HL-LHC Collimators:
Materials, Mechanical Components and Overview of its Industrial Production
2nd HiLumi Industry Day – October 31st 2016

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On behalf of the LHC Collimation Team
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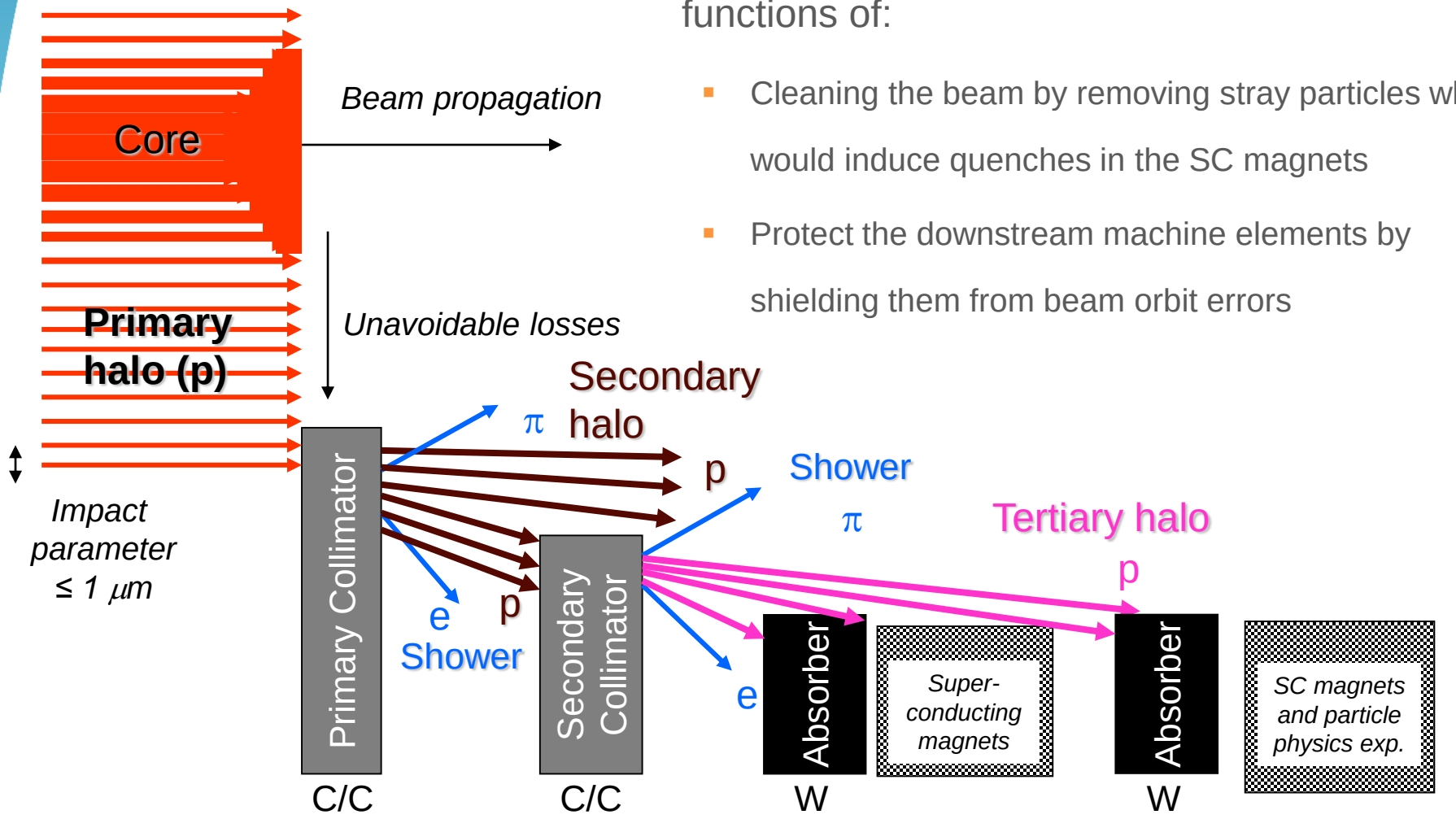
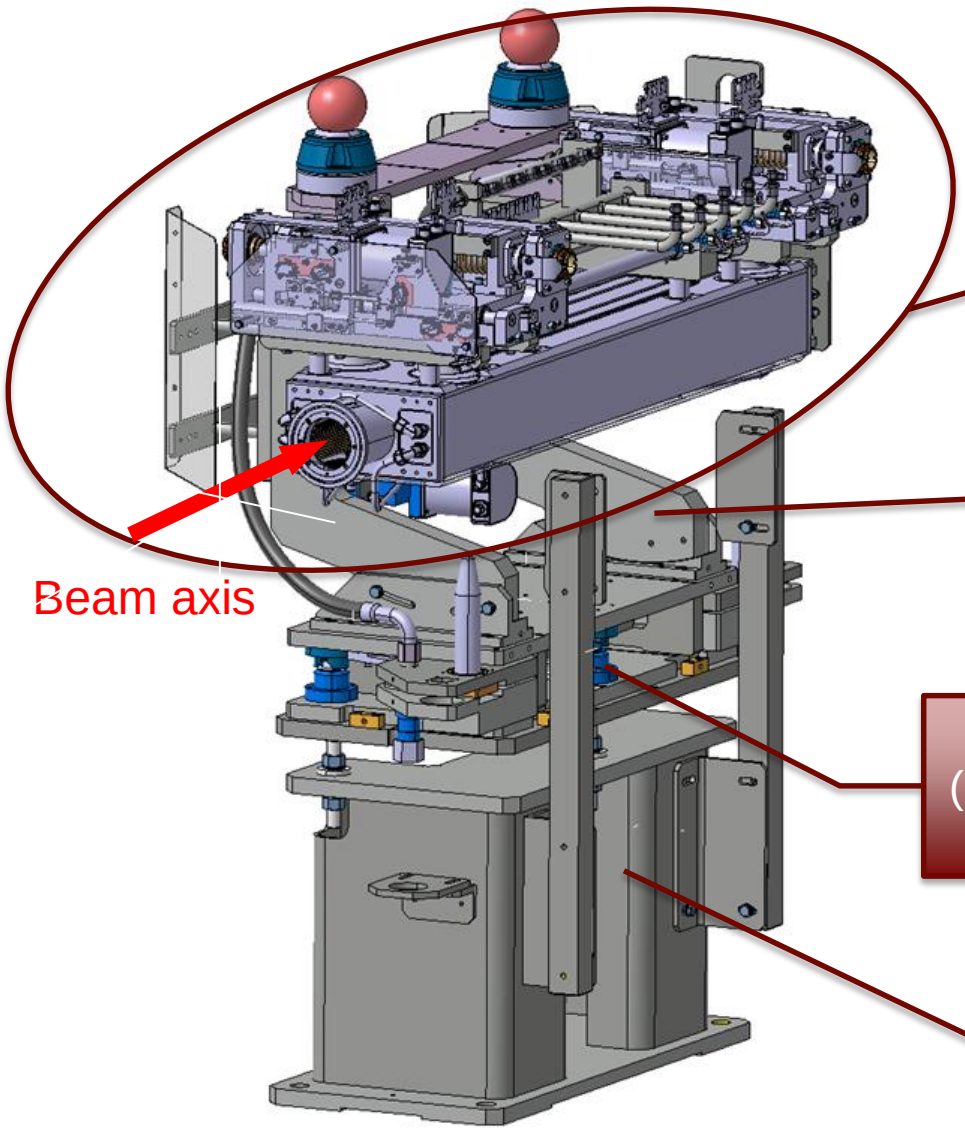
Introduction to LHC collimators

- **B**eam **I**ntercepting **D**evices with the main functions of:
  - Cleaning the beam by removing stray particles which would induce quenches in the SC magnets
  - Protect the downstream machine elements by shielding them from beam orbit errors



Introduction to LHC collimators



Overall length: 1480mm

Tank width: 264mm

Collimator assembly

Adjustable (Horizontal) Stand

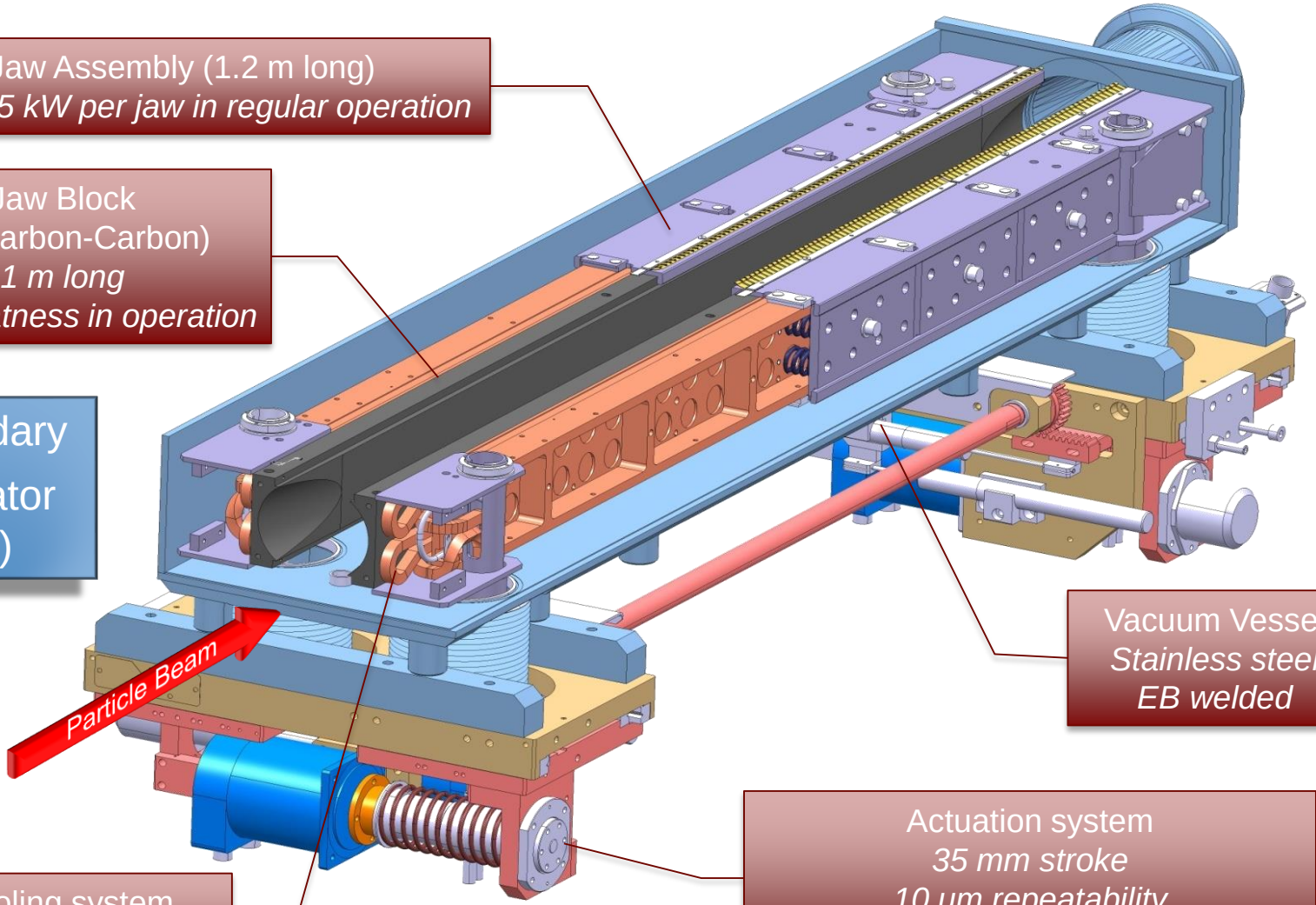
(Al Alloy)

Plug-in system
(integrates mechanical, hydraulic and electrical quick connections)

Fixed Support

(Stainless Steel)

Introduction to LHC collimators



Jaw Assembly (1.2 m long)
Up to 15 kW per jaw in regular operation

Jaw Block
(2D Carbon-Carbon)
1 m long
40 μm flatness in operation

Secondary Collimator (TCSG)

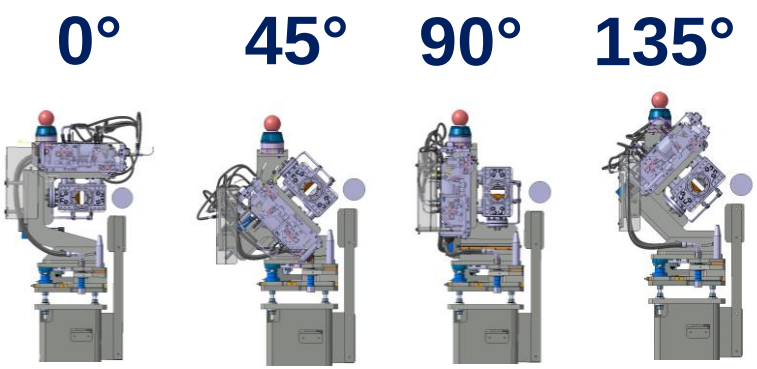
Vacuum Vessel
Stainless steel
EB welded

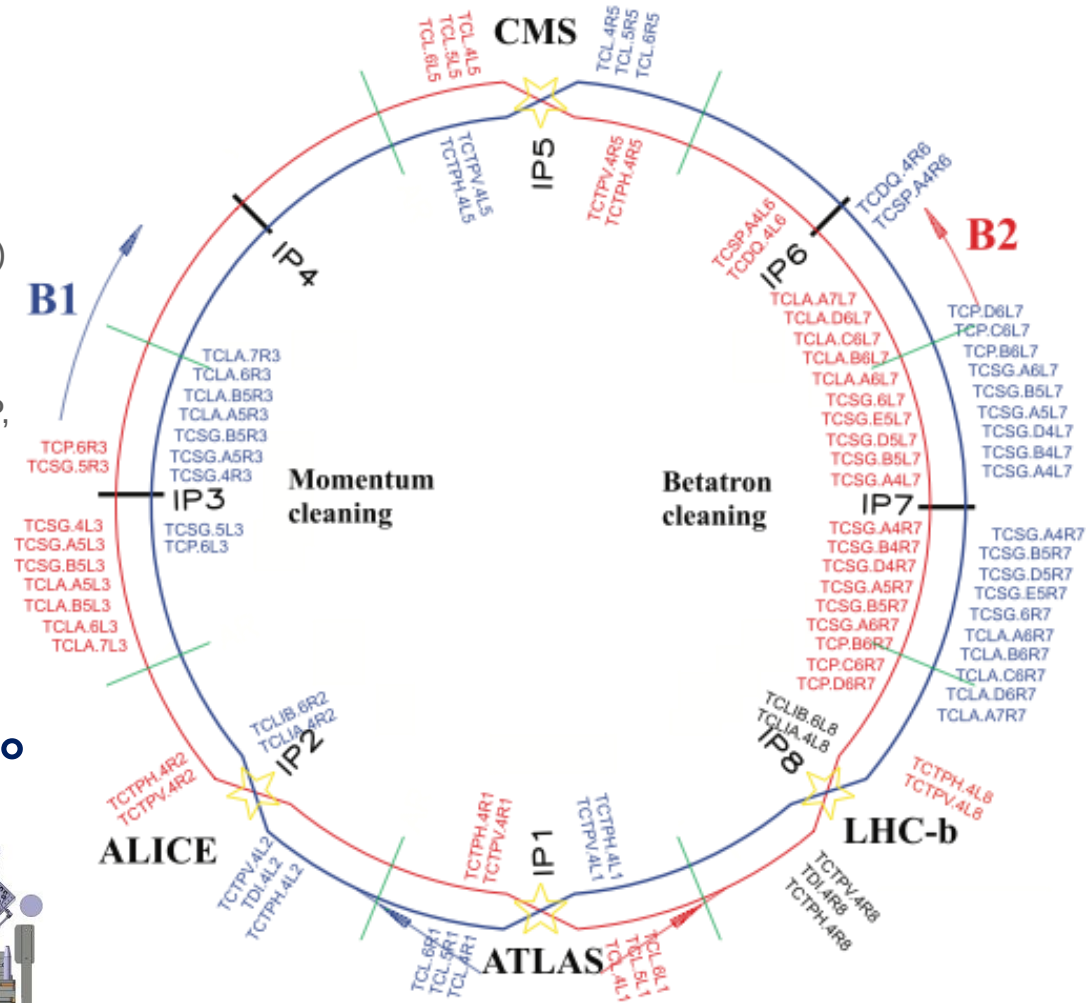
Actuation system
35 mm stroke
10 um repeatability
High radiation compliant

Jaw Cooling system
Cu-Ni Pipes

Introduction to LHC collimators

- 2 cleaning insertions: Momentum cleaning & Betatron cleaning (TCP, TCSG, TCLA)
- Injection regions (TDI, TCDD, TCLIA/B)
- Extraction regions (TCDQ, TCSG)
- Experimental regions (TCT, TCL, TCTP, TCTPW)
- **Total of 118 collimators**
- **More than 10 different designs**

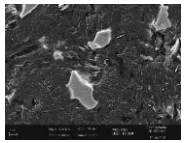
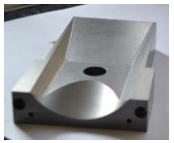




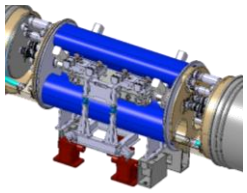
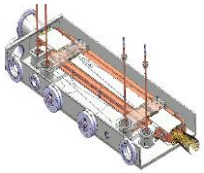
Collimation upgrade for HL-LHC project & consolidation

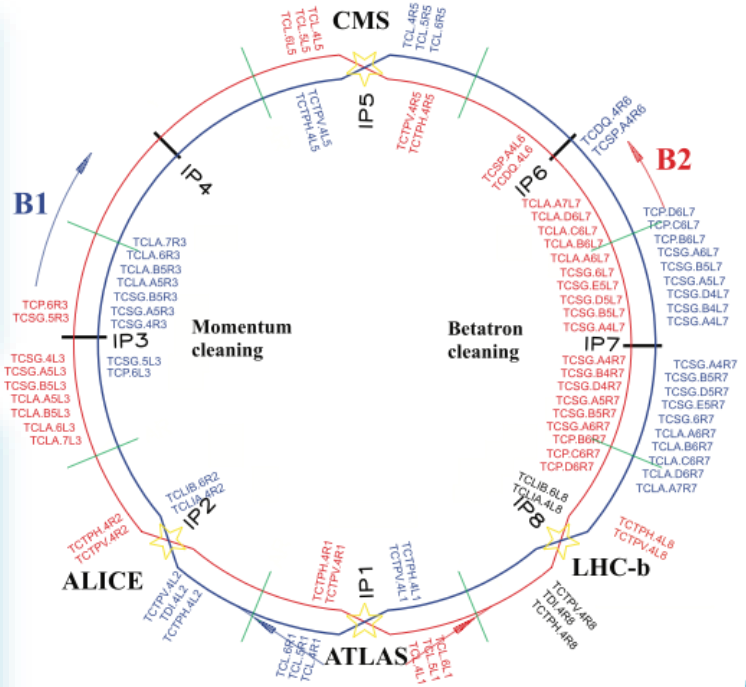
- TCPP(m): 8 units IP3/IP7
- TCSP: 8 units IP3
- TCSPM: 22 units IP7
- TCTPM: 20 units IP1/IP2/IP5/IP8
- TCLD: 4 units IP2/IP7
- TCL: 4 units IP1/IP5
- TCLX: 4 units IP1/IP5
- TCLM: 8 units IP1/IP5
- TDIS: 4 modular units IP2/IP8
- Total HL + Consolidation: 54 units + 30 units
- **Over 100 collimator units to produce**

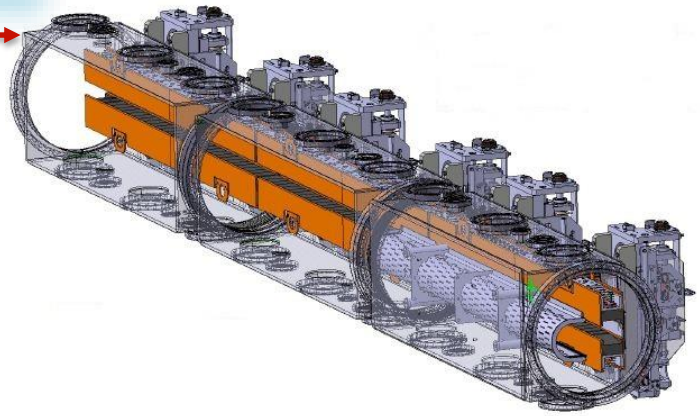
Low impedance collimators
New design, novel **advanced materials**

DS collimators + 11T dipoles

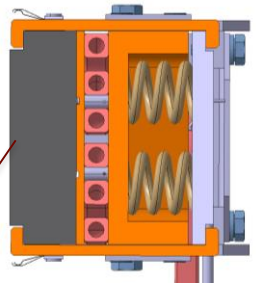




Collimation upgrade for HL-LHC project

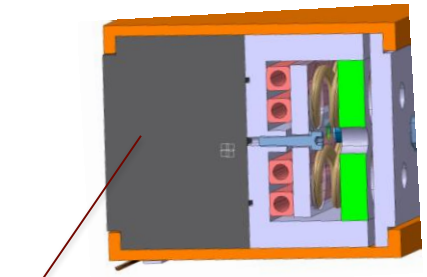
- Materials of the **jaws** are the **critical component** because of the tough requirements (**robustness**, **geometrical stability**, **electrical conductivity**, **radiation resistance** ...)
- **New advanced materials** being investigated for HL-LHC

TCPP /TCSP (LHC and HL-LHC)



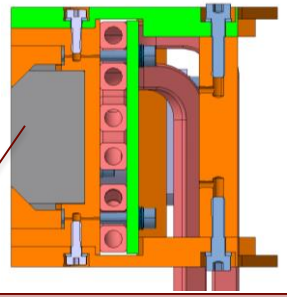
2D Carbon-Carbon

TDIS (HL-LHC)



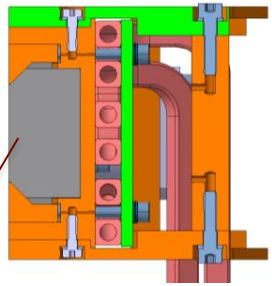
Graphite-Al-CuCrZn

TCSPM (HL-HLC)



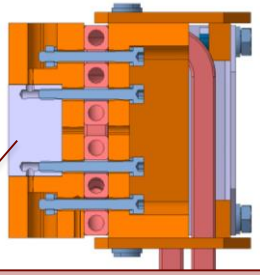
MoGr

TCTPM (HL-HLC)



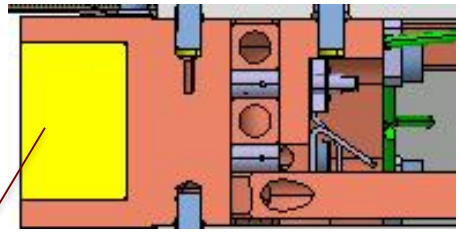
CuCD

TCTP (LHC and HL-LHC)



Tungsten Heavy Alloy
(95 W - 3.5 Ni - 1.5 Cu)

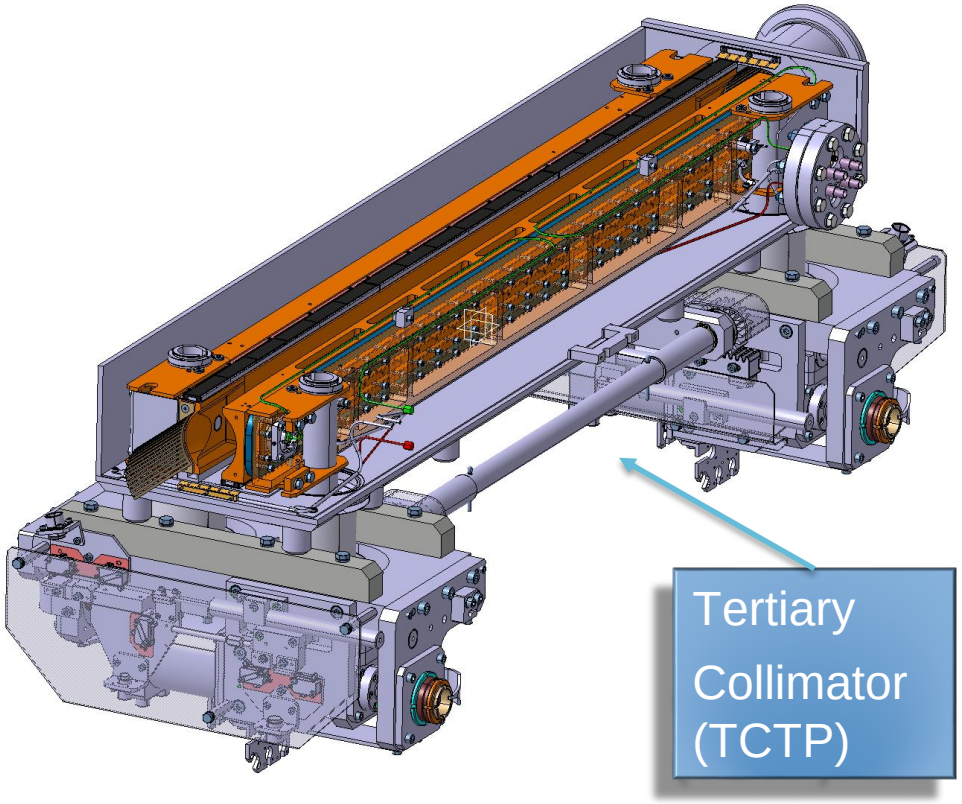
TCLD (LHC and HL-LHC)



Tungsten Heavy Alloy
(95 W - 3.5 Ni - 1.5 Cu)

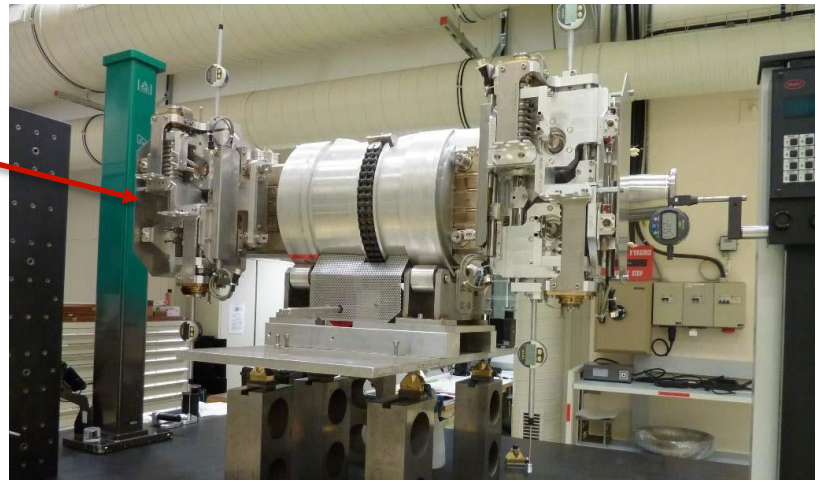
Competences and Technologies involved in the manufacturing of a LHC collimator

- Manufacturing Engineering
- High Precision Dry Machining
- Surface Treatments
- UHV Cleaning
- Vacuum Brazing
- EBW and TIG welding
- UHV leak testing and outgassing
- Assembly of UHV components in precise mechanisms
- 3D metrology and assembly adjustments



Competences and Technologies involved in the manufacturing of a LHC collimator

- **Manufacturing Engineering**
- Ability to produce 2D execution drawings and 3D models, as well as time and methods production process analysis.
- CERN manufactures the collimator **prototype** in house.
- A set of drawings are produced by CERN.



- The external firm will have the responsibility to produce all the execution drawings based on its own manufacturing processes that will have to be approved by CERN.

Competences and Technologies involved in the manufacturing of a LHC collimator

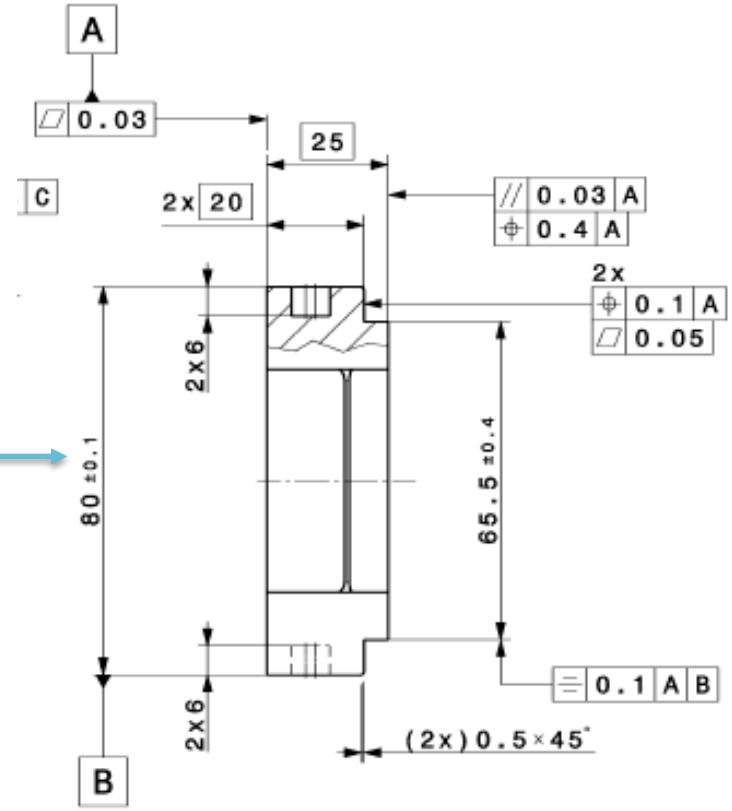
- **High Precision Dry Machining**
- Production of precise pieces complaint with UHV requirements (without oil/lubrication) and stress relief heat treatments.
- Milling, turning, bending, etc.
- Some pieces have challenging dimensional tolerances.
- The planarity and position of the absorbing material beam surface (as piece on its own and after assembly) is a must.
  - The planarity of the tungsten surfaces must be 0.04 mm, they must be parallel at 0.04 mm with reference to the beam axis.

Competences and Technologies involved in the manufacturing of a LHC collimator

- **High Precision Dry Machining**

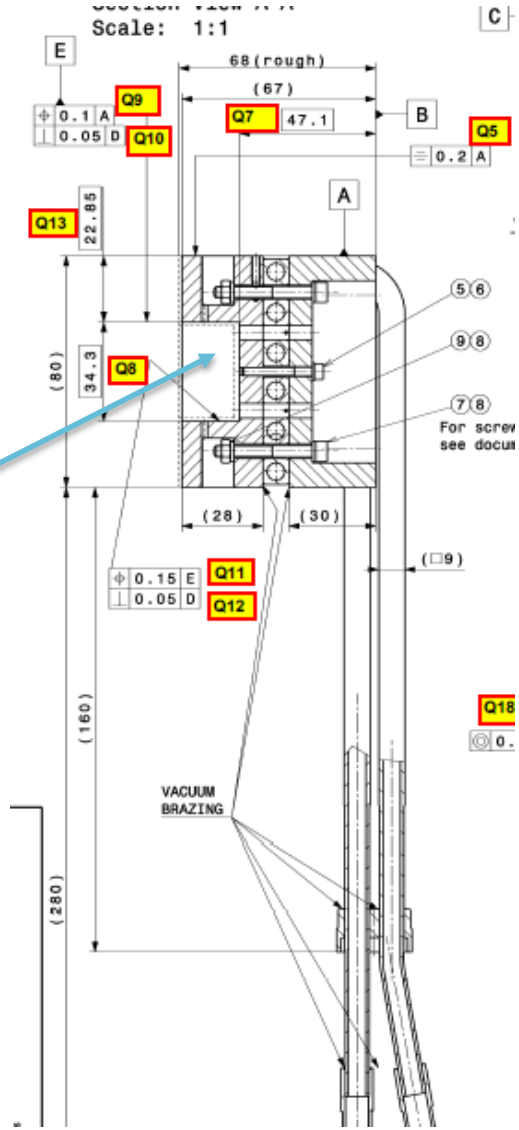
CfC Absorbing block

1000mm length



Competences and Technologies involved in the manufacturing of a LHC collimator

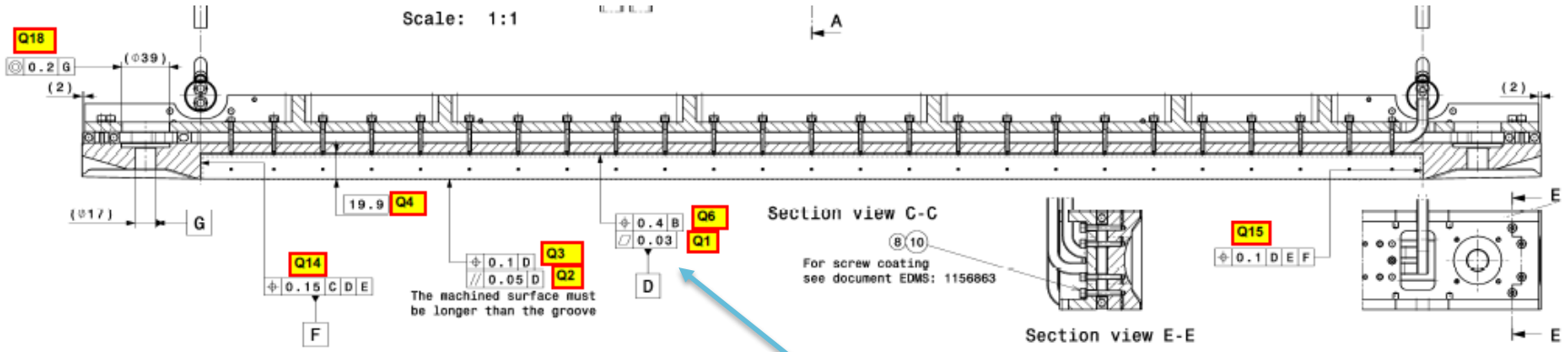
- **High Precision Dry Machining**



TCTP jaw housing to be machined after vacuum brazing

Competences and Technologies involved in the manufacturing of a LHC collimator

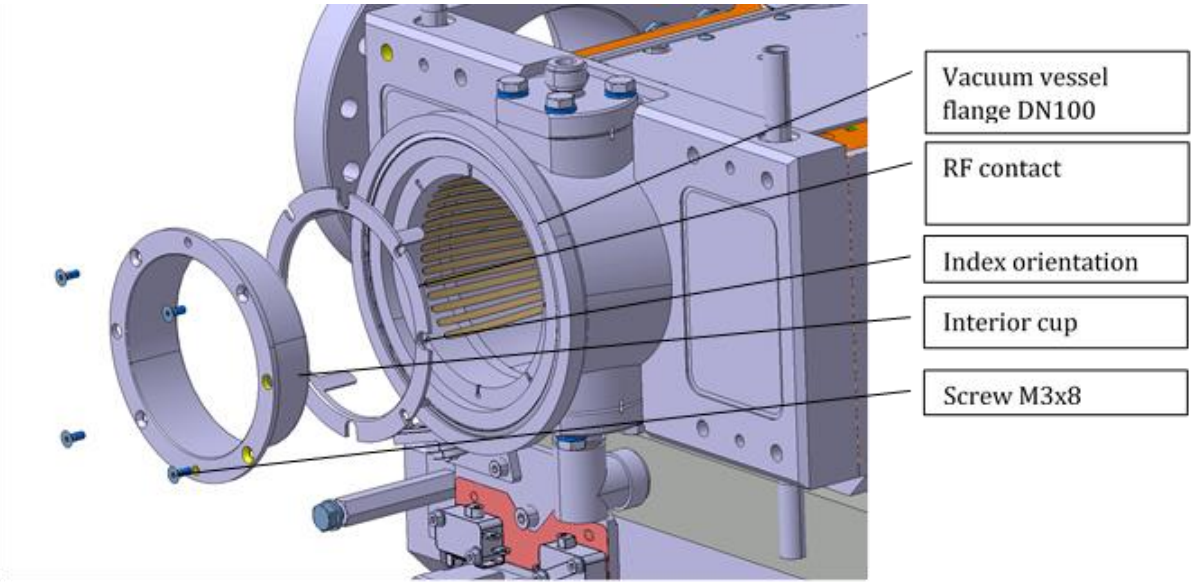
- **High Precision Dry Machining**



TCTP jaw to be machined after vacuum brazing

Competences and Technologies involved in the manufacturing of a LHC collimator

- **Surface Treatments**
  - Electroplating, Ag plating, NiRh plating, Ni plating, Cu plating.
  - Chemical edging/pickling.
  - Passivation.
  - Thermal Treatments.

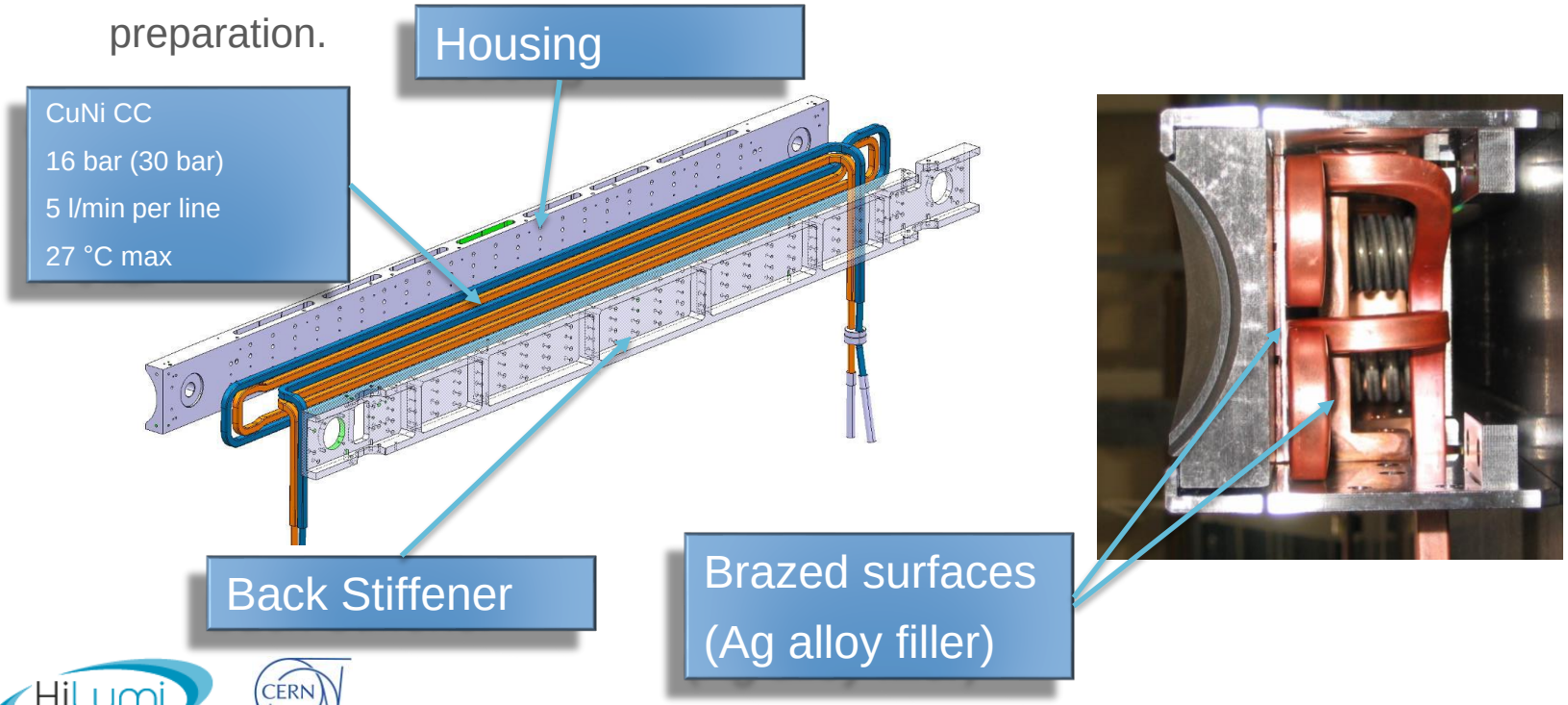


Competences and Technologies involved in the manufacturing of a LHC collimator

- **UHV Cleaning**
- **Several materials:**
  - St. Steel 304L, 316L, 316LN, Copper based alloys (CuNi, Glidcop, CuBe), Tungsten based alloys
- **Cleaning procedure according to material of the piece and its posterior use:**
  - **Solvent based cleaning procedure**
  - **Water based cleaning procedure (alkaline detergent solution)**
  - **Circulation during X time at X T**
  - **Ultrasonic Agitation to X W/l - X kHz for X minutes**
  - **Rinsing (demineralize water/ethanol)**
  - **Clean compressed N2 jet**
  - **Drying**
  - **Thermal Treatment**
  - **Packing in white Kraft paper and inside a polyethylene fil bag closed by thermal welding and under vacuum**

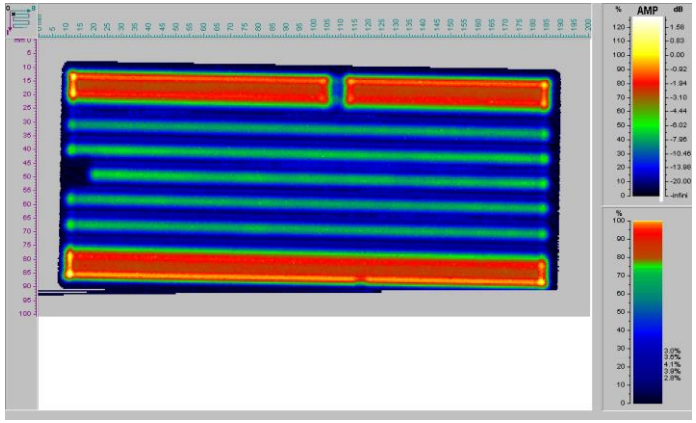
Competences and Technologies involved in the manufacturing of a LHC collimator

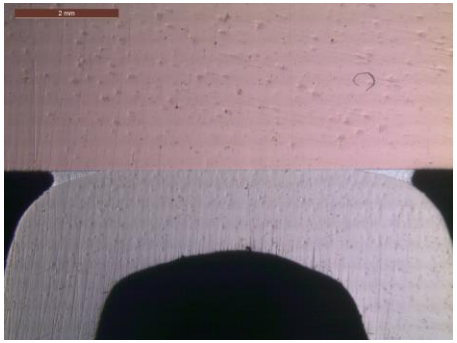
- **Vacuum Brazing**
- Critical step to assure thermal contact.
- On Copper based materials (Glidcop and CuNi) and stainless steel including its preparation.



Competences and Technologies involved in the manufacturing of a LHC collimator

- **Vacuum Brazing**
- Maximum admitted flatness on the two lateral surfaces of the pipes must not exceed 0.05 mm under a uniform load of 800 N.
- US, Metallography, TCC test bench

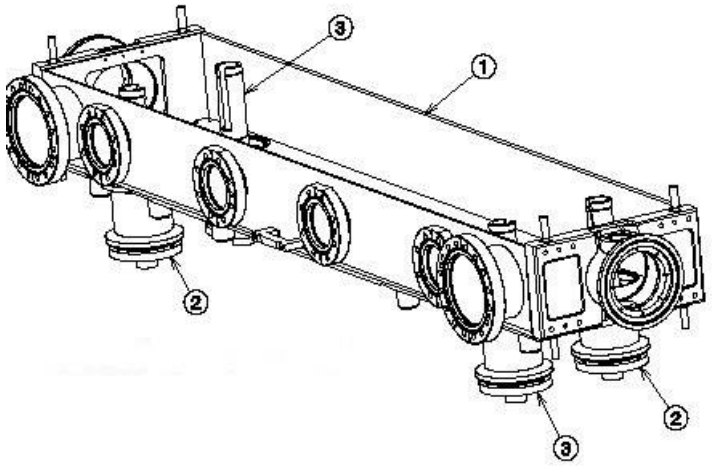


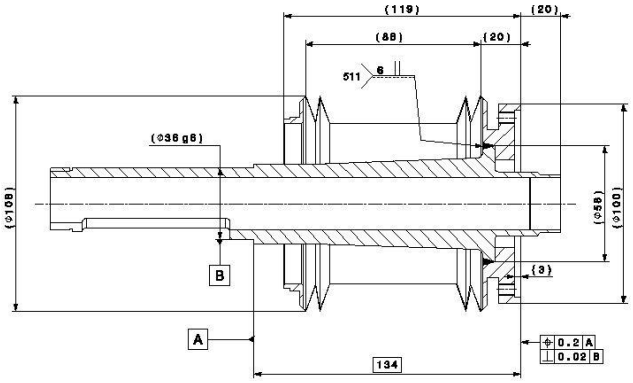


TCC ~9000 W/(m2K)

Competences and Technologies involved in the manufacturing of a LHC collimator

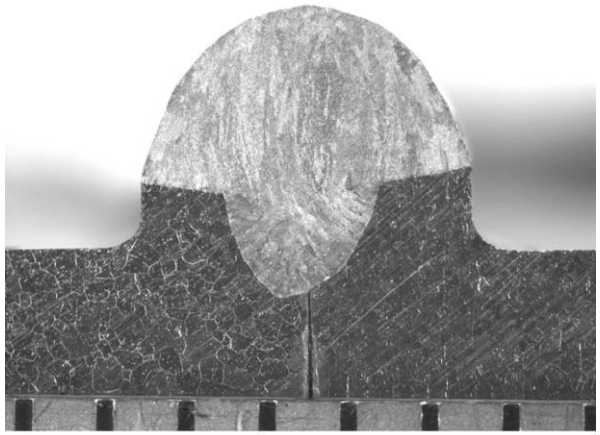
- **EBW and TIG welding**
- High quality welded joins are essential for maintaining the vacuum of the collimator.
- EBW for the main parts of the vacuum vessel (weld on parallel lips, circular butt weld, transparency weld).
- TIG welding for the other parts that cannot be accessed by EBW



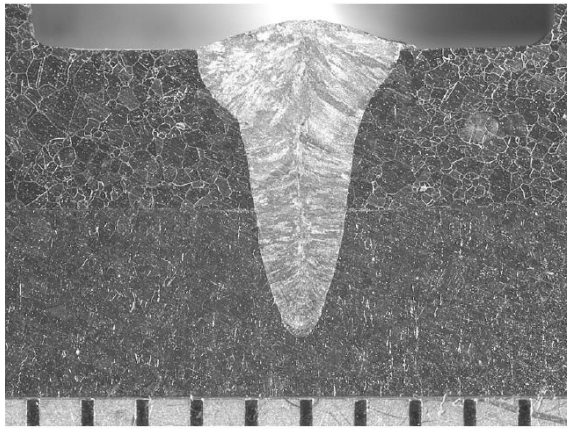


Competences and Technologies involved in the manufacturing of a LHC collimator

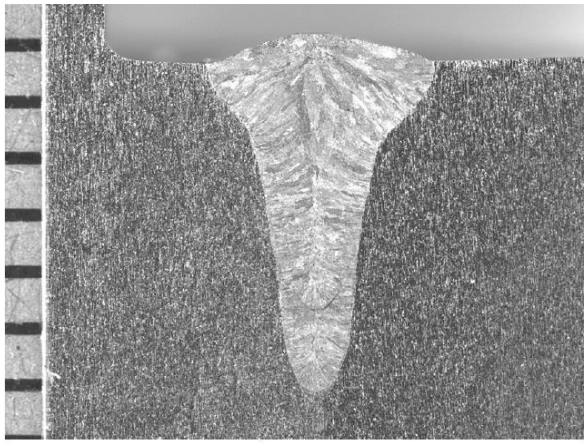
- **EBW and TIG welding**
- Welds must be 100% penetration and not ground finish
- A leak rate less than 5x10-10 mbar.l.s-1 is acceptable



Internal identification 30109 A2	Customer identification Type n° 1 - Joint n° 1
Magnification 19X	Etching Oxalic acid el.
Penetration measured 3,5mm (minimum required 3,0mm)	



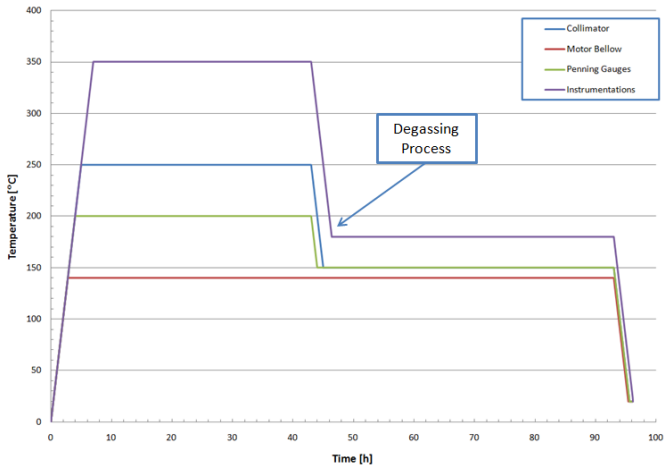
Internal identification 30109 A3	Customer identification Type n° 1 - Joint n° 2
Magnification 14X	Etching Oxalic acid el.
Penetration after plates interface measured 2,3mm (minimum required 2,0mm). Width of the weak at the plates interface measured 1,7mm (minimum required 1,0mm)	

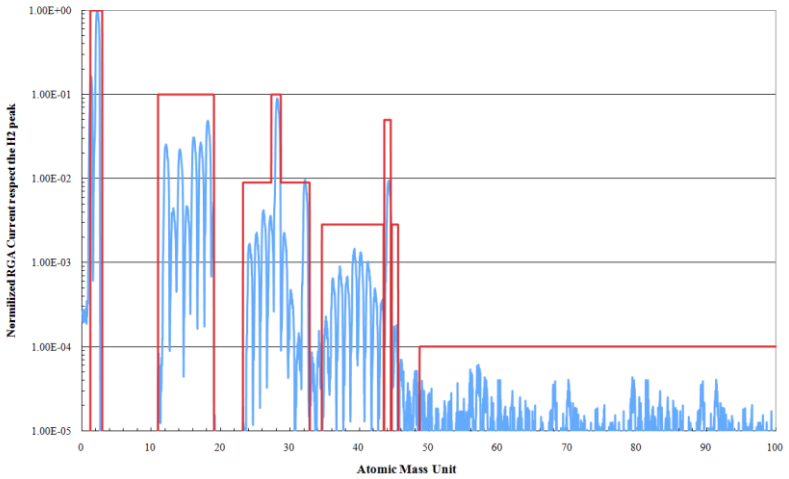


Internal identification 30109 B2	Customer identification Type n° 2 - Joint n° 3
Magnification 14X	Etching Oxalic acid el.
Penetration measured 5,9mm (minimum required 5,0mm)	

Competences and Technologies involved in the manufacturing of a LHC collimator

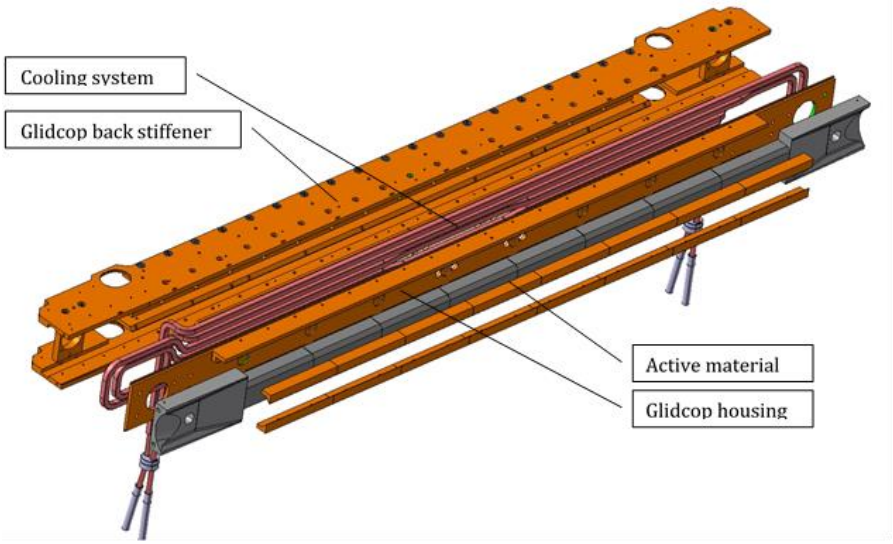
- **UHV leak testing and outgassing**
- The vacuum pumping is performed by a 40 l/s turbo molecular pump
- Static pressure of 5x10-7 Pa (~5.0x10-9 mbar),
- The sensitivity of the leak detection should be lower than 5x10-10 mbar l/s
- Bake-out cycle
- The acceptance test for the collimator is an outgassing rate value less than ≤2x10-7 [mbar l/s] after bake-out
- Final RGA scan

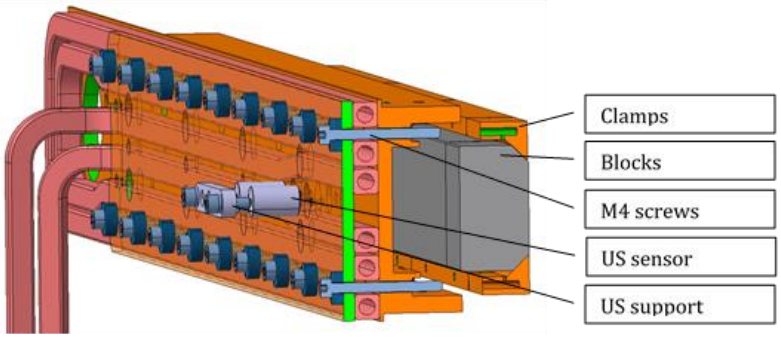


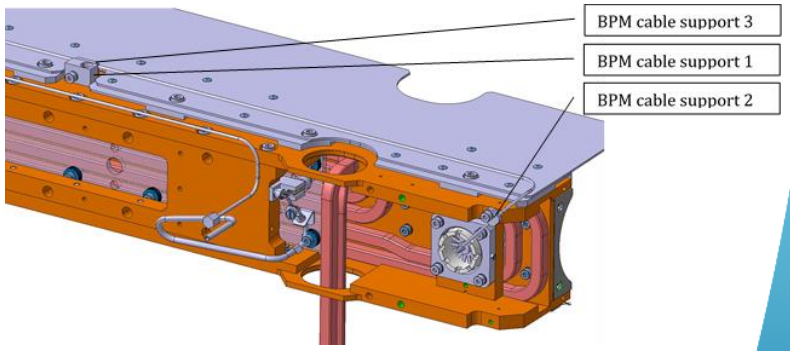


Competences and Technologies involved in the manufacturing of a LHC collimator

- **Assembly of UHV components in precise mechanisms**
- **Clean Room is a must**

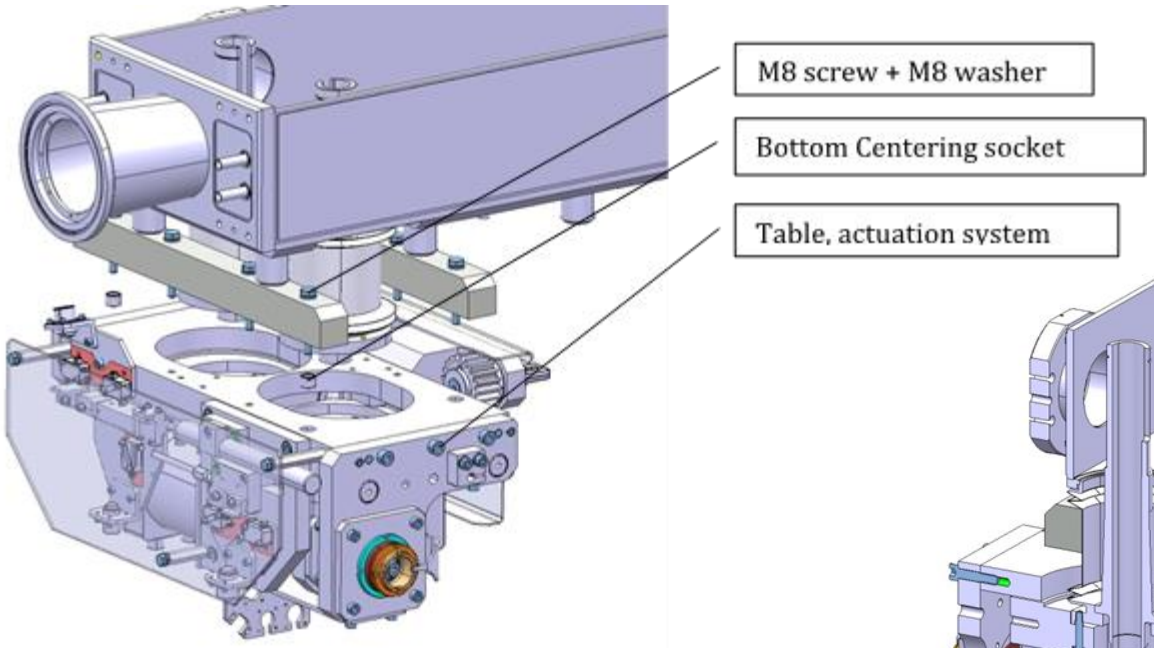


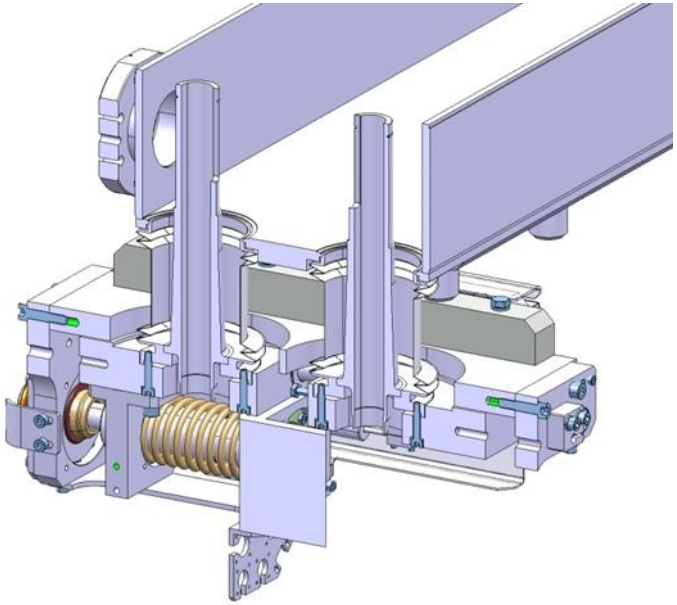




Competences and Technologies involved in the manufacturing of a LHC collimator

- **Assembly of UHV components in precise mechanisms**





Competences and Technologies involved in the manufacturing of a LHC collimator

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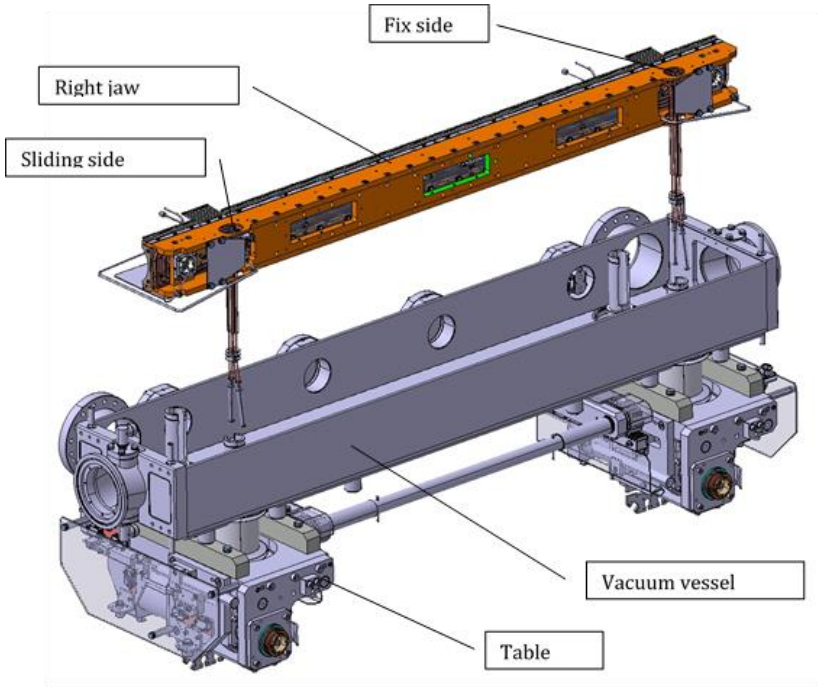
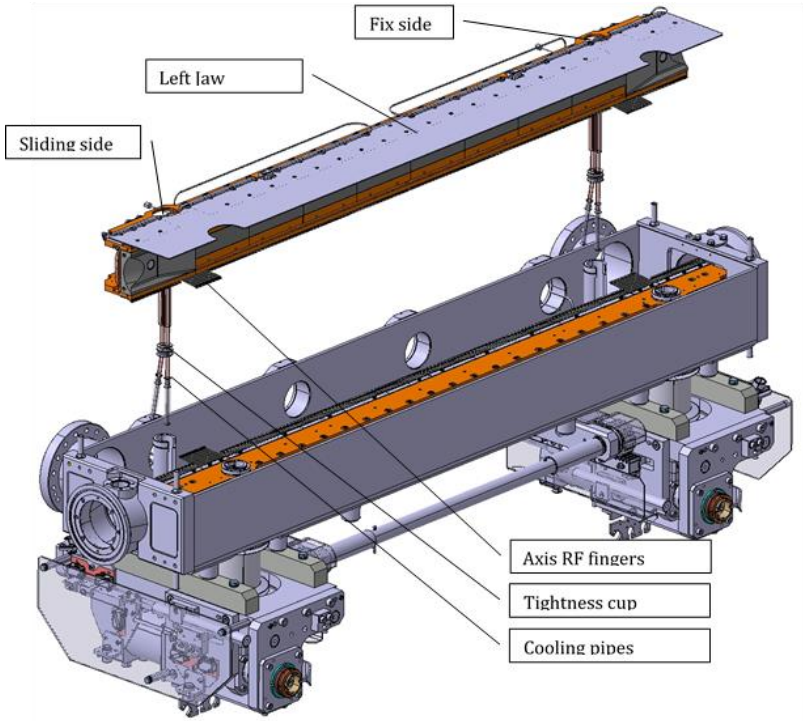
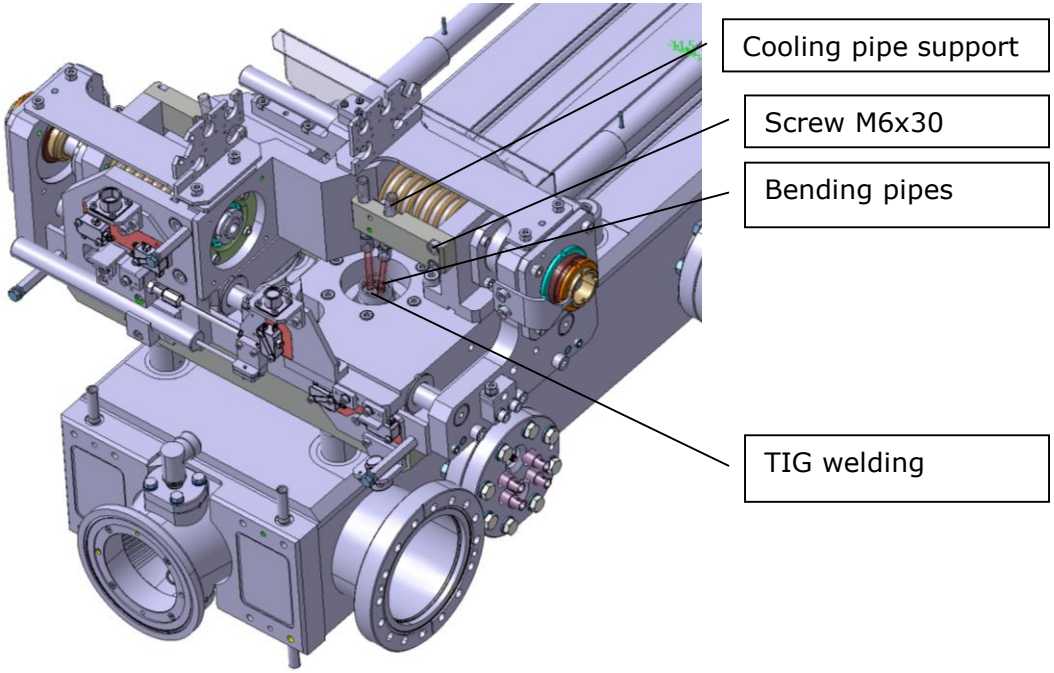




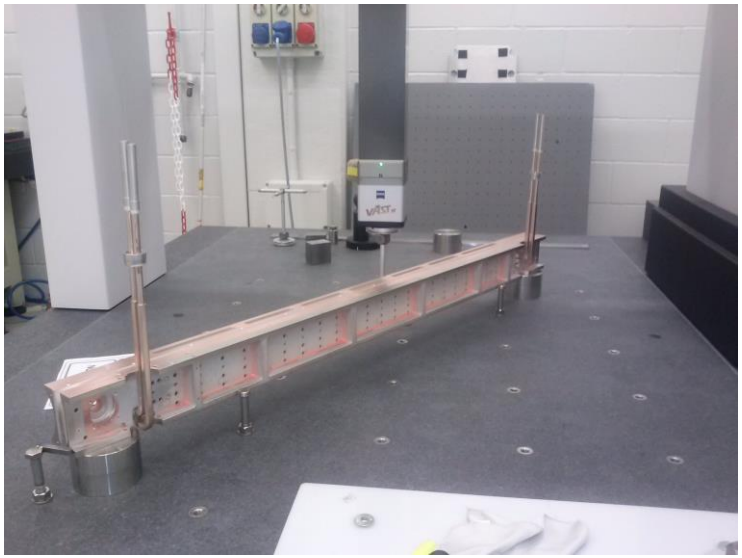
Competences and Technologies involved in the manufacturing of a LHC collimator

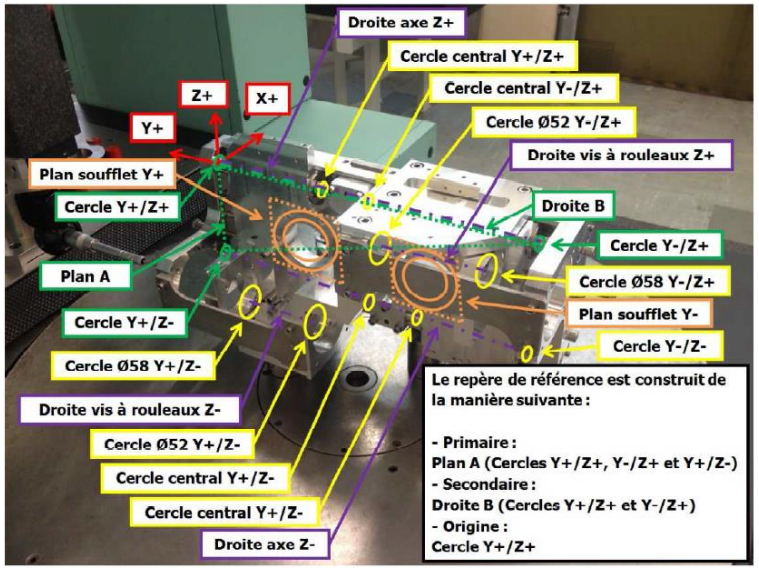
- **Assembly of UHV components in precise mechanisms**



Competences and Technologies involved in the manufacturing of a LHC collimator

- **3D metrology and assembly adjustments**
- A metrology workshop stabilised at ± 1°C is needed, with dimensions suited to verify the collimators geometry, and with equipment able to provide 3D measurement with an accuracy better than ± 5 µm over 1500 mm minimum.





Concluding remarks

- Given the very high stored energy of the HL-LHC, collimation is one of the most critical systems of the accelerator.
- A complex system made of ~120 units is presently installed and fully operational.
- To meet HL-LHC tougher requirements, a significant fraction of the current system is expected to be replaced/updated/complemented.
- Intensive R&D is currently ongoing to develop novel materials particularly for low-impedance collimators.
- Turn-key units will be procured in the industry. Over 100 collimators will need industrial production.
- Motorization, electronics, diagnostics and control systems (not covered here) represent a procurement effort as important as mechanics.

Thank you for your attention