beampipe vacuum studies in ET

Nick van Remortel
Universiteit Antwerpen

CERN BPV workshop
March 27 2023

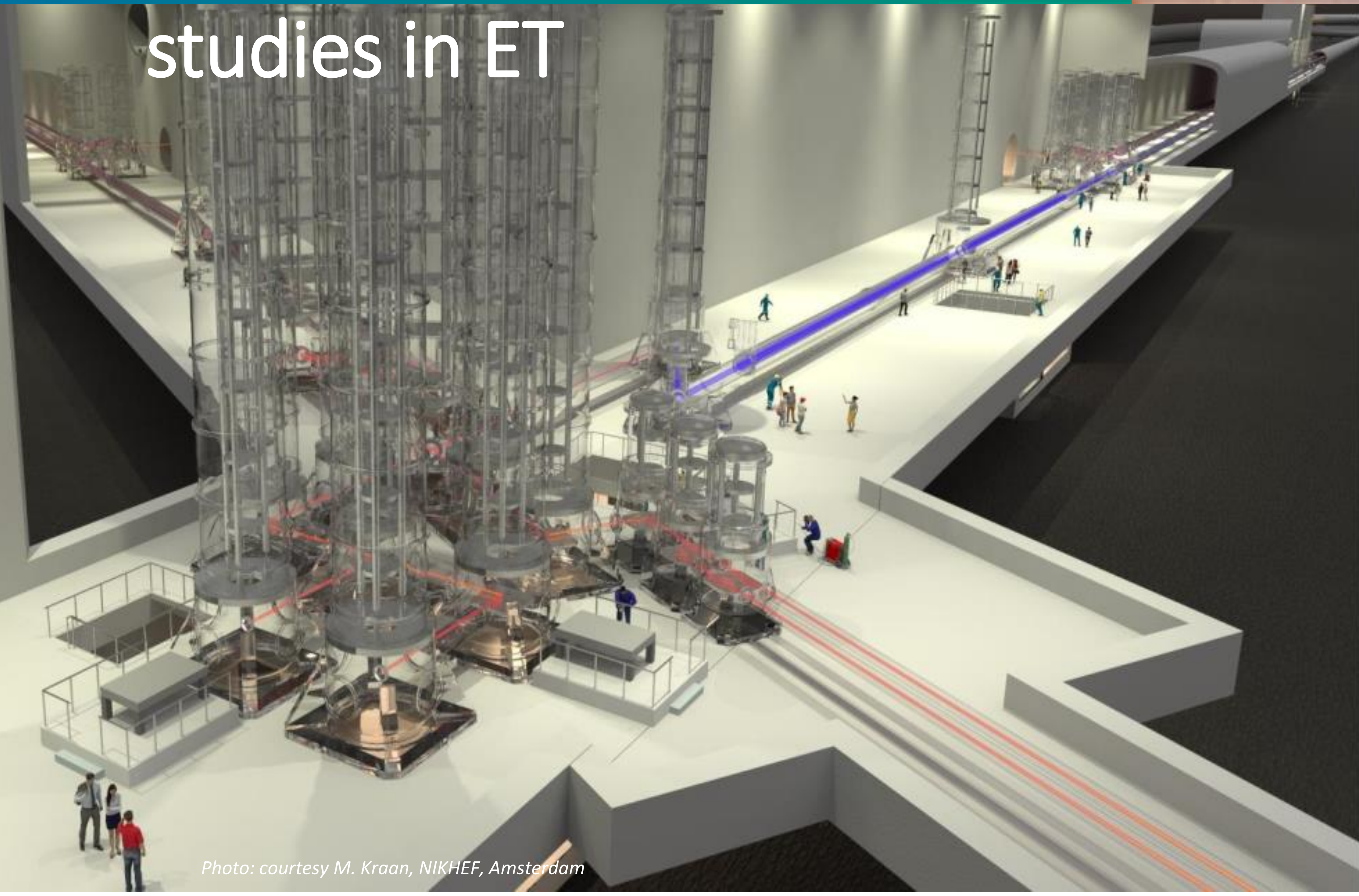
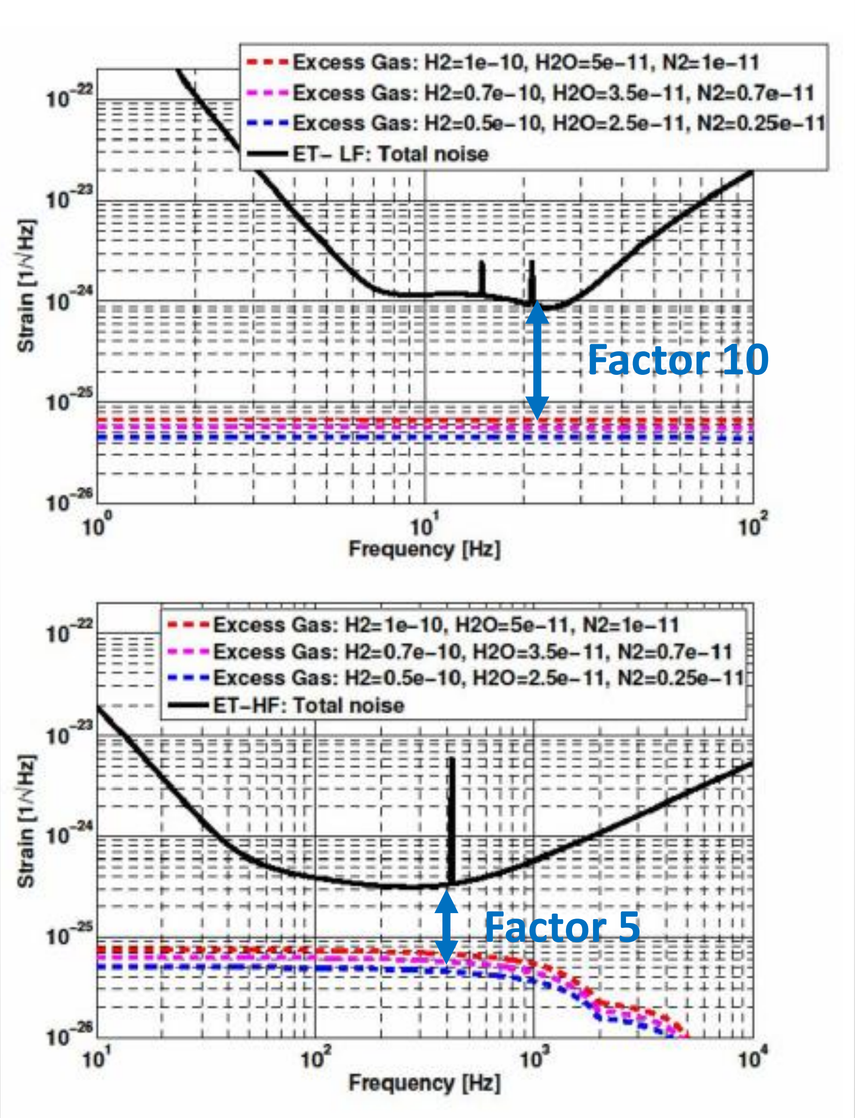


Photo: courtesy M. Kraan, NIKHEF, Amsterdam

Requirements for ET LF and HF system



- ET vacuum dimensions:
  - Diameter beam tubes: ~1m
  - Total Length vacuum system: 120 km

surface: 400.000 m^2
Volume: 100.000 m^3

- Partial presssure:
  - H2 gas: 10^{-10} mbar
  - Water vapor: 5.10^{-11} mbar
  - Nitrogen: 10^{-11} mbar
  - Hydrocarbons: <10^{-14} mbar
- Material Choice:
  - Type material: stainless (austenitic), low carbon steel, ferritic austenitic, aluminum, …
  - Balance cost/properties/durability/machinability
- After treatments:
  - Cleaning and/or polishing
  - Welding and beam pipe forming
  - bakeout: duration & temperature
- Requirements document: https://www.overleaf.com/project/63bfe8cfea42cf35c7402c0e

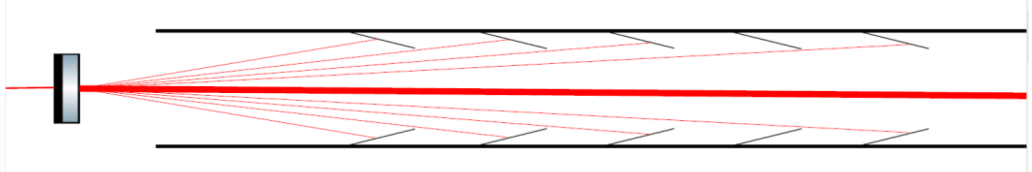
ET BPV requirements

- Functional
  - Scattered light: IFAE Barcelona
    - Implications on:
      - Tube diameter,
      - Baffles (number, placement, dimensions, edges, materials),
      - Roughness and reflectivity of inner surface of vacuum pipe,
      - Tolerances on vibration of the beam pipe
  - Beampipe pressure: INFN, KIT, CERN, …
    - Implications on:
      - Material choices: including corrosion, inner & outer coatings, …
      - Tolerable outgassing rates for H_2O, H_2, …
      - Bakeout procedure: temperature and duration
      - Pressure profile along beam: → Pumping scheme: capacity, getter vs other, and placement
  - Dust: INFN, NL
    - Implications on:
      - Material (after-) treatment
      - Getter materials
      - Coating
  - Mechanical properties: stiffness, alignment, vibration: CERN, BEL
    - Implications on:
      - Beam pipe wall thickness, section length, support,
      - Corrugated vs non-corrugated
      - Alignment ad mechanical interfaces
      - Welding procedures
      - Valves
  - Electromagnetism, UV radiation, …

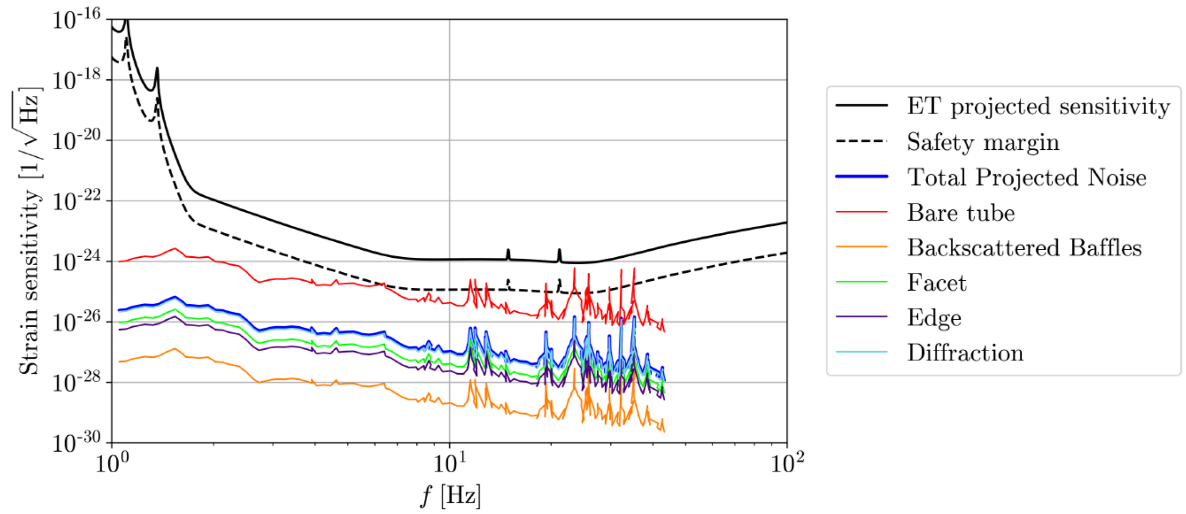
ET BPV requirements

- Interfaces
  - Size and weight
    - Implications on:
      - Tunnel diameter
      - Structural support
      - Assembly and maintenance
  - Bakeout and heating
    - Implications on:
      - Temperatures in tunnel: heat evacuation, ventilation, …
      - Electrical power
  - Environment
    - Implications on:
      - Corrosion, Humidity, Rodents , …
      - Storage and treatment facilities: clean room, welding quality and leak testing, …
      - Vibrations: Transfer of seismic movement, pumps, …
      - Health and safety

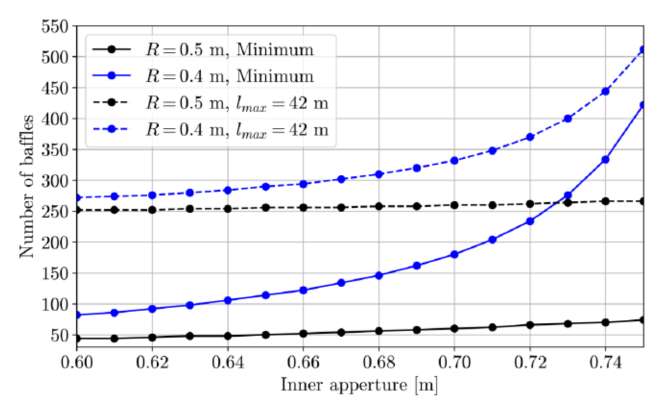
Scattered light: IFAE Barcelona

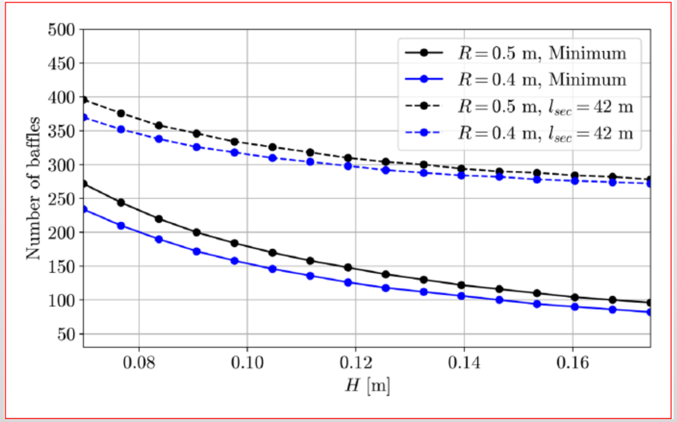


Marc Andrés-Carcasona, M. Martinez et al.

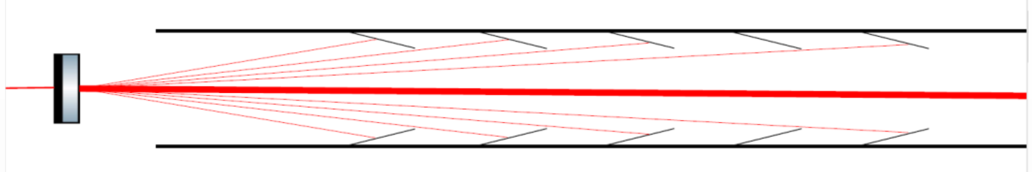


- Optical simulation:
  - Optical waist with FINESSE
  - Scattered light studies with SIS and Zemax software: ongoing discussion to move to non-sequential software
    - Diffraction, Backscattering, Shining facet, Baffle edges
    - Translation to strain noise
  - Amount and optimal placement of baffles:
    - O(300) assuming sections of 42m, for length of 10km
  - Size and aperture of baffles and beam pipe radius
    - Different radius for HF and LF part?
    - How big is safety margin
    - Connection with tunnel size

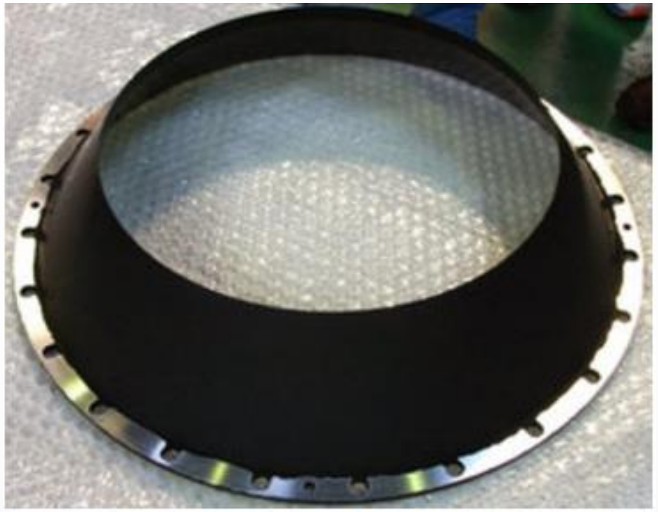


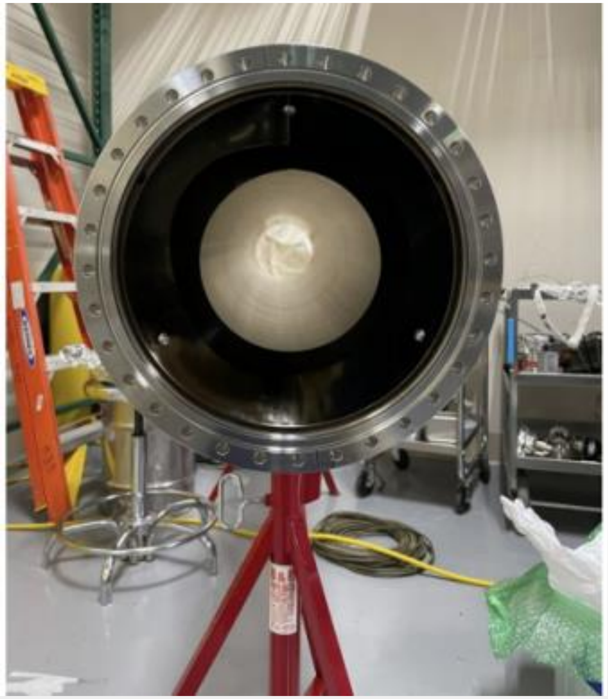


Baffle manufacturing & integration: IFAE Barcelona

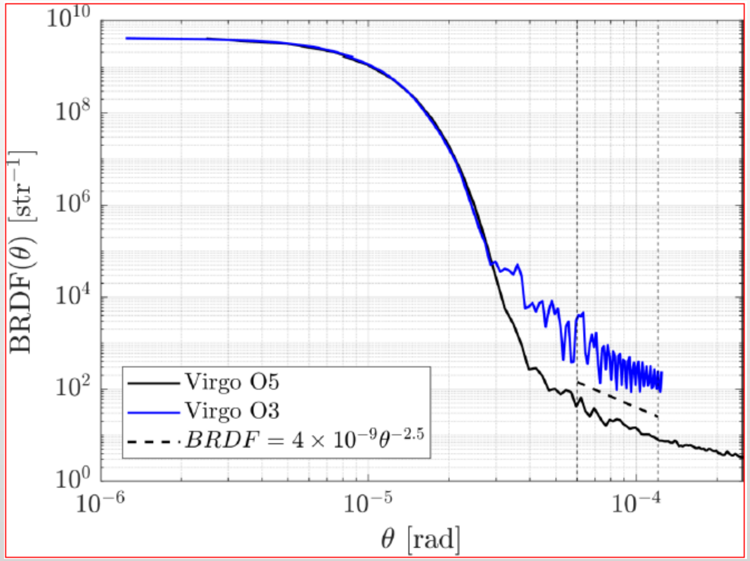


M. Martinez et al.





- Prior experience in Virgo context
- Sizes and apertures
- Materials and edges
- Helical vs circular
- Integration: welding, vs mounting vs tension
- Instrumented baffles: near Test masses
- Cost analysis



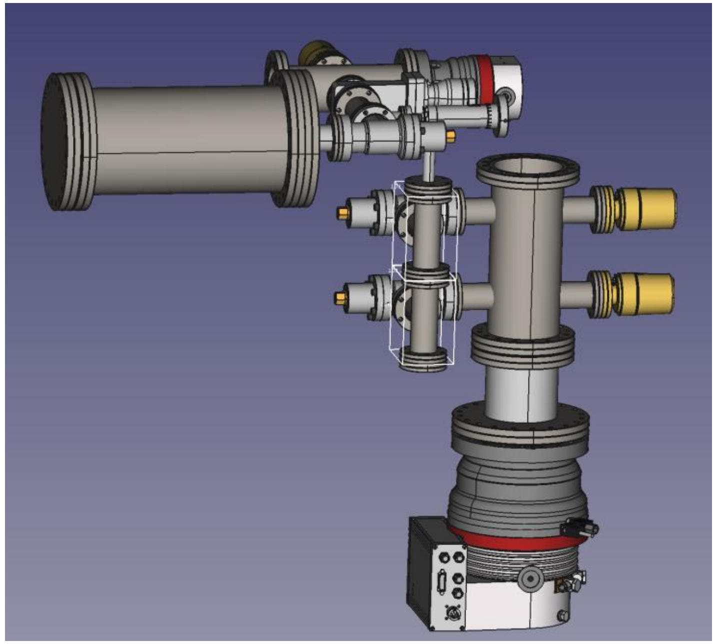
Study of low outgassing materials suitable for UHV vessel & HC contamination

- Degassing stations @ EGO - A. Pasqualetti, J, Gargiulo
- Set up of a degassing station at the Astronomical Observatory in Naples
  (INAF OAC) to study materials for the beampipe
  – A. Grado, V. Mennella, F. Cozzolino,

Investigation of steel with low H_2 outgassing rate in order to reduce/avoid air-firing that is too expensive for ET

Expected first results in the next 6 months

- ETIC project: development of a method to assess the hydrocarbon surface contamination in-situ – A. Grado, L. Limatola, F. Getman



Outgassing station @EGO
Courtesy A. Pasqualetti

ETIC project: *Study of hydrocarbon contamination on surfaces in UHV systems*

Cosmic Physics Laboratoy - INAF OAC Naples

- Of relevance in cosmic dust studies is the attribution of the so called 3.4 µm band due C-H aliphatic bonds, observed in the ISM, comets and meteorites. A similar band is also characteristic of hydrocarbon contamination in UHV systems.

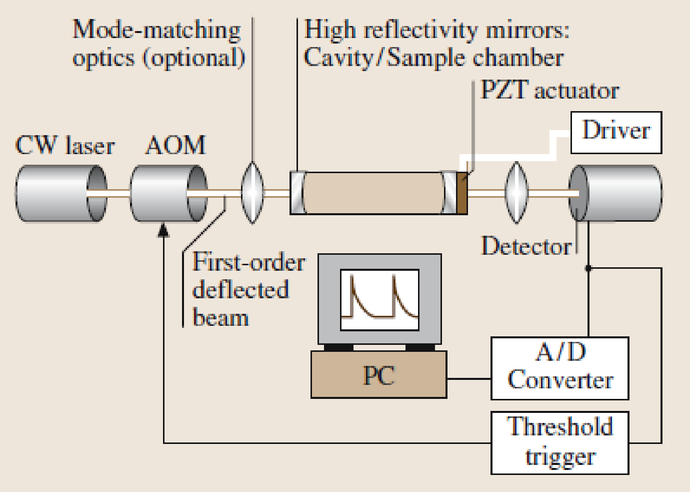
Analytical techniques:

- SEM with EDX,
- x-ray diffraction
- Spectrometry from 200 nm to 2 mm) & Micro IR spectroscopy
- Raman Spectroscopy,
- Mass spectroscopy 1-200 amu,
- HPLC

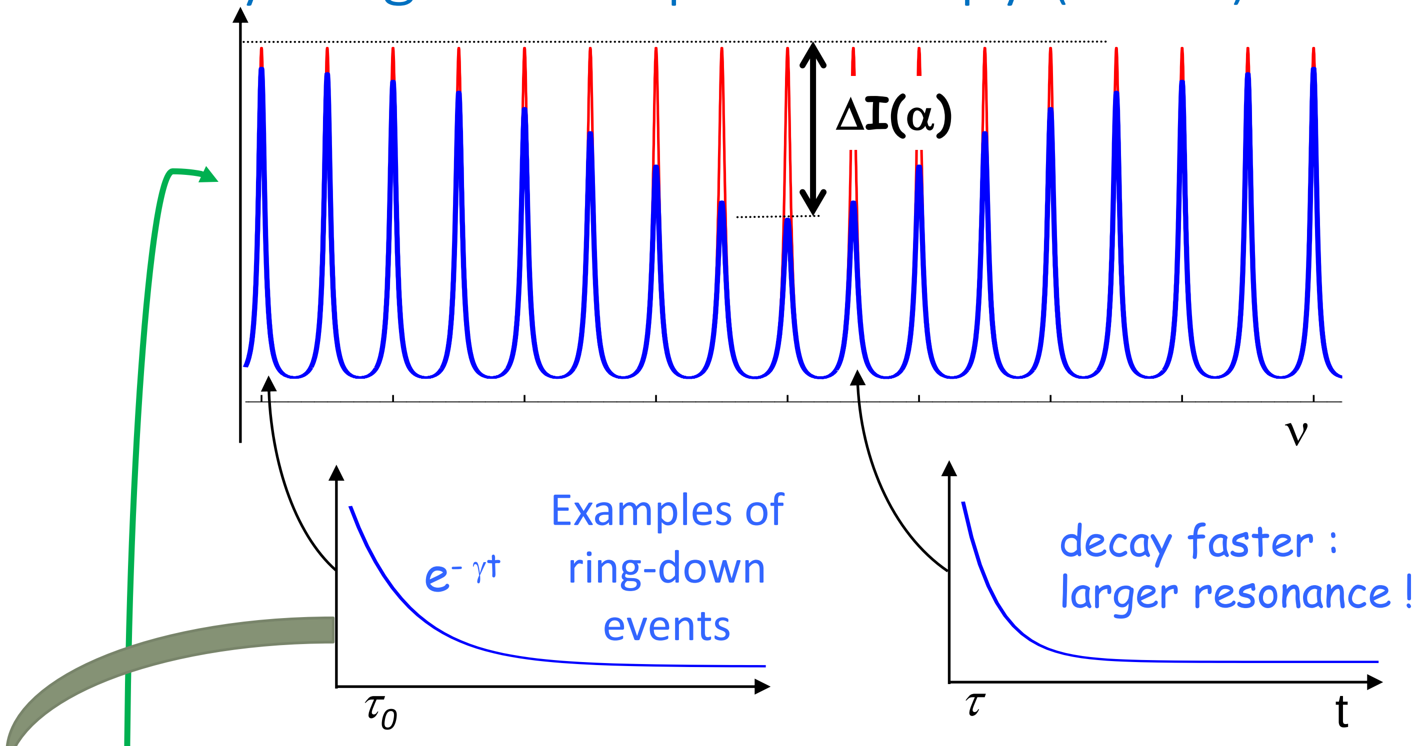
R&D

Università degli Studi della Campania Luigi Vanvitelli

ETIC project: development of a selective and sensitive method to trace amounts of hydrocarbons in UHV by means of comb-assisted Cavity Ring-Down Spectroscopy (CRDS)



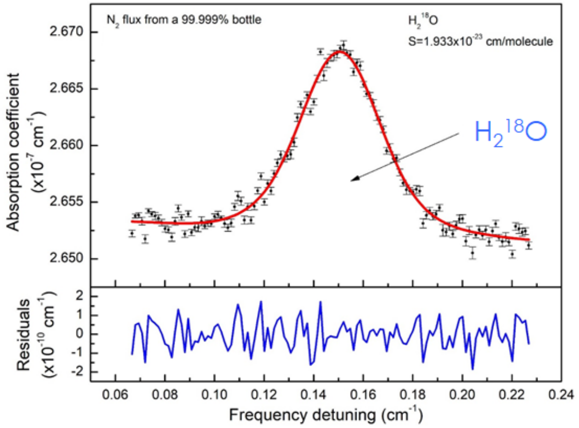
Simplified scheme



Cavity transmission **WITH** and **WITHOUT** the absorbing gas sample

$$\alpha(\nu) = \frac{\tau_0 - \tau}{c\tau_0\tau}$$

→ N (molecules/cm^3)



CRDS detection of $H_2^{18}O$ in nitrogen at the ppb level

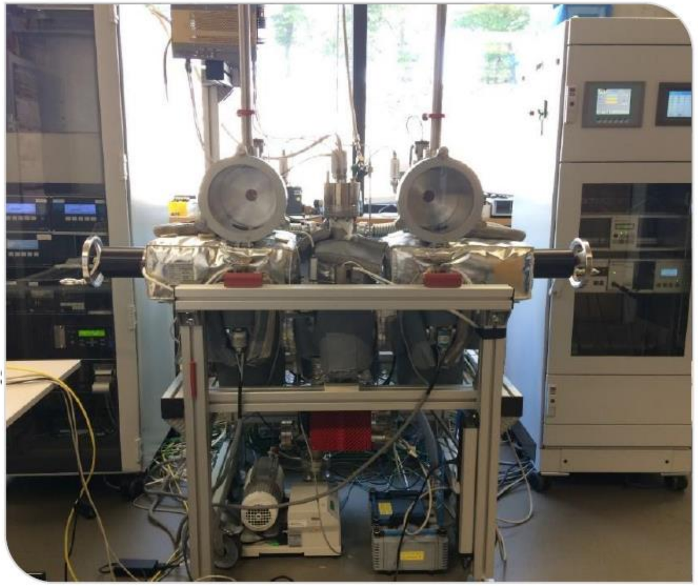
Antonio Castrillo, Eugenio Fasci, Livio Gianfrani, Emanuele Tofani, Aniello Grado: Laser Spectroscopy Laboratories - CIRCE

Outgassing and (cryo) pumping at KIT (Karlsruhe)

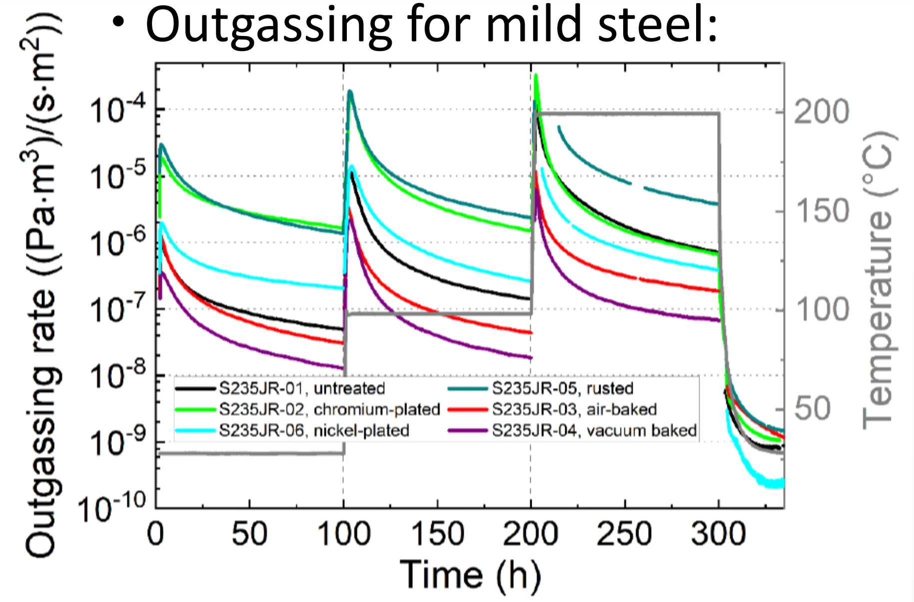
K. Battes, Chr. Day, S. Hanke, …

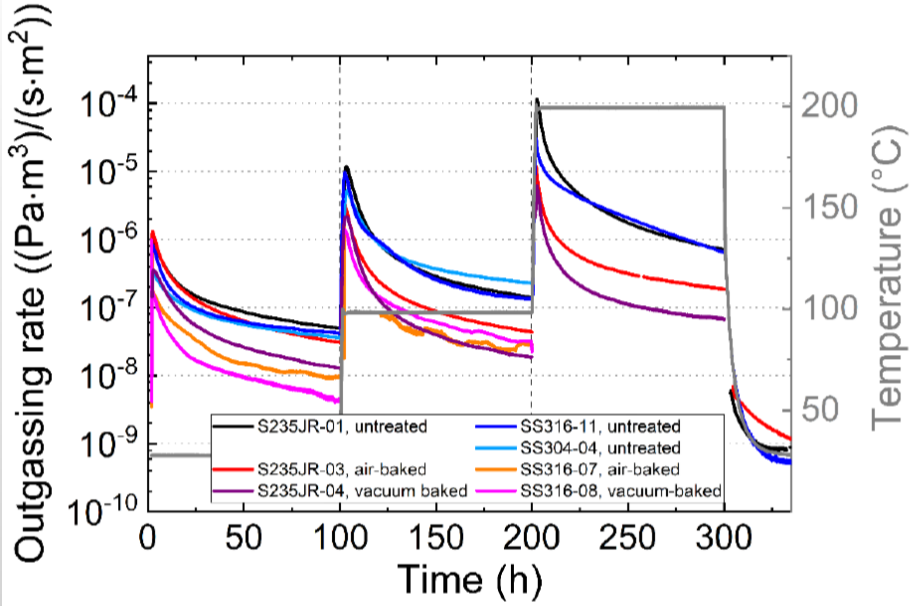
- **Modified throughput method** with second identical chamber to directly subtract background
- Specific outgassing rates from about 10^{-2} to 10^{-9} Pa $m^3/(s\ m^2)$
- Temperatures from 20 to 300 °C
- Quadrupole mass spectrometer

- Outgassing test facility: OMA



- Outgassing for mild steel:

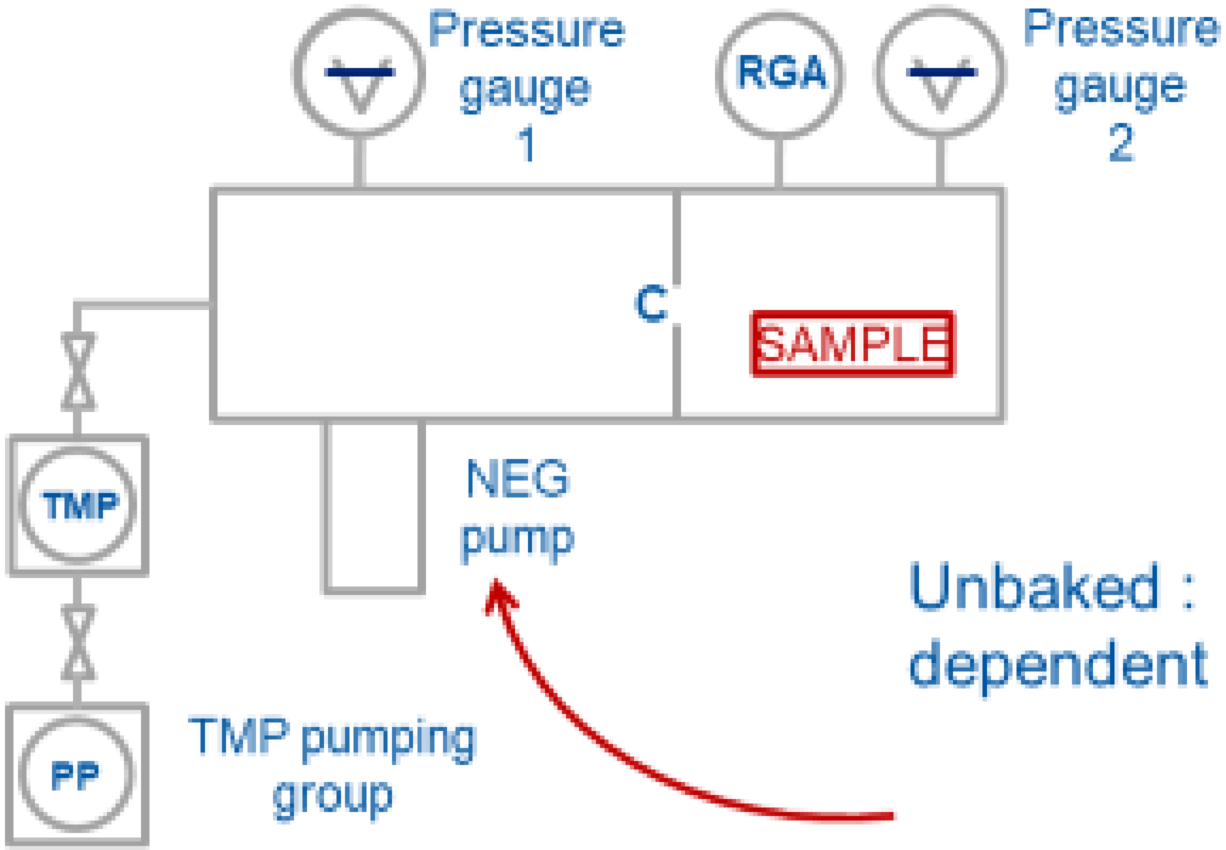




Ongoing activities:

- Comparison out outgassing rates with those measured at CERN
- Exchange of samples between CERN and KIT
- Asessment of pumping speed vs outgassing rate

Measurement methods: Throughput



Sample & background — background

$$Q = \left(\frac{C\,(P_2 - P_1) - C\,(P_{2bg} - P_{1bg})}{A_{sample}} \right)$$

Q in mbar l s^{-1} cm^{-2}

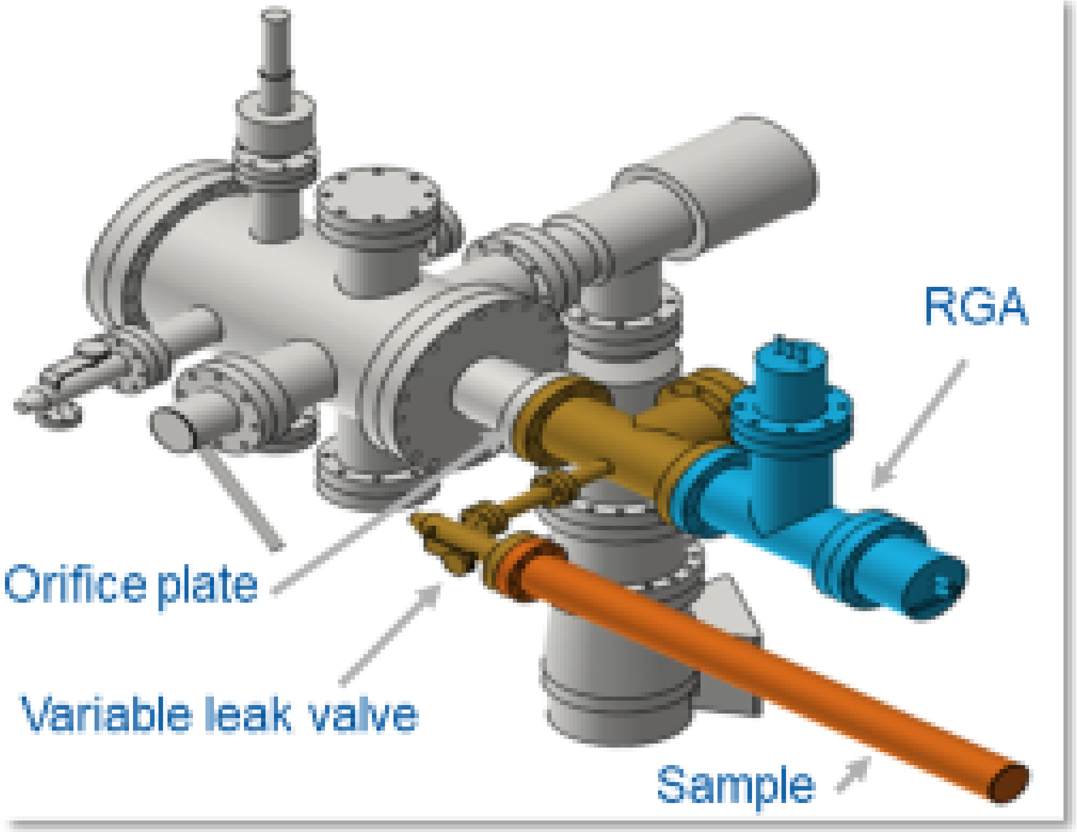
Unbaked : outgassing of water – time dependent

Cold cathode ionization gauges

Baked: outgassing of (mainly) hydrogen

hot cathode ionization gauges

Measurement methods: Coupled-method



All system components are baked to temperatures ranging from 200ºC to 350ºC

Sample and variable leak valve are heated to requested temperature and duration

Prior to cooldown all instrumentation is degassed

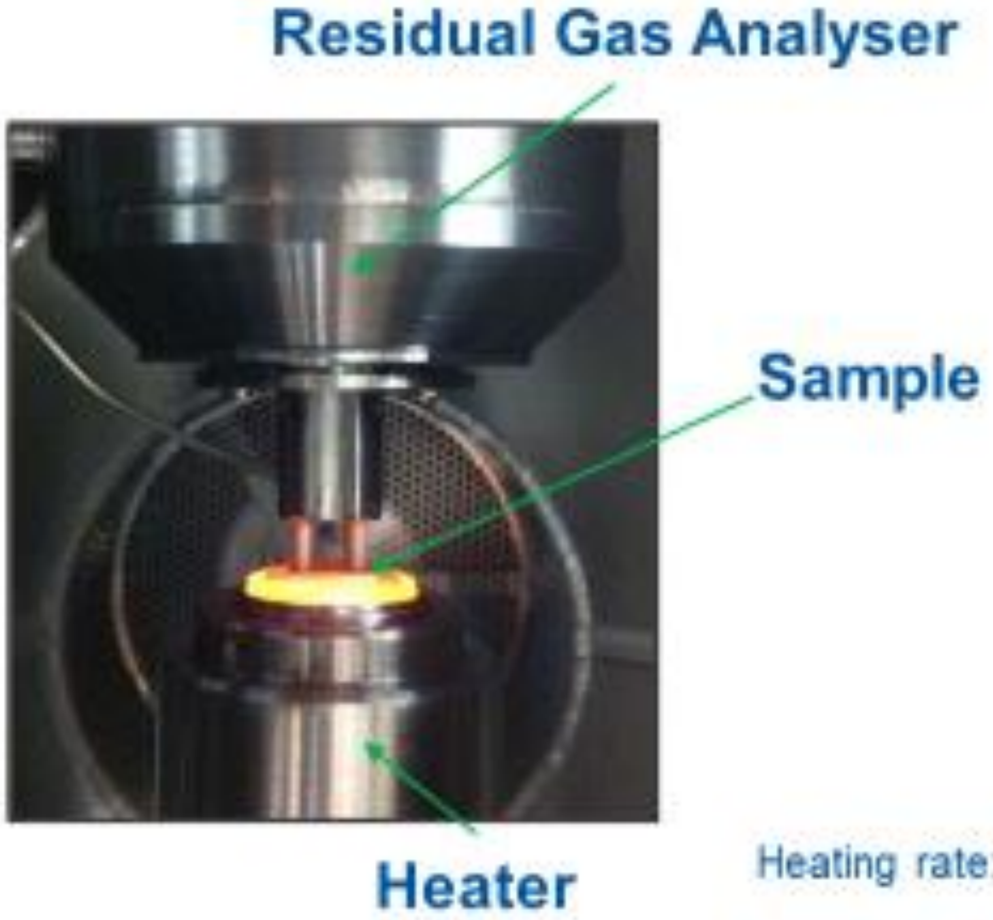
Variable leak valve body has been vacuum fired to minimize contribution

24 hours at room temperature before the start of the first measurement

Not suitable for gasses that can be reabsorbed (water)

RGA has been calibrated to an in-house calibrated hot cathode ionization gauge

Measurement methods: Thermal Desorption



Heating rate: 5K/min

Material properties and selections @ NIKHEF

- Financed R&D project between NIKHEF, TATA steel and VDL ETG
- Material inventory and selection:
  - Stainless steel
  - Low carbon steel
  - Aluminium

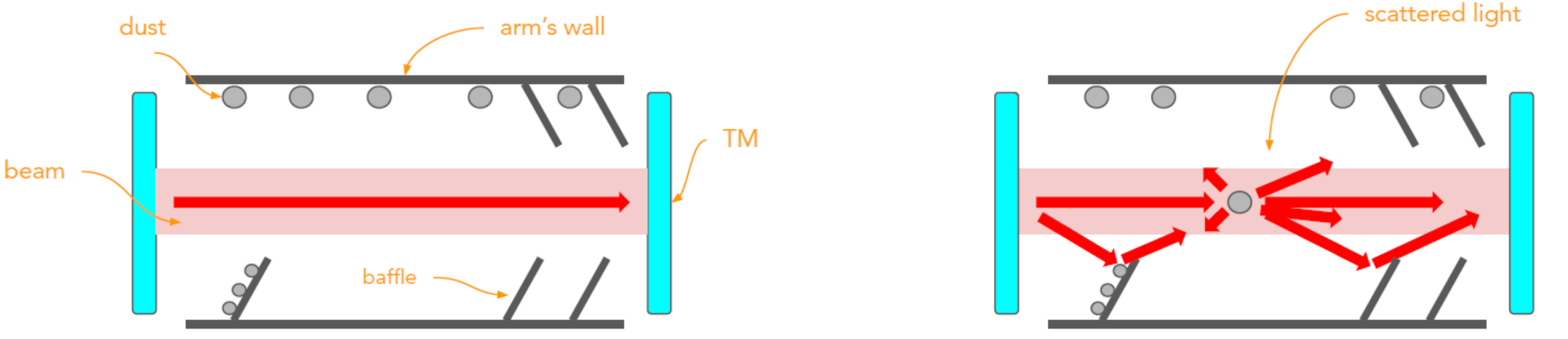
Metal	Grade	Thickness (mm)
Stainless steel	SS304L	3.0
Low-Carbon Steel	IF01	3.4
Low-Carbon Steel	ULC01	2.53
Low-Carbon Steel	LC01	3.06
Low-Carbon Steel	LC01	3.7
Aluminium	6061, T6	3.17
Aluminium	6061, T651	6.1

Outgassing test method	Required sample dimensions (mm x mm)
• Thermal desorption analysis (TDA, Kratos)	10 mm x 10 mm
• Thermal desorption spectroscopy (TDS, Bruker)	120 mm x 25 mm
• Throughput method (NIKHEF)	Maximum size Ø 105 mm x 47 mm Maximum weight = 1 kg

Stray light from dust

A. Moscatello, L.Conti, G.Ciani

- Dust introduced by:
  - Surface (un)cleanliness
  - Ion and getter pumps
- Dust location:
  - Falling from top of inner wall
  - Accumulation on baffles
- Light-Dust interaction



1. forward scattering at small angles to TM
2. backward scattering at small angles to TM
3. scattering at large angles: may re-enter the beam only scattered again by baffles/pipe walls before going to the TM

- Funded R&D project in BelgiumReal-time particle deposition measurement in vacuum

the vision competence center

SAC Nederland

pdm

www.particle-deposition.com

M3 engineering

M3engineering

VAMAC NV

VAMAC NV

On-Site production of quasi-continuous UHV pipes

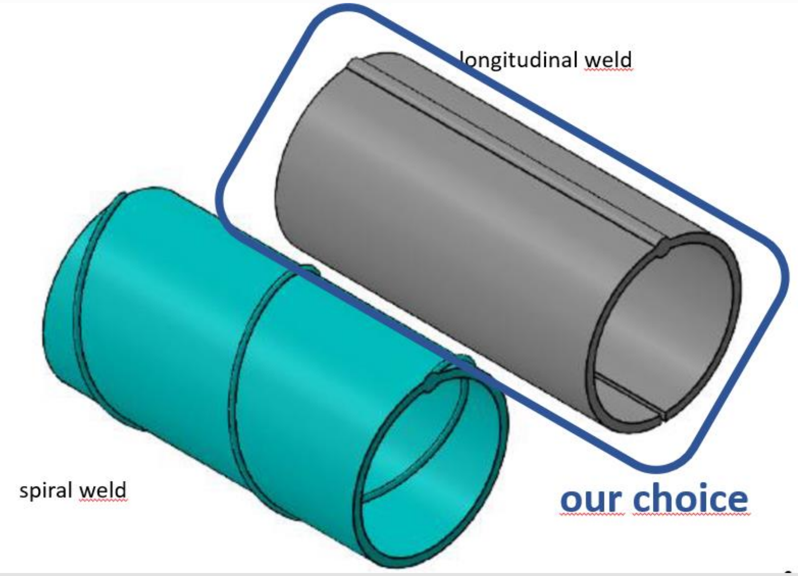
April to November 2022; EU contribution: 49.350,00 €

FEF Besser fügen.
Lead partner
(SME, Aachen)
Specialist in welding

WERKHUIZEN HENGELHOEF
Partner
(SME, Flandern)
Specialist in sheet metal forming

aperam
Partner without funding
(large enterprise, Flandern)
Steel producer

RWTH AACHEN UNIVERSITY
Associate Partner
(my institute)



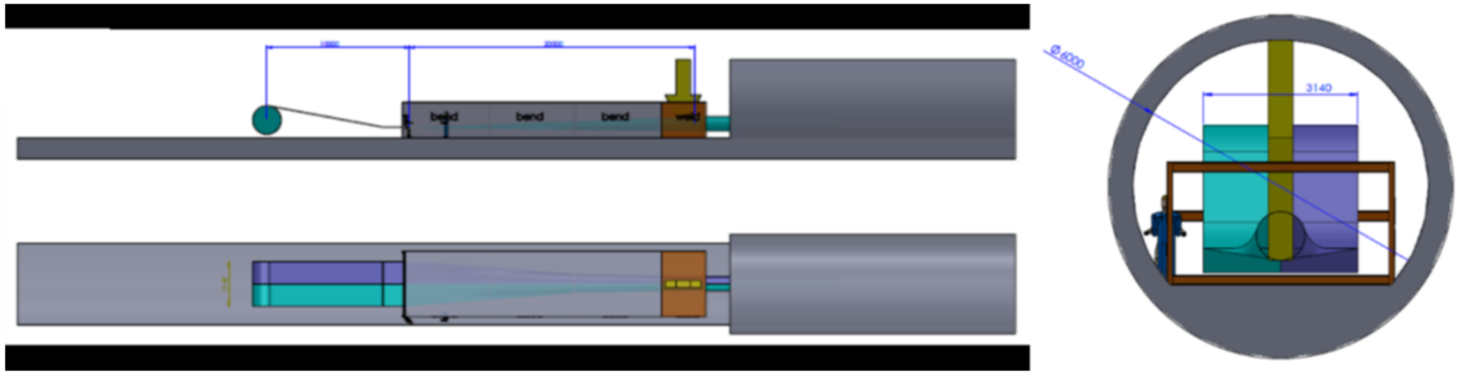
Production strategy: two options

- Robot in the cavern:
  pipe pushed into tunnels
- Robot moving through tunnel:
  pipe produced in position

our choice

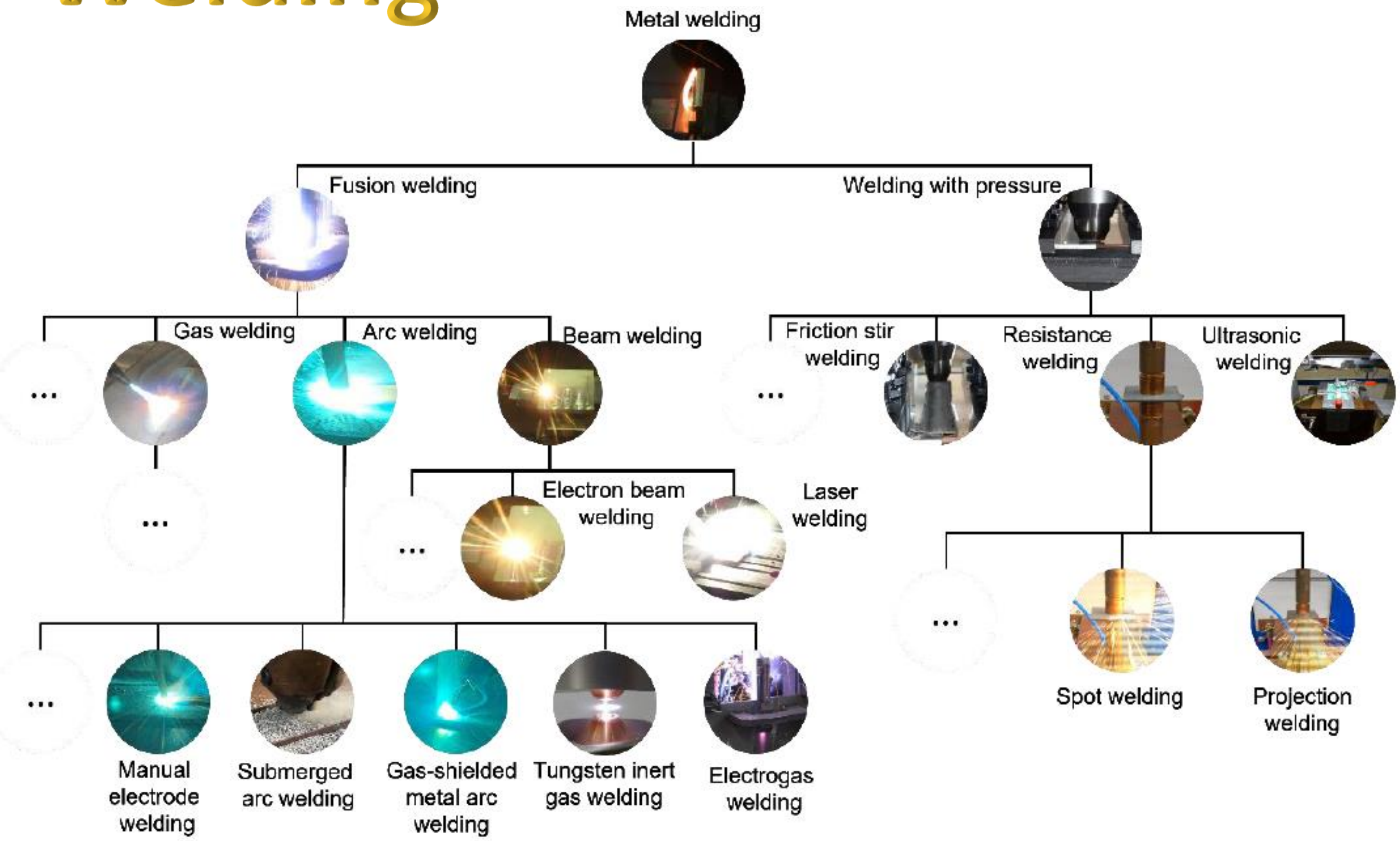
Dimensions

- fits a 6 m tunnel
- length 20 m
  plus input coils (10 m)



Welding

Investigated many different options.



Our choice:

Laser welding under vacuum

Moving vacuum (30 mbar)

- very stable weld pool
- little hydrogen introduced
- no oxidation
  (no post treatment)
- filler wire can be used

Production time

Single 500 m section

- preparation: 1 day (8 hours)
- production (0.5 m/min) 1 day (17 hours)
- down-time (service) 1 day (8 hours)

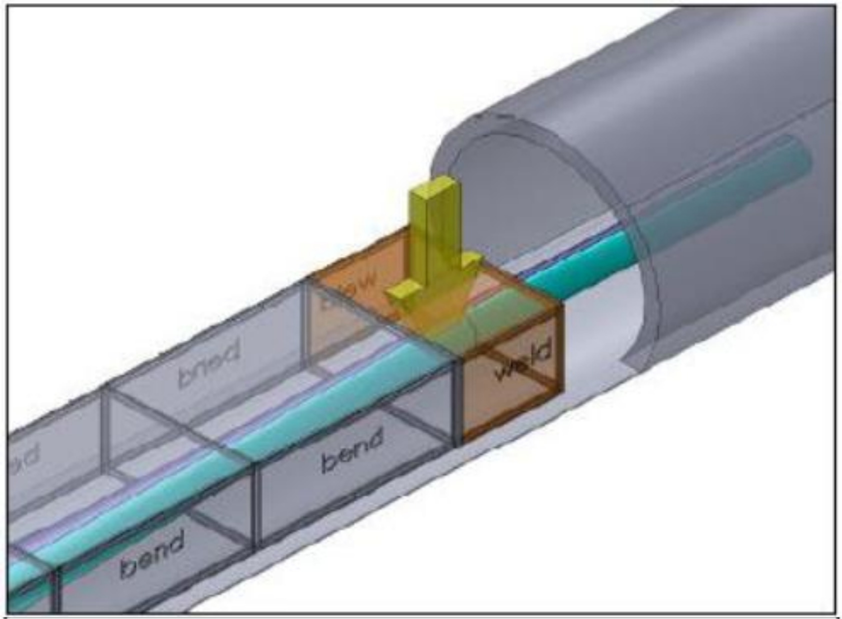
total: 3 days

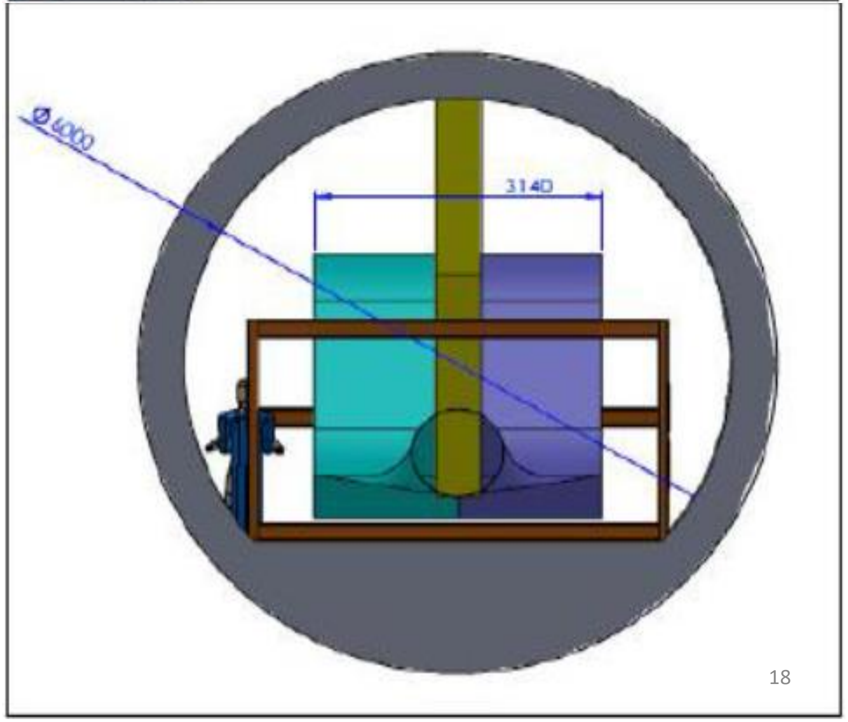
Personnel

3 teams of 5 persons each + back office

Total production time (1 machine)

720 days → 2 to 3 years





Cost

Material

Price :			
	304L:	€/kg	3,50
	316L:	€/kg	5,00
Price coil 510 m :			
	304L:	€	€ 177.787
	316L:	€	€ 253.982
Price tube 10 km			
	304L:	€	€ 3.555.749
	316L:	€	**€ 5.079.641**
Price tube 120 km			
	304L:	€	€ 42.668.983
	316L:	€	**€ 60.955.690**

61 Mio. €

Basic Investment

Coil prefabrication machine ground level:			
	number:	pcs	1
	budget :	€	€ 2.500.000
	Total:		**€ 2.500.000**
Coil forming machine in tunnel :			
	number:	pcs	1
	budget :	€	€ 5.000.000
	Total:		**€ 5.000.000**
Coil transport machines:			
	number:	pcs	5
	budget :	€	€ 250.000
	Total:		**€ 1.250.000**
Total:			**€ 8.750.000**

Elevator:			
existing elevator			
	adaption for machines	€	€ 500.000
	adaption for coils	€	€ 500.000
	Total:		**€ 1.000.000**

9.8 Mio. €

Personnel

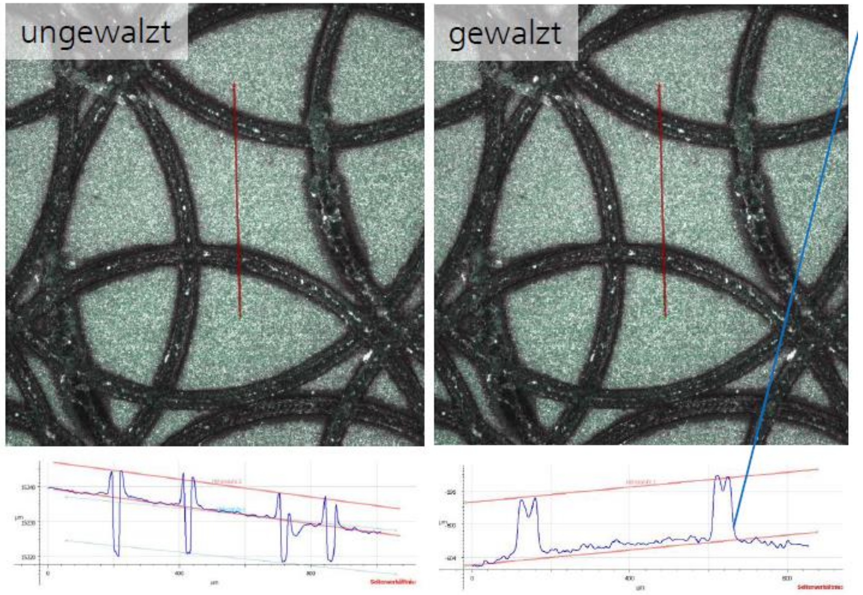
Operations:			
	teams	3	
	persons per team	5	
	annual cost person		€ 72.000
			€ 1.080.000
Backoffice costs:			
	annual costs		€ 750.000
Total:			**1.902.000**

1.9 Mio. €

Innovative fiberglass/steel liner pipes

Composite UHV pipe:
glass fiber reinforced epoxy + steel liner

Fraunhofer IPT + Physics Institute III RWTH AACHEN UNIVERSITY



6 mm glassfiber reinforced epoxy
0.8 / 0.5 mm stainless steel liner (304L)
10 cm diameter
50 cm long
Welded to conventional flanges

Advantages:

- less amount of steel
  - lower cost of material
  - potential for vacuum firing
  - easier to form
- less weight
- simpler bake-out
  - less thermal mass
  - higher ohmic resistance
  - integrated insulation
- integration of sensors
  - thermal sensors for bake-out
  - stress sensors for leak detection

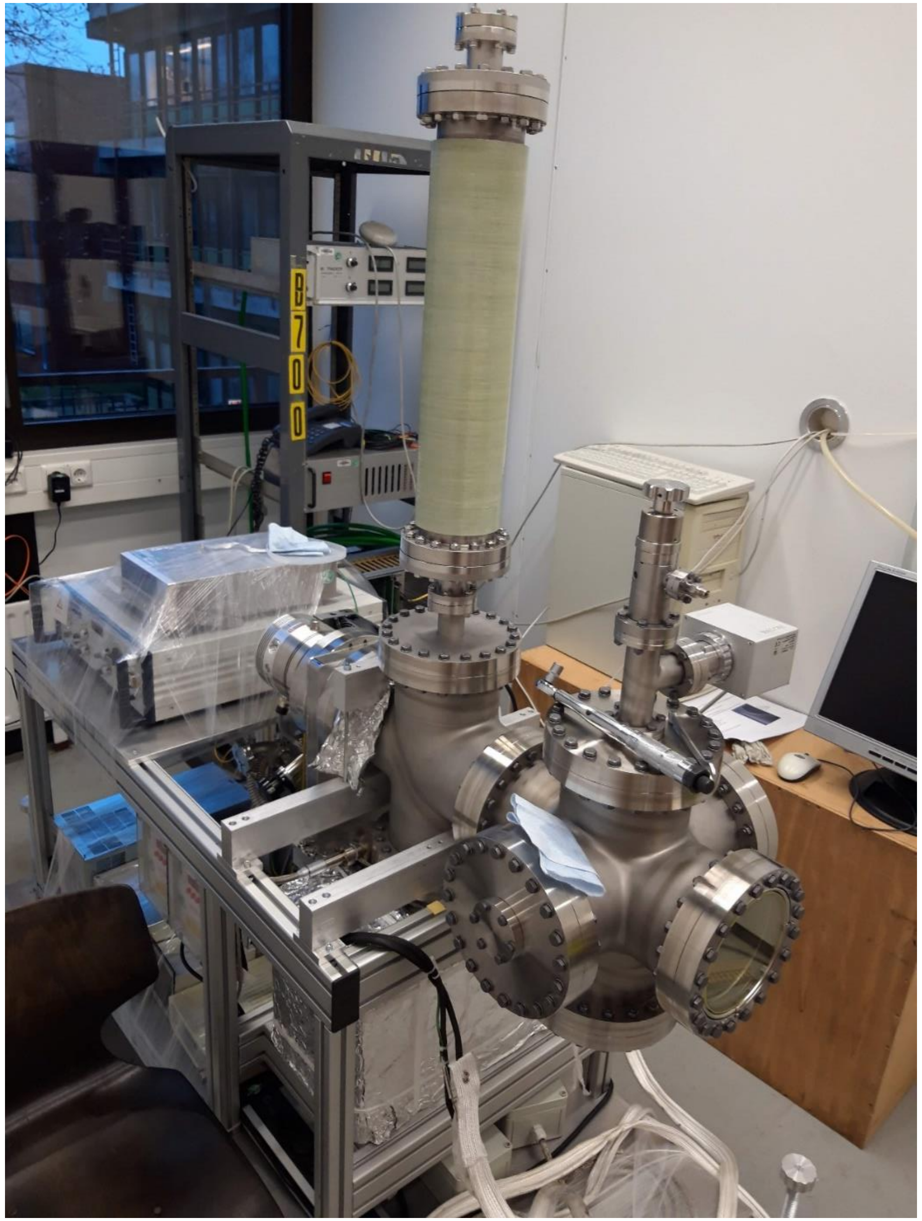
Innovative pipes: 1. prototype

Results:

- reached 10^{-8} to 10^{-9} mbar (limited by pumps)
- Demonstrated bake-out with current through pipe.
- survived around 10 heating cycles to 120° C. (some over heating at the flanges)

Epoxy and steel liner delaminated after approx. 10 heating cycles.
Two problems identified:

- laser structuring largely flattened during pipe forming.
- different longitudinal thermal expansion of steel and outer pipe.
- welds can be improved



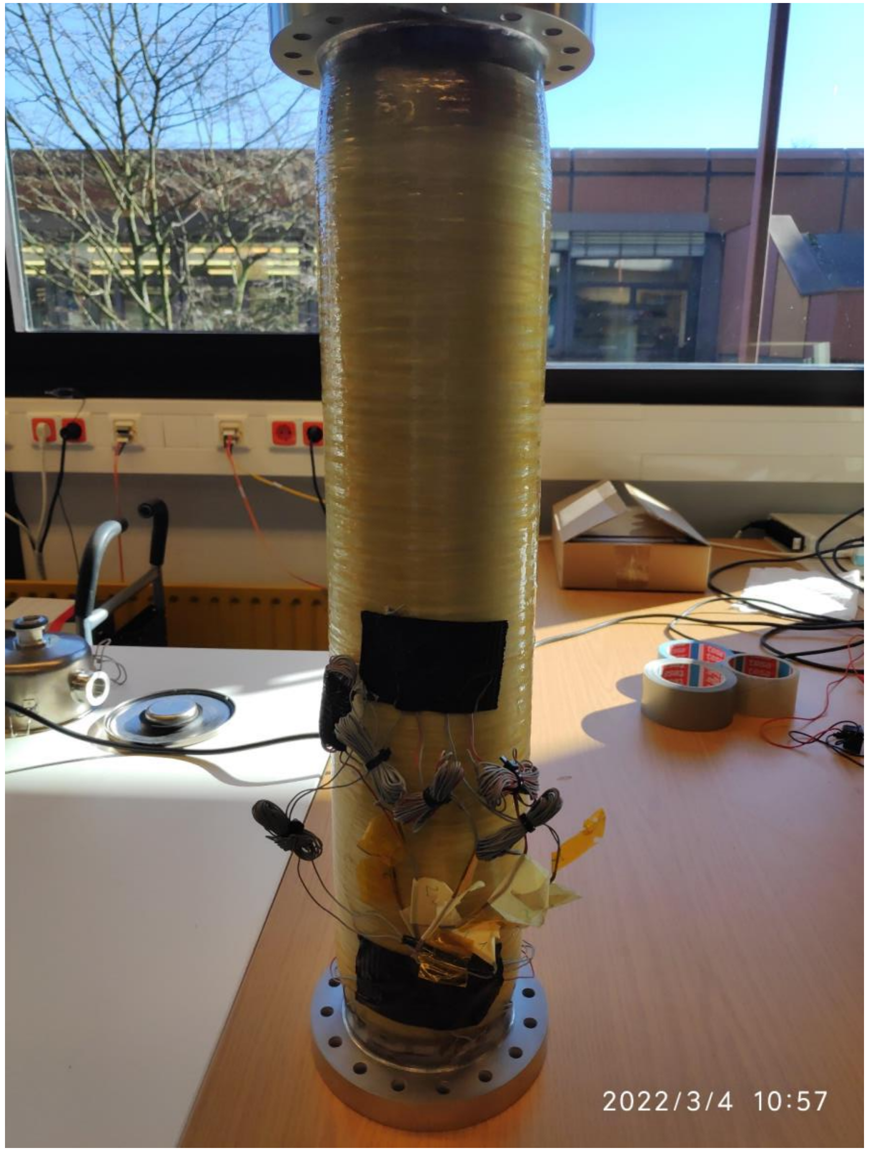
Innovative pipes: 2. prototype

Results:

- reached $2\cdot10^{-10}$ mbar
  (limited by H-outgasing)

Plans:

- Preparation of over-pressure test:
  - 5-bar water pipe.
  - 5-bar He-atmosphere.
- Strain sensors:
  - Bragg-fiber broken
  - Convnetional sensors to be tested
- Preparing samples to determine strain limits
- Designing the outer pipe to match thermal expansion of steel
  (fiber orientation, materials, fiber-to-volume ratio)



Teflon-coating

Revive coopeartion with a local company:
The company built a teflon-coated UHV-chamber for COSY

Hopes:

- Reduced attachment of water to surface
  → avoid bake-out for water
- Acceptable F-outgazing
  → thin layer, low-temperature bake-out (60°C ?)

Status:

- Preparation of samples for coating

Einstein Telescope R&D ecosystem in EMR region: Joint infrastructure co-owned an co-financed by research institutes and universities in Netherlands-Belgium-NR Westphalia

ETpathfinder

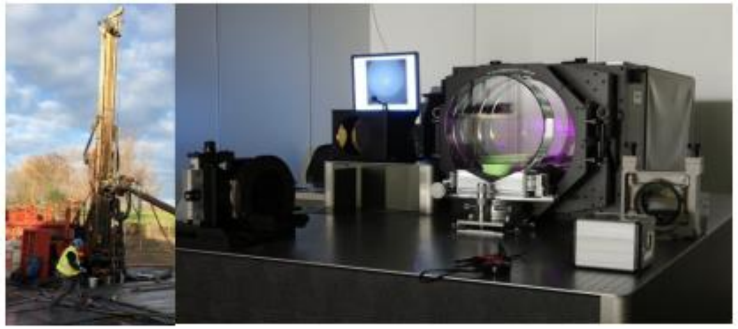
Objective: Development of a model infra-structure for testing new gravitational wave detector technologies and concepts in a complete interferometer in an ET-like environment

Location: UMaastricht-NL

Budget: € 14,8 million

Duration : 2019 – 2022

E-TEST



Objective: Development of ET-technology

- Geological exploration of the EMR and determination of the optimal ET location.
- Developement of advanced prototypes for cryogenics, optics and seismic isolation.

Location: CSL ULiège - BE

Budget: € 15,0 million

Duration : 2020 – 2023

ET2SMEs

Objective: Promotion of cooperation between SMEs, large companies and R&D institutions that deal with ET-relevant key technologies in a broad understanding and towards multiple application fields by initiating SME-driven cross-border R&D projects.

Budget: € 2,23 million

Duration : 2021 – 2023

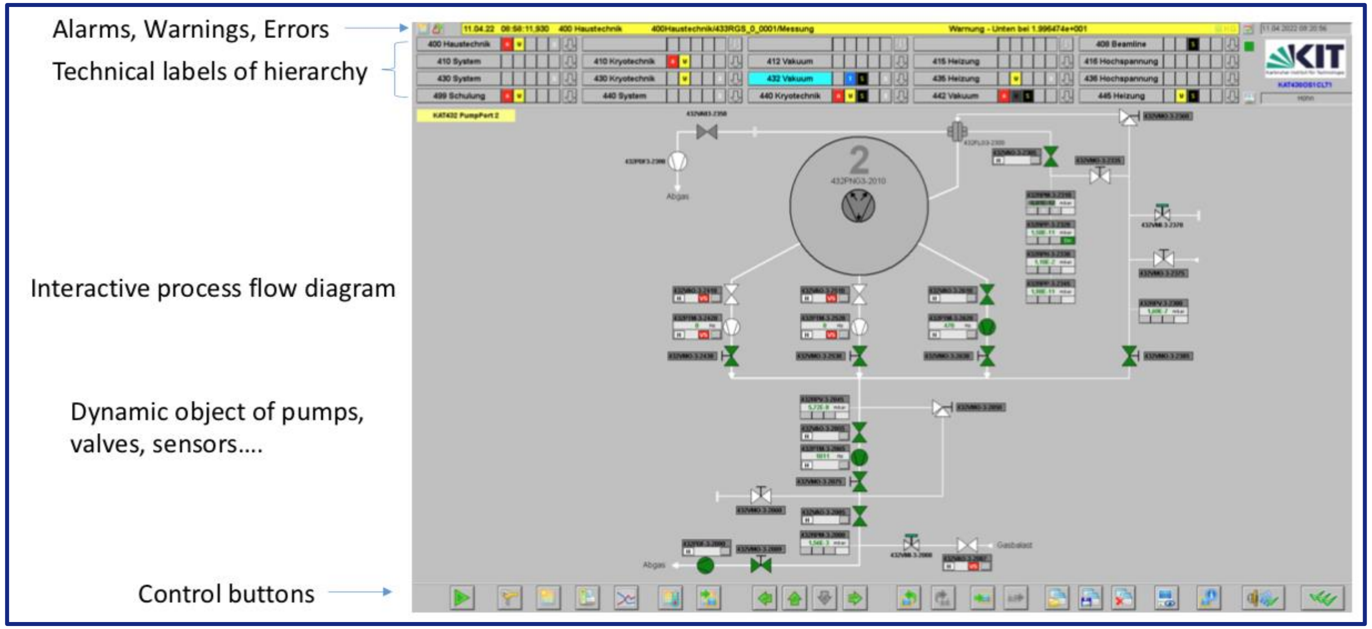
Etpathfinder R&D platform…

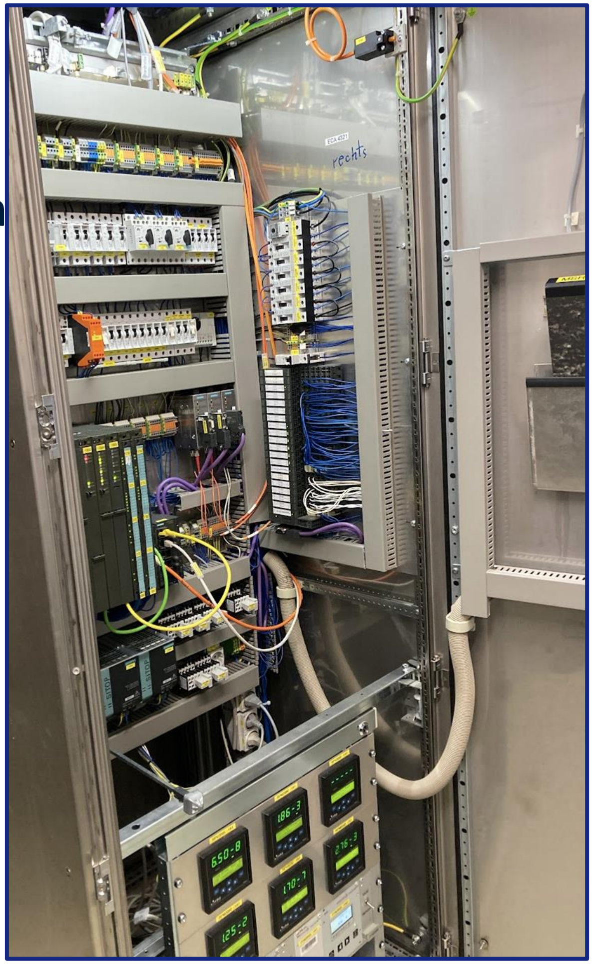
Summer 2022

February 2023

Karlsruhe Institute of Technology (KIT)

- Katrin group happy to take care of the ETpathfinder vacuum system control. (More than 100 active components, i.e. pumps, valves, sensors etc).
- Very experienced group (Katrin much more challenging as includes also tritium handling, a much larger vacuum system on HV etc).
- Developed own libraries within Siemens PCS7 system for many components very similar to ours.





ETpathfinder: a cryogenic testbed for interferometric gravitational-wave detectors

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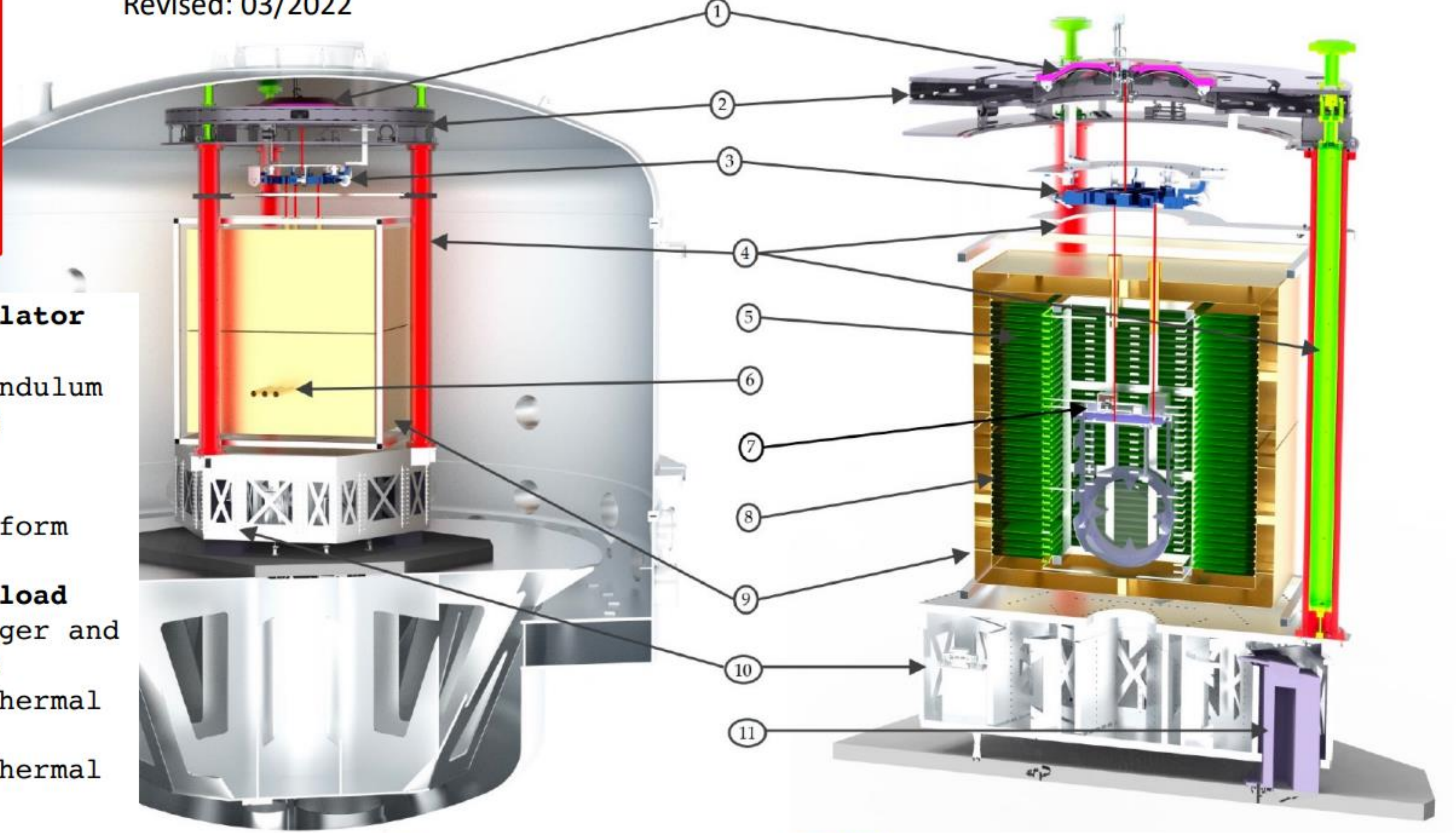

Vibration isolator
1)GAS filter
2)Inverted pendulum (IP) platform
3)Marionette
4)IP legs
9)Active platform

Cryogenic payload
5)heat exchanger and cold platform
7)25K inner thermal shield
8)80K outer thermal shield