

HL-LHC Crab Cavities: DQW HOM couplers & FPC challenges

Simon Barrière, Eric Montesinos – CERN
on behalf of the WP4 manufacturing team



Outline

- A status update on **ongoing productions** and some **fabrication highlights** for:
 - DQW High-Order Modes Couplers;
 - RFD & DQW Fundamental Power Couplers;

with particular focus on:

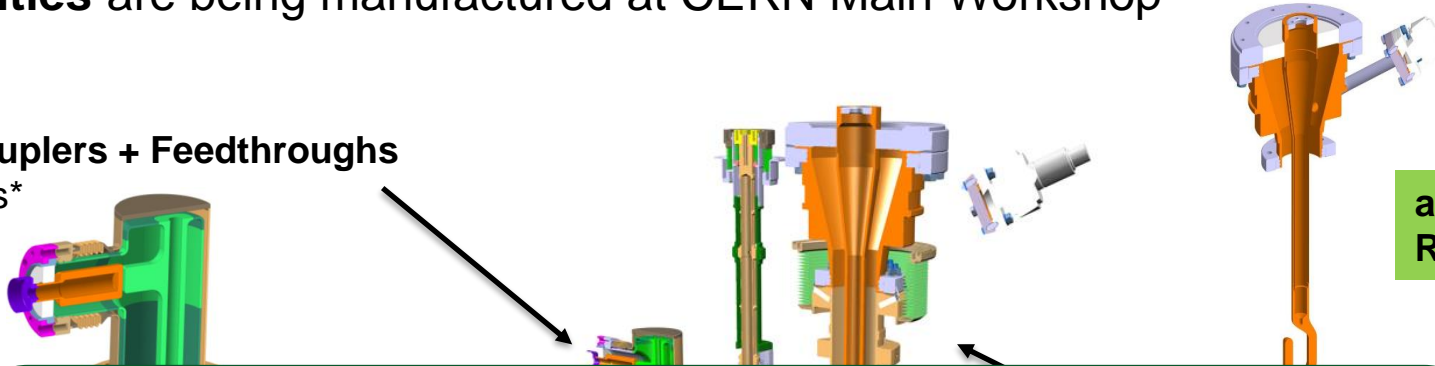
- Scope of Production
- Status & Planning
- Manufacturing Challenges & Highlights

Many interactions between HL-WP4 teams

Production Scope

- HOM Couplers, Feedthrough & Field Antennas for **all LHC-series* DQW crab cavities** are being manufactured at CERN Main Workshop

HOM Couplers + Feedthroughs
x 34 units*

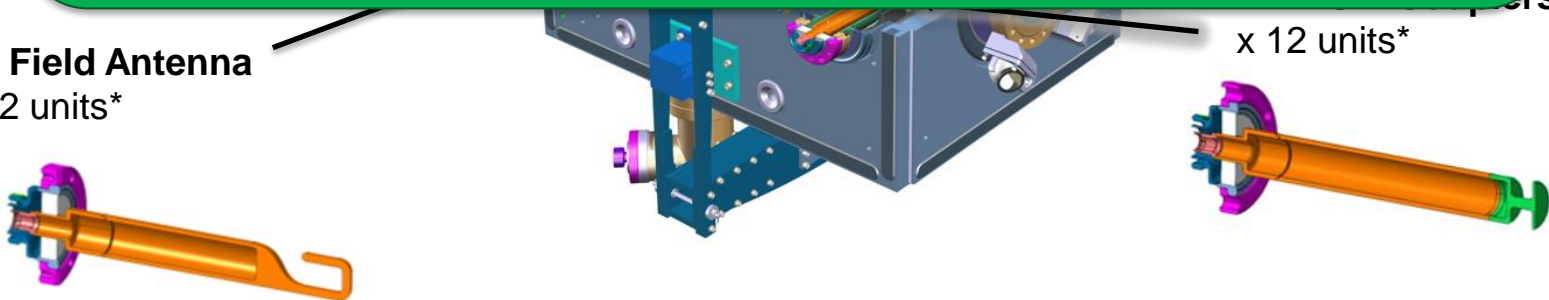


also for
RFD series

Production kicked-off in Q4-2021:

- Definition of project team, mandates & milestones
- Launch of raw materials procurement
- Preparation & approval of MIPs

RF Field Antenna
x 12 units*



x 12 units*

*quantities for 8 cavities including spares

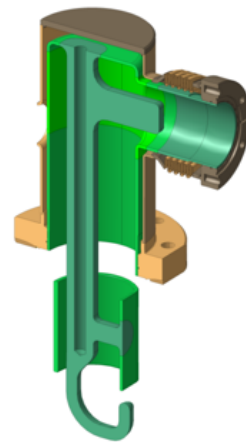
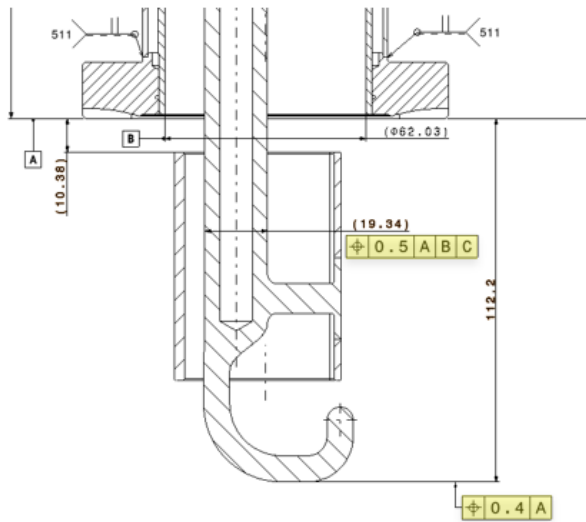
Why are these Objects a Manufacturing Challenge?

Specific (and expensive!) materials

- Extra-pure niobium, OFE copper, titanium grade 23 (TA6V ELI), stainless steel 316LN

(S)RF performance highly dependent on geometry and surface quality

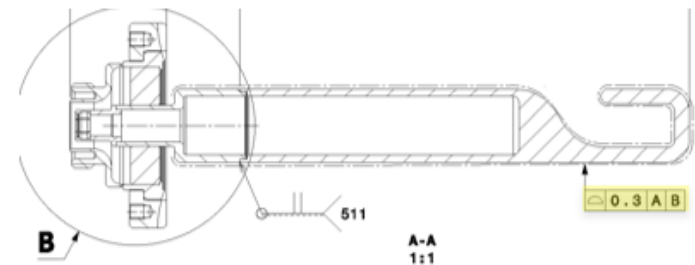
- Final tolerances in **few tens of millimetres** after many assembly (welding!) steps
- Machined and welded RF surfaces = specific parameters



DQW HOM Coupler



DQW RF Antenna

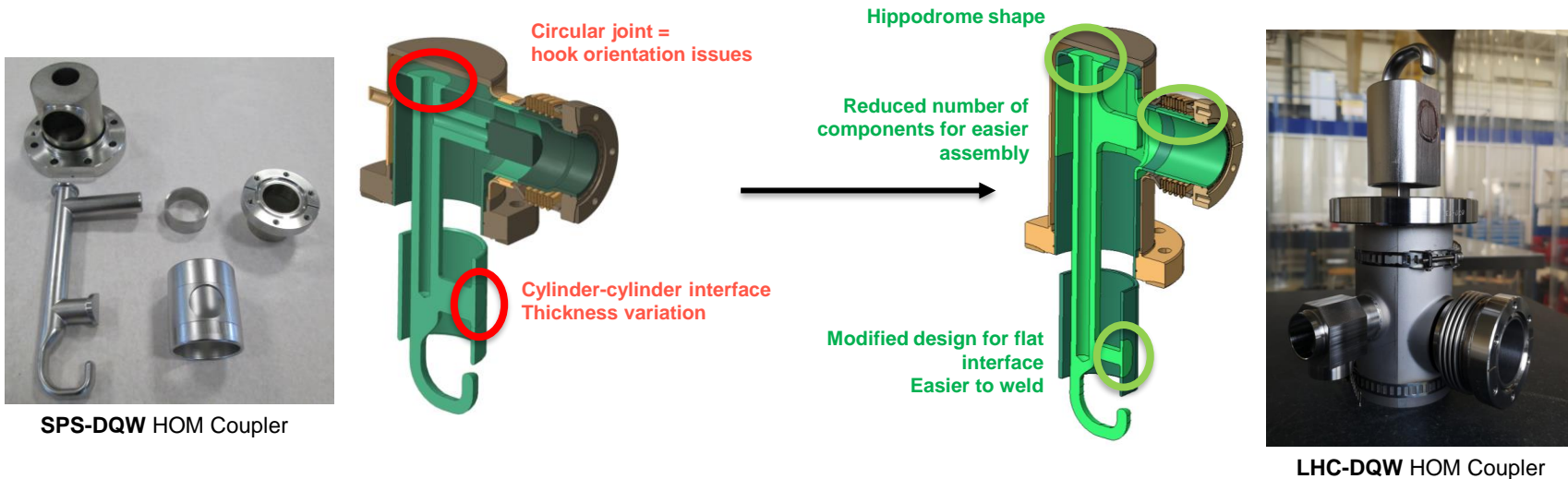


Multi-Technology components with pressure joints

- ~13 technologies involved and intertwined
- Multiple activities and actors in parallel in different groups
- Advanced follow-up to fulfil HL-LHC quality standards (*PED-related normative, MTF steps, traceability*)

From Prototypes to Series Production

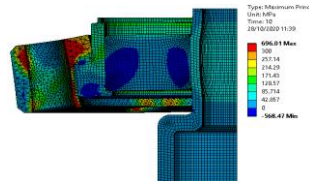
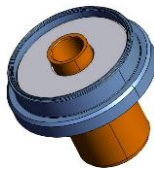
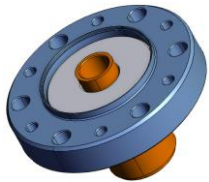
- DQW series production built according to consolidated design thanks to prototyping at CERN: **DQW SPS** (2015 – 2016) & **RFD SPS** (2019 – 2020)
- Key updates:
 - Easier welding configurations to ease assembly and improve precision



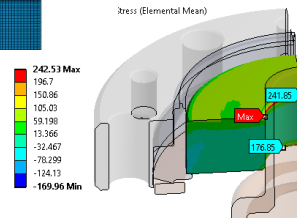
- Brazed feedthrough design: stress reduction on ceramics

Fixed flange
(more titanium = higher strains)

Rotative flange



Stress analysis



Production Status



Manufacturing and Inspection Plans

- Strong commitment from WP4 teams to fulfil HL-LHC quality standards

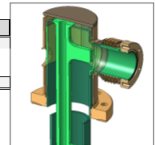
Engineering Department MME Mechanical & Materials Engineering

Title: HL-LHC WP4 crab cavities: DQW LHC HOM Couplers
Crab Series LHC HOM Couplers

Plans: LHCACFHC0428
Operation:

S/PH	PLAN	DESIGNATION DES PHASES
		DOCUMENTS DE REFERENCES Certificats matiere suivant EDM5 serie Procédure brasure TL-Chématique-Cu suivant EDM5 serie Vérifying Book sur EDM5 serie
		MATERIEL

Nickium Sheets DAI 79M799
Nickium Thick Products DAI 79M605
St. Steel Sheets MAG 8788205
St. Steel Flanges MAG 8786205



Numero JOB: J3058940
Title: HL-LHC WP4 crab cavities: Pre-Series LHC DQW HF-HOM Coupler
CRAB LHC_DQW HF-HOM Coupler

S/PH	PLAN	DESIGNATION DES PHASES
		DOCUMENTS DE REFERENCES Procédure BCP sur EDM5 serie Procédure brasure TL-Chématique-Cu suivant EDM5 serie Matériaux BCP sur EDM5 serie
		MATERIEL Coûture Bred Coûture OFE #39 Roue #75 Bricolage pour montage UHF TMS
		OUTILLAGES

LHCACFHC0320
LHCACFHC0204
LHCACFHC0214
LHCACFHC0243
LHCACFHC0243/H0204
LHCACFHC0328
LHCACFHC0315
LHCACFHC0217
LHCACFHC0219/H0217
LHCACFHC0319
LHCACFHC0215
LHCACFHC0219/H0215
LHCACFHC0319
LHCACFHC0312
LHCACFHC0321
LHCACFHC0319/0321
LHCACFHC0322
LHCACFHC0322

From detailed manufacturing sequences...

Equipment Identifier: HCACFHC003-CR000003
Other Identifier: None
Description: DQW HOM Coupler Series

Main Made of Equipment data Manufacturing Operation Non-conformities Documents History Map

Actions: Add extra step

Workflow Diagram
No workflow diagram is defined for this equipment

Workflow Steps	Step#	R/E	Other name	Description	Status	Last Repeated	INC
1	1			Traceability of materials	Pending		
5	5			Metrology of the Hook after machining and cleaning (*)	Done	Ok	
10	10			Metrology of the Nb Collar	Pending		
15	15			NDTs EB W40 Hook Collar (VT) (**)	Done	Ok	
20	20			Metrology after W40 (*)	Done	Ok	
25	25			Metrology Tee section after machining and cleaning (*)	Done	Ok	
30	30			NDTs EB W20 (VT, RT) (**)	Done	Ok	
35	35			NDTs EB W60 (VT, RT) (**)	Done	Ok	
40	40			NDTs EB W50 (VT, RT) (**)	Done	Ok	
45	45			Final Metrology Full Assembly after machining and cleaning (*)	Done	Ok	
50	50			Preparation for Brazing	Done	Ok	
55	55			NDTs B10/B20 (VT, UT) (**)	Done	Ok	
60	60			Leak Check brazed assembly (*)	Done	Ok	
65	65			Dimensional Control	Done	Ok	
70	70			NDTs EB W112 Outer Section (VT) (**)	Done	Ok	
75	75			Metrology Capot	Cancelled	Cancelled	
80	80			Preparation for final assembly	Done	Ok	
85	85			NDTs EB W70 (VT, RT) (**)	Done	Ok	
90	90			NDTs EB W80 (VT) (*)	Done	Ok	
95	95			NDTs EB W110 (VT) (*)	Done	Ok	
100	100			NDTs EBW120 (VT, RT) (*)	In Progress	Ok	
105	105			NDTs EB W130 Full Assembly (VT) (**)	Pending		
110	110			Leak Check Full Assembly (*)	Done	Ok	

More than 120 assets to be managed in MTF!

HL-LHC: Quality Manufacturing and Inspection Plan

EDMS NO. 2726491 REV. 1.0 VALIDITY VALID
REFERENCE: LHC-ACFHC-FP-0001

Project: HL-LHC
Supplier: CERN (EN-MME-MA, EN-MME-FW & EN-MME-MM)
Item Eq. Code: ACFHC (HOM)
Asset Code (LHC Part Identifier): HCACFHC003-CR000003-36

Work Package: WP4 - Crab Cavities & RF
Client: CERN (EN-MME-EDM)
Item description: DQW HOM Coupler Series
EDMS Report No:

No	ACTIVITY / OPERATION	APPL. STANDARDS / NORMES APPL.	REV. DOC.	INSPECTION / CONTRÔLE				REV. DOC.	NOTES / COMMENTAIRES
				SUPPLIER / CONTRÔLE	CLIENT / VÉRIFICATION	3 rd PARTY / SURVEILLANCE	INSPECTION REPORT / RAPPORT D'INSPECTION		
0	Preparation of materials. Traceability	Material certificate EN 10204 3.1	Traceability Sheet	H/R					Material Certificates
1	MANUFACTURING Hook		Drawings N° LHCACFHC0425						
1.1	Machining (Milling) Rough and finishing		Drawing N° LHCACFHC0447	H					
1.2	Cleaning and BCP (2: 90 microns + 30 microns)		Drawings N° LHCACFHC0447 BCP Procedure EDM5 1825148	H					

...To MIPs and MTF assets

- HCACFDC003-CR000009 - DQW Dressed Cavities
- HCACFHT006-CR000001 - DQW He Tank Series
- HCACFHC224-CR000002 - DQW HF-HOM Coupler Series
- HCACFHC003-CR000003 - DQW HOM Coupler Series**
- HCACFHC227-CR000004 - DQW HOM Feedthrough Series
- HCACFHC003-CR000005 - DQW HOM Coupler Series
- HCACFHC003-CR000006 - DQW HOM Coupler Series
- HCACFHC227-CR000002 - DQW HOM Feedthrough Series
- HCACFPU003-CR000002 - DQW Pick-up Field Antenna Series



Raw Material Procurement

- **316LN stainless steel, OFE copper**

CERN “standard” materials, no shortages expected as of today (procurement anticipated)

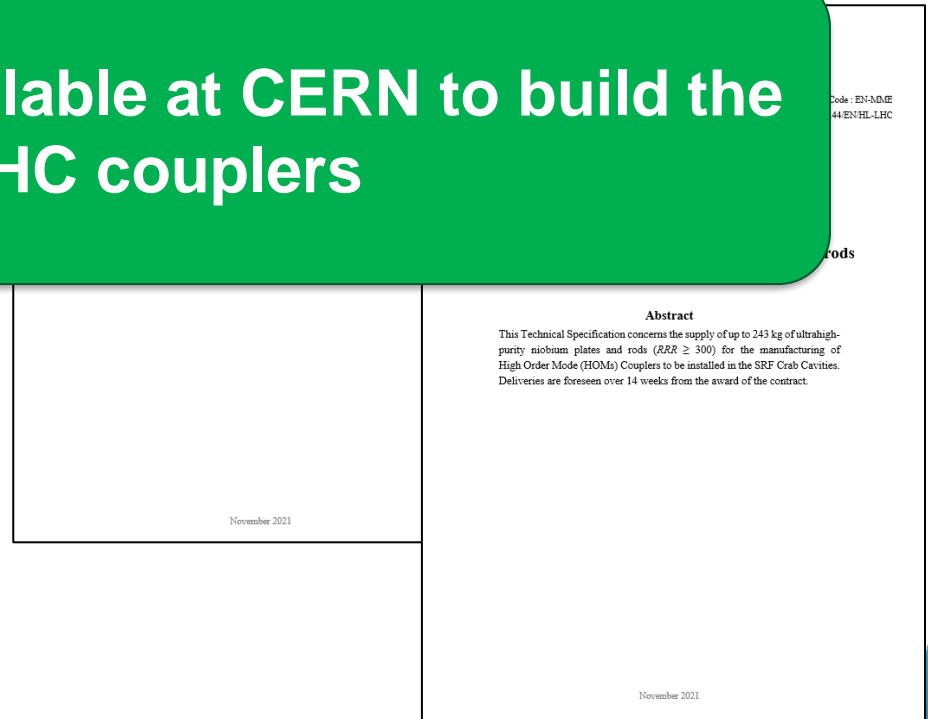
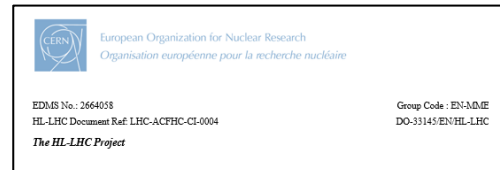
- **Titanium Grade 23**

Remaining quantities of titanium for
remain

**All raw materials available at CERN to build the
DQW LHC couplers**

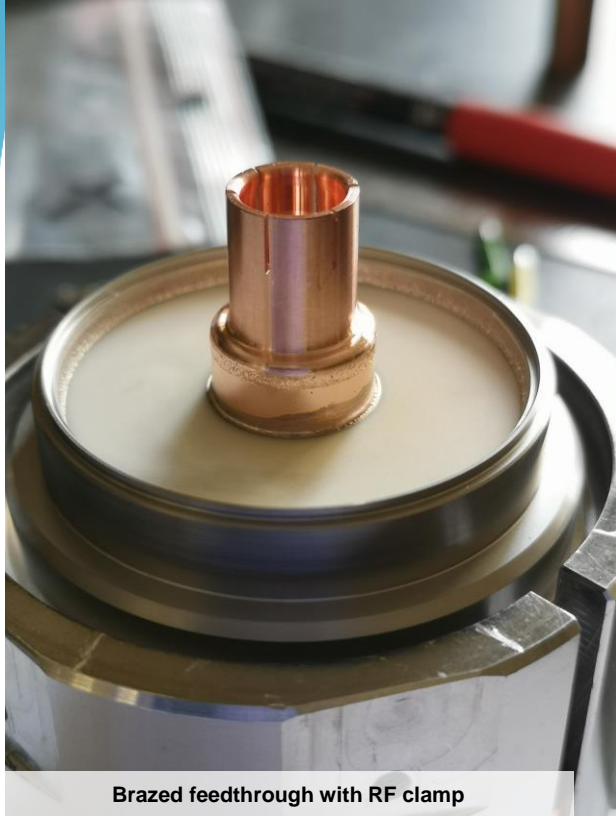
- **RRR**

320 kg of ordered in 2021 (rods,
plates, sheets)



RF Field Antennas Status

- Bulk-machined OFE copper hook welded to a “standard” 25Ω RF brazed feedthrough



Brazed feedthrough with RF clamp



EB weld tooling for last weld



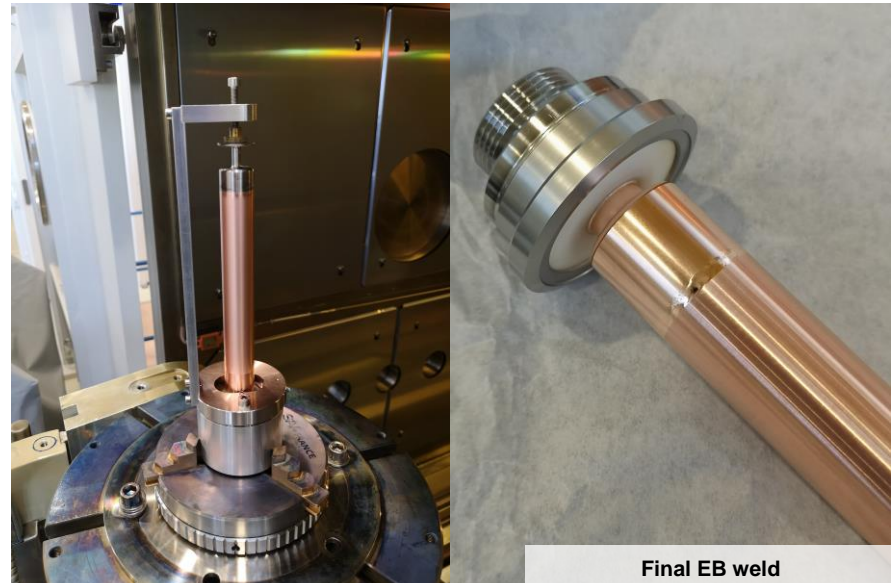
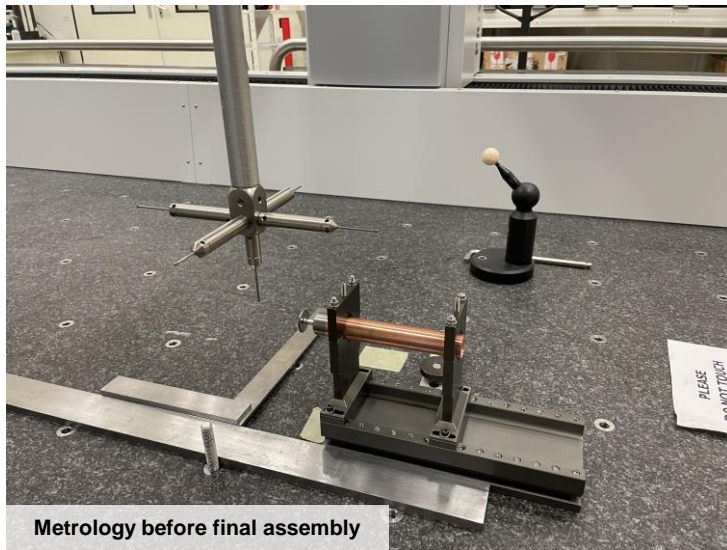
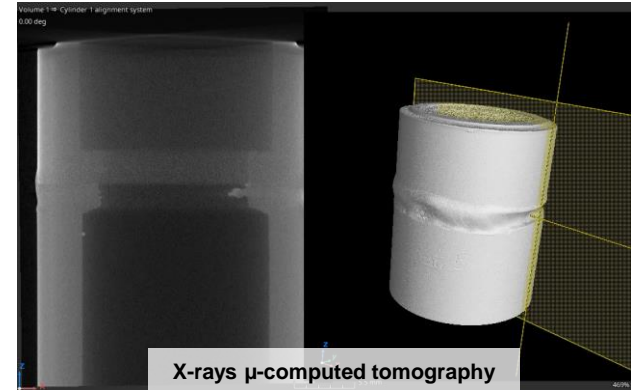
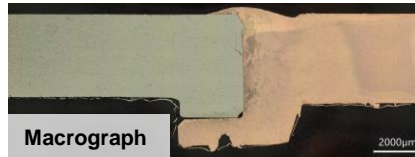
Final assembly

2022												2023												2024											
06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12					
◆ 3x Field Antenna						◆ 5x Field Antenna						◆ 4x Field Antenna																							

HF-HOM Couplers Status

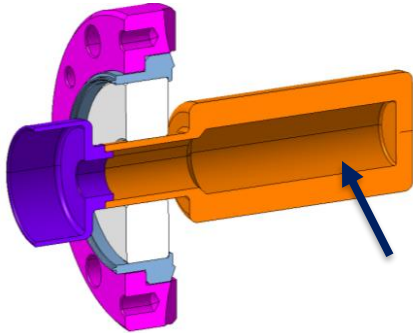
Cu-Nb transitions

- Complex joining of two heterogenous materials
- New process developed at CERN **fully tested and qualified**

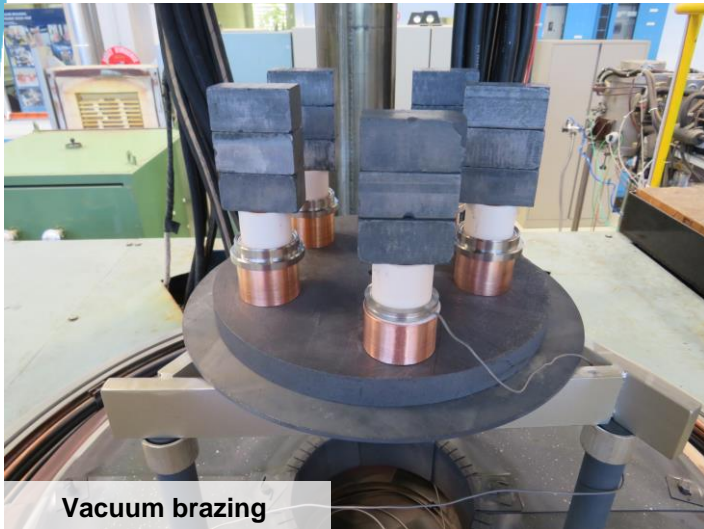


2022												2023												2024											
06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12					
◆ 3x HF-HOM						◆ 5x HF-HOM						◆ 4x HF-HOM																							

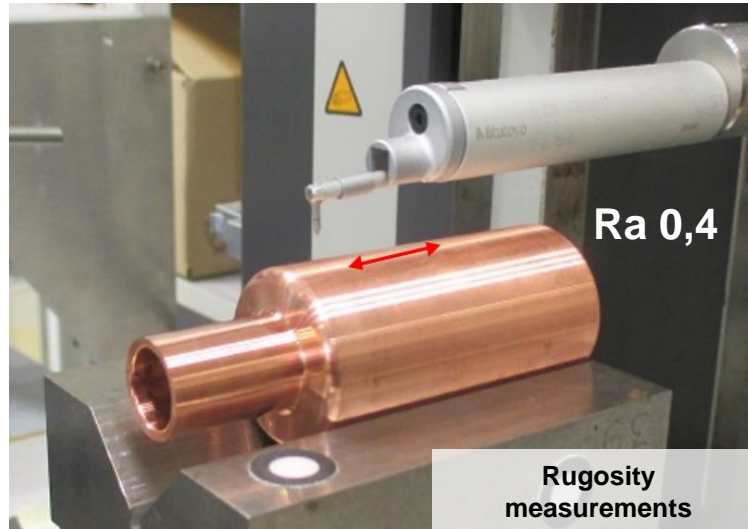
Brazed HOM Feedthrough Status



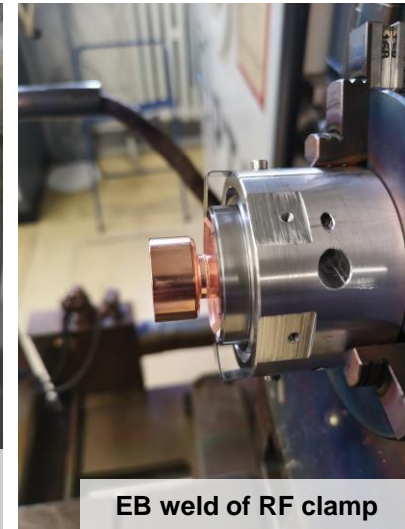
- Machining of inner volume to reduce weight as much as possible
- Improved quality control thanks to μ -computed tomography (quality and dimensions of inner surfaces)



Vacuum brazing



Rugosity measurements

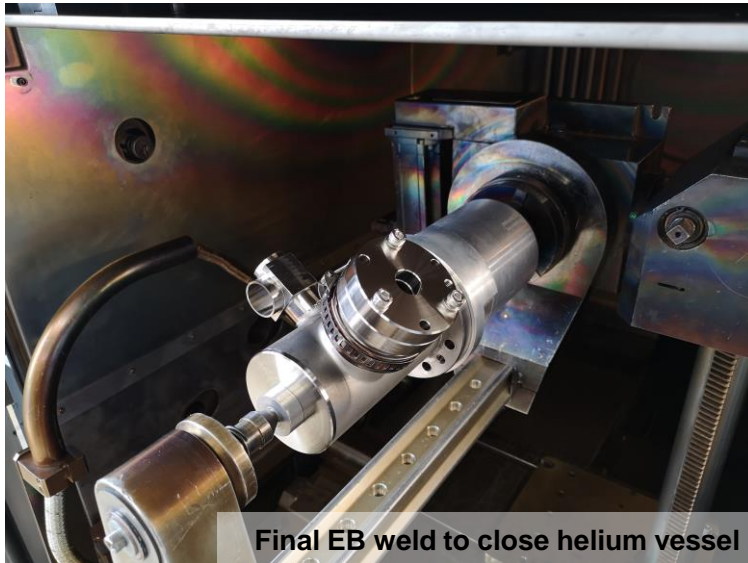
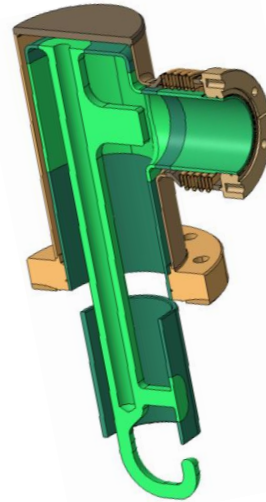


EB weld of RF clamp

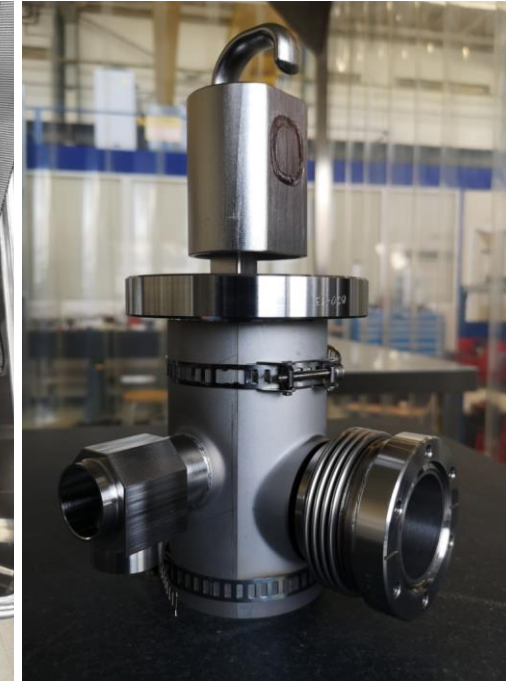
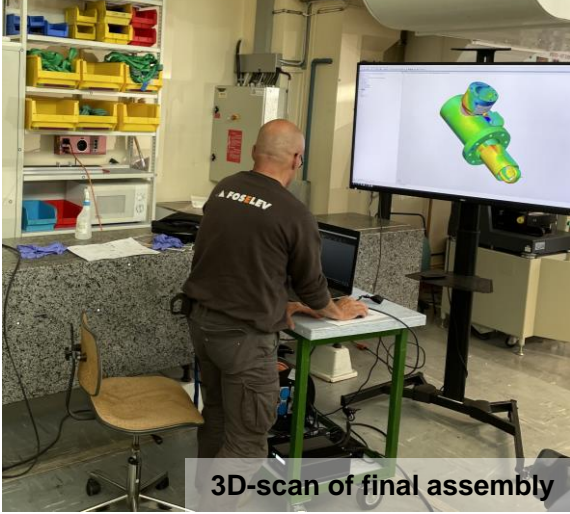
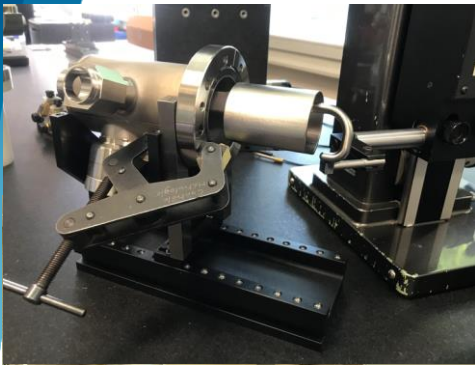
2022												2023												2024																						
06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12																
◆							◆												◆	◆											◆															
8x HOM Feedthrough						6x HOM Feedthrough						8x HOM Feedthrough						14x HOM Feedthrough																												





HOM Couplers

- 160+ fabrication steps to be managed in series production: **intense intertwining of techniques**
- PED requirements impose full qualification of all weld & inspection processes with full traceability down to all subcomponents

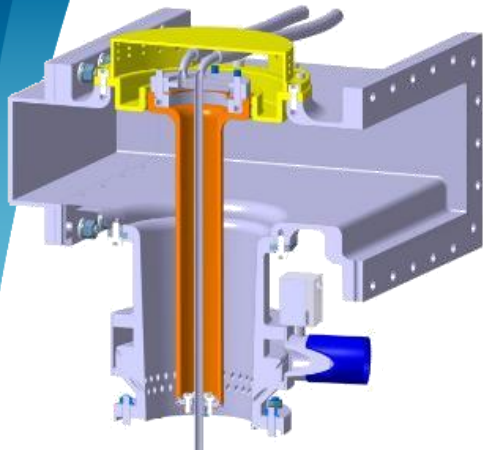


HOM Couplers



2022					2023							2024																		
06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12
 8x HOM Coupler					 8x HOM Coupler							 10x HOM Coupler						 10x HOM Coupler												

FPC Status

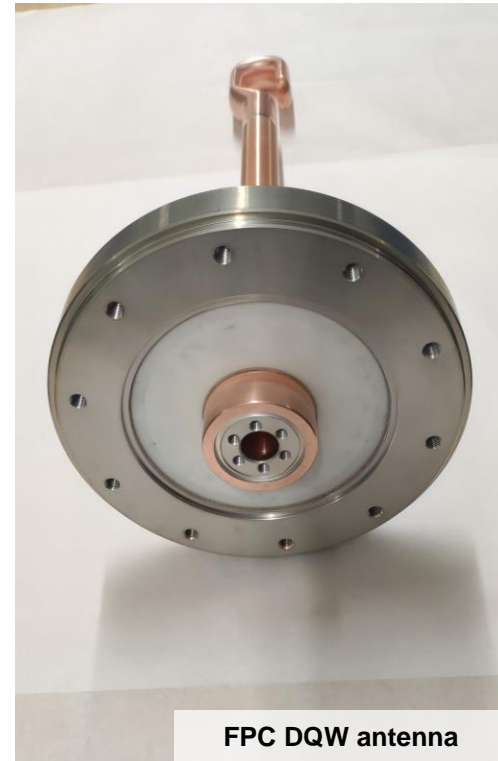


Air side
100% of production complete!

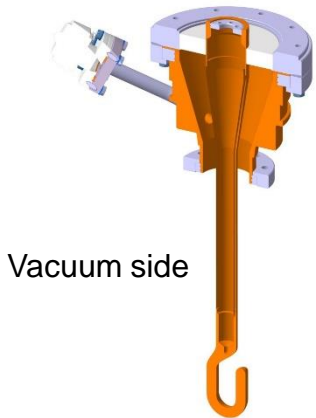
Transport engineering also ongoing!



Vacuum bodies



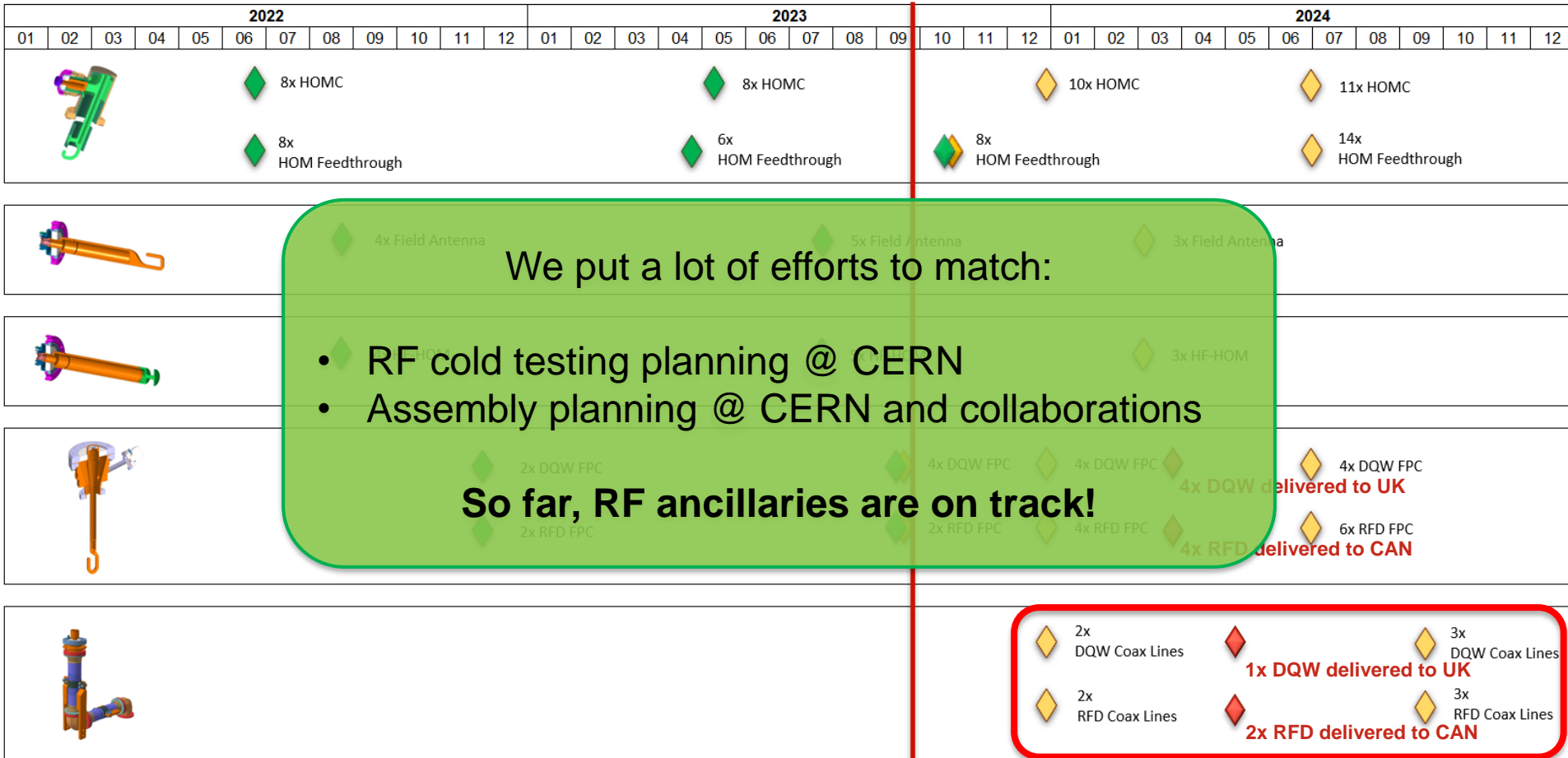
FPC DQW antenna



Vacuum side

2022					2023						2024																																						
06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12																			
					◆								◆	◆					◆												◆																		

Master Planning



We put a lot of efforts to match:

- RF cold testing planning @ CERN
- Assembly planning @ CERN and collaborations

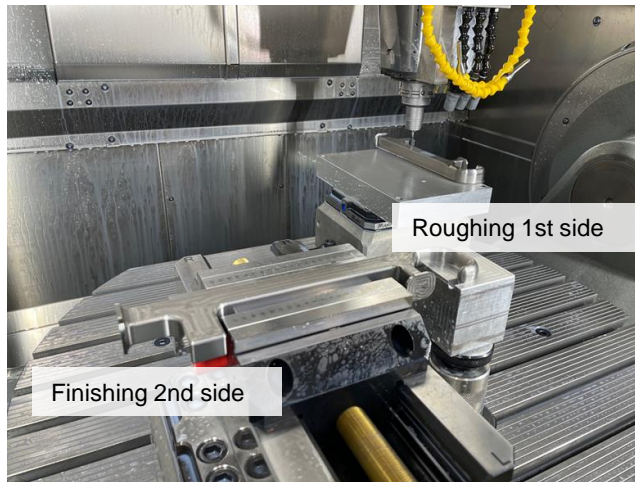
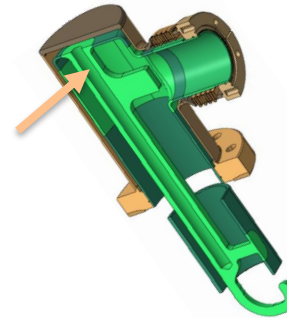
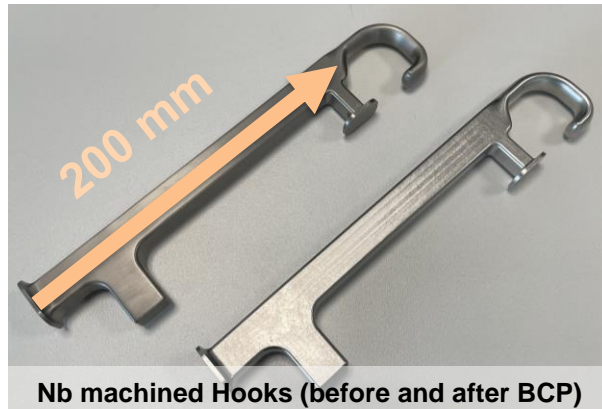
So far, RF ancillaries are on track!

Effort is now on RF Lines for first modules

A Few Technical Highlights

Machining

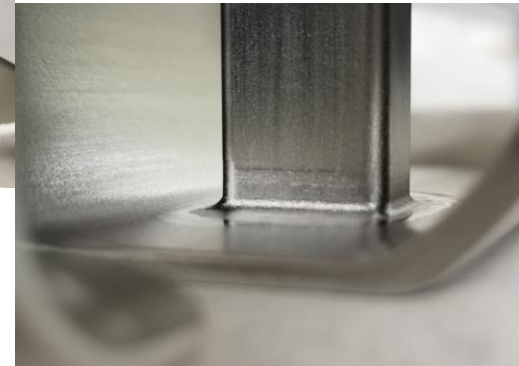
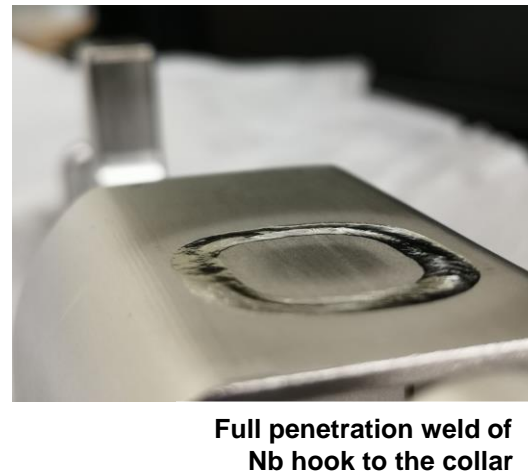
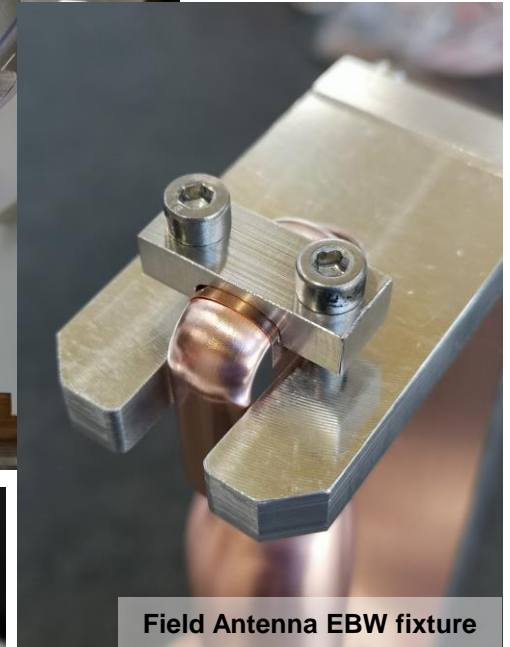
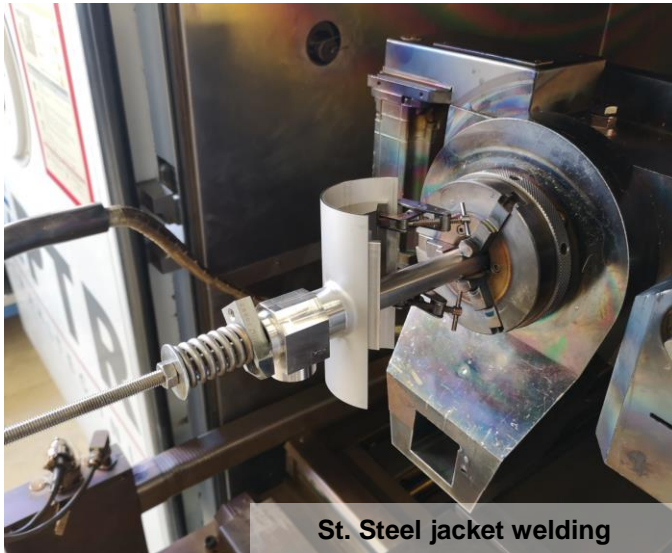
- Recent developments for hook machining & drilling (200 mm depth in Nb!)



- Machining is key to ensure **optimum EB welding morphology** (thickness uniformity, 3D profiles)

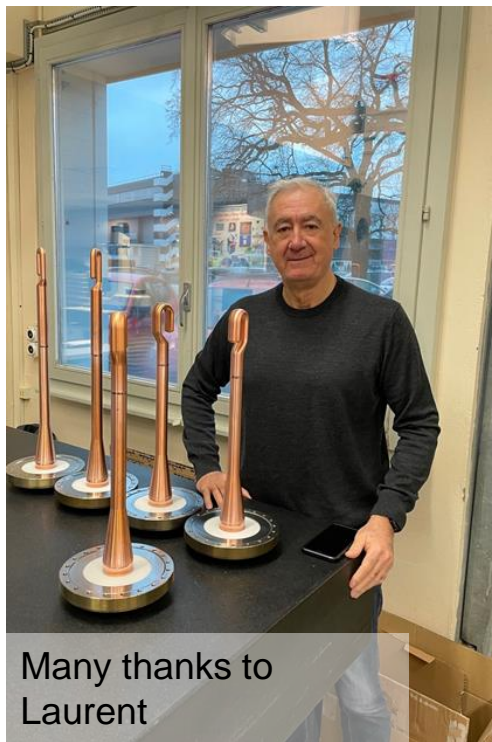
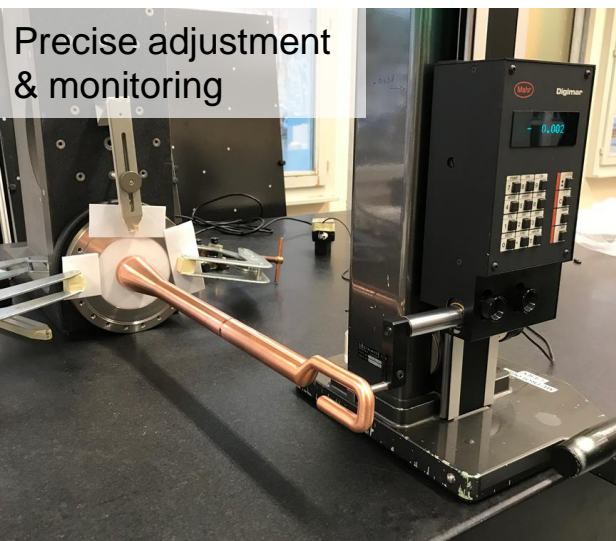
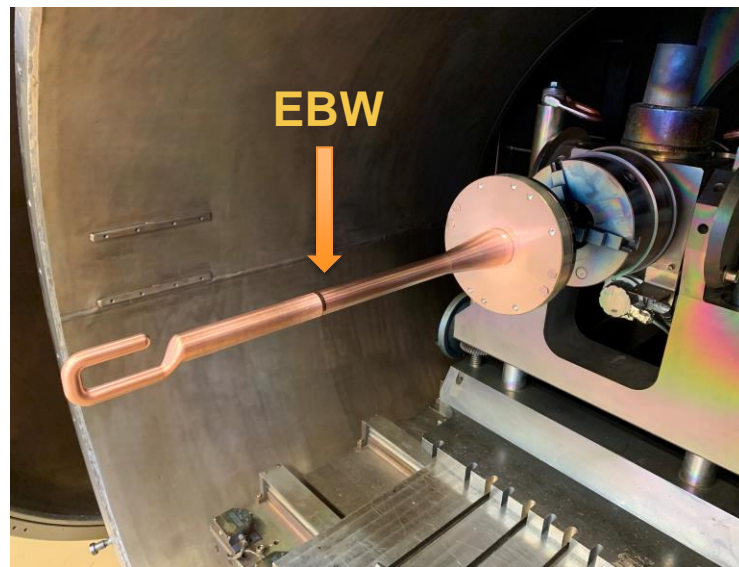
Electron Beam Welding

- Neat processes for series production of SRF ancillaries (tooling, shrinkage management)



Calibration

- Final EB welds on FPC antennas induce deformation leading to hook position out of tolerance ($> 0,5$ mm)
- Manual (delicate!) calibration needed to bring the hooks closer to nominal position

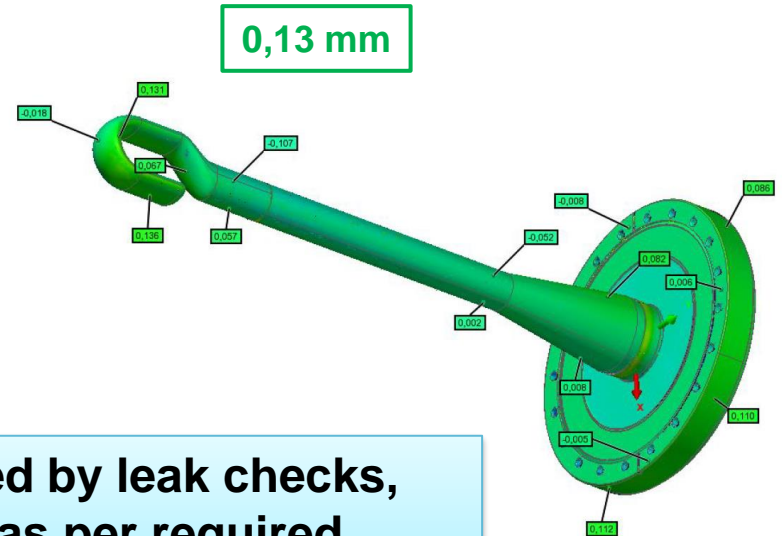
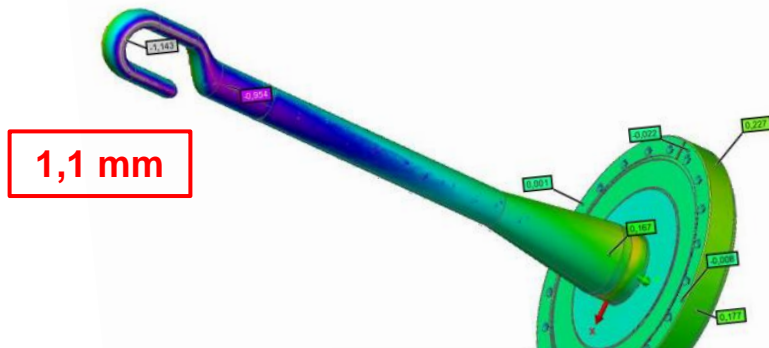


Many thanks to
Laurent

and Jean-Philippe!

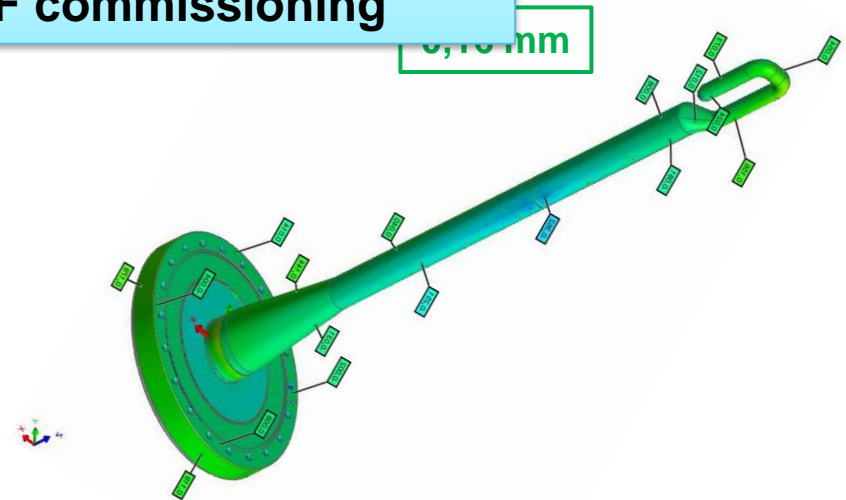
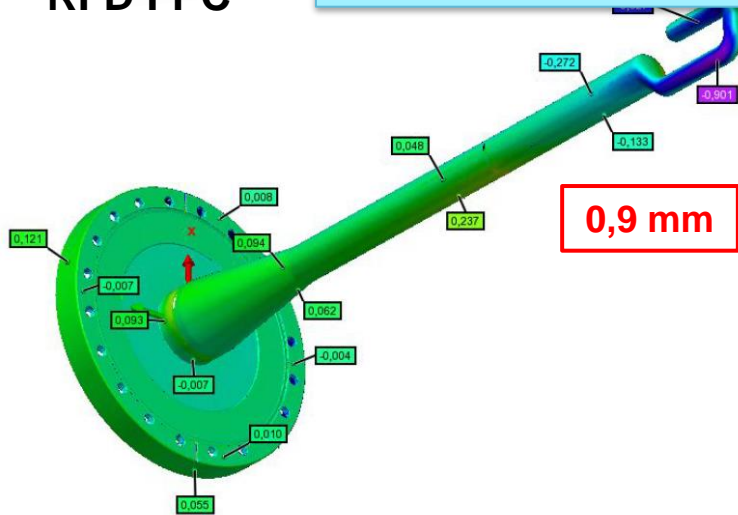
3D Laser Scans

- DQW FPC



Calibration is followed by leak checks, visual inspection (as per required standards) and RF commissioning

- RFD FPC



Lessons Learned

- **Many techniques intertwined:** advanced coordination and follow-up daily through all processes
- **Fragile and high added-value components:** require specific processes for **clean** handling and storage, especially for series production. Logistics, packaging, transport... **to be tackled as soon as possible**
- Typical issues inherent to this kind of productions **debugged and documented on the field**, NCR written and checked by project when needed



Synergy between SY-RF, EN-MME and TE-VSC groups at CERN

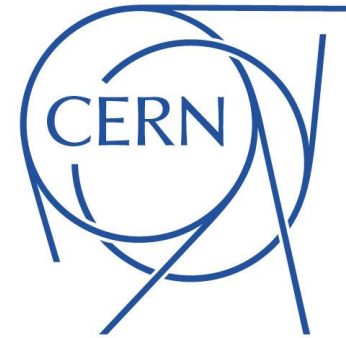
Conclusion

- Fabrication of RF couplers & antennas at CERN for DQW series is currently on track **for assembly on series cavities** in coming months/years
- We are still **learning many things on-the-field** during this series production phase and implementing actions to improve quality & production lead times.
- RF Lines will be another challenge – **efforts are ongoing to conclude production for 1x DQW and 1x RFD cryomodule as soon as possible**
- We stay attentive and flexible **to meet the Project needs**, both for CERN and collaborations activities



Many thanks to all the colleagues involved in the production of such beautiful objects!

Special thanks to Thomas, Julien, Sébastien, Stefanie & Eric for the inputs



Thank you!