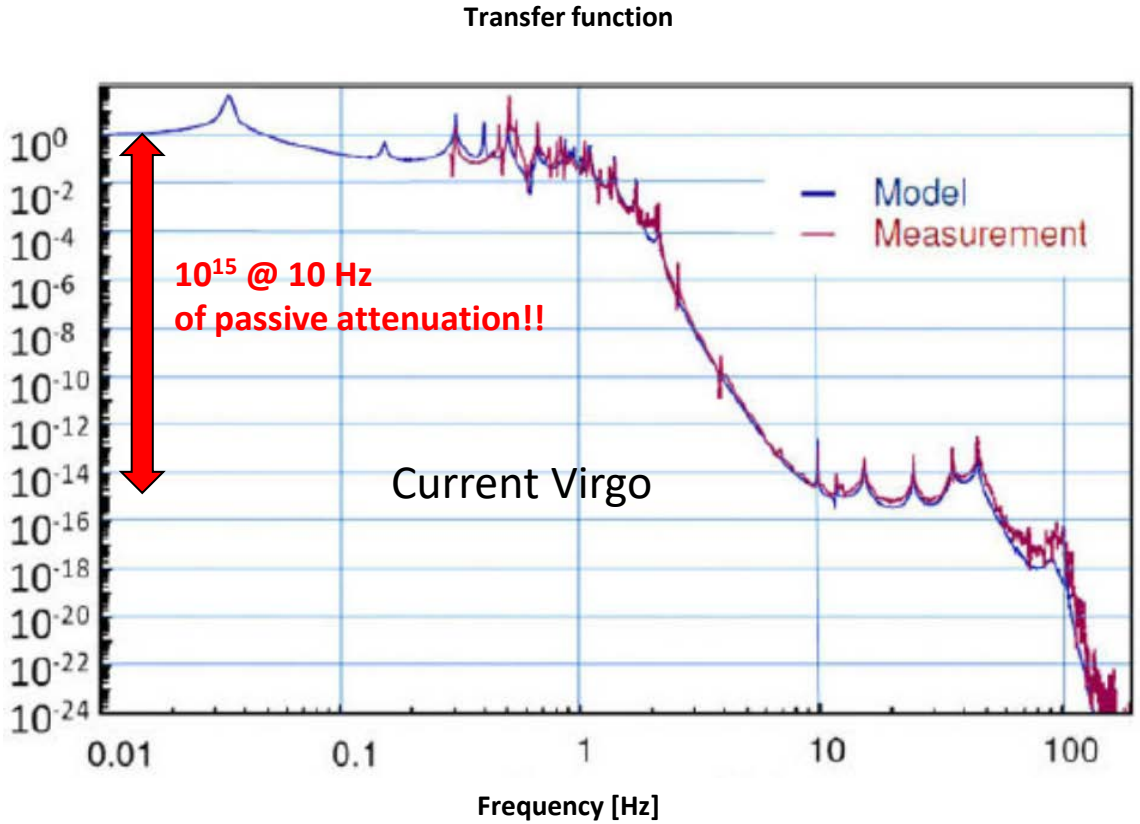
- Detection band: 3 Hz – 10 kHz
- Control band: overlaps up to ten(s) of Hz
- Extends down to 100 μHz (tides)

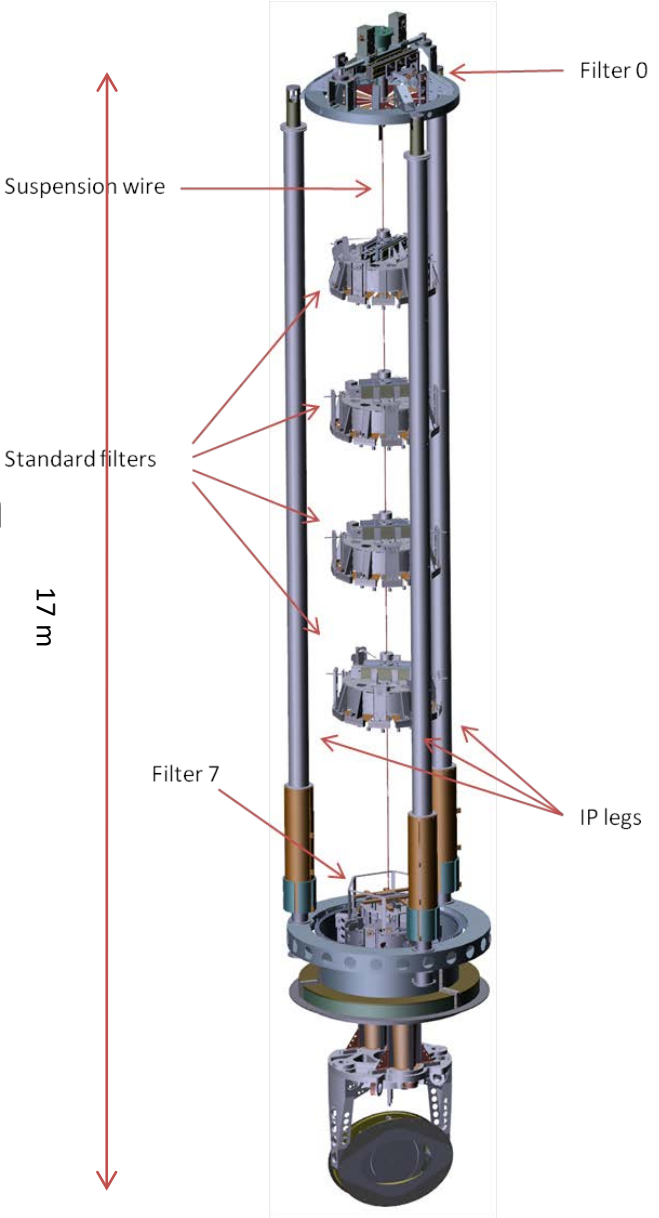
To be compared with vibrations from vacuum pumps, cooling devices



The Superattenuator

- Provides passive vibration isolation in 6 degrees of freedom above normal mode frequencies (around 1 Hz)
- Nominal solution based on Virgo Superattenuator but lengthened to 17 m (R&D aims at 10 m, if there is a gain

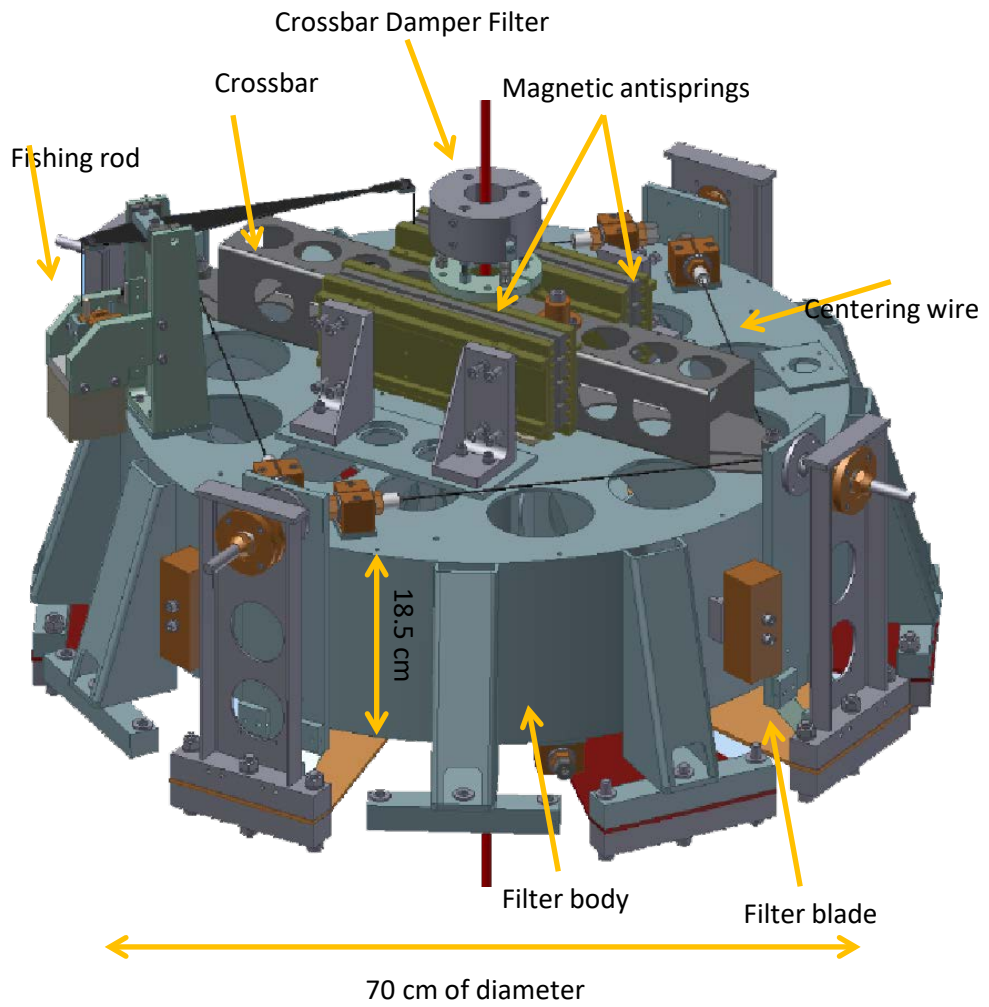




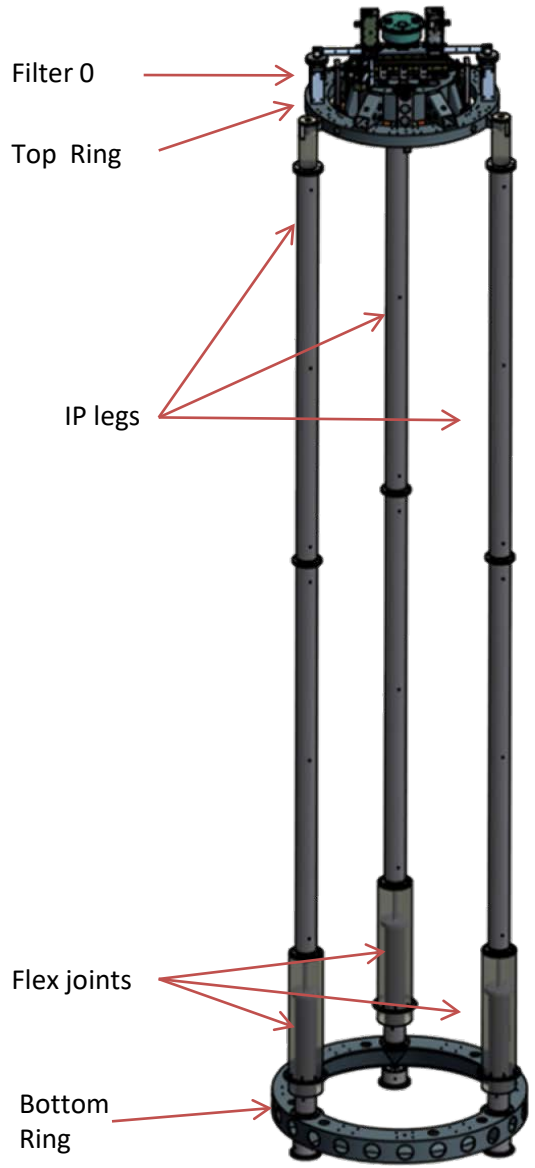
Component: seismic filter

- Supports also signal cables to payload
- Rigid steel
- Ni-plated maraging steel
- Rare earth magnets
- LVDT copper coils
- Stepping motor for vertical adjustment

- Materials successfully used in Virgo at room temperature
- R&D toward simpler structure

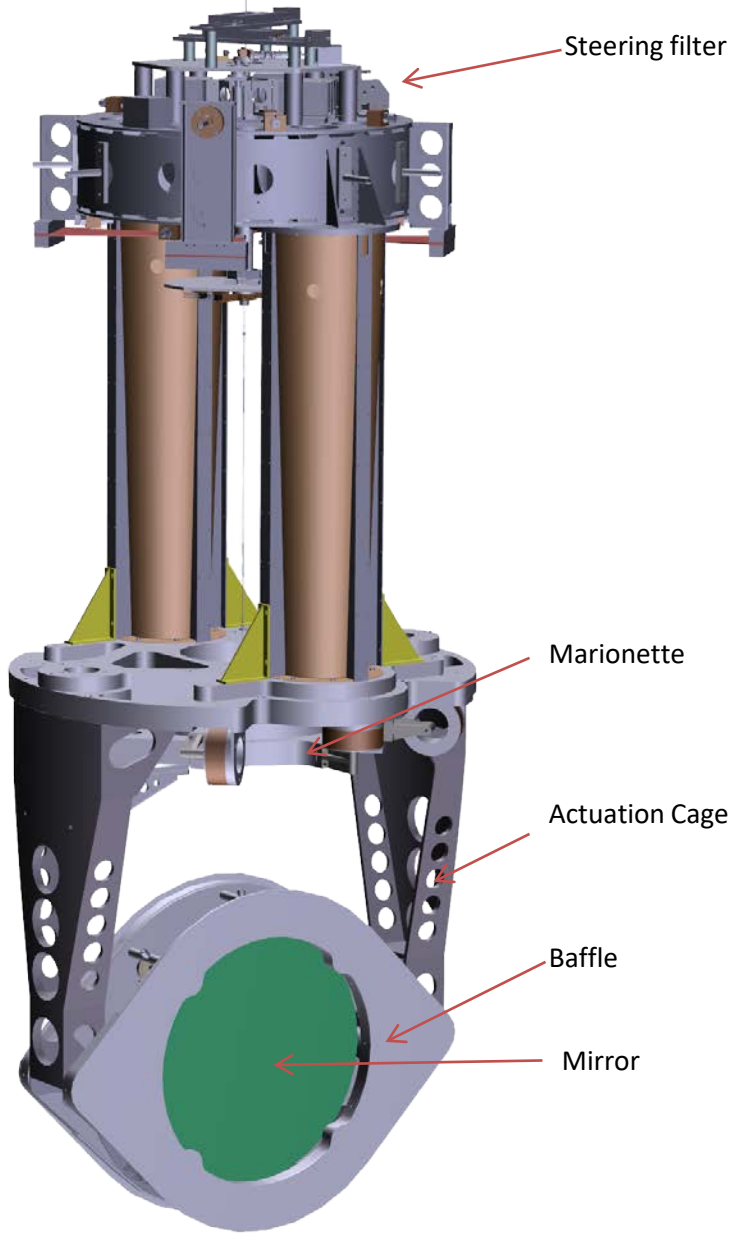


Component: inverted pendulum

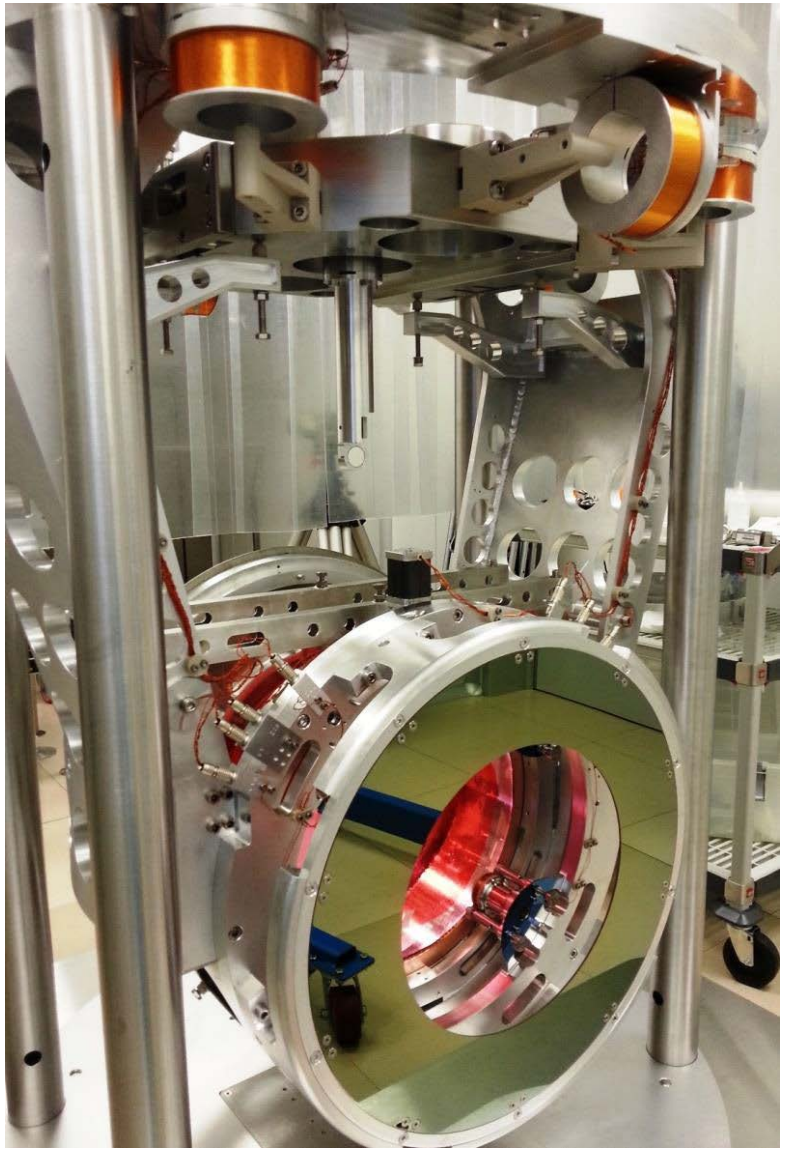


- Very low eigenfrequency low pass filter
- Stainless steel, Aluminum
- Supports signal cables that go down to the payload
- Filter 0 similar to filters + copper coils for actuation
- Piezoelectric actuators
- Bottom ring: interface to supporting structure and ground

Component: the payload



- Includes:
  - Coils for mirror and marionetta steering
  - Baffle for diffused light
  - Actuation cage and safety structure



Control components

AdVirgo Superattenuator: Control system setup

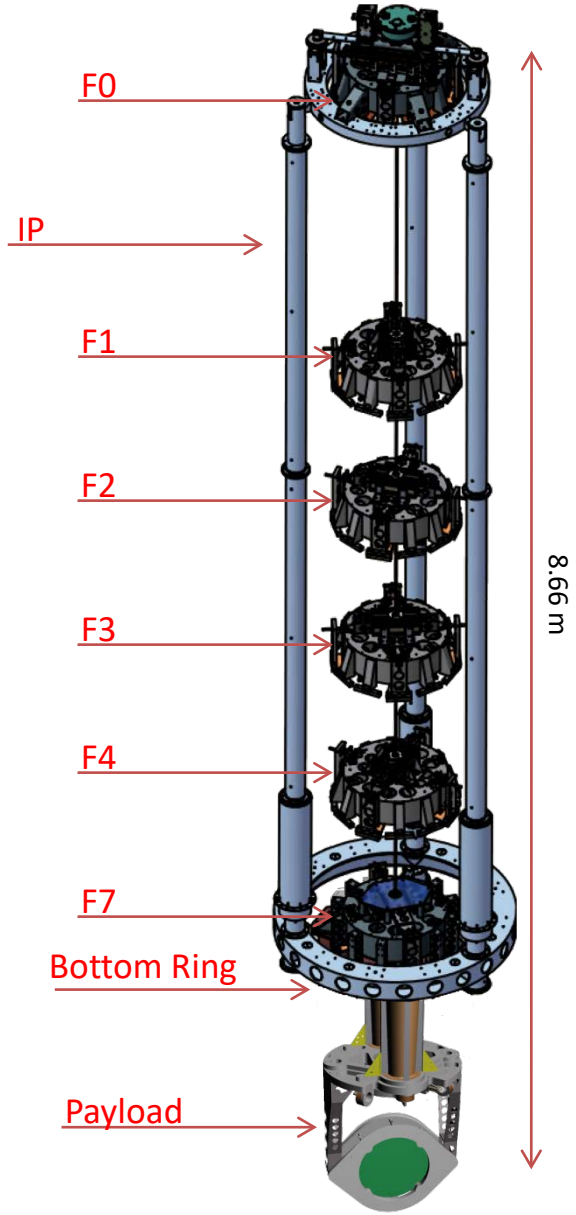
- 18 LVDTs of 3 different types
  - 9 Vertical LVDTs (F0 – F7 Crossbar, Bottom Ring)
  - 3 F0 Horizontal LVDT
  - 6 F7 LVDTs

- 5 Accelerometers of 2 different types installed on F0:
  - 3 Horizontal Accs
  - 2 Vertical Accs

- 23 Coils of 4 different types
  - 5 F0 Coils
  - 6 F7 Coils
  - 8 Marionette coils
  - 4 Mirror coils

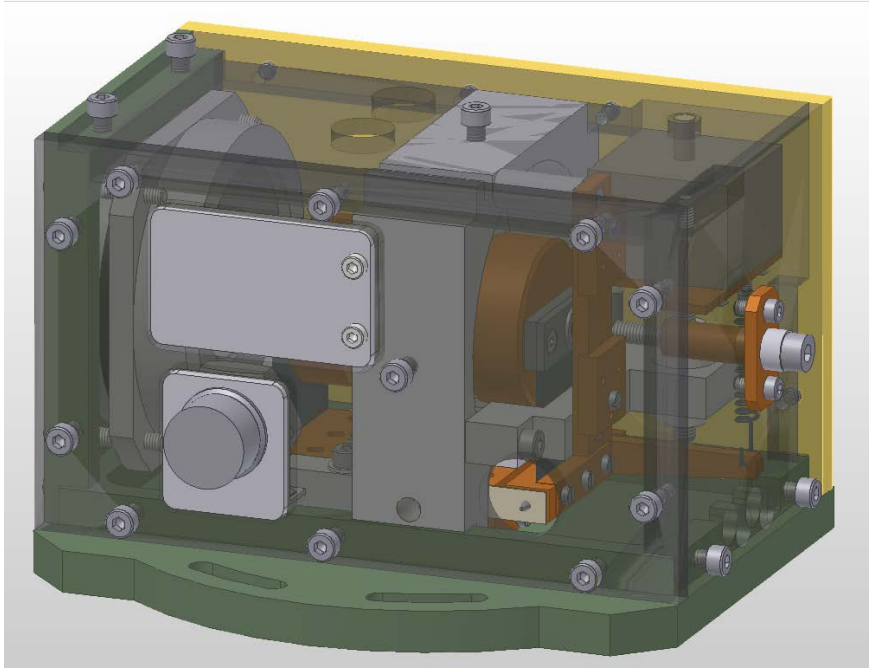
- 3 Piezos on bottom ring

- 21 Motors
  - 1 Top screw F0 vertical motor
  - 3 F0 trolley motors
  - 6 Fishing rod motors
  - 2 Marionette motors
  - 4 F7 motors
  - 5 Accelerometer motors



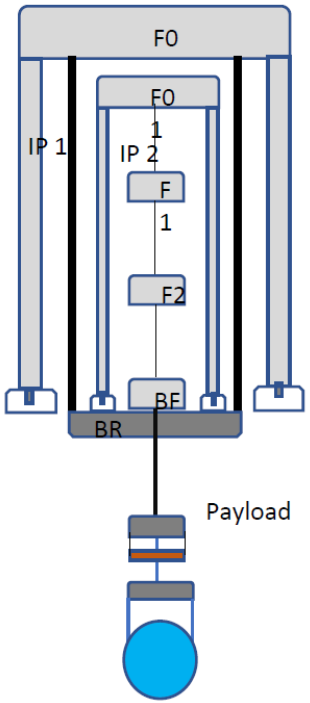
Control components: sensors

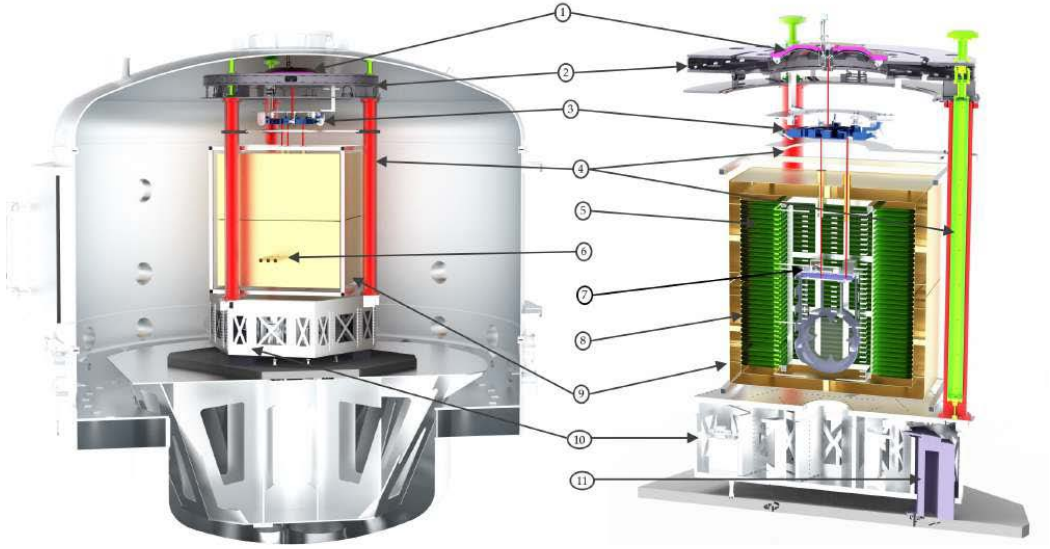
- Sensors under development, currently e.m. read out, development of optical read out
- Typical em read out devices



Height reduction

- Reduction of cavern height is expected to reduce costs (to be evaluated)
- Need to increase attenuation, preferrably early in the chain
- Developments:
  - Nested Inverted Pendulum (L Trozzo, NGSA INFN project)
  - Susp chain (BHETSA MIUR project)
  - Active seismic platform E-TEST (C Collette, Interreg Euregio Meuse-Rhine)



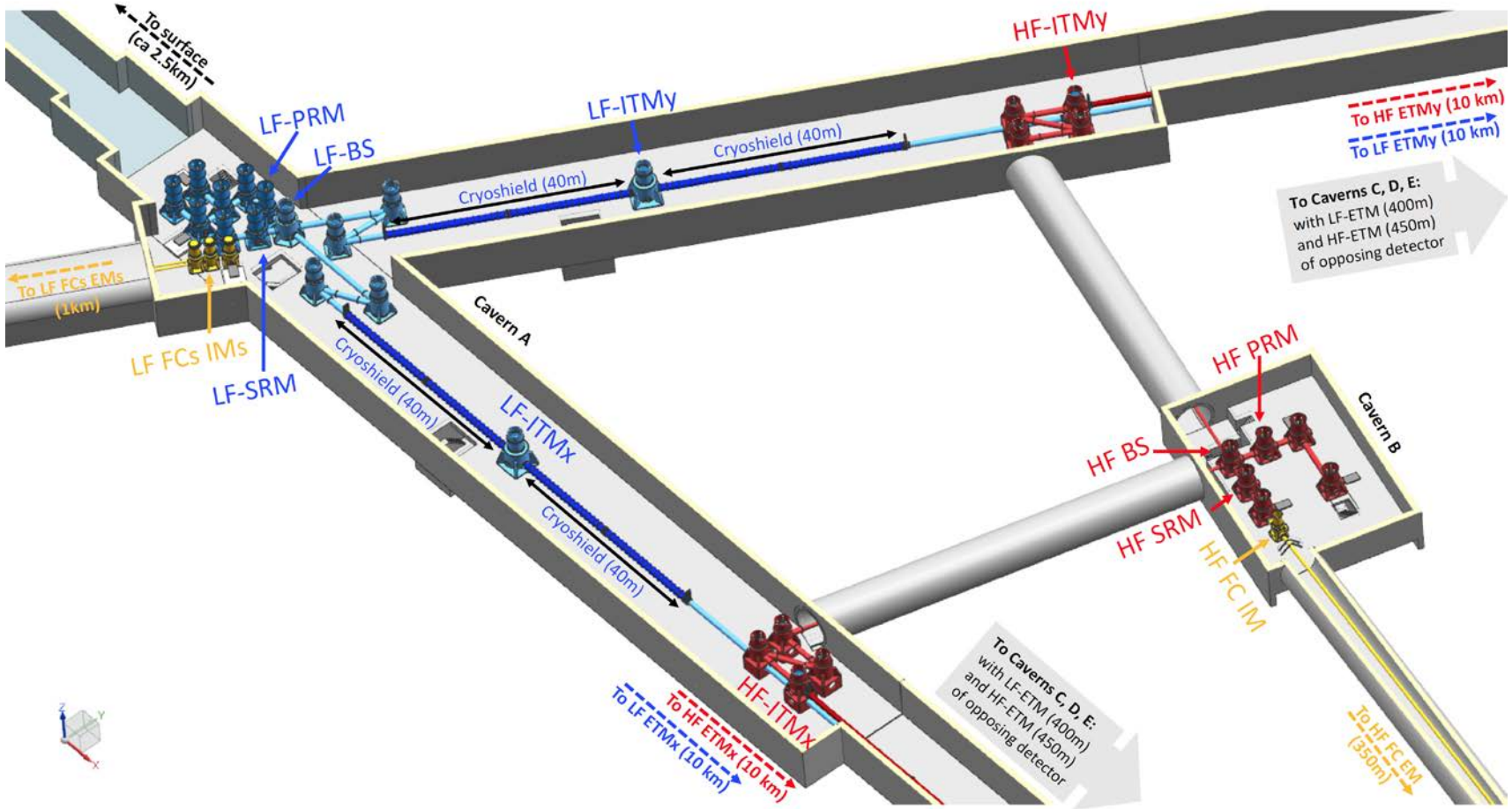


Access needs and cleanliness

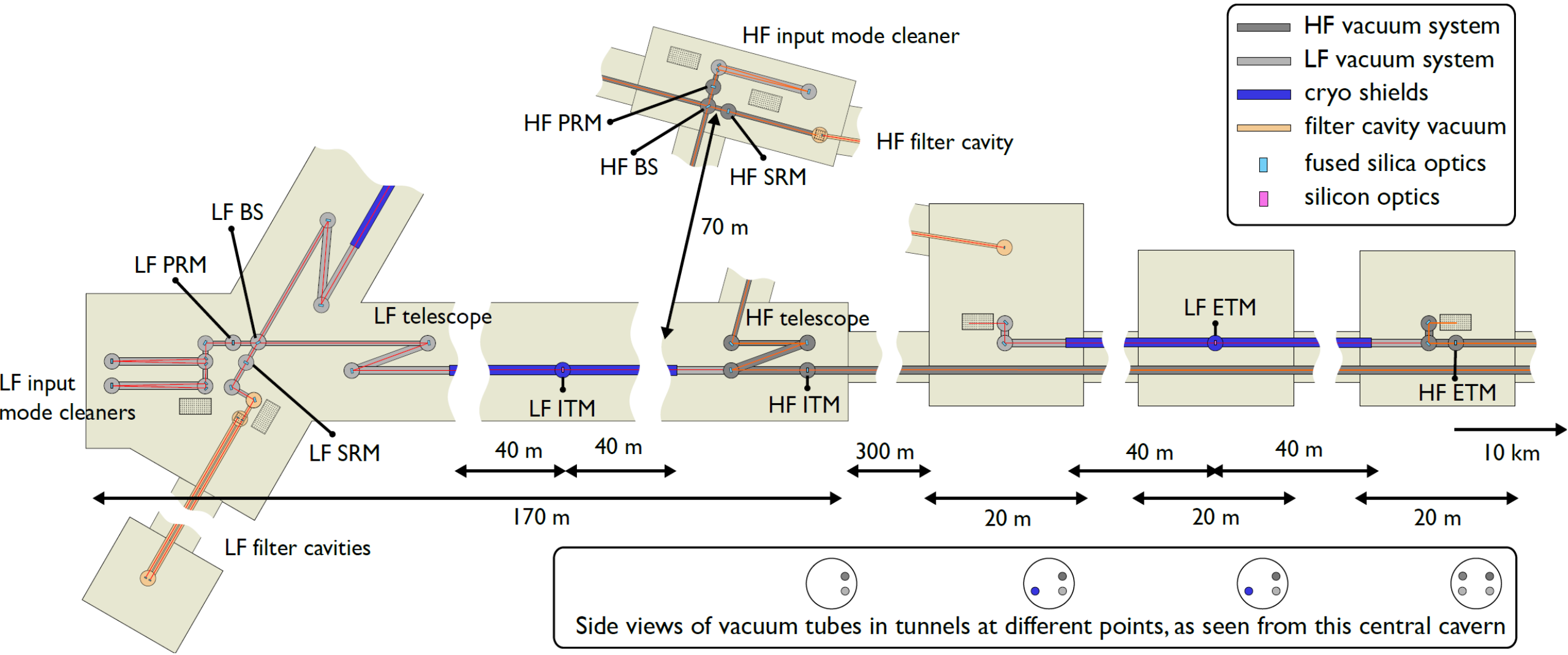
- Unless a different (space) approach is adopted, access to suspensions is required for tuning and repair, without considering mirror access
- Implications on:
  - Cleanliness, dust
  - Outgassing
  - Accidents with mirrors, …
- Differential vacuum?
- Movable separating roof + conductance for wire suspension?
- Vacuum section
- Heating and cooling?
- Electrostatic charging

Layout and floor occupancy

- Current scheme at one triangle vertex



Layout and floor occupancy



Diffused light

- Interferometry uses a coherent monochromatic beam
- Information is included in sidebands resulting from main beam phase modulation
- In presence of matter, there is light diffusion at some level
- Diffused light bounces back from vibrating surfaces
- If it makes to the photodiodes, it degrades the phase information

- Vibration isolated light absorbers
- Viewport antireflective coatings

Cold mirror special needs

- Cryogenics
- Insulation
- Screens from warm surfaces
- Height for thermal noise reduction
- Local position control: line of sight between mirror, marionetta to reference laser and sensor
- Current vacuum tank with triple insulation (see talk by Stefan Hanke, Paola Puppo, Steffen Grohmann): 4.7 m diameter, 6.4 m height

Suspension baseline

The suspension baseline includes in vacuum

- An inertial platform, actively controlled
- An inverted pendulum on top of the inertial platform
- A seismic attenuation chain
- A steering filter
- A marionette
- A mirror with reaction mass
- Signals (currents) have to be sent and collected -> cabling and feed-through
- Suspension for cold fingers (ET-LF)-> Cooling circuit

Considering:

- optical fiber signal transmission for sensing and control
- Power supply using light + photovoltaic conversion
- Height reduction to 10 m

Auxiliary suspensions

To suspend benches, beam folding mirrors, photodiodes for auxiliary beams

Noise requirements lower with respect to main mirrors

RMS position requirements similar to main mirrors' (TBC)

Many of them, with different requirements

Modular design?

Inertial platform

- Massive: suspension weight 1T+
- Equipped with local sensors (accelerometers)
- Possibly with interferometric readout
- Powerful actuation
- Tilt control requires a wide base

Seismic chain

- Seismic filters need to be hooked and cabled
- Some tuning at first installation
- Working under a tent, clean room class ?

Payload

- Mirror suspension is through low dissipation (fragile) fibers
- Protection needed during installation
- Mirror has a protection film to be removed in situ
- Cold payload has to be accessed in presence of thermal screens

Suspension division organization

ISB SUSP	WP1	Suspension chain	Passaquieti, Gerberding	design of standard filtering stages, interface stage between chain and payload and local controls for active damping of chain modes	seismic isolation platform, Payload design
	WP2	Cold payload design	Puppo, Hennig	payload thermal noise engineered design for ET-LF, design of mechanical interface with the cryocooler, design of mechanical interface with the last suspension stage, mirror and marionette local controls	suspension chain, test mass suspension stage, cryogenics, thermal compensation system
	WP3	Warm payload design	Frasconi, Barton	payload thermal noise engineered design for ET-HF, design of mechanical interface with the last suspension stage, mirror and marionette local controls	suspension chain, test mass suspension stage, thermal compensation system
	WP4	Test mass suspension	Hammond, Travasso	engineering design of fused silica (ET-HF) and crystalline silicon (ET-LF) suspension elements. Bonding technique selections. Manufacturing method selection. Fabrication.	cold and warm payload design
	WP5	Seismic isolation platform	Collette, Gennai	mechanical design and design of controls using advanced seismic sensors	suspension chains, inter-platform global controls
	WP6	Auxiliary optics suspensions	van Heijningen	mechanical design of suspensions for IMC, optical benches, filter cavities mirrors, etc.	inter-platform global controls, interferometer global controls, scattered light mitigation

Interface identification

- Meetings with other ISB divisions to identify interfaces
- Meeting with Vacuum and cryogeny identified a series of questions
- To be answered while proceeding in design
- Interface matrix filled in https://wiki.et-gw.eu/ISB/Suspensions/ISB_Susp_Interfaces

Tower vacuum

Suspension Division			I.1	I.2	I.3	I.4	I.5	I.6
			Suspension chain	Cold Payload Design	Warm Payload Design	Test-Mass Suspension	Seismic Isolation Platform	Auxiliary Optics Suspensions
WP IV.1 Tower Vacuum	**Antonio Pasqualetti**		Rigidity, resonant frequencies Cleanliness and residual gas pressure Feedthrough, electric and optical Access Modular system •Test mass suspensions •Recycling cavities •Auxiliary optics: mirrors, benches, passive and active elements	•Isolation of tower support concrete slab from concrete floor? •Scaling law for the vacuum chamber vs floor occupancy (structural analysis) •Presence of a separating roof + conductance? •Openings and access to the upper interferometer •Shield and operator interaction, frequent access and opening times, recovery from incidents •Shields and scattered light •Interaction of air streams with fibers, etc	•Isolation of tower support concrete slab from concrete floor? •Scaling law for the vacuum chamber vs floor occupancy (structural analysis) •Presence of a separating roof + conductance? •Openings and access to the upper interferometer •Shield and operator interaction, frequent access and opening times, recovery from incidents •Shields and scattered light •Interaction of air streams with fibers, etc	•Interaction of air streams with fibers, etc	•Isolation of tower support concrete slab from concrete floor? •Scaling law for the vacuum chamber vs floor occupancy (structural analysis) •Presence of a separating roof + conductance? •Openings and access to the upper interferometer	Modular system •Test mass suspensions •Recycling cavities •Auxiliary optics: mirrors, benches, passive and active elements

Cryostat and cryopumps

Suspension Division			I.1	I.2	I.3	I.4	I.5	I.6
			Suspension chain	Cold Payload Design	Warm Payload Design	Test-Mass Suspension	Seismic Isolation Platform	Auxiliary Optics Suspensions
WP IV.3 Cryostats and Cryopumps	**Christian Day**	**Roberto Cimino**	Space occupancy					

Cryogenic infrastructure

Suspension Division			I.1	I.2	I.3	I.4	I.5	I.6
			Suspension chain	Cold Payload Design	Warm Payload Design	Test-Mass Suspension	Seismic Isolation Platform	Auxiliary Optics Suspensions
WP IV.4 Cryogenic Infrastructure	**Steffen Grohmann**			Cooling •Mirror cooling •Definition of requirements on heat links •Suspension of heat links to be done by SUSP? •Where is the cryolink with respect to the suspension Cooling plant •Distance and floor occupancy •Noise and vibrations •Magnetic fields				

Detector cooling

Suspension Division			I.1	I.2	I.3	I.4	I.5	I.6
			Suspension chain	Cold Payload Design	Warm Payload Design	Test-Mass Suspension	Seismic Isolation Platform	Auxiliary Optics Suspensions
WP IV.5 Detector Cooling	**Piero Rapagnani**	**Steffen Grohmann**	Suspension of heat links to be done by SUSP?	Environment of test mass •Shields and scattered light •Shield and operator interaction, frequent access and opening times, recovery from incidents •Separating roof present + conductance? Heat Links interfaces		Cooling •Mirror cooling •Definition of requirements on heat links •Suspension of heat links to be done by SUSP? •Where is the cryolink with respect to the suspension (Newtonian Noise)		

Final comments

- The interaction between mirror suspensions and the vacuum and cryogeny system is complex:
  - Functionality
  - Constraints on materials
  - System design
  - Procedures
- Several iterations are needed to arrive at taking decisions that
  - allow to reach the performance required
  - do not spoil future developments
  - lead to a reliable and manageable system
  - lead to an affordable system

Thank you