Carbon coating technology

P. Costa Pinto, V. Baglin, P. Chiggiato, P. Cruikshank, S. Fiotakis, A. Granadeiro Costa, M. Himmerlich, H. Kos, N. Kos, M. Taborelli, J. Tagg

1. Introduction to a-C films with low Secondary Electron Emission
   - Secondary Electron Yield (SEY, δ) of carbon materials
   - Effect of Impurities
   - Ageing in air
   - Ageing
2. Coating technology at CERN
   - Coating techniques
   - Adapt the coating technique to the constrains
   - The SPS case
   - The HL-LHC case
3. Summary

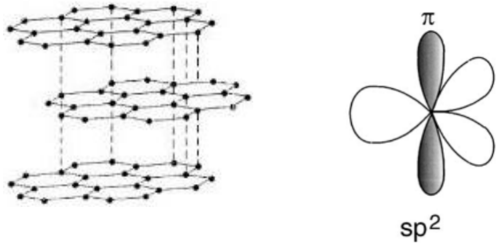
TRIUMF 2021 EIC Accelerator Partnership Workshop

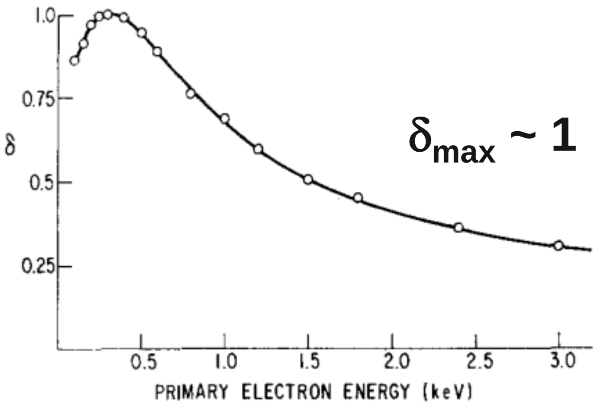
EIC2021 Accelerator Partnership Workshop

1 – Introduction to low SEE a-C films

The SEY (δ) of carbon materials depend on the molecular bonds between carbon atoms.

Graphite =>low SEY

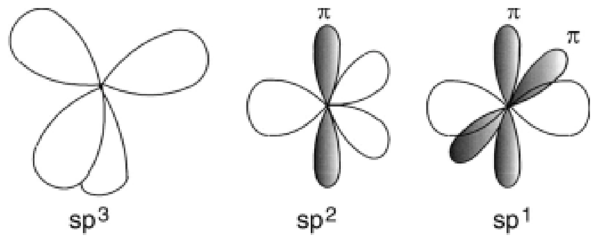




$\delta_{max} \sim 1$

N. REY WHETTEN JOURNAL OF APPLIED PHYSICS VOLUME 34. NUMBER 4 (PART 1) APRIL 1963

Carbon thin films



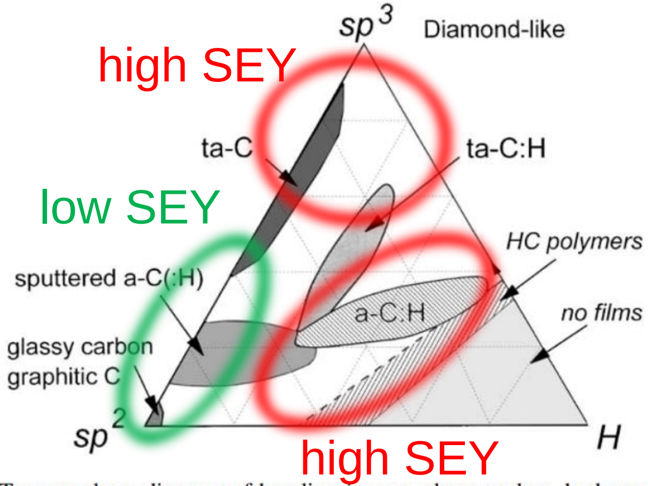
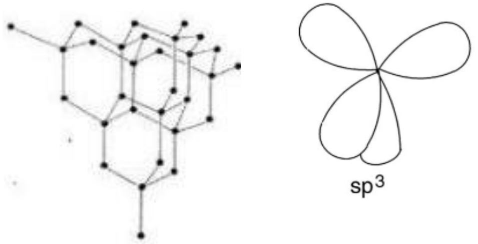
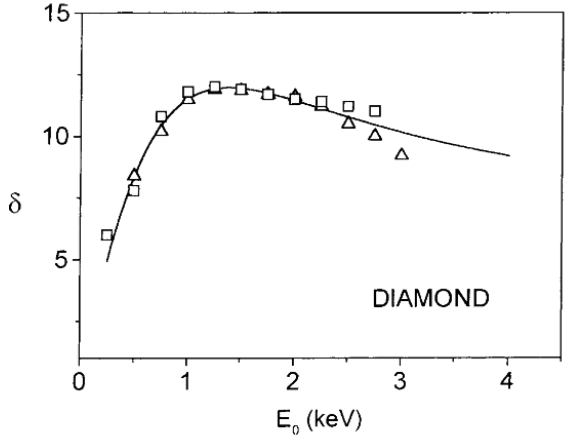


Fig. 2. Ternary phase diagram of bonding in amorphous carbon–hydrogen alloys.

J. Robertson/Materials Science and Engineering R 37 (2002) 129–281

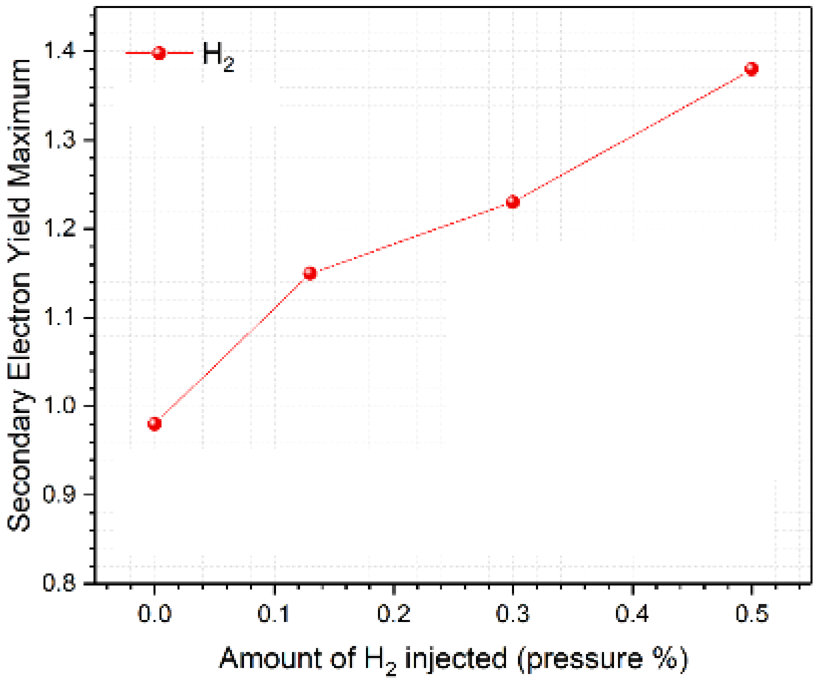
Diamond => high SEY

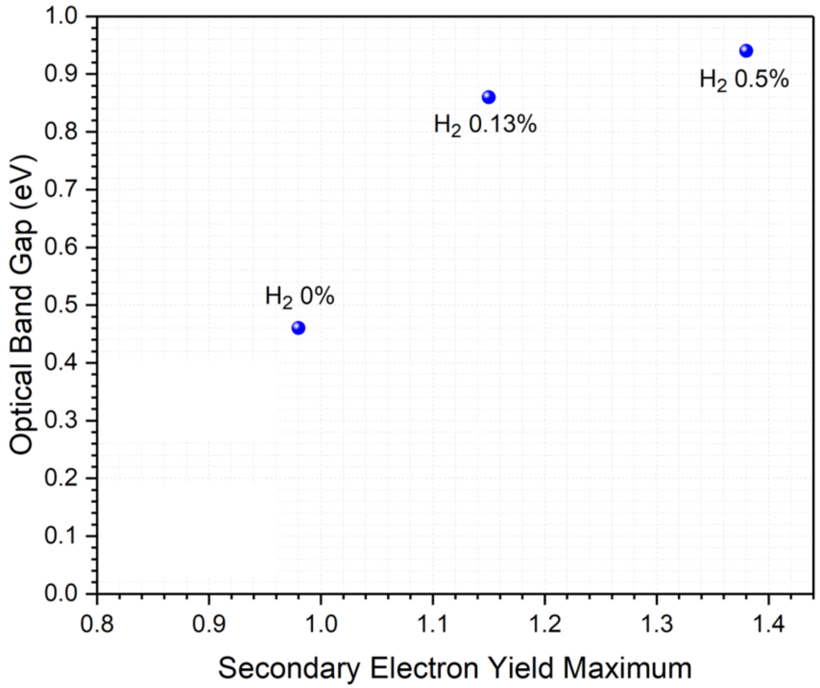




JACQUES CAZAUX, Mikrochim . Acta 132, 173±177 (2000)

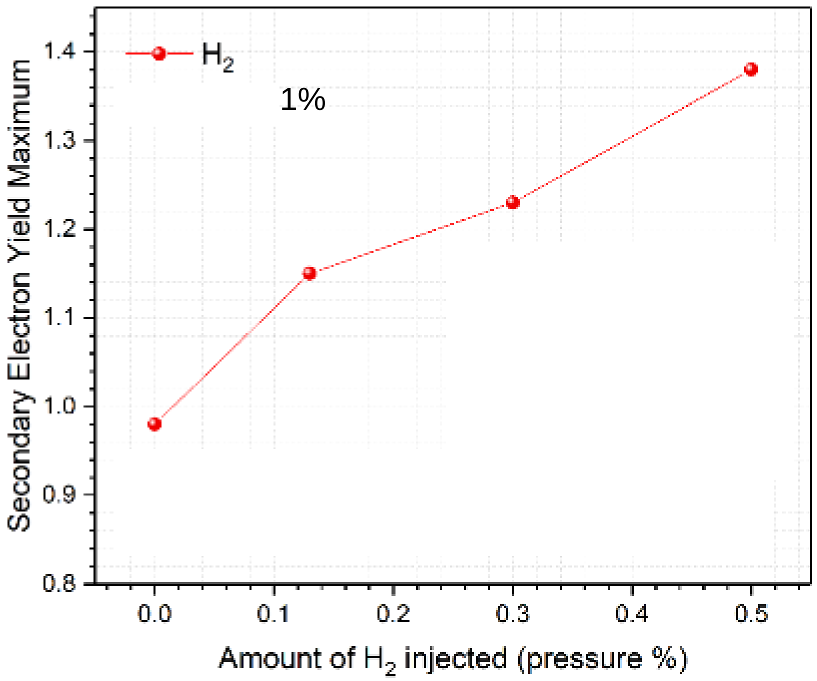
The effect of impurities: hydrogen is bad

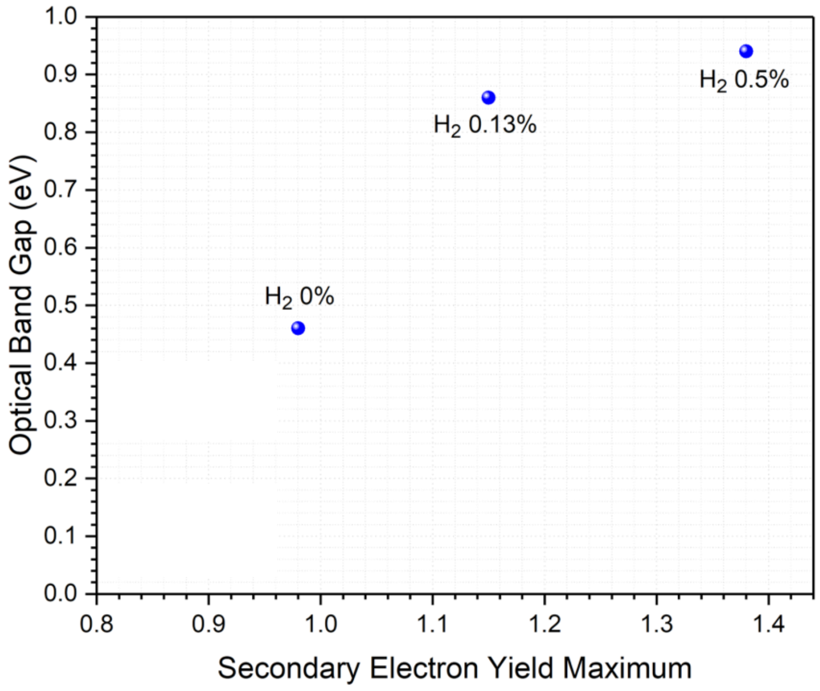




Applied Surface Science 542 (2021) 148552

The effect of impurities: hydrogen is bad nitrogen is good





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Ageing

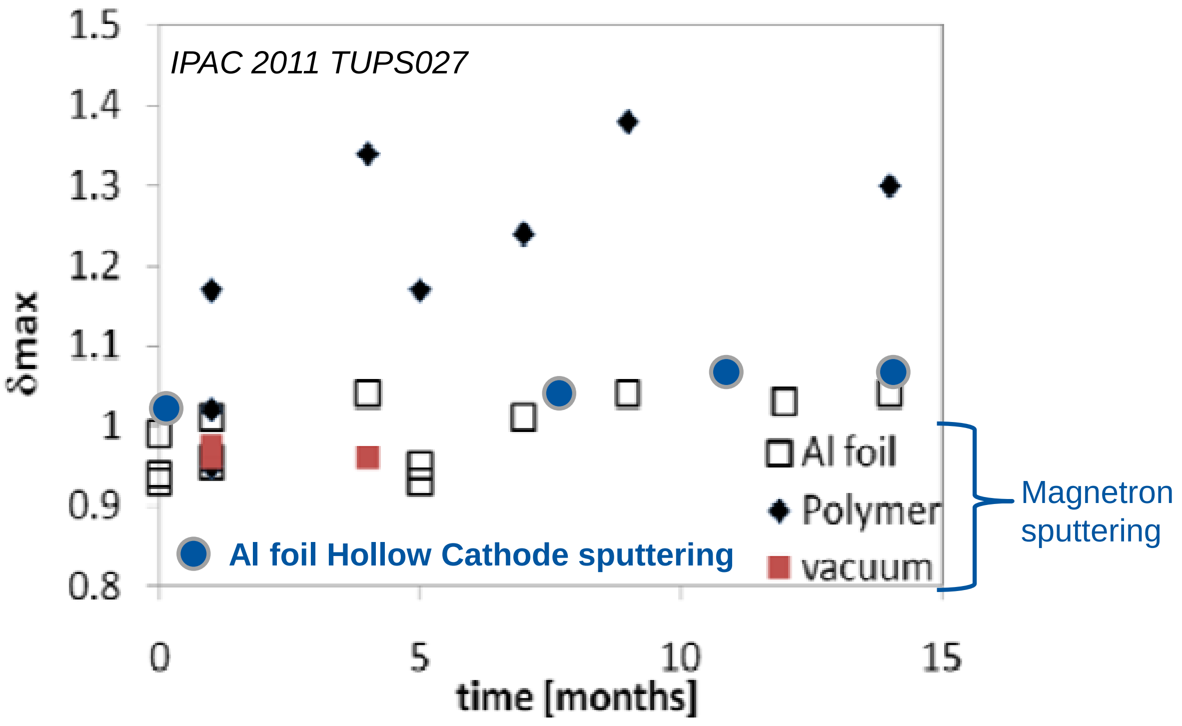

Figure 4: Change of the SEY as a function of time and storage.

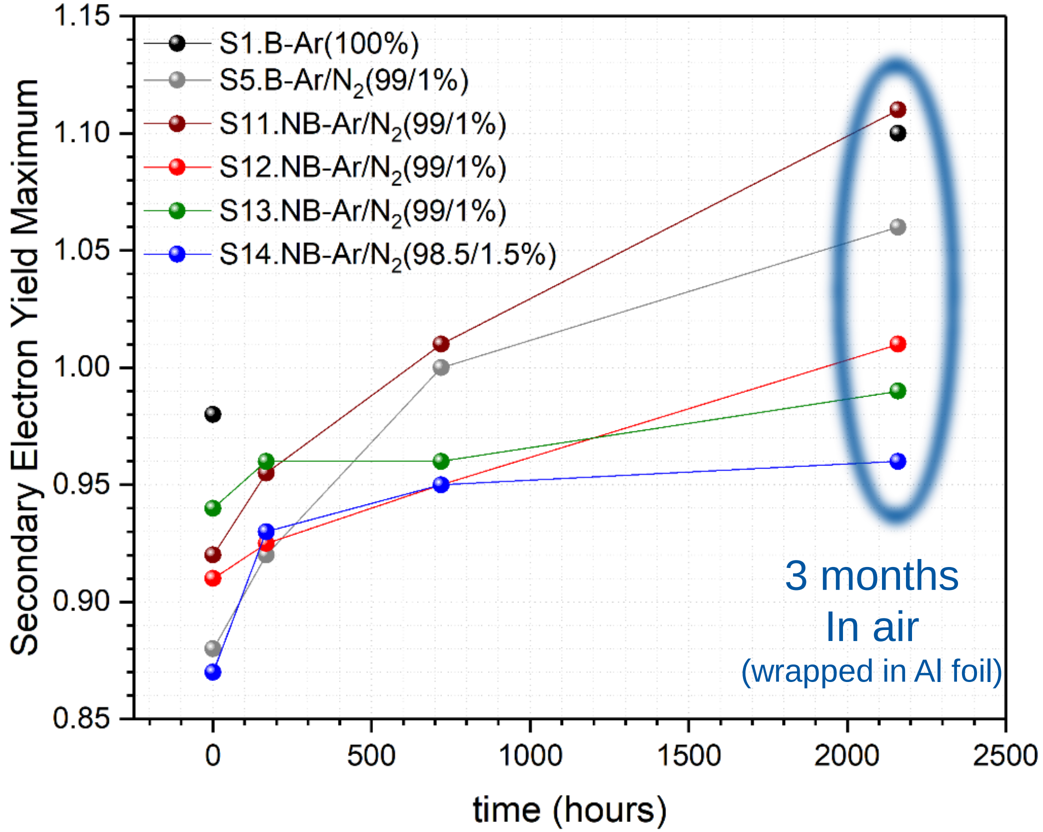

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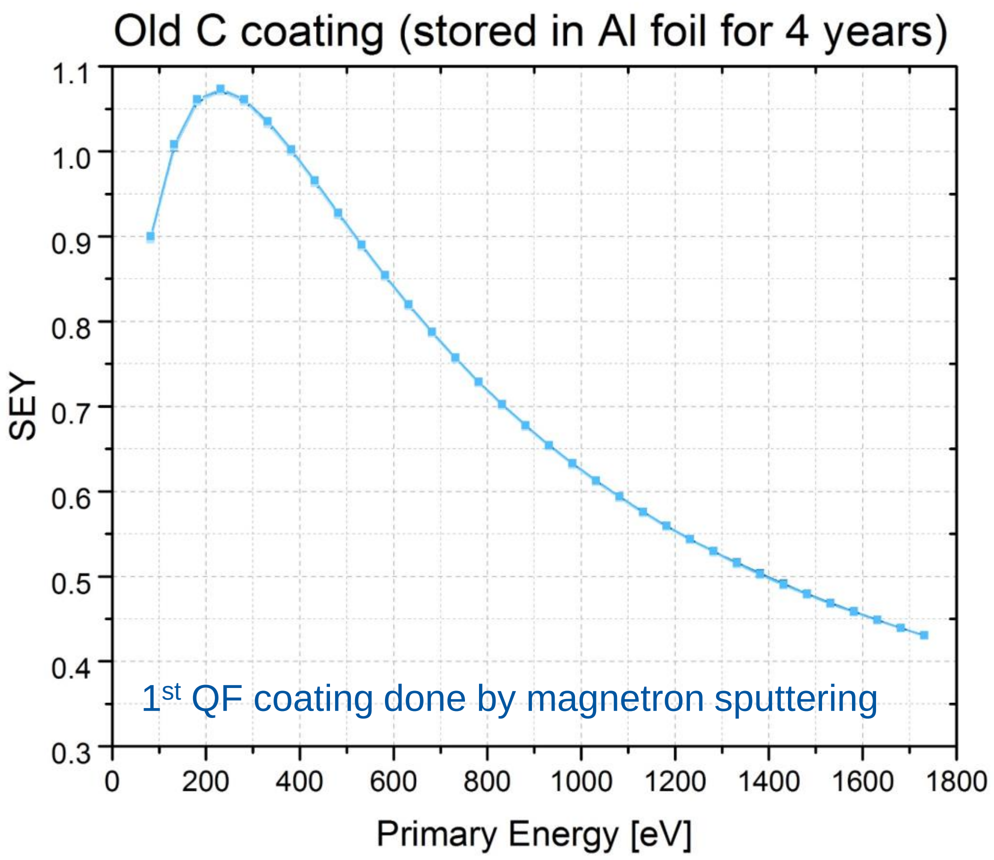
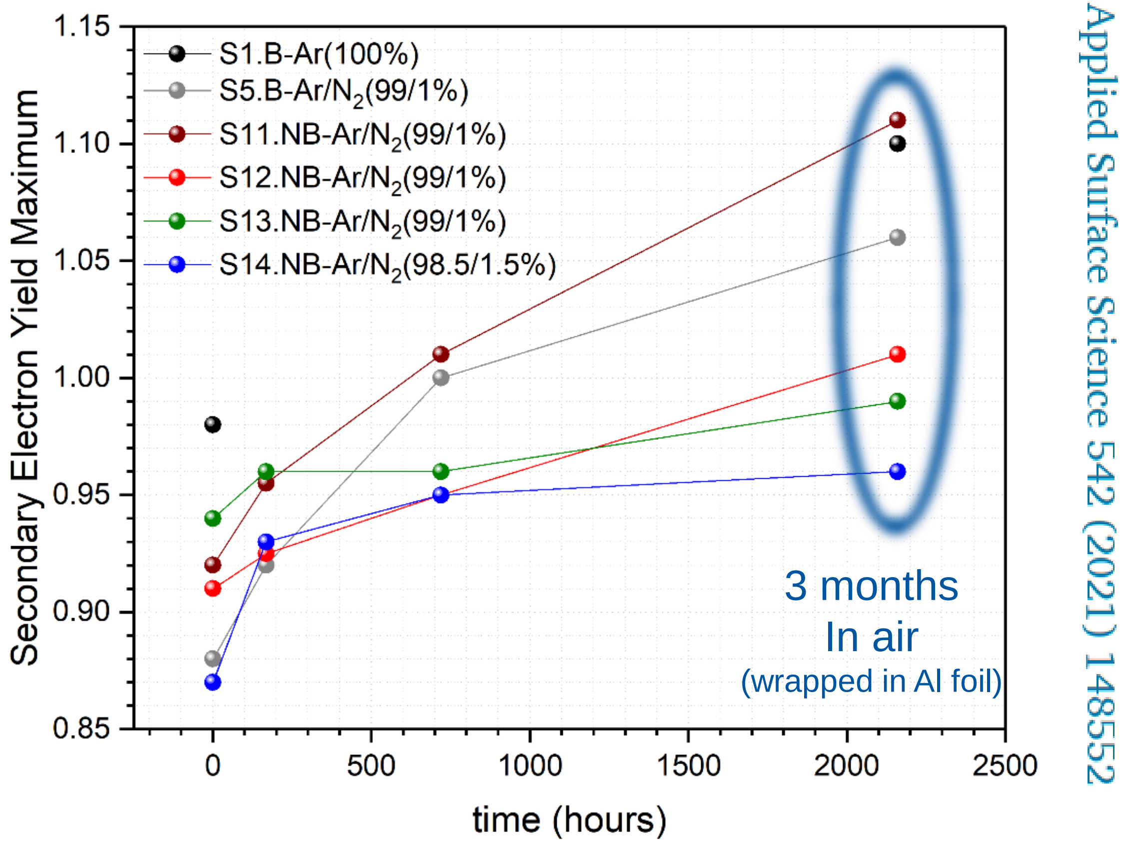
Figure 1 Evolution of the SEY maximum in a relation of storage time in Al foil for different samples prepared without hydrogen addition into the discharge.

1 – Introduction to low SEE a-C films

Ageing





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2 – Coating technology at CERN

Coating techniques

- Sputtering
- PLD
  Pulsed Laser Deposition
- Thermal evaporation
- Thermal CVD
  Chemical Vapour deposition
- Cathodic Arc
- Plasma Assisted CVD

Not tested at CERN

2 – Coating technology at CERN

Coating techniques

Sputtering

Plasma Assisted CVD

PLD
Pulsed Laser Deposition

High deposition rate and easy to scale up

SEY_{max} > 1.4 due to high hydrogen content from precursor gases (CH_4, C_2H_2)

SEY_{max}~1

Adaptable to a wide range of geometries

Low deposition rate
(sputtering yield)

SEY_{max}~1 if performed at high pressure (to quench the energy of the C atoms)

Poor adhesion on Cu

2 – Coating technology at CERN

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Adapt the coating technique to the constrains

- Geometry of the object to be coated: cylindrical, planar, ellipsoidal, etc.
- Accessibility: tube with/without flanges; already inserted in a yoke of a magnet; in the accelerator tunnel;
- Adhesion: substrate material, surface treatments, bakeout before coating?
- Residual gas during coating: outgassing / pumping (materials; bakeout before coating? thermal treatments)
- Schedule & budget
- Whenever possible, **integrate the coating process from the design phase.**

2 – Coating technology at CERN

The SPS case

Beam pipes with different geometries:

Quad and dipole chambers are embedded in the yoke.
(bakeout not possible)

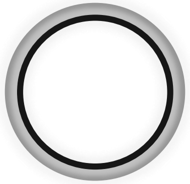
Keep quads and dipoles in the ring => coat *in-situ*

2 – Coating technology at CERN

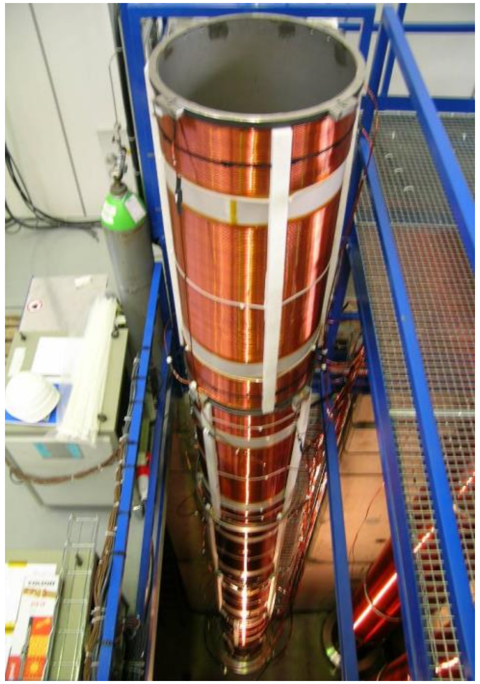
The SPS case

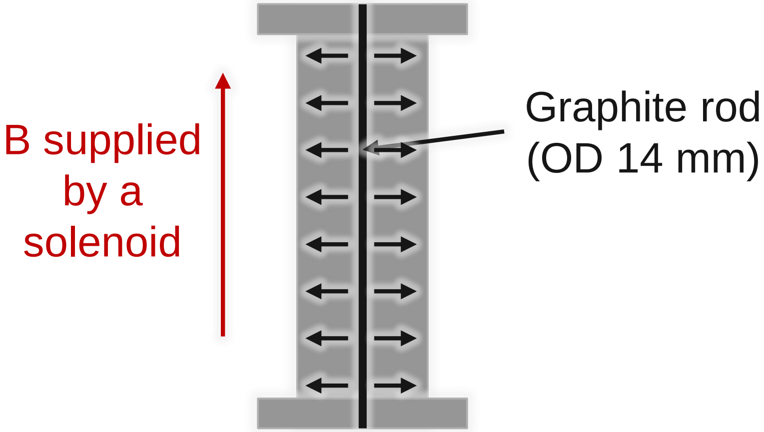
Beam pipes with different geometries:

Drift chambers
ID 159 mm



Coat ex-situ by DC cylindrical Magnetron sputtering (solenoid)





Bakeout before coating (24@150 oC)

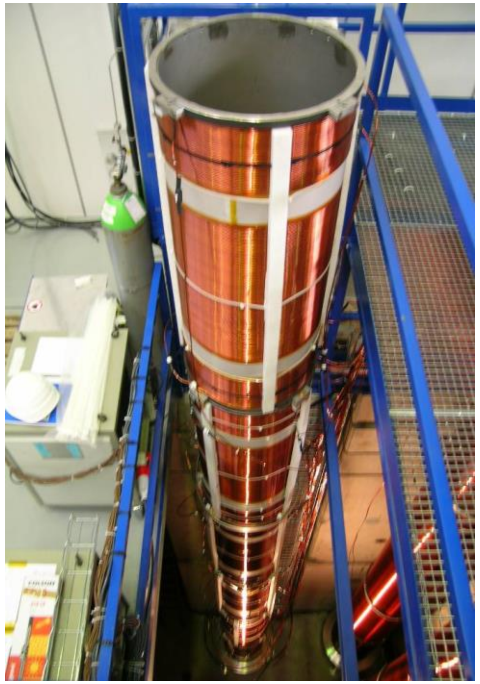
Pressure Ar ~$4x10^{-2}$ mbar

Power density ~ 200 W / meter of target

Sputtering rate ~ 12 nm / hour

The SPS case

Beam pipes with different geometries:



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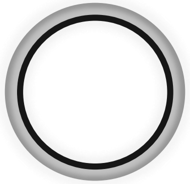
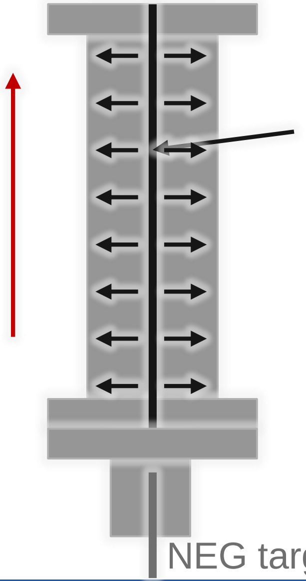


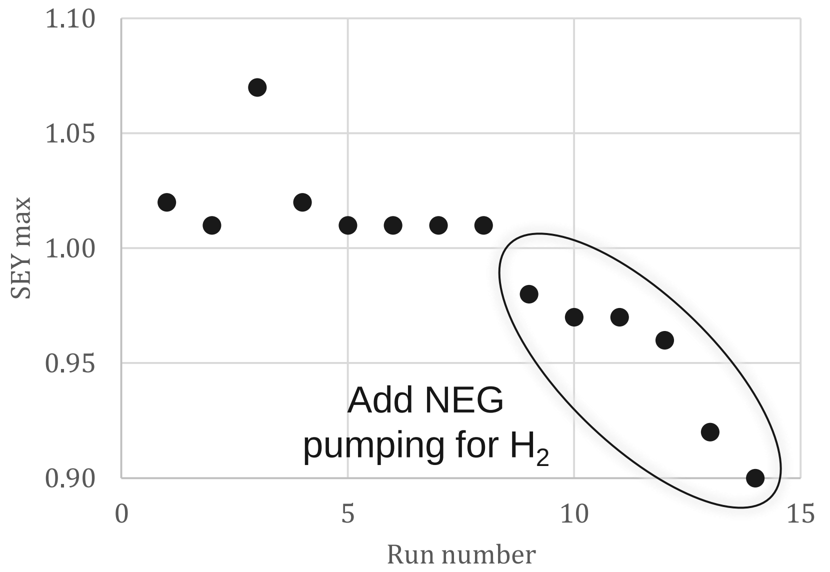
Coat ex-situ by DC cylindrical Magnetron sputtering (solenoid)

B supplied by a solenoid



Graphite rod
(OD 14 mm)

NEG target (flashes)

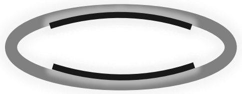


2 – Coating technology at CERN

The SPS case

Quad chambers
Ellipsoid

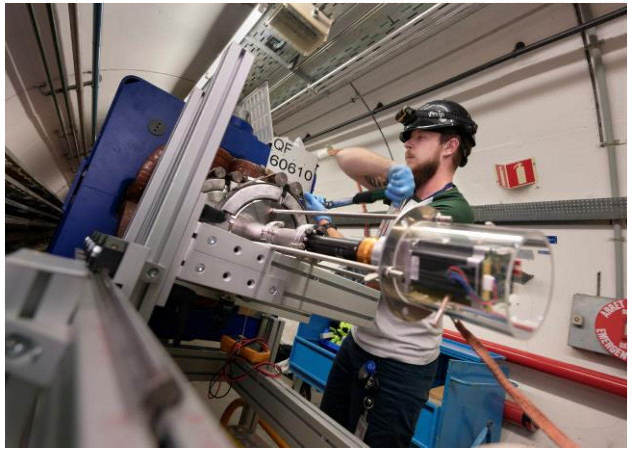
QF quads

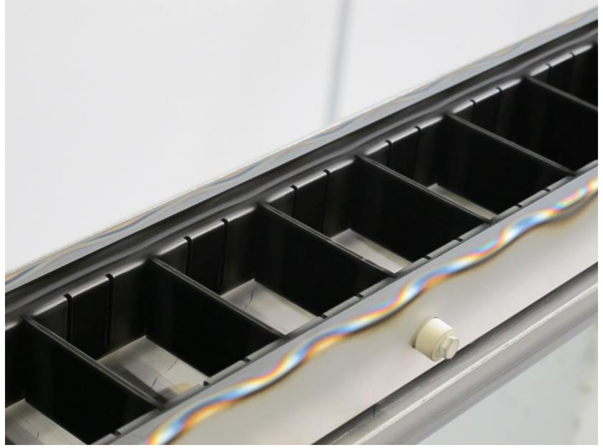


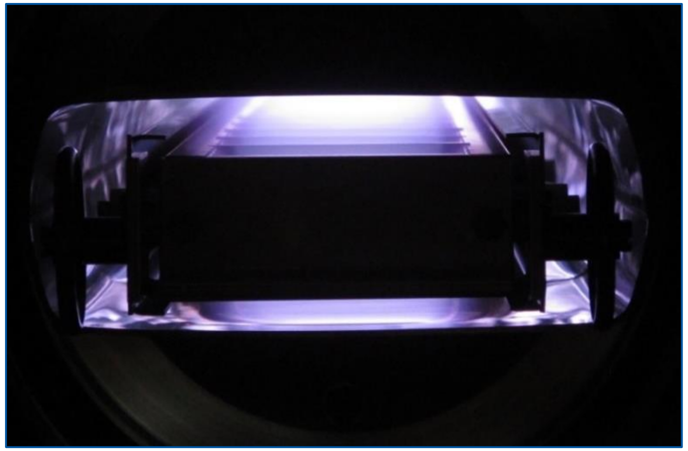
Coat in-situ by
DC hollow cathode
sputtering

Dipole chambers
racetrack

MBB dipoles







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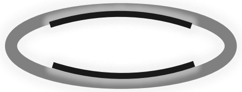

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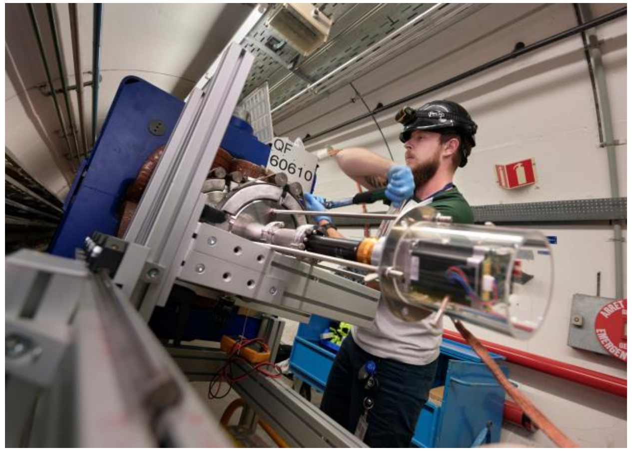
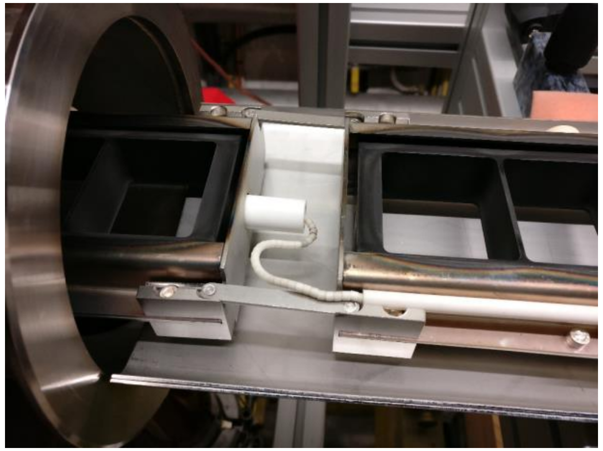
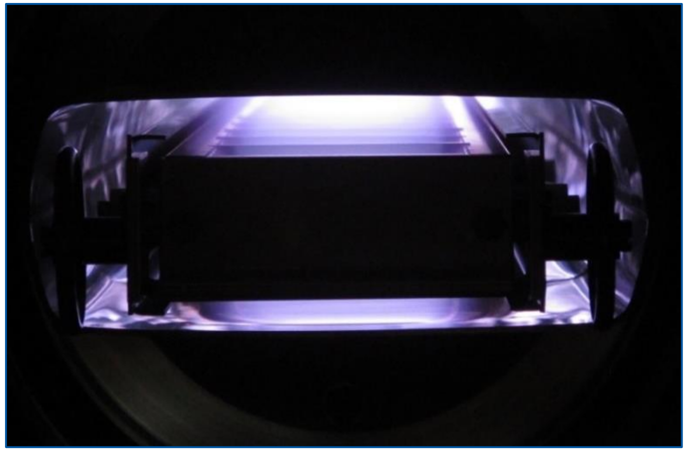




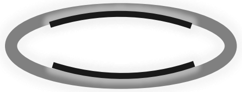


2 – Coating technology at CERN

The SPS case

QF quads

Quad chambers
Ellipsoid



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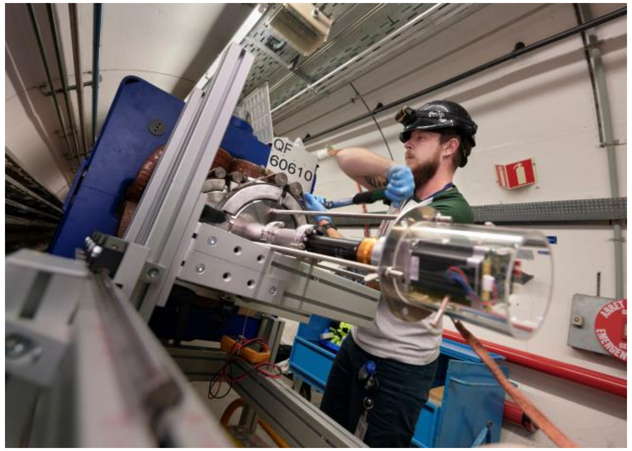
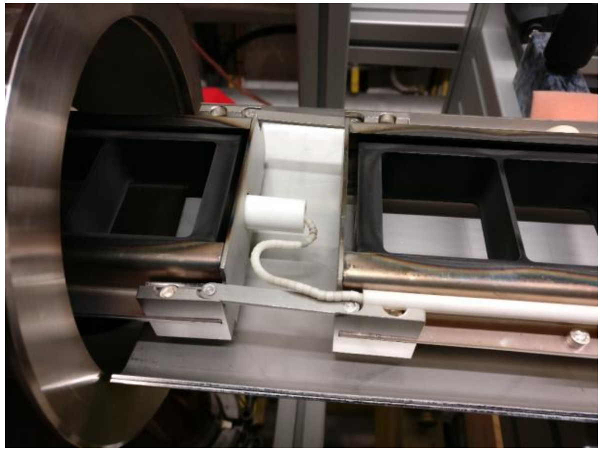




No bakeout before coating

Pressure Ar ~1.1x10^{-1} mbar

Power density ~ 120 W / m

Sputtering rate ~ 20 nm / hour

20 hours -> 400 nm films

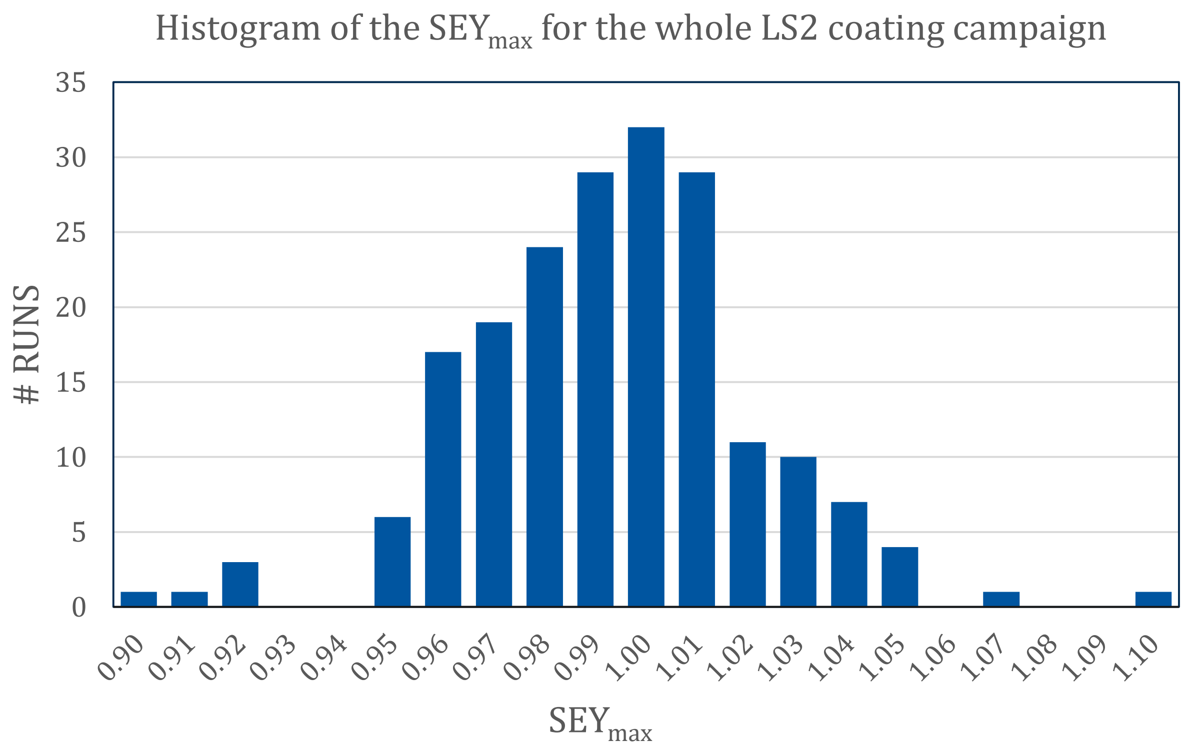
The SPS case

The first large scale production in the SPS during the CERN Long Shutdown (**212 coating runs**):

88 QF quadrupole magnets (294 m) coated in-situ 2 runs / week with 2 systems

110 Short straight Section elements (104 m) coated ex-situ 2 runs / week with 2 systems

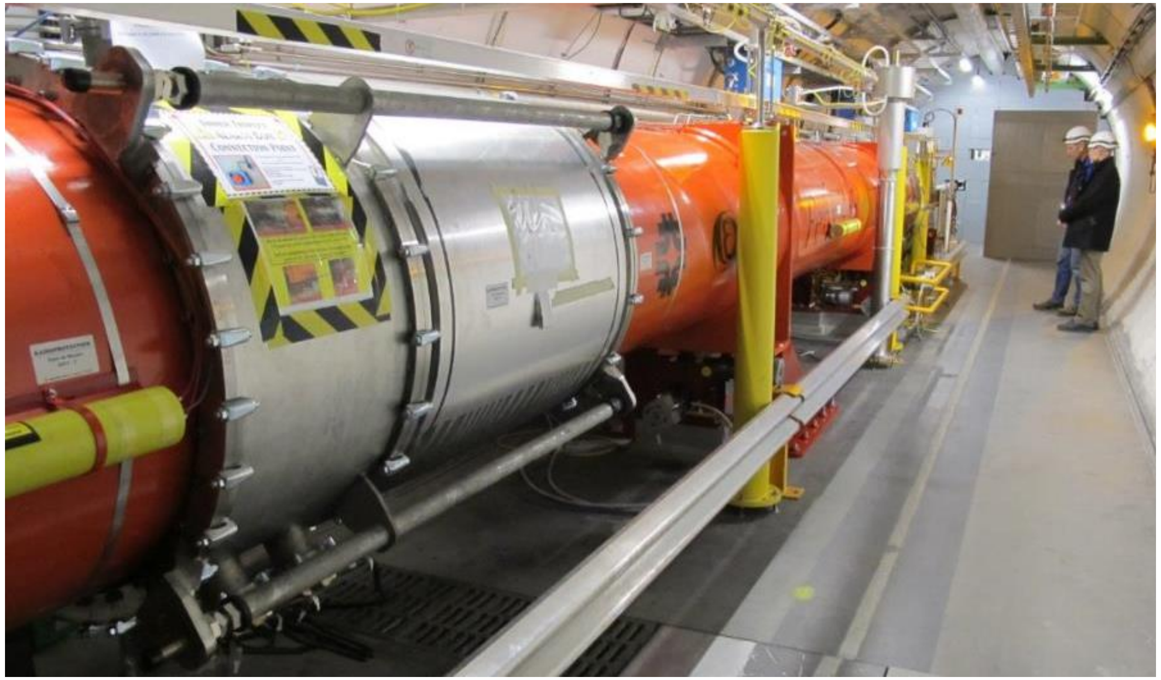
29 Drift vacuum chamber (80 m) coated ex-situ 2 runs / week with 2 systems



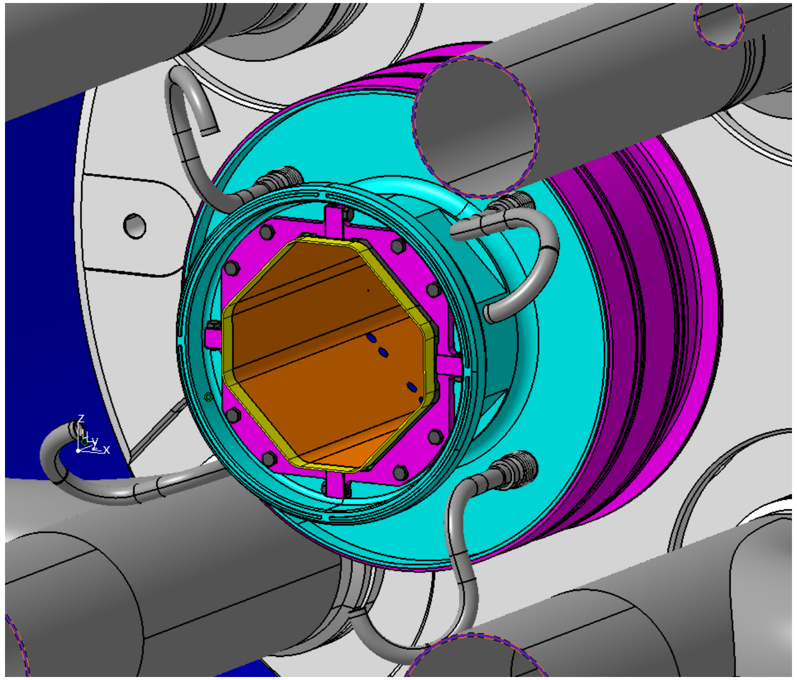
2 – Coating technology at CERN

The HL-LHC case

In-situ coatings
(inner triplets ALICE and LHCb)



Ex-situ coatings
(New inner triplets ATLAS and CMS)



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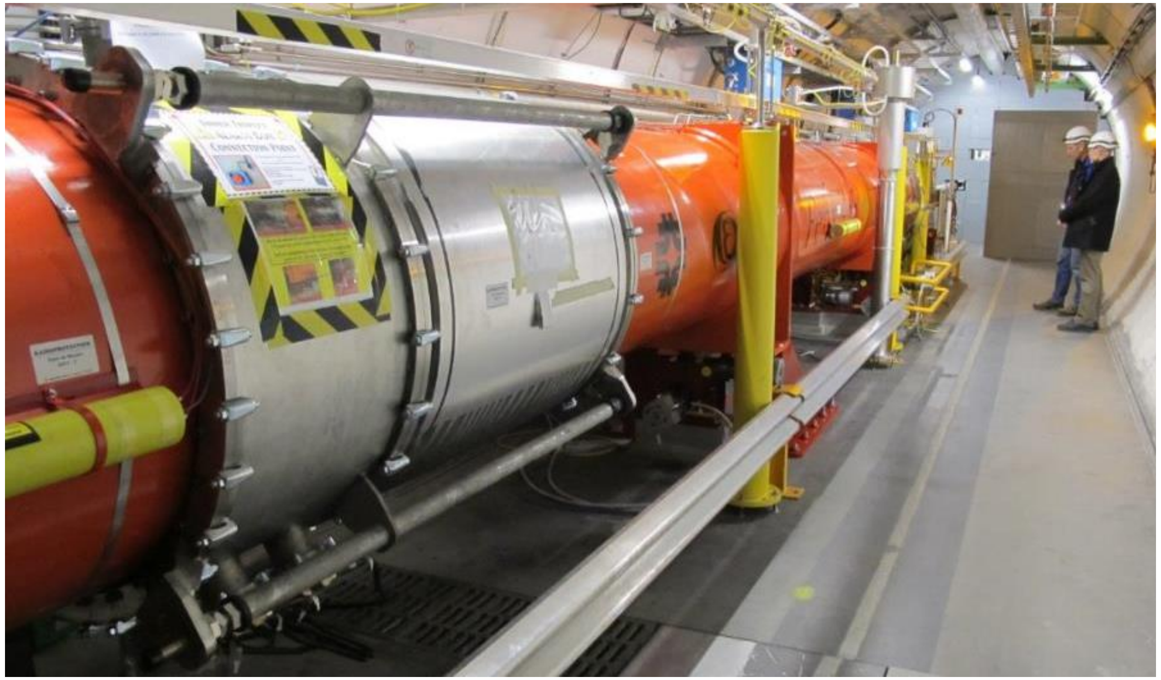

Only 150 mm to insert the coating device => modular sputtering source

High outgassing of H_2O and H_2 => Ti gettering

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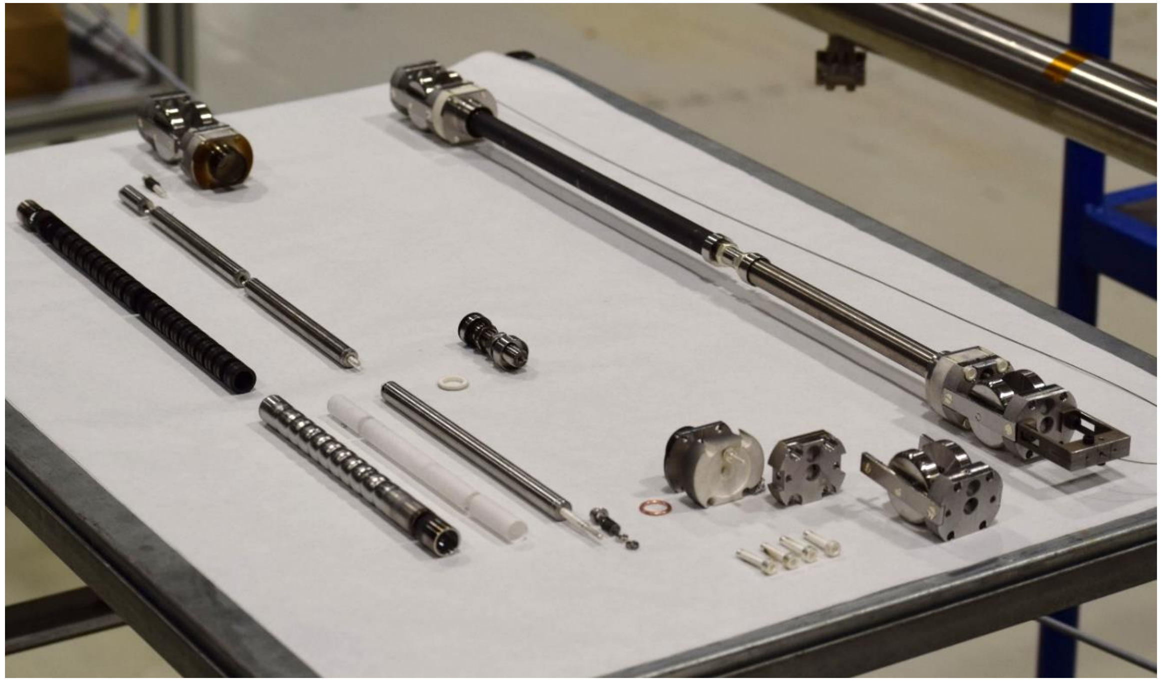

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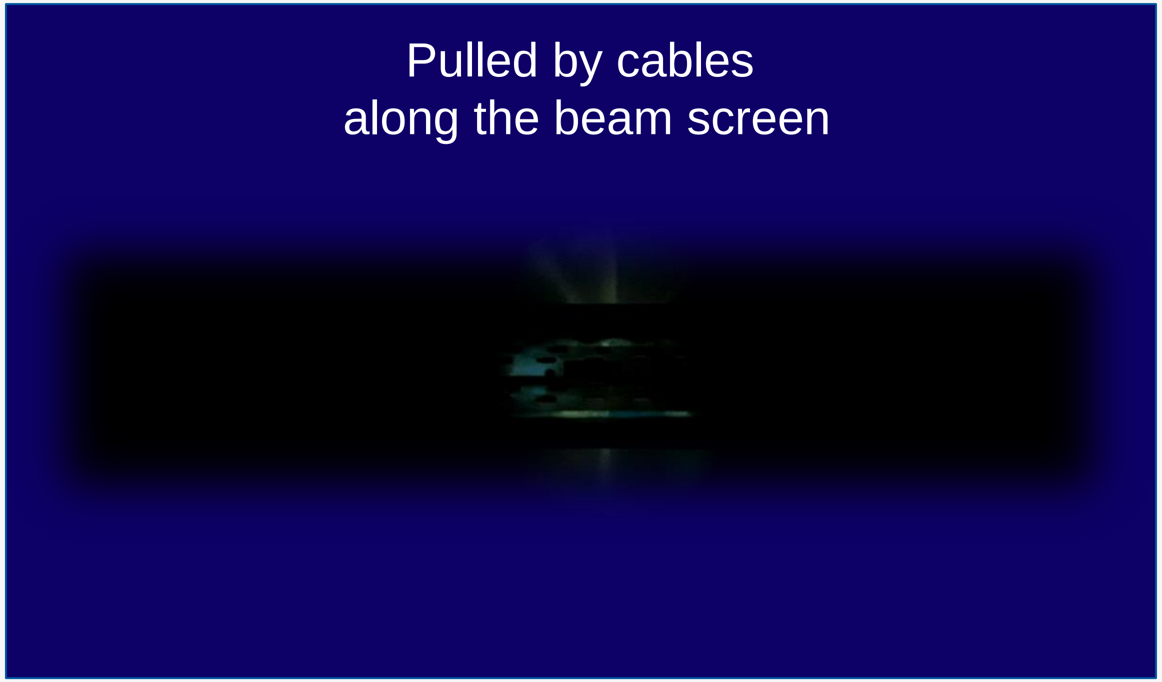

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Cu substrate => critical for adhesion => ion etching + Ti underlayer

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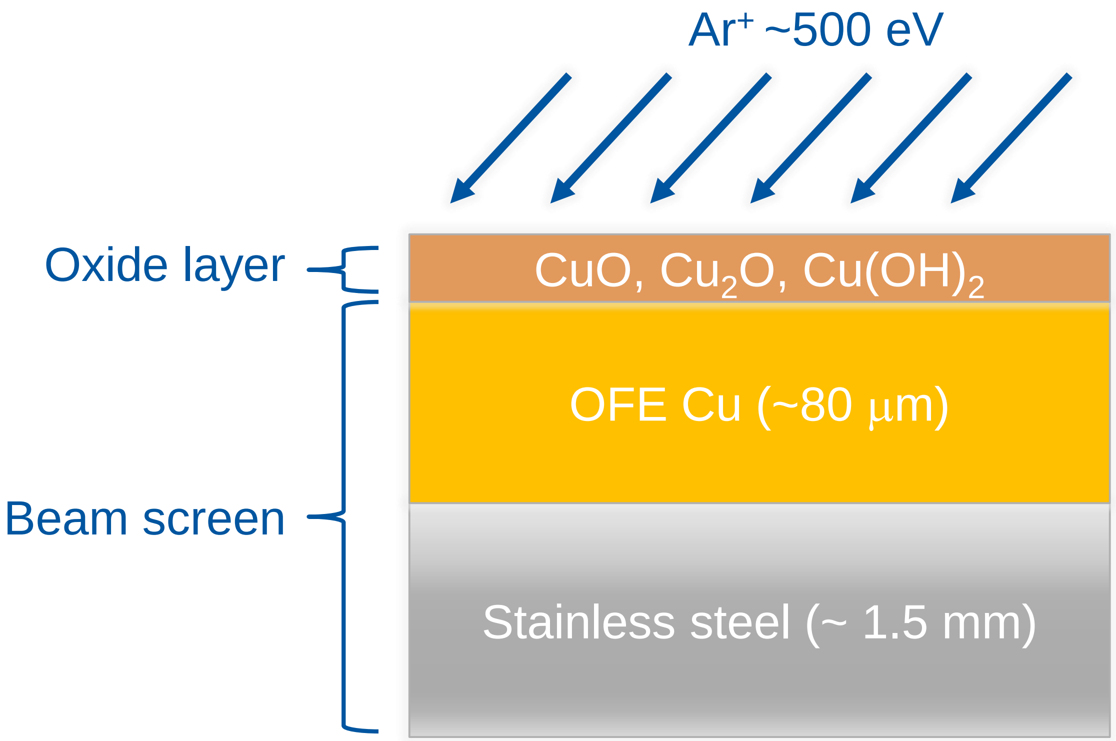

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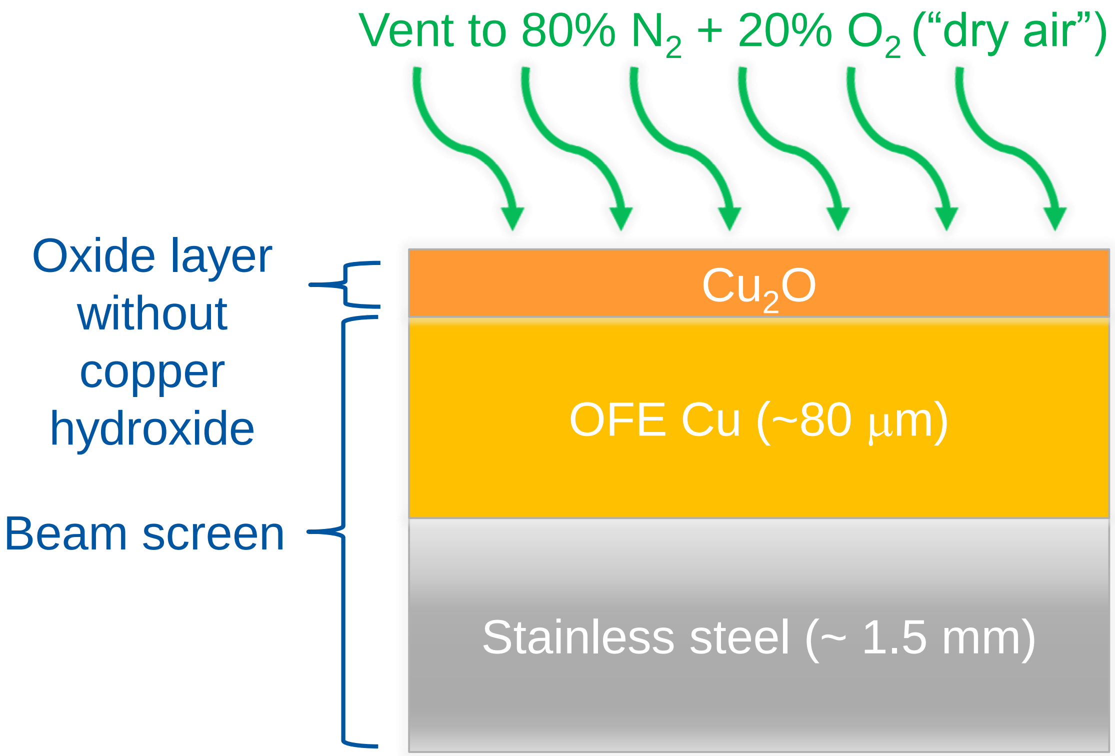

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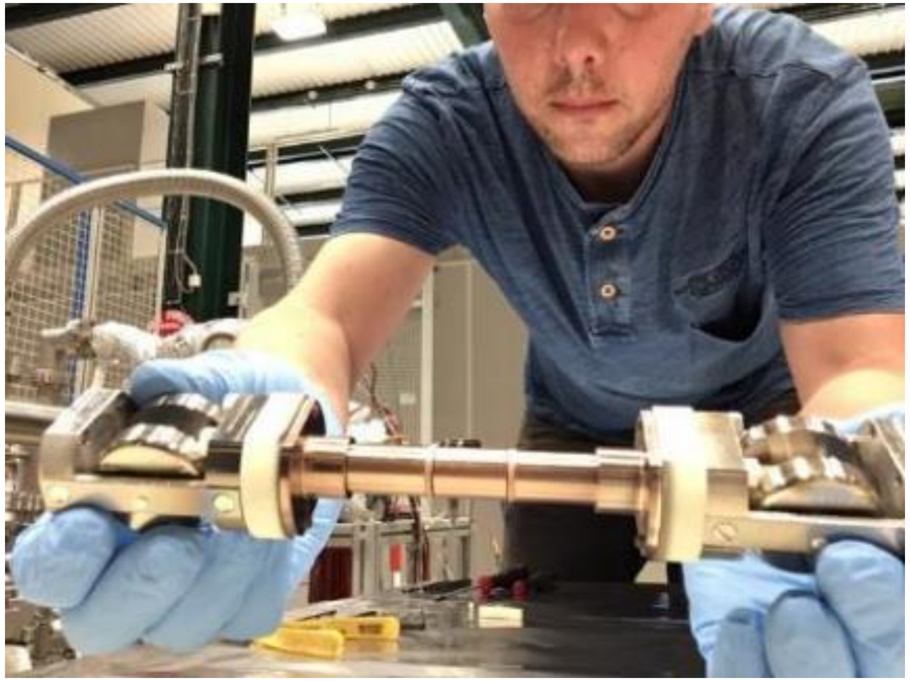

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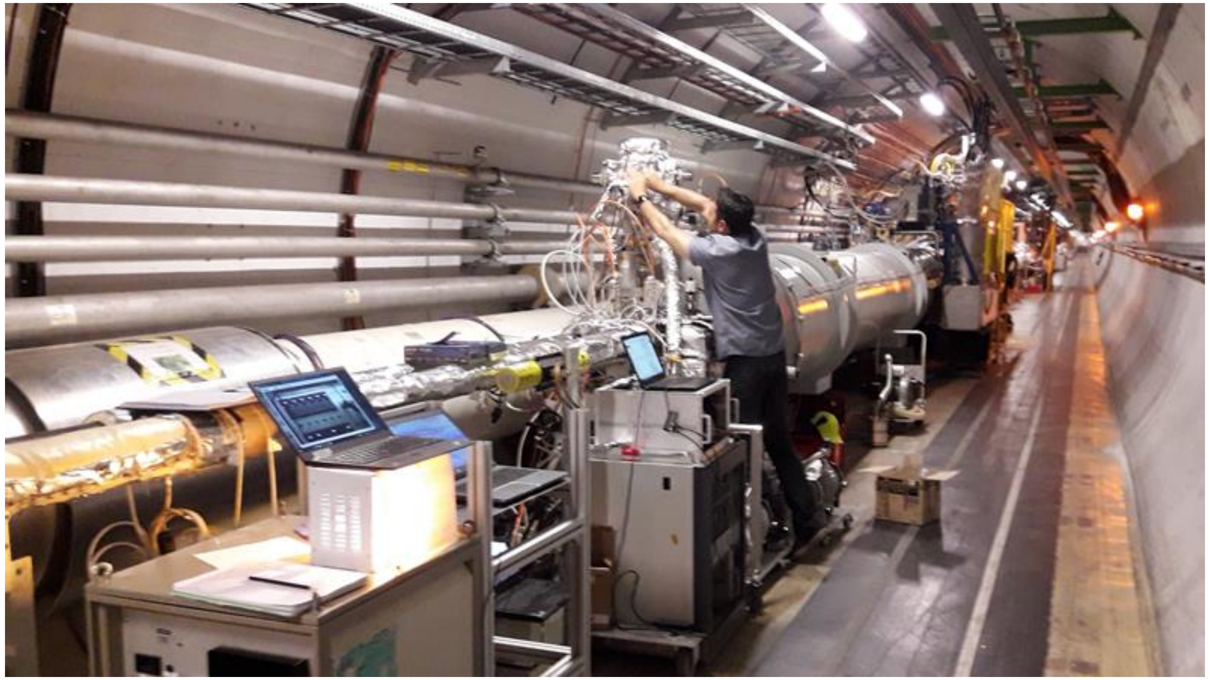

Only 150 mm to insert the coating device => modular sputtering source

High outgassing of H_2O and H_2 => Ti gettering

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3 weeks to coat a 14 m long quad => several systems in parallel

The HL-LHC case

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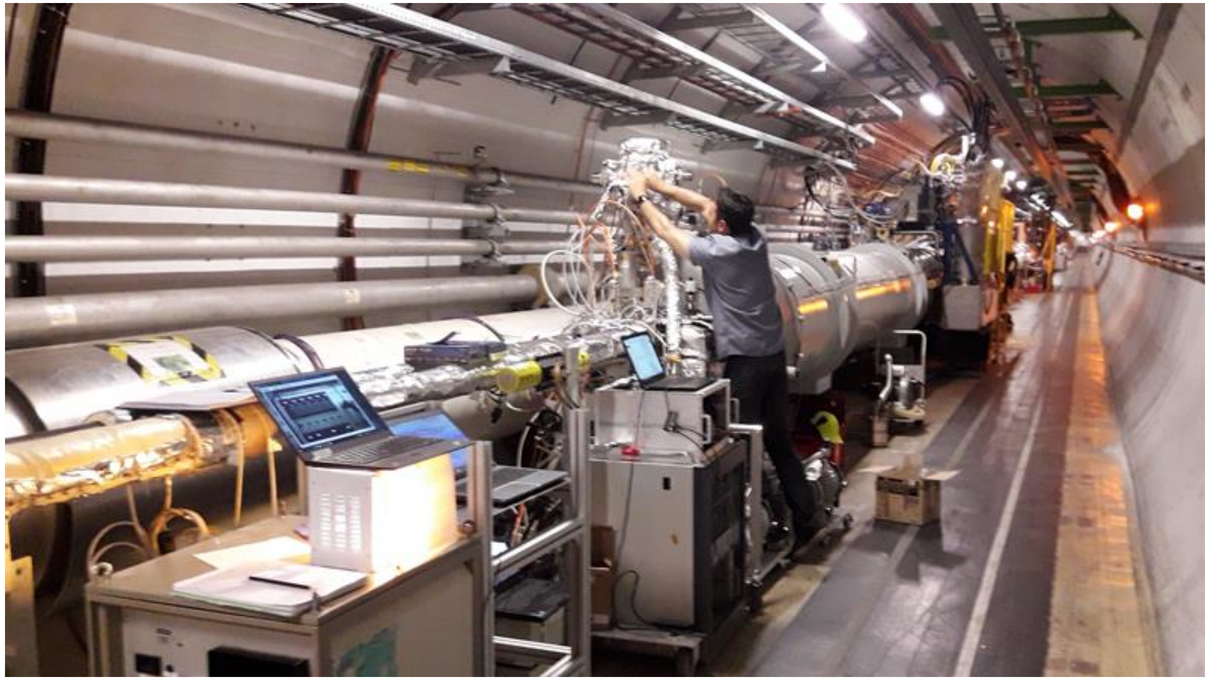

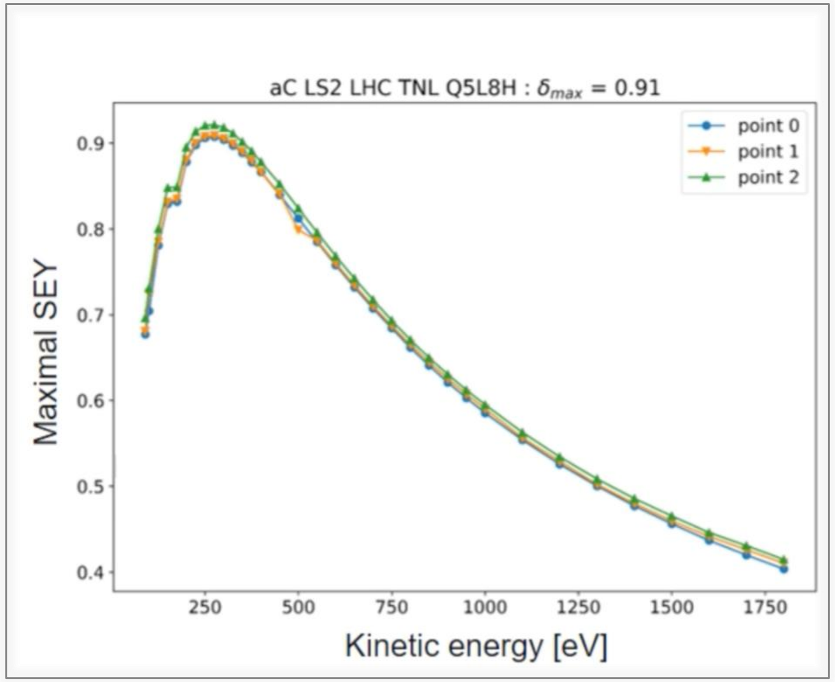

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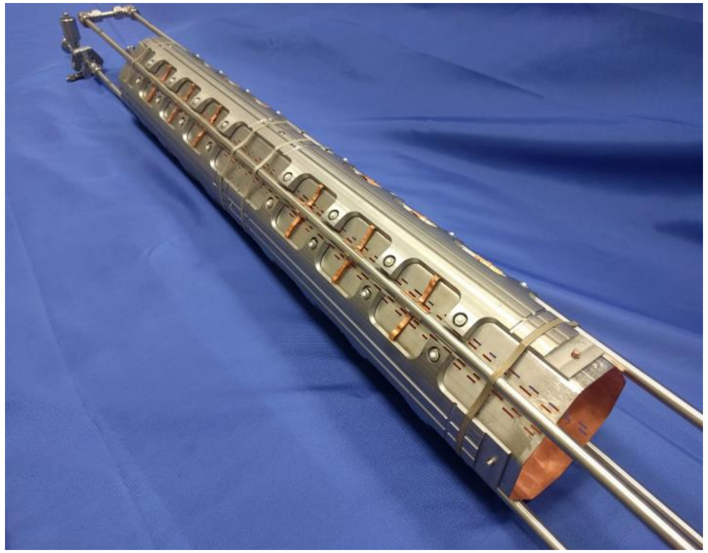
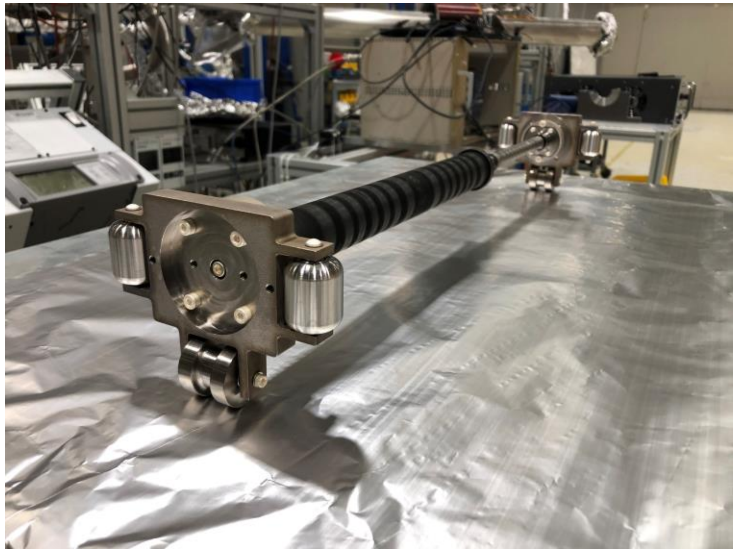
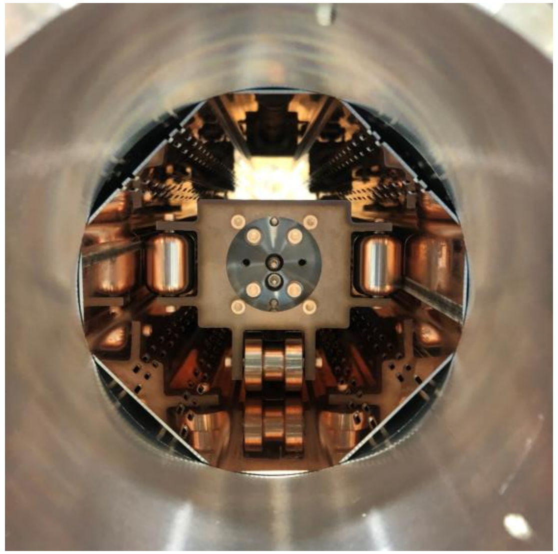
(New inner triplets ATLAS and CMS)

=> Adapt the in-situ technology to the new geometry







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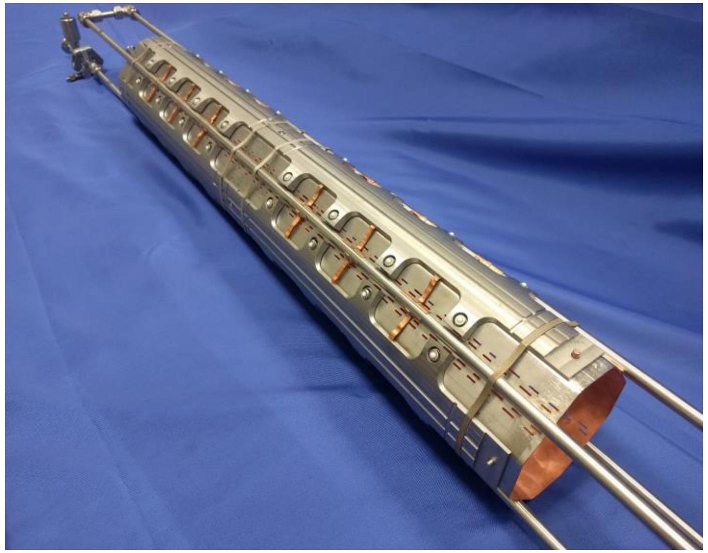

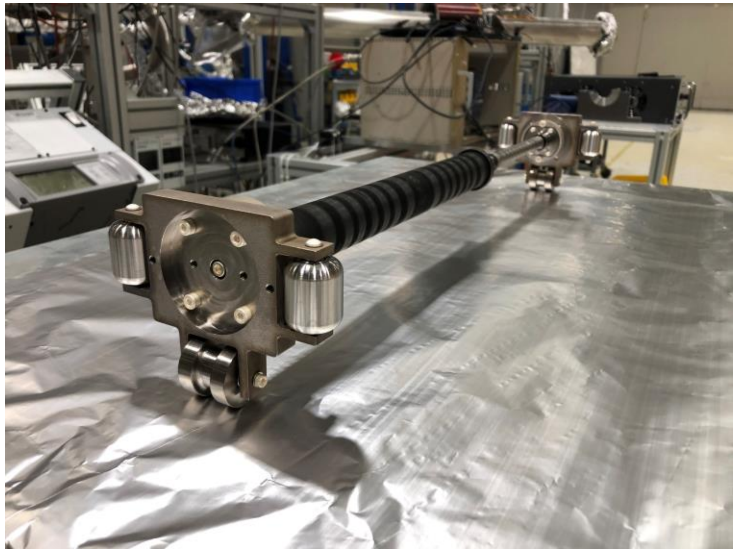

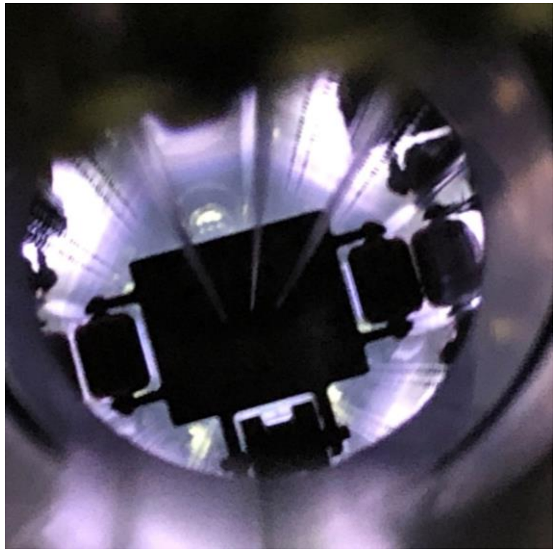

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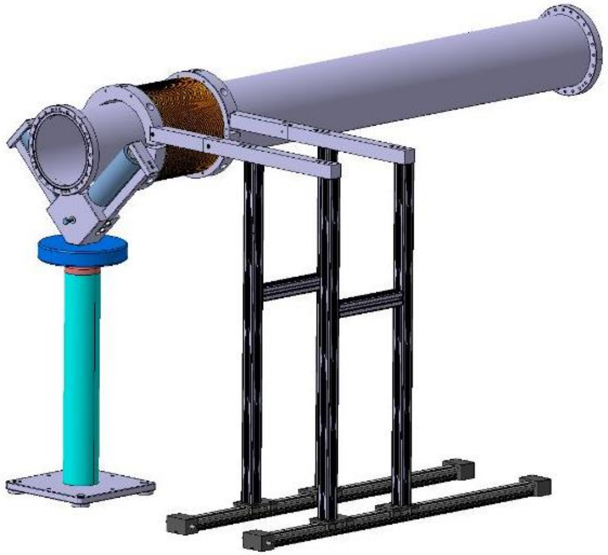

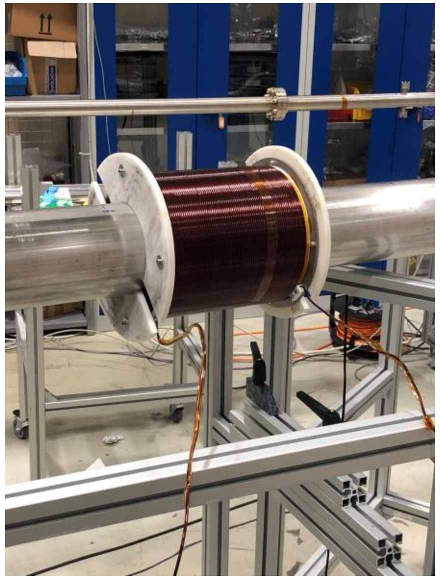

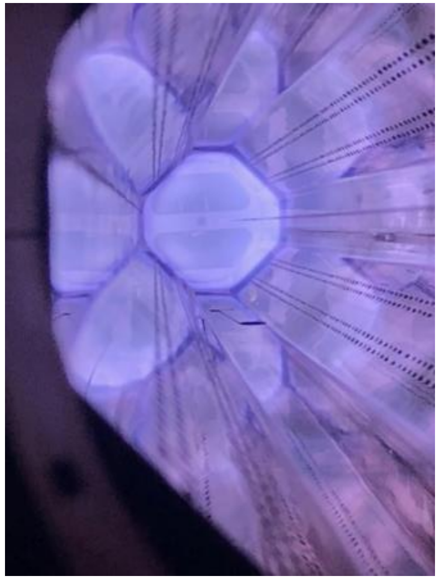

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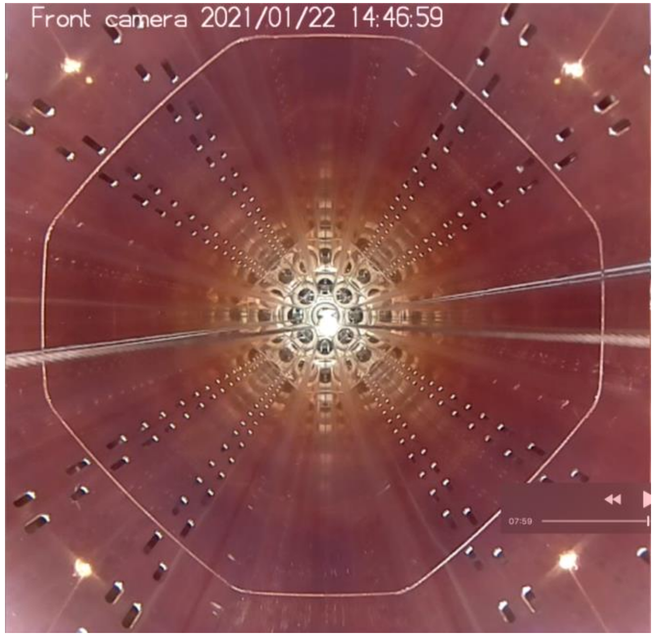
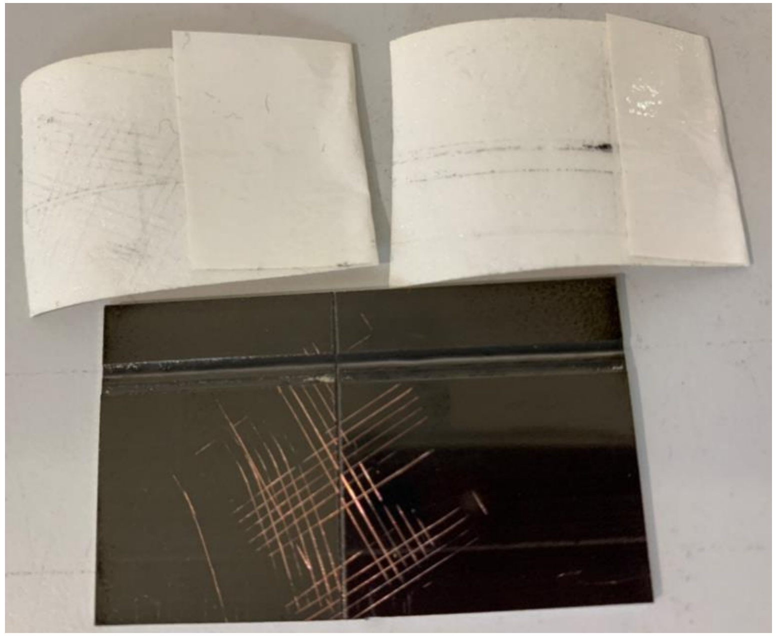
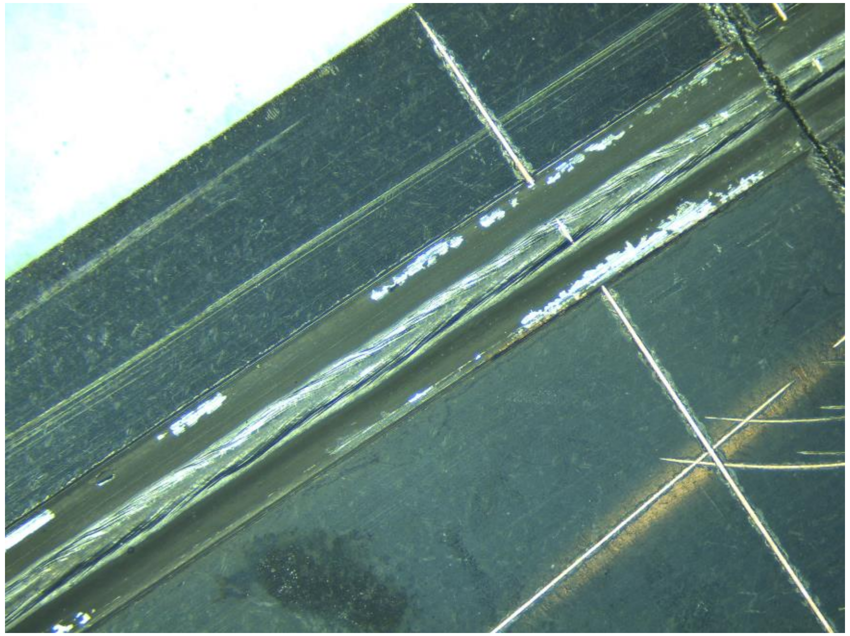


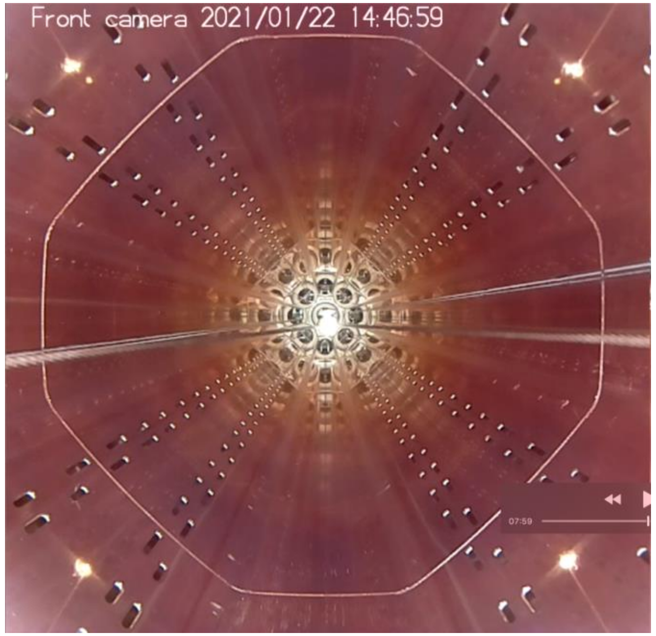


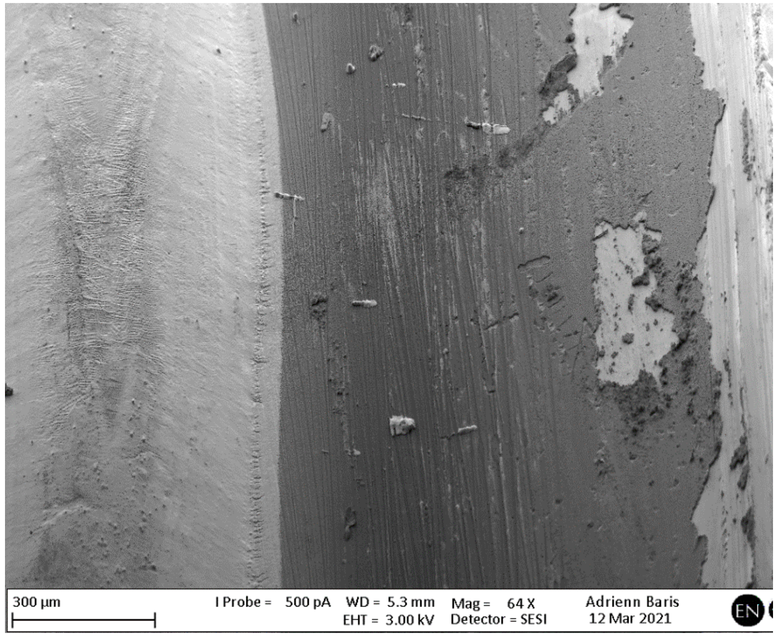


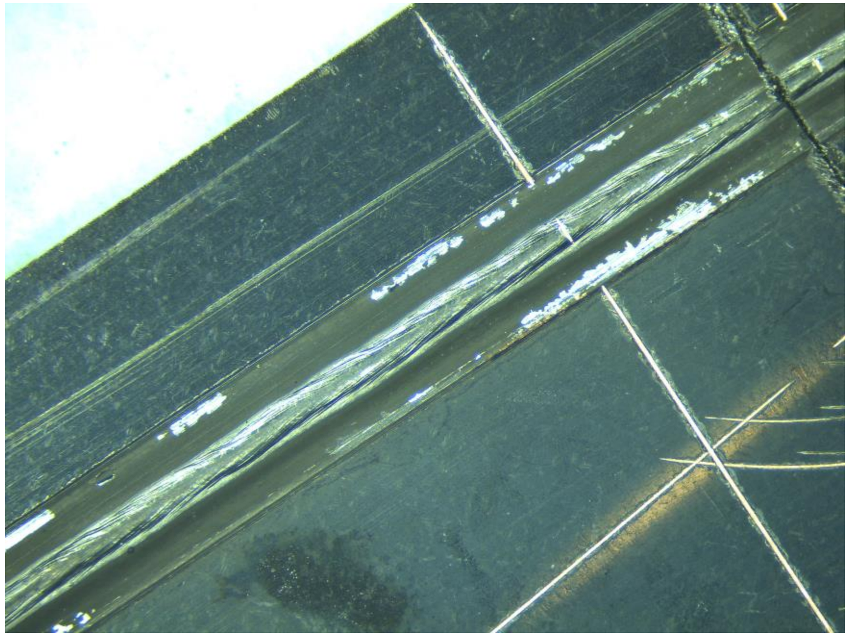
The HL-LHC case

Ex-situ coatings
(New inner triplets ATLAS and CMS)

=> Adapt the in-situ technology to the new geometry







The HL-LHC case

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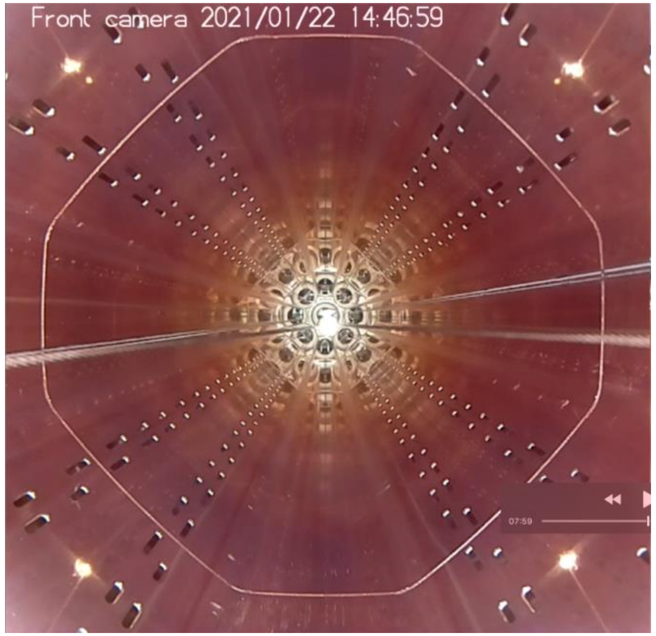
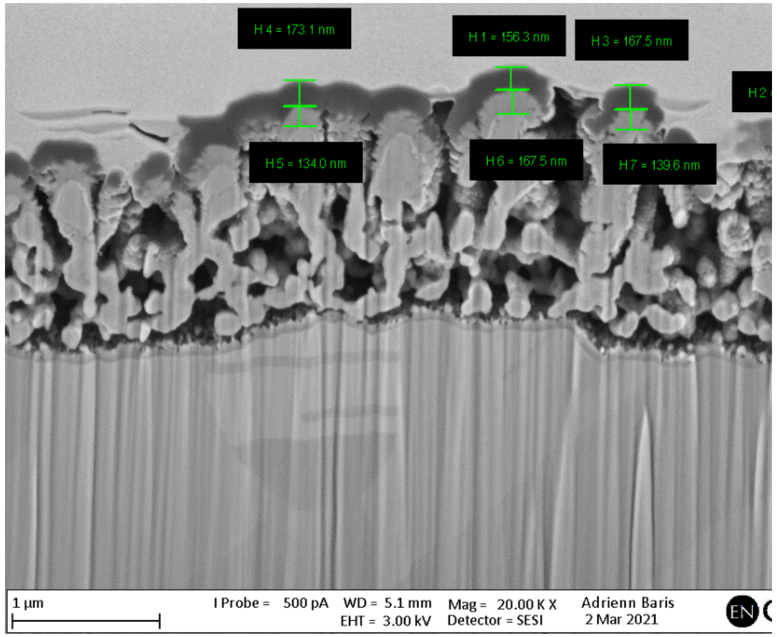
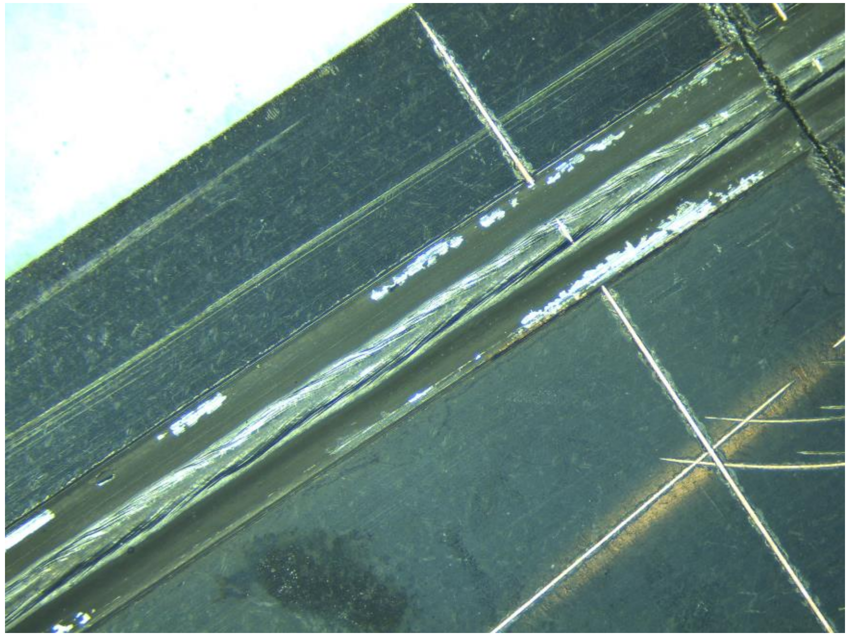




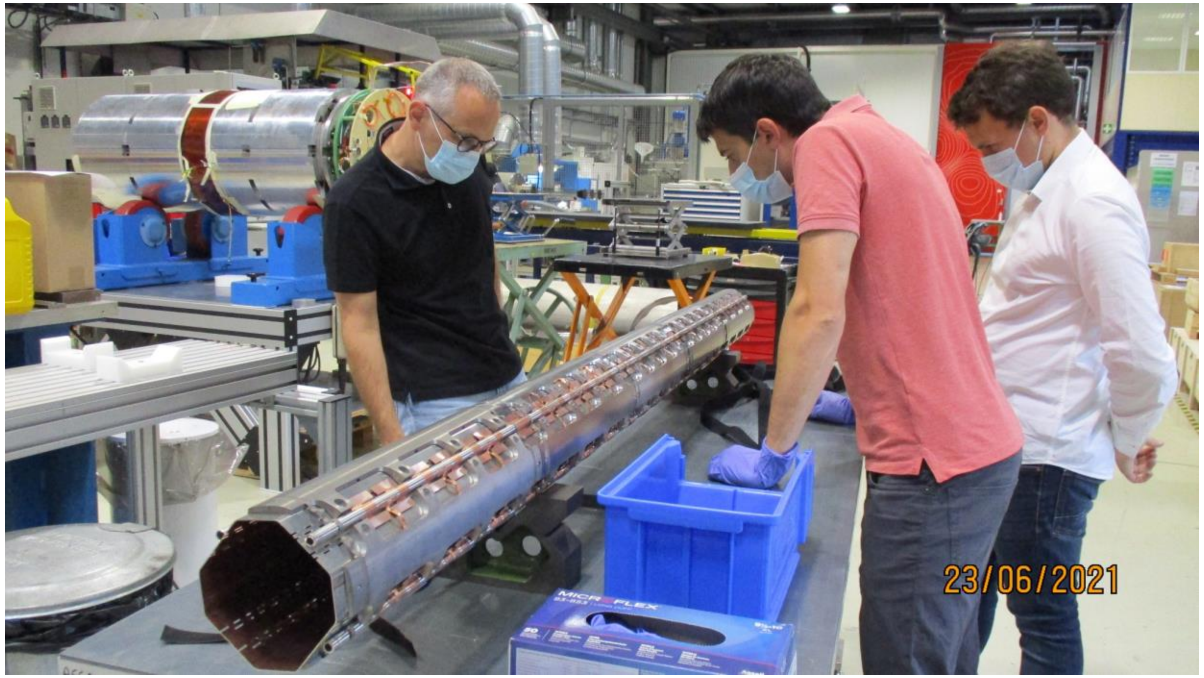


2 – Coating technology at CERN

The HL-LHC case

Ex-situ coatings
(New inner triplets ATLAS and CMS)

=> Adapt the in-situ technology to the new geometry

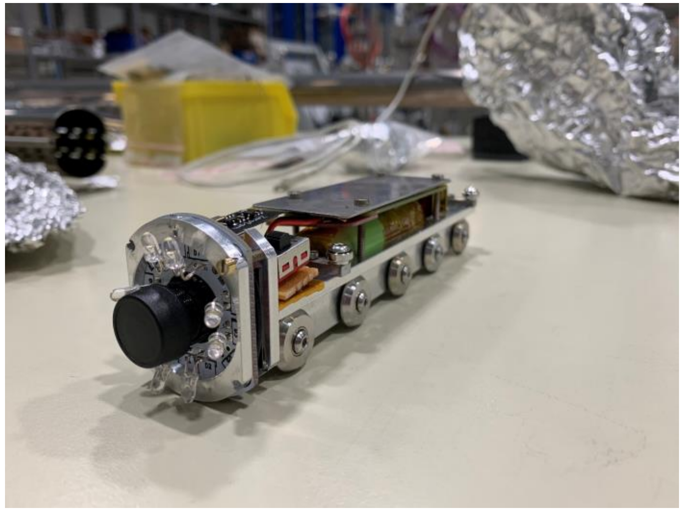


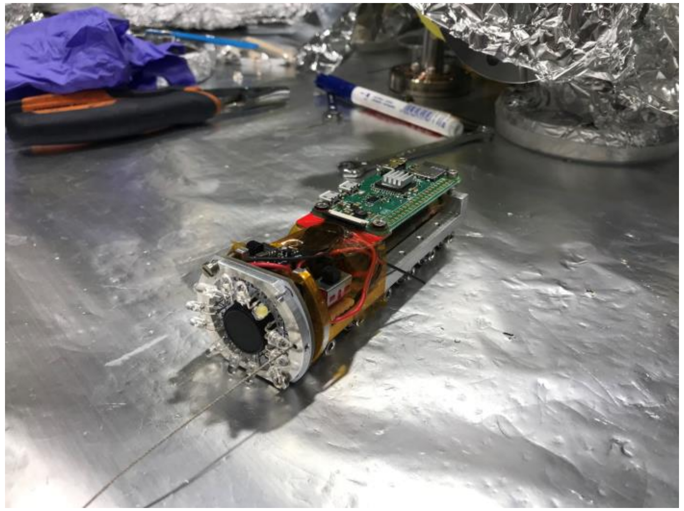
The a-C film resisted to the deformations induced by quenching at nominal currents.

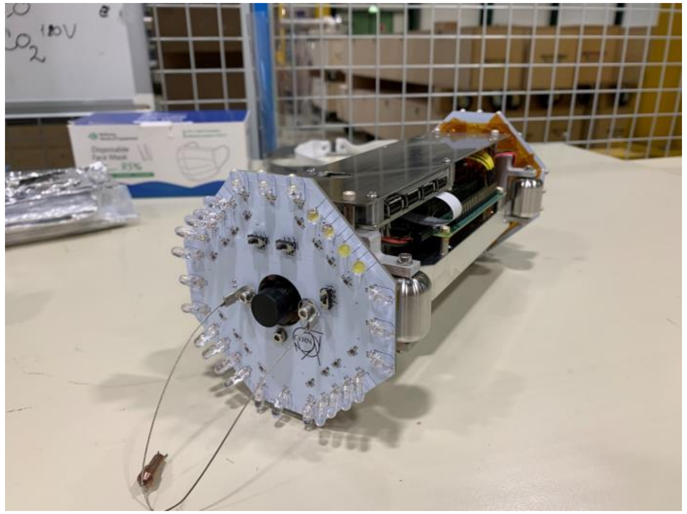
Tests at 4x nominal current ongoing.

The HL-LHC case

Optical inspection devices (before / after coating)







Raspbery Pi camera + motherboard + battery + LED based light system

3 – Summary

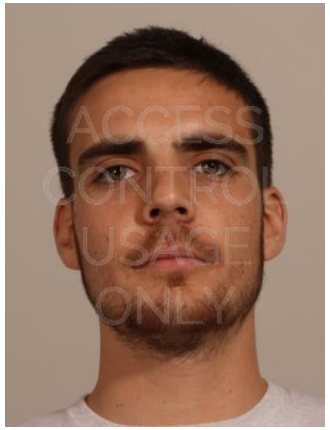
- The coating technique to produce carbon films with low SEY must favor sp2 hybridization (sputtering, PLD). SEY increases with H content and decreases with N content.
- A growing technological *corpus* is available to cope with the constrains of the particle accelerator's community: in-situ / ex-situ; getter co-deposition; N doping; re-set of copper oxide; optical inspection devices…
- Large scale production is feasible: more than 200 coating runs during the LS2 coating campaign in the SPS resulted on a average SEY ~1. (in-situ + ex-situ coatings). More to come during LHC run 3 (ex-situ) and LS3 (in-situ).
- **No pre-defined recipe: the coating technique & process should be adapted to each specific case. Take into account the coating from the design phase is the bet practice.**










Thank you for your attention