



Toward Beam Screen Series Production

Cédric Garion

HL-LHC annual meeting, Uppsala, 20th September 2022

Toward Beam Screen Series Production

Outline:

Reminder:

- Function – requirements
- Boundary conditions

Beam screen manufacturing:

- Procurement: main components; beam screen tube manufacturing and pre-assembly
- Assembly
- Amorphous carbon coating
- Integration in the cold masses

Infrastructure

Schedule & next milestones

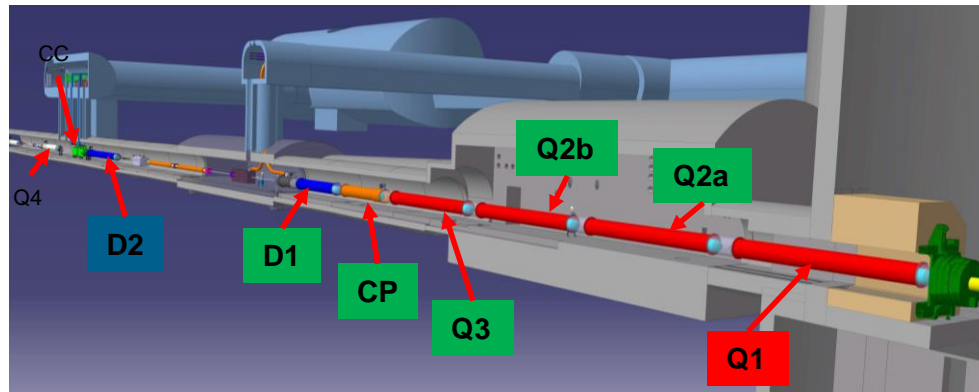
Conclusion

HL-LHC Beam Screens

The LHC cryogenic vacuum system is based on a beam screen. For HL-LHC, new beam screens will be installed in the insertion areas in PT1 & 5, especially shielded beam screens.

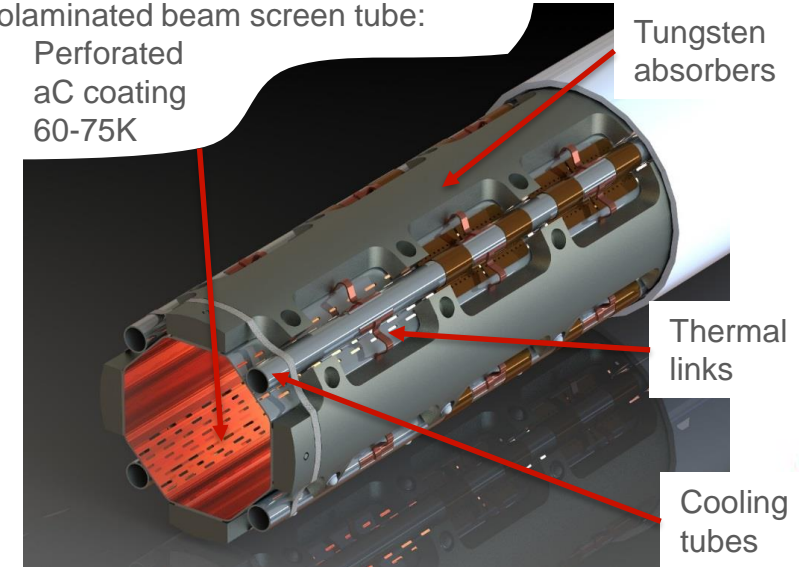
These components ensure:

- vacuum performance
- screening the 2K cryogenic bath from beam induced heating
- shielding the superconducting coils from physics debris



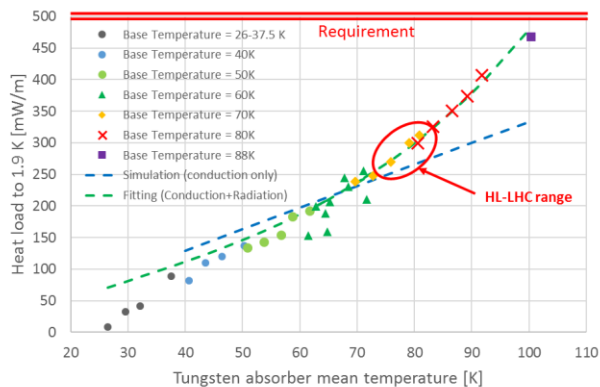
Colaminated beam screen tube:

- Perforated
- aC coating
- 60-75K

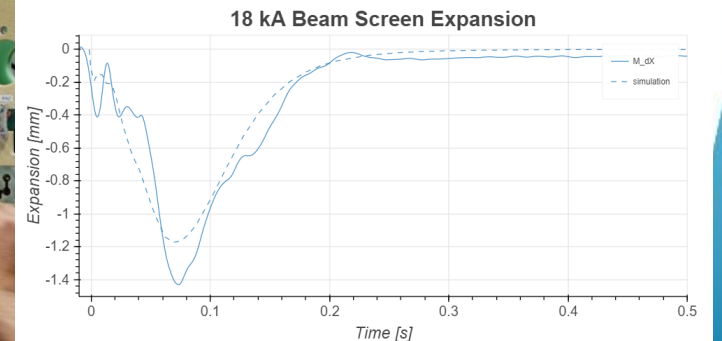


Main features of the shielded beam screens

The thermal mechanical behaviour of the shielded beam screens has been validated:



Prototyping and thermal characterisation and validation tests



Prototyping and characterisation and validation tests in magnets (field quality and quench)

HL-LHC Beam Screen Production Boundary Conditions

For HL-LHC, beam screen production comprises:

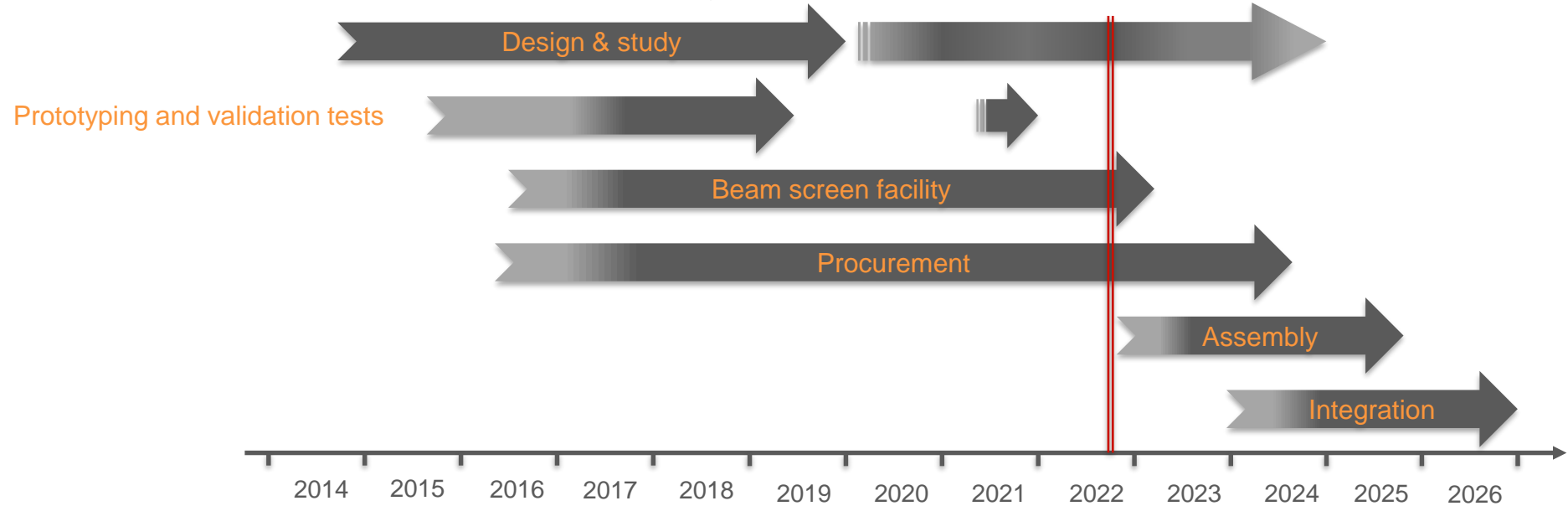
- **29 shielded beam screens:** 24 for the machine + 5 spares
 - 4 + 1 Q1 type.
 - 20 + 4 Q2 type (including Q2, Q3, CP and D1).
- 10 (8 + 2) D2 non-shielded beam screens.
- ((8+2) Q4 non-shielded beam screens based on existing LHC parts.)

Production is driven by “new” type HL-LHC beam screens (shielded + D2).

Integrations in magnets will start in 2024, ramp up in 2025 and continue until end 2026 (new HL-LHC beam screens).

Beam Screen Simplified Timeline and Workflow

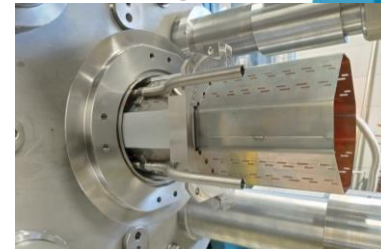
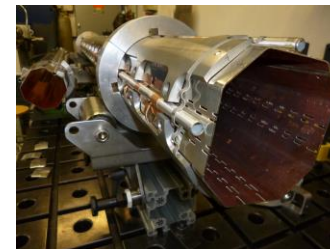
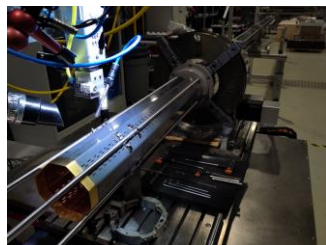
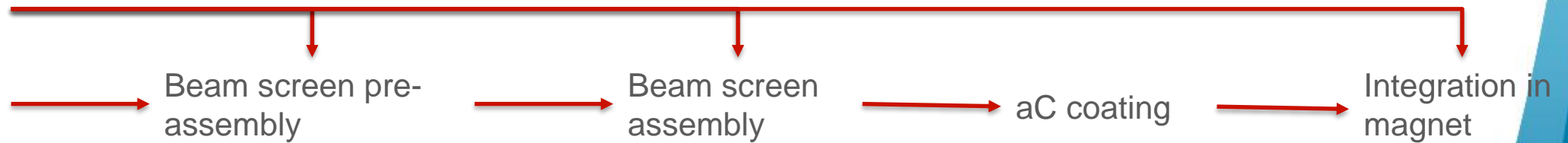
Simplified timeline for the HL-LHC beam screen project:



Simplified workflow for the HL-LHC beam screen production:

Component procurement

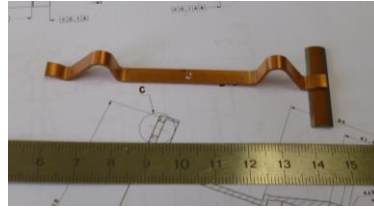
Beam screen tube manufacturing



HL-LHC Shielded Beam Screen - Procurement

Thermal links:

- **Internal manufacturing**
- Preseries done for Q1 and Q2 types
- Production of Q1 and Q2 types in progress



Brazing thermal links/absorbers:

- Order placed
- Qualification of brazing process ongoing
- Pre-series expected by end 2022

Tungsten alloy blocks:

- 40% received
- 26 % cleaned
- 26% vacuum acceptance tested.



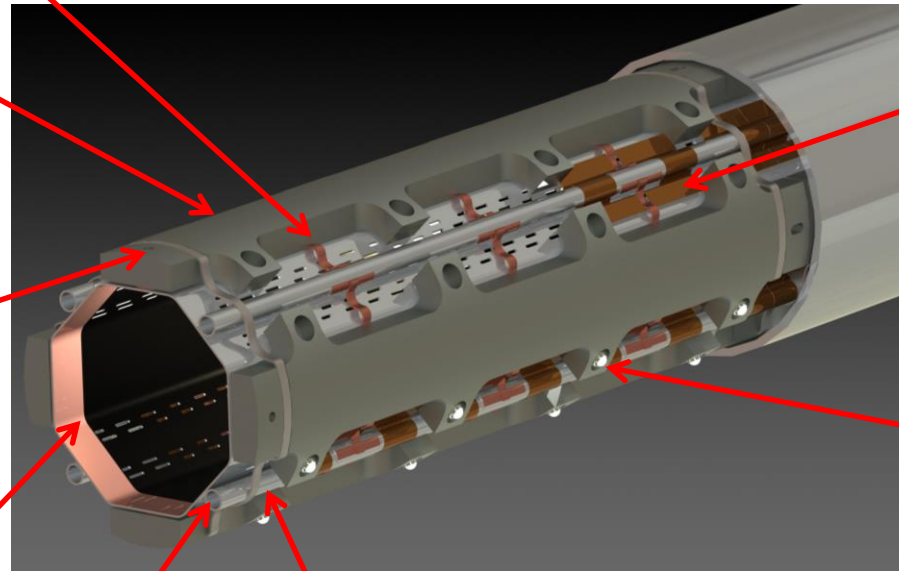
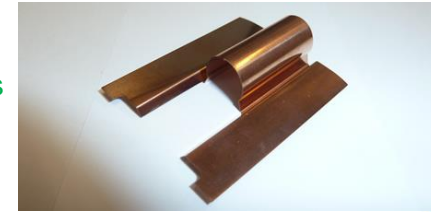
P506 pins:

- Q2 type at CERN and cleaned
- Order for the Q1 type series machining to be placed



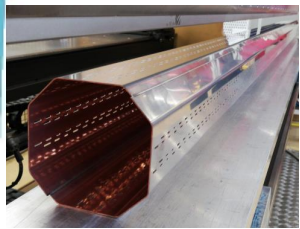
Pumping slot shields

- 100% received.
- To be cleaned



Beam screen tubes:

- **Mainly internal fabrication**
- Production of ~3 m long segments and full-length beam screen tubes in progress



P506 cooling tubes:

- At CERN
- Leak/pressure tests and cleaning completed for shielded and D2 beam screens

Ti elastic rings:

- 30 % received (Q1 & Q2 types)
- To be cleaned



Ti springs:

- 25 % received (Q1 & Q2 types)
- To be cleaned

Ceramic balls:

- At CERN
- To be cleaned



Beam Screen Tube Manufacturing

The beam screen tubes are done from colaminated copper stainless steel in coils with successive main operations:

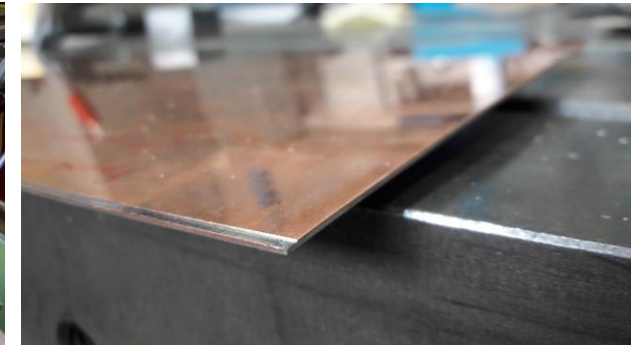
- Levelling,
- Cutting (~ 3m long segment),
- Machining,
- Copper removal at the edges,
- Punching,
- Forming in half shells,
- Longitudinal butt welding,
- Calibration,
- Cutting to length,
- Circumferential butt welding.



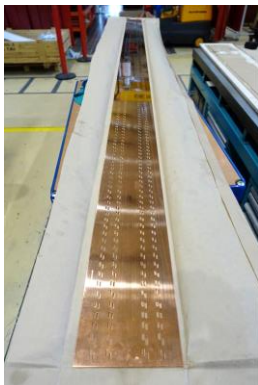
Levelling of the sheets in industry



Machining to width and length



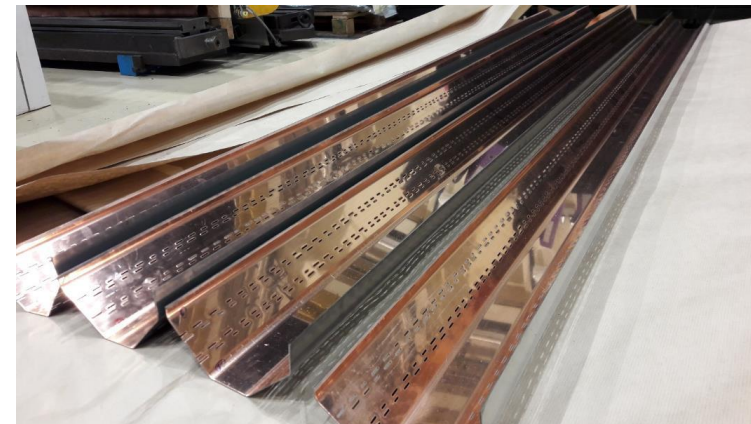
Copper removal at the edges



Punching of the strips in industry



Forming of the half shells



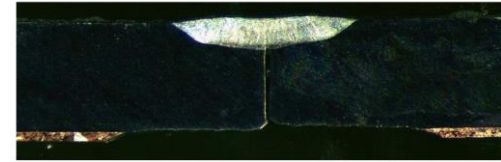
Beam Screen Tube Manufacturing

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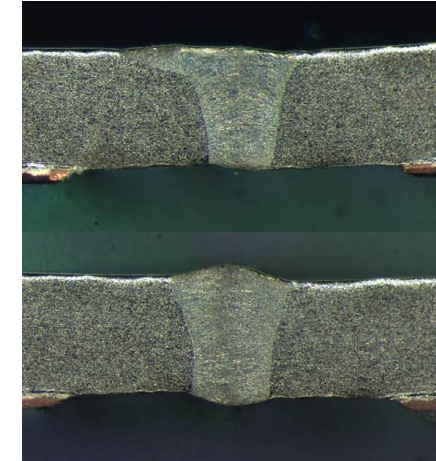
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Tack welding tooling



Micro-TIG tack welding



Metallography for butt weld qualification



Longitudinal welding



Longitudinal welding tooling



Beam screen segment

Welding procedure specification and welding procedure qualification record done.

Beam Screen Tube Manufacturing

The beam screen tubes are done from colaminated copper stainless steel in coils with successive main operations:

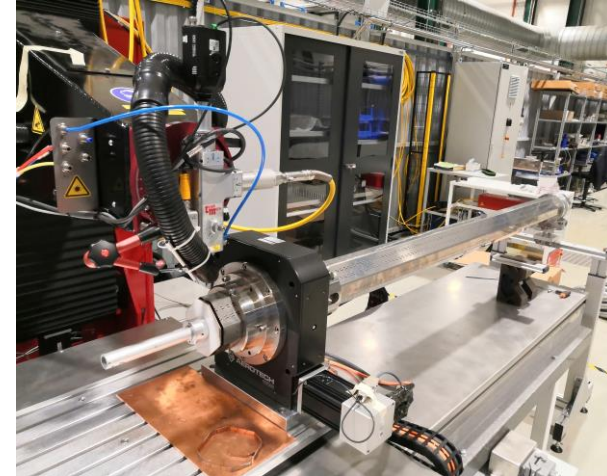
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Calibration of the beam screen segments



Cutting to length of the beam screen segments



Butt welding of the beam screen segments

Welding procedure specification and welding procedure qualification record done.

Beam Screen Tube Manufacturing

- ✓ All procedures for the beam screen tube manufacturing have been fully validated on the Q2 type pre-series.
- ✓ All tooling are available for the Q2 type beam screens, almost completed (95%) for Q1 and D2.
- ✓ Welding procedure specifications and welding procedure qualification records are available.

Beam Screen Tube Pre-Assembly

The beam screen tube pre-assembly consists in:

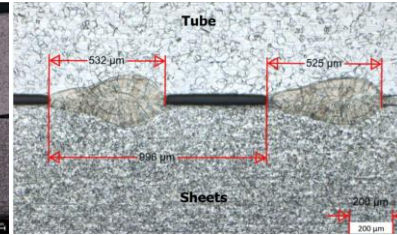
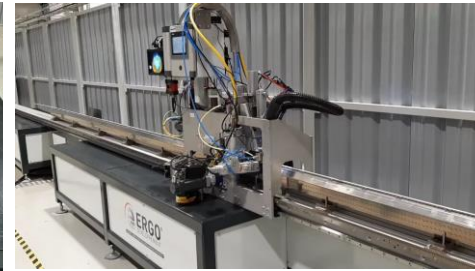
- Laser welds of the gold plated contact rings,
- Laser spot welds of the cooling tubes,
- Laser hole drilling
- Laser fillet welds of the cooling tube supports and fixed points
- Capacitor discharge stud welds (Q2 type) or laser welds (Q1 type) of the absorber pin supports

Welding procedure specification and welding procedure qualification record done.

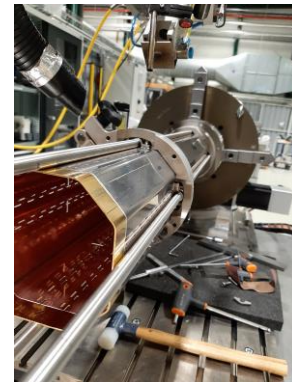
Laser and stud welding benches are available.



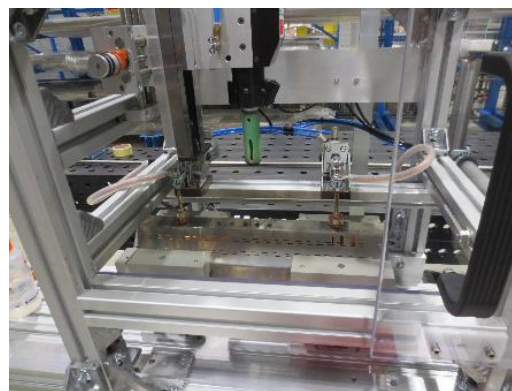
Laser welding bench for the cooling tube welding



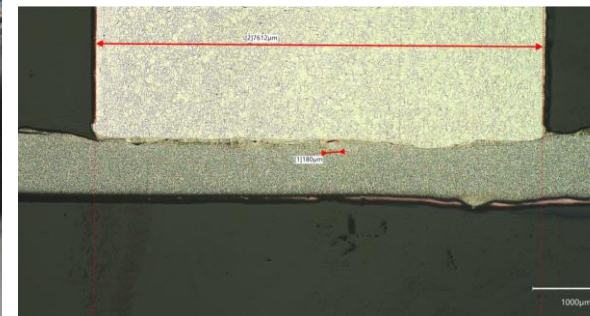
Metallography for the cooling tube weld qualification



Welding of the contact rings, cooling tube supports and fixed points



Dedicated bench for the stud welding of the absorber pin supports



Metallography for stud weld qualification

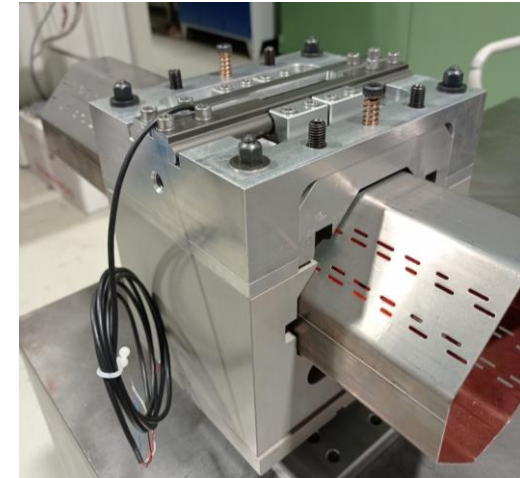
Beam Screen Pre-Assembly Quality Control

Quality controls carried out on the beam screen pre-assemblies:

- Leak tightness of the cooling tubes – 100%
- Mechanical strength of the stud welds (Q2) – 100%
- Metrology – 100%



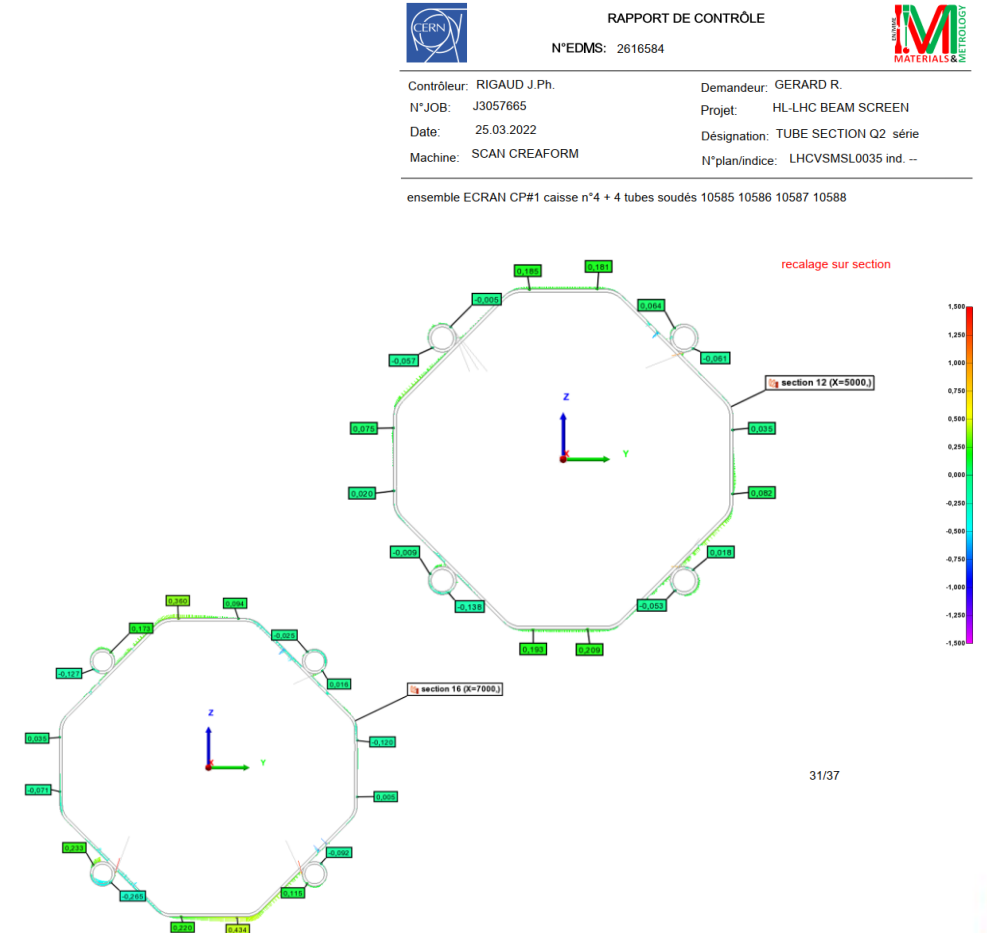
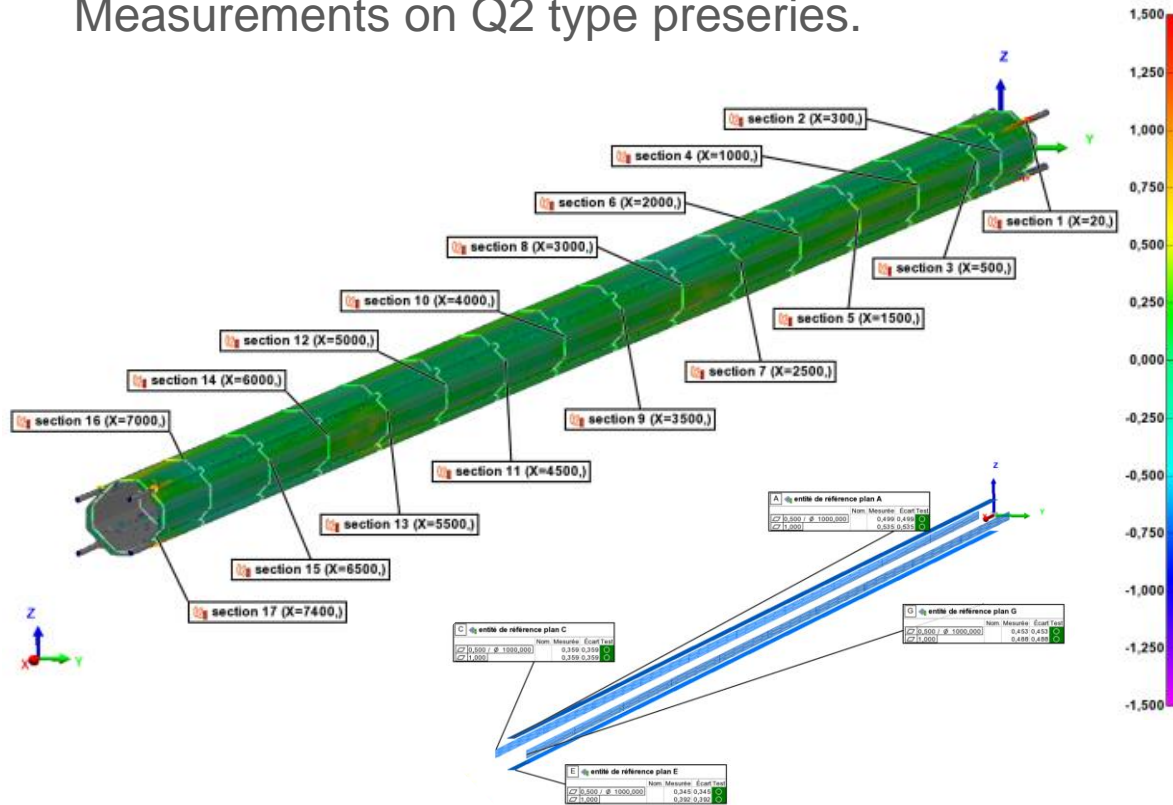
Bench for metrology with a Metrascan 3D




Tooling for stud welding quality check


Beam Screen Pre-Assembly Metrology

Measurements on Q2 type preseries.





RAPPORT DE CONTRÔLE
N°EDMS: 2616584



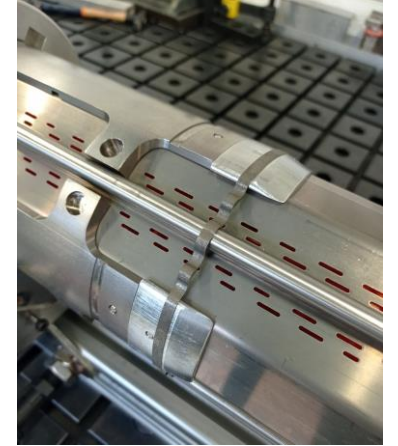
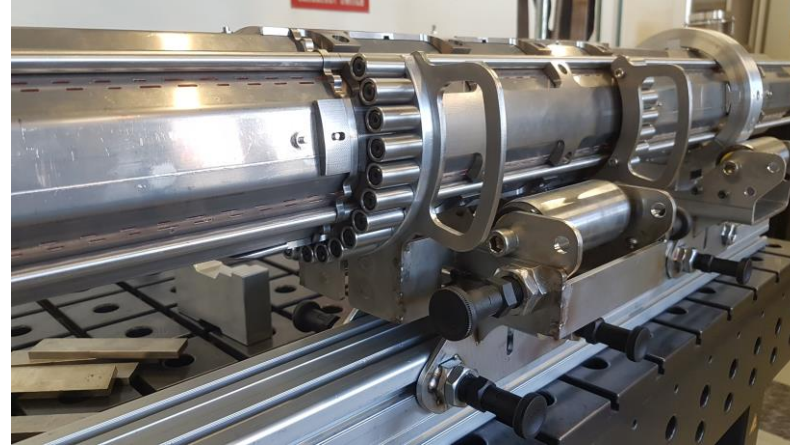
Contrôleur: RIGAUD J.Ph. Demandeur: GERARD R.
 N°JOB: J3057665 Projet: HL-LHC BEAM SCREEN
 Date: 25.03.2022 Désignation: TUBE SECTION Q2 série
 Machine: SCAN CREAFORM N°plan/indice: LHCVMSL0035 ind. --

ensemble ECRAN CP#1 caisse n°4 + 4 tubes soudés 10585 10586 10587 10588

Geometry of the beam screen pre-assembly is good:

- Cross-sectional shape is within specification (0.5 mm) with some localised and slight deviations at the extremities, corrected with a calibrated piece during the beam screen integration.
- No twist observed.
- Straightness of the beam screen tube is good. Effect of the butt welds is barely visible.

Beam Screen Assembly



Assembly bench prototype

Procedure is defined.

First assembly bench is ready.

Tooling (collars, wedges, holding system,...) are available and cleaned.

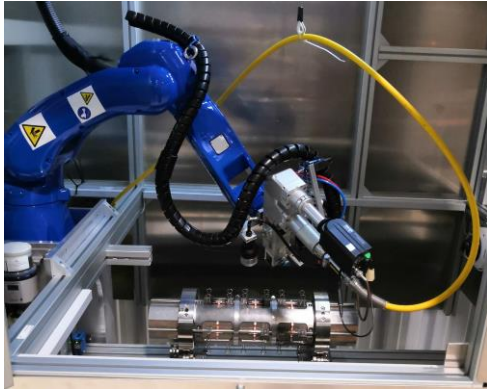


Assembly benches

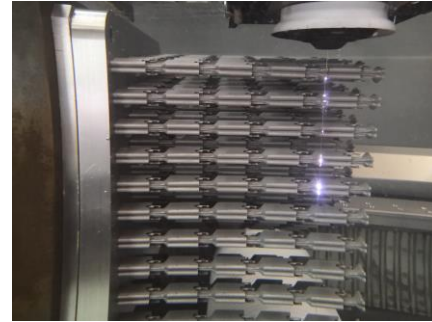


Assembly wedges

Beam Screen Assembly



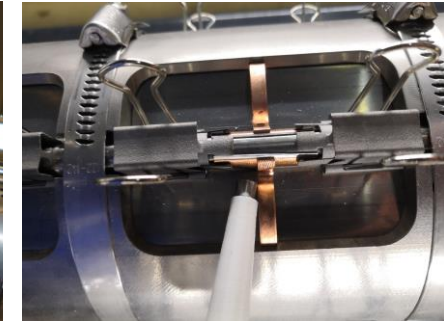
Laser welding robot



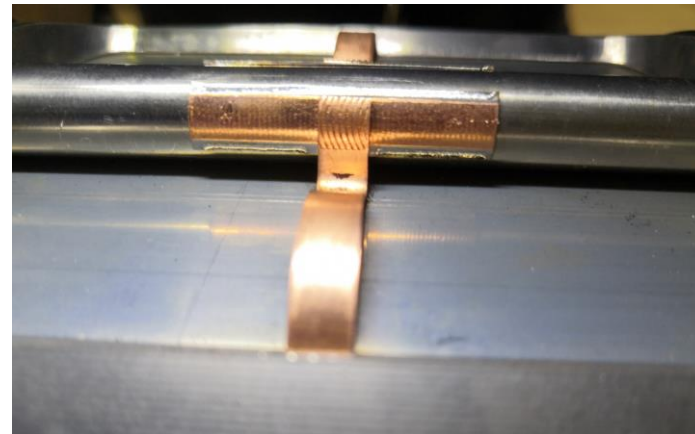
Clamp manufacturing



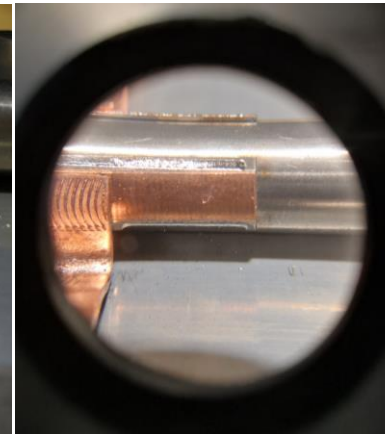
Beam screen assembly before laser weld



Bench with laser welding robot



Welds between the cooling tube and the interface plate



Metallography for the thermal link weld qualification

Final commissioning of the laser welding robot for the thermal links has been carried out. Tooling (clamps, collars) are available (to be cleaned).

Welding procedure specification and welding procedure qualification record are ongoing.

Pressure and leak tightness test of the cooling tubes is carried out after welding (control for the cold test bench being done).

Beam Screen aC Coating

The procedure for the HL-LHC beam screen aC coating is:

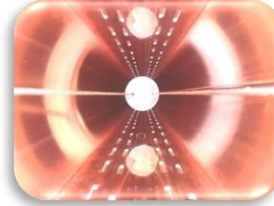
Optical inspection



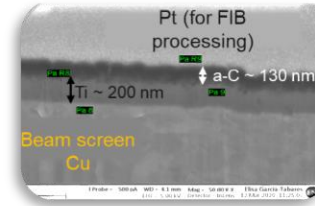
Ion etching + controlled oxidation



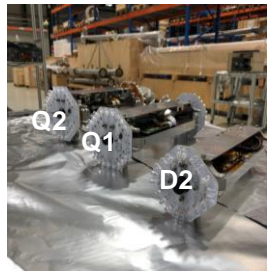
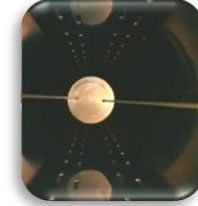
Optical inspection



Ti pre-layer (100 nm) + a-C (100 nm) & Ti flashes (+100 nm)



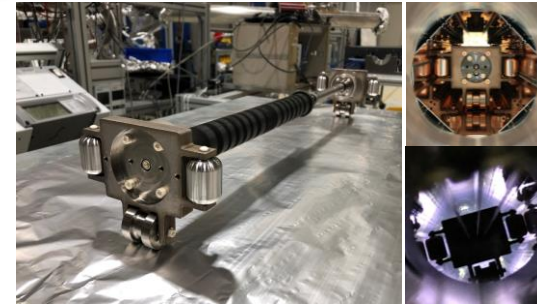
Optical inspection



✓ Optical device



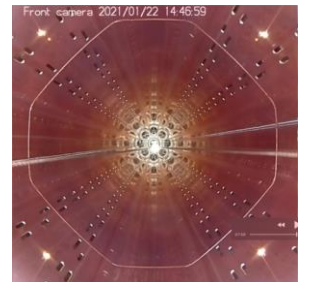
✓ Ion etching



✓ aC coating device



✓ Adhesion test



✓ Visual inspection



✓ 2 aC coating benches with chambers

The aC coating facility in SMA18 has been used to produce 2m long prototype and is ready to start the series production.

Beam Screen Integration

The beam screen integration in the cold mass is done in three phases:

- Fixed point and BPM assembly on a dedicated bench
- Insertion of the beam screen/BPM assembly in the cold mass
- Mobile point assembly and welding to the cold mass

Series production of all machined parts of the beam screen extremities is ongoing.

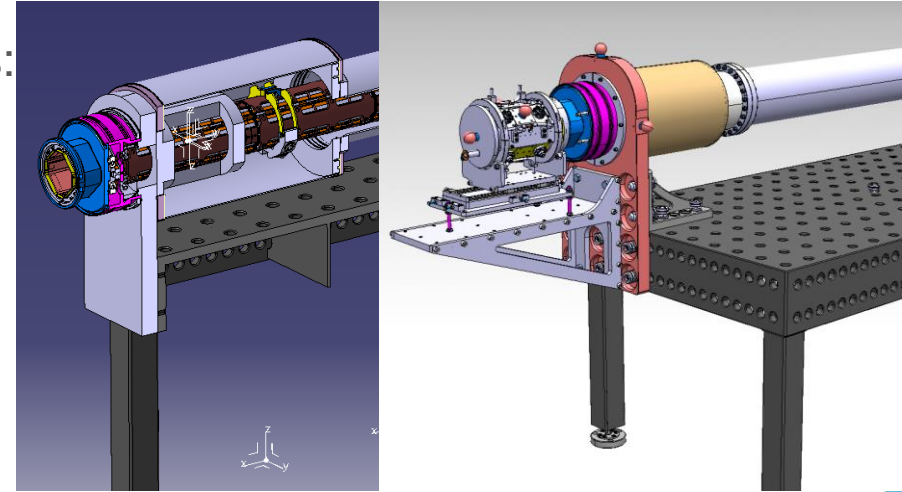
The design of the dedicated bench for the fixed point assembly is completed and components are in production.

Main tooling (bending of the cooling tubes) are available for the Q2 type beam screens.

The insertion bench is being assembled. Some interface tooling are being designed.

Leak testing tooling to be done (known technology).

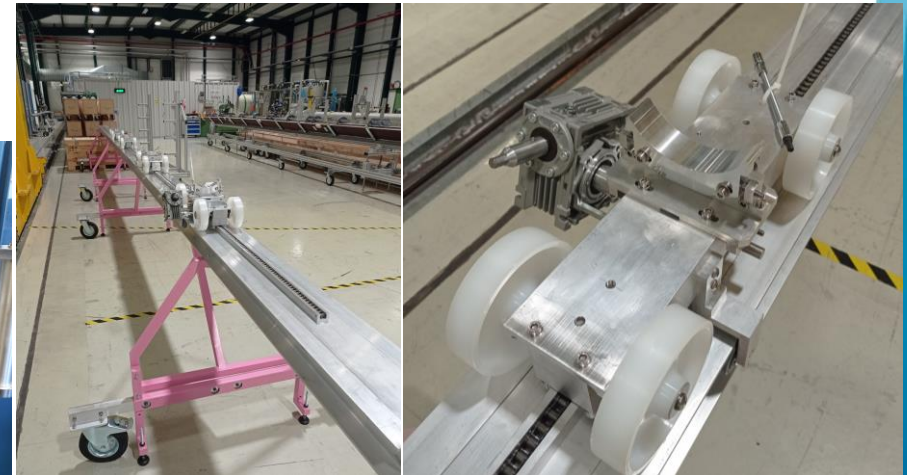
Welding machines are available. Some interface tooling to be procured.



Design of the bench for the fixed extremity & BPM assembly



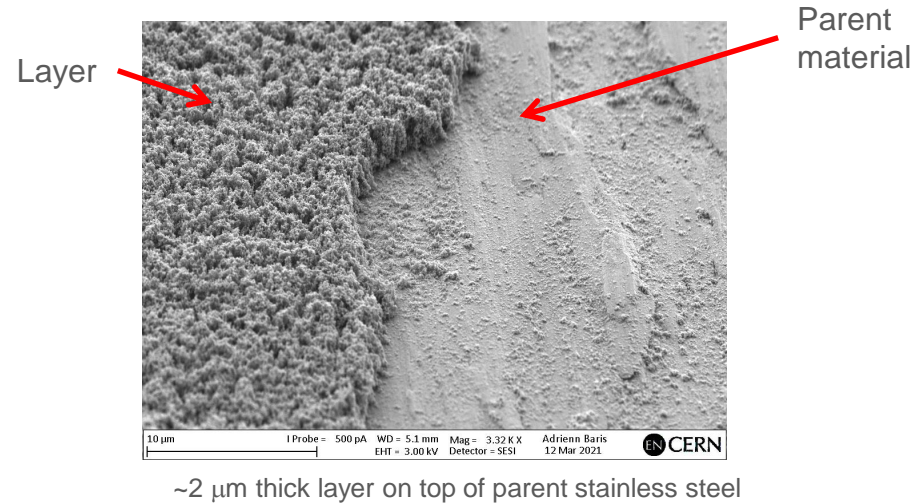
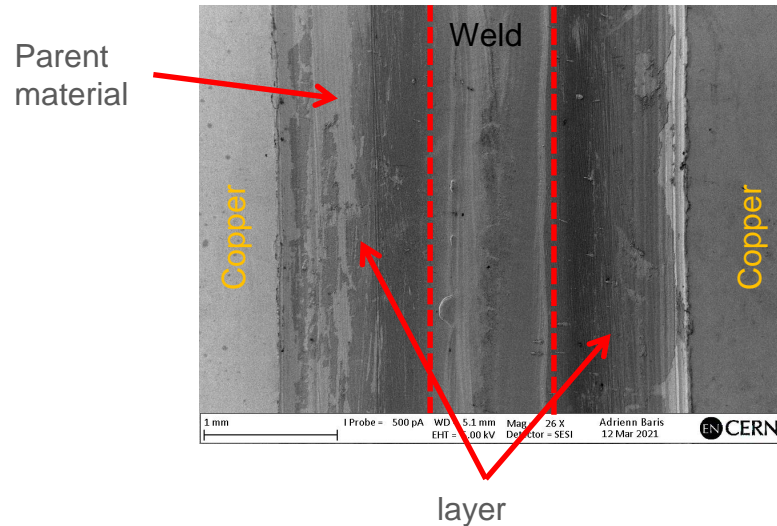
Cooling tube bending tooling (Q2 type)



Insertion bench

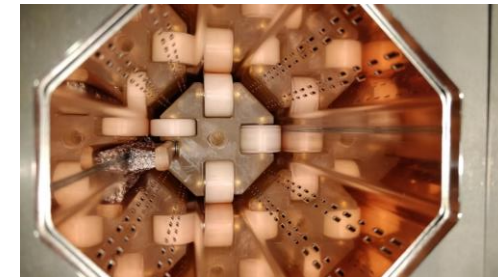
Longitudinal Weld of Beam Screen Tubes

A blackish layer occurred on the inner surface during the fully penetrated longitudinal welds of the preseries segments: Sublimated stainless steel during laser welding redeposits on the surface with a LESS like structure. This layer is poorly adherent and not compatible with subsequent aC coating. No problem on partially penetrated welds (e.g. butt welds).



Actions:

- Preserie: Brushing, CO2 cryoblasting and cleaning with ultrasound
- Series:
 - Welding parameter optimisation
 - Brushing and cleaning with ultrasound
- Visual inspections by endoscopy



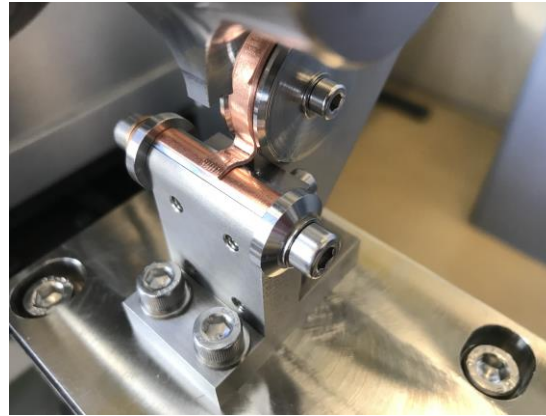
aC coating tests and scratch/adhesion tests have been successfully concluded.

Thermal Links Manufacturing and Brazing

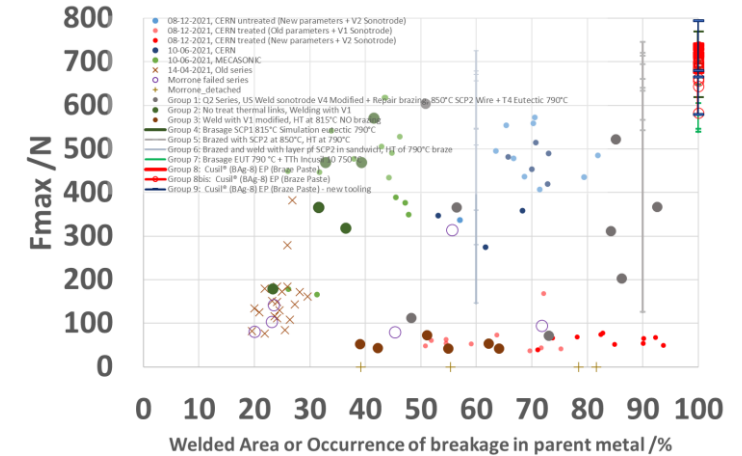
Joints between the copper strips and the interface plates were foreseen with ultrasound welding. Mechanical tests carried out after a subsequent brazing cycle have shown a drastic decrease of the strength.

Actions:

- Ultrasound welding is replaced by brazing.
- New procedure (filler material) has been defined.
- Tooling has been procured and production started.



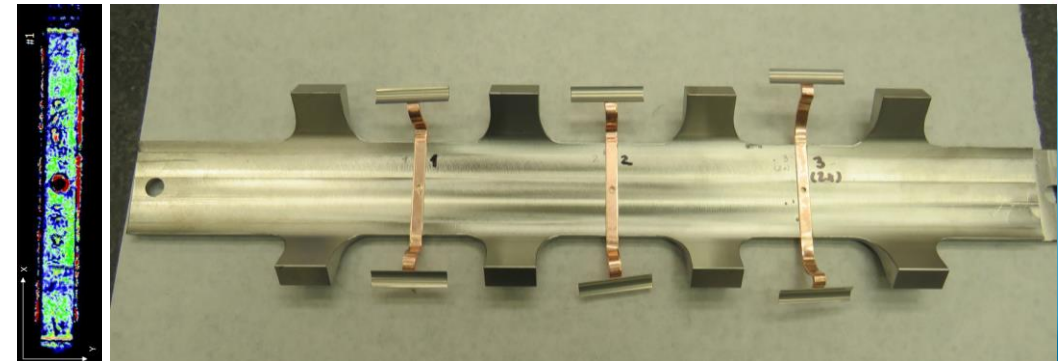
Ultrasound welding



The brazing of the interface plates/strips impacts the subsequent brazing between the thermal links and the absorbers carried out in industry.

Iterations with the company and at CERN lead to:

- Choice of the filler material InCuSil and of the process parameters.
- Improvement of the interface plate preparation and flat copper part of the thermal link:
 - Additional etching to remove copper traces on the stainless steel to be welded.
 - Flattening of the massive copper part to ensure good brazing.



Beam Screen Facility



Tack welding of beam screen tube segments



Storage of segments and beam screen tubes



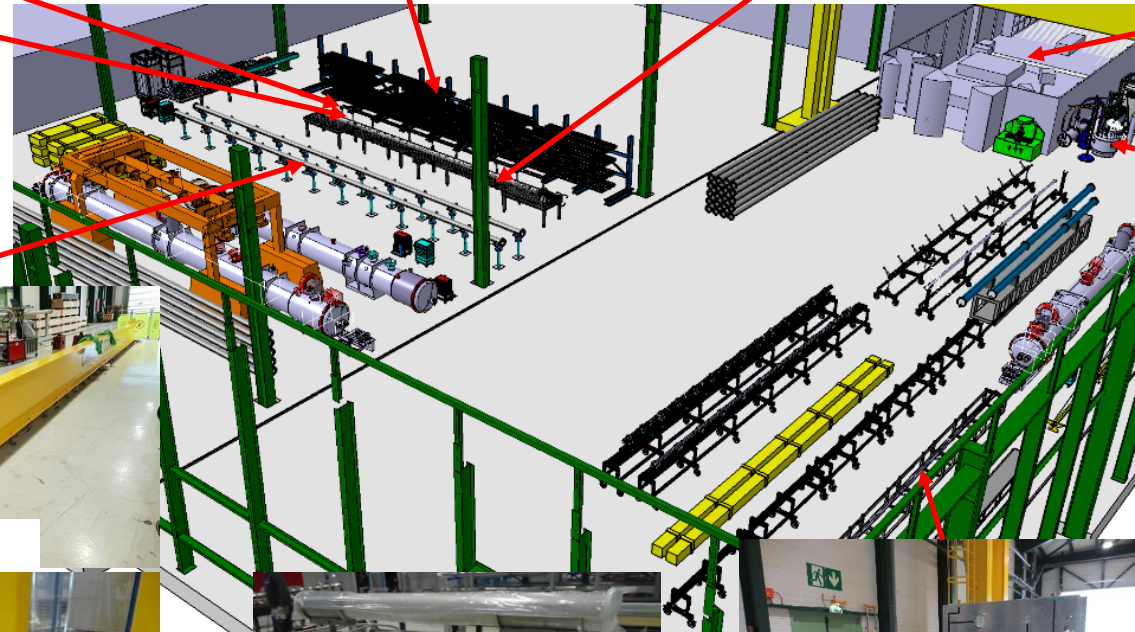
Metrology/calibration



Class 4 laser facility with laser machine and bench



Cold leak/pressure test



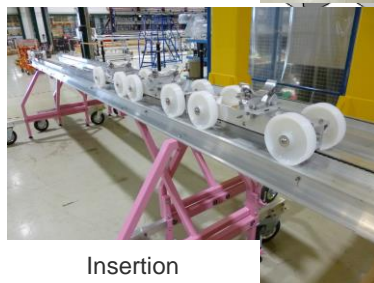
Stud welding



aC coating



Lifting beam



Insertion



Assembly



Movable adjustable support



Pressure test of cooling tubes



Cleaning facility by circulation

Manufacturing Planning – Production Rate

Pre-series (4 CP and 3 D1) of beam screen pre-assemblies is nearly completed.

Type	BS tube quantity	Punching	Forming	Tack welding	Long. Welding	Butt welding	BS tube ready	Contact ring & holes	Cooling tube welding	Contact ring & holes & ancillaries	Beam screen pre-assembly
Q2...D1	24+8	Finished	Finished	Finished	Finished/ started*	Finished/*	7	Finished/*	Finished/*	Finished/*	0/*
Q1	5+2	Finished	Finished	Finished			0				0
D2	10+2	Finished	Finished	Finished			0				0

*:Preseries (7 eq. beam screen tube)/series

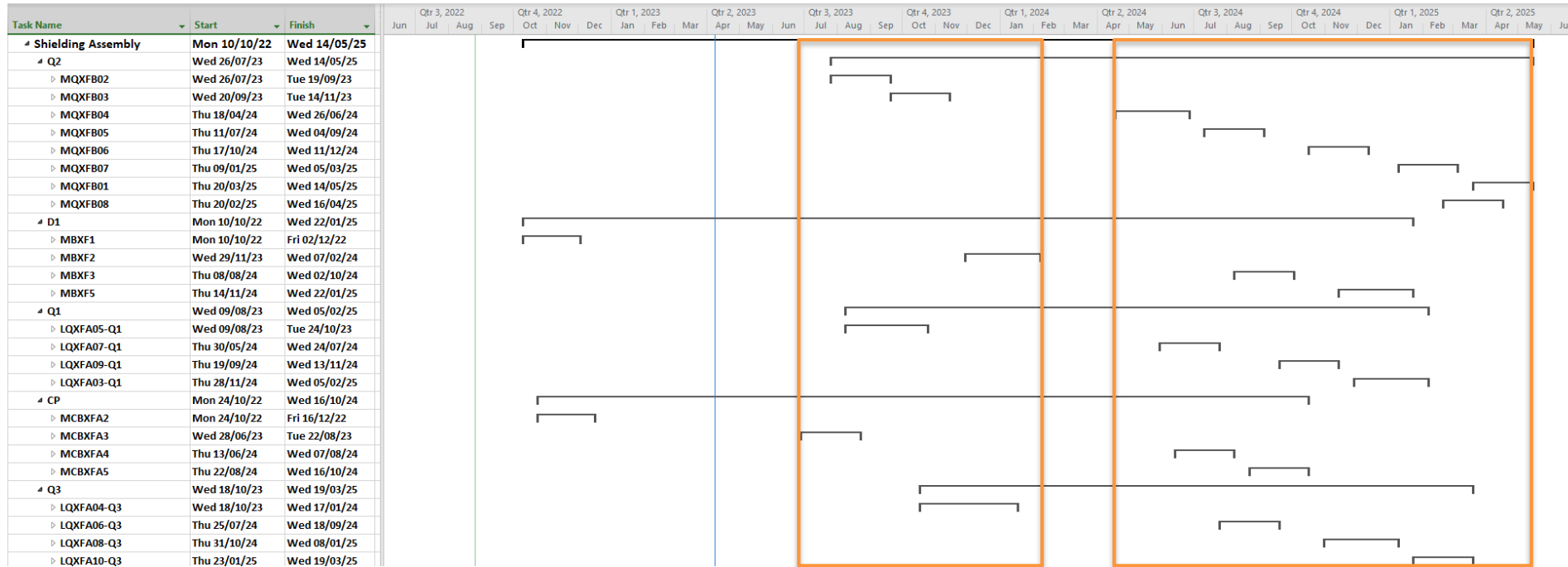


Manufacturing of the beam screen tube segments, i.e. longitudinal welding, will be done in one batch per type.

Brazing of the thermal links on the absorbers are on the critical path:

- Brazing tests in the company still not satisfying (oxidation and filler flow to the multilayer strips) but in good track. A first batch (equivalent to 1 CP) will be done at CERN.
- The assembly of the first shielded beam screen is foreseen end 2022.

Manufacturing Planning – Production Rate



Tentative schedule to be updated (beam screen spares not included)

After a preserie end of 2022/early 2023 (most likely 2 CP units), the assembly of the beam screens is foreseen in two batches. The first one is expected in S2 2023.

Expected series production rate of beam screen assembly is 1 beam screen every two weeks.

Production planning is flexible. The beam screen pre-assembly and assembly can be tuned according to magnet delivery dates.

Next steps

Continue the series production of all beam screen tubes with first the welding in production mode of all segments (Q1, Q2 and D2);

Then, re-assess priority for first batch of pre-assembled beam screens.

Complete the Q1 pre-assembly preparation: Tooling for small Q1 pin welding.

Pursue different activities for the beam screen integration:

- Assembly drawings.
- Assembly procedures.
- QA/QC documentation.
- Tooling for the leak detection.
- Q1 integration tooling (in particular the production of the in-situ bending tooling of the cooling tubes).

Carry out a dry assembly and insertion test with a dummy beam screen (series components but absorbers without thermal links).

Conclusion

Series production of the HL-LHC beam screens has started:

- All blocking points have been solved for the beam screen pre-assembly manufacturing.
- Most of the subcomponents are in series production.
- Two important activities have been internalised: beam screen tube and thermal link manufacturing.

First assembled beam screen is foreseen end 2022, brazing of the thermal links on the absorbers being on the critical path.

Beam screen facility has been upgraded for the shielded beam screen manufacturing, assembly and integration.

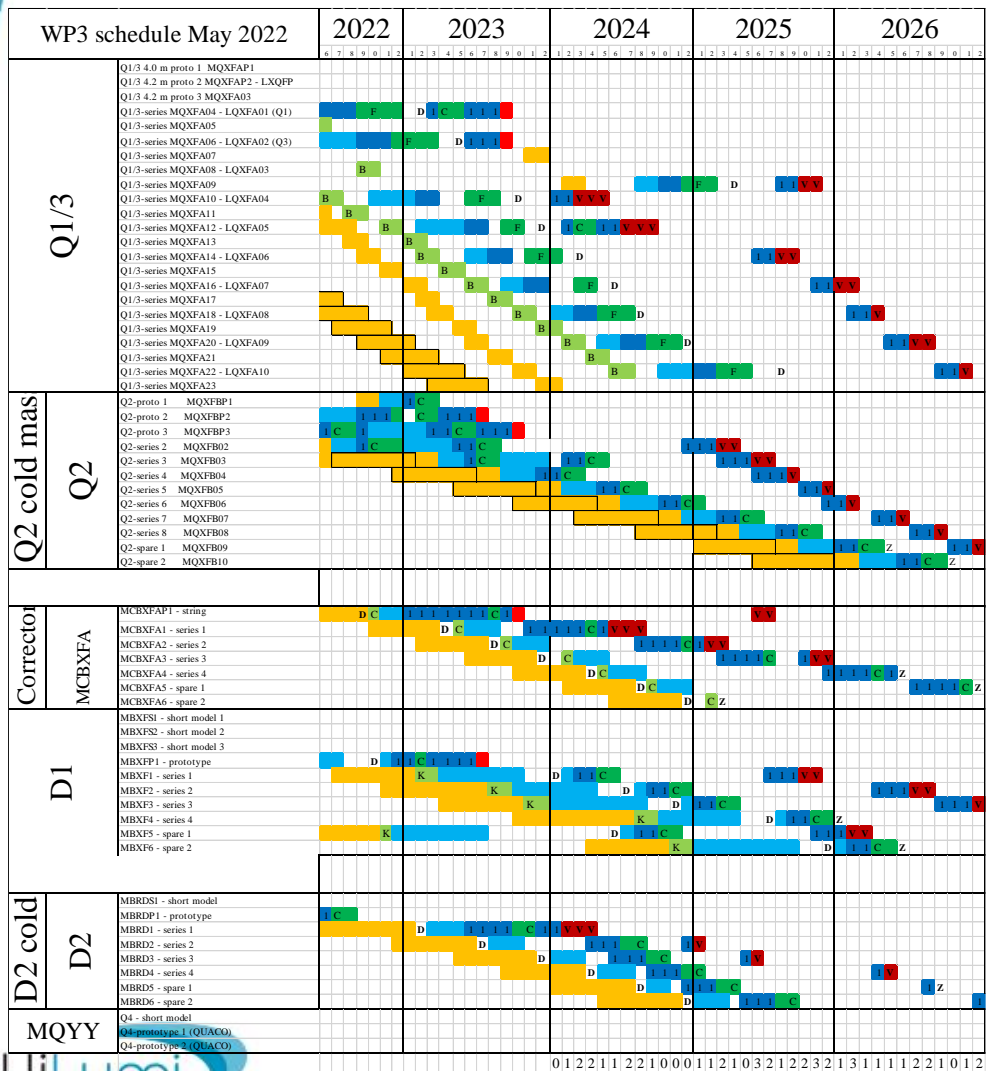
Production planning is compatible with the magnet delivery dates.



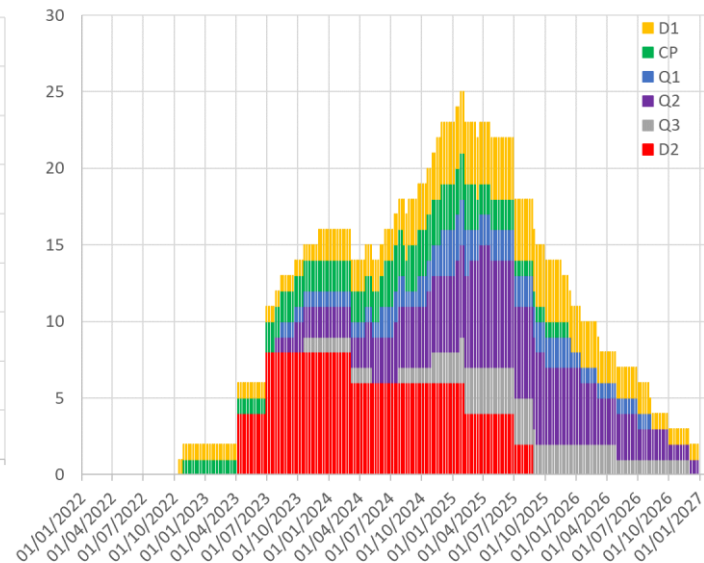
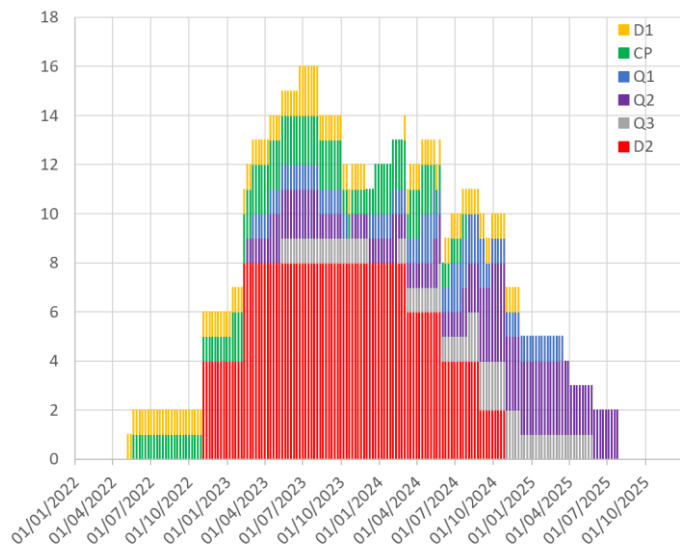
***Thanks to MME and VSC colleagues for
their contributions in this project.***

Thank you for your attention

Impact of WP3 schedule change



Working planning



Expected quantities of beam screens to be stored before insertion (spares not included)

Beam screens to produce

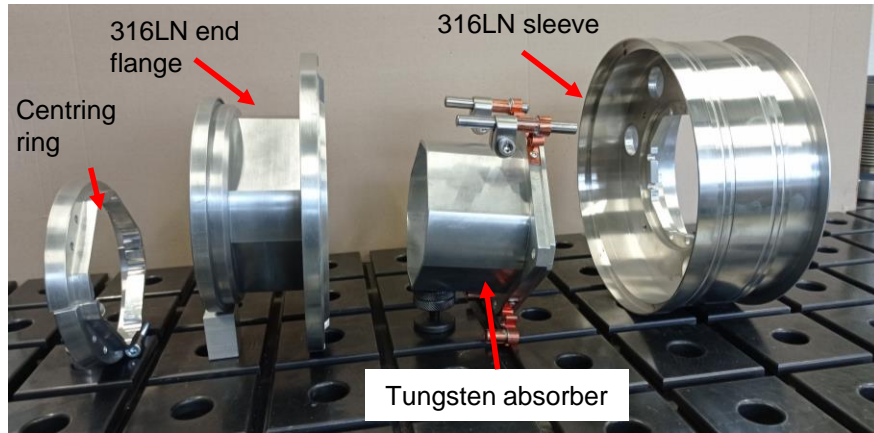
	Beam screen length	Aperture	Unfolded half width	Beam screen quantity					Cumulative length of segments (per type)
	[mm]	[mm]	[mm]	(EDMS 1949666)	Machine	Minimum spare	Qty of beam screen tubes	Qty of segments	[m]
Q1	10722	99.7	165.4	5	4	1	7	32	92
Q2 a & b	10287	119.7	191.1	9	8	1	11	55	359
Q3	10602			5	4	1	7	28	
CP	7456			5	4	1	7	21	
D1	8499			5	4	1	7	21	
D2	14124	86	135.2	10	8	2	12	70	201
Total				39	32	7	51	227	652

125 Q2 type segments

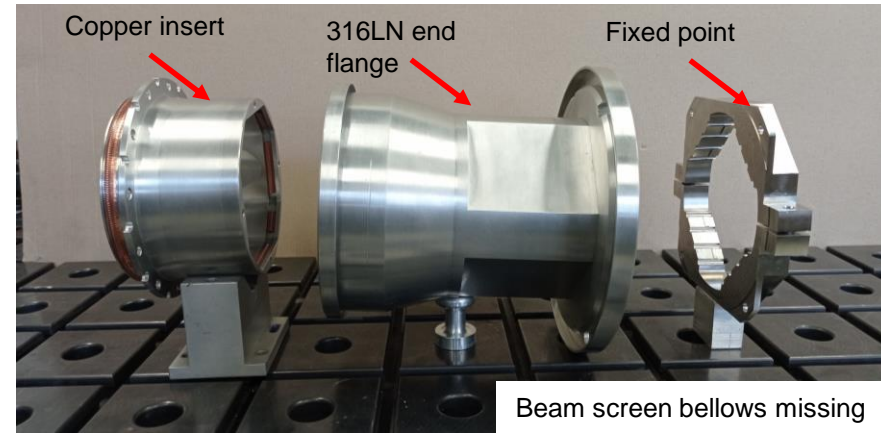
Length of beam screen to produce: ~ 420 m

Length of beam screen tube segment to produce: ~ 650 m

Beam screen extremities



Interconnection component prototypes (fixed point side)



Interconnection component prototypes (sliding point side)

