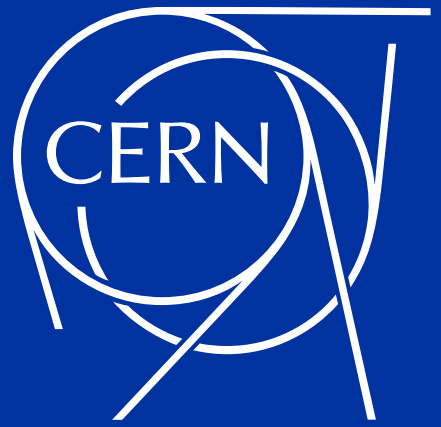


EN-MME contribution to the ET project: the vacuum system

Anité Pérez – EN-MME-MM

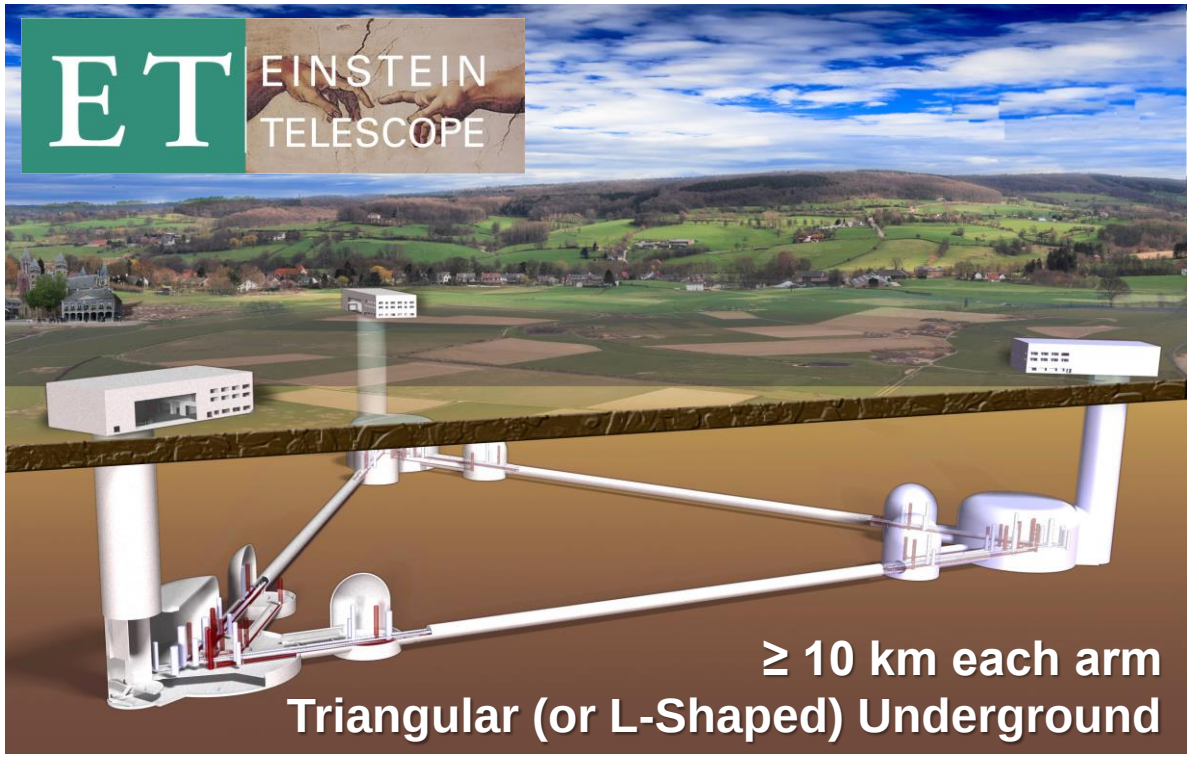
2024-12-06

Outline

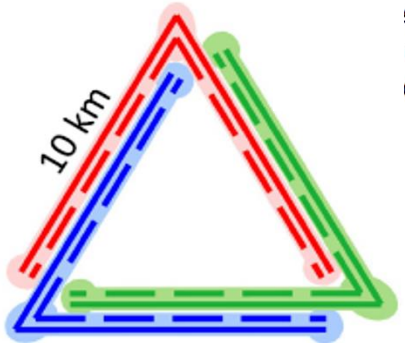
- **Einstein Telescope (ET)**
- **ET Vacuum System**
- **EN-MME contribution**
- **Summary and perspectives**

Einstein Telescope (ET)

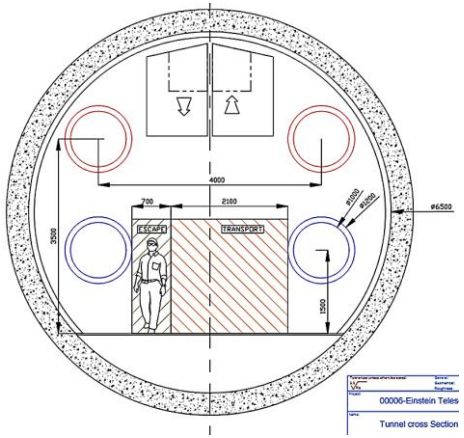
Next generation of GW detectors



ET concept



Triangle

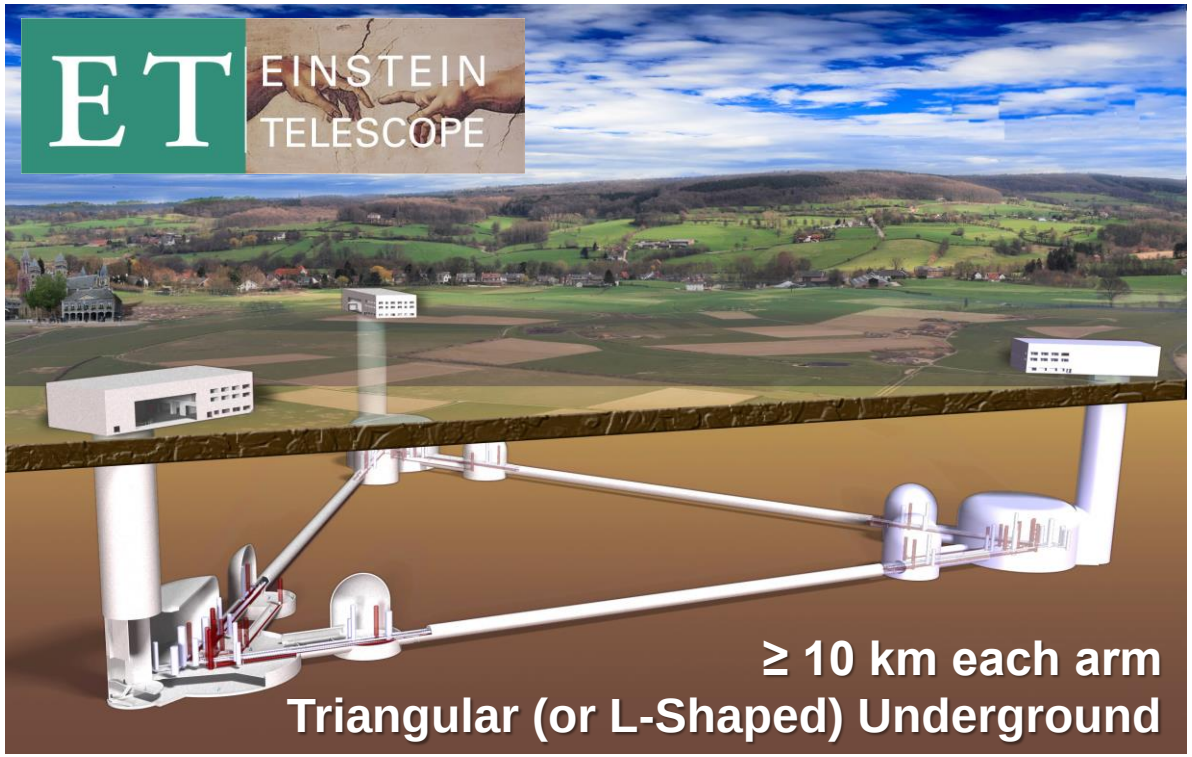


- **Underground** Infrastructure: **200 – 300 meter**
- Probably largest **UHV system** ever built: **120 km!**

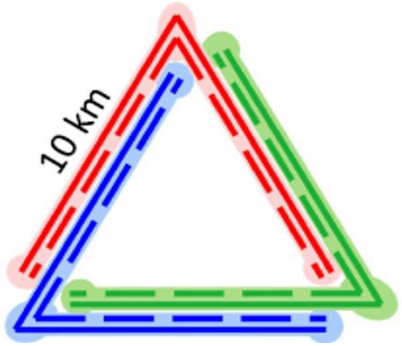
Current detectors observe about one signal per week.
Next generation →100.000 to 1.000.000 binary black holes mergers per year! And many other new sources!

Einstein Telescope (ET)

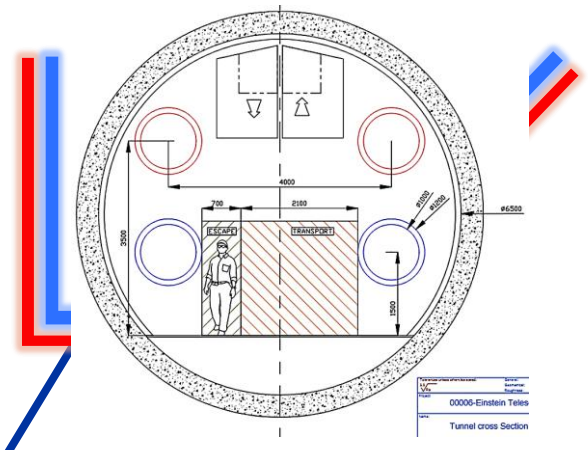
Next generation of GW detectors



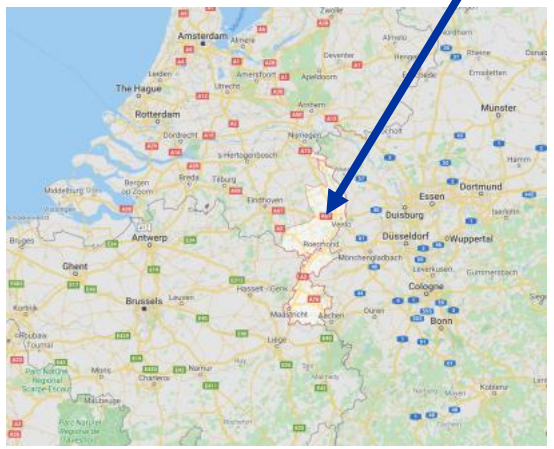
ET concept



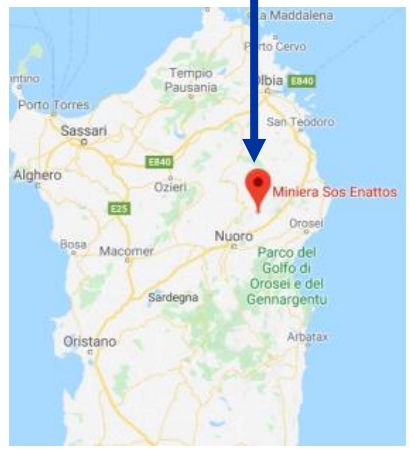
Triangle



- **Two locations** presented their candidature (**NL** & **IT**)
- Saxony (**DE**) is very present in ET and ETpathfinders



Limburg (NL)



Sardinia (IT)

ET vacuum system

Conceptual Design?

Pilot sector at CERN

MoU in 2022 between CERN, INFN, Nikhef and since 2023 also IFAE

Are there cost-effective alternatives (material, design, manufacturing, post-processing treatments) to achieve the needed vacuum performance?

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

ET vacuum system

Baseline based on VIRGO vacuum pipes [5]:

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

ET vacuum system

Baseline based on VIRGO vacuum pipes [5]:

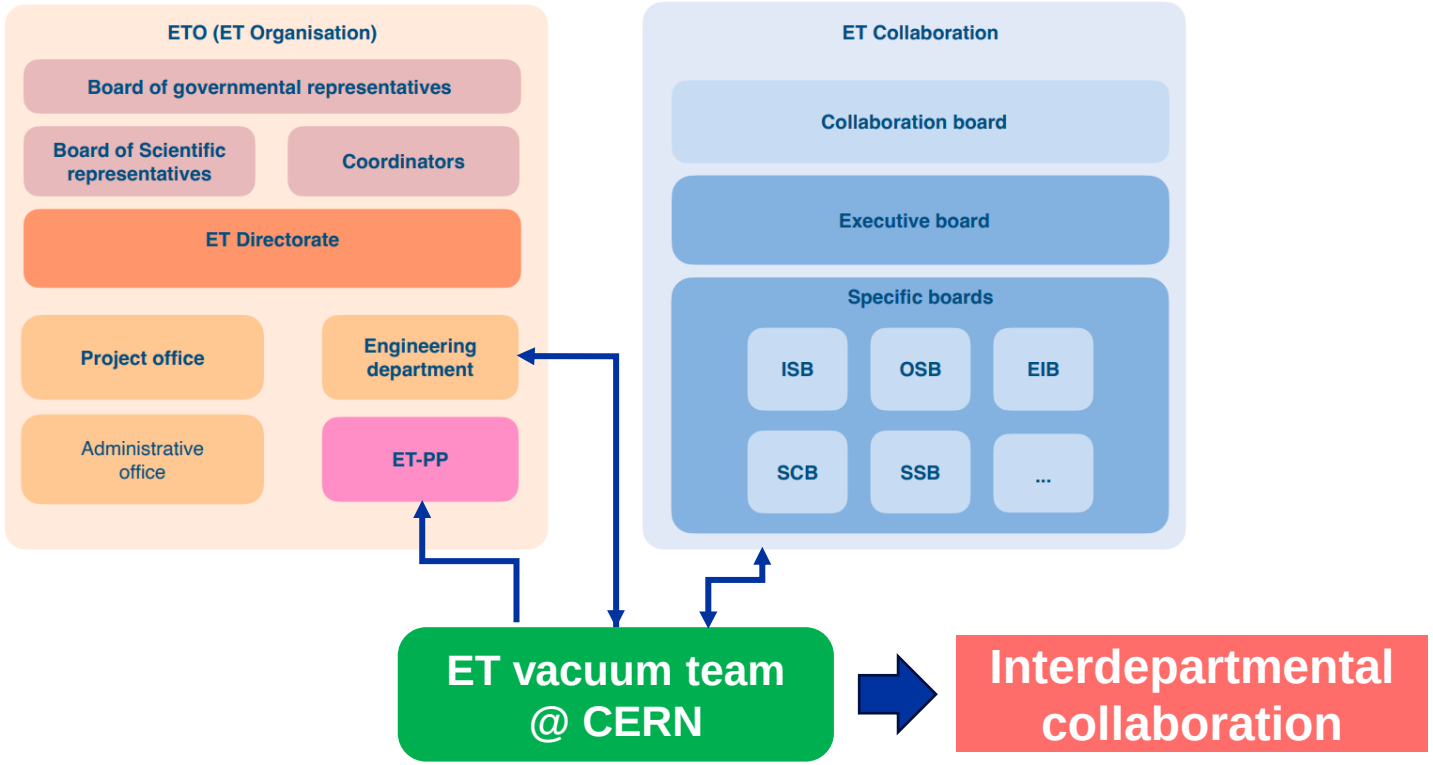
Objectives:

- 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**

ET vacuum system



Monthly updates on activities:
ETC: Aniello Grado, Nick Van Remortel
ETO: Patrick Werneke, Fernando Ferroni (Giovanni Bisoffi), Andreas Freise, Mario Martinez

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

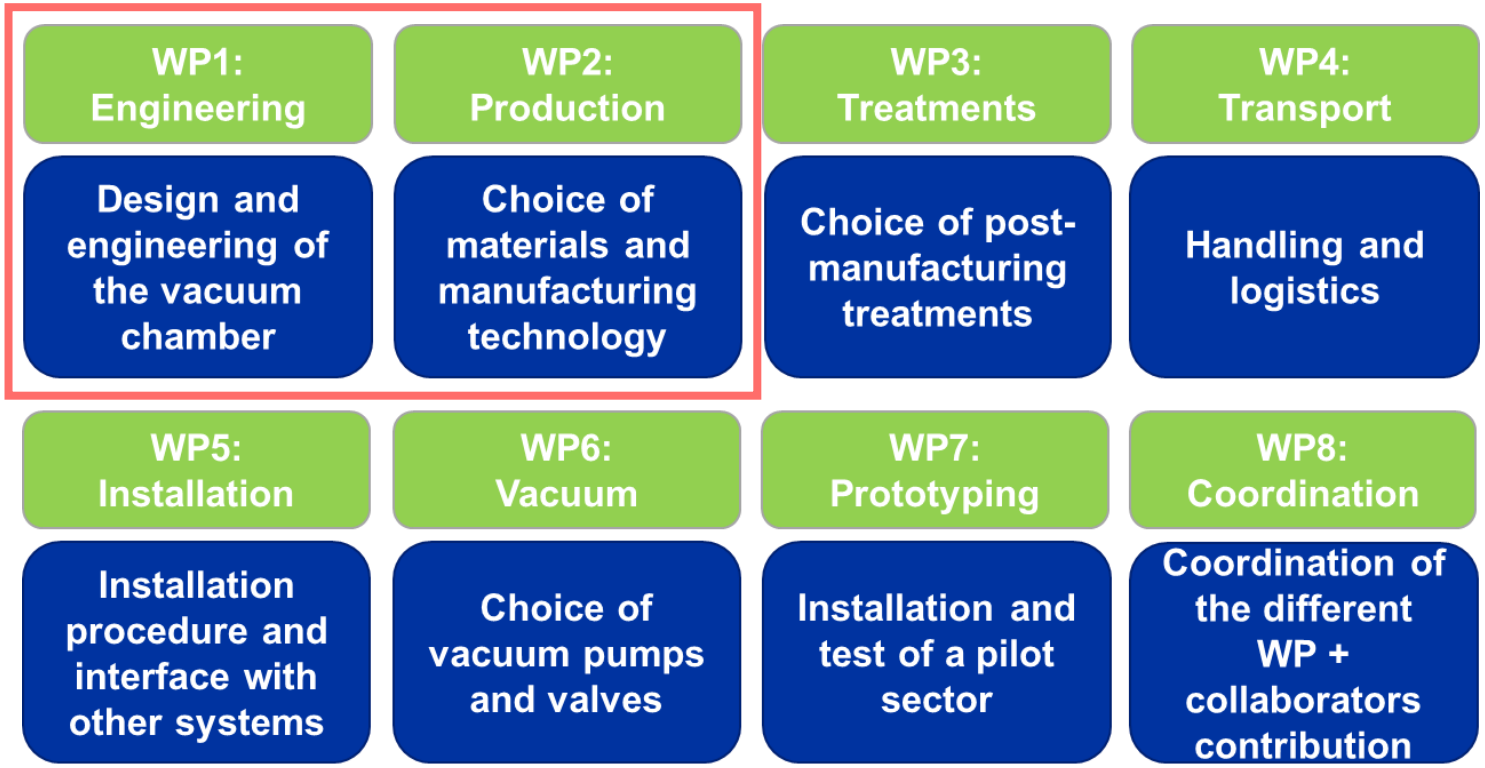
Objectives:

- 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**

ET vacuum system



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

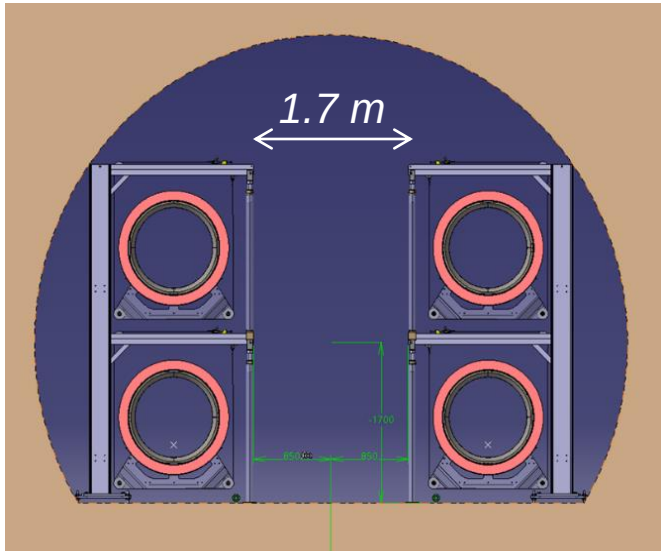
EN-MME activity:

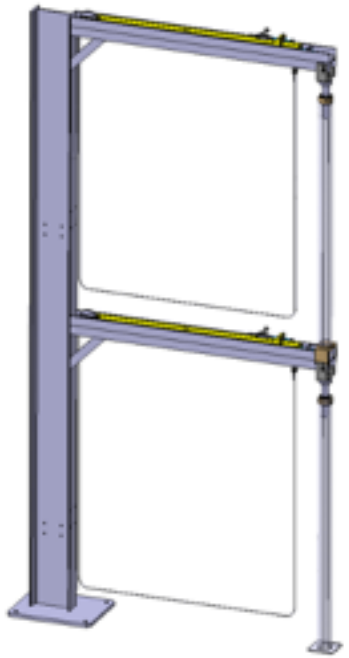
- Design office
- Materials, metrology and NDT
- Mechanical workshop
- Assembly and metal forming
- Technical subcontracting service

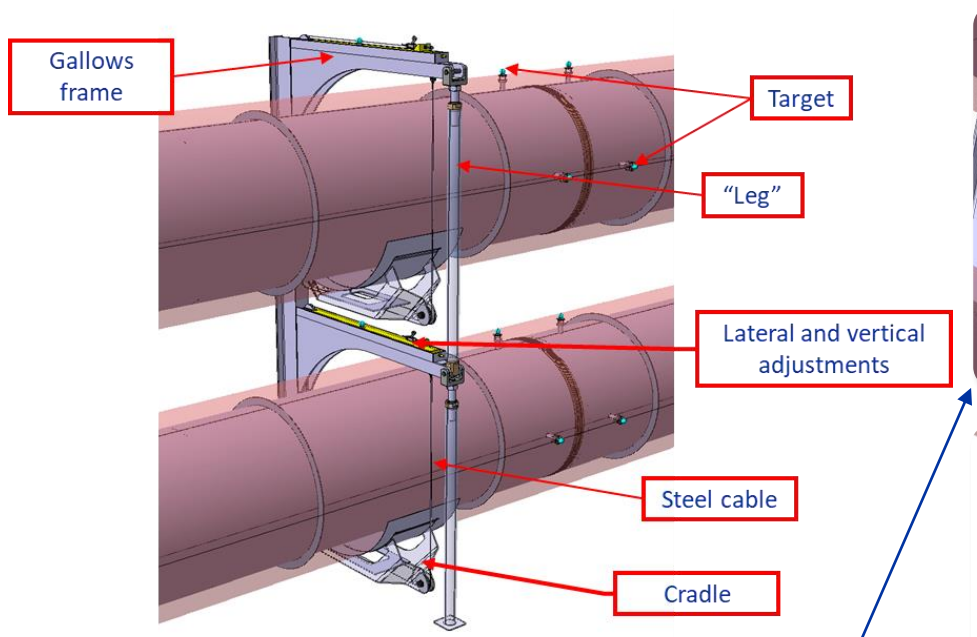
EN-MME contribution:

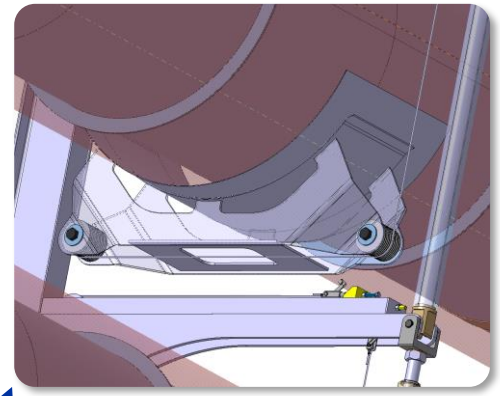
Design and manufacturing drawings for beampipes and supports of pilot sector → Applicable for ET

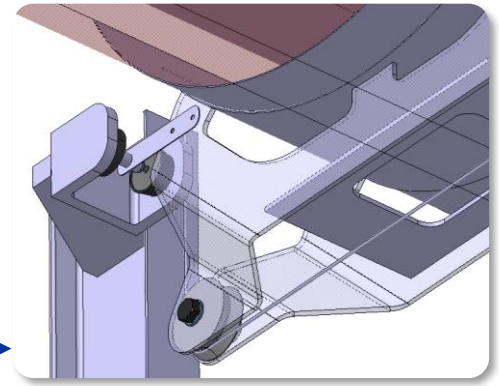
- In ET, the space required for the supporting structure shall be minimized allowing welding and future inspections
- Vacuum chamber position is adjustable within +/- 20 mm in both directions











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

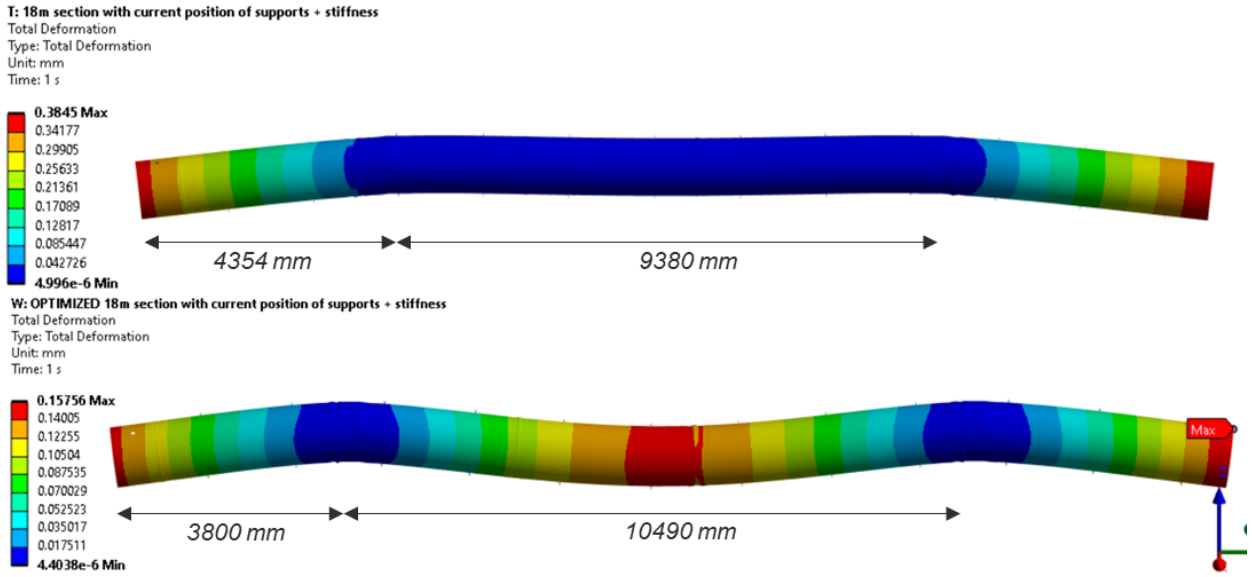
The insulated vacuum chambers lies on the cradle
Conceptual design of dampers

EN-MME contribution:

Finite element studies to optimize the supports dimensions and their positioning

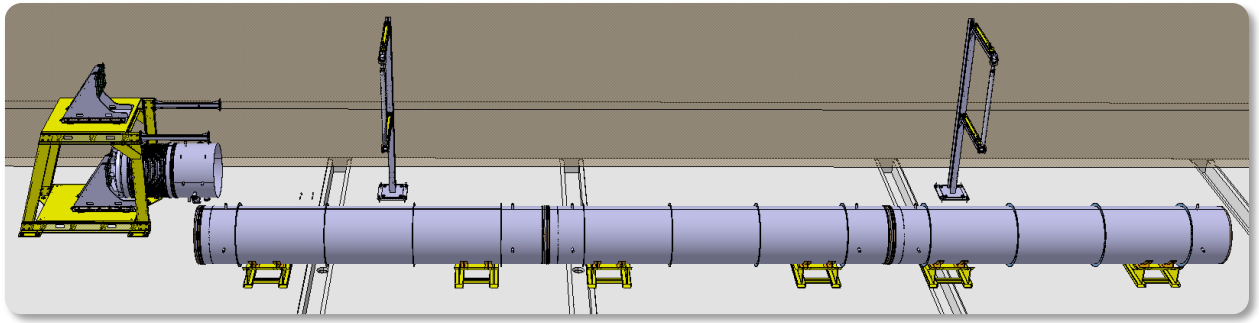
Stresses

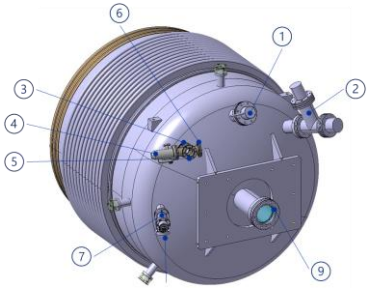
Eigenbuckling

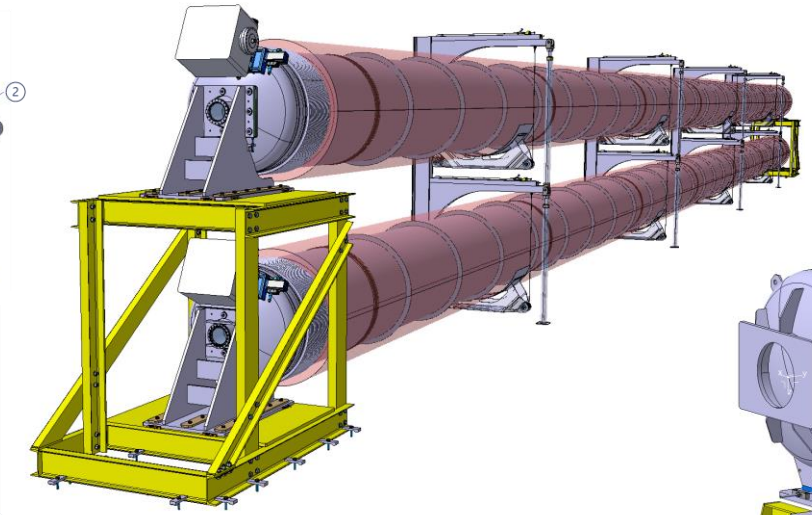


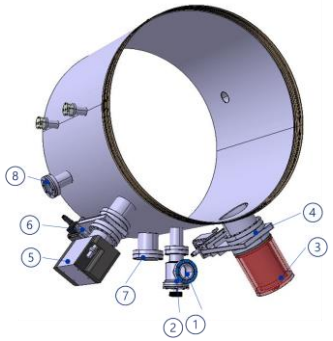
EN-MME contribution:

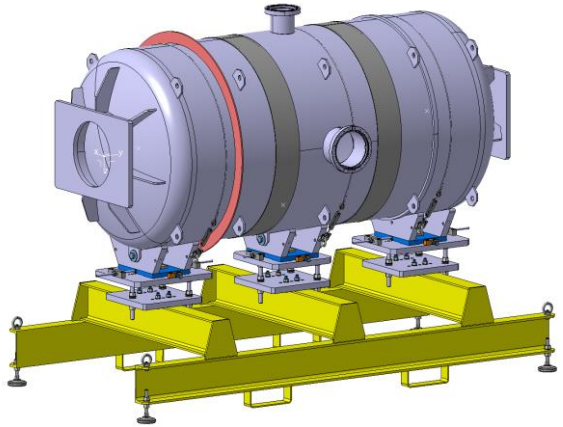
Design of complementary parts, prototypes and supports



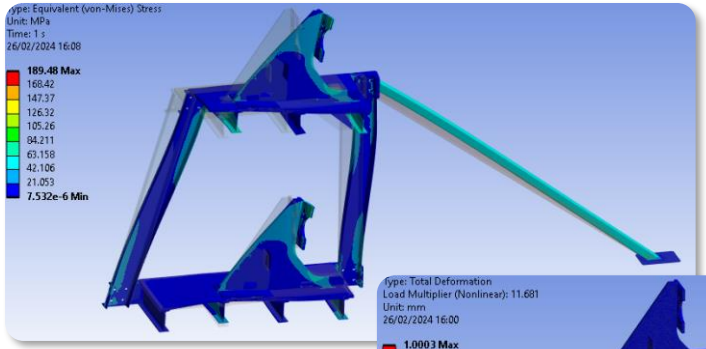




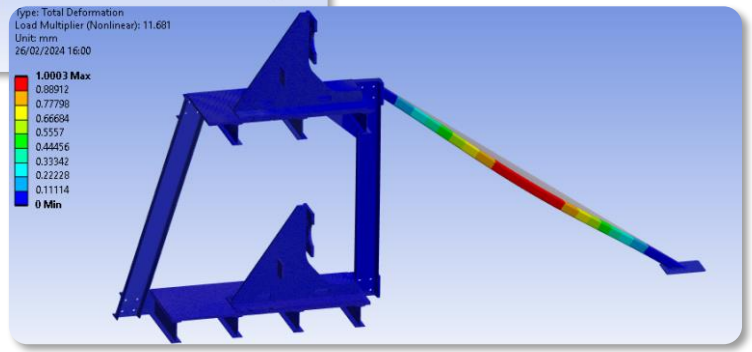




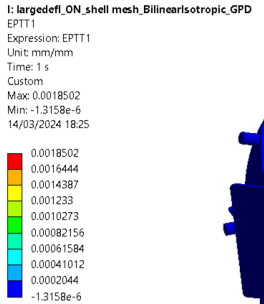
Finite element analysis for end caps end supports

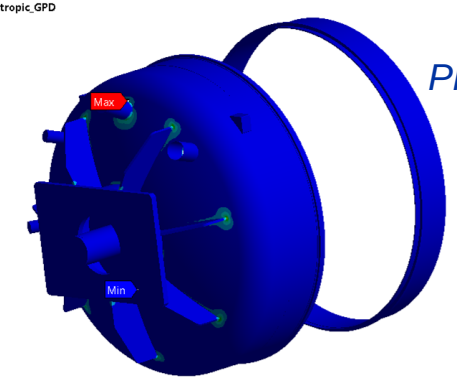


Von Mises stresses



Buckling mode

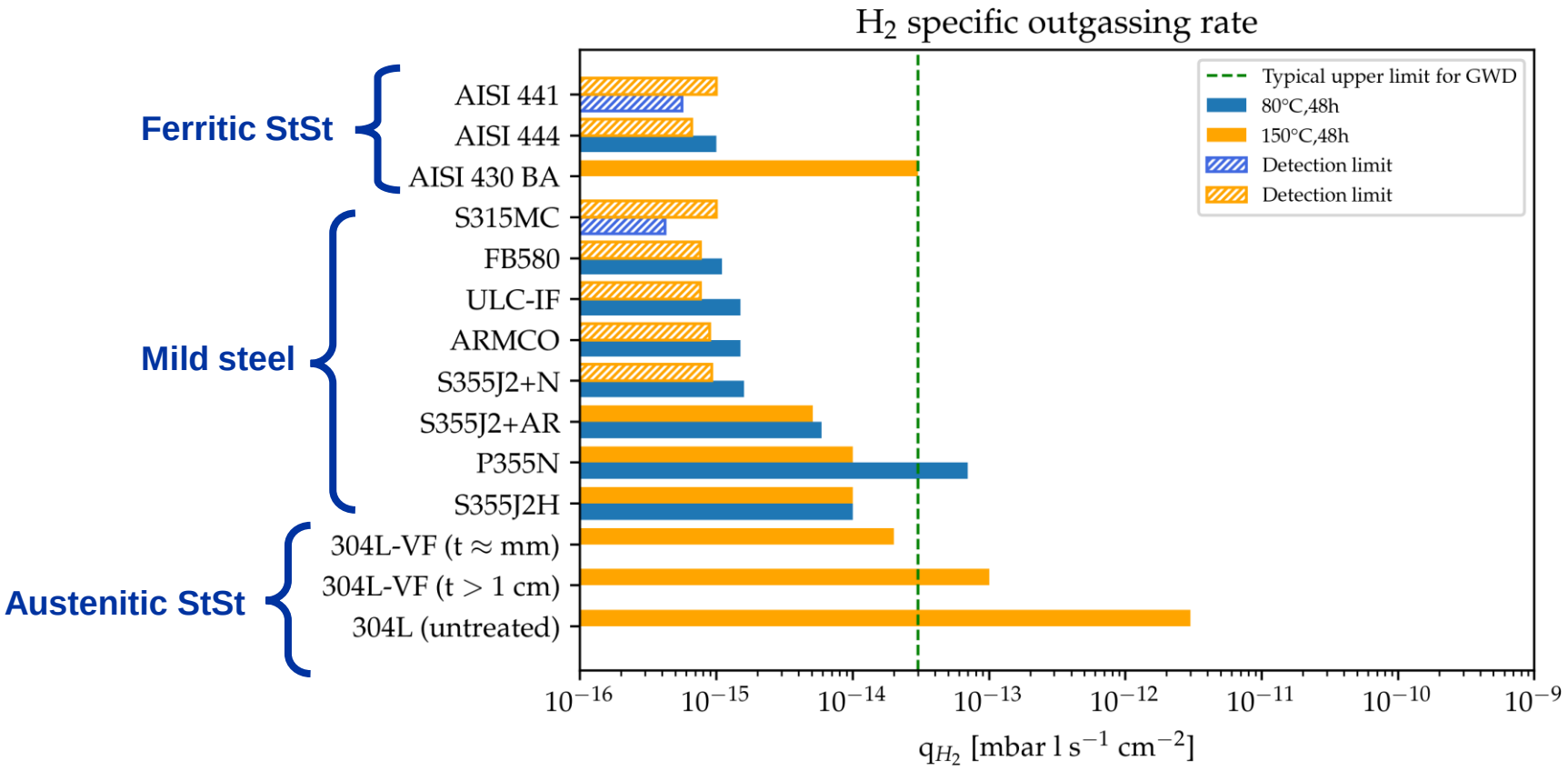




Plastic strain

EN-MME contribution:

Select alternative materials with low H_2 content/outgassing rate



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

Courtesy of C. Scarcia

The native H_2 content of ferritic grades is comparable to that of vacuum-fired austenitic StSt

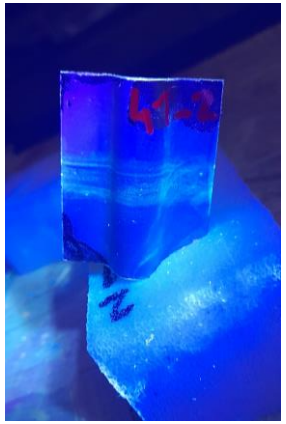
Vacuum properties
+
Availability and lower cost
+
Formability and weldability
+
Corrosion resistance

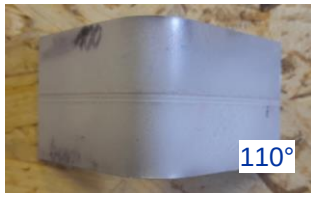
Ferritic StSt AISI 441
Low C, iron-chromium alloy
With addition of Ti and Nb

EN-MME contribution:

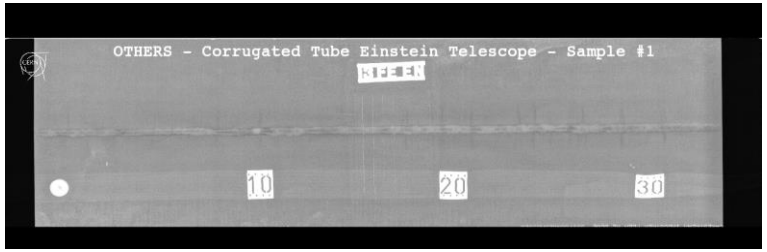
Welding testing and qualification for UHV applications

Non-destructive testing



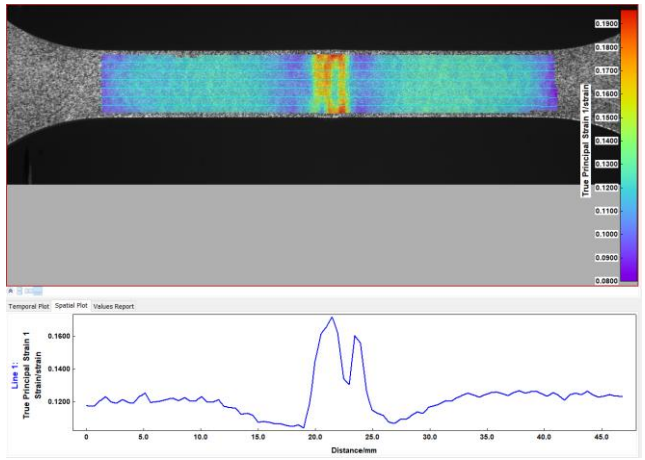


Dye penetrant testing after flexural test

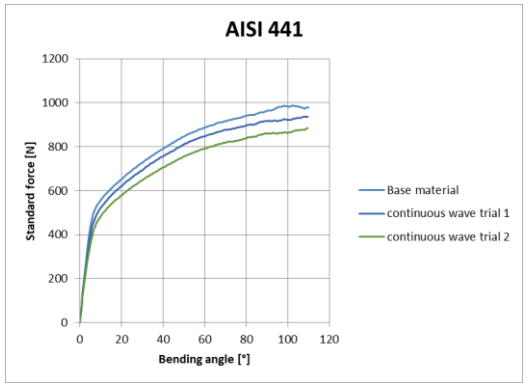


Radiography testing

Mechanical testing

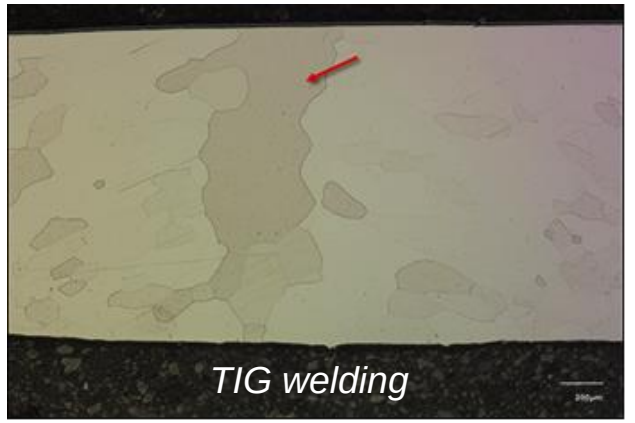


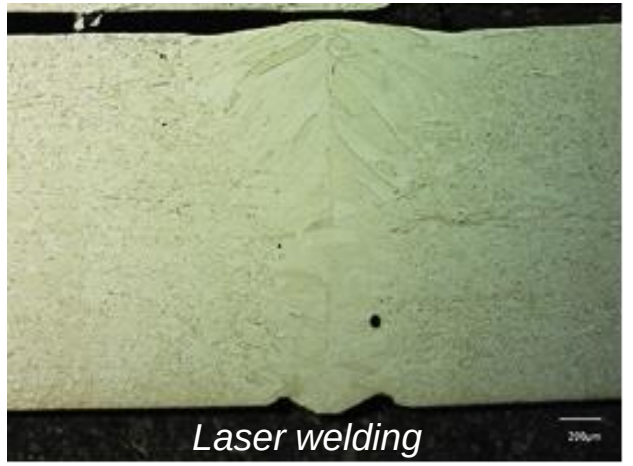
Tensile testing with DIC



Flexural testing

Metallurgical analysis





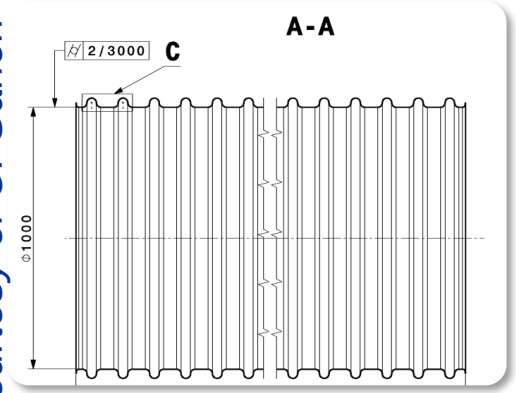
Optical microscopy on weld's cross sections

EN-MME contribution:

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

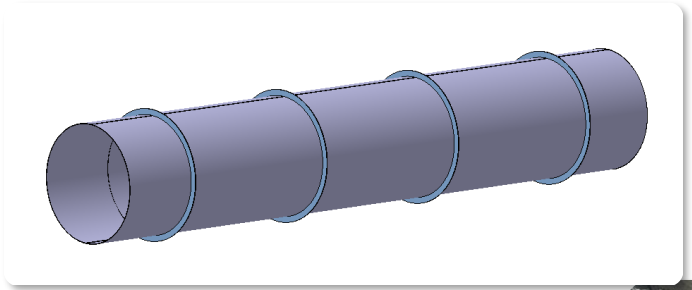
Two technical solutions:

Courtesy of C. Garion



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

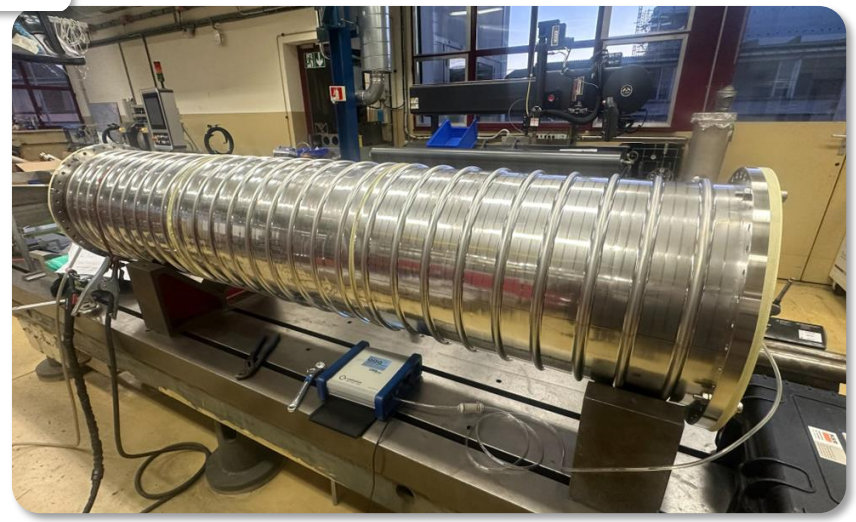
Prototypes

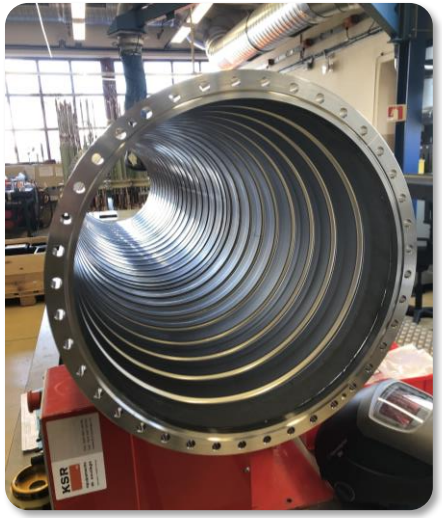


Smooth pipes
4 mm thick
Longitudinal welding
Reinforced by stiffeners

Pilot Sector

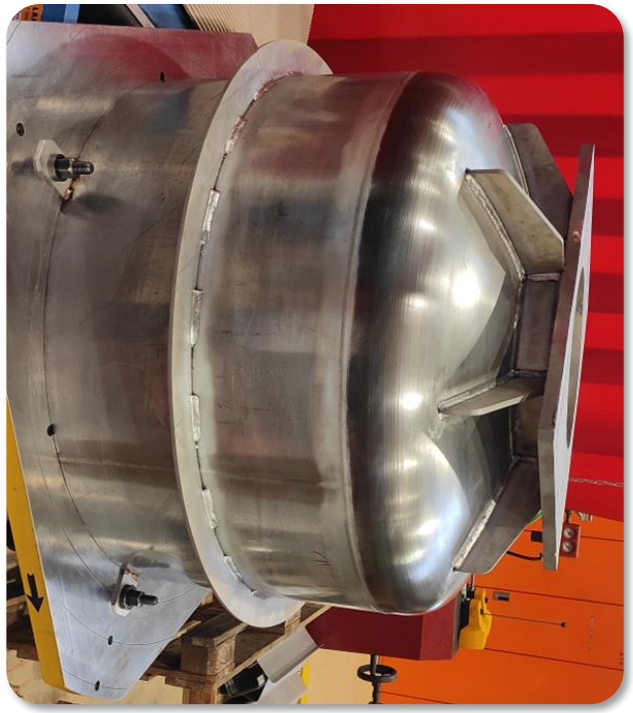
Annular corrugation performed at CERN



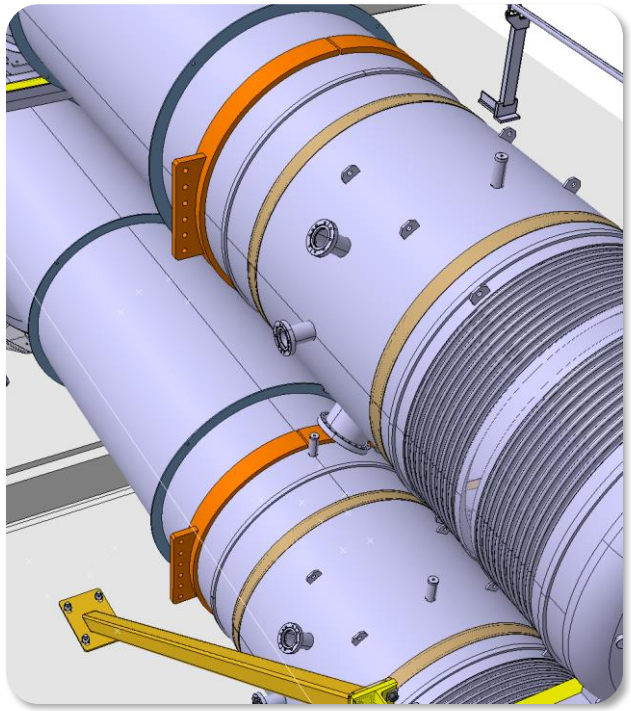


EN-MME contribution:

Manufacture of prototypes, pilot sector components

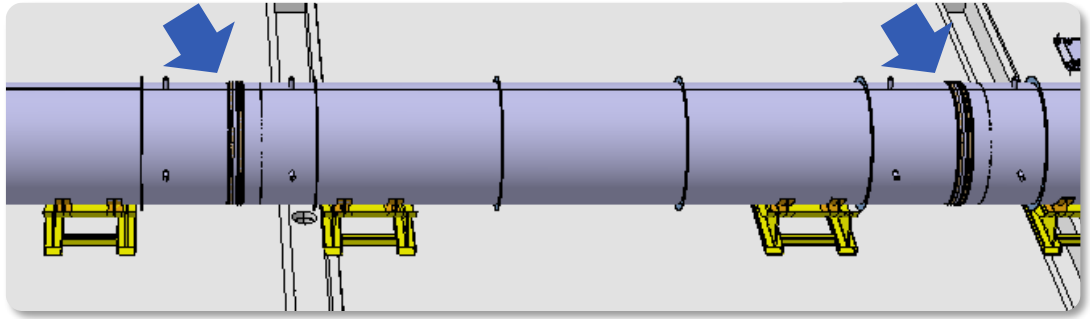


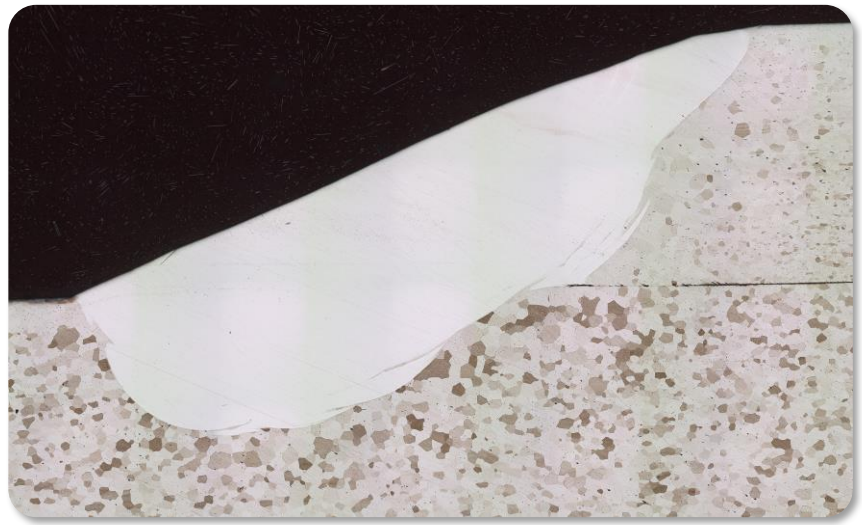
Mock-up manufacturing and assembly



End caps and pumping modules for pilot sector

Propose and test innovative solutions for pipe's connection (also applicable for ET)

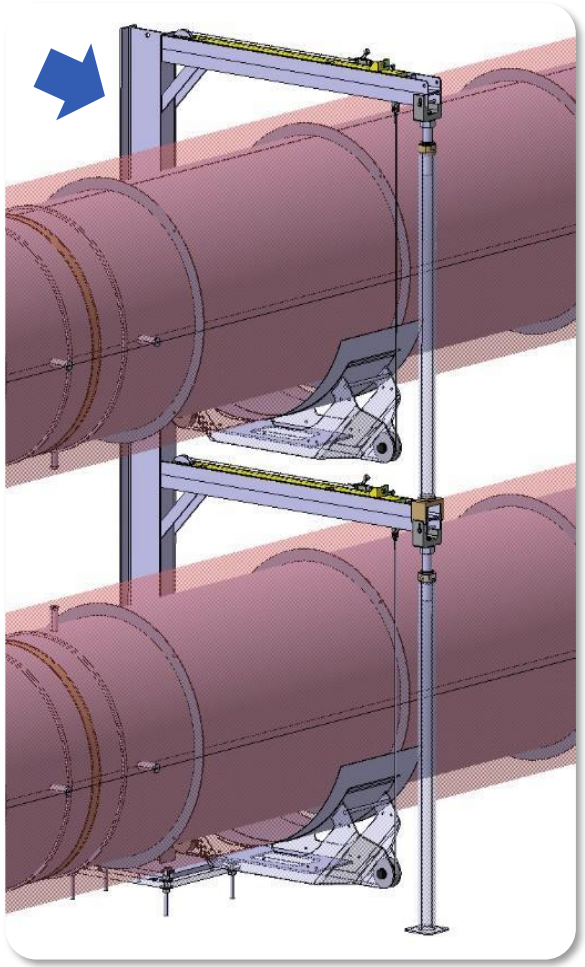


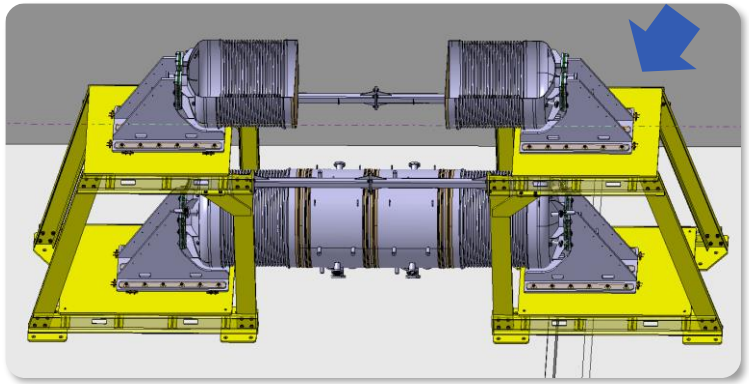


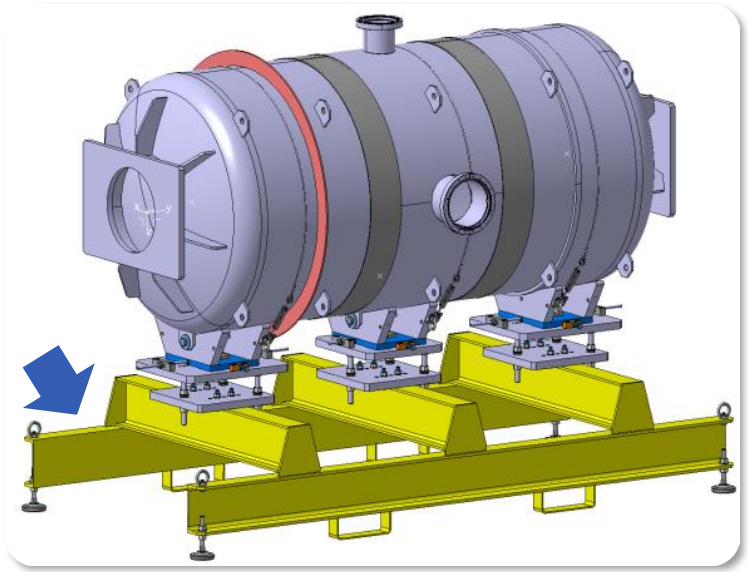
Sleeves testing for pilot sector sections connection

EN-MME contribution:

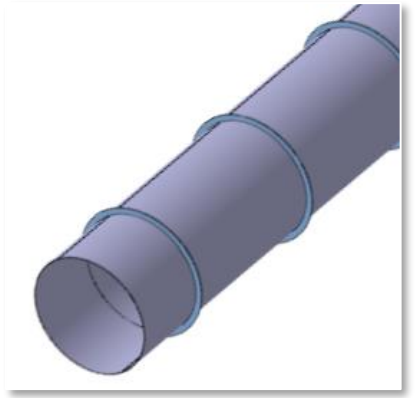
Sub-contracting the manufacturing of main support system, beampipes and complementary structures







Primary solution:



Smooth pipes
4 mm thick
Longitudinal welding
Reinforced by stiffeners

Pilot Sector (externalized)

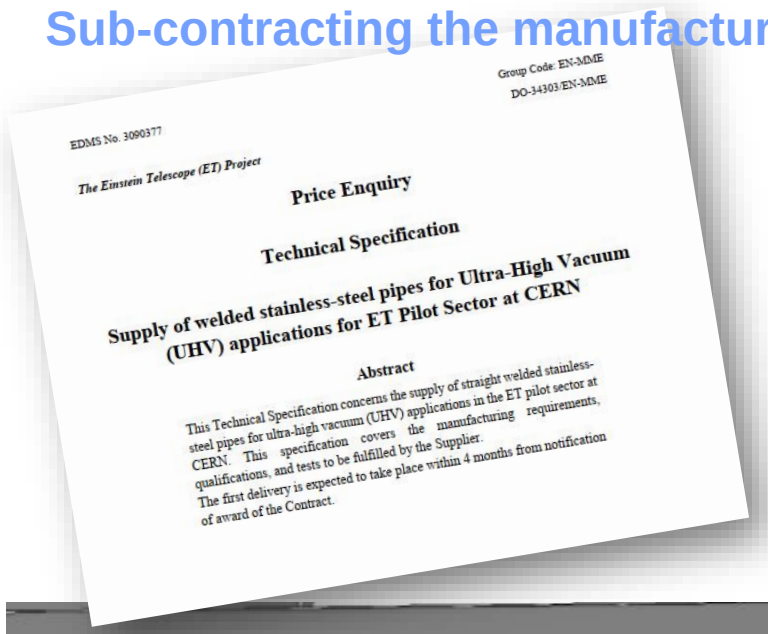
Innovative solution:

Corrugated pipes
Thin walls (≤ 2 mm)
Spiral welding + helicoidal corrugation simultaneously

Pilot Sector (externalized)
Development needed!

EN-MME contribution:

Sub-contracting the manufacturing of main support system, beampipes and complementary structures



EDMS No. 3090377

Group Code: EN-MME
DO-34303/EN-MME

The Einstein Telescope (ET) Project

Price Enquiry

Technical Specification

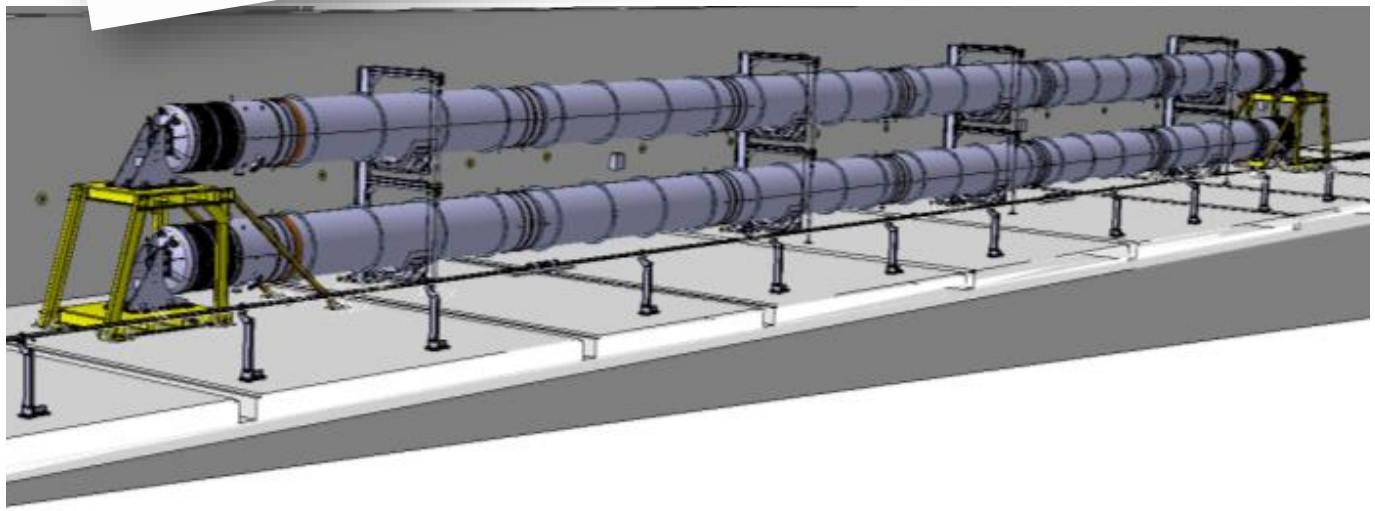
Supply of welded stainless-steel pipes for Ultra-High Vacuum (UHV) applications for ET Pilot Sector at CERN

Abstract

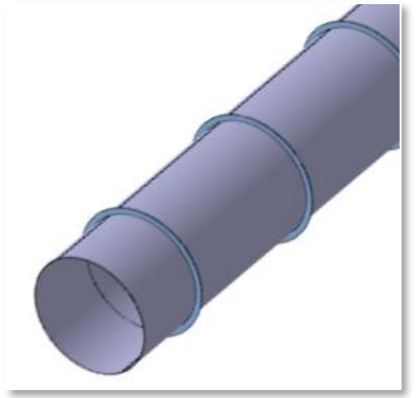
This Technical Specification concerns the supply of straight welded stainless-steel pipes for ultra-high vacuum (UHV) applications in the ET pilot sector at CERN. This specification covers the manufacturing requirements, qualifications, and tests to be fulfilled by the Supplier.
The first delivery is expected to take place within 4 months from notification of award of the Contract.

Redaction of technical specifications for the price enquiries and market survey processes

Close follow-up of the production



Primary solution:



Smooth pipes
4 mm thick
Longitudinal welding
Reinforced by stiffeners

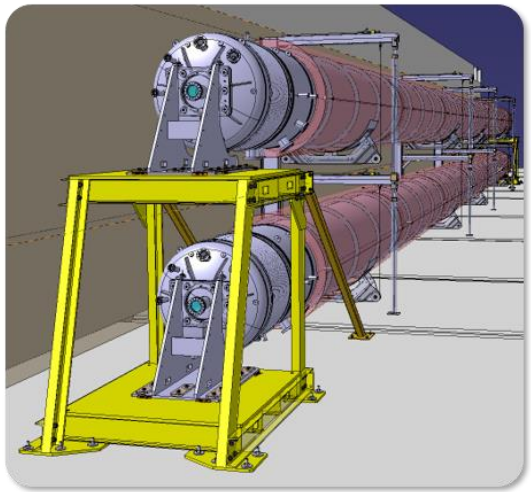
Pilot Sector (externalized)

Innovative solution:

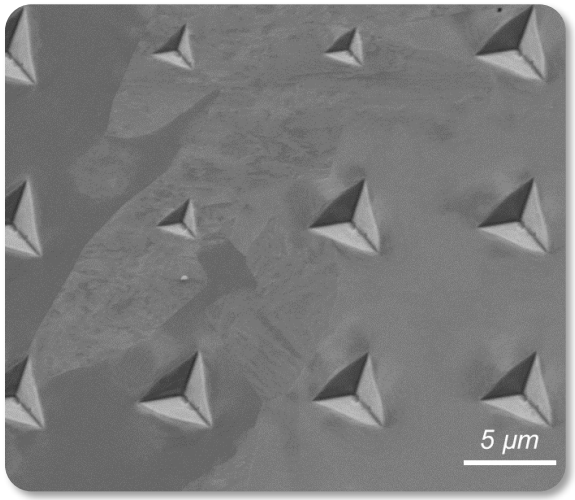
Corrugated pipes
Thin walls (≤ 2 mm)
Spiral welding + helicoidal corrugation simultaneously

Pilot Sector (externalized)
Development needed!

Summary and perspectives



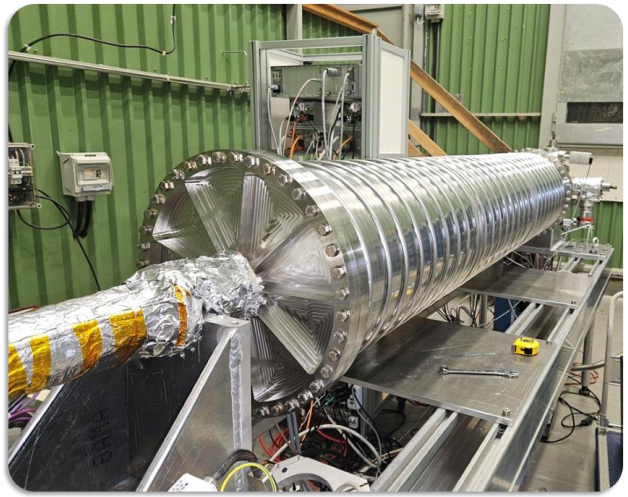
Design, simulations and manufacturing drawings for supports and components



Selection and testing of alternative material (ferritic StSt AISI 441)

Corrosion studies

GHENT UNIVERSITY



Manufacturing parts, welding procedures compatible with UHV

Dust control studies

UNIVERSITÀ DEGLI STUDI DI PADOVA

Sub-contracting pilot sector structural support and 1st beamline in ferritic StSt

2nd beamline

2025:
Finalize the installation and testing of the pilot sector at CERN + TDR

Thanks for your attention!

References

[1] Video | Ripples in Spacetime Pond | LIGO Lab | Caltech

[2] What is an Interferometer? | LIGO Lab | Caltech

[3] ET collaboration, Einstein Telescope preliminary cost book, 2020

[4] ET Science Team, Einstein gravitational wave Telescope conceptual design study, 2011

[5] Ultra high vacuum beam pipe of the Einstein Telescope project: Challenges and perspectives. A. Grado et al. Journal of Vacuum Science & Technology (2023)

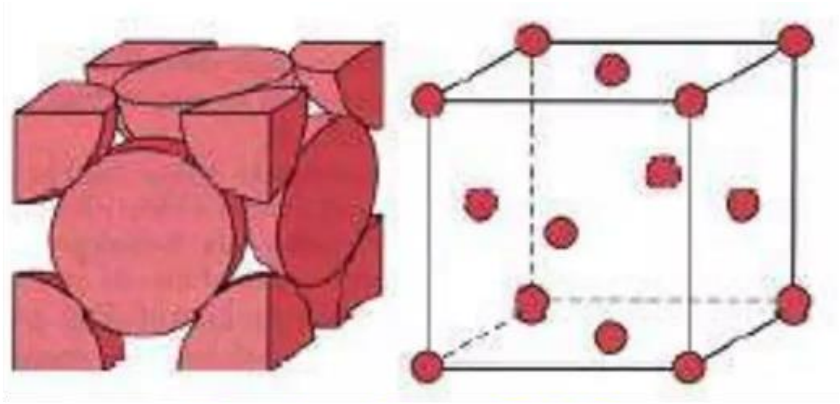
[6] Outgassing properties of vacuum materials for particle accelerators. P. Chiggiato

[7] Vacuum for Accelerators: Introduction to Materials and Properties. S. Sgobba

[8] Study of selected mild steels for application in vacuum systems of future gravitational wave detectors. C. Scarcia et al. Journal of Vacuum Science & Technology (2024)

EN-MME contribution:

Select alternative materials with low H_2 content/outgassing rate



Austenite - FCC

(used in Virgo [5], LIGO and ET baseline)

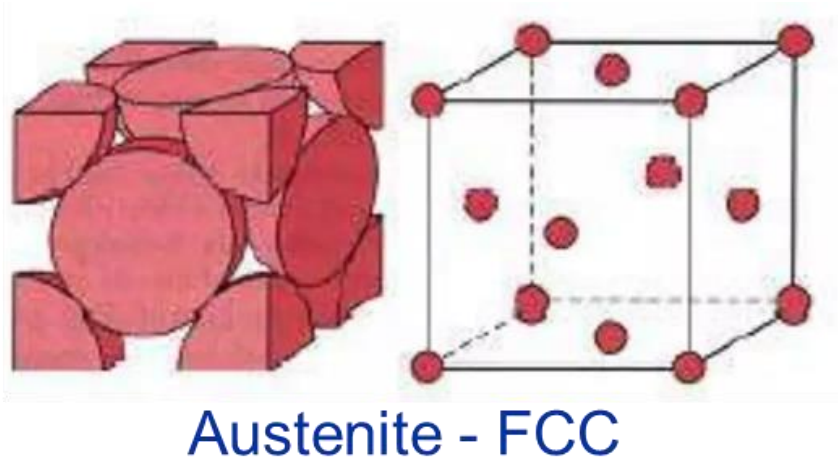
Air bake-out 410°C
on finished tubes (15 m long)
5 days cycle in electrical furnace

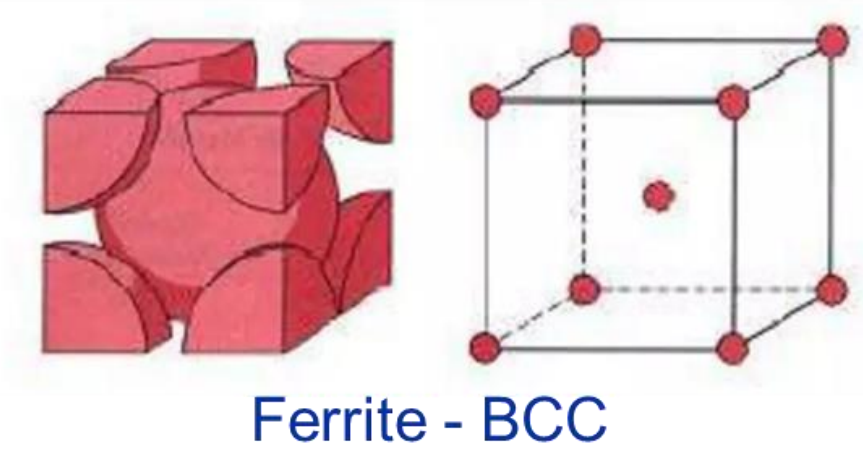
Production Bottleneck!

- Austenitic StSt, specifically **AISI 304L**, are a standard material for UHV applications in scientific equipment. To reduce H_2 outgassing at RT to acceptable levels **high-temperature treatments (firing)** are needed [6, 7]
- The methods applied to reduce the H_2 outgassing in current GWD include **ex-situ heating** at high temperatures in a vacuum or air furnace (vacuum or air firing) and **in-situ bakeout** at medium temperatures [5]

EN-MME contribution:

Select alternative materials with low H_2 content/outgassing rate





- Austenitic StSt, specifically **AISI 304L**, are a standard material for UHV applications in scientific equipment. To reduce H_2 outgassing at RT to acceptable levels **high-temperature treatments (firing)** are needed [6, 7]
- The methods applied to reduce the H_2 outgassing in current GWD include **ex-situ heating** at high temperatures in a vacuum or air furnace (vacuum or air firing) and **in-situ bakeout** at medium temperatures [5]
- **Ferritic - bcc - structures** present lower residual H_2 and higher diffusivity compared to the **close-packed fcc** resulting in a faster degassing at lower temperatures (≤ 150°C) [8]

Broader CERN involvement

- **Vacuum system:** MoU in 2022 between CERN, INFN, Nikhef and IFAE → Dedicated activity ongoing and sharing the knowledge with **Cosmic Explorer**

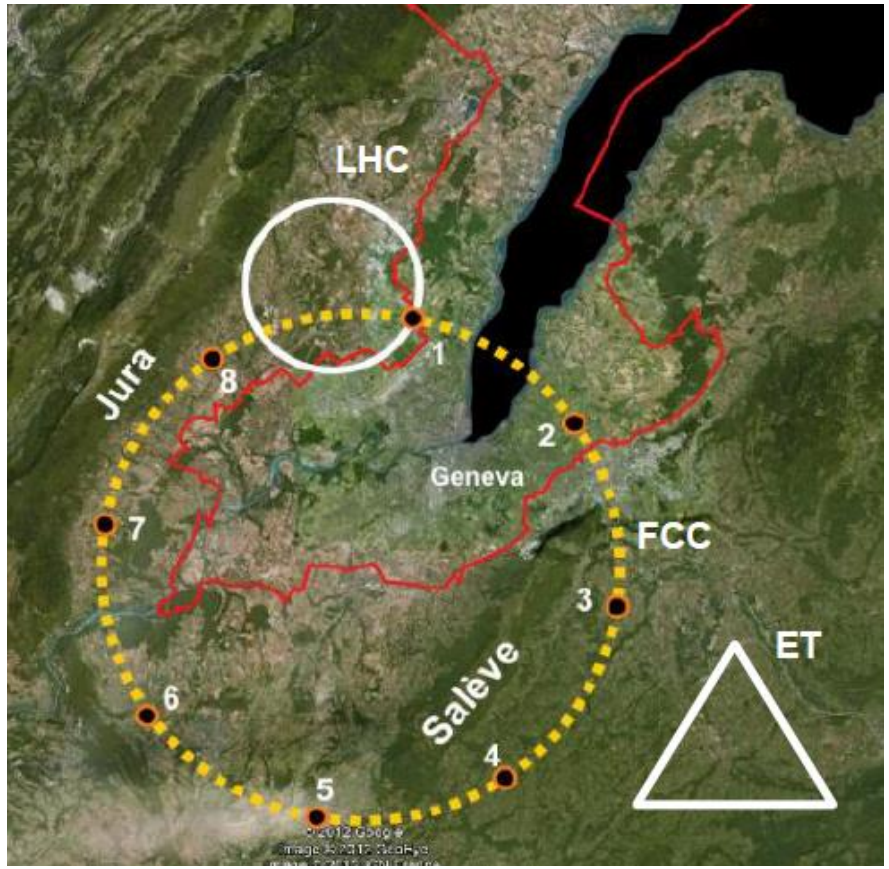
- **Civil engineering:** MoU in 2023. CERN will provide consultancy and technical support towards the creation of the **TDR for the civil engineering and technical infrastructure for 2026**

Beampipes for Gravitational Wave Telescopes Workshop (CERN, March 2023)

ET Civil Engineering Workshop (CERN, April 2024)

Broader CERN involvement

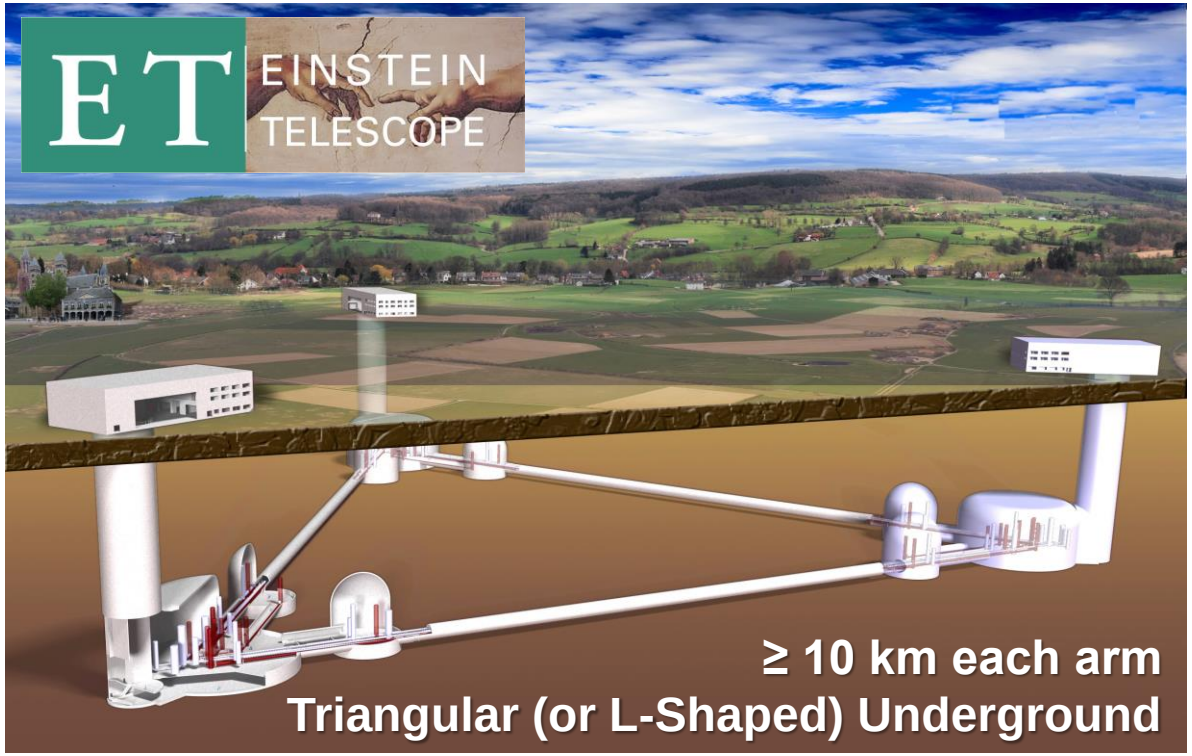
- **Vacuum system:** MoU in 2022 between CERN, INFN, Nikhef and IFAE → Dedicated activity ongoing and sharing the knowledge with **Cosmic Explorer**
- **Civil engineering:** MoU in 2023. CERN will provide consultancy and technical support towards the creation of the **TDR for the civil engineering and technical infrastructure for 2026**
- **Document management:** Project management required specific tools (i. e. EDMS) and CERN is providing support for a pilot study
- **Engineering support:** Discussions are ongoing for a dedicated support for the design of the technical infrastructure
- **Other subjects** related to occupational health and safety, integration, planning, support for costing, cryogenic infrastructure, survey…

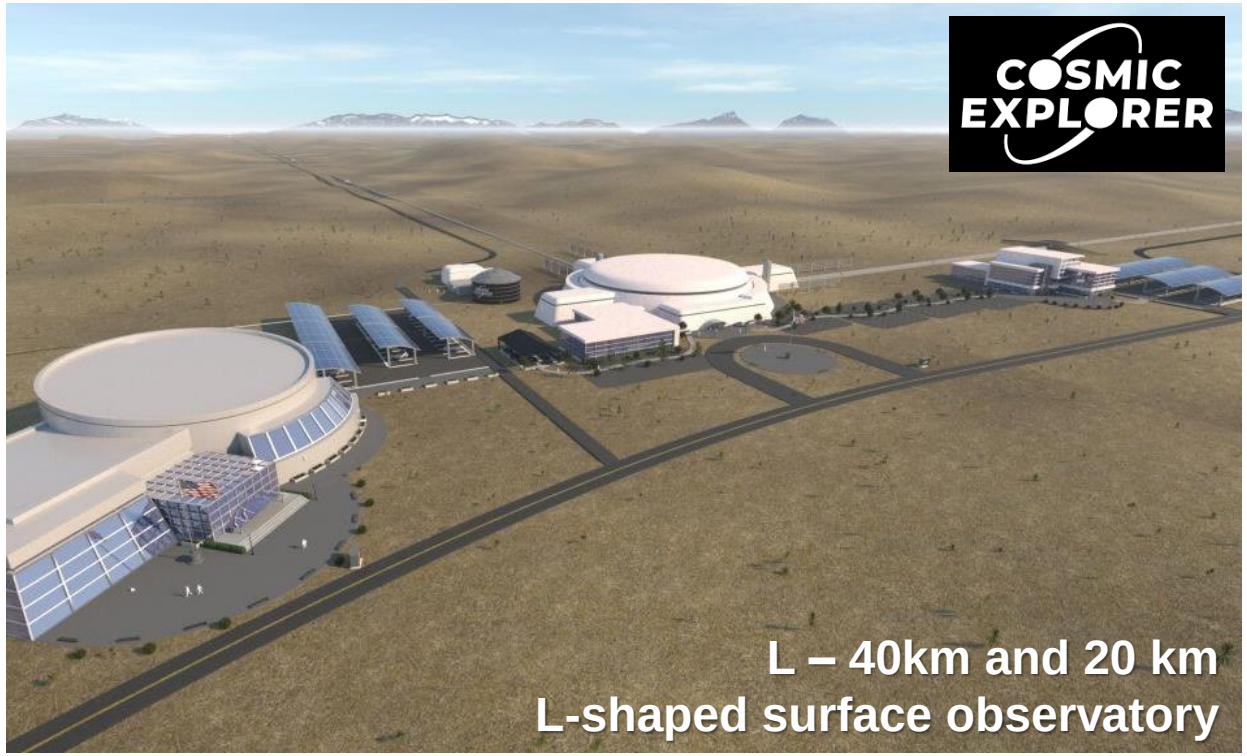


Dimensions comparison

What's the Einstein Telescope?

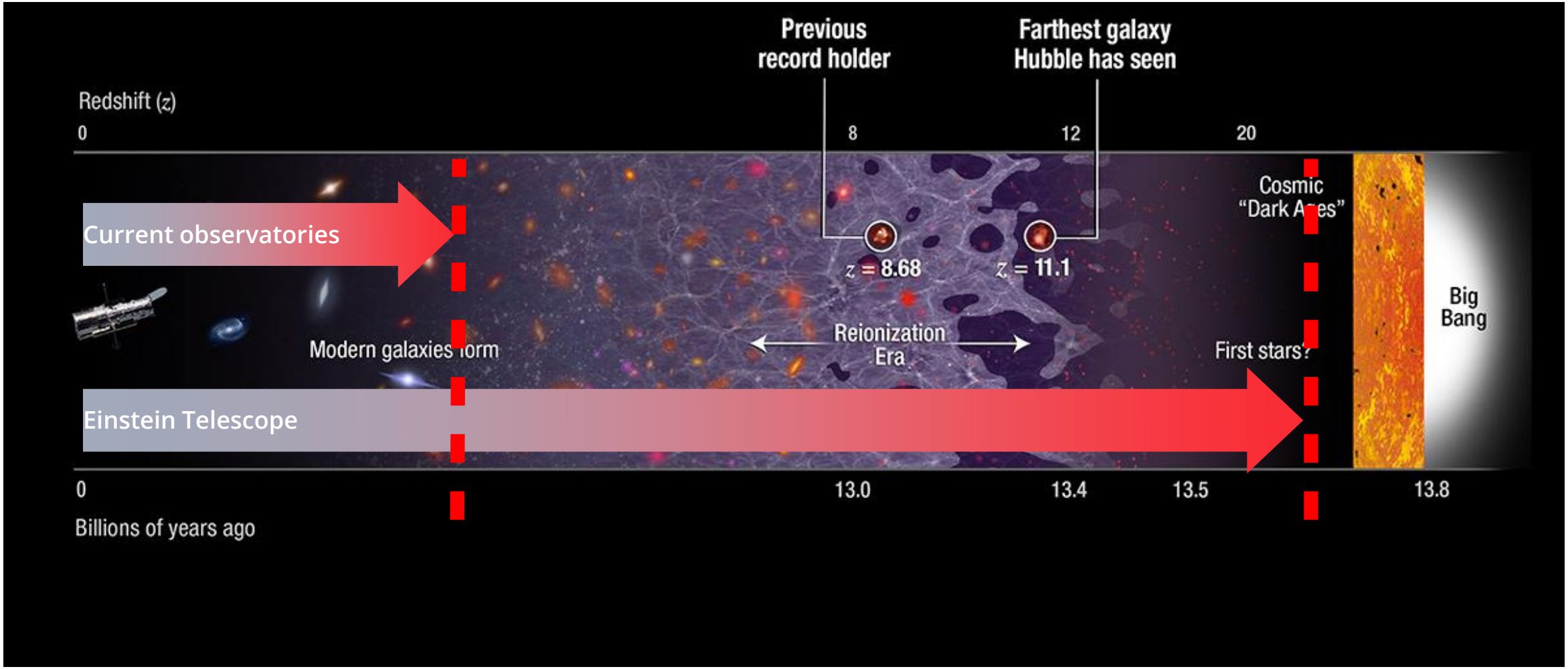
Next generation of GW detectors



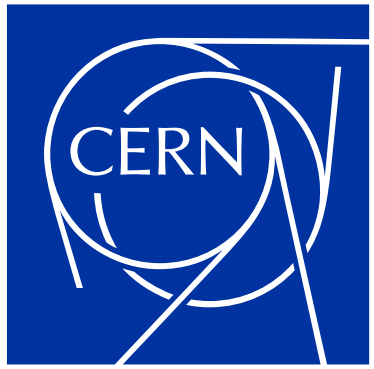


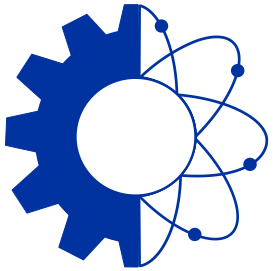
Current detectors observe about one signal per week.
Next generation →100.000 to 1.000.000 binary black holes mergers per year! And many other new sources!

Let’s push the Universe exploration!



Courtesy of P. Werneke

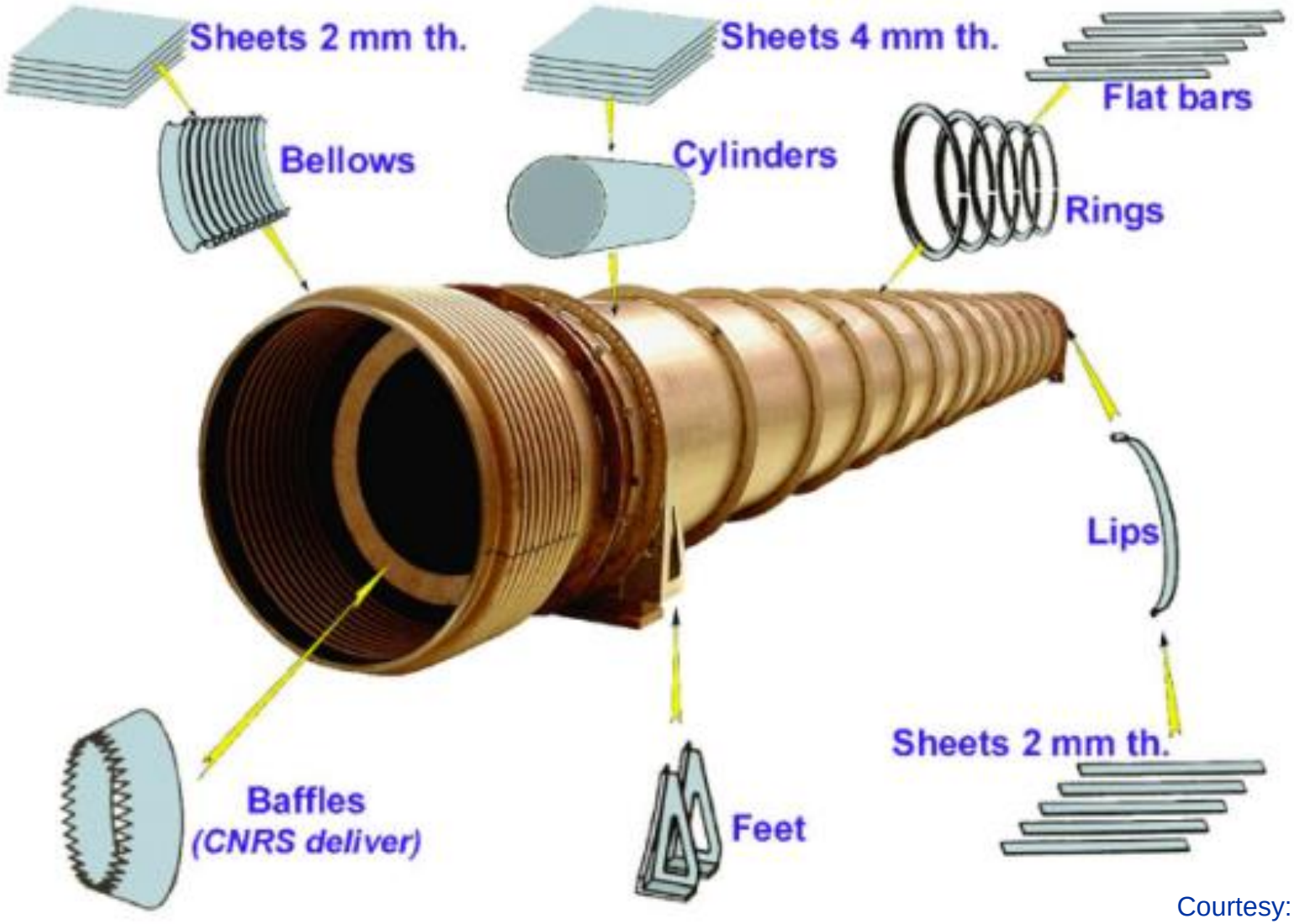




ENGINEERING
DEPARTMENT

home.cern

Virgo Pipes



Courtesy: A. Pasqualetti