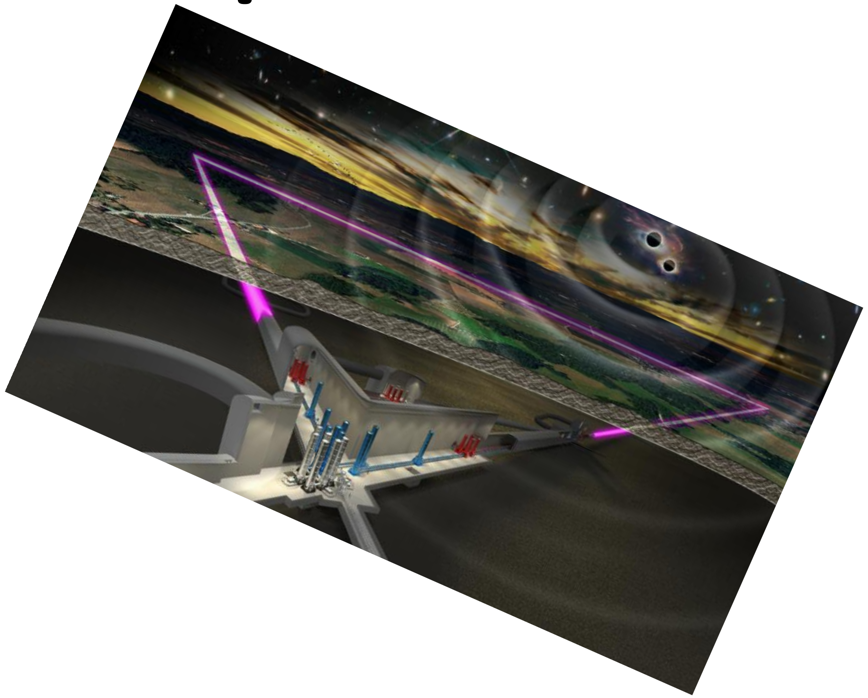
Status of the beampipe development



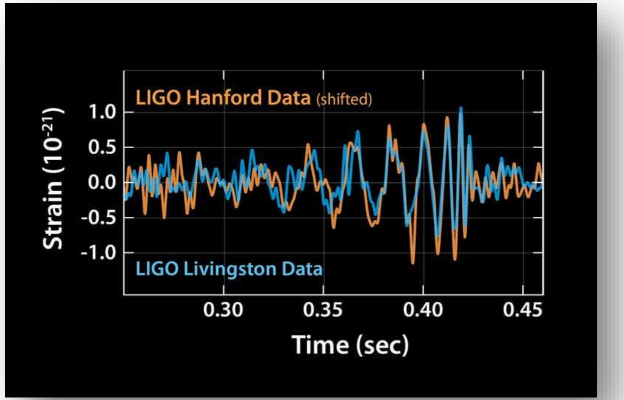
Patrick Werneke, Marije Barel

September 3, 2024

Content

- Why build ET: Vacuüm arms of the Einstein Telescope
- What to build: Requirements
- How to build:
  - CERN as partner
  - Upcoming challenges

WHY



WHAT

HOW

Why? See documentation

- ET conceptual design report CDR (2011)
- Einstein Telescope: Science Case, Design Study and Feasibility Report (”30 pages” ESFRI document), ET-0028A-20, 2020
- ET design report update 2020 (”long ESFRI document”), ET-0007A-20, 2020
- Science Case for the Einstein Telescope, arXiv:1912.02622, 2020
- ET cost book, ET-0000A-20, 2020
- Socio-economic impact of the Einstein Telescope - Executive Summary, ET-0001A-20, 2020
- Einstein Telescope: An assessment of its economic, social and environmental impact in Sardinia, ET- 0008A-20, 2020
- Management structure of the ET Collaboration (Working document), ET-0069A-20, 2020
- Tevens kan veel materiaal worden gevonden via de Workshop Beampipes for Gravitational Wave Telescopes 2023: https://indico.cern.ch/event/1208957/timetable/?view=standard
- De ontwerpeisen voor de vacuumbuizen voor de delta configuratie kunnen worden gevonden in het volgende document. Voor de 2L configuratie kan men voorlopig uitgaan van vergelijkbare condities, aan een uitbereiding wordt gewerkt: Einstein Telescope beampipe requirements, ET-0385A-24, 2024


Einstein Telescope beampipe requirements

ET-0514A-23

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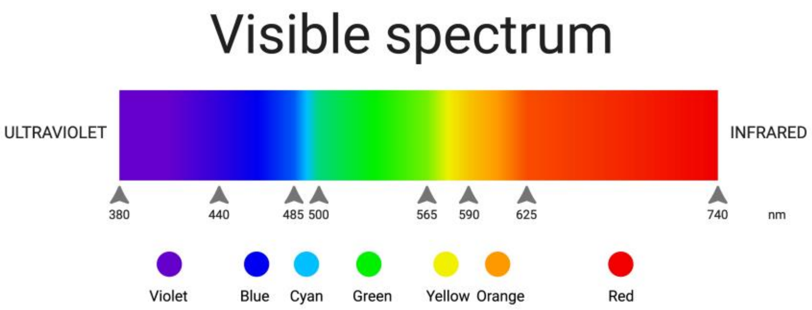
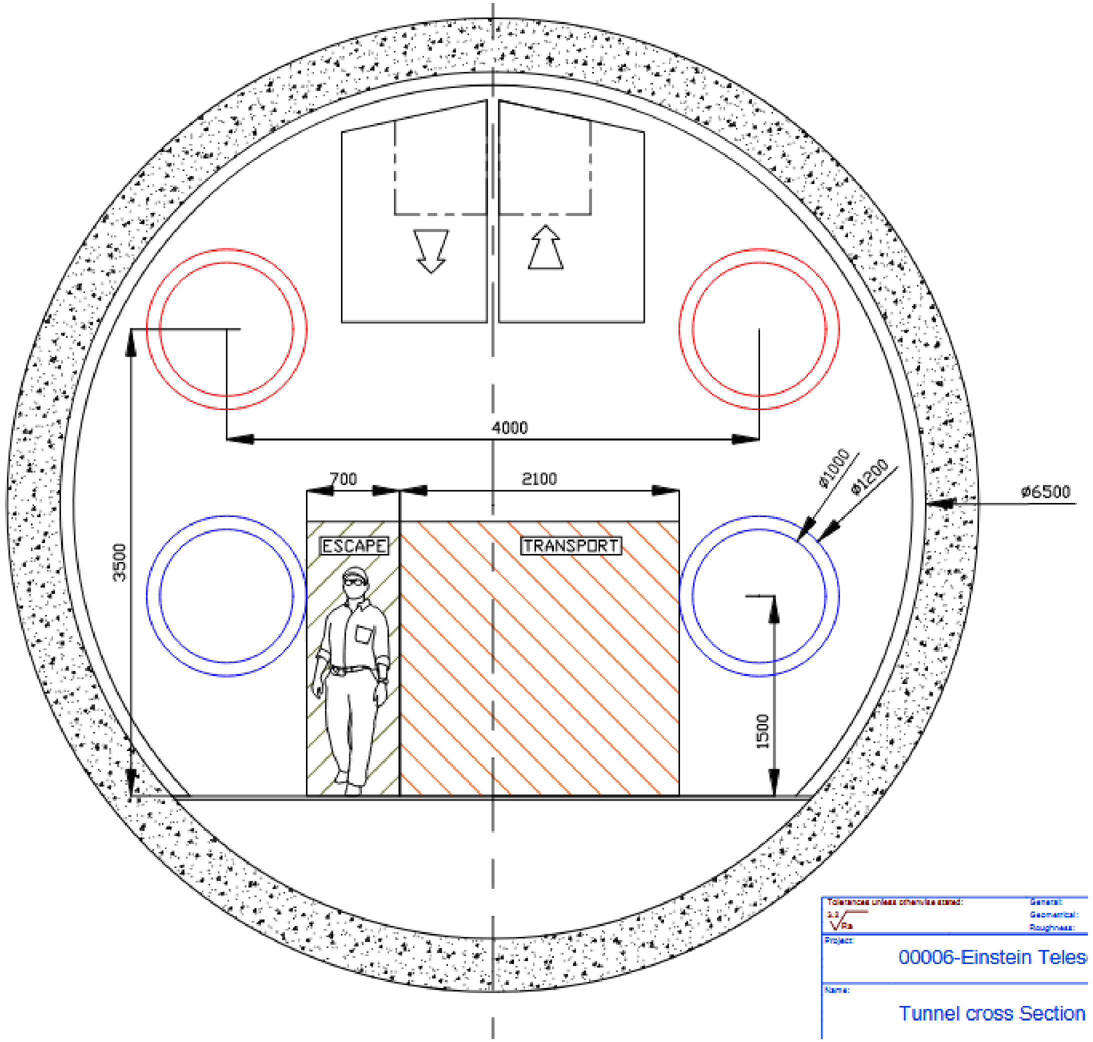
What to build?

The ET might features a configuration of underground tunnels, each 10 - 15 kilometers in length, housing laser interferometers.

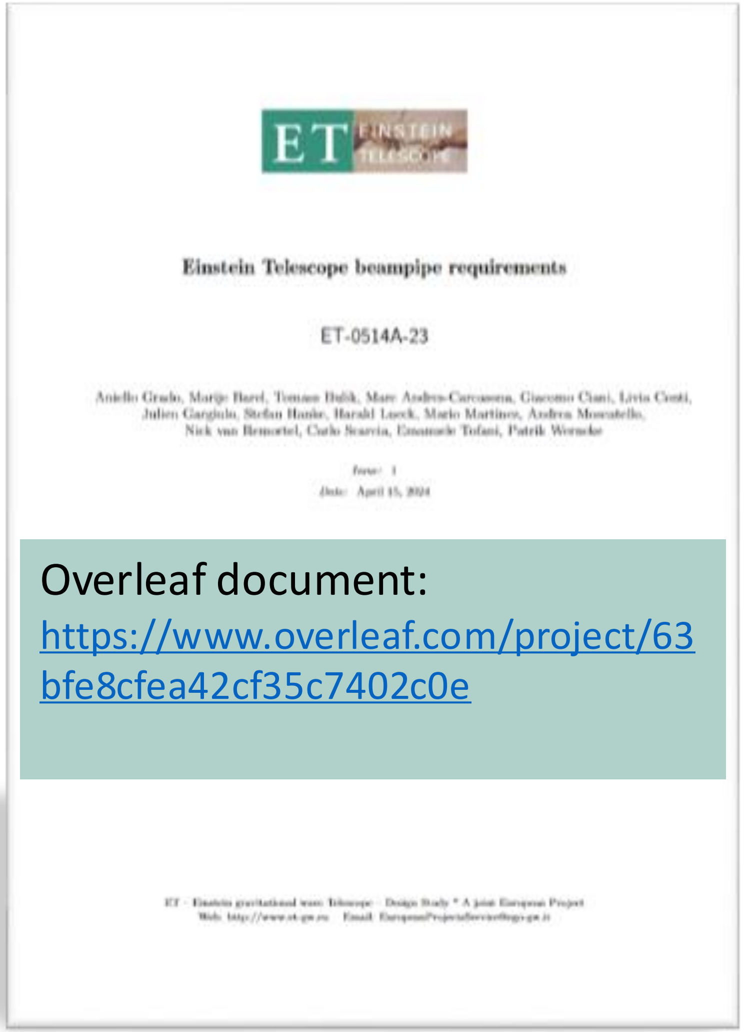
Low Frequency (LF: 1550nm laser) and High Frequency (HF: 1064nm laser),

To be built **200-300 m** underground





Vacuüm arms requirements

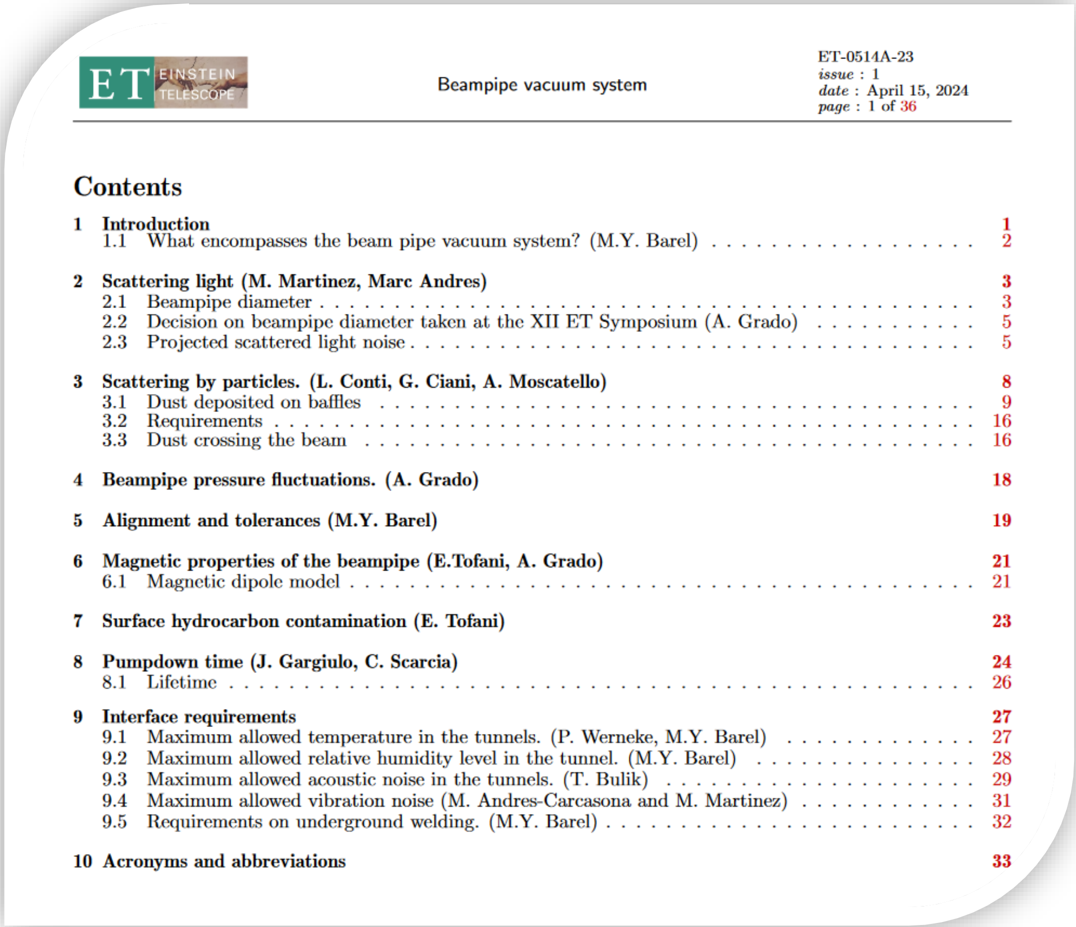


Einstein Telescope beampipe requirements

ET-0514A-23

Date: April 15, 2024

Overleaf document:
https://www.overleaf.com/project/63bfe8cfea42cf35c7402c0e



Contents

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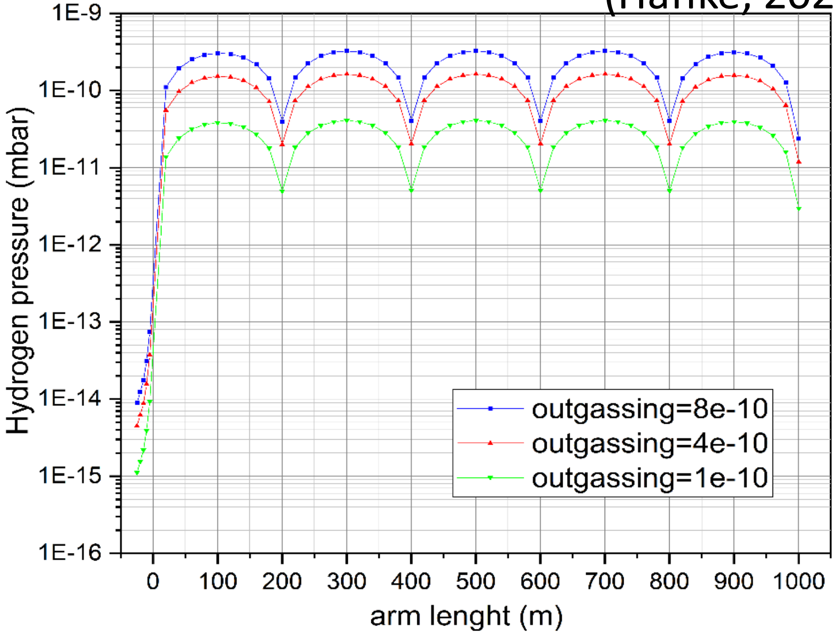
How to build:

Tabel 1: Partiele druk eisen (Zie ET-0385A-24)	
Gas Species	Max.restdruk [mbar]
H_2	5.3×10^{-11}
H_2O	9.6×10^{-12}
N_2	5.6×10^{-12}
CO	2.2×10^{-12}
CO_2	2.0×10^{-12}
Carbohydrates	9.1×10^{-14}

(Hanke, 2022)



Example of distributed pumping

CERN as partner

For your industry knowhow

Tabel 1: Partiele druk eisen (Zie ET-0385A-24)	
Gas Species	Max.restdruk [mbar]
H_2	5.3×10^{-11}
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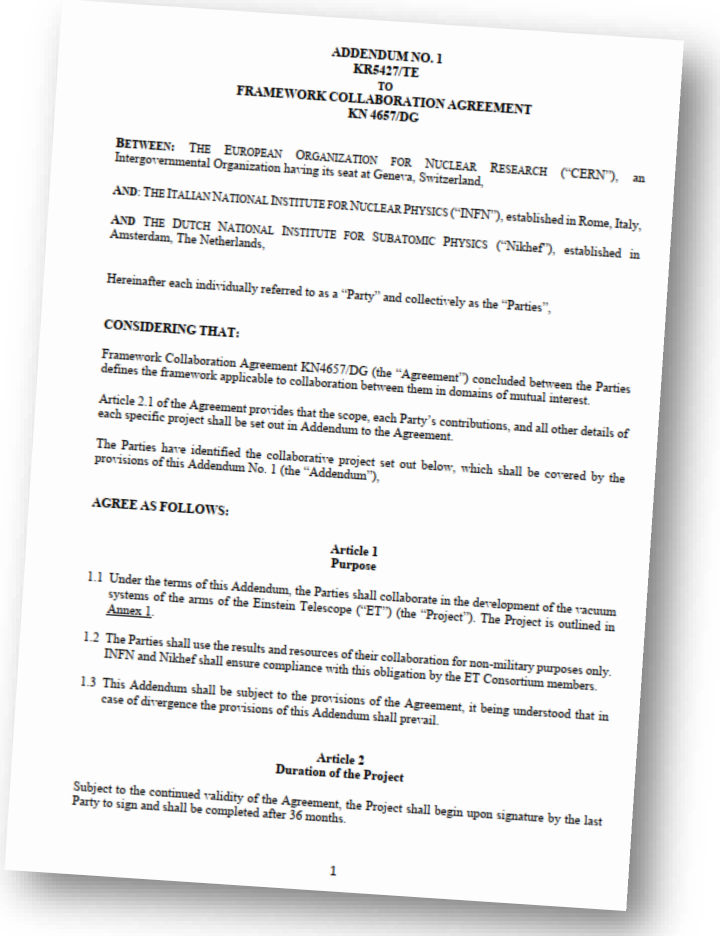
N_2	5.6×10^{-12}
CO	2.2×10^{-12}
CO_2	2.0×10^{-12}
Carbohydrates	9.1×10^{-14}

Is this a special type of pressure cooker?

MoU with CERN on contributing to beampipes

- The main objectives are:
  - **Coordinate the contributions** of all Parties involved in the study of ET beampipes.
  - Preparation and writing of the '**Technical Design Report**' for the vacuum systems of the ET's arms, including cost estimations.
  - Design, manufacturing, assembling, and tests of a **pilot sector** of the selected ET-beampipe vacuum systems.
  - Contact and sharing of information with **Cosmic Explorer**
  - *Find a cost effective solution -*

- **In the process of extending the contract for the vacuum beampipe until August 2027**



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

The work structure

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

Each work package will provide input for the TDR and cost estimation

WP1: Beampipe profile design

Straight beampipe
(LIGO/VIRGO-like)

- **3-4 mm thick tube**
- **Requires bellows & stiffeners**
- **Discontinuous manufacturing flow**

Corrugated beampipe
(CERN proposal)

- **1-2 mm thick tube**
- **30% less current joule bakeout***
- **No bellows & stiffeners**
- **~60% lighter modules [kg/m]**
- **Continuous manufacturing flow**

Credit: LIGO

Credit: CERN

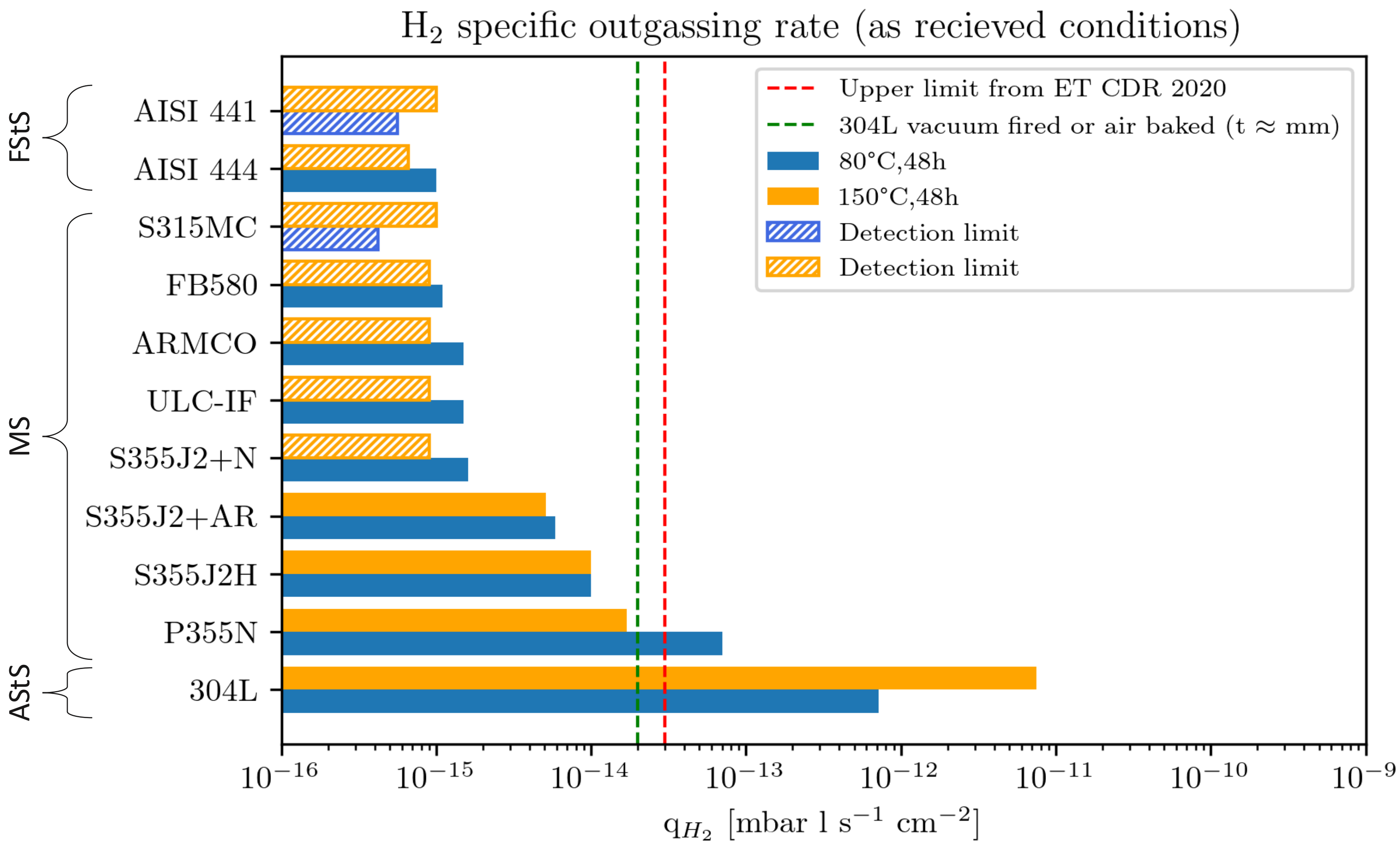
*DC bakeout with the same insulation material

WP2: Vacuum characterization of ferritic alloys

H_2 outgassing rate

Ferritic alloys
Mild steel and ferritic SS

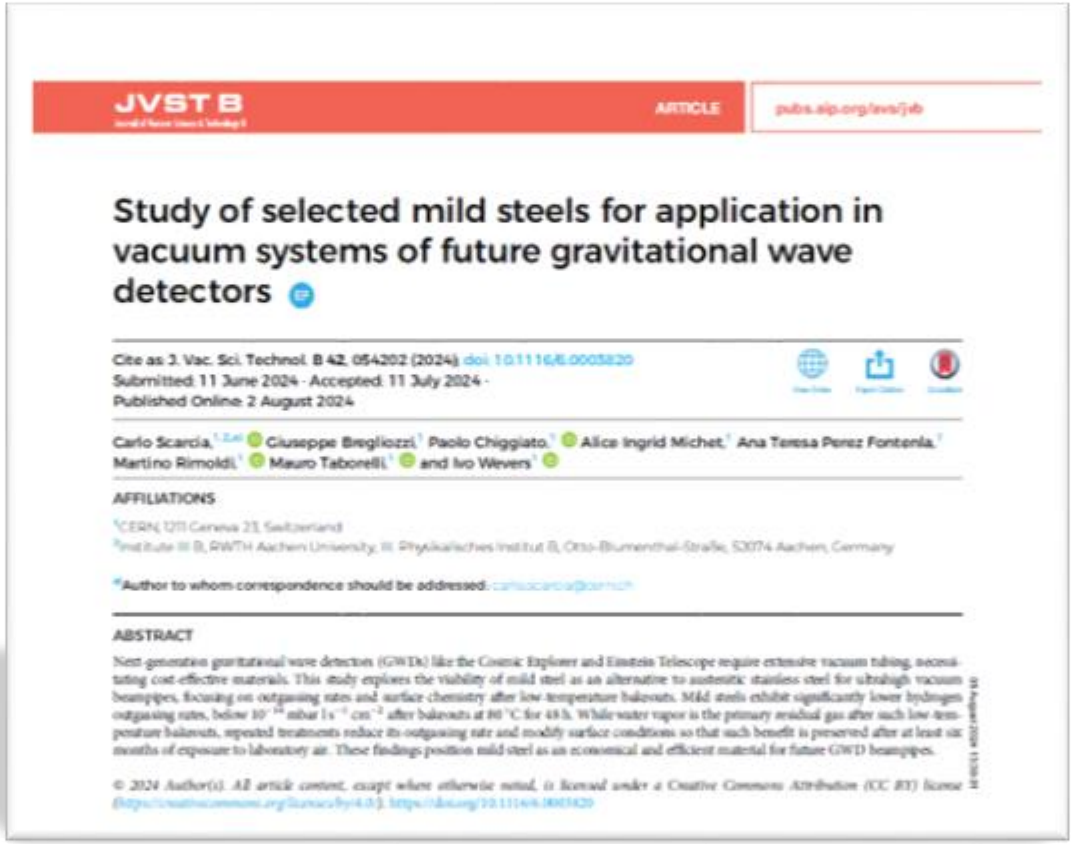
- **Outperform austenitic StS outgassing rates without requiring HT treatment**
- **Lower material cost (>30% saving)**



CH_4, CO and CO_2 were also investigated.

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

Carlo Scarcia, "Study of selected mild steels for application in vacuum systems of future gravitational wave detectors," *Journal of Vacuum Science and Technology,* 5 august 2024


JVST B

ARTICLE

pubs.aip.org/avs/jvb

Study of selected mild steels for application in vacuum systems of future gravitational wave detectors

Cite as: J. Vac. Sci. Technol. B 42, 054202 (2024); doi: 10.1116/6.0003820
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ABSTRACT

Next-generation gravitational wave detectors (GWDs) like the Cosmic Explorer and Einstein Telescope require extensive vacuum tubing, necessitating cost-effective materials. This study explores the viability of mild steel as an alternative to austenitic stainless steel for ultrahigh vacuum beampipes, focusing on outgassing rates and surface chemistry after low-temperature bakeouts. Mild steels exhibit significantly lower hydrogen outgassing rates, below 10^{-14} mbar l s^{-1} cm^{-2} after bakeouts at 80 °C for 48 h. While water vapor is the primary residual gas after such low-temperature bakeouts, repeated treatments reduce its outgassing rate and modify surface conditions so that such benefit is preserved after at least six months of exposure to laboratory air. These findings position mild steel as an economical and efficient material for future GWD beampipes.

Reports from the ETT project from 2023

Please note that these have partially overlapping material studies with CERN, Carlo Scarcia.
Ferritic StSt 441 was not part of the ETT project of 2023.

- D2.1. Performance Matrix
- D2.2. Inventarisatie randvoorwaarden constructie
- D2.3. Literature review outgassing
- ETT Plenary Progress Meetings
- D2.4. Samples base materials
- D2.5. Setups for Outgassing Measurements
- D2.7. Coatings and outgassing
- D2.6. Design Test Structures
- D2.8. Outgassing measurement results
- D2.9. Surface Analysis of Samples
- D2.11. Inventory of limitations
- D2.12. Concept production process
- D2.13. Cost-Benefit Analysis
- D2.10. Analysis of test results


ET Technologies

Titel Deliverable	2.13 Material performance analysis (org: Kosten-baten en SWOT analyse)

EUROPESE UNIE

OPZuid

provincie limburg

1. Conclusion and recommendations

The materials currently under examination encompass Stainless Steel (SS304L), Low-Carbon Steel variants[1] (IF01, ULC01, LC01, LC02), and Aluminium in two forms (6061, T6 and 6061, T651). Different alloys were chosen to be able to compare the effects of Carbon content. IF and ULC have a low C content while LC01 and LC02 have a increasing C content. The aluminium alloys differ in their stress-relief treatment. In this summary we aim at comparing the steel to mild steel and aluminium and leave out these alloy differences. This summary of the extensive cost-benefit report, identified as deliverable D2.13, aims to address the pivotal question:

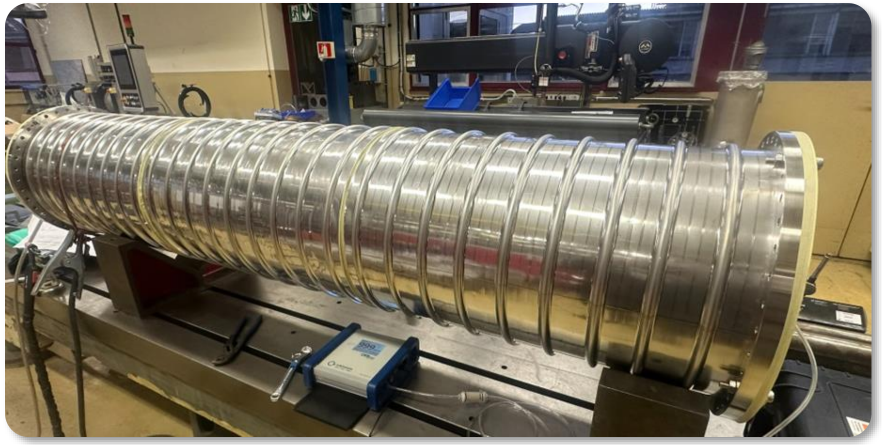
"How do the selected materials perform on operation and cost within the design of the beampipes for the Einstein Telescope?"

Furthermore it is recommended to:

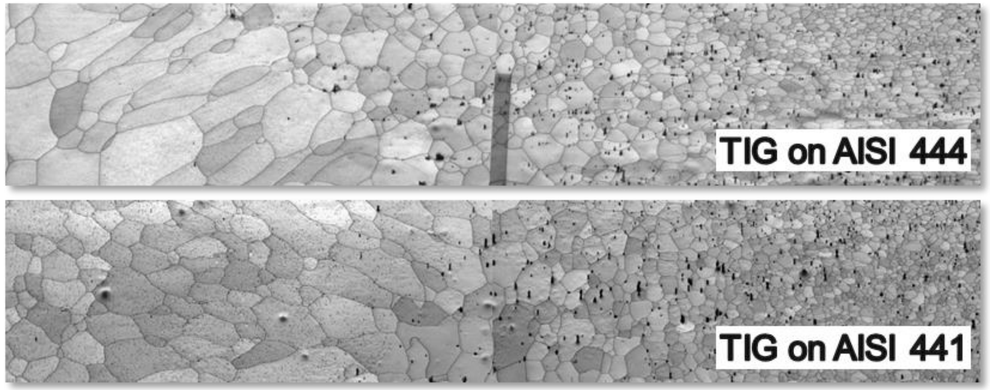
- investigate the design of the surface engineering and cleaning. More study is needed for the samples with regards to the surface morphology of the oxides and the surface morphology due to surface mechanical treatments / production process. There is a need for investigating the outgassing with respect to surface morphology, specifically rusted metal.
- investigate the possibility of an industrial vacuum anneal step.
- continue the work on the welding especially on weld reliability.
- improve price estimations and give better sources. Information references for prices estimated in this report are weak.

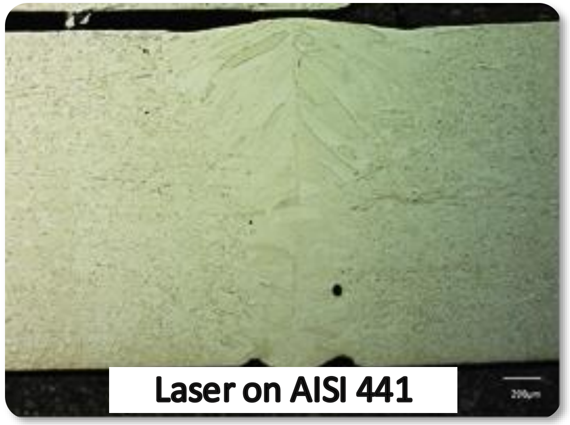
WP2: Manufacturing

Prototypes manufacturing



Welding optimization and alternative design





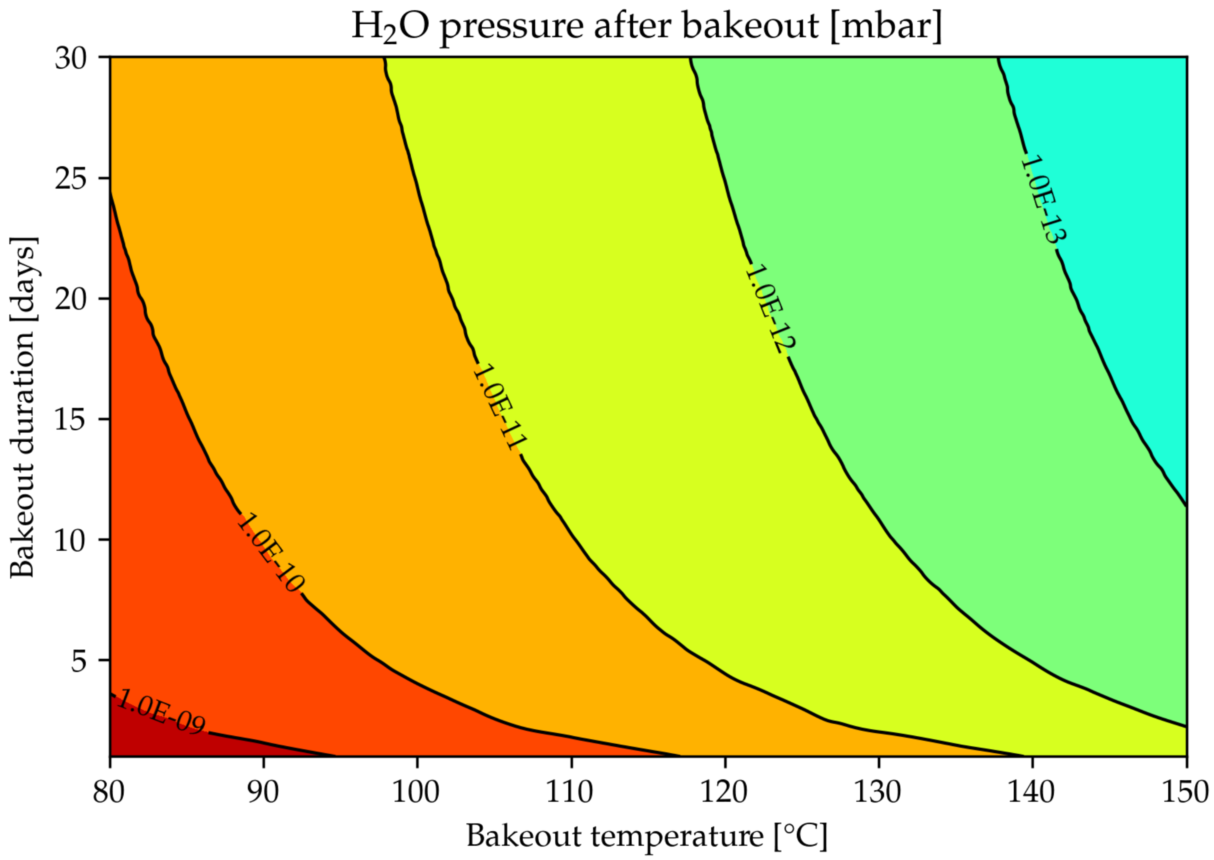
WP6: Bakeout optimisation

Post-bakeout outgassing modelling

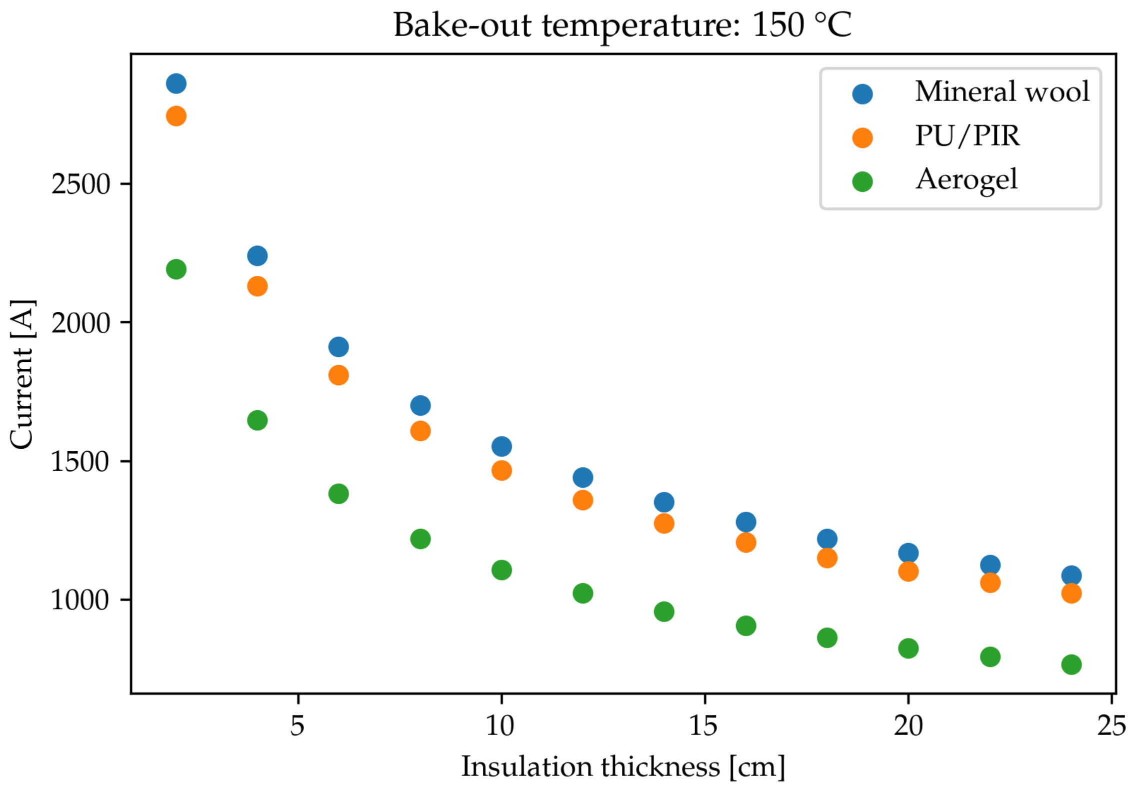
- **Bakeout temperature** and **duration**
- **Pumps size** (commercial) and **distribution**

Insulation material characterisation

- **Different material** and **thicknesses**
- **Cost optimization (~ 10 M€)**

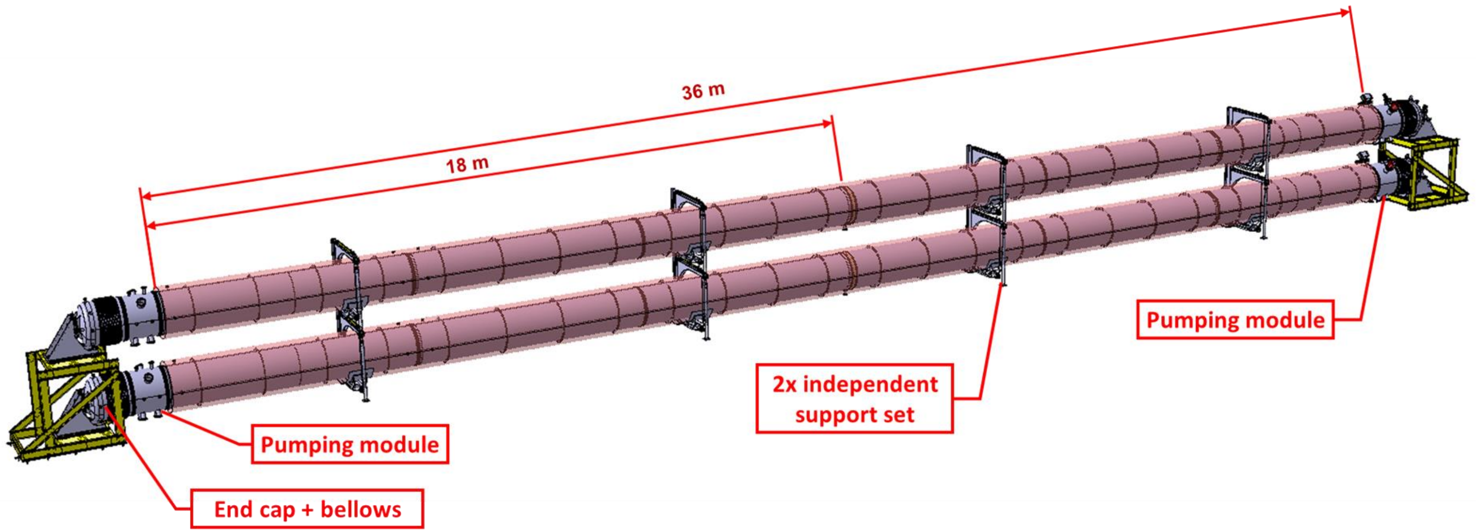


Pumps distribution:1 Turbomolecular pump (1000 l/s nominal) every 1250 m



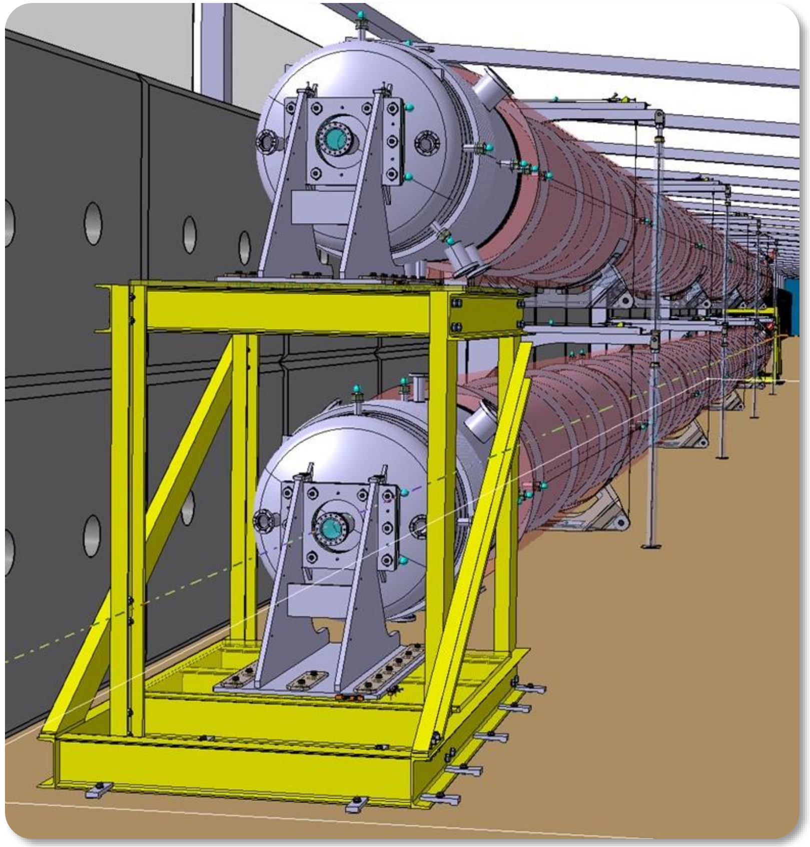
The ET pilot sector @ CERN

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



First pilot sector (2025)
“Optimised baseline”

AISI 441 VIRGO-like pipe
Ø 1.08 m x 4 mm x 36 m (6 m sections)



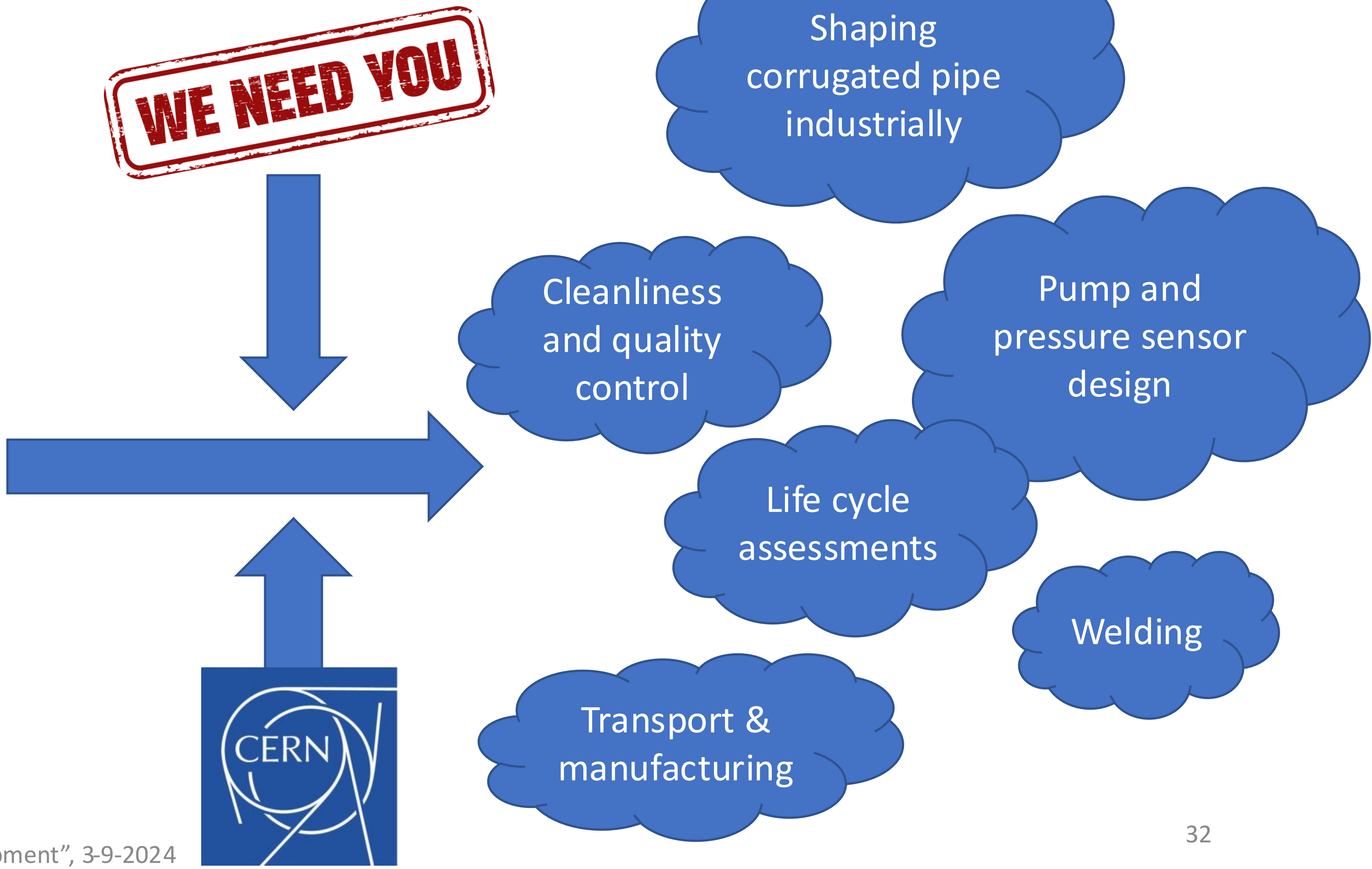
Location: TT4 (underground technical tunnel)

Concluding

- AISI 441 is currently the preferred beampipe material
  - Welding for UHV is an issue and corrosion resistance is being tested.
- The corrugated beampipe is still considered a cost effective solution for ET
  - Less material, no bellows and less power for bake-out
  - Thin material is more important for 304L, due to the need of vacuum firing
- Pilot sector to test the production and QA/QC steps
- AISI 304L and reinforced straight tube is back up solution

Upcoming challenges

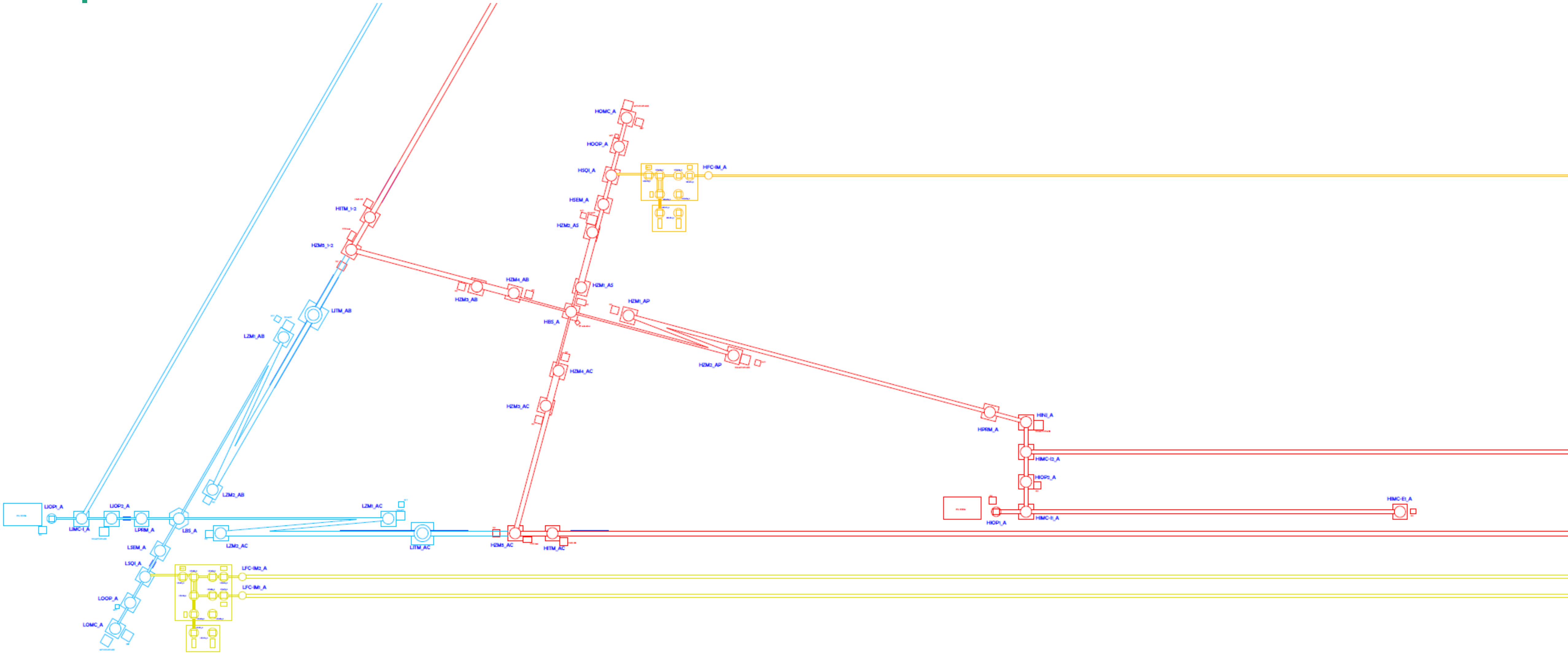
"Hoe bouwen we de 120 km aan UHV vacuümbuizen voor de armen van de Einstein Telescoop, dat aan alle eisen voldoet?"

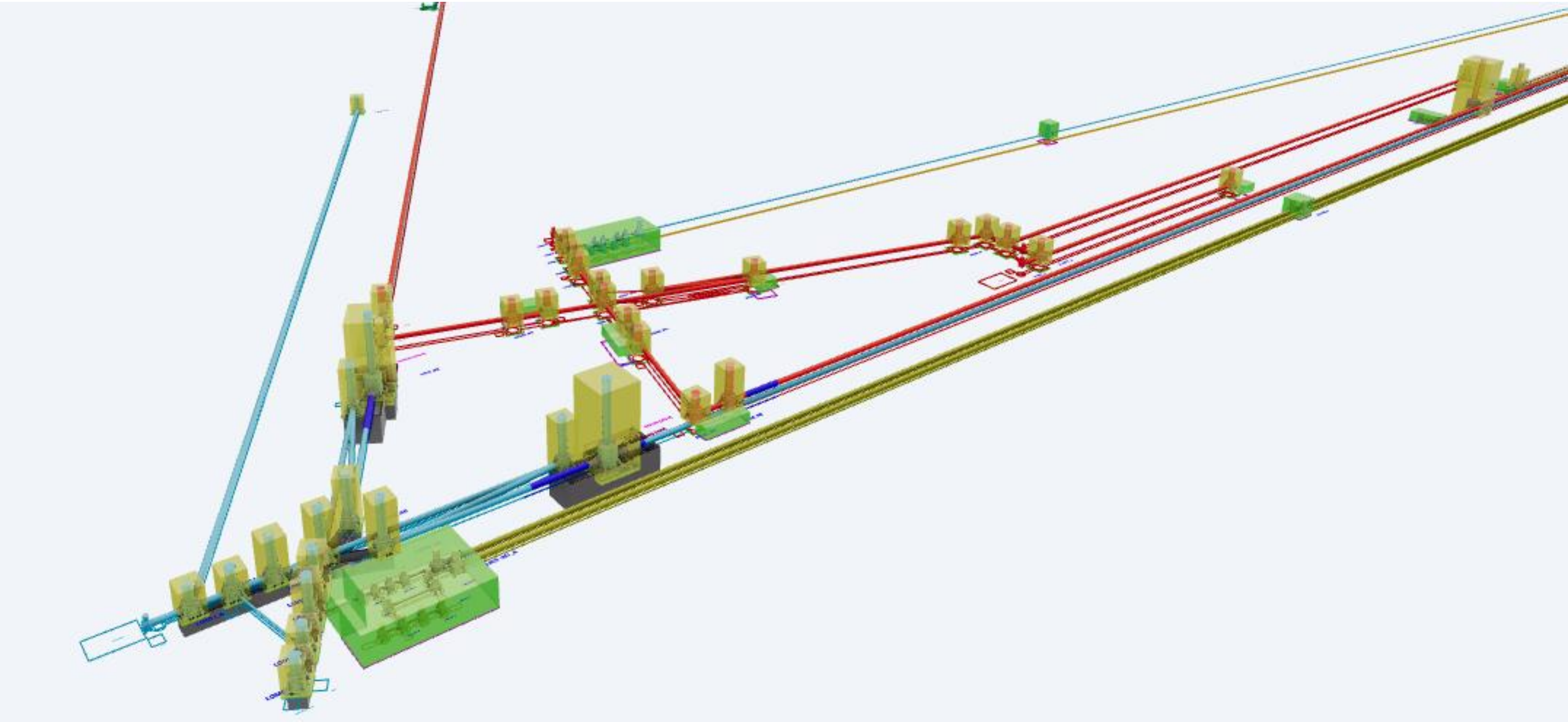


Suggestions / Questions?

ET EINSTEIN TELESCOPE

Optical Layout





The Einstein Telescope Collaboration

- **87 Research Units (+1 request pending)**
- **1609 members (12/02/2024)**
- **Total: 233 Institutions in 27 Countries**

- **ET member database**

ET Member‘s affiliation map

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