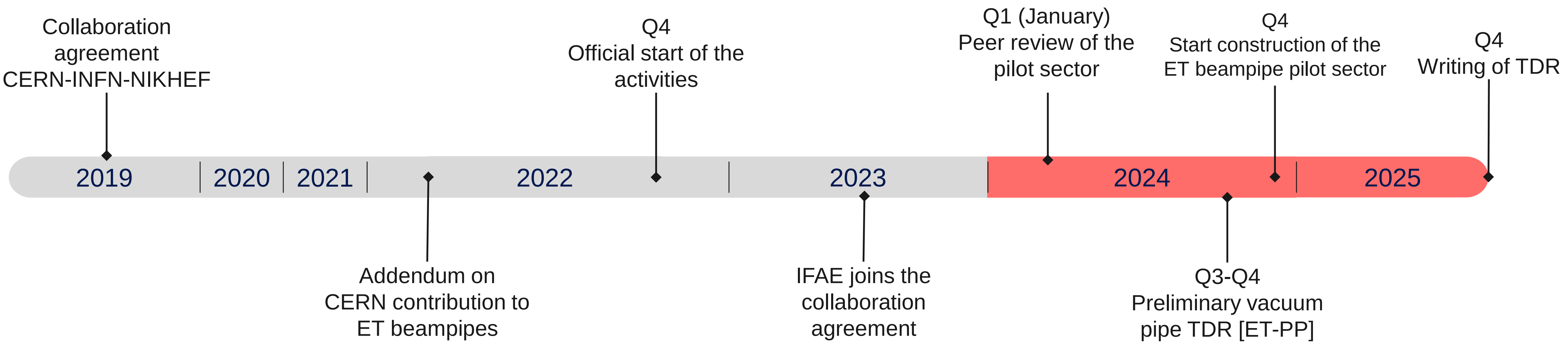
Updates from beampipe vacuum studies at CERN

CARLO SCARCIA on behalf of the ET beampipe vacuum studies group at CERN

XIV ET Symposium, Maastricht, 06-10 May 2024

ET-0180A-24

CERN activities on ET beampipe vacuum



2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025

2019: Collaboration agreement CERN-INFN-NIKHEF

2022: Addendum on CERN contribution to ET beampipes

2022: Q4 Official start of the activities

2023: IFAE joins the collaboration agreement

2024: Q1 (January) Peer review of the pilot sector

2024: Q3-Q4 Preliminary vacuum pipe TDR [ET-PP]

2024: Q4 Start construction of the ET beampipe pilot sector

2025: Q4 Writing of TDR

The main objectives are:

- **Coordinate the contributions** of all parties involved in the study of ET beampipes.
- Design, manufacture, assemble, and test a **pilot sector** of the selected ET beampipe vacuum systems.
- Preparing and writing the ‘**Technical Design Report**’ for the vacuum systems of the ET’s arms, including cost estimations.
- Contact and sharing of information with the **Cosmic Explorer community**.

Conclusions from the 2nd ET annual meeting

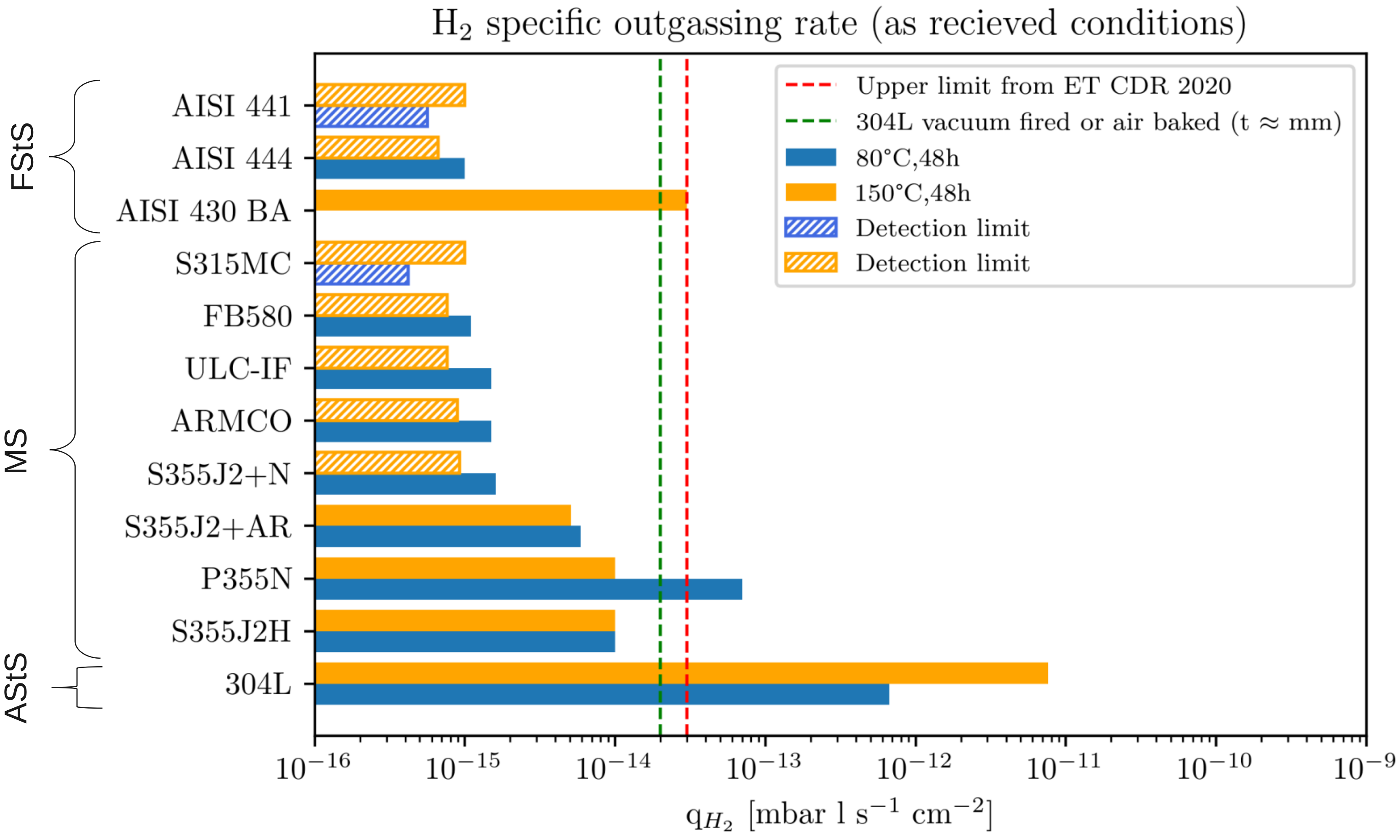
XIII ET Symposium	Ferritic alloys Mild steel and ferritic SS • **Outperform 304/316L outgassing rates w/o requiring HT treatment.** • **Lower (>30%)** raw **material cost.**	Corrugated beampipe 1-2 mm thick tube • **No bellows & stiffeners.** • **Low kg/m** of **material.** • **Less current** input if Joule effect **bakeout.**	ET pilot sector • **Location at CERN.** • **Conceptual design**. • Preliminary **measurement plan.**
2nd ET annual meeting	**Identify optimal alloys** and **investigate pre-prototypes vacuum performance.**	**Find** a **commercial partner** for the **pilot sector manufacturing.**	**Site preparation and detailed design of the infrastructure/system**
Objective from the 2nd annual meeting	**Finalization** of the **pre-prototypes vacuum tests.**	**Design finalization** and **procurement** of the beampipe modules.	**Peer review** of the **project, finalization** of the **design**, and **procurement.**
	Material/Vacuum	**Design**	**Prototyping**

Material/Vacuum: Overview of alternative alloys for beampipe

Ferritic alloys

Mild steel and ferritic SS

- **Outperform 304/316L outgassing rates w/o requiring HT treatment.**
- **Lower (>30%)** raw **material cost.**



AStS: Austenitic Stainless Steel, FStS: Ferritic Stainless Steel, MS: Mild Steel. Vacuum Fired (950°C, 2h), Air baked (450 °C, 5d). Measurement error: ±40%; Detection limit: 50% of background

Material/Vacuum: ET beampipe pre-prototypes

System characteristics

DN400 – 2100 mm (t < 2 mm)

AISI 304L-VF
(AStS)

AISI 441
(FStS)

S315MC
(MS)

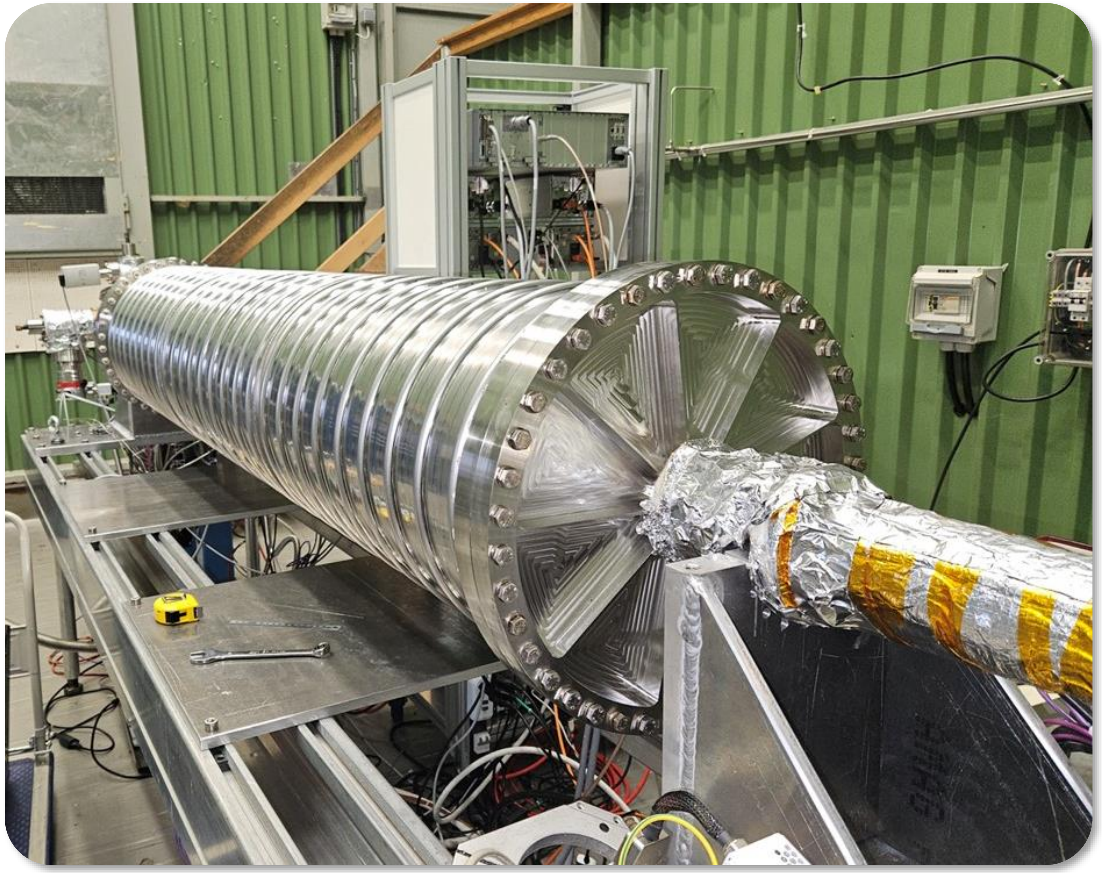
Pumping speeds scaled to ET conditions

Objectives

Ultimate pressure after 80°C and 150°C bakeout

Verify water outgassing **modelling**

Test the **effect** of the **increasing pumping speed during bakeout** on ultimate pressure

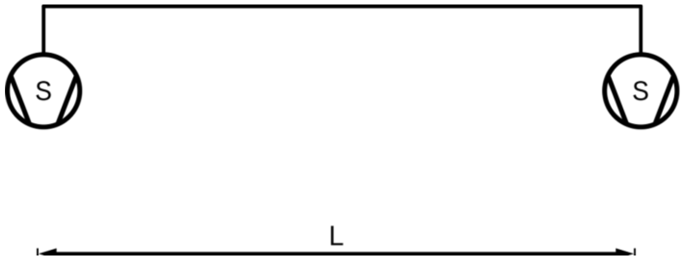


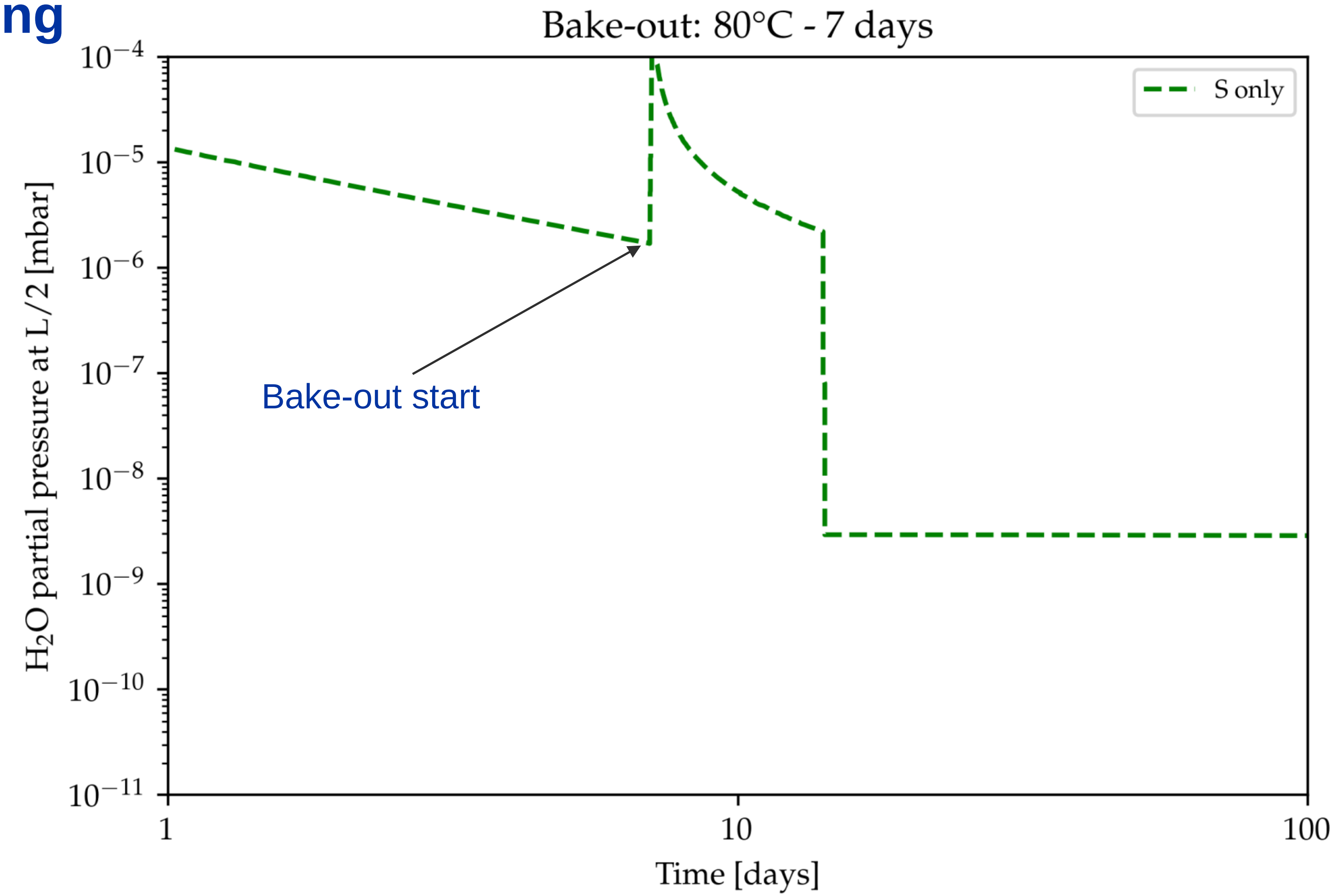
AISI 441 corrugated chamber. Credit: CERN

Material/Vacuum: ET beampipe pre-prototypes

Water outgassing modelling

Modelling of effects of increased pumping speed during heating

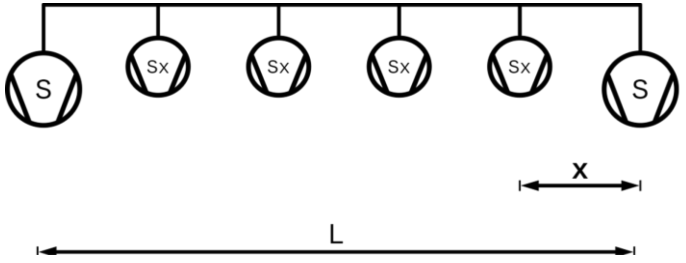




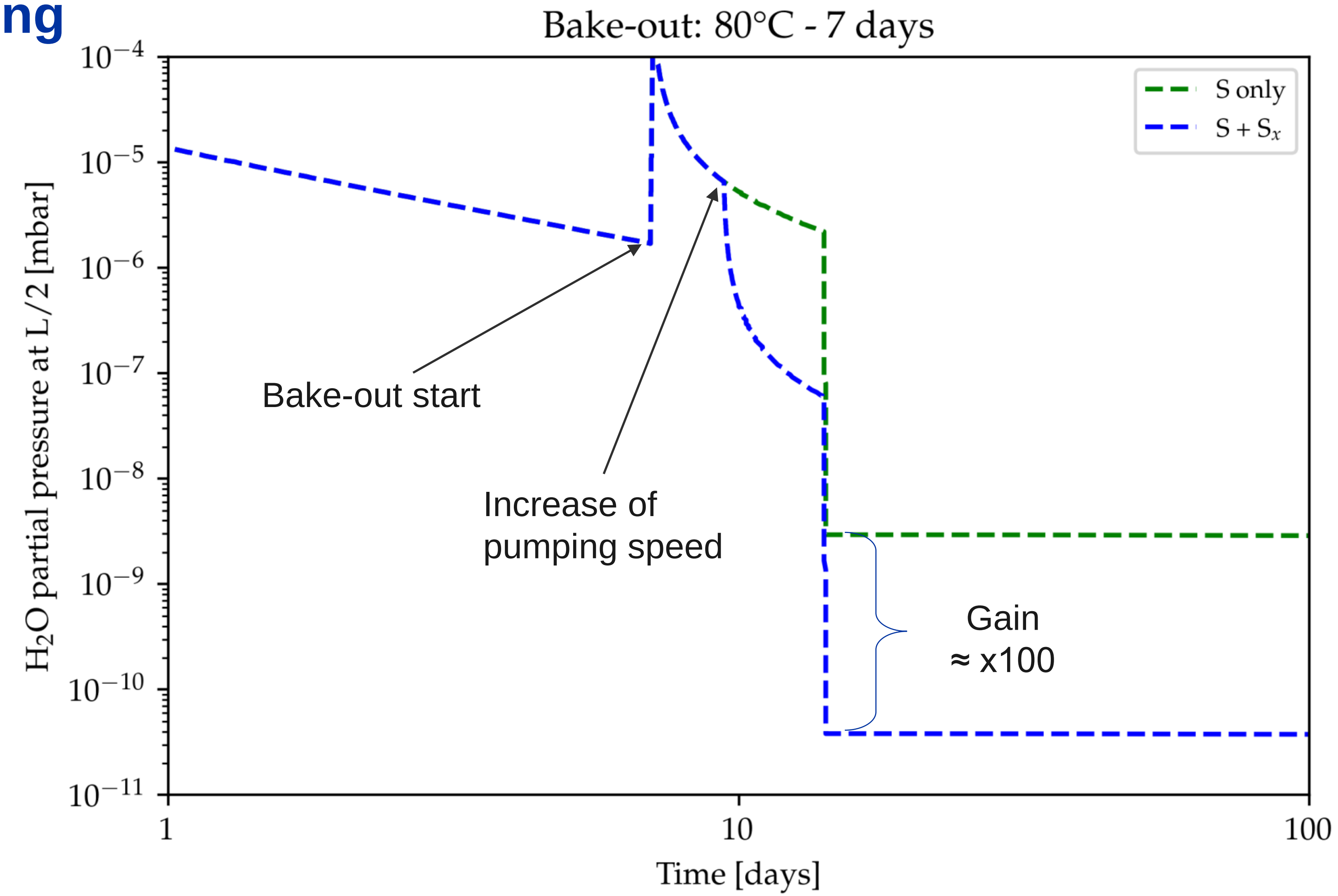
Material/Vacuum: ET beampipe pre-prototypes

Water outgassing modelling

Modelling of effects of increased pumping speed during heating



We could exploit the use of NEG pumps [SAES proposal, 2010]



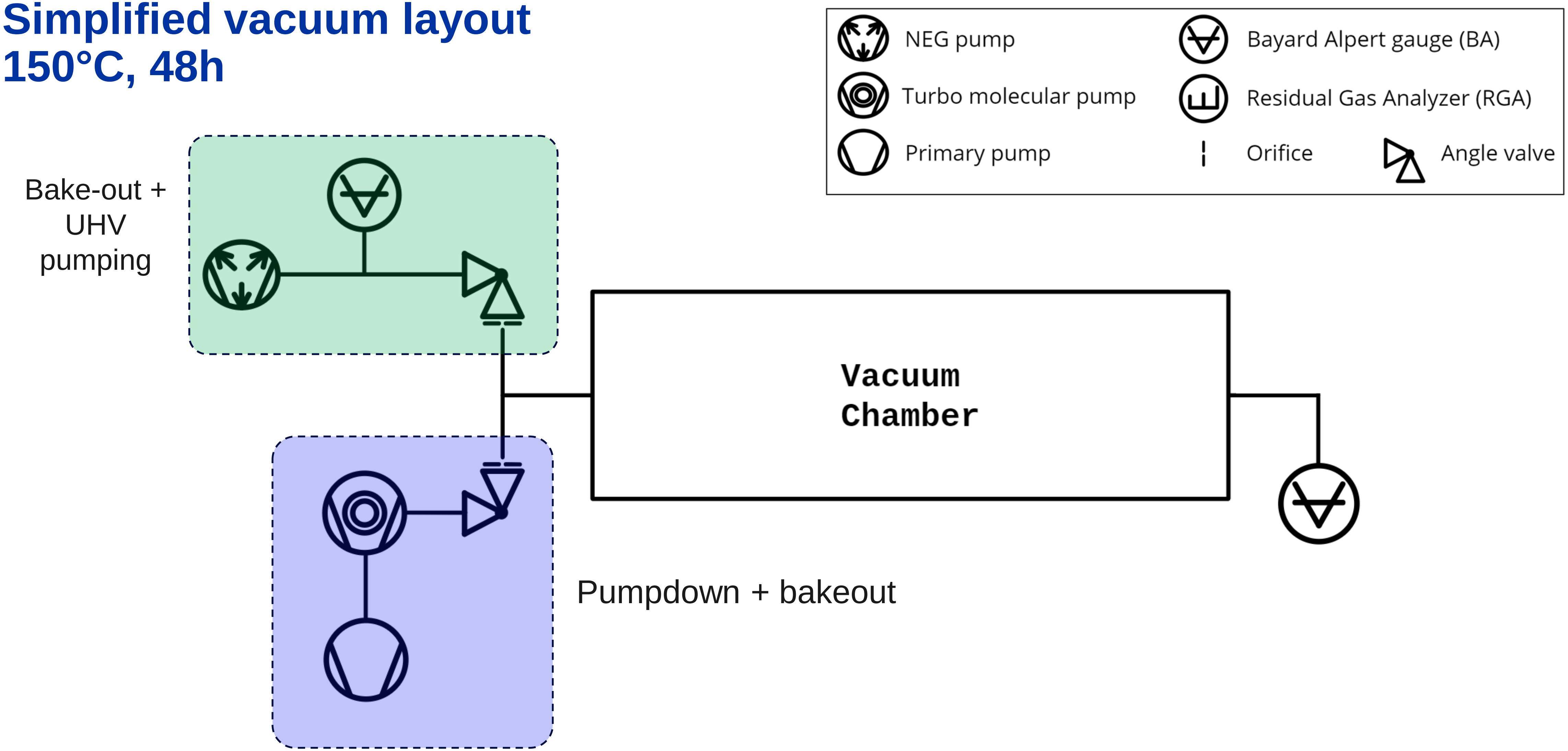
Bake-out start

Increase of pumping speed

Gain
≈ x100

Material/Vacuum: ET beampipe pre-prototypes

Simplified vacuum layout
150°C, 48h



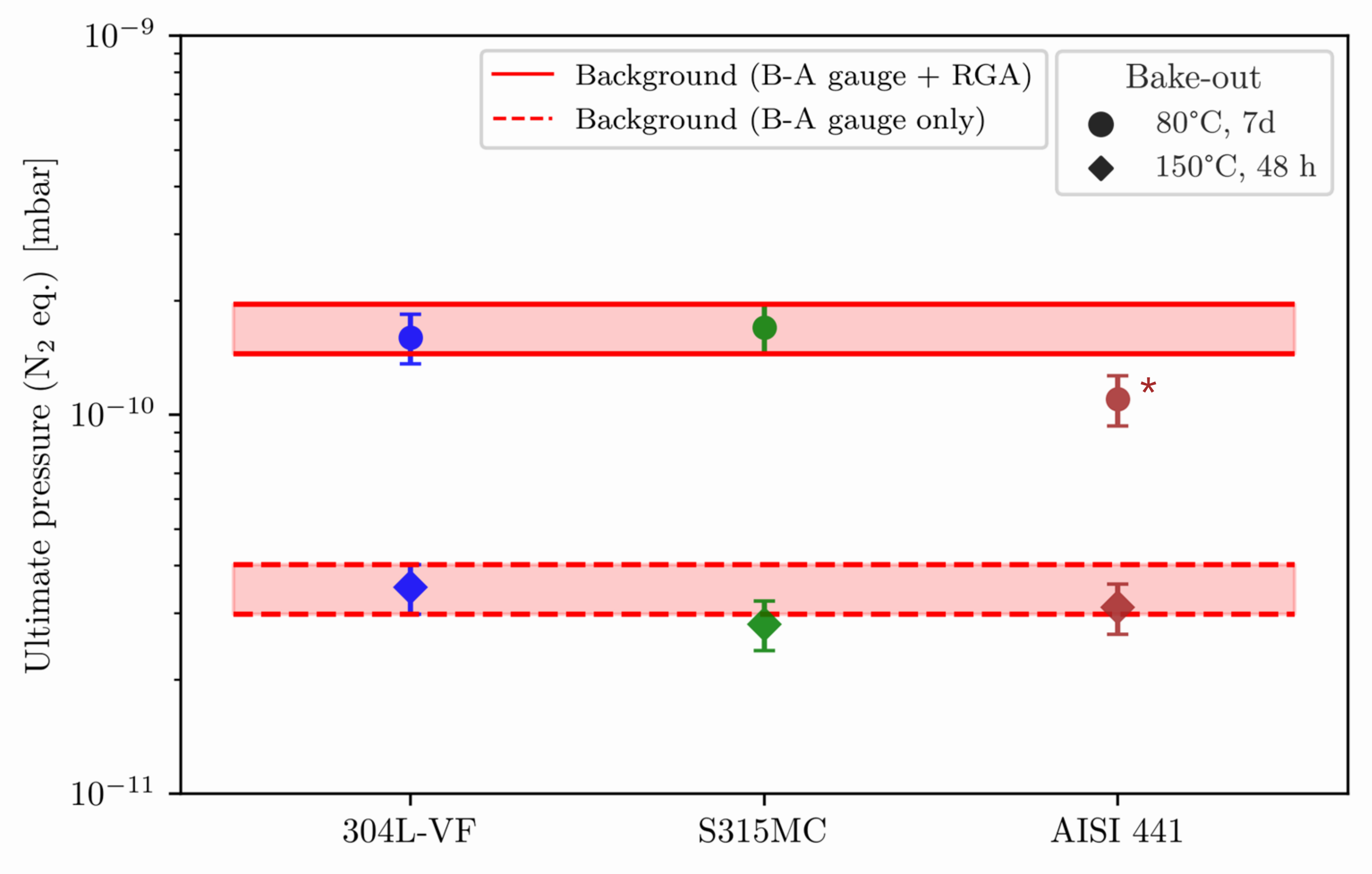
Bake-out + UHV pumping

Vacuum Chamber

Pumpdown + bakeout

Material/Vacuum: ET beampipe pre-prototypes

Ultimate pressure after 80°C and 150°C bakeout



Orifice limited: 31 l s^{-1} for H_2, N_2 to H_2 conversion factor: 2.19, B-A gauge error: 15%. B-A: Bayard-Alpert, RGA: Residual Gas Analyser.

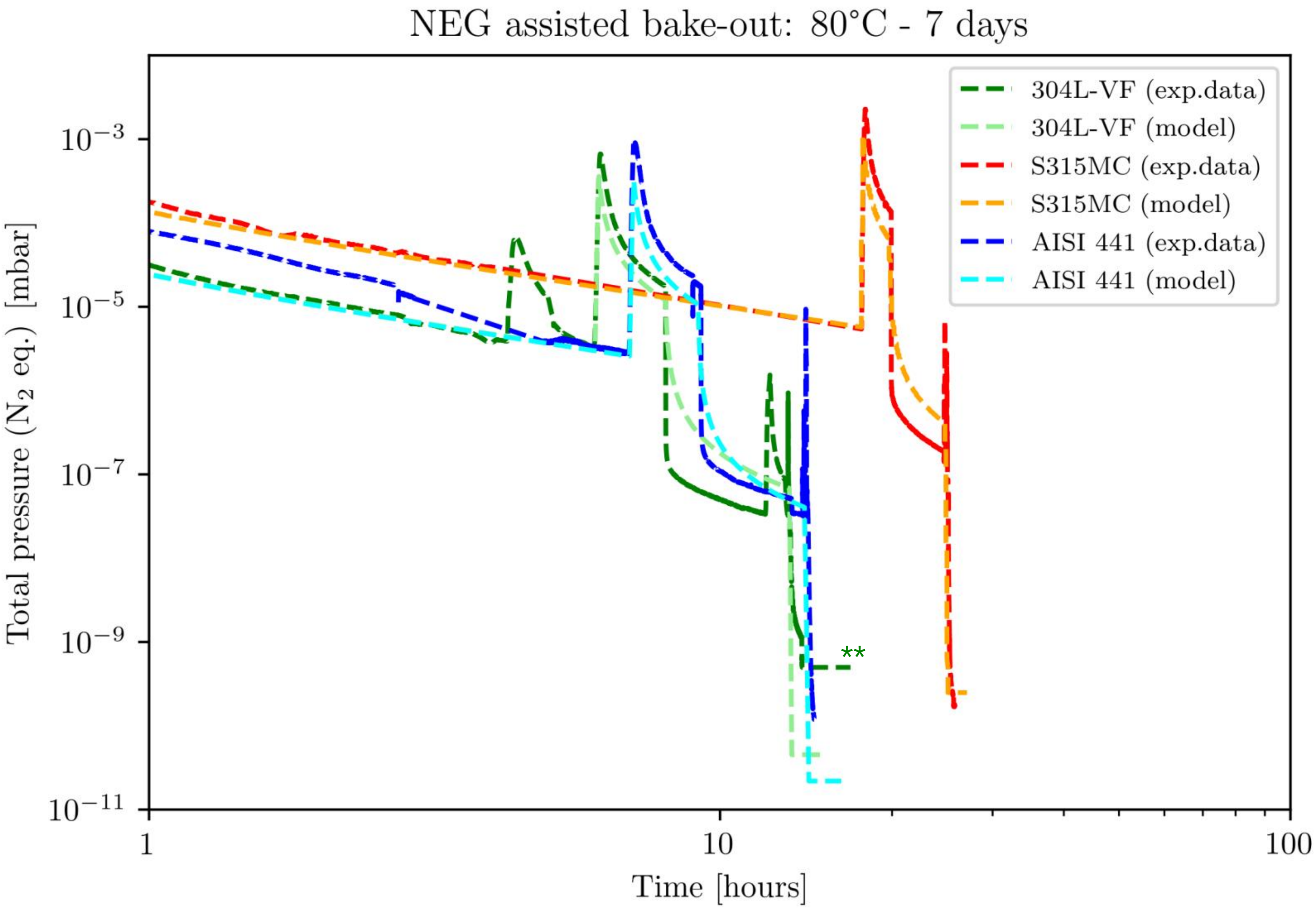
As predicted, for all the chambers, **ultimate pressures limited** by **instrumentation outgassing rates**.

H_2 outgassing rate:
< 8 10^{-14} mbar l s^{-1} cm^{-2}

(better estimation is not possible because of the intrinsic limitation of the system)

* Improvement of the background contribution (RGA outgassing rate)

ET beampipe pre-prototypes : conclusions



For all three chambers:

1. **Good matching between** the **model** and **experimental data**.
2. The **model**'s **predicted water partial pressure** values **generally align with** the **values** from the **mass spectrometer signal**.
3. The **increase of pumping speed during** the **bakeout** is **proven** to be a **viable solution to shorten** the **duration.**

** DN400 closing flanges erroneously fired before machining

LoLA: Low outgassing Large Apparatus

Measurements

After repeated 80°C,48h (heating step)

- **Ultimate pressure** & **mass scan**.
- **H_2, CH_4, CO and CO_2 outgassing rates**.
- **Residual water outgassing rate.**

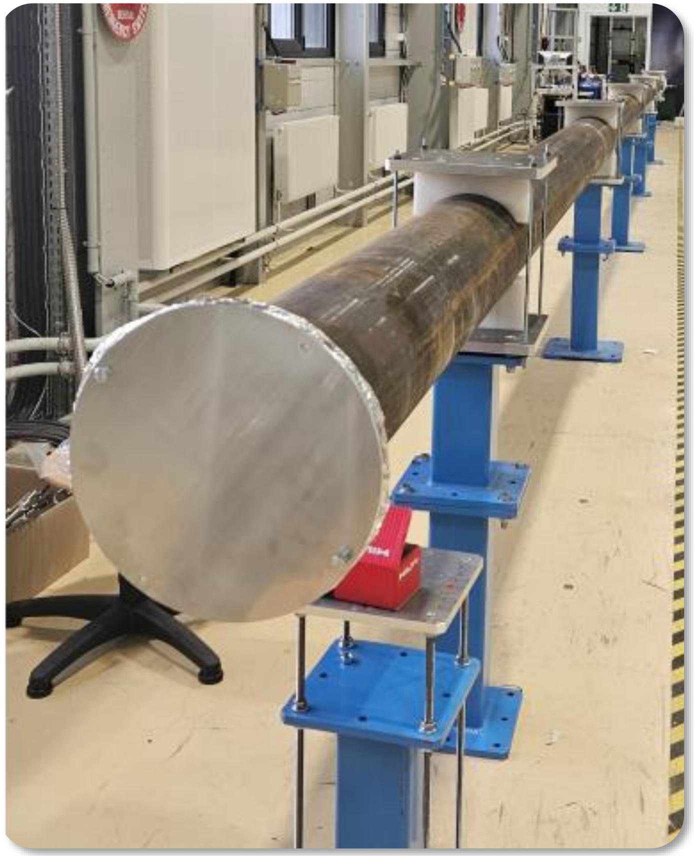
Main objectives

- **Track** the **evolution** of **water outgassing** rate after **low-temperature long-duration bakeout**.
- **Extrapolate outgassing** rates **model** for **ferritic alloys**.

Pumping speed

Pumping speeds not scaled to an **ET sector**

LoLA: Materials and dimensions



P355N 16m chamber. Credit: CERN

AISI 441 chambers. Credit: CERN

Materials and dimensions

Mild steel chamber

Chamber material: **P355N**
Final chamber dimensions: **Ø219 x 6 mm** - **16 m**
Closing flanges [DN250]: S355J2+N (forged)

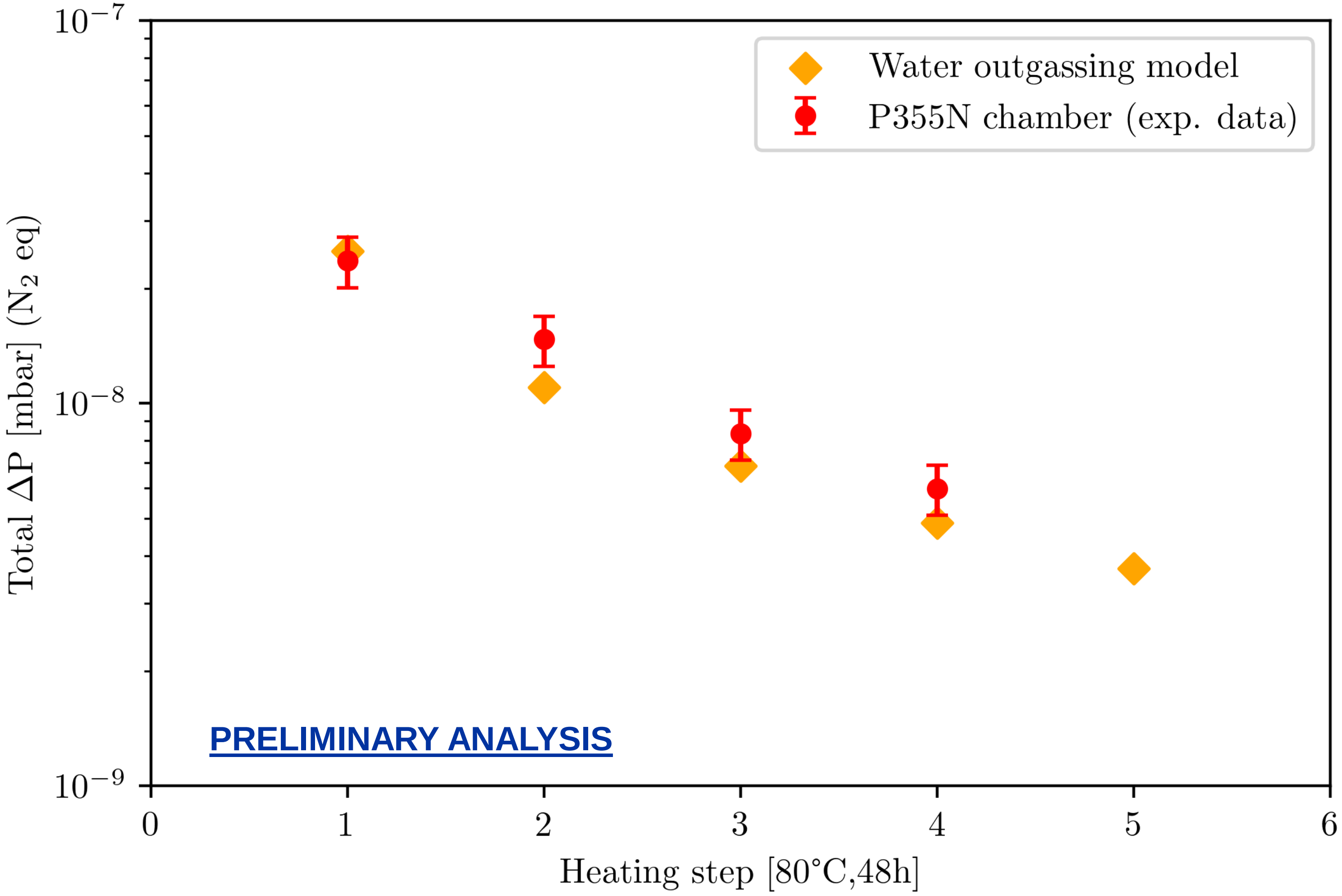
UNDER TEST

Ferritic StS. chamber

Chamber material: **AISI 441**
Final chamber dimensions: **Ø80 x 2 mm** - **15 m**
Closing flanges [DN100]: AISI 316LN (VF)

UNDER CONSTRUCTION

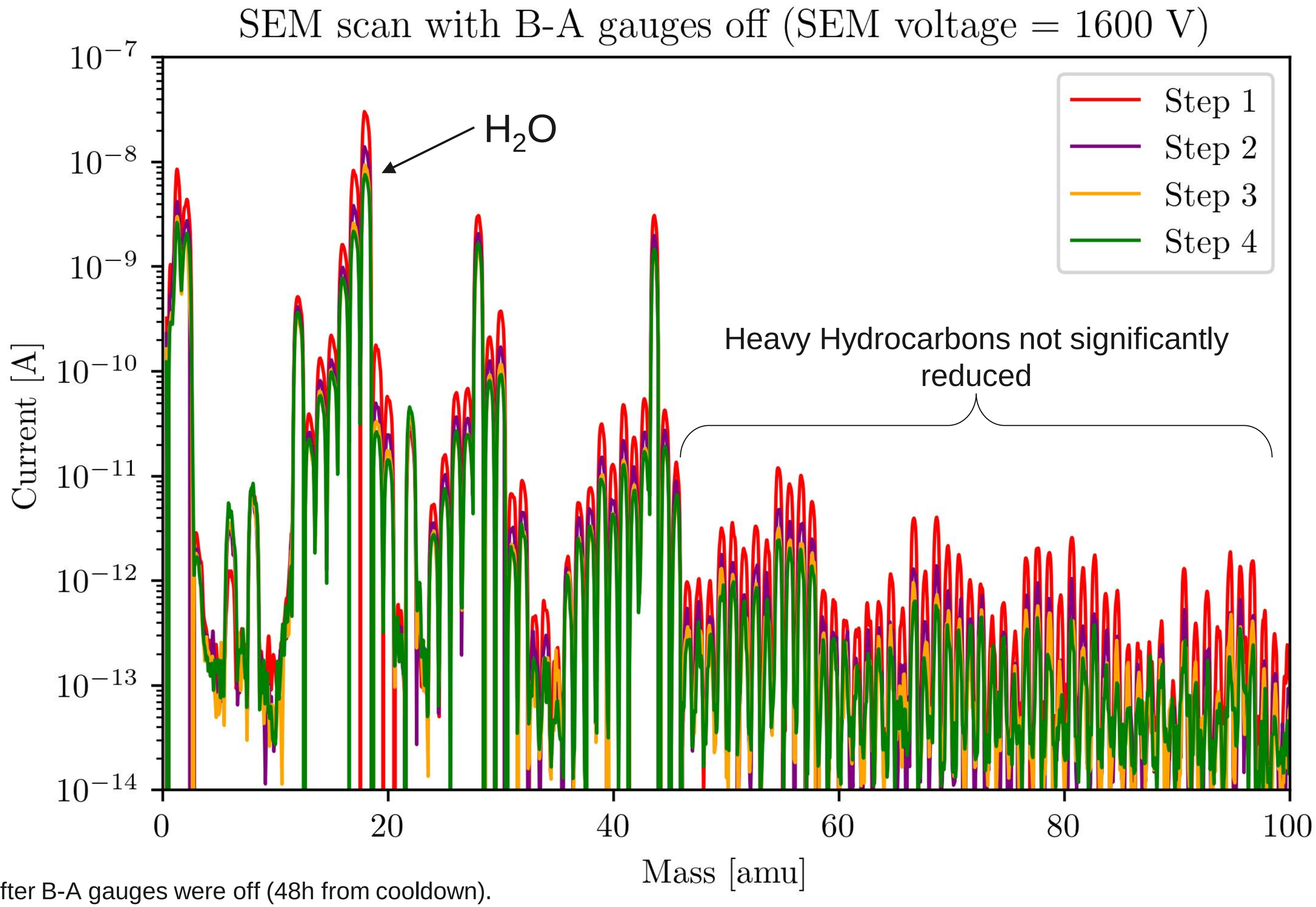
LoLA: mild steel chamber ultimate pressure after bakeout



Good agreement between the experimental data and the model.

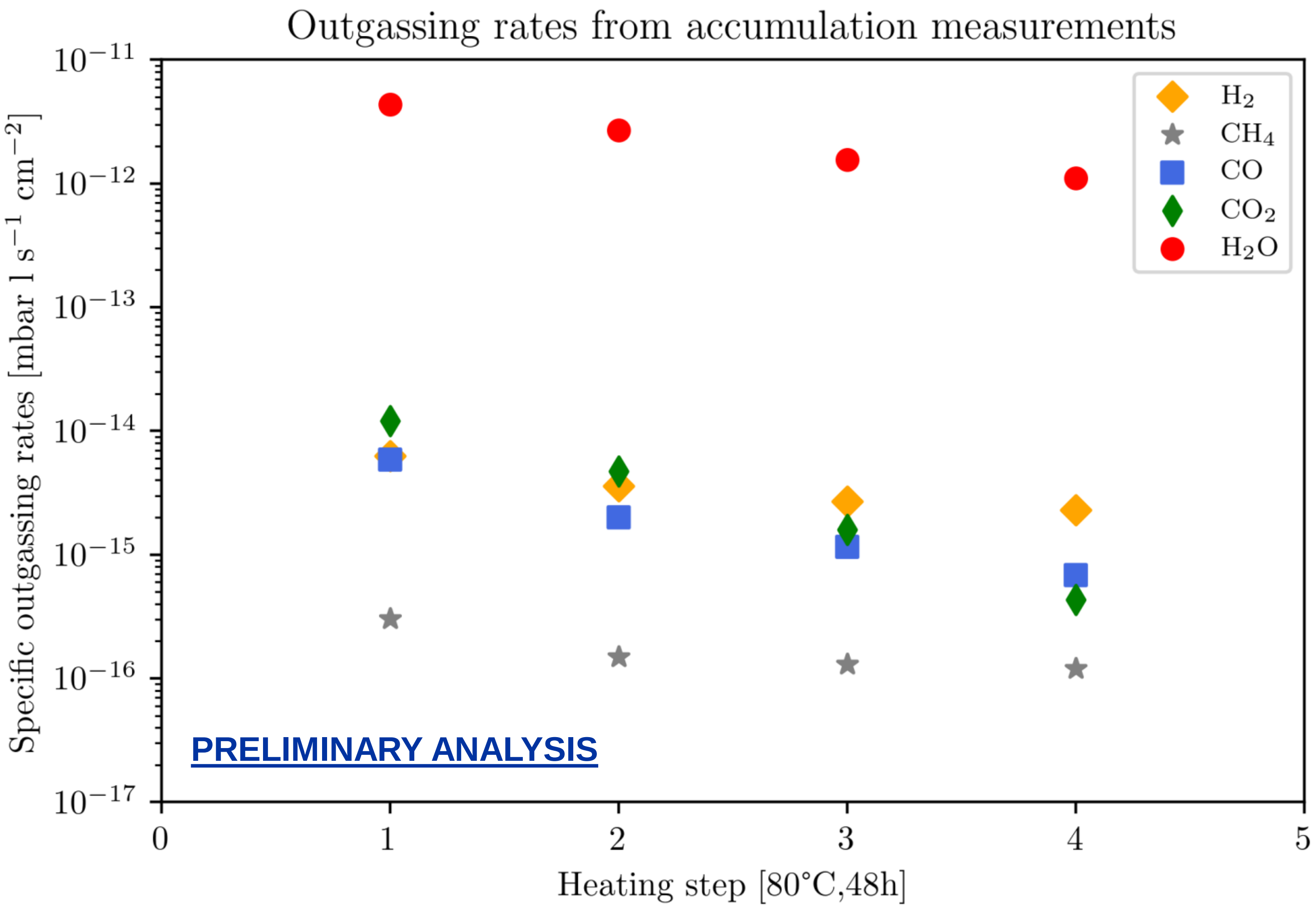
Orifice limited: 19.5 l s^{-1} for H_2O, B-A gauge error: 15%. The measurements are done at 294K.

LoLA: mild steel chamber mass scan after bakeout



SEM scan taken 24h after B-A gauges were off (48h from cooldown).

LoLA: mild steel chamber outgassing rates after bakeout

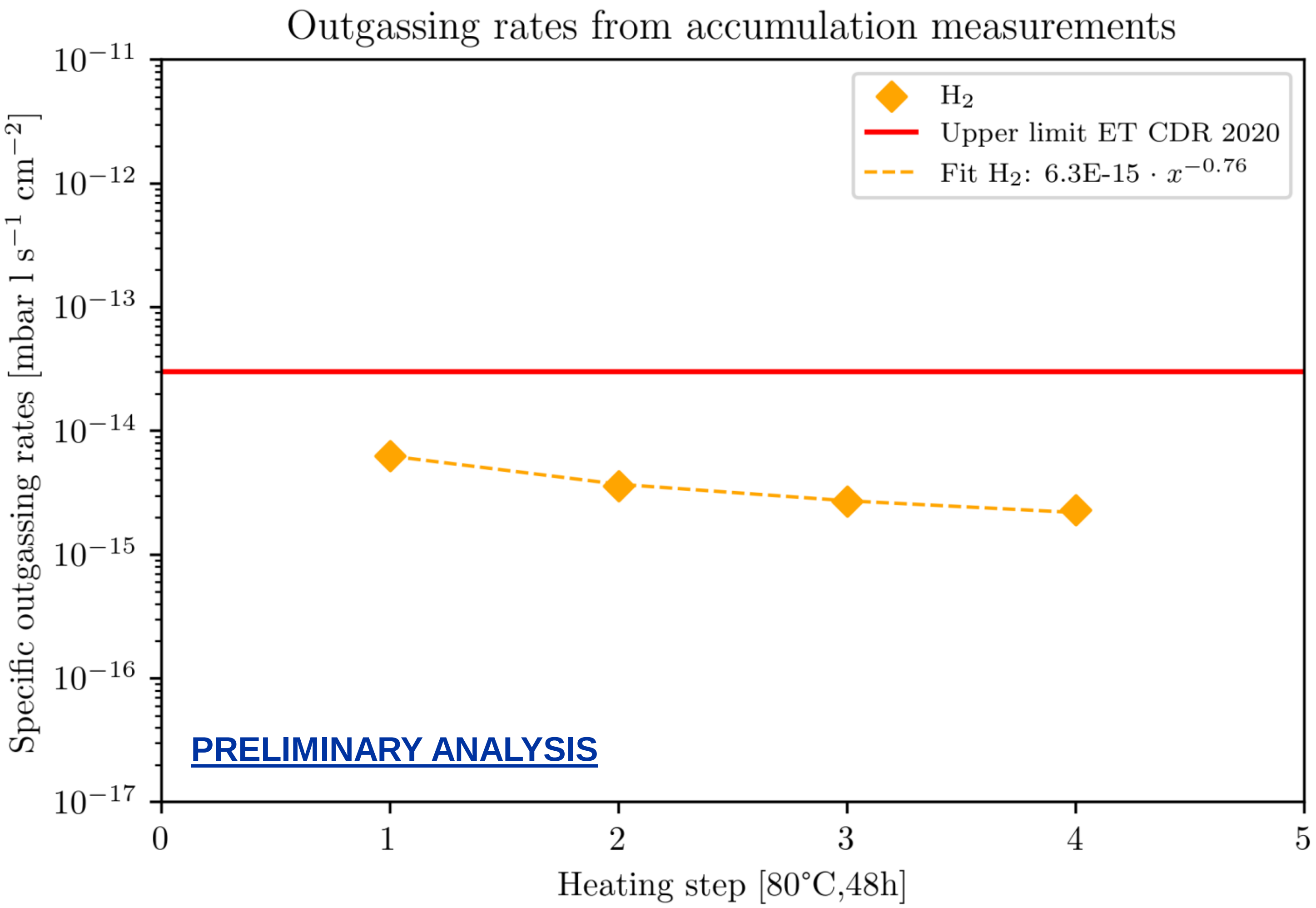


H_2O specific outgassing rates can be **extrapolated** from throughput and accumulation measurements.

CO and CO_2 outgassing rates after the first heating step compete with H_2 one.

Measurement error: ±40% (estimated). The measurements are done at 294K.

LoLA: mild steel chamber outgassing rates after bakeout



Measurement error: ±40% (estimated). The measurements are done at 294K.

H_2 outgassing rates are **in line** with preliminary **requirements** from **ET CDR 2020**

Next main step:
understand the **desorption mechanism** and **model**

LoLA: Preliminary considerations on mild steel chamber results

Low temperature (80°C) bakeout was discussed with Cosmic Explorer colleagues as potential cost saving solution. However…

Thick wall tubes
(~ 1 cm thick)

Mild steel
(much cheaper than AStS)

Current needed **for a bakeout* at 150°C:**
~ 6000 A

Lower bakeout temperature
(150°C → 80°C)

Current needed **for a bakeout* at 80°C:**
~ 4000 A

Poor vacuum performance

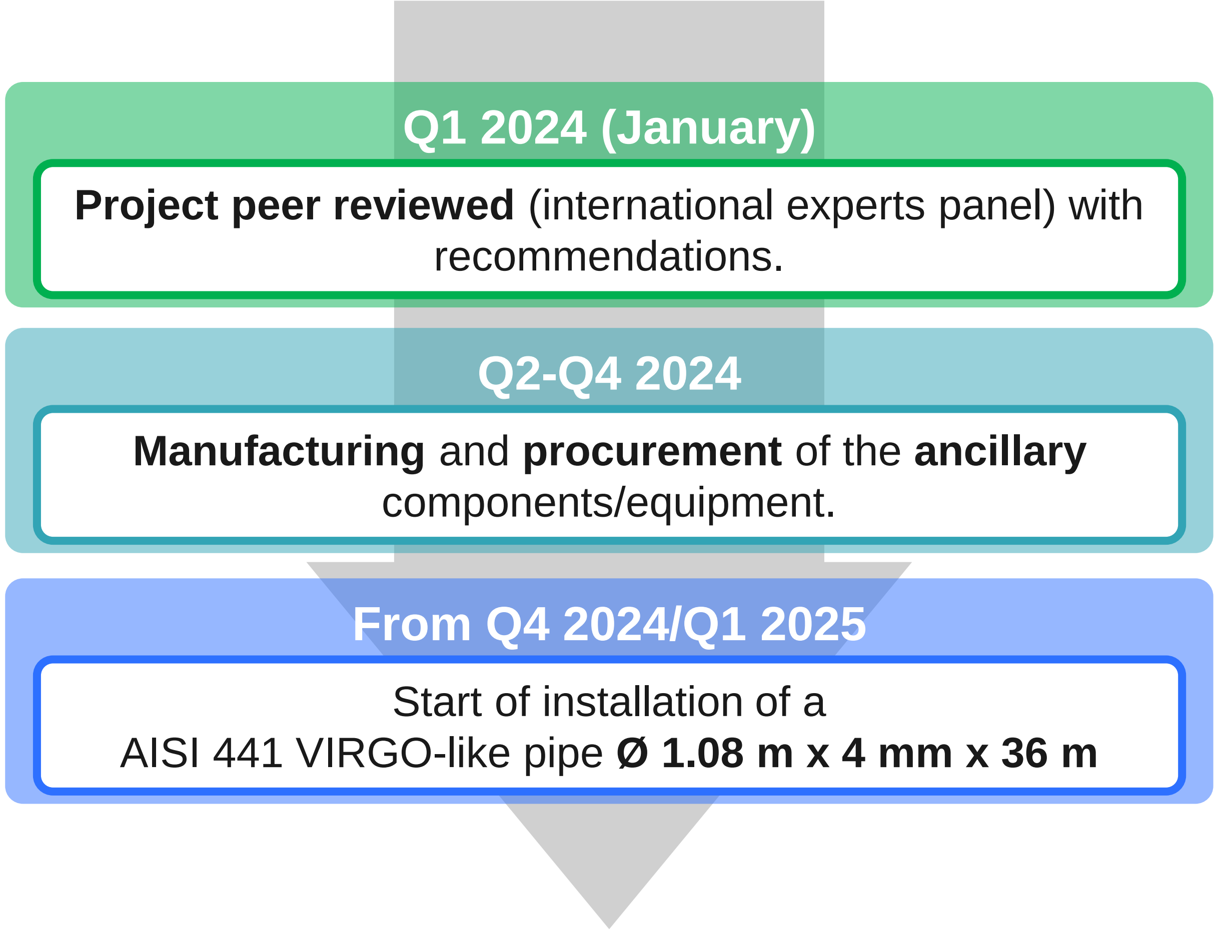
Months long bakeout to reach ~10^{-11} mbar

Inefficient Heavy hydrocarbon reduction

*DC bakeout, insulation: mineral wool, thickness: 15 cm

ET pilot sector

The pilot sector aims to **test the design, fabrication, installation and commissioning** of the proposed **beampipes and support system**. It also aims to compare the feasibility of a selected number of technical choices.



Q1 2024 (January)

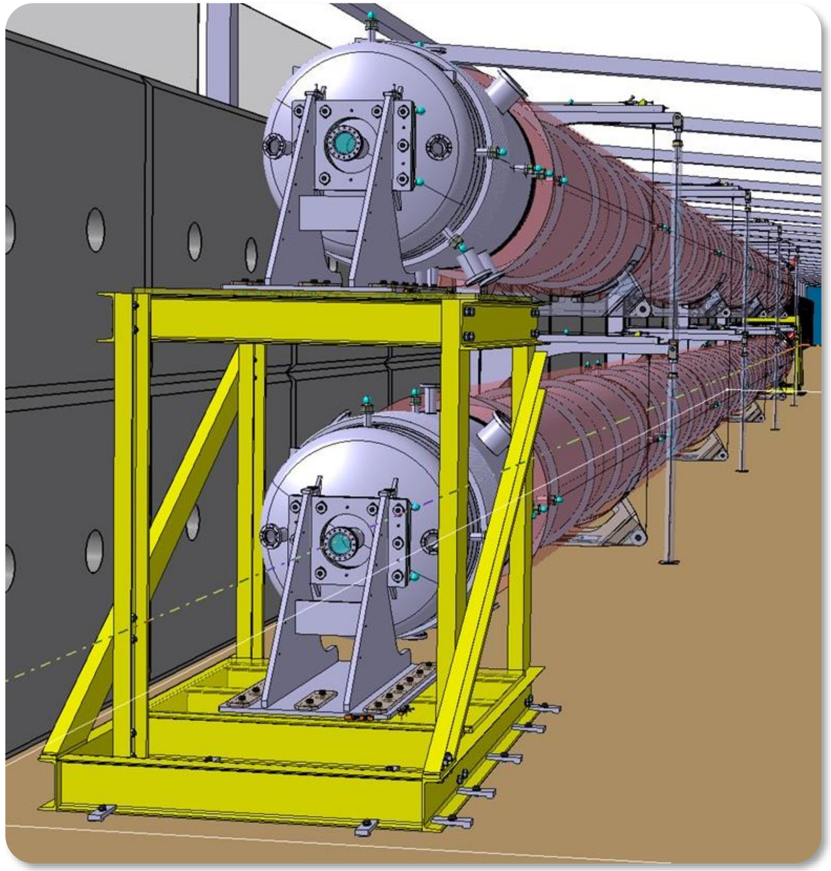
Project peer reviewed (international experts panel) with recommendations.

Q2-Q4 2024

Manufacturing and **procurement** of the **ancillary** components/equipment.

From Q4 2024/Q1 2025

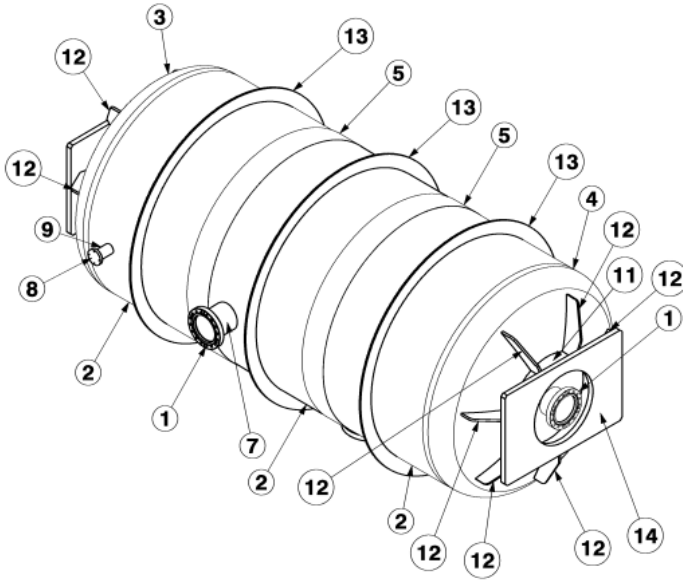
Start of installation of a
AISI 441 VIRGO-like pipe **Ø 1.08 m x 4 mm x 36 m**



ET pilot sector

Preliminary tests/verifications/validations :

- Installation and alignment of supports and beampipes.
- In-situ welding and assembly.
- Integration of thermal insulation, instrumentation and vacuum components.
- Leak detection procedure during fabrication and assembly.
- Pumpdown time.
- Bakeout: temperature distribution and efficiency.
- Ultimate partial pressures and outgassing rates.
- Validate the calculated vibration transmission matrix.
- Efficiency of the methods used to reduce the quantity of dust



Courtesy of M. Dakshinamurthy and A. T. Pérez

3 segments of 850 mm diameter, 500 mm length
(rolled & welded cylinders)

Mock-up to test welding process and parameters optimization for reduction of potential virtual leaks (fabrication to be completed early Q3, NDTs and leak detection will follow)

ET pilot sector

Preliminary tests/verifications/validations :

- Installation and alignment of supports and beampipes.
- In-situ welding and assembly.
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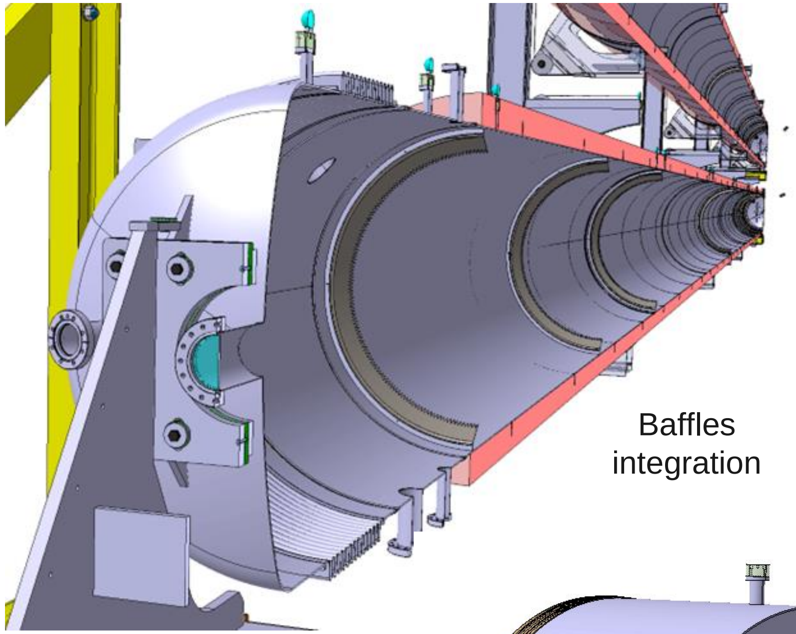
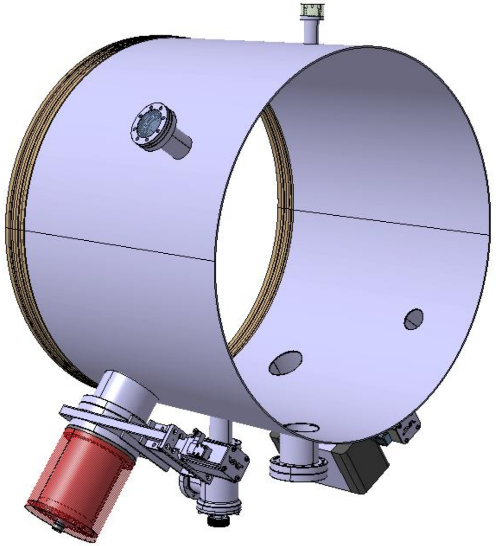


Baffles integration



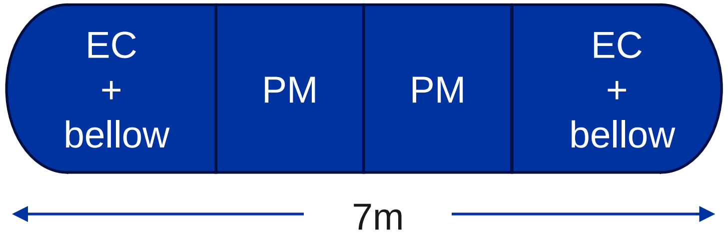
3D model of the pumping module

ET pilot sector: vacuum system

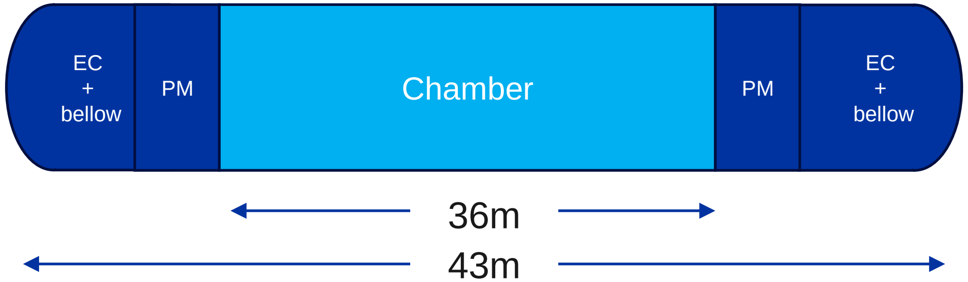
Vacuum measurement sequence: Four steps

	Step 1	Step 2	Step 3	Step 4
Instrumentation	🟩			🟩
Valves	🟩	Only on the mobile pumping group		🟩
Pumps	🟩	Mobile pumping group only		🟩
Measurements	**Ultimate vacuum**	**Accumulations** (H_2, CH_4, CO and CO_2 outgassing rates)	**Accumulations** (H_2, CH_4, CO and CO_2 outgassing rates)	**Ultimate vacuum**

Reduced system (Background)



Full system



EC: End Cap
PM: Pumping Module

ET pilot sector: vacuum system

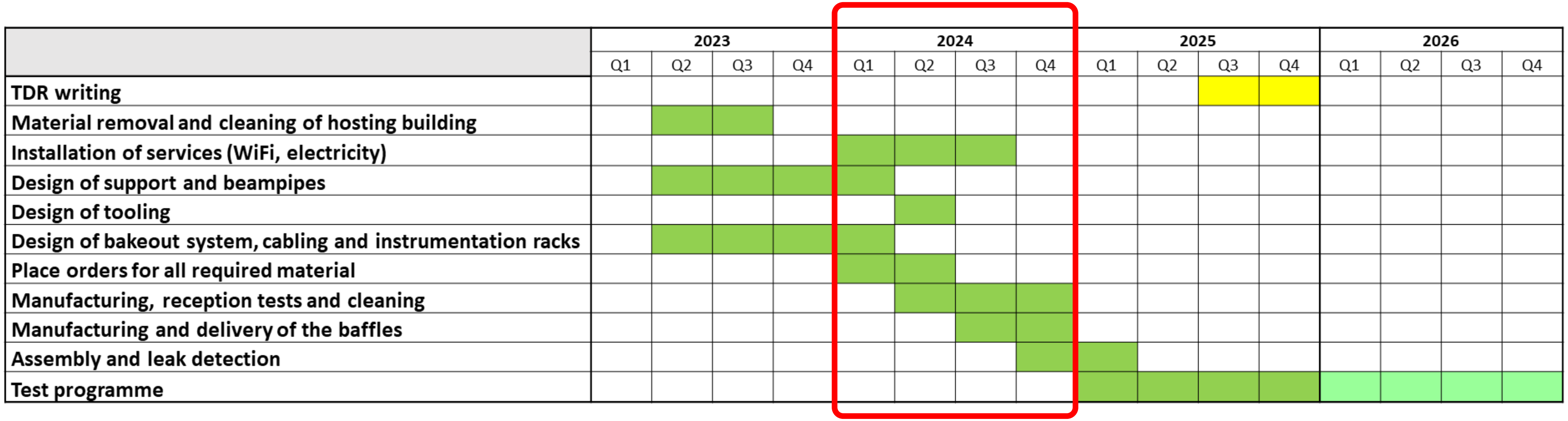
Preliminary experimental programme (2024)

Conditioning and **outgassing rate measurements** of all the **valves**, **instrumentation**, **flanges** and **non-ferritic StS components** (Q2-Q3 2024).

Design of the **leak detection measurement/campaign** (Q2-Q4 2024)

Outgassing rate measurements of **baffle's material surface treatments** and **coatings** (Q2-Q3 2024) [in **collaboration** with **IFAE**].

Detailed measurement procedure to be written **before Q4 2024.**



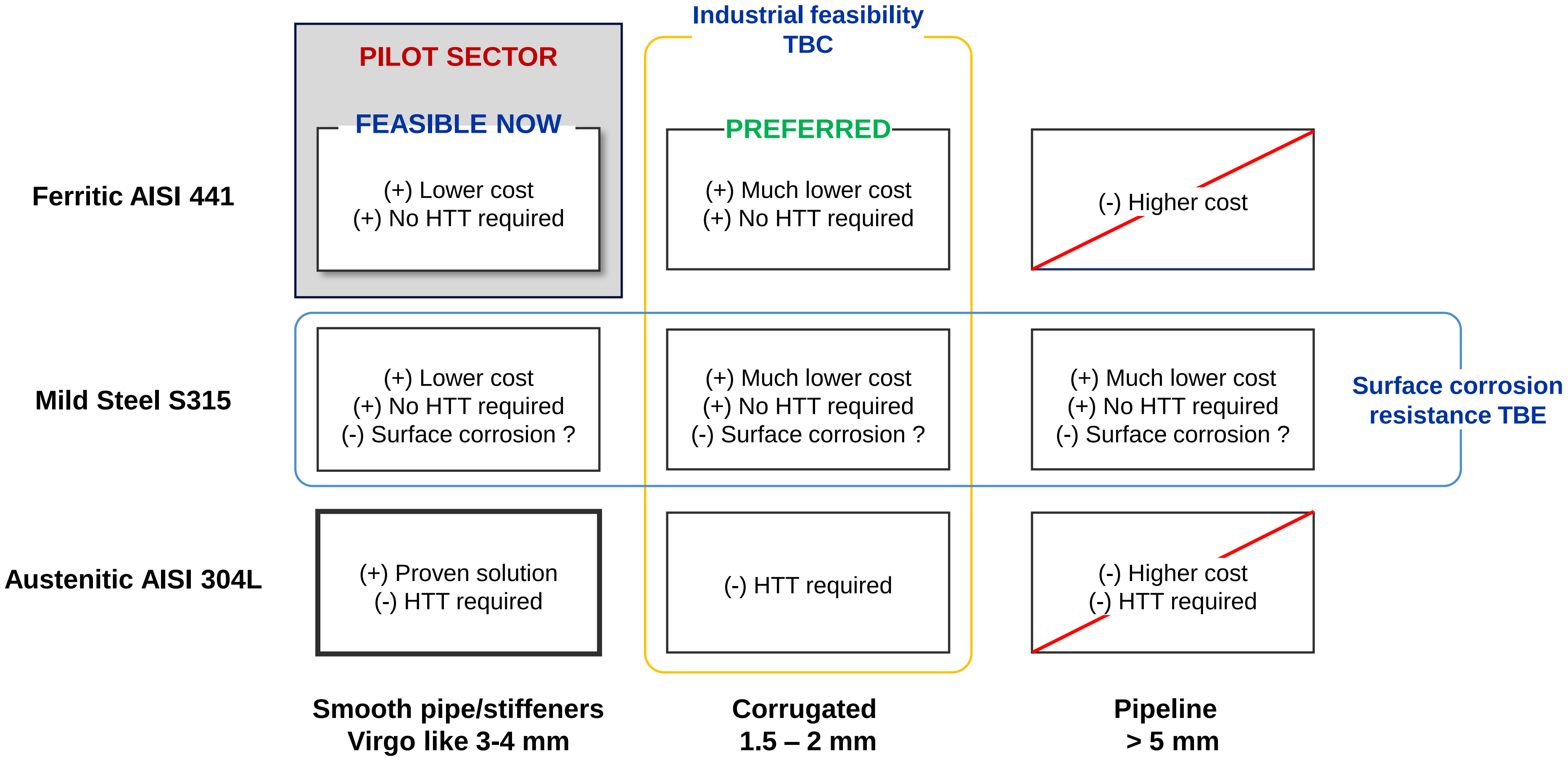
	2023				2024				2025				2026			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
TDR writing											🟨	🟨				
Material removal and cleaning of hosting building		🟩	🟩													
Installation of services (WiFi, electricity)					🟩	🟩	🟩									
Design of support and beampipes		🟩	🟩	🟩	🟩											
Design of tooling						🟩										
Design of bakeout system, cabling and instrumentation racks		🟩	🟩	🟩	🟩											
Place orders for all required material					🟩	🟩										
Manufacturing, reception tests and cleaning						🟩	🟩	🟩								
Manufacturing and delivery of the baffles							🟩	🟩								
Assembly and leak detection								🟩	🟩							
Test programme									🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

ET pilot sector: peer review recommendations

Recommendation	Action
Investigation on corrosion resistance of ferritic stainless steels (tunnel environmental conditions)	Contract with UGhent to be launched for comparative corrosion studies
Use pilot sector as testbed for extrapolation of ET leak detection	Methodologies and tooling under investigation
ET pilot sector to be used to test different insulation materials and solutions (installation, removal)	Contact with companies started
Implementation of large gate valves (DN1000+) to test thermal cycling, stroke cycling, treatments etc.	See Luigi's presentation
Implementation of temperature control systems in selected building	
Consider launching a parallel test on a corrugated chamber (perhaps through external contribution)	

home.cern

Summary of design/material/vacuum



PILOT SECTOR

FEASIBLE NOW

Industrial feasibility TBC

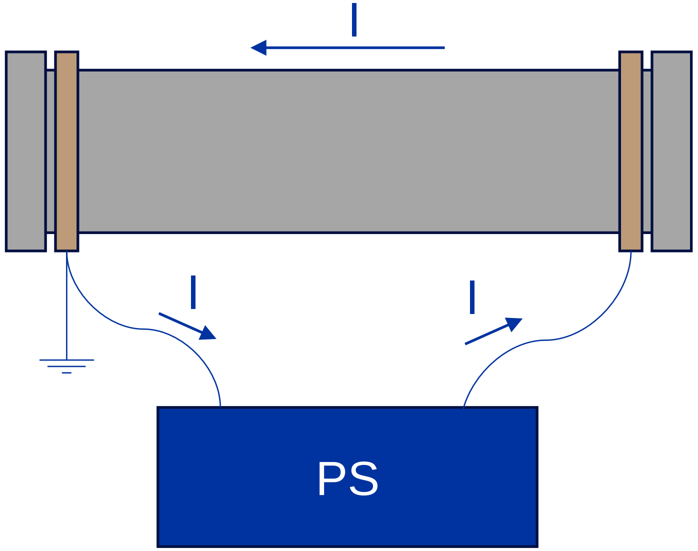
PREFERRED

Surface corrosion resistance TBE

	Smooth pipe/stiffeners Virgo like 3-4 mm	**Corrugated 1.5 – 2 mm**	**Pipeline > 5 mm**
Ferritic AISI 441	(+) Lower cost (+) No HTT required	(+) Much lower cost (+) No HTT required	(-) Higher cost
Mild Steel S315	(+) Lower cost (+) No HTT required (-) Surface corrosion ?	(+) Much lower cost (+) No HTT required (-) Surface corrosion ?	(+) Much lower cost (+) No HTT required (-) Surface corrosion ?
Austenitic AISI 304L	(+) Proven solution (-) HTT required	(-) HTT required	(-) Higher cost (-) HTT required

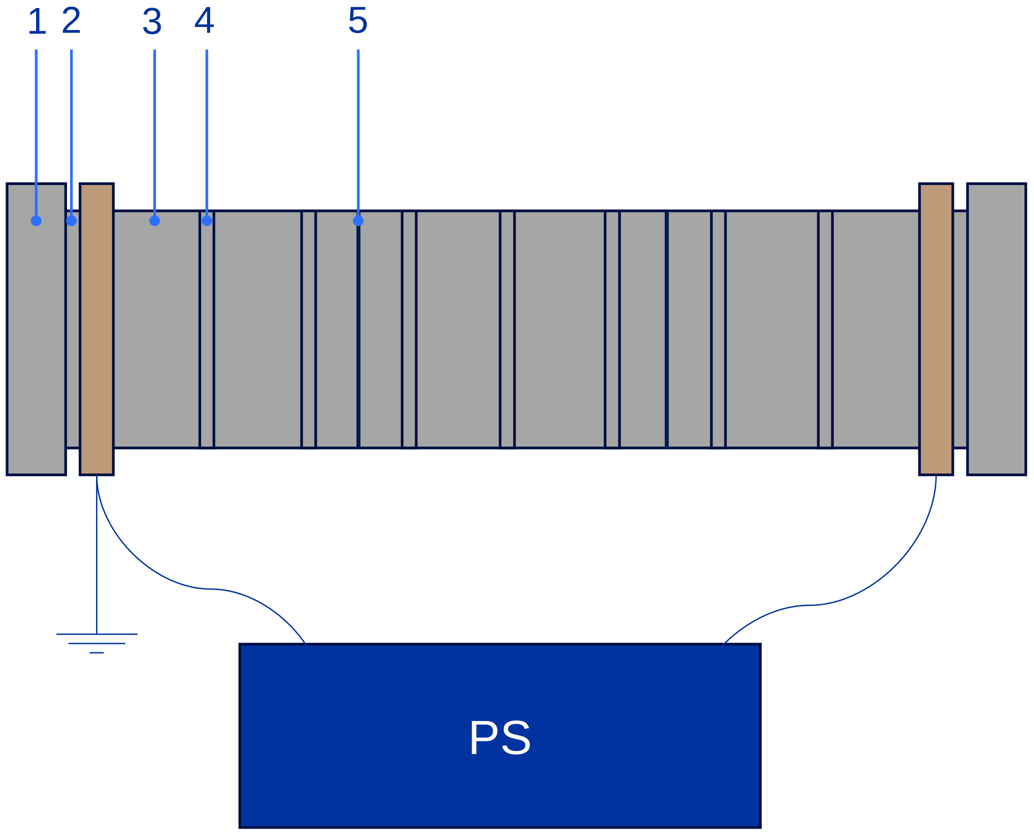
HTT - High Temperature Treatment
Costs - relative to the Virgo like baseline.

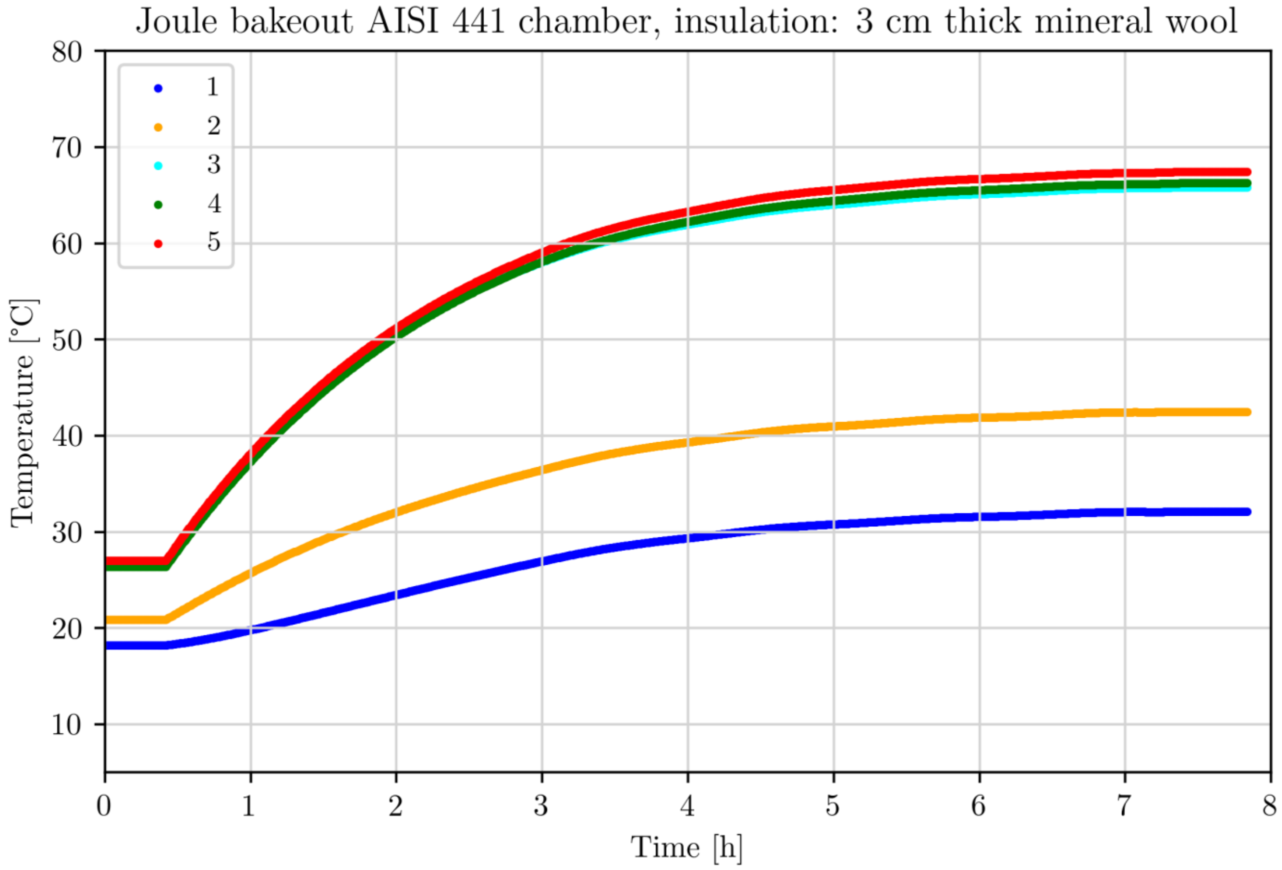
Joule bakeout @ CERN



Power supply max current: 400A

Joule bakeout @ CERN





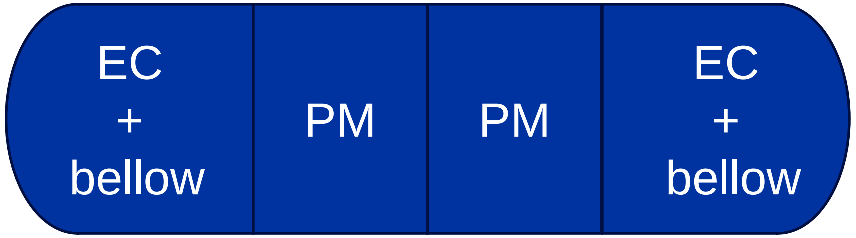
Chamber:
AISI 441 (400 x 1.5 x 2050 mm)

Max temperature according to heat transfer model: 64°C
Max recorded temperature: 66°C

ET pilot sector vacuum layout

Measurement sequence

Reduced system (background)



Note:

EC, bellows and PM bakeout with heating jackets, tapes, and collars.

Step 1

Instrumentation, valves, and all pumps mounted.

Measurements

- Ultimate pressure and tot. outgassing rate.
- Isosteric measurements.

Step 2

Instrumentation, valves, and all pumps removed (VF flanges mounted)
but mobile pumping group.

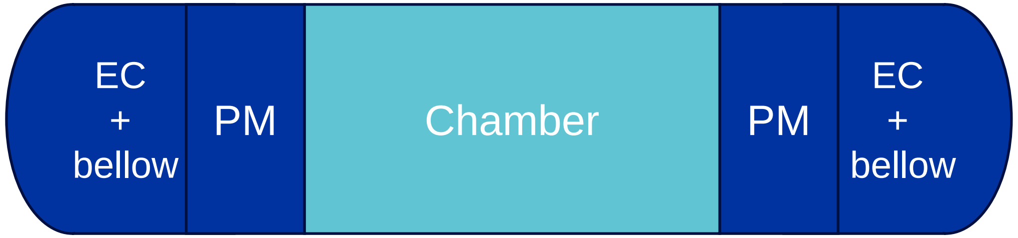
Measurements

- Accumulations for specific outgassing rates assessment (H_2, CH_4, CO and CO_2).
- Isosteric measurements.

ET pilot sector vacuum layout

Measurement sequence

Full system (chamber)



Note:

ECs, bellows and PMs bakeout with heating jackets, tapes, and collars.

Chamber heated by joule effect.

Step 3

Instrumentation, valves, and all pumps **not yet mounted** but mobile pumping group.

Measurements

- Accumulations for specific outgassing rates assessment (H_2, CH_4, CO and CO_2).
- Isosteric measurements.

Step 4

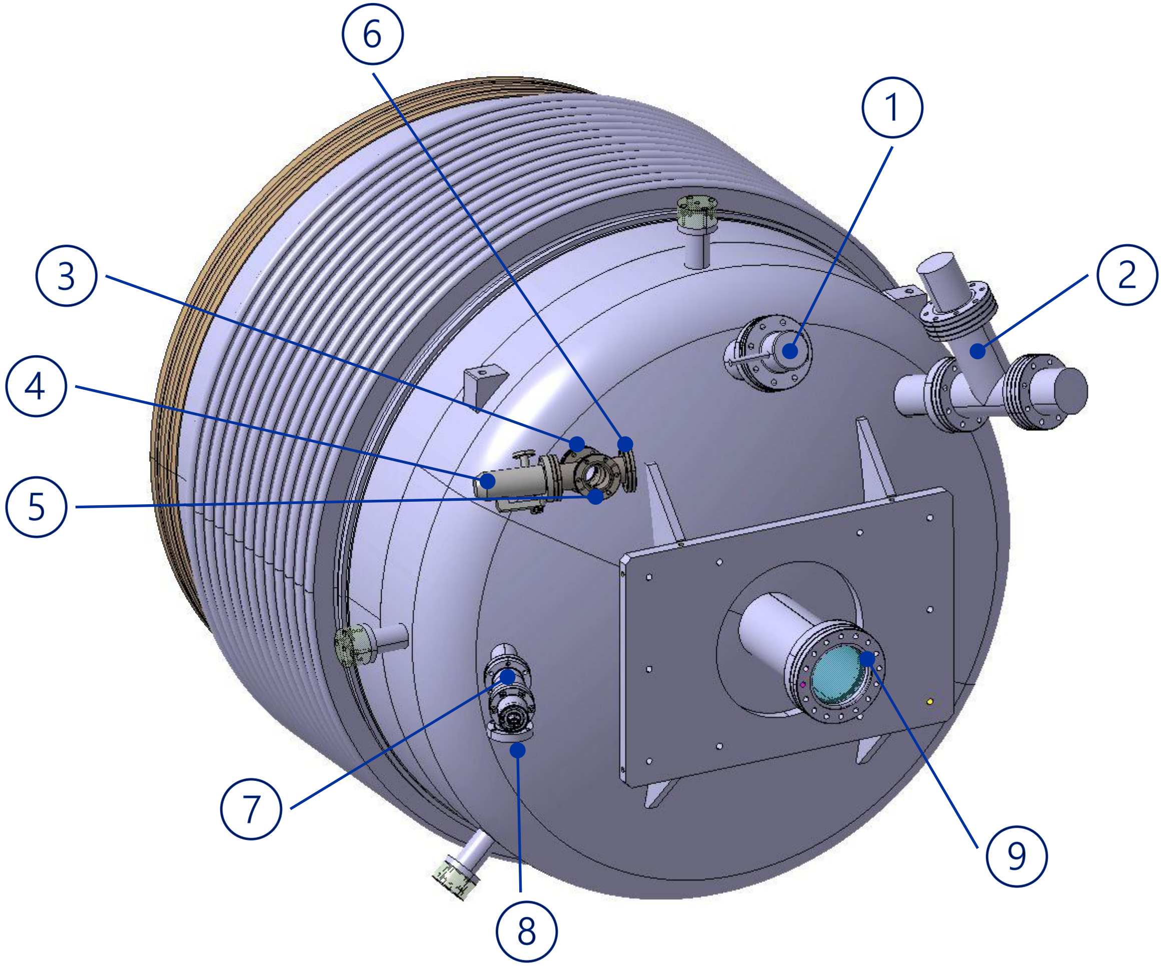
Instrumentation, valves, and all pumps mounted.

Measurements

- Ultimate pressure and tot. outgassing rate.
- Isosteric measurements.

ET pilot sector vacuum layout

Instrumented End Cap (EC)

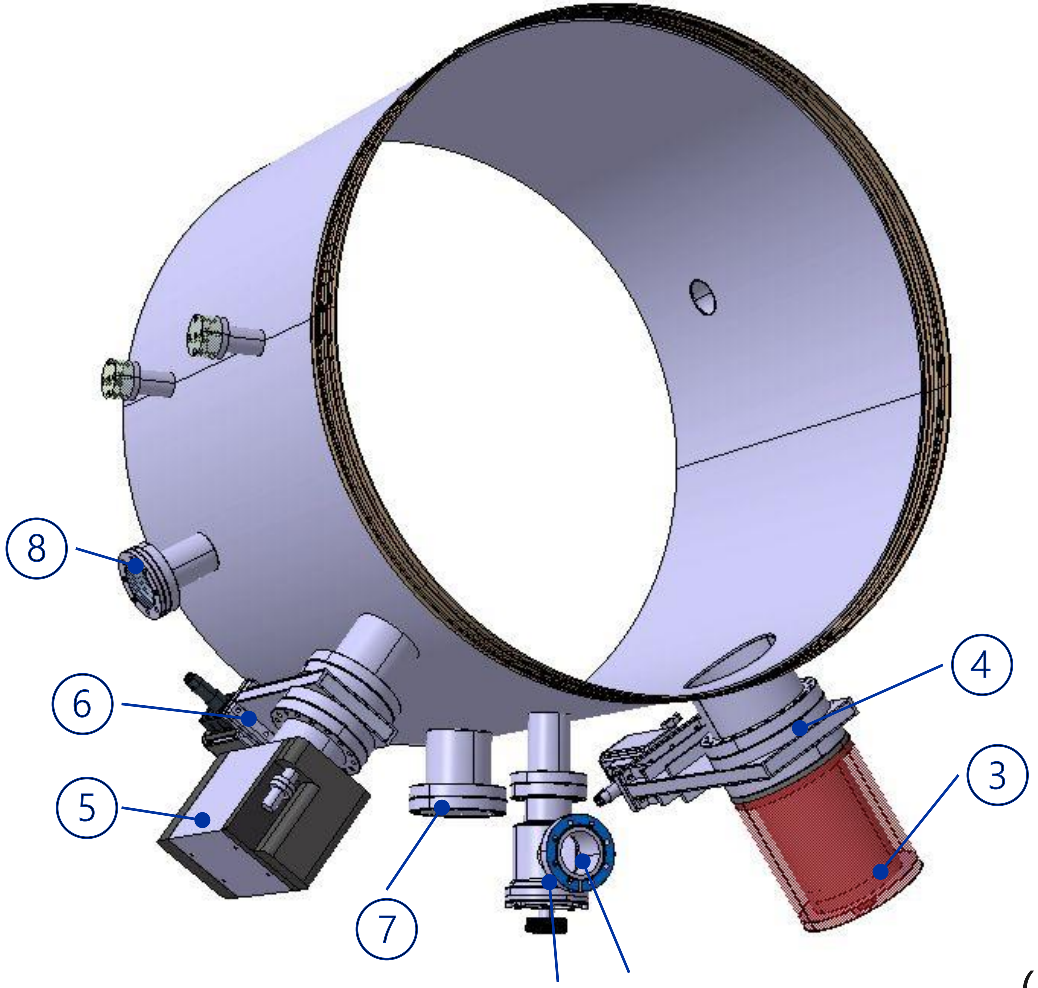


Component

- ① B-A gauge [DN63]
- ② RGA [DN63]
- ③ 4-way cross [DN40]
- ④ Variable leak valve [DN40]
- ⑤ Venting valve + dust filter [DN40]
- ⑥ Capacitance gauge [DN40]
- ⑦ Angle valve [DN40]
- ⑧ SRG [DN40]
- ⑨ Viewport for future laser [DN100]

ET pilot sector vacuum layout

Pumping Module (PM)



Component

① TMP group

② Angle valve [DN63]

③ NEG pump [DN150]

④ Gate valve [DN150]

⑤ Sputter Ion pump [DN100]

⑥ Gate valve [DN100]

⑦ Silicon wafer port [DN100]

⑧ Viewport [DN63]

Pumping speeds scaled to an ET sector
(P_{max} pilot sector = P_{max} middle point between two pumps in ET)