Mechanical & Materials Engineering – Fabrication technologies & Subcontracting Service

Jorge GUARDIA, Simon BARRIERE on behalf of the EN-MME Main Workshop

Thematic Industry Day-Precision Machining

https://indico.cern.ch/event/1447719/

Outline

- **EN-MME group: mandate and structure**
- **The EN-MME Main Workshop**
- **Subcontracting activities**

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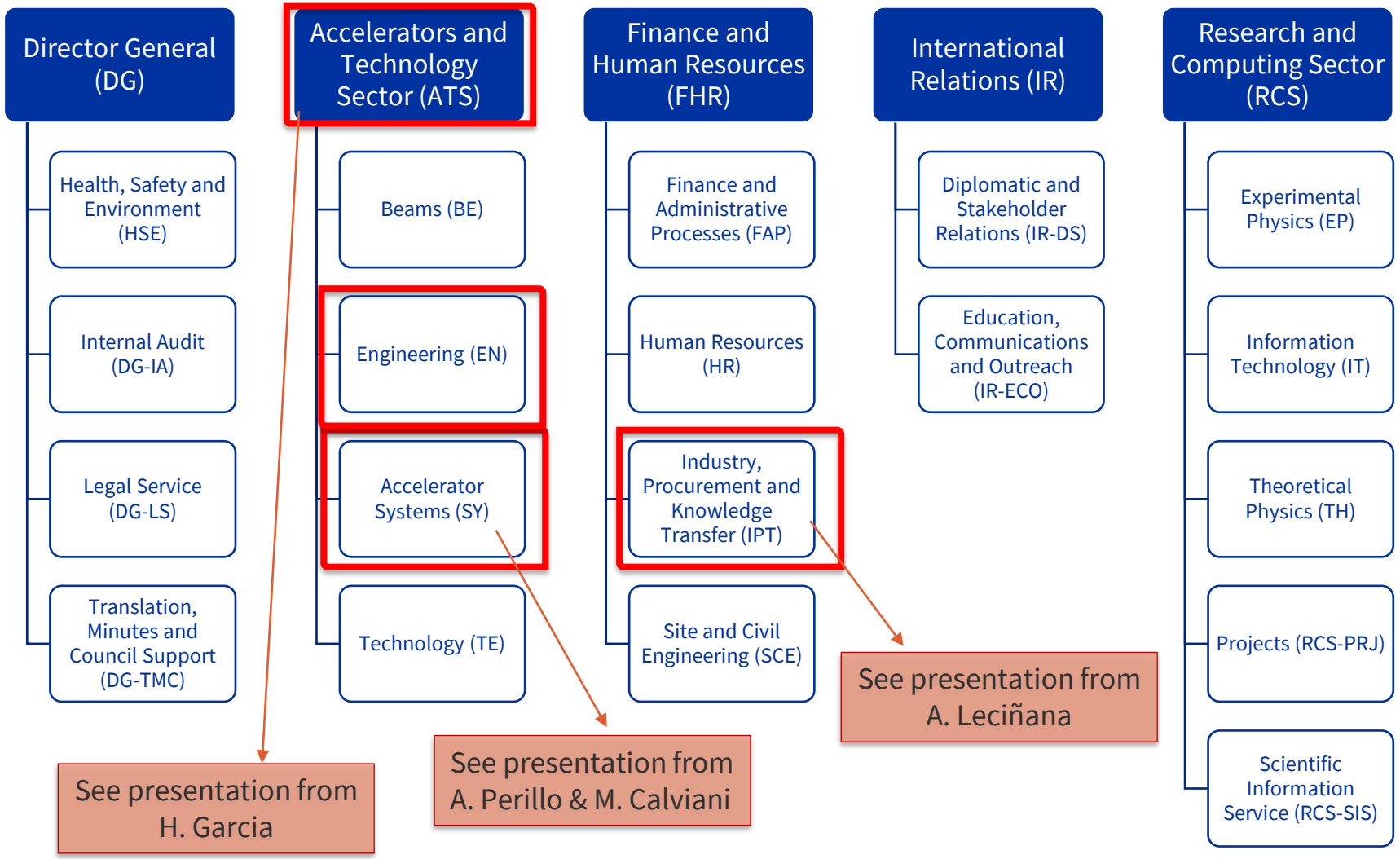
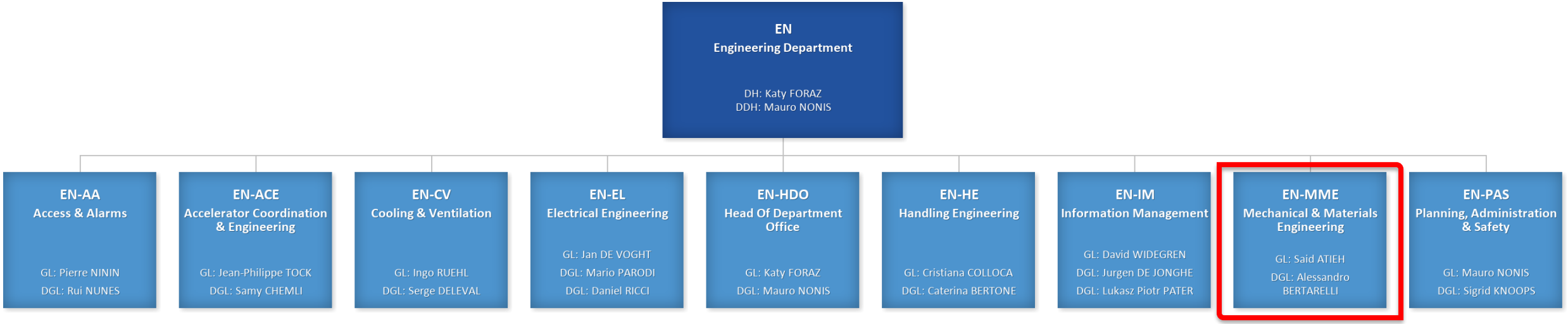
CERN Organisation: Sectors, Departments and Units



Engineering Dept. Structure

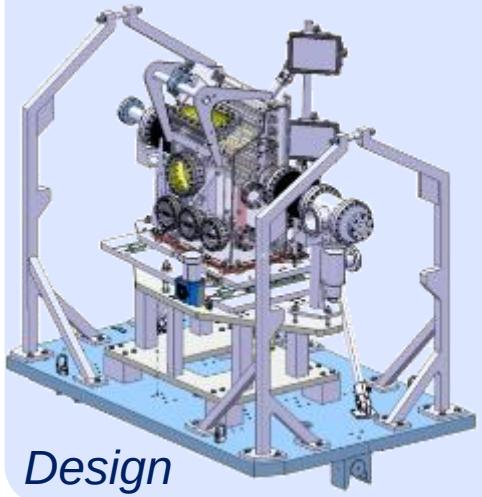


- Operation
  - Technical Infrastructures
  - Accelerators Maintenance
- Projects
  - Consolidation
  - Upgrades
  - New facilities
  - Design & Manufacturing
- Studies

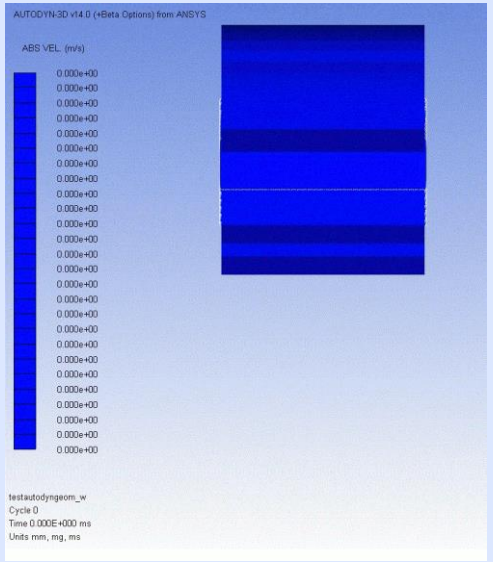
Mechanical & Materials Engineering (EN-MME) Group Mandate:

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.

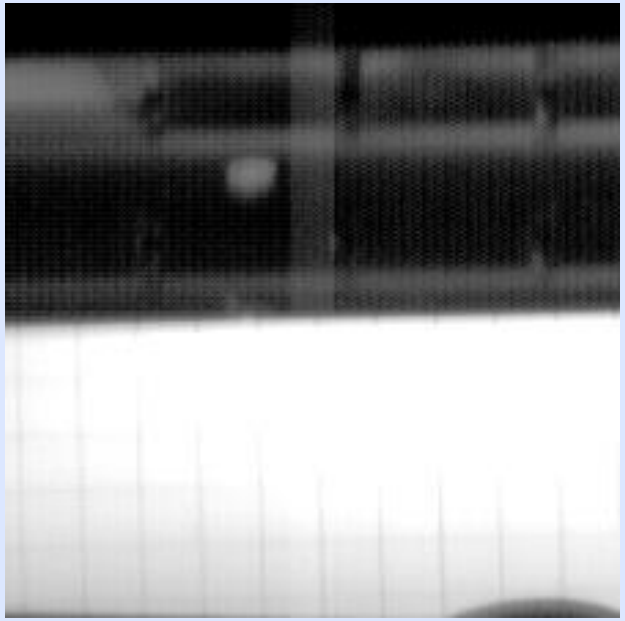
Particle Beam Impact: comparison between simulation and experiment



Design

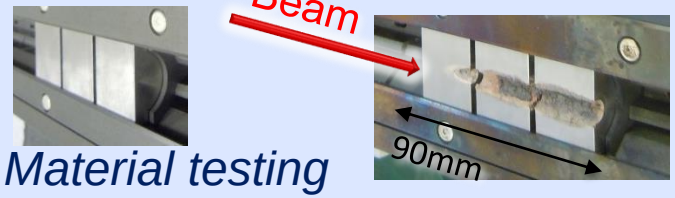


F.E. Calcs



Live Acquisition system by MME Mech. Lab

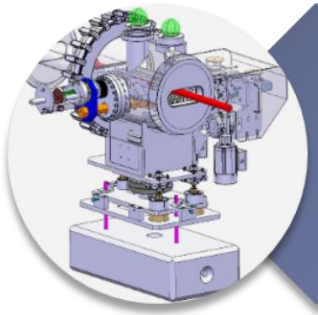
Fabrication and Assembly



Material testing pre and post-irradiation

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

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



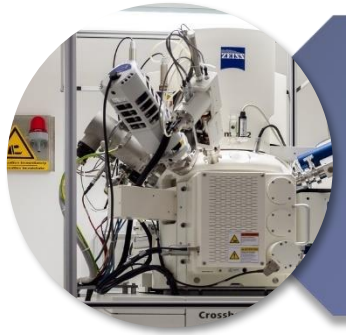
Design, Simulations and Measurements

- **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)

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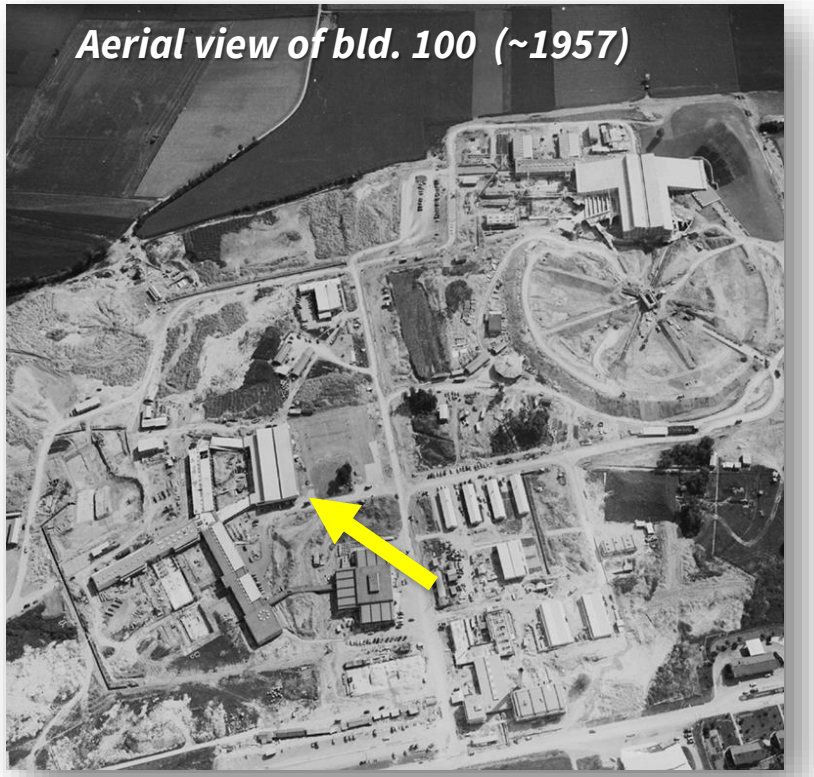


MME Mechanical Workshop

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**

Knowledge Transfer to external collaborations and suppliers

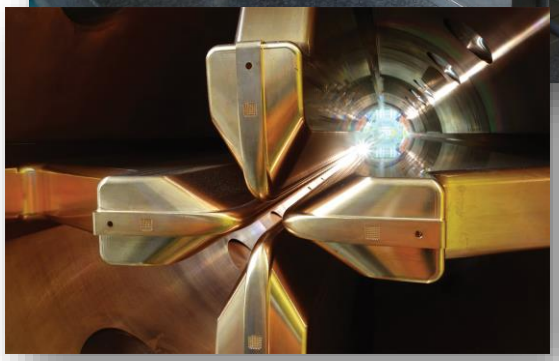
Some numbers…

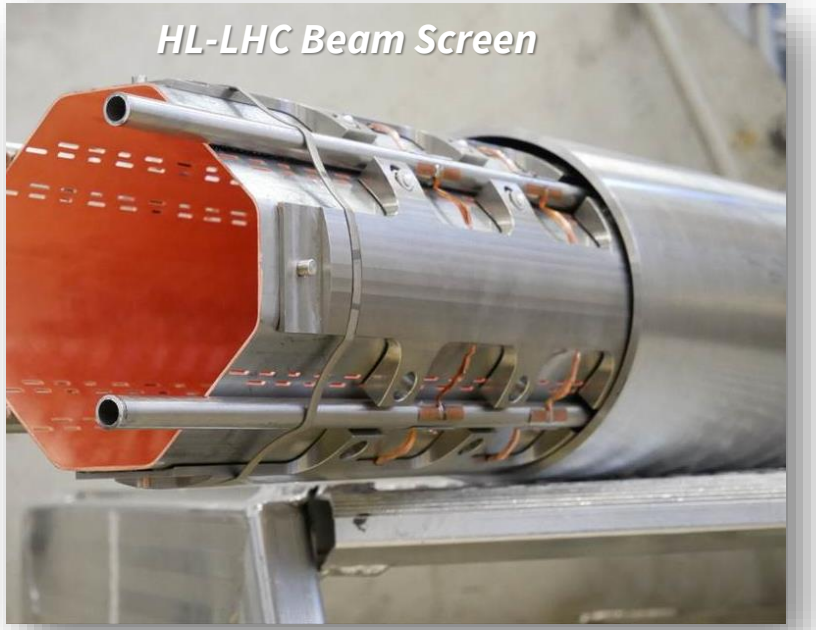
- Total workshop surface of ~**4000** m2
- Featuring **40**+ conventional and unconventional machines
- ~**90** highly-skilled technical personnel
- Yearly turnover ~**2500** fabrication ‘’jobs’’

Multi-technology Components

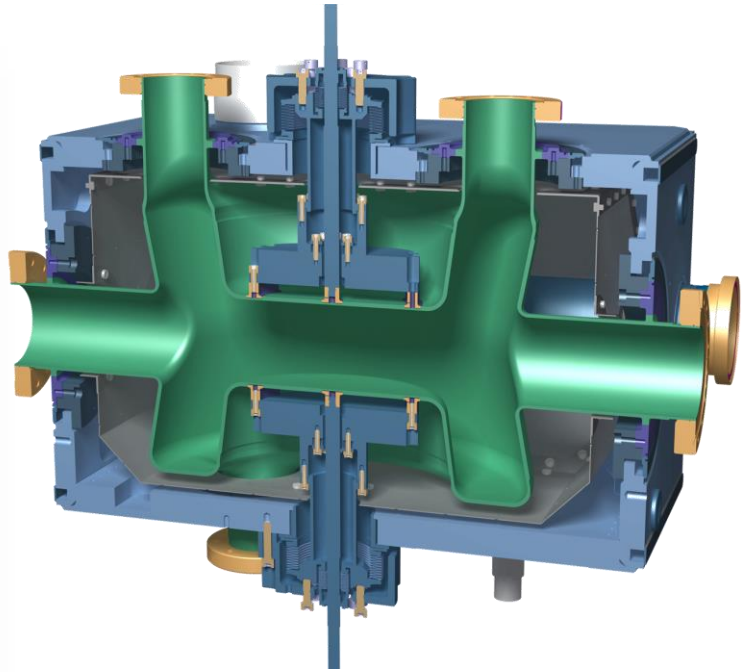
Most of the equipment produced calls for (simple to) **complex interlacing** of different fabrication **technologies**

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**

Machining Technologies

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

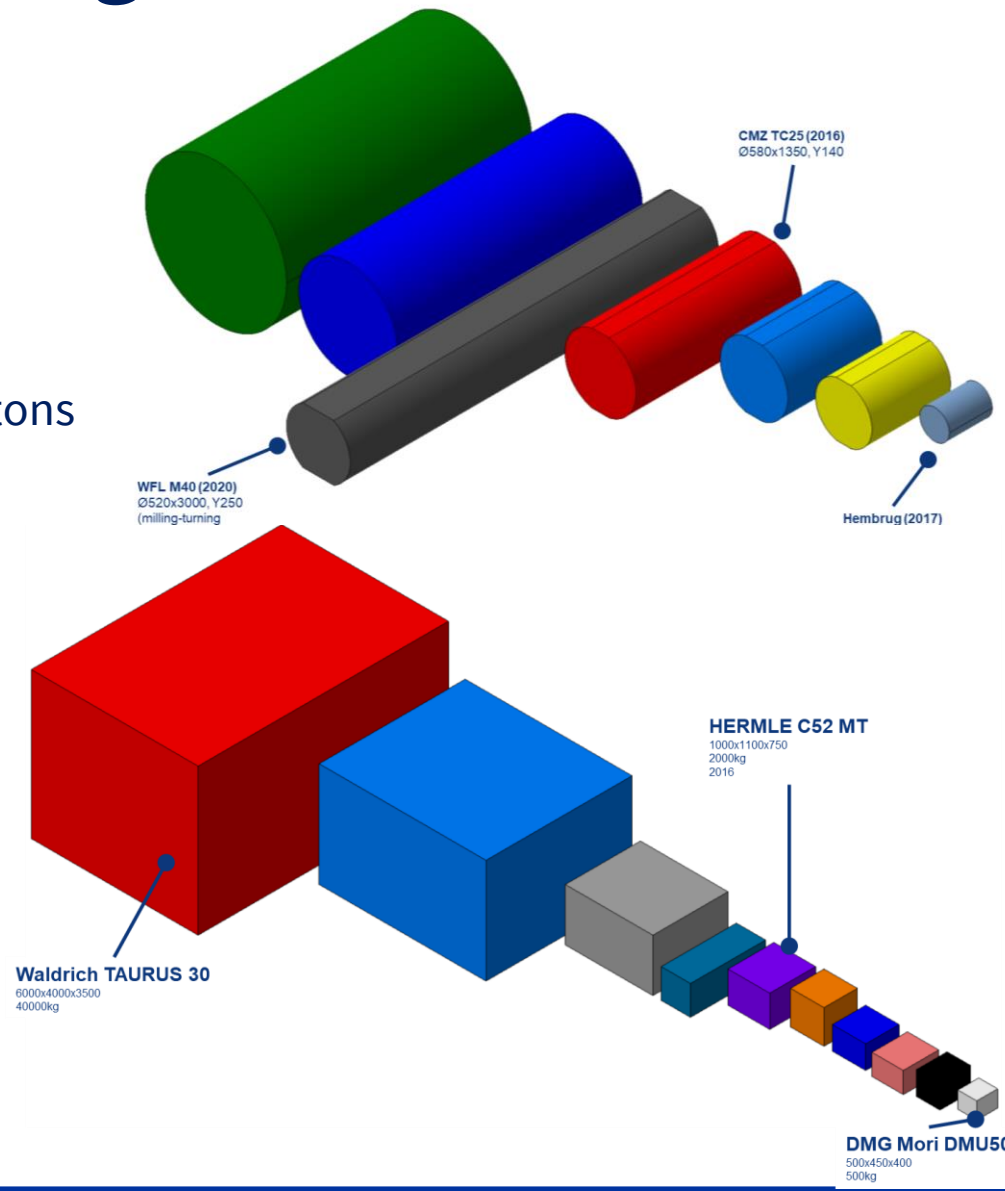
Attainable features :

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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HIE-ISOLDE Monoblock Cavity


SWELL Cavity


1,3 GHz Bulk Cavity

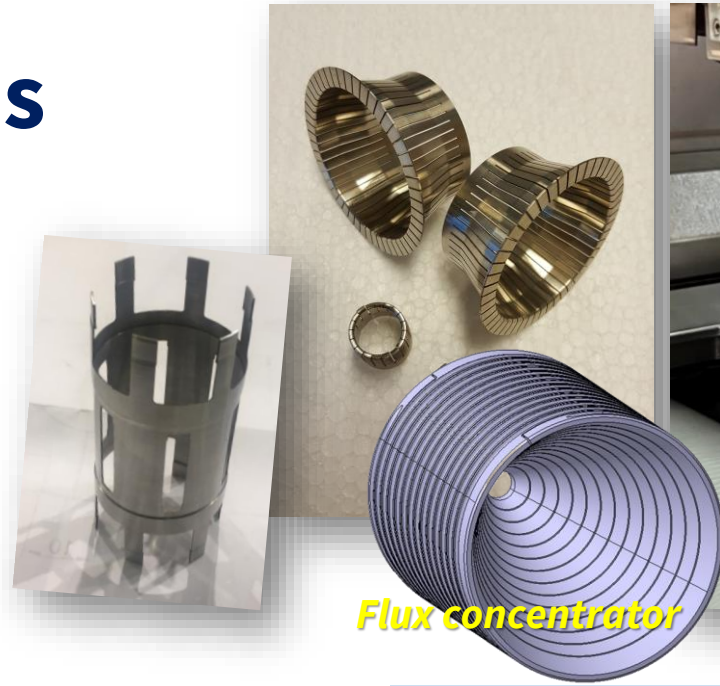

Crab HOM Coupler


5-axis Milling ConFlat Flange Knife

Non-Conventional Technologies

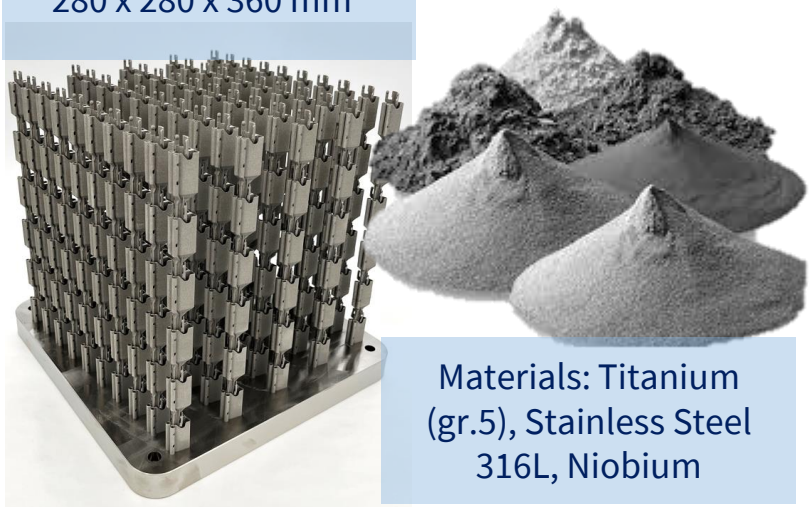
Spark Erosion

- **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)

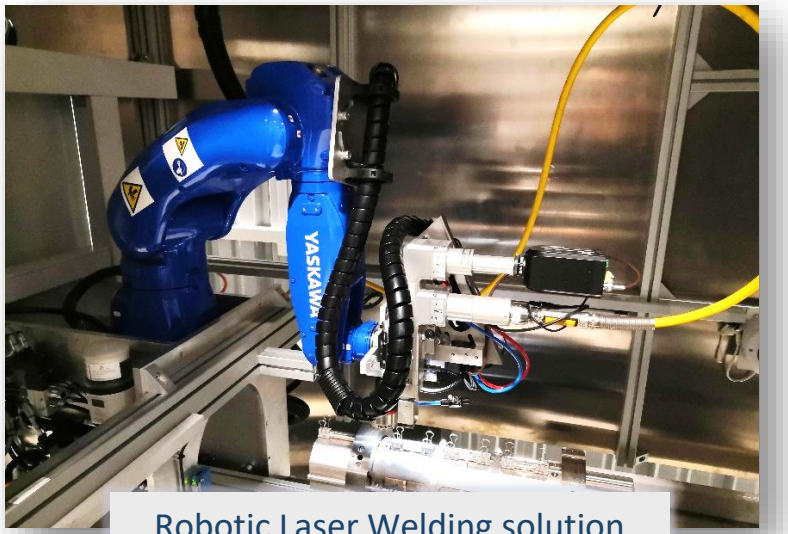
Sheet Metal Forming & Joining Techniques

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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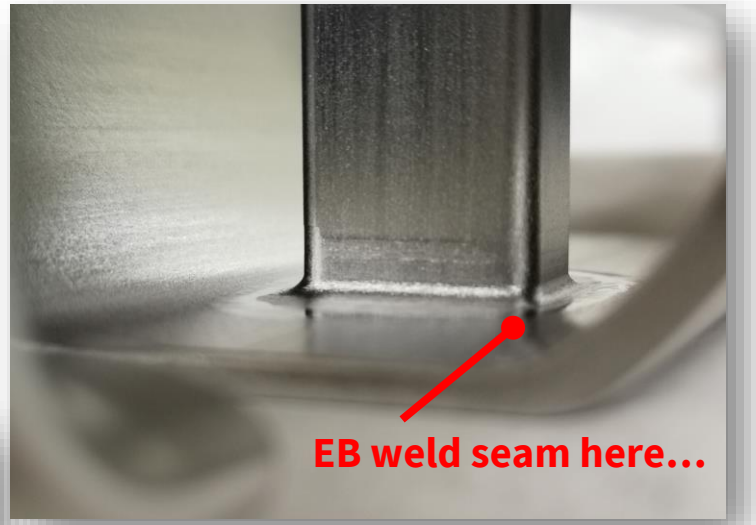
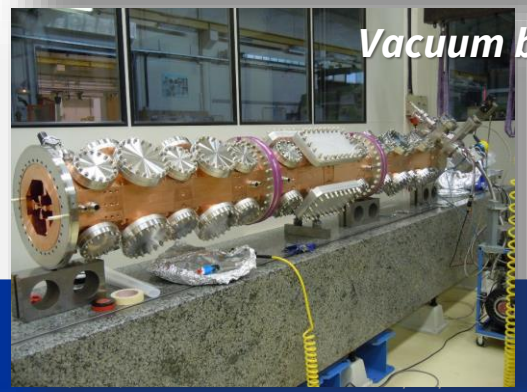
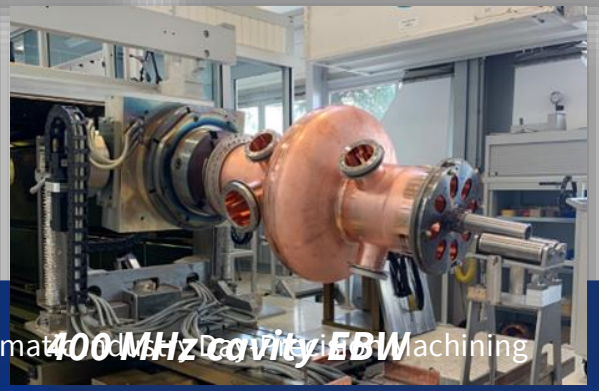






Dimensional Metrology

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

Most accurate equipment:

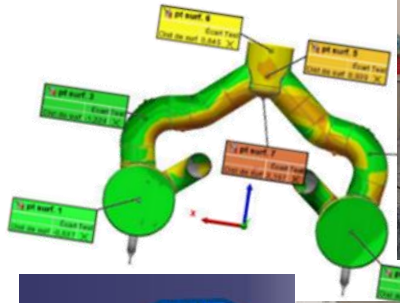
Leitz PMM-C Infinity

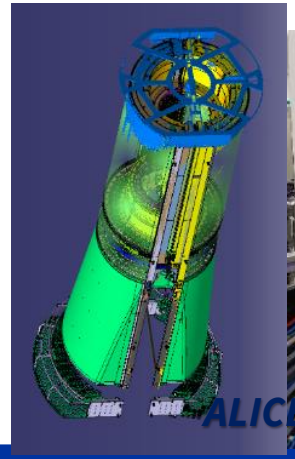
- Accuracy of 0.3 + L/1000 [µm]
- Airlock environment to maintain T and humidity conditions (VDE/VDI 2627)

Optical & Laser Systems

MetraSCAN & HandySCAN

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



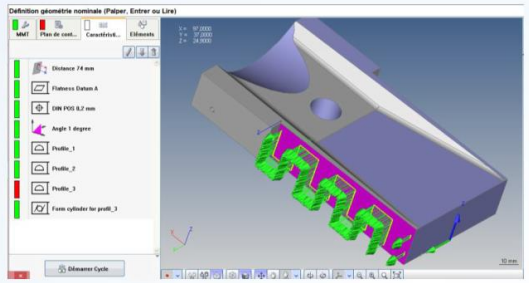


ALICE ITS Detector

Computer µTomography

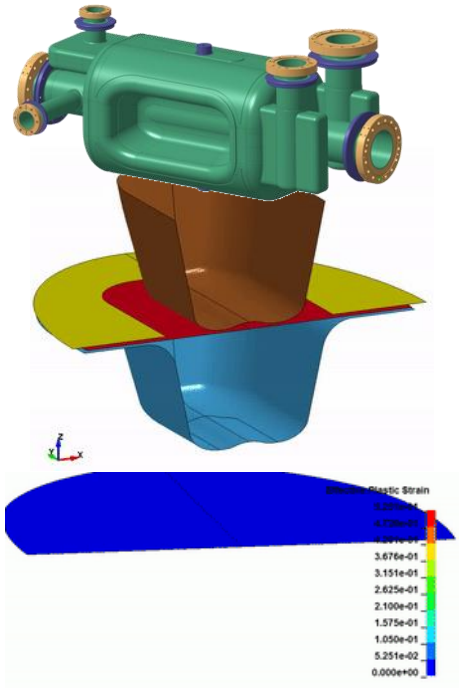
Zeiss Metrotom CT 1500

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



CLIC - X-BAND SPIRAL LOAD

Fabrication Process Simulations



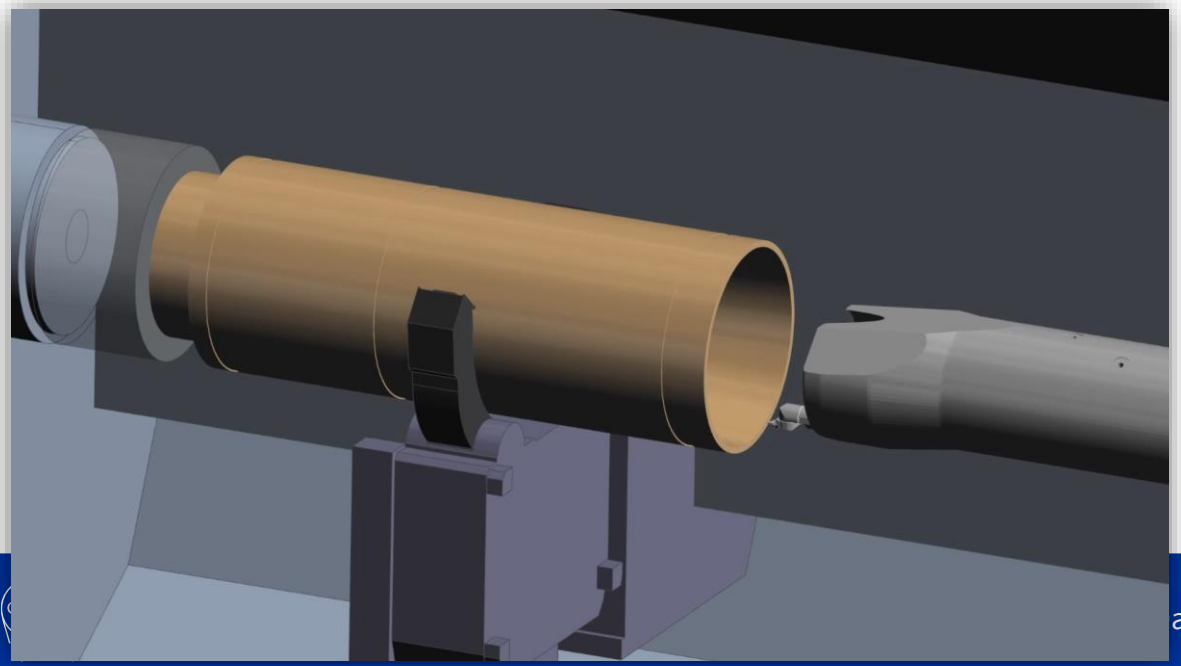
Easier and faster transition from process conception to produced parts. **Less costs**

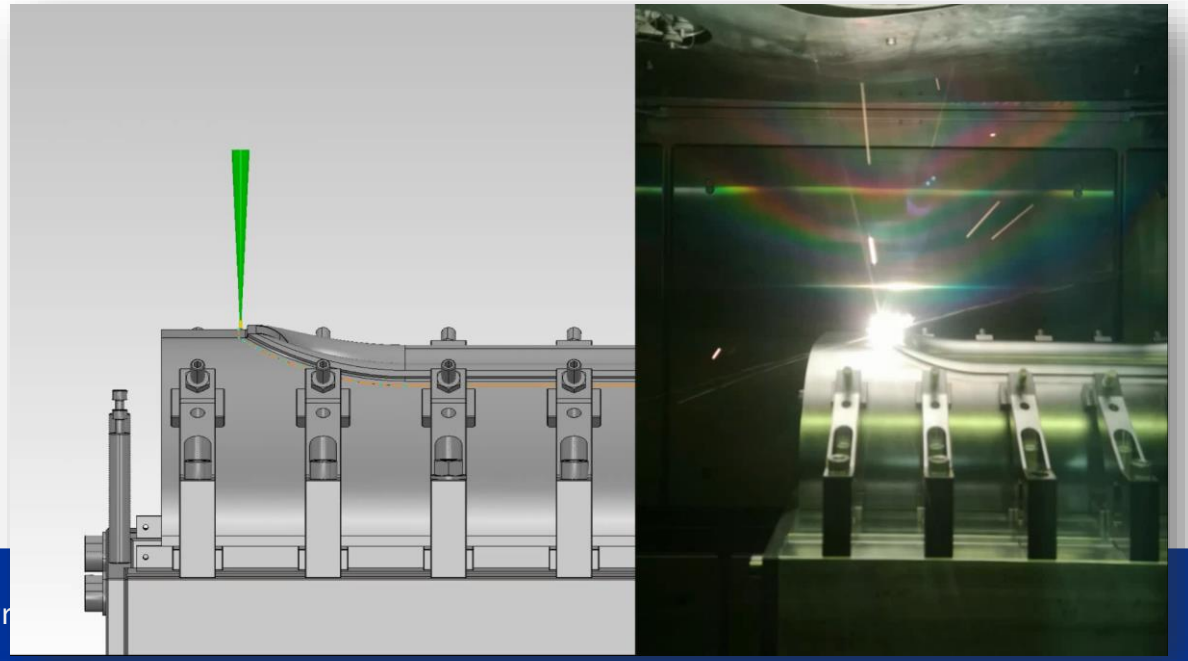
- Streamline tool design activities and choice of process parameters
- Optimisation of trial phase
- Reduction of ‘’human error’’ (complex tasks and high added value equipment)
- Better reproducibility & traceability

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

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

EdgeCAM
Powermill
WorkNC

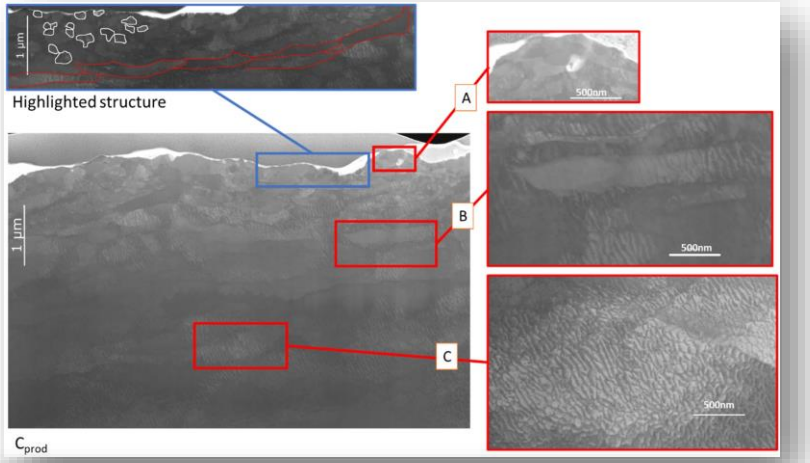




Some R&D

- **Multiple R&D routes** being followed
- Within workshop major technologies & stemming **from needs of the accelerator community**

Milling/turning parameters & tools.
Effect on coating and RF performance

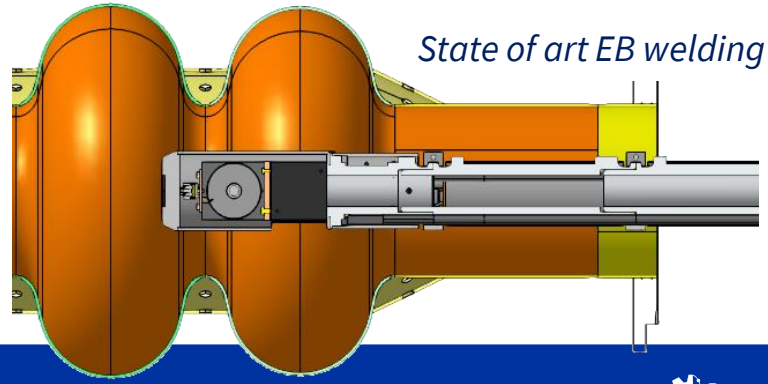


Novel lubrication strategies (cryogenic, MQL,..)

Joining heterogeneous materials (e.g. Nb/Cu)

Shaping and welding world's thinnest Alu bellows

State of art EB welding



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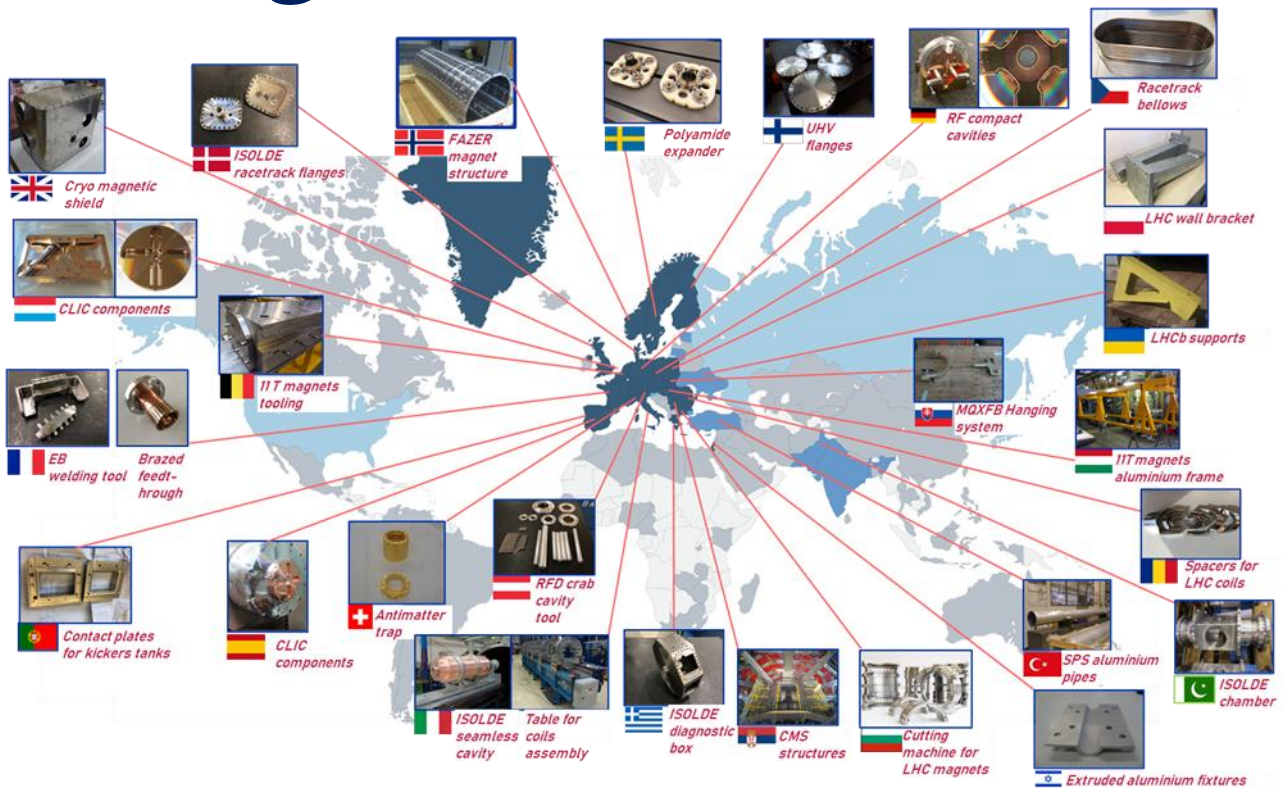
- **Subcontracting activities**

MME Subcontracting Service:

- In **close collaboration with the CERN Procurement Department**
- Strong contribution to **balance the industrial return**
- **2000-2500** contracts/year
  ~40% of overall production for mechanical components @ CERN

Subcontracting:
~ 40% of semi-finished parts
~ 60% of finished / turnkey components
900+ suppliers in all Member States



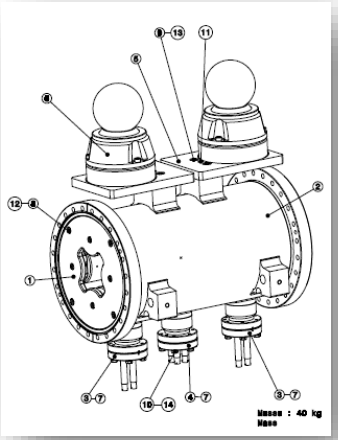
Full Complementarity with in-house portfolio… …series… additional technologies

	Invoiced Jobs							
	2016	2017	2018	2019	2020	2021	2022	2023
Subcontracting MME-FS (MCHF)	10	13	13,5	10,7	8	6	8	8

MME Subcontracting Service: Core & Recent Activities

Magnets

Prototypes & series of different magnets

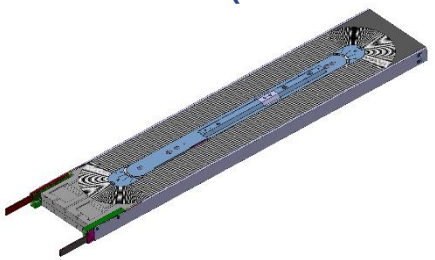


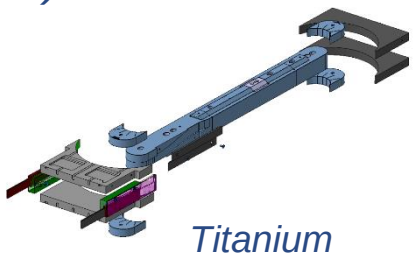
ELENA – Series production of electrostatic quadrupoles (x60). Synergy between EN-MME Workshop and EU suppliers.

- *High precision CNC of small to large equipment*
- *Stamping, wire cut of laminations*
- *Cryostats*

3x RMM prototype Coils for FCC project (R&D)

- *High precision CNC machining*
- *EDM (wire erosion)*

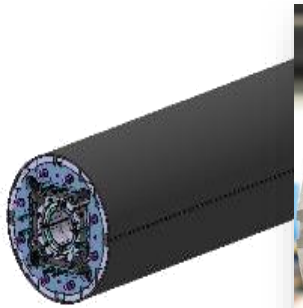


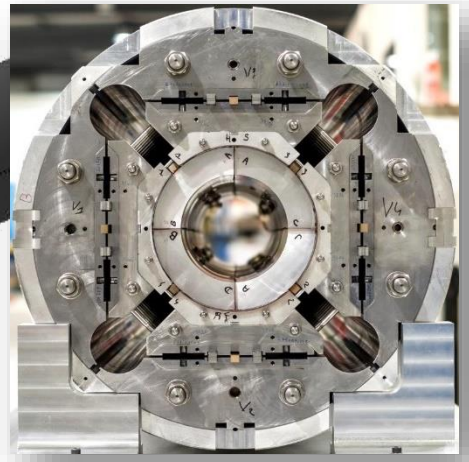


Titanium

MQXF Superconducting Magnet

..5 axes CNC machining, turning, EDM..





Titanium end spacers

Poles

St. Steel 316L

St. Steel 316L

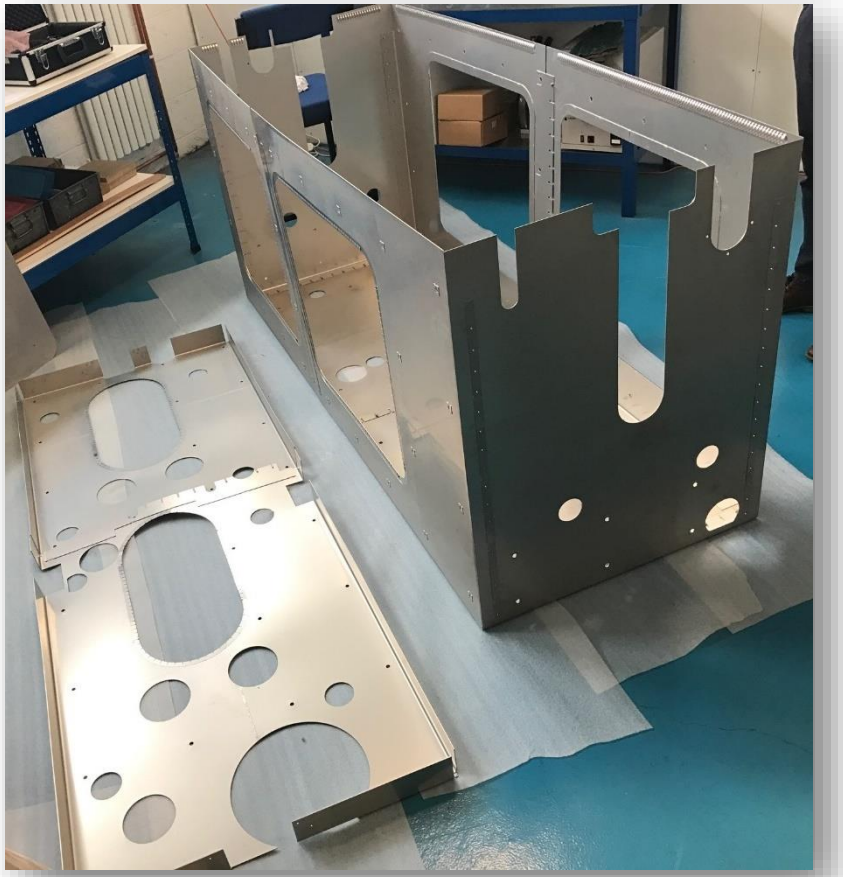
Magnets Tooling

Large Precise Tools for Magnet assembly

Rotating Table for SC magnets assembly

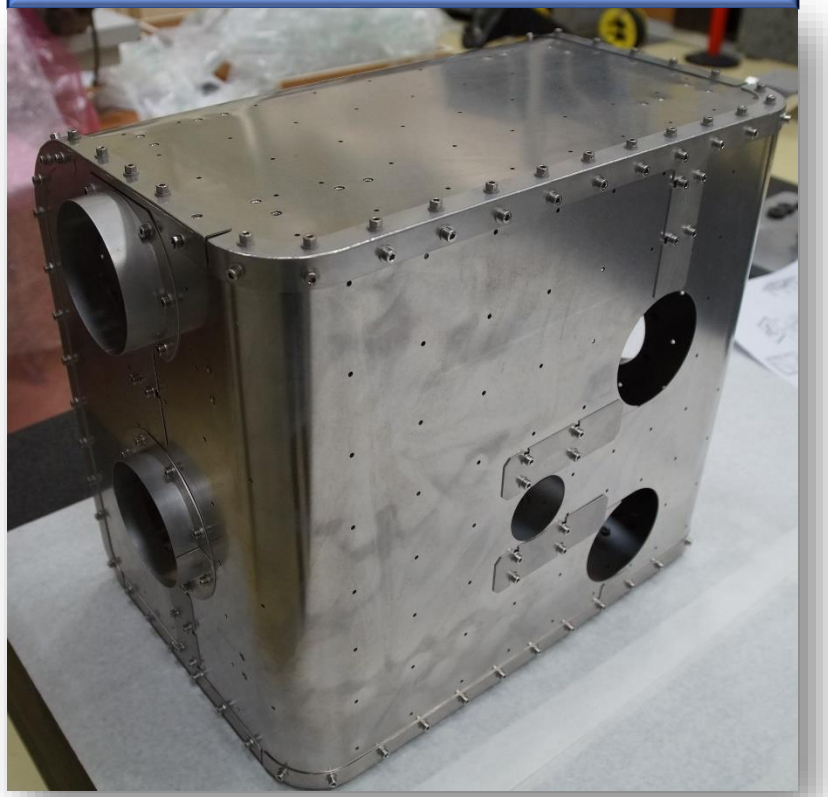
MQXF & FRESCA Magnet Impregnation & Curing Tools

Magnetic Shields



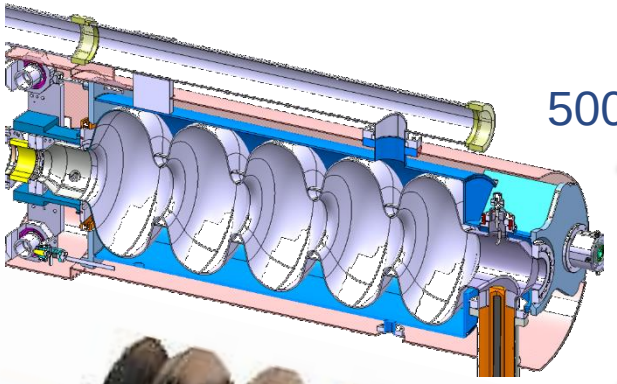
Warm Magnetic Shield
MuMetal, 2m wide

Cryo Magnetic Shield
Cryophy, precise forming and thermal treatment



Superconducting RF Cavities

- *Prototype: .. Precise forming & joining of Niobium sheets (in-house).. **Precise Tools***
- *Series: 100% industry*
- *Precision and surface quality of utmost importance for cavity performance*

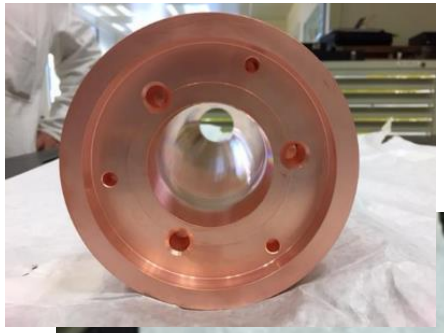


SPL Cavity

..Spinning..
EB welding

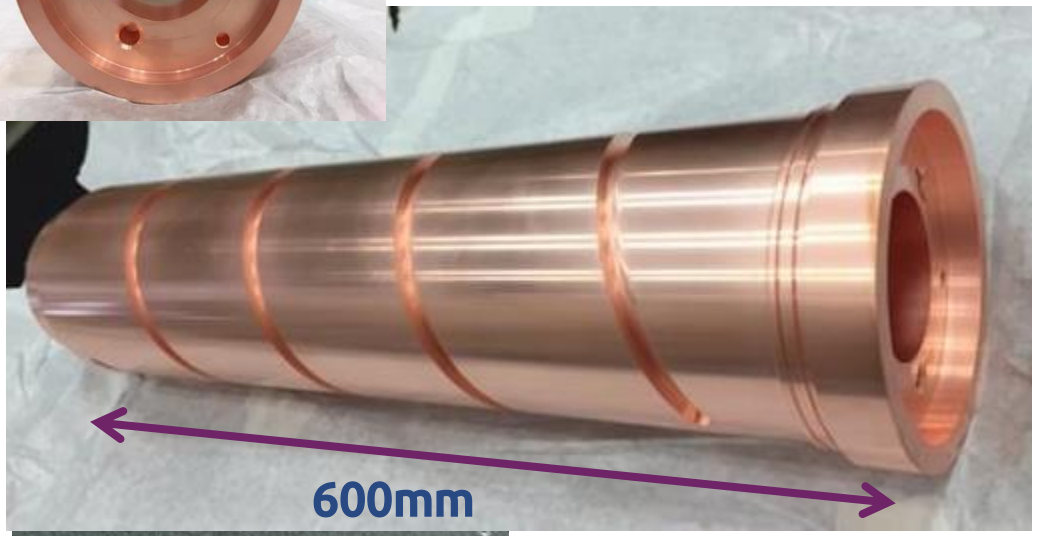
CRAB Cavity

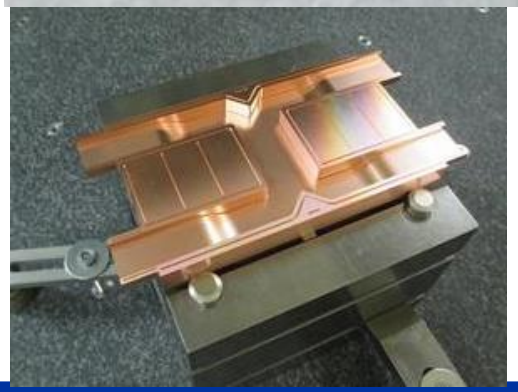
« Warm » RF Cavities



RF Pulse Compressor

Turn/mill process on Cu OFE 3D forged



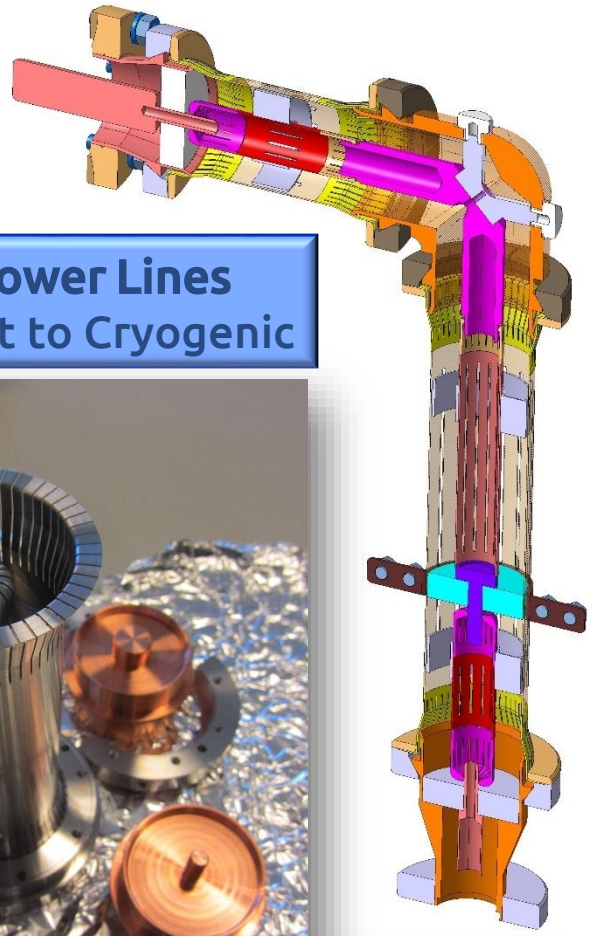


Copper Waveguide Coupler

HIE- Isolde Cavities

- *Long Overhang Machining from Monoblock Copper*
- *D320 x L900*
- *Tolerances in the tenth of mm..*

Diverse RF Equipment



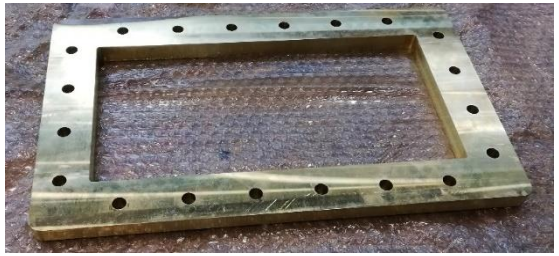
RF Power Lines
Ambient to Cryogenic

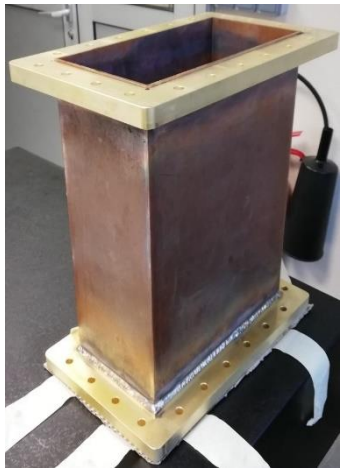
Crab Cavity:
RF Feedthrough

- *EB welding & Ceramic brazing in reduced volume*
- *Machining*

RF waveguides

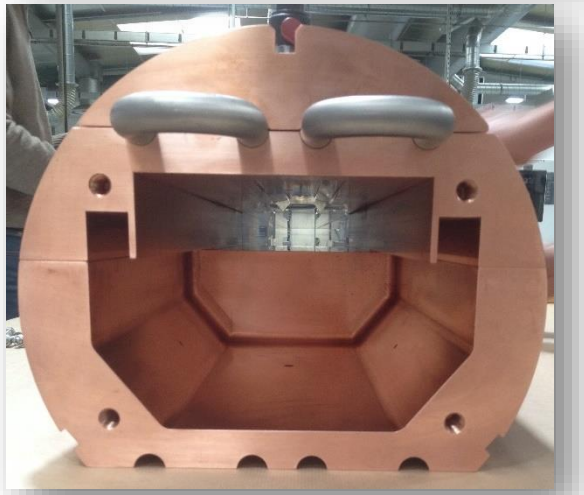
Brass flanges





Beam Intercepting Devices: TIDVG4

Assembling
..welding and tests in house..

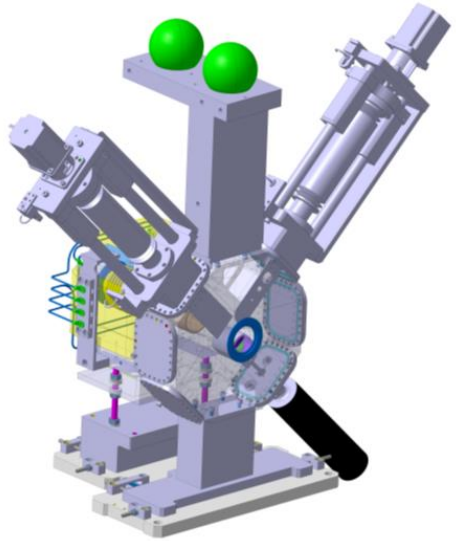


Copper blocks*: Large CNC milling*

Assembly inside tunnel

Beam Diagnostic Components

- Complex bulk pieces with knife-edges for UHV applications
- Raw material from CERN (316LN 3D forged blanks)



Handling, Lifting, Assembly Equipment

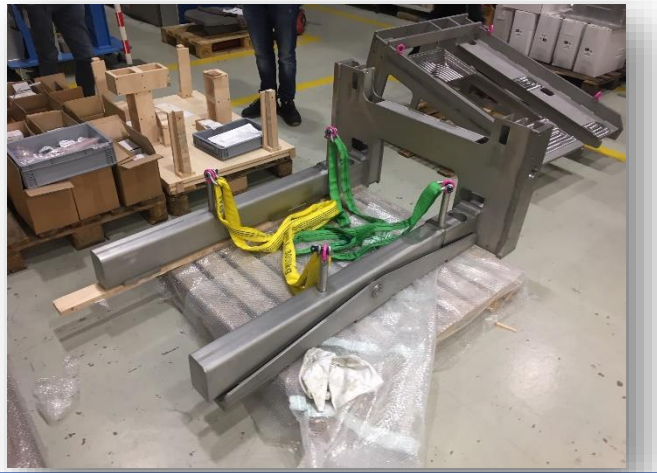
Handling Tool for Chemical Etching

Bespoke Mechanical Lifting Equipment

Lifting Equipment for WOW Cavity

Remote Handling System for LHC Collimators

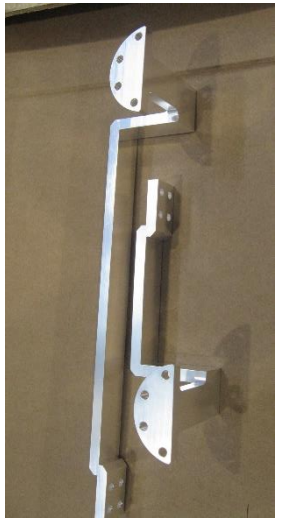
AD Remote Handling Trolley



Electronic / Power Racks

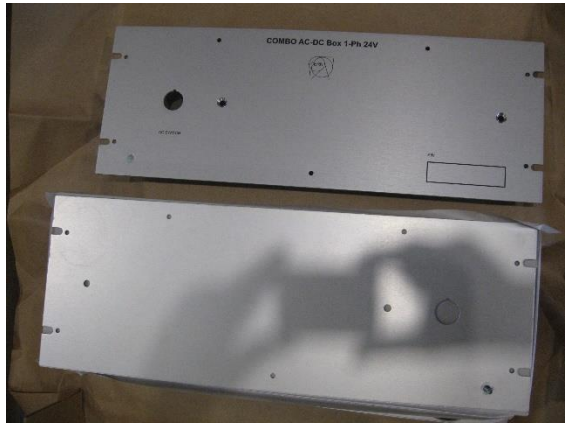
Custom electronic racks

Cooling system



Cu busbars + Ag coating

Custom power racks, with busbars



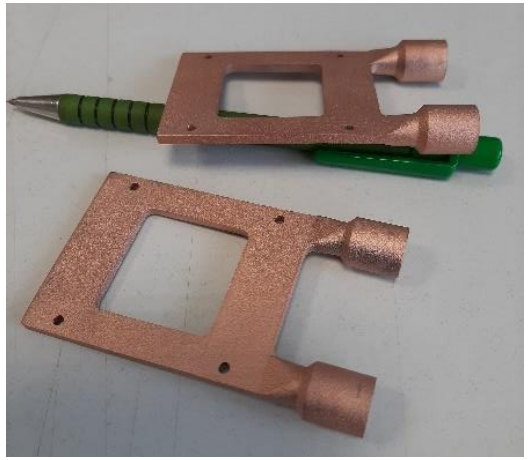
Custom boxes/panels + paint/coating + screen print / laser engraving

Electro-mecanical parts

Electrical locks

Magnets aluminium parts + gold coating

Polymer isolators



IGBT copper cooling system (additive manufacturing)

Faraday boxes

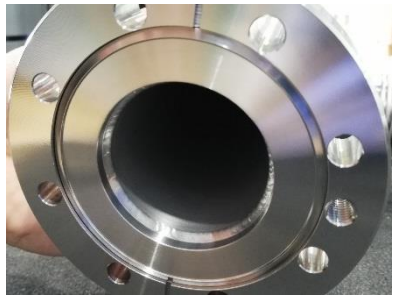
Micro screws

Ceramic isolator

Micro Brass nuts

High Vacuum Components

Pumping bypass for LHC



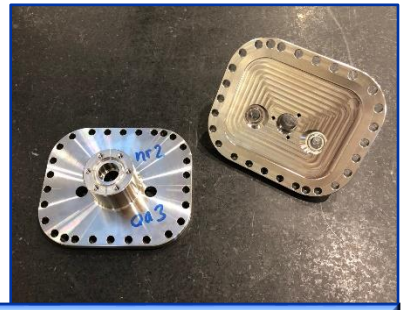
Collimator beam impact test

Technologies:

- Precision forming
  (Rolling, Bending, Extrusions..)
- Vacuum brazing & heat treatments
- High precision CNC machining
- Bellows
- Electron beam welding / TIG welding
- Metrology
- UHV capabilities

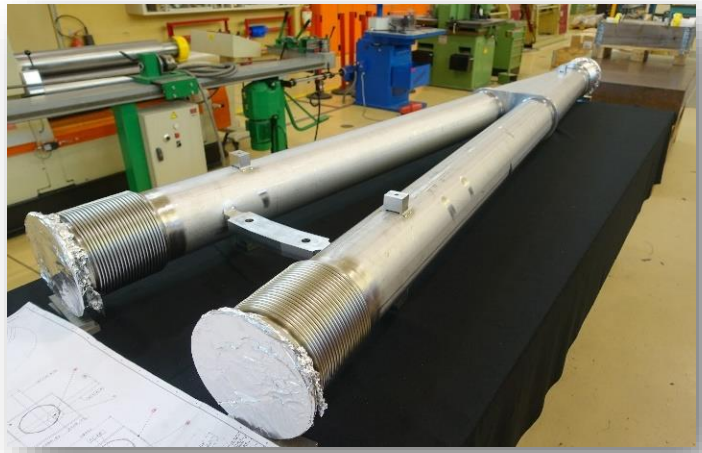
Materials:

- Stainless Steel
- Inconel
- Titanium
- Aluminium
- Copper alloys



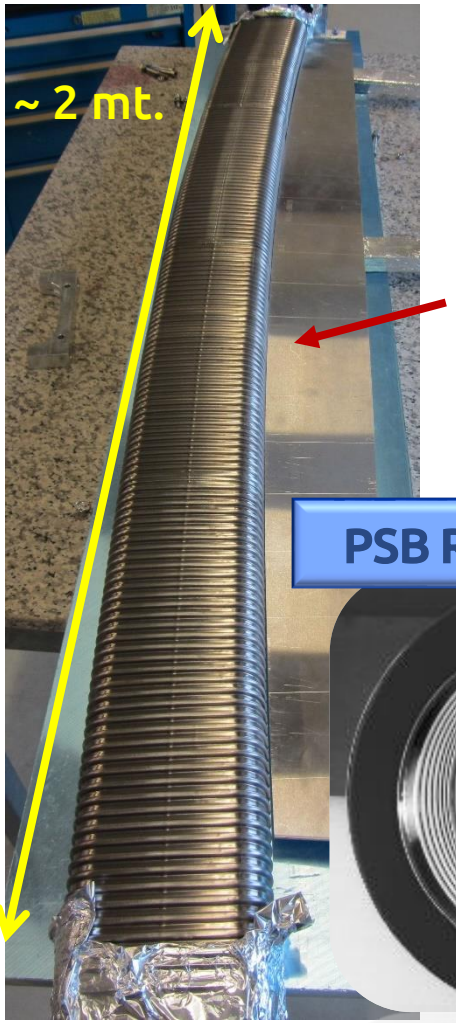
ISOLDE UHV Flanges

Y-chambers



Cryocooler Test Chamber

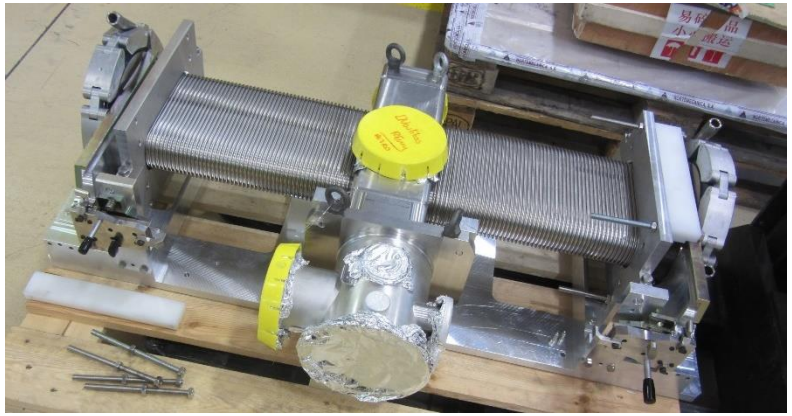
Vacuum Chambers

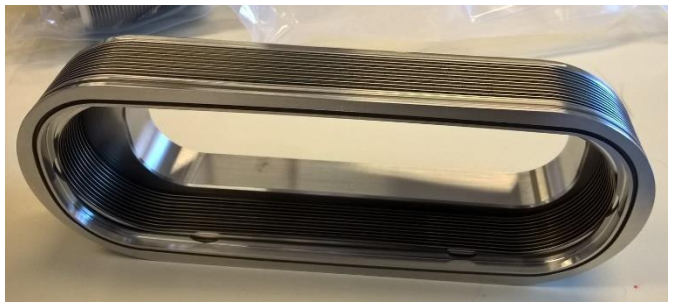


- Precise forming into chambers of different sizes
- Inconel & SS alloys
- UHV compliant fabrication

PSB Ring

PSB Injection





Hippodrome edge-welded bellows

Vacuum Vessels

Always on the lookout for:
Precision Vacuum Components

Technologies:

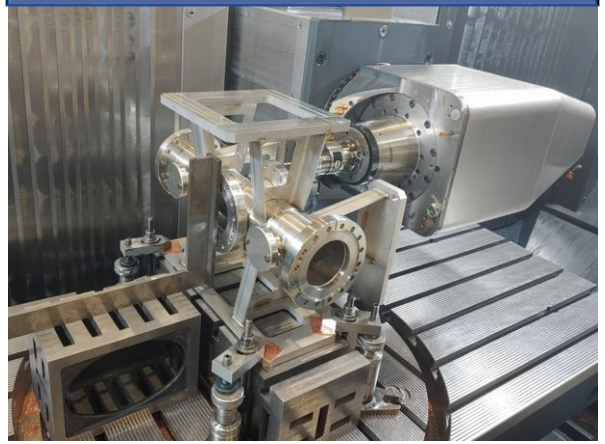
- Precision forming
  (Rolling, Bending, Extrusions..)
- Vacuum brazing & heat treatments
- Electron beam welding
- Precise machining
- Metrology
- UHV capabilities

Materials:

- Stainless Steel
- Inconel
- Titanium
- Aluminium

Vacuum Vessels

Vacuum Chambers



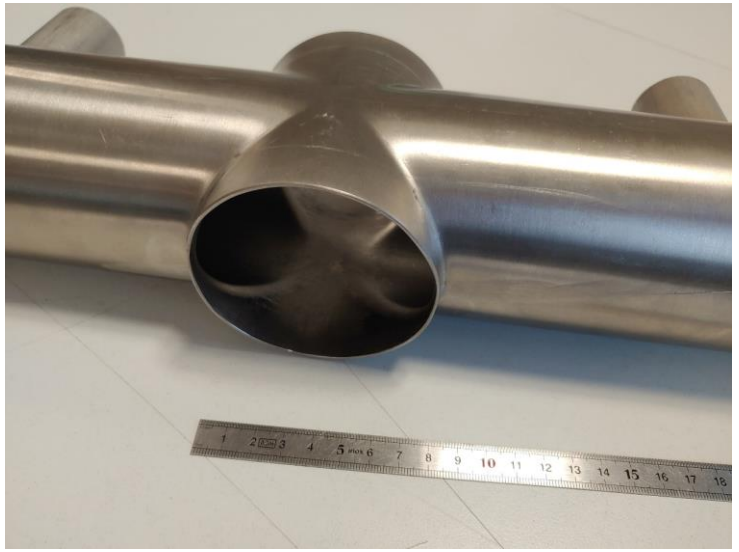
Pulled-nozzle chambers

Y-chambers

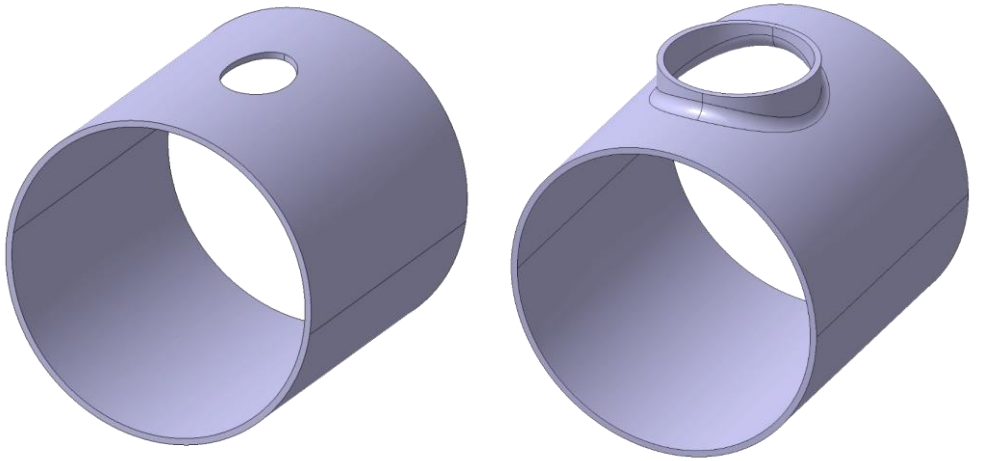
Pulled nozzles

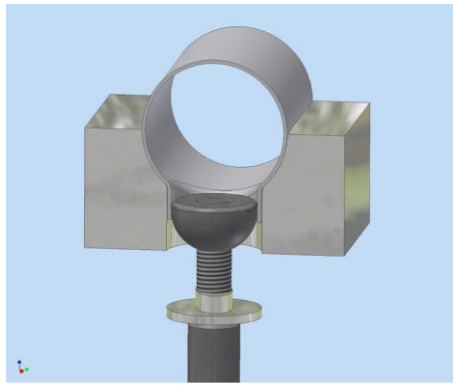
Neck shaped by plastic deformation
Obtained via pulling ogive through initial hole

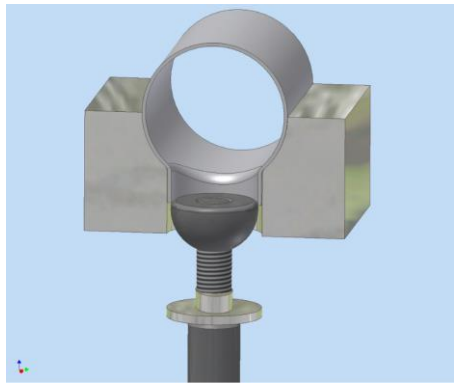
Avoids welded saddle connections → Buttweld
[+] easier weld, better quality
[++] vacuum, RF, weld-induced deformations
[++] possibility of NDT (X-Ray)



Pulled nozzle on pipe





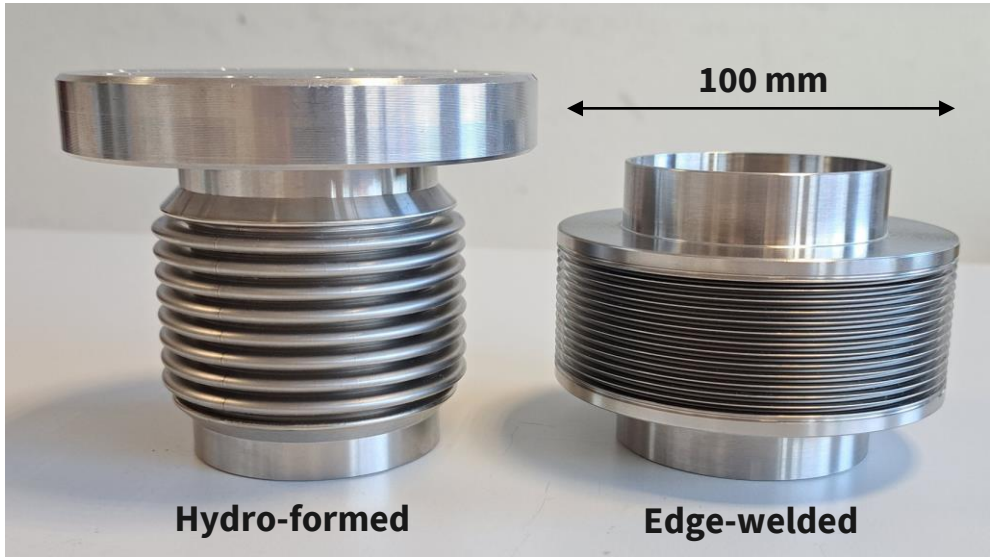


Always on the lookout for: Bellows

…UHV, cryogenics, pressure equipment…

Typical Dimensions: ~ Ø60, Ø80÷Ø120, ~Ø160

Edge-welded & Hydro-formed	Avg. per year (2018÷2022)	Peak year (2019)
Number of POs	14	20
Envelope (kCHF)	130	372



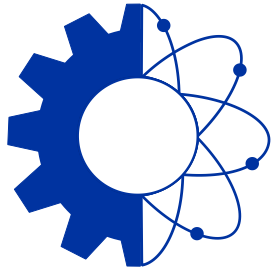
Always on the lookout for: Plastics, Ceramics & Composites

- Magnet shims
- Insulators, spacers
- Standard components (washers, screws)
- Tools for assembly and protection
- …

	Avg. per year (2014÷2017)	Peak year (2017)
Number of POs	115	160
Envelope (kCHF)	370	460

Materials:

- POM, PP, Plexi, PVC
- PE at different densities
- PEEK, PTFE, PVDF, VESPEL
- EPGCxxx
- Alumina, Macor®
- …



ENGINEERING
DEPARTMENT