Vacuum technologies of existing and future GW interferometers

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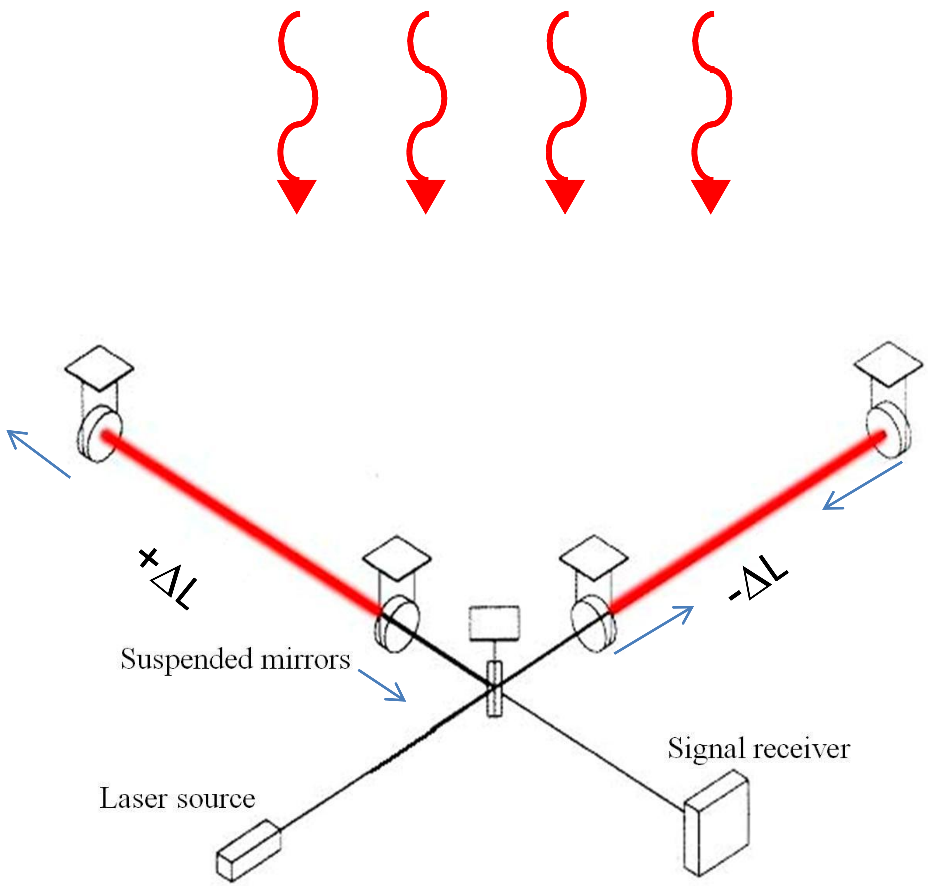
GW RESEARCH with INTERFEROMETERS (Ground Based)



GW's alternately squeeze and stretch space in two perpendicular directions

To detect GWs , the laser interferometers allow to monitor the relative displacements of free masses (mirrors): order of 1E-18m (frequency band 10Hz-10KHz) for mirrors at km of distance

Optics and laser beam are under vacuum to avoid several disturbances (index statistical fluctuation, gas damping , acoustic effects)

GW ground based INTERFEROMETERS, present and future

Present detectors are being upgraded to increase their sensitivity x 10 (events x 1000)

ET = third generation European interferometer is under design (EU design study completed) *www.et-gw.eu*

Evolution timeschedule

Advanced Detectors

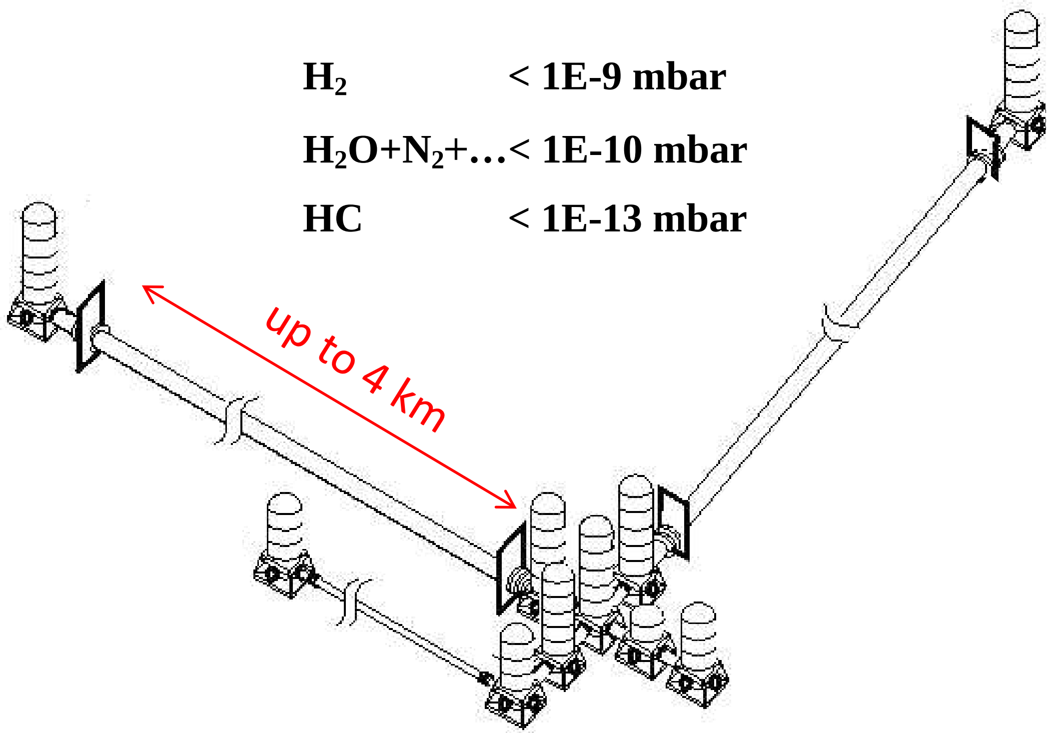
• Stop data taking and start costruction works	in progress
• Finalization and procurement of new parts	2012-2013
• End of commissioning	2015

ET

• design study achieved (funded by EU - FP7)	done, 2011
• tecnichal design, R&D on technologies	2012-2020
• construction (1 detector)	2020-2026
• end of commissioning	2030

VACUUM SYSTEM LAYOUT

H_2	< 1E-9 mbar
$H_2O+N_2+\ldots$	< 1E-10 mbar
HC	< 1E-13 mbar



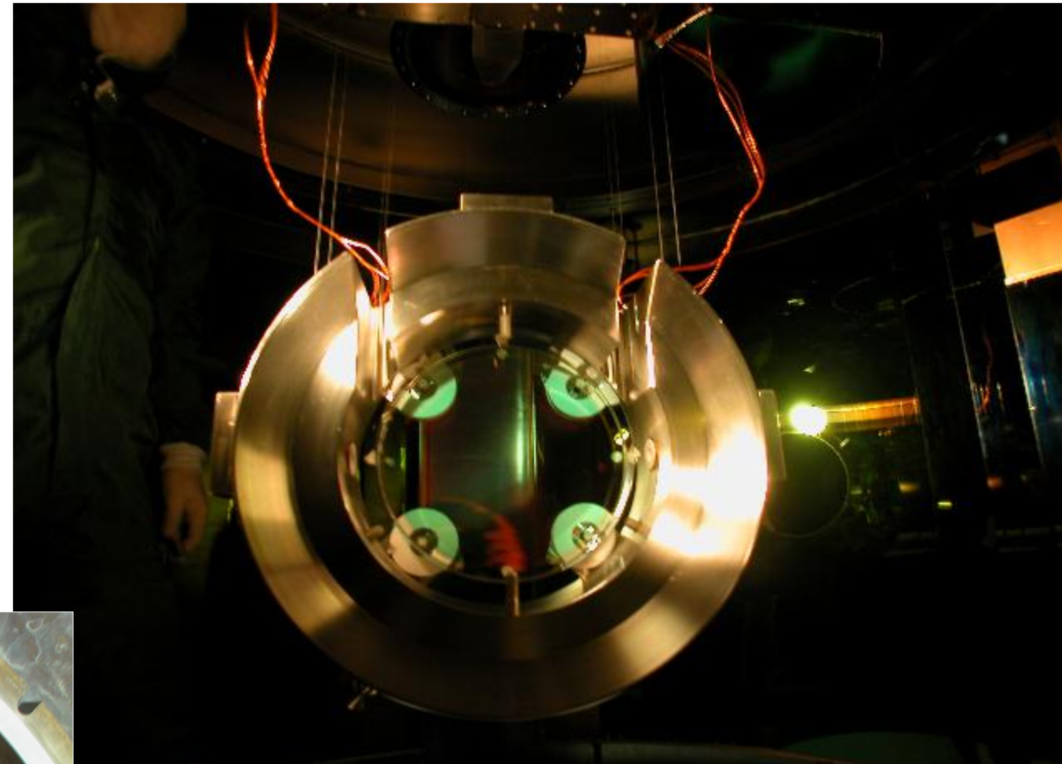
UHV and HV are divided by a 3rd intermediate region (and quartz window)

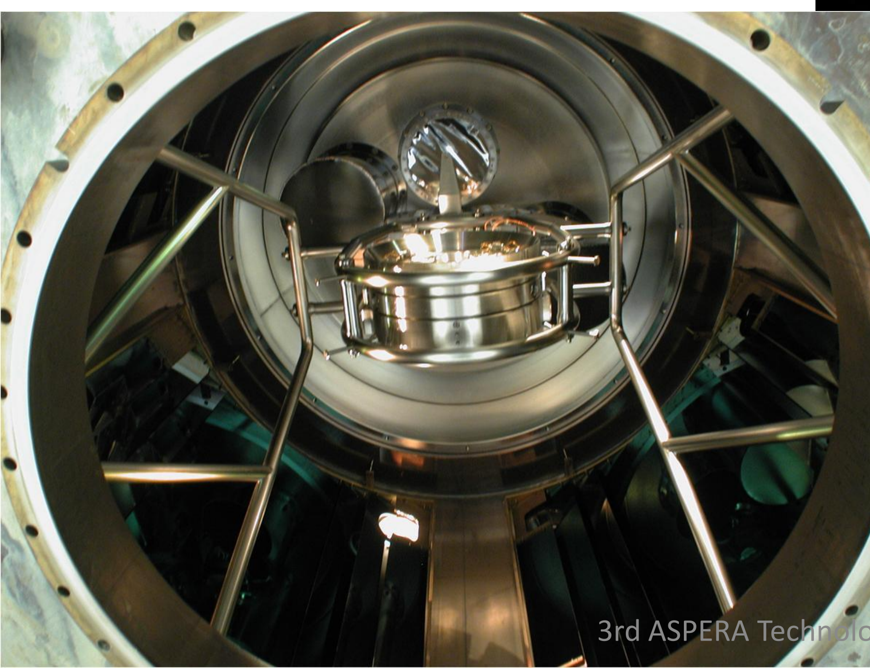
Main vacuum chambers (I and II generation detectors):

Tubes:
Contain just the laser beam
Lenght 2 x 600m to 4km
diameter = up to 1.2m
Volume up to 9000 m^3 !
10^{-7} mbar for initial detectos
10^{-9} for advanced ones
(Noise scales as e P)
Mirror chambers
Order of 10 chambers (one per principal mirror) several m^3 each
Contaminants free (optics degratation)
Large valves 1m diameter typical , to isolate , vent and access the mirror chambers
HV or low vacuum chambers for optical benches and other parts

Inside a Mirror chamber: a principal mirror with its positioning controls (Virgo suspended payload).

- ❑Glass baffles covers the chambers walls to absorb scattered light.
- ❑Not evident, equipment for thermal compensation of mirror curvature





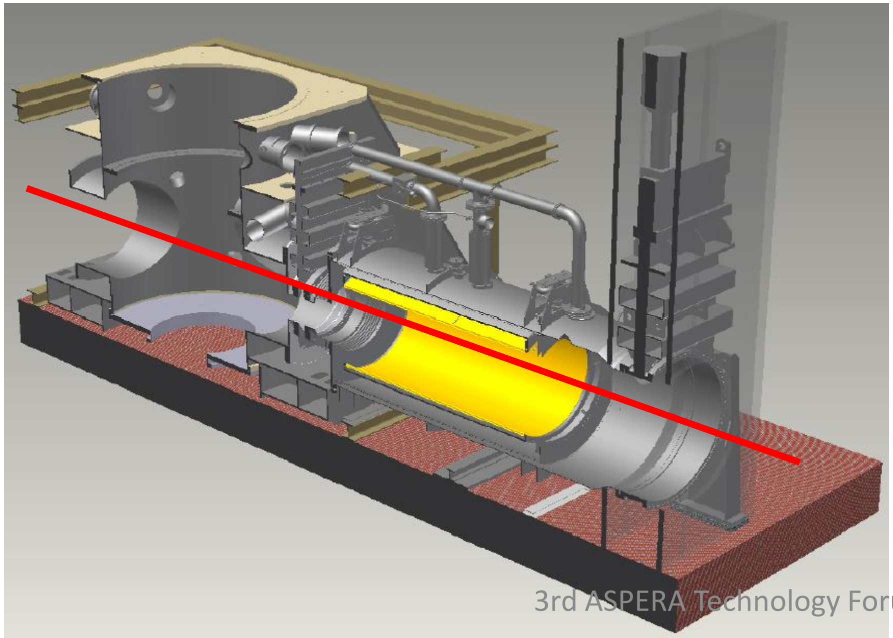
- ❑Mirror chambers are normally baked once before optic inserption for cleaning purposes, and not baked with optics in – situ .
- ❑ periodically accessed by personnel for tuning the equipment

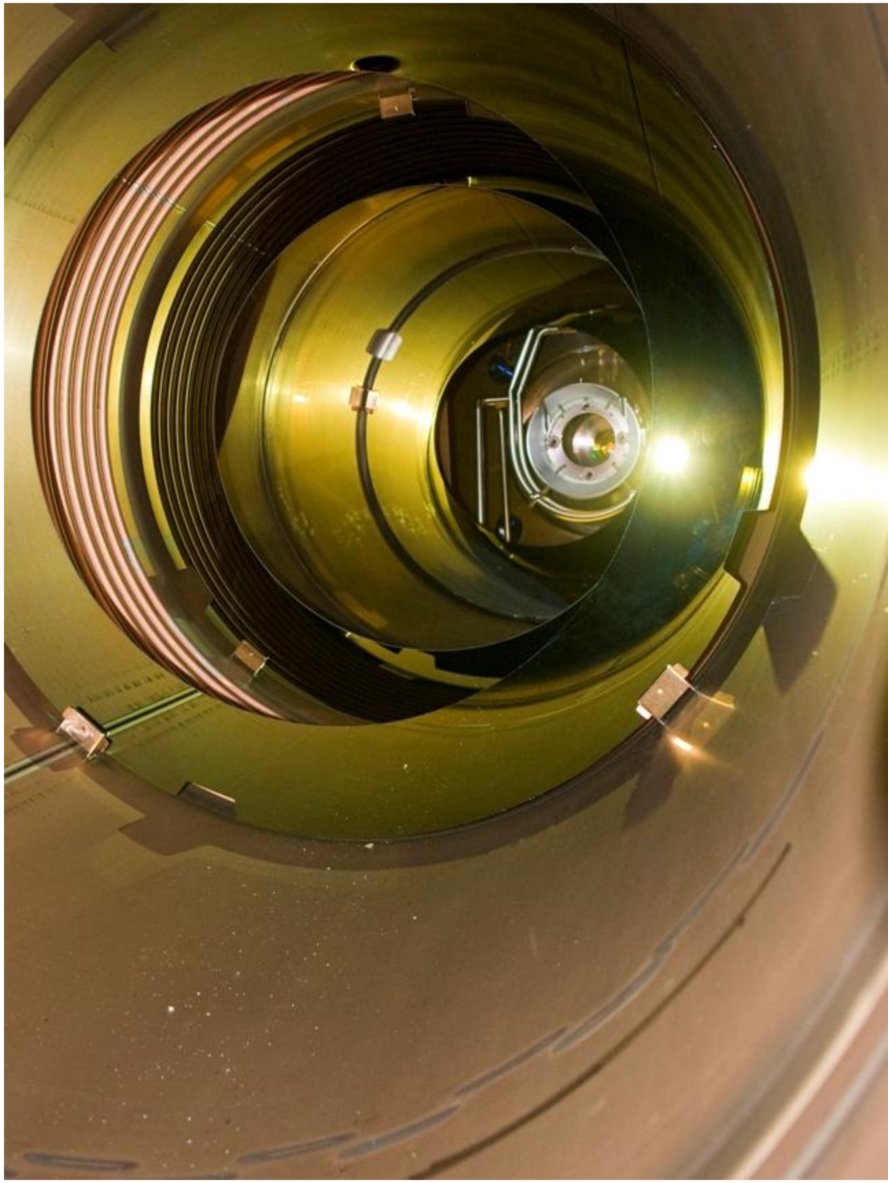
'Central hall': mirror chambers design depends on the seismic attenuation system

- 2m diameter in average, up to 11m high
- Normally metal sealed (or double o-ring), single o-ring for HV compartments
- raw material: 304L (316L)
- Can incorporate order of 100 viewports in total (custom and standard design, BK-7, ZnSe, FS) and signals feedthroughs

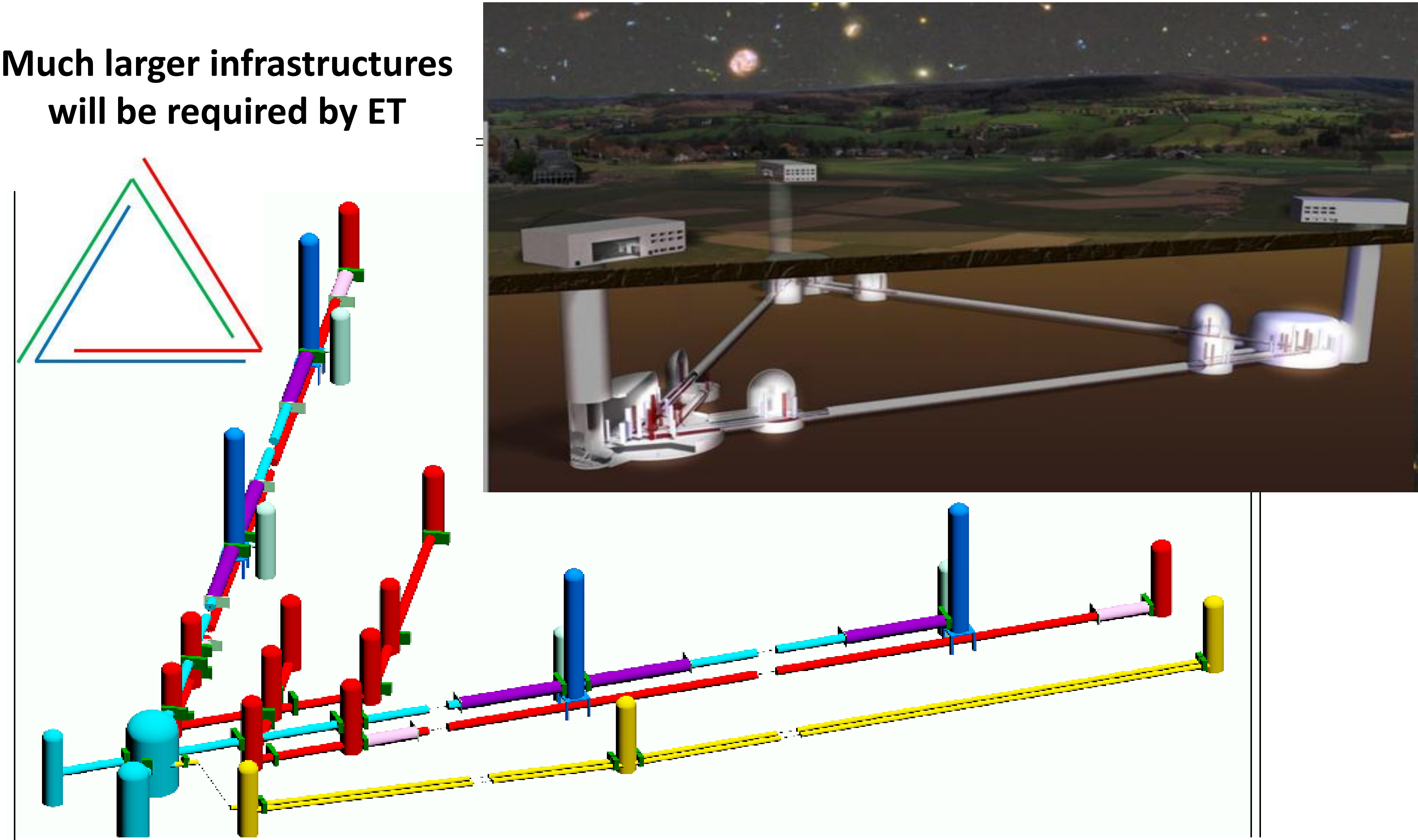
The end mirror seen from the tube (Virgo)

- ❑tube contains just baffles (st. steel) to mitigate light scattering from pipe walls and the laser beam
- ❑The gas load from an entire baked tube (hydrogen) is normally less than from unbaked mirror chambers (recharged at each venting).
- ❑Baking of a km tube is an expensive and time consuming effort preserved with large cryogenic pumps (LIGO, and AdV) condensing water vapor on 77K surfaces.





Much larger infrastructures will be required by ET



1 detector = low frequency cryo-interferometer + high frequency interferometer

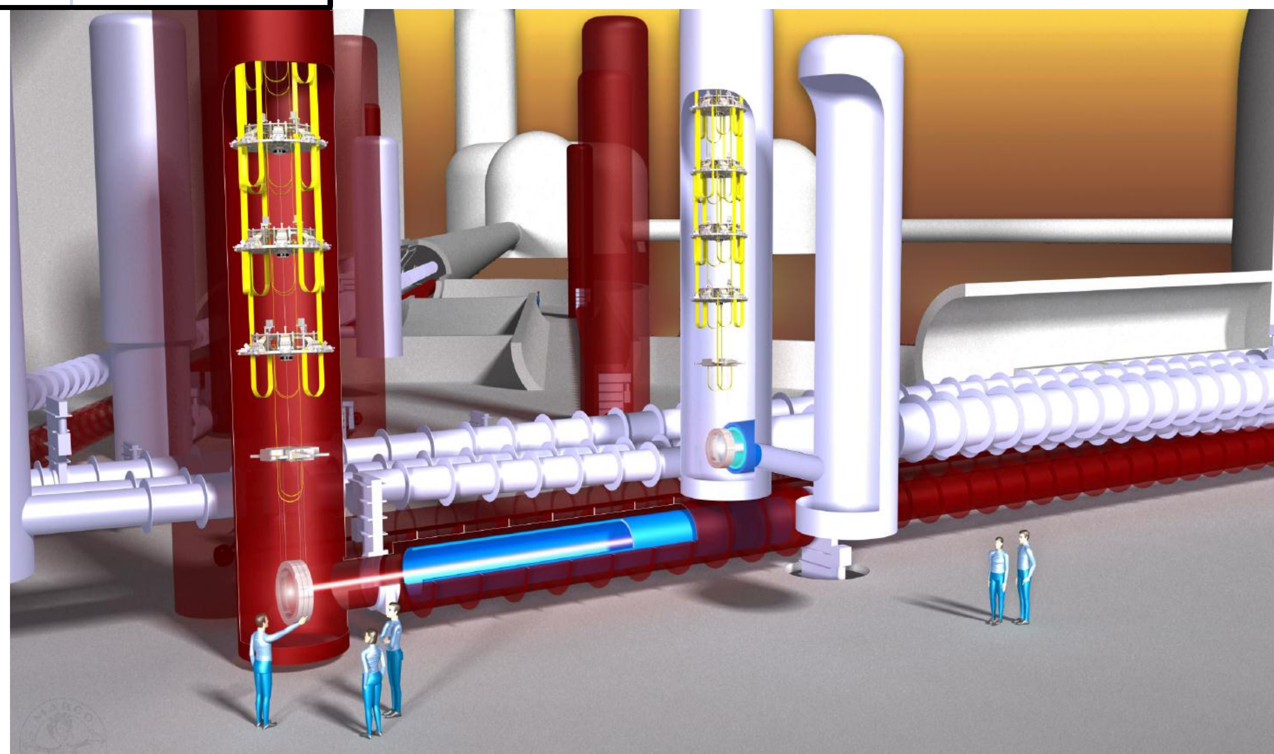
Infrastructure	arm length	10 km
	number of 10 km pipes (HF=0.9m dia , LF=0.75m dia)	6
	large valves	35
	large "pseudo-valves"	10
	number of towers (HF + LF interferometer)	21, of which 4 cryogenic
pumps	number of pumping stations	≈ 100
	77K cryotraps	4
	4K cryotraps	6

Some figures for ET

(single detector configuration)

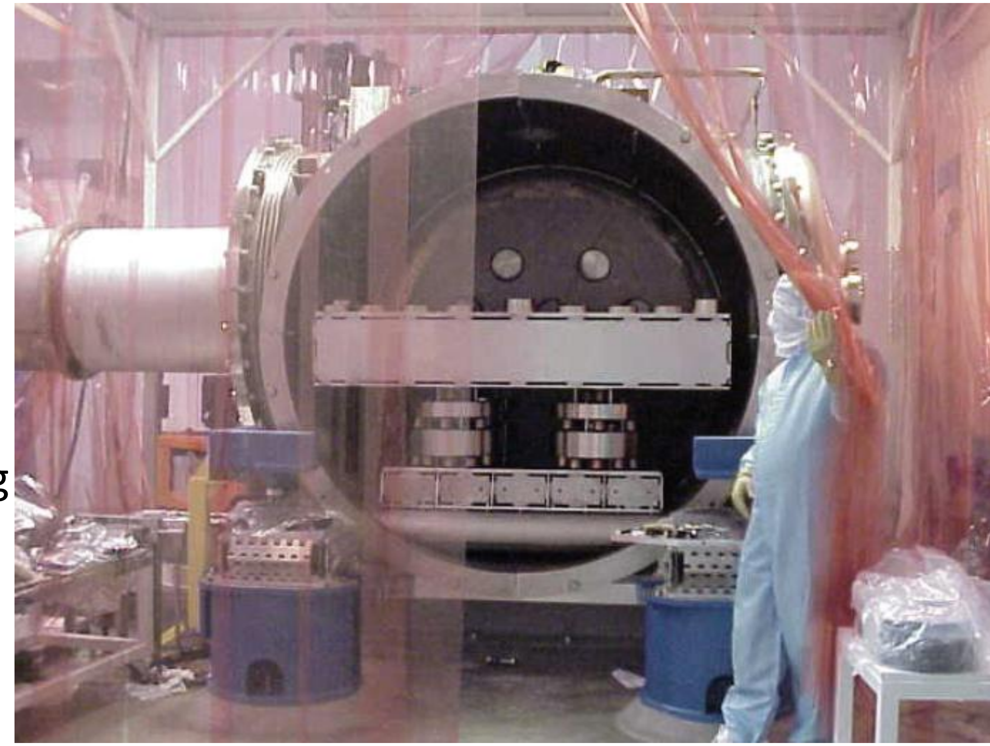
Pressure level in tubes = 10^{-10} mbar

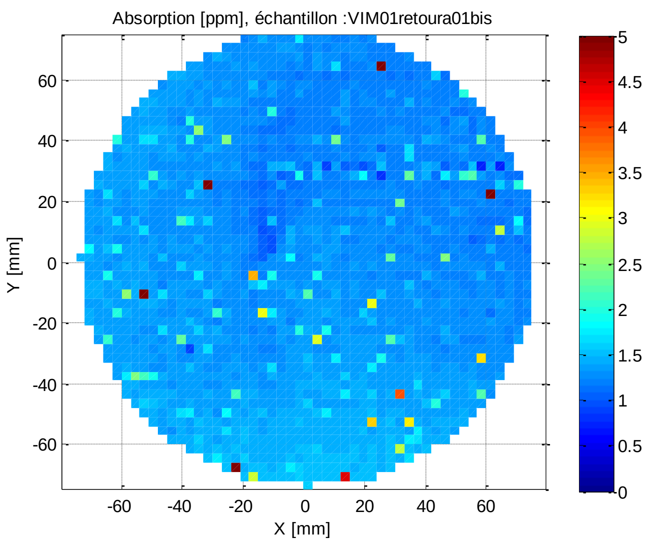
view of the central hall



Dust and contamination would increase scattering and absorption of optical surfaces

When vented, mirror and optical chambers become sort of 'clean room' (class 100 normally) thanks to filtered air flushing inside. Staged cleanliness control: they are opened only vs permanent or portable clean rooms (picture by LIGO) and also the general building cleanliness is cured





Absorption map of NI mirror, Ø300mm, average <2 ppm

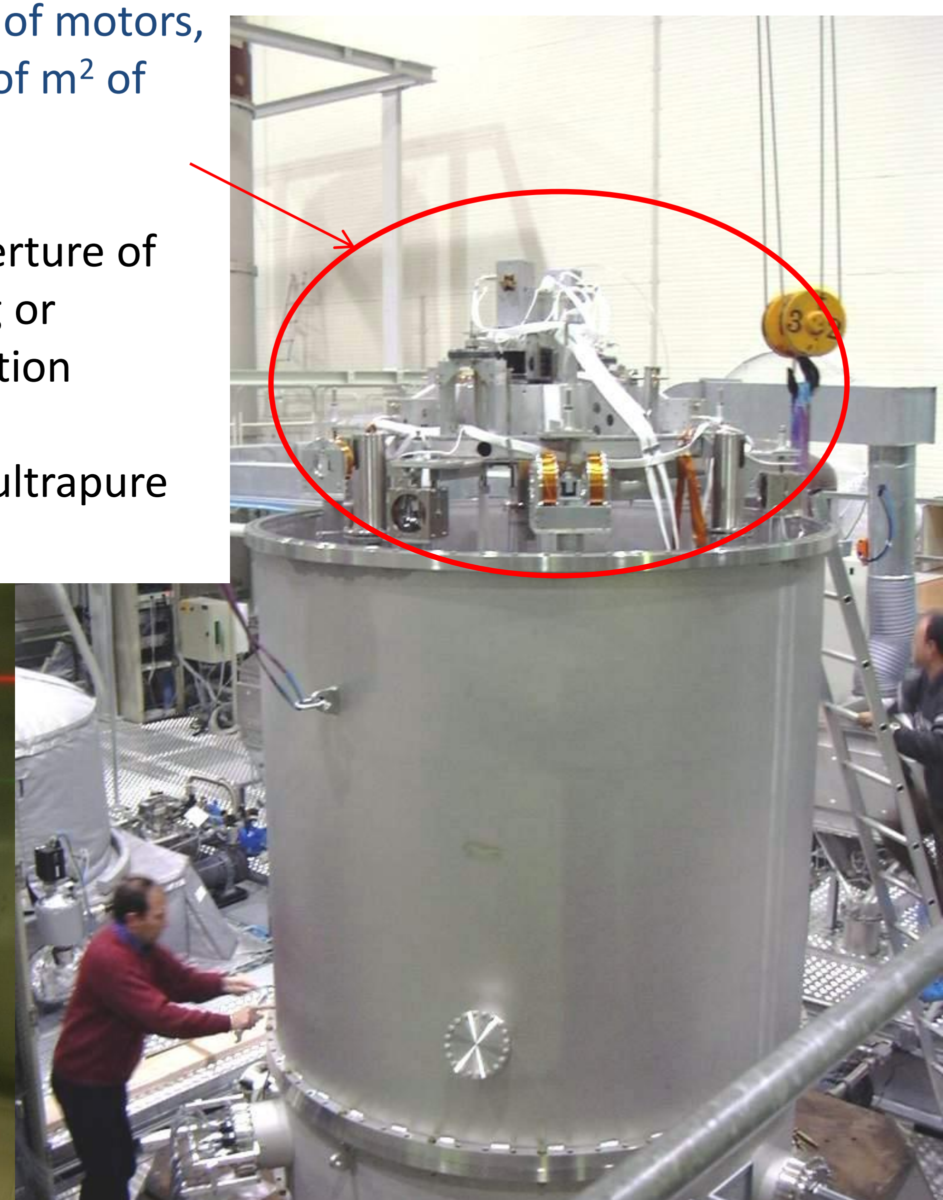
After the 8 years of service we have not experienced degradations of the core optics, apart from dust (Virgo) . Some point absorbers have been found , their origin is under study

HV compartments, with lower vacuum reqts, can contain:

Tens of m of Viton seals, a few km of cables, tens of motors, gears and complex metallic parts, magnets, tens of m^2 of kapton and teflon, epoxy adhesives...

Normally are glass-separated (viewports with aperture of 350mm or more) or through differential pumping or cryogenic trap as a precaution against contamination

Cleaning facilities on site: large ultrasonic baths, ultrapure water equipment, baking ovens



Tubes technologies

Raw material 304L, 1000 tons (Virgo or LIGO)
1.2m - 0.6 m diameter, cost >10% of total apparatus
Two designs:
_ Plain wall (3.2 or 4 mm thick), stiffeners and bellows
_ corrugated wall, 0.8mm thick (316L, GEO600)

Assembled joining modules from 5 to 20m length
Joints welded in-situ: butt (LIGO) or lip (Virgo, GEO600)

Tube technologies

In vacuum surface = 30000 m^2

'Firing' as outgassing reduction treatment (hydrogen) = 400°C in air for 1-3 days, rates of a few 10^{-14} *mbar.l/s.cm² @20°C* Applied on raw material (LIGO) or on finished modules (Virgo)

Test procedures during assembly:

_Leak test on each module

_Leak test on each single welded joint (LIGO) or on sections of assembled modules (Virgo, including bake)

Baking in vacuum: modules are yhen wrapped with thermal insulation and heated DC joule effect up to 150C for some days

ET challenges about tubes:

•Economics

•Assembly underground in narrow space

•Tests, repairs and quality controls

•Baking (heat exhaust, pseudo valves)

Pumping system requirements:

- ❑ each main chamber has a complete pumping system to go from atmosphere to specified vacuum level
- ❑ Oil free pumps are used, against contamination risk
- ❑ Low acoustic / seimic / em emissions to not perturb (pumps drivers included)
- ❑ Long running without frequent maintenances to accomplish long data taking

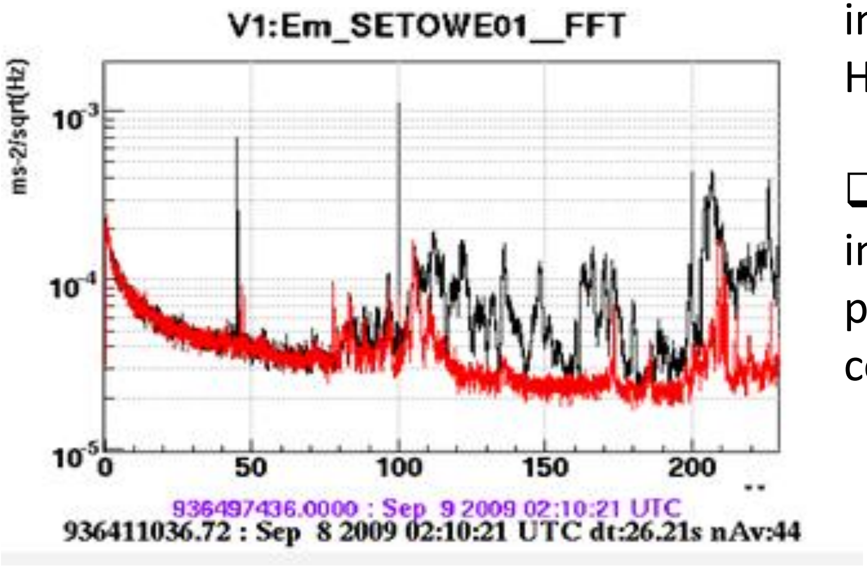
Ion / TSP / cryogenic (liquid bath) pumps
or magnetic bearings turbo-pumps
are normally used in data taking phase
(here 2 x 2500 l/s N_2 Ion pumps - LIGO)

An example of statistic (Virgo)

25 Dry rough/backing pumps
7 + 16 Turbo-molecular pumps
28 Auxiliary Ion pumps
38 Titanium sublimation pumps
20 Residual gas analyzers
221 Angle valves
111 Gate valves (size up to 250mm or similar)
4+6 Large gate valve 1m to 400mm diameter
150 Pressure gauges

Thanks to the large tube conductance, pumping stations are a few (Virgo)

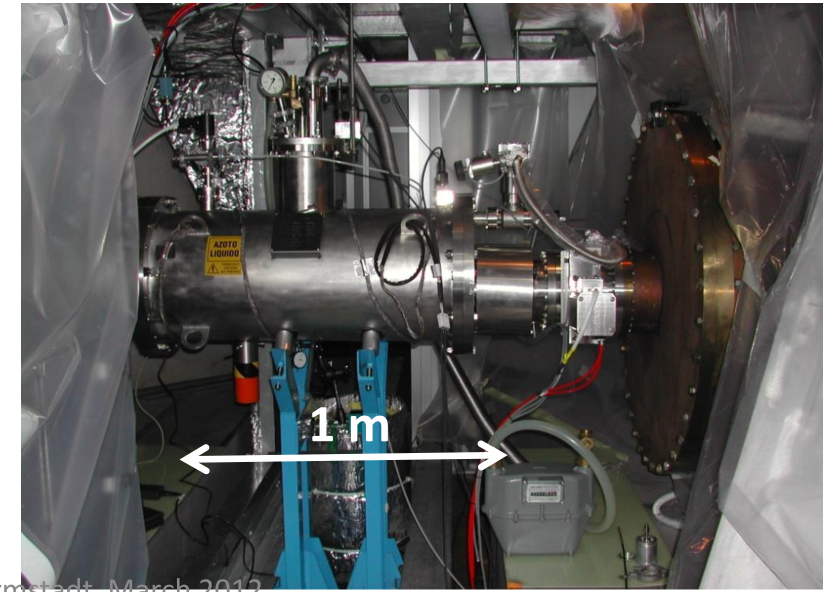
Pumping system details

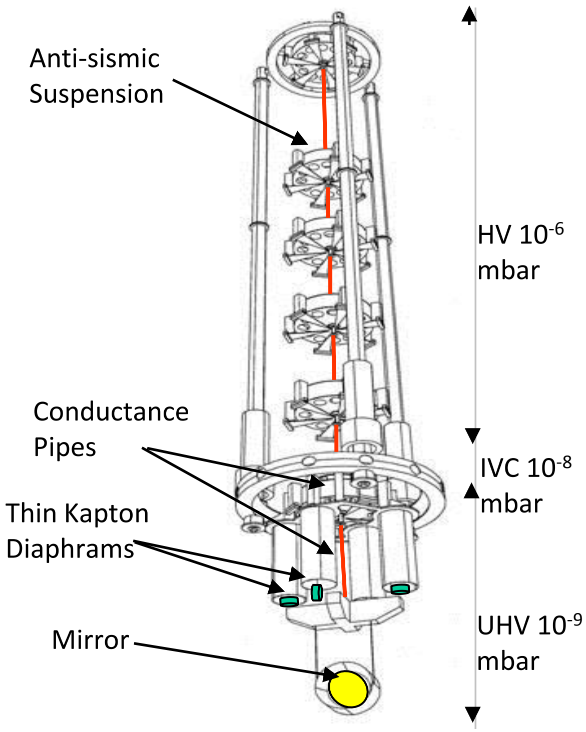


❑Mechanical vibrations: (100-1000Hz) the magnetic turbomolecular pumps are normally installed with bellows while the backing pumps (25 Hz) are displaced far away or run intermittently

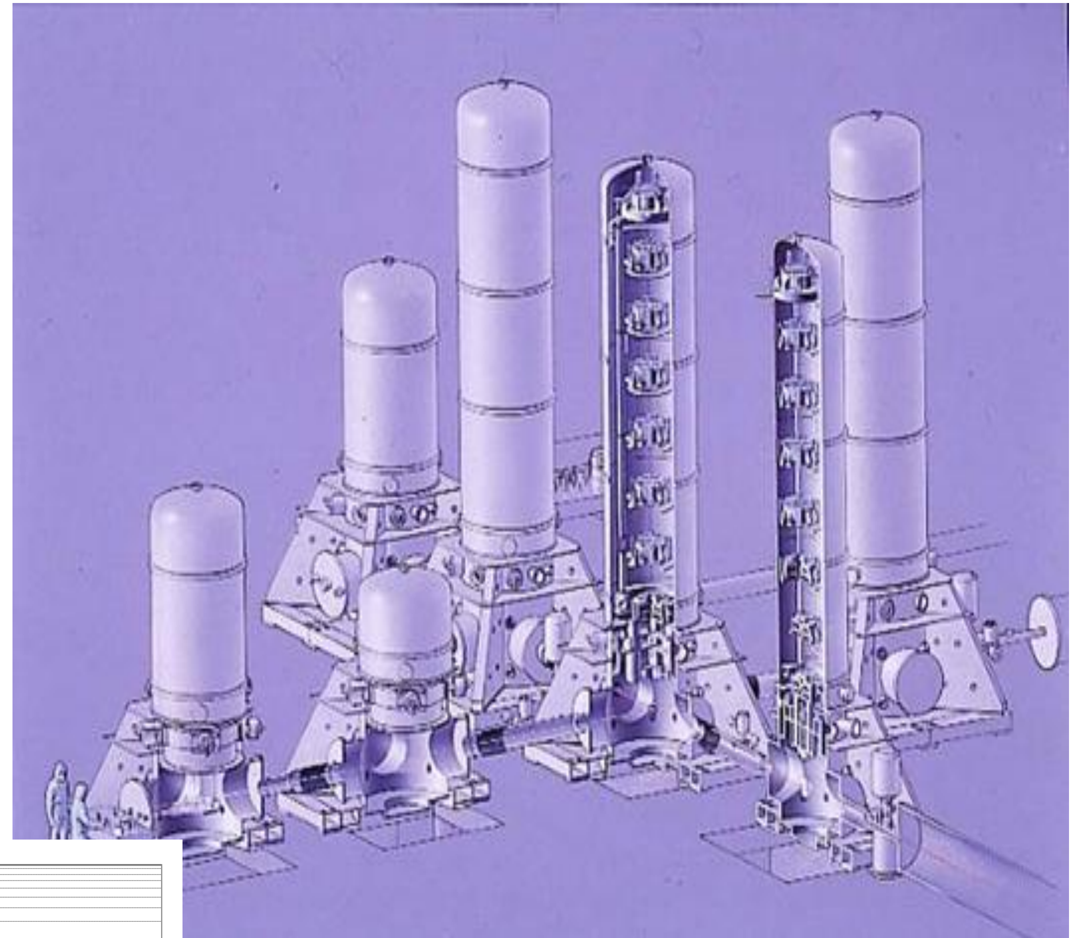
❑Control system SW & HW becoming more integrated with experiment; pumps and gauges permanently monitored also to check possible coeherences = disturbances

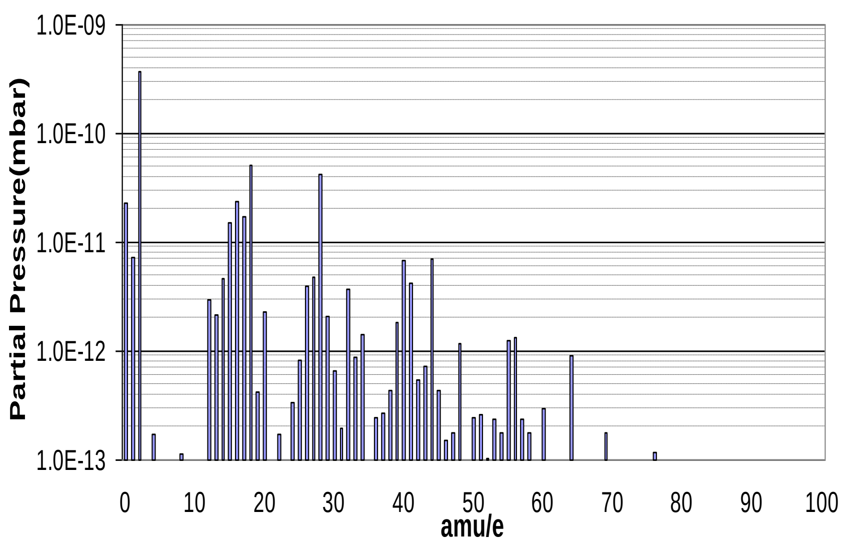
❑Cryogenic pump under evaluation (with low seismic/acoustic noise) order of 5000l/s for instance, to pump water and residual air down to 10^{-9} mbar shortening recovery times of frequently vented chambers





Anti-sismic Suspension
Conductance Pipes
Thin Kapton Diaphrams
Mirror
HV 10-6 mbar
IVC 10-8 mbar
UHV 10-9 mbar





Partial Pressure(mbar)
1.0E-09
1.0E-10
1.0E-11
1.0E-12
1.0E-13
0
10
20
30
40
50
60
70
80
90
100
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