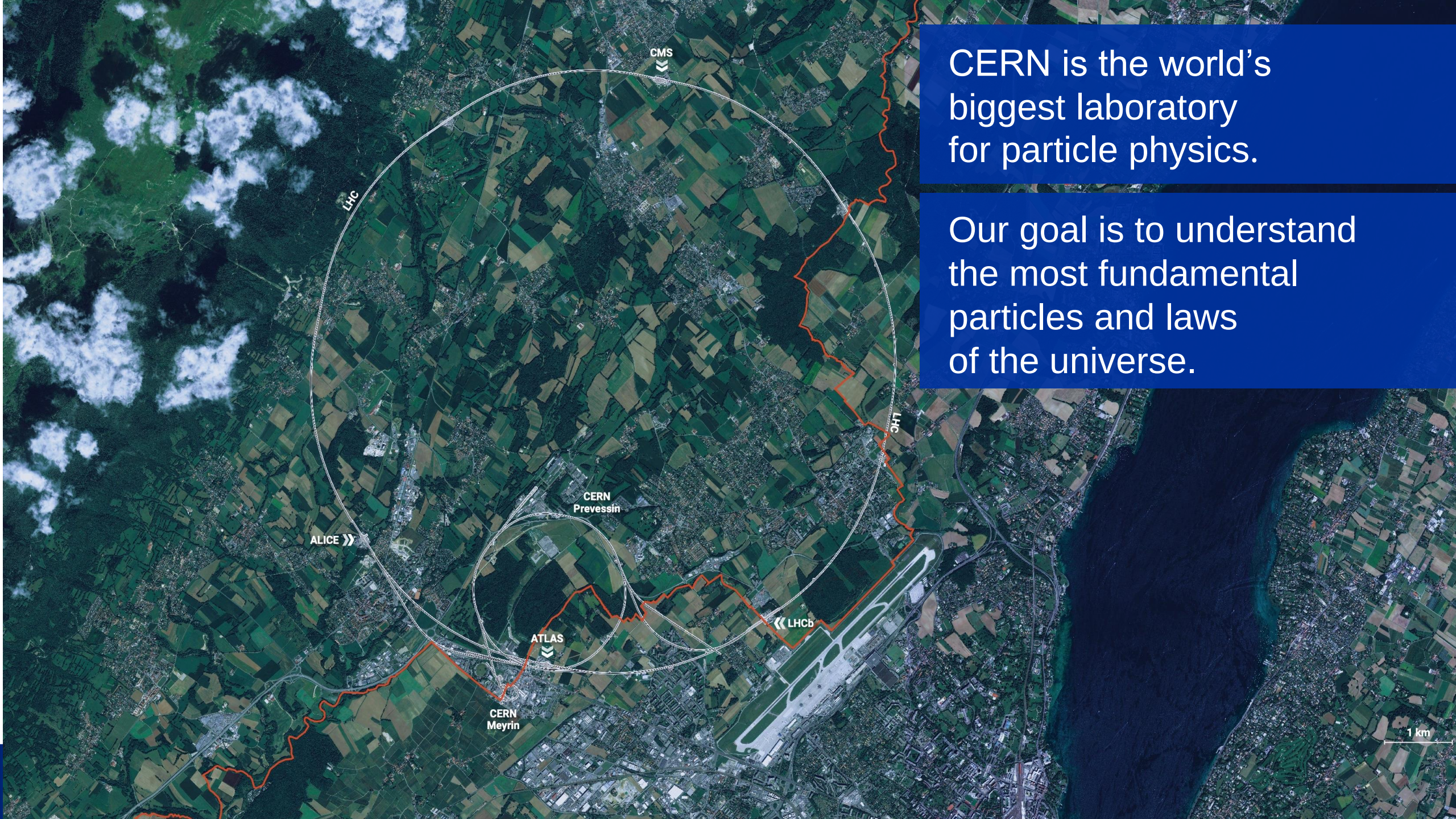
Welcome from CERN Mechanical and Materials Engineering Group

Alessandro Bertarelli (CERN)

CERN Accelerator School in Mechanical & Materials Engineering for Particle Accelerators and Detectors

3rd June 2024



CERN is the world's biggest laboratory for particle physics.

Our goal is to understand the most fundamental particles and laws of the universe.

EN-MME – Organization and Domains of Activity

MME
Materials & Mechanical Engineering
GL: S. Atieh
DGL: A. Bertarelli

- **EDM** – **Engineering Design & Measurements** – *O. Capatina*
- **EDS** – **Engineering Design & Simulation** – *A. Bertarelli*
- **FS** – **Fabrication Methods & Subcontracting** – *A. Dallocchio*
- **FW** – **Forming & Welding** – *G. Favre*
- **MA** – **Machining & Maintenance** – *M. Garlaschè*
- **MM** – **Materials, Metrology & Ndt** – *S. Sgobba*

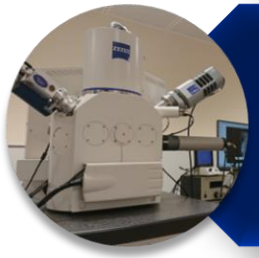
The mandate of the MME group is to provide to the CERN community specific **engineering solutions combining mechanical design, fabrication and material sciences**, using in-house and industry facilities, for accelerator components and physics detectors.

Design

- **Design Office**
- **Engineering Unit**
- **Mechanical Measurements Laboratory**
  - 45+ designers and technicians and 15+ engineers

Fabrication

- **Mechanical workshop (4000 m2)**
  - 60+ technicians and 10+ engineers
  - CNC machining . Assembly & Metal forming
  - Welding (TIG, MIG, EBW, laser) & Vacuum Brazing
- **Technical Subcontracting unit**



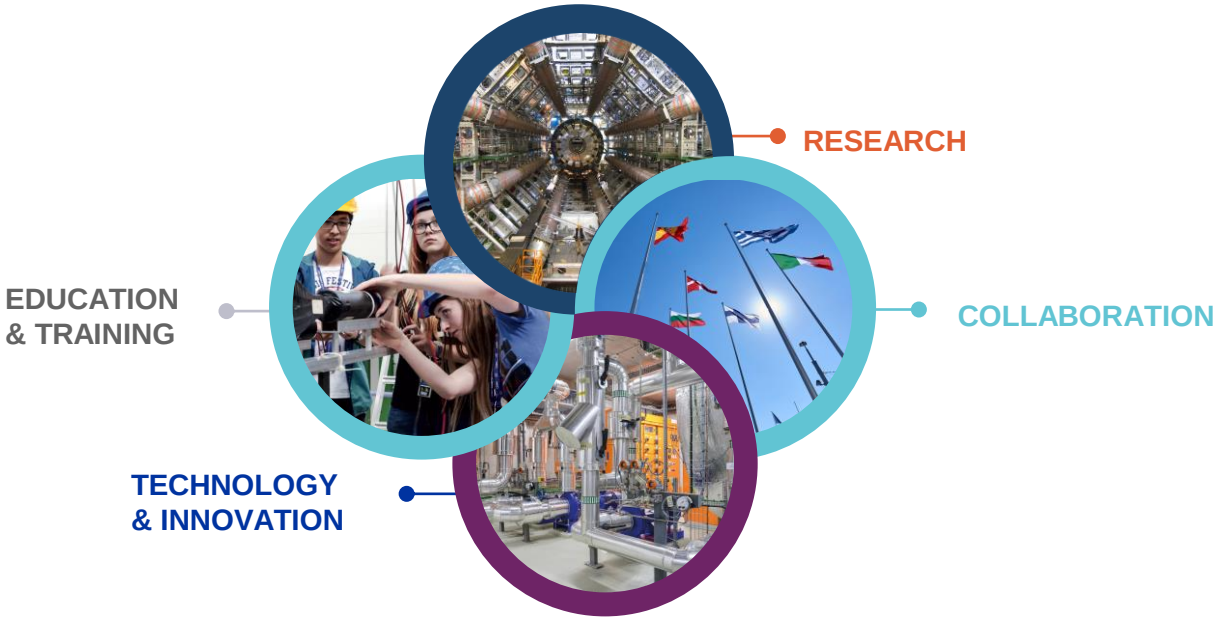
Materials

- **Material science consultancy**
  - Metallurgical analyses, microscopy including FIB, Mechanical tests
- **NDT:** UT, radiography, microtomography
- **Metrology:** 350 m^2 Lab., several CMM

EN-MME mission

Our mission is to conduct cutting-edge engineering services and development that drives technological innovation and meets the needs of our users.
We strive to stay at the forefront of industry trends and advancements and foster a culture of creativity and innovation within our group, department and CERN wide.

CERN mission

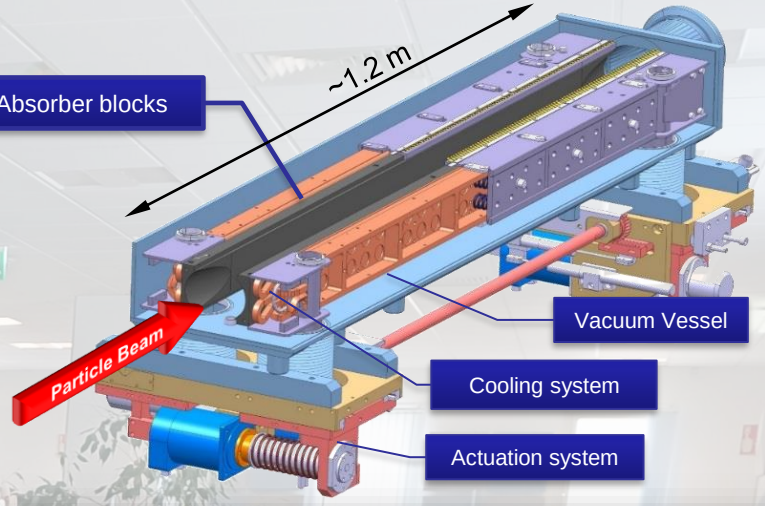


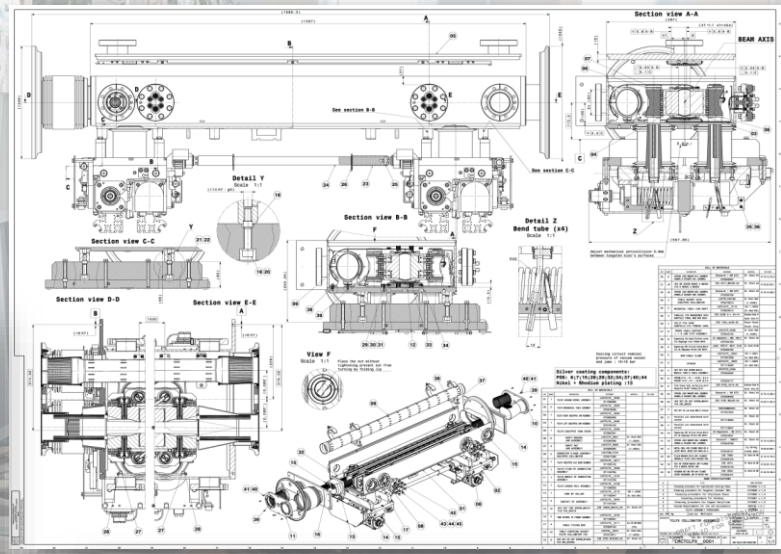
Our Values

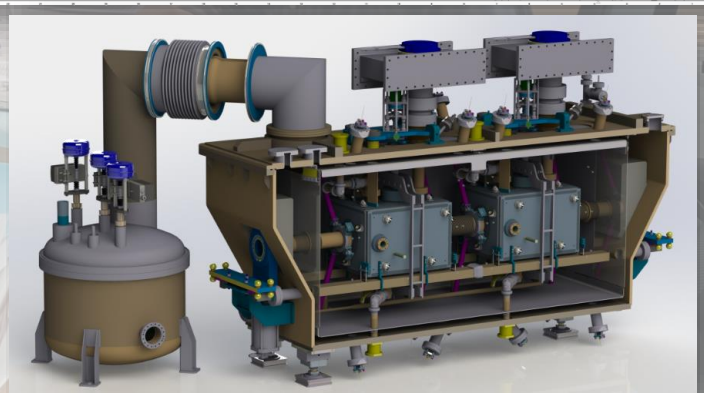
Integration, Service, Collaboration, Diversity, Commitment, Flexibility, Innovation, Passion

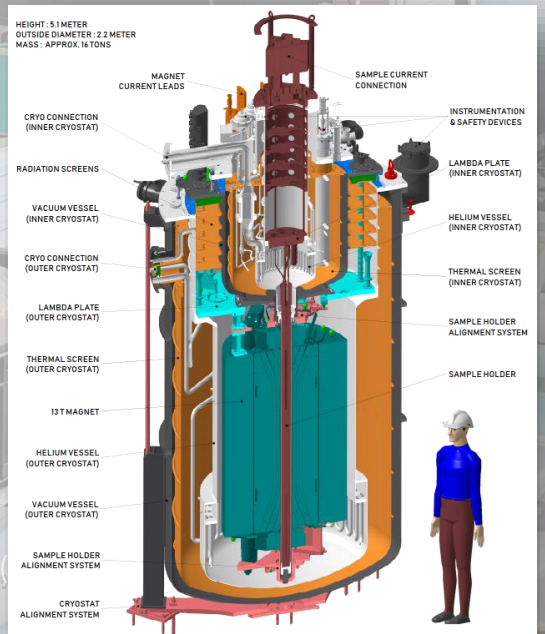
Design Pole – Mechanical Design Office

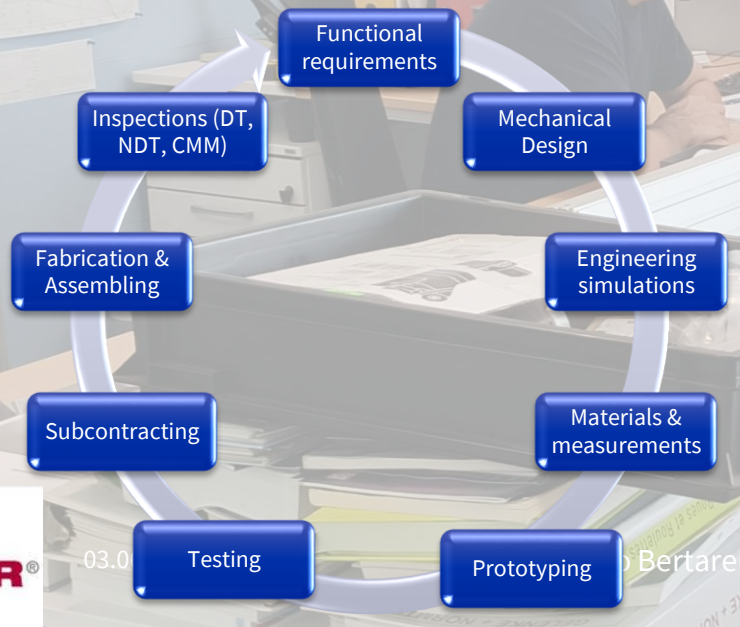
- EN-MME hosts **CERN**'s **largest Mechanical Design Office** (~45 Designers) for design activities required across the Organization
- Main competencies span **all domains of Mechanical Engineering**
- Various levels of requests, ranging from **turn-key integrated project** to **simpler design** or **drafting tasks**
- Design carried out relying on **CATIA v5** 3D CAD integrated with **PDM/PLM**
- 2D drawings produced in line with **ISO-GSP Geometrical Dimensioning and Tolerancing**











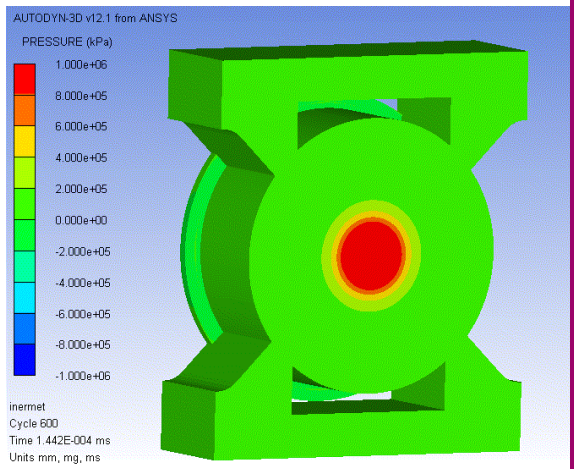
CATIA

SMARTEAM

aras INNOVATOR®

Design Pole – Engineering Unit

- Formed by **~15 persons** (Staff, Fellows, Contractors, **S**tudents, Associates, Trainees …) trained in **mechanical engineering** and **materials science**
- In charge of **advanced mechanical computations** at the service of a diverse community **throughout CERN**
- Developed **first-class know-how** in advanced mechanical, **multiphysics analyses** (e.g. explicit simulations of fast/large deformation events)
- Strong **crosslinks/transversality** across projects
- A "**breeding ground**" for **talented young students** and **newly graduated engineers** and **material scientists**, with diverse background (BEng, MSc, MEng, PhD)
- Possibility of **Master** and **Doctoral Theses** in collaboration with leading European Universities



Implicit

ANSYS

COMSOL

SIMULIA ABAQUS

Explicit

Ansys AUTODYN

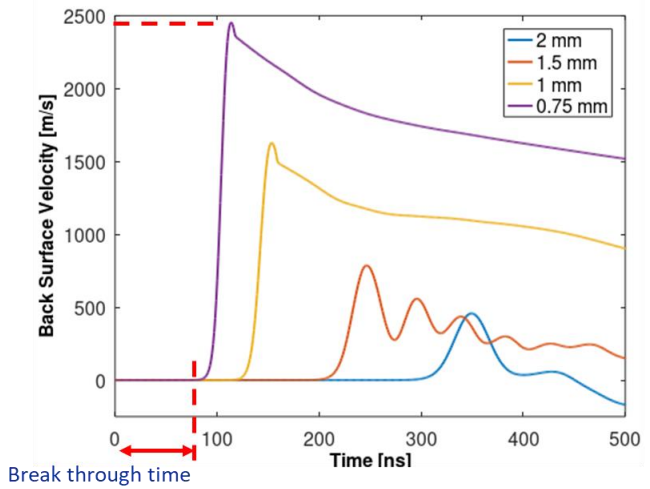
LS-DYNA

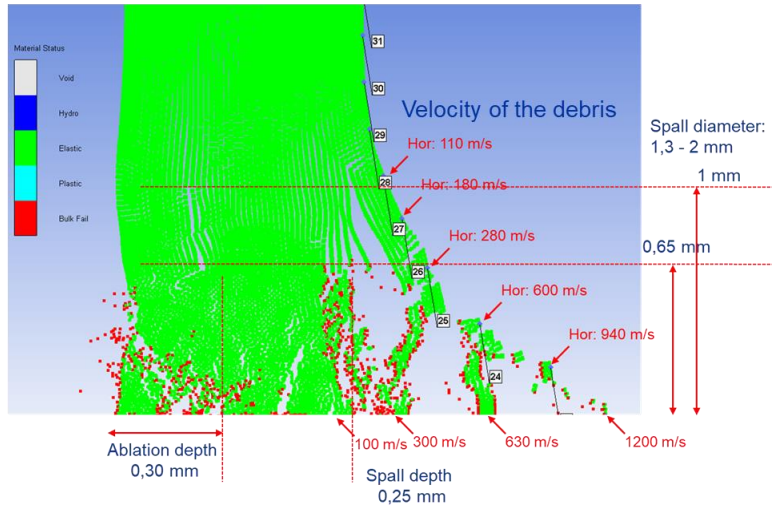
SIMULIA ABAQUS

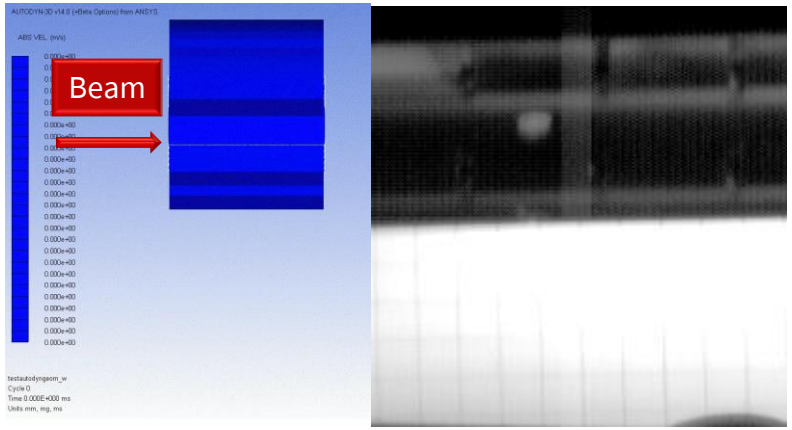
Engineering Unit: Laser and Particle Beam impacts

Laser and Particle beam impacts

- **Beams impacting on matter** (e.g. dumps, targets, collimators, etc…)
- Quasi-instantaneous heat deposition, expansion prevented by inertia
- **Stress waves, changes of phase, ablation, explosion**, …

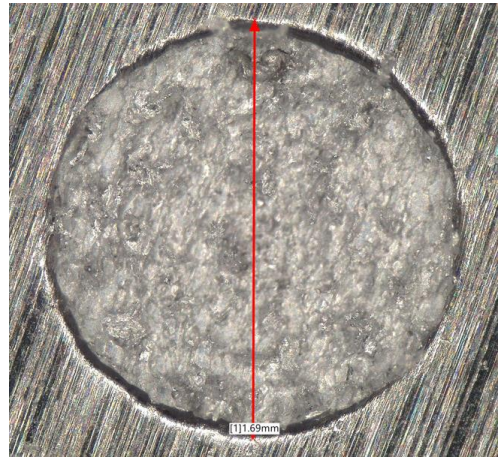






Numerical model

- Strong nonlinearities, short times → explicit (Autodyn)
- Can simulate changes of phase, material fragmentation, etc…
- Power densities with **laser experiments** comparable to those in **FCC-hh accidental impacts**
- **PHELIX laser experiment at GSI in 2021**

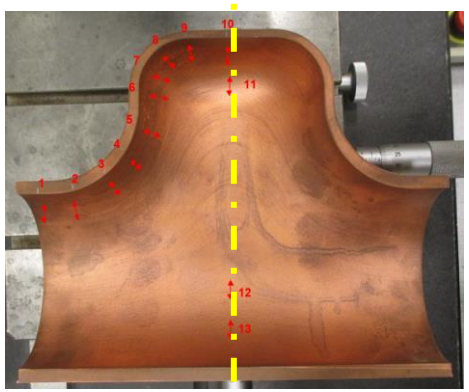


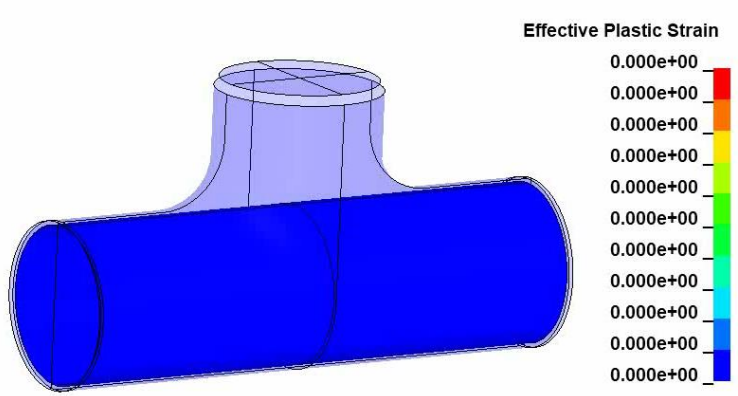
Engineering Unit: Fabrication Technologies

Fabrication technologies at CERN main workshop

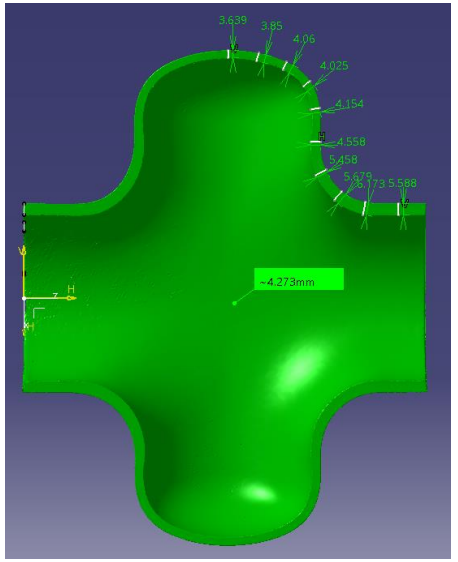
- **Forming, hydroforming, bending, stamping**: long processes, with high deformations that can be simulated with explicit tool (LS-Dyna)
- Numerical techniques are necessary to speed up the calculation time (explicit codes are usually for short times!)

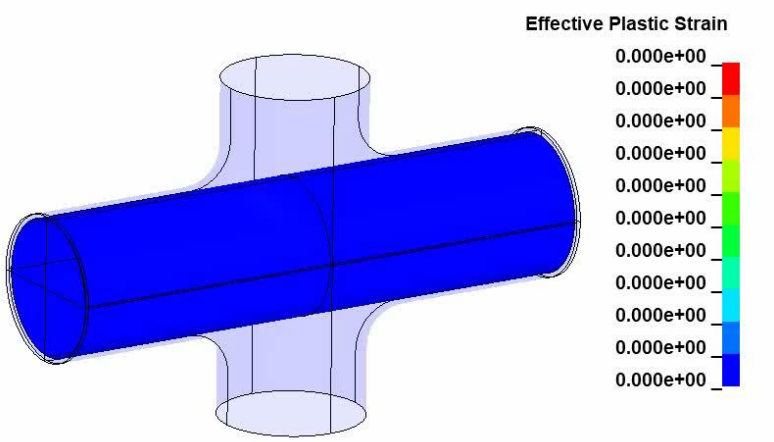
Pipe joints





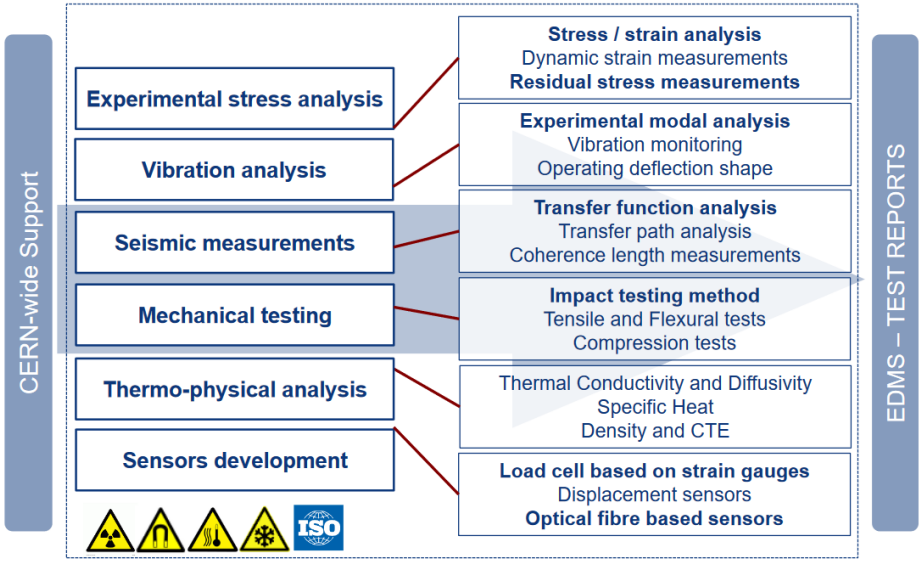
CERN SPS dump, hipping pipe

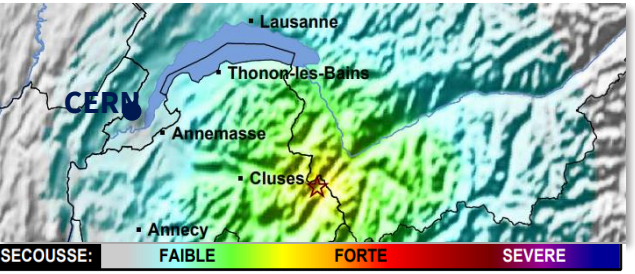


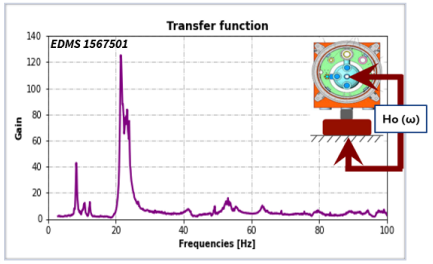


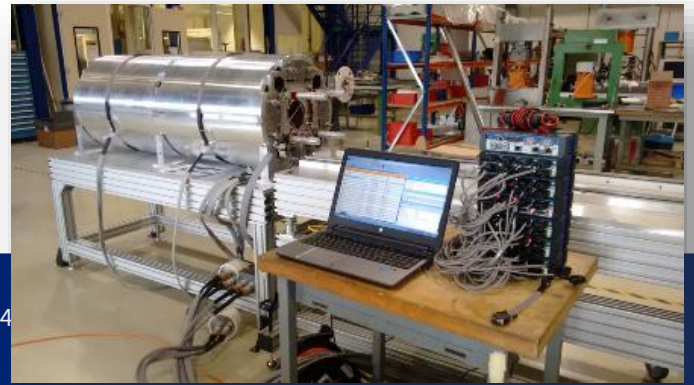
Design Pole – Mechanical Measurement Laboratory

- **Reference laboratory** for mechanical and physical measurements (stress/strain, vibrations, seismic, thermal properties …) for a wide range of CERN components and facilities;
- **Measurements** are used to define **input properties** for **Finite Element Analyses** and **benchmark FEA predictions** on real components, in various environmental conditions
- **Ground motions** are measured to **predict vibration effects on LHC beam stability** during civil engineering activities









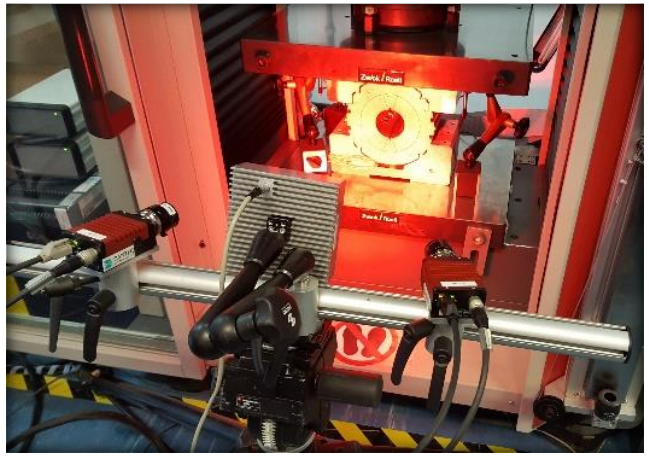
MML: Experimental Stress Analysis

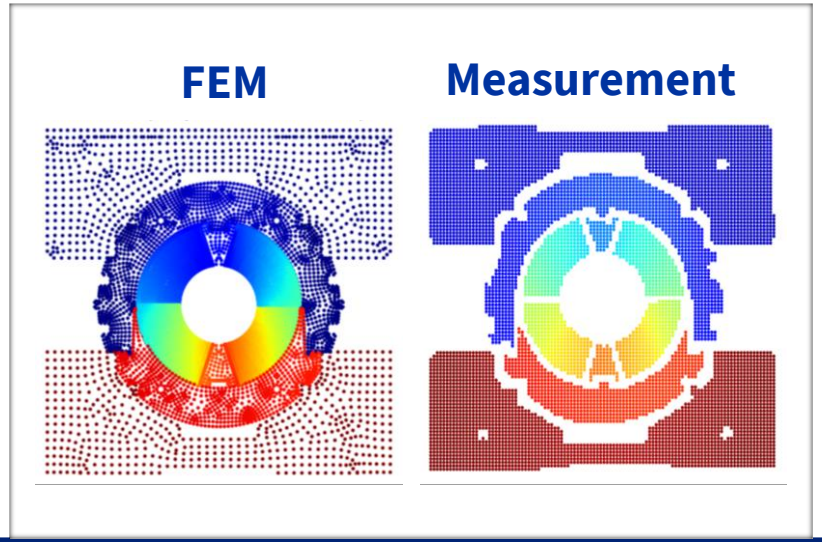
Experimental stress analysis is performed on several types of components: superconducting magnets, dumps and detectors, in different conditions as electro-magnetic fields, highly turbulent water, vacuum, radiation, etc.

- Online control of the mechanical integrity of the structures during their whole lifetime
- Validation of the FEM models for increased confidence
- Acceleration of the prototyping phase of the projects

FEM Benchmarking

11T Mockup



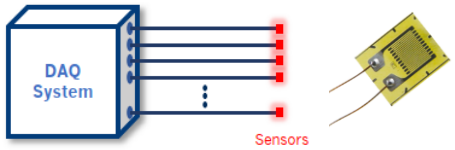


MML: Strain Sensing Techniques

80's → 2011 → 2021

Electrical Strain Gauge (ESG)

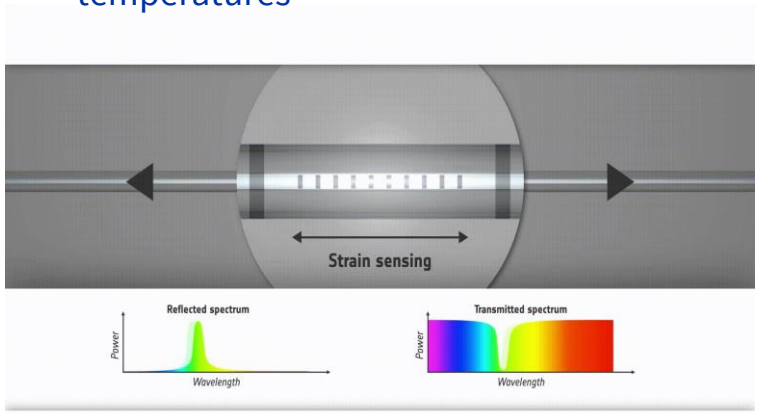
Multiple Copper Wires Per Sensor



Fiber Bragg Grating (FBG)

Discrete

- Single optical fiber
- Challenging bonding process for cryogenic temperatures



Source: FBGS

Rayleigh Backscattering (RBS)

Distributed

- Single optical fiber
- Sub mm spatial resolution
- Challenging bonding process for cryogenic temperatures

New Develoment!!

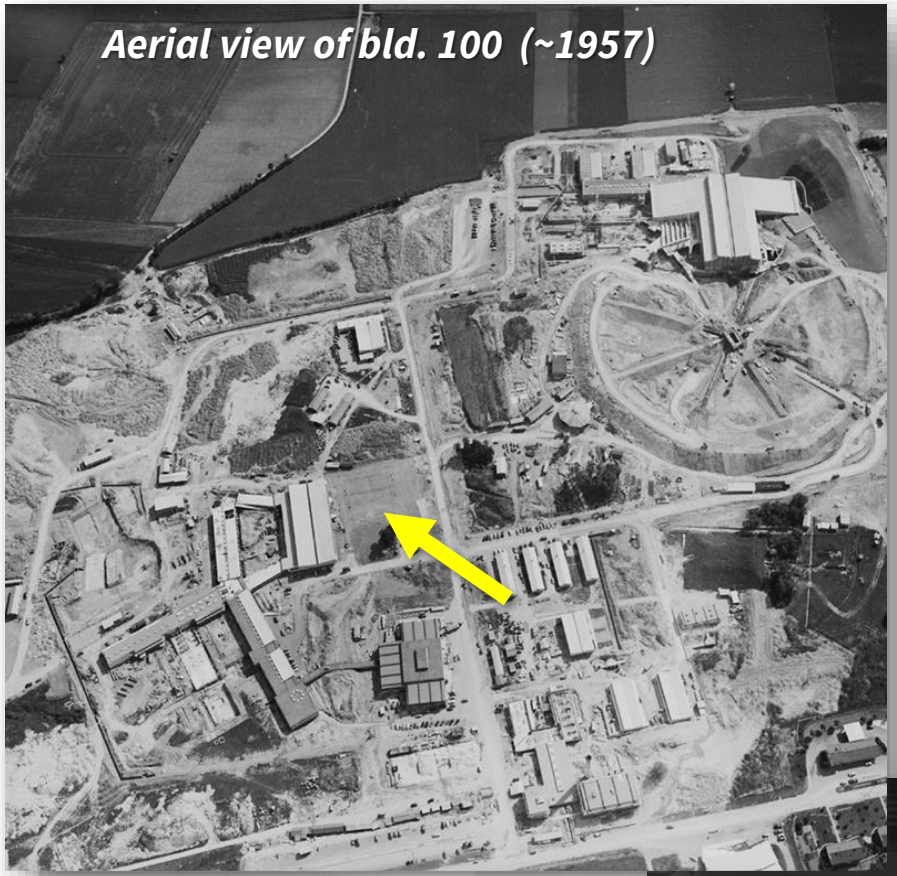
Outcomes of the last years of development disseminated in

27th International Conference on Optical Fiber Sensors
OFS 2022
August 29–September 2, 2022 | The Westin Alexandria | Alexandria, Virginia, USA

90 min tutorial talk

Distributed and Discrete Optical Strain Measurements down to Cryogenic Temperatures. K. Kandemir

Strain monitoring of prototypes is crucial to confirm the mechanical response of structures and validate Finite Element Analysis. Optical fiber-based strain sensors offer many advantages with respect to electrical strain gauges, such as being less invasive and intrinsically immune to electromagnetic fields [1,2].



Fabrication Pole – Main Workshop

A real **heritage of CERN** (1957-2022)
Guaranteeing 70 years know-how in **fabrication of mechanical component 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**

Knowledge Transfer to external collaborations and suppliers

Some numbers…

- Total workshop surface of ~**4000** m2
- Featuring **40**+ conventional and unconventional machines
- ~**90** highly-skilled technical personnel
- Yearly turnover ~**2500** fabrication ‘’jobs’’

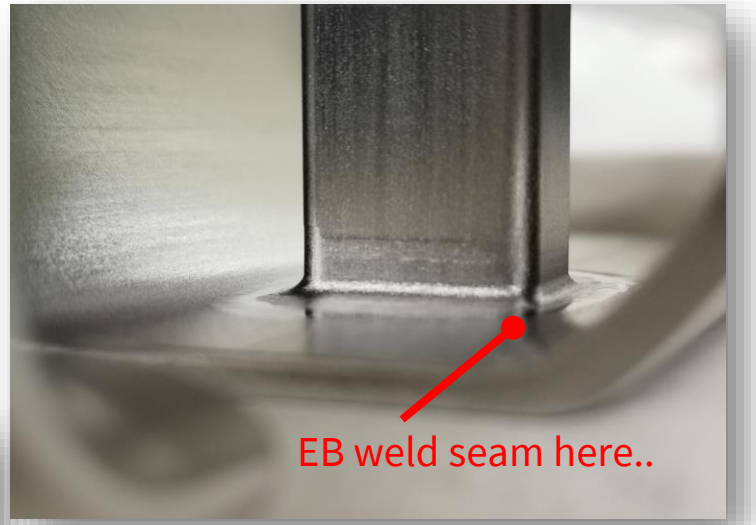
Fabrication Pole – Sheet Metal Forming & Joining Tech

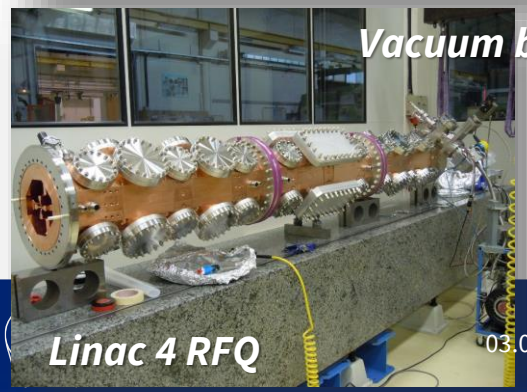
Wide **variety of technologies & equipment**:

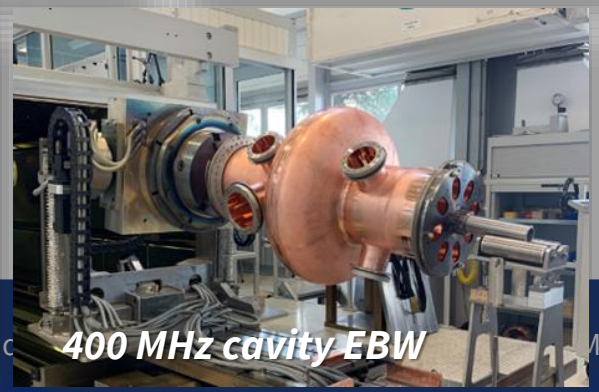
- Rolling, Bending, Deep Drawing, Spinning
- Arc welding (TIG, MIG, Plasma), Beam welding (Electron Beam & Laser Beam)
- Vacuum Brazing & Thermal treatments

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

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





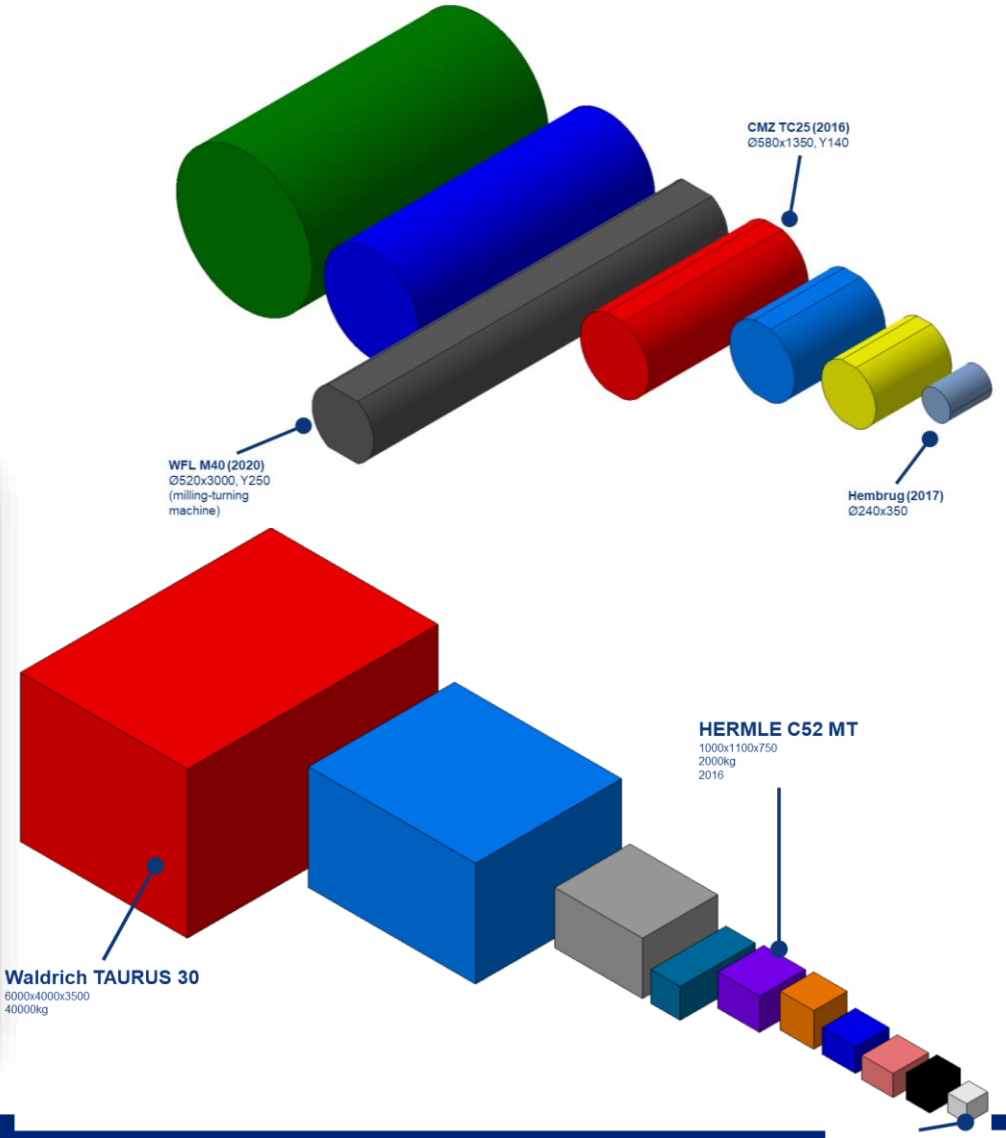


Fabrication Pole – Machining Technologies

Multi-axis machining: 5 axes Milling / 4 axes Turning, Angled head

Attainable features : - **accuracy** : **few µm**
- **roughness** (Ra) : down to few nm

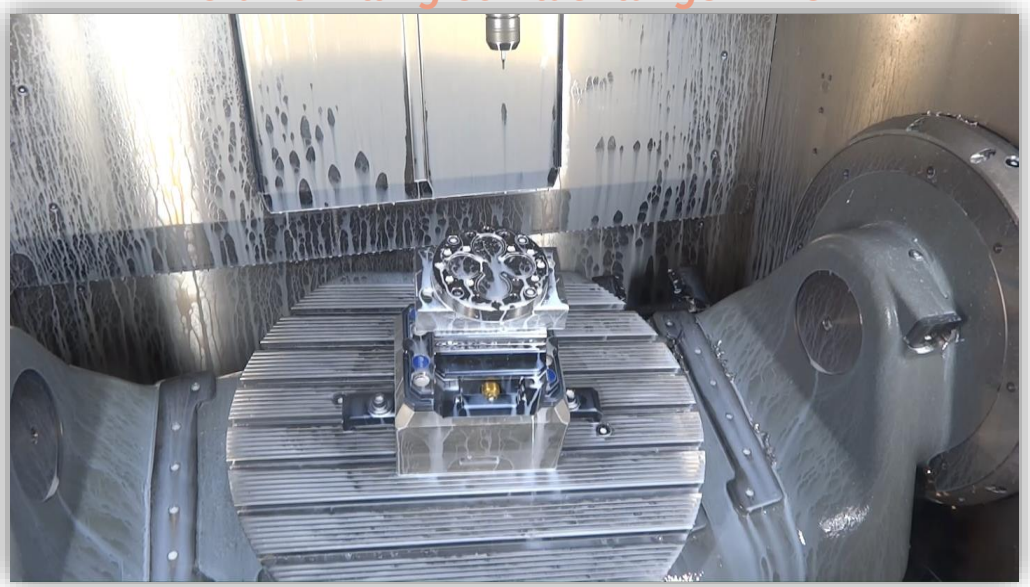
Capable workpiece dimensions : **1cm³ → 6m×4m×3.5m** // up to 20 tons

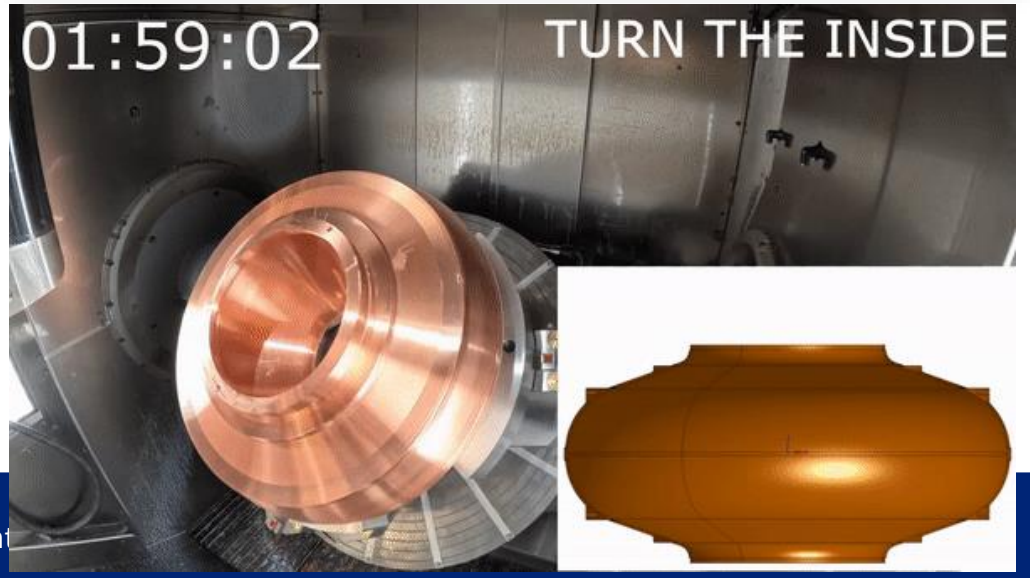


Fabrication Pole – Machining Technologies

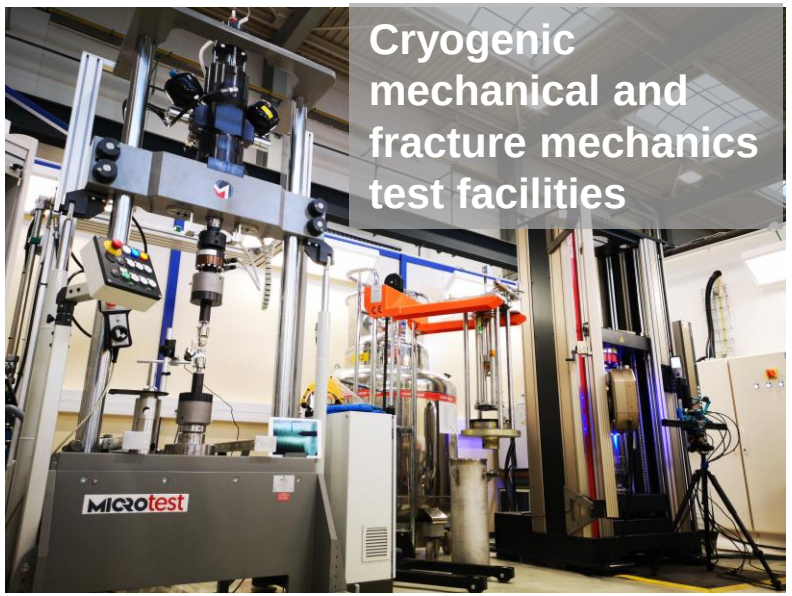
HIE Isolde Monoblock Cavity

5-axis Milling Conflat Flange Knife

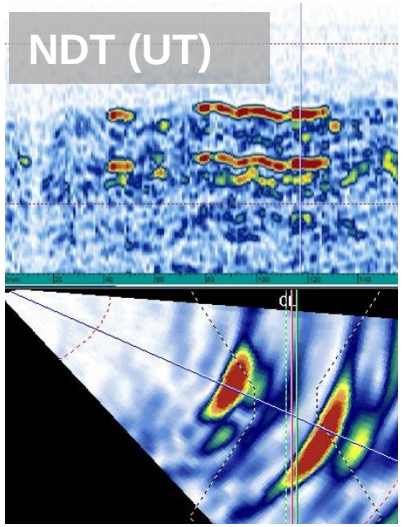




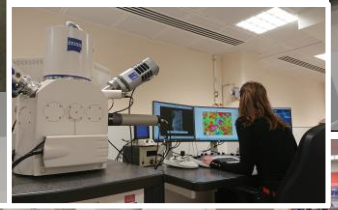
Materials Pole – Overview

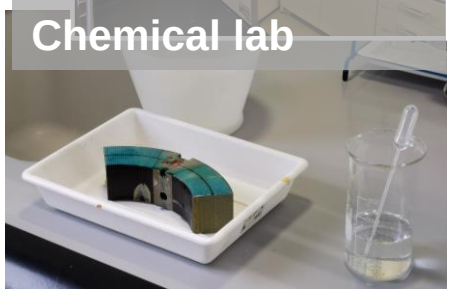


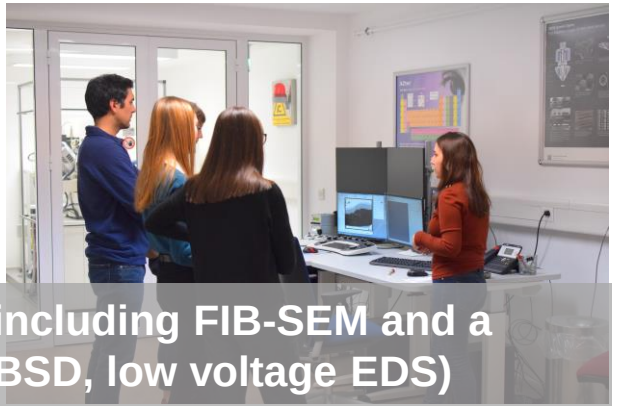
Offices= 239 m²
Materialography Lab. =184 + 139 m²
Mechanical testing area = 35 m²
Nanoindentation lab = 21 m²
NDT = 169 + 58 m²



See also EN-MME-MM



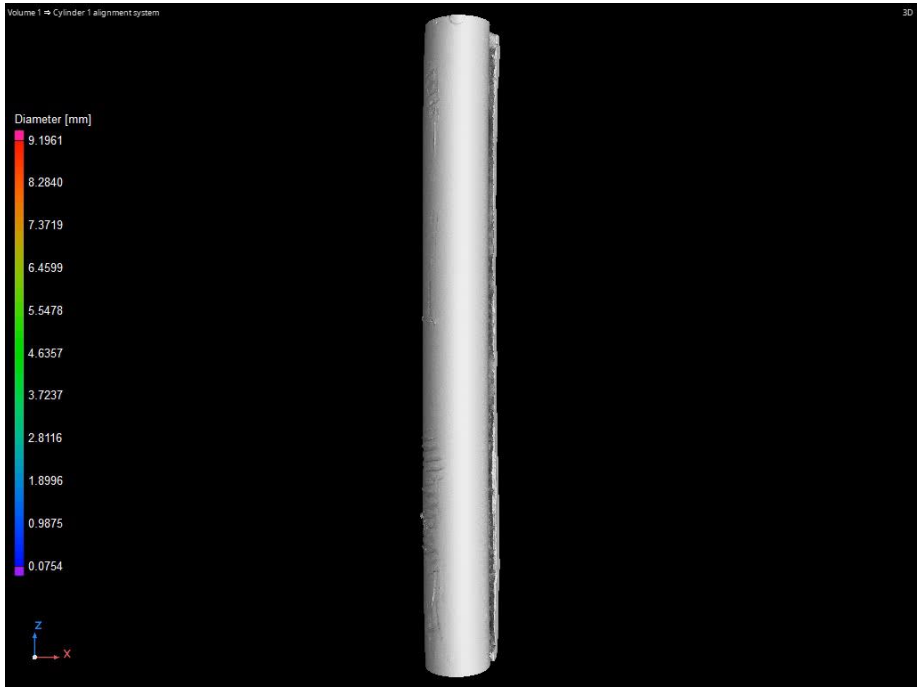




Materials Pole – Characterization techniques

MM section undertakes the **development, selection, specification, characterisation** and **analysis of materials** such as metals and their alloys, composites, ceramics and thin films. It provides support for the **quality control of materials and components** including **Non-Destructive Testing (NDT)** and **dimensional controls**. The team conceives and realises a large range of **static and dynamic mechanical tests** including at **cryogenic temperature** and performs **failure analyses**.

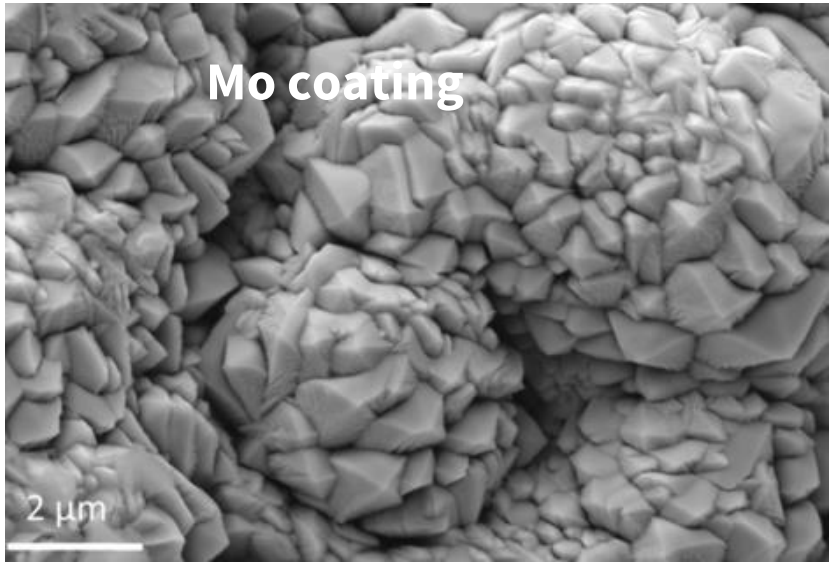
Materials consulting



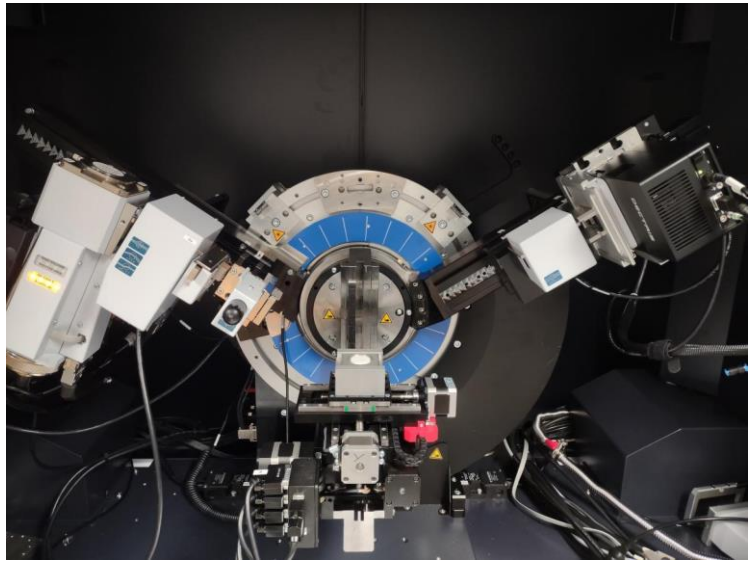
NDT: computed tomography

Tensile test at 4 K

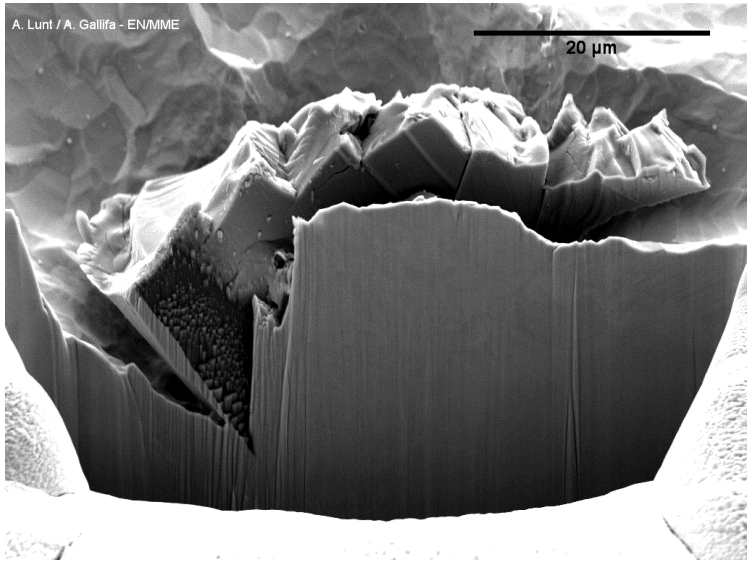
Materials Pole – Characterization techniques



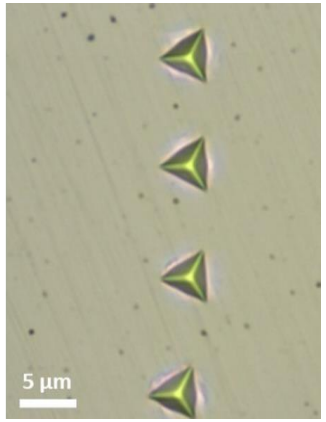
Advanced SEM



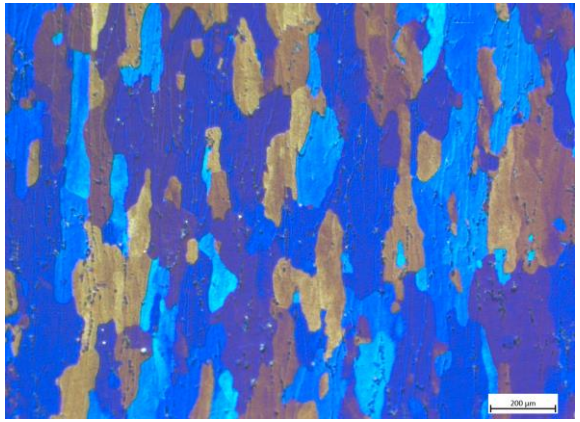
XRD



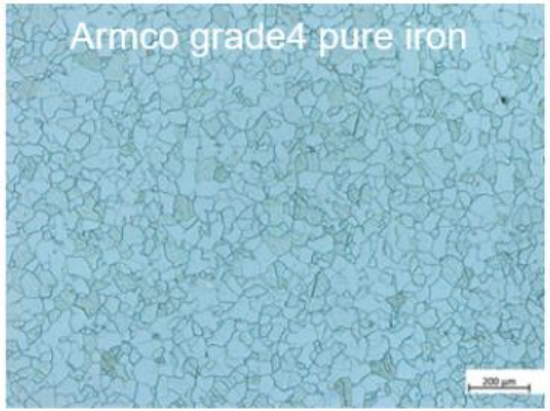
FIB tomography



Hardness and Micro-hardness tests

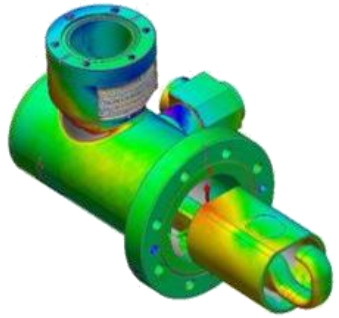


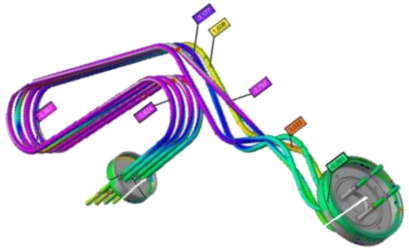
Materialography



Optical microscopy

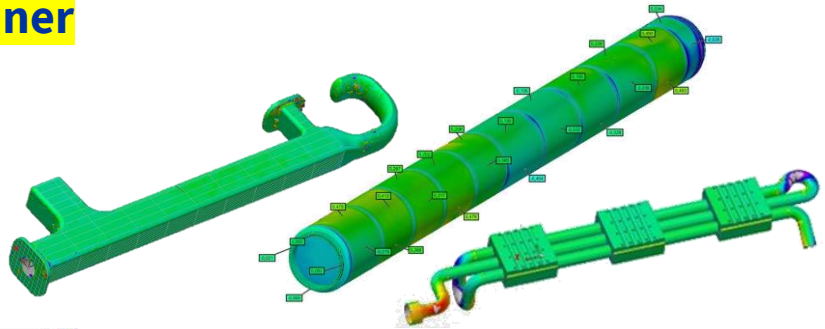
Materials Pole – Large Scale Metrology

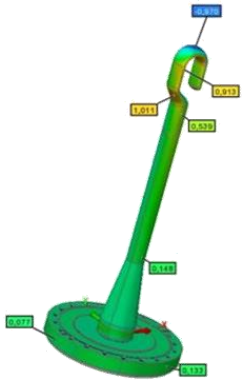


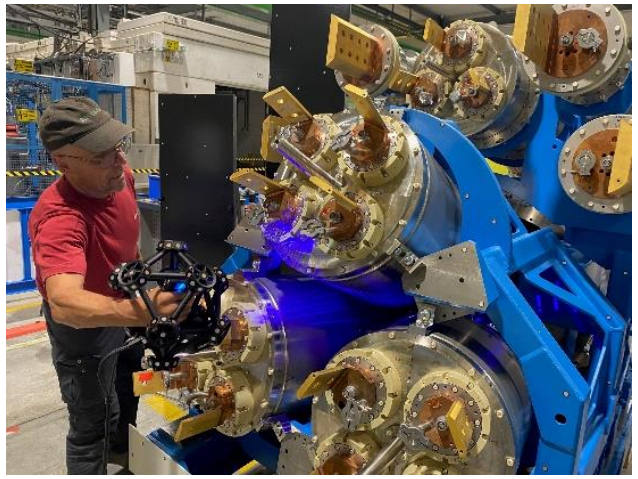


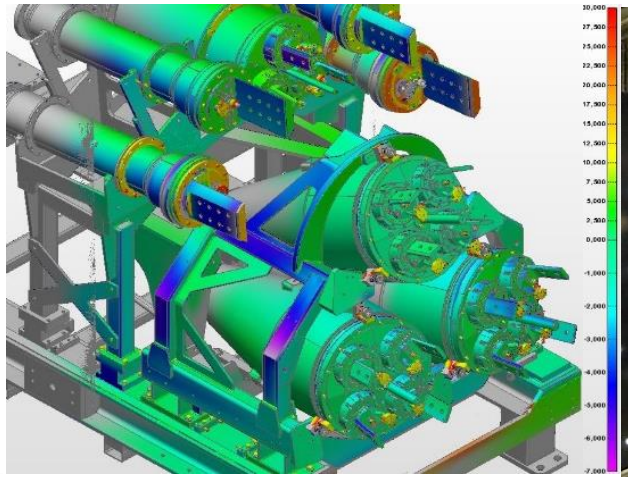
METRASCAN - Large volume laser scanner

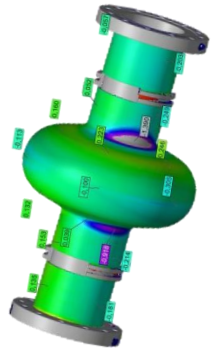
- For parts between 200 mm and 6 m
- Volumetric accuracy:
  - 0.064 mm for 9.1 m^3
  - 0.078 mm for 16.6 m^3

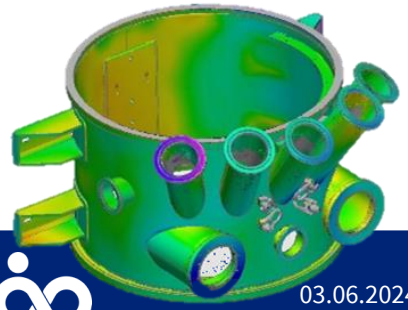


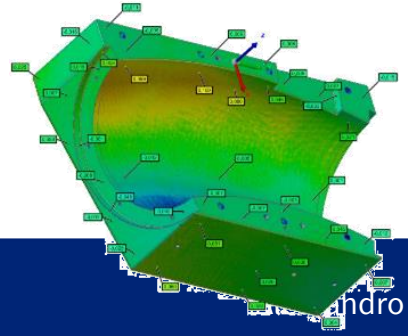


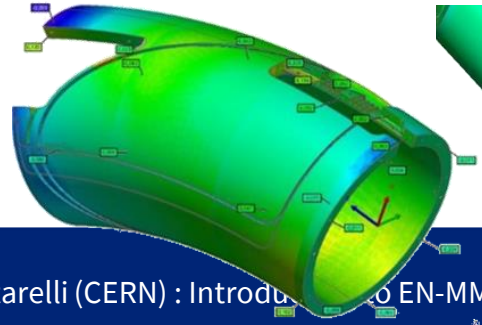


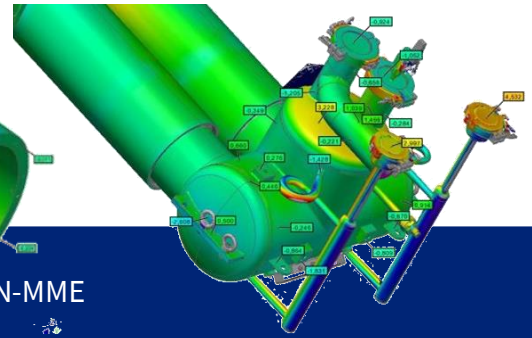


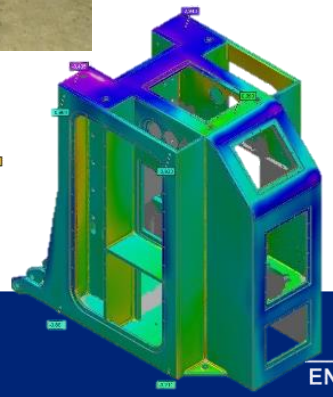












Summary

The CERN Accelerator School

In collaboration with Nikhef (National Institute for subatomic physics in the Netherlands) the CERN Accelerator school is organizing a topical course on:

Mechanical Materials Engineering for Particle Accelerators and Detectors

Hotel De Ruwenberg
2 - 14 November 2020
Sint-Michielsgestel, Netherlands

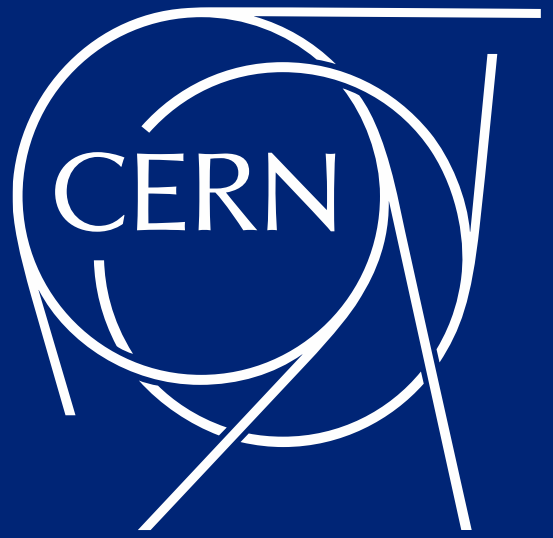
Many thanks to NIKHEF , Francesco Bertinelli (CERN) and Hermann Schmickler for initiating this School in 2020!

...ERN Accelerator School, a course on Mechanical engineering is organized. The focus of the ...al engineers from their general knowledge obtained during their past education to techniques ...ecific for accelerator applications. In the mornings, a complete lecture program is foreseen covering a ...l engineering aspects. These lectures are complemented by a series of application reports in the field of ... afternoons four blocks of so-called "hands-ON" experiments are foreseen, during which the students will be ...actical work including visits of professional companies close by.

Sin... a student without prior knowledge of mechanical engineering will not be able to follow the course, we have prepared a self-evaluation test on our website. We kindly ask every interested student to exercise this test and apply only for the course, if a sufficient high score is obtained in the test.

Contact: CERN Accelerator School
CH – 1211 Geneva 23
cas.web.cern.ch
Accelerator.school@cern.ch

Nikhef

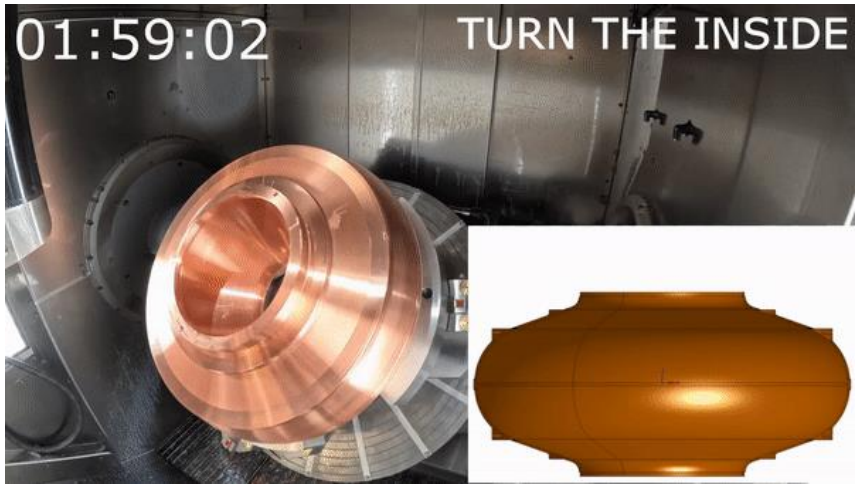

CERN

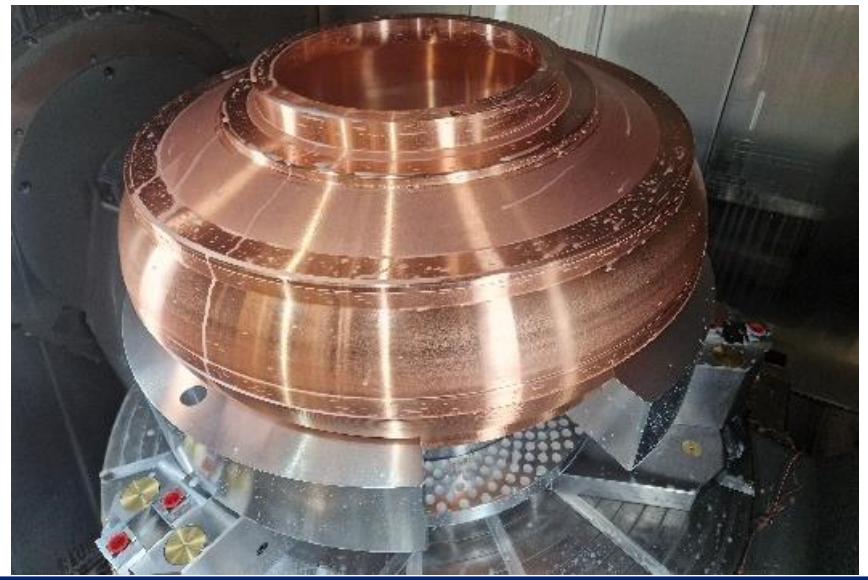
Summary

- **Materials and Mechanical Engineering** (MME) group, part of **the Engineering department** (EN), provides engineering solutions in mechanical systems **combining design**, **fabrication** and **material sciences**
- MME relies both on **in-house assets** and **contributions from industrial partners** for accelerator components and physics detectors
- The group particularly values **on-the-job training** of talented **students** and **junior professionals** in all the fields of **mechanical engineering** and **materials science**, in fruitful collaboration with member states **universities** and **laboratories**
- MME **Subcontracting Service**, in close collaboration with Procurement and Industrial Service group, strives to fairly share industrial return, constantly scouting new firms and industrial partners in all member states

FCC Activities

400 MHz Monoblock prototype



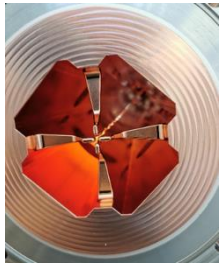


Successful **1.3 GHz Hydroforming** (KEK Collaboration)

FCC Sextupole demonstrator

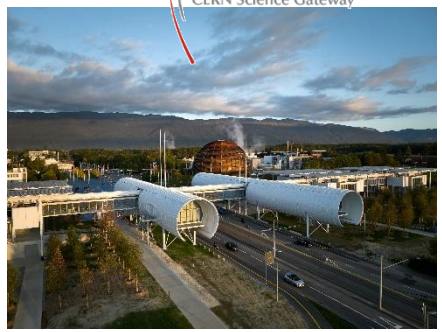
ENGINEERING DEPARTMENT

Elisa

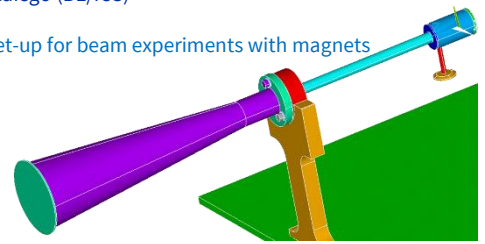


Borja Adiego (BE/ICS)

CERN Science Gateway

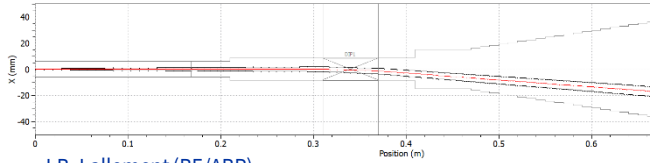


Set-up for beam experiments with magnets

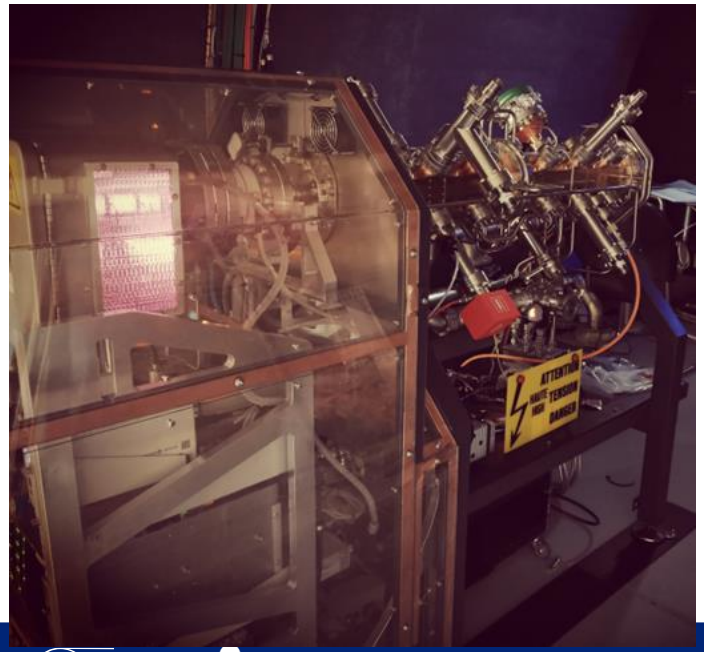


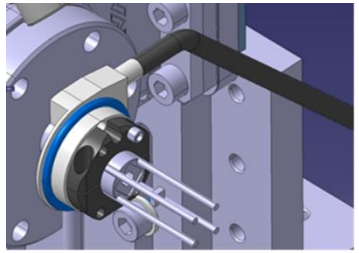
Experiments with gas

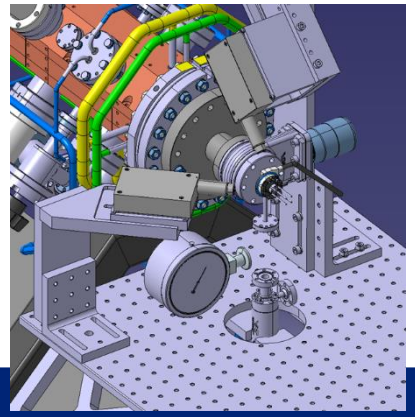
Beam simulation



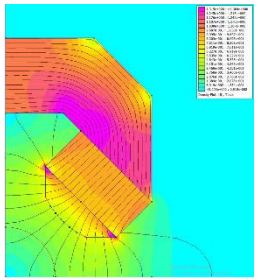
J.B. Lallement (BE/ABP)





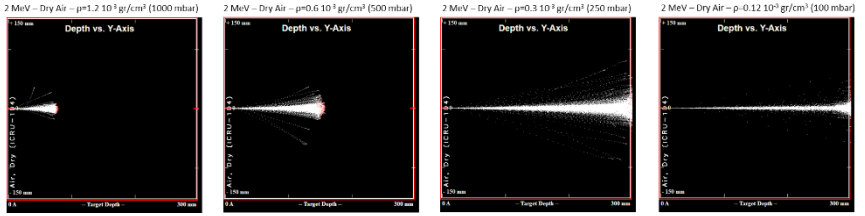


Magnet design

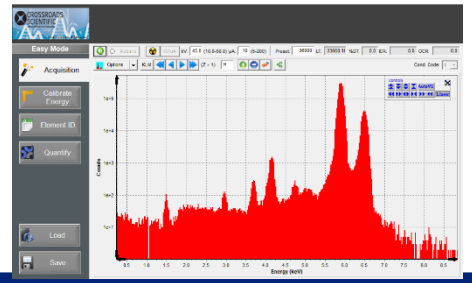


P. Thonet (TE/MSC)

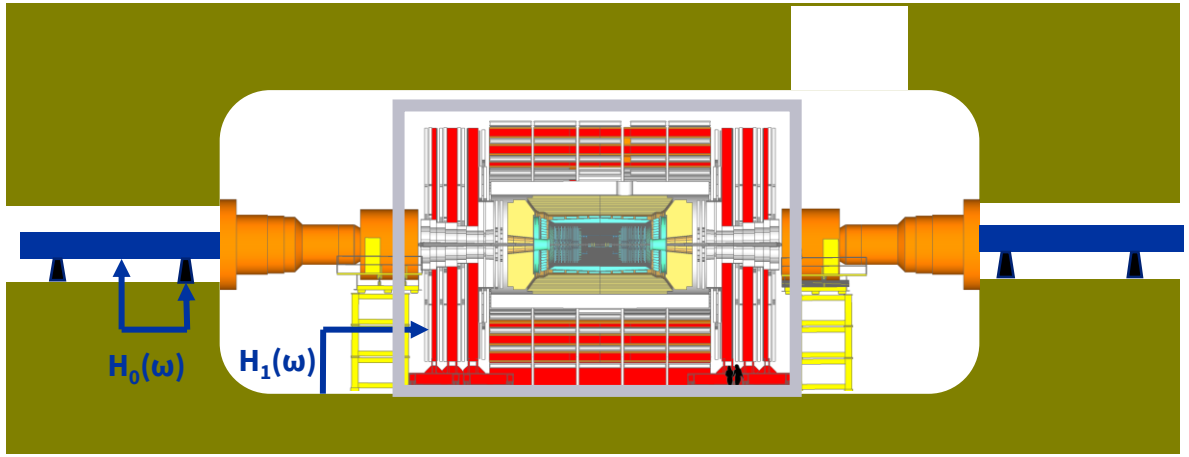
Beam versus air pressure



X-ray spectroscopy

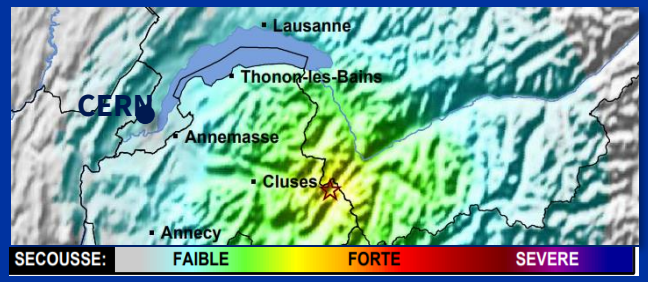


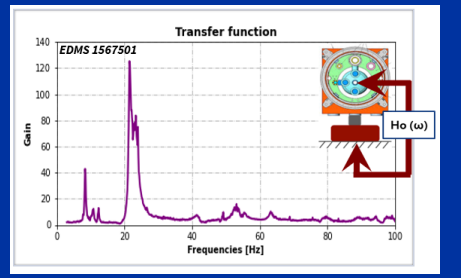
MML: Dynamic Measurements



Ground Motion Measurements

CERN Seismic Network

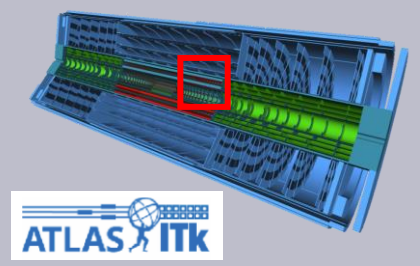




Study of seismicity and cultural noise in the accelerator complex dynamic behavior

Experimental Modal Analysis

Laser Doppler Vibrometry



Determination of the natural frequencies and mode shapes

Measurement of the damping

Evaluating the overall dynamic behavior of the structure prior to commissioning

Online Vibrations Monitoring

Observation of the transport-induced dynamic loads in delicate equipment

Detection of anomalies