Mechanical & Materials Engineering Group: From Technology Development to Industrial Knowledge Transfer

Alessandro DALLOCCHIO, CERN

on behalf of the Mechanical & Materials Engineering Group (EN-MME)

CERN-Türkiye Knowledge Transfer Summit
30 September - 1 October 2025

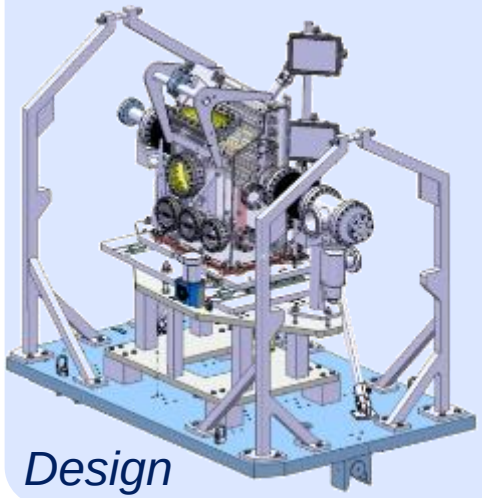
Outline

- **Mechanical & Materials Engineering Group (EN-MME): mandate**
- **EN-MME: Multi-Technology Skills and Expertise**
- **From Technology Development to Industrial KT: Highlights**

Mechanical & Materials Engineering (EN-MME) Group Mandate:

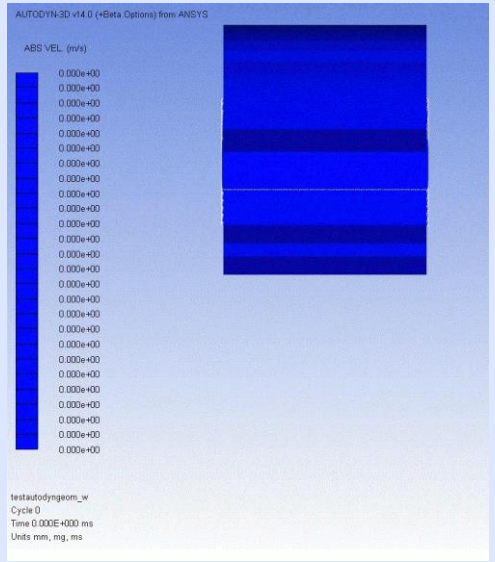
The mandate of the MME group is to provide the CERN community with **specific engineering solutions combining mechanical design, fabrication and material science**, using **in-house and industry facilities**, for accelerator components and physics detectors.

Particle Beam Impact: comparison between simulation and experiment

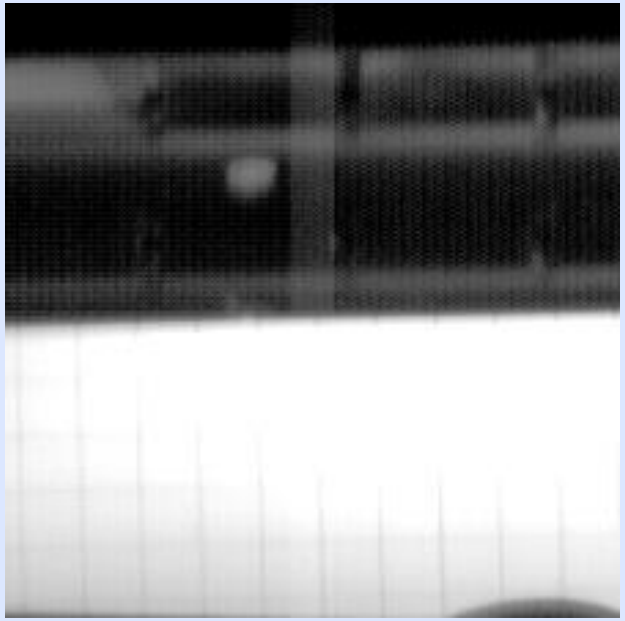


Design

Beam



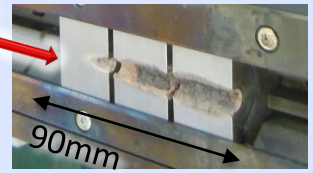
F.E. Calcs



Live Acquisition system by MME Mech. Lab

Fabrication and Assembly

Beam



Material testing pre and post-irradiation

Thermal Management Materials – MoGr and CrG

- **Materials industrially produced by spark plasma sintering (graphite ~90-95 vol.%):**
  - Catalytic graphitisation + through-plane reinforcement ⇒ very high thermal conductivity; improved mechanical properties vs isotropic graphite
  - Molybdenum-Graphite (MoGr) developed by CERN, Brevetti Bizz (IT) and Nanoker (ES) for HL-LHC collimators
  - Chromium-Graphite (CrGr) developed within European Projects (IFAST) as a cheap to MoGr (can be sintered at <2000°C vs ~2600°C for MoGr → energy and cost
  - Sintering process can be tailored (T, p, t) to obtain required dens applications: heat sinks, braking systems, high-temperat

Thermo-physical and mechanical properties o

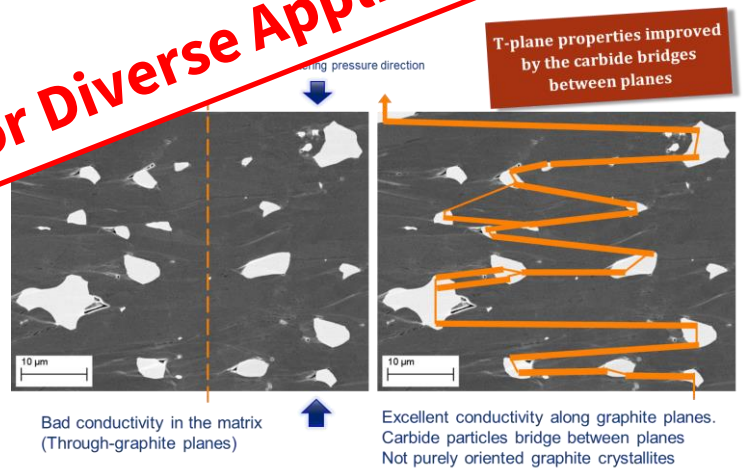
~ < Aluminium

Direction				
Density (g c				
Electrical				
Spe				
Ther				38
Therma			700	65
CTE		12	5	11
Flexu		10-12	100	22
Elastic	60-85	4-5	60	5
Flexural str	pture (%) 0.18-0.26	0.45-0.72	0.33	0.42

2+ x Copper

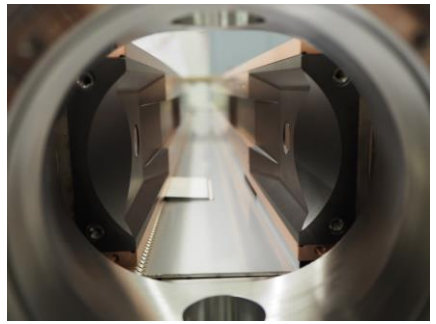
can match semiconductors

SPOILER:
From High Energy Physics to Knowledge Transfer with Industrial Partners,
Leveraging the MME Multi-Technology Skills and Capabilities
→
New Thermal Management Material with High Potential for Diverse Applications!



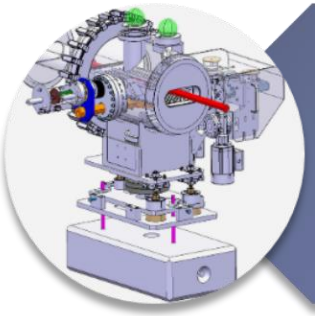
Microstructure of MoGr.

MoGr parts machined for HL-LHC collimators



Mechanical & Materials Engineering (MME) Group : domains of activities

https://en.web.cern.ch/group/MME



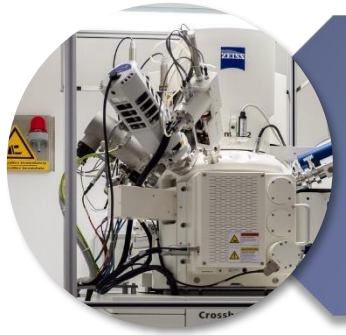
Design, Simulations and Measurements

- **Largest design office at CERN** using computer-aided design (CAD) software: 40 designers (Staff and Industrial Support).
- **Engineering Unit:** Advanced calculations, analyses and numerical simulations.
- **Mechanical Measurements Lab**: stress and strain, pressure, vibration and thermo-physical characterisation (4 K – RT – 2000 °C).

Fabrication

- Machining & Maintenance
- Preparation & Subcontracting
- Assembly & Forming

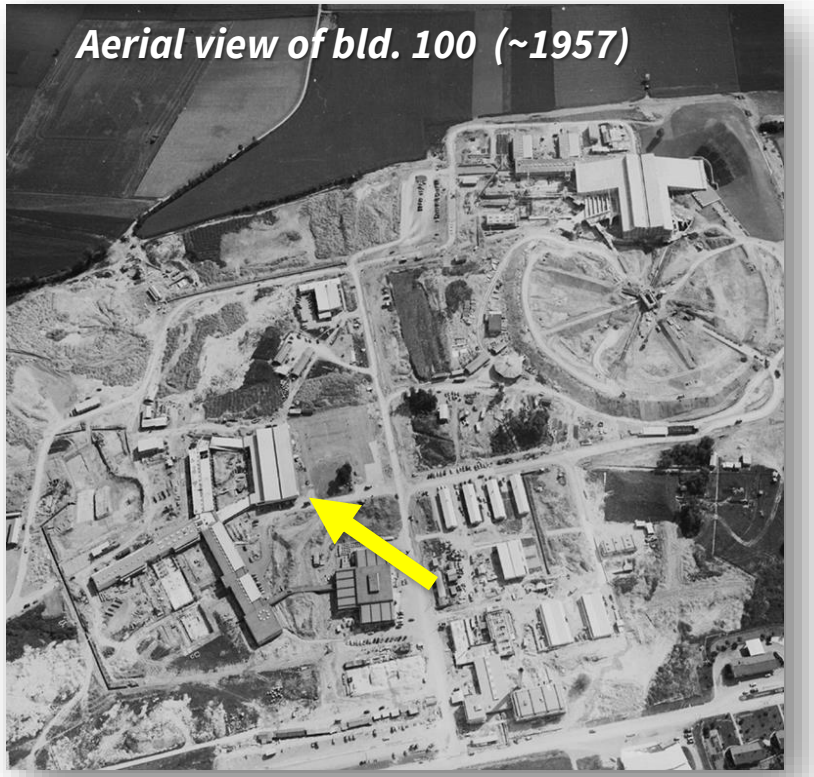
- 4000 m^2 of internal **workshop facilities with state-of-the-art equipment,** 50 technicians (Staff and Industrial Support): CNC machining, sheet metal work & welding, electron beam & laser, vacuum brazing, metallic additive manufacturing.
- **External subcontracting service.**



Materials, Metrology & NDT

- **Material selection, analysis & metallurgy**: optical microscopy, FIB, SEM, XRD, thin-film characterisation, mechanical testing (4 K – RT) and failure analysis.
- **NDT**: ultrasounds, radiography, micro computed tomography.
- 350 m^2 of **internal metrology facilities**: 3D Coordinate Measuring Machines (CMM)

MME Mechanical Workshop

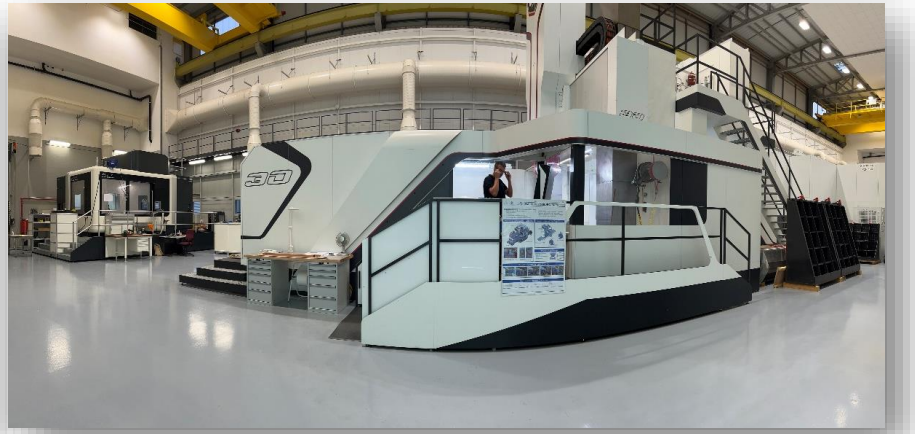


A real **heritage of CERN** (1957-2024)
Guaranteeing 70 years know-how in **fabrication of mechanical components for accelerator and experiments**

Its core mission is to provide service to the Organization for:

- **Urgent needs** (repairing, tunnel interventions, urgent fabrication…)
- **Prototypes / proof of principle**
- **Multi-technology fabrication projects**

Subcontracting to industry
Knowledge Transfer to external collaborations and industrial partners



EN-MME: Multi-Technology Skills and Expertise

An Overview…

Machining Technologies

Multi-axis machining: **5-axis Milling / 4-axis Turning**, angled heads

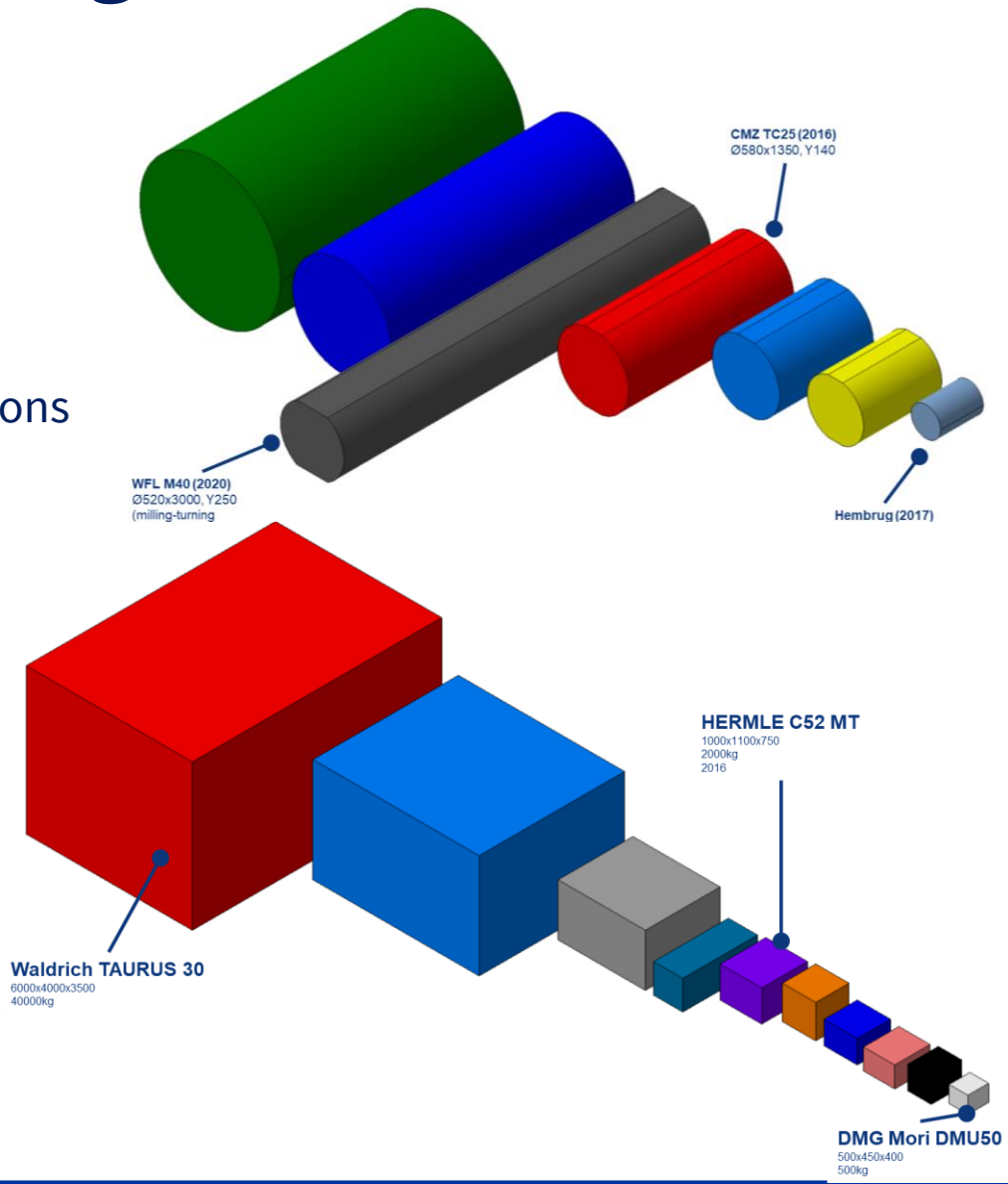
Attainable features :

Accuracy : **few µm**

Roughness (Ra / Sa) : **down to few nm**

Capable workpiece dimensions : **1 cm³** up to **6 m × 4 m × 3.5 m** // up to 20 tons

Large Milling Centers Hall (bld. 156)



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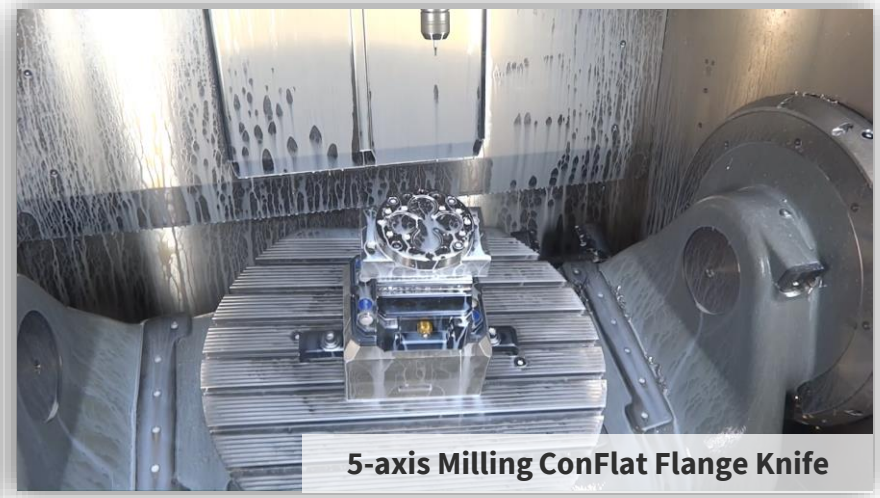
SWELL Cavity

1,3 GHz Bulk Cavity

Crab HOM Coupler

HIE-ISOLDE Monoblock Cavity

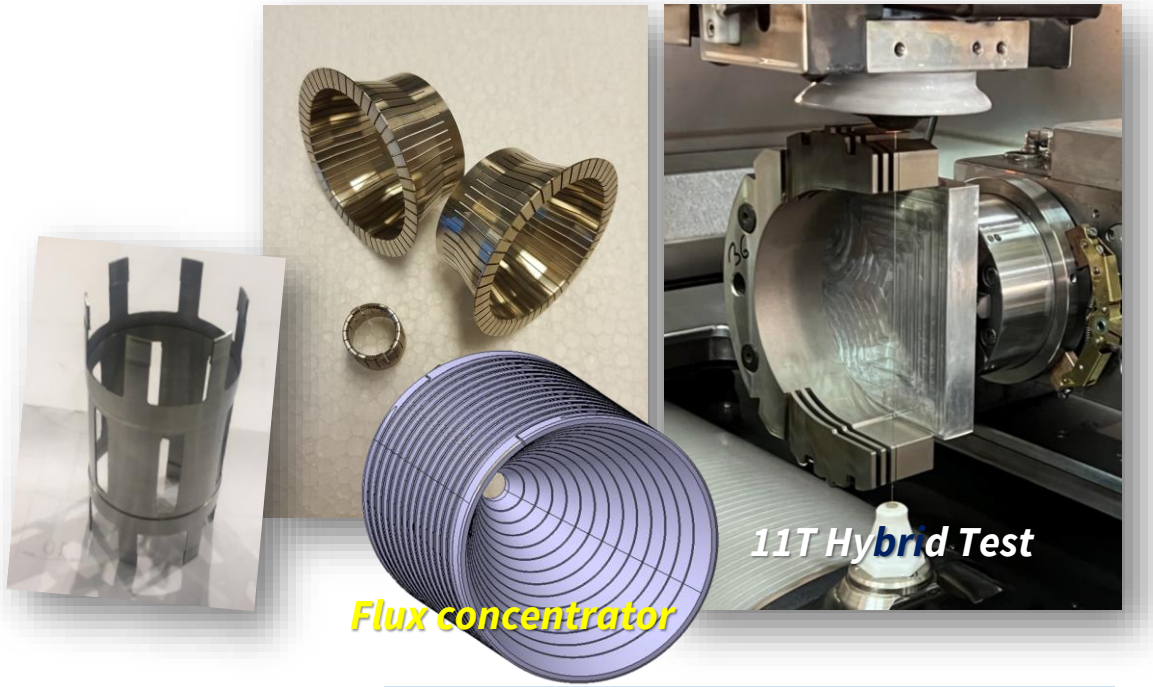


5-axis Milling ConFlat Flange Knife

Complementary Technologies

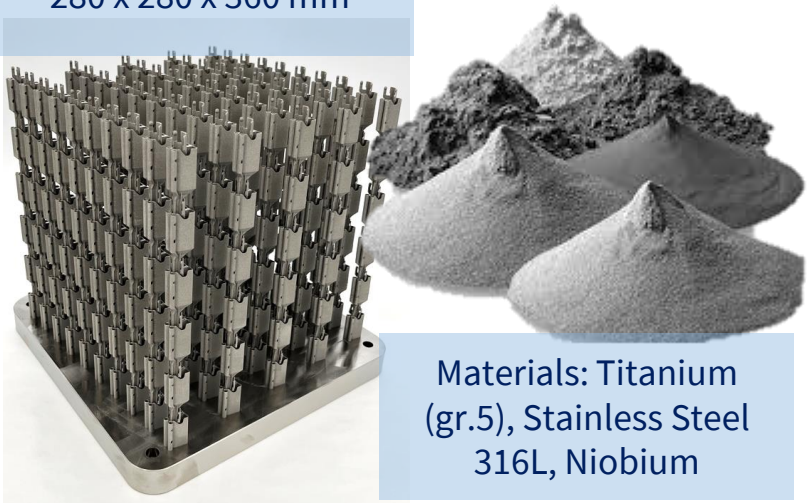
Spark Erosion

- **Wire** EDM (**5 axis**) :
  - Taper angle (± 29° max), Rotary axis (Ø120 max)
  - Attainable features: Accuracy down to ± 5 µm, Ra 0.2
- **Die sink**
  - Attainable features: Ra 0.8



Additive Manufacturing (SLM)

Volume
280 x 280 x 360 mm³



Materials: Titanium (gr.5), Stainless Steel 316L, Niobium

Typical Applications:
Lightweight, Complex components, cooling channels, small series

Fast Wire Scanner
(Ti gr.5)

HOM Coupler DQW
(Niobium)

Sheet Metal Forming & Joining Techniques

Wide **variety of technologies & equipment**:

- Rolling, Bending, Deep Drawing, Spinning
- Arc welding (TIG, MIG, Plasma), Beam welding (Electron Beam & Laser Beam)
- Vacuum Brazing & Thermal treatments

Strong emphasis on welding/brazing quality (ISO 3834 approach)

Specific know-how for on-site interventions in accelerator complex and Experiments

Robotic Laser Welding solution

High precision forming & welding

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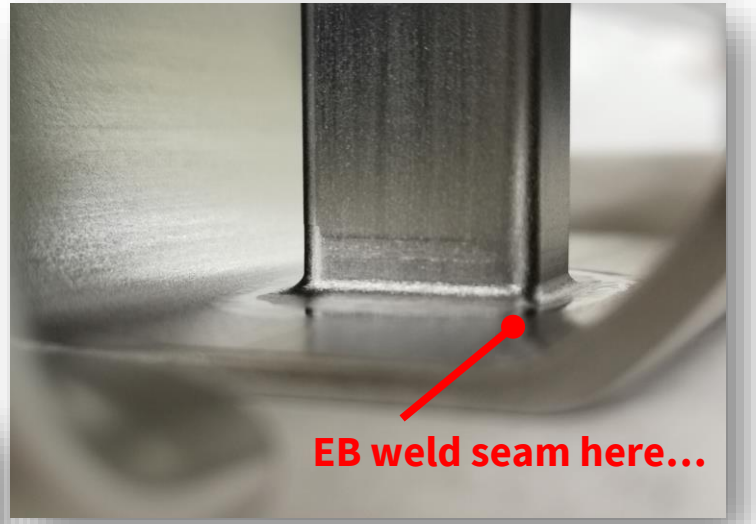
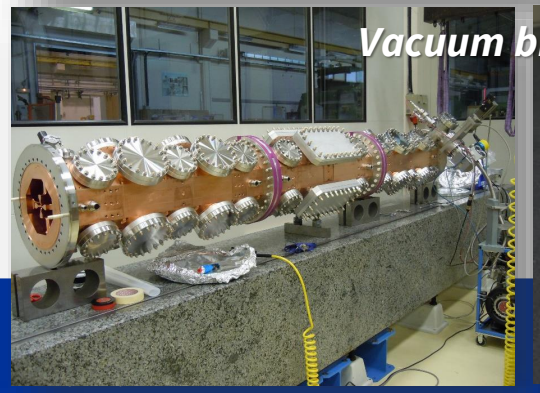
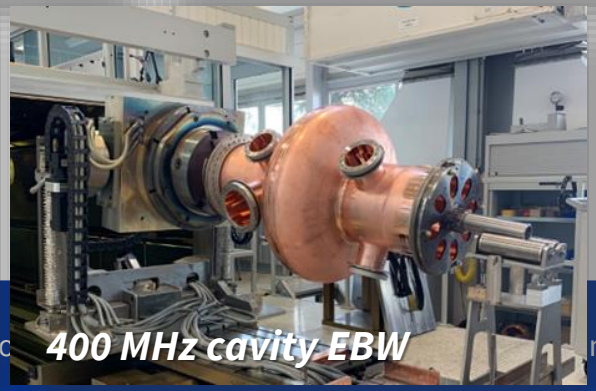
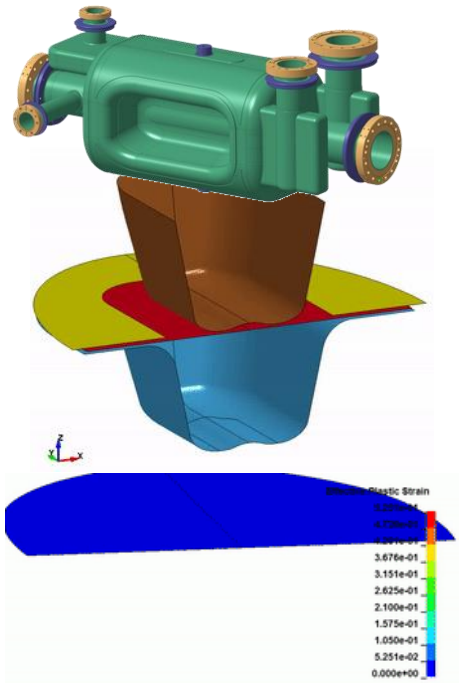






Fabrication Process Simulations



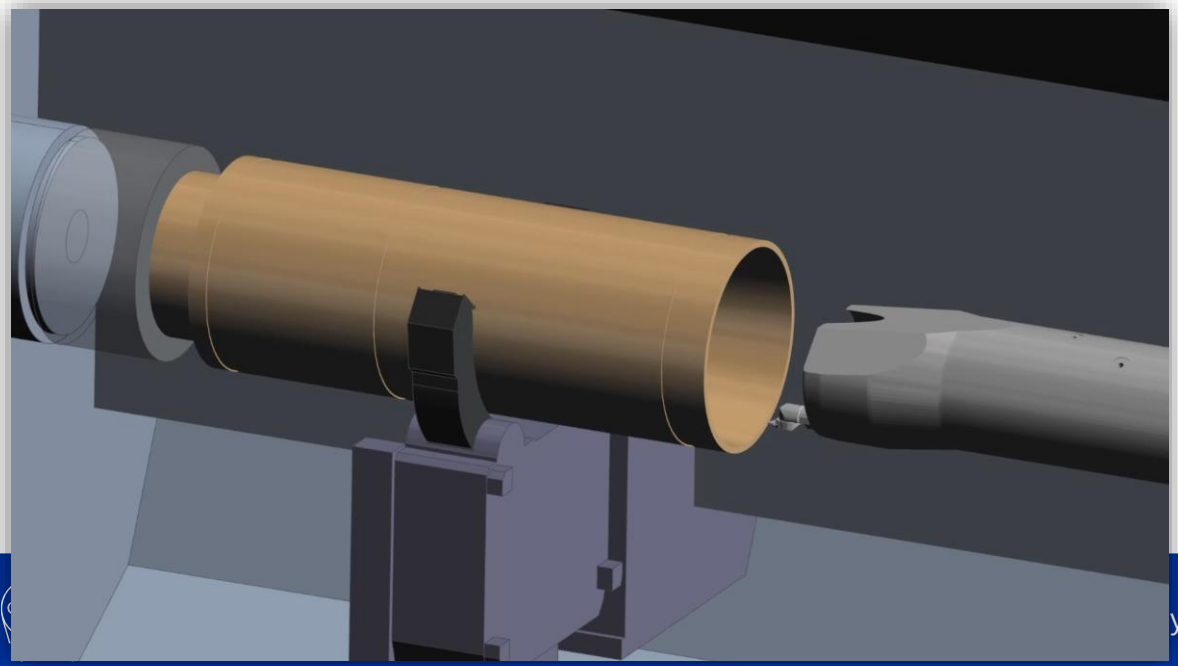
Easier and faster transition from process conception to produced parts. **Less costs**

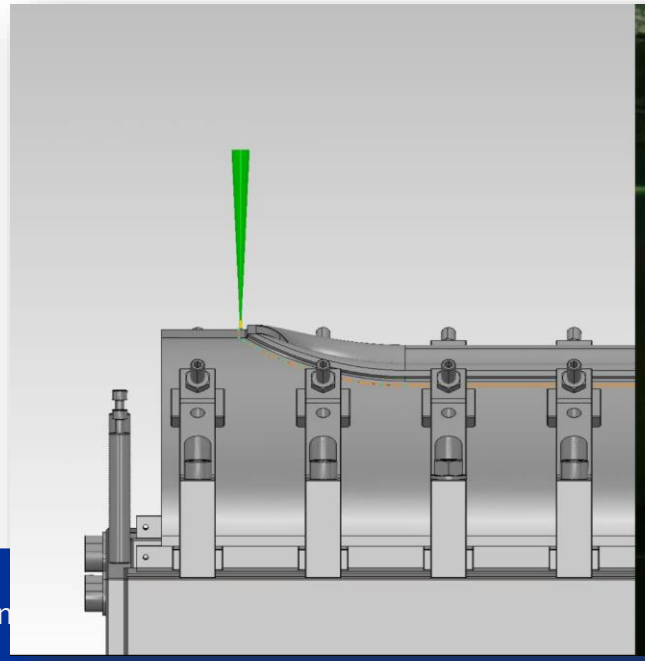
- Streamline tool design activities and choice of process parameters
- Optimisation of trial phase
- Reduction of ‘’human error’’ (complex tasks and high added value equipment)
- Better reproducibility & traceability

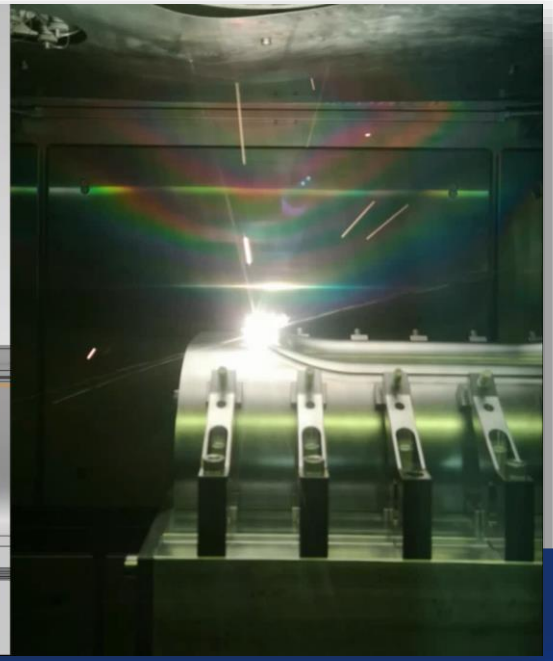
<u>CAM-Based</u> : Cinematics, Process Parameters & Tools

Multi-axial Milling & Turning, Wire Erosion, EB Welding

EdgeCAM
Powermill
WorkNC







Dimensional Metrology

State of the art equipment to cover the full dimensional metrology. Accuracy from submicron. Size up to the several metres

Most accurate equipment:

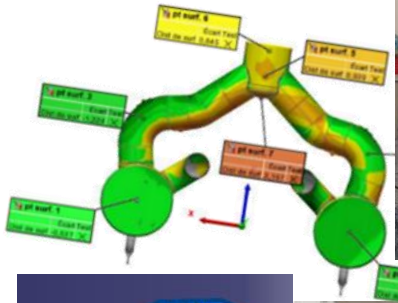
Leitz PMM-C Infinity

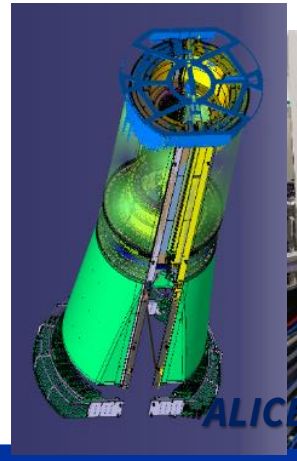
- Accuracy of 0.3 + L/1000 [µm]
- Airlock environment to maintain T and humidity conditions (VDE/VDI 2627)

Optical & Laser Systems

MetraSCAN & HandySCAN

- Accuracy: 65 µm – 80 µm
- Compt. Size**:** 0.2 m – 6 m



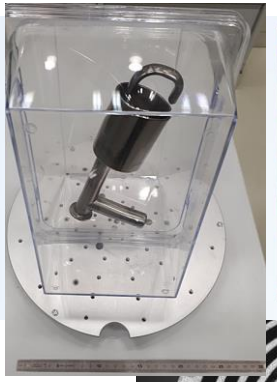


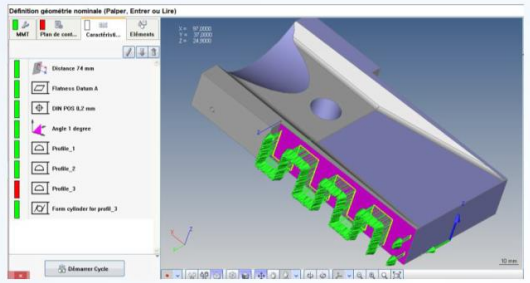
ALICE ITS Detector

Computer µTomography

Zeiss Metrotom CT 1500

- Accuracy: 9 µm + L/50
- Compt. Size: Ø430 x 800 [mm]
- Voxel: ~ 7 µm
- Integr. Thckn.: Steel 50 mm



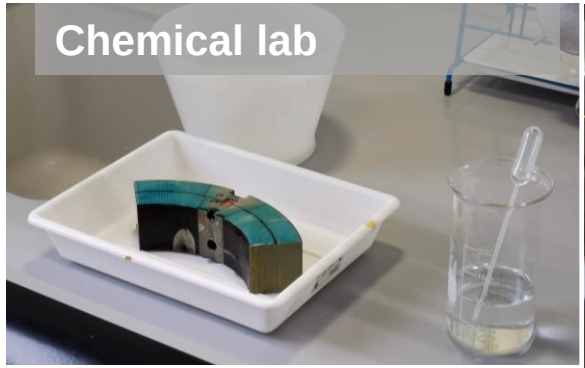


CLIC - X-BAND SPIRAL LOAD

Metallurgy, Mechanical Measurements & NDT

See also EN-MME-MM

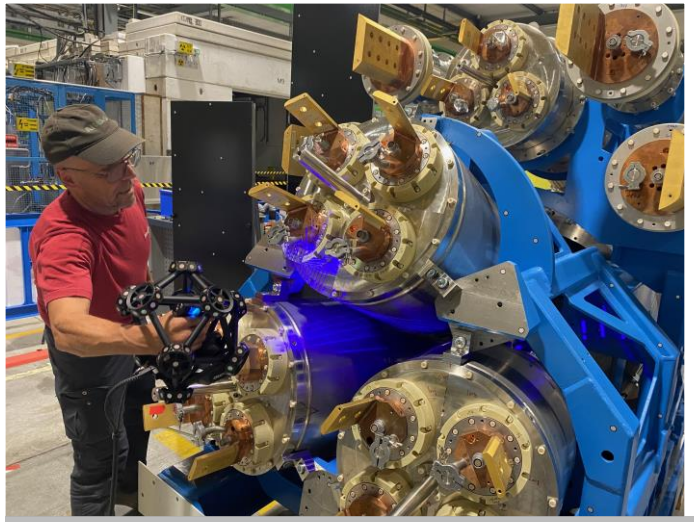
Cryogenic mechanical and fracture mechanics test facilities



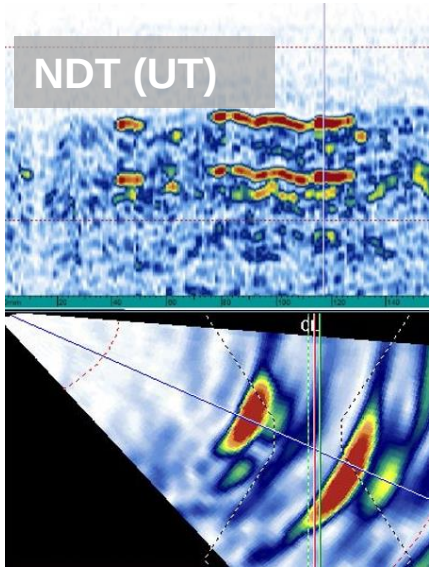
Chemical lab

Preparation

Microoptical observation

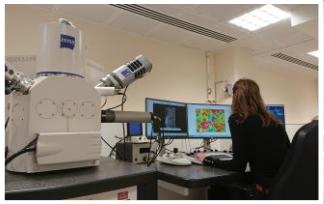


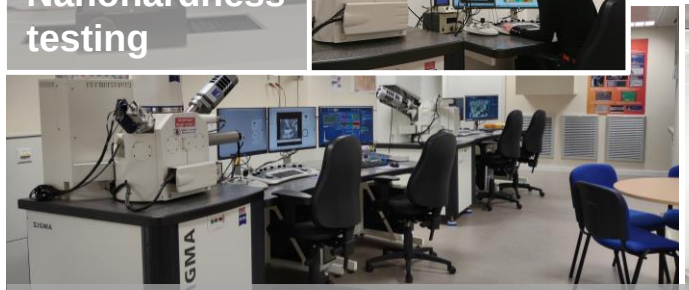
State of the art metrology + CT



NDT (UT)

Nanohardness testing



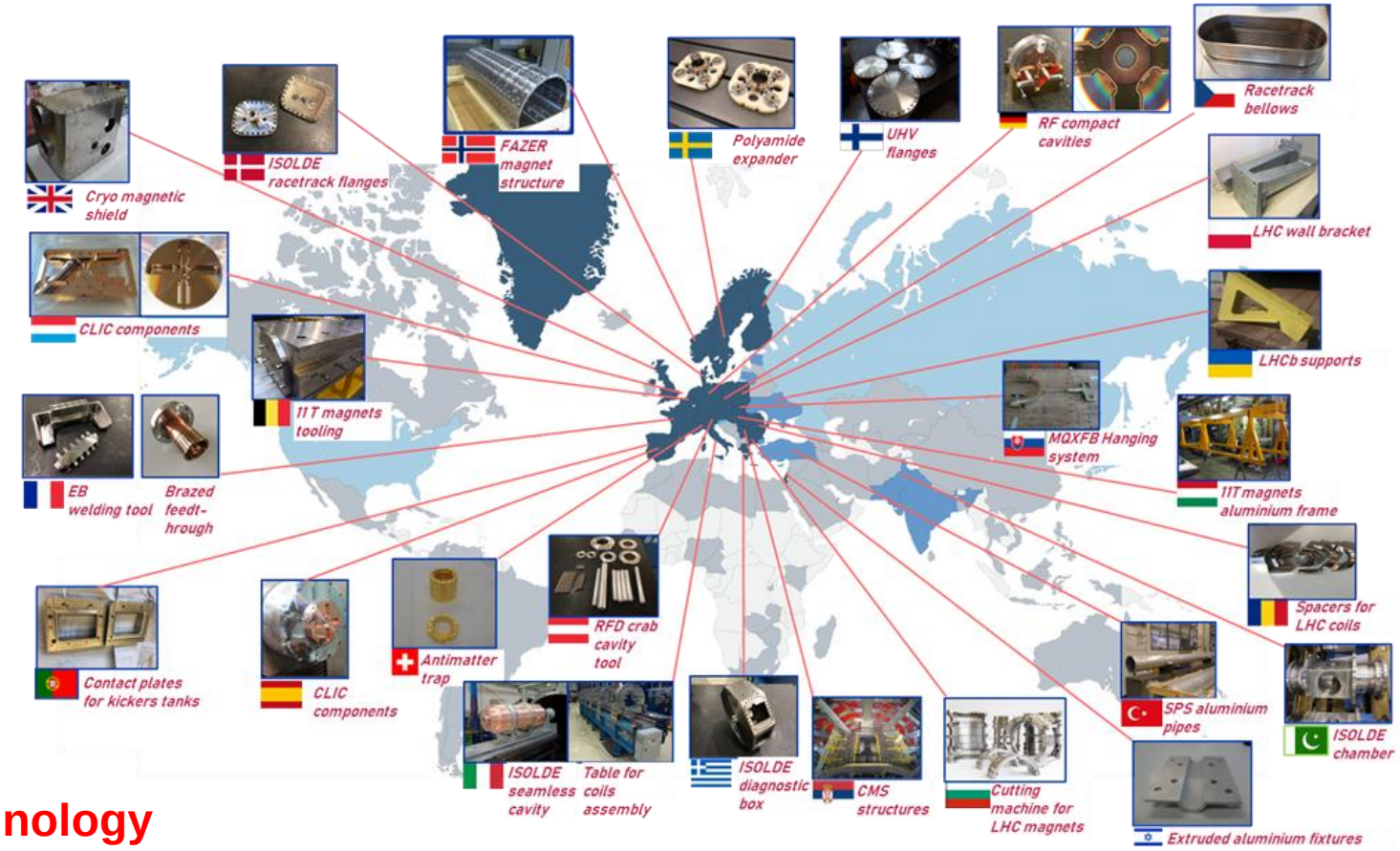


Advanced electron microscopy including FIB-SEM and a wide range of detectors (EDS, EBSD, low voltage EDS)

MME Subcontracting Service:

- In **close collaboration with the CERN Procurement Group**
- Strong contribution to **balance the industrial return**
- **~1500** contracts/year (~10MCHF)
  ~40% of subcontracted production for mechanical components @ CERN

Subcontracting:
~ 40% of semi-finished parts
~ 60% of finished / turnkey components
Industrial Partners in all Member States

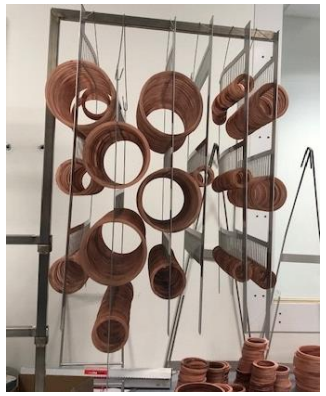


Full Complementarity with the In-House Technology Portfolio…Series Production…Knowledge Transfer

MME Subcontracting Service: Make or Buy

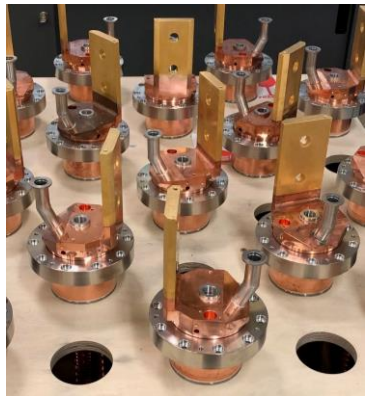
Series production of 157 Current Leads:

- **Estimated budget: 3.73MCHF**
- **Make or Buy Strategy**
- **~ 50 orders (75% of the Production) via Suppliers in 14 Member States**
- **Internal manufacturing activities focused on critical manufacturing steps**
- **Final clean machining, UHV cleaning, EBW, TIG welding, surface coating and pressure/leak tests…**



Copper rings before silver coating

Head and exchanger CL 7KA after final turn/milled machining and brforevfinal vaccum brazing



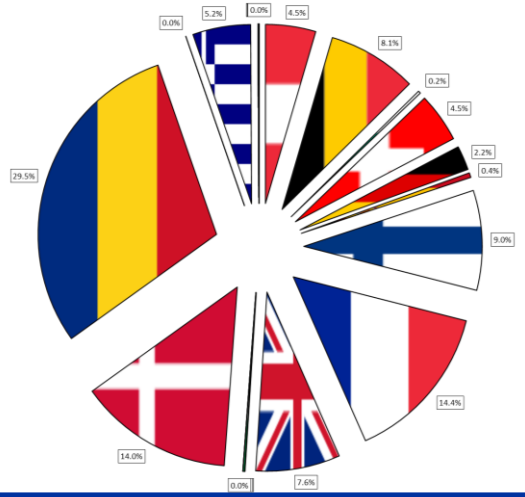
Head and exchanger CL 7/2KA gold coated before electron beam welding

Preseries:
CL 18KA (2x)

Preseries:
CL 7KA (1x3)

Preseries:
CL 2KA (2x4)

Member states distribution



CL 7KA before and after shrink fitting with honed St. Steel tube

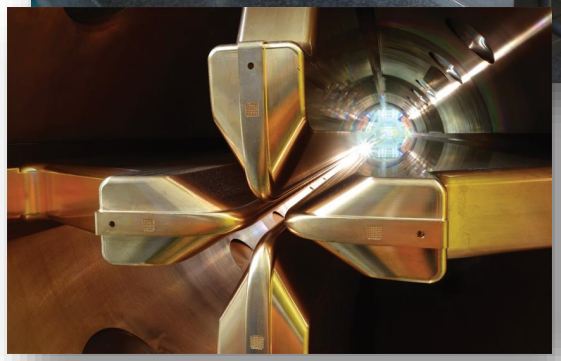
CL 7/2KA and 600A ROHACELL insulation components

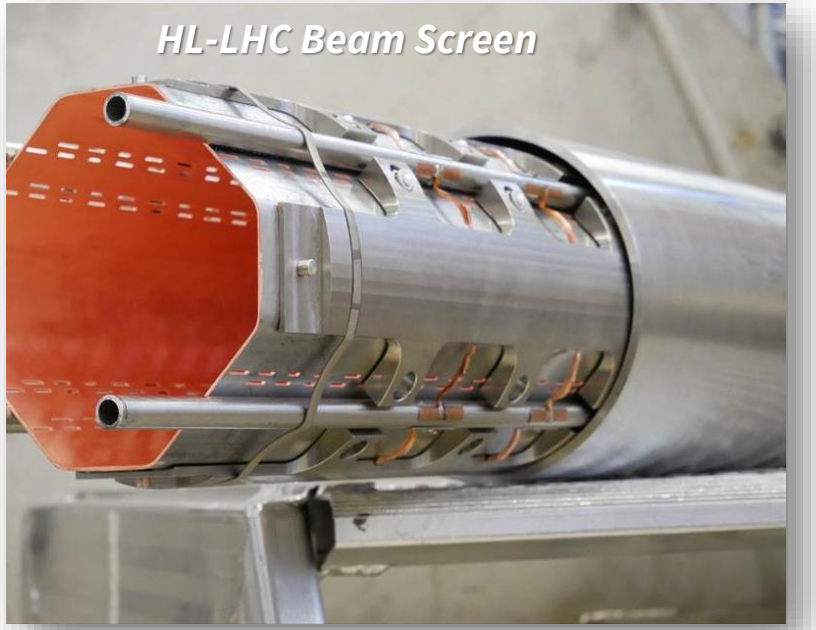
Visual control of CL600A pressure vessel assembled at CERN.
Performed by A.Proust, welding Engineer in charge of the safety files

EN-MME: Multi-Technology Skills and Capabilities

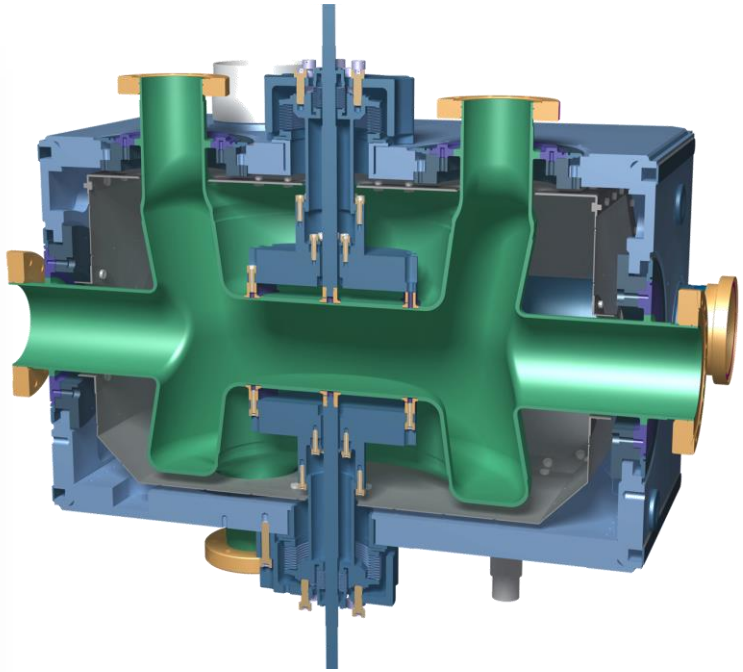
Most of the equipment produced calls for (simple to) **complex interlacing** of different fabrication **technologies**

LINAC4 RFQ Spare - Segment





HL-LHC Beam Screen



Jacketed HL-LHC Crab Cavity

Behind these pics….

- **800+ fabrication steps**
- **20+ technologies involved**
- **1.1 MCHF**

From Technology Development to Industrial Knowledge Transfer

HIGHLIGHTS in Machining Technologies

Ultra High Precision Machining

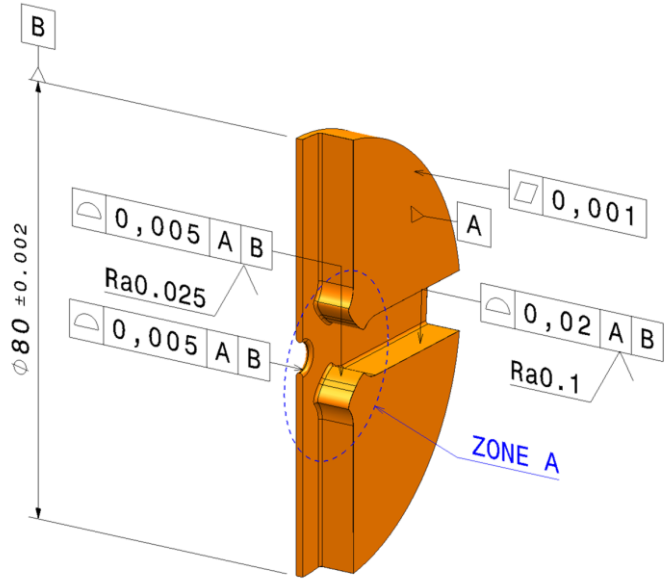
UHP Diamond turning & milling of OFE Cu RF components:

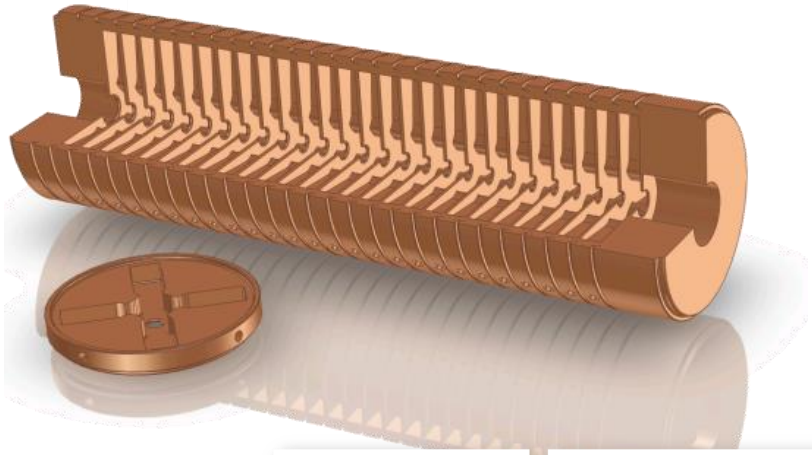
[+] Shape **accuracy**: few µm // **Roughness**: few nm
[+] **Minimal damaged layer**

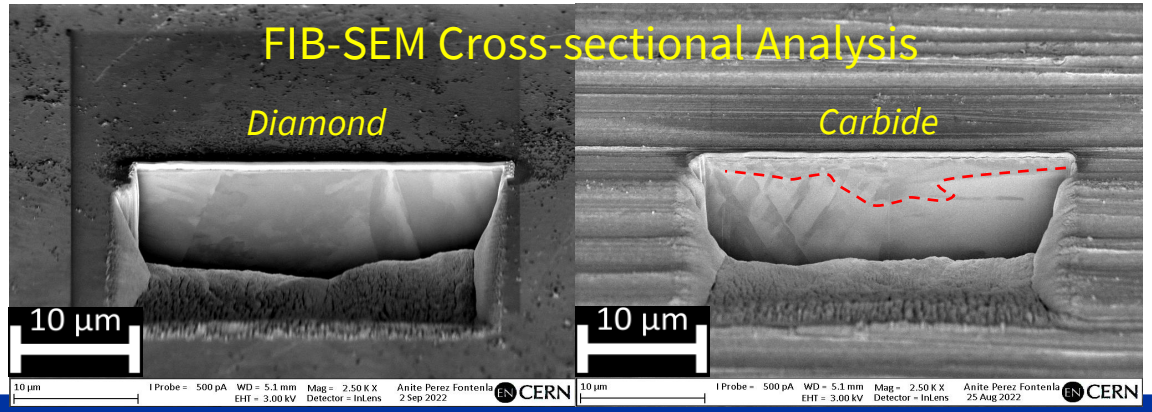
[-] needs **dedicated machines**

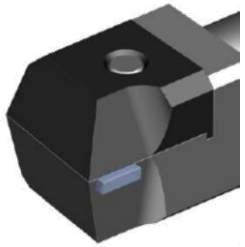
[-] greatly **restricted** in ferrous and other materials, due to high chemical reactivity with diamond tool

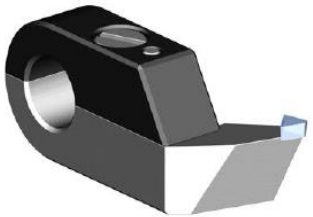
diamond tool-tip → graphitization→ diffusion into the workpiece → quick **tip erosion and tool wear**

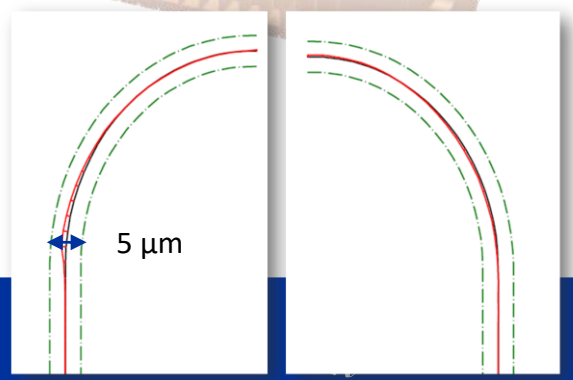








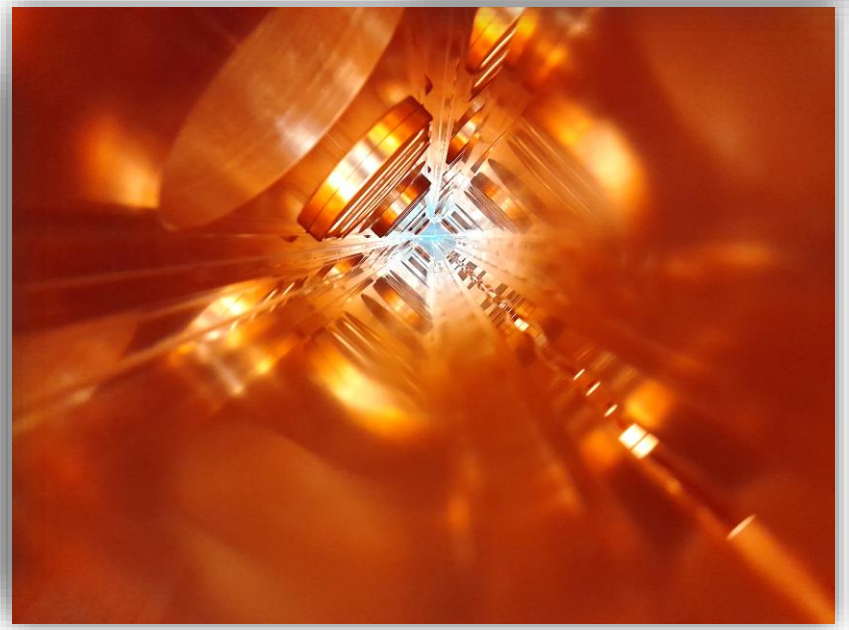




Radio Frequency Quadrupole RFQ

LINAC4 RFQ Main Technologies:

- High-precision Machining
- Ultra pure Cu
- Vacuum Brazing
- Specific Thermal Treatments



RFQ Technologies: From HEP to Medical Application and…

RN Accelerating science

Knowledge Transfer
Accelerating Innovation

ABOUT US ACTIVITIES & SERVICES TECHNOLOGIES

NIMMS and other radi

CERN's Next Ion Medical Machine Study and new European projects are building on

NIMMS: Towards the new generation of compact and cost-effective ion-therapy facilities

CERN has been actively transferring its technologies to radiotherapy for decades. In 2019, CERN launched the Next Ion Medical Machine Study (NIMMS) to develop cutting-edge accelerator technologies for a new generation of compact and cost-effective ion-therapy facilities. The goal being to propel the use of ion therapy, which uses carbon and other ions heavier than protons. Proton installations are already commercially available but only four such ion centres exist in Europe, all based on bespoke solutions.

ELSEVIER

Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms

Volume 459, 15 November 2019, Pages 153-157

The CERN PIXE-RFQ, a transportable proton accelerator for the machina project

S. Mathot [a], G. Anelli [a], S. Atieh [a], A. Bilton [a], B. Bulat [a], Th. Callamand [a], S. Calvo [a], G. Favre [a], J.-M. Geisser [a], A. Gerardin [a], A. Grudiev [a], A. Lombardi [a], E. Montesinos [a], F. Motschmann [a], H. Pommerenke [a], P. Richerot [a], K. Scibor [a], M. Timmins [a], M. Vretenar [a], F. Taccetti [b]…L. Giuntini [b d]

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https://doi.org/10.1016/j.nimb.2019.08.025

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Abstract

CERN has been building a transportable RFQ for use in the examination of art masterpieces based mainly on the PIXE (Proton Induced X-ray Emission) technique with an extracted beam. This new PIXE-RFQ accelerator is very compact, only one meter in

Cutting Fluids

Chemical composition of **cutting fluids** greatly impacts **vacuum compatibility, chemical long-term stability, machinability** (surface, damaged layer, …)

Ideal lubricants : oil-free, fully water soluble, no Sulphur, no Silicon, efficiently removed by solvents

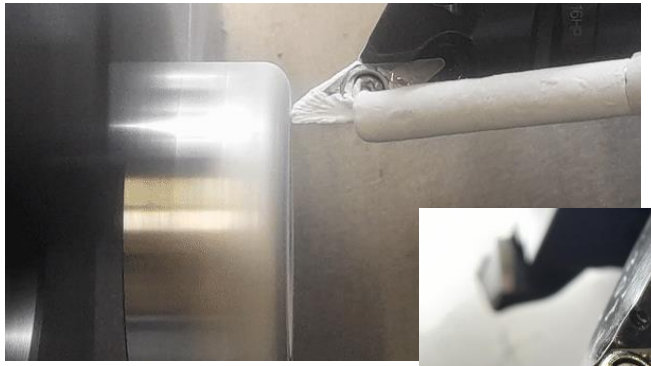
Some applications:

- **UHV clean** machining : dry-machining, ethanol as cutting fluid
- **Cryogenic** Lubrication : anything which needs material fragilization, also for UHV clean
- Minimum Quantity Lubrication (**MQL**) : fluid only in the working area, [+] great reduction in lubricant quantity, not adapt when heat evacuation is key (SRF Nb, roughing,…)

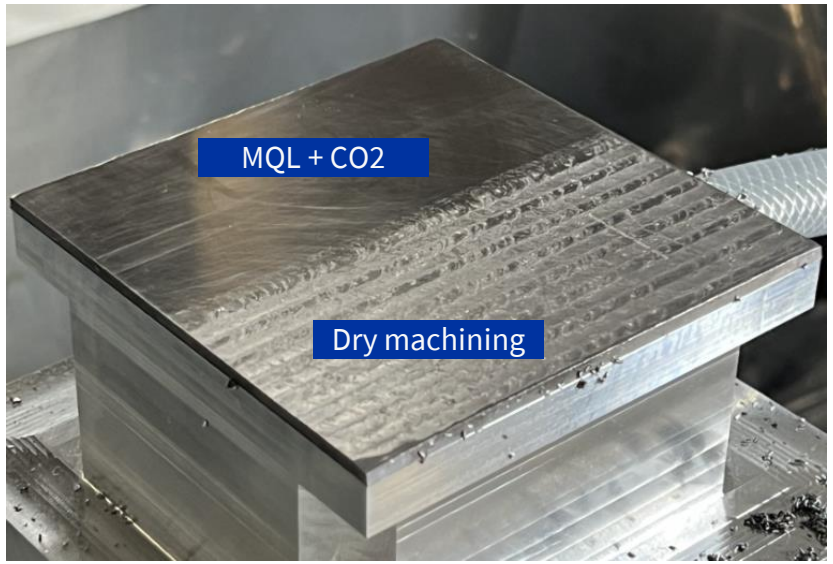
Any newcomer must be tested!

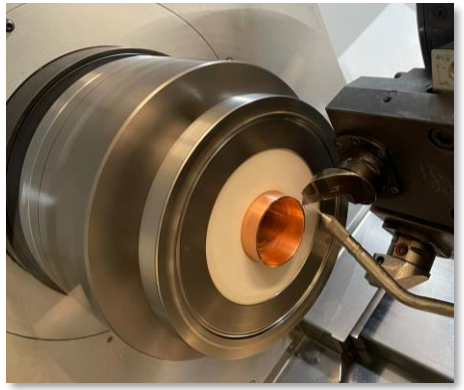
Example used @ CERN : Blasocut BC 35 LF SW
Mineral oil-based coolant, without additives containing sulphur, chlorine, zinc or phosphor.
Qualified, by CERN surface treatment service, as UHV compliant

Cryo Co2 Turning



Clean Milling of Lead piece





MQL Turning

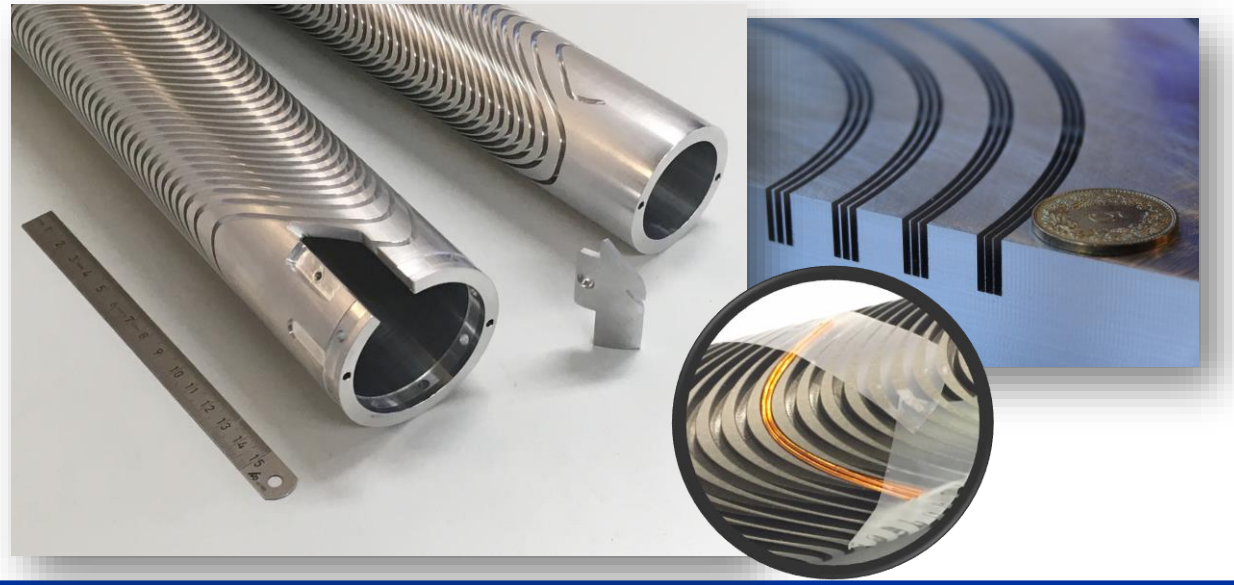
CCT Magnets

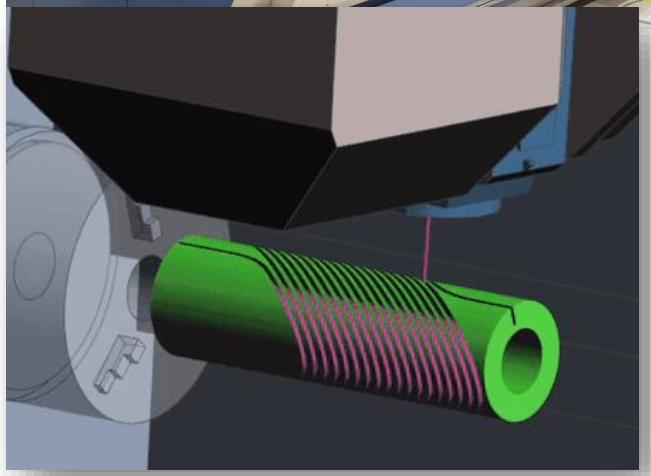
Alternative to standard magnet design

Field quality depends on machining precision

- Since 2015: Ongoing studies to **optimize the design** and fabrication process (HL-LHC, medical, FCC-ee)
- Multiple prototypes and simulations to **push the limits of machining**

CCT FCC-ee: quadrupole → sextupole





WFL M40 high-precision turning milling centre

CCT Magnet: From HEP to Medical Application

A curved magnet with much potential

Rope winding and giant pasta shapes meet particle physics in Fusillo, in a new magnet prototype with possible medical applications in hadron therapy

24 FEBRUARY, 2025 | By Insa Meinke

Frédéric Garnier controls the process of inserting the inner former into the outer former. The grooves in the outer former, into which the cable was

From Technology Development to Industrial Knowledge Transfer

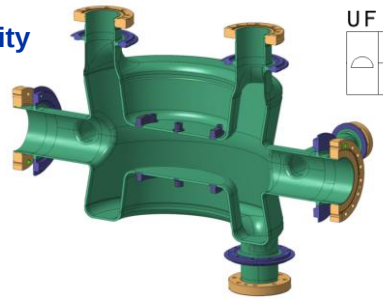
HIGHLIGHTS in Complex Sheet-Metal Forming Technologies

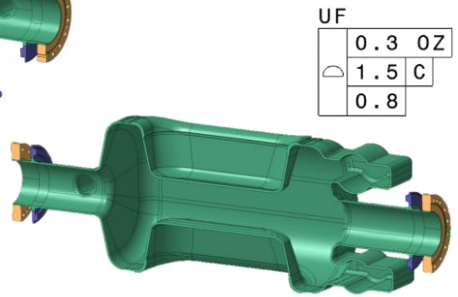
Superconducting RF CAVITIES (Nb-bulk)

Crab Cavities feature specific design constraints:

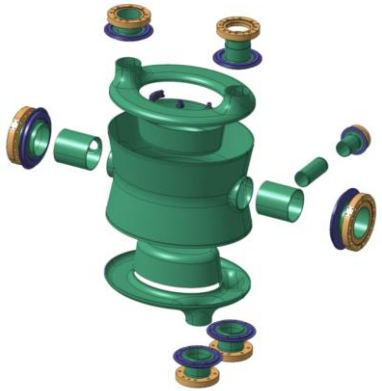
- Non axial-symmetric shapes with sub-millimetre precision
- Expensive & exotic materials (Nb, Nb55Ti, 316LN)
- Demanding requirements on surface quality for SRF performance

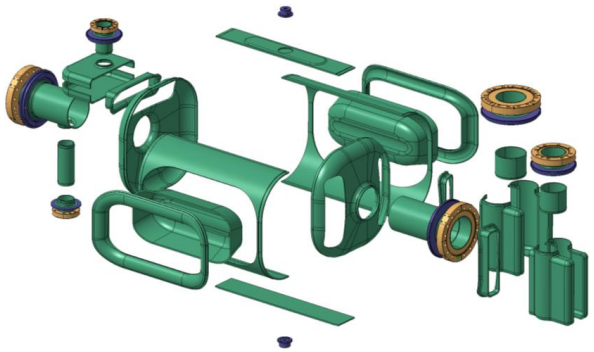
DQW Crab Cavity





RFD Crab Cavity





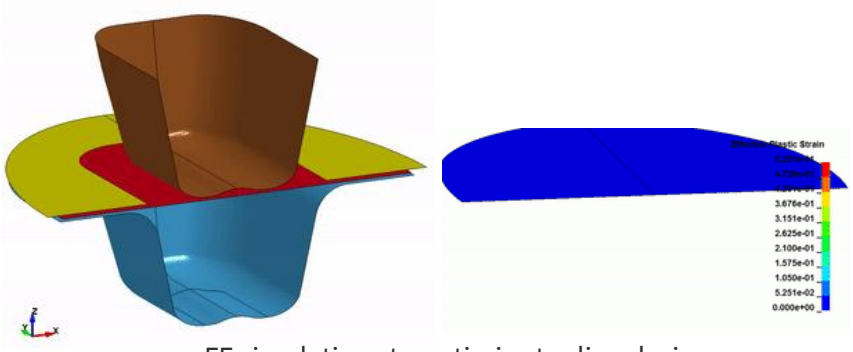
1 cavity is more than 600 fabrication steps!

Manufacturing process imposes substantial intertwining of fabrication techniques:
Complex Shaping + Machining + Electron Beam Welding…
…but also metrology, brazing, assembly, adjustment, surface treatments…

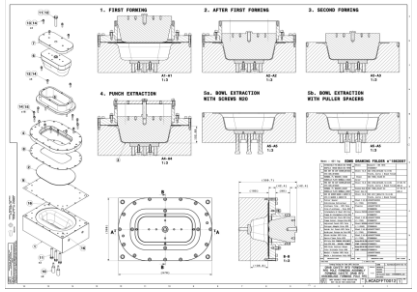
Knowledge Transfer to Industry for Series Production

- Extensive simulations campaigns to **validate and optimize fabrication parameters**
- Fine definition of **tooling & processes** for all components and techniques

  Tooling engineering ⟶ copper trials ⟶ production with niobium



FE simulations to optimize tooling design



2D design & forming sequence

Copper trials for tooling & process validation

Niobium initial sheet

Deep-drawing

Machining & Coining

Finished Pole

From Technology Development to Industrial Knowledge Transfer

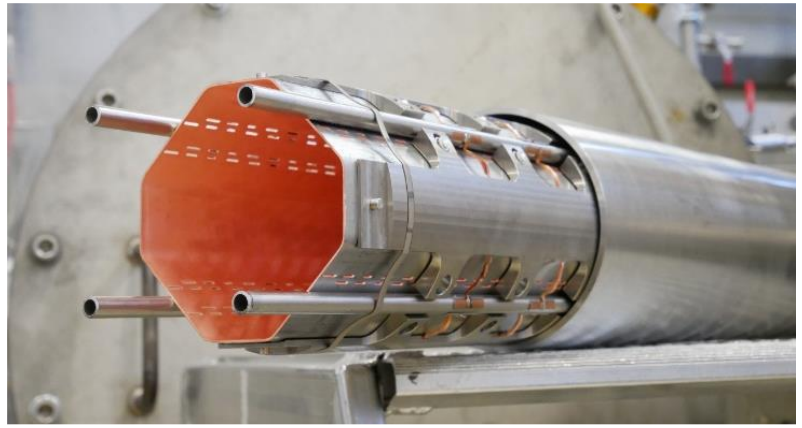
HIGHLIGHTS in Material selection, Analysis & Metallurgy

Material Selection

Large Nitronic 50 components for the Precompression Structure of the ITER Central Solenoid, 2018

Functional requirements → Identification of materials / production routes → Specification → Prototyping, testing → Series production → Inspections (DT, NDT, metrology) → End of life / Failure analysis

⇐ P506 steel for the LHC and HL-LHC beam screens and cooling pipes, 1997-present



Low permeability 304L for the CMS HG CAL detector, IT-IT-4655/EP (Supply of 600 t of plates), 2021-2022 ⇒

Large EN AW 5083 seamless rolled rings for the external cylinder of CMS, 2004 ⇒

HGCAL 1:1 scale 1.4306 half disks

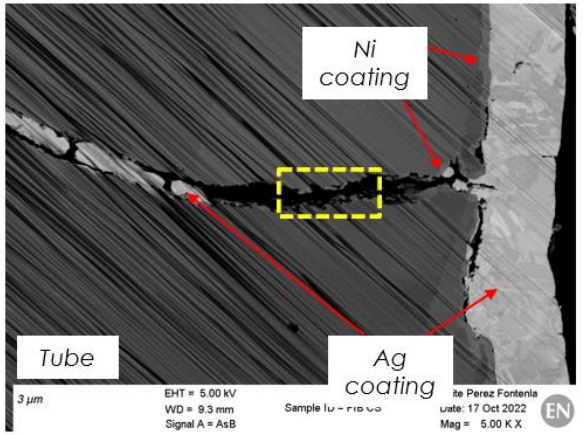
CERN-ITER, RCA of the ITER Vacuum Vessel Thermal Shields (VVTS)

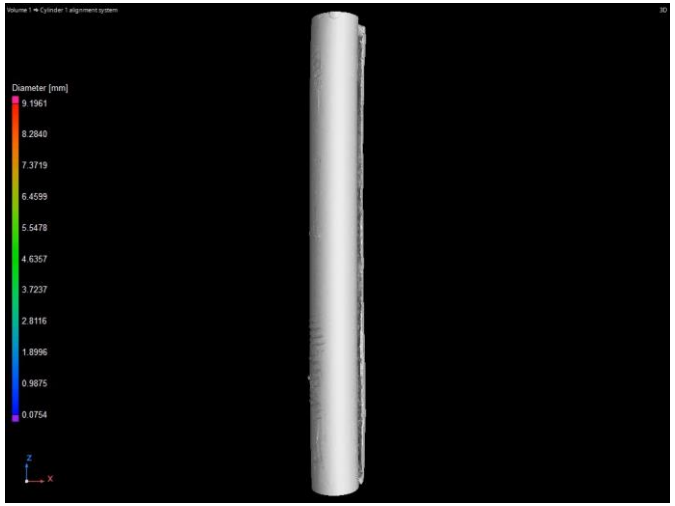
Leaks were found in an uninstalled TS, and **corrosion spots** have been observed in a large quantity both in installed and uninstalled TS cooling pipes' welds. These components are **very large panels** (2000 m^2), cooled down by ~**23 km of piping**, **stitch welded** for an improved thermal efficiency and **silver coated** to reduce their emissivity.

⇑ Silver coated thermal shields, with the stitch – welded cooling pipes

Investigations were based on **high resolution CT** (~ 150 CT scans), **metallographies** at targeted positions, and **advanced SEM** (including FIB).

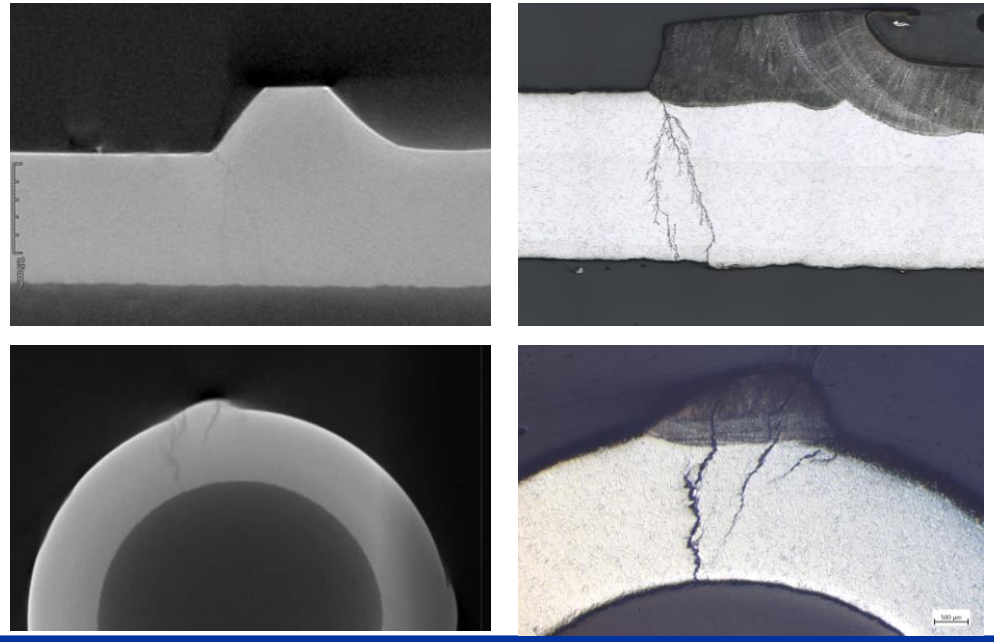
FIB cut showing cavities underneath the Ag coating (top). The detection of Cl inside them was possible thanks to the X-max Extreme Detector with an extreme light element sensitivity ⇒

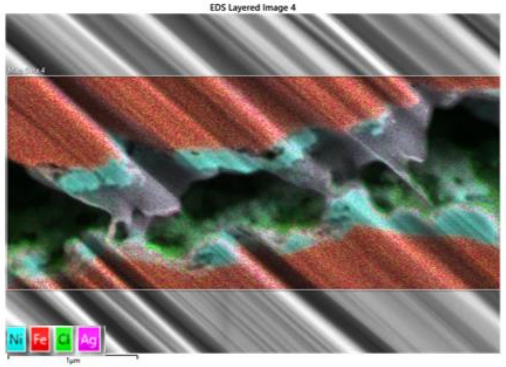




⇑ Computed tomography was used for the first time to show the 3D trajectory of the leak provoked by the SCC.

CT scans (left) and metallographic preparations (right) of the same positions showing through thickness cracks by SCC⇒



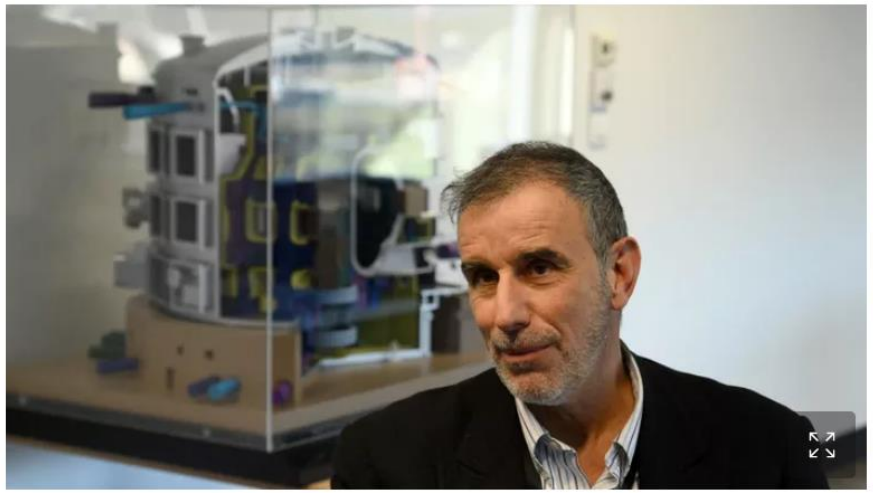


CERN-ITER, RCA of the ITER Vacuum Vessel Thermal Shields (VVTS)

Défauts et retards pour le projet international de fusion nucléaire Iter

Par Le Figaro avec AFP
Publié le 06/01/2023 à 17:50 , mis à jour le 06/01/2023 à 18:16

Écouter cet article 00:00/02:34



Pietro Barabaschi a été nommé à la tête du programme Iter en septembre 2022. *NICOLAS TUCAT / AFP*

Deuxième défaut relevé, des traces de corrosion sur les «*écrans thermiques*» qui doivent protéger de la très forte chaleur émise lors de la fusion. Ce qui pourrait aboutir à des fuites de l'hélium utilisé dans le circuit de refroidissement. Ces réparations vont retarder le projet. «*Ça n'est pas un processus qui prend des semaines, mais des mois, voire quelques années*», a expliqué Pietro Barabaschi, qui doit élaborer d'ici la fin de l'année un nouveau calendrier des opérations.

EN/MME-MM contribution to the root cause analysis, including the active participation with a leading role in an international working group, **was deemed essential**, and triggered the repair actions which were recommended.

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FUSION NUCLÉAIRE \ BOUCHES-DU-RHÔNE \ TECHNOS ET INNOVATIONS

Le projet de réacteur à fusion Iter doit réparer des composants clés du tokamak, au prix d'importants retards

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Defects found in two key components of ITER's tokai

22 November 2022

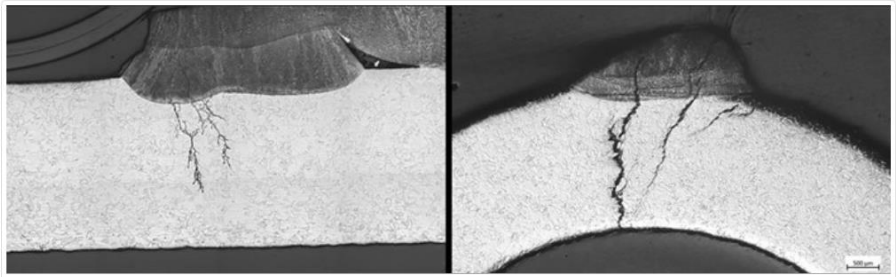
The International Thermonuclear Experimental Reactor (ITER) project has announced defe discovered in the thermal shields and vacuum vessel sectors and warned that the consequ schedule and cost "will not be insignificant".

ITER NEWSLINE -

21 NOV, 2022 | Print | Read the latest published articles

Machine assembly

KEY COMPONENTS TO BE REPAIRED



Investigative techniques (high-resolution CT scanning, scanning electron microscope, energy-dispersive X-ray spectrometer, and metallographic observation) revealed cracks in thermal shield cooling pipes such as the ones pictured here. At left, the crack is 1.5 mm deep. At right it is 2.2 mm deep and crosses the full width of the pipe.

"The risk is too high, and the consequences of a leaking thermal shield panel during operation are too dire. We must assume the problem is extensive," says ITER Director-General Pietro Barabaschi. "Dealing with it in the pit on the module that has already been assembled would be enormously difficult. This means we have to lift out the installed module and disassemble it in order to proceed with the repairs. We are exploring different possibilities, from on-site repair to re-manufacturing in an outside facility,

Material Specifications and Welding for Liquefied Gas Container

CERN-GTT agreement, https://edh.cern.ch/Document/General/TTC/9848968ref:

- KR5807/KT/EN/903S, ADDENDUM 1.1 to general framework agreement KN5752/KT/EN/TE/903C, *"Review of Welding Procedures and Materials Specifications"*, Project start date: October 2022, Project duration: 2.5 years (up to 150 person-days during this period, with the possibility of extending if required and always subject to availability of CERN experts)

Project Lead: Gilles Favre, Stefano Sgobba

Hydrogen economy and materials for cryogenics

GTT gets DNV approvals for liquefied hydrogen tech

REGULATION & POLICY

July 28, 2022, by Sanja Pekic

Classification society DNV has awarded the French LNG containment specialist GTT two approvals in principle (AIP) for the design of a membrane-type containment system for liquefied hydrogen (LH2) and for the preliminary concept design of an LH2 carrier.

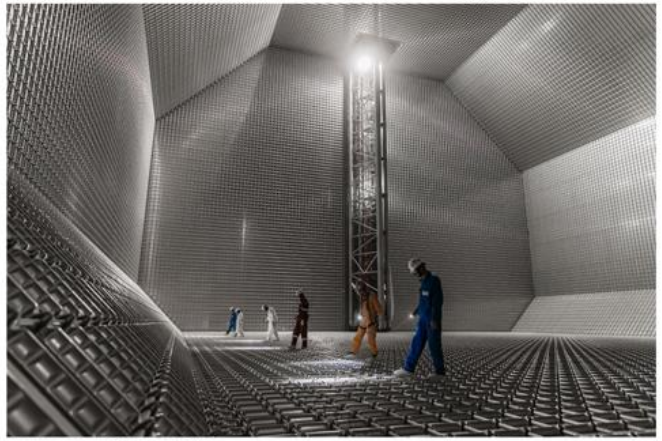
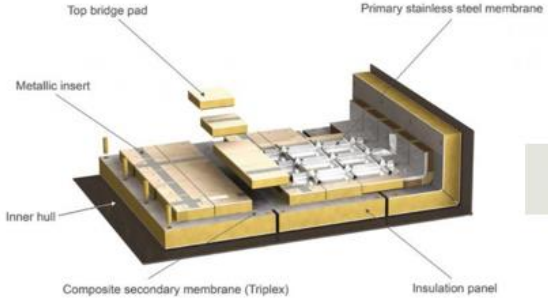


Illustration only; Courtesy of GTT

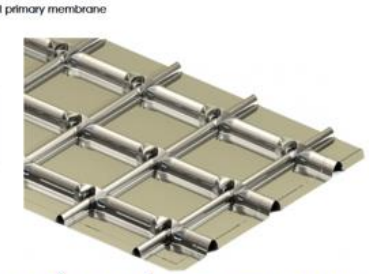
GTT notes this is an important milestone in liquefied hydrogen transport.

GTT inches forward on liquid hydrogen tank for next generation carrier

Mark III concept



Courtesy of GTT



European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

KR5807/KT/EN/903S
ADDENDUM 1.1 to general framework agreement
KN5752/KT/EN/TE/903C

Project: Review of Welding Procedures and Materials Specifications

a) **Project type:** Consultancy and Services

A 'Consultancy and Services' Project consists of a Project executed by CERN, with a content determined by, and for the benefit of, GTT. Its main objective is not the creation of Results, but the use of CERN Background or CERN infrastructure to apply to a GTT use case.

b) **Project Lead:** Gilles Favre, Stefano Sgobba

c) **Project start date:** October 2022

Ongoing cooperation contract with GTT - leading engineering company in containment systems for the shipping and storage in cryogenic conditions of liquefied gas:

- **review GTT's design, specifications and procedures for metallic material selection, metallic components assembly and welding procedures;**
- **advise and recommend best practices and design methodologies**

2023-10-18 MME – Ma

Material Selection and Characterization for Nuclear Fusion Industry

CERN-Kind agreement, https://edh.cern.ch/Document/General/TTC/9812121, ref:

- Agreement KR5777/KT/EN/903S, *"For consultancy and services related to the characterisation at cryogenic temperature of the mechanical properties of high-strength austenitic stainless steel large forgings for fusion machines"* - Partner: Rolf Kind GmbH, Germany
- **Technical Representative Ignacio Aviles Santillana**

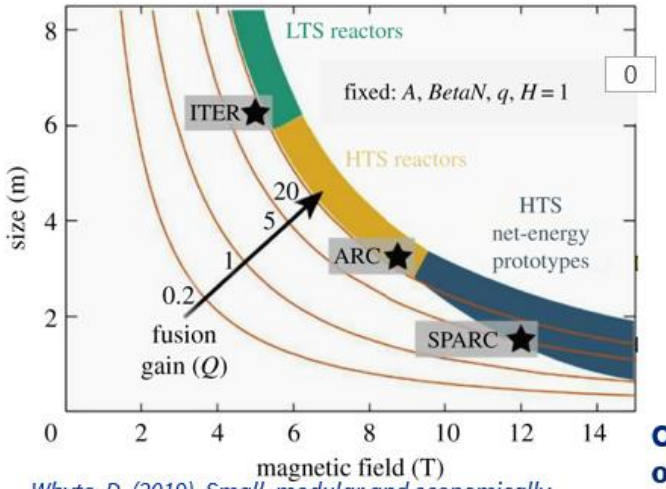
Fusion beyond ITER: the SPARC project

European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

Agreement KR5777/KT/EN/903S

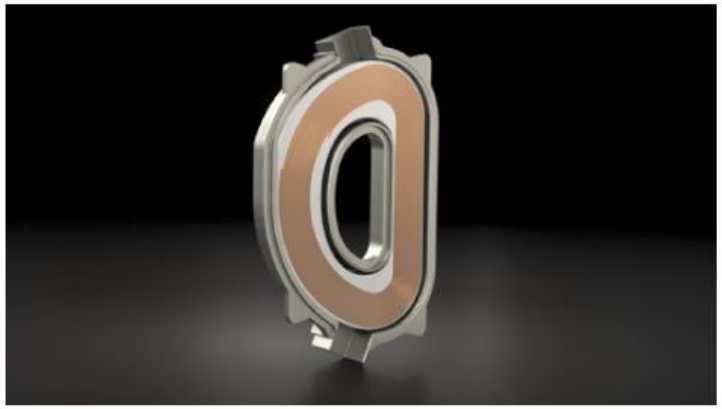
FOR CONSULTANCY AND SERVICES RELATED TO

The characterisation at cryogenic temperature of the mechanical properties of high-strength austenitic stainless steel large forgings for fusion machines



Whyte, D. (2019). Small, modular and economically attractive fusion enabled by high temperature superconductors. Philosophical Transactions of the Royal Society A, 377(2141), 20180354.

- **SPARC is a project of Commonwealth Fusion Systems (CFS), spin – off of MIT.**
- **Compact reactor (40 times smaller than ITER in volume).**
- **Relies on high temperature superconducting (HTS) magnets**



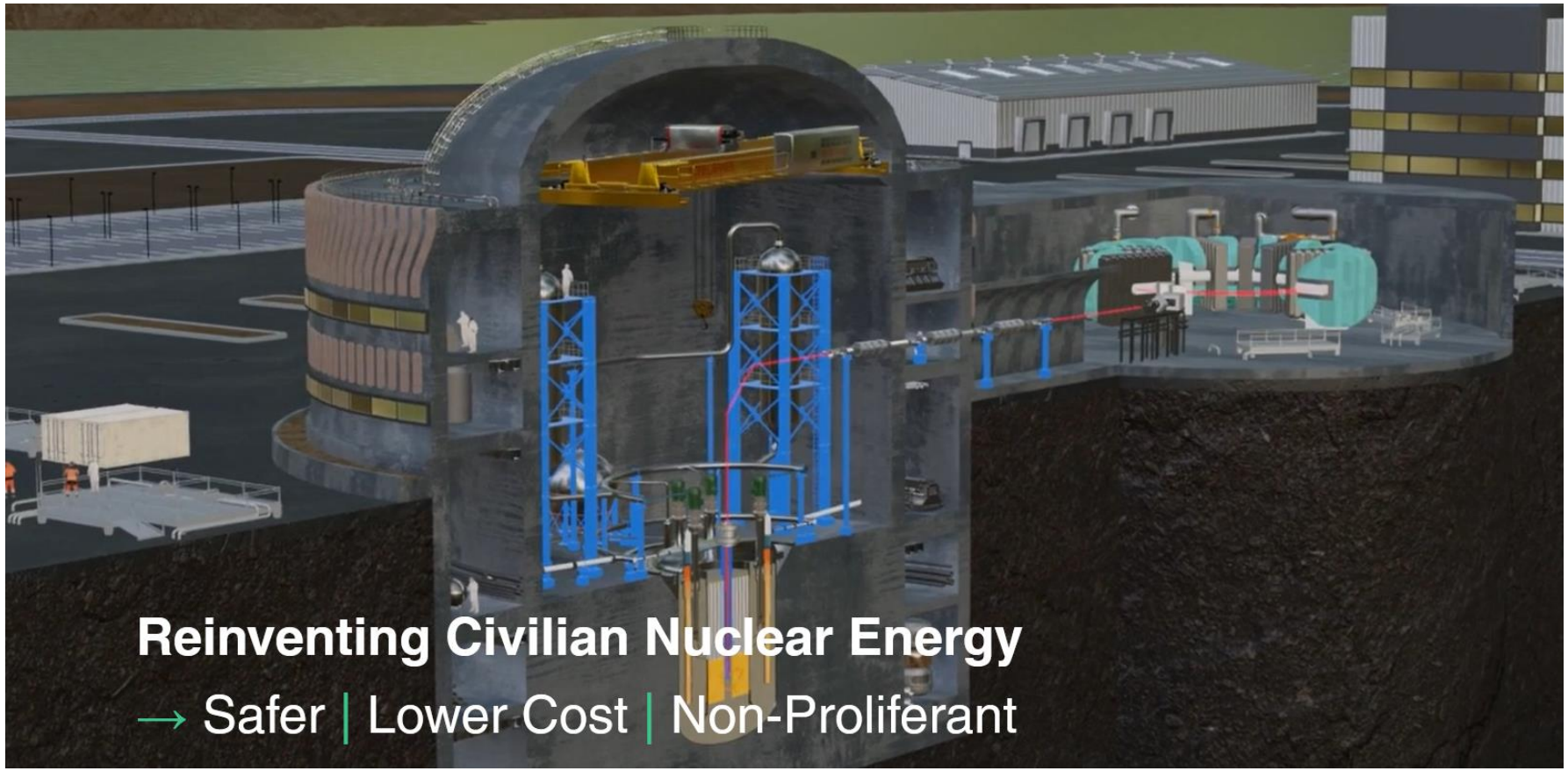
Ongoing cooperation contract with R. Kind, a company that specialises in the production of large size forgings in high-alloy stainless steels to precisely meet customer needs and find the optimal process for each piece. They are in charge of forging the casings of the toroidal magnets of SPARC. EN/MME-MM is providing expertise in cryogenic mechanical testing and material characterization.

Material Selection and Characterization for Nuclear Fusion Industry

Agreement Transmutex - Materials selection including structural and welding considerations

- KR5053/KT/IPT/BE/001S, “Consultancy Agreement on Accelerator Driven Systems related technologies”, Partner: Transmutex SA, Switzerland

Responsible person Stefano Sgobba/Marco Calviani for CERN



Conclusions

- **EN-MME Multi-technology Expertise:** a key CERN asset for accelerator development
- **Strong Collaboration with Industry:** bridging research and application
- **Together Enabling Knowledge Transfer:**

  that drives advances in fabrication methods and new technologies

Thank you for your kind attention

Acknowledgments

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