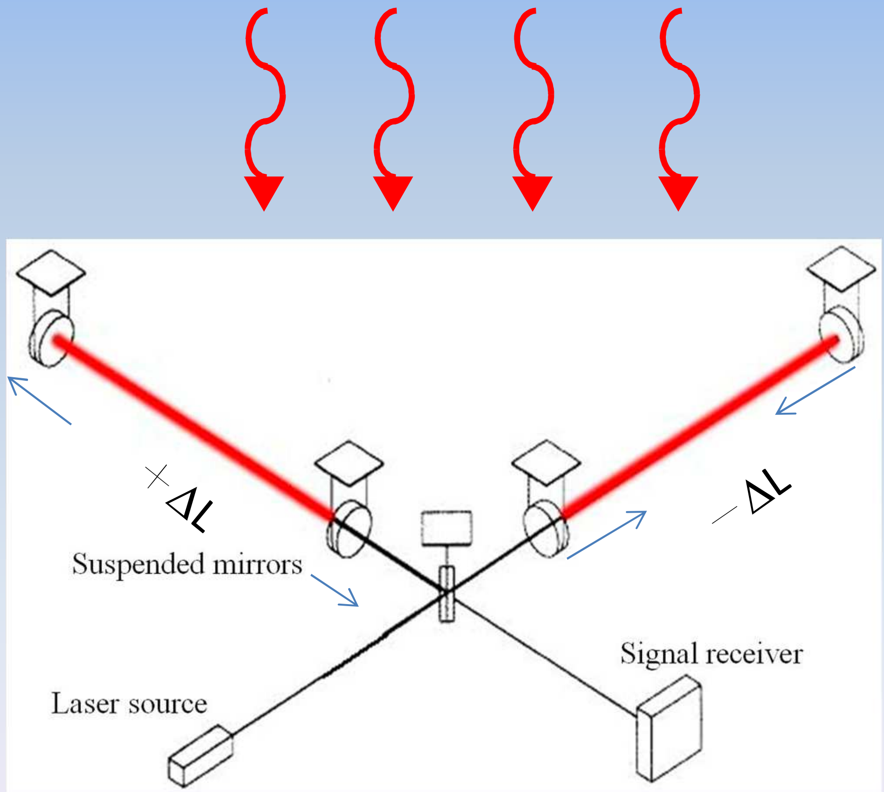
VIRGO Vacuum System

Overview

GW RESEARCH with INTERFEROMETERS



GWs, produced by neutron star or black hole interactions, alternatively squeeze and stretch space in two perpendicular directions

To detect GWs , laser interferometers monitor relative displacements of free masses (mirrors) at the order of 10^{-18} m (frequency band 10Hz-10kHz) for mirrors at km distance

Optics and laser beams are under vacuum to avoid several disturbances

VACUUM SYSTEM LAYOUT

Optics and laser beam are under vacuum to limit perturbations from outer envirornment (gas density fluctuations, 'gas damping' effects, acoustic noise...)

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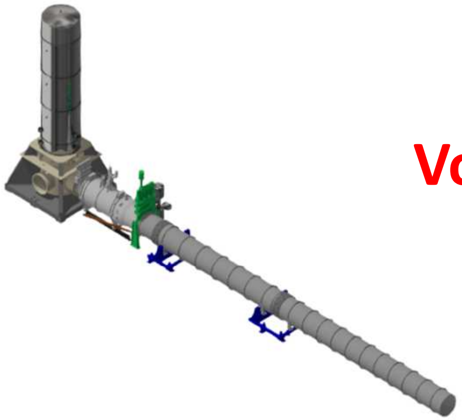
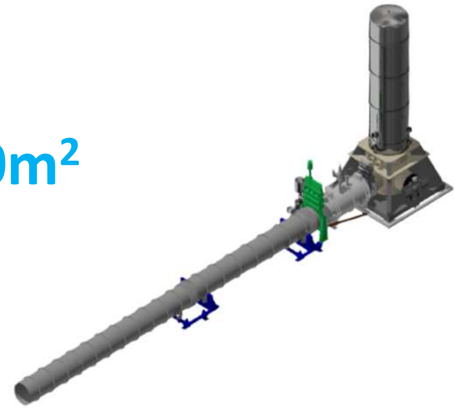
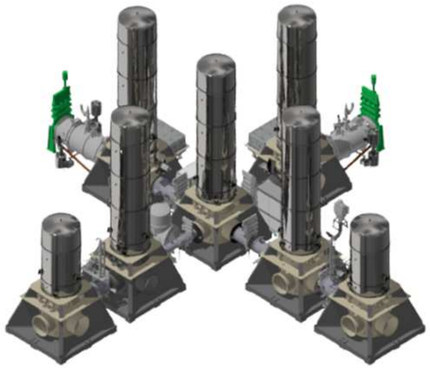
VIRGO 'LARGE' VACUUM SYSTEM



Volume ≈ 7000 m^3 - **Surface ≈ 24000m^2**





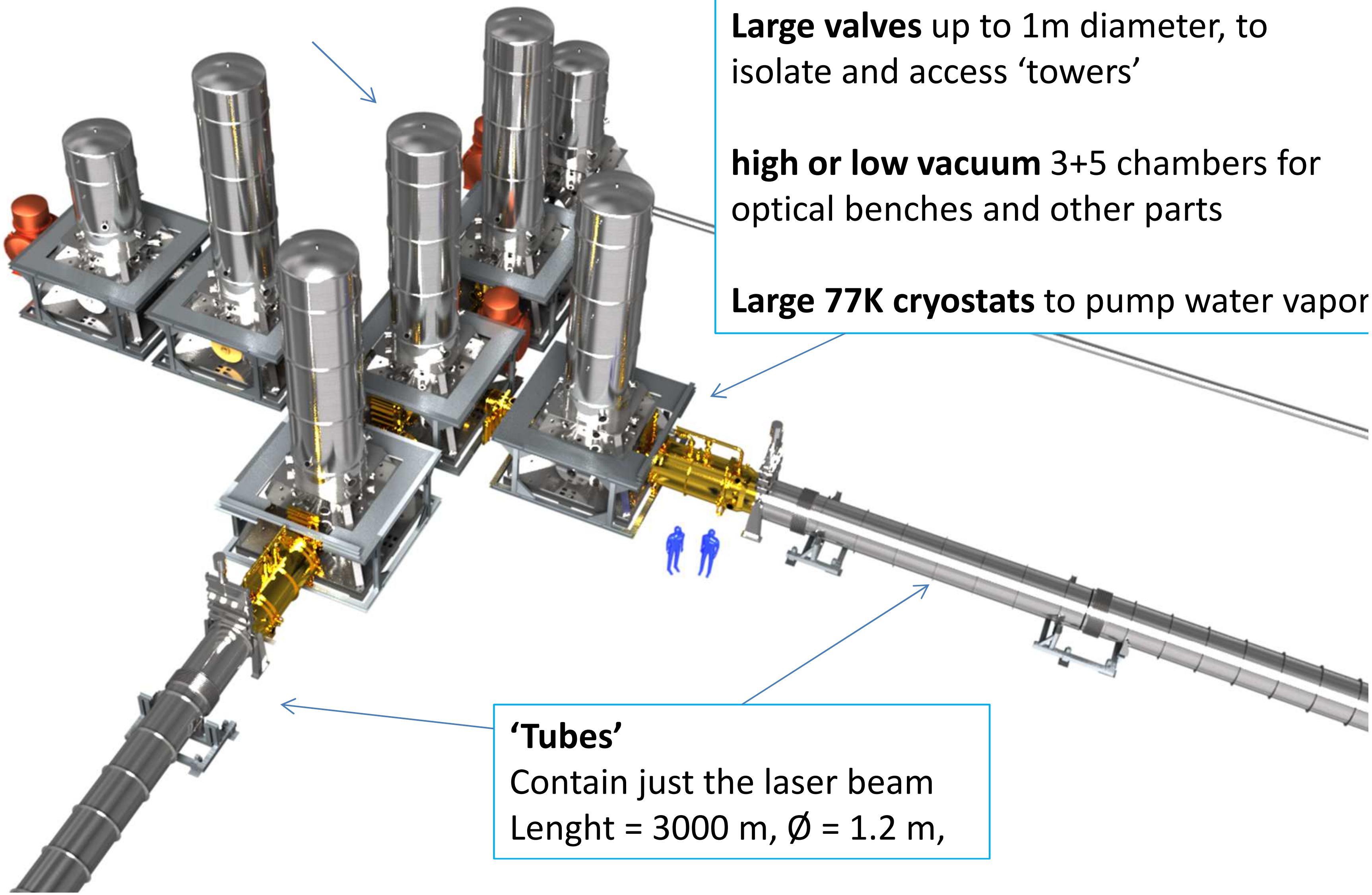
VIRGO VACUUM CHAMBERS

‘Towers’
7+3 chambers (core optics)

Large valves up to 1m diameter, to isolate and access ‘towers’

high or low vacuum 3+5 chambers for optical benches and other parts

Large 77K cryostats to pump water vapor



‘Tubes’
Contain just the laser beam
Lenght = 3000 m, Ø = 1.2 m,

Vacuum level goal (Arm Tubes)

Main function is to reduce the statistical fluctuations of molecules number along the path of the laser beam

Residual Pressure Goal (arm tubes)

10^{-7} mbar for initial detectors

10^{-9} mbar for advanced ones

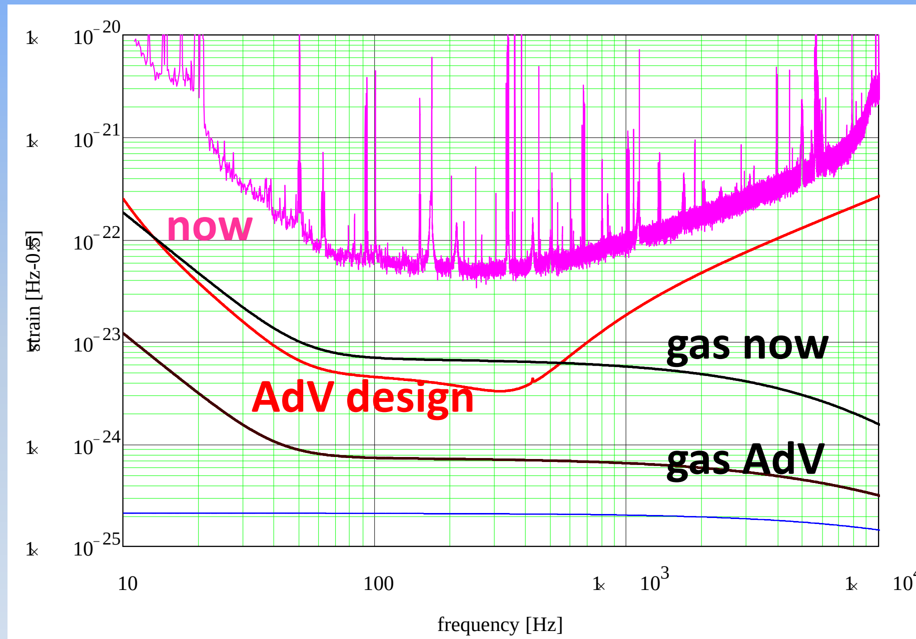
Gas species	hydrogen	water	others	Total
Pressure (mbar)	**10^{-9}**	**10^{-9}**	**$<10^{-9}$**	**$2.5\ 10^{-9}$**
Phase noise ($Hz^{-0.5}$)	*$2.1\ 10^{-25}$*	*$7.0\ 10^{-25}$*	*$6.1\ 10^{-25}$*	*$9.5\ 10^{-25}$*

Advanced Virgo, now under commissioning

Advanced Virgo

sensibility improves x 10 times

(probability of GW events x 1000)

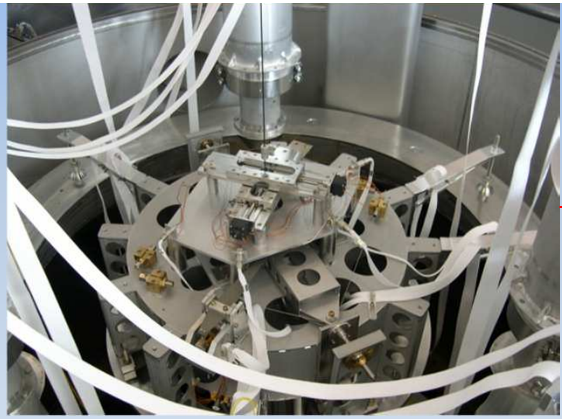


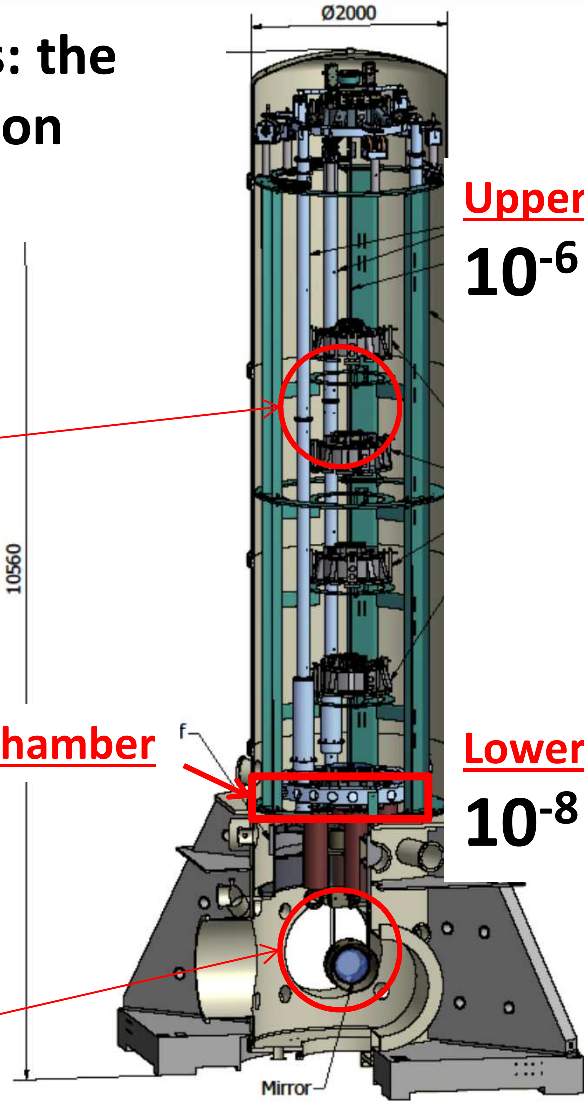
For the Vacuum System, it requires:

1. Vacuum level improvement in the UHV 3km tubes, with towers chamber unbaked to maintain the present easiness of intervention -> cryogenic traps (+ tube baking if required)
2. A different layout of the optics -> new chambers (a few m^3 each): mintowers, enlarged links, 1 full tower, 1 'small' cryogenic pump, and additional pumps

‘Towers’ – two vacuum compartments

Towers are divided in two compartments: the upper one contains the seismic attenuation system, the lower one the core optics





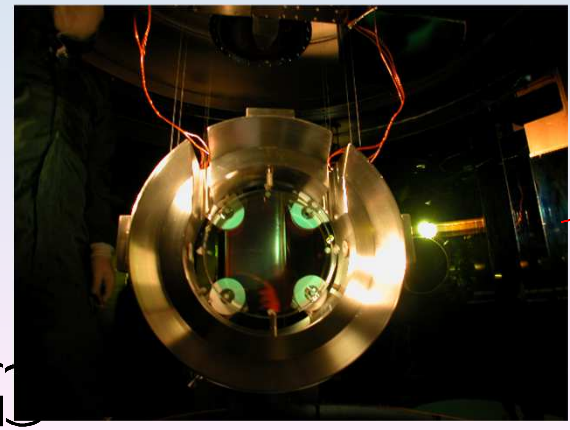
differentially pumped chamber

Upper Part

10^{-6} mbar

Lower part

10^{-8} mbar



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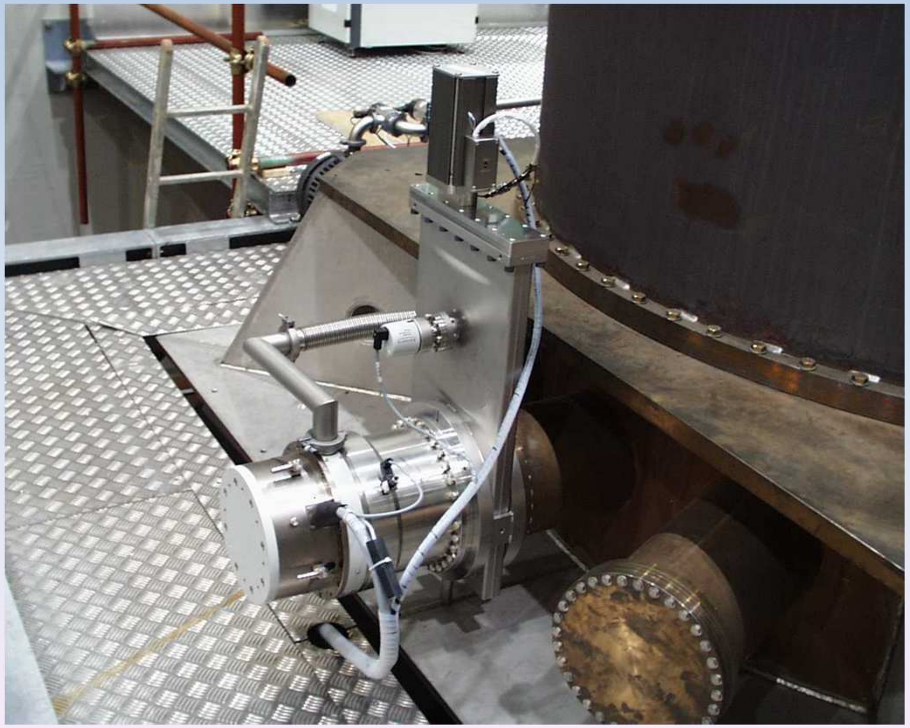
‘Towers’ during early installation

- ‘lower’ part of a tower chamber
- raw material = 304L air-baked at 400°C

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 / seismic / EM emissions
- Long running without frequent maintenances to accomplish long data taking

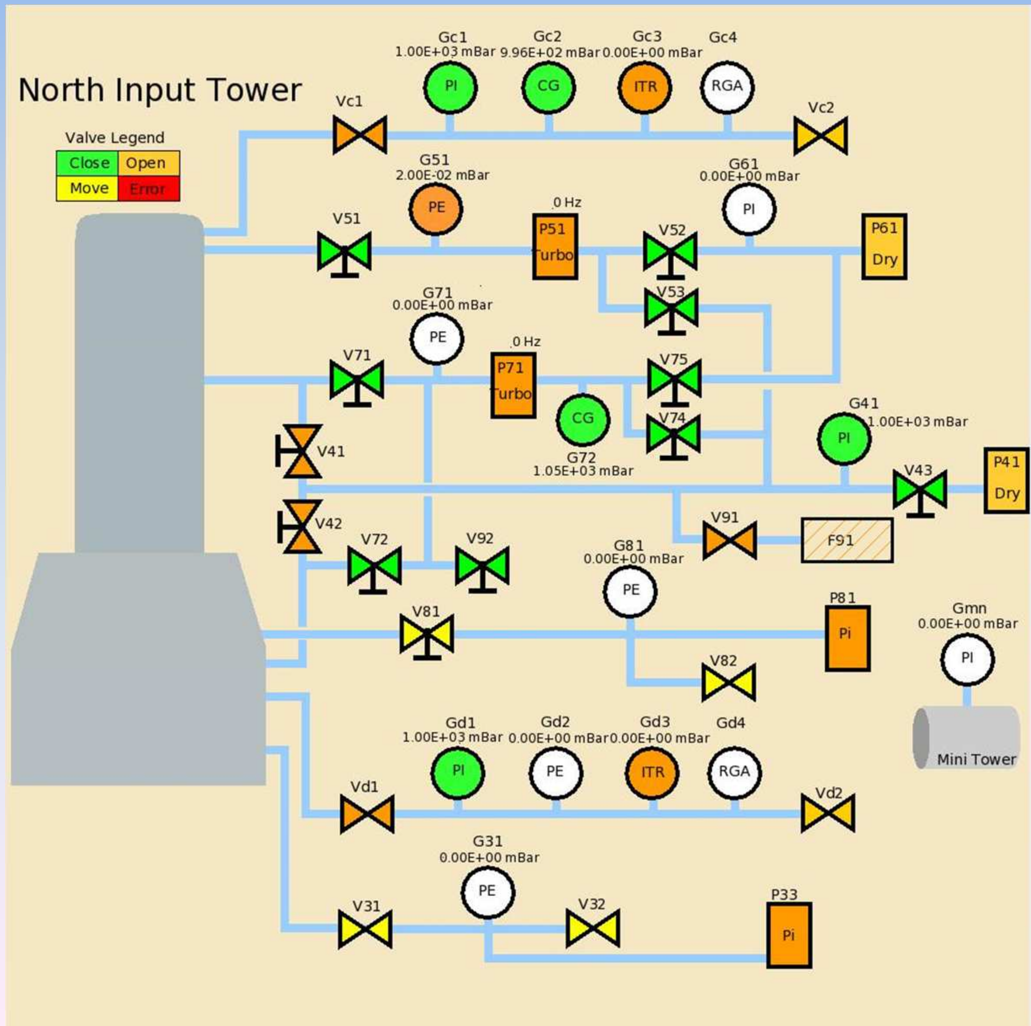
Ion / TSP / cryogenic (liquid bath) pumps
or magnetic bearings trbo-pumps
are used in data taking phase



Control system

One 'control rack' per 'tower'

Logic of operation is managed by a PLC and all parameters are recorded



PUMPING SYSTEM STATISTIC

29 Roughing/backing dry pumps

21 Turbo-molecular pumps

28 Ion pumps

38 Titanium sublimation pumps

20 Residual gas analyzers

221 Angle valves

111 Gate valves

4 Large gate valve 1m diameter

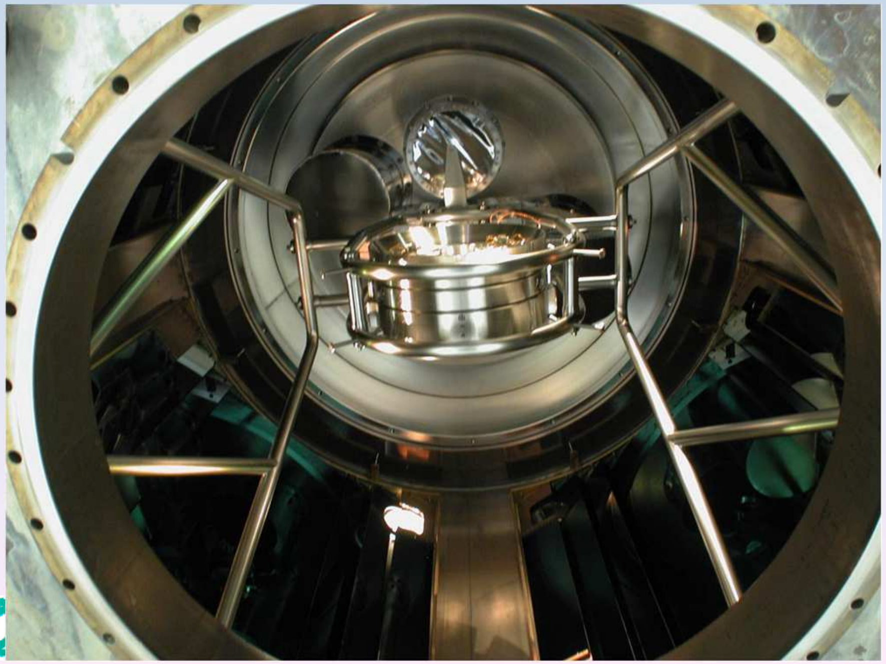
153 vacuum gauges

VACUUM CHAMBERS in ‘CENTRAL HALL’

Vacuum cleanliness inside Towers

Optical surfaces free from contamination (presence of high power laser)

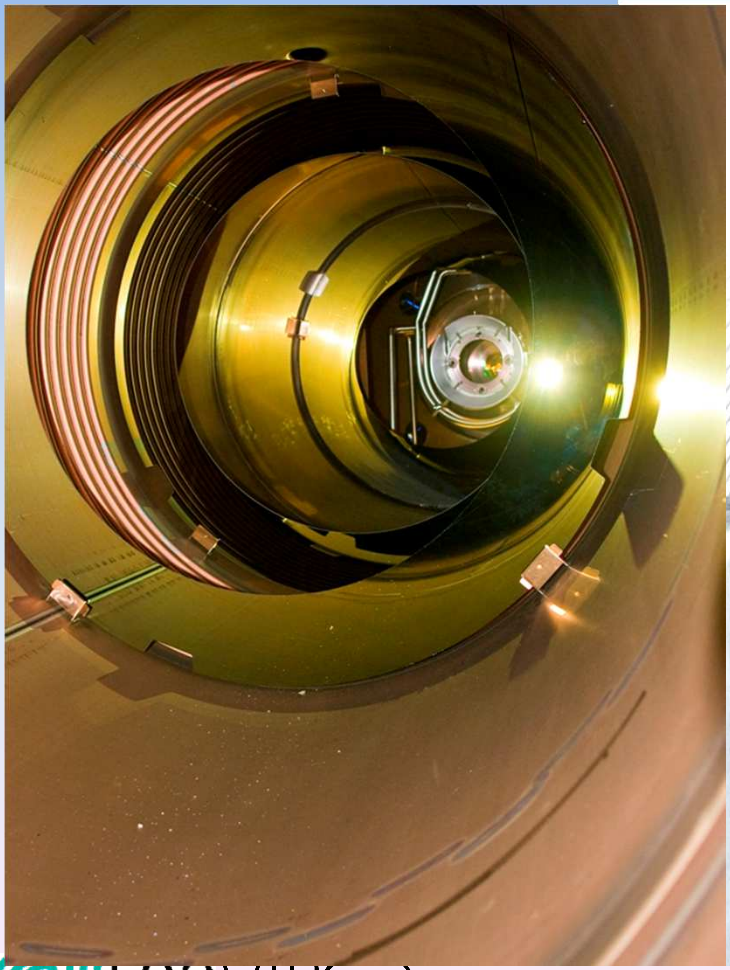
Dust and contamination would increase scattering and absorption by optical surfaces . When vented, ‘towers’ become a white room (class 100)



Mirror chambers have been baked-out before optic inserption for cleaning purposes (never with optics in situ).

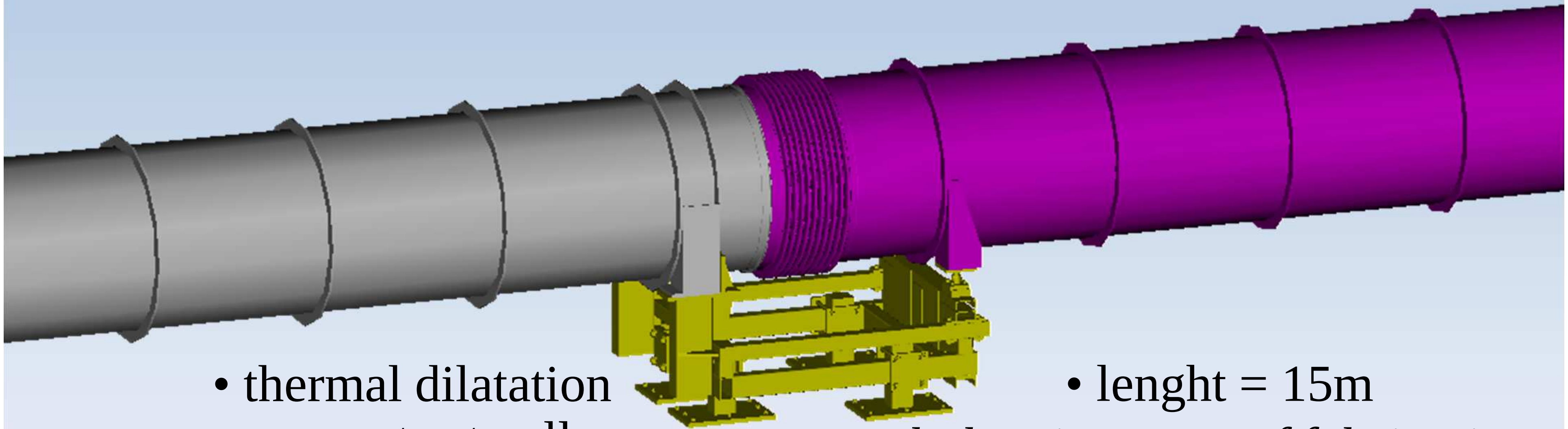
2 x 3 km Vacuum Tubes

They contain only optical baffles, in addition to the laser beam



TUBES DESIGN

- Raw material 304L, plain wall 4 mm thick, stiffeners and bellows
- prefabricated modules to be joined by welding
- cost >10% of total apparatus



- thermal dilatation compensator to allow heating up to 150°C

- lenght = 15m

balancing costs of fabrication + transportation vs installation (joints, building foundations, number of supports...)

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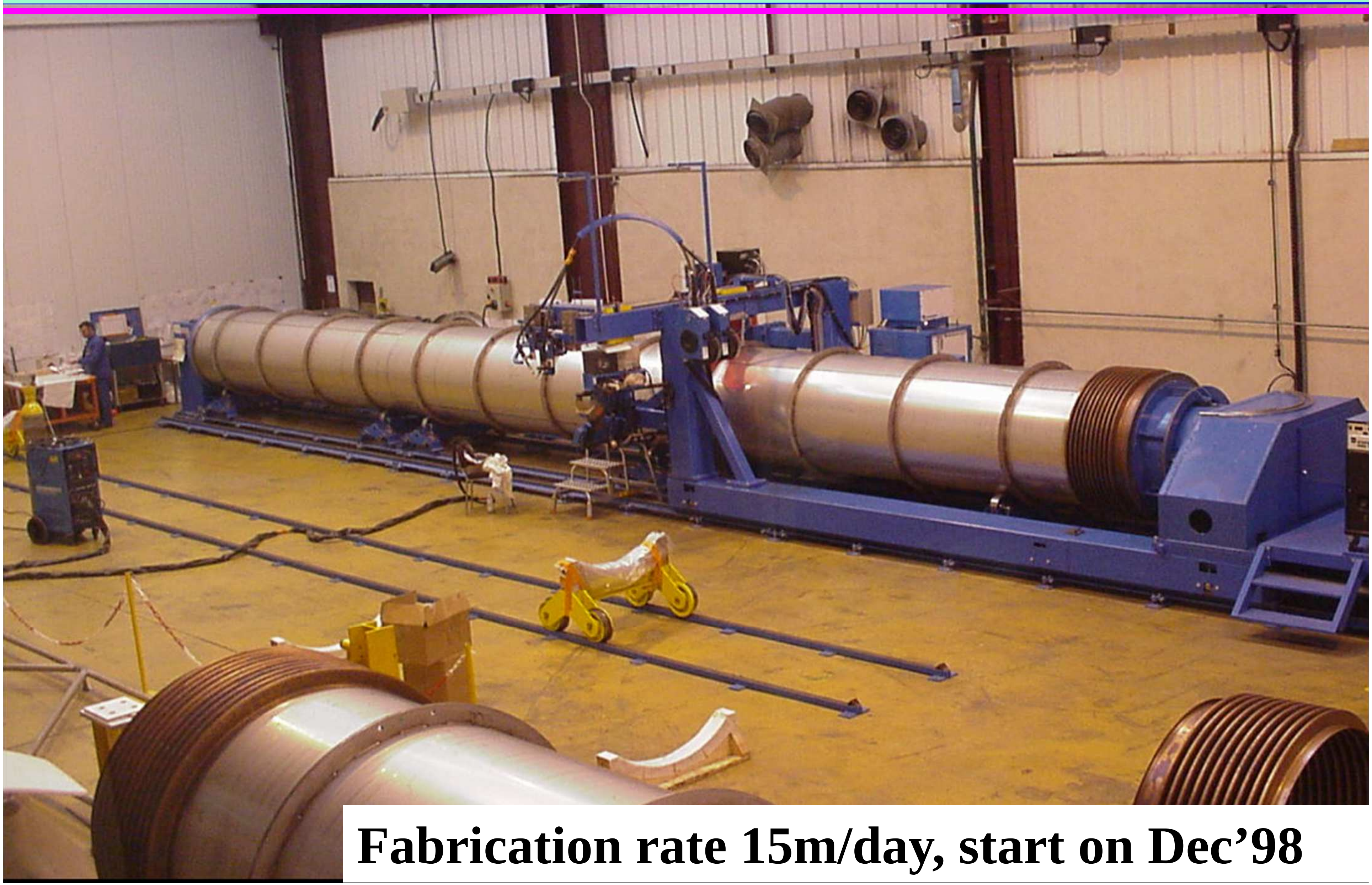
CIRCULAR WELDING MACHINE
GENERAL ASSEMBLING



Fabrication rate 15m/day, start on Dec’98

Tubes technologies

Air-baking (400°C in air) involves a ''simple'' oven and it is able to reduce the walls H_2 outgassing by over a factor 100: **rates of a few 10^{-14} *mbar.l/s.cm^2 @20°C* have been obtained.**

Testing procedures included:
_Prototypes qualification
_Leak/RGA test on each module
_Full vacuum tests on series of assembled sections .

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

Air-baked tube modules with oxidized surfaces

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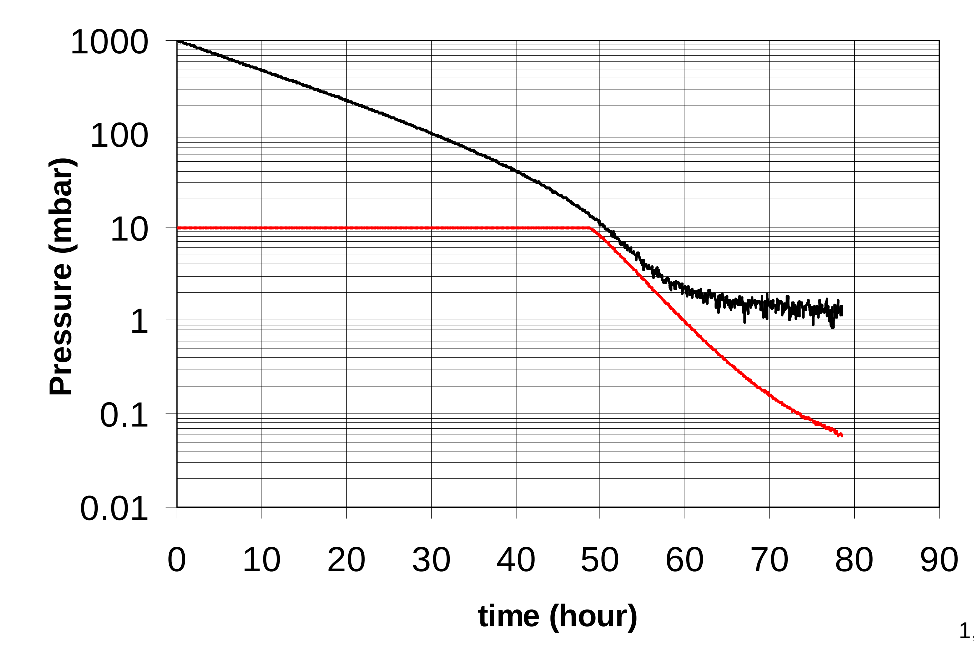
TUBE MODULES INSTALLATION

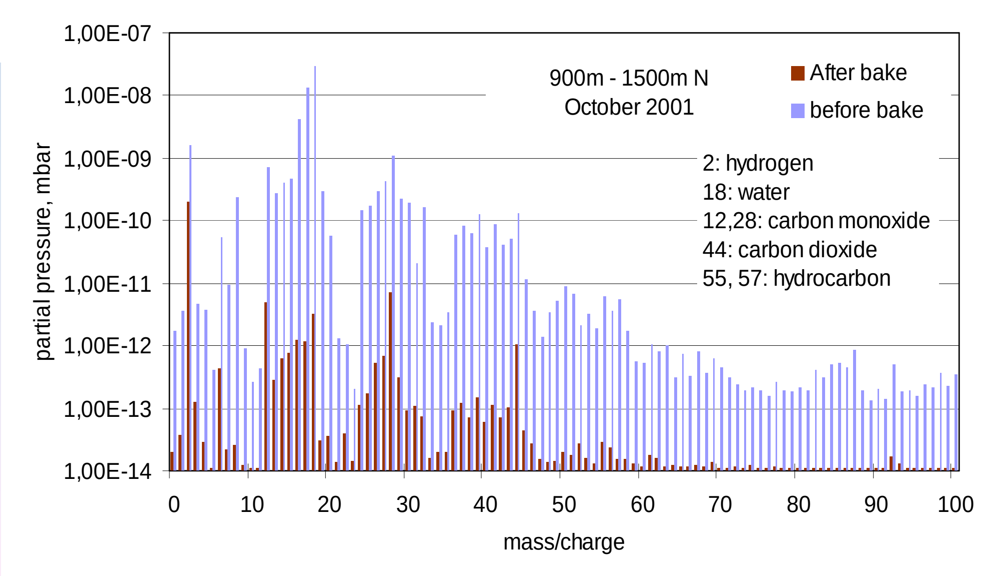
Tube module entering in 'tunnel'
A thermal insulation layer has been added to the outer surface
Assembly rate = 30m/day

Vacuum level evolution



80 hours for roughing down

Residual gases after bake-out: total pressure below 10^{-9} mbar, mostly hydrogen



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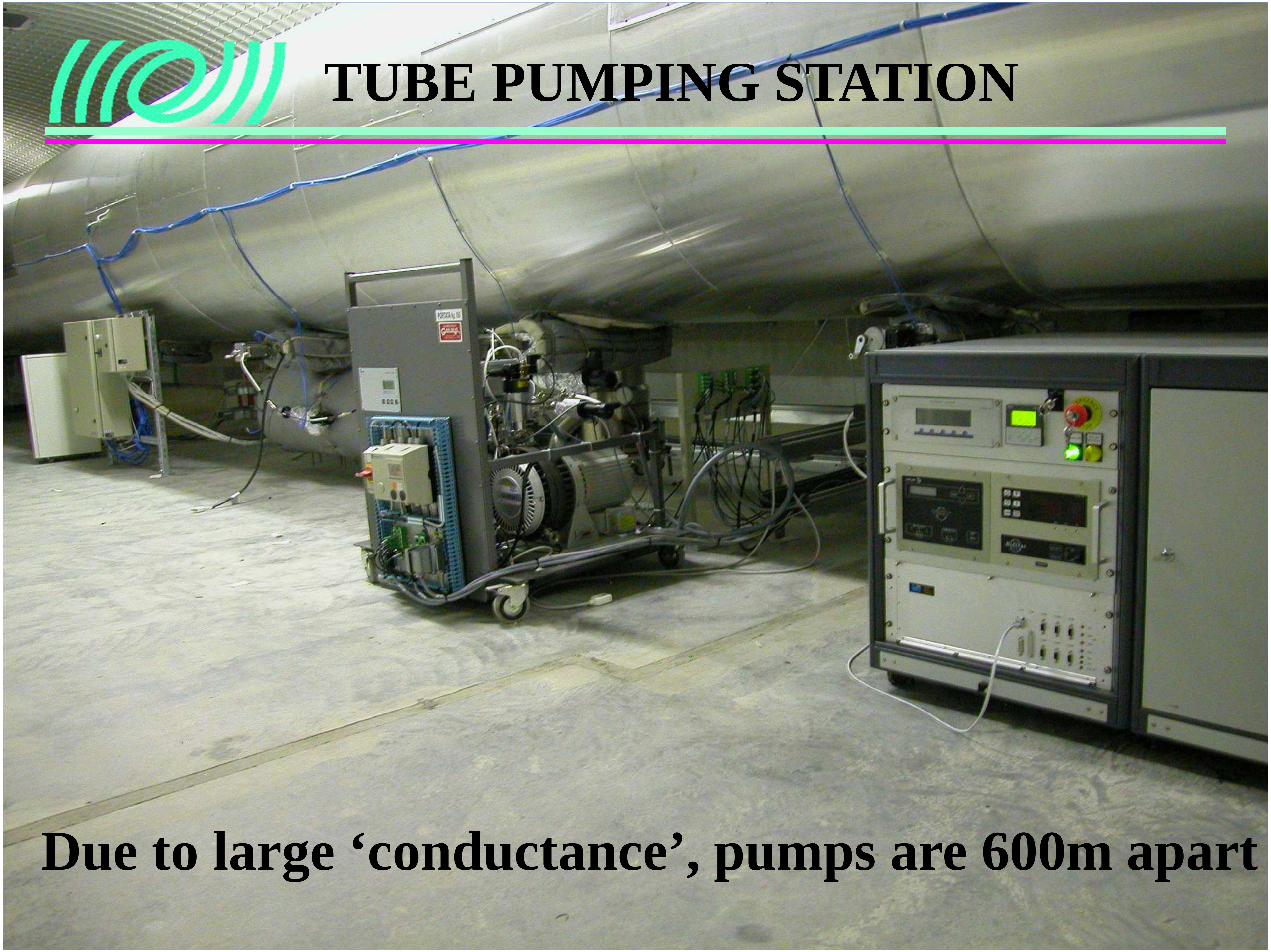
TUBE PUMPING STATION



Due to large ‘conductance’, pumps are 600m apart

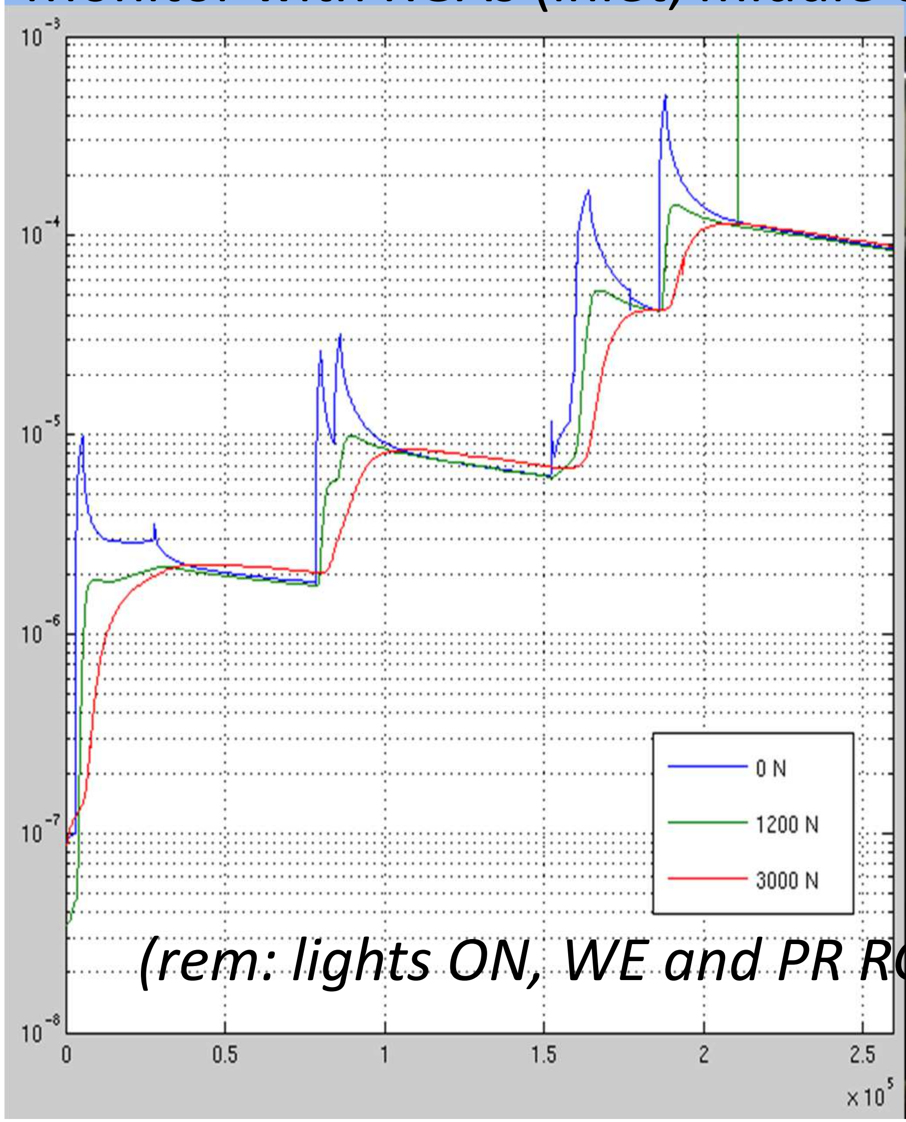
Advanced Virgo

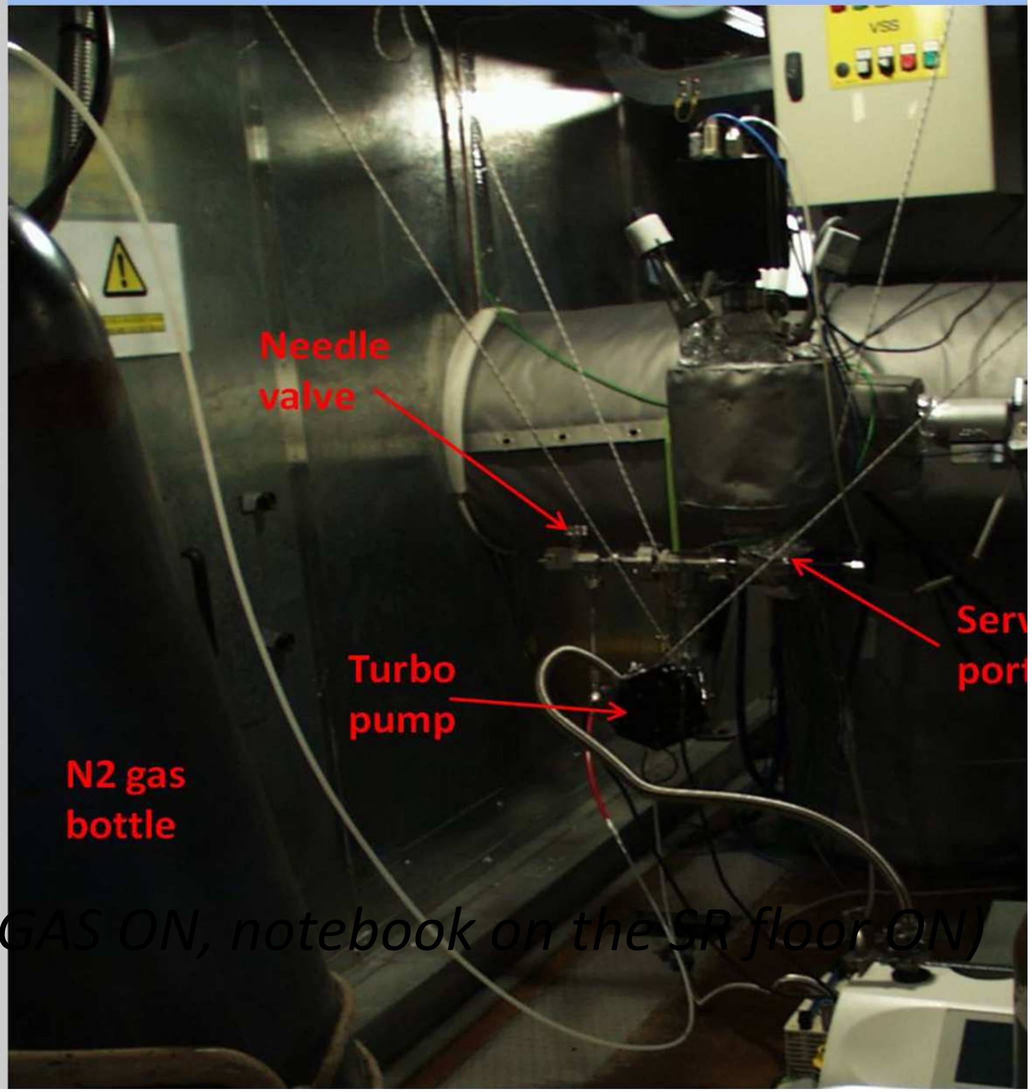
EGO European Gravitational Observatory

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

Gas inlet setup

Injected nitrogen from SR –BS link, waiting some hours for uniformity
Monitor with RGAs (inlet, middle of tubes, end towers) to get N_2 >90%

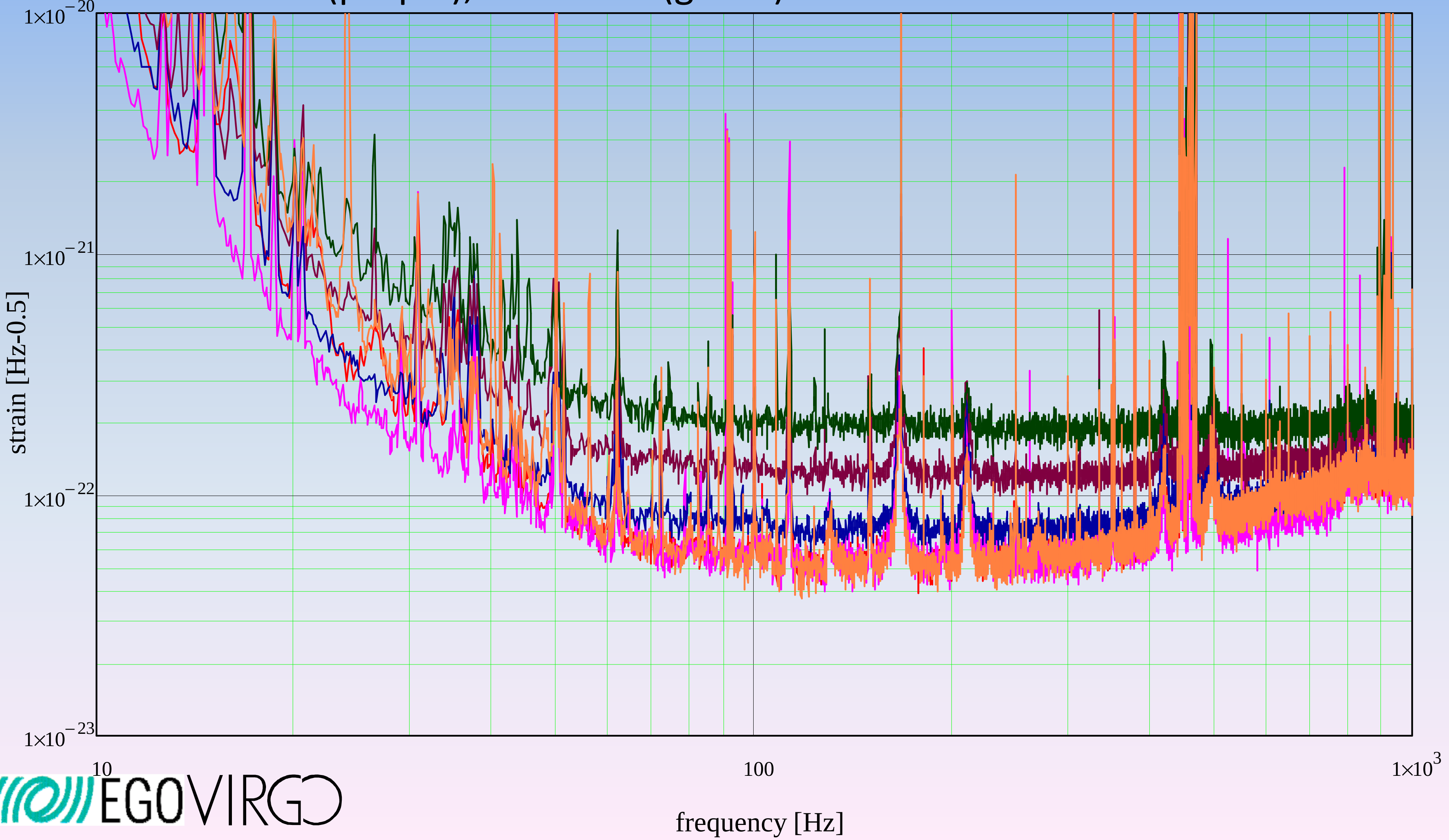




(rem: lights ON, WE and PR RGAS ON, notebook on the SR floor ON)

h_20000 noise emerging with the pressure (Nov 2011)

VSR4 Sens (pink), just before test (orange), 2E-6mbar (red), 8E-6mbar (blue), 4E-5mbar (purple), 1E-4mbar (green) . *Pressure values are nominal ones*



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Large Vacuum valves

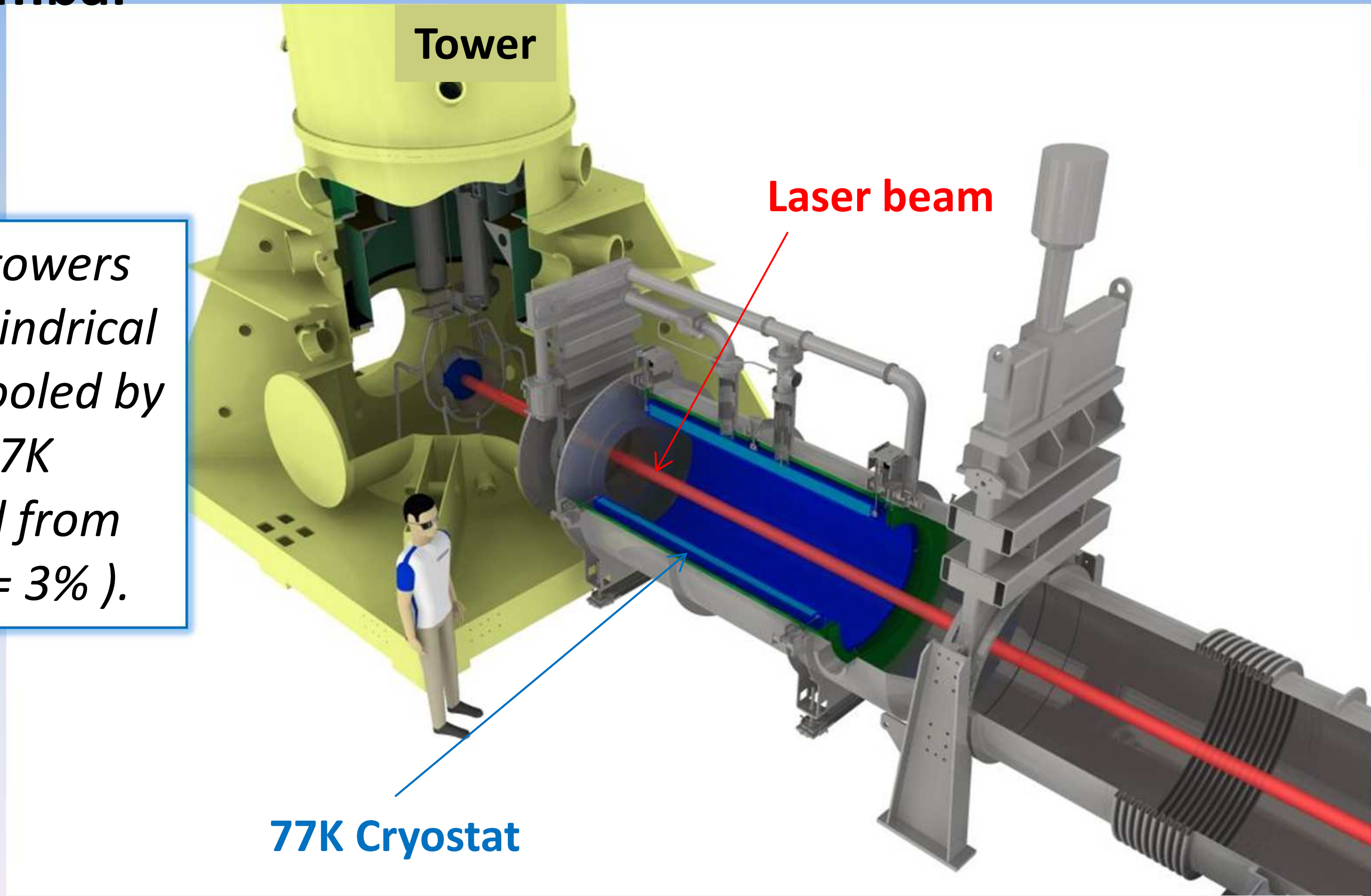
4 large Valves isolate the 'tubes' from the 'towers'

Stainless steel body, air-baked
Metal sealed
Viton o-ring on the gate
bakeable at 150°C
Extensively vacuum tested
Large economic cost

Cryogenic traps

Large cryogenic pumps are installed in between ‘towers’ ≈E-8 mbar and ‘tubes’ ≈E-9 mbar

Water vapor from towers is condensed on cylindrical sections 2m long cooled by liquid nitrogen at 77K (molecules escaped from ‘towers’ to ‘tubes’ = 3%).



LN2 boiling (5 l/hr) is a possible source of noise (micro mechanical vibrations): accurate design to avoid ‘heat concentration spots’ + seismic isolation of the cryostat

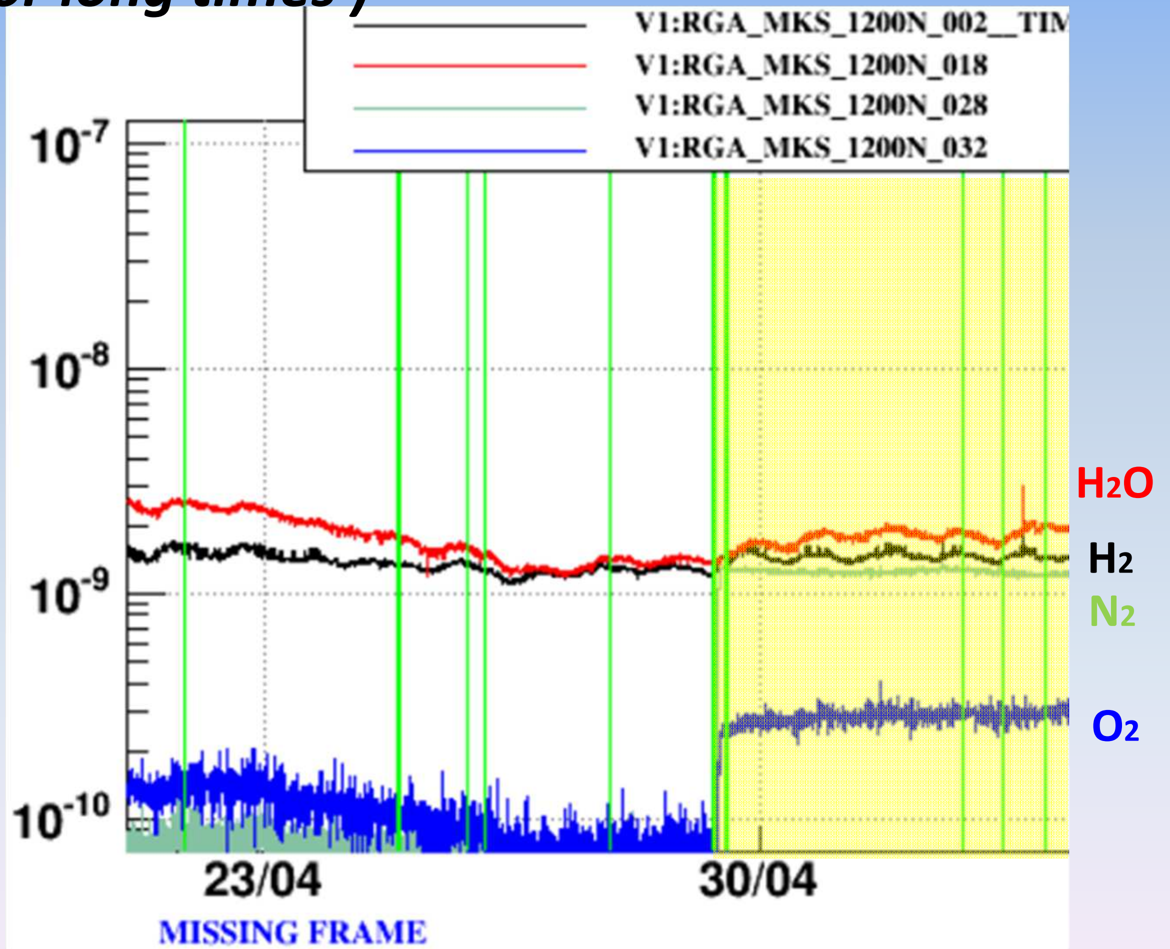
LN2 Cryostats

- **Outer vacuum vessel (room temp.) made of stainless steel**
- **Inner vessel (cold) of 300 liters capacity realized in aluminum, 2 m long , 0.9 m inner aperture (laser beam passage)**
- **Cryogen consumption order of 5 lt/hr**
- **Reached vacuum level <1E-9 mbar (after bake-out)**

Cryotrap before its integration at 'West arm end'

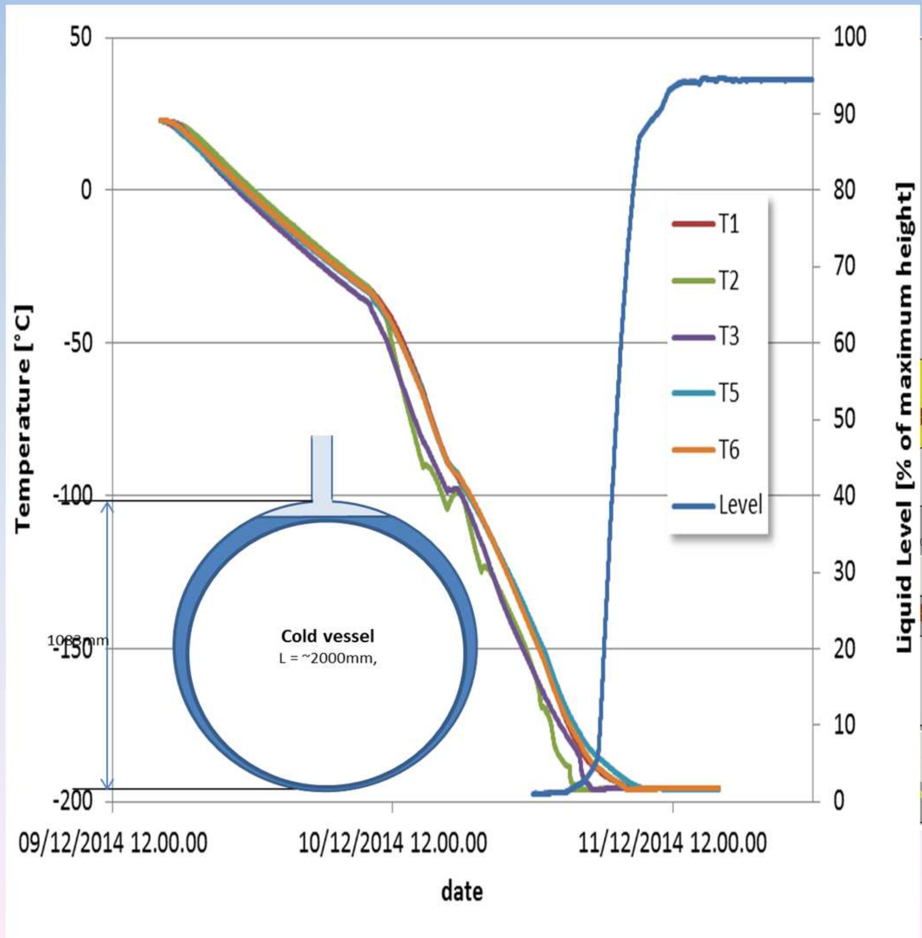
Towers restart

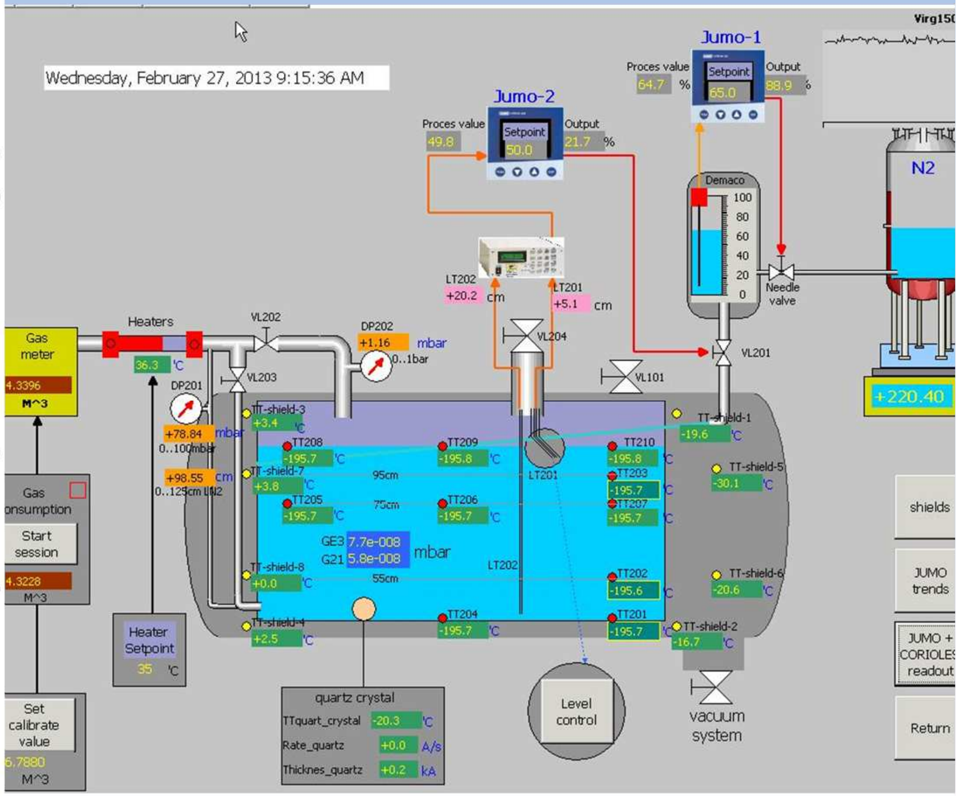
Air recharged in towers after every venting enters in tubes (to be pumped for long times)



Cryogenic equipment

Cool-down takes about 2 days, after that steadty conditions are kept refilling countinuously liquid nitrogen through a phase separator and a level control





Cryogenic equipment

Storage of cryogen on site:
3 external tanks
= 2 x 10000 l + 1 x 30000 l
(3 weeks autonomy)

Refill operations during 'maintenance breaks' = about 1 hour per tank, the whole operation is completed within a few hours