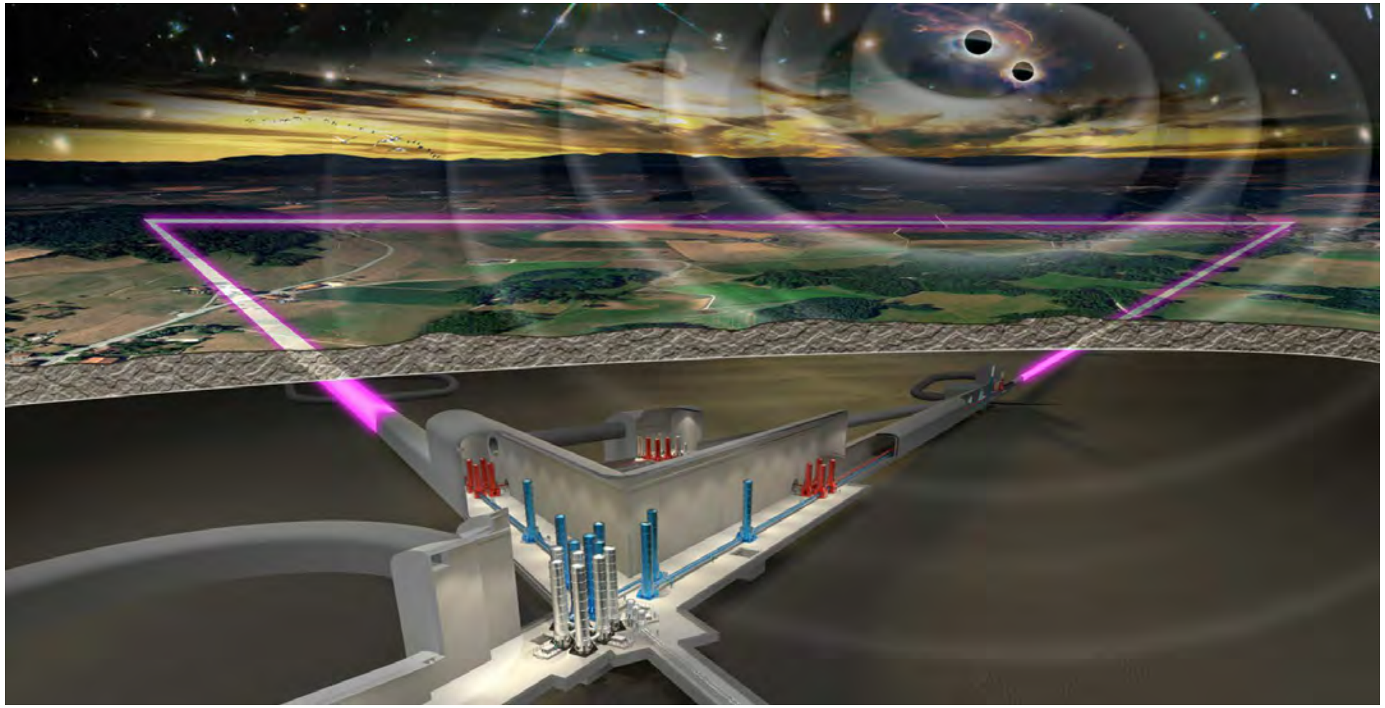
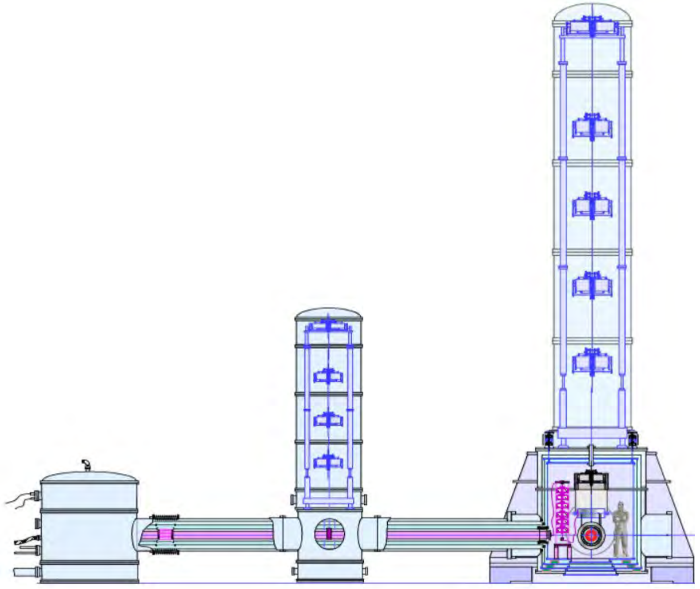
Einstein Telescope

Challenges in seismic isolation and vacuum

Mathijs Baars, Nikhef

Courtesy to LIGO, Virgo, KAGRA, and Einstein Telescope for pictures





Nikhef

ET EINSTEIN TELESCOPE

Introduction

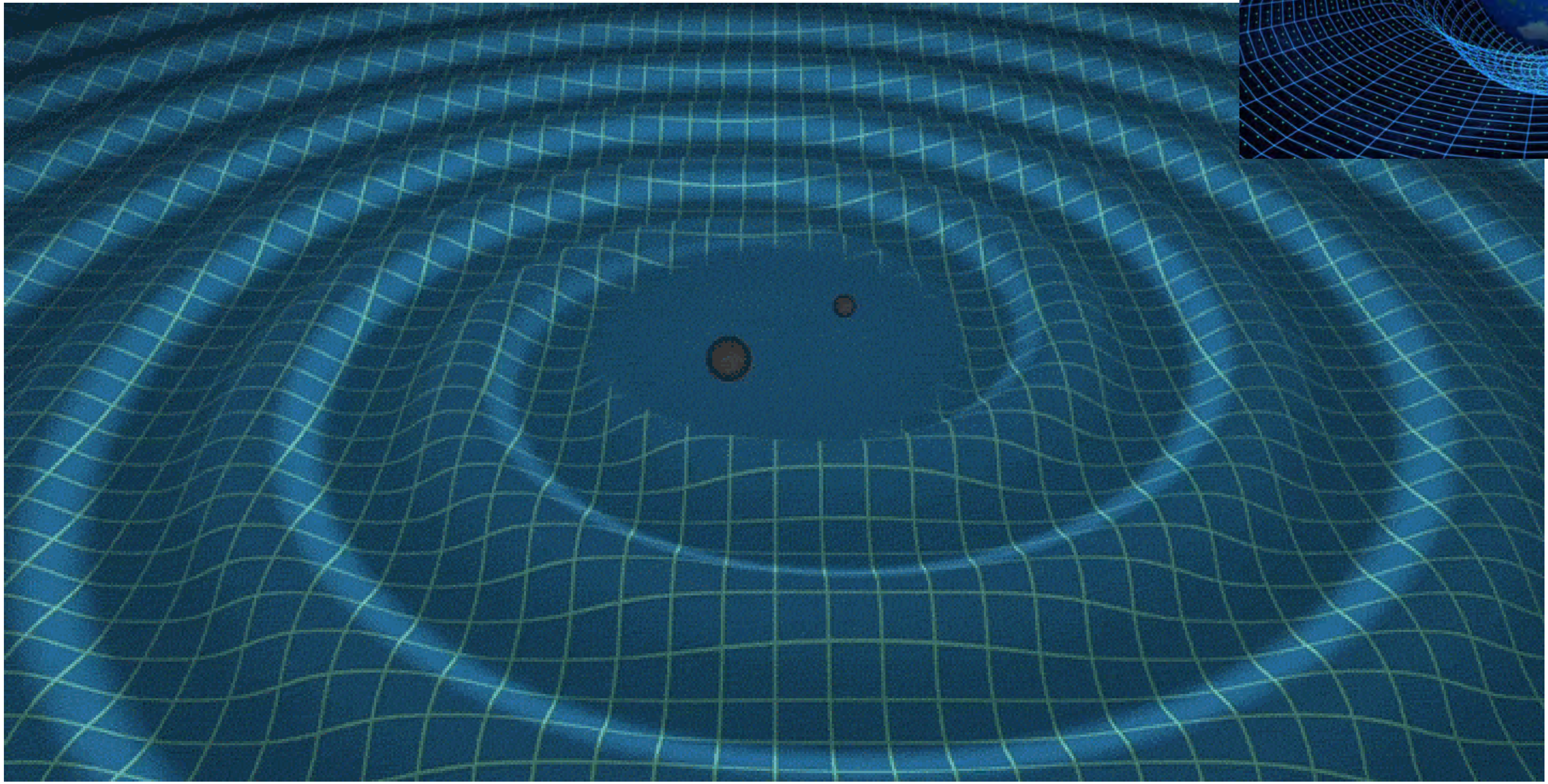
- Bachelor in mechanical engineering
- 4 years working experience at Nikhef as Design Engineer
- ETpathfinder from concept phase to installation
- Starting on ET

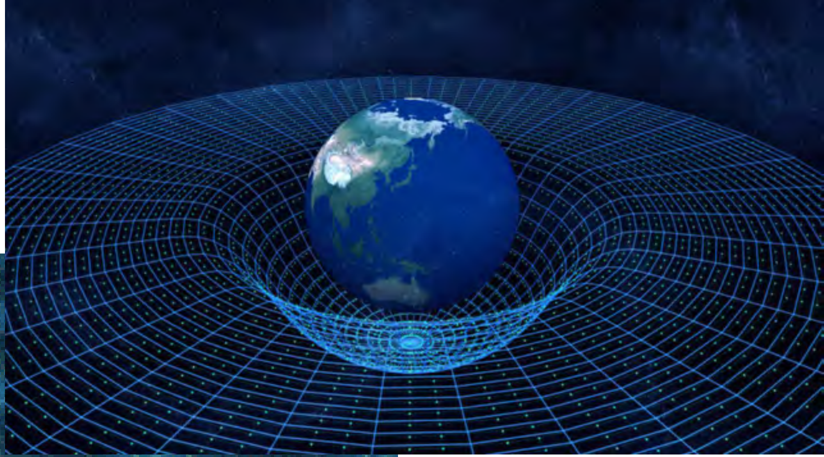
www.etpathfinder.eu

Einstein Telescope

- Gravitational wave detector
- Preparatory Phase 1: Design and Preparation phase.
  This phase will end with the selection of the site: EMR or Sardinia.

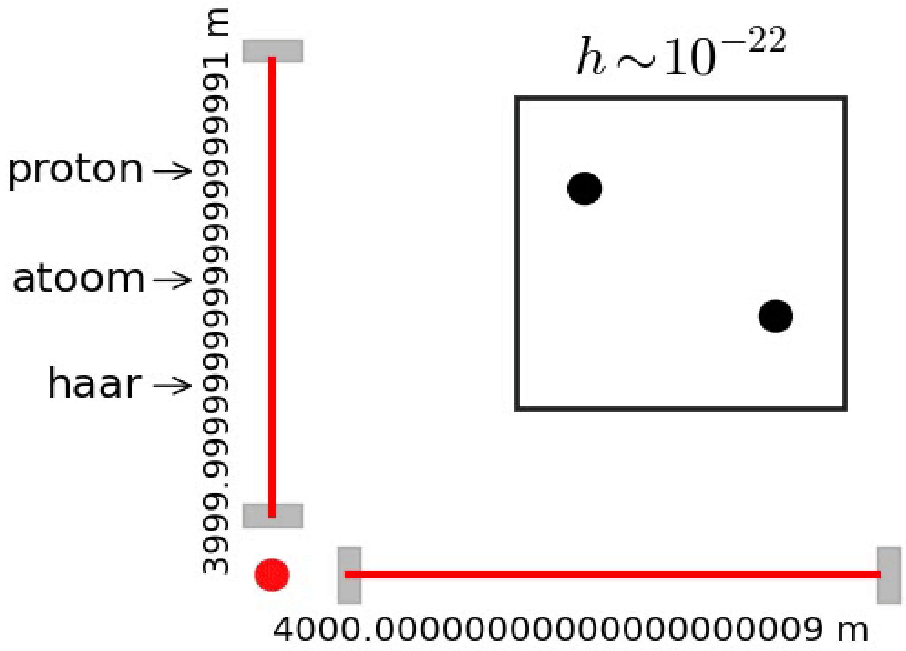
What is a gravitational wave?

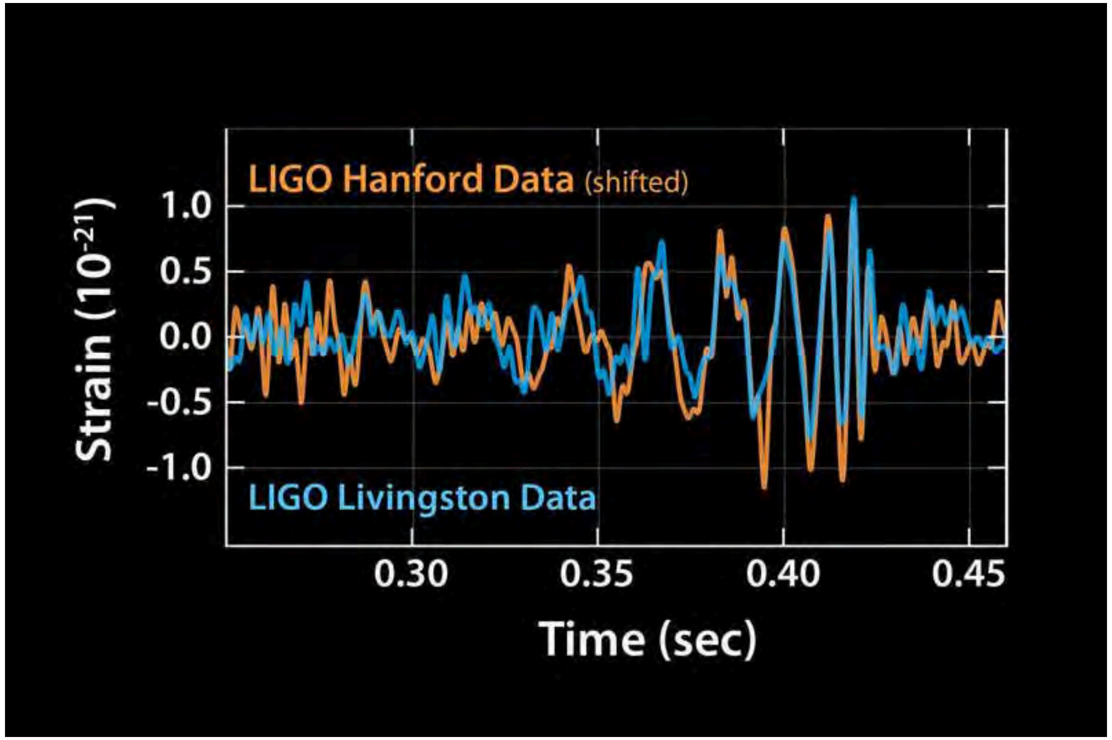




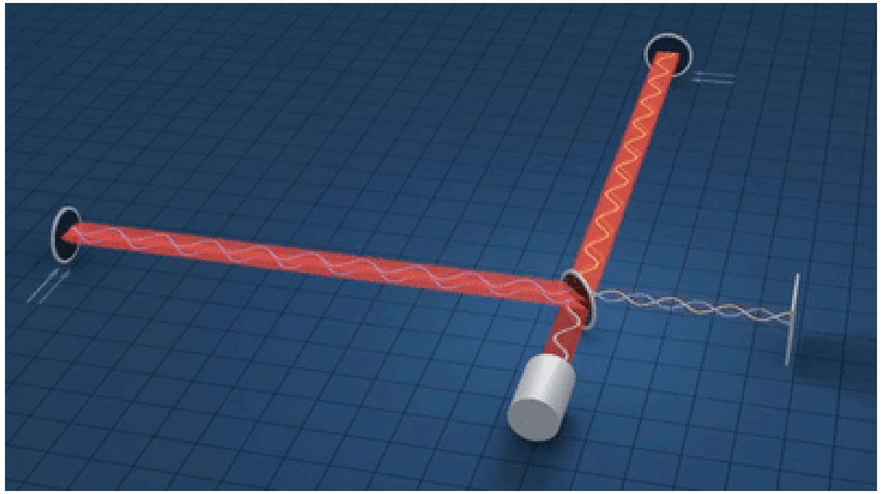
What is a GW detector?

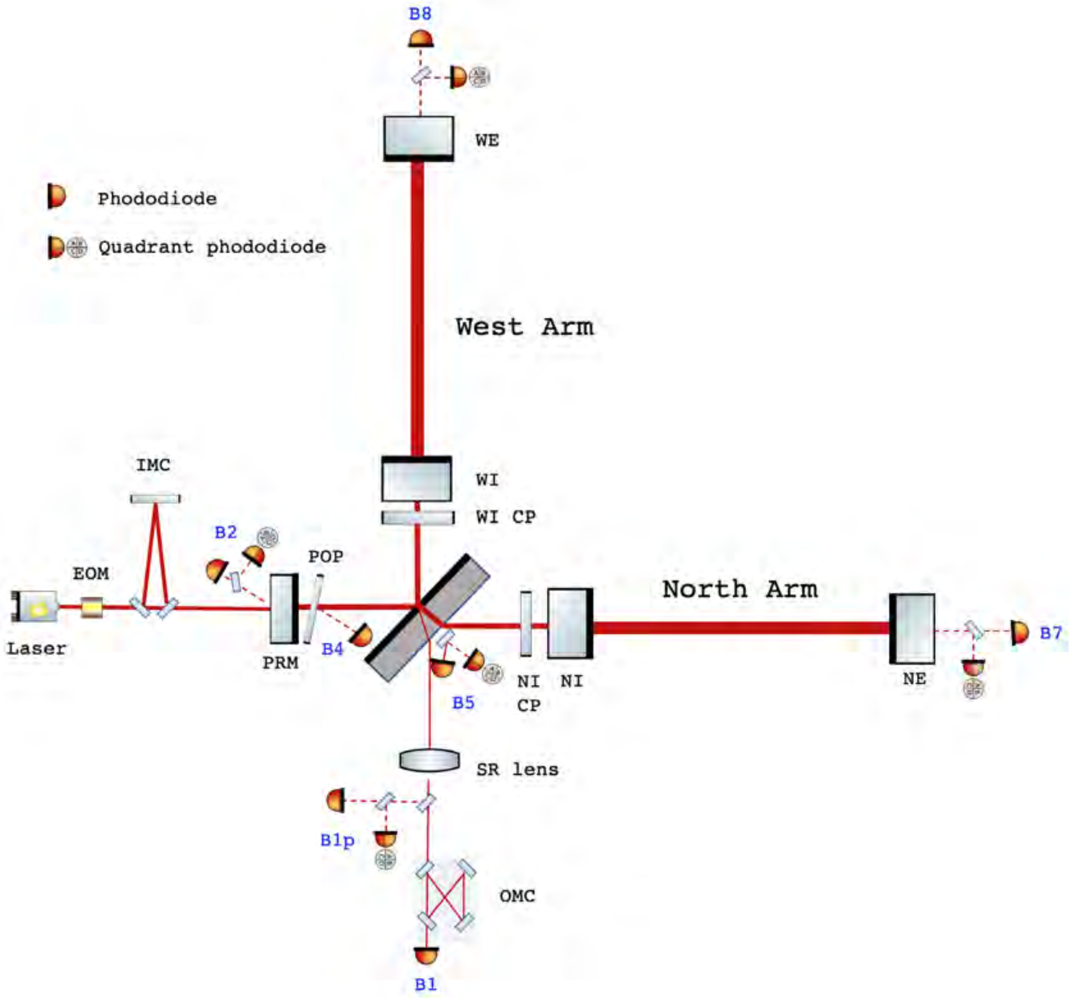
- Very precise length measurement (10^{-21} m)
- First detection in 2015





What is a GW detector?



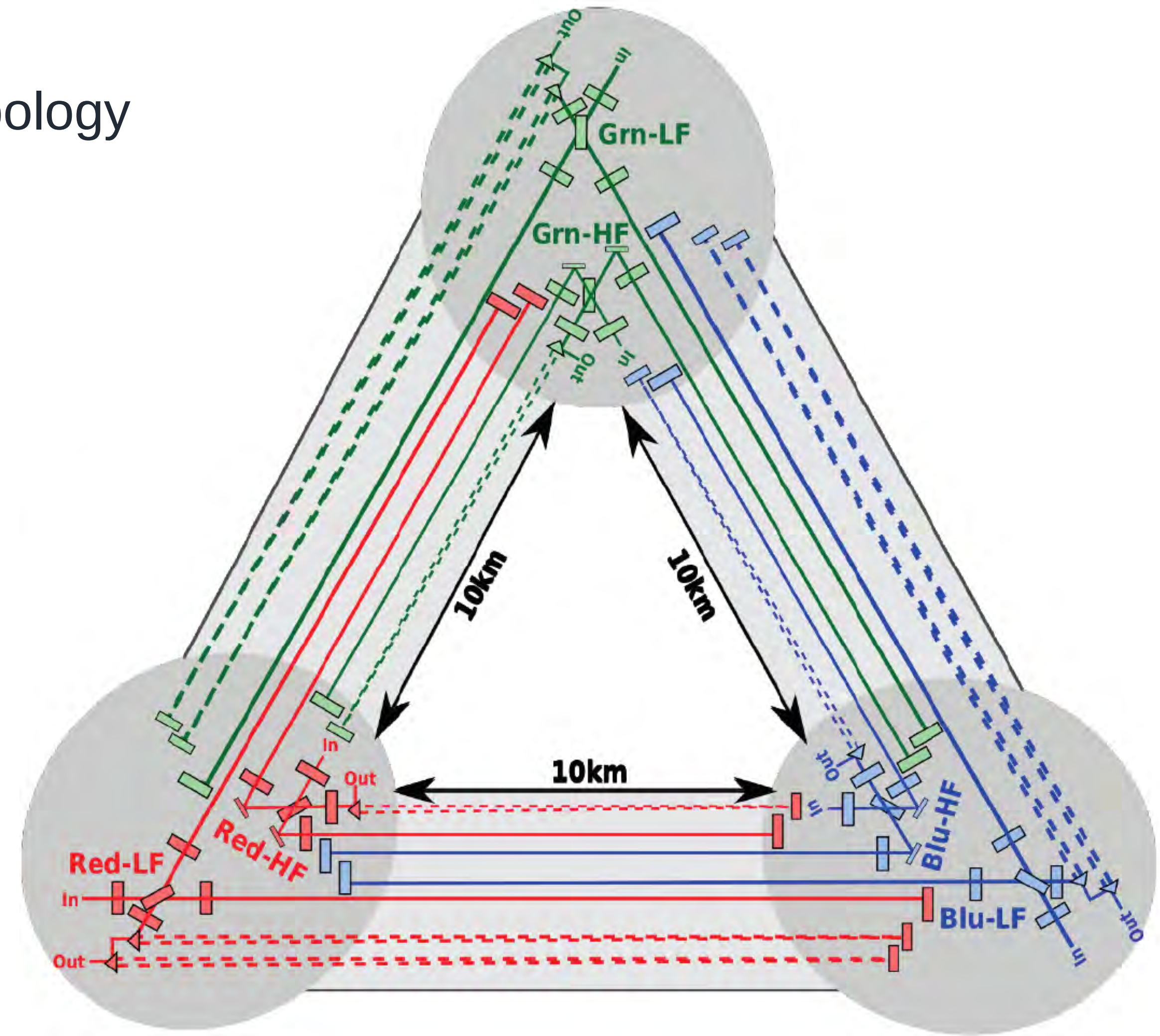


What is a GW detector?

- LIGO, Virgo, KAGRA
- Performance parameters:
  - Arm length
  - Seismic noise levels
  - Effectiveness of noise control
  - Number of interferometers in parallel

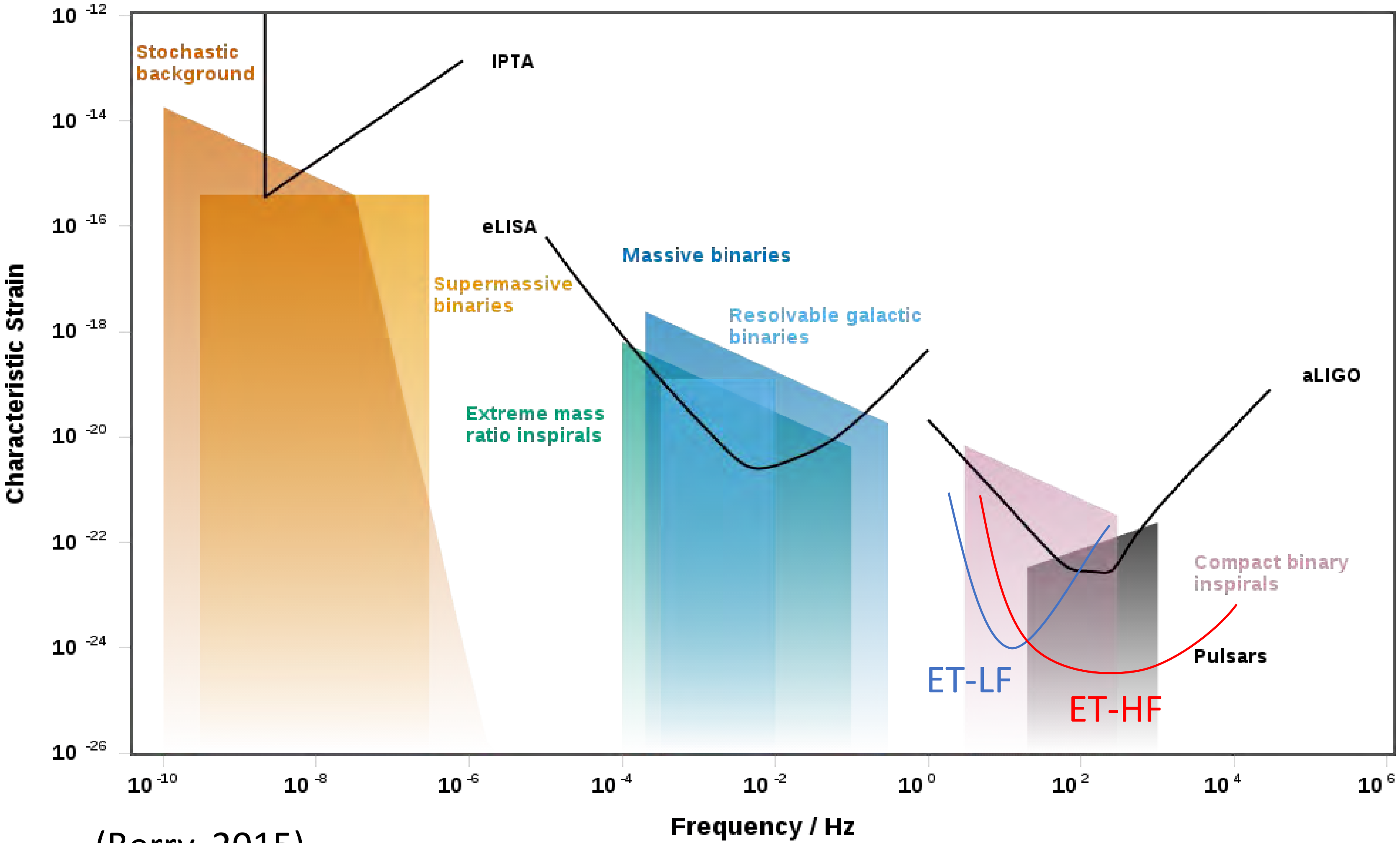
Detector – ET outline

- **6** nested interferometers in a triangle topology
- 3 x Low Frequency (LF: 1550nm laser)
- 3 x High Frequency (HF: 1064nm laser)
- Arm length of ~**10 km**
- To be built ~**250 m** underground
- In **Limburg or Sardinia** or … ?



ET science case

- Current detectors observe about one signal per week.
- ET will observe about 100.000 to 1.000.000 binary black holes mergers per year! And many other new sources!

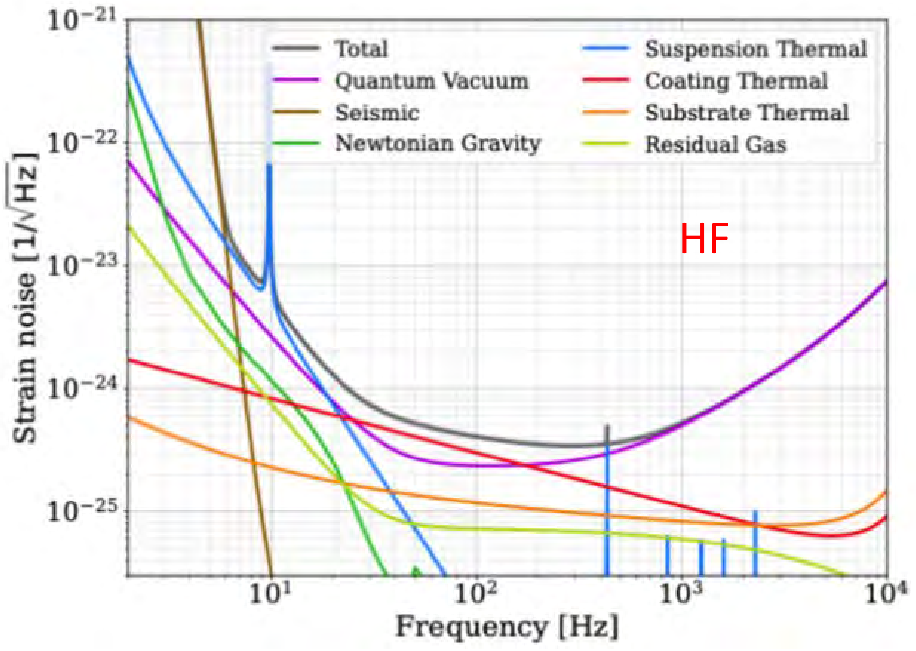


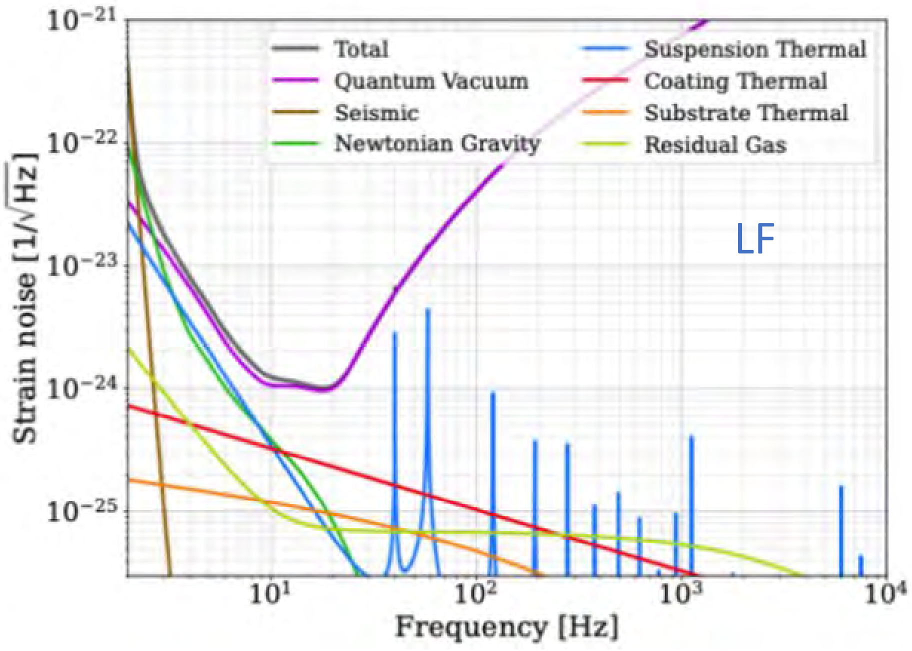
(Berry, 2015)

Detector specifications

I will talk about:

- Vacuum
- Passive and active seismic isolation
- Cryogenic cooling of the mirrors (for LF)





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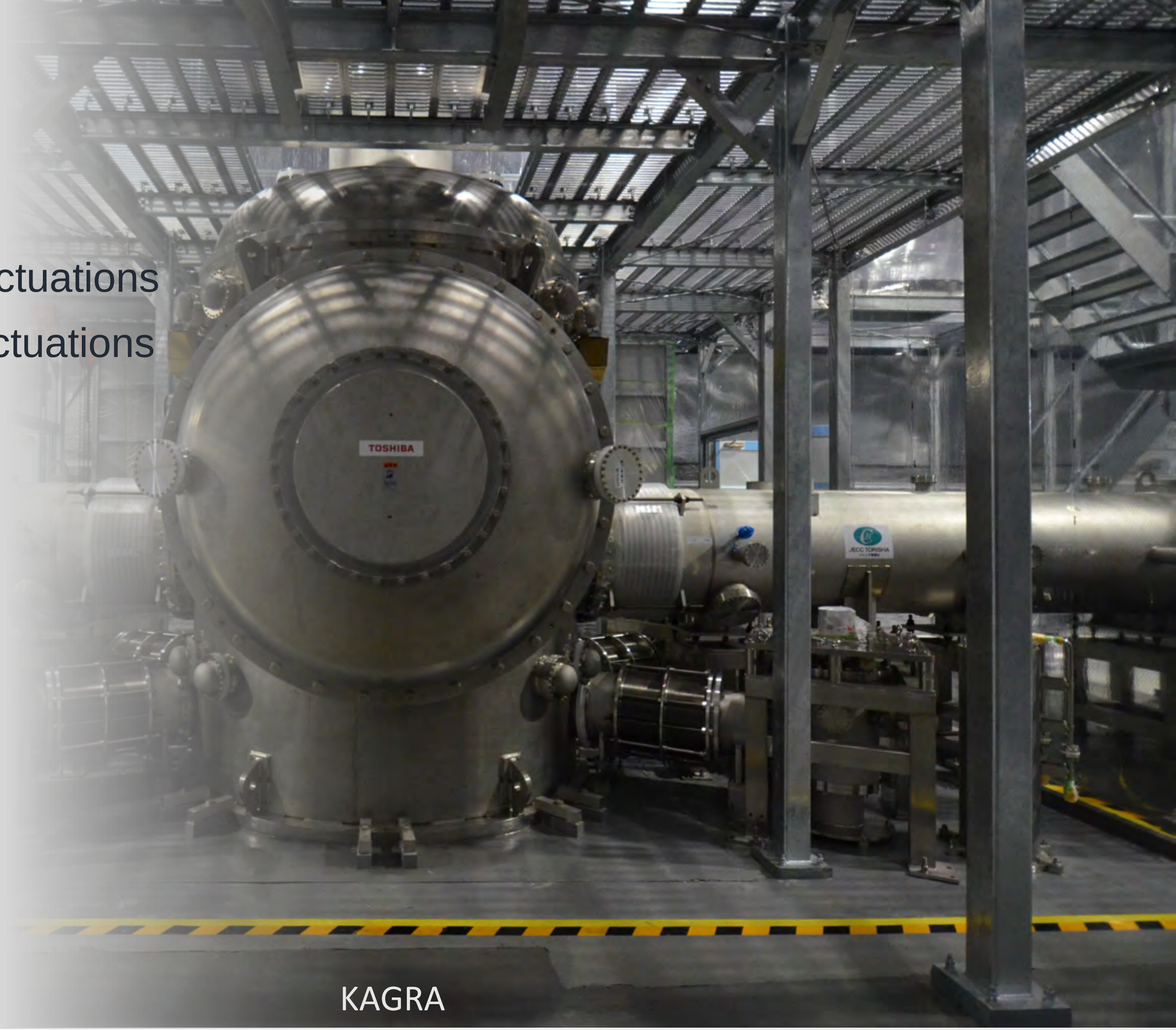
Vacuum

Reduce:

- Beam scattering due to pressure fluctuations
- Mirror excitation due to pressure fluctuations
- Acoustic noise

- Mandatory for foreseen cryogenics



KAGRA

Vacuum specs.

- Beampipes: **1.5E-10 mbar**
- LF towers: **3E-10 mbar**
- HF towers: **3E-9 mbar**

- Limiting factor is expected to be hydrogen
- Must be < **1E-14 mbar l/(cm^2 s)**

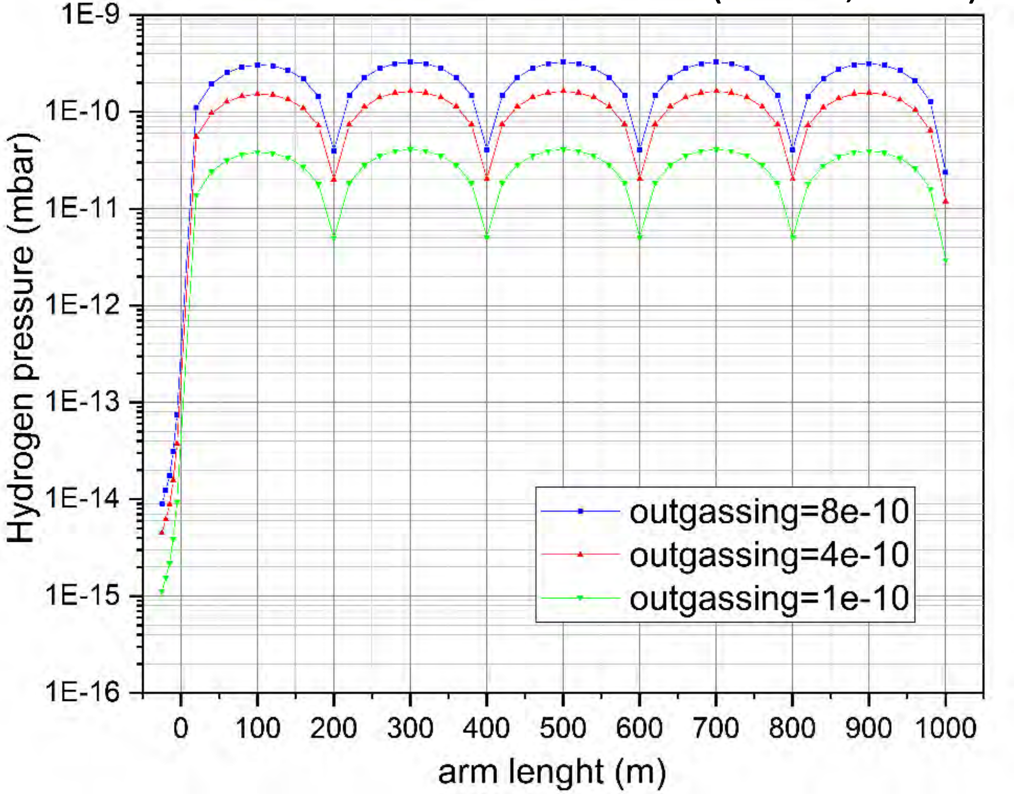
- Total volume ~**120,000 m^3**

For comparison, the LHC at CERN has a beamtube volume of ~2,000 m^3

Pumping

- TMPs etc. during pumpdown, but too noisy during detector operation
- Getter pumps, cryo pumps, etc. to maintain final vacuum
- Significant pressure gradient between pumping stations

(Hanke, 2022)



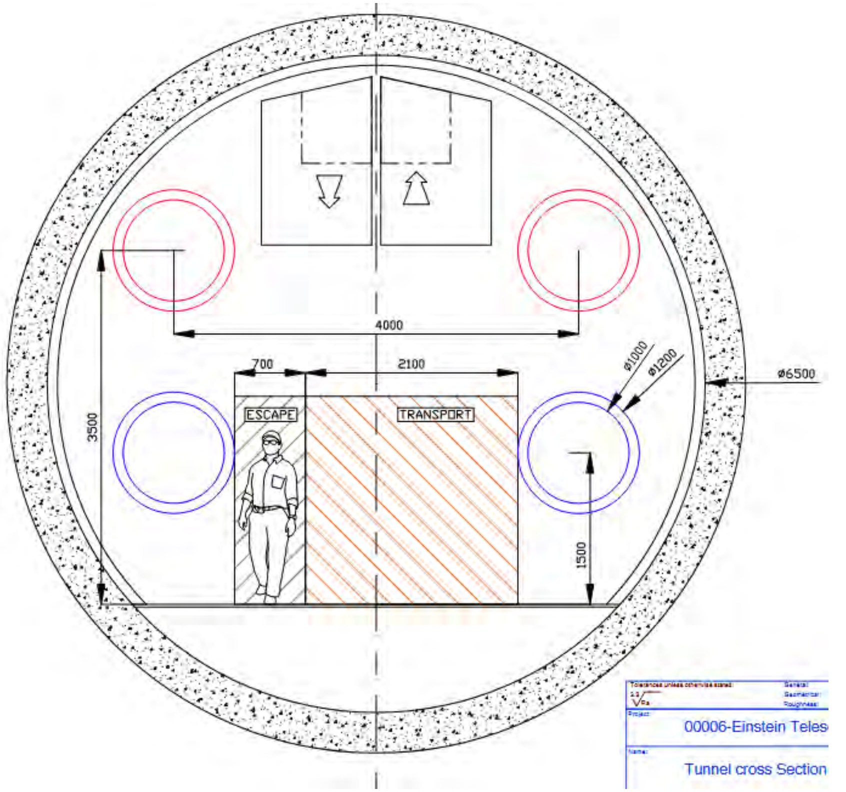
Vacuum beampipes

- ~**120 km** of ~**1 m** diameter beampipe in total
- Stainless steel has high hydrogen content

Together with industry and CERN:

- Carbon steels / ferritic stainless steels
- and/or coatings as possible alternatives

- Required pressure and being underground complicates things
  - Welding
  - Baking (water and possibly hydrogen)
  - Cleanliness
  - QC



Vacuum towers

- Tower for each interferometer component

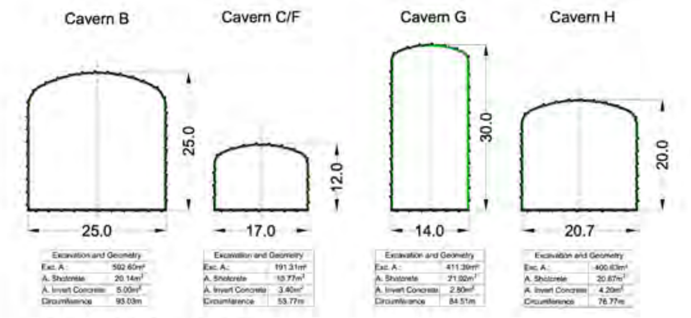
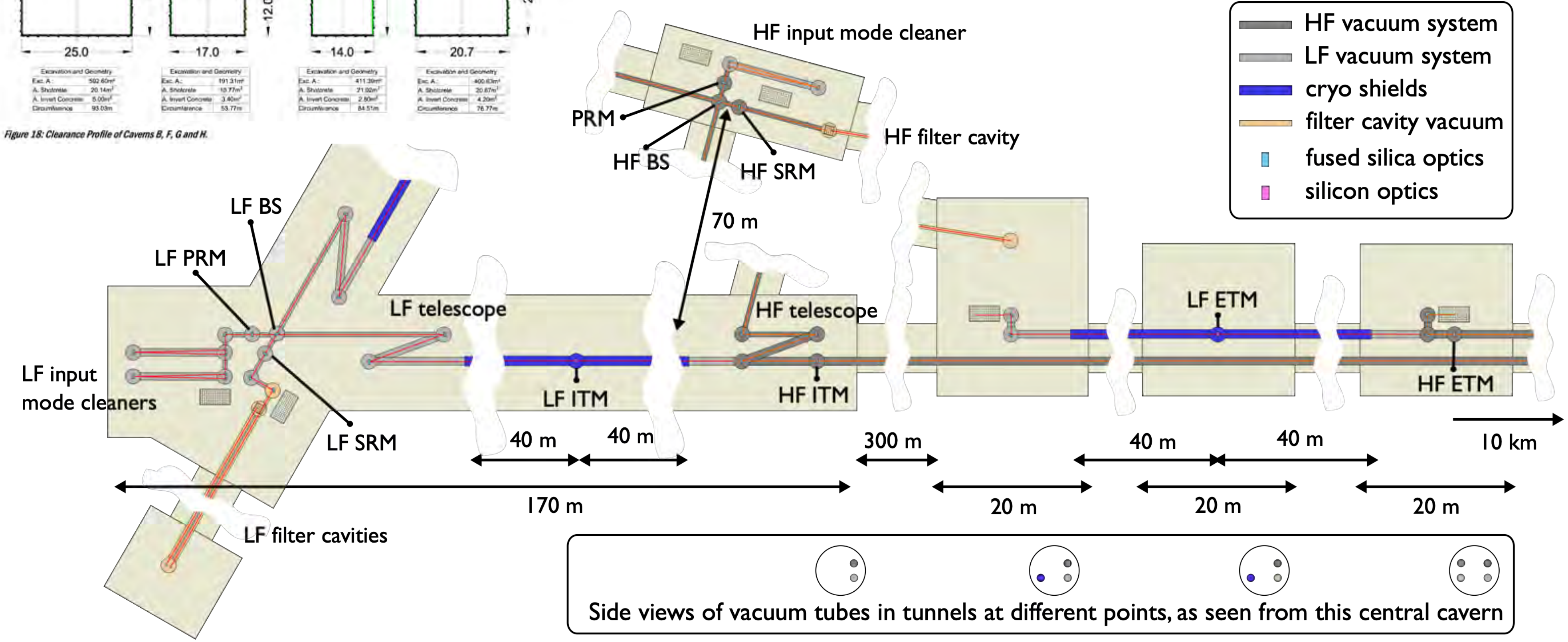


Figure 18: Clearance Profile of Caverns B, F, G and H.



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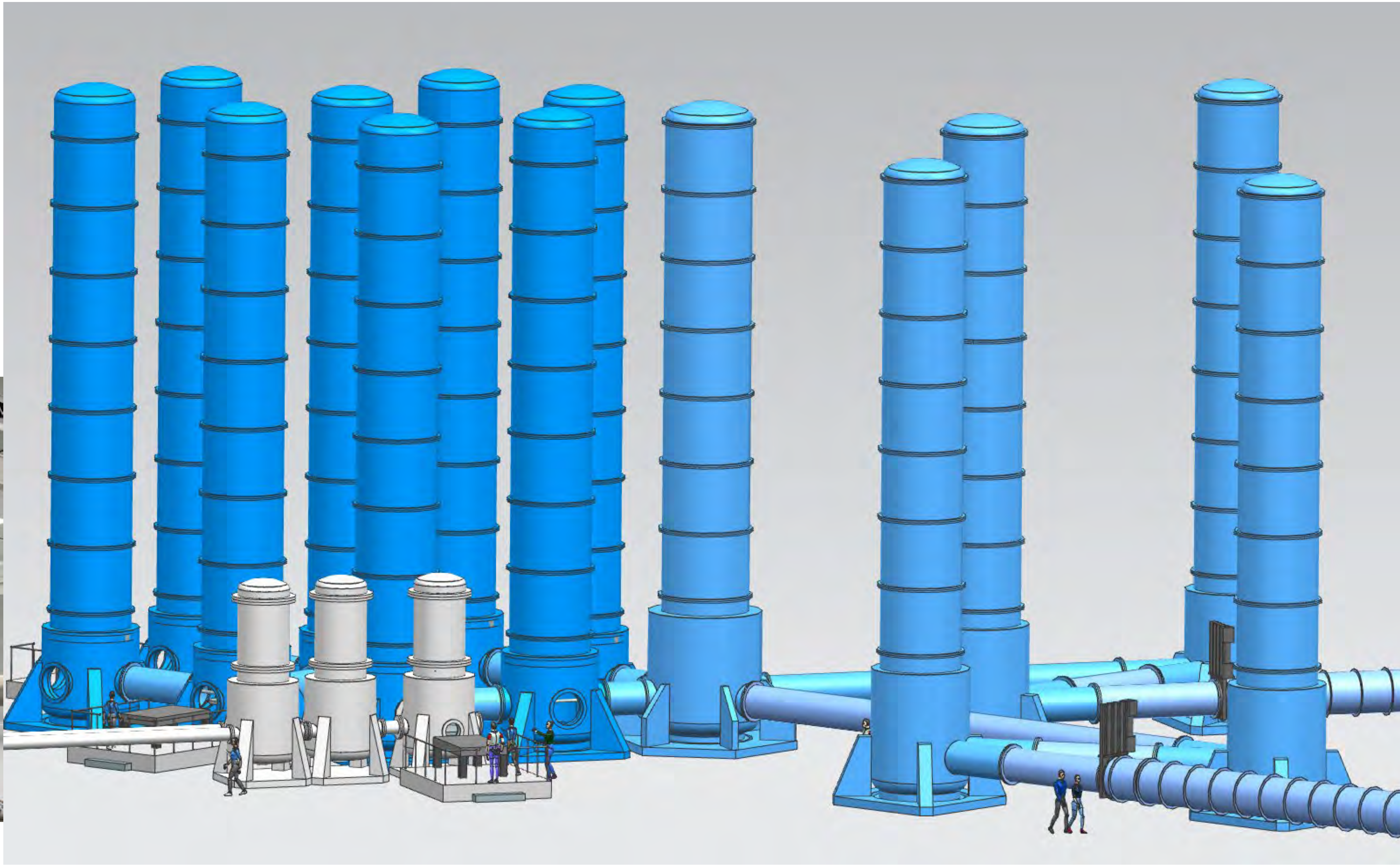
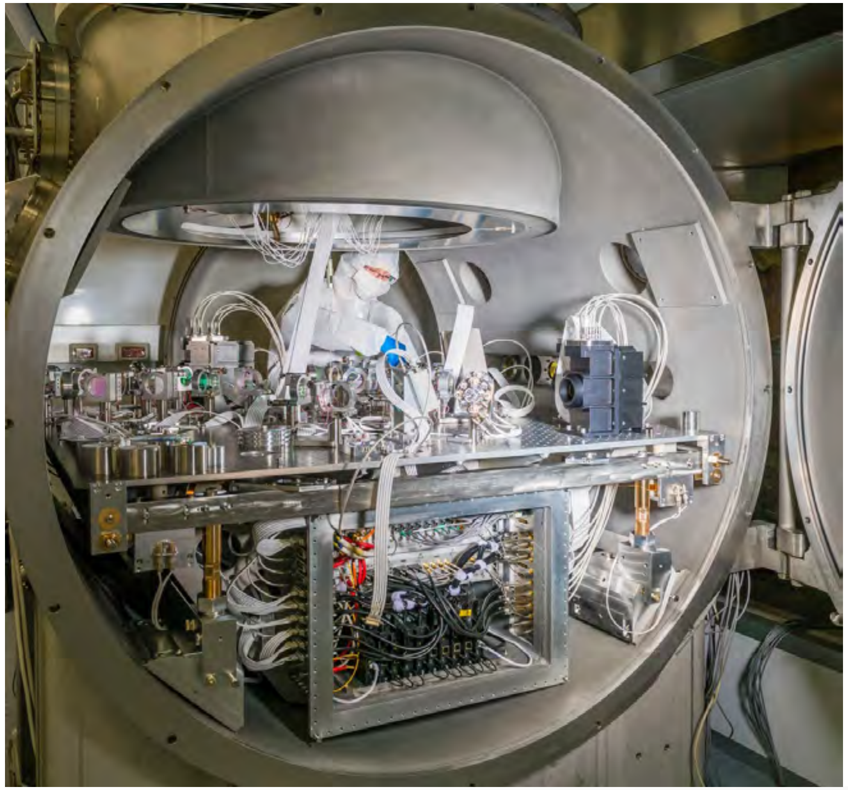
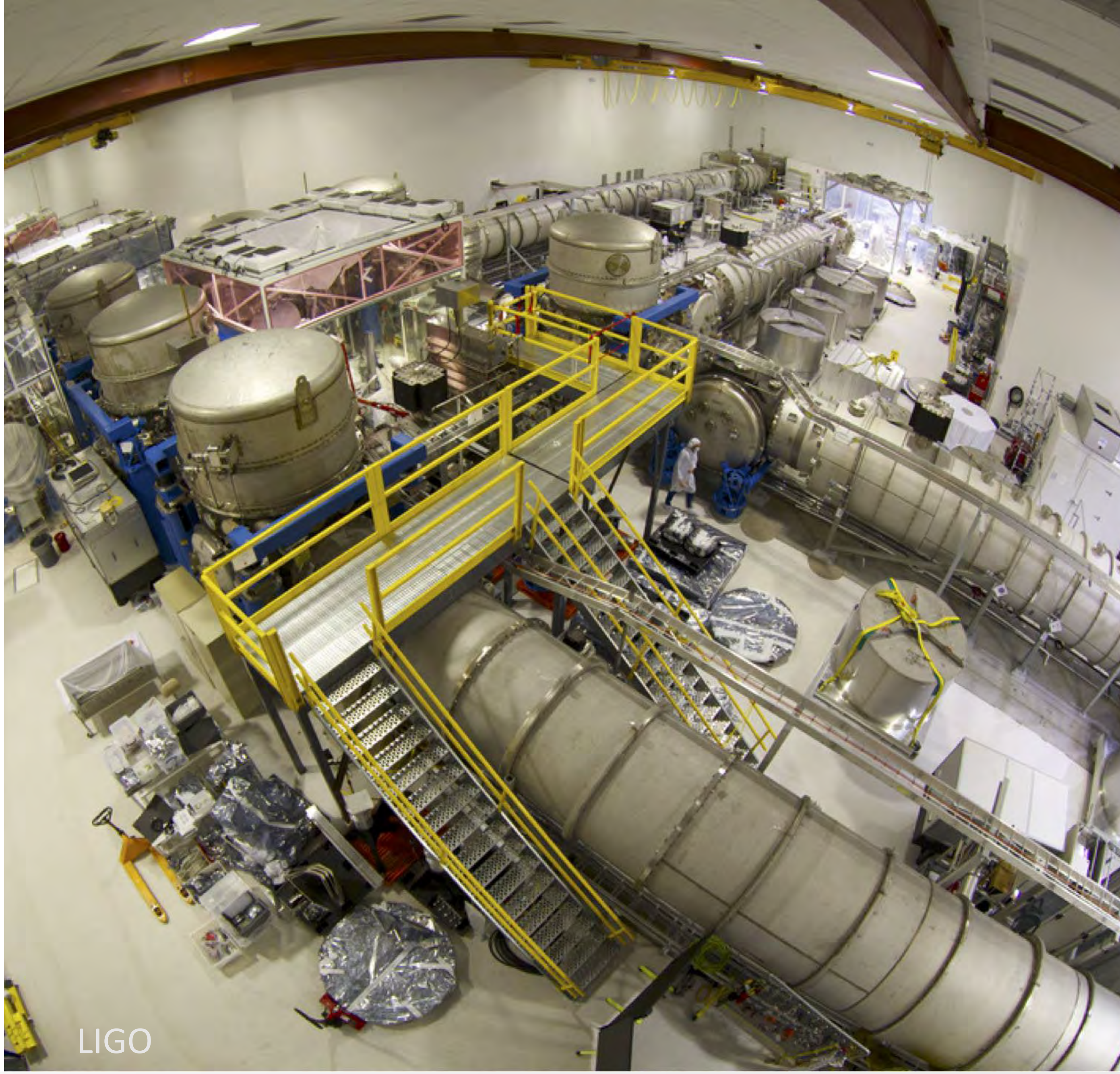


Vacuum towers

- Ballpark **120 towers** (40 per corner)
- Heights of tens of meters (10 – 20m)
- Diameters of several meters (3 – 5m)



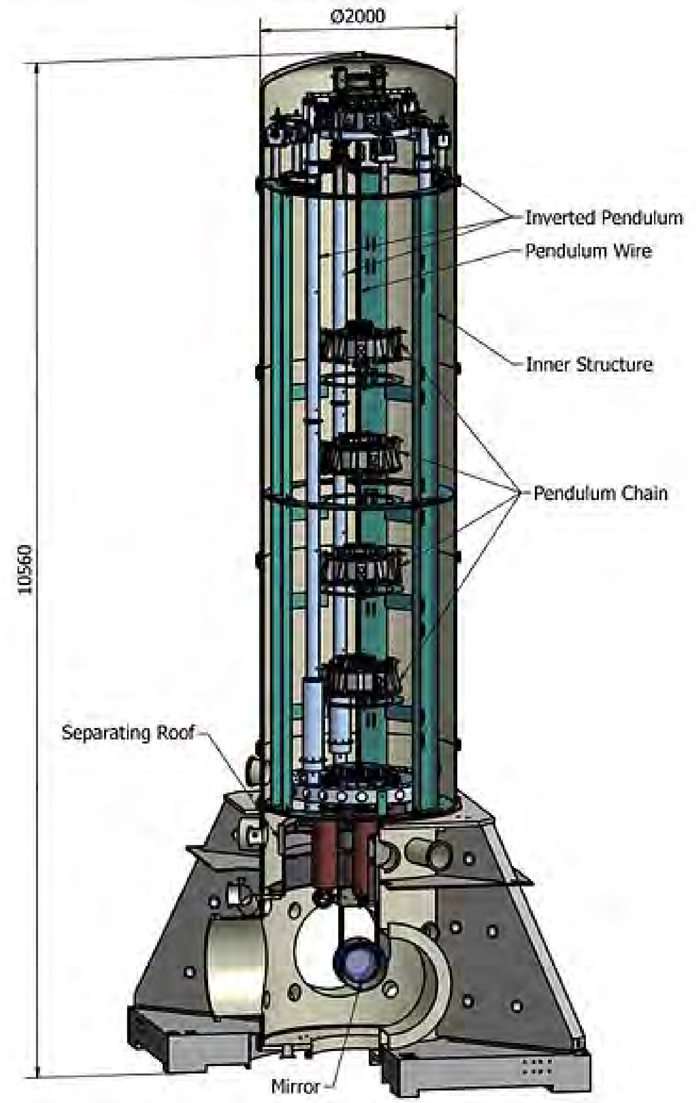


Seismic isolation

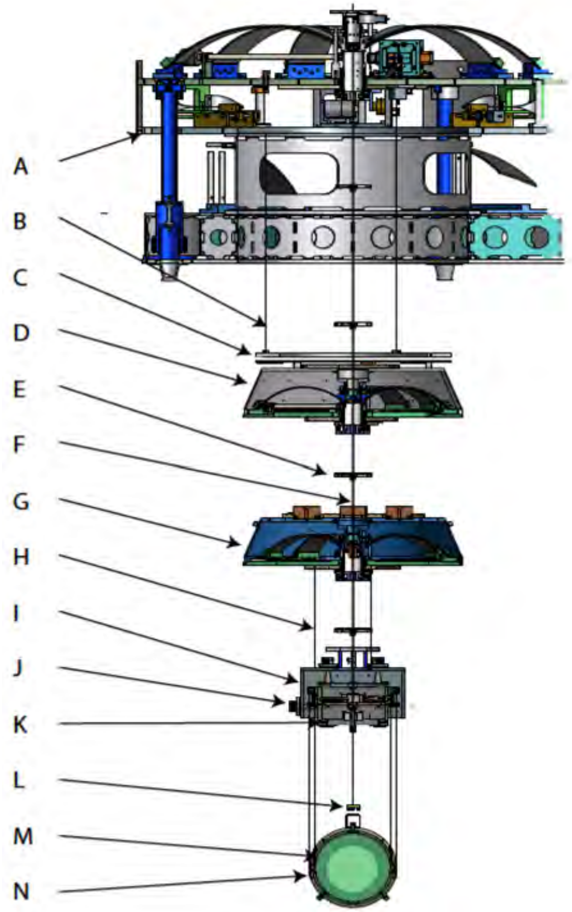
- Attenuate everything above **1 Hz** (for LF)

Building blocks:

- Inverted Pendulum (IP) pre-isolation stage
- Negative stiffness based vertical filters
- Active pre-isolation stage



Virgo Super Attenuator (SA)

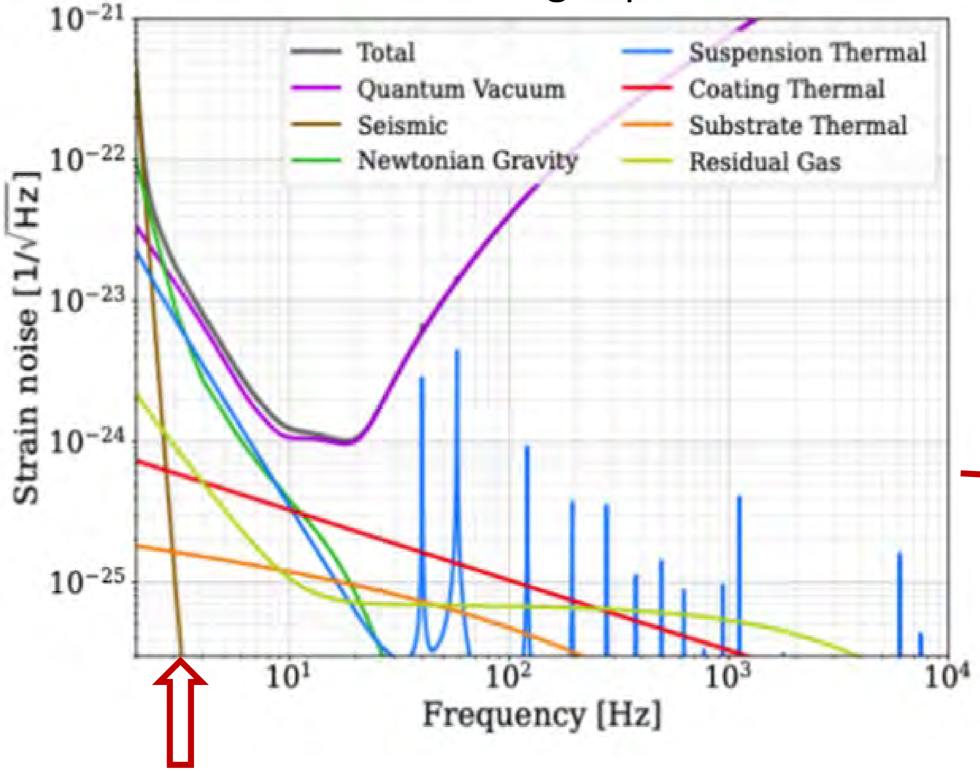


KAGRA suspension

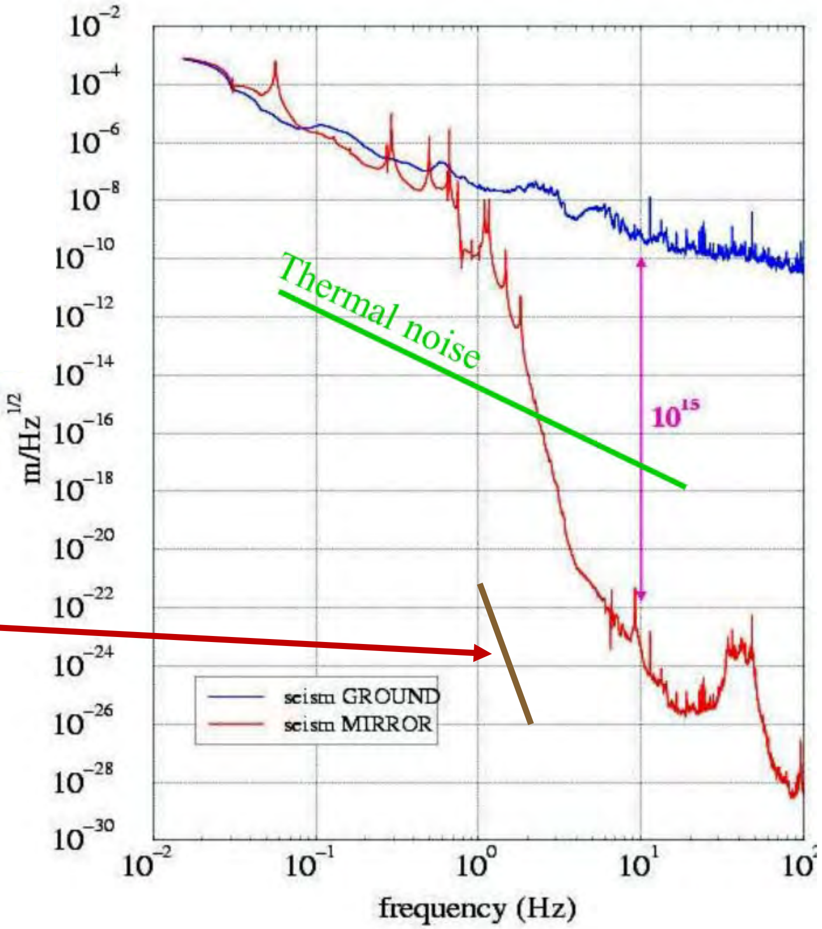
Seismic isolation

- How much do we need?
- Seismic isolation is limiting factor!

ET LF design spec.

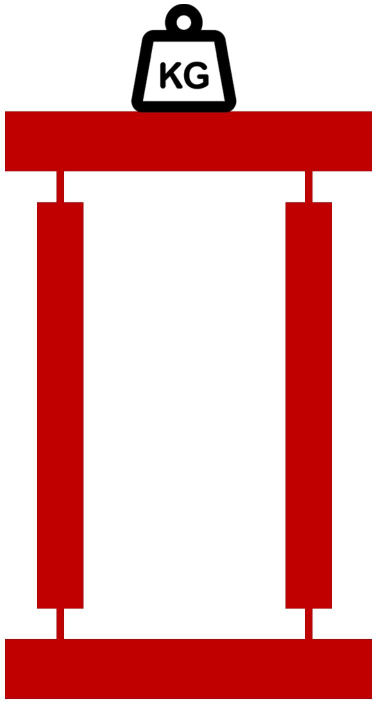


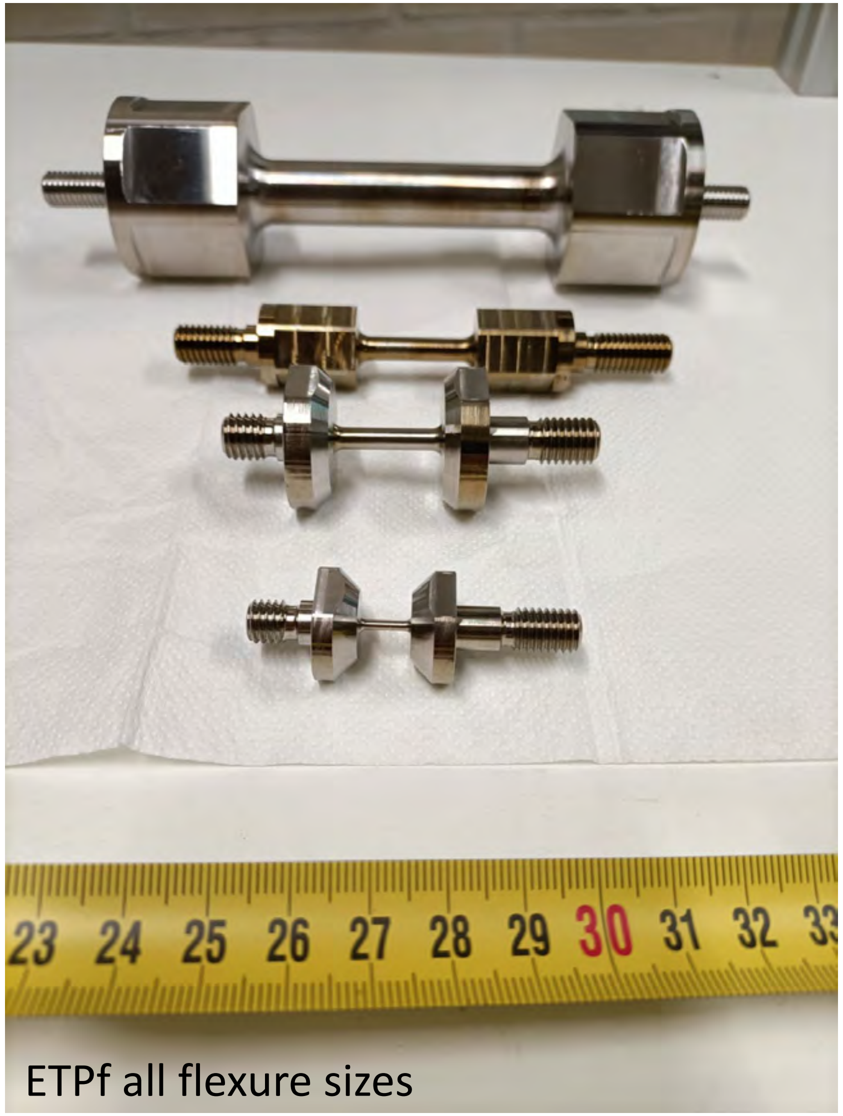
Virgo
seismic attenuation measurement



Inverted pendulum

- Seismic isolation in horizontal plane
- Longer legs gives lower frequency
- Thickness of flexures dictate load capacity

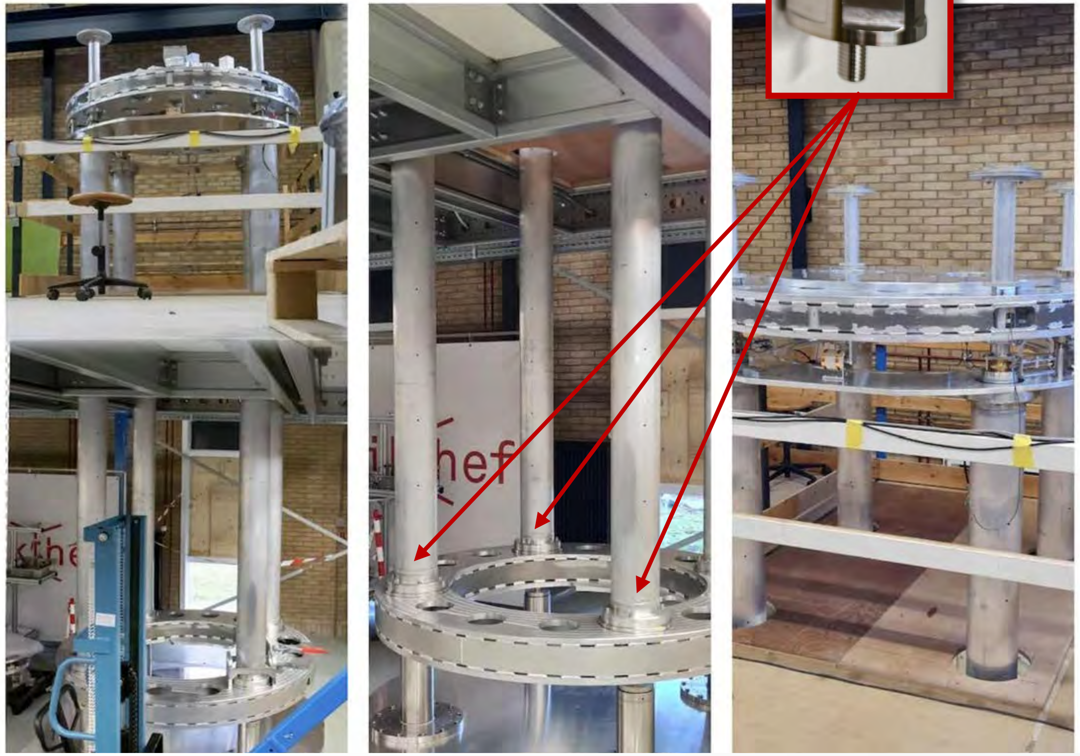




ETPf all flexure sizes

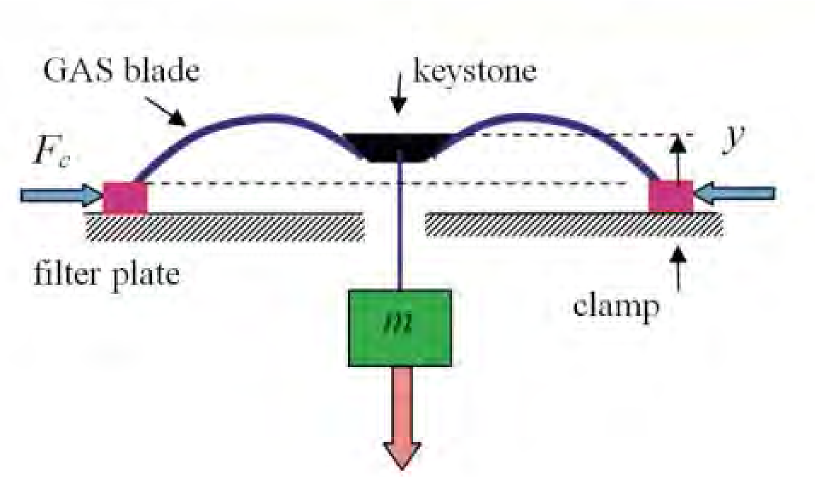
Inverted pendulum

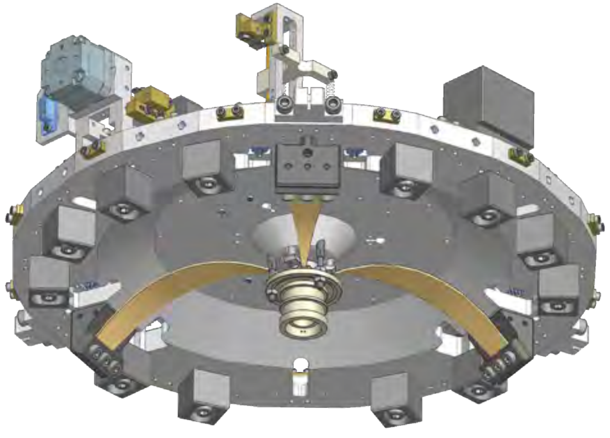
- Nikhef ETPf IP prototype
- **50 mHz** natural frequency
- ~**650 kg** load

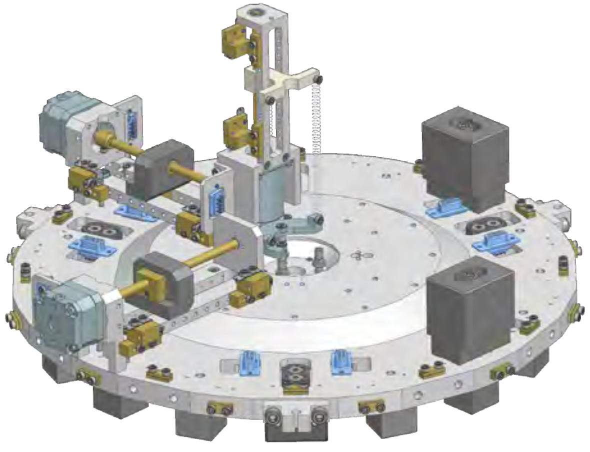


Negative stiffness based vertical filters – GAS filters

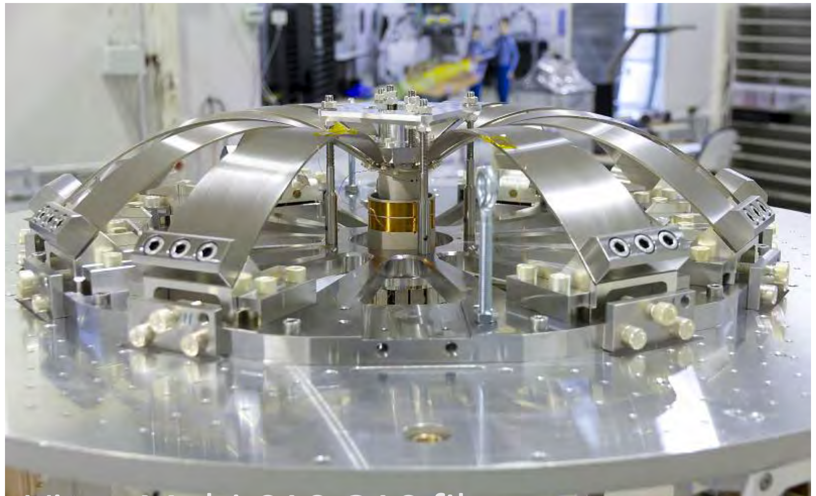
- Geometric Anti Spring – used at Virgo and KAGRA
- Usually tuned to **~200 mHz**
- High strength material (>1 GPa nominal stress)
- Cascading in long pendulum chains
  longer chain gives lower frequency







ETPf last (smallest) GAS filter

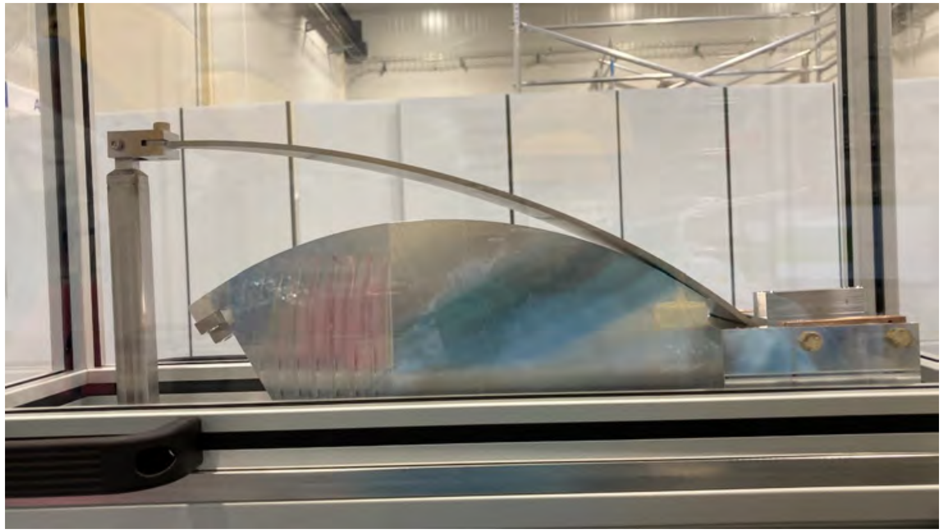


Virgo Multi-SAS GAS filter

Blade springs

- Maraging blades show hydrogen embrittlement
- Difficult to predict
- Difficult to minimize risk
- Many many blades, 1 breaks = detector downtime

- There are alternatives but not as strong as maraging (or?)



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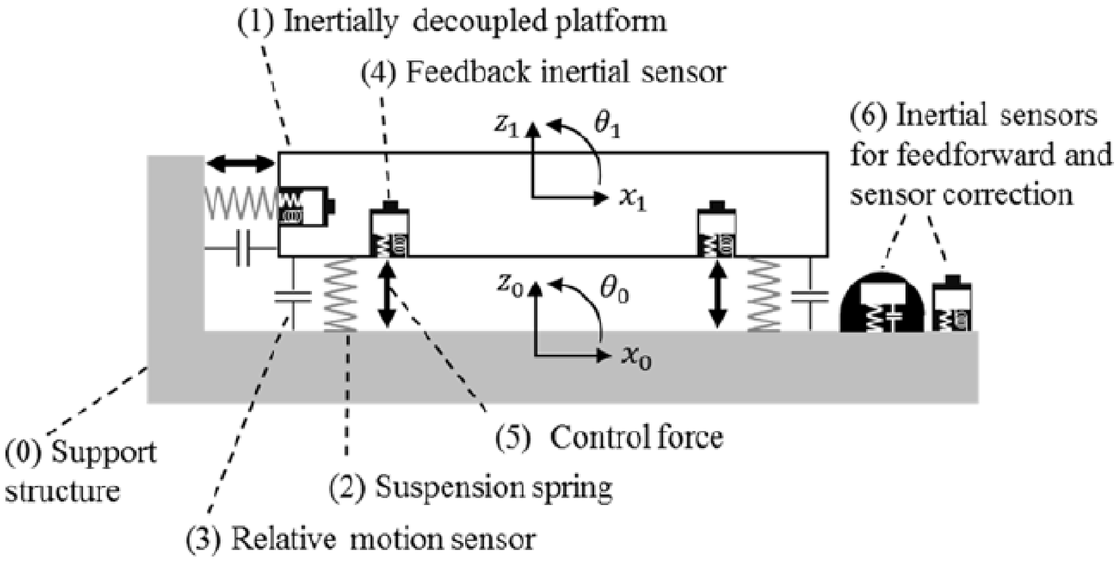
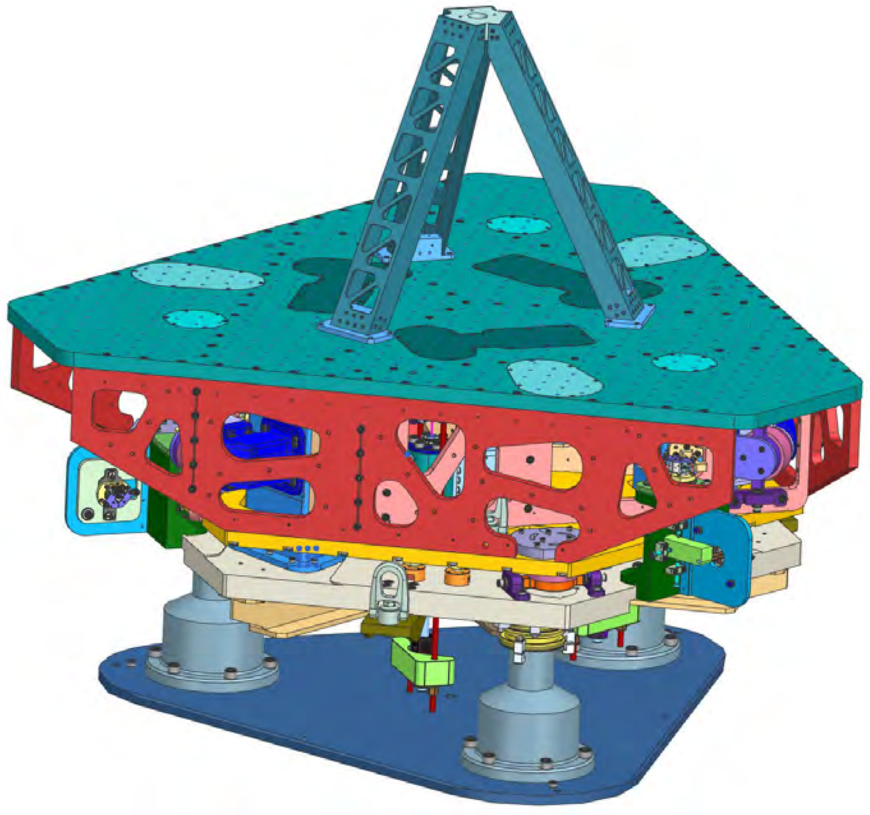
Active isolation

- Stiff suspension springs
- More complex sensing and actuation
- Much more compacted
- Sensor noise is limiting factor
- Attenuates very well at low frequencies by nature





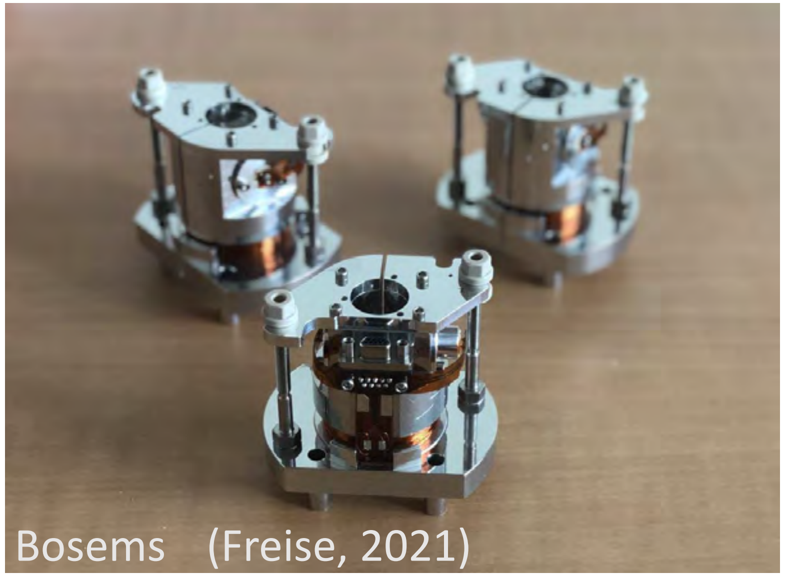
OmniSens

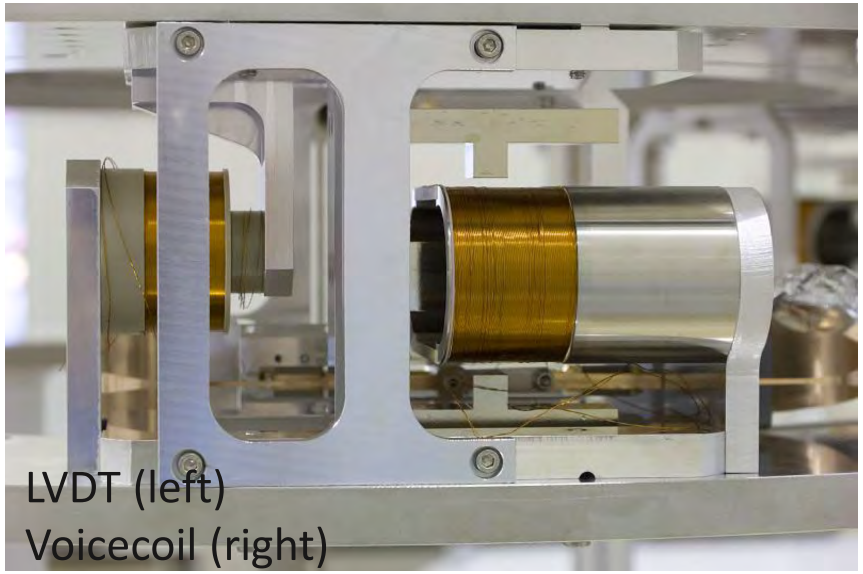
Sensing & actuating

- LVDTs
- (B)osems
- HoQi (new)

- Voicecoils

- Mostly “homemade” in gravitational wave community


Bosems (Freise, 2021)


LVDT (left)
Voicecoil (right)


HoQi’s (Mow-Lowry, 2022)

Seismic isolation – to conclude

- Size increase is *very* expensive
- Use shown building blocks to get to ET requirement
- Currently starting up conceptualization phase

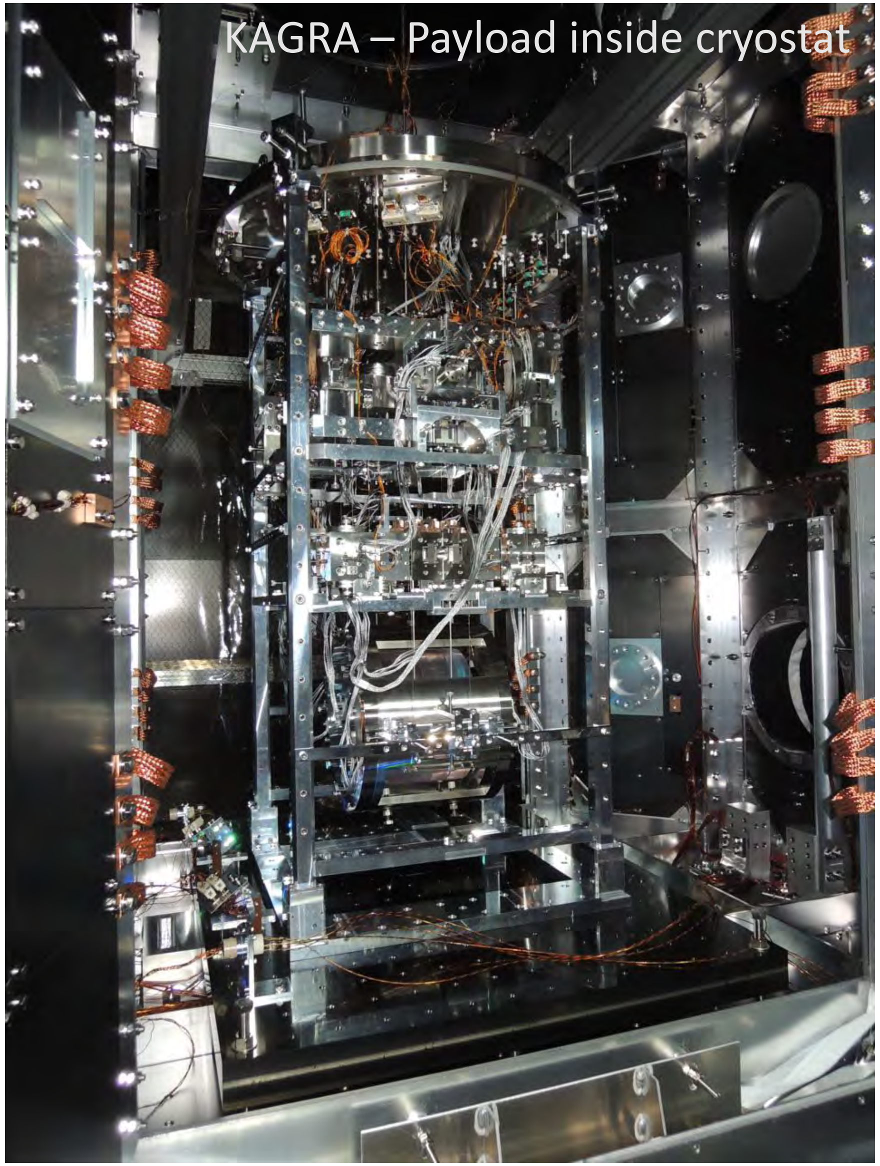
Cryogenics

- Minimize thermal noise

Cryostat baseline:

- Inner shield: **~4 K**
- Mirror: > **4 K**
- Second shield: **~ 80 K**
- Outer radiation shield

- Seismic isolation is a major challenge



Cryogenics – noise management

- Noise from compressors or other cooling machines
- Noise from flowing or boiling liquid

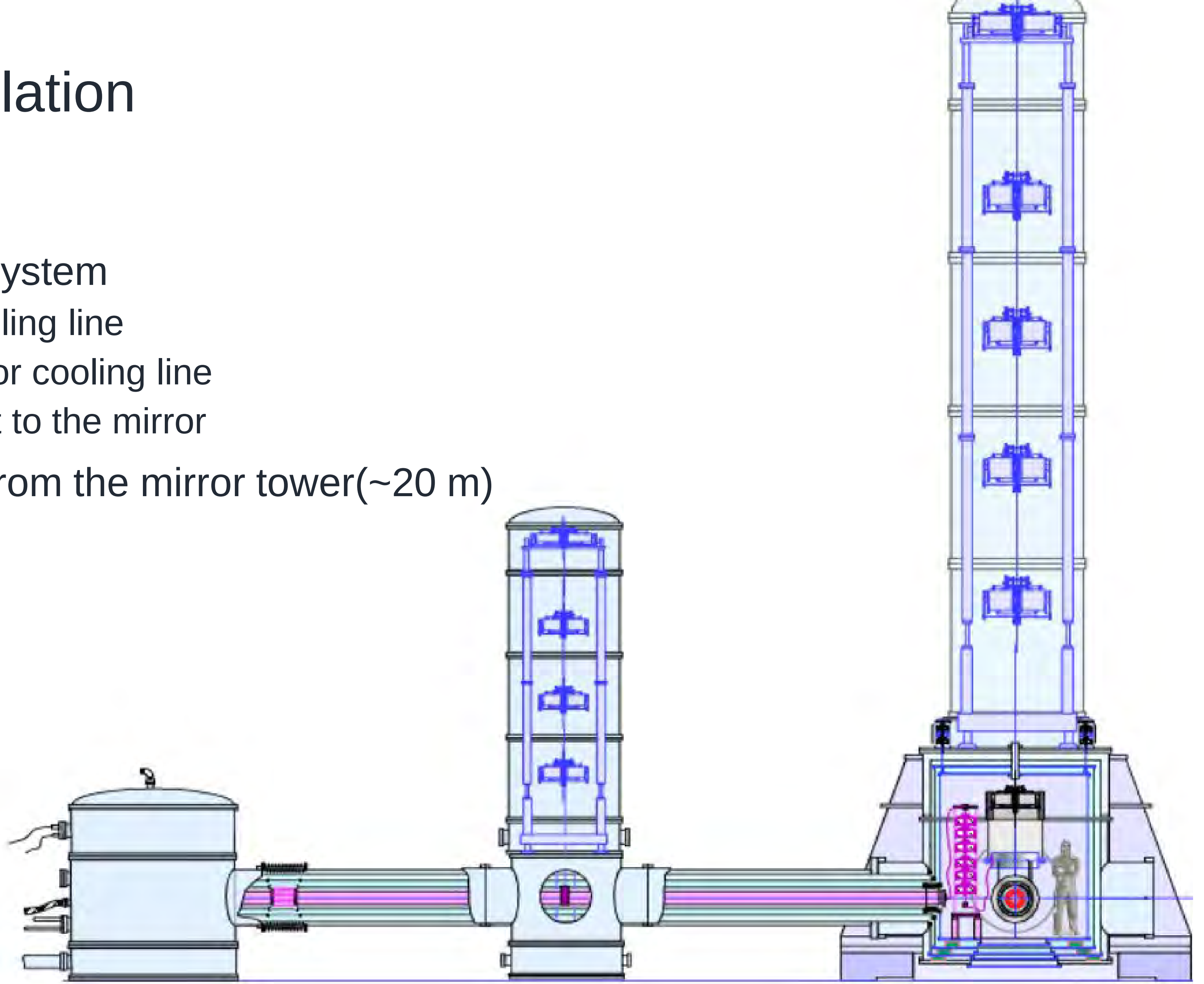
- Radiative cooling by itself won't be enough at ~4 K

- Also minimal seismic noise to cryostat itself (causes beam scattering)

Cryogenics – seismic isolation

Baseline:

- Dedicated cooling line isolation system
  - Flex coupling from cooler to cooling line
  - Dedicated suspension system for cooling line
  - Second suspension chain to get to the mirror
- Noisy cooler is placed far away from the mirror tower(~20 m)

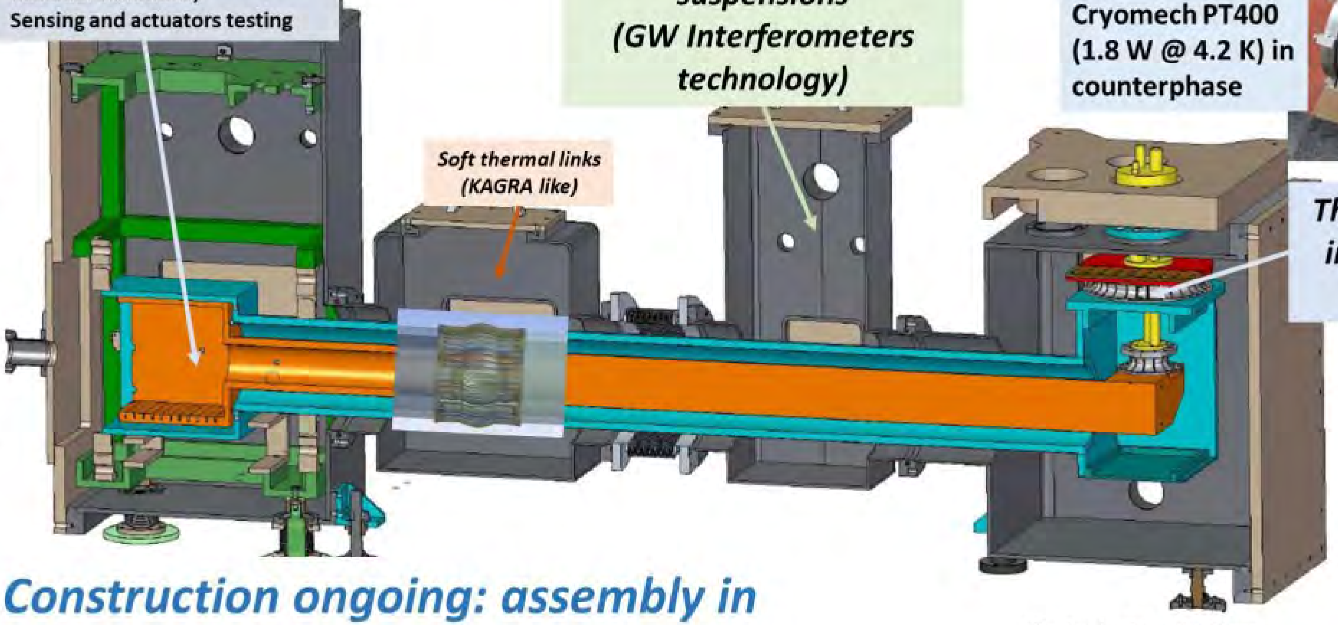


INFN Roma & Sapienza-Dip. di Fisica for ET

Istituto Nazionale di Fisica Nucleare

Pulse Tube Cooling Station prototype for Rome1 Test Facility

Cryogenic test Chamber:
- Dissipation Measurements,
- Residual vibrations,
- Sensing and actuators testing



Credit to P. Rapagnani, 2022

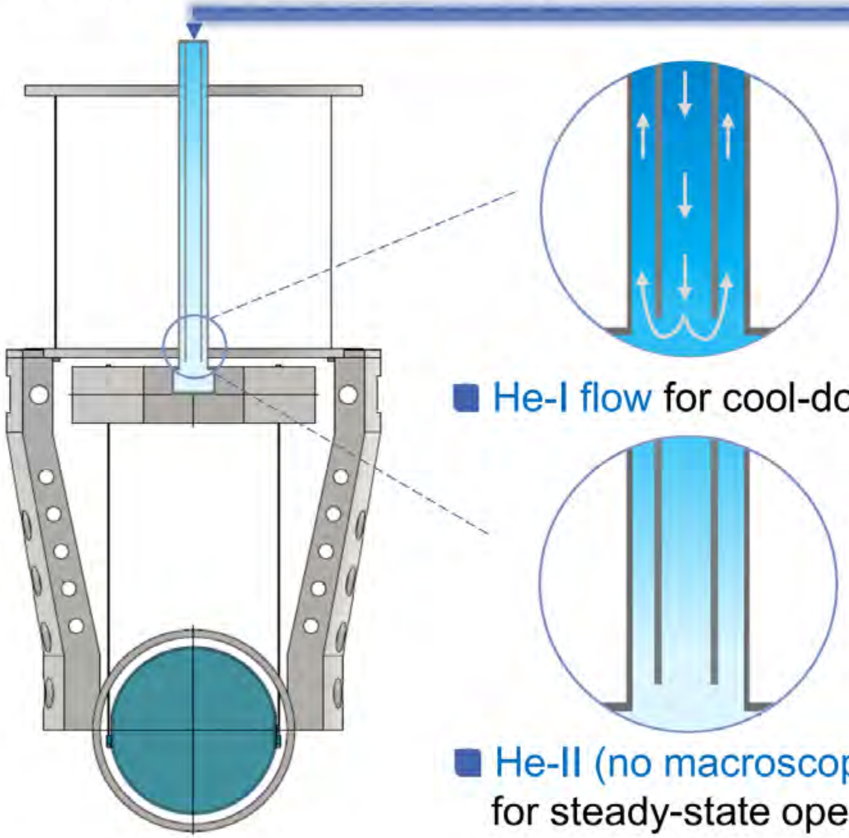
More details in A. Cruciani's talk

Construction ongoing: assembly in summer 2022

Design by Antonio Marra, Franco Bronzini

L. Naticchioni - Einstein Telescope - Retreat INFN Roma1 2022 32

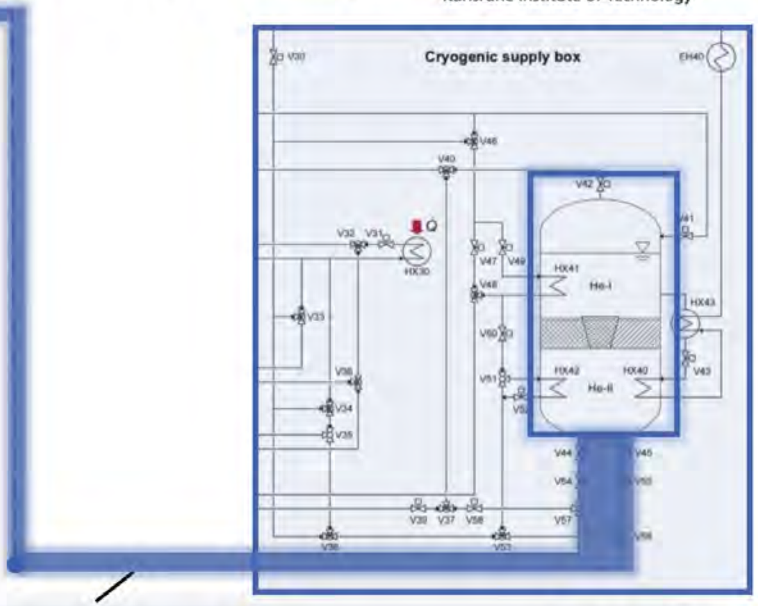
ET-LF payload: Cooling via He-II suspension capillary



- He-I flow for cool-down

- He-II (no macroscopic flow) for steady-state operation

Courtesy of M. Stamm (2021)



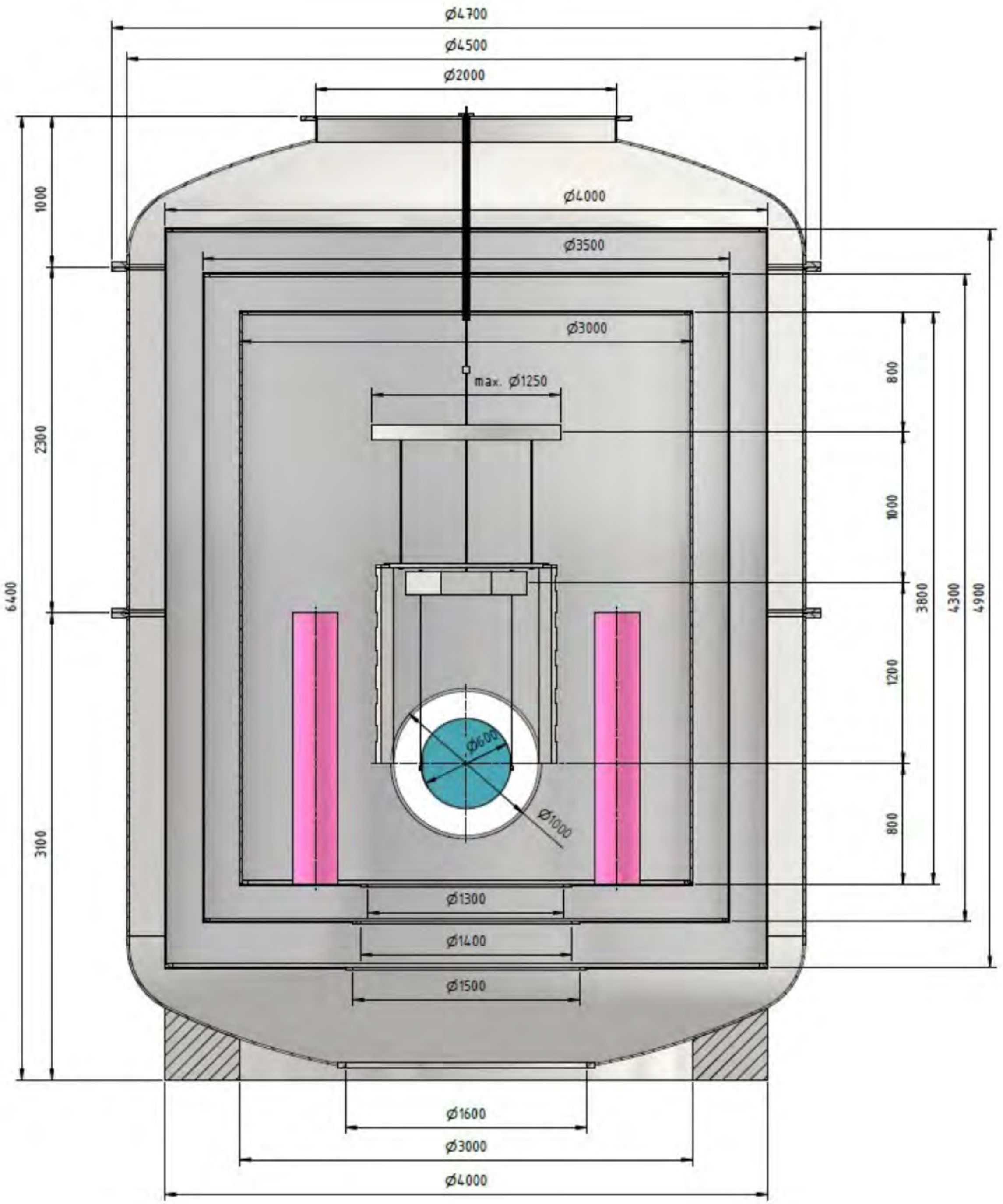
L. Busch (KIT, 2021)

He supply capillaries:

- Cryogenic supply box ↔ Payload (i.e. suspension capillary) connection
- Length ~ 10-20 m → cryogenic supply box away from cryostat tower to reduce vibration input

Cryogenics – scale

- Conceptual design stage
- Outer shield of Ø4 m – 5 m tall
- Must be able to work inside inner shield
- Limiting factor for tower size



(Possibly will need it's own seismic isolation stage!)

In conclusion

- Physics specs are being translated to design specs
- Lots of simulations and test setups
- Design conceptualization is progressing (updates on 2020 baseline)

Urgent:

- Beampipe design → Tunnel size
- Internal mechanics size → Tower size → Cavern size

Nikhef

Stefan Hild – s.hild@nikhef.nl

Einstein Telescope for business

PARTICIPATE

Who is the valorization program for?

To stimulate innovation and accelerated development of new technologies for the Einstein Telescope (ET), the ET valorization program starts. One of the first concrete support opportunities from the program is an R&D scheme soon to be launched for high-tech companies. For this, €12.085 million is available. The scheme will be open to partnerships (consortia) around five technology domains relevant to the Einstein Telescope. The consortia can consist of startups and SMEs, large companies (corporates) and knowledge institutions.

www.einsteintelescopeforbusiness.nl

R&D scheme

The first call (call) of the R&D scheme technology domains Einstein Telescope will open on Oct. 23. For the total scheme - which has five technology domains - €12.085 million is available. That amount was allocated in 2022 in the 2nd round of projects from the National Growth Fund. The first call is for the technology domain "vibration-free cooling. Companies can be eligible for a grant of up to €2.585 million in this opening. The five technology domains are:

1. Vibration-free cooling: development of vibration-free cooling of mirrors to temperature 10 - 20 K.
2. Vacuum technology: cost savings of vacuum system and design of production facility and installation scenario.
3. Vibration damping: development of optimal combination of passive and active vibration damping.
4. Optics: development of large Si mirrors and coating for application at temperature 10 - 20 K.
5. Technical deformations: development of technology to monitor and compensate for thermally induced deformations.

www.liof.nl/einsteintelescope