

ET vacuum team at CERN:

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With the collaboration of Alexandre Lacroix (**LAPP, Annecy**)

ET-PP (WP6.2)

ET beampipe activities at CERN

Anité Pérez on behalf of the ET vacuum team at
Barcelona, 05/05/2026

Introduction

WP6.2 aims to write the **final TDR for the ET vacuum pipe system**. The ET vacuum pipes are 1-m diameter metallic tubes through which laser beams propagate in an ultrahigh vacuum (UHV) between the input and end mirrors of the interferometers. The length of such tubes is 120 km.

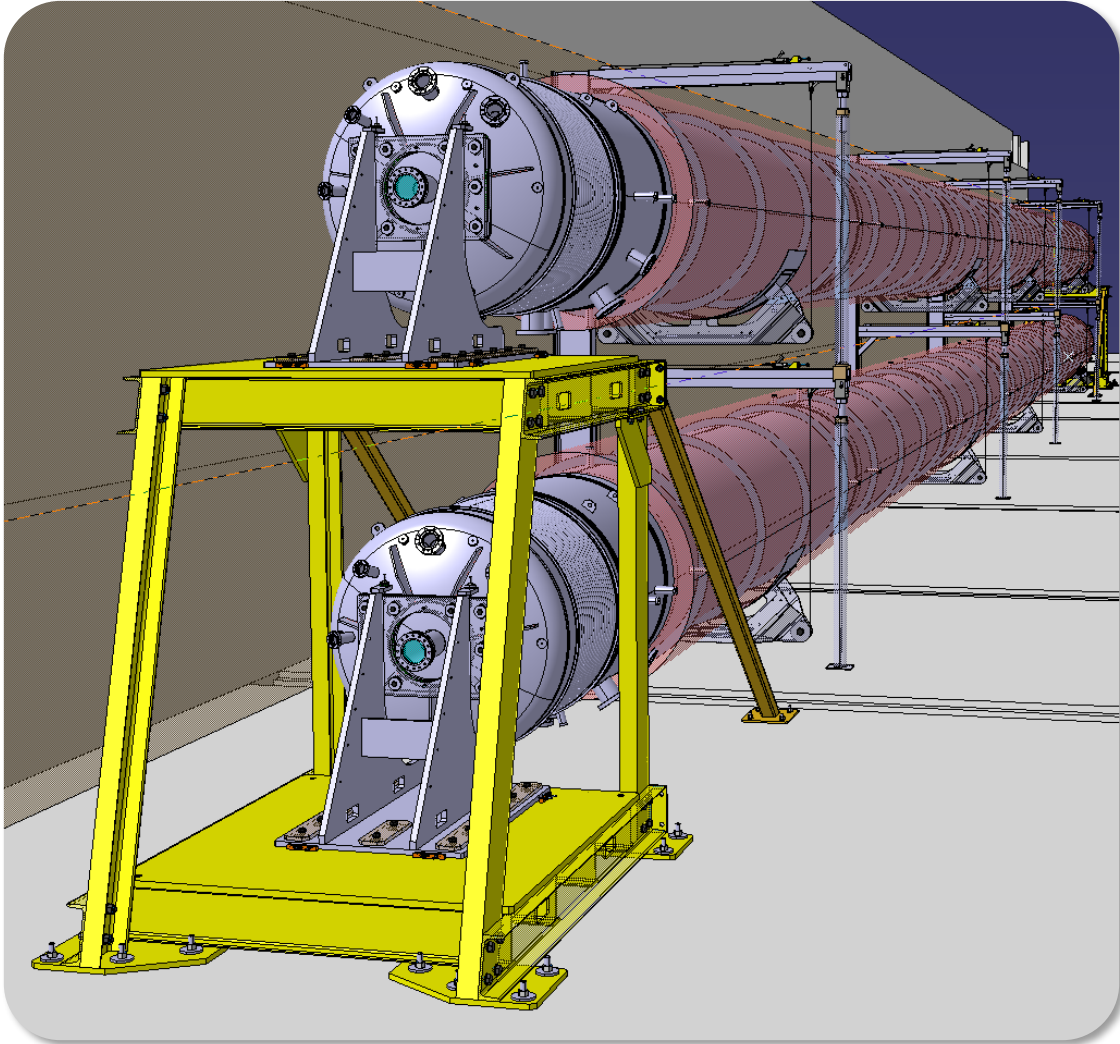
The objective is attained in steps of increasing complication :

- Design and laboratory study.
- Material and welding studies.
- Production and tests of smaller diameter prototypes
- Manufacturing, assembling, and testing a pilot sector.

The team includes CERN staff members contributing the equivalent of 2 FTEs, along with two CERN graduates. An engineer from the [University of Antwerp](#) joined the team in 2024. We are contractually linked to [INFN](#), [Nikhef](#), and [IFAE](#), and maintain open collaboration with [LAPP-CNRS](#) (Annecy, FR) and parallel initiatives such as [MacBeth \(NL\)](#) and [BeamPipes4ET \(DE, BE, NL\)](#).

We report to the Engineering Department of the ET Organisation (**ETO**).

The WP6.2 is led by Paolo Chiggiato and Ana Teresa Perez Fontenla



Outline

Work Overview

- 2025 & 2026 milestones

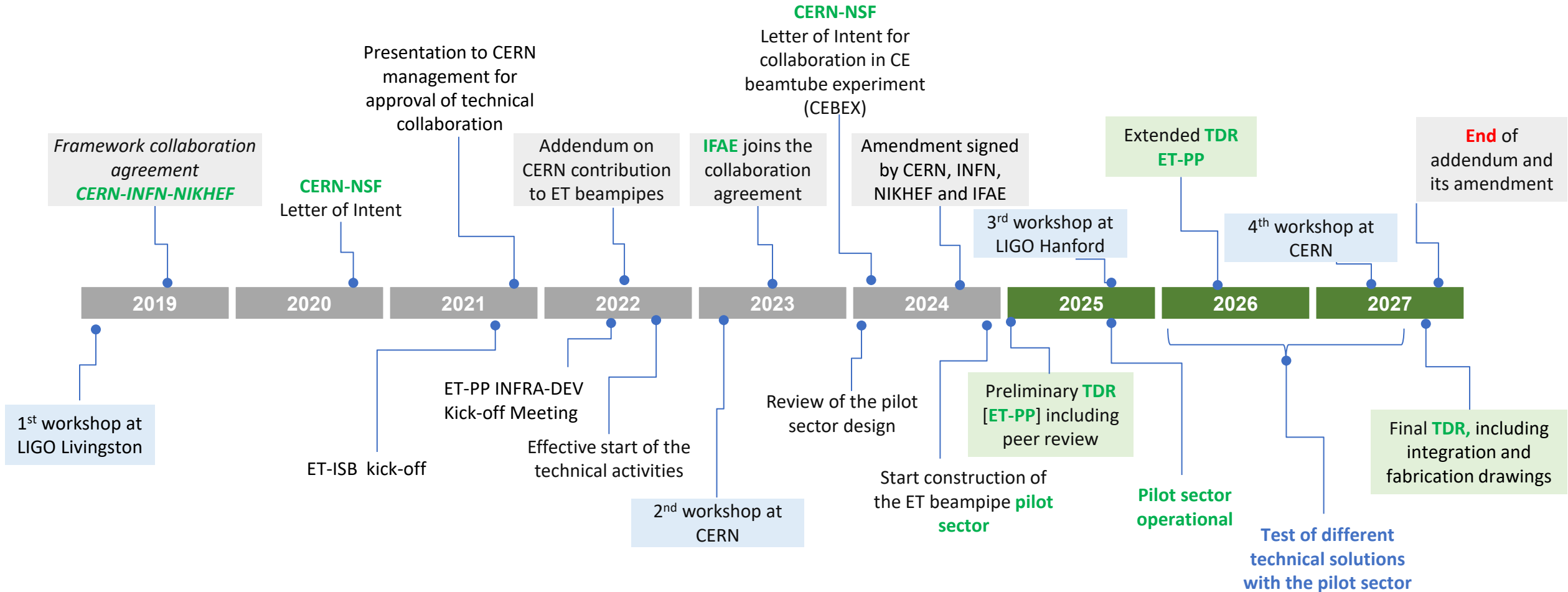
Ongoing developments

- Material & welding studies
- New support system design
- New vacuum components design
- New assembly strategies

Pilot Sector at CERN:

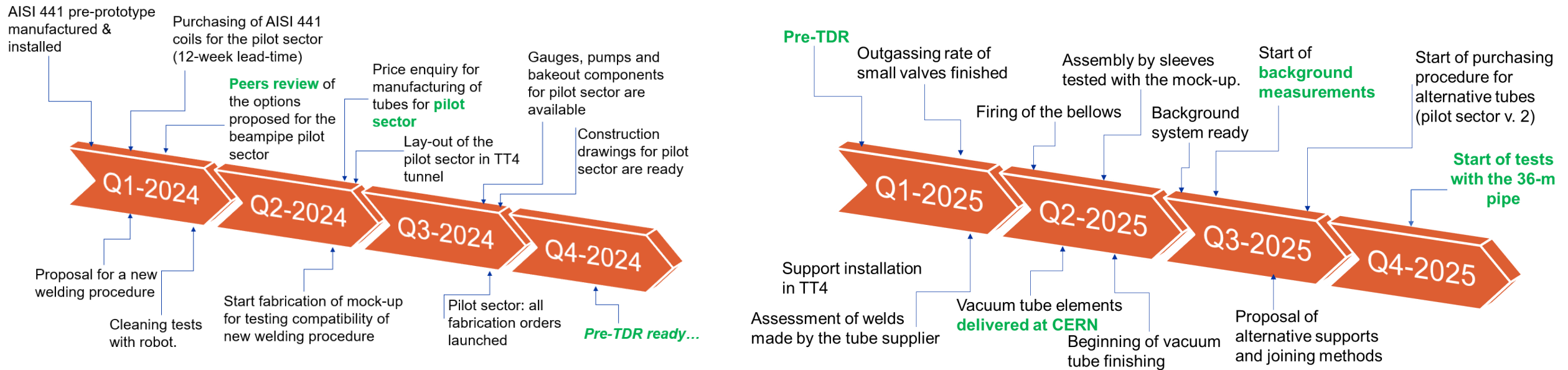
- Work progress
- Latest results
- Next Steps

Timeline of our organizational work



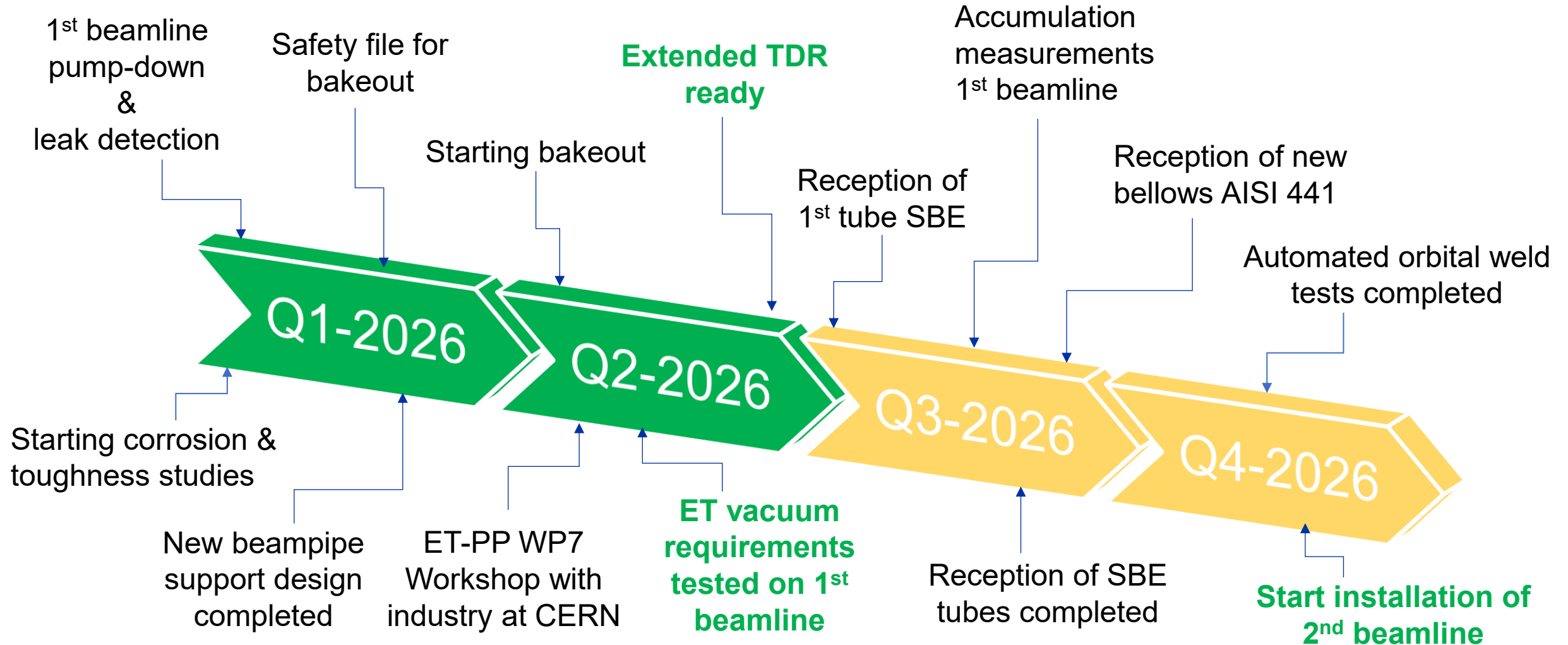
Timeline of our technical work until end of 2025

Technical results and achievement presented at the **October 2025** ET-PP review:



Timeline of our current technical work in 2026

Technical results and achievements:



The ET beam tube vacuum system TDR(s)

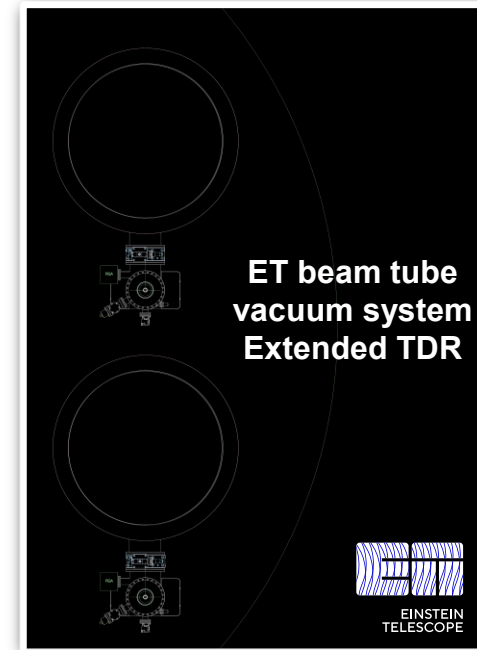
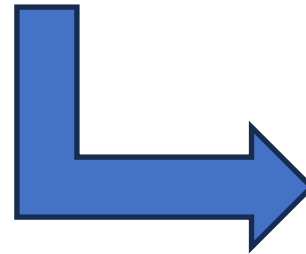


Q1 2025
Pre-TDR

Description of the system,
materials, assembly,
commissioning and risks
identification

Ongoing developments: Driven by previous work and pre-TDR review feedback

- Material and welding studies
- New support system design
- New vacuum components design
- New assembly strategies



Q2 2026
Extended TDR

Detailed chapters, in-depth reports.
Logistics and sustainability further investigated.
Preliminary cost estimation.
Integration with civil engineering.

Material & Welding Studies: Corrosion Behavior

Objective: The study aims to compare the selected grades and welding processes used in the pilot sector against the baseline AISI 304L

Status & Results → *Report under preparation*

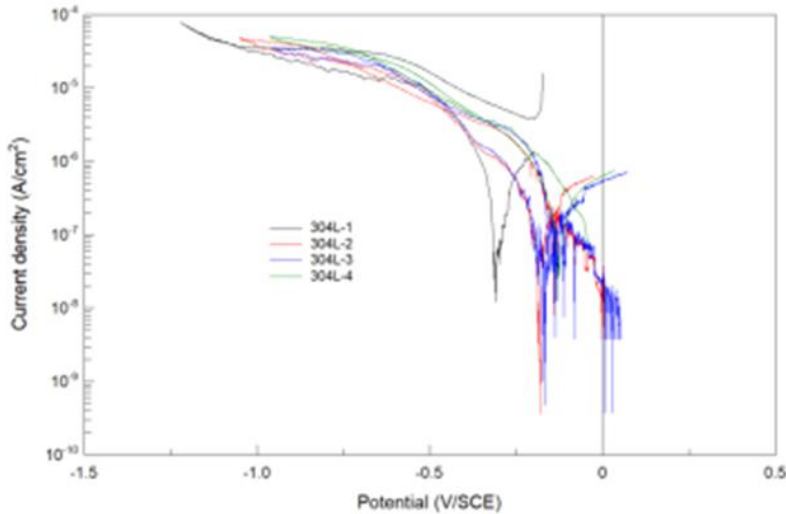
Preliminary study in collaboration with Universiteit Gent (B)

Electrochemical testing in CETIM (FR)

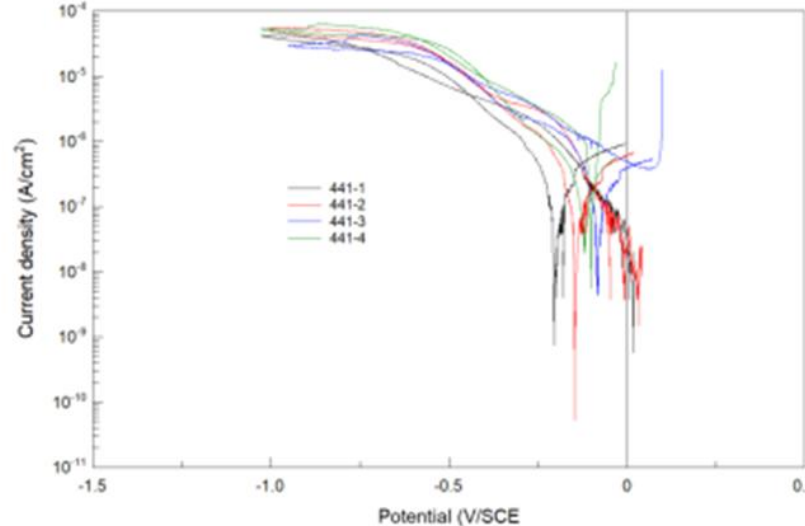
- 441 and 444 show similar behavior than 304L
- No galvanic coupling risk

Overlapping polarization curves confirm similar behavior

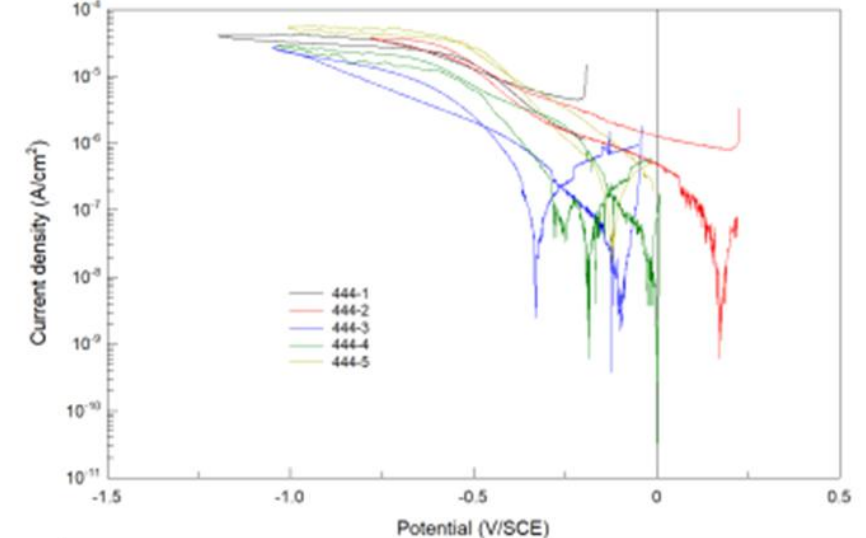
304L



441



444



Material & Welding Studies: Corrosion Behavior

Objective: The study aims to compare the selected grades and welding processes used in the pilot sector against the baseline AISI 304L

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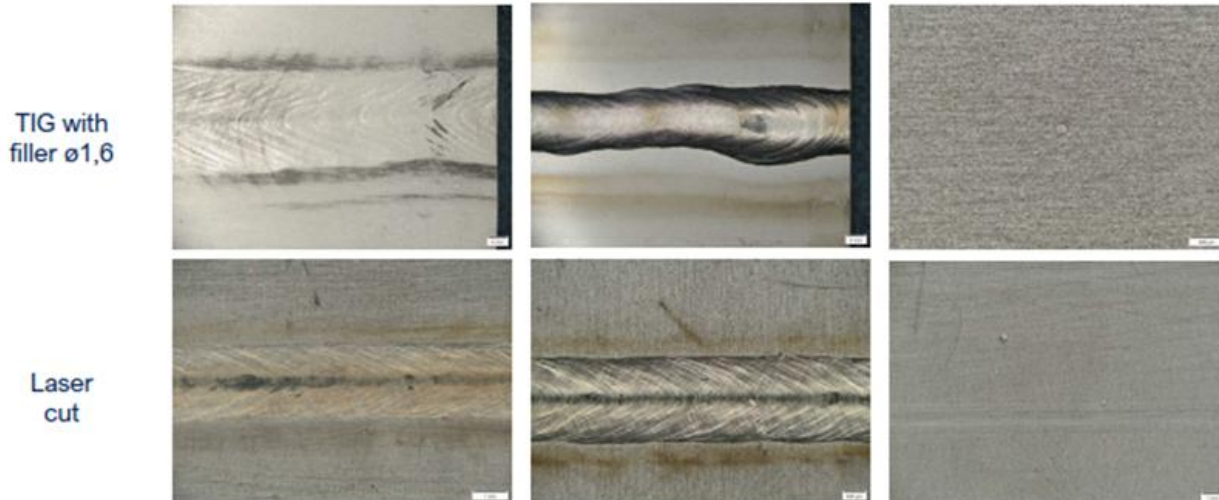
- 441 and 444 show similar behavior than 304L
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Immersion test in CETIM (FR)

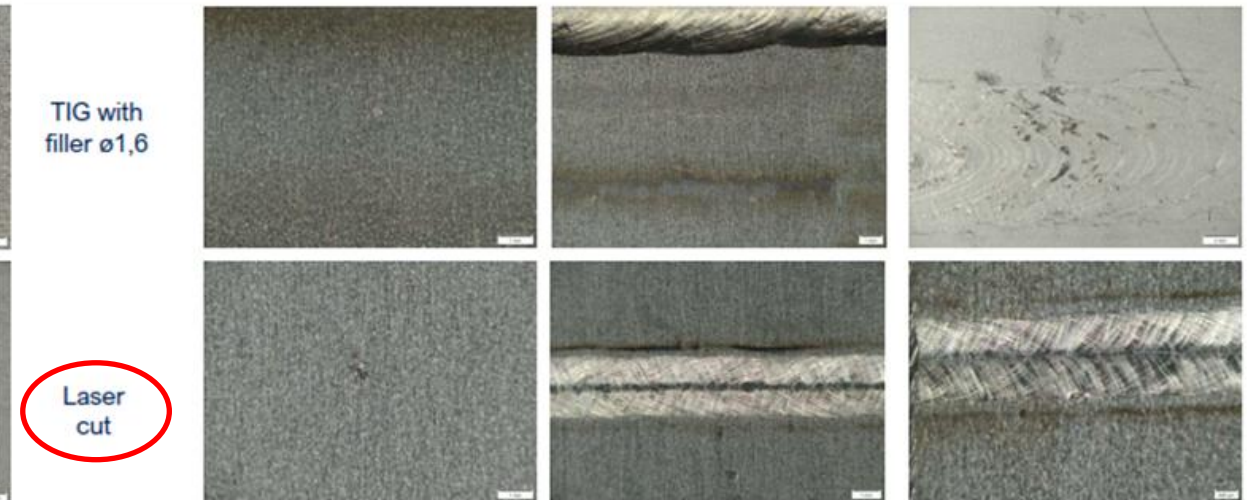
- No general corrosion (3 months, severe conditions)
- Localized corrosion only (pitting / crevice) for all materials
- 444 best overall performance (Mo effect)
- 441 HAZ more sensitive in some welding configurations

Immersion results confirms that ferritic grades are suitable

304L samples after 3 months



444 samples after 3 months



Material & Welding Studies: Impact Resistance

Objective: The study aims to evaluate the mechanical resistance of the Ferritic Stainless Steel AISI 441 using various welding methodologies (TIG, laser, plasma) with and without filler metal

Status & Results → Test campaign on-going

Preliminary results: TIG autogenous AISI 441

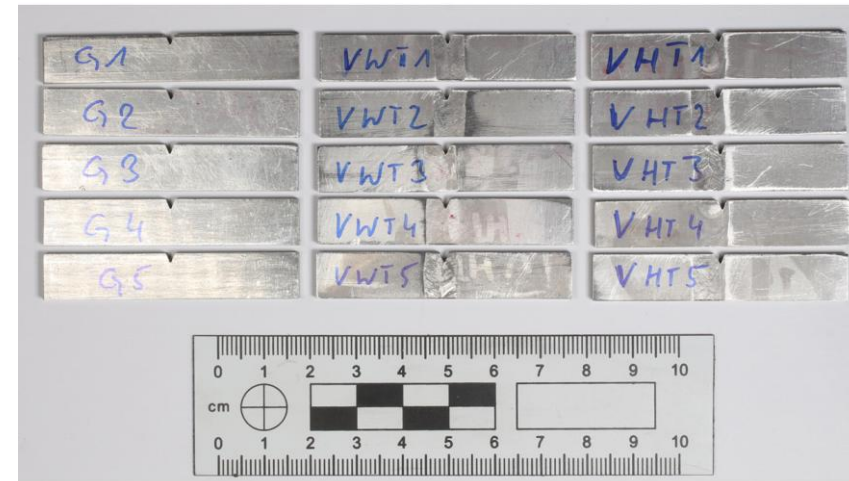
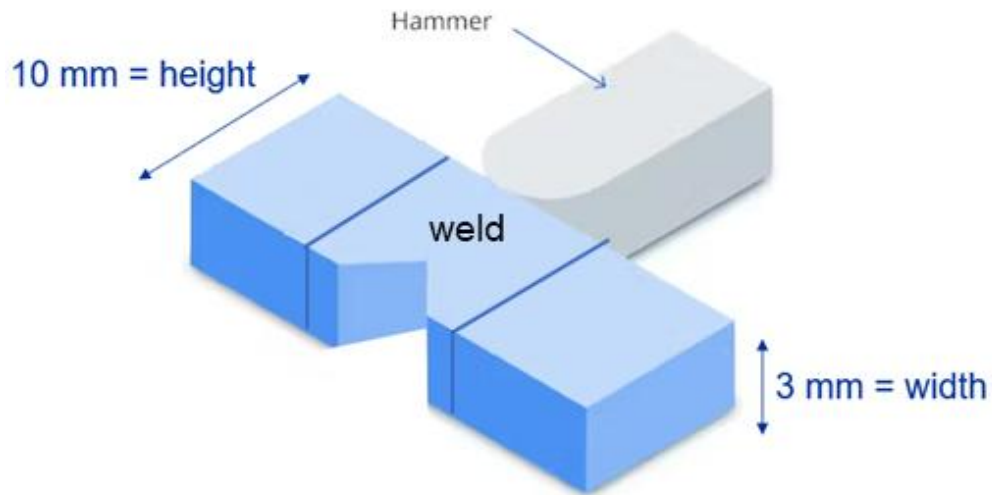
Currently under testing: TIG (with austenitic filler) & laser

Fractography at CERN: on-going / next step

Charpy V-notch impact test in Linde (DE) → ISO 9016

- HAZ (TIG autogenous) → reduced impact toughness
- Bake-out (150°C, 7 days) → no influence on behaviour

HAZ is the limiting zone for impact resistance (preliminary)



Base metal (G) | Weld metal (VWT) | Heat-affected zone (VHT)

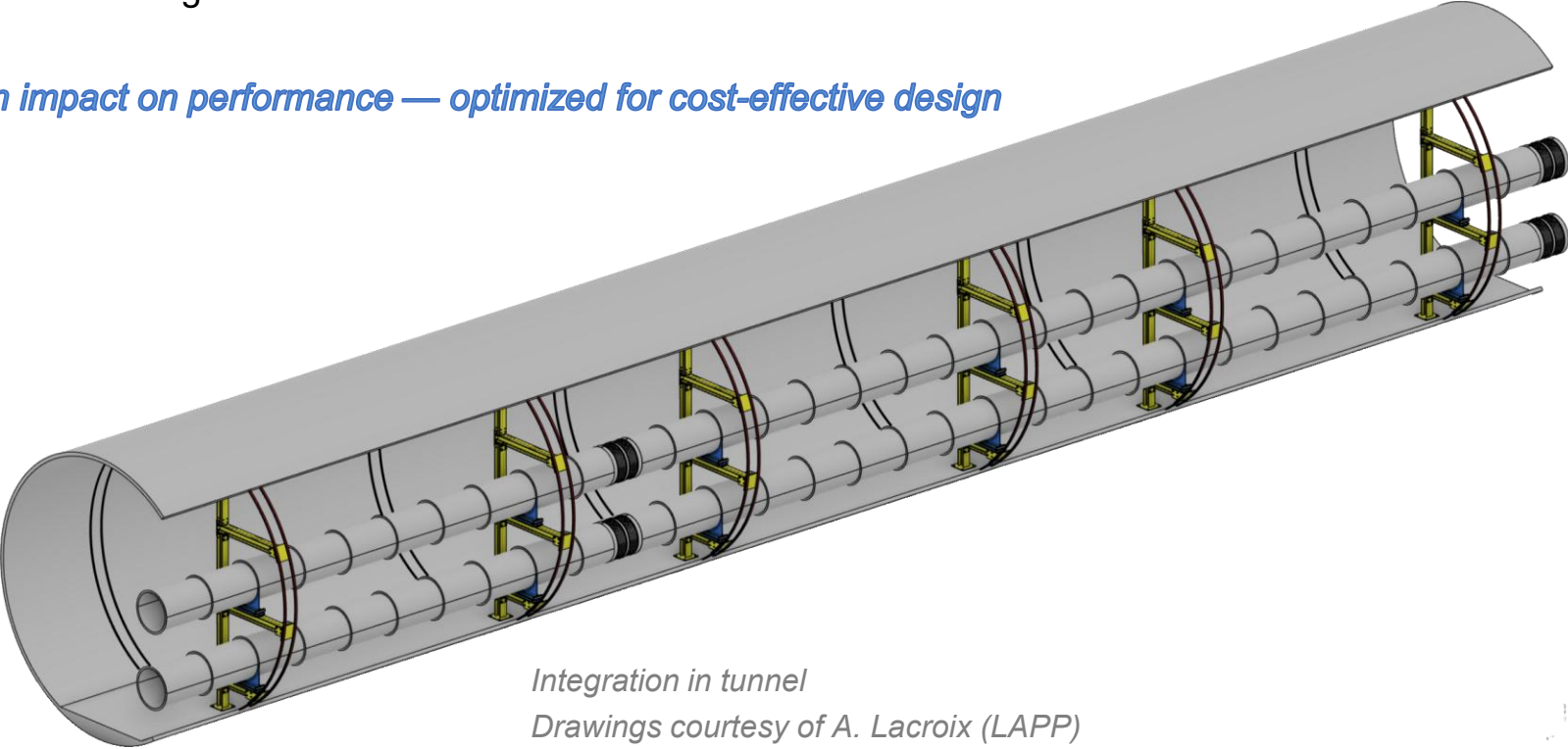
New support design in collaboration with LAPP

Objective: The study aims to improve support and alignment system design following pre-TDR feedback

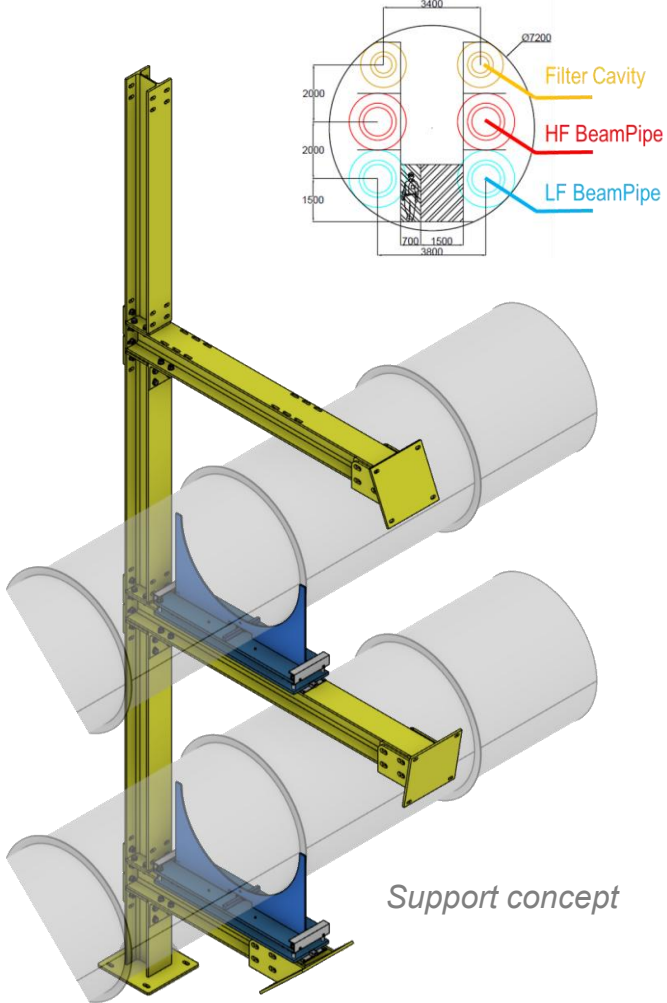
Status → Development on-going by LAPP-CNRS (FR)

- Lightweight and rigid support design
- Transfer function analysis completed
- Tunnel integration under evaluation

High impact on performance — optimized for cost-effective design



*Integration in tunnel
Drawings courtesy of A. Lacroix (LAPP)*



Support concept

New vacuum components design by SVAPET

Objective: Develop compact and reliable vacuum components for ET (flap valve, bellows, joints) to reduce both infrastructure costs and vacuum sector length

Status → Work on-going with Swiss industrial partners:

- Established collaboration SVAPET (Swiss Vacuum & Precision – ET)
- Led by PSI (Paul Scherrer Institute)
- First flap valve prototype expected by early 2027

Key components for ET are under development with industry, with a clear path to industrialization



Scheme courtesy of Romain Ganter (PSI)

New assembly strategy, including baffle integration

Objective: Assembly concepts are being redesigned to simplify installation and improve baffle alignment (in collaboration with IFAE)

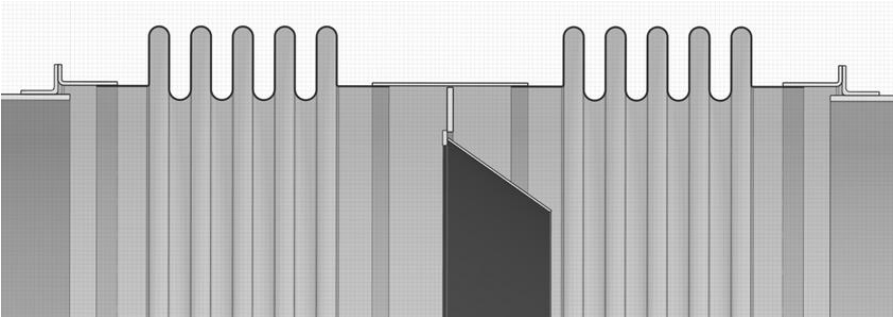
Status → *Work on-going*

Current limitations

- Risk of metal-to-metal contact → particle generation
- High sensitivity to tube tolerances (shape & dimensions)

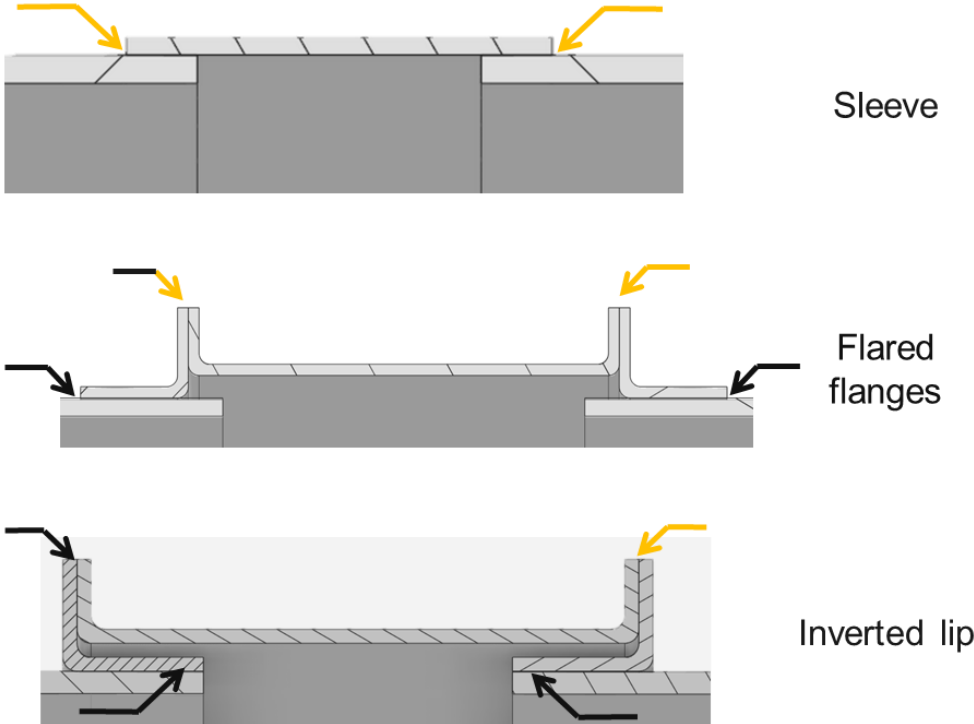
Design objectives

- Minimize particle generation
- Reduce installation time in tunnel
- Simplify baffle integration & alignment
- Ensure UHV compatibility & cleanability
- Enable reparability



*New baffle mounting scheme under discussion
The sketch showed above is not in scale and not representative of the final installation configuration.*

Move from complex on-site assembly to clean, pre-assembled solution



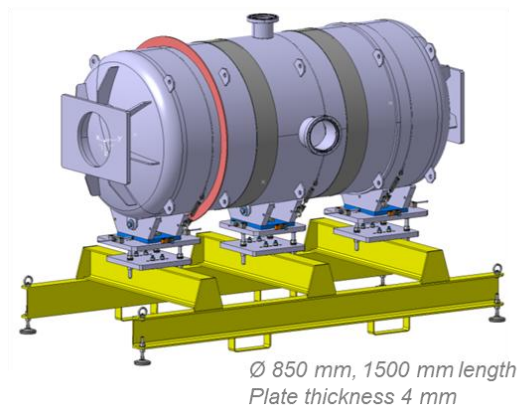
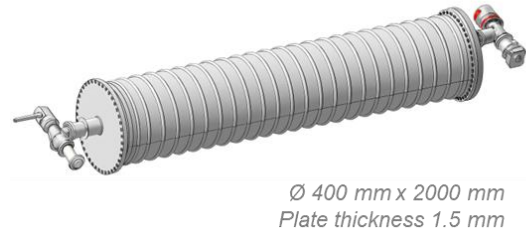
↙ : Ex-situ weld ↘ : In-situ weld

Possible joint design for 2nd beamline of the Pilot Sector

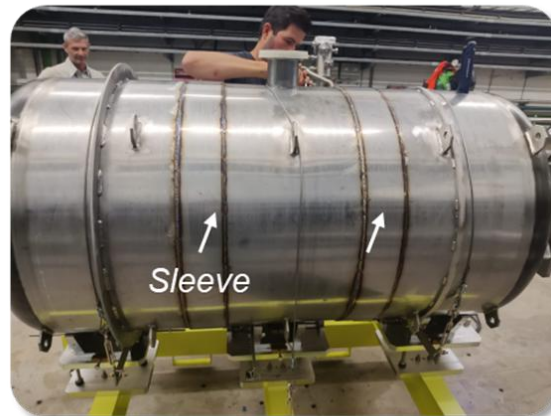
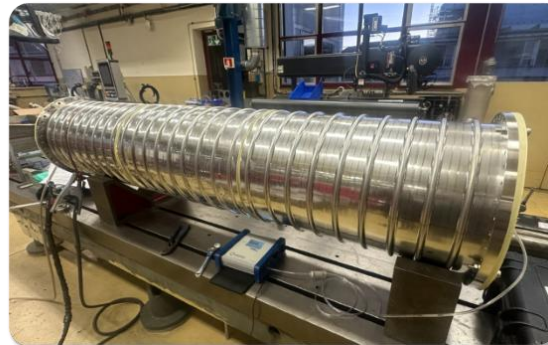
Pilot Sector: Validation Through Progressive Prototyping

- **Multiple design options** were evaluated and refined
- Each step validated a **critical risk** (buckling, weldability, dust control) before scaling to the ET Pilot Sector
- **Background system** measurements were successfully completed mid-2025

Design & Requirements



Manufacturing Processes

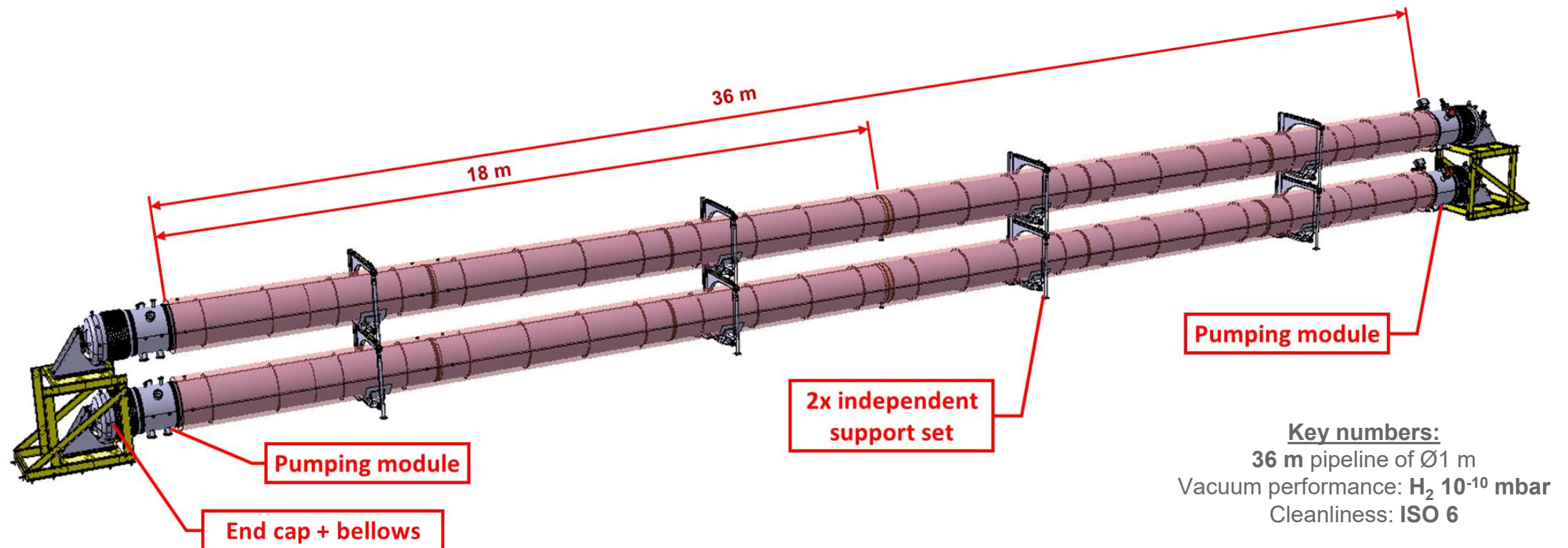


Additional tests & Integration



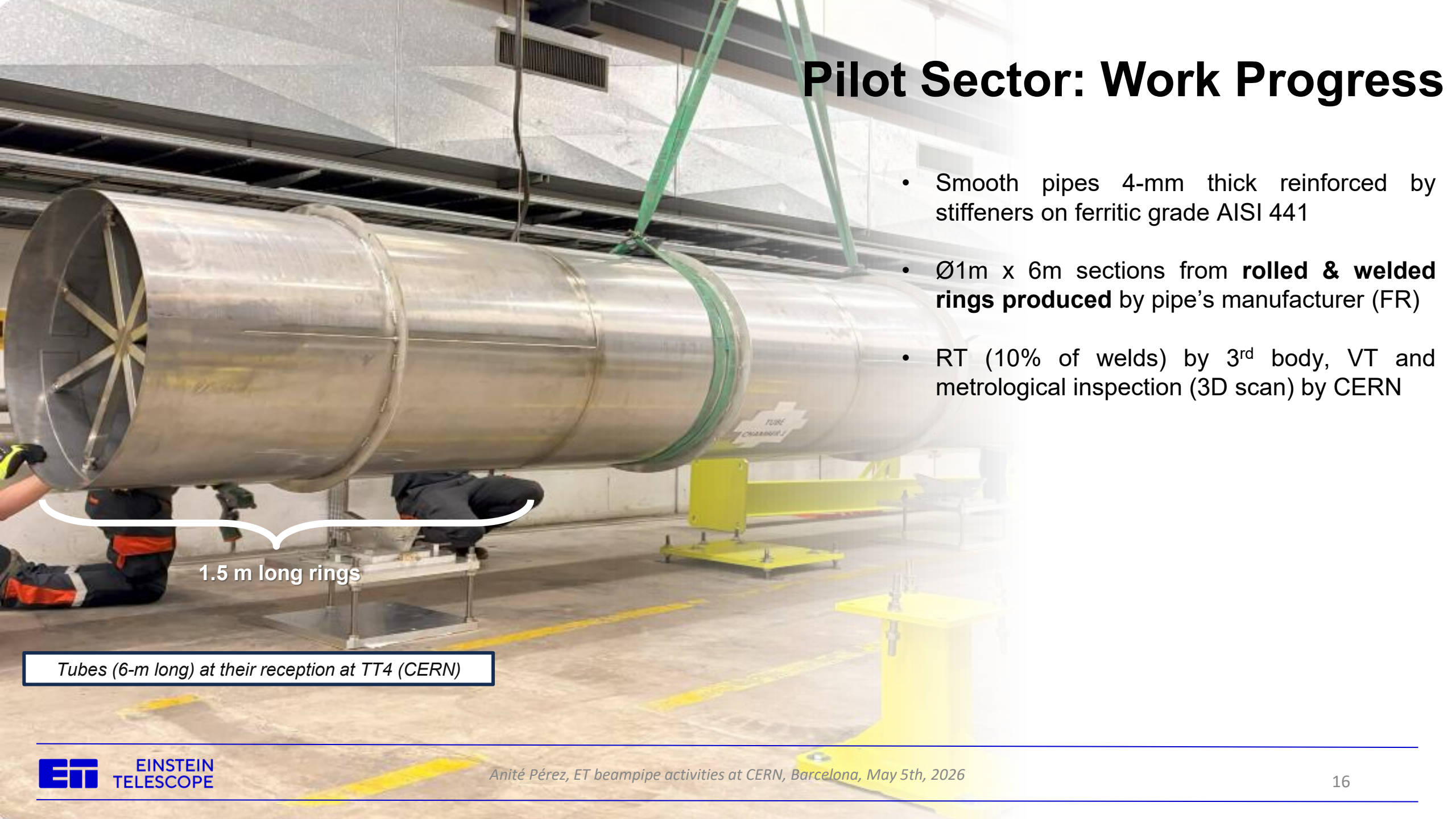
Pilot Sector: Two-Line Integration Test Bench

- Two-lines model to validate material, welding, assembly and **full system integration**
- Installation under realistic constraints with ancillaries → **reveals possible limitations**
- Identical pipe design and boundary conditions → controlled evaluation of **improvements**
- Second line implements improvements → **assembly, dust control, welding automation, baffles integration**



Pilot Sector: Work Progress

- Smooth pipes 4-mm thick reinforced by stiffeners on ferritic grade AISI 441
- Ø1m x 6m sections from **rolled & welded rings produced** by pipe's manufacturer (FR)
- RT (10% of welds) by 3rd body, VT and metrological inspection (3D scan) by CERN



1.5 m long rings

Tubes (6-m long) at their reception at TT4 (CERN)

Pilot Sector: Work Progress

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- Pre-cleaning of the components at CERN

Pre-cleaning

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- Pre-cleaning of the components at CERN
- Leak-tightness performed by CERN on 6-m long sections → **all parts compliant for the 1st beamline**
- Fiducialisation of the parts

6 beam pipes: $LR < 10\text{-}10 \text{ mbar l s}^{-1}$

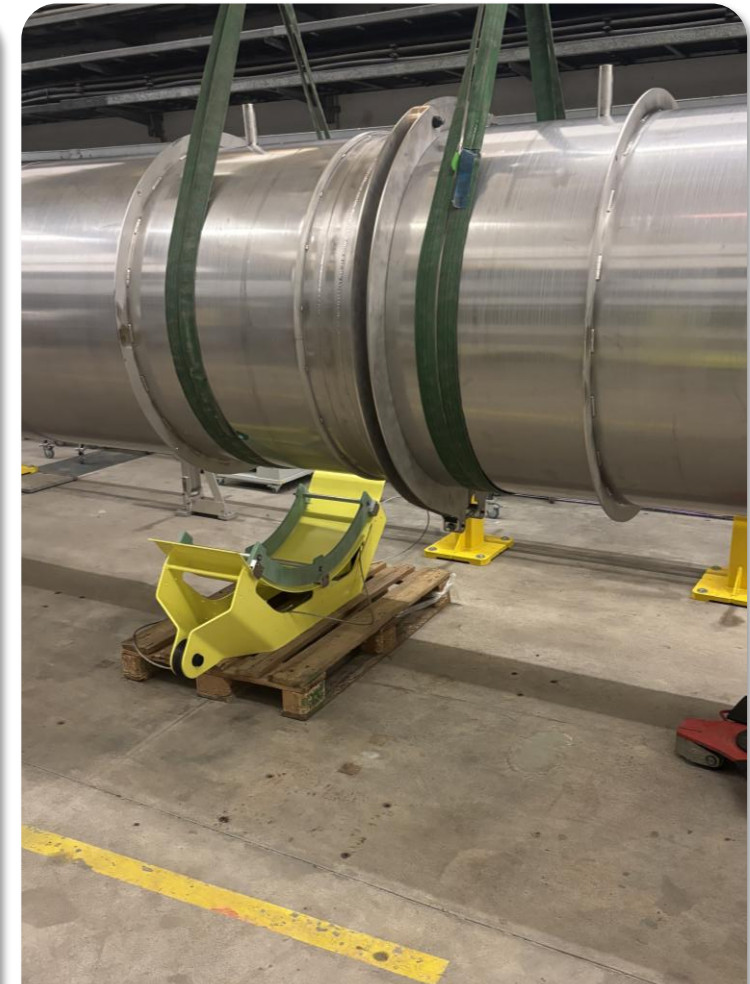
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- Fiducialisation of the parts
- Cleaning dust-controlled packaging

Beam pipe packaged in ISO 6 conditions after degreasing

Pilot Sector: Work Progress

18-m array assembly completed



3 x 6 m tubes pre-alignment → Cleanroom installation for each joint → Protection removal → Sleeve installation → Manual welding → Installation on supports

Pilot Sector: Work Progress

1st beamline bakeout completed



1st ET-PS beamline in position & leak tight → Electrical test (safety check implied 2 months delay but can be translated to ET) → Thermal insulation installation → Bakeout

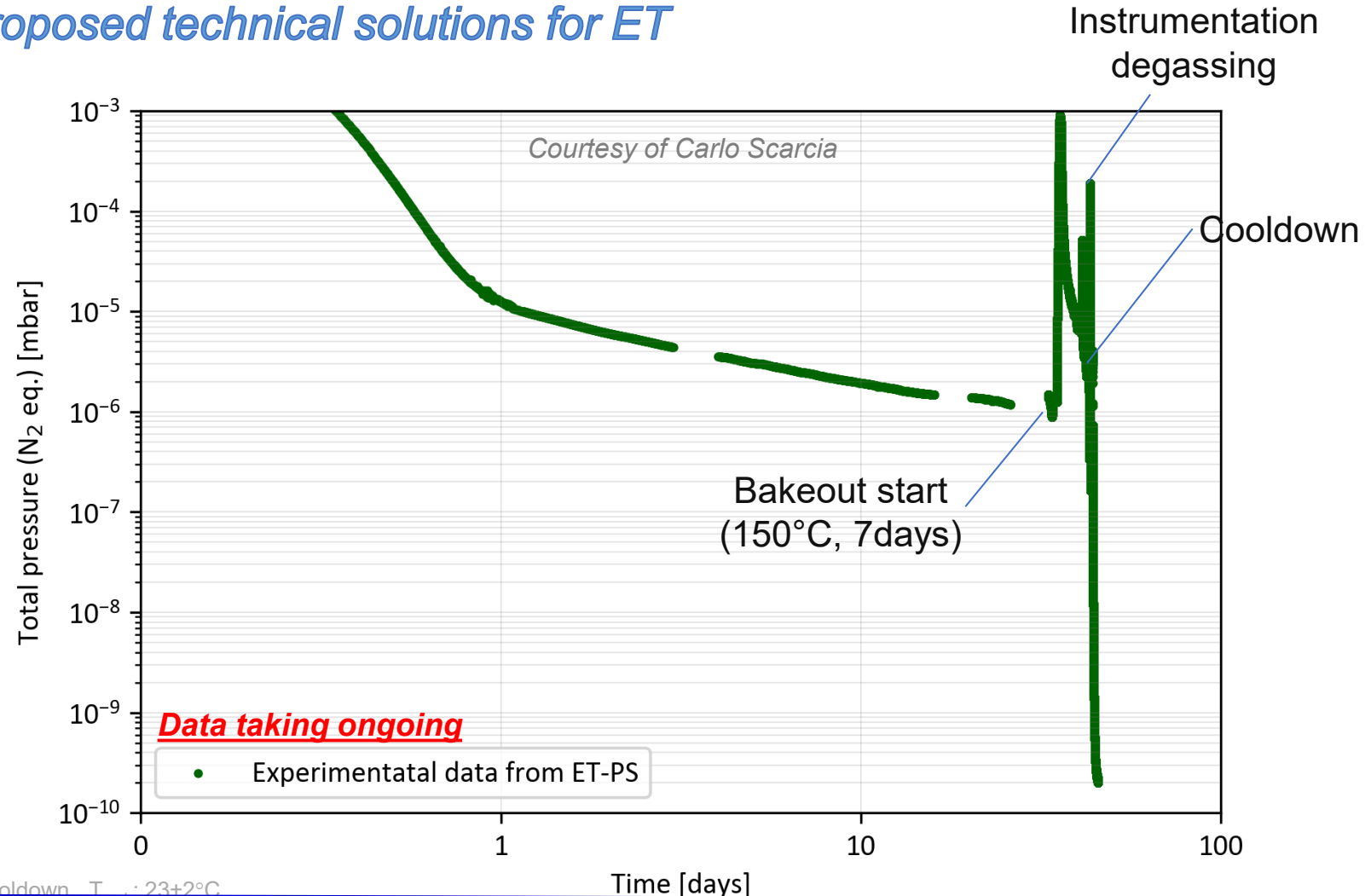
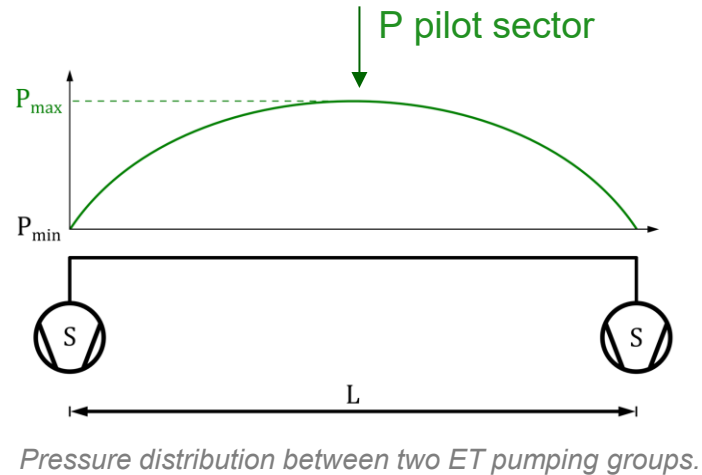
Pilot Sector: Work Progress

1st beamline vacuum commissioning completed

Important milestone to validate the proposed technical solutions for ET

Successful bake out at 150°C for 7 days!

Pressure at room temperature is limited by the instrumentation's outgassing rate



S: 6.1 l/s (H₂O) during pumpdown and bakeout. S: 45.8 l/s (H₂) after cooldown. T_{amb}: 23±2°C

Outlook & Next Steps



2nd line manufacturing and integration



Bellows in 441 manufacturing & testing



Baffle integration optimization



New joining design validation



Integration of the new valve concept (SVAPET)



Cost estimation → contributing to ETO exercise

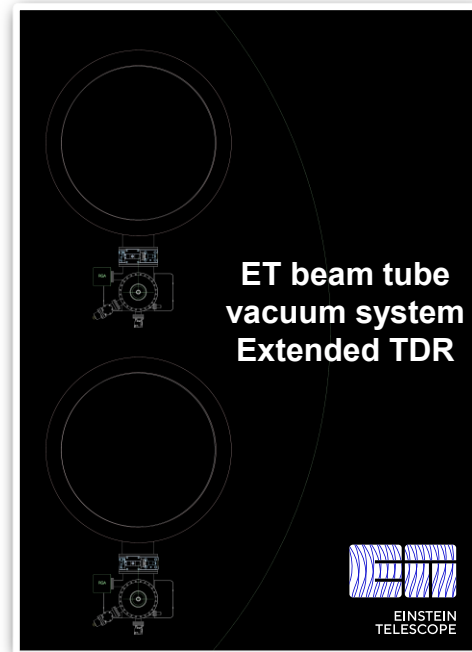


The ET beam tube vacuum system TDR(s)



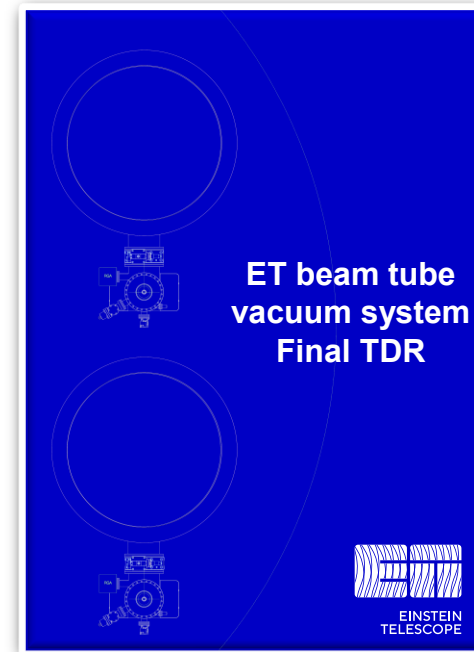
Q1 2025
Pre-TDR

Description of the system, materials, assembly, commissioning and risks identification



Q2 2026
Extended TDR

Detailed chapters, in-depth reports. Logistics and sustainability further investigated.
Preliminary cost estimation.
Integration with civil engineering.

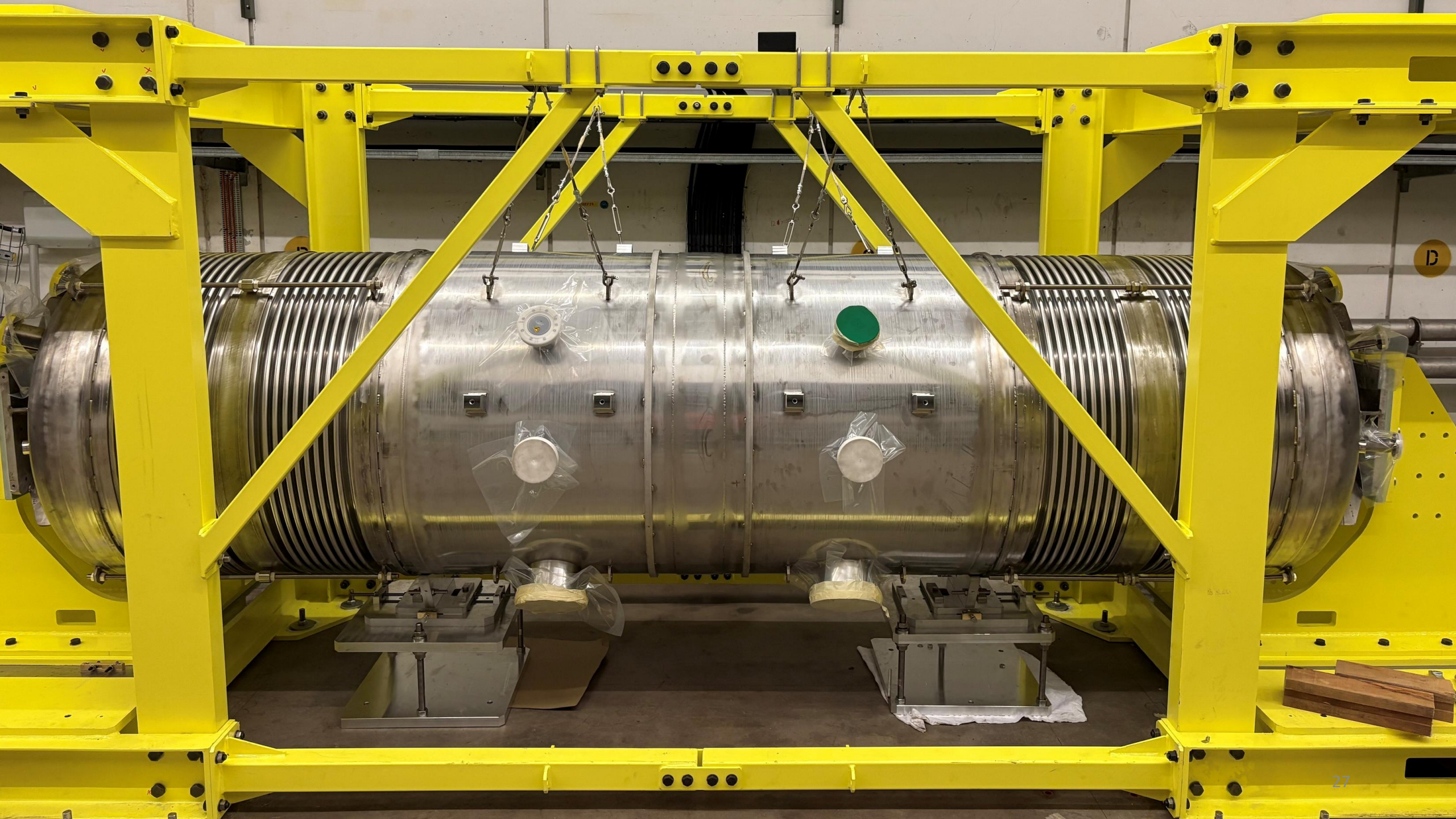


Q4 2027
Final TDR

Final version with optimal solutions.
Full integration with civil engineering considering all the other services (HVAC, fire safety, ...).

Thanks to the CERN team
and thank you for your attention!



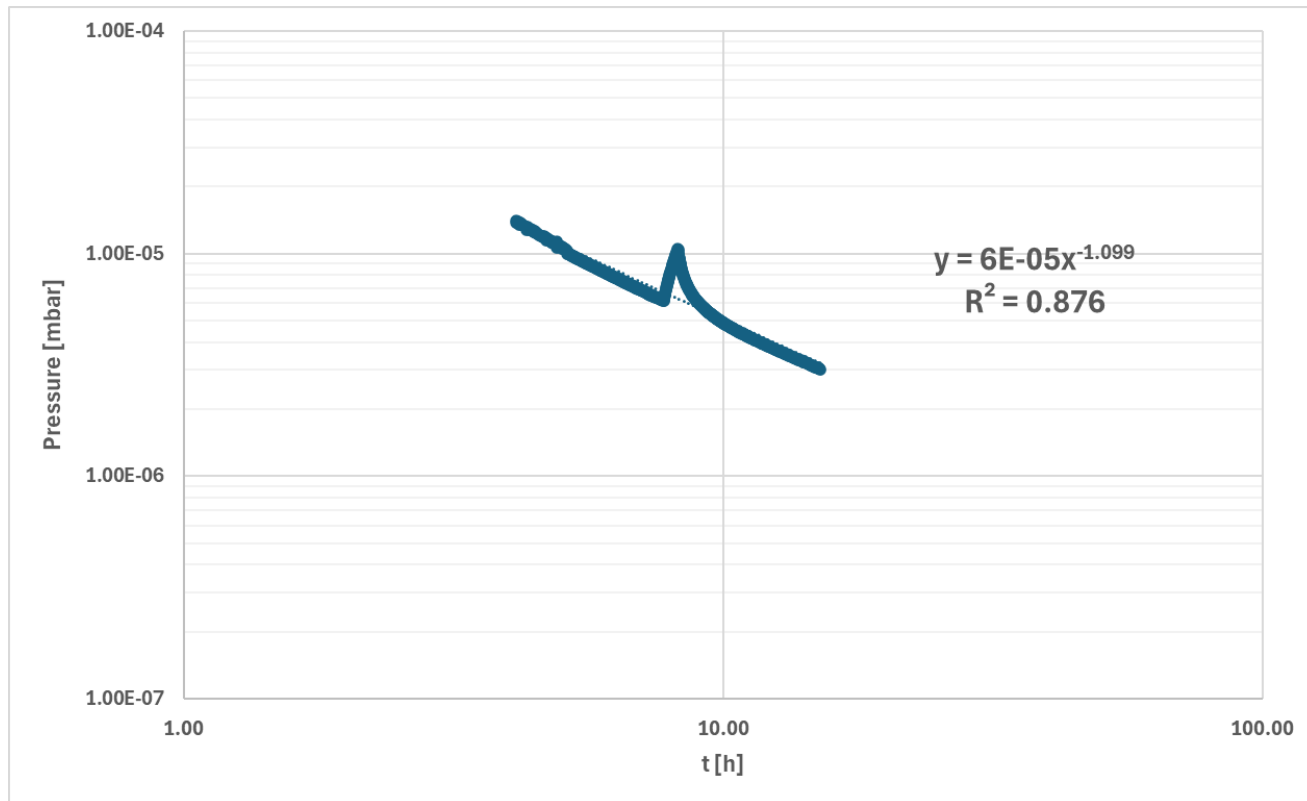


D

Background system

The leak detection was performed last week. **No leak detected** with a sensitivity better than 10^{-10} mbar l s⁻¹.

This week the system is **being prepared for bakeout**. The first results are expected in 10 days: virtual leak rates, total gas loads (with and without pumps, instruments and valves).



At 10 h of pumping

$$Q_{\text{H}_2\text{O}} = 3.4 \cdot 10^{-10} \text{ mbar l s}^{-1} \text{ cm}^{-2}$$

$$Q = \frac{3 \cdot 10^{-9}}{t [h]} \left[\frac{\text{mbar l}}{\text{s cm}^2} \right] \text{ empirical law}$$

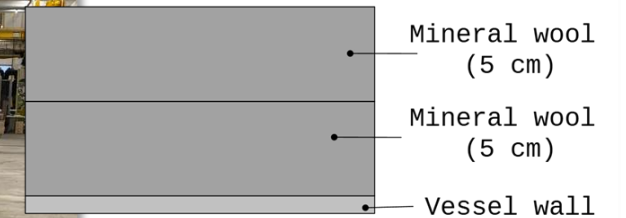
So far, so good!

1st beamline bakeout

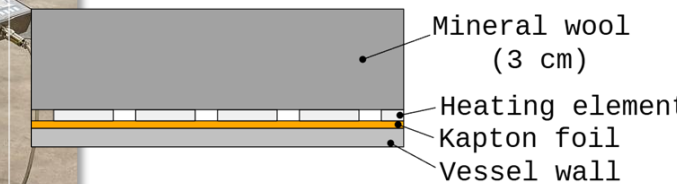
Pilot Sector: Work Progress



Beamline [Direct joule bakeout]



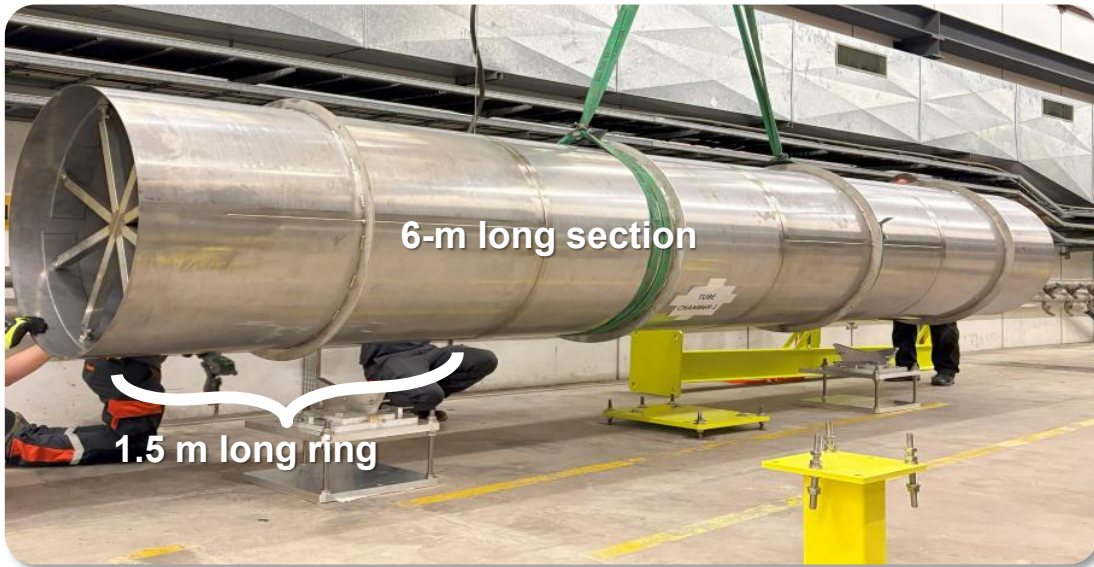
Extremities [Standard bakeout] (heating tapes, jackets, collars, etc.)



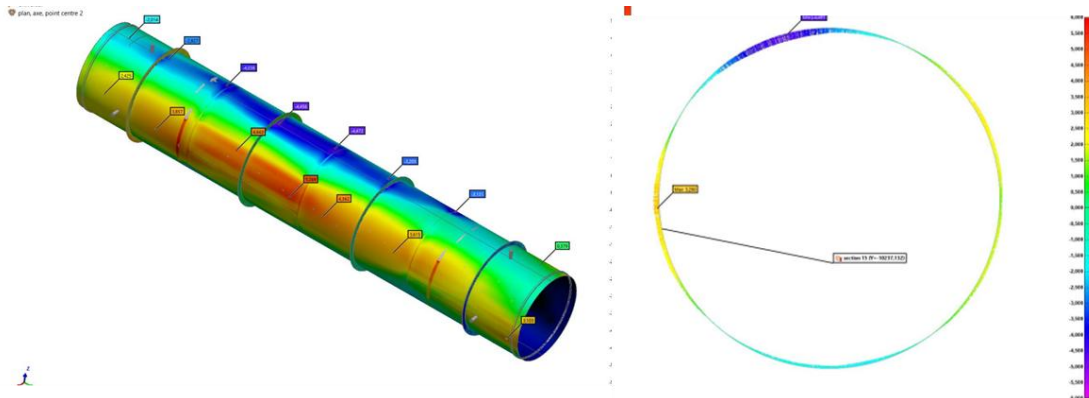
1st ET-PS beamline in position & leak tight → Electrical test (safety check implied 2 months delay but can be translated to ET) → thermal insulation installation → bakeout

Pilot Sector: Industrial Constraints & Current Limitations

Smooth pipes 4 mm thick reinforced by stiffeners



- Ferritic stainless steel in plate/coil format → **max. width 1.5 m**
- Pipe production (external supplier) → $\text{Ø}1 \text{ m} \times 6 \text{ m}$ sections from **rolled & welded rings (1.5 m each)**
- UHV validation → Leak-tightness performed by CERN on the 6-m long sections → all parts compliant for the 1st beamline
- Manufacturing approach **limits dimensional accuracy** → cylindricity deviation $\pm 6 \text{ mm}$ measured at the extremities making sleeve welding more complex and increasing particle generation



Industrial challenges:

- Continuous manufacturing solutions
- Improved tolerances

ET-PS: leak detection

6 beam pipes:
 $LR < 10^{-10} \text{ mbar l s}^{-1}$

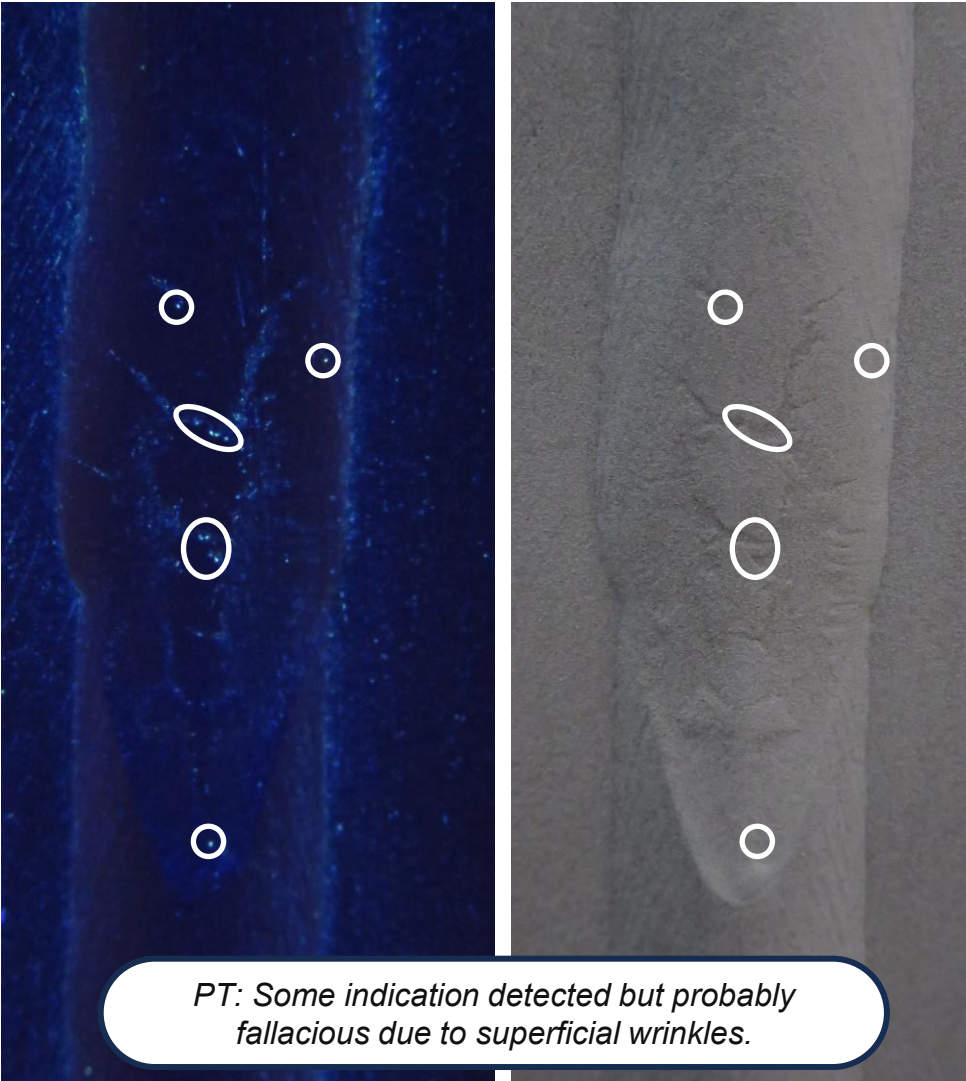
1 beam pipe:
 $LR \sim 3 \times 10^{-10} \text{ mbar l s}^{-1}$
(\approx hundreds of nanometres defect)



*The leak is located on a circumferential weld.
It seems to come from an overlapping weld bed.*

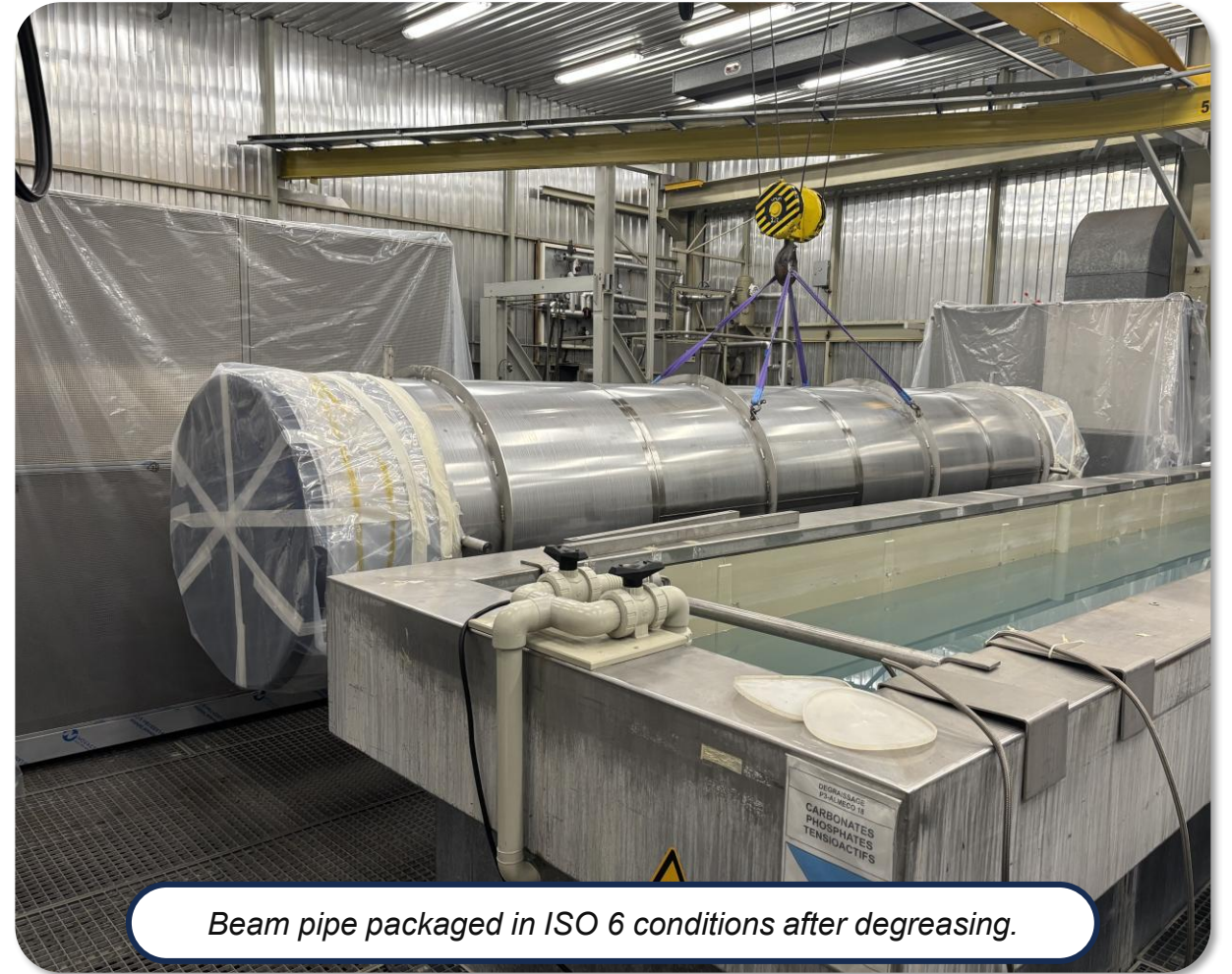
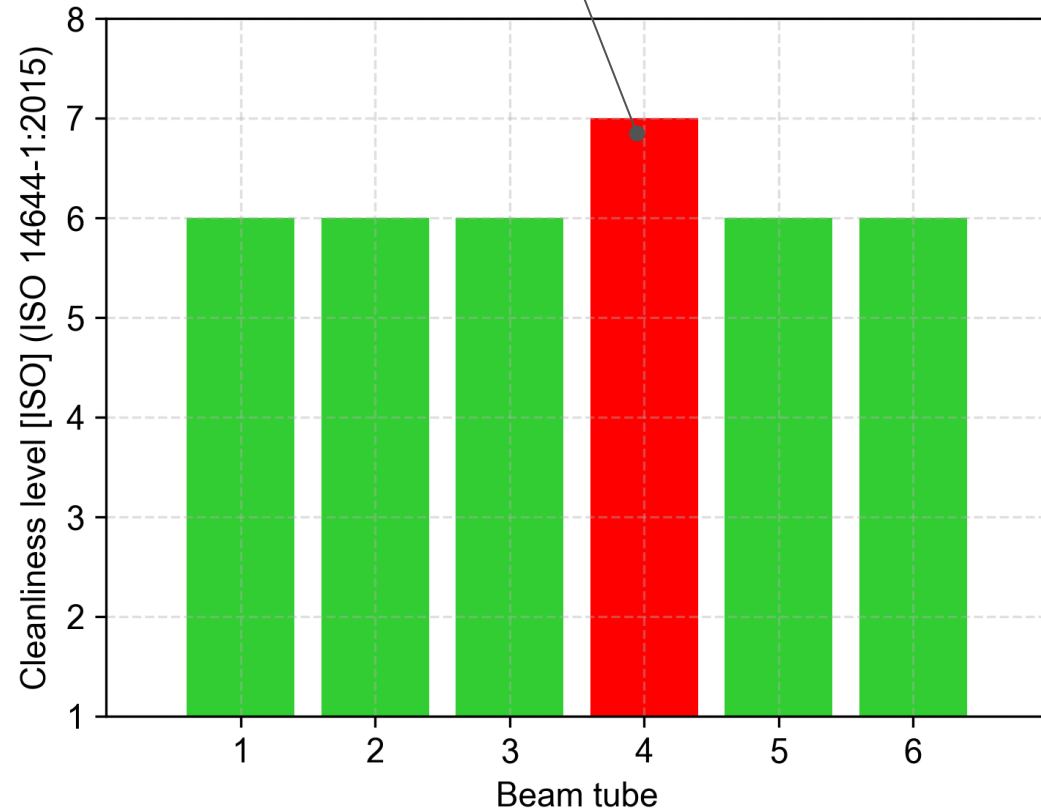
ET-PS: leak detection

Leak detection – NDT on leaking tube



ET-PS: dust-controlled packing

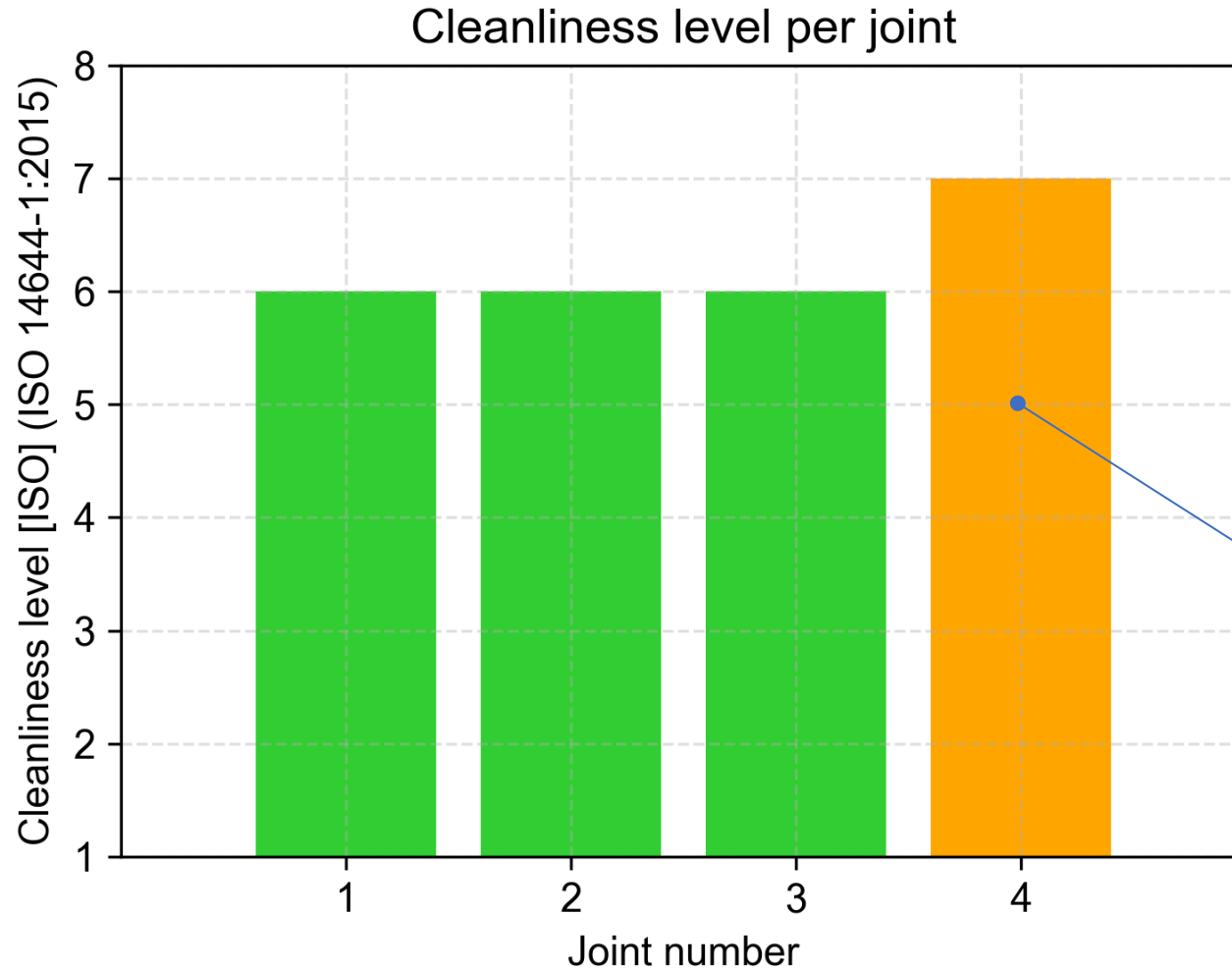
Beam tube 4: Back packaged before front.
Excessive passages in front of HLF with extremity still exposed.



HLF: Horizontal Laminar Flow. Minimum five measurements (2' duration each). Sampled volume: 100 L/side. Packaging: 1) Protective film, 2) Plastic cap, 3) Protective film (outer layer)

ET-PS: 18 meter array assembly

Summary dust cleanliness during installation



Challenging installation.
50% of the joints were keeping ovalisation even
with a rounding tooling installed.

After protection removal.
Only 0.3 μm particulate above limits.
The cause might be the storage.

From pilot sector to full scale production

Scaling from 36m-long prototype to **120 km** requires defining an industrial production and acceptance strategy

Full UHV manufacturing and testing at supplier

Complete fabrication + UHV validation at specialized facilities

Components delivered **ready-to-install (UHV compliant)**

Ensures **high QC/QA**

Challenging for logistics, transport constraints, sustainability, cost

Pipe sections (non-UHV) manufactured at industry

Final transformation into **UHV components near installation site** (surface facilities and/or inside tunnel)

Reduced transport constraints (~15 m long sections)

More **flexible industrialization**

On-site controlled processes (cleanliness, welding, QC/QA)

In-situ production in tunnel

Manufacturing + assembly **directly in the tunnel**

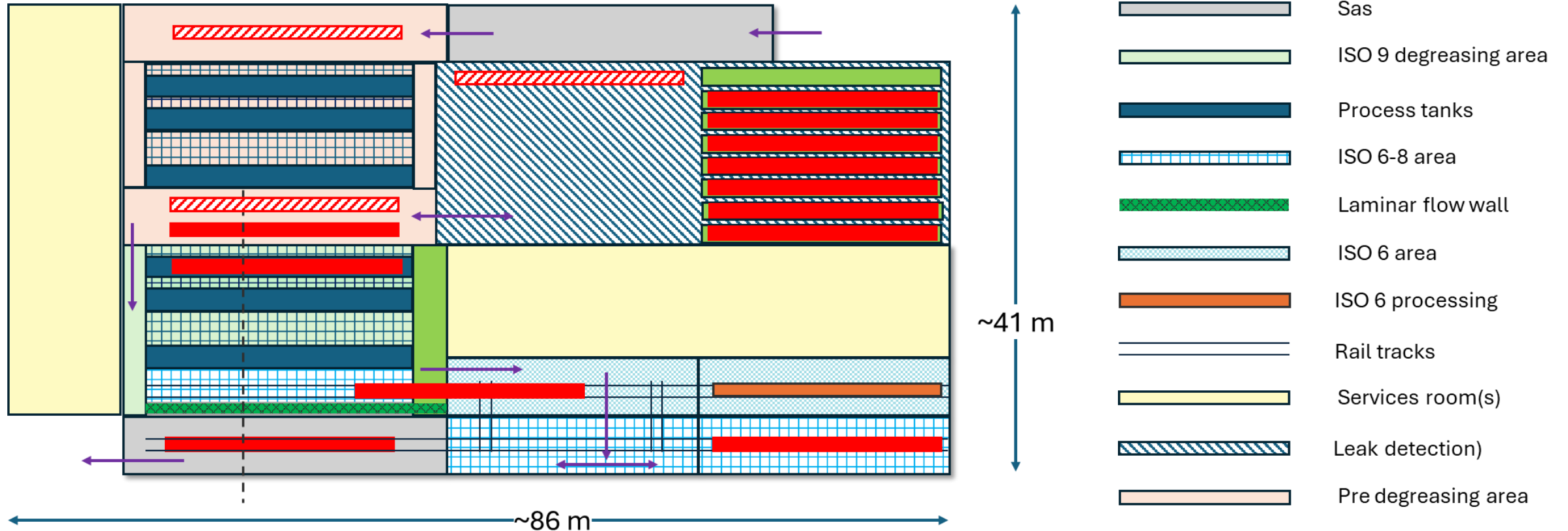
Minimizes transport, handling, logistics

Lower industrial maturity

Highest constraints (environment, QC/QA, cleanliness)

Cleaning facility design and cost estimation

Cleaning facility to be built near the installation site to feed the front of the installation as it advances and reduce storage of conditioned tubes.



More information at: [Surface finishing of the ET beam tube - Leonel Marques Antunes Ferreira \(CERN\)](#)