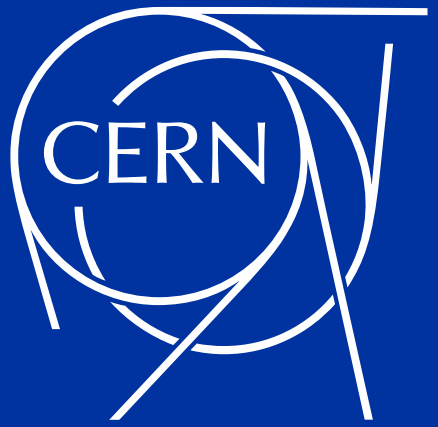


Pilot Sector of the ET Vacuum Pipe

CE/ET BEAMTUBE WORKSHOP III – Ana T. Pérez

Contributions from: ***M. Dakshinamurthy,*** *C. Accettura, E. Berthome, P. Chiggiato, A. Dallocchio, G. Favre, C. Garion, L. Gentini, J. Hansen, L. Marques, R. Misler, P. Moyret, P. Revathi, C. Scarcia, S. Sgobba, M. Toscan I. Wevers*

October 2025

Pilot Sector at CERN

The approved agreement

KN5637/TE/Einstein Telescope Collaboration Agreement

Collaboration Agreement KN5637/TE/Einstein Telescope
(Replacing KN4657/DG/Einstein Telescope)

Between

The European Organization for Nuclear Research
("CERN")

And

the Lead Institutes of the Einstein Telescope Collaboration:

The Italian National Institute for Nuclear Physics
("INFN")

And

The Dutch National Institute for Subatomic Physics
("Nikhef"),

And

The Institut de Fisica d'Altes Energies
("IFAE"),

(hereinafter "Party" and collectively "Parties")

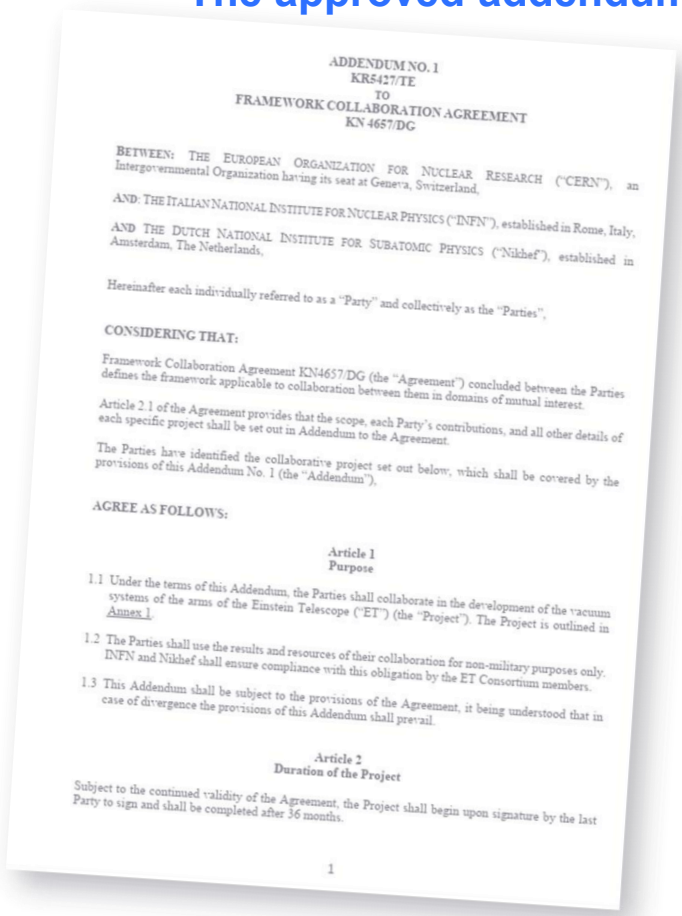
Concerning

Collaboration on the design of future gravitational wave detection experiments

2023

Page 1

The approved addendum



ADDENDUM NO. 1
KR5427/TE
TO
FRAMEWORK COLLABORATION AGREEMENT
KN 4657/DG

BETWEEN: THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH ("CERN"), an Intergovernmental Organization having its seat at Geneva, Switzerland,

AND: THE ITALIAN NATIONAL INSTITUTE FOR NUCLEAR PHYSICS ("INFN"), established in Rome, Italy,

AND THE DUTCH NATIONAL INSTITUTE FOR SUBATOMIC PHYSICS ("Nikhef"), established in Amsterdam, The Netherlands,

Hereinafter each individually referred to as a "Party" and collectively as the "Parties",

CONSIDERING THAT:

Framework Collaboration Agreement KN4657/DG (the "Agreement") concluded between the Parties defines the framework applicable to collaboration between them in domains of mutual interest.

Article 2.1 of the Agreement provides that the scope, each Party's contributions, and all other details of each specific project shall be set out in Addendum to the Agreement.

The Parties have identified the collaborative project set out below, which shall be covered by the provisions of this Addendum No. 1 (the "Addendum"),

AGREE AS FOLLOWS:

Article 1
Purpose

1.1 Under the terms of this Addendum, the Parties shall collaborate in the development of the vacuum systems of the arms of the Einstein Telescope ("ET") (the "Project"). The Project is outlined in Annex 1.

1.2 The Parties shall use the results and resources of their collaboration for non-military purposes only. INFN and Nikhef shall ensure compliance with this obligation by the ET Consortium members.

1.3 This Addendum shall be subject to the provisions of the Agreement, it being understood that in case of divergence the provisions of this Addendum shall prevail.

Article 2
Duration of the Project

Subject to the continued validity of the Agreement, the Project shall begin upon signature by the last Party to sign and shall be completed after 36 months.

1

General agreement between CERN, INFN, Nikhef and IFAE in 2022

Main objectives:

- **Coordinate the contributions**
- Preparation **TDR** for ET vacuum systems
- Systematic exchange with **CE**
- **Design, manufacture & tests Pilot Sector at CERN**

Pilot Sector at CERN

The approved agreement

The approved addendum

The approved amendment

Collaboration Agreement KN5637/TE/Einstein Telescope
(Replacing KN4657/DG/Einstein Telescope)

Between

The European Organization for Nuclear Research
("CERN")

And

the Lead Institutes of the Einstein Telescope Collaboration:

The Italian National Institute for Nuclear Physics
("INFN")

And

The Dutch National Institute for Subatomic Physics
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And

The Institut de Fisica d'Altes Energies
("IFAE"),

(hereinafter "Party" and collectively "Parties")

Concerning

Collaboration on the design of future gravitational wav
detection experiments

ADDENDUM NO. 1
KR5427/TE
TO
FRAMEWORK COLLABORATION AGREEMENT
KN 4657/DG

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AND: THE ITALIAN NATIONAL INSTITUTE FOR NUCLEAR PHYSICS ("INFN"), established in Rome, Italy,

AND THE DUTCH NATIONAL INSTITUTE FOR SUBATOMIC PHYSICS ("Nikhef"), established in Amsterdam, The Netherlands,

idividually referred to as a "Party" and collectively as the "Parties",

THAT:

oration Agreement KN4657/DG (the "Agreement") concluded between the Parties
ork applicable to collaboration between them in domains of mutual interest.

greement provides that the scope, each Party's contributions, and all other details of
shall be set out in Addendum to the Agreement.

ntified the collaborative project set out below, which shall be covered by the
ddendum No. 1 (the "Addendum"),

OWS:

Article 1
Purpose

f this Addendum, the Parties shall collaborate in the development of the vacuum
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shall ensure compliance with this obligation by the ET Consortium members.

all be subject to the provisions of the Agreement, it being understood that in
the provisions of this Addendum shall prevail.

Article 2
Duration of the Project

validity of the Agreement, the Project shall begin
completed after 36 months.

1

AMENDMENT NO. 1
TO
ADDENDUM NO. 1
KR5427/TE
TO
FRAMEWORK COLLABORATION AGREEMENT
KN 5637/TE (REPLACING KN 4657/DG)

BETWEEN: THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH ("CERN"), an Intergovernmental Organization having its seat at Geneva, Switzerland,

AND: THE NATIONAL INSTITUTE FOR NUCLEAR PHYSICS ("INFN"), established in Rome, Italy,

AND: THE DUTCH NATIONAL INSTITUTE FOR SUBATOMIC PHYSICS ("Nikhef"), established in Amsterdam, The Netherlands,

AND: THE INSTITUT DE FISICA D'ALTES ENERGIES ("IFAE"), established in Barcelona, Spain,

Hereinafter each individually referred to as a "Party" and collectively as the "Parties",

CONSIDERING THAT:

Framework Collaboration Agreement KN 5637/TE (the "Agreement") concluded between the Parties defines the framework applicable to collaboration between them in domains of mutual interest and cancels and replaces Collaboration Agreement KN4657/DG/EinsteinTelescope;

Addendum No.1 KR5427/TE (the "Addendum") provides that the Parties shall collaborate in the development of the vacuum systems of the arms of the Einstein Telescope ("ET") (the "Project");

Article 9 of the Addendum provides that any amendment shall be made in writing and signed by the authorized representatives of the Parties;

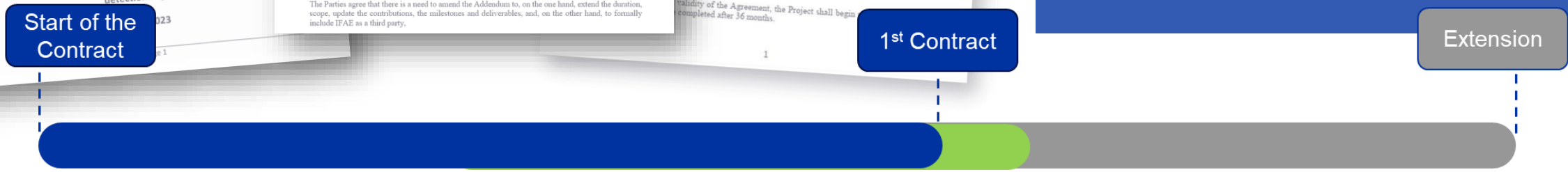
The Parties agree that there is a need to amend the Addendum to, on the one hand, extend the duration, scope, update the contributions, the milestones and deliverables, and, on the other hand, to formally include IFAE as a third party,

General agreement between CERN, INFN, Nikhef and IFAE in 2022

Main objectives:

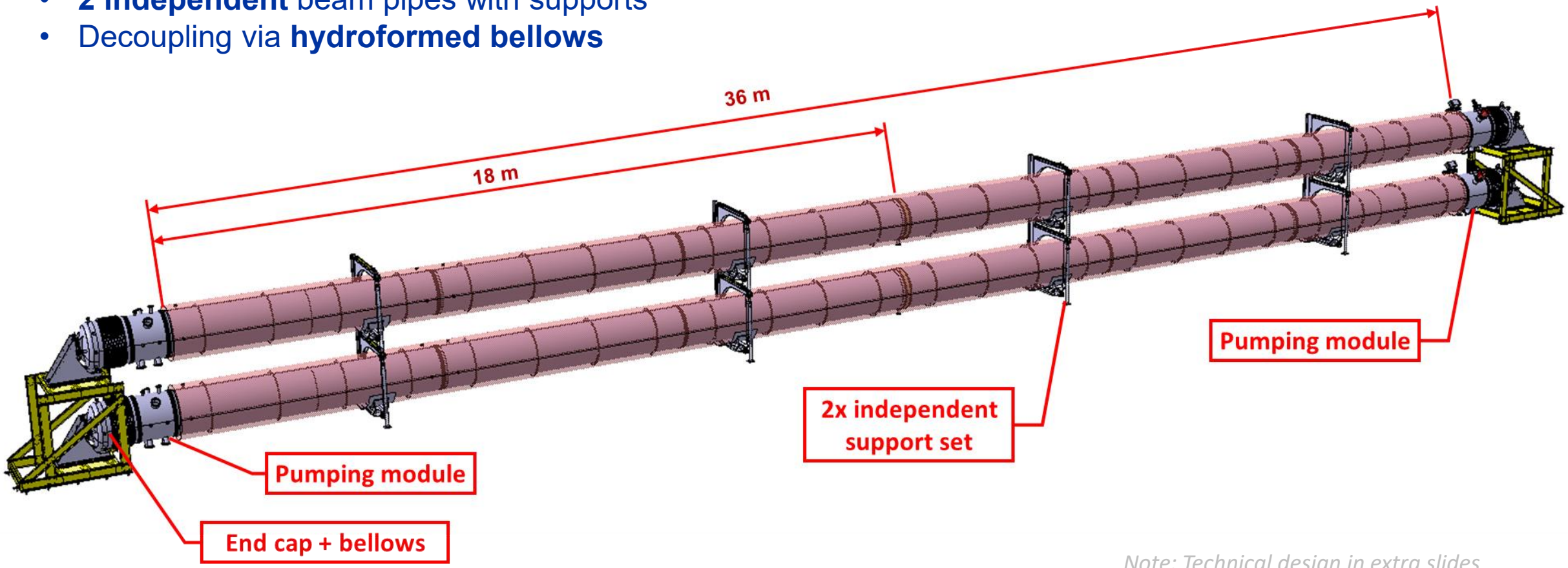
- **Coordinate the contributions**
- Preparation **TDR** for ET vacuum systems
- Systematic exchange with **CE**
- **Design, manufacture & tests Pilot Sector at CERN**

Amendment extends CERN's contribution until **October 2027**



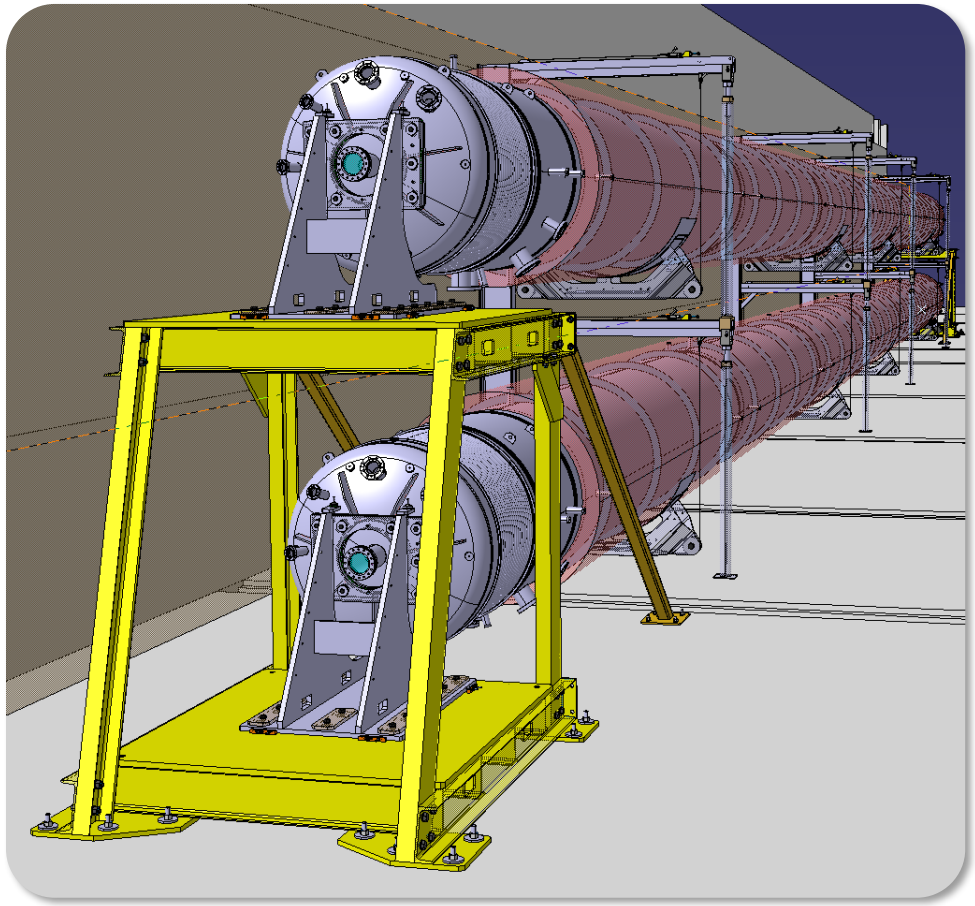
Pilot Sector at CERN

- Installed in **tunnel TT4** at CERN
- 40 m total length (**36 m pipes + end modules**)
- **2 independent** beam pipes with supports
- Decoupling via **hydroformed bellows**

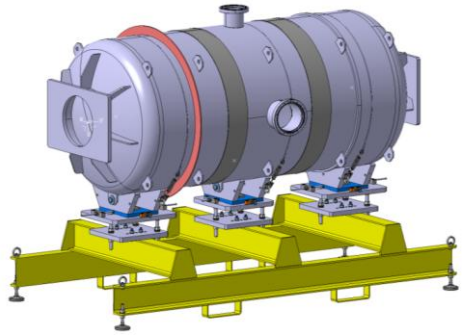


Note: Technical design in extra slides

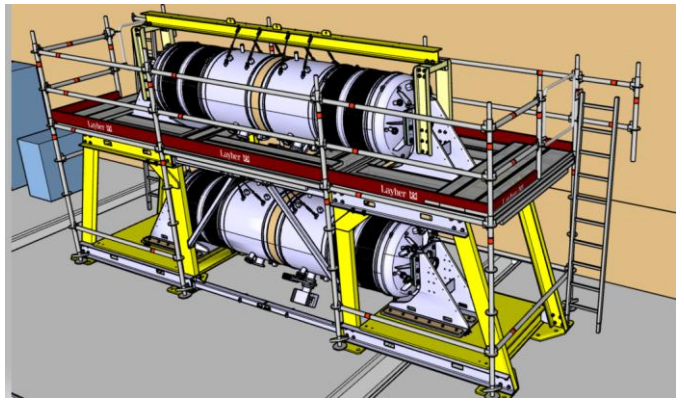
Pilot Sector at CERN



Preliminary tests:

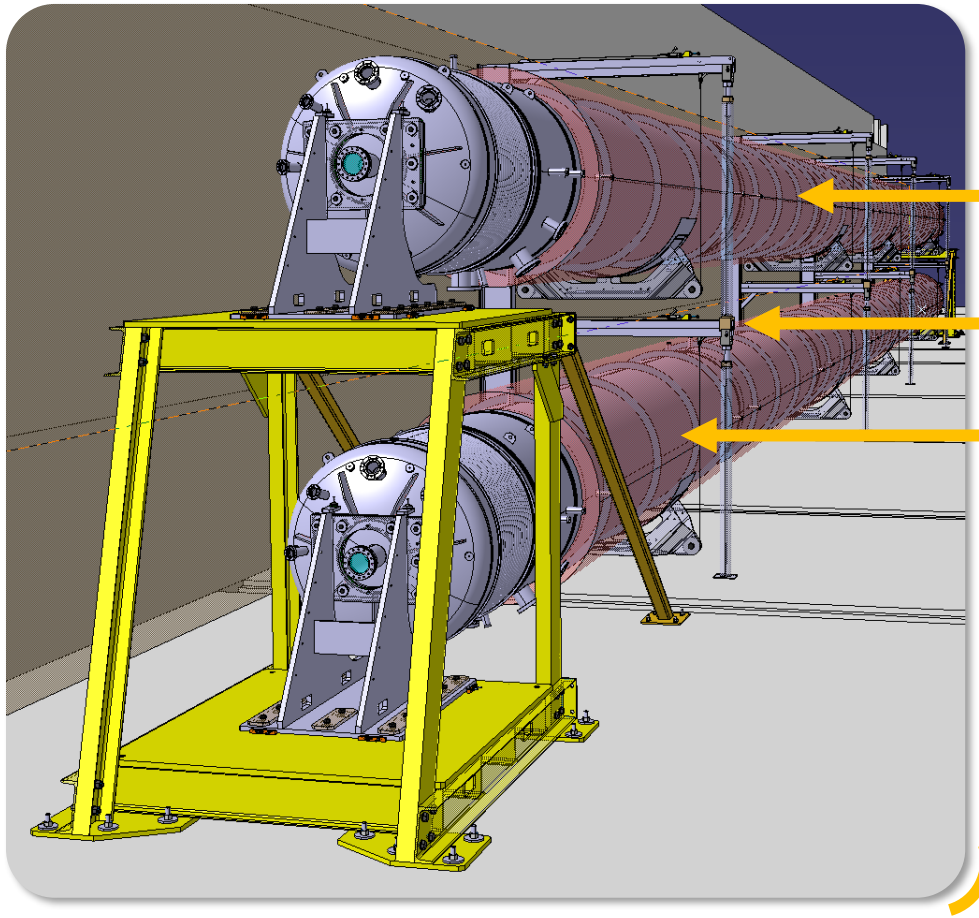


Mock-up Ø850mm
to validate assembly strategy



***Background system** to assess total gas load without prior to tubes installation*

Pilot Sector at CERN



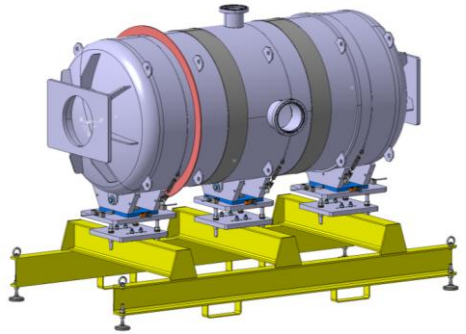
Beamtubes:
Design
Materials
Manufacturing & QA
Installation

Supports

Insulation

Lessons learned & Perspectives

Preliminary tests:



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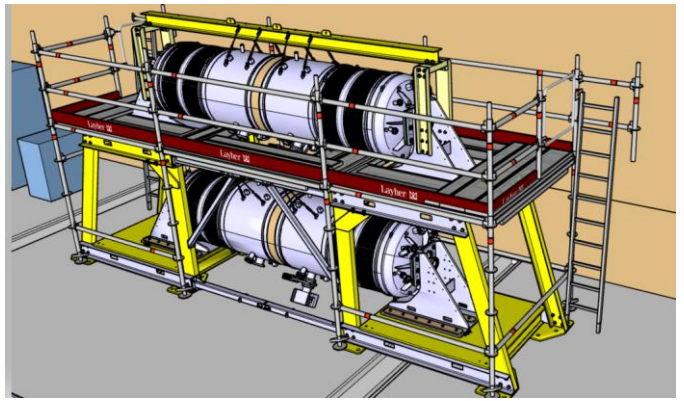
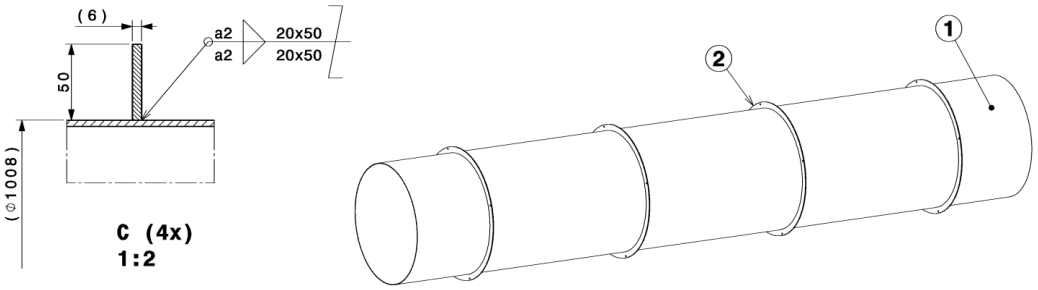


***Background system** to assess total gas load without prior to tubes installation*

Beamtubes: Design

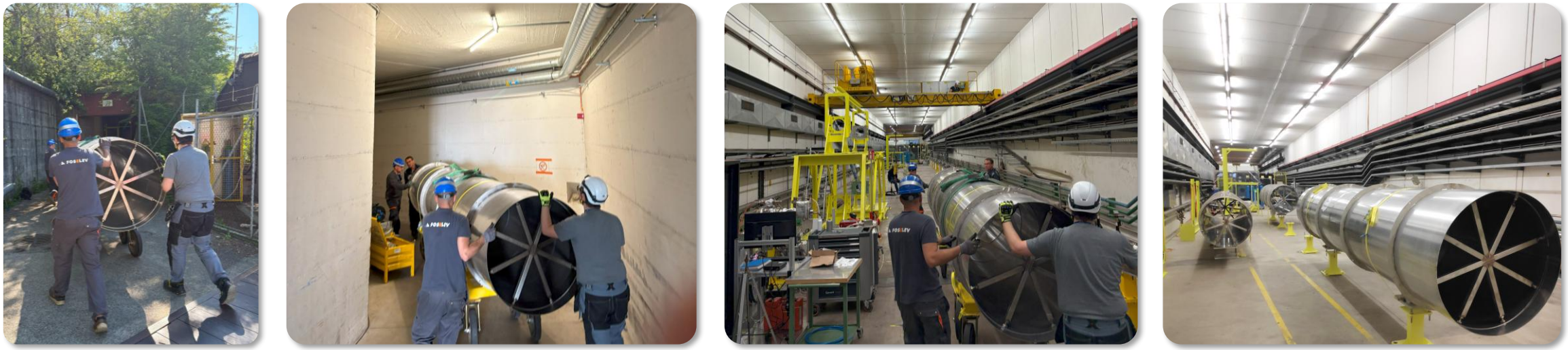


Note: Pipe' technical design in extra slides

Based on VIRGO-like vacuum pipes

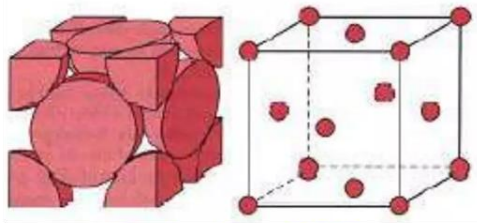
Pipe	Material	Thickness	Dimensions
VIRGO	AISI 304L	4 mm	Ø1.2 m x 15 m
PILOT SECTOR	Alternative	4 mm	Ø1.0 m x 6 m

Exploring **alternative materials** to **optimize total cost & performance**
Ø1.0m = ET requirement and **6-m length** = maximum length accessible in TT4 tunnel

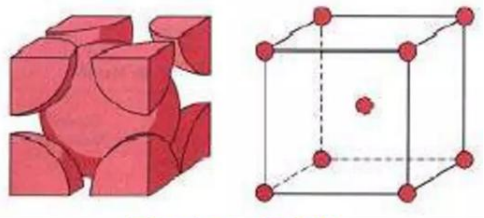


Handling & transport of 6 m sections into TT4

Beamtubes: Alternative Materials



Austenite - FCC

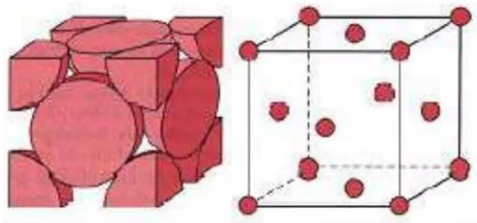


Ferrite - BCC

Why Consider Ferritic Steels?

- **Austenitic (FCC):** Standard for UHV → Needs high-T treatments (firing) for H_2 degassing
- **Current approach:** ex-situ heating in vacuum or air furnace + in-situ bakeout. (i. e. VIRGO cycle 5 days/410°C on coils + in-situ bakeout of pipes) → **Production Bottleneck!**
- **Ferritic (BCC):** lower residual H_2 + higher diffusivity → **faster degassing at lower temperatures (≤ 150°C)**

Beamtubes: Alternative Materials



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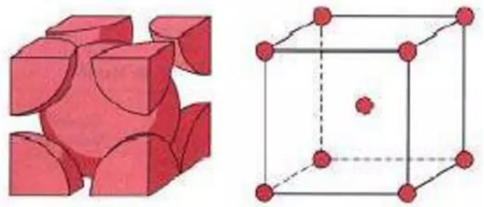
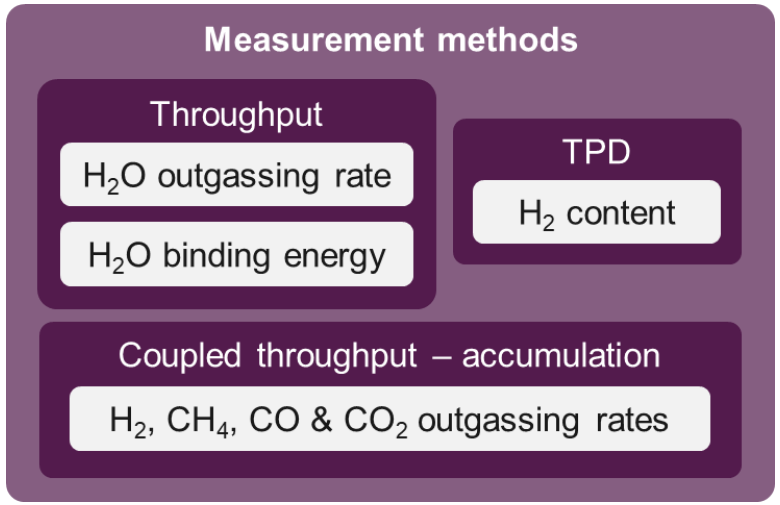


Ferrite - BCC

Courtesy of I. Wevers and C. Scarcia



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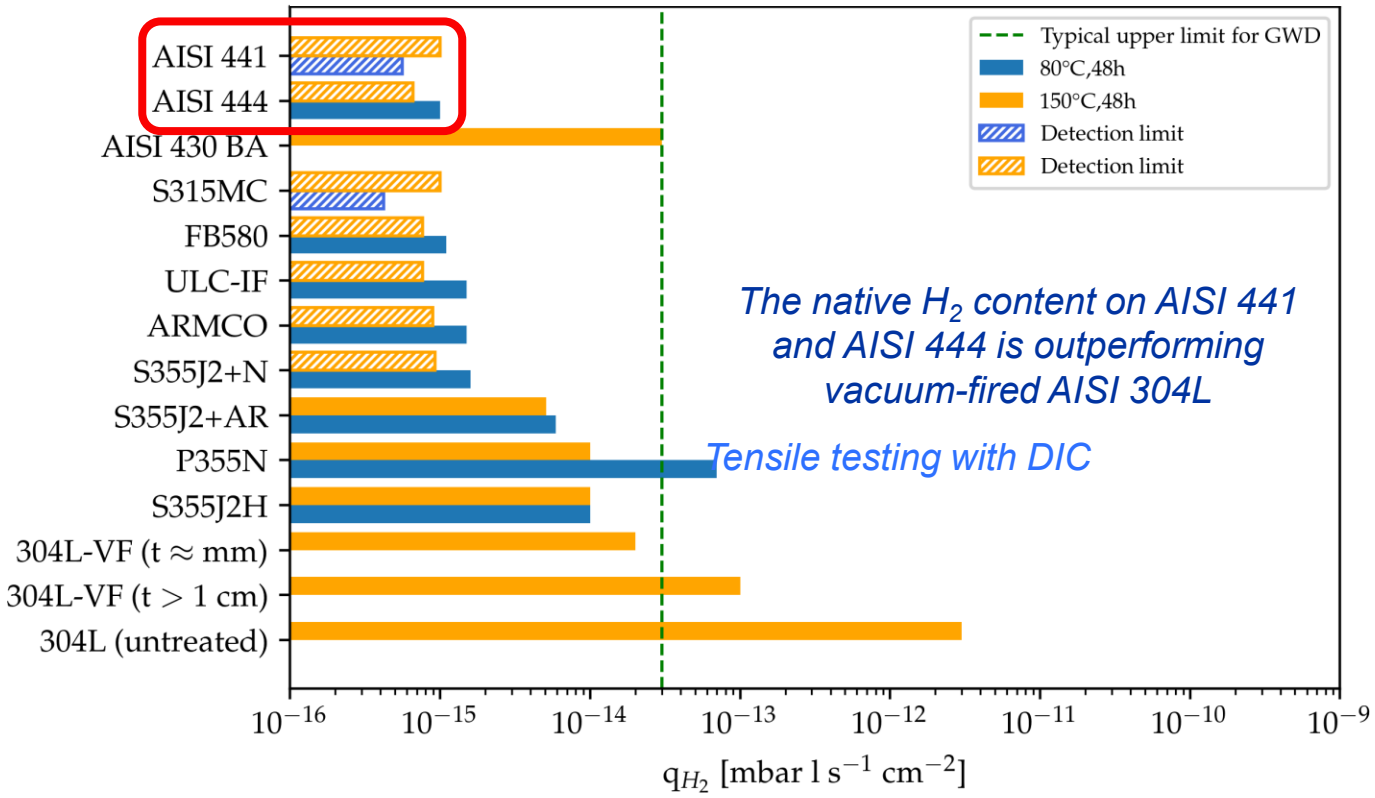
- **Ferritic (BCC):** lower residual H_2 + higher diffusivity → **faster degassing at lower temperatures (≤ 150°C)**
- **CERN evaluation:** tested multiple ferritic steels with various methods → **Ferritic stainless steels selected** → best balance of vacuum performance & corrosion resistance

Ferritic StSt for Pilot Sector

AISI 441 Selected Grade for Pilot Sector → Low C, Stabilized with Ti & Nb + Better Weldability

H2 specific outgassing rate



The native H_2 content on AISI 441 and AISI 444 is outperforming vacuum-fired AISI 304L

Tensile testing with DIC

Measurement error: ±40%; Detection limit: 50% of background

Mechanical testing summary on welds

	Welding methods	Tensile trans.	Tensile long.
AISI 430	TIG	A=8%	-
	Laser	A=26%	-
AISI 444	TIG	A= 26%	A=22%
	Laser	A=29%	A= 30%
AISI 441	TIG	A= 24%	A=26%
	Laser	A=30%	A= 29%

Courtesy of I. Wevers and C. Scarcia

Beamtubes: Manufacturing & QA

From 1.5 m wide sheets to 6-m long pipe sections

Component/s	Plates #	Thickness (mm)	Dimensions (mm)	Finishing
Pipe's sections, pumping modules, pumping ports and end caps	67 8	4	1500 x 3200 1500 x 3700	2B
Sleeve connections	8	2	1500 x 3200	2B
Baffles manufacturing test	4 4	1.5 3	1400 x 900 1000 x 2000	2B/2D

Beamtubes: Manufacturing & QA

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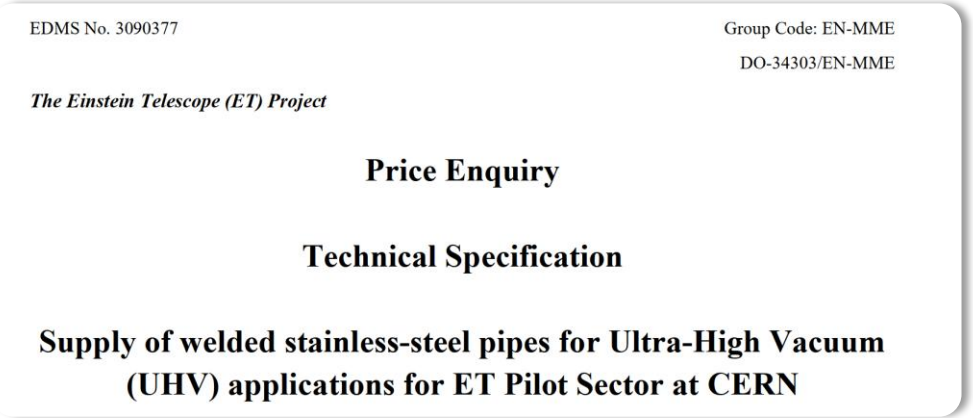
From design to fabrication of UHV components

- **Practical approach adopted** → "pipe manufacturing" prioritized over "UHV component"
- Order placed Feb. 2025 with **French supplier** (Ravanat) → components **delivered May 2025**
- Close supplier follow-up → while there is **room for improvement**, **the pipes are ready for installation**



EDMS No. 3090377 Group Code: EN-MME

DO-34303/EN-MME

The Einstein Telescope (ET) Project

Price Enquiry

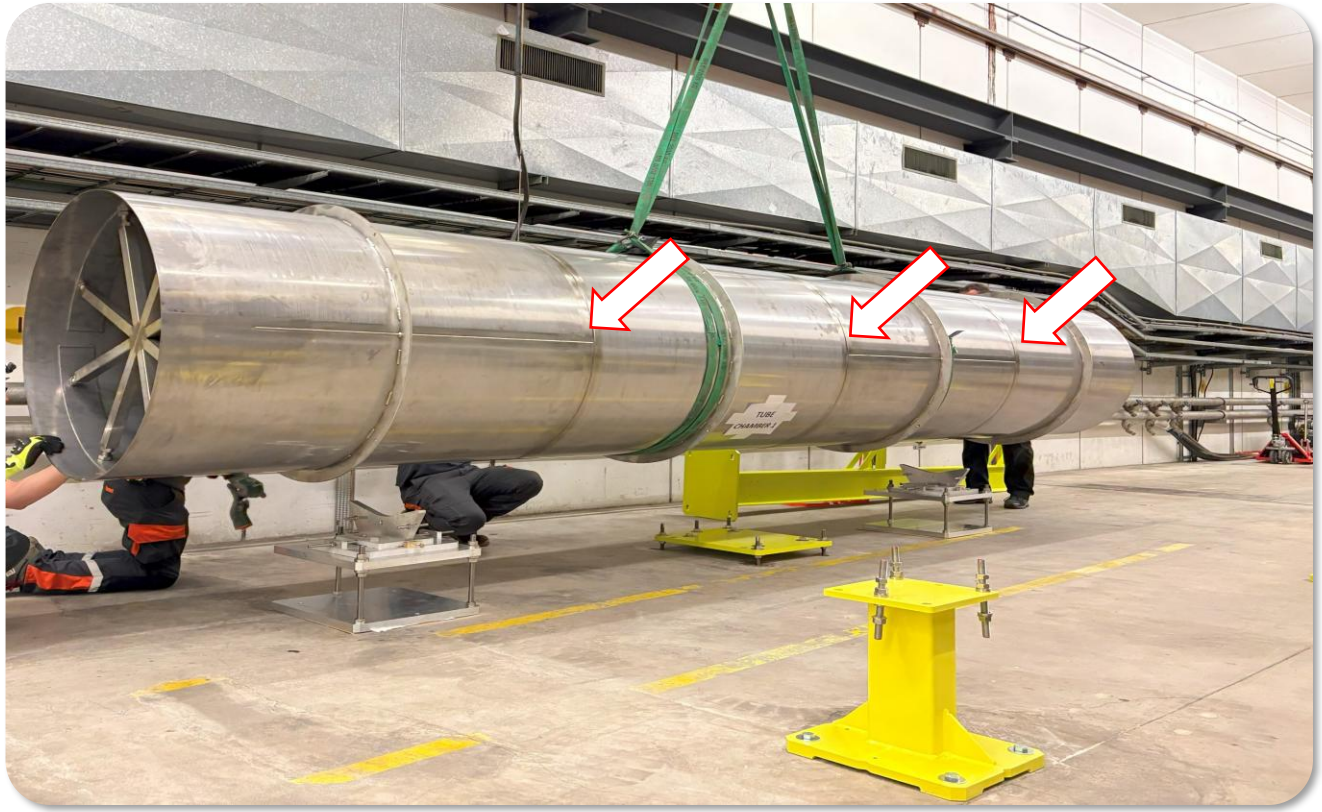
Technical Specification

Supply of welded stainless-steel pipes for Ultra-High Vacuum (UHV) applications for ET Pilot Sector at CERN

Beamtubes: Manufacturing & QA

Factory acceptance test

✅ Welding procedure and welders' qualification validated by CERN before production
✅ Qualification plates (NDTs + metallurgy + mechanical testing)
✅ VT of all external & accessible internal welds
✅ RT of 100% of longitudinal–circular crossings



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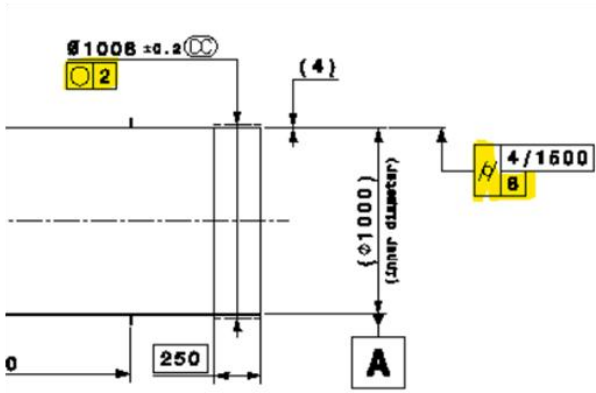
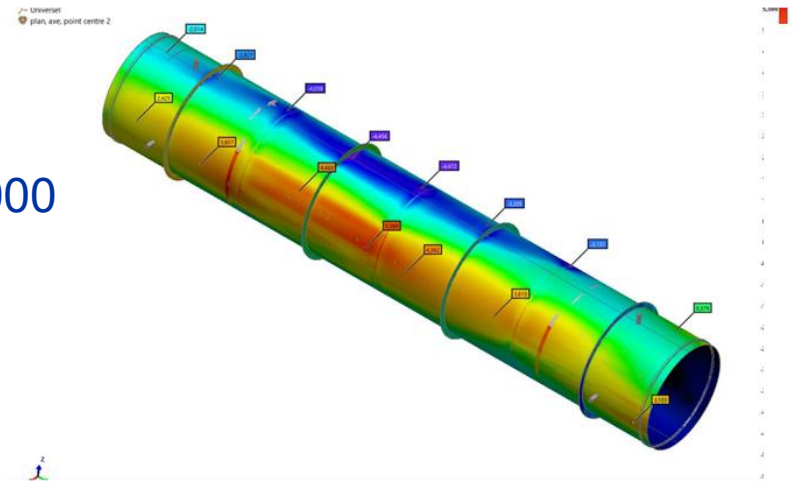
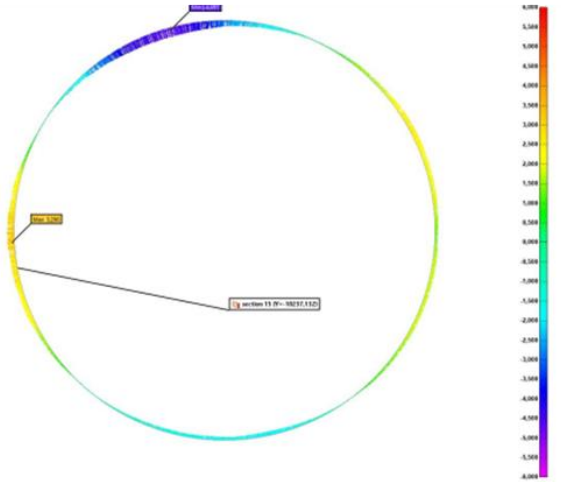
QC after reception

✅ VT of external & accessible internal welds
Dimensional metrology by 3D scanner:
- ✅ Circumference **in the tolerance** limits ±1,000
- ⚠️ Cylindricity up to 4 mm **out of tolerance**
- ⚠️ **Banana shape** (less critical)







Work and report by R. Heisserer

Beamtubes: Manufacturing & QA

Factory acceptance test

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QC after reception

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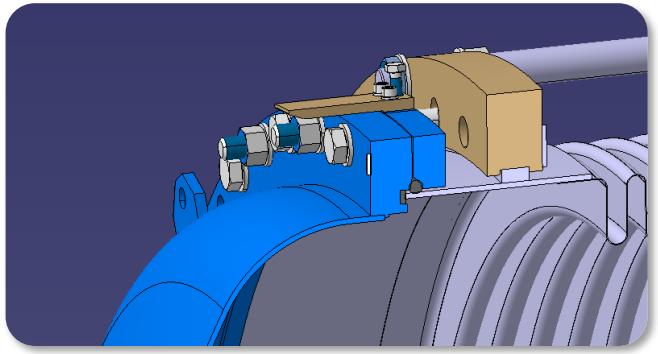
Dimensional metrology by 3D scanner:
- ✅ Circumference **in the tolerance** limits ±1,000
- ⚠️ Cylindricity up to 4 mm **out of tolerance**
- ⚠️ **Banana shape** (less critical)

✅ Leak tightness test of each section

Double gasket with differential pumping



LD with external He pockets

Beamtubes: Installation

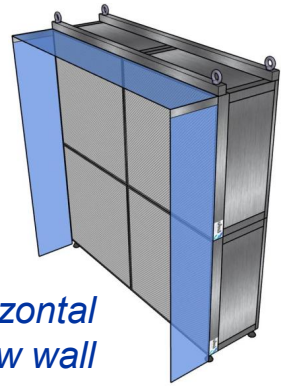
Cleaning for UHV

- Large size & handling challenges
- CERN UHV procedure → detergent cleaning by ultrasound agitation + rinsing
- Cleanliness verified via witness samples

Dust control

- Critical to meet ET requirements
- ISO 6 standard (ISO 14644-1) expected
- Laminar flow at extremities during drying

Portable Cleanroom (ISO 6)



Horizontal laminar flow wall

Beamtubes: Installation

Cleaning for UHV

- Large size & handling challenges
- CERN UHV procedure → detergent cleaning by ultrasound agitation + rinsing
- Cleanliness verified via witness samples

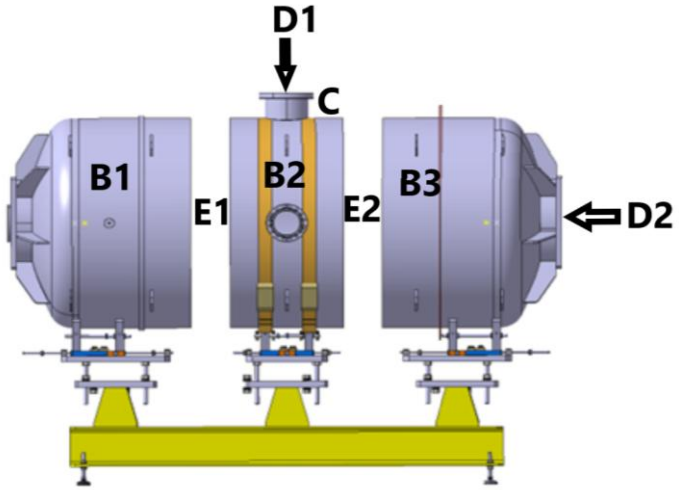
Dust control

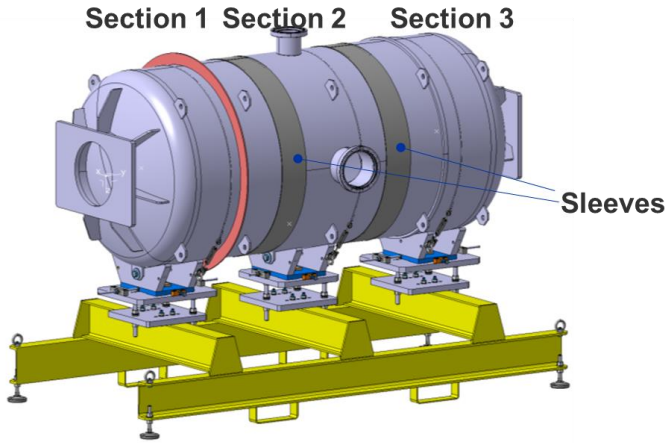
- Critical to meet ET requirements
- ISO 6 standard (ISO 14644-1) expected
- Laminar flow at extremities during drying

- Packaging with double bag + end covers
- Clean working area on TT4 tunnel

Objective → Minimize dust accumulation in the pilot sector with minimum investment

Mock-up: Dust monitoring





Sections connected via 2 mm thick sleeves

Monitoring during different assembly steps

Tack welding in portable cleanroom

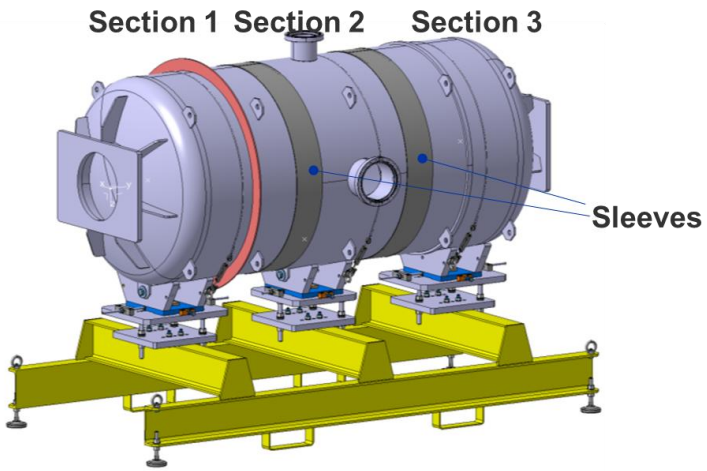
Assessment before and during assembly

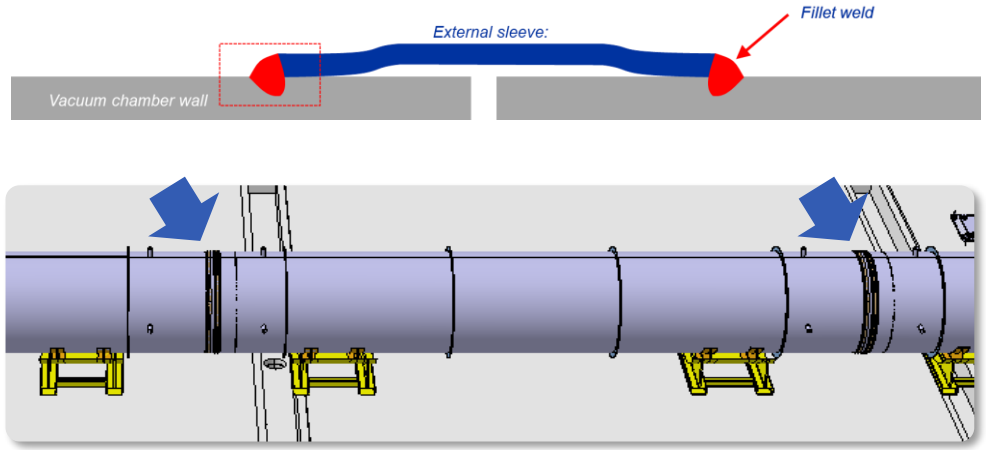
Measured ISO-8 (very high 0.3–1 µm particles)
Monitoring helped to identify critical steps

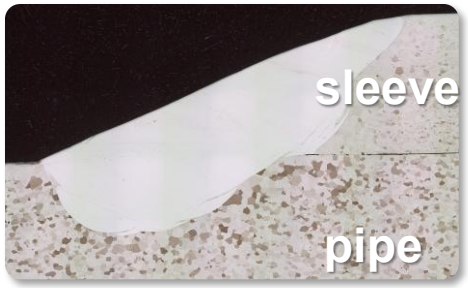
Table 1: Dust assessment at different locations during different operations

Activities	Balda quin	Mock-up surface				Inside mock-up		Between sections	
	A	B1	B2	B3	C	D1	D1	E1	E2
Only operators	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6
Operator + welders (3 people)	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6
Operator + welders +Equipment's	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6
Plastic caps removal S1 (day1)	ISO 6	ISO 6	ISO 7	ISO 7	ISO 7	ISO 6	ISO 6	ISO 7	ISO 6
Sleeve positioning S1	ISO 6	ISO 6	ISO 7	ISO 7	ISO 7	ISO 6	ISO 6	ISO 7	ISO 6
Tack weld S1	ISO 6	ISO 6	ISO 7	ISO 7	ISO 7	ISO 7	ISO 6	ISO 7	ISO 6
Sleeve closure + tack weld S1	ISO 6	ISO 6	ISO 8	ISO 8	ISO 8	ISO 8	ISO 6	ISO 8	ISO 6
Plastic caps removal S2 (day 2)	ISO 6	ISO 7	ISO 7	ISO 7	ISO 7	ISO 6	ISO 7	ISO 7	ISO 7
Sleeve positioning S2	ISO 6	ISO 7	ISO 7	ISO 7	ISO 7	ISO 7	ISO 7	ISO 7	ISO 7
Tack weld S2	ISO 6	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8
Sleeve closure + tack weld S2	ISO 6	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8
Assembly completed + settling down(~2hrs)	ISO 6	-	-	-	-	ISO 7	ISO 7	-	-
Final welding outside baldaquine	-	-	-	-	-	ISO 8	ISO 8	-	-
1 day after welding	ISO 6	-	-	-	-	ISO 8	ISO 8	-	-
2 days after welding	ISO 6	-	-	-	-	ISO 8	ISO 8	-	-
5 days after welding	ISO 6	-	-	-	-	ISO 7	ISO 7	-	-
Before leak detection	ISO 6	-	-	-	-	ISO 7	ISO 7	-	-

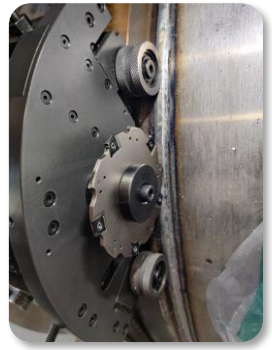
Mock-up: Sleeve validation







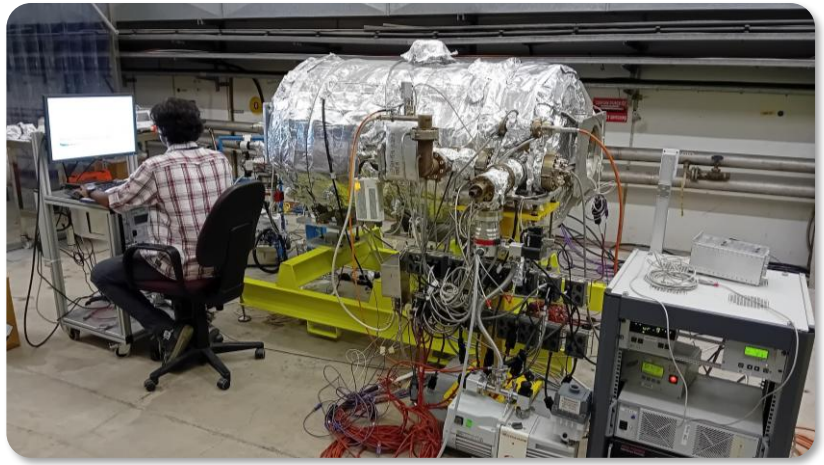
Fillet weld metallography



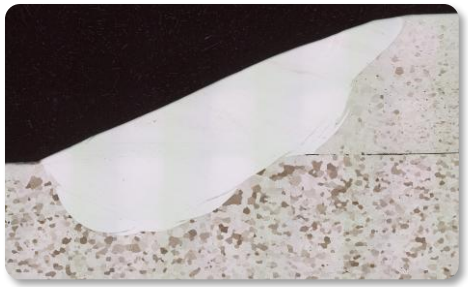
Cutting tool available at CERN

- Sleeve connection → cost-effective and allows future repairs

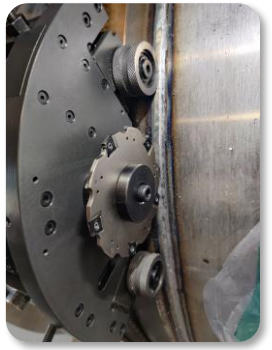
Mock-up: Sleeve validation



Bakeout and vacuum measurements on mock-up and preparation work for background test



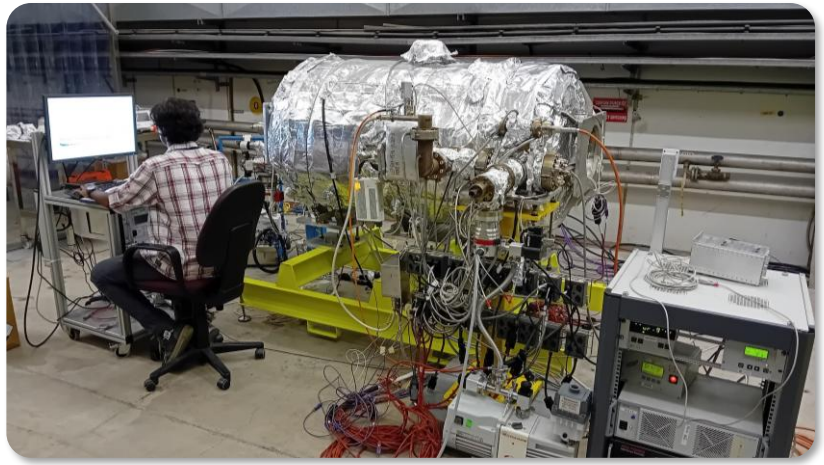
Fillet weld metallography



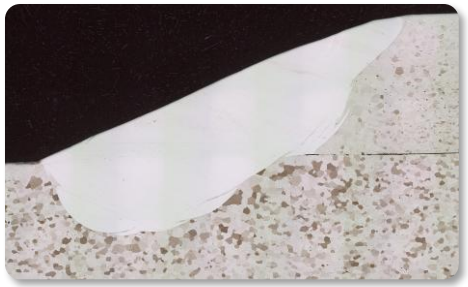
Cutting tool available at CERN

- Sleeve connection → cost-effective and allows future repairs
- Assembly on the mock-up was successful → **No virtual leaks**
- Sleeve positioning and tack welding → identified as the most **critical for dust generation**

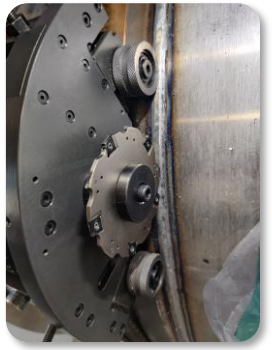
Mock-up: Sleeve validation



Bakeout and vacuum measurements on mock-up and preparation work for background test



Fillet weld metallography



Cutting tool available at CERN

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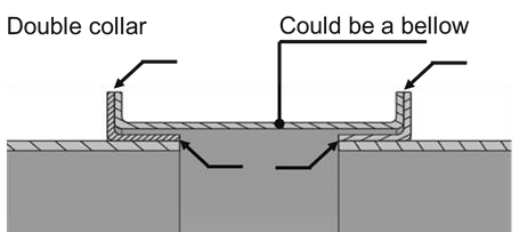
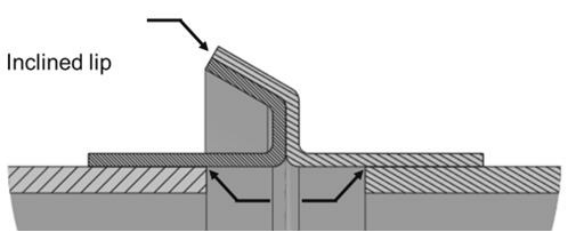
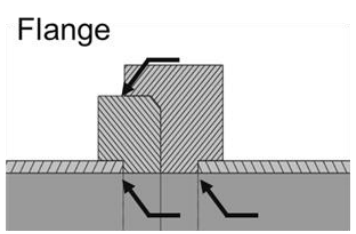
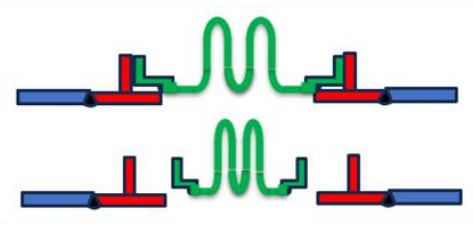
- Positioning **tedious & time consuming** → Requires optimization → Alternatives **for 2nd beamline** under study!

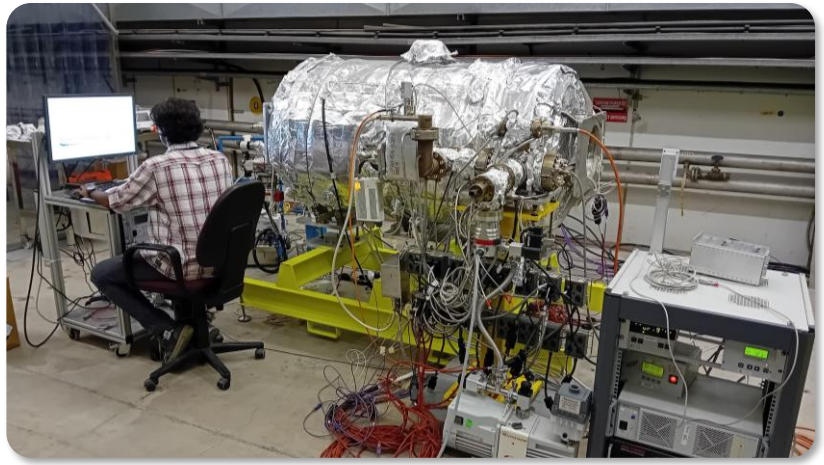




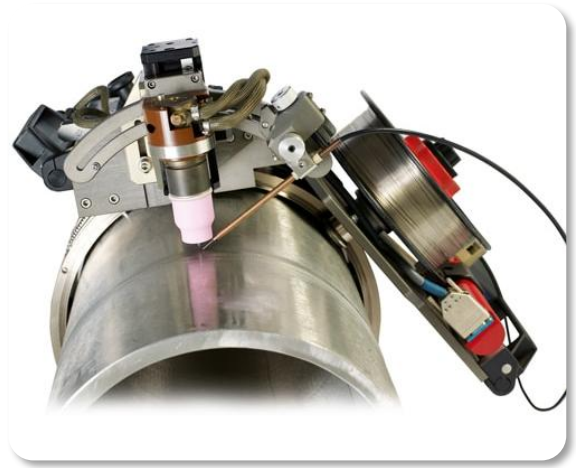




Mock-up: Sleeve validation



Bakeout and vacuum measurements on mock-up and preparation work for background test



Automatic orbital TIG welding machine

- Sleeve connection → cost-effective and allows future repairs
- Assembly on the mock-up was successful → **No virtual leaks**
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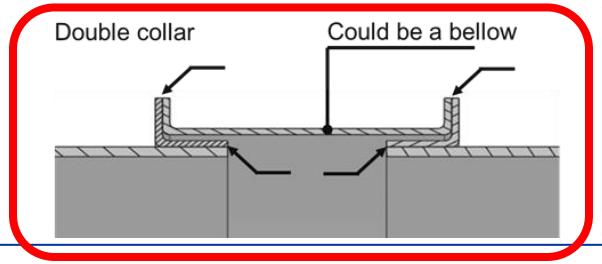
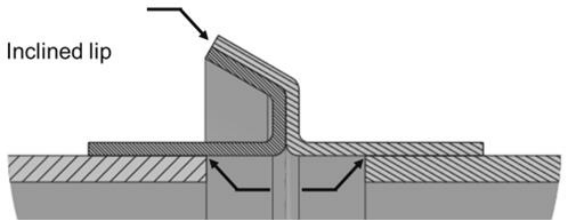
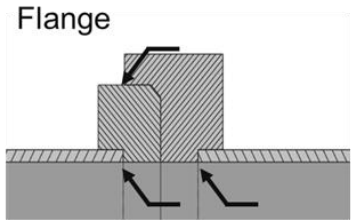
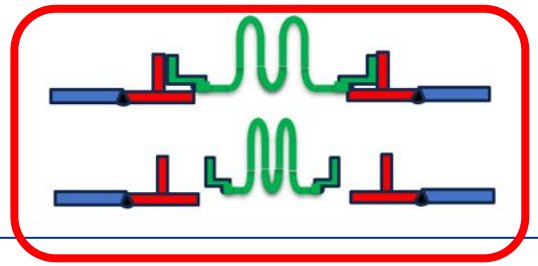


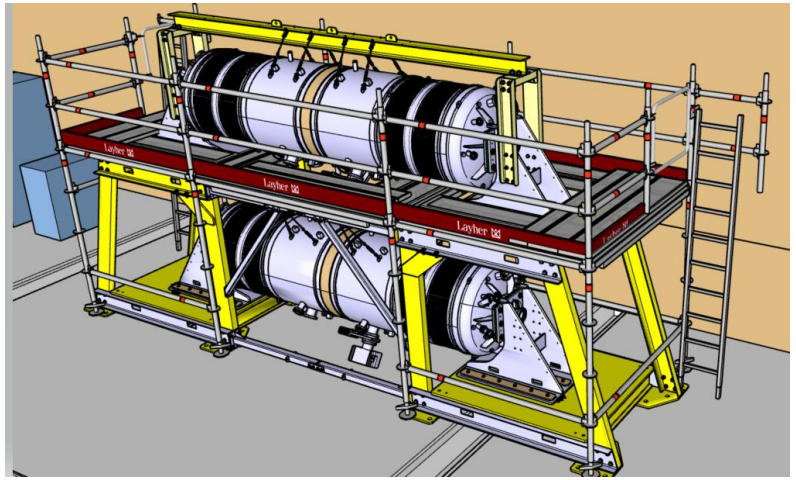


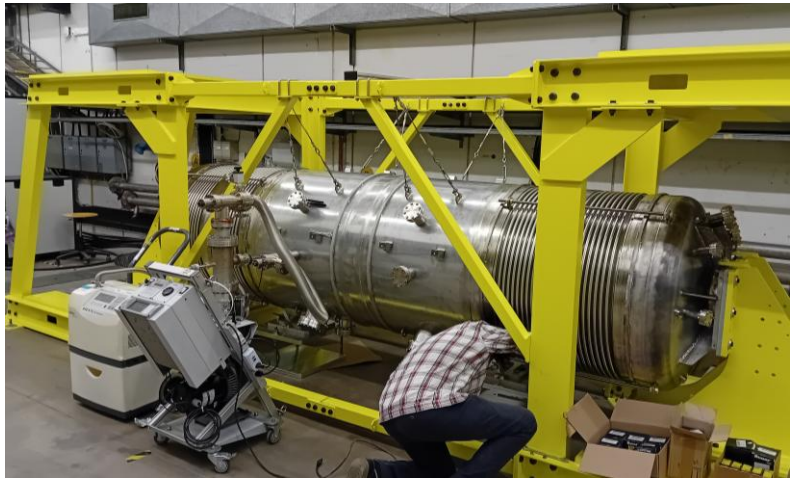




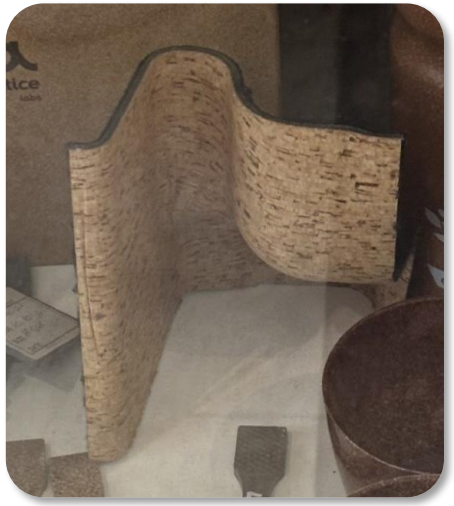
Background system: Sleeve testing

Same approach used for background system → **still no leaks so far!**

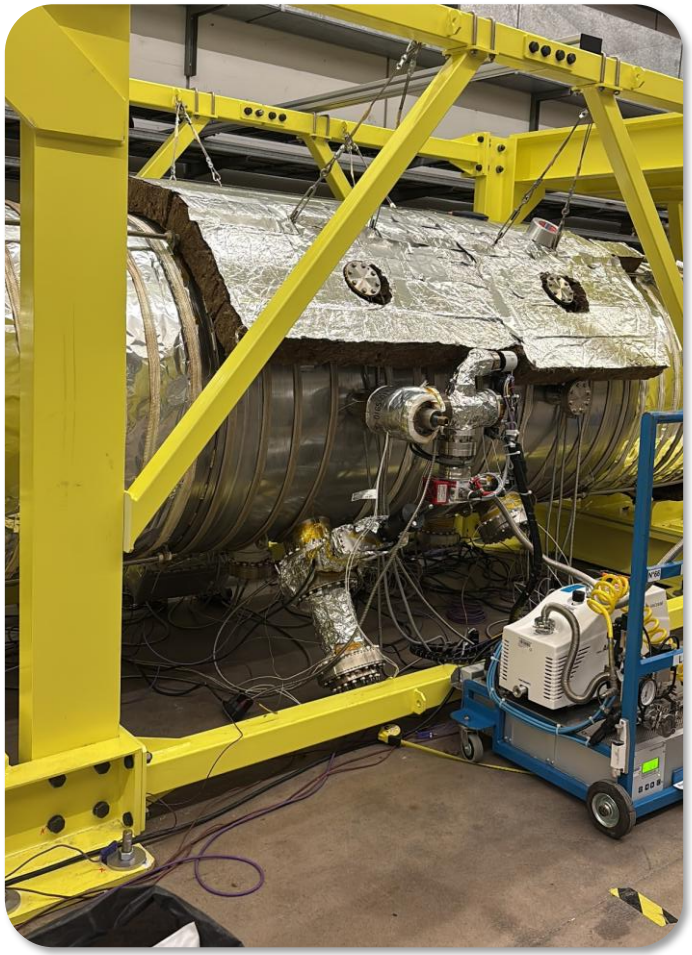




Background system: Insulation testing



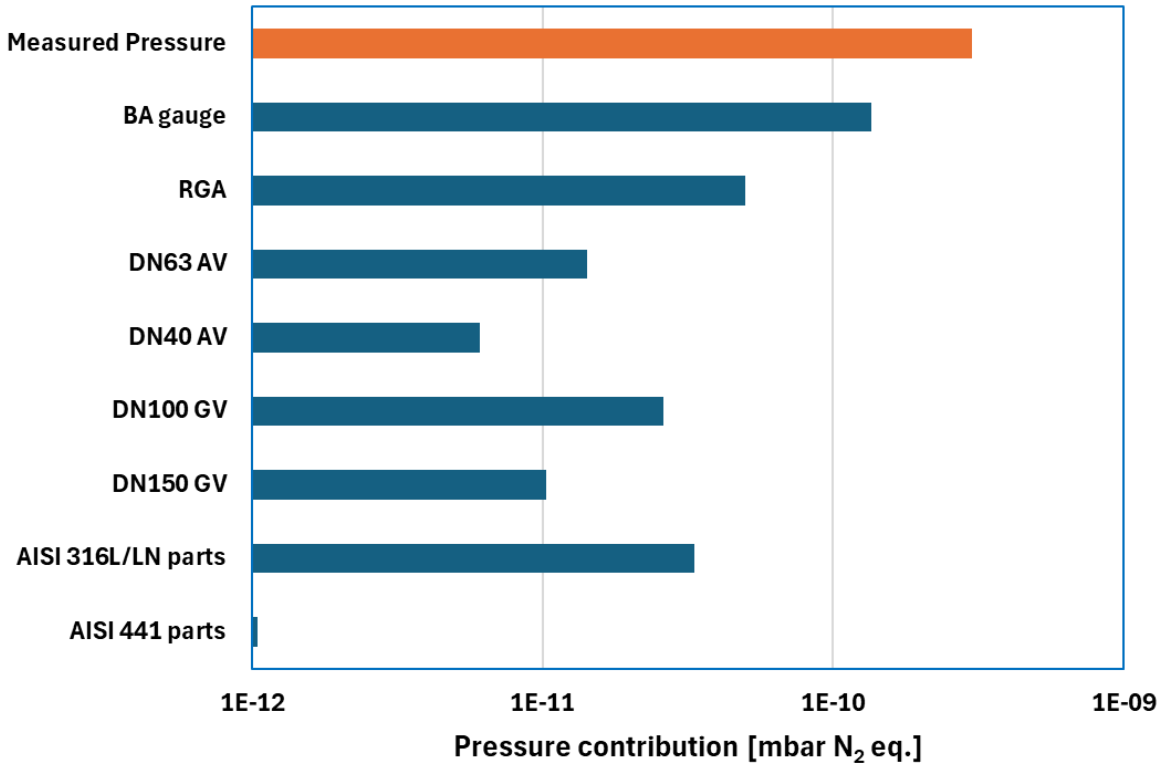
- Cork composites offer a promising alternative for bakeout thermal insulation
- Work on-going in partnership with PIEP (University of Minho, Brage, Portugal)



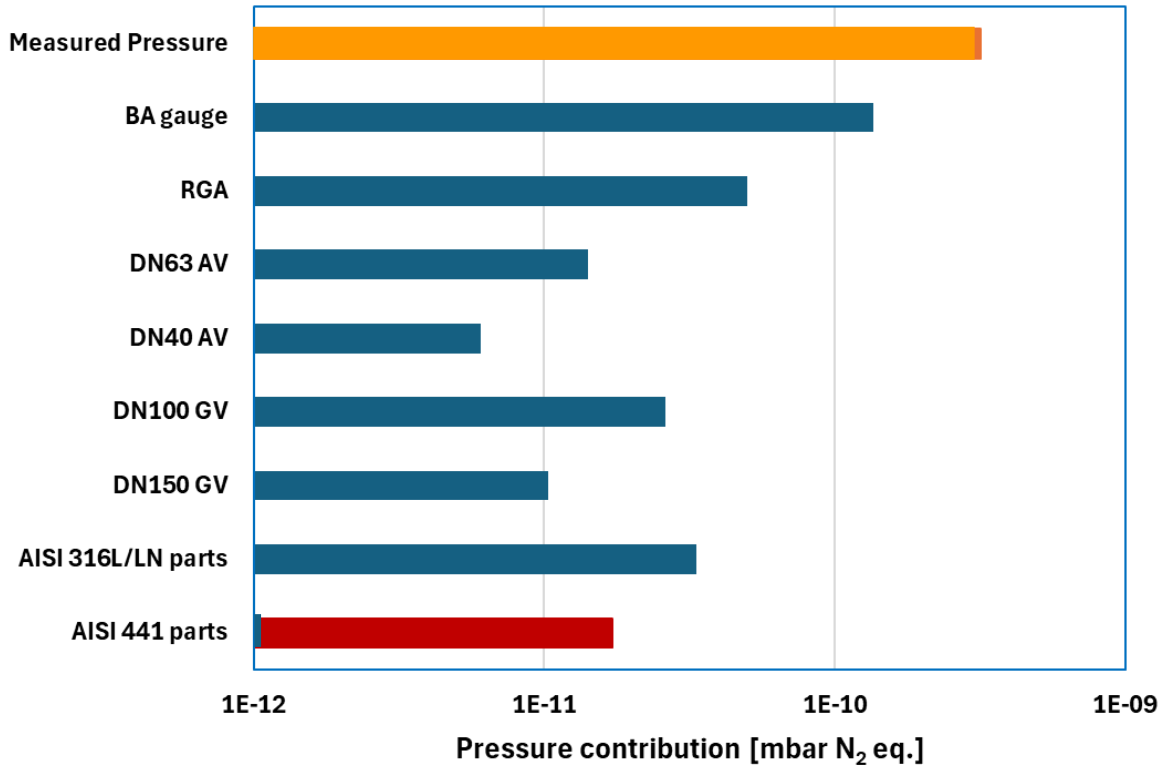
Mineral wool installation (3 and 10 cm thick)

Background system: Vacuum testing

4 days after the end of bakeout an **ultimate pressure of 3.0 10^{-10} mbar N_2 eq. was achieved**



The pressure contribution from AISI 441 is less than 0.4% while the AISI 441 surface area is 31% of the total



Adding 6 pipes $Ø_{int}$ 1 m x 4 mm x 6 m of AISI 441 will increase the pressure contribution to only 5.4%

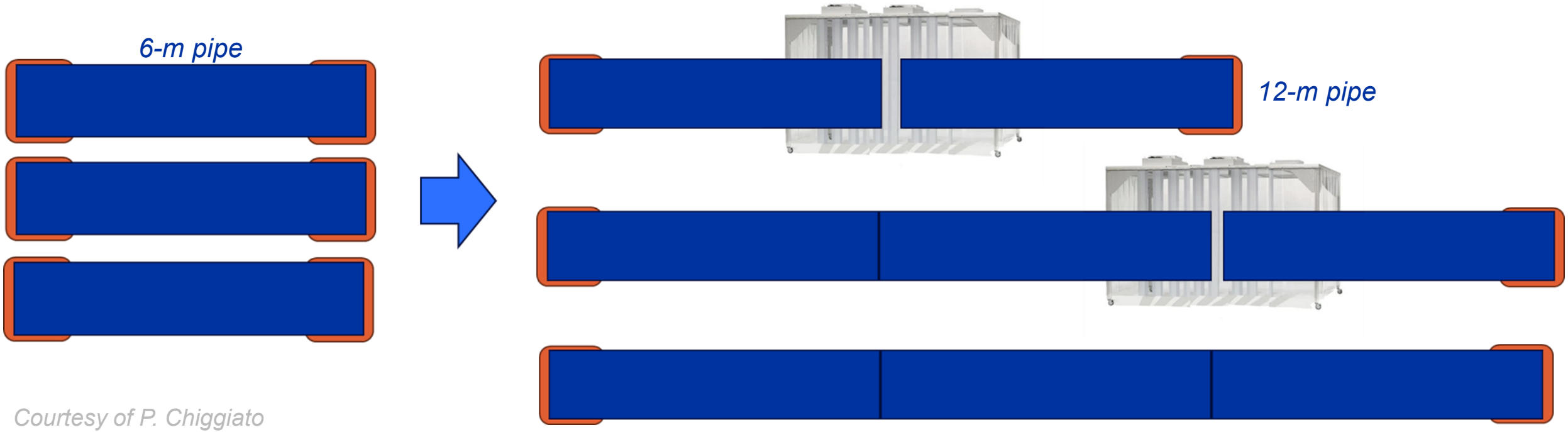
q_{H_2} for AISI 441 = 1.5 10^{-15} mbar l s^{-1} cm^{-2} & q_{H_2} for vacuum fired 316LN = 2 10^{-14} mbar l s^{-1} cm^{-2} or 2 10^{-13} mbar l s^{-1} cm^{-2} depending on thickness.

1st beamline: Installation plan

Procedure to assemble the 18-m long sections

- Section-to-section connection of the 1st beamline → **sleeves**
- Start with **cleaned & stored 6-m pipes**
- **Welding in portable cleanroom** → 12-m pipe
- **Second weld in cleanroom** → 18-m pipe
- **QC**: leak test → thermal insulation → positioning in structural support

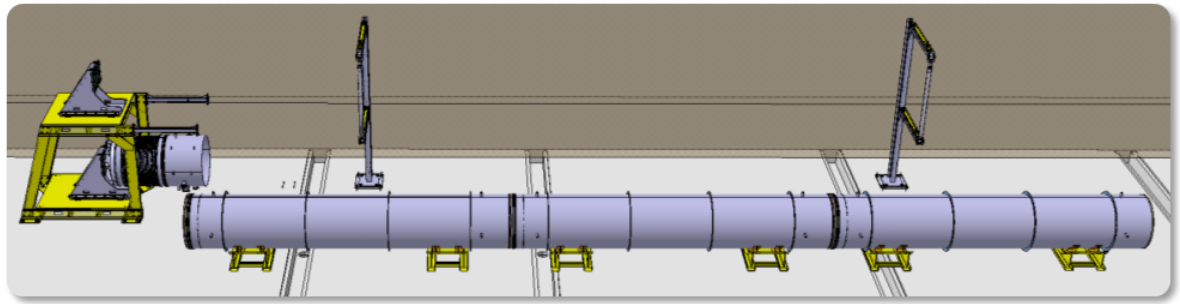
Pre-alignment test Sept. 2025



Courtesy of P. Chiggiato

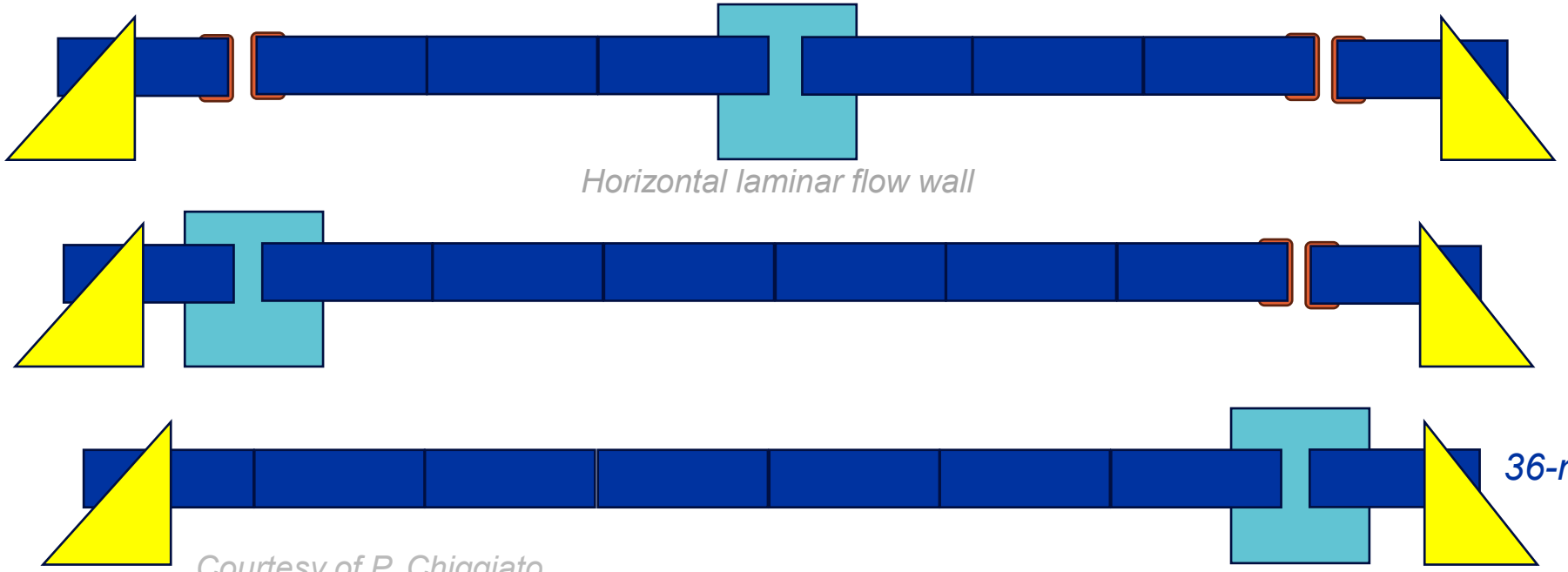
1st beamline: Installation plan

Procedure to assemble the full 36-m line



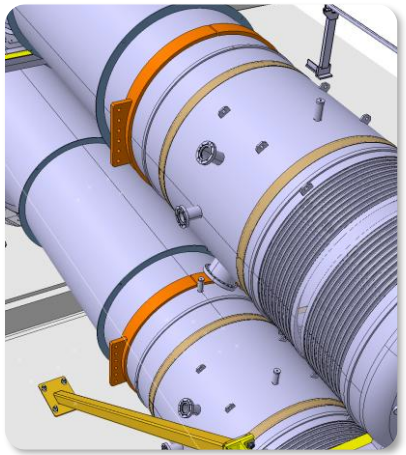
Section-to-end-modules connection → **sleeves**
Witness samples for dust studies:

- Pre-conditioned in ISO 4 cleanroom
- Follow all steps, including final welds
- Analysis at **Padova University** (Italy)



Horizontal laminar flow wall

Courtesy of P. Chiggiato



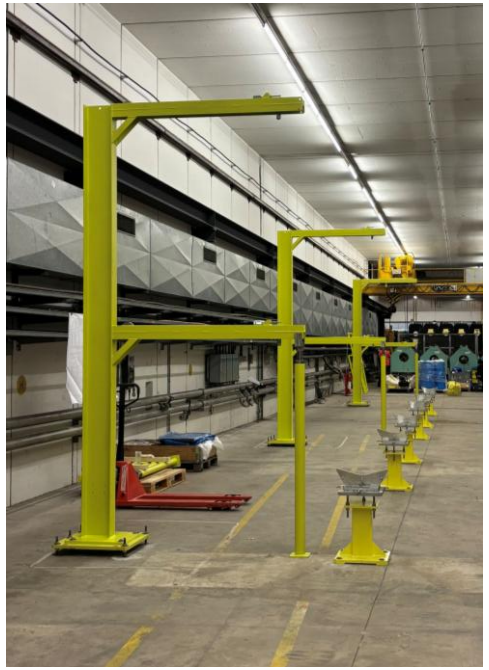
36-m pipe ready for global leak detection

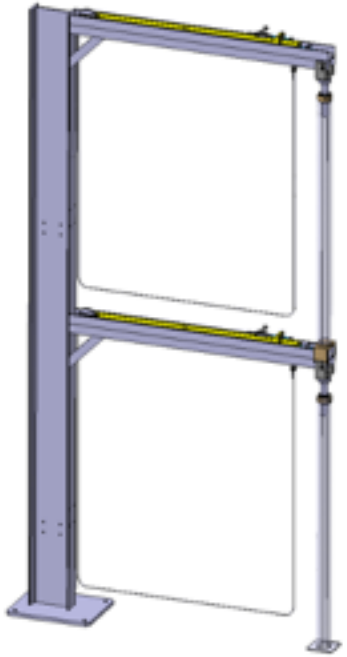
Commissioning!!

Support:

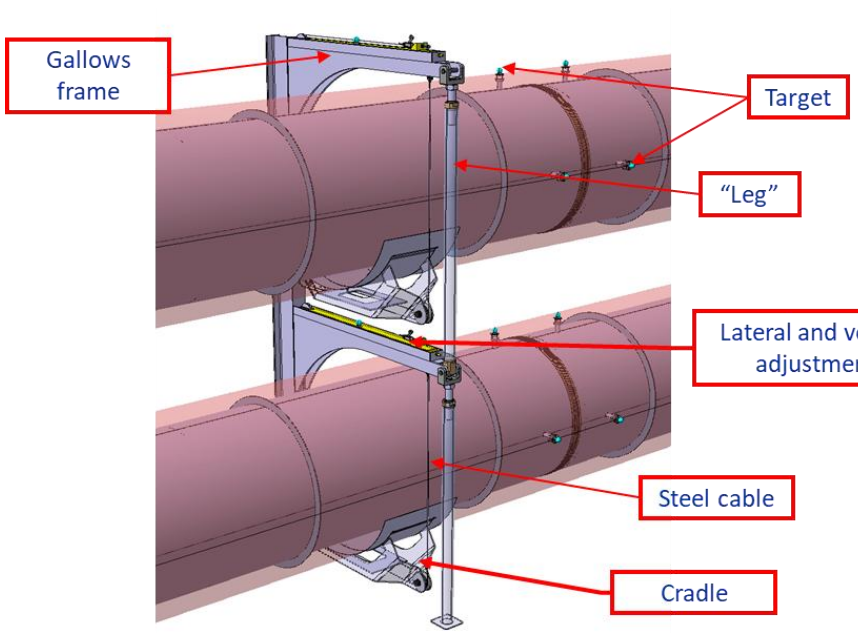
Compatible with ET requirements

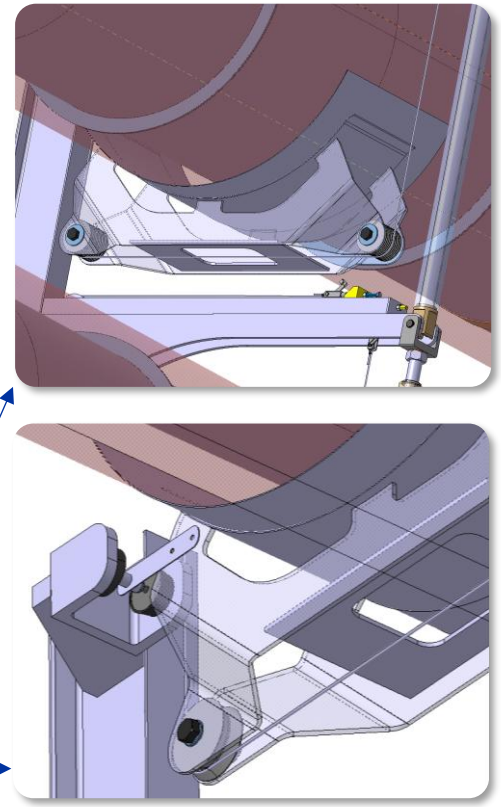
- In ET, the space required for the supporting structure shall be minimized allowing welding and future inspections
- Different options are being studied





Light supports based on standard beams with additional leg
Vacuum chambers suspended by cables (high strength synthetic ropes)





The insulated vacuum chambers lies on the cradle
Conceptual design of dampers

Lessons learned & perspectives

1. **Materials**
   - **Corrosion tests** ongoing → AISI 304L vs. ferritic StSt grades (electro chemical & immersion test)
   - **Impact test** on welds → as-welded and after thermal cycles (150C)
   - 1st beamline **bellows in 304L vacuum fired→ AISI 441 bellows qualification in progress**

Lessons learned & perspectives

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2. **Fabrication**
   - **2nd beamline** similar to 1st line with **design optimization** and **better fixture** during welding protocol
   - **2nd beamline** will test the integration of **baffles** and **new connection approaches**
   - Other solutions (e.g. 3 mm, corrugated…) will be investigated at **demonstrator scale**

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   - Other solutions (e.g. 3 mm, corrugated…) will be investigated at **demonstrator scale**

3. **Connection**
   - Sleeve positioning of sleeve & tack welding → identified as **main dust source**
   - **Sleeve concept** is technically viable but **requires optimization** (tooling, time consuming)
   - **Alternative connections** → under study → compatible with automatic welding

Lessons learned & perspectives

4. **Dust Control**
   - **Remains challenging,** especially during positioning, caps removal, baffle integration…
   - Laminar flow & portable cleanroom improved conditions but did **not ensure ISO-6** during assembly
   - **Key: refine protocol**→ reduce metal friction, minimise the clearance during welding…
   - Witness samples & Padova's collaboration **to define realistic achievable requirements**

Lessons learned & perspectives

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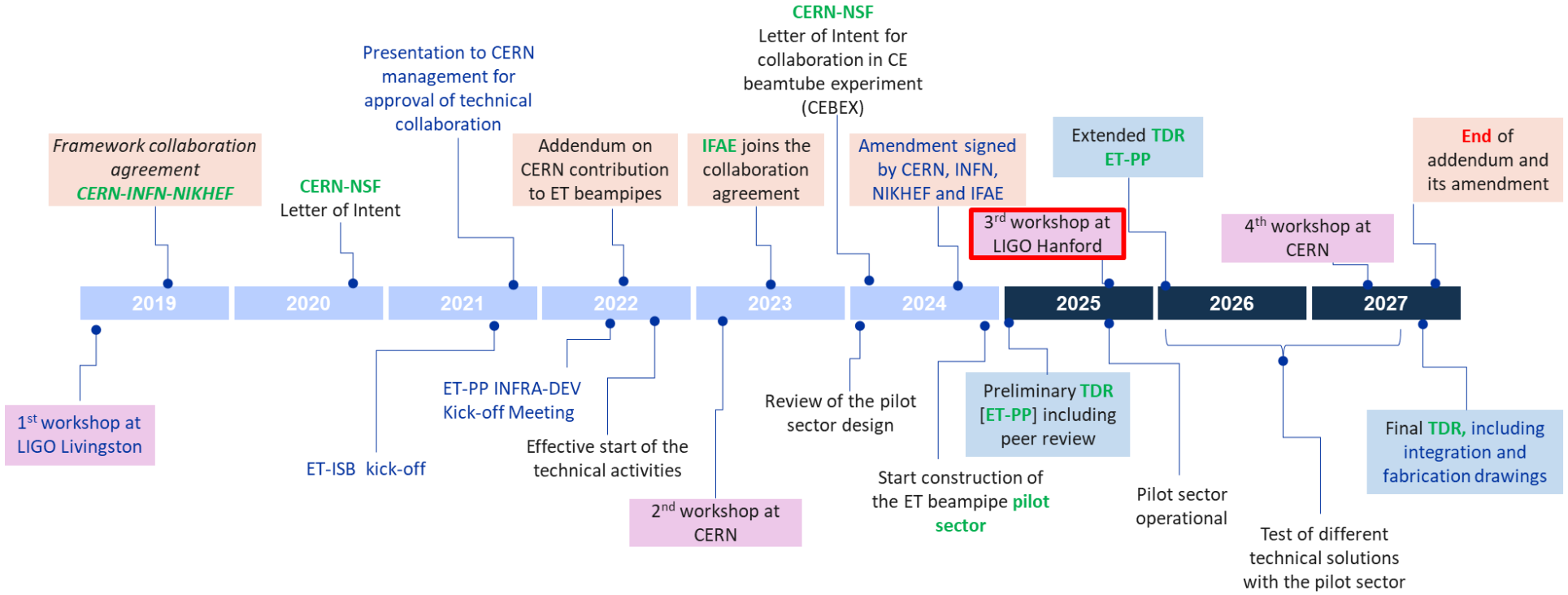
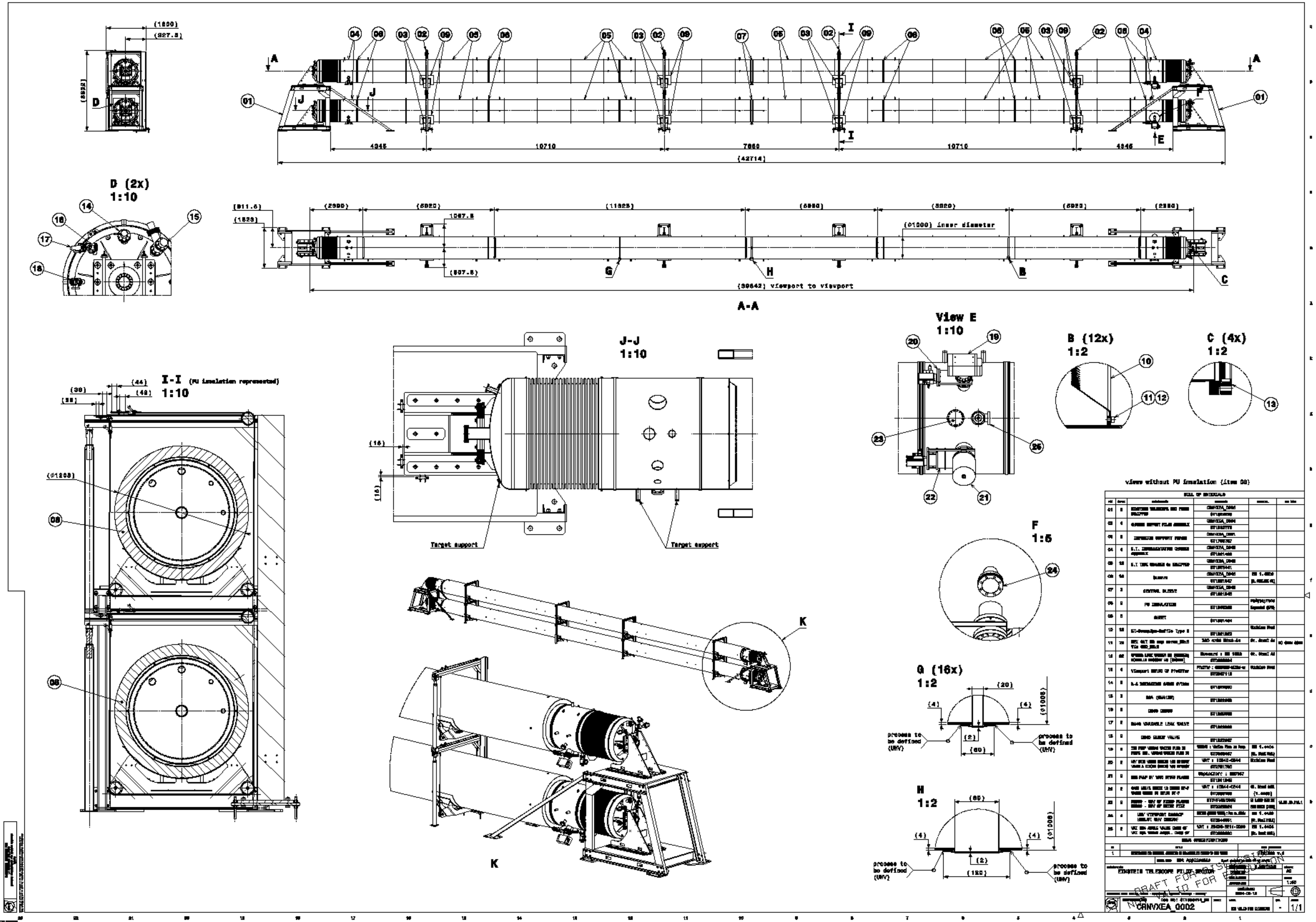
Timeline



Thanks for your attention!



BILL OF MATERIALS					
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01	2	[illegible]	[illegible]		
02	4	[illegible]	[illegible]		
03	8	[illegible]	[illegible]		
04	4	E.T. [illegible]	[illegible]		
05	12	E.T [illegible]	[illegible]		
06	14	SLEEVE	[illegible]	EN 1.[illegible]	
07	2	CENTRAL SLEEVE	[illegible]		
08	2	PU INSULATION	[illegible]	[illegible]	
09	2	SHEET	[illegible]		
10	12	ET-[illegible]-Baffle Type [illegible]	[illegible]	[illegible]	
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	
13	4	Viewport [illegible] Pfeiffer	[illegible]	[illegible]	
14	2	[illegible]	[illegible]		
15	2	RGA [illegible]	[illegible]		
16	2	[illegible]	[illegible]		
17	2	[illegible] VARIABLE LEAK VALVE	[illegible]		
18	2	[illegible] VALVE	[illegible]		
19	2	[illegible]	[illegible]	EN 1.4404	
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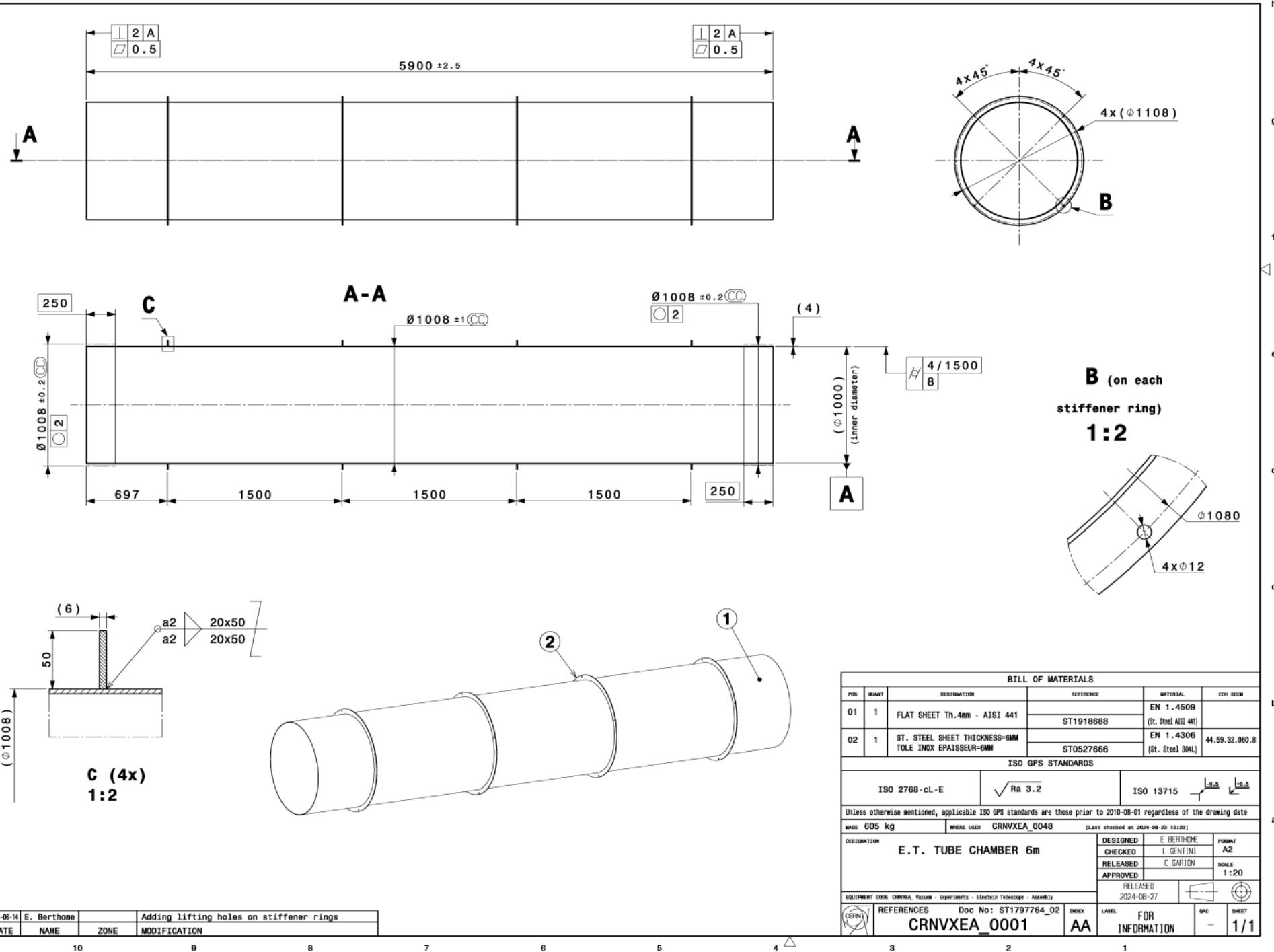
EINSTEIN TELESCOPE PILOT SECTION

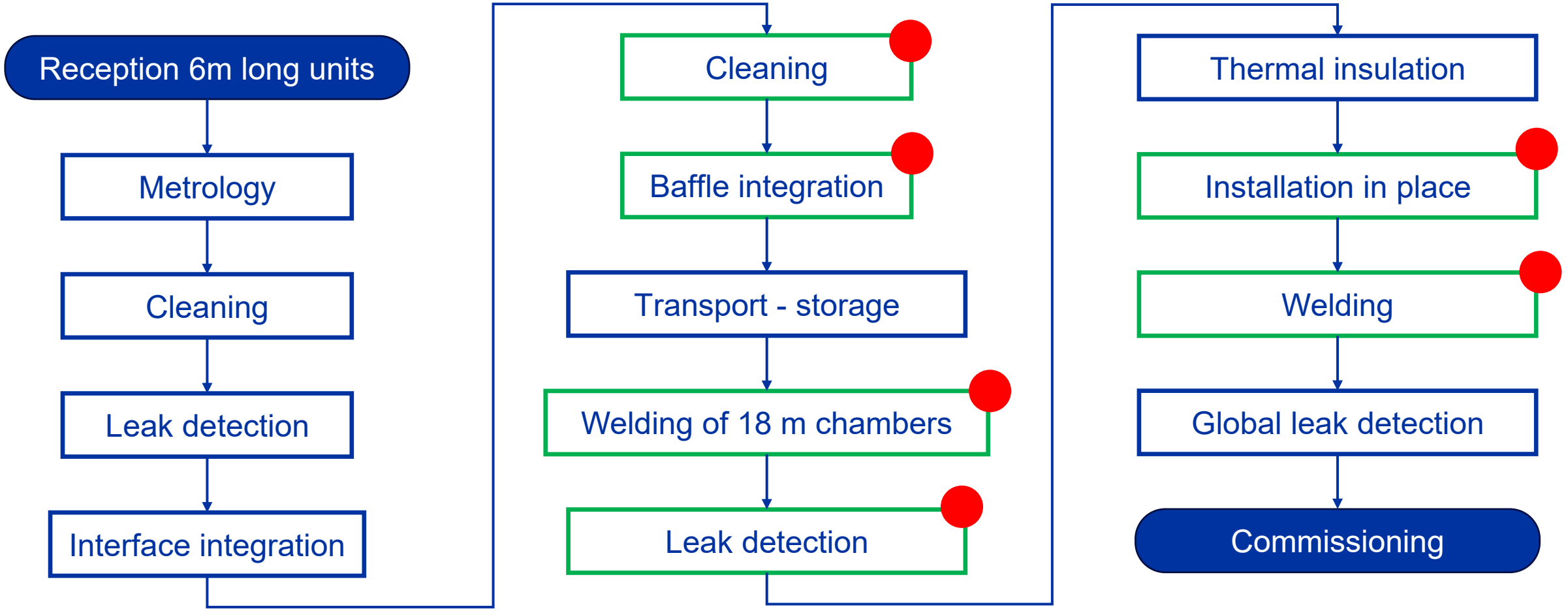
CRNVXEA_0002

Scale 1:50 — Sheet 1/1


5900 ±2.5
4x45°
4x45°
4x(Φ1108)
B
A-A
250
C
Ø1008 ±1 CC
Ø1008 ±0.2 CC
2
(4)
4/1500
8
(Φ1000)
(inner diameter)
Ø1008 ±0.2 CC
2
697
1500
1500
1500
250
B (on each stiffener ring)
1:2
Φ1080
4xΦ12
(6)
a2
a2
20x50
20x50
50
(Φ1008)
C (4x)
1:2
1
2
BILL OF MATERIALS
POS | QUANT | DESIGNATION | REFERENCE | MATERIAL | EDH SCEM
01 | 1 | FLAT SHEET Th.4mm - AISI 441 | ST1918688 | EN 1.4509 (St. Steel AISI 441) |
02 | 1 | ST. STEEL SHEET THICKNESS=6MM TOLE INOX EPAISSEUR=6MM | ST0527666 | EN 1.4306 (St. Steel 304L) | 44.59.32.060.8
ISO GPS STANDARDS
ISO 2768-cL-E
Ra 3.2
ISO 13715
Unless otherwise mentioned, applicable ISO GPS standards are those prior to 2010-08-01 regardless of the drawing date
MASS 605 kg
WHERE USED CRNVXEA_0048 [Last checked at 2024-08-23 13:39]
DESIGNATION E.T. TUBE CHAMBER 6m
DESIGNED E. BERTHOME
CHECKED L. GENTINI
RELEASED C. GARION
APPROVED
FORMAT A2
SCALE 1:20
RELEASED 2024-08-27
EQUIPMENT CODE CRNVXEA_ Vacuum - Experiments - Einstein Telescope - Assembly
REFERENCES Doc No: ST1797764_02
CRNVXEA_0001
INDEX AA
LABEL FOR INFORMATION
QAC –
SHEET 1/1
A | 2024-06-14 | E. Berthome | | Adding lifting holes on stiffener rings
IND. | DATE | NAME | ZONE | MODIFICATION
ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
GENEVE

Workflow of the vacuum chambers

Courtesy of P. Chiggiato



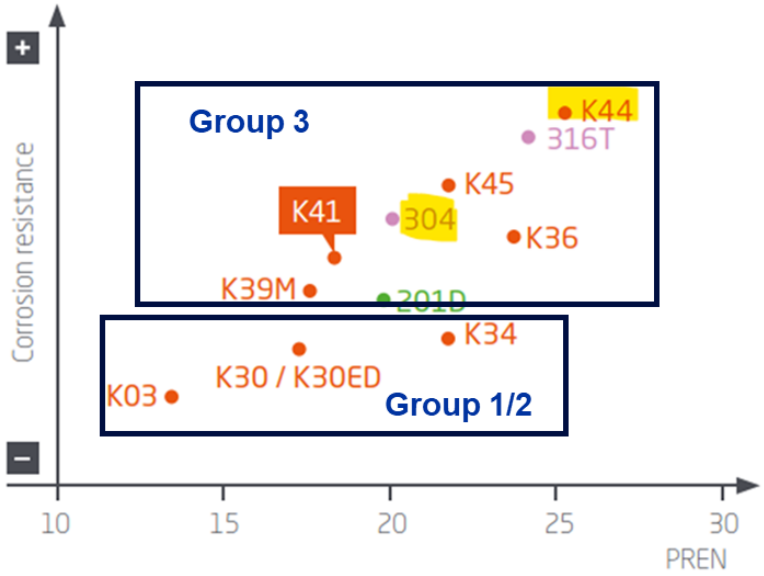
Standard procedure

Specific procedure to maintain dust cleanliness (soft wall cleanroom)

Lessons learned & perspectives

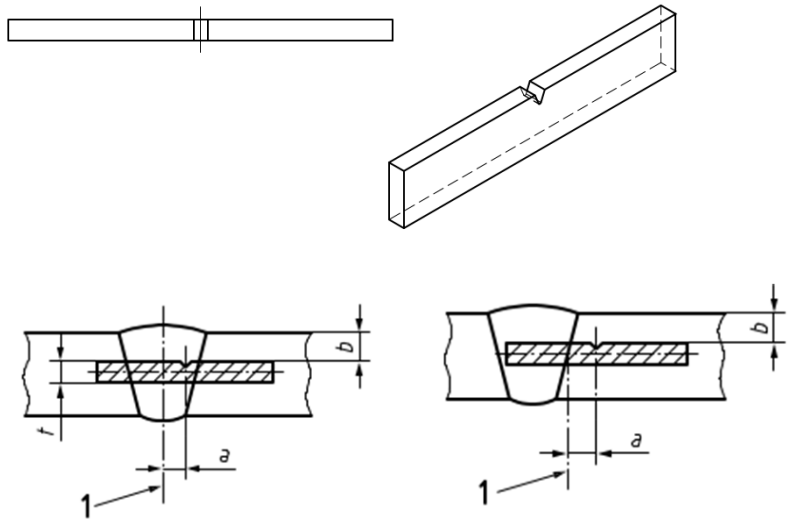
1. **Materials**
   - **Corrosion resistance** study ongoing → AISI 304L vs. ferritic StSt grades (electro chemical test & immersion test in water)
   - **Impact test** on welds → as welded and after thermal cycle (150C)
   - **1st beamline bellows in 304L vacuum fired.** Qualification on-going to use **AISI 441 on 2nd beamline**

Corrosion test



PREN = %Cr + (3.3 x %Mo) + (16 x %N)

Charpy test



Specimen extracted from centre of the weld

Specimen extracted from HAZ

Vacuum firing of 304L bellows

Objective for ET beampipe

Class	Maximum particles/m^3 [a]						FED STD 209E equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	
ISO 1	10[b]	[d]	[d]	[d]	[d]	[e]	
ISO 2	100	24[b]	10[b]	[d]	[d]	[e]	
ISO 3	1,000	237	102	35[b]	[d]	[e]	Class 1
ISO 4	10,000	2,370	1,020	352	83[b]	[e]	Class 10
ISO 5	100,000	23,700	10,200	3,520	832	[d,e,f]	Class 100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7	[c]	[c]	[c]	352,000	83,200	2,930	Class 10,000
ISO 8	[c]	[c]	[c]	3,520,000	832,000	29,300	Class 100,000
ISO 9	[c]	[c]	[c]	35,200,000	8,320,000	293,000	Room air

[a] All concentrations in the table are cumulative, e.g. for ISO Class 5, the 10 200 particles shown at 0,3 µm include all particles equal to and greater than this size.

[b] These concentrations will lead to large air sample volumes for classification. Sequential sampling procedure may be applied; see Annex D.

[c] Concentration limits are not applicable in this region of the table due to very high particle concentration.

[d] Sampling and statistical limitations for particles in low concentrations make classification inappropriate.

[e] Sample collection limitations for both particles in low concentrations and sizes greater than 1 µm make classification at this particle size inappropriate, due to potential particle losses in the sampling system.

[f] In order to specify this particle size in association with ISO Class 5, the macroparticle descriptor M may be adapted and used in conjunction with at least one other particle size. (See C.7.)

Source: https://en.wikipedia.org/

Mockup dust control

The mock-up was used to measure dust size and content during critical phases of the assembly

- The two halves of the mock-up were conditioned in a softwall portable cleanroom. ISO 6 conditions were measured inside and outside the mock-up.
- Sleeve assembly → ISO 6 (in the mock-up)
- Tack welding → ISO 7 (high in 0.3 to 1 µm particles)
- Final assembly → ISO 7 (high in 0.3 to 1 µm particles)
- Final welding → ISO 8 (very high 0.3 to 1 µm particles) ⟶ Outside cleanroom

Remarks:

- now we have a reference for improvement, and elements for discussion about the requirements
- The collaboration with the university of Padua was intensified to address the topic

Table 1: Dust assessment at different locations during different operations

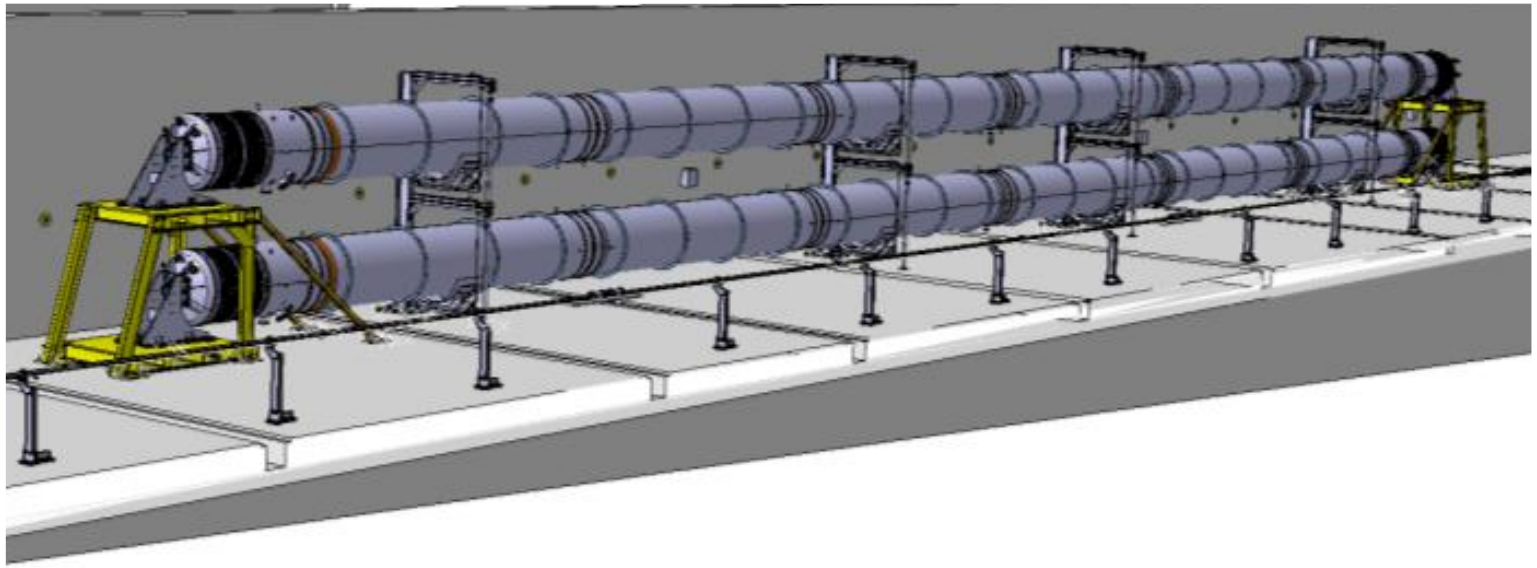
Activities	Baldaquin	Mock-up surface				Inside mock-up		Between sections	
	A	B1	B2	B3	C	D1	D1	E1	E2
Only operators	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6
Operator + welders (3 people)	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6
Operator + welders +Equipment's	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6	ISO 6
Plastic caps removal S1 (day1)	ISO 6	ISO 6	ISO 7	ISO 7	ISO 7	ISO 6	ISO 6	ISO 7	ISO 6
Sleeve positioning S1	ISO 6	ISO 6	ISO 7	ISO 7	ISO 7	ISO 6	ISO 6	ISO 7	ISO 6
Tack weld S1	ISO 6	ISO 6	ISO 7	ISO 7	ISO 7	ISO 7	ISO 6	ISO 7	ISO 6
Sleeve closure + tack weld S1	ISO 6	ISO 6	ISO 8	ISO 8	ISO 8	ISO 8	ISO 6	ISO 8	ISO 6
Plastic caps removal S2 (day 2)	ISO 6	ISO 7	ISO 7	ISO 7	ISO 7	ISO 6	ISO 7	ISO 7	ISO 7
Sleeve positioning S2	ISO 6	ISO 7	ISO 7	ISO 7	ISO 7	ISO 7	ISO 7	ISO 7	ISO 7
Tack weld S2	ISO 6	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8
Sleeve closure + tack weld S2	ISO 6	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8	ISO 8
Assembly completed + settling down(~2hrs)	ISO 6	-	-	-	-	ISO 7	ISO 7	-	-
Final welding outside baldaquine	-	-	-	-	-	ISO 8	ISO 8	-	-
1 day after welding	ISO 6	-	-	-	-	ISO 8	ISO 8	-	-
2 days after welding	ISO 6	-	-	-	-	ISO 8	ISO 8	-	-
5 days after welding	ISO 6	-	-	-	-	ISO 7	ISO 7	-	-
Before leak detection	ISO 6	-	-	-	-	ISO 7	ISO 7	-	-

Importance of dust control

The presence of **dust** can negatively impact the **performance of the baffles and mirrors**. This is particularly critical for the ET, where **light scattering** from the mirror surfaces must meet stringent requirements

Limit the dust: ISO 6 standards (as defined in ISO 14644-1) is requisite to limit dust contamination during all post-cleaning processes where the inner surfaces of vacuum pipes are exposed to air.

The choice and validation of cleaning techniques, cleaning agents, facilities and packing/transport materials and, in general, the procedure to be used to install the pilot sector lines should be based on preliminary trials, using appropriate cleanliness assessment techniques



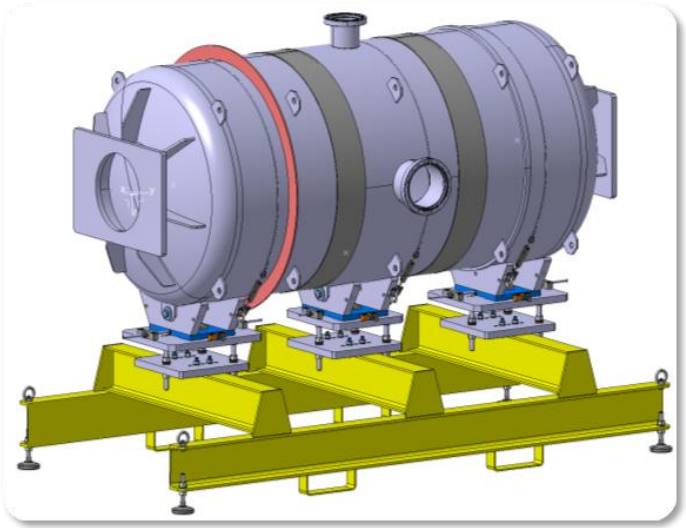
Our present approach

Objective: Our proposal is to minimize dust accumulation in the pilot sector as much as possible within our current capabilities. This will be achieved using **portable soft-wall cleanrooms** and **unidirectional airflow components** (horizontal and/or vertical), aiming to protect the pipes from worker-related contamination and environmental dust from the TT4 tunnel.

Preliminary Test: During the mock-up (Ø850 mm) cleaning in Building 107 and the assembly in TT4, dust levels will be monitored using standardized instruments (**dust counters**) and evaluated through **witness samples** (carbon stickers). **The goal** is to assess the dust level and its composition in the different steps of the fabrication using existing means and a pragmatic procedure.

Are we meeting the ISO 6 environmental conditions?

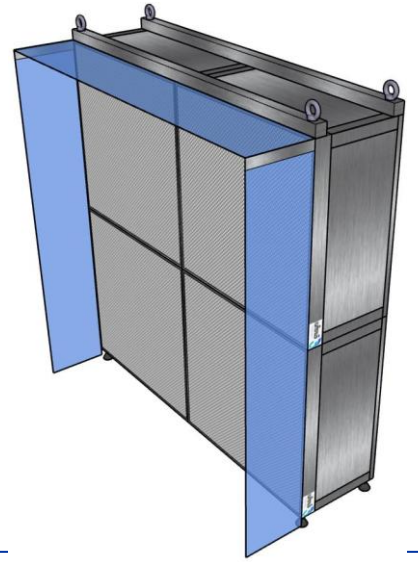
Mock-up



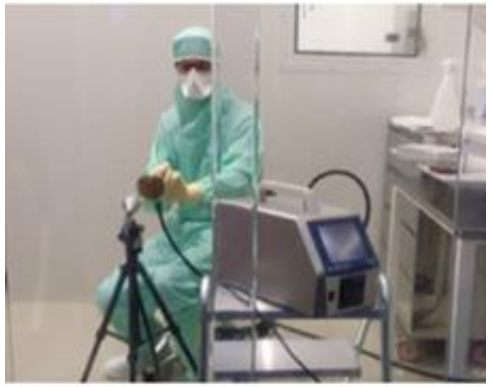
Vertical laminar flow

Portable Cleanroom, Softwall Curtains, Wheels, ISO 6

Horizontal laminar flow wall



Dust counter



Procedure

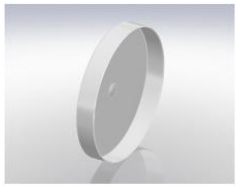
Cleaning: The final cleaning step is considered as the 'time zero' for dust accumulation in the beampipes. After the standard cleaning procedure for UHV StSt components at CERN (detergent cleaning by ultrasound agitation and rinsing) the components will be placed in less than 5 minutes on the drying position within the horizontal laminar flow. *Assessment to be performed in b. 107 for the mock-up*

Packing and transport: When dry, the extremities are closed by cleanroom packaging sheets, UHV compatible adhesive tape, and plastic pallets protecting also the welding area on the external part of the wall.
Flushing the outer film with N2 to clean the dust settled during the transport might be useful before accessing the clean area in TT4

Installation in TT4: The floor has been cleaned, and a portable cleanroom is being installed in the working area. *The final cleaning is foreseen Dec. 2nd*
All components (valves, gauges, gaskets…) will be cleaned with particle free ionized nitrogen. After 5 minutes using a gas throughput of abut ten l/min, less than about 10 particles/minute larger than 0.3 μm should be detected.


Cleaning facilities

Courtesy of P. Revathi

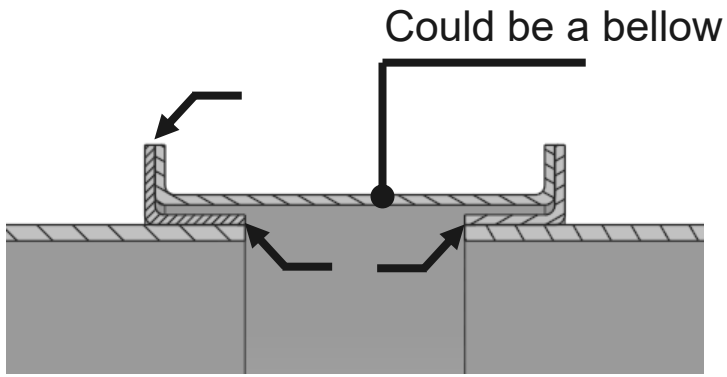

(a) Plastic cap

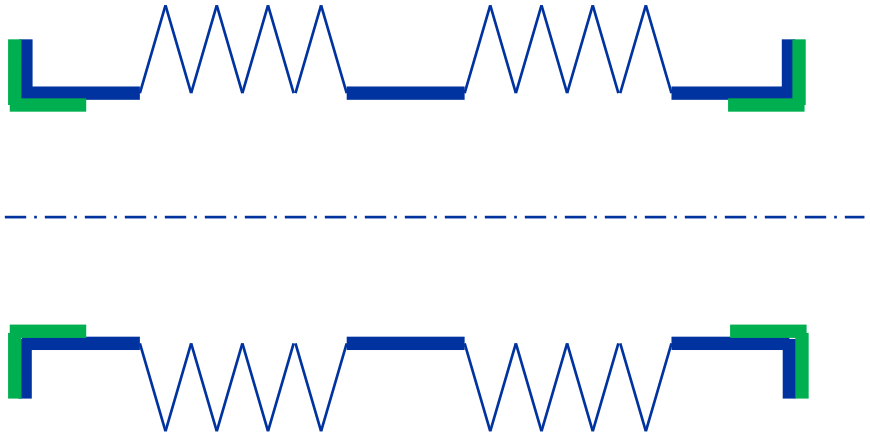

(b) Plastic pallet


(c) PE film


Working area in TT4

Joining techniques: Alternative proposals





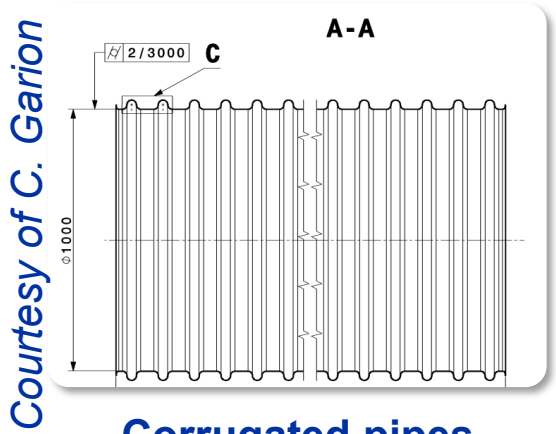
- No machining for tube ends
- Tolerant to extremities ovalization
- Collars could be made by spinning metal or deep drawing
- Possibility to weld only one side in the tunnel
- Cut and welding out of tube direct view
- Requires external pumping O-ring for leak detection of the collar (existing solution – needs implementation.)

ET-PS bellow.

EN-MME contribution:

Define fabrication and welding procedures applicable to the pilot sector and ET beampipes

Two technical solutions:

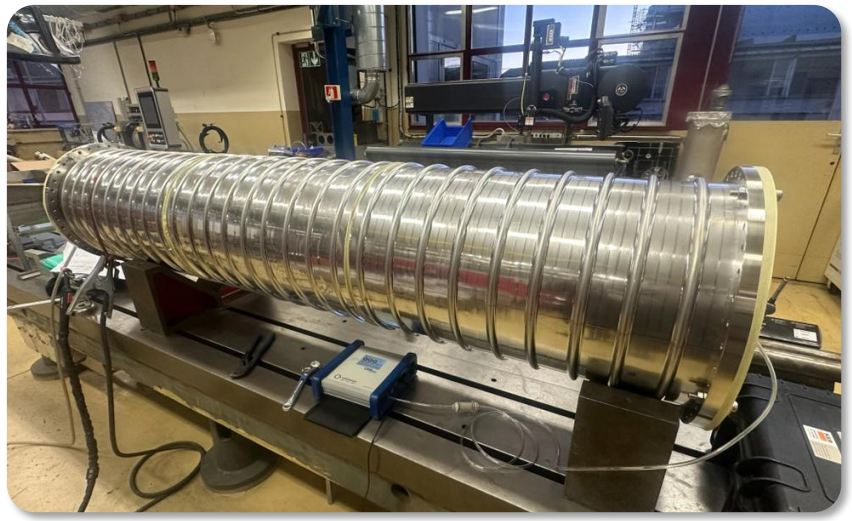


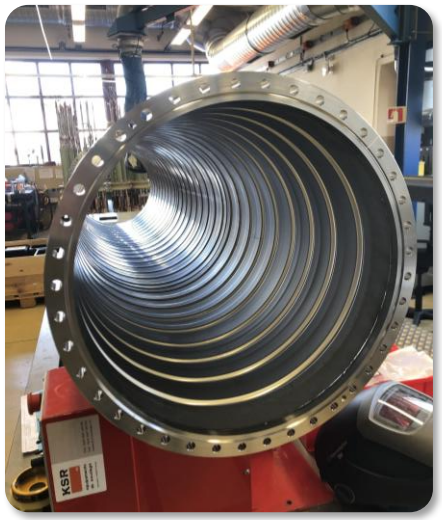
Courtesy of C. Garion

Corrugated pipes
Thin walls (≤ 2 mm)
Longitudinal welding
Corrugation after welding

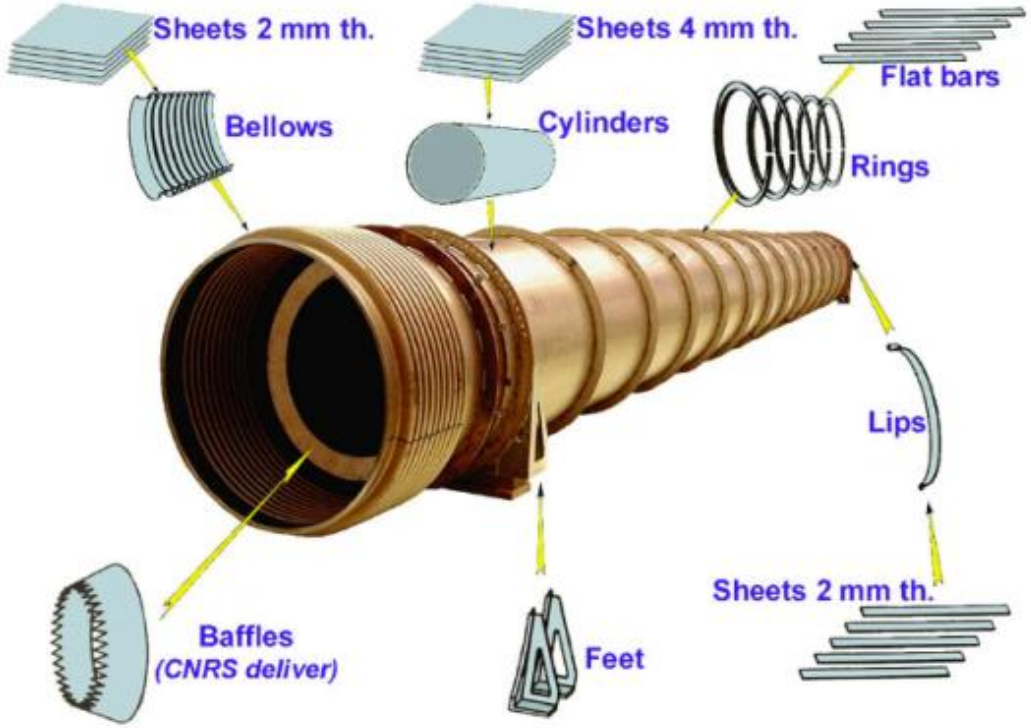
Prototypes

Annular corrugation performed at CERN





Virgo Pipes



Courtesy: A. Pasqualetti

Vacuum measurements

Configuration 0

The 2 endmodules welded together with a sleeve

Cut sleeve welding

Reclean the endmodules dust-free

Install & weld 6 chambers and endmodules

Configuration 1

The 2 endmodules & 6 pipes welded together with sleeves

Measurement setup

A. **All pumps (with orifice) and instrumentation mounted**
Ultimate pressure
Isosteric measurement

B. **Accumulation system mounted with a VLV**
Outgassing measurement
Isosteric measurement

ET vacuum system

Interdepartmental collaboration

Project leader Paolo Chiggiato (**TE-VSC**)
Deputy Anité Pérez (**EN-MME**)

CERN staff members (contributing an amount equivalent to 2 FTE), 2 fellows, 1 PhD student and 1 engineer of the University of Antwerp (joined in 2024)

WP1: Engineering	WP2: Production	WP3: Treatments	WP4: Transport
Design and engineering of the vacuum chamber	Choice of materials and manufacturing technology	Choice of post-manufacturing treatments	Handling and logistics
WP5: Installation	**WP6: Vacuum**	**WP7: Prototyping**	**WP8: Coordination**
Installation procedure and interface with other systems	Choice of vacuum pumps and valves	Installation and test of a pilot sector	Coordination of the different WP + collaborators contribution

Objectives:

- To design and test **technical solutions** that fulfil the ET requirements and **cost effective**
- To manufacture, assemble and test a **pilot sector** (in TT4)
- To write the **TDR**, including cost estimations

Main requirements in ET:

- Beampipes of **Ø1 m x 120 km**
- **UHV** (H_2 partial pressure 10^{-10} mbar)
- Fast production and easy to handle in an **underground facility**
- **Supports** capable of holding, aligning and dumping the pipes
- Lifetime **50 years**