Les enjeux matériaux pour la maîtrise de la pression dynamique dans les accélérateurs de particules de haute énergie

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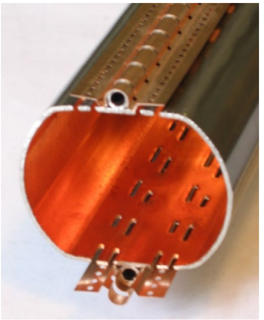
Les enjeux matériaux

Lignes faisceaux



Propriétés

- Resistance mécanique
- Conductivité thermique
- Conductivité électrique
- Compatible UHV
- Résistance aux radiations
- Soudabilité, formabilité

Matériaux

- Cuivre
- Aciers inox
- Alliage Al
- …

Limitation des performances

- Limiter le multipacting (nuage d'électrons)
- Limiter la désorption de molécules adsorbées
- Maîtriser la pression dynamique

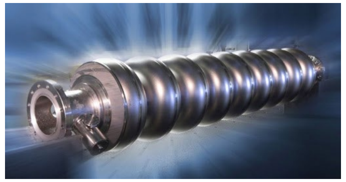
Amélioration des propriétés (I)

- Dépôts NEG (alliages Ti-V-Zr)
- Dépôts C-amorphe
- Couches minces TiN

Amélioration des propriétés (II)

- Couches ultra minces
- Nouvelles compositions
- Nouveaux procédés (Fab Ad)

Cavites SRF



Propriétés

- Resistance mécanique
- Formabilité
- Conductivité thermique
- Supra en régime RF
- Compatible UHV

Matériaux

- Niobium
- ….

Amélioration des performances

- Améliorer le facteur de qualité (diminuer Rs)
- Augmenter le champ accélérateur
- Limiter le multipacting
- Réduire les coûts cryogénique (augmenter Tc)

Amélioration des propriétés

- Améliorer les traitements de surface
- Traitements thermiques optimisés (dopage, infusion,…)

Matériaux alternatifs

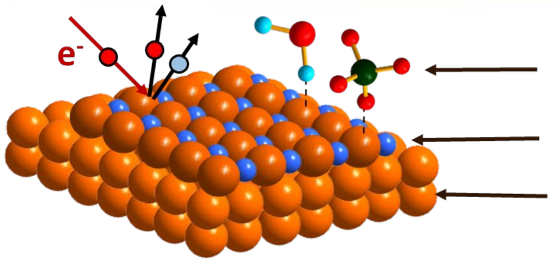
Couches minces :

- Nb_3Sn
- MgB_2
- NbN
- Multicouches SIS
- Base fer HTC

Conserver les propriétés du bulk et améliorer les propriétés des surfaces (dépôts de couches minces)

→ science des surfaces = étude des phénomènes physiques et chimiques qui se produisent à l'interface entre la surface du matériau et le vide

OUTLINE



1. Context

2. Electron emission from technical copper

- Influence of the C-layer thickness on the SEY
- Influence the native oxides of the metal : e.g. CuO on Cu
- Impact of surface roughness on SEY : copper by additive manufacturing
- Comparison with other materials

3. Non-Evaporable Getter (NEG) as a low-SEY coating

- NEG and FCC-ee
- NEG coatings elaborated at CERN
- NEG coatings at IJCLab
- The future of the NEG ?

4. Conclusion and perspectives

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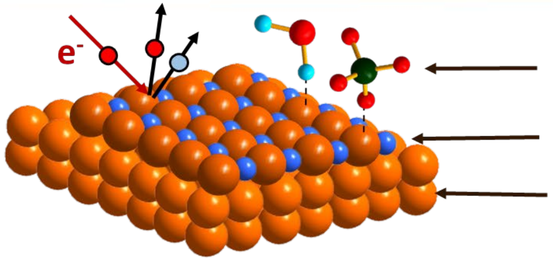

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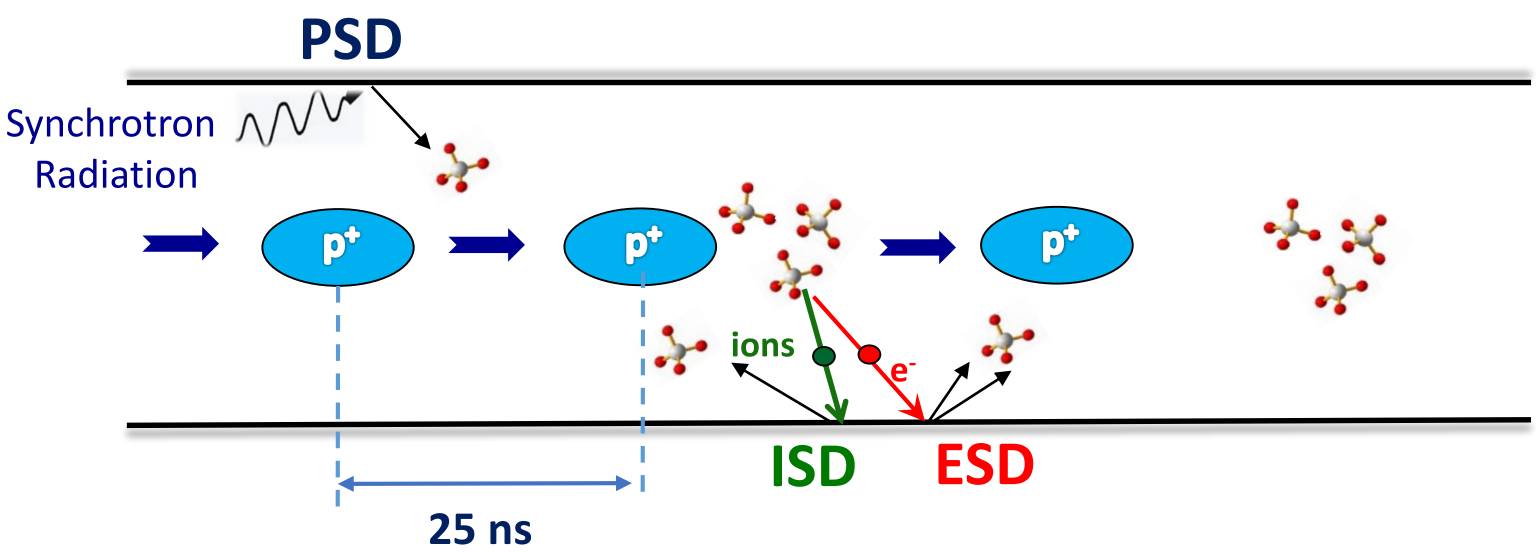
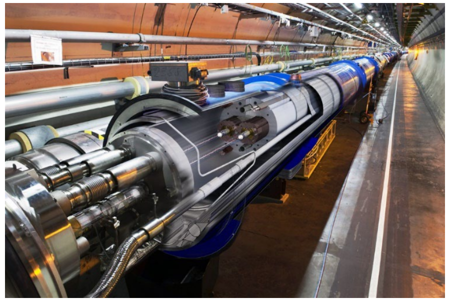
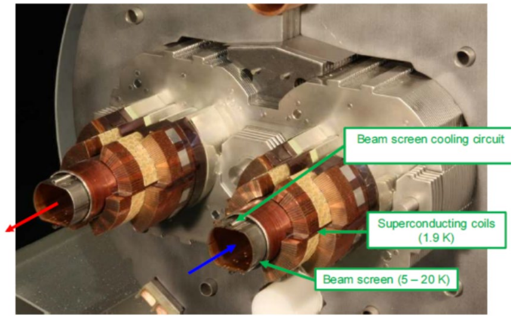
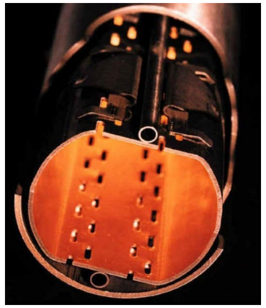
Stimulated desorption



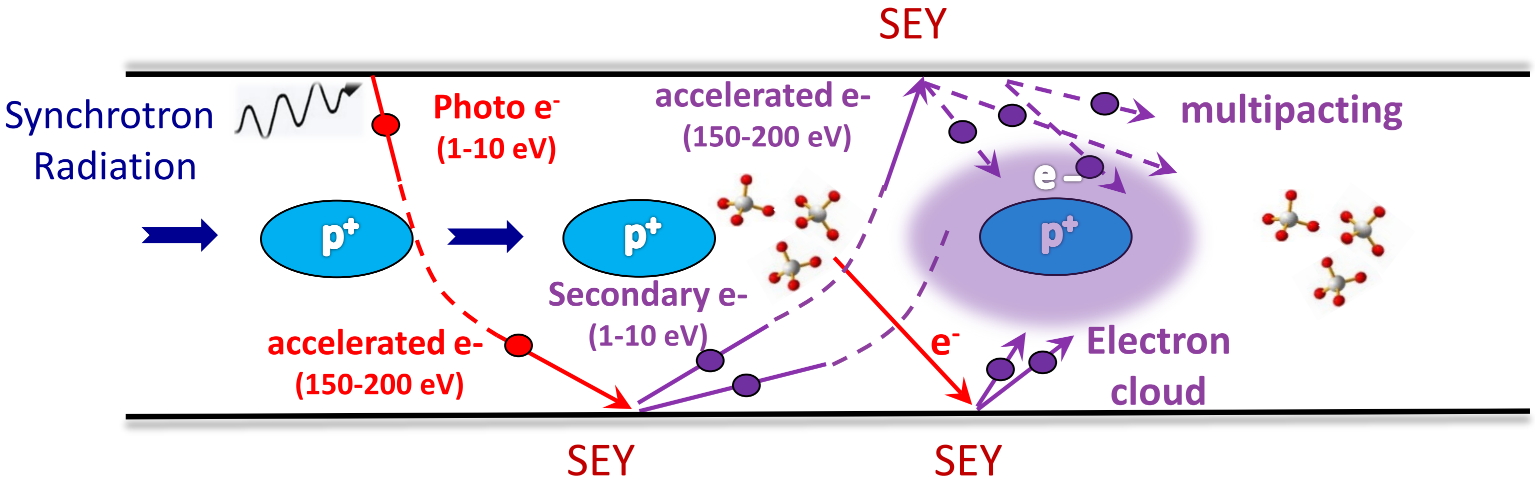






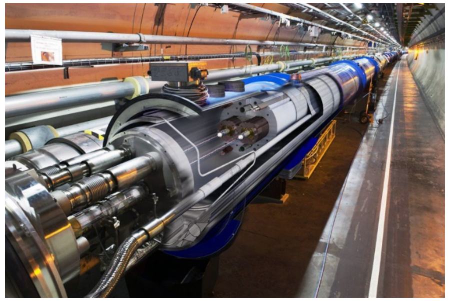
Context : LHC as an example

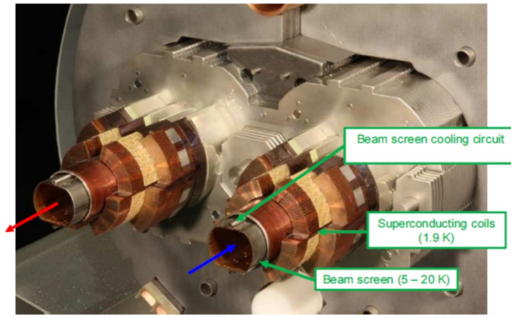
Secondary particle production

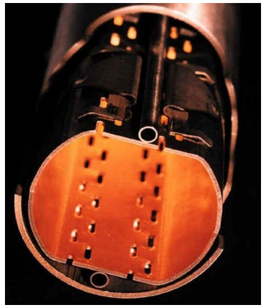


=Secondary Emission Yield

$$SEY = \frac{I_{secondary\ e-}}{I_{incident\ e-}}$$







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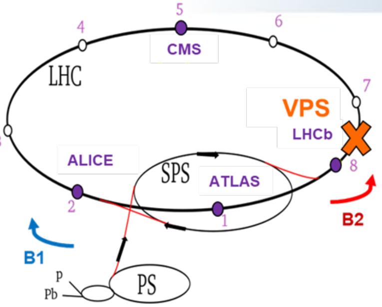
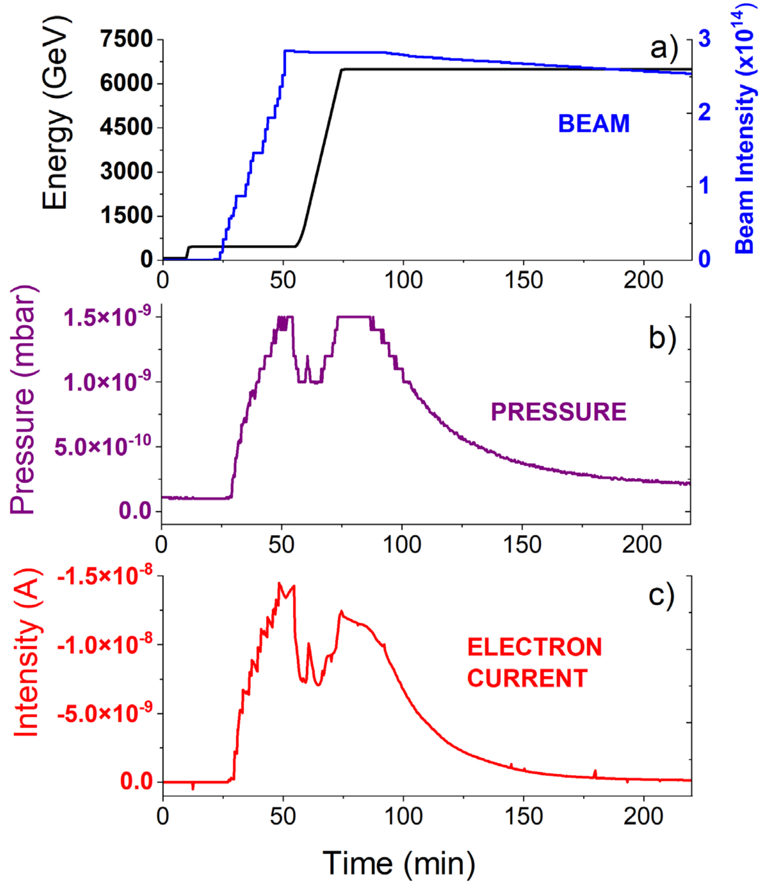
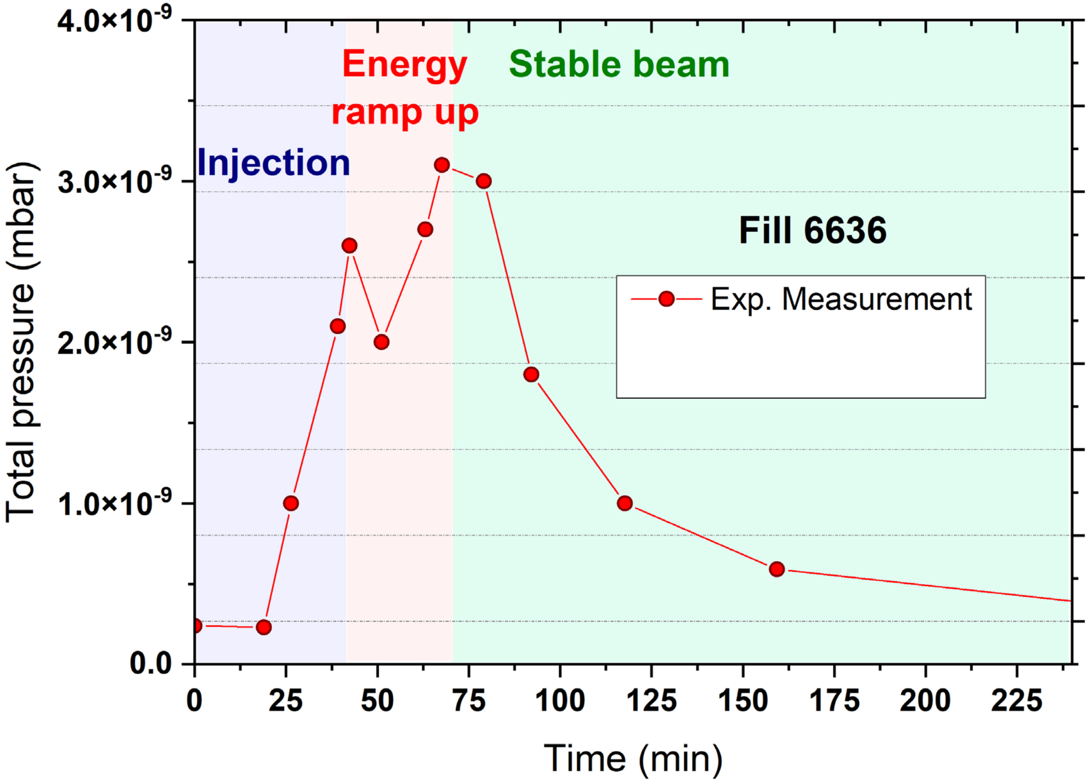


Pression et courant d'électrons mesurés dans le LHC (station 4 du VPS- Run 2 - Fill 7319)



S. Bilgen et al PRAB 25, 083101 (2022)

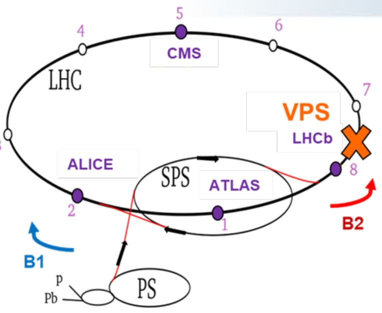
Simulation de la pression dynamique avec le code DYVACS



Thèse S. Bilgen 2020
Collab V. Baglin, CERN

The electron cloud mainly contributes to the pressure rises in the LHC

Context : LHC as an example



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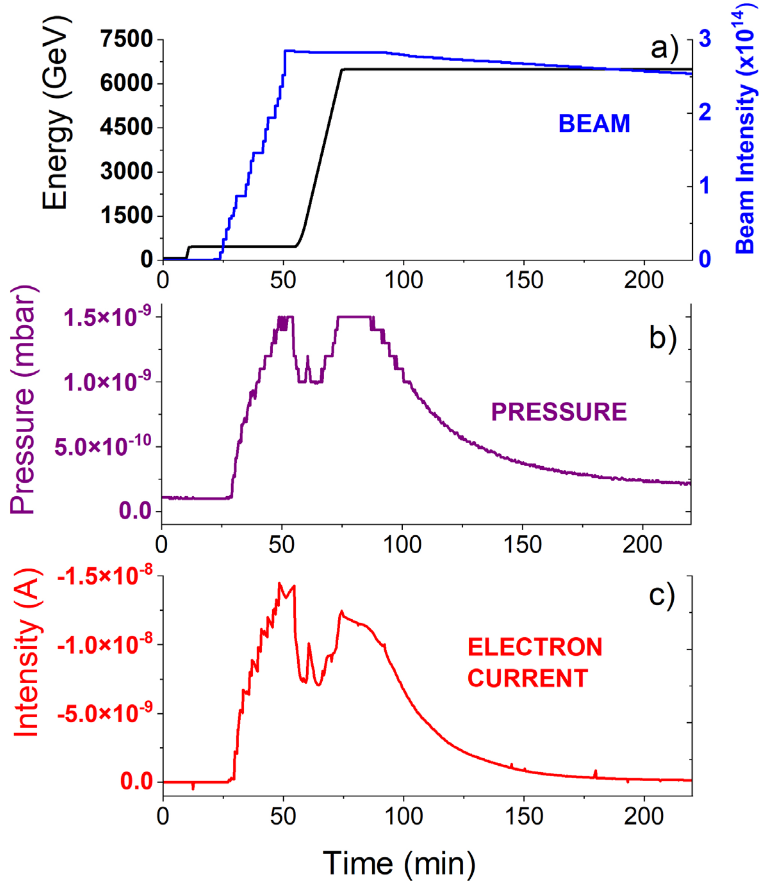

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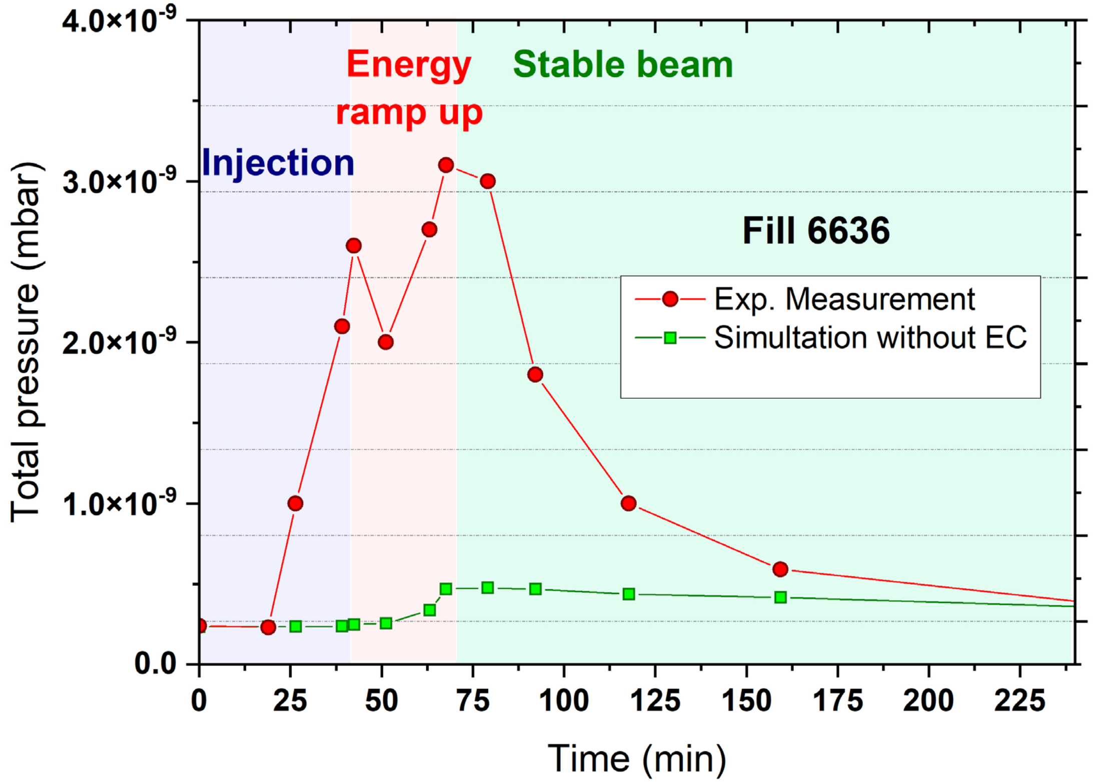

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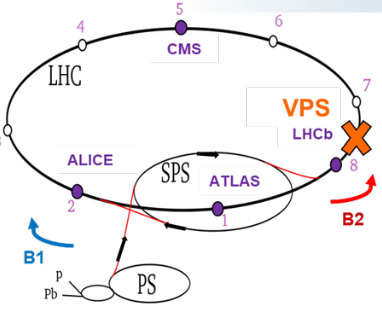

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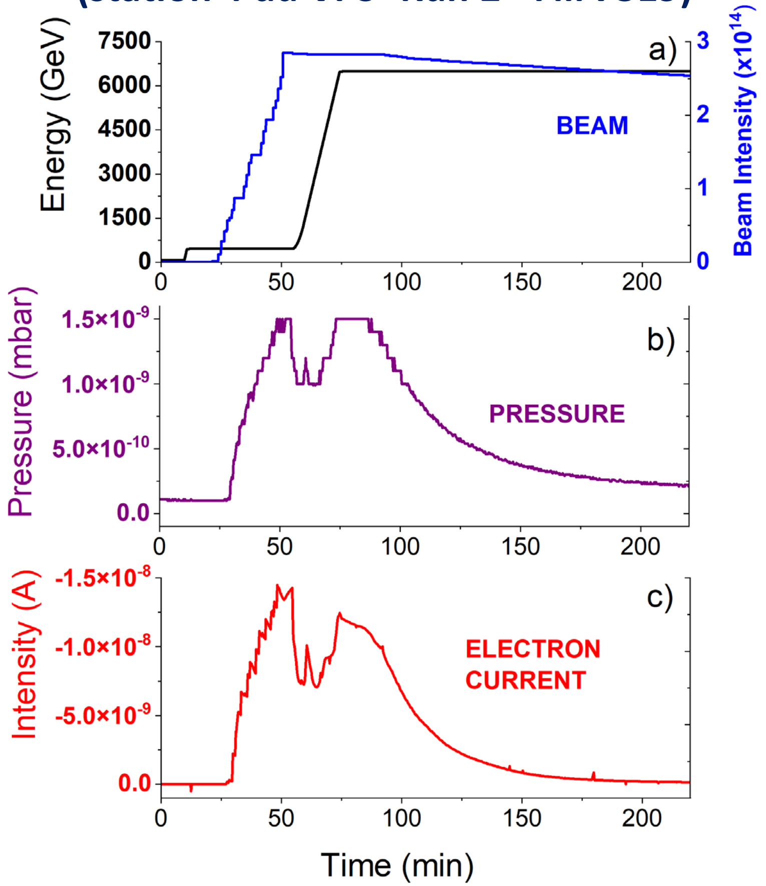

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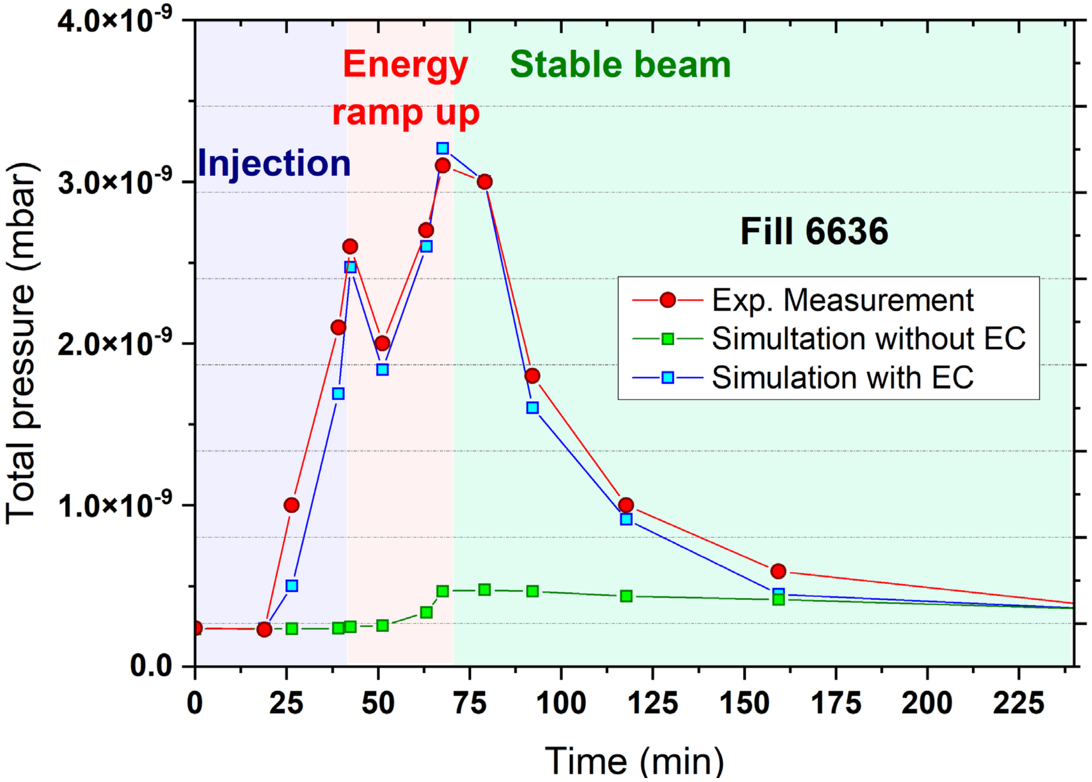

Thèse S. Bilgen 2020
Collab V. Baglin, CERN

The electron cloud mainly contributes to the pressure rises in the LHC
Dynamic pressure depends on material surface properties (SEY, stimulated desorption yields…)

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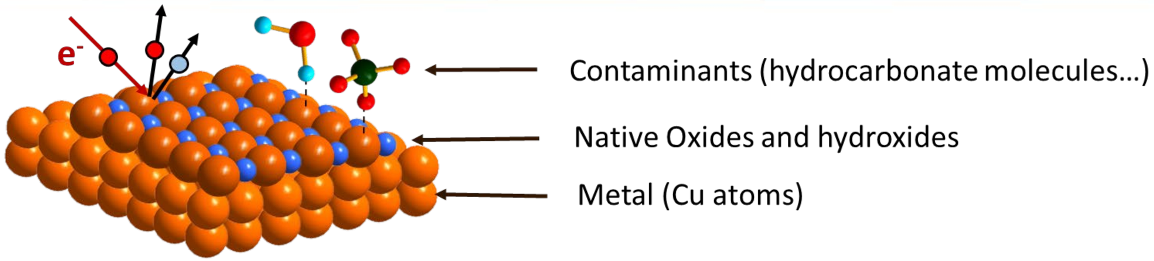

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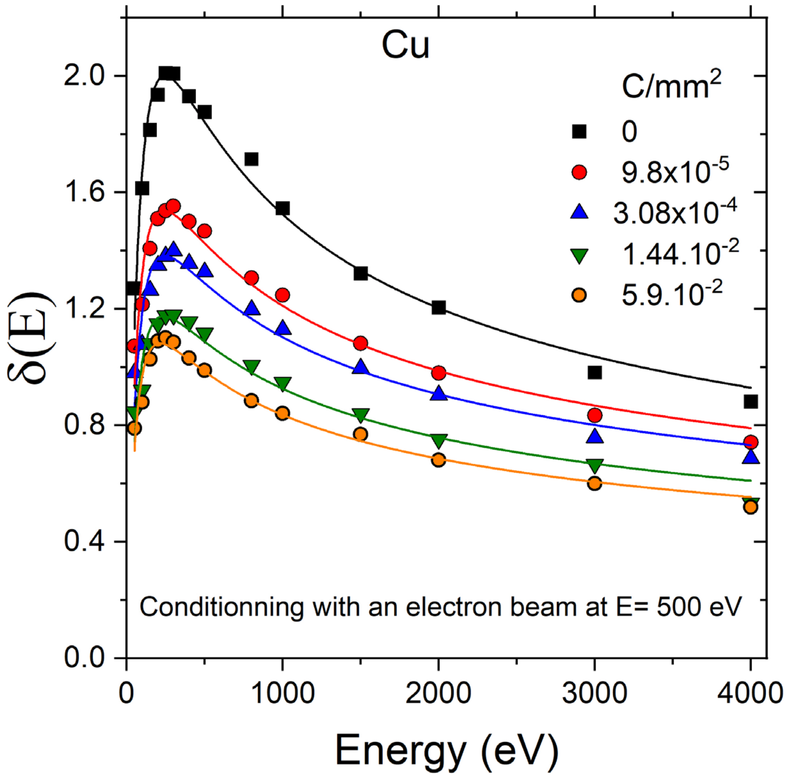
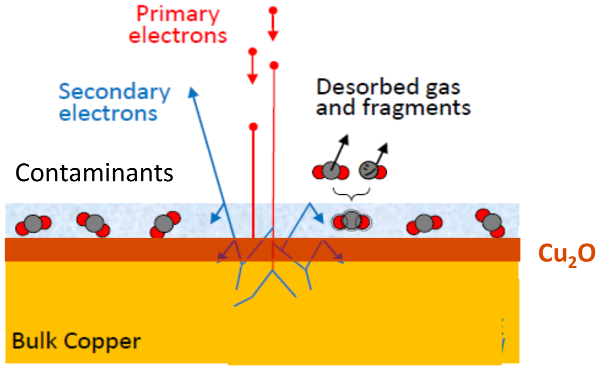
Conditioning of copper and SEY : reminder

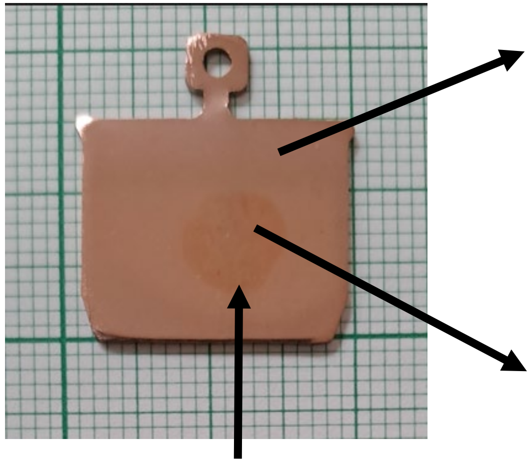
IJCLab

SEY

No conditioned surface : SEY ≈ 2.1
Fully conditioned by e- irradiation : SEY ≈ 1.1



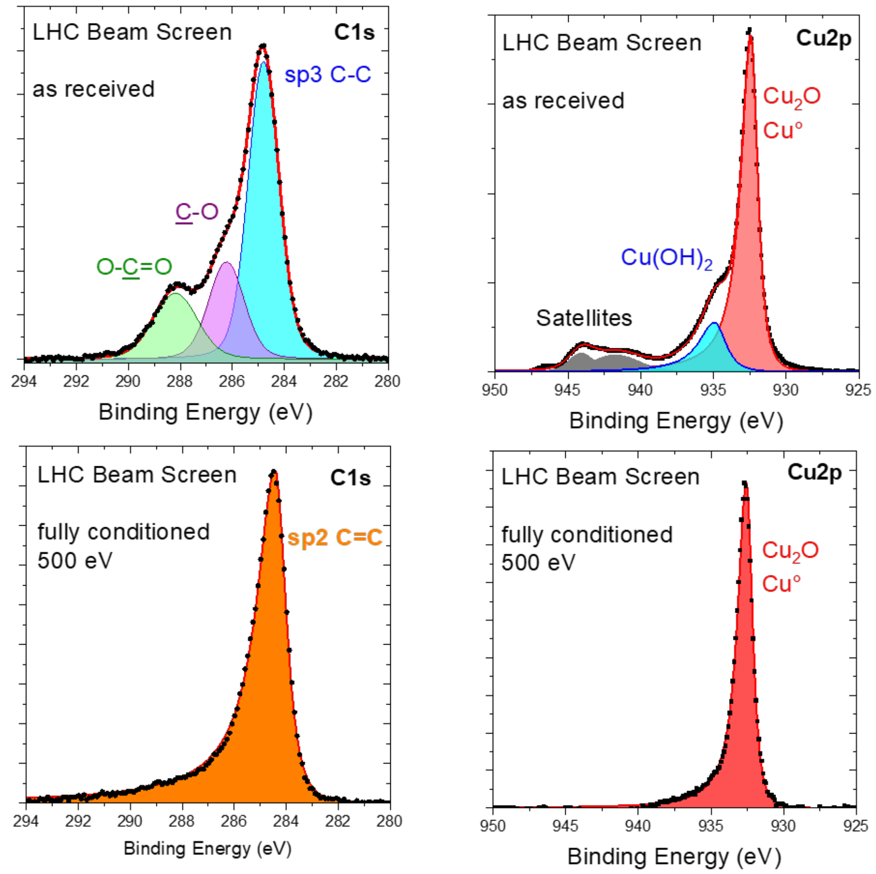




Analyse de surface : XPS

C1s peak

Cu2p peak



Adventitious carbon (C-O, O-C=O) is removed by electron irradiation:
Specific peaks associated with organic molecules on the surface, disappear after the surface cleaning by the e- bombardment.

Modification of the C hybridization induced by electron irradiation:
Shift of the max of the peak towards low energies (XPS analysis): signature of a modification of C chemical bonds: from C-C bonds (sp3) to C=C bonds (sp2)
→ in agreement with the literature [R. Cimino et al, 2020] [V. Petit , 2019]

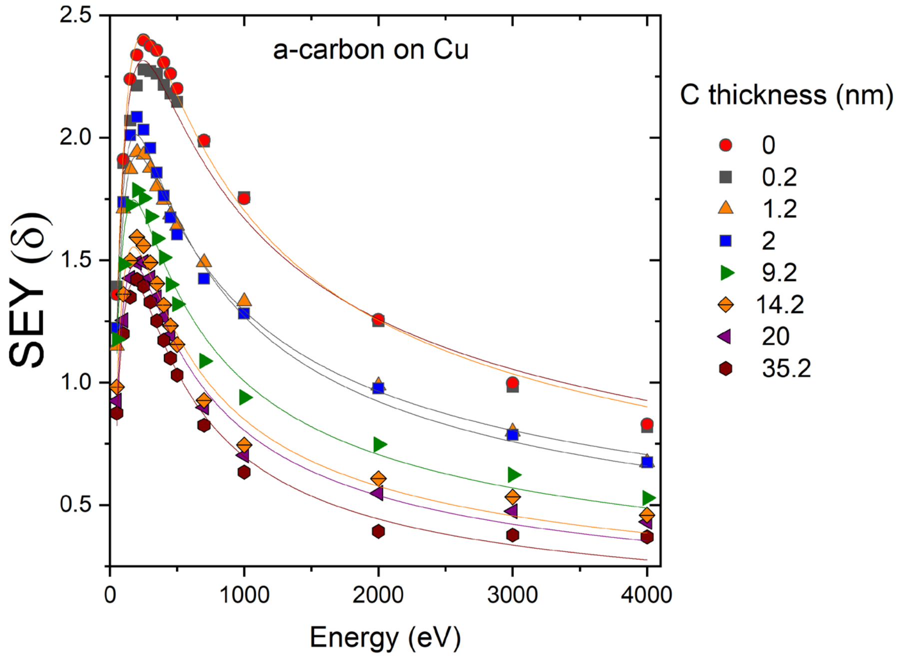
C-coating on Cu : SEY of as-received sample

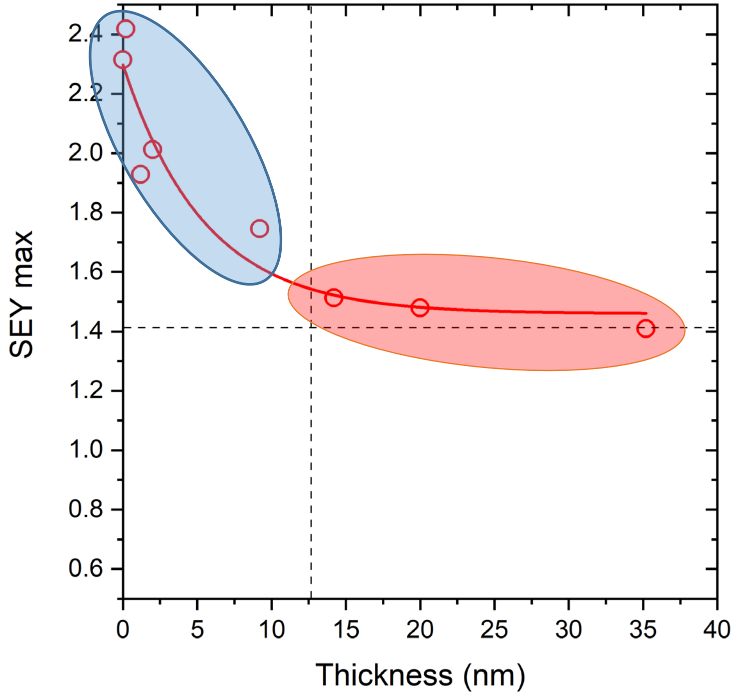
IJCLab

- Cu Flag + polishing with SiC grinding paper (grit 1000) + ethanol cleaning + glow discharge plasma cleaning

- C-layer on Cu by evaporation coating with several thicknesses (0.2 to 35.2 nm measured with a quartz crystal microbalance)

Before conditioning





Thickness < 12 nm
- Electrons emitted by the surface both by C-coating and Cu-substrate
- SEY driven by both materials properties

Thickness > 12 nm
SEY dominated by the C-layer properties

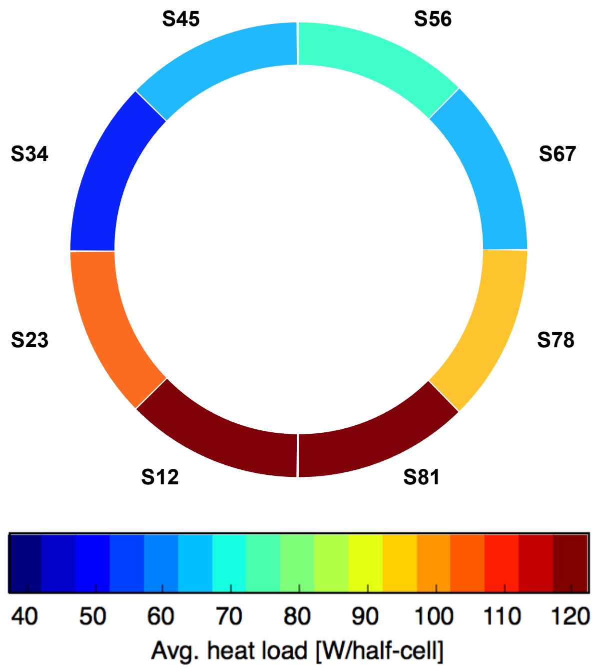
δ_{max} decreases (from ≈ 2.3 down to ≈ 1.4) when the thickness of the C-coating increases
It reaches a threshold ≈ 1.4
A thickness of ≈ 12 nm is sufficient to reach the minimum SEY value before conditioning

Copper oxides : a “hot topic” at CERN !

CERN

V. Petit PhD Thesis (CERN, 2020) / V. Petit et al COMMUNICATIONS PHYSICS (2021)

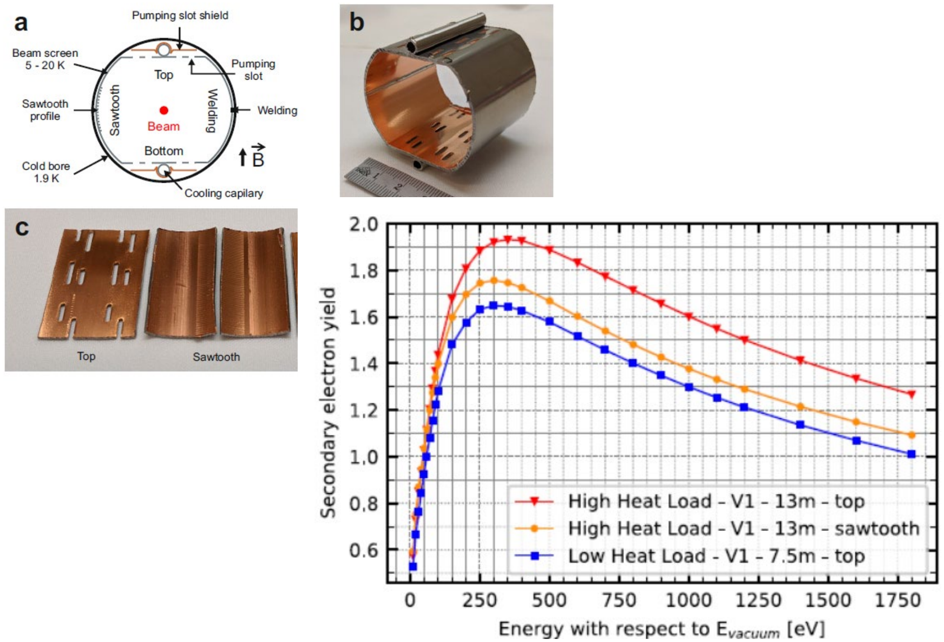
Heat load from the EC in the LHC

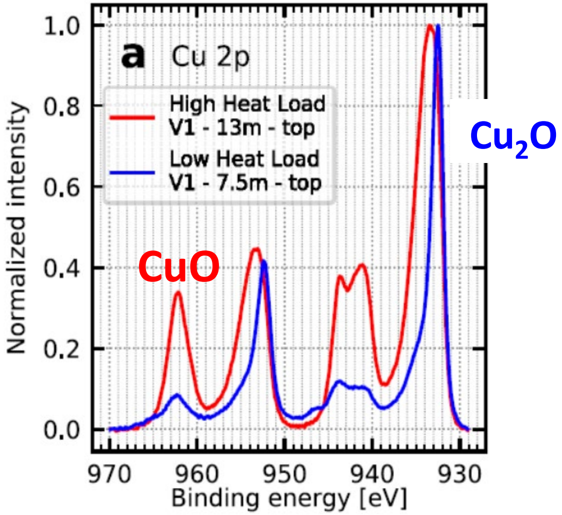


Giovanni Iadarola, CERN
E-CLOUD workshop 2018

- heat load is inhomogeneous along the ring
- machine appears to be splitted into two parts:

Blue arcs average heat load are lower (so less EC) that other arcs (with an important EC activity)



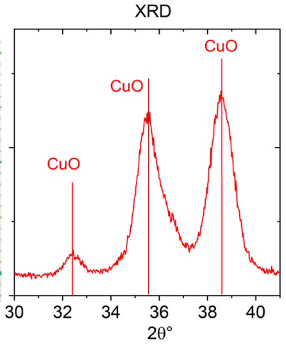


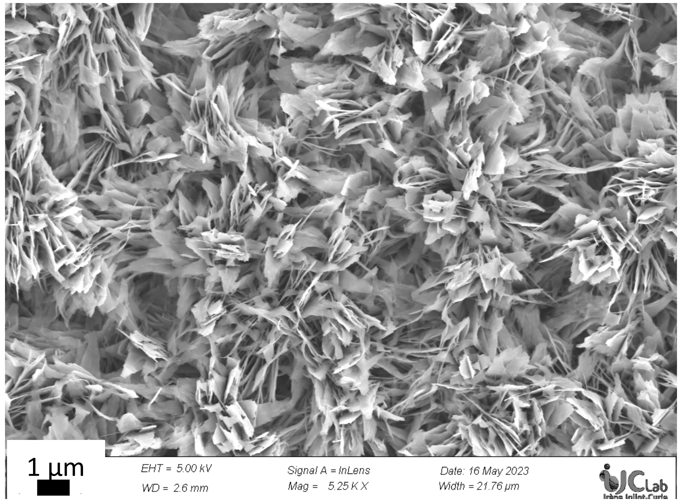
- Beam screen extracted from the LHC beam pipe
- High Heat Load parts exhibit a higher SEY than the Low Load parts
- **CuO was detected (and not the native oxide Cu_2O) in High Heat Load parts** (high EC activity because more e- produced) **!**

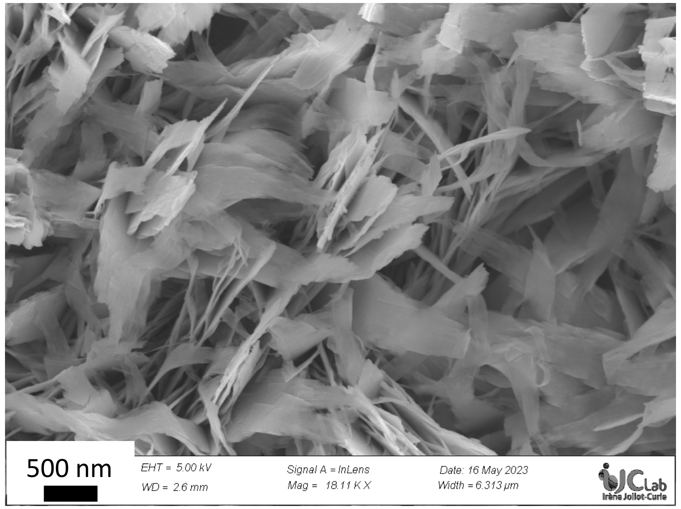
CuO is responsible for the higher SEY observed on this sample (responsible for the high heat loads measured in some arcs)

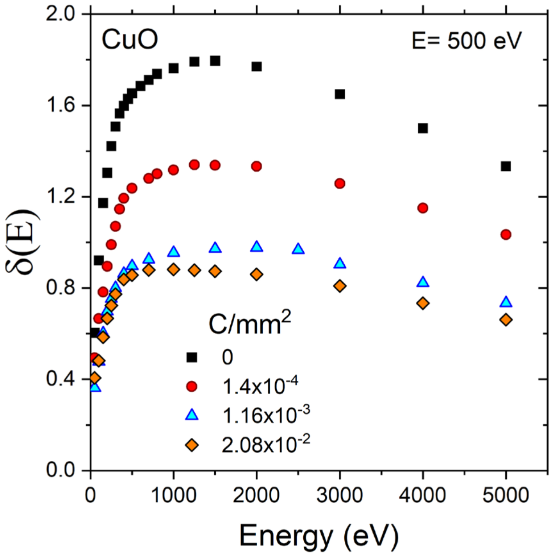
CuO : SEY and conditioning

CuO sur Cu
(chemical route)









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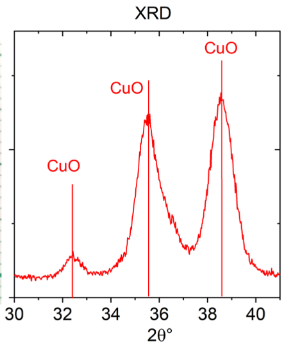
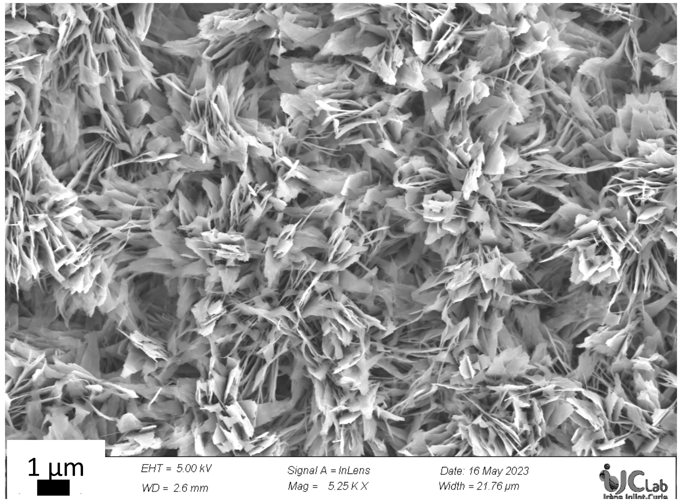
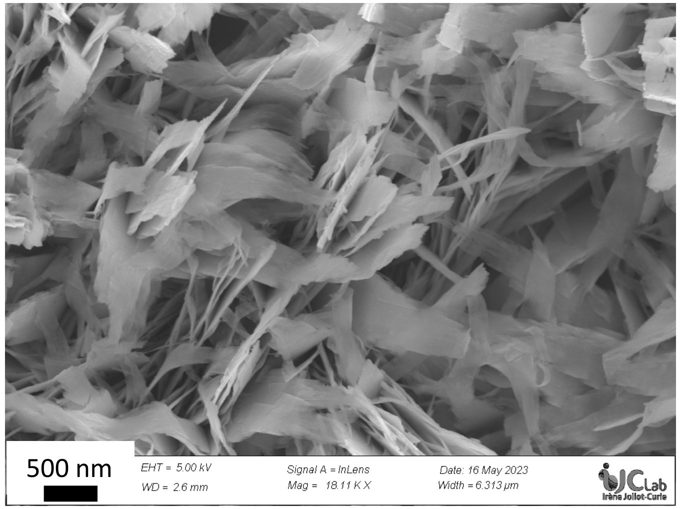
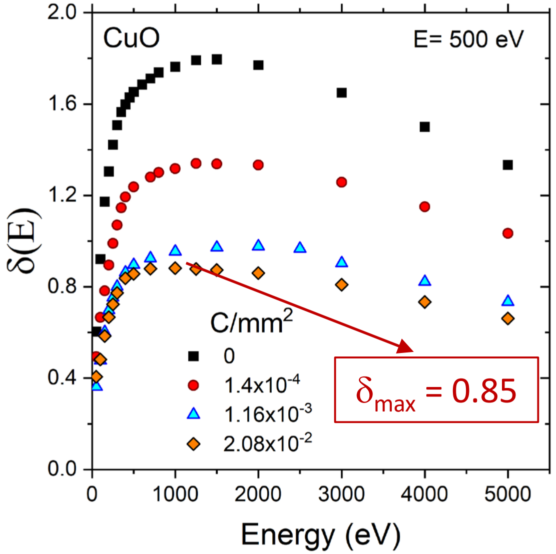
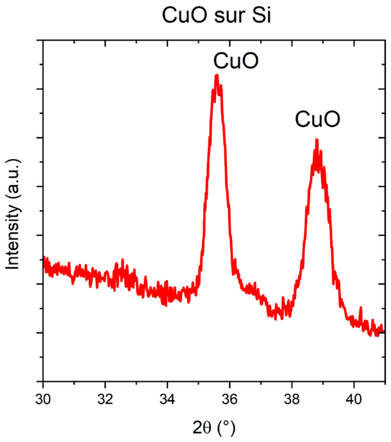




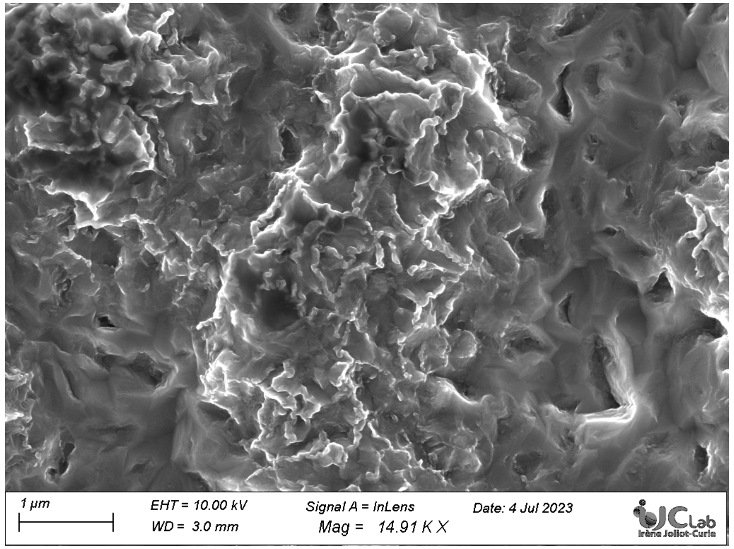


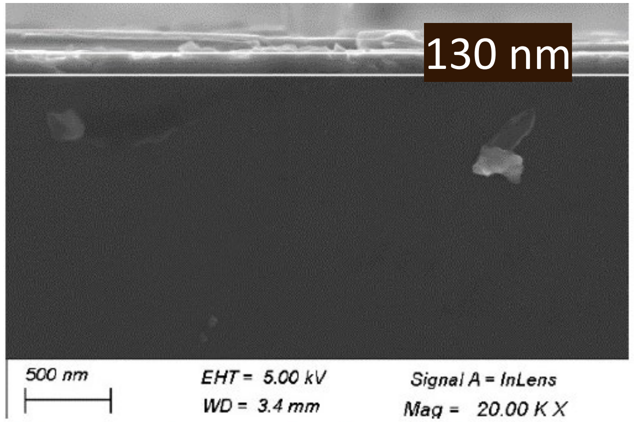


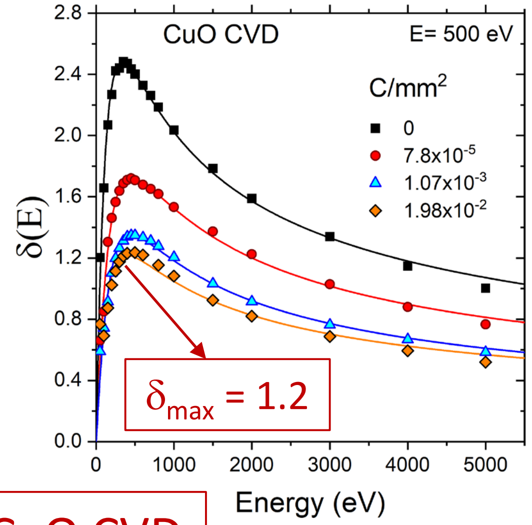
CuO par CVD sur Si



collab. N. Prudhomme ICMMO



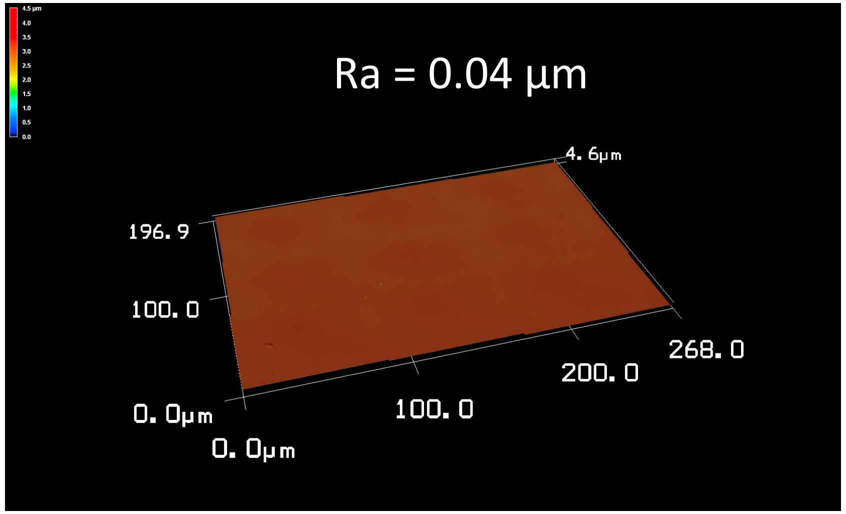




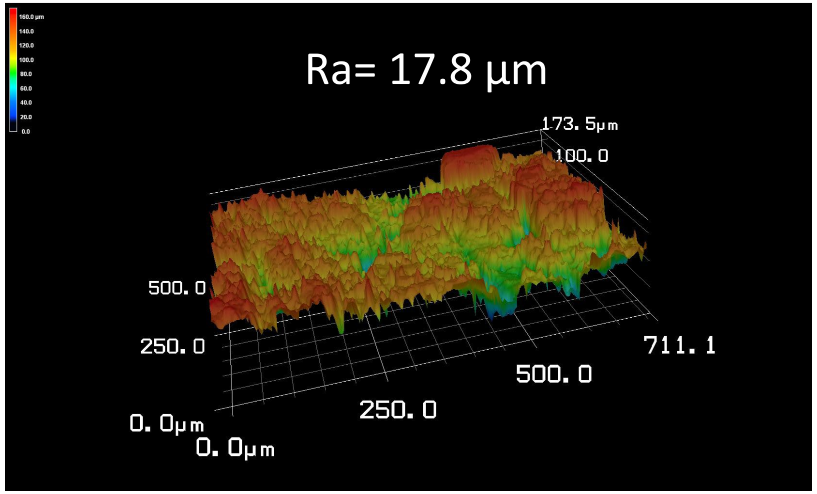
δ_{max} CuO chem < δ_{max} Cu < δ_{max} CuO CVD

Cu : Additive Manufacturing

Cu after polishing



Cu by Additive Manufacturing



C. Verdy, L. Vitu (ICB - LERMPS – UTBM) / E. Toffin, S. Jenzer (IJCLab)

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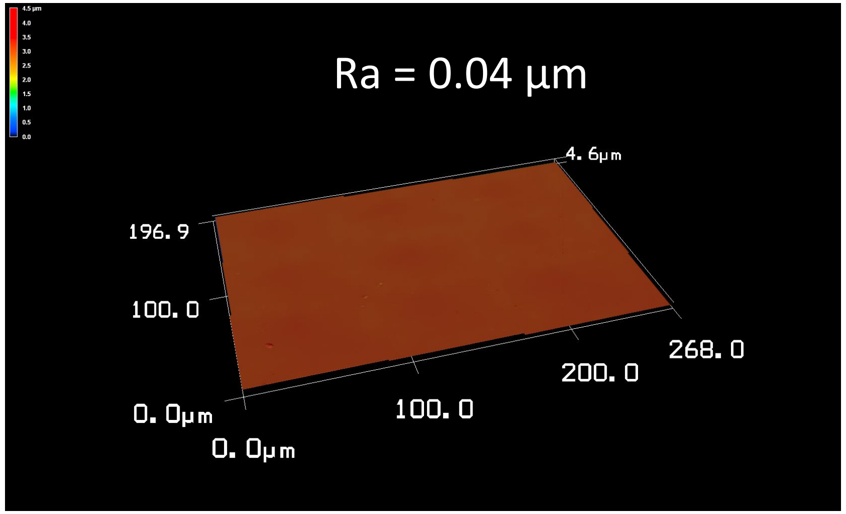

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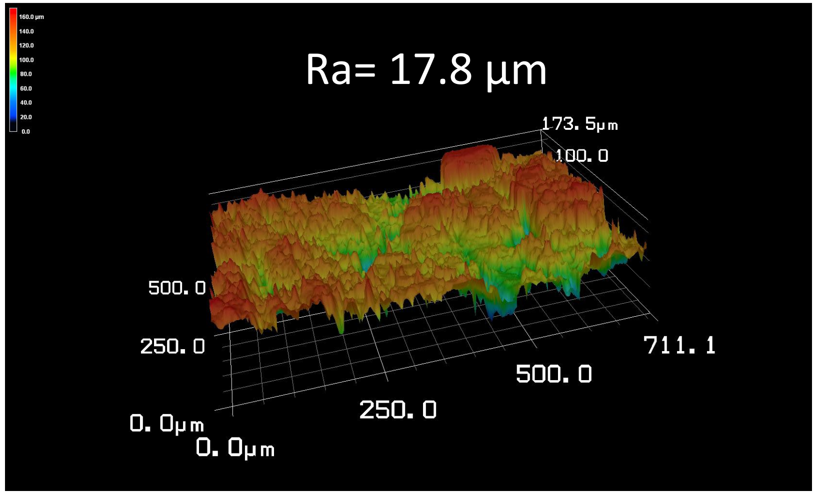
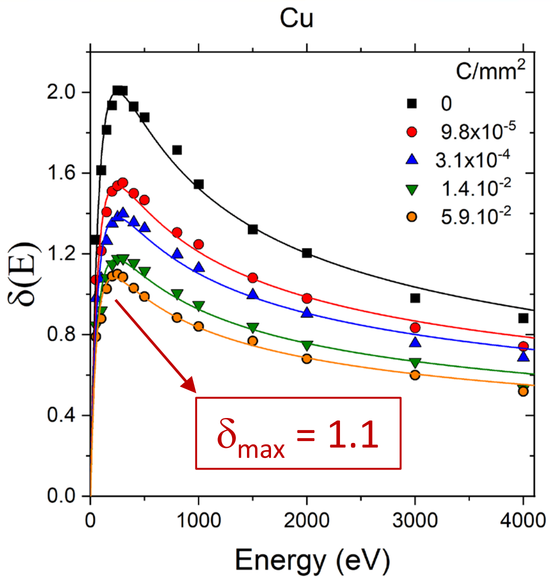
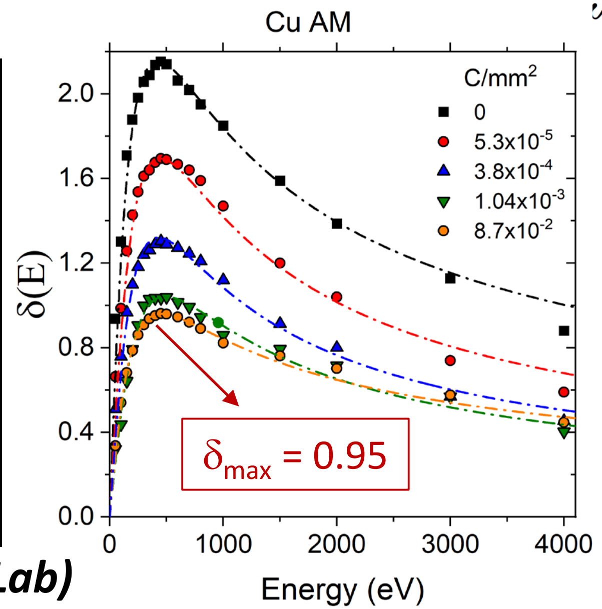
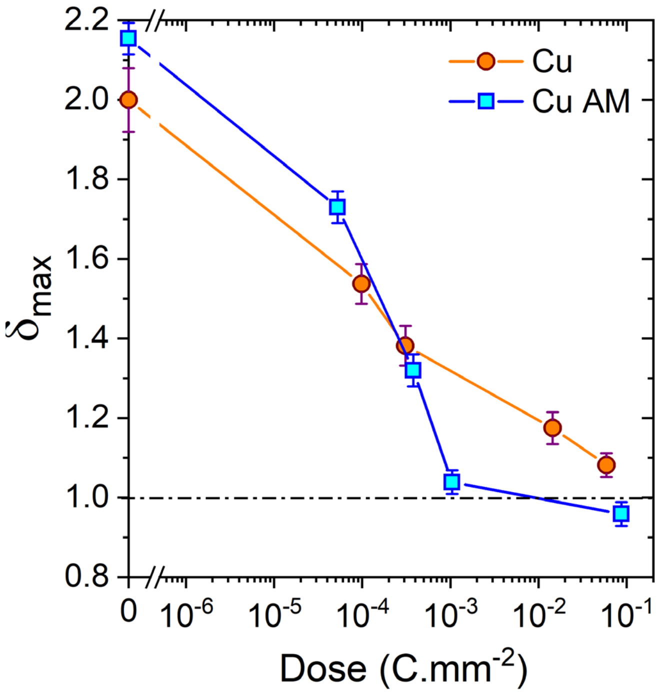






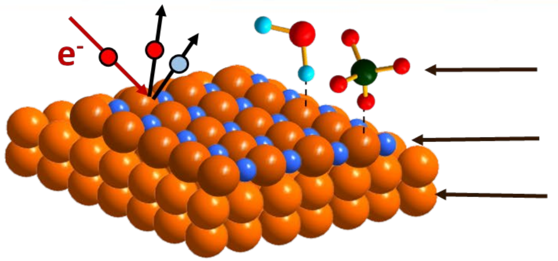


δ_{max} Cu AM < δ_{max} Cu

➢ Effect of roughness

C. Verdy, L. Vitu (ICB - LERMPS – UTBM) / E. Toffin, S. Jenzer (IJCLab)

OUTLINE



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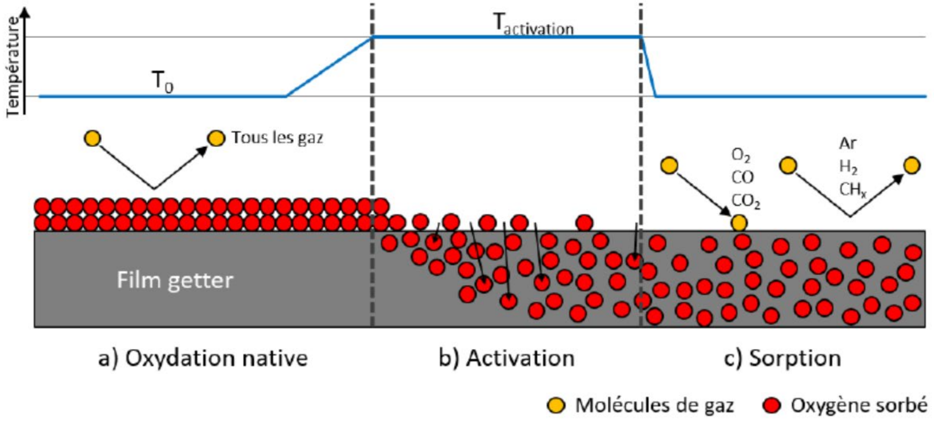
NEG = Non Evaporable Getter coatings

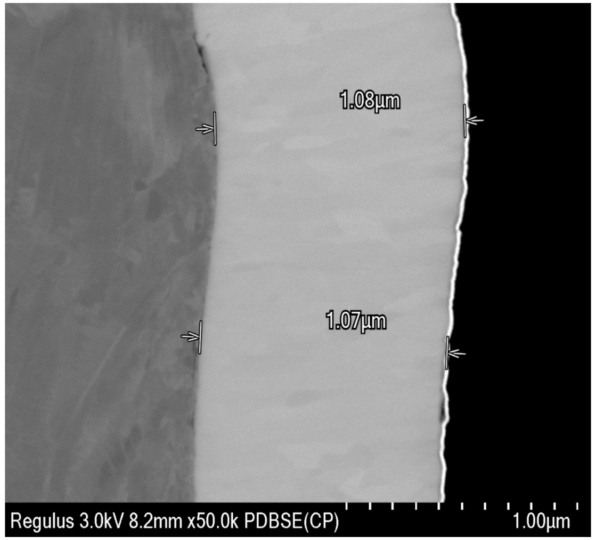


Activation of getter, oxygen diffusion in depth

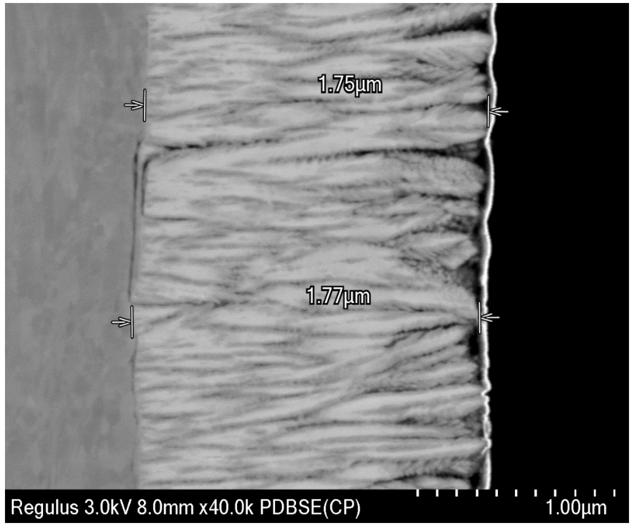
trapping of gaseous species

Material properties:

- High O_2 diffusion coefficient
- High oxygen solubility
- High H_2 incorporation capacity
- deposit for distributed pumping/sorption pumping (H_2, CO, CO_2 but not noble gas and CH_4)
- CERN : **Ti-V-Zr alloy**



In a **dense structure**, it acts as barrier between a vacuum chamber material and an inner vacuum

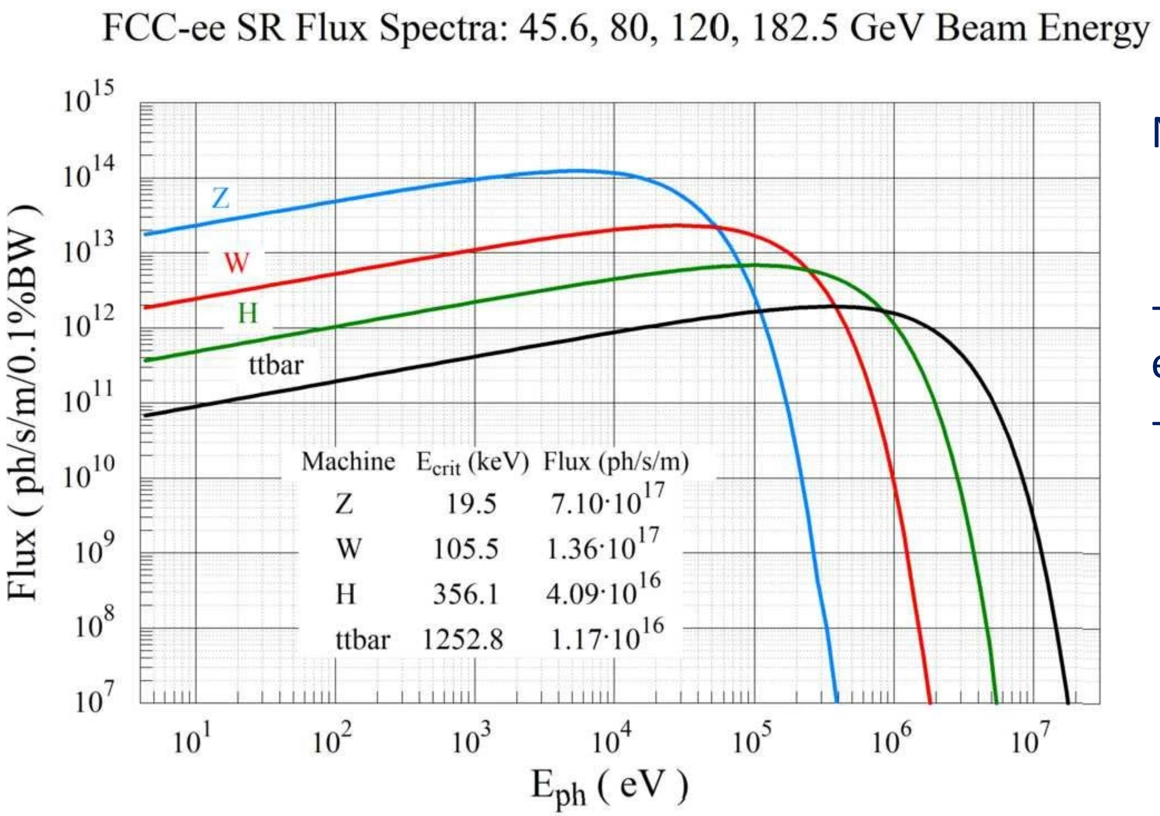


In a **columnar structure**, it has a large surface area, hence, a fully coated vacuum chamber has large distributed pumping speed

R. Sirvinskaite et al. Vacuum 179, 109510 (2020)

In activated state, the NEG coating has low secondary electron (SEY) yield that helps to supress electron multipacting and electron cloud in high intensity accelerators.

NEG-coating for Vacuum in FCC-ee



Flucka calculation, F. Cerutti et al FCC study kick-off meeting. Geneva. 2014

High emission of synchrotron radiation (SR)

- surface heating
- SR-induced molecular desorption (PSD)
- generation of photoelectrons

NEG-coating has been proposed to:

- keep the PSD contribution low
- reduce the number of photoelectrons and their contribution to the electron-cloud effect
- provide distributed pumping to the system

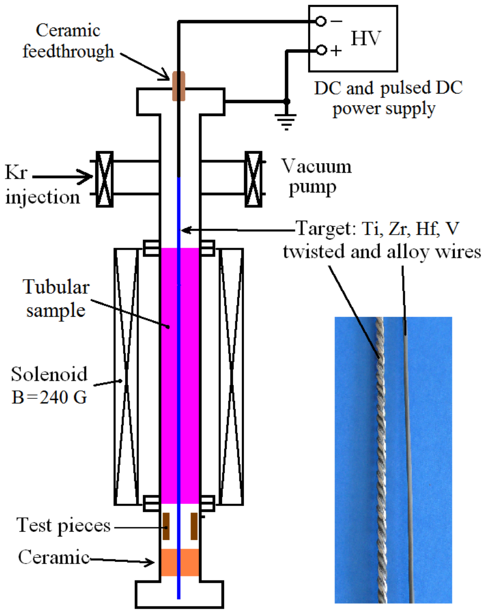
BUT :
thickness of deposits limited to 250 nm to avoid increasing the impedance of the walls

CERN studies :
NEG Compo : 28 at.% Ti, 29 at.% Zr, 43% V
87 nm ≤ Thickness ≤ 1100 nm

Eleonora Belli, P. Pinto Costa et al eeFACT2018

IJCLab

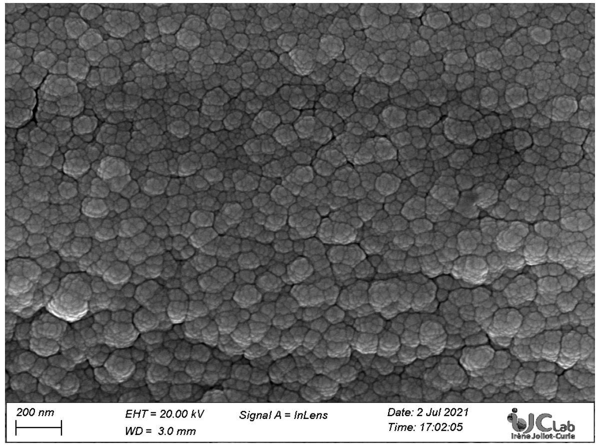
Cylindrical magnetron deposition for vacuum chambers

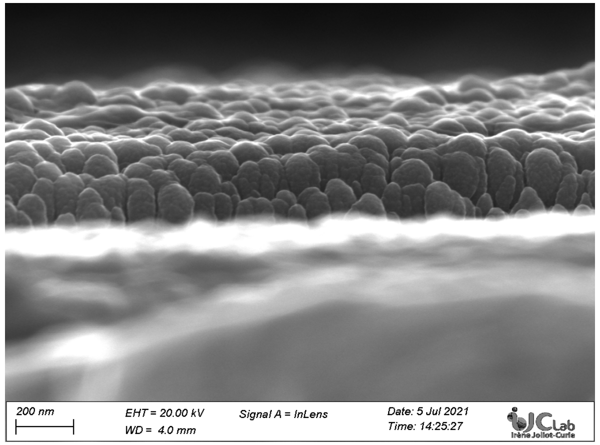


before

after

40 at.% Ti, 25at.% Zr, 35% V





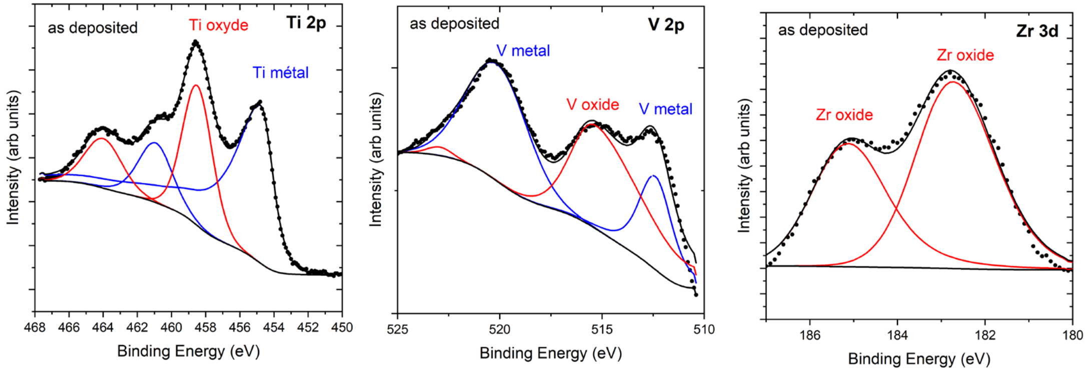
$T_{activation}$ = 180°C – 200°C

α_{CO} = 0.08, α_{H2} = 7×10^{-3}

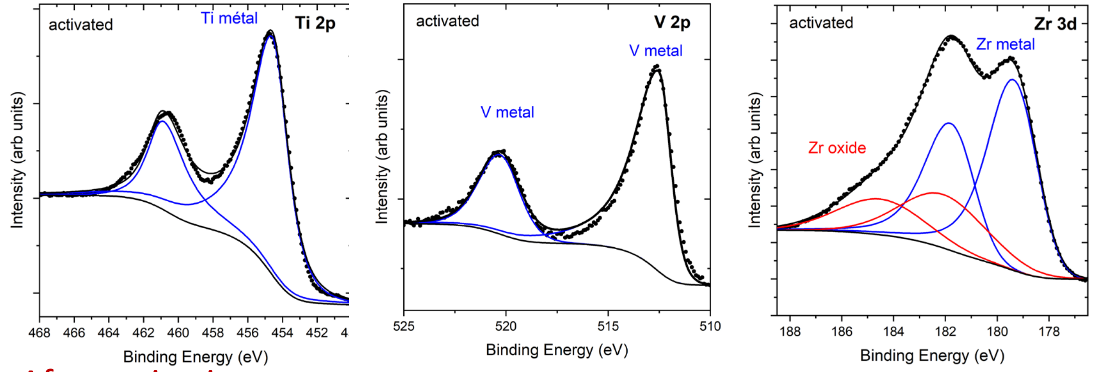
α sticking coefficient = probability that a gas molecule coming into contact with the material will adsorb on its surface

XPS - *in situ* activation

As deposited



Activated



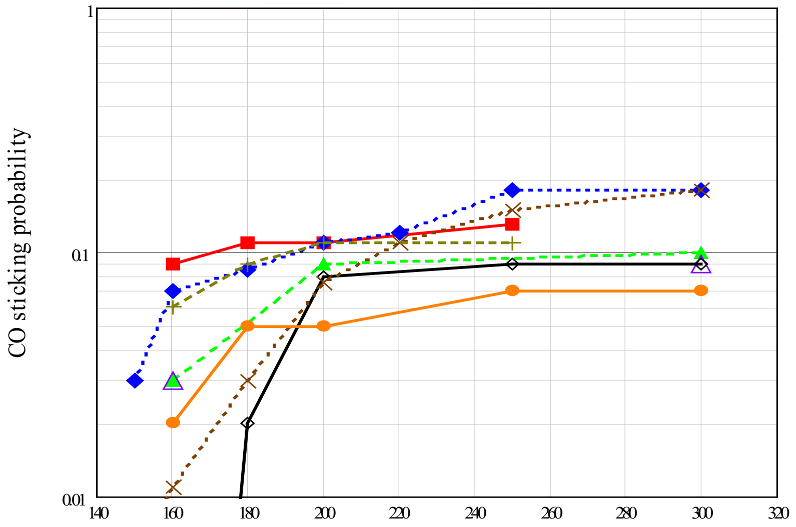
After activation:

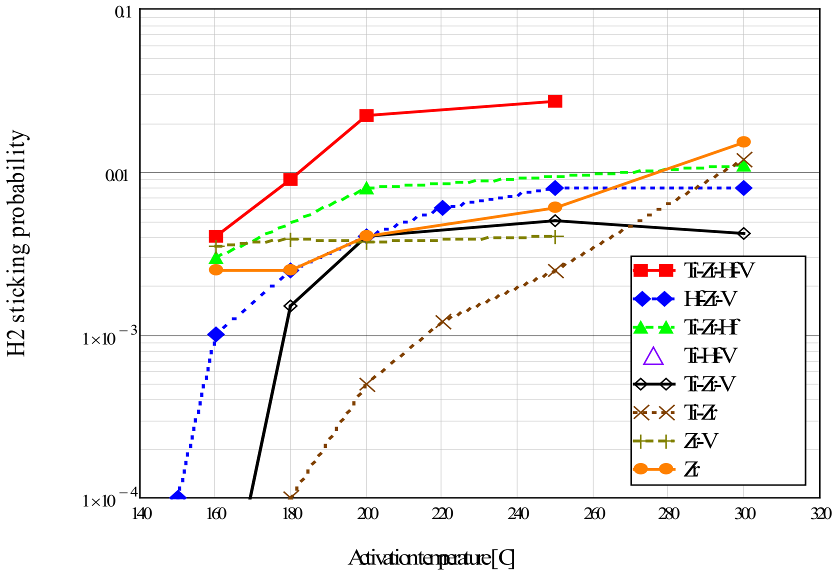
- Mainly metallic components on Ti and V
- On Zr, oxide component remains partially

Problem to check : number max of activation cycles?

C. Boutelaa, J. Yemane, É. Mistretta , T. Gerardin, B. Mercier, S. Bilgen, G. Sattonnay (IJCLab)

Pumping performance of NEG coatings





ASTEC Daresbury

Ti-Zr-Hf-V performed the best

- ✓ Activated at 150-160 °C for a columnar film
- ✓ $\alpha_{CO} \leq 0.15$, $\alpha_{CO2} \leq 0.6$, $\alpha_{H2} \leq 0.03$

Reza Valizadeh, O.B. Malyshev ASTeC Daresbury Laboratory, Ecloud2022

- **Ti-Zr-Hf-V : new composition to test at IJCLab**
- **Incorporation of Y could increase the performance (decreasing of T activation, high solubility of H)**
- **Influence of roughness : NEG coatings on additive manufacturing Cu to decrease the SEY**

IJCLab

Conclusion and perspectives

- **Increasing the performance of accelerator components requires improving the surface properties of materials**
  - (i) the phenomena involved occur in the first 100 nm of thickness
  - (ii) Investigation of surface properties is mandatory
  - (iii) Use thin film coating or specific surface treatments to improve performances

- **SEY depends on composition, thickness, roughness, morphology of coatings**

- **Additive manufacturing could be used for accelerator components : beneficial effect of roughness on the SEY ?**

- **Thin layer of NEG (<300nm) : encouraging investigation in progress**

- **Perspectives R&D**:
  - (i) influence of cryogenic temperature on the SEY (a new multitechnic setup will join our characterization platform in 2024)
  - (ii) investigation of the electron stimulated desorption (ESD) at RT and cryogenic temperature
  - (iii) study of EDS with high energy electrons (FCC-ee)
  - (iv) new NEG compositions must be investigated
  - (v) new compositions of low-SEY layers must be investigated (TiN_xC_{1-x} see Y. Pisi poster)

Thanks to

MAVERICS team

MAVERICS
ACCELERATOR PHYSICS
MATERIALS-VACUUM-SUPERCONDUCTING RF

Vacuum and Surfaces platform

SURFACES
VACUUM

Suheyla, David, Chahinez, Jonathan, Eric, Thibault, Camille, Bruno, Guillaume, Denis, Mohammed, Yanis

Thanks for your attention

Travaillons ensemble

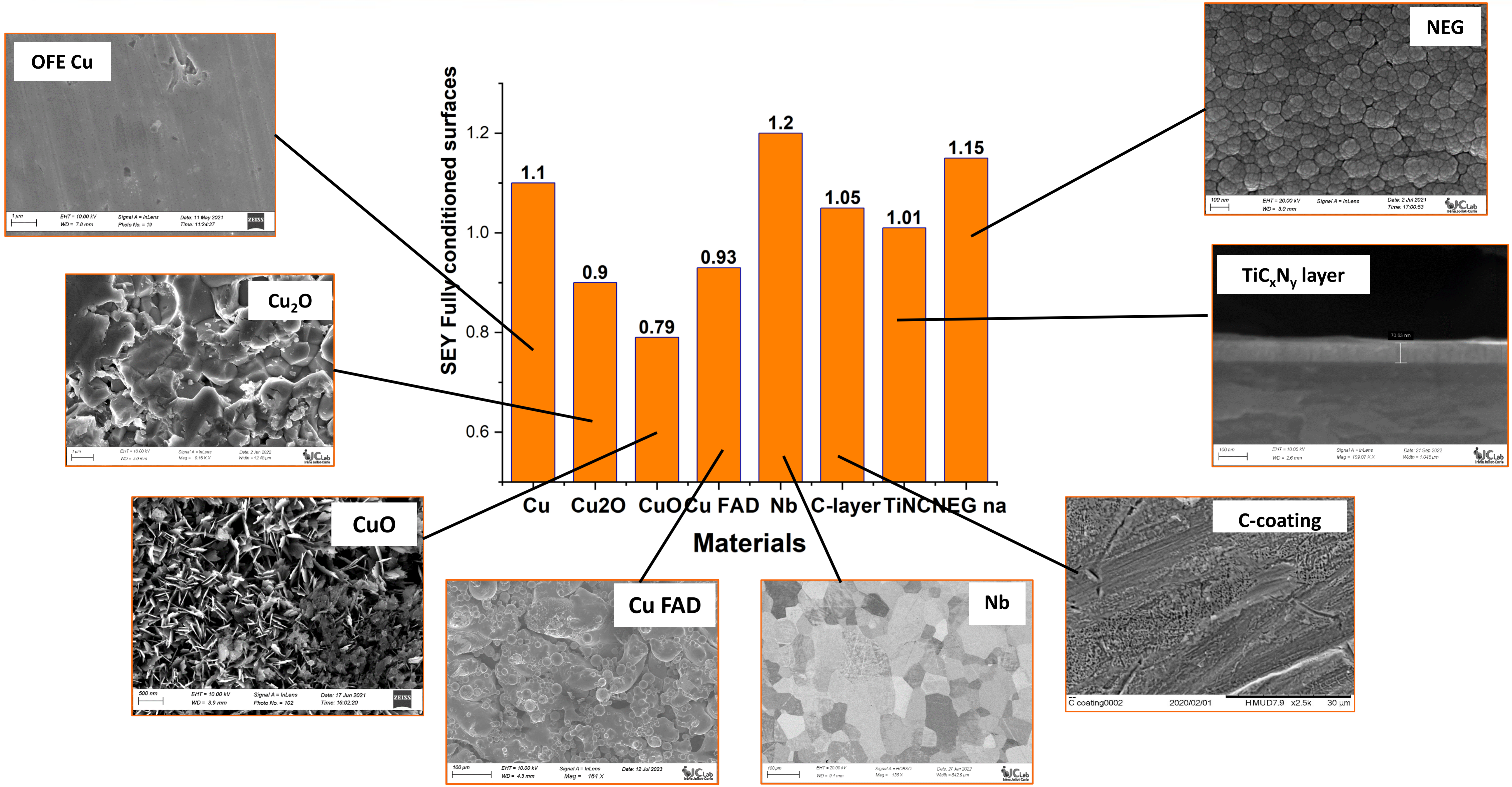
Elaboration couches minces supra haute Tc pour application cavités SRF

Elaboration couches minces supra sur Si, Cu
(high Tc iron-based superconductor FeSe, NbN, MgB_2)

Caractérisation
-structure, morphologie microstructure couche
Propriétés supra (RRR, Tc)

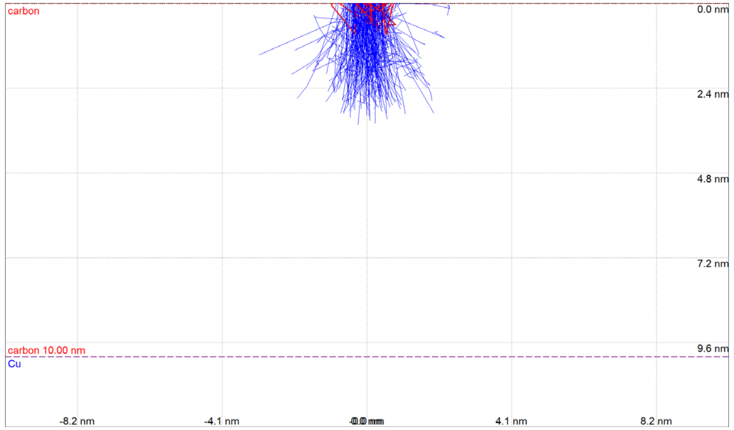
ICMMO — SIMaP ⟷ IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis — SUPRATech — SURFACES VACUUM

Summary : Comparison of SEY for several conditioned materials

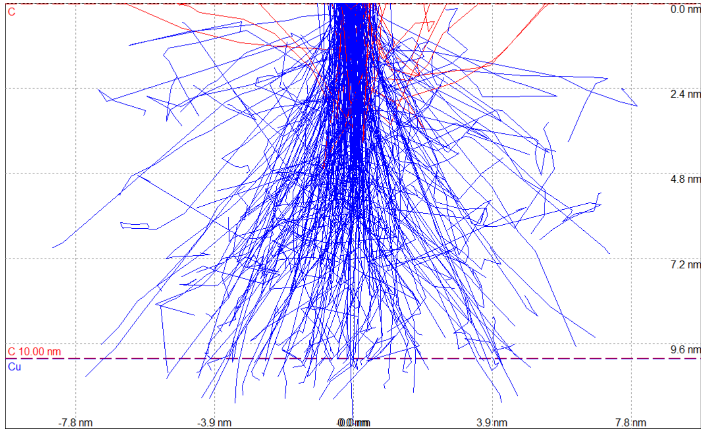


Penetration depth of electrons in carbon

E=200eV



E=500eV



E=1000eV