Einstein Telescope

the European 3rd generation Gravitational Wave Detector

The pipe vacuum system

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Credits: Harald Lueck, Yoshi Saito, C. Bradaschia, Michael Zucker, ET collaboration

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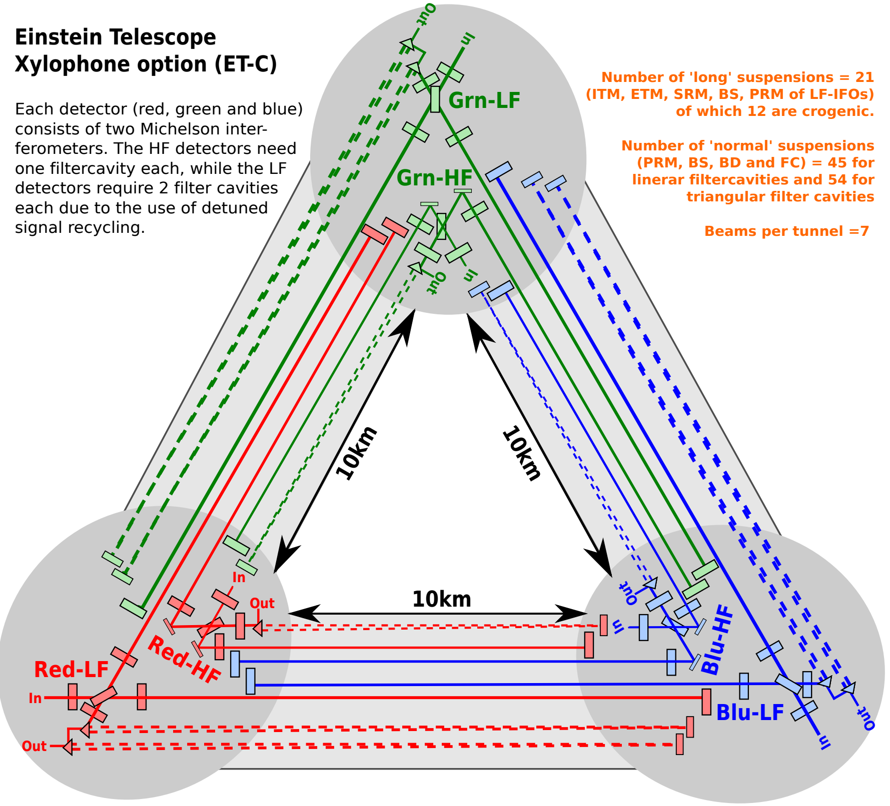
[c] Virgo vacuum responsible

XXIV SIGRAV Conference 7-9 September, Urbino

Einstein Telescope in a nutshell

- The Einstein Telescope (ET) will be a new 3rd generation (3G) GW observatory
- 3G means a factor ~10 better than advanced (2G) GW detectors, **and ~1000 more universe to explore**
- A completely **new infrastructure is needed**
- **2 possible sites: Sardinia (Italy) and Dutch-German-Belgium border**
- ~ 200 m underground
- 30 km ~7 m diameter galleries + caverns (30x30x60 m)
  -> total excavation 5.4 Mm^3
- 6 interferometers arranged in triangular shape
- 120 km 1 m beam tubes UHV (10^{-10} mbar)
- ~200 in-vacuum towers to host the seismic isolation systems
- Mirrors 200 kg
- Some part under criogenics operation (~ 20 k)
- > 500 W ultra stabilized lasers
- Lifetime: 50 years
- Total cost ~ 1.7 Geuro + R&D



ESFRI announces new RIs for Roadmap 2021

30.06.2021

PRESS RELEASE

ESFRI announces the 11 new Research Infrastructures to be included in its Roadmap 2021

€4.1 billion investment in excellent science contributing to address European challenges

After two years of hard work, following a thorough evaluation and selection procedure, ESFRI proudly announces the **11 proposals** that have been scored high for their science case and maturity for implementation and will be included as new Projects in the **ESFRI 2021 Roadmap Update**.

Very good news !!

The new ESFRI Projects are:

- **EBRAINS** - European Brain ReseArch INfrastructureS, a distributed digital infrastructure at the interface of neuroscience, computing and technology, offering scientists and developers advanced tools and services for brain research.
- **EIRENE RI** - Research Infrastructure for EnvIRonmental Exposure assessment in Europe, the first EU infrastructure on human exposome (environmental determinants of health).
- **ET** - Einstein Telescope, the first and most advanced third-generation gravitational-wave observatory, with unprecedented sensitivity that will put Europe at the forefront of the Gravitation Waves research.
- **EuPRAXIA** - European Plasma Research Accelerator with Excellence in

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Press Release-New Projects for ESFRI Roadmap 2021

Latest news

06.07.2021

ESFRI Days 2021

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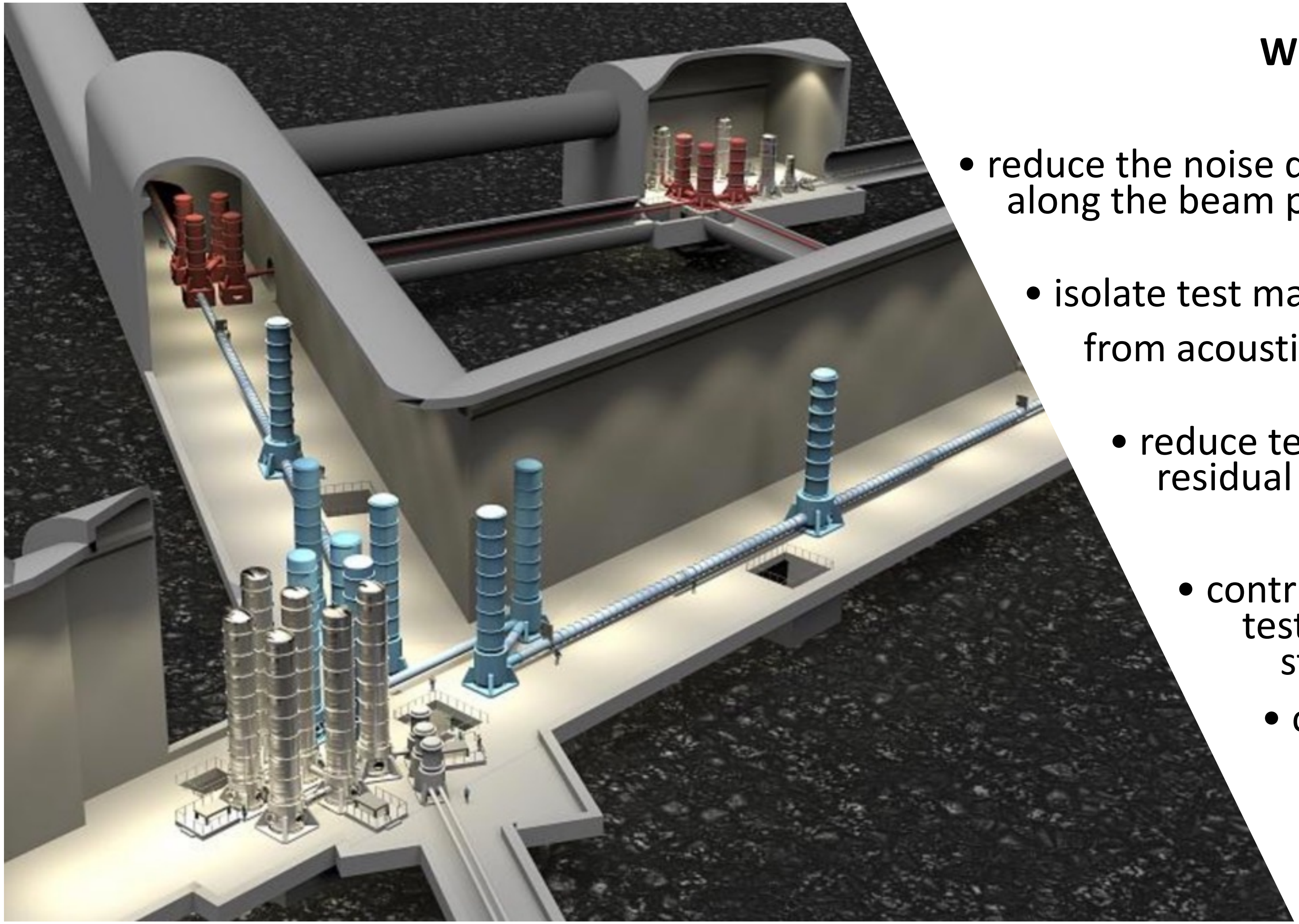
Latest ESFRI tweets

A new ambition for #ResearchInfrastructures in the #European Research Area" lays out the specific role research inf... https://t.co/w8vQOY2uqD

ET vacuum



Why under vacuum?

- reduce the noise due to residual gas fluctuations along the beam path to an acceptable level;
- isolate test masses and other optical elements from acoustic noise;
- reduce test mass motion excitation due to residual gas fluctuations,
- contribute to thermal isolation of test masses and of their support structures;
- contribute to preserve the cleanliness of optical elements.

Effect of gas pressure on detector sensitivity

Fluctuations of residual gas density induces a fluctuations of refractive index and then of the laser beam optical path

Power spectral density fluctuations of optical path

Gas optical polarizability

Interferometer arm lenght

Molecules number density

$$S_L(f) = \frac{(4\pi\alpha)^2}{v_0} \int_0^L \frac{\rho(z)\, \exp\left[-2\pi f\, w(z)/v_0\right]}{w(z)}\, dz$$

Average molecules speed

Laser beam gaussian radius

ET beam tubes requirements

- Tube diameter ~ 1m
- Total lenght 120 km

Surface: $3.8\text{x}10^5$ m^2
Volume: $9.4\text{x}10^4$ m^3

- Total residual pressure: H_2 10^{-10} mbar, H_2O $5\text{x}10^{-11}$ mbar, N_2 10^{-11} mbar (more stringent reqs comes from ET-HF)
- Hydrocarbon partial pressure < 10^{-14} mbar
- Material ?(2G detectors: SS 304L or 316L)
- Life time: 50 years

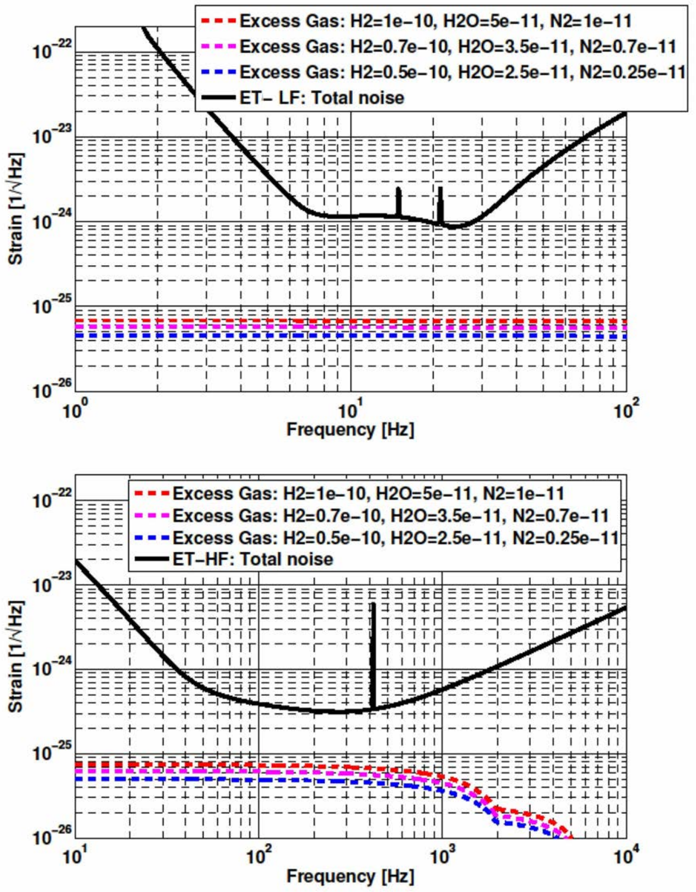


Figure 6.16: Phase noise given by the residual gases compared to the expected sensitivity, computed for the appropriate beam profile for different gas compositions. (Goal gas composition: Hydrogen [$1\ 10^{-10}$ mbar], Water [$5 \cdot 10^{-11}$ mbar], Nitrogen [$1\ 10^{-11}$ mbar])

ET technical report 2020

To reach UHV

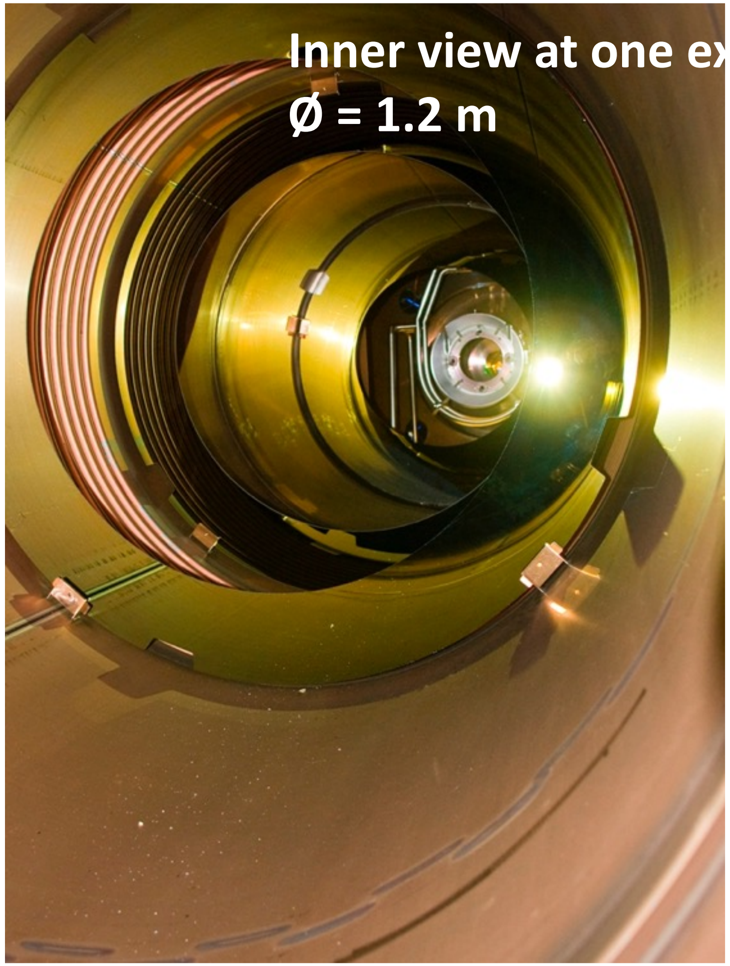
Two main treatments for austenitic stainless steel

- Air-firing
  - High temperature (400 - 450 ^{o}C) in oven with dry air flux in order to remove the H from bulk material. Factor 3 - 4 depletion of H_2 content. Permanent

- Bake-out
  - Treatment at ~200 ^{o}C in-situ under vacuum to remove the tightly bonded H_2O from the surfaces. If vented to air needs to be repeated

Virgo 6 km UHV TUBES

- 24000 m^2 walls!
- They contain “only” optical baffles and the laser beam



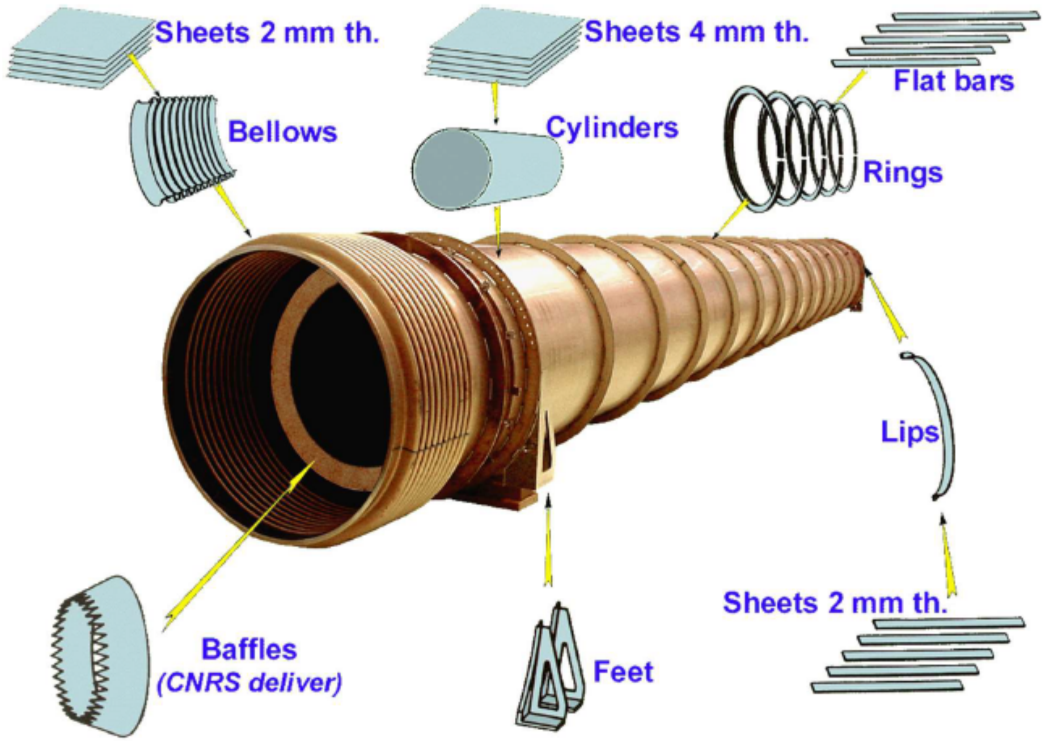
MODULES MANUFACTURING

Technical requirement:

- 404 modules (2 x 3 km)
- Leak rate: 3.10^{-10} $mbar.l.s^{-1}$
- Dimensions: L 15 m x Ø 1.2 m
- Thickness: 4 mm
- Tolerances: see dwg
- Material: 1.4307 (SS304L)

Schedule requirement:

- Workshop ready: 10 months
- First-of-a-kind: 2 months
- Serial units: 1 module/day



Courtesy CNIM

The Virgo experience
TUBE manufacturing

-304L cold rolled sheets / solution annealed - surface finish 2B (EN1.4307 by Avesta S.)

'Conventional' industrial tools, rate = 1 module / day (it took about 2 years).
- modules realized in 3 consecutive cylinders plus the hydroformed bellows.
- UHV recipes (specific machining oil, dirt free rolling, separated halls and tools, ...)

Circumferential + longitudinal plasma welds

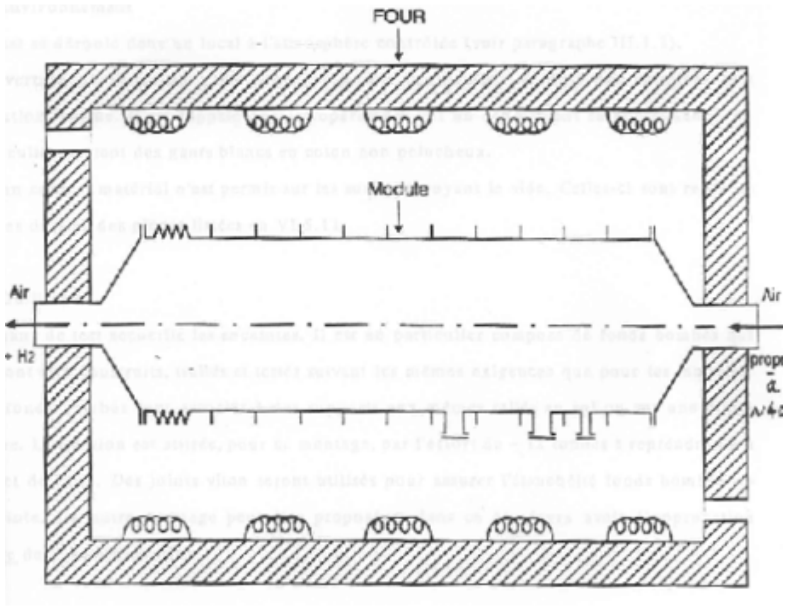
Courtesy: A. Pasqualetti

Virgo experience: AIR-BAKE OUT

Base material conditioning was required to meet vacuum goals (24000 m^2 walls).

heating at ~ **400°C in air** involved a "simple" oven and reduced the hydrogen outgassing by a factor ~ 100; our result: **$q(H_2) \leq$ 3E-14 mbar.l.$s^{-1}cm^{-2}$ @ 20°C**
Original studies pointed to 'bulk ordinary sites role', not conclusive (*)

The industrial specification was: $q(H_2)$ = 5E-14 - NOT CONTRACTUAL -



- Applied to finished modules
- Electrical oven, 'sealed' modules
- 410°C +20/-10 , plateau 72h
- Hot air purge 8 m^3h^{-1}
- 5 days long cycle
- H content raw mat. ≤ 2 ppm wt - CONTRACTUAL -

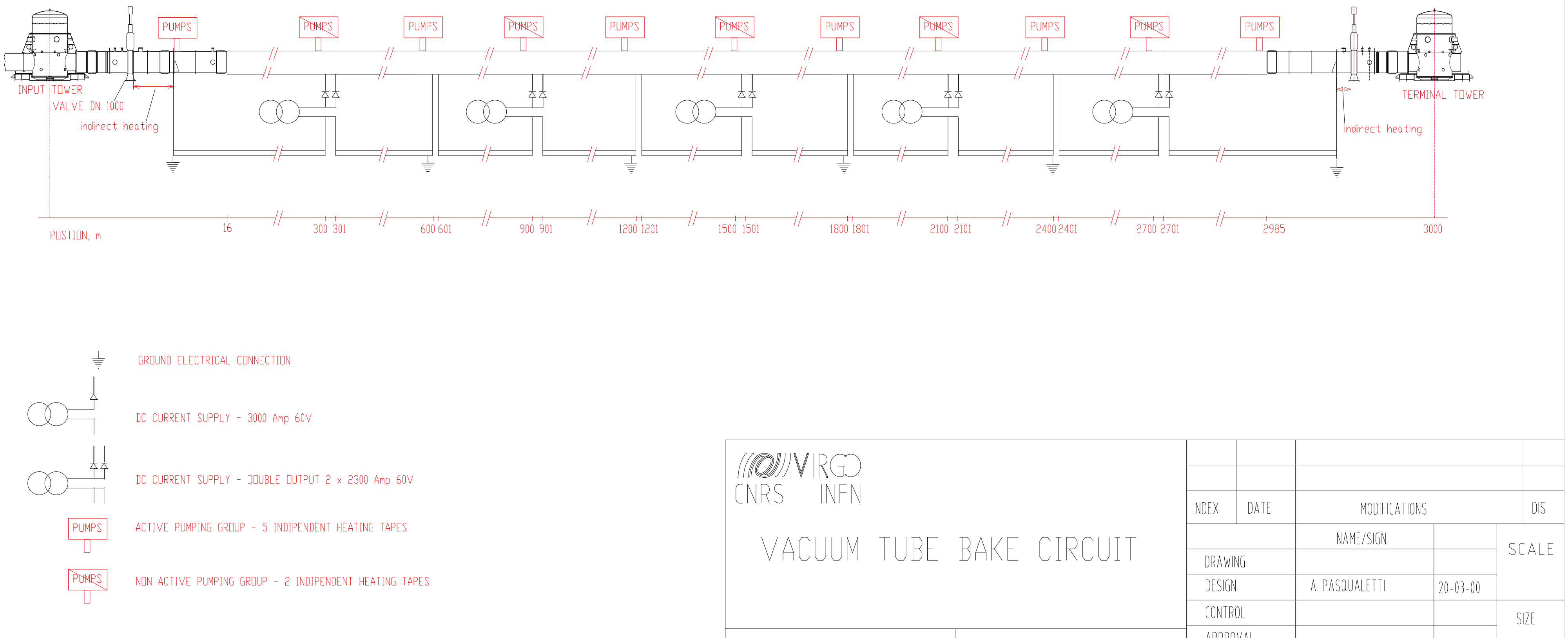
Courtesy: A. Pasqualetti

Virgo TUBES: BAKE-OUT in situ

- Chamber at 150°C uniform and at a controlled rate (~1 week for SAT stage)
- 1 Mwatt to heat one tube (15 cm thick thermal insulation)
- Joule effect: 2000 A flowing through tube walls
- diesel generators: ~ 10^5 litres of fuel to bake one tube

Normally to be performed just one time.

North or West Tube bake-out



GEO 600 experience

- Stainless steel (316LN)
- 60 cm diameter
- 2 * 133 * 4.5m segments
- 0.8 mm wall thickness
- 30 mm wave period
- Weight 2 * 12 t

Advantages:

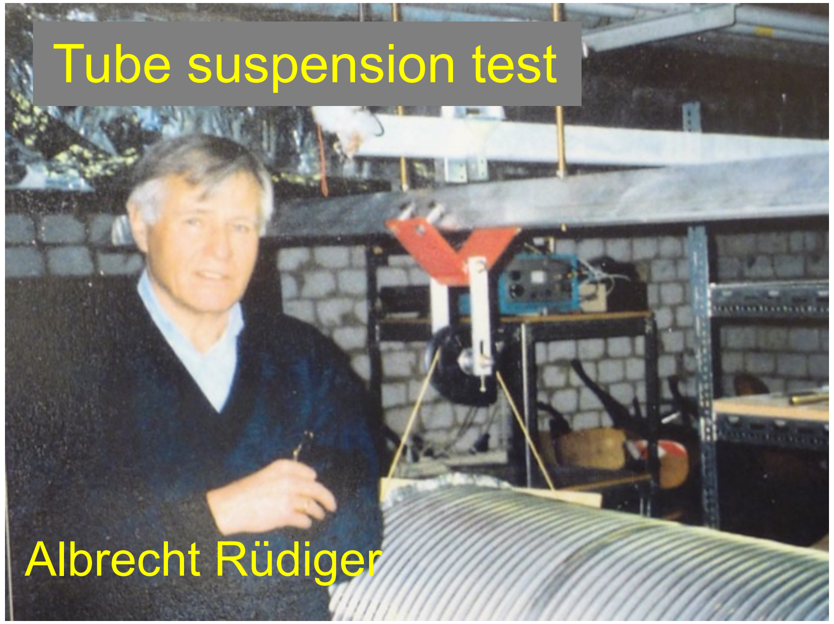
1. Weight easier assembly, little material (costs),
2. No bellows needed
3. easy bake-out

GEO 600 experience

Despite of the harsh condition one leak after 20 years due to MIC, a second leak after 25 years at an attached valve in trench
(lower quality stainless steel)

Chip and clever solutions

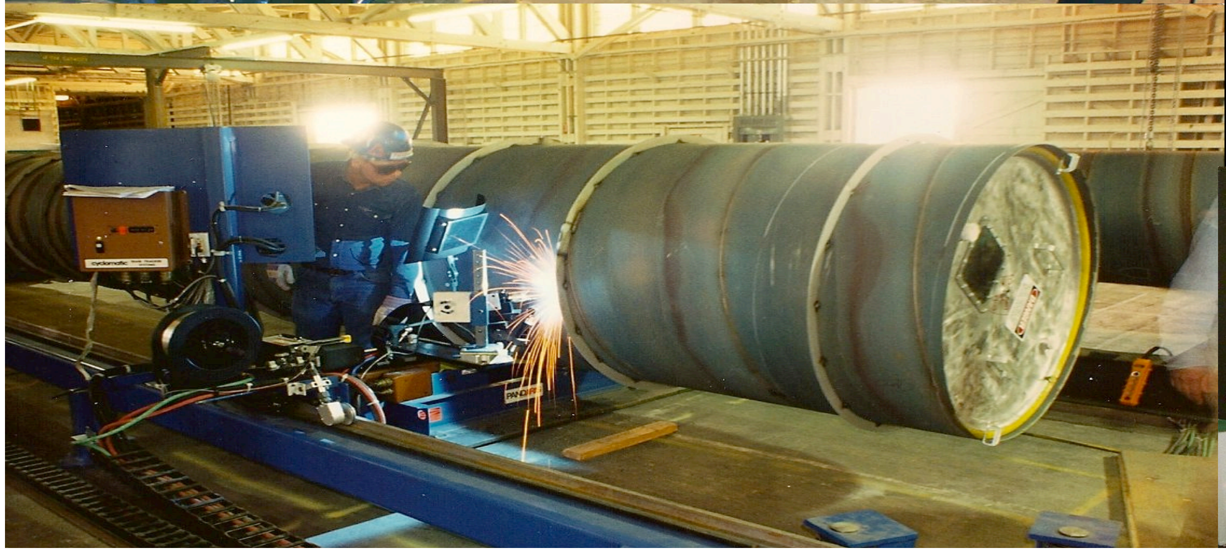
Very successful !!!!



First segment of tube being pushed into the trench

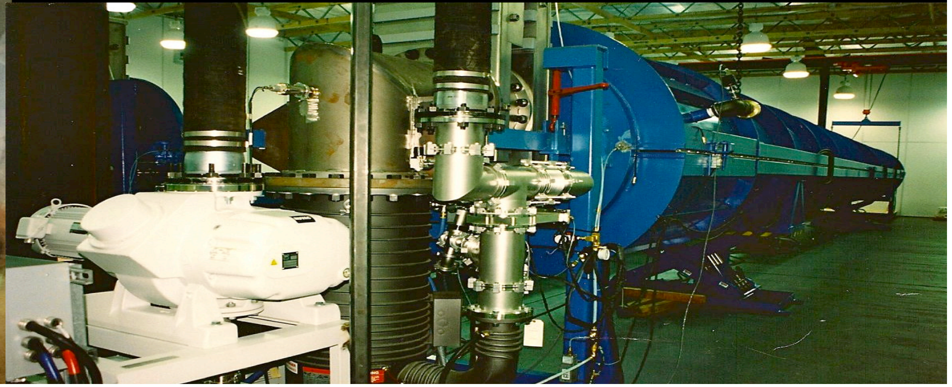
Only 60kg
per segment

LIGO experience



Beam Tubes

- 304L SS
- 3.2 mm thick with external stiffeners
- Raw stock air baked 36h @ 455C
  - Final $J_{H2} < 1e\text{-}13$ Tl/s/cm^2
- coil spiral-welded into 1.2m tube 16m long
  - method adapted from sewer pipe industry
- 16m sections cleaned, leak checked
- FTIR analysis to confirm HC-free
- sections field butt-welded together in travelling clean room
- Over 50 linear km of weld



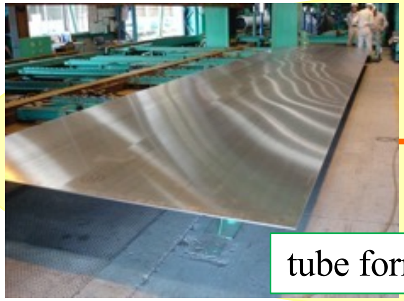
KAGRA

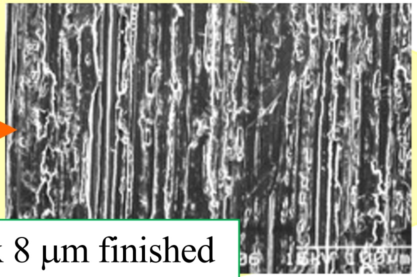
4. Production Process and Installation

** surface finish of tubes and chambers*

** flange and gasket*

unit tube of 12-m long and 0.8-m in diameter

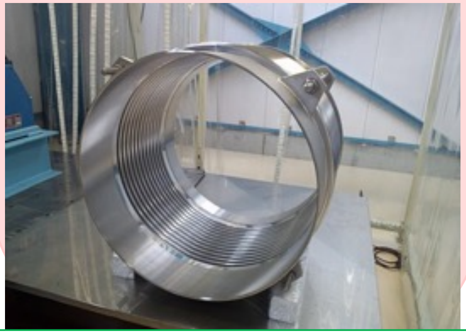




tube forming; SS304L, 8 mm thick, Rmax 8 μm finished

Yoshi Saito et al., JVSJ, Vol.54, No.12, pp.621-626 (2011)

flange; SS F304, Rotary forging

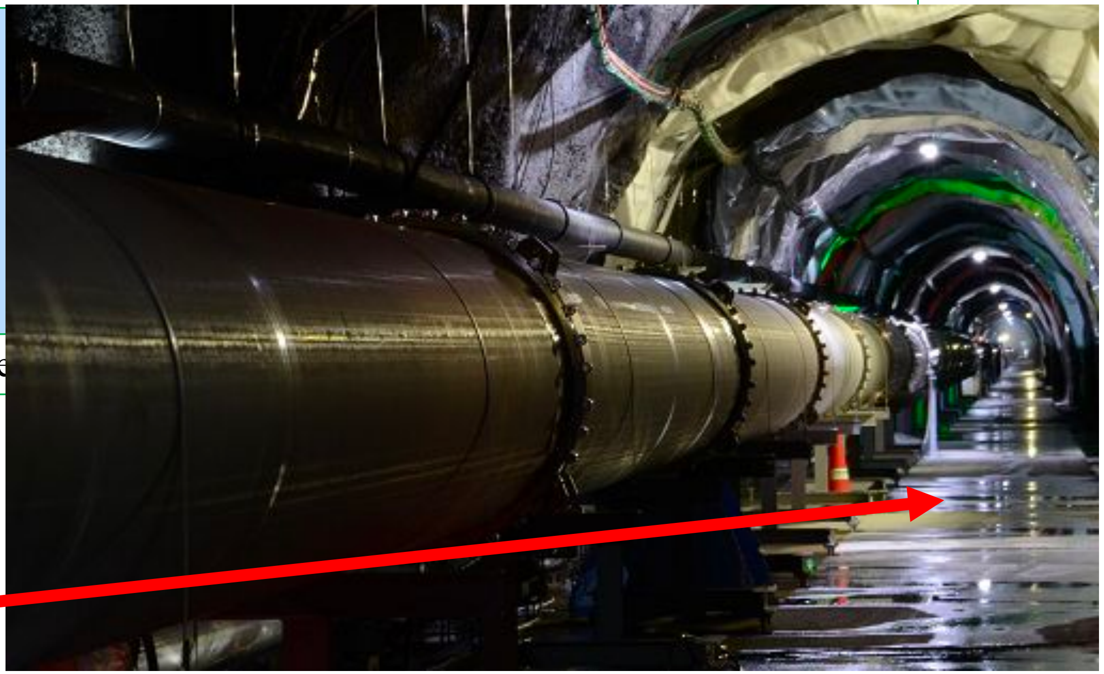


hydro-formed bellows;
SS316L, 0.6 mm thick, chemical polished

TIG-weld Assy

removing 25 μm of outermost laye

electrolytic polishing (EP) and rinsing with ultra pure water;
Rmax 2.5 μm



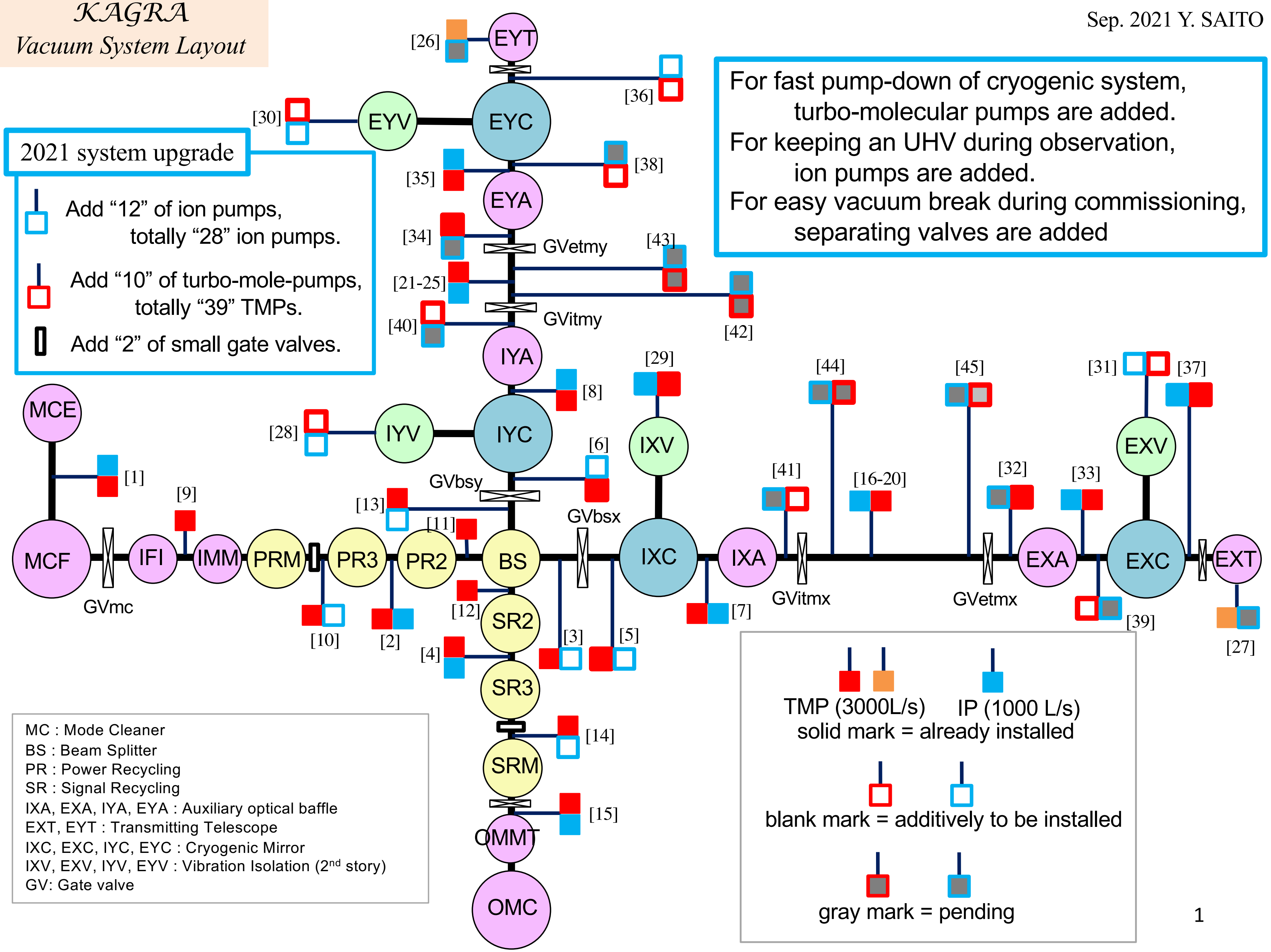
Credits: Yoshi Saito

Very harsh conditions: 95-99 % umidity !

KAGRA
Vacuum System Layout

Sep. 2021 Y. SAITO

For fast pump-down of cryogenic system, turbo-molecular pumps are added.
For keeping an UHV during observation, ion pumps are added.
For easy vacuum break during commissioning, separating valves are added



MC : Mode Cleaner
BS : Beam Splitter
PR : Power Recycling
SR : Signal Recycling
IXA, EXA, IYA, EYA : Auxiliary optical baffle
EXT, EYT : Transmitting Telescope
IXC, EXC, IYC, EYC : Cryogenic Mirror
IXV, EXV, IYV, EYV : Vibration Isolation (2nd story)
GV: Gate valve

Beam tubes comparison

	Virgo	LIGO	KAGRA	GEO600
Material (AISI)	304L	304L	304L	316L
Length (Km)	6	2x8	6	1.2
Diameter (m)	1.2	1.24	.81	0.6
Section length (m)	15	20	12	4.5
Thickness (mm)	4	3.23	8	0.8
Tube type	Sheet welded	Spiral weld	Sheet welded	Sheet weld +cold formed deep corrugated
Pipe cost (euro/m)	2400	2200	4745[a]	440
Vacuum (H_2O) mbar	5.6×10^{-10}	1.3×10^{-10}	1.5×10^{-8}	1.5×10^{-7} [b]
Distance among pumps (m)	600		600	
Firing Temp (°C)	400	455	200	200
Firing duration	5 days	36 h	20 h	48 h
Bakeout Temp	150	160	Electro-polishing	250
Bakeout duration	1 week	3 weeks		5 days
pumps	Turbo, Ion + Ti Sub. pumps	Turbo, Ion +NEGs	Turbo, Ion	6xTurbo

[a] bellowsSS316L, flanges, crow clamp, EP-finished, baked

[b] upgrade vacuum system foreseen this year

ET vacuum

2 main problems:

- Material/processing costs
- Outgassing -> bakeout underground

Just scaling the Virgo vacuum costs to ET it would requires

> 500 Meuro !!

Pumping system design

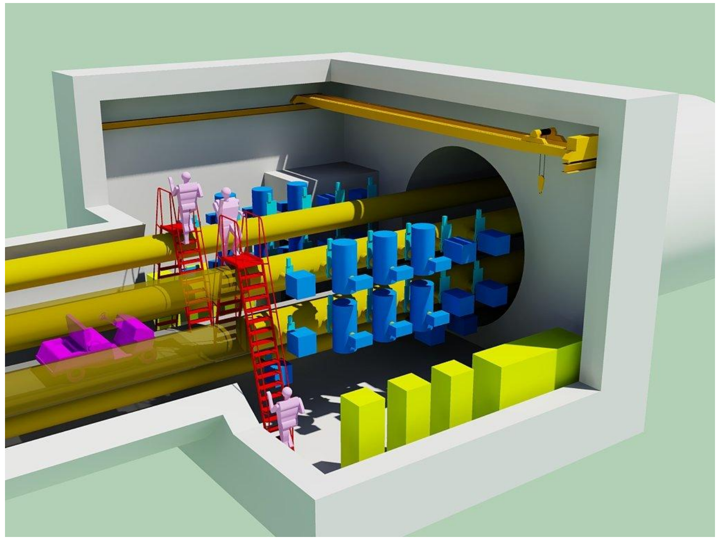


Figure 6.22: 3D view of a pumping station: the blue objects represent the pumps and sensors, the yellow ones the cabinets for pumps control and baking power supply (1 cabinet for all). A separate small room is reserved for the high voltage electrical transformer.

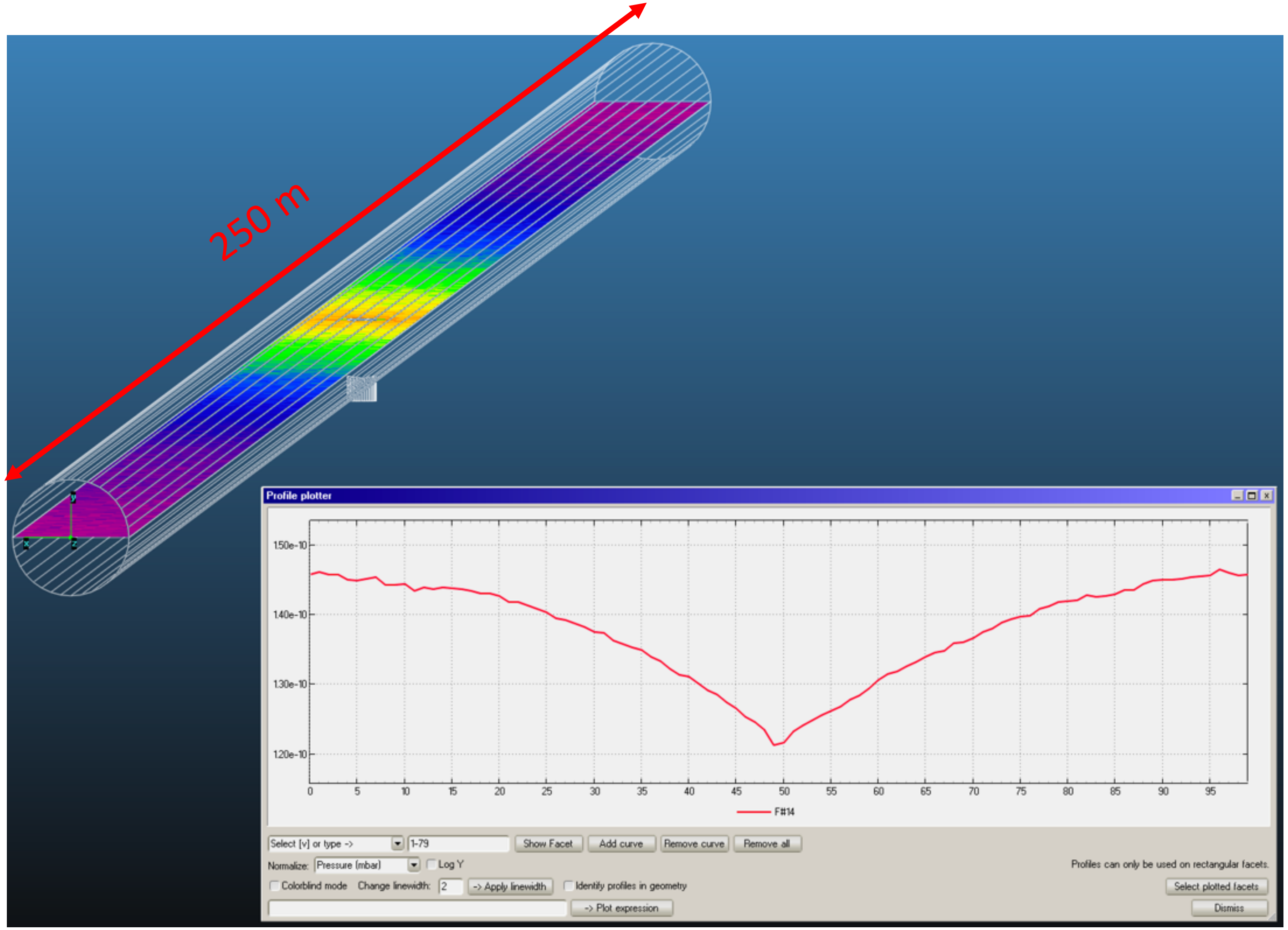
In Virgo 15% of the budget went in pumping

- Reach the target vacuum
- Management of the mechanical vibrations and acoustic noise
  - Usage of getter pumps ?
  - Development of low profile getter pumps
- A carefull design and pumps distribution optimization

Pipe section simulation (Molflow+ 2.8.6)

250 m section pipe with one pump in the middle 3000 l/s

Assumed outgassing rate = 1.3E-15 mbar l s^{-1} cm^{-2} (after firing)

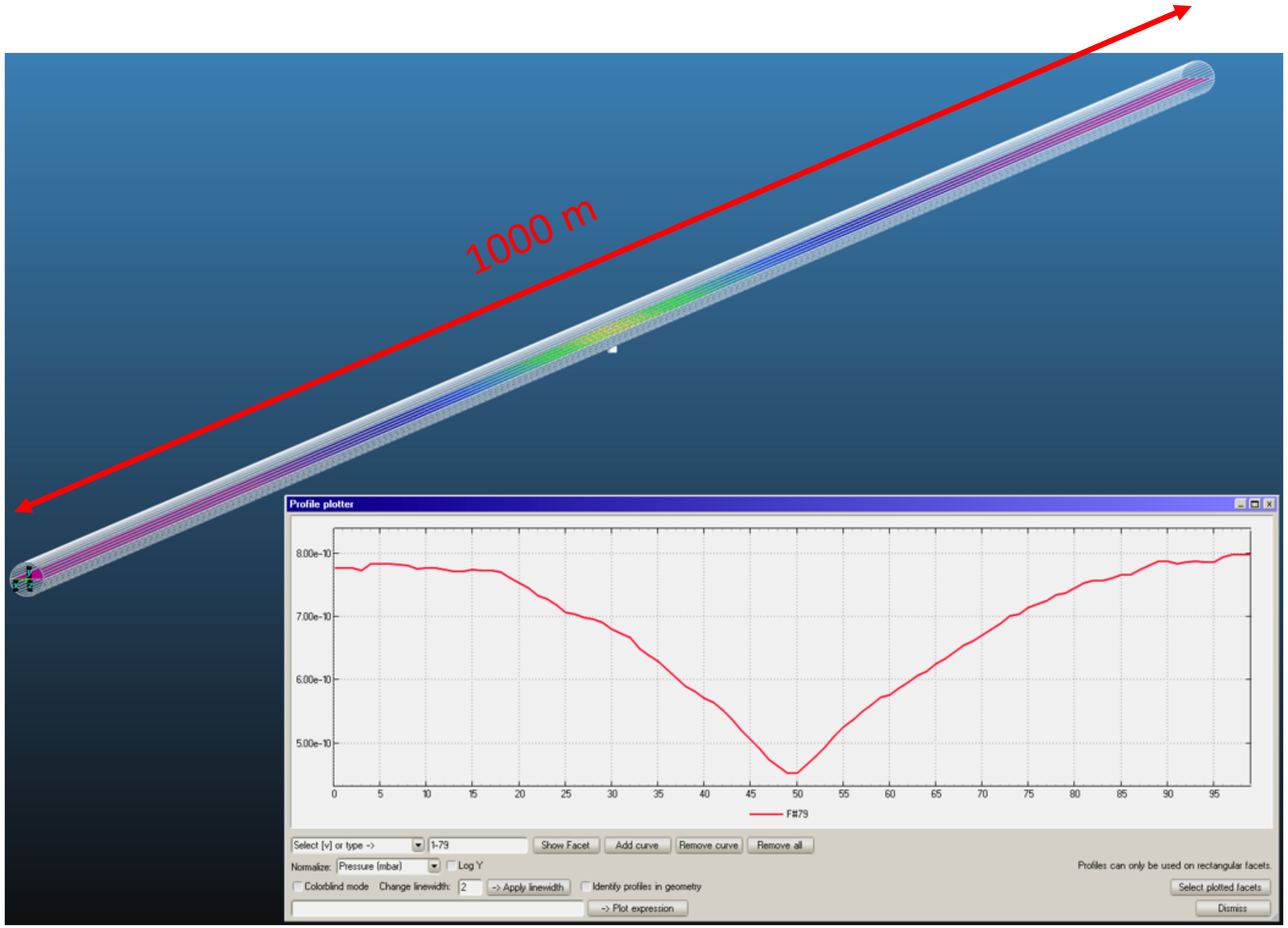


H_2 pressure profile between 1.2E^{-10} and 1.46E^{-10} mbar

Pipe section simulation (Molflow+ 2.8.6)

1000 m section pipe with one pump in the middle 3000 l/s

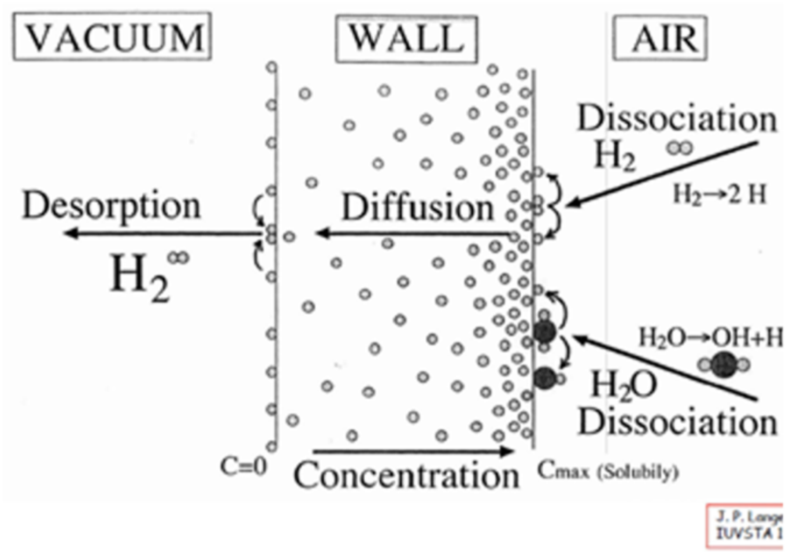
Assumed H_2 outgassing rate = 1.3E-15 mbar l s^{-1} cm^{-2} (after firing)



H_2 pressure profile between 4.5E^{-10} and 8E^{-10} mbar

R&D on vacuum system

- Materials: austenitic, low carbon steel, aluminium, other?
  - cost effective solution, low H_2 content, UHV compatible
  - comparative outgassing tests
- Cheap surface cleaning scalable to large area (~400000 m^2)
- Inner surface passive coating
  - hydrogen permeation barrier scalable to large area
- corrosion



ET beam pipe some tought

- Size scaling is not enough. We must consider the production time

  For Virgo the production rate was 1 section/day

  Air-firing took 5 days for 4 modules (oven loaded with 4 modules)

  Installation took 2 modules/day

  For ET we need 8000 15m sections

  If we want to install the pipes in 3 years we need ~10 ovens for the air-firing working in parallel (each processing 4 modules) and a production/installation rate of 8 modules/day

- Pseudo-valves: start R&D on cheap valves to create pipe sectors. Helps installation, bakeout, maintenance

- RAMS needed: careful evaluation of a catastrophic event underground ⟷ coupling with tunnels design

Thank you for your attention