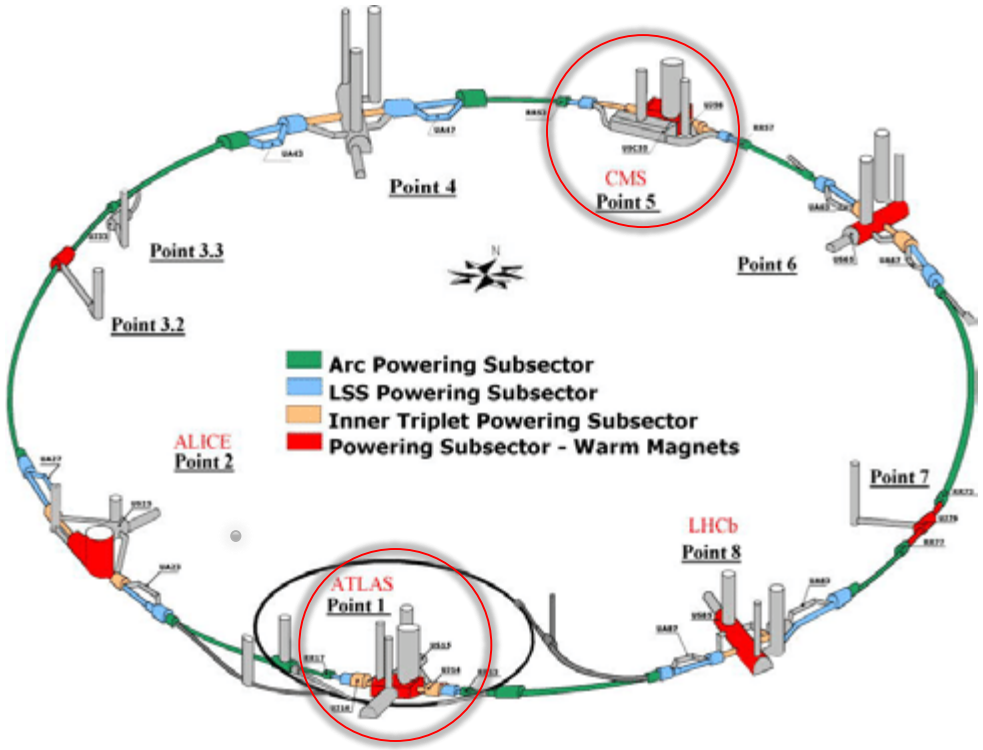

CERN

Production of a-C coatings for new HL-LHC beam screens

1. Introduction
2. Coating process
3. Coating technology
4. Final remarks

1 - Introduction

New inner triplet magnets for ATLAS and CMS



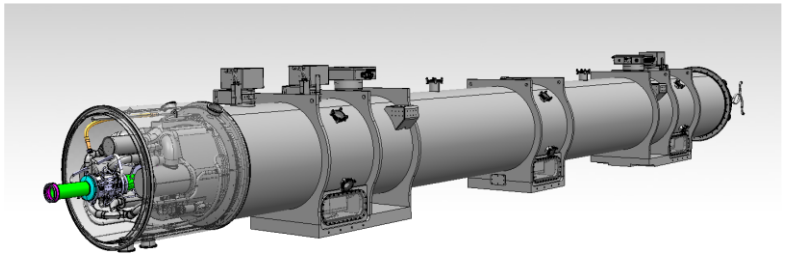
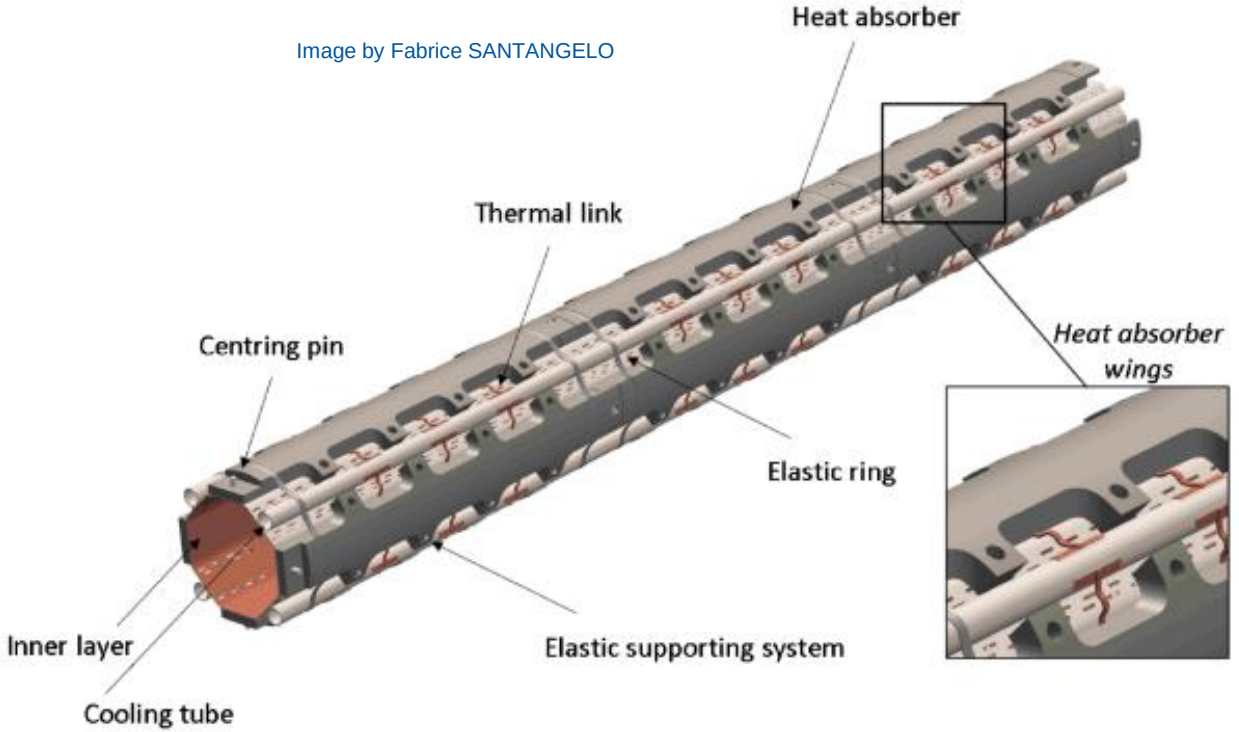


Image by Fabrice SANTANGELO

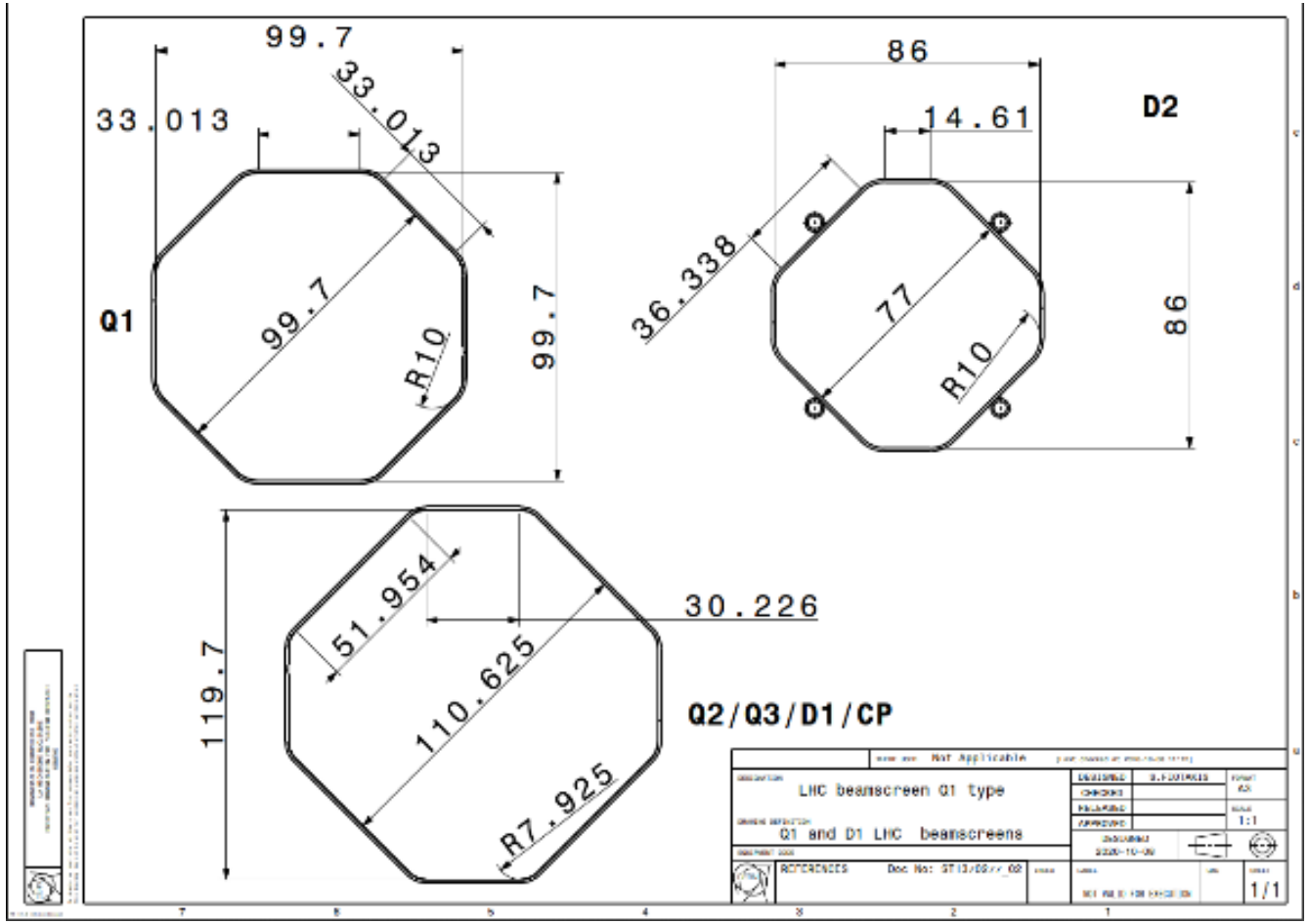


1 - Introduction

New inner triplet magnets for ATLAS and CMS

Different types of beam screens to be coated (lengths varied 7.5 m to 14.2 m)

Variation of the weight from 140kg up to 600kg

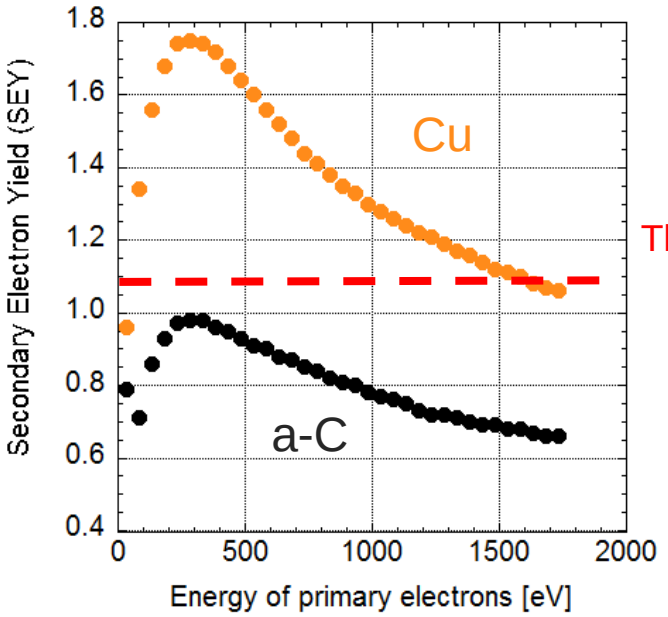


Total number of beam screen = 34

Equal to ~320m total coatings

1 - Introduction

Why we need the Coating?
Increase of the beam intensity in HL-LHC leads to E-cloud



Threshold for E-cloud

Secondary electron emission form the walls of the beam pipe (SEY)

↓

E-cloud

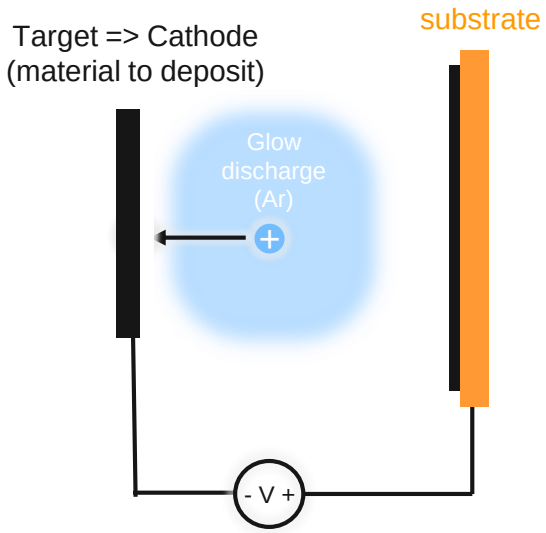
↓

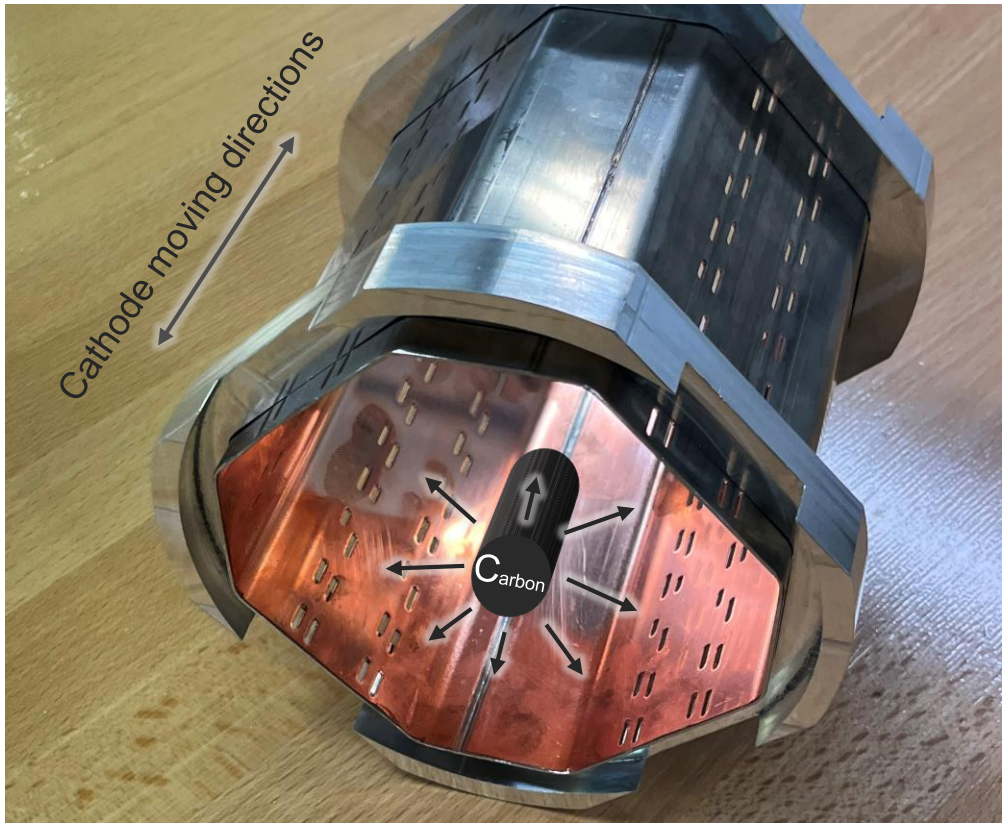
Heat load

in the inner triplet

How we do the coating

Sputtering





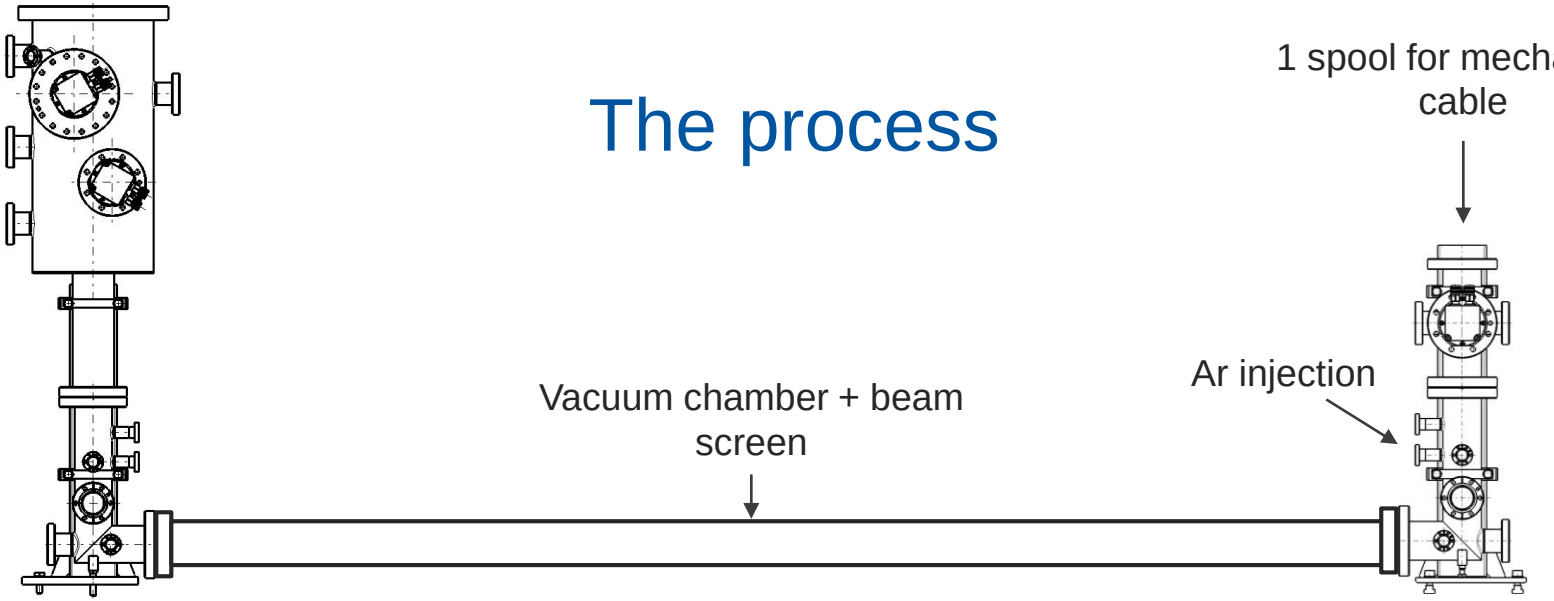
Substrate = Copper (LHC beam screen)
Cathode = Carbon
Process gas = Ar

2 – Coating process

Assembly the vacuum chamber + beam screen

1 spool for mechanical cable
+
2 spools for electrical cables

The process

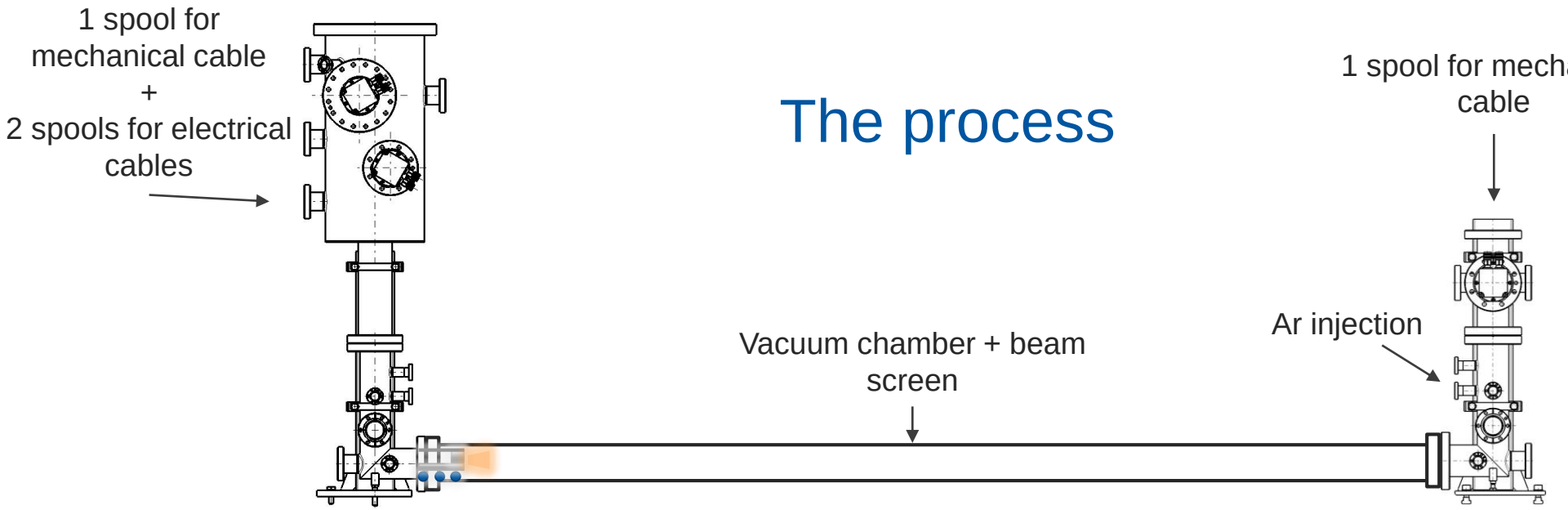


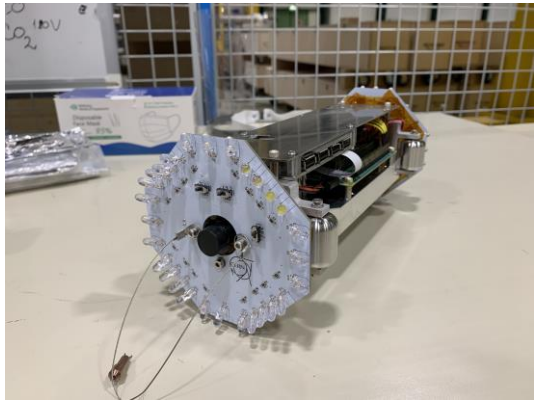
2 – Coating process

Assembly the vacuum chamber + beam screen

Optical inspection

The process

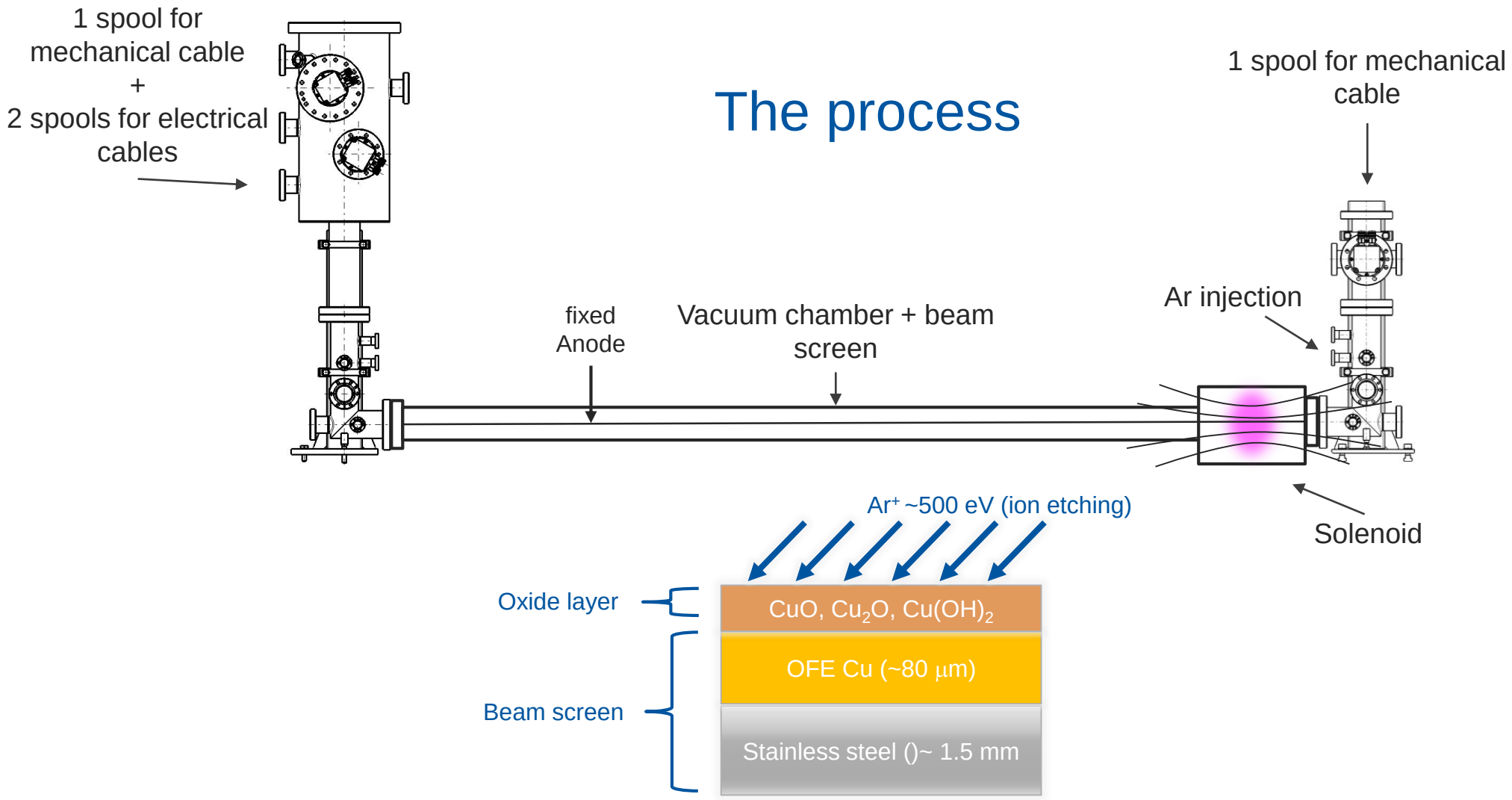




2 – Coating process

- Assembly the vacuum chamber + beam screen
- Optical inspection
- Ion etching to enhance adhesion

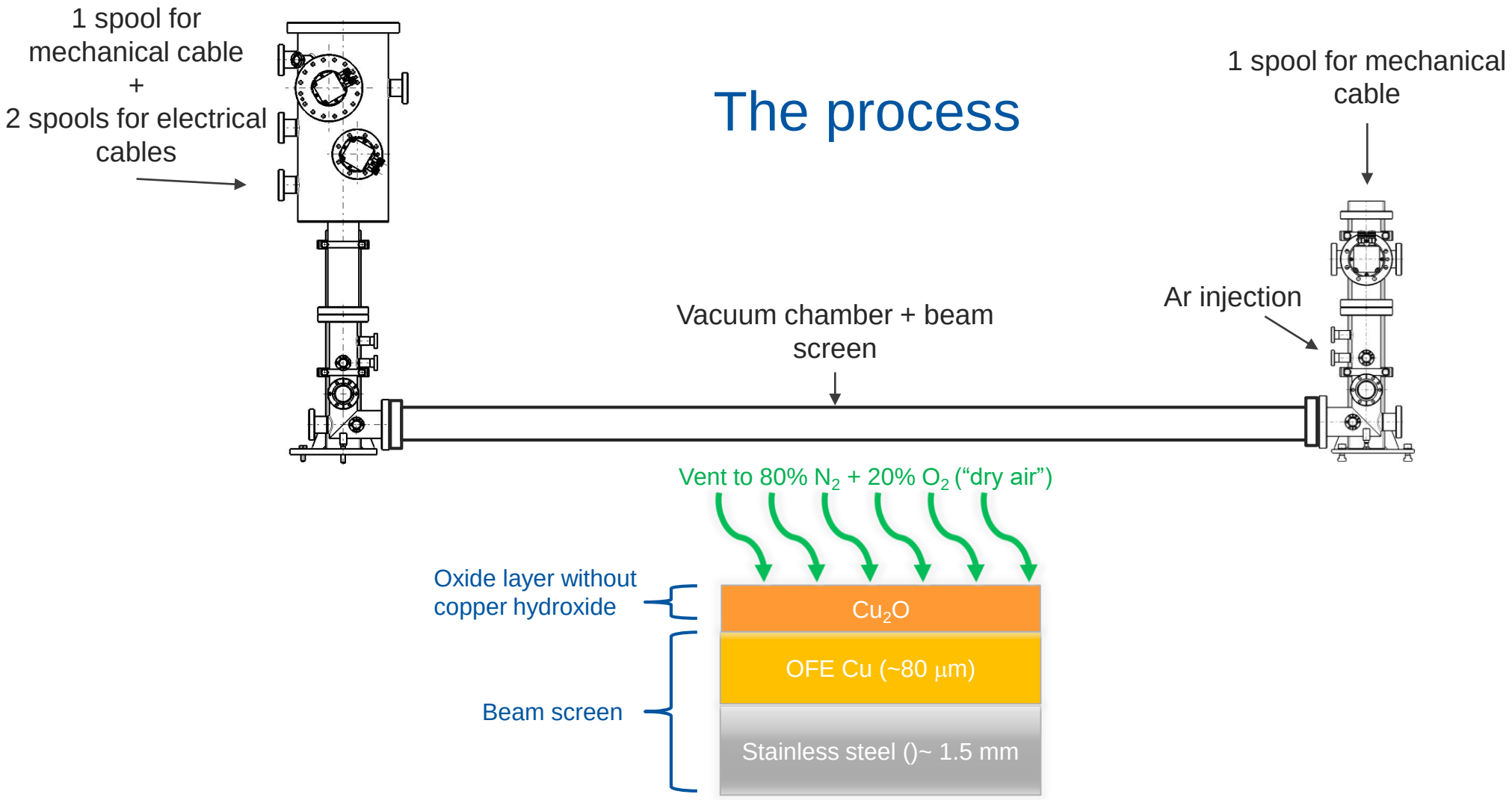
The process



2 – Coating process

- Assembly the vacuum chamber + beam screen
- Optical inspection
- Ion etching to enhance adhesion
- Vent to N_2-O_2 mixture & Assemble coating

The process



2 – Coating process

- Assembly the vacuum chamber + beam screen
- Optical inspection
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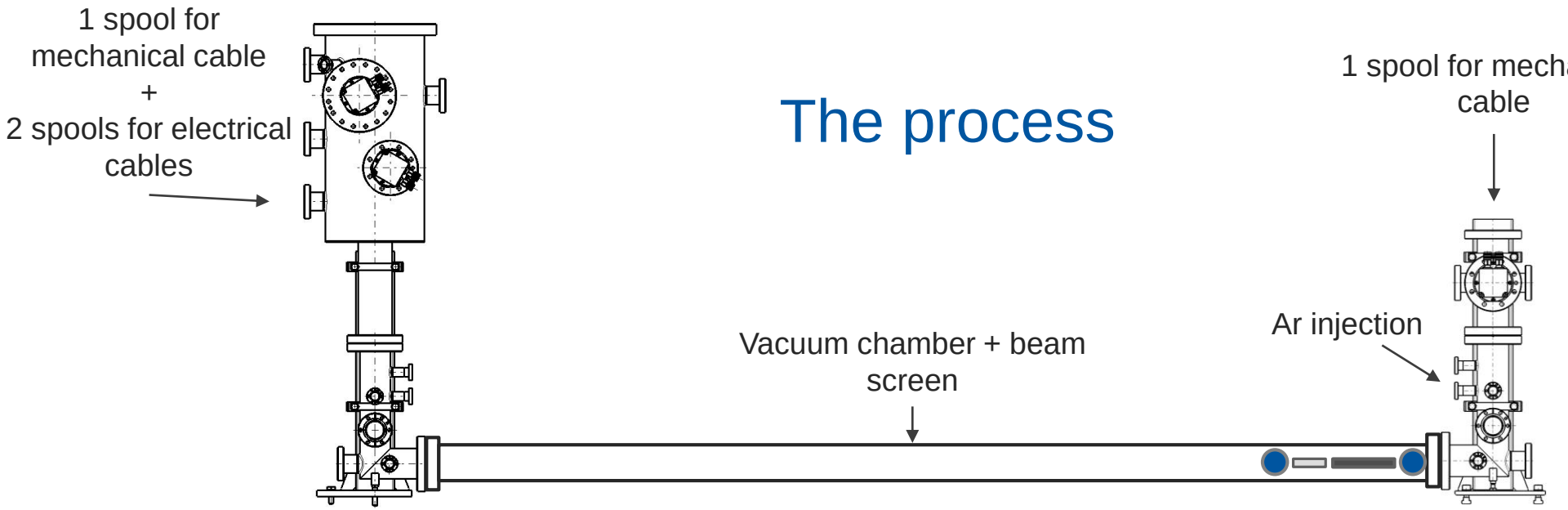
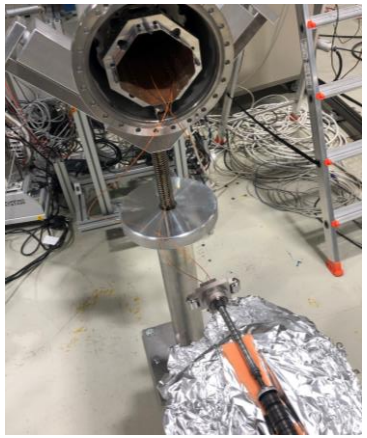
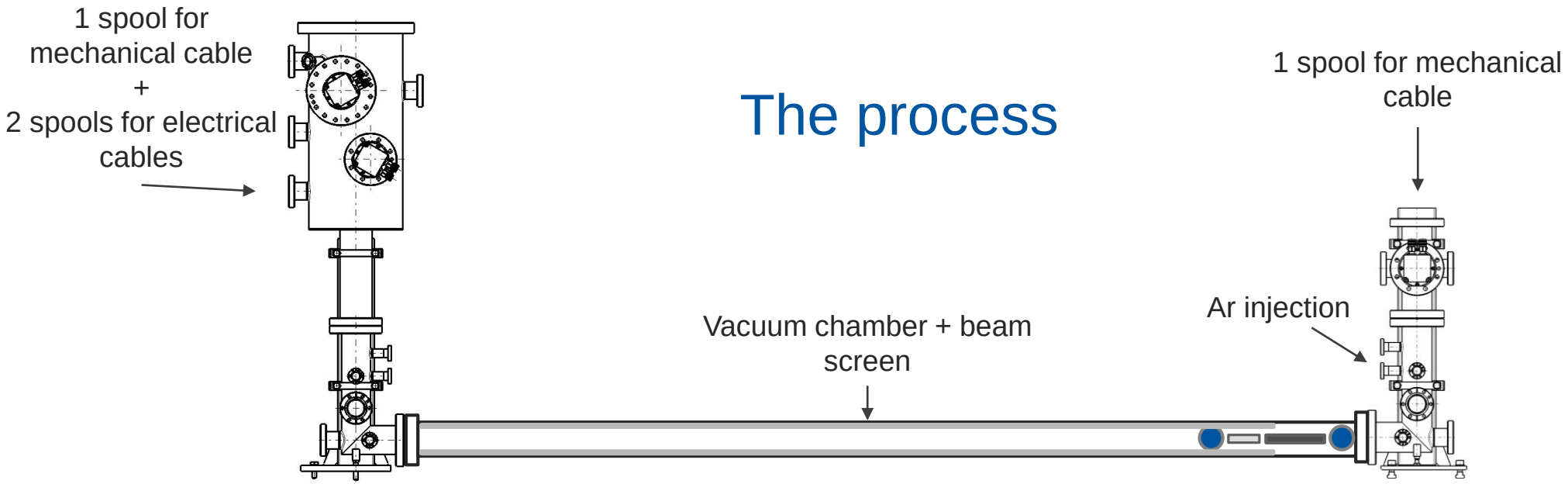


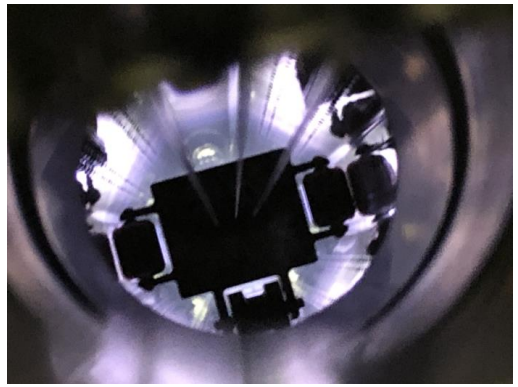


2 – Coating process

- Assembly the vacuum chamber + beam screen
- Optical inspection
- Ion etching to enhance adhesion
- Vent to N_2-O_2 mixture & Assemble coating
- Ti pre-layer ~100 nm

The process



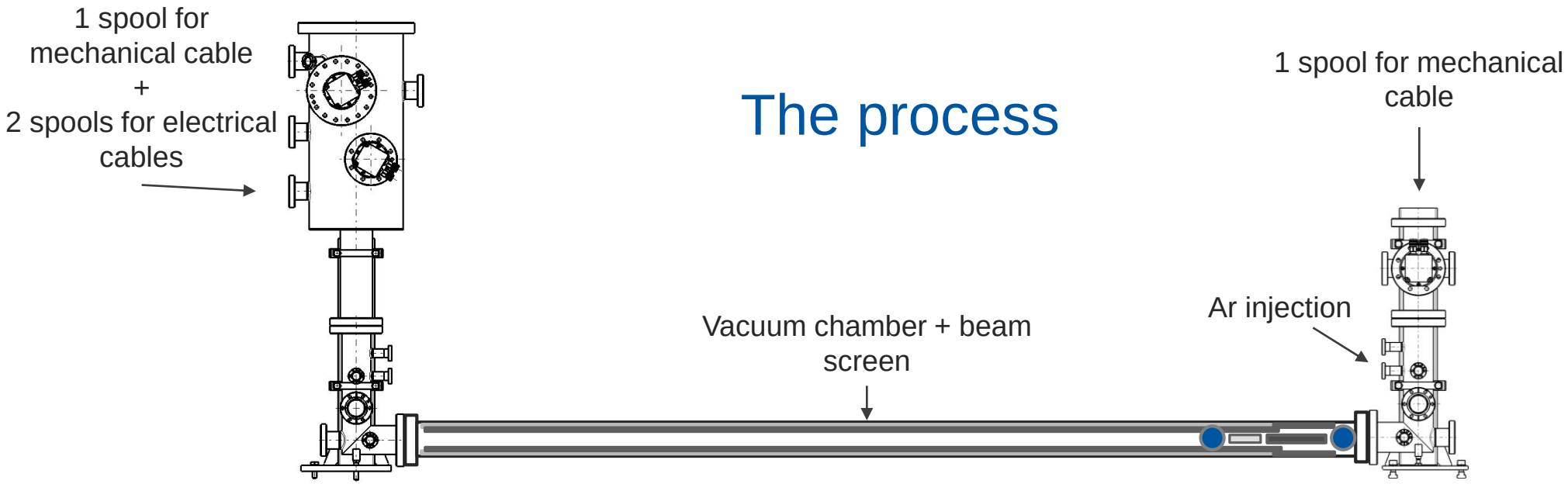


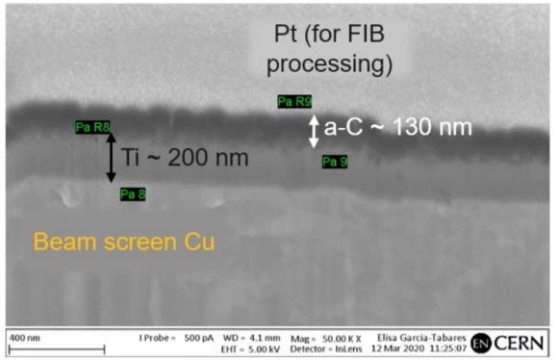
1st step: Ti pre-coating (~100 nm)

2 – Coating process

- Assembly the vacuum chamber + beam screen
- Optical inspection
- Ion etching to enhance adhesion
- Vent to N_2-O_2 mixture & Assemble coating
- Ti pre-layer ~100 nm
- C coating with Ti flashes ~100 nm C; ~150 nm Ti

The process





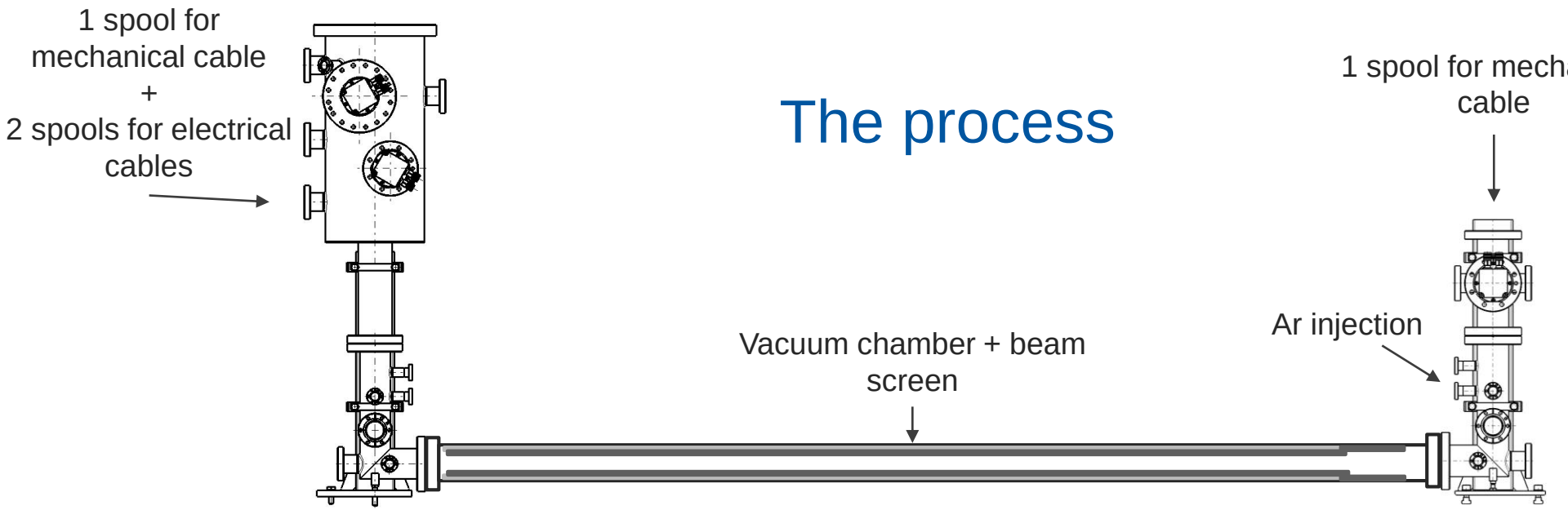
1st step: Ti pre-coating (~100 nm)

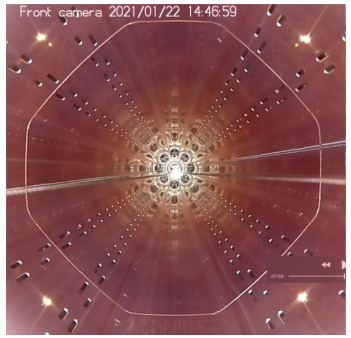
2st step: carbon coating ~100 nm (with Ti flashes ~150nm)

2 – Coating process

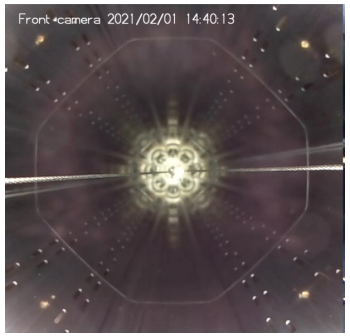
- Assembly the vacuum chamber + beam screen
- Optical inspection
- Ion etching to enhance adhesion
- Vent to N_2-O_2 mixture & Assemble coating
- Ti pre-layer ~100 nm
- C coating with Ti flashes ~100 nm C; ~150 nm Ti
- Optical inspection

The process





Before coating



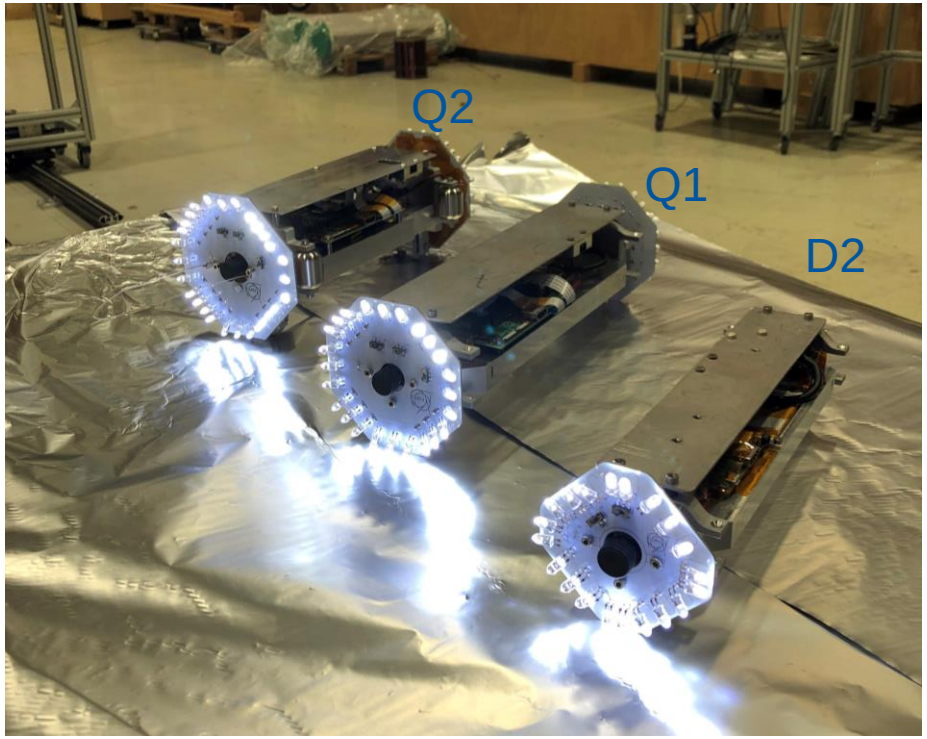
After coating

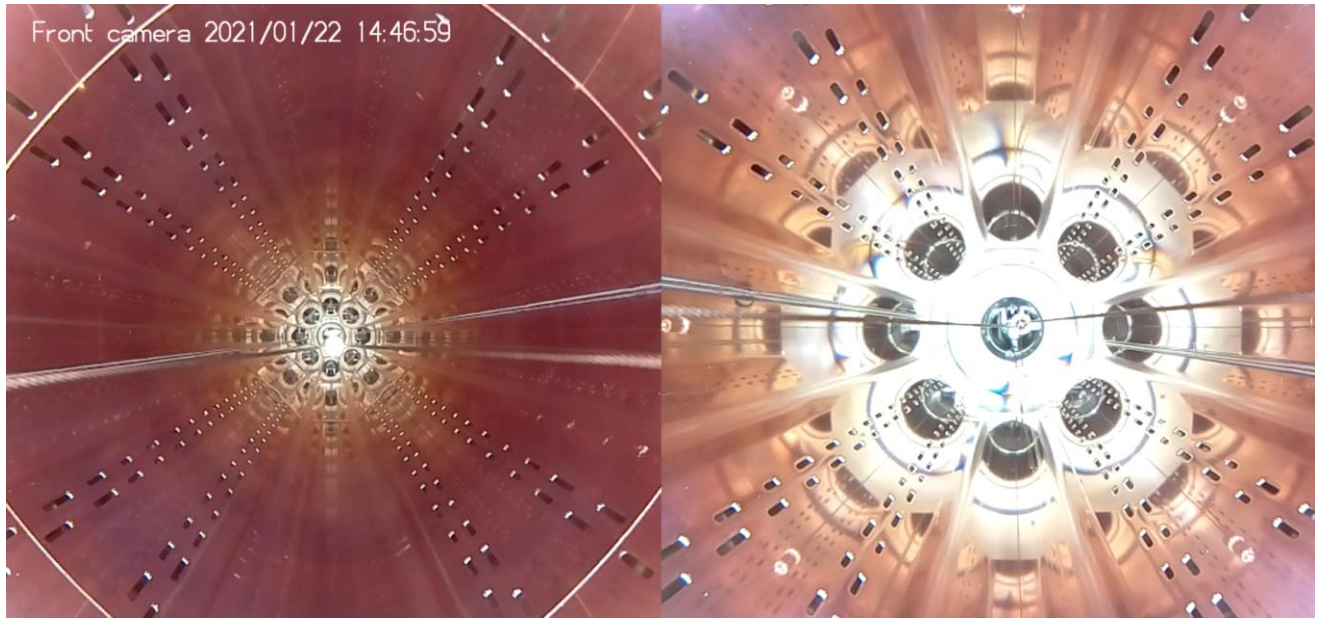
3 – Coating technology

- Visual inspection
- Ion Etching
- Coating
- Coating facility

Visual inspection

Visual inspection is performed at different steps to check the status of the beam screen.

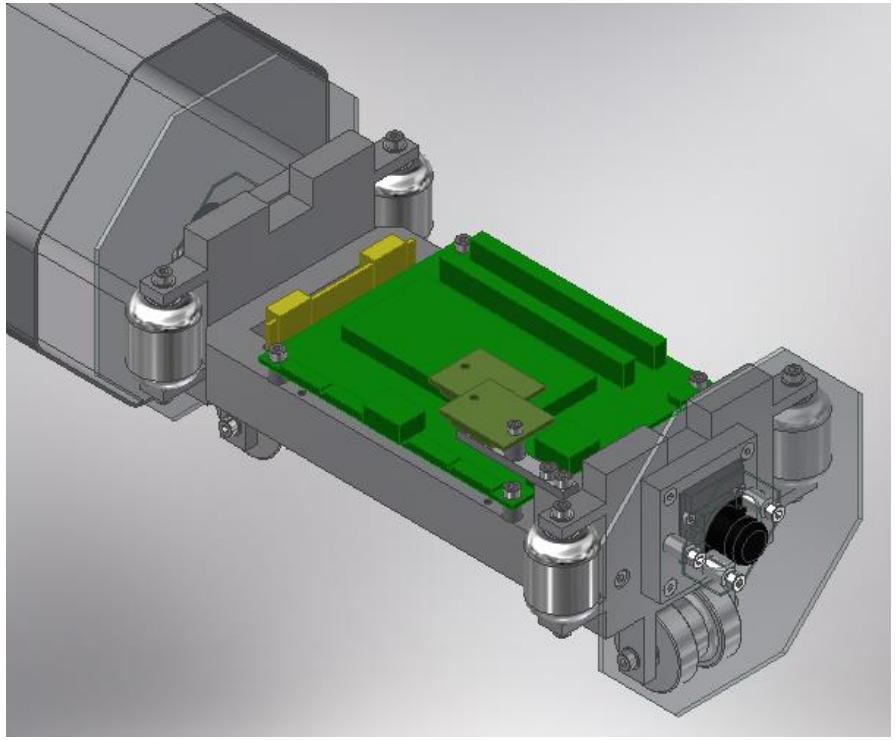


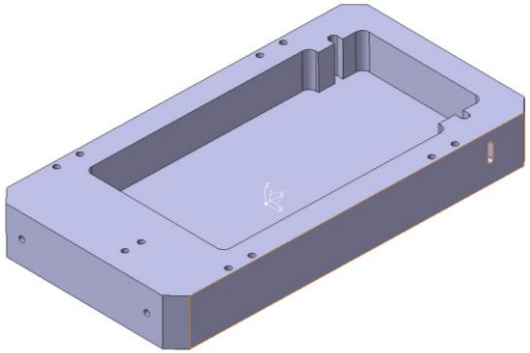


Camera device for each type of beam screen

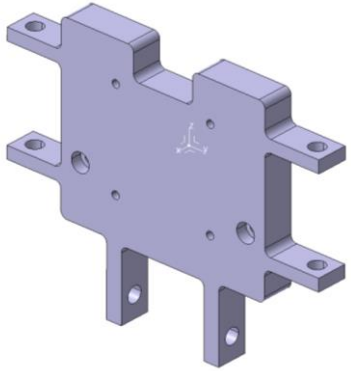
Visual inspection

Electronic boards assembly





Main body of the camera train, to enclose all the electronic part.

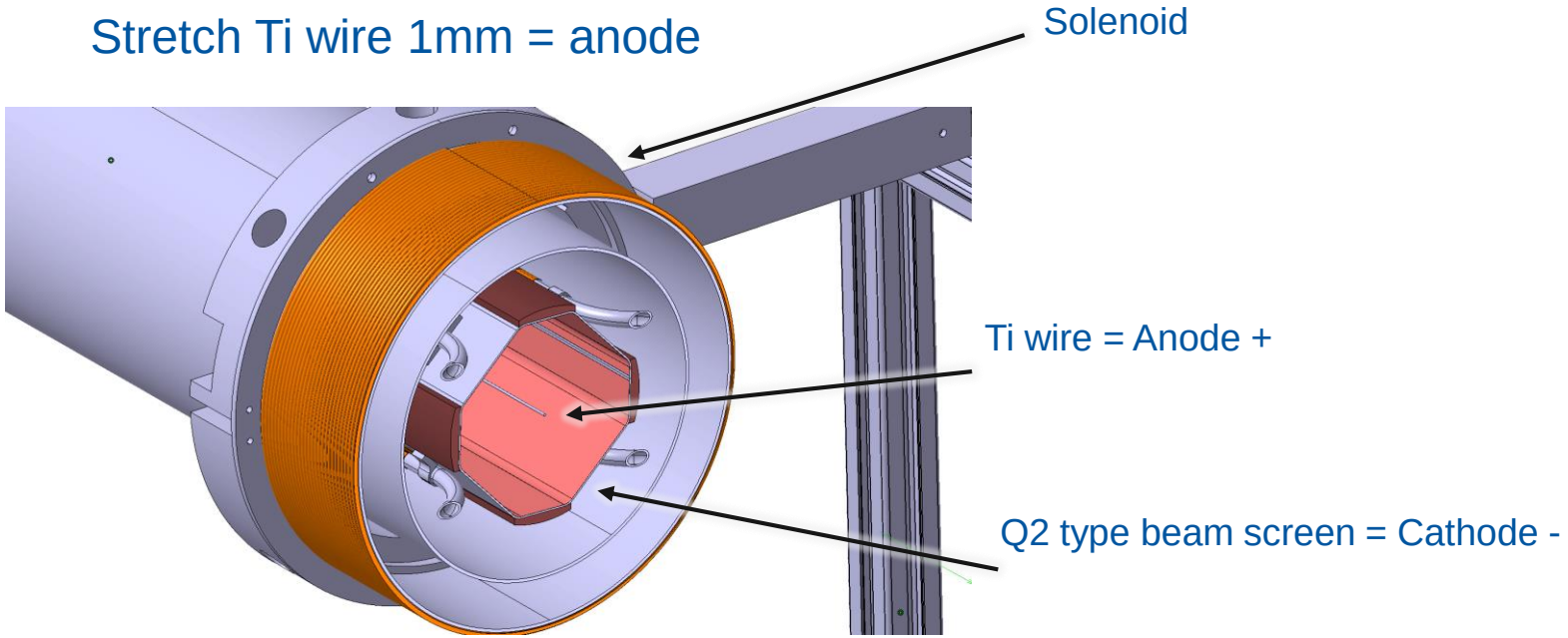


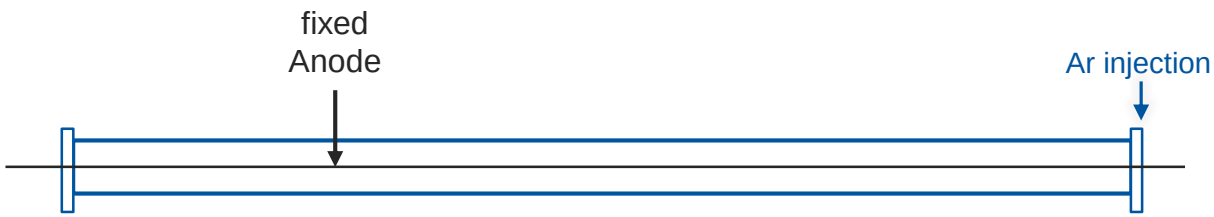
Front piece to hold the camera and the LED lights

Due to their complex shape CNC machining was used

Ion etching system

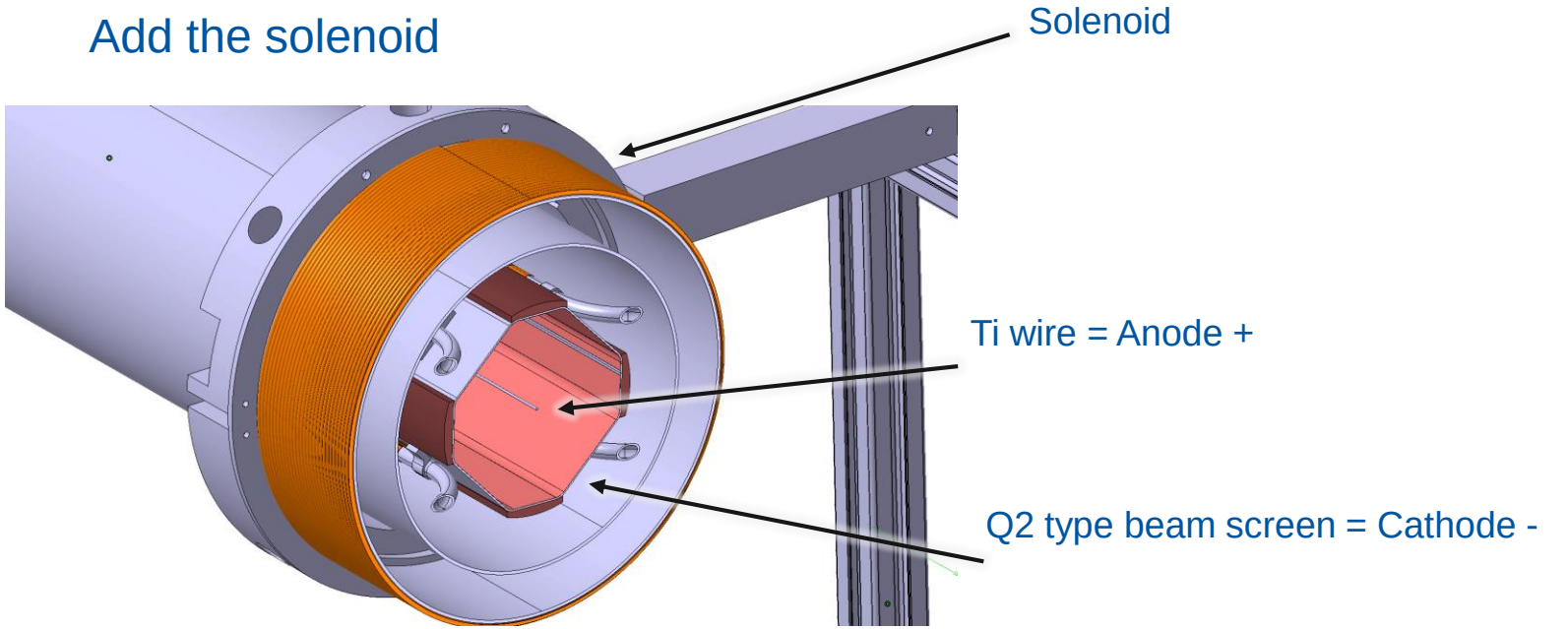
Stretch Ti wire 1mm = anode

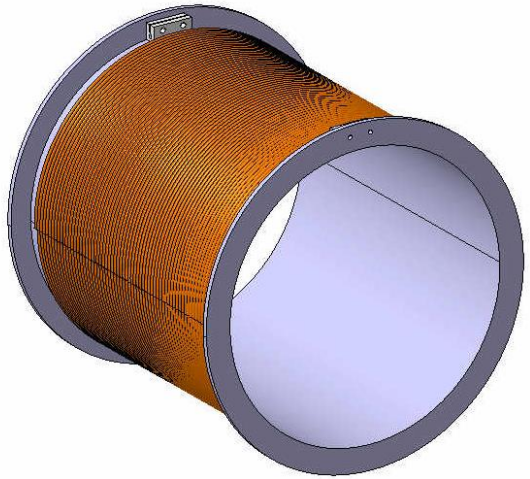


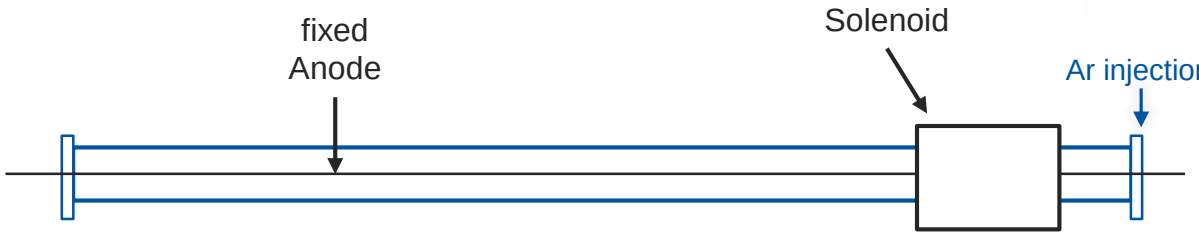


Ion etching system

Add the solenoid

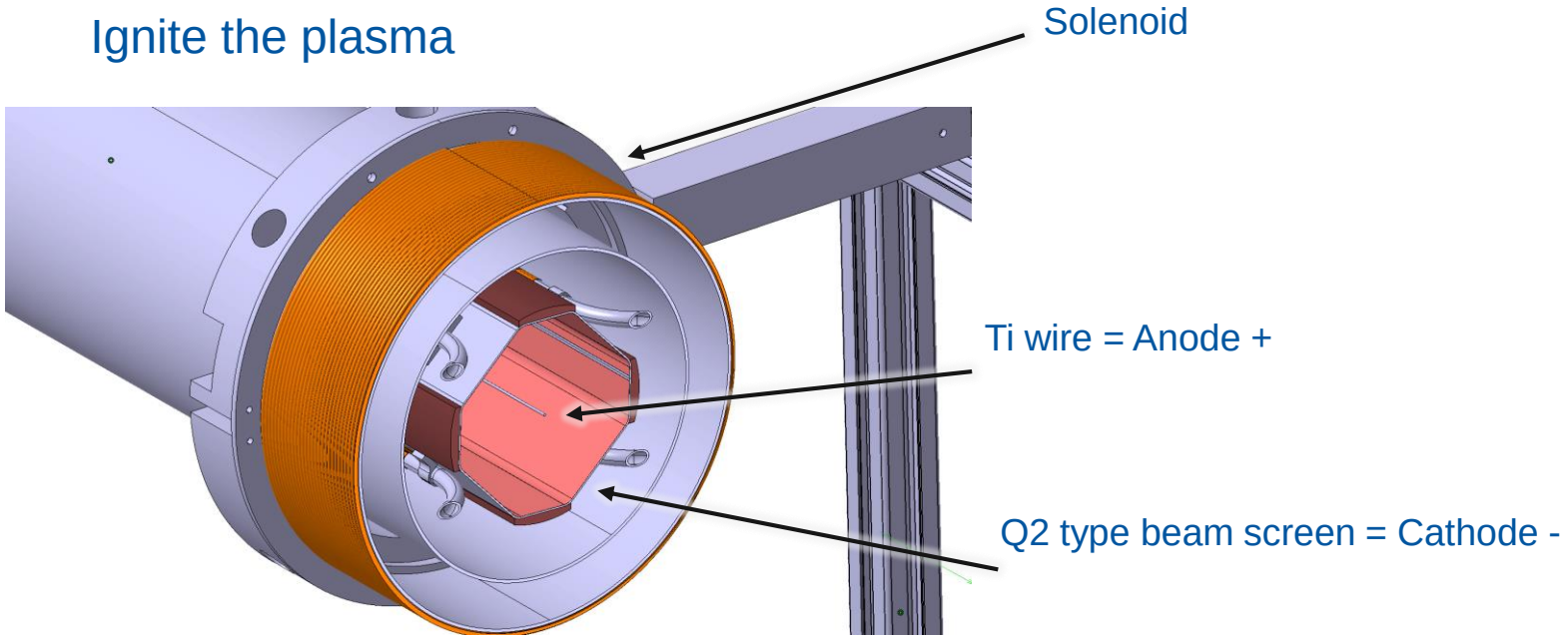






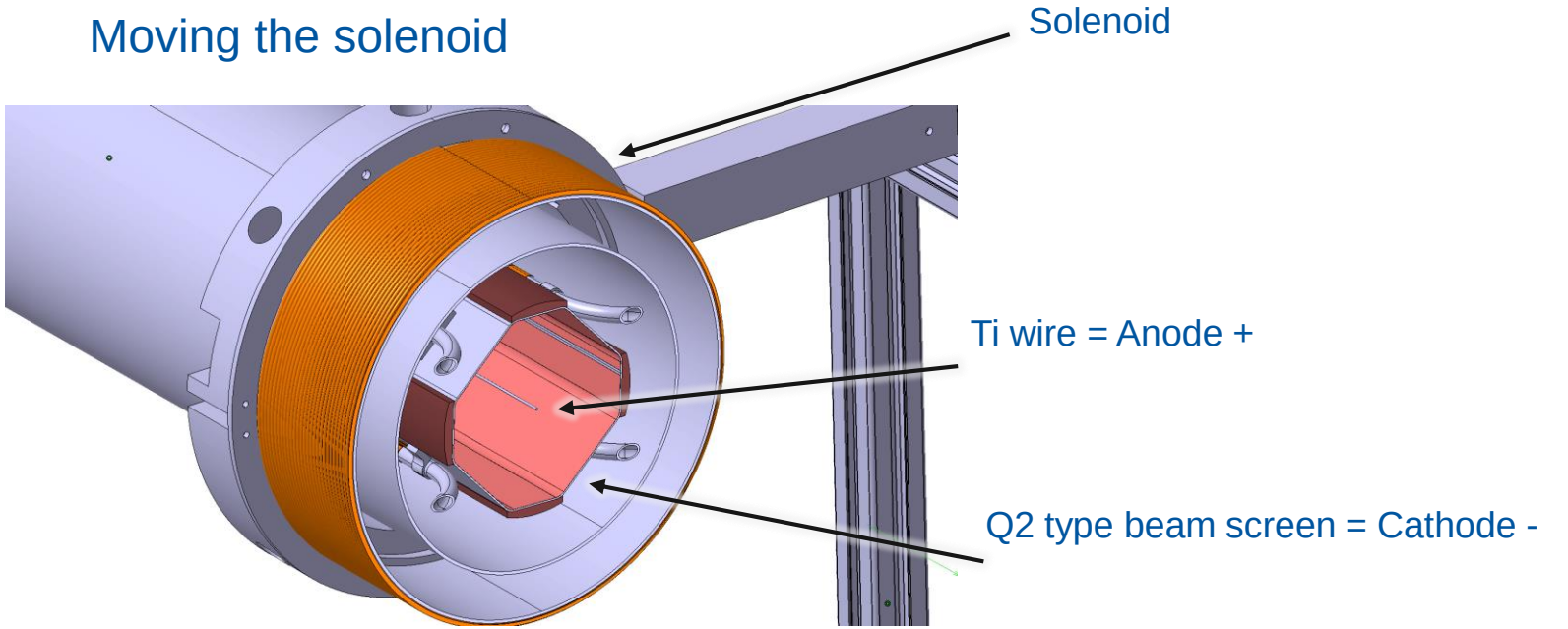
Ion etching system

Ignite the plasma



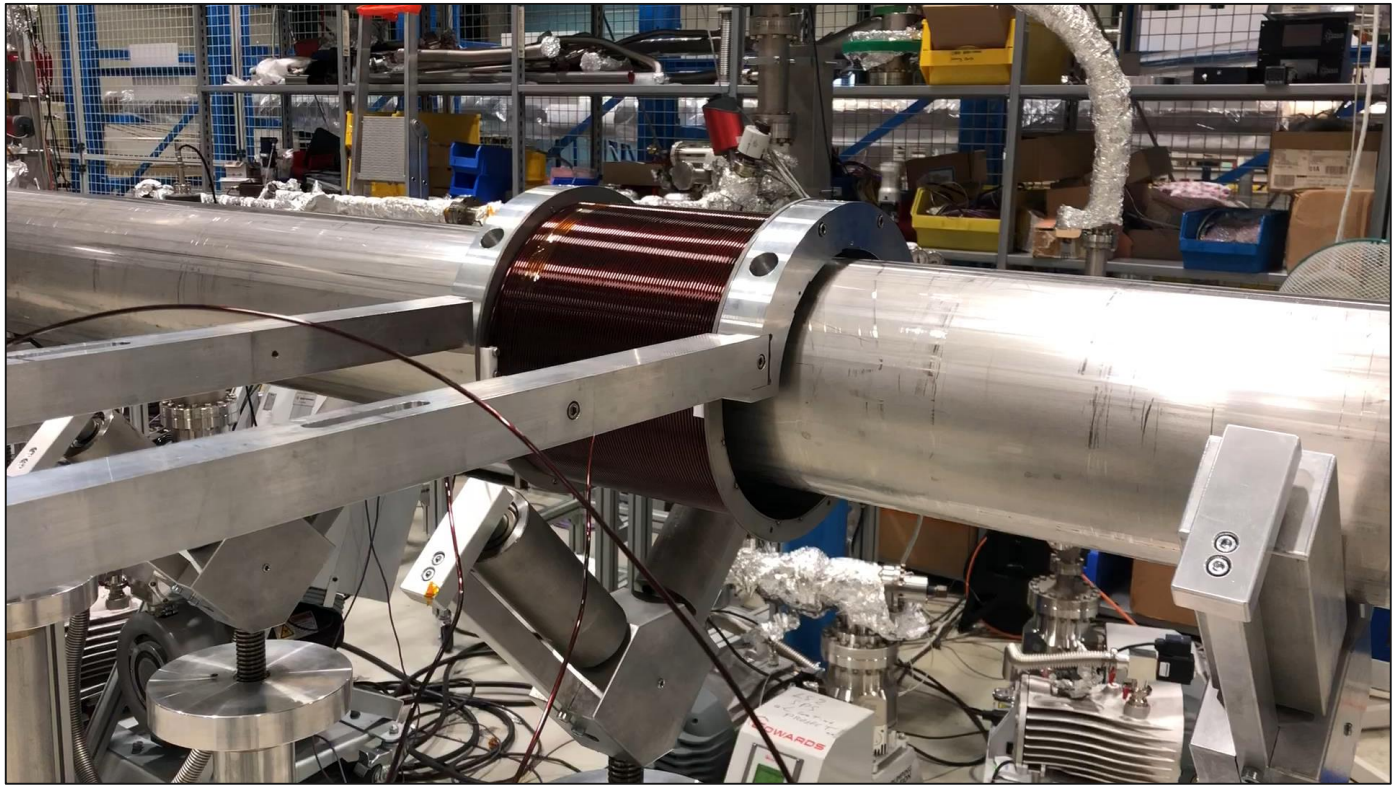
Ion etching system

Moving the solenoid



Ion etching system

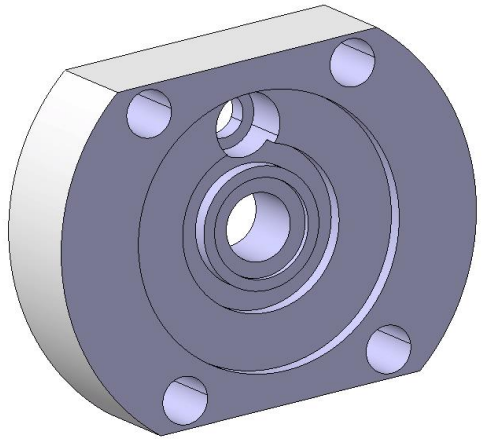
Rail displacement system



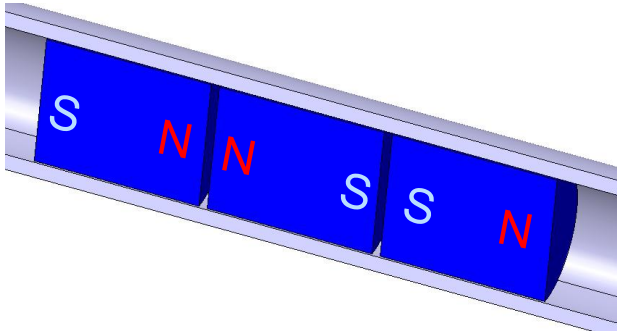
Coating device

Graphite target

Ceramic for electrical isolation

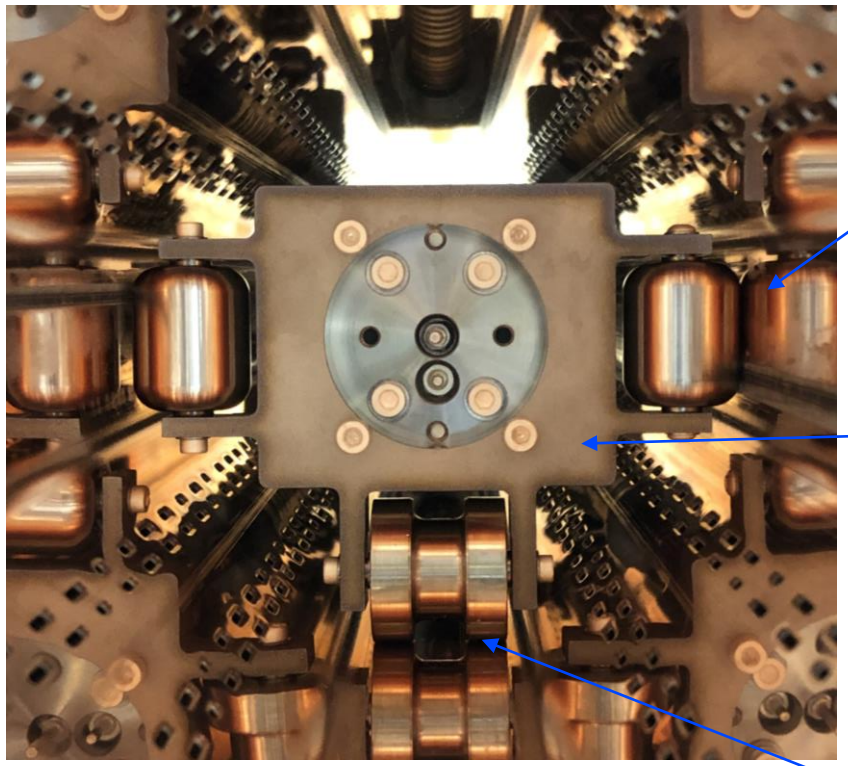


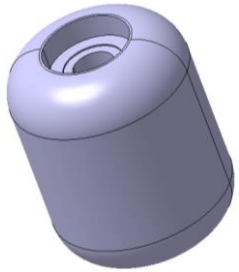
Magnetic circuit with permanent magnets



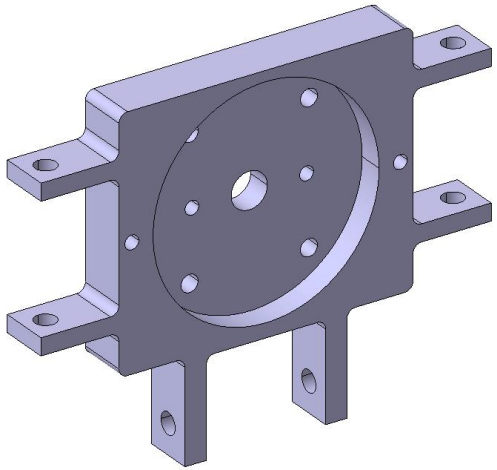
Ti target used as getter pump

Coating device

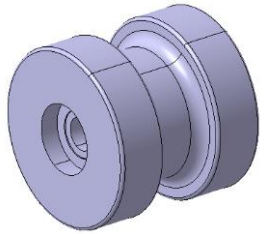




Sides wheels with special shape in order not to scratch the surface

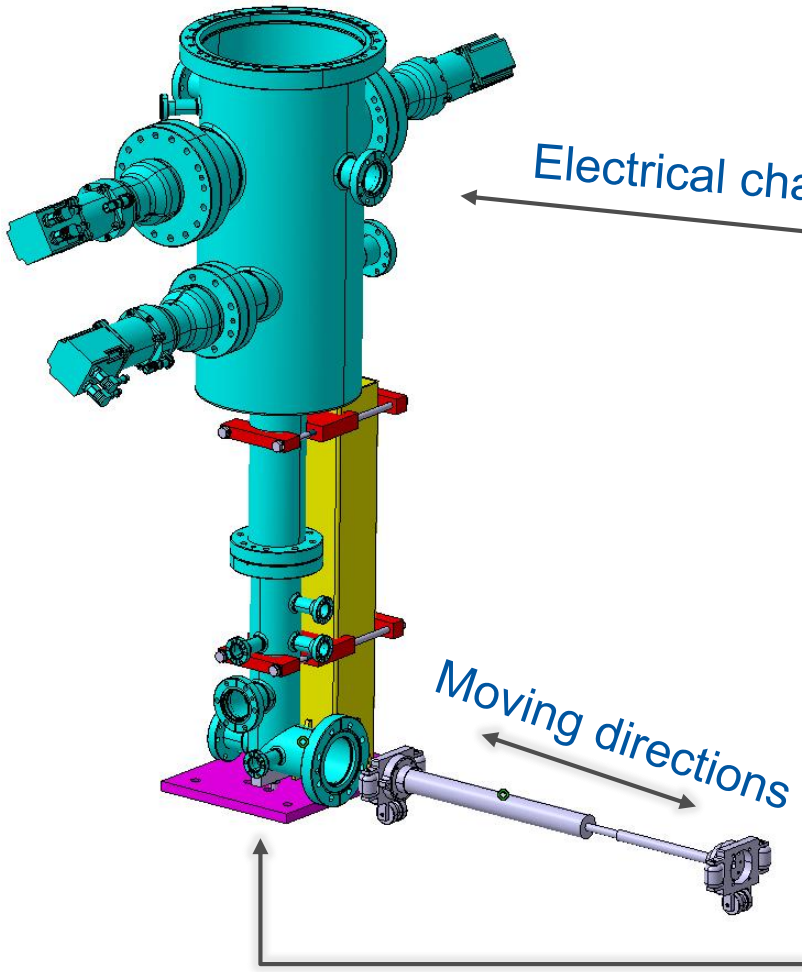


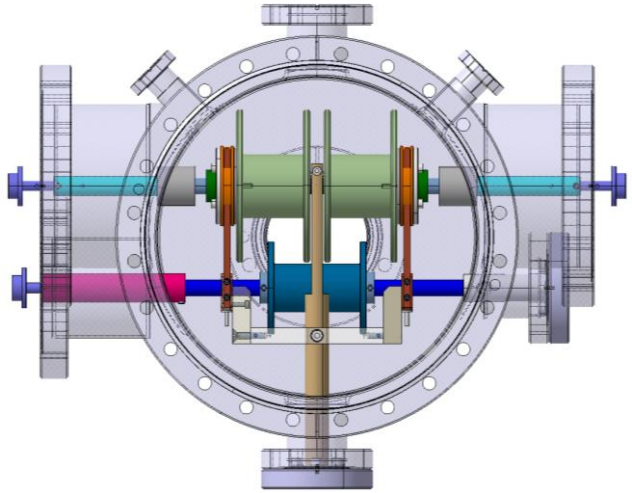
Guiding, centering support to hold the wheels and the cathode. Made from Ti in order to limit the forces from the weight on the film



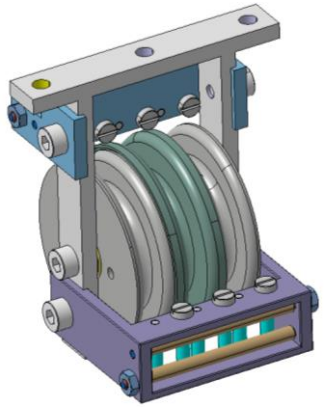
Central wheel rolling in the flat area of the beam screen

Coating system



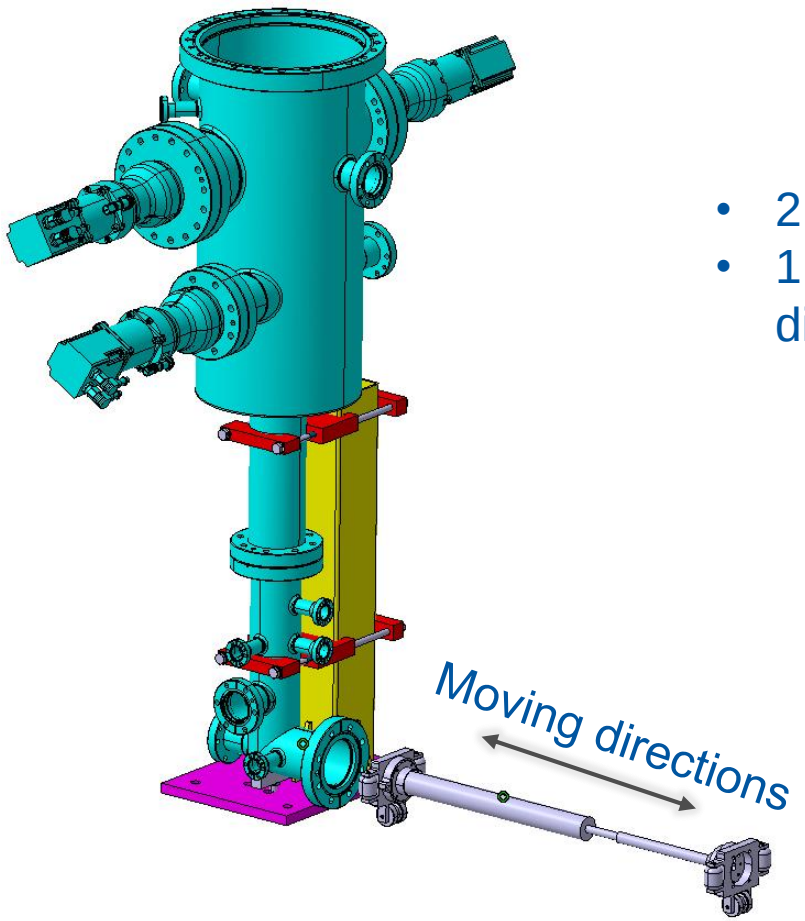


1 spool for mechanical cable
+
2 spools for electrical cables

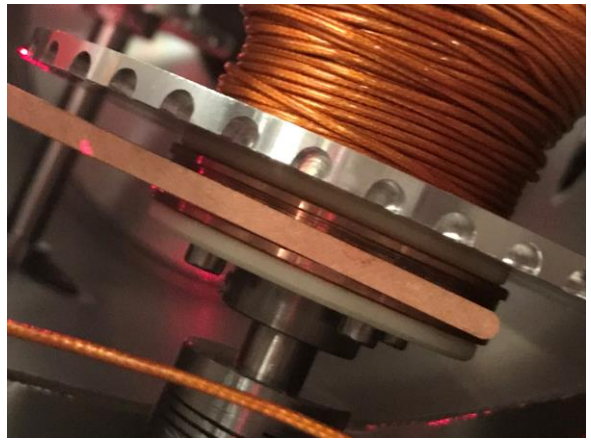


Coating system

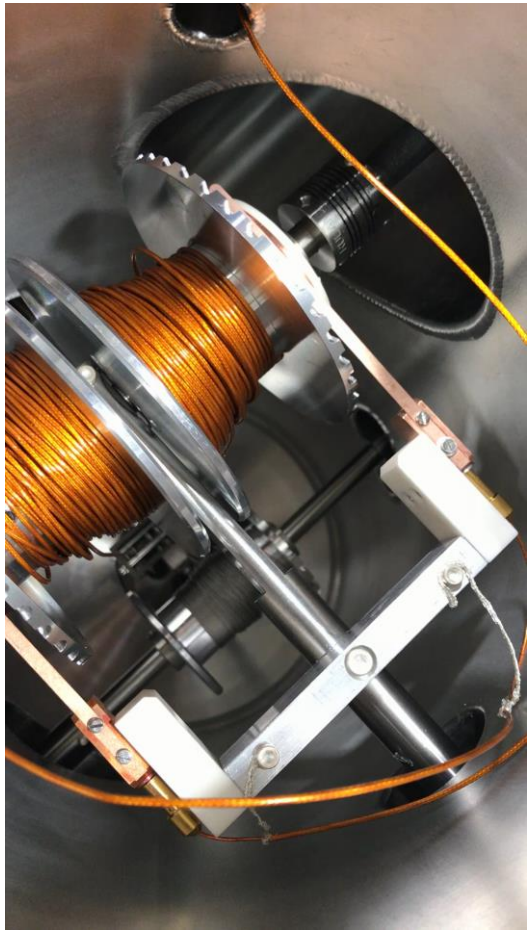
Electrical chamber



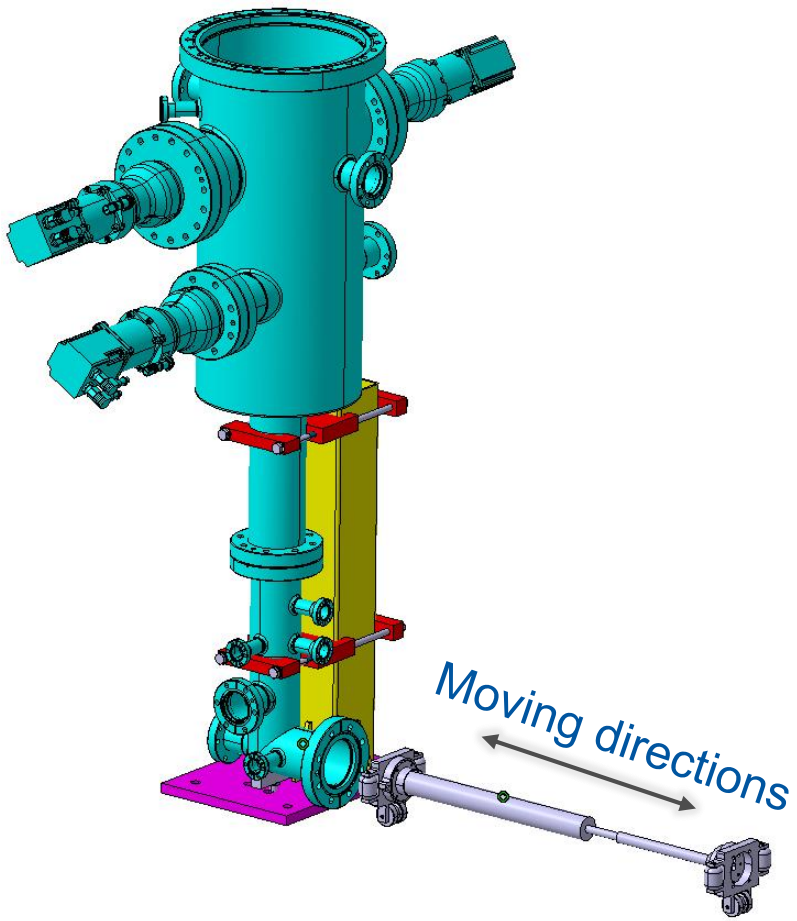
- 2 electrical cables to power the 2 cathodes
- 1 mechanical wire to move the train on both directions



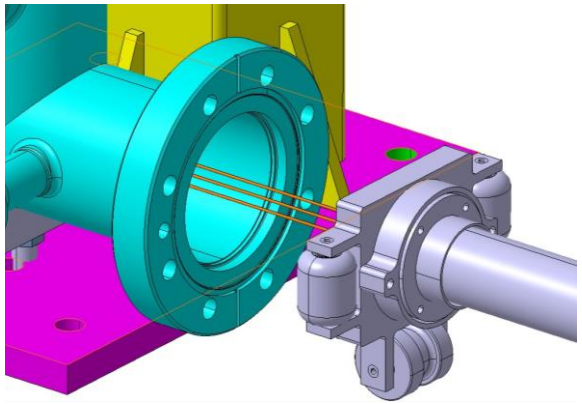
Beryllium copper finger in order to have continuously electrical contact while turning

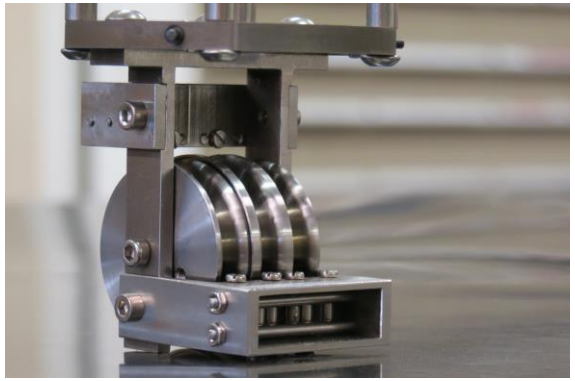


Coating system



Guiding for wires





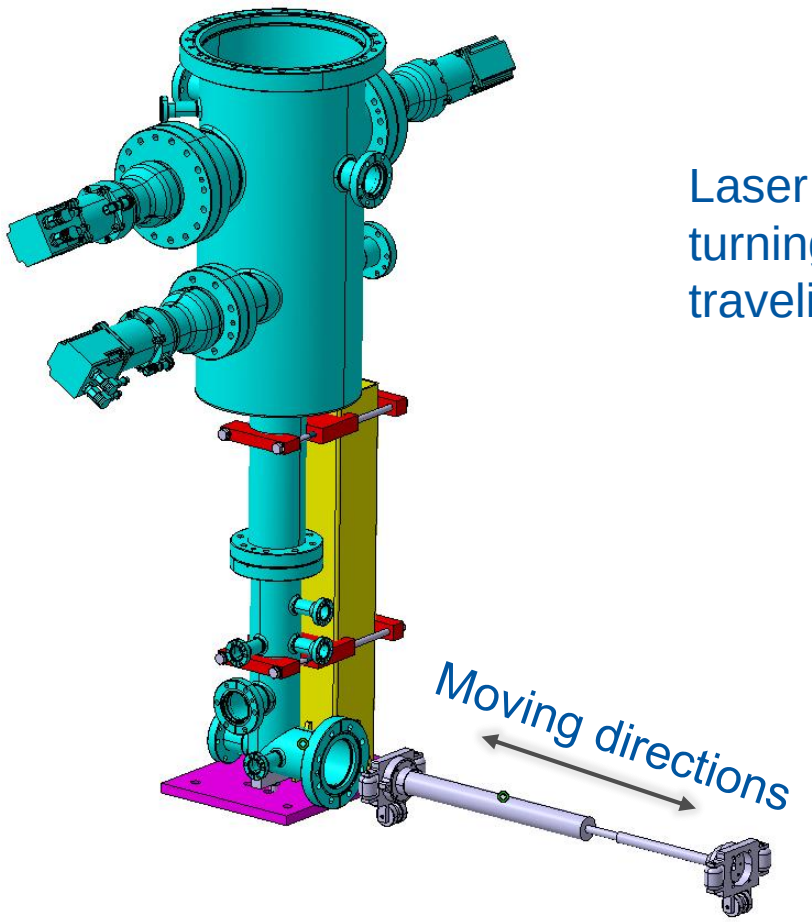
3 independent spools

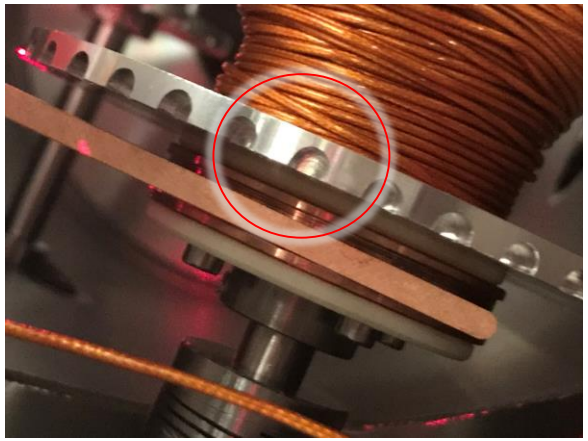
Wire rollers to avoid friction

Coating system

Laser encoders

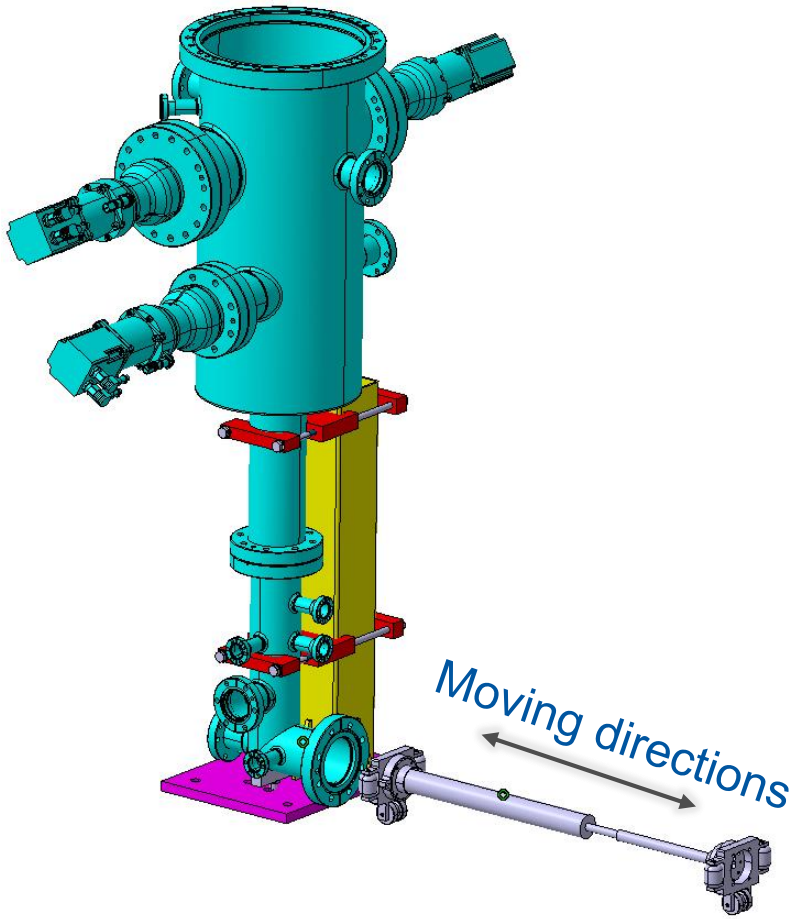
Laser encoders used to insure the consecutive turning of the spools and measure the traveling distance of the trains





Groove for the signal

Coating system



First mechanical assembly in 2016

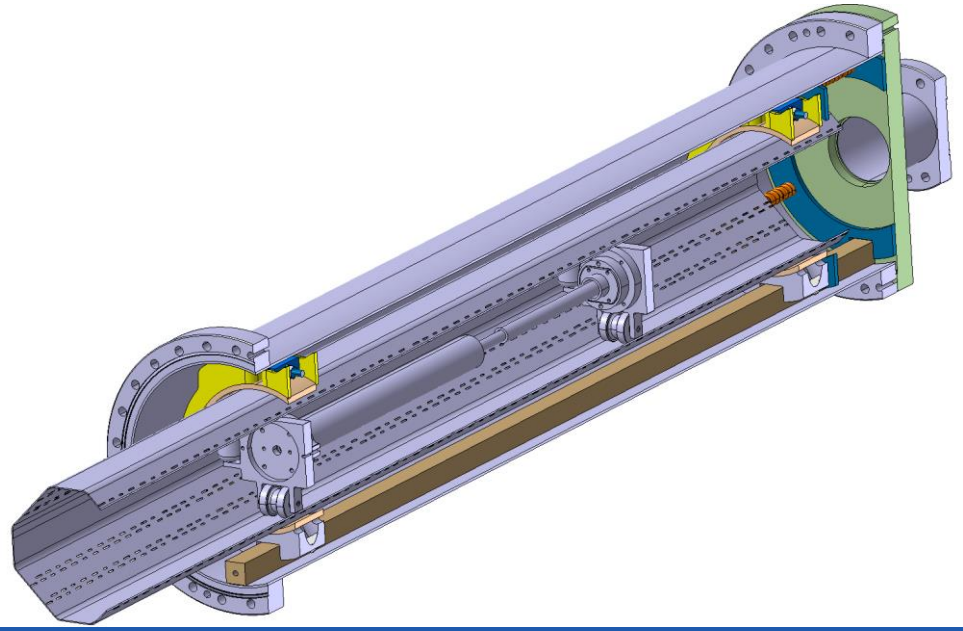
First full assembly of the production system in 2022

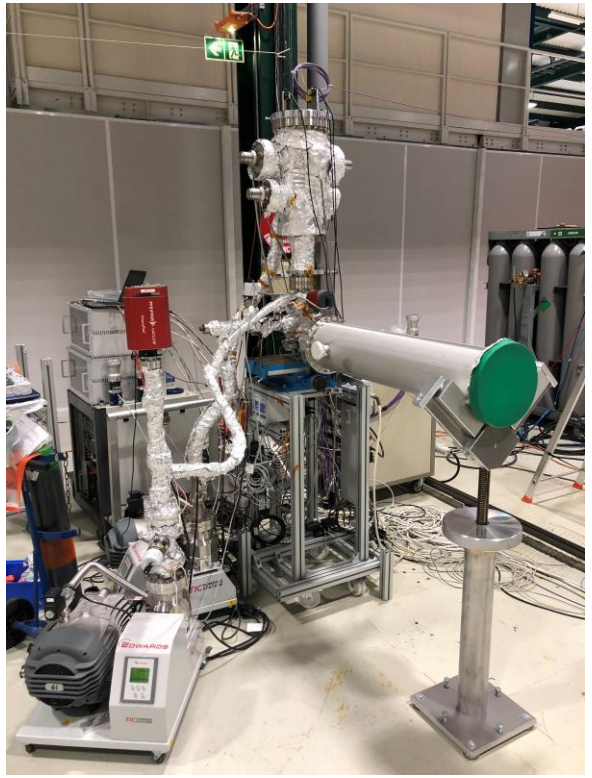
Coating facility in SMA18

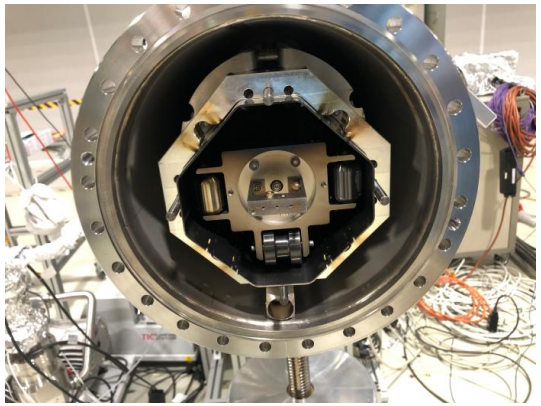
1m extensions were added in each extremity.

Purposes of the extensions

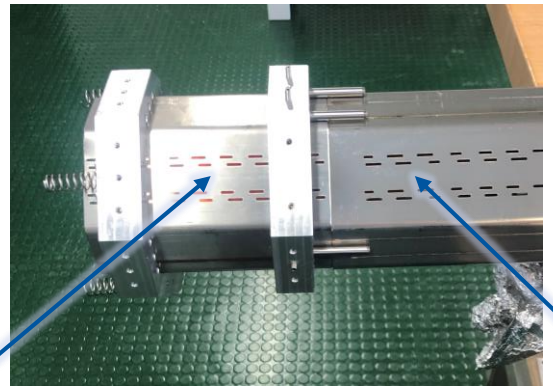
- Storage of the train cathode between different run
- Place to burn-in the targets
- Insure thickness uniformity in the extremities
- Ensure the interconnection with the beam screen







Fist prototype of the extension



Coating facility in SMA18

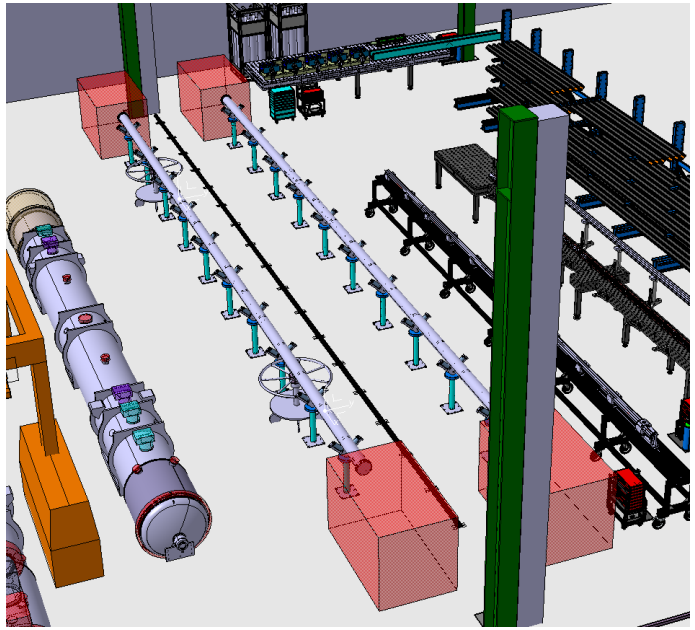


Image by Fabrice SANTANGELO

3 weeks to coat 1 beam screen

+

2 coating benches

=

2 beam screens coated every 3 weeks

Starting the first 5 beam screens in 2023 ramp up the production in 2024-2025

4 – Final remarks

- As we couldn’t buy a system to perform the a-C coating in the new beam screen for the new inner triplet magnets, we design and built 2 systems.

- The system was validated for the film adhesion and the SEY and it is ready for the production phase.

People work in this

Thank everybody for your contribution
Merci à tous

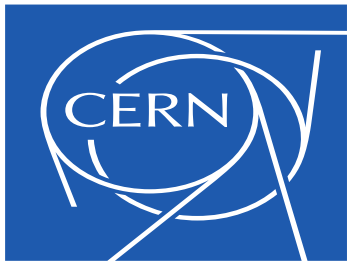
TE-VSC

EN-MME

Pedro COSTA PINTO, Angelo COSTA, Nicolaas KOS, Hendrik KOS, Herve RAMBEAU, Fabrice SANTANGELO, Marco MORRONE, Marc THIEBERT, Pierre MAURIN, Florent FESQUET, Louise VIEZZI, Marcel HIMMERLICH, Martino RIMOLDI, Mauro TABORELLI, David MURGUE, Cedric GARION, Gilles FAVRE, Romain GERARD, Jean-Marie GEISSER, Ana Teresa PEREZ FONTENLA, Stephan PFEIFFER, Antonio MONGELLUZZO, Ian SEXTON, Giovanni MARINARO, Luigi LEGGIERO

Questions?


CERN



www.cern.ch

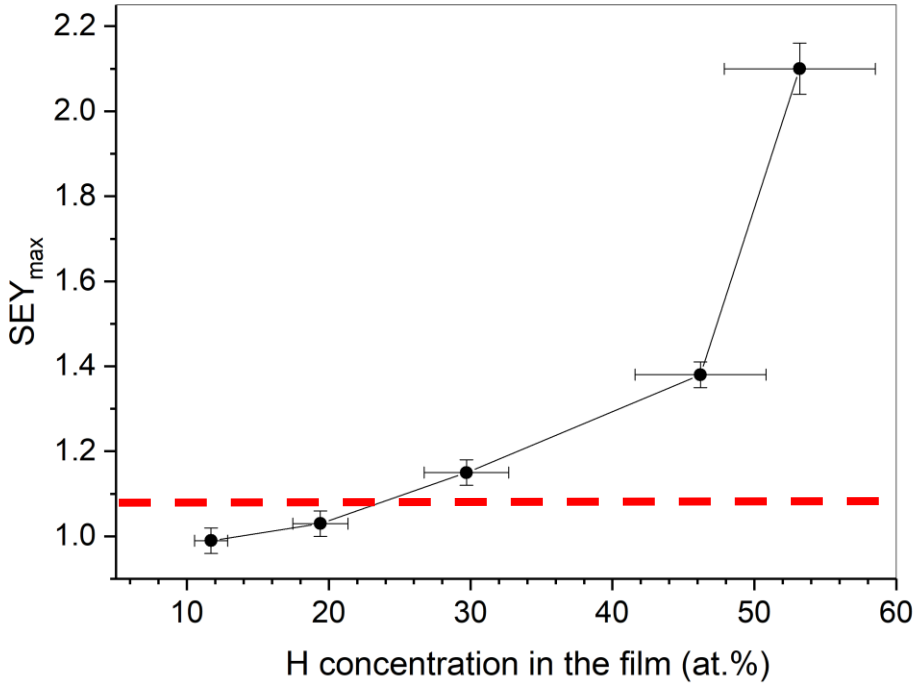
Back up slides

Main Challenges

1. Low Secondary electron emission yield (SEY)
2. Good adhesion

2 – Main Challenges

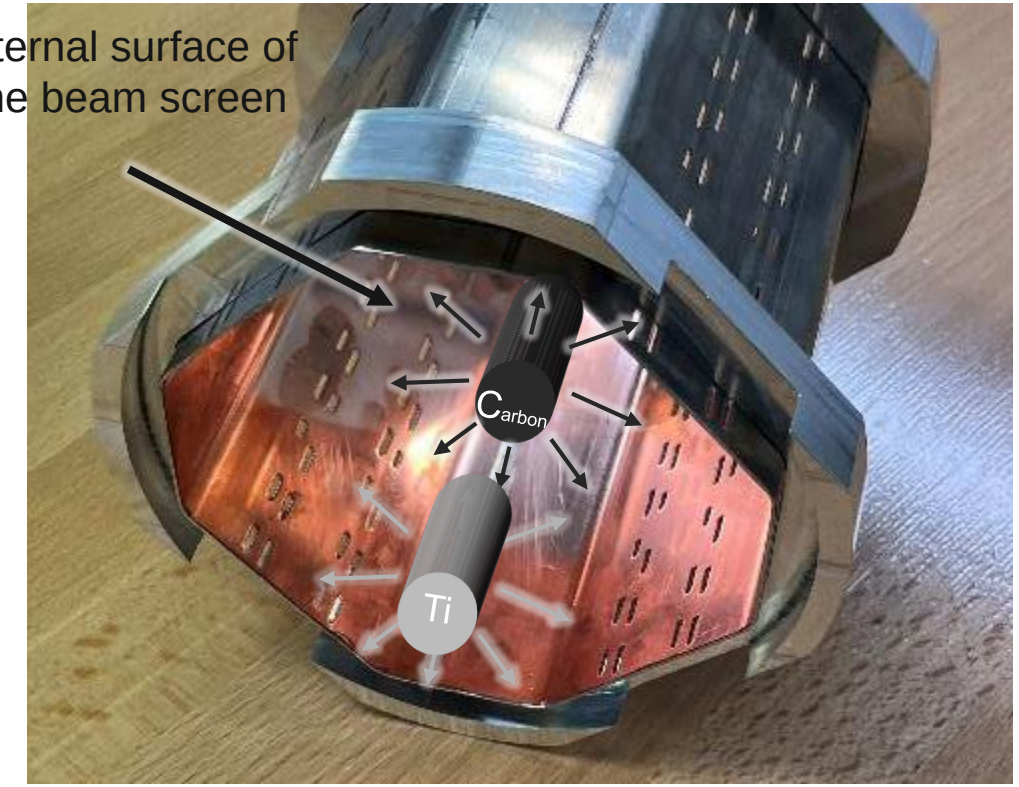
1- Low SEY

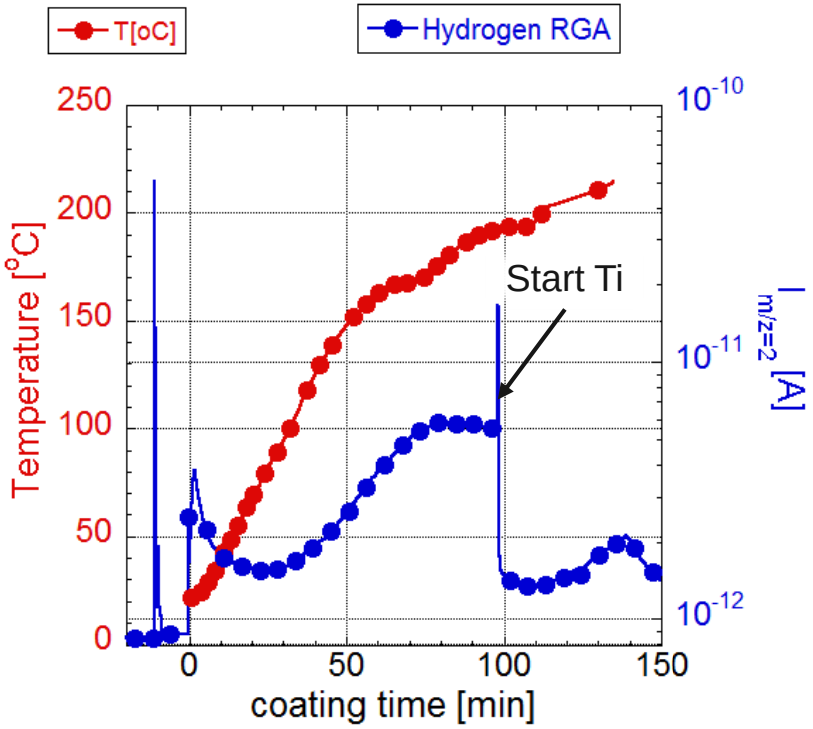


Threshold for E-cloud

H_2 in the discharge gas => H_2 in the carbon film = increase SEY

1- Low SEY





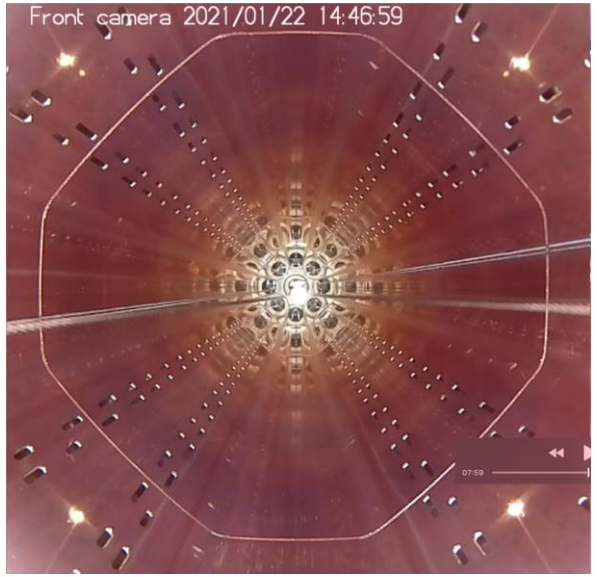
- Ti used as getter pump to reduce Hydrogen in the film

3 – Coating system and process

a-C coating Test – Validating the whole coating process (SEY, adhesion)

BS are manufactured at CERN:

- Sections of 2 m are made of 2 half-shells weld together (longitudinal weld)
- 2m sections weld together (orbital weld), to fulfill the total length



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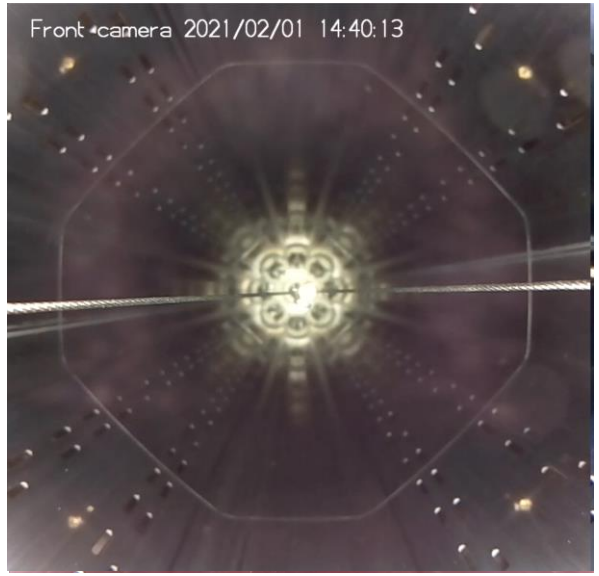
To test the adhesion on the welds, we coated a 2 m BS built from 5 short sections (cut specifically for this test).



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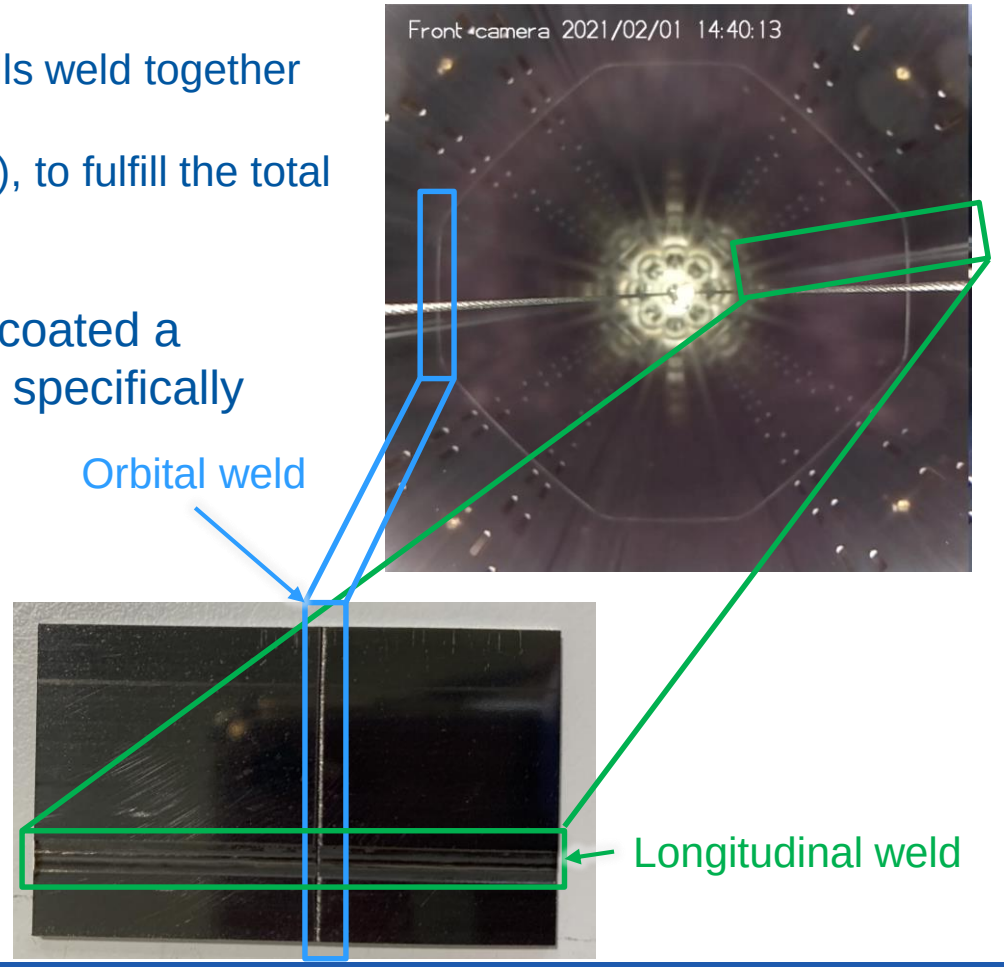
To test the adhesion on the welds, we coated a 2 m BS built from 5 small sections (cut specifically for this test).

Several samples, that contain both orbital and longitudinal welds, were cut.

$SEY_{max} = 1.02$ ✓

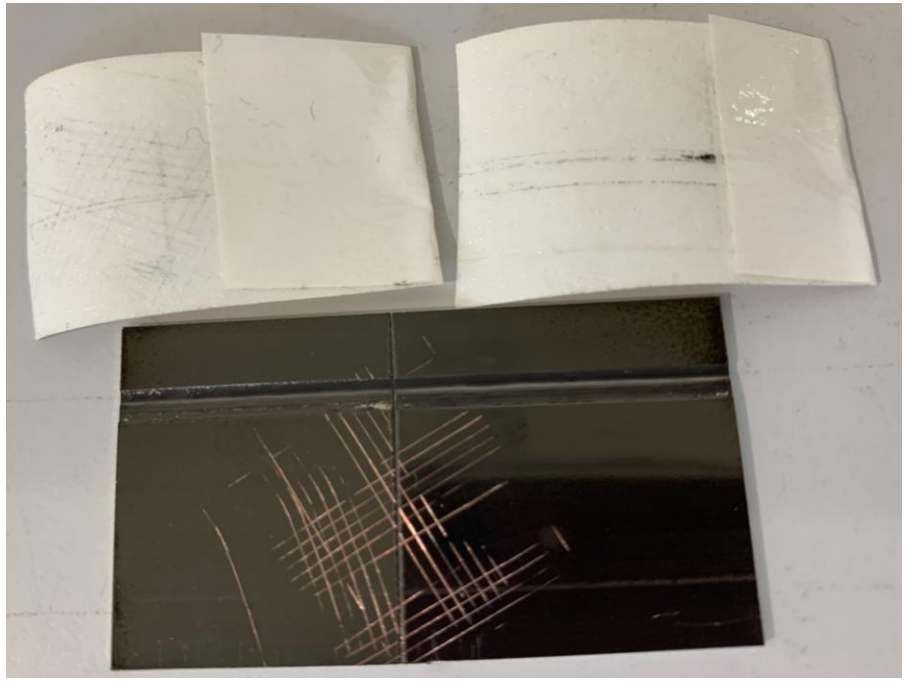


3 – Coating system and process

a-C coating Test – Validating the whole coating process (SEY, adhesion)

Adhesion Test by the ”cross-hatch” method – ***after 10 thermal quenches by dipping in liquid N_2***

- Good adhesion on the copper surface even after the thermocycling procedure



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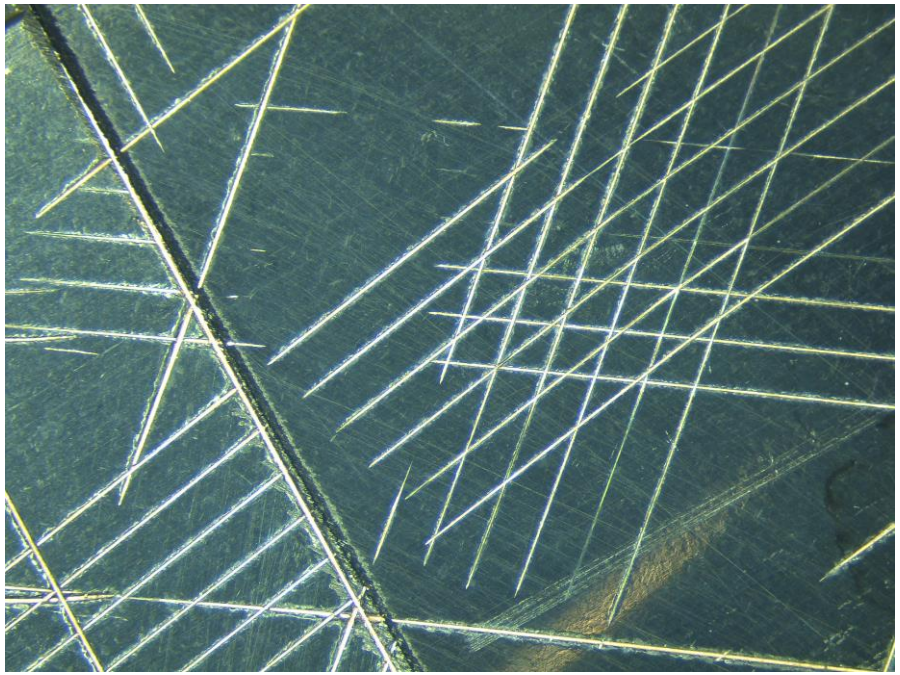

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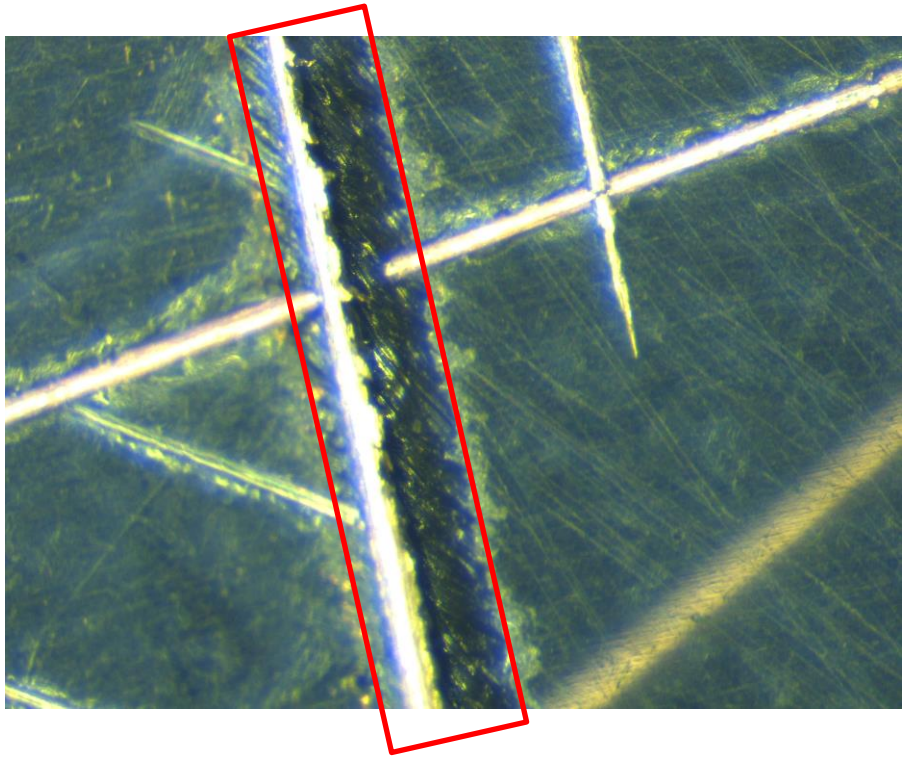
- Good adhesion observed on the **orbital weld** that joins different beam screens



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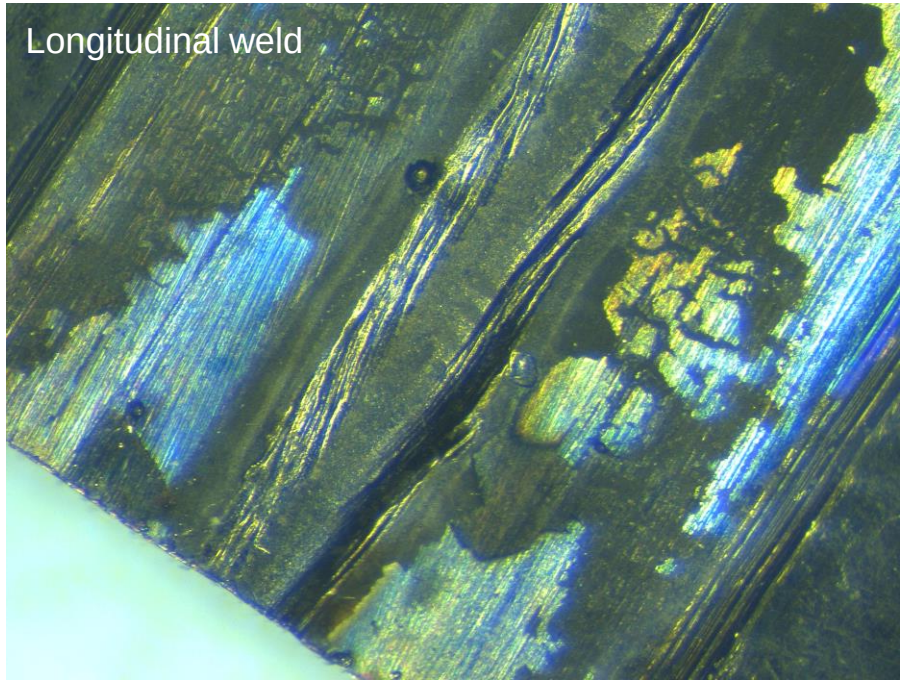
- **Delamination** on the longitudinal weld



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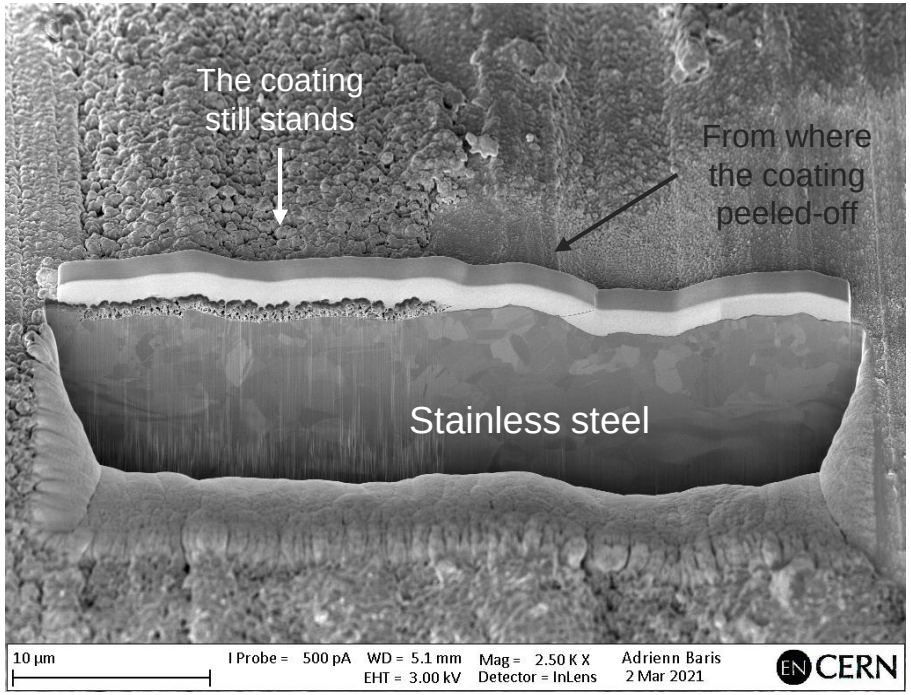


Validation process

Solution found by changing 2 critical domains

1. Changing the welding parameters
2. Add brushing after the welding process

4 – Working plan

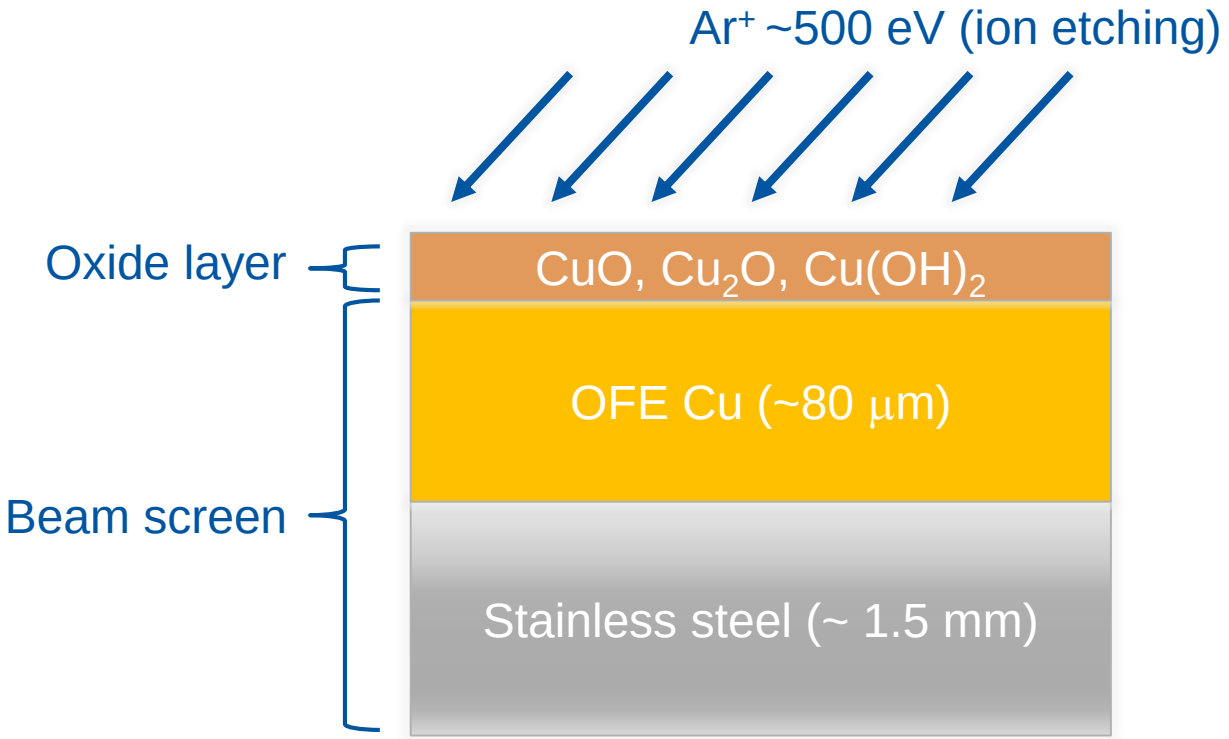
Coatings foreseen for 2023:

- 1 CP early 2023
- 2 D2 mid 2023
- 1 Q3 and 1 Q1 from mid to end 2023

Production rate will increase in 2024-2025, with a maximal capacity of 2 BS every three weeks

2- Good adhesion

Adhesion on copper surfaces is hindered by the presence of hydrocarbons and copper hydroxide
In-situ ion etching + passivation with N_2/O_2 mixture (no H_2O)



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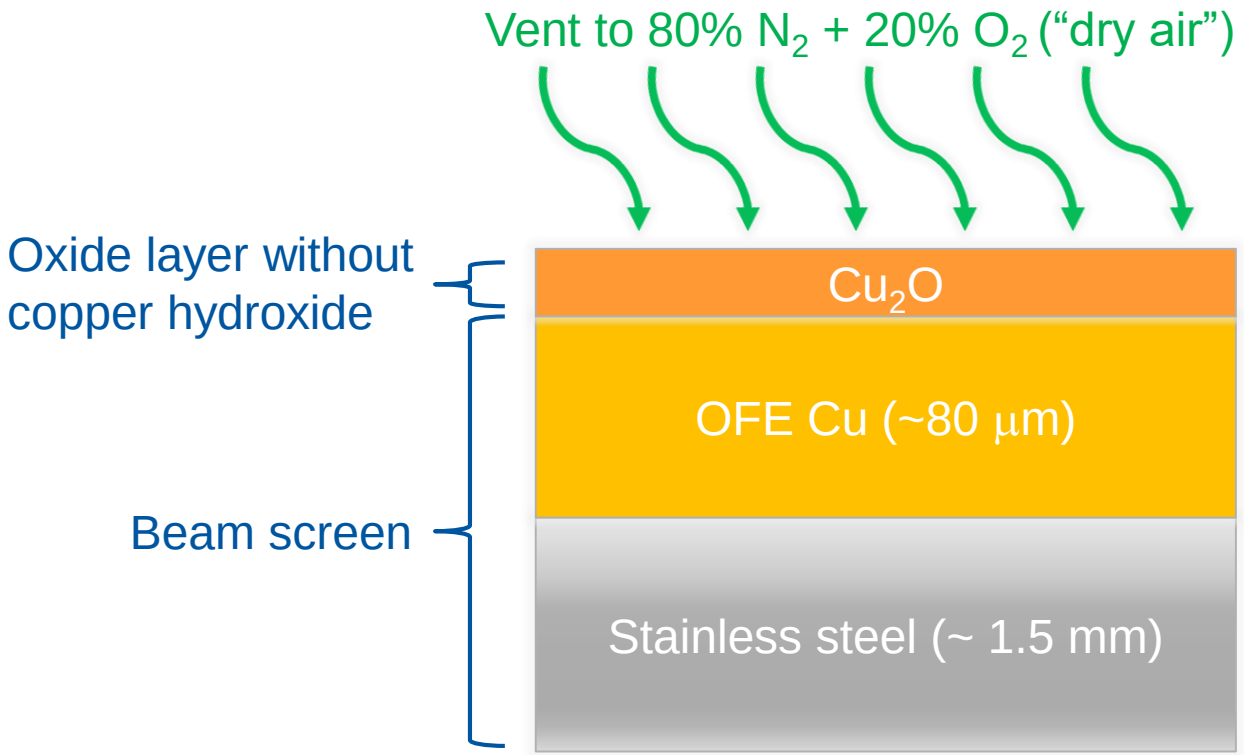

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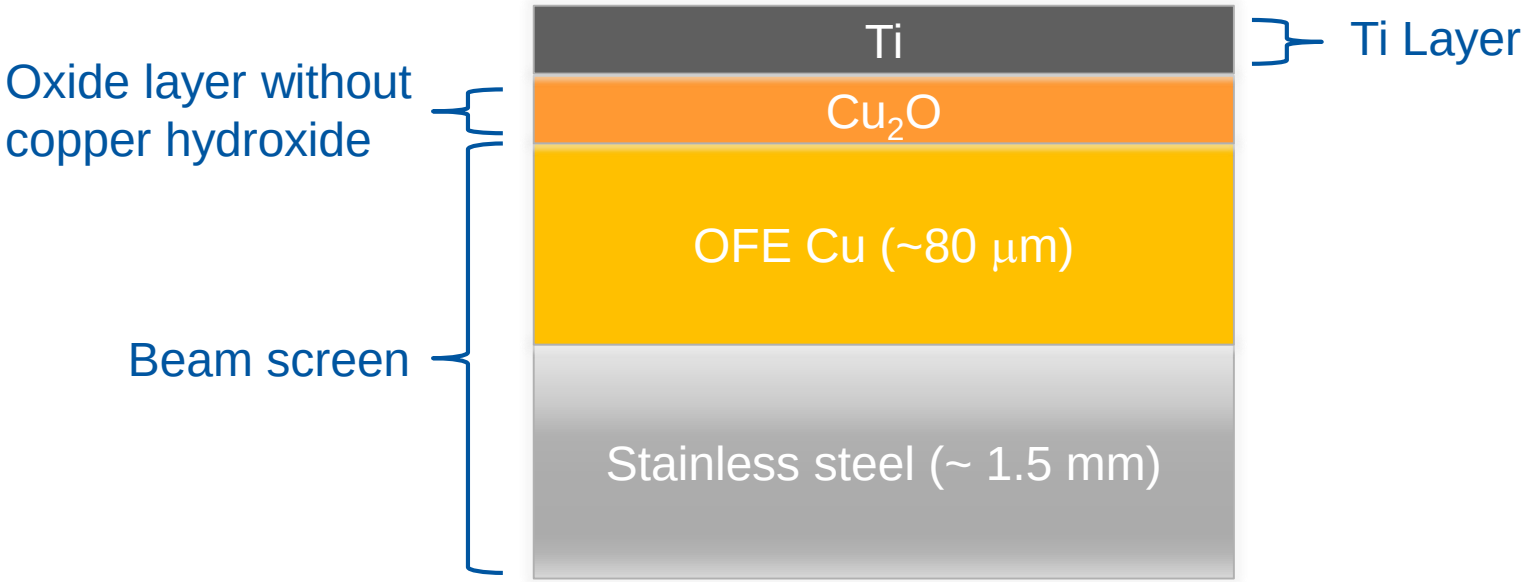

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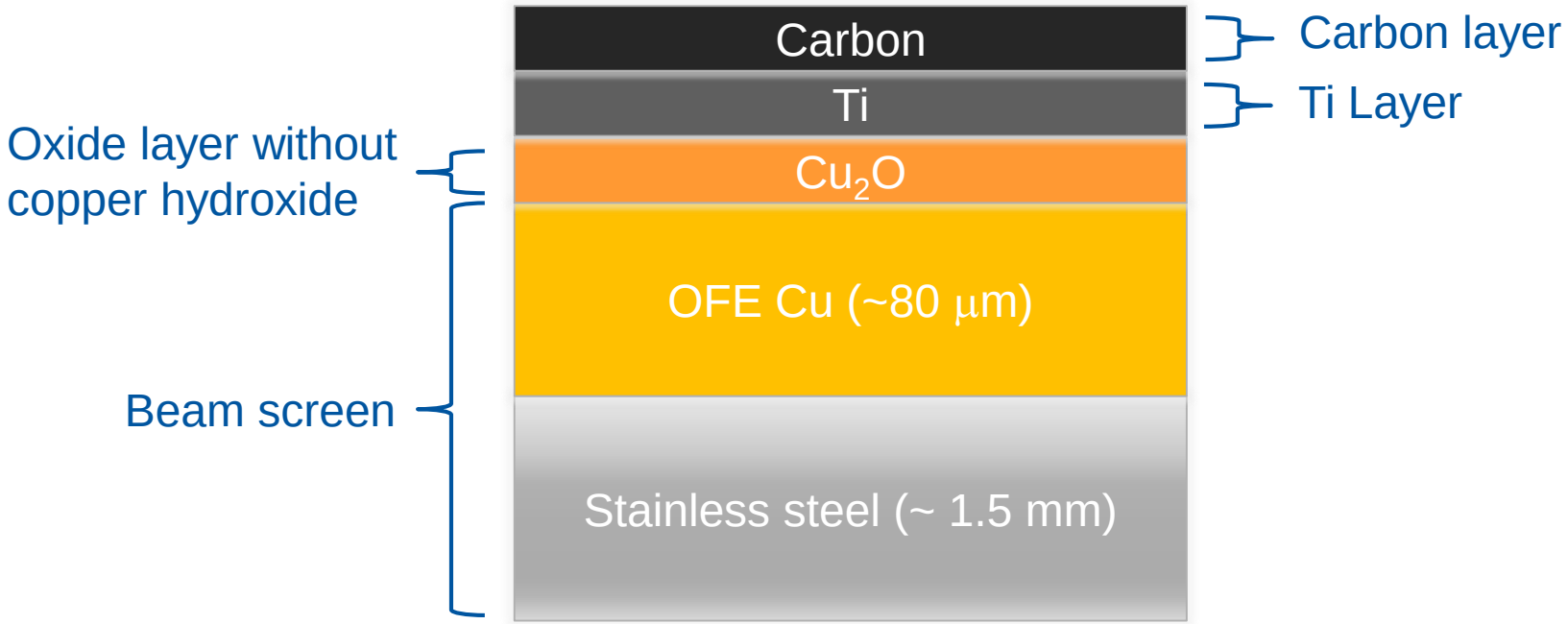

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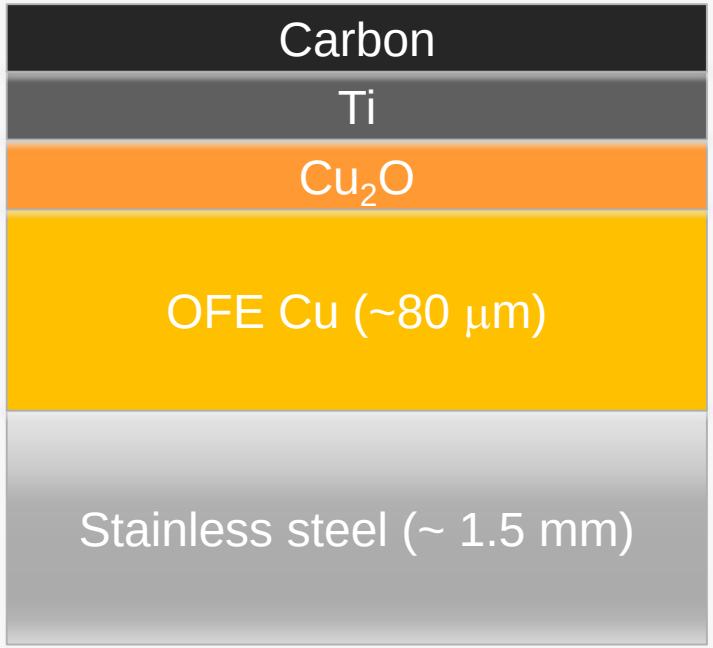

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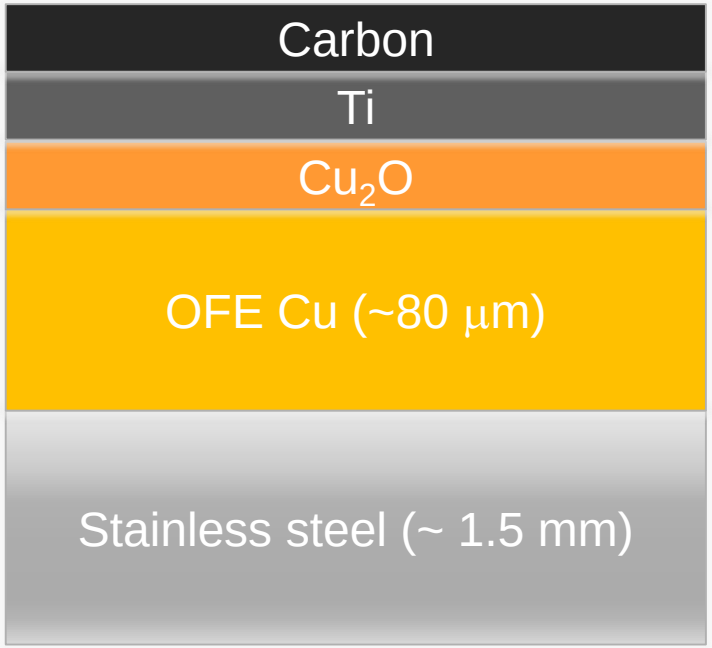

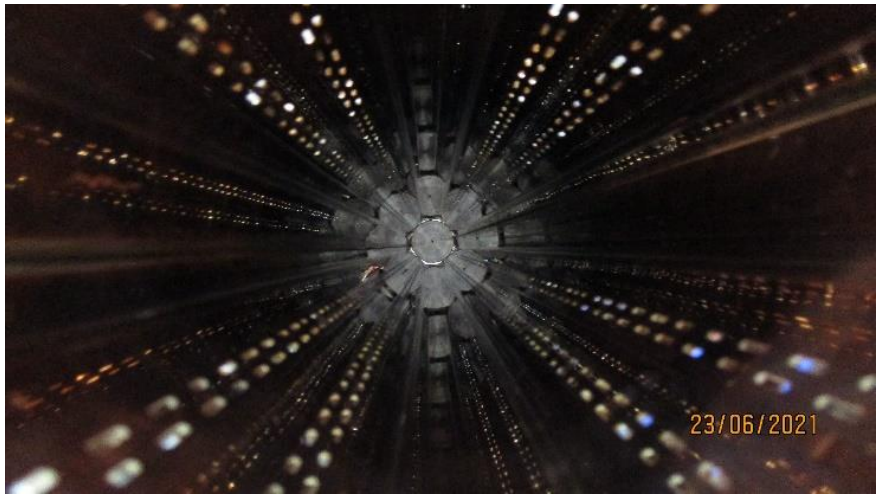

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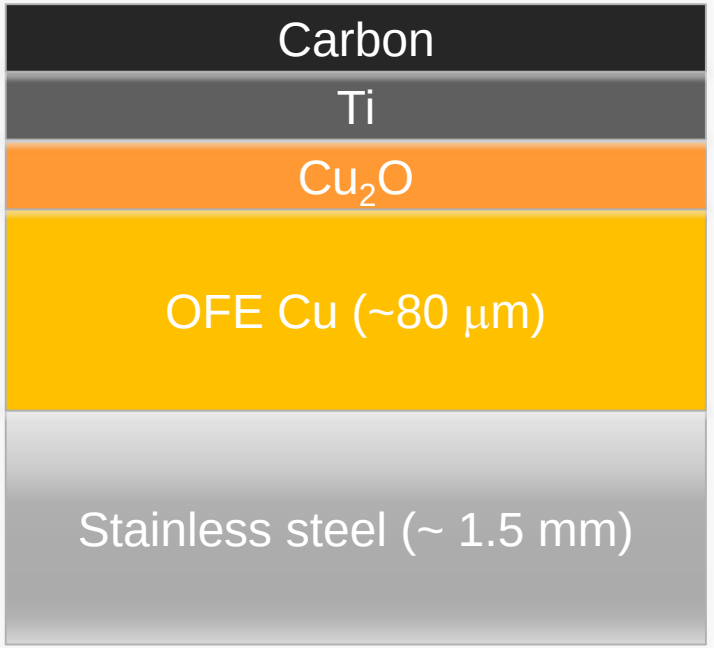
Uncleaned copper



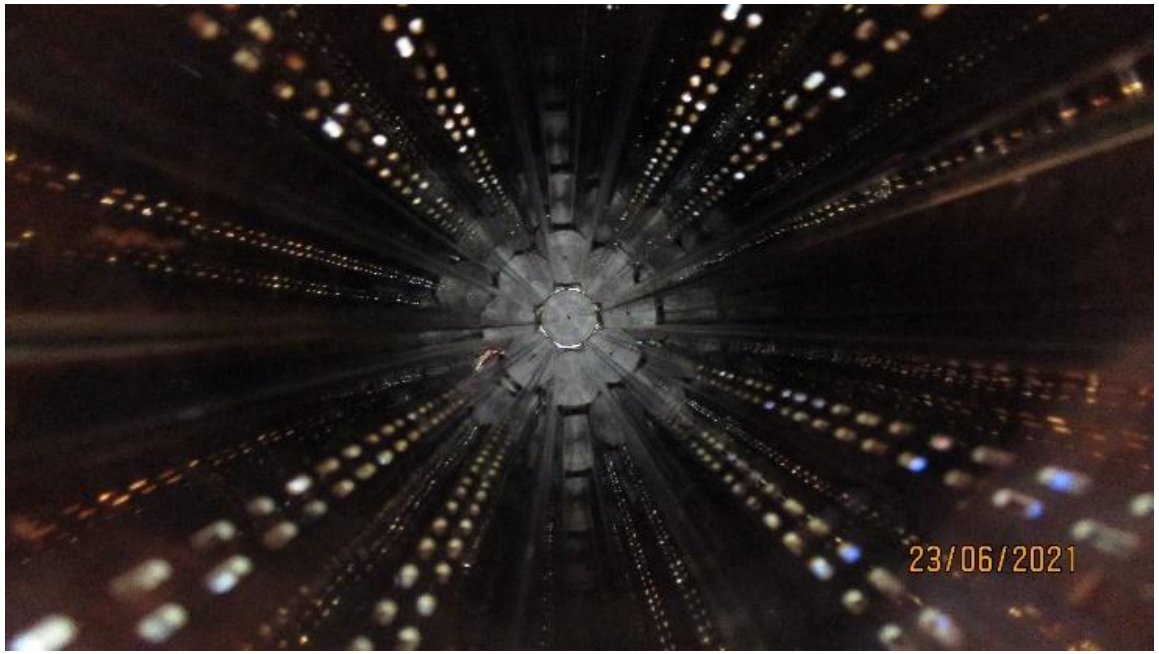
Uncleaned copper

↓

Ion etching

2- Good adhesion

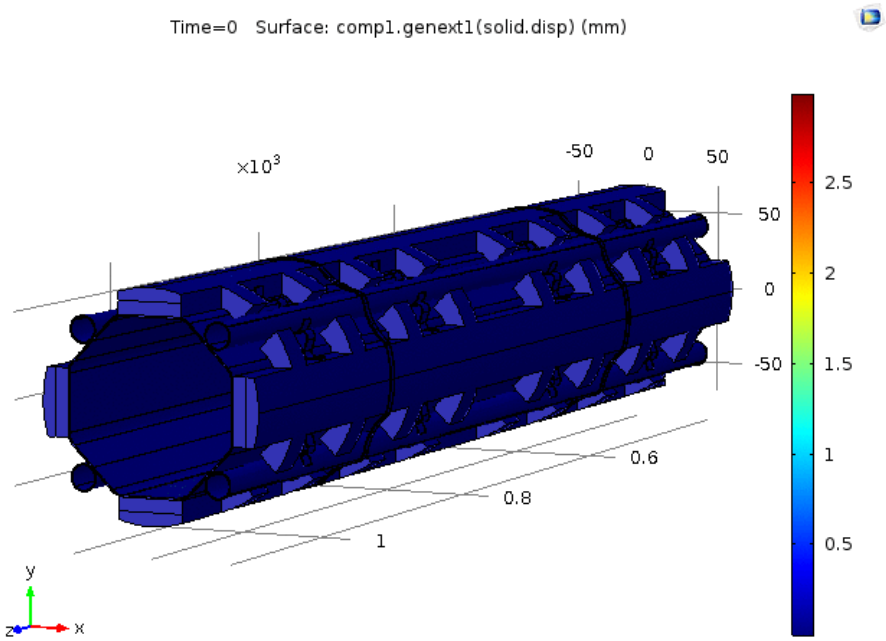
First quench test in 2M Q2 coated beam screen



Successful results after the quench test the film can cope with the mechanical deformation

2- Good adhesion

The film must cope with the deformation of the beam screen in case of magnetic quench



Quench heaters.

2- Good adhesion

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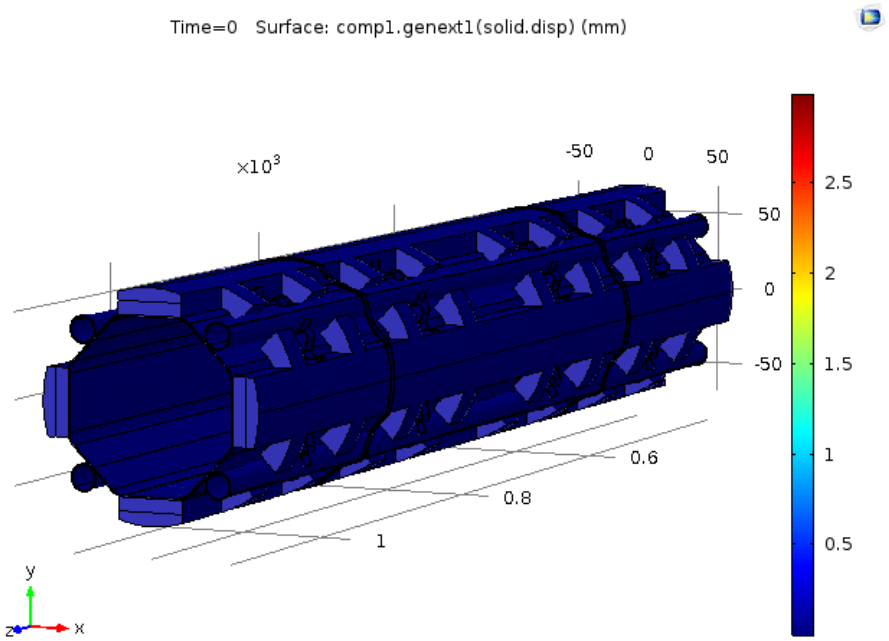
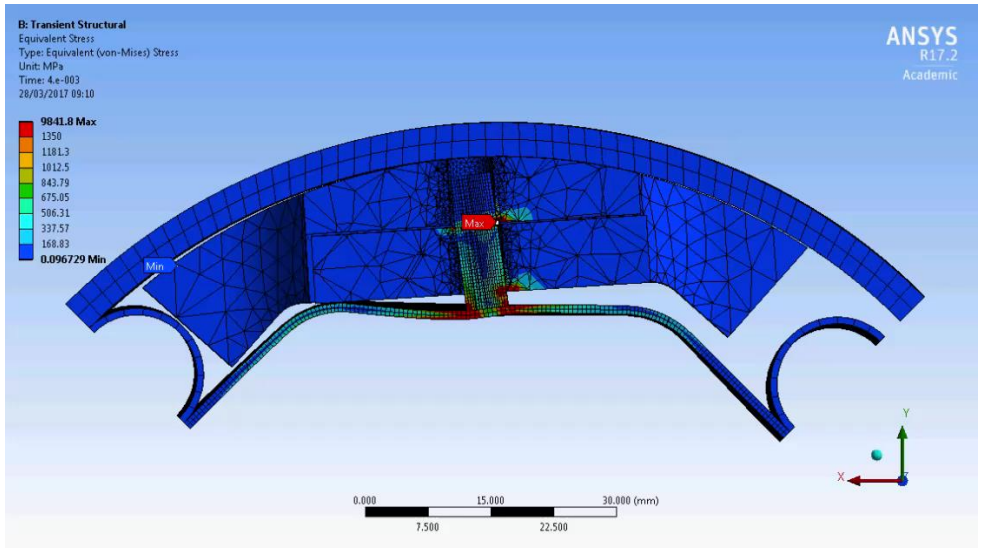
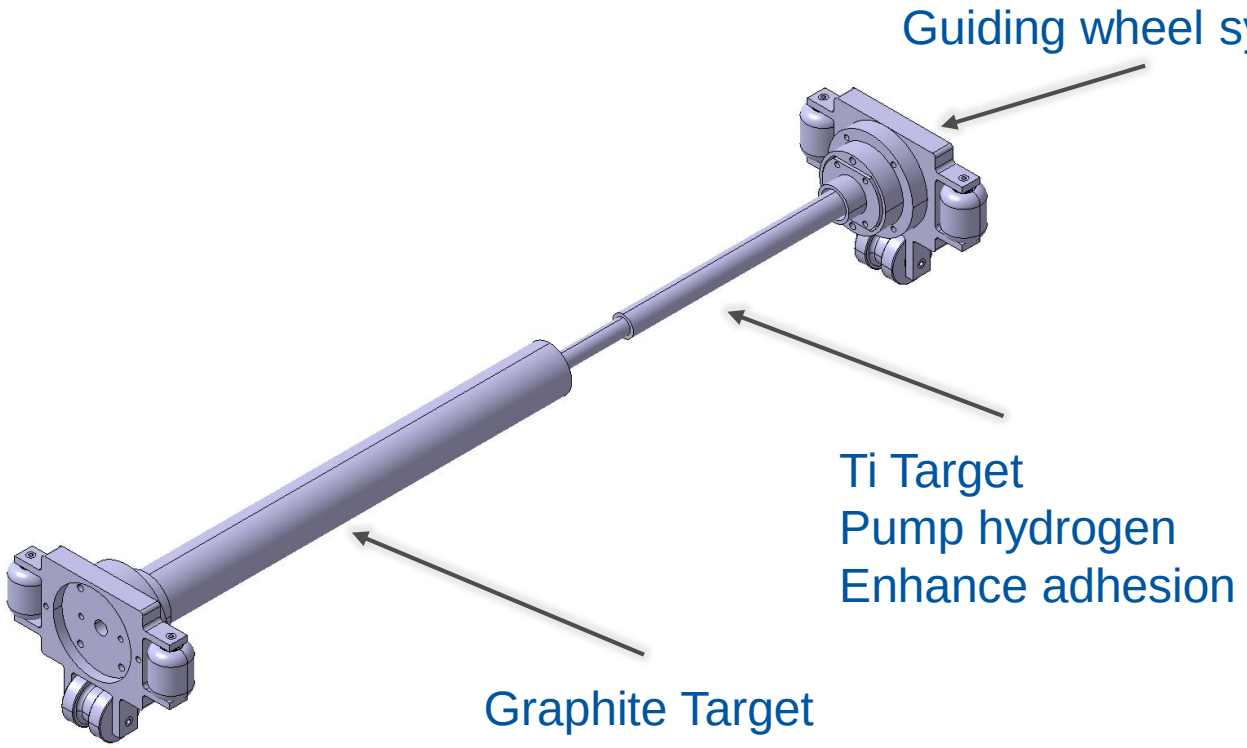




Quench heaters.

1 - Introduction

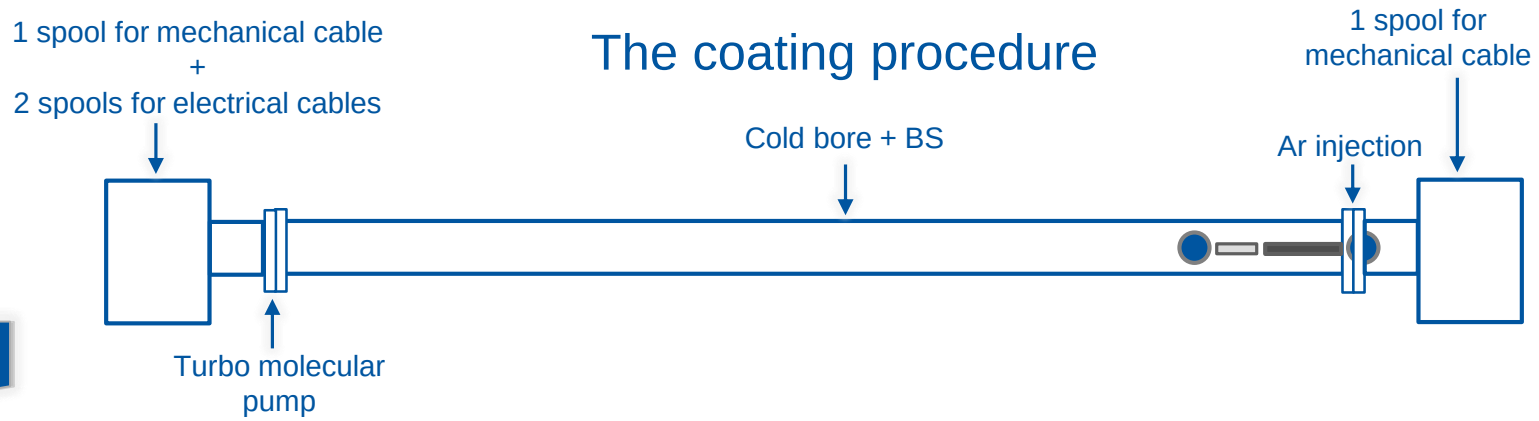
The sputtering device is consist of two cathodes. One graphite target and one Ti target.

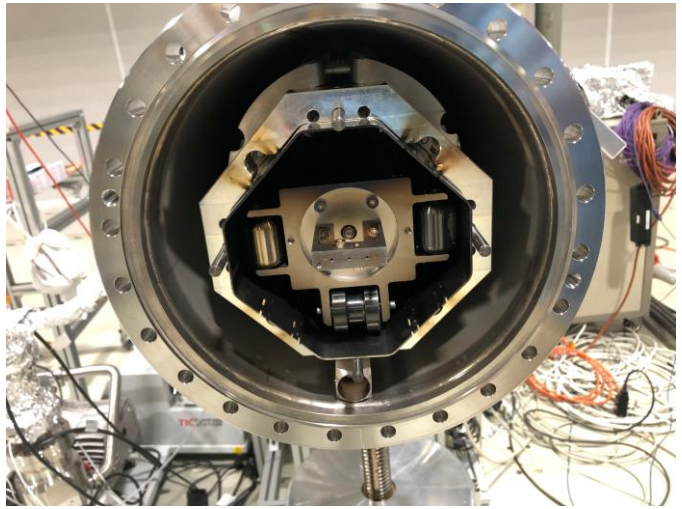


Sputtering coating in LHC beam screen Arc type

3 – Coating system and process

assemble coating system

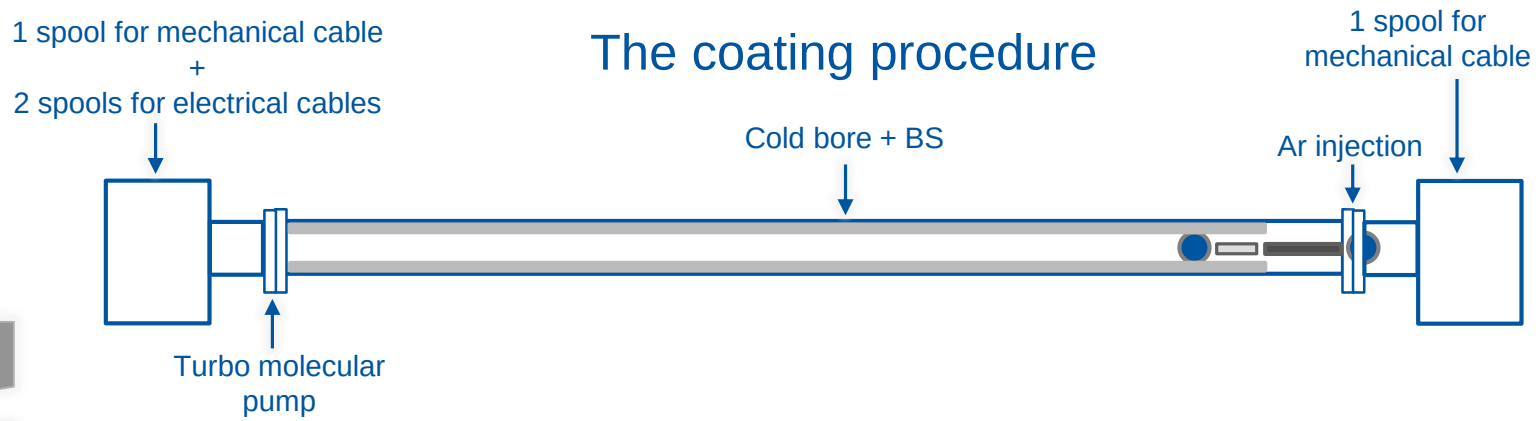




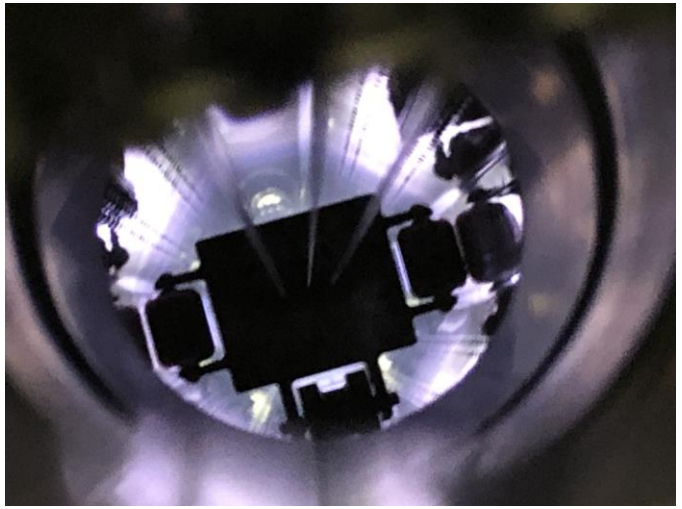
3 – Coating system and process

assemble coating System

Ti pre-layer ~100 nm



1st step: Ti pre-layer coating (~100 nm)



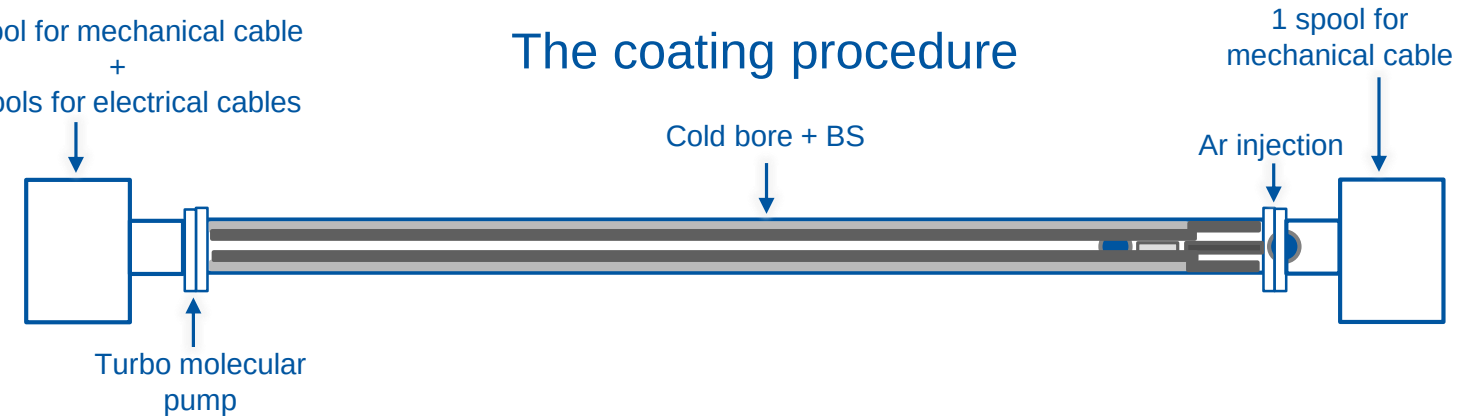
3 – Coating system and process

assemble coating System

Ti pre-layer ~100 nm

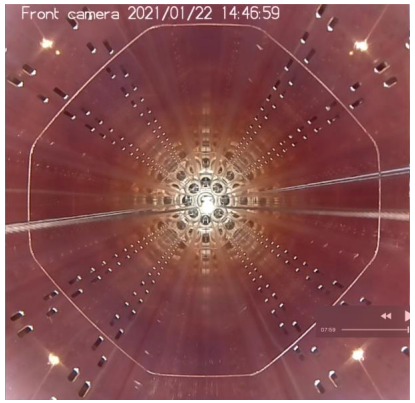
C coating ~100 nm + Ti flashes ~150 nm

The coating procedure

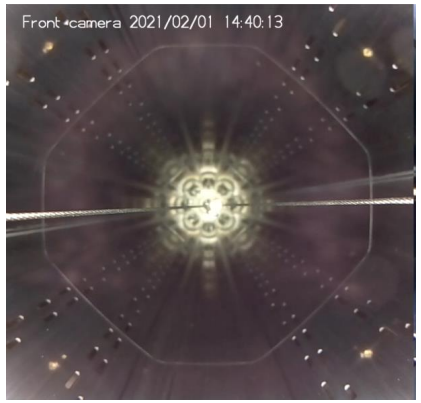


1st step: Ti pre-layer coating (~100 nm)

2st step: carbon coating (~100 nm) + Ti flashes ~150 nm

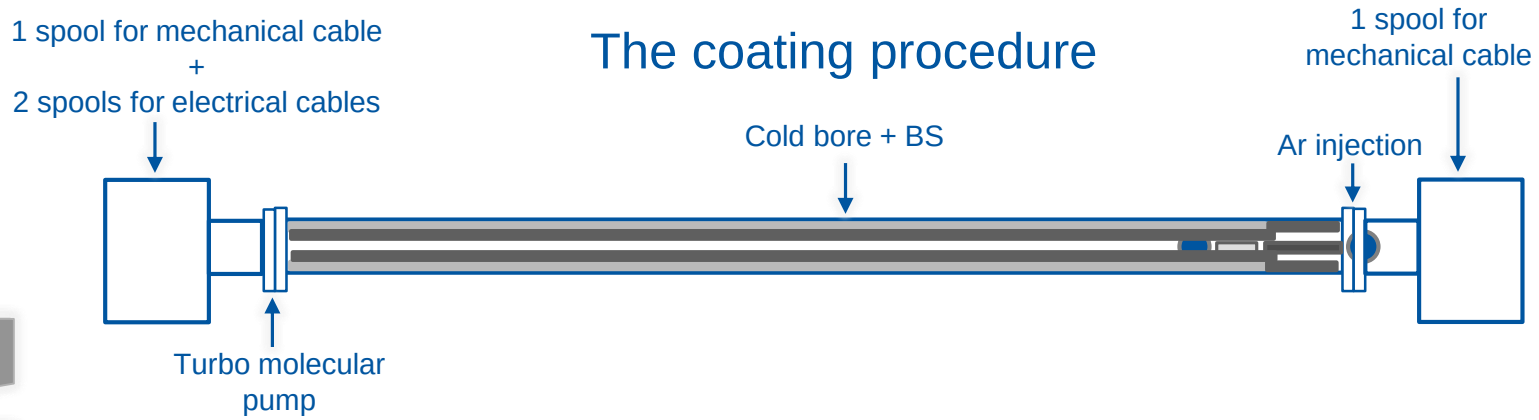


Uncoated



Carbon coated

3 – Coating system and process



- assemble coating System
- Ti pre-layer ~100 nm
- C coating ~100 nm + Ti flashes ~150 nm
- Storage under N2

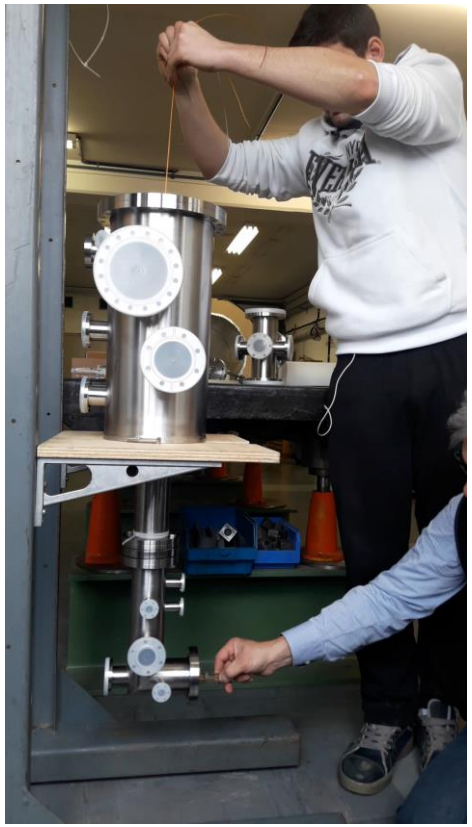
1st step: Ti pre-layer coating (~100 nm)

2st step: carbon coating (~100 nm) + Ti flashes ~150 nm

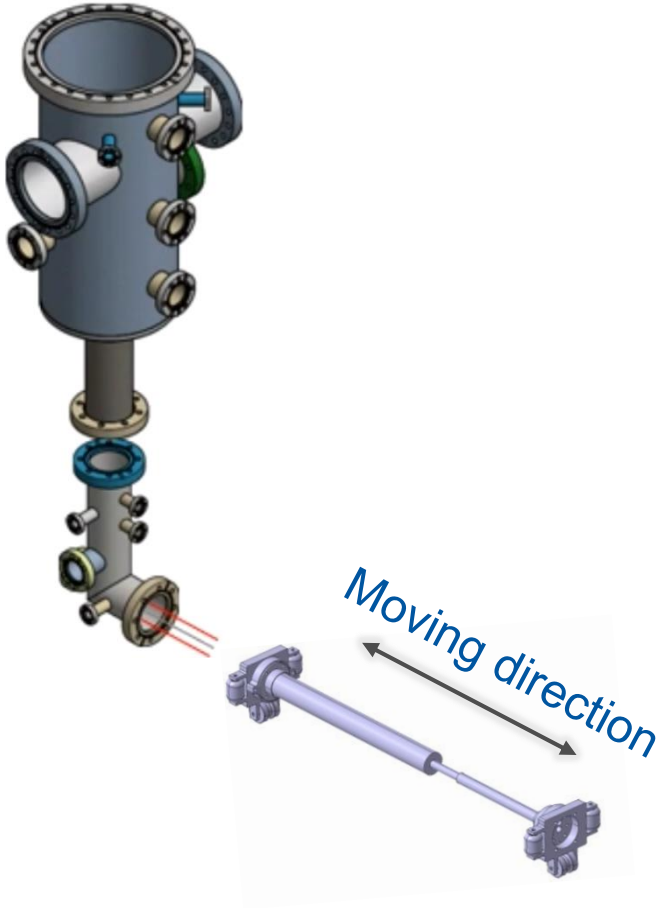
Storage will be with the pinch off technic (pump down + storage under N2)

Every single beam screen will arrive with an individual vacuum chamber witch will be the storage chamber till the date of the assembly in the magnet

Coating system



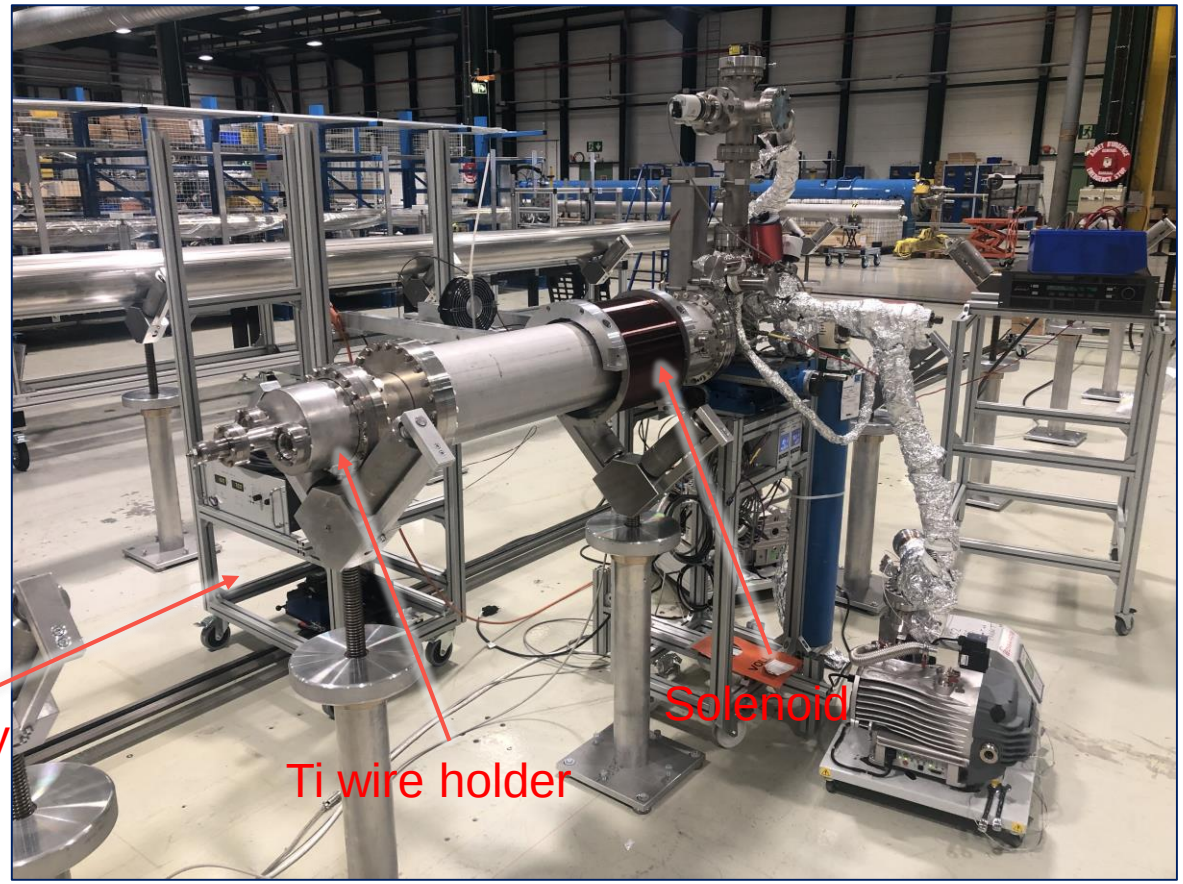
First mechanical assembly in 2016



First full assembly of the production system in 2022

Ion etching system

- Ti wire 1mm = anode
- Movable Solenoid to confine the Ar plasma
- Rail system to move the Solenoid
- Beam screen = cathode



Thank you - Merci

Questions?