Rôle de la chimie de surface sur les propriétés des matériaux pour accélérateur : conditionnement et émission électronique secondaire

MAVERICS
ACCELERATOR PHYSICS
MATERIALS-VACUUM-SUPERCONDUCTING RF

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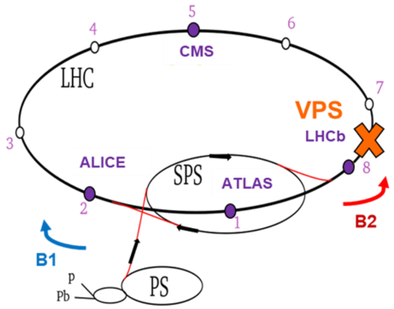
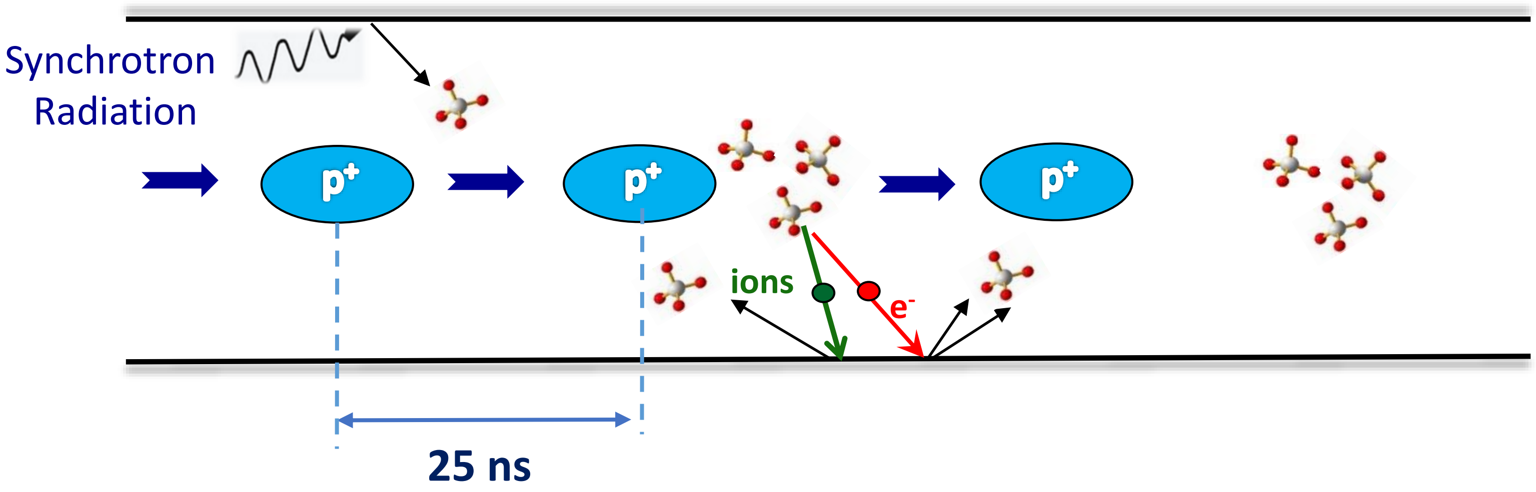
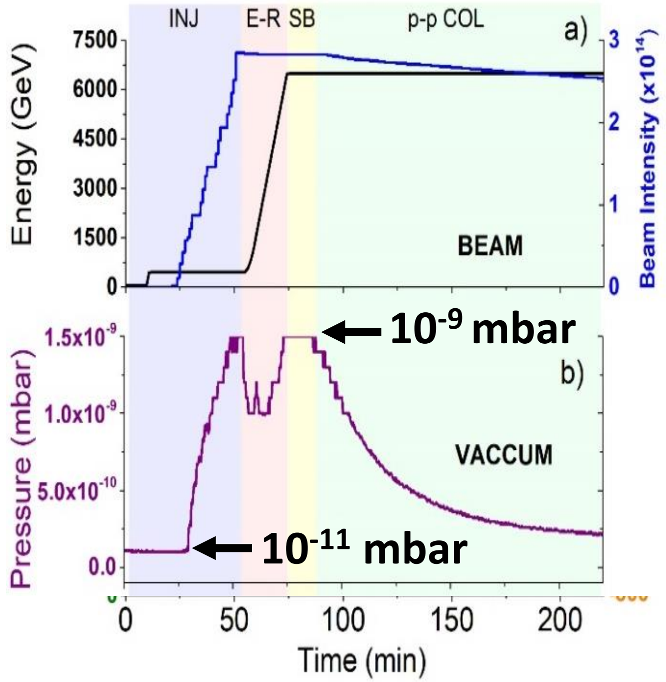
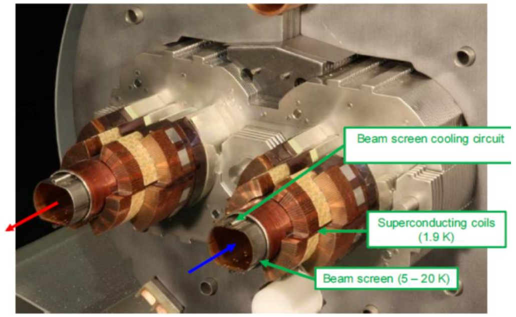


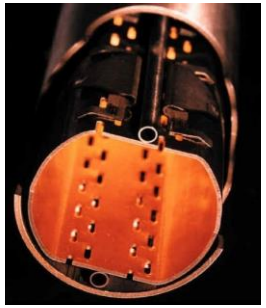
Désorption Stimulée



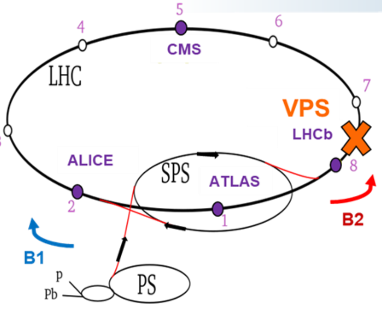
Evolution du vide dynamique dans le LHC (station 4 du VPS)



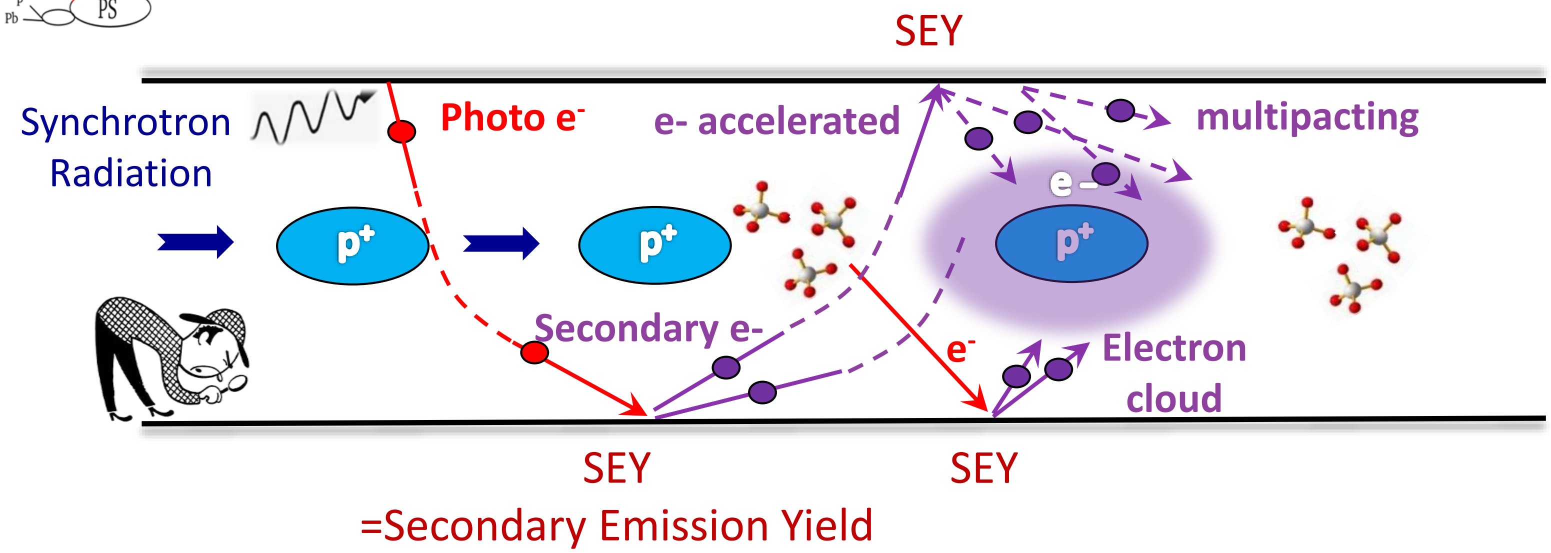




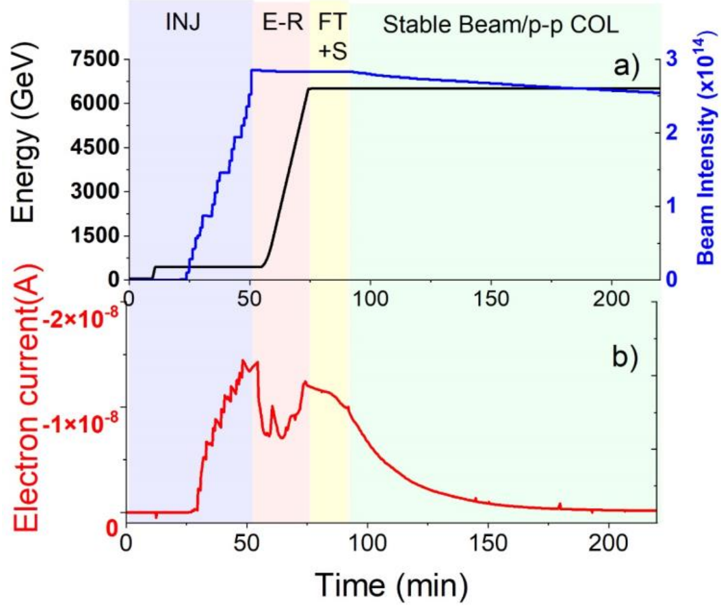
Contexte : l’exemple du LHC



Création de particules secondaires



Evolution du courant d’électrons dans le LHC (station 4 du VPS)



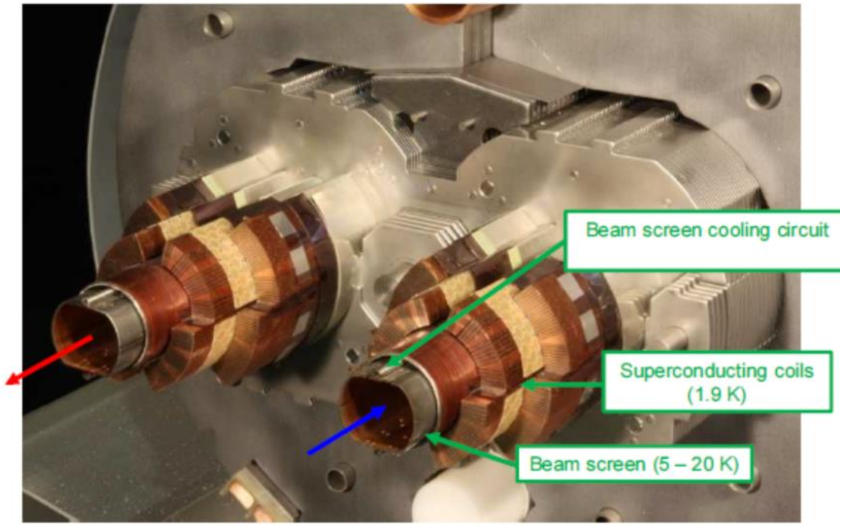
All of these phenomena may limit the performance of the LHC :	2018 LHC RUN 2 13 TeV, 2556 b, 1.1×10^{11} ppb	*vs*	NOMINAL PARAMETERS LHC 14 TeV, 2808 b, 1.2×10^{11} ppb

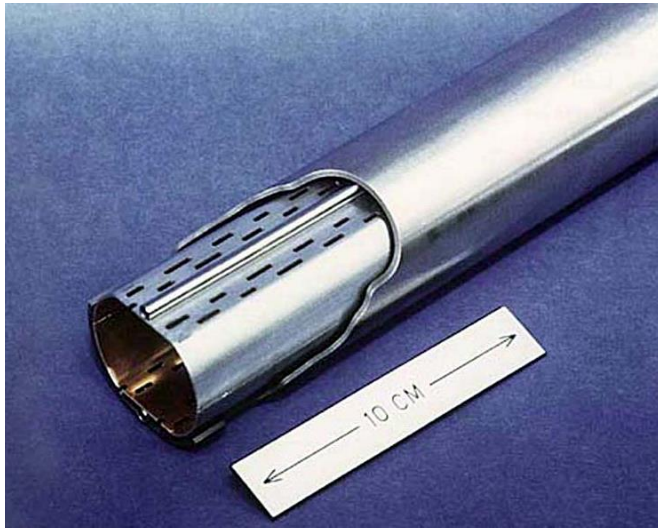
Main objectives

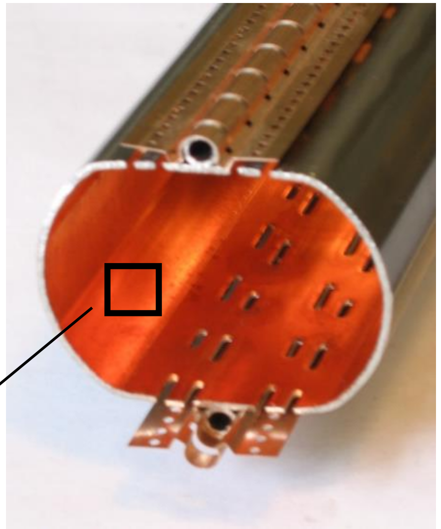
→ Mitigation of detrimental collective effects inside the beam lines

→ Influence of the surface chemistry on these phenomena + modification of the surface chemistry under irradiation

LHC beam screen samples







Oxygen-Free Electronic copper colaminated onto stainless steel.

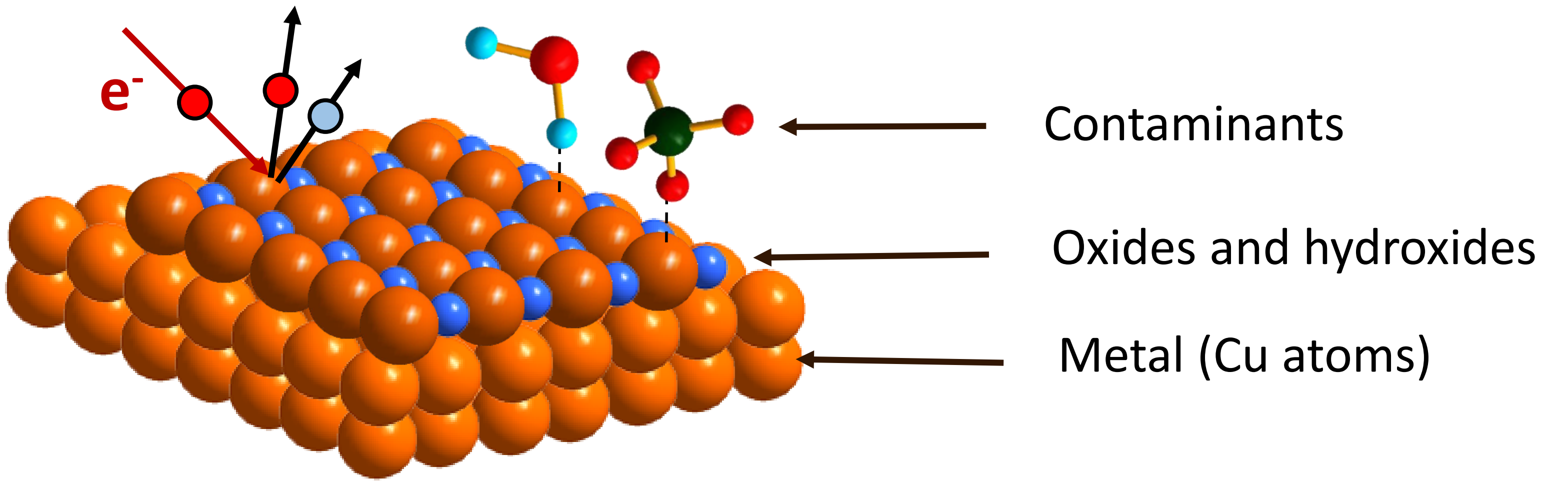
OFE copper = 99.99% pure copper with 0.0005% oxygen content to avoid undesirable chemical reactions with other materials

5 mm

- high electric conductivity
- high thermal conductivity
- low outgassing rate
- non-magnetic material

dimensions: 5 x 5 x 2 mm thick from the CERN's stock.

Analysis of technical surfaces

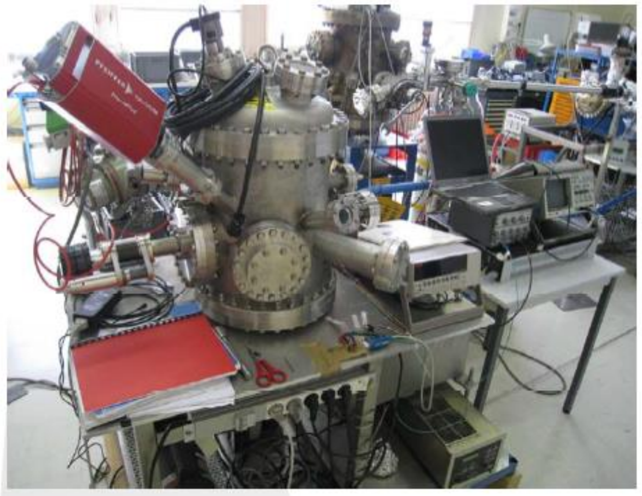


- there are **always contaminants** deposited on the surface + native oxide layers (Cu_2O et $Cu(OH)_2$)
- investigated surfaces in accelerators are **technical surfaces** (and not pure Cu surfaces)

➢ Rôle du carbone (via les molecules hydrocarbonées initialement presentes) ?
➢ Rôle des oxydes/hydroxydes natifs de cuivre ?

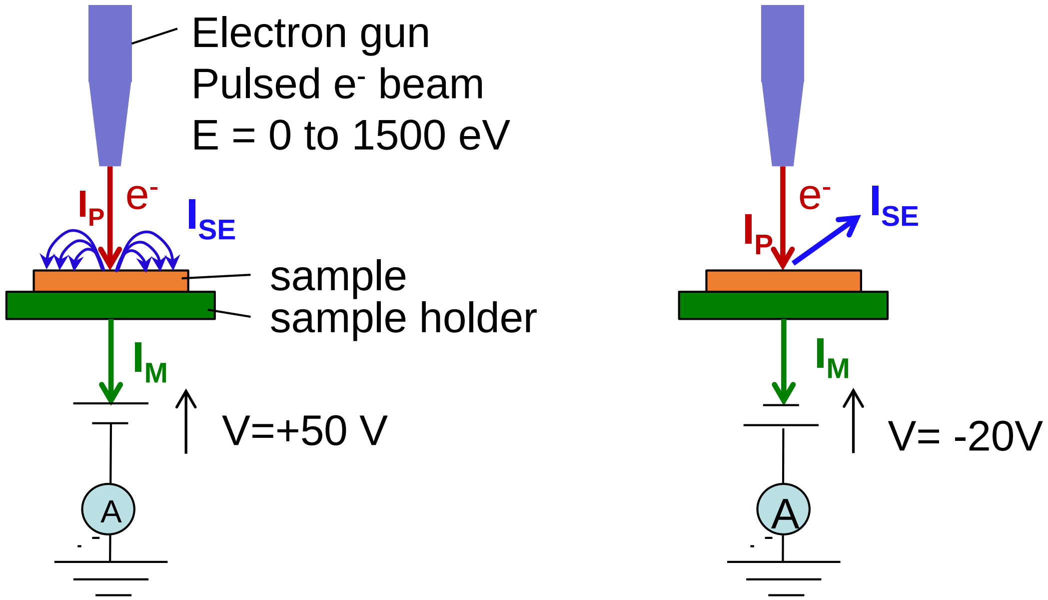
} **Sur le SEY**

SEY measurements and conditioning in lab



- base pressure: 5x10^{-10} mbar
- pulsed electron beam
- energy range 10 to 1500 eV
- During measurement I= qques nA
- During conditioning: I=5 µA
- SEY error (about 10%), since elastically backscattered electrons can escape
- beam spot 2.8 mm in diameter during conditioning

SEY measurements

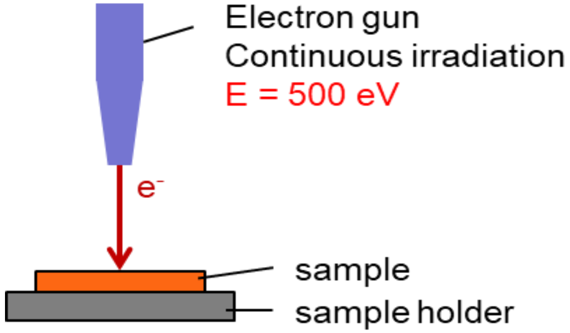


$I_M(+50V) = I_P$

$I_M(-20V) = I_P - I_{SE}$

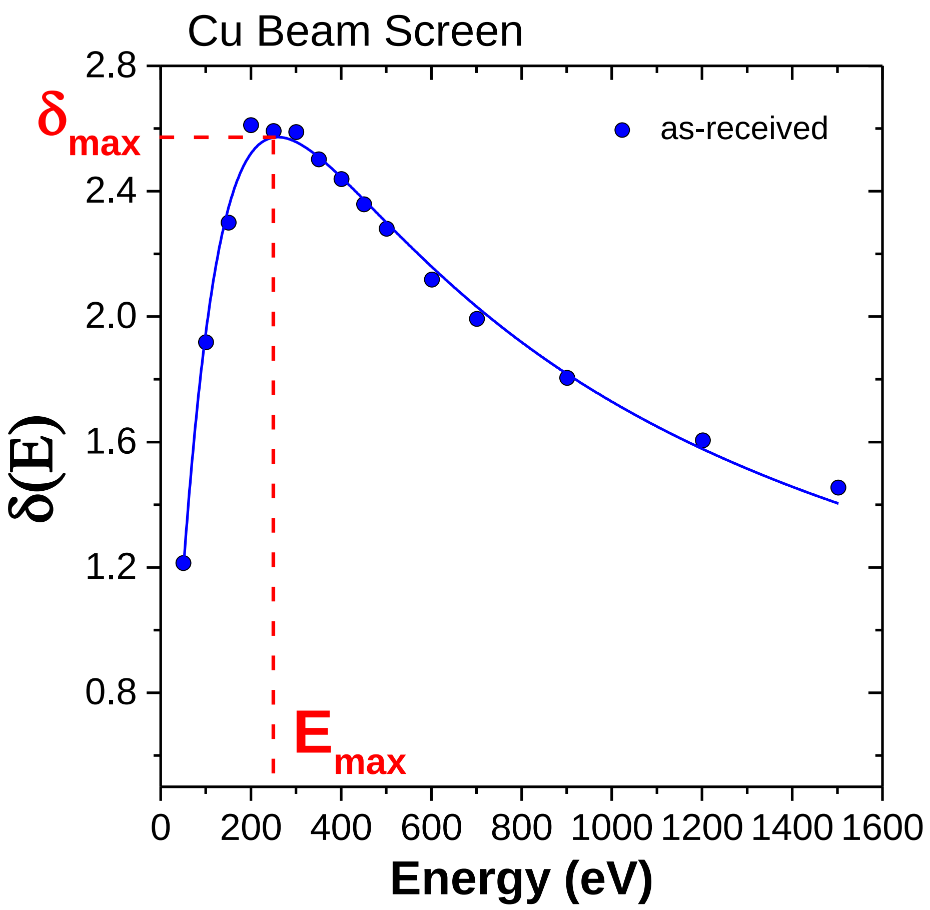
$$SEY: \quad \delta = 1 - \frac{I_M(-20V)}{I_M(+50V)}$$

Conditioning by e- irradiation



SEY measurements : copper beam screen

$$SEY = \frac{number\ of\ SE}{incident\ e-}$$

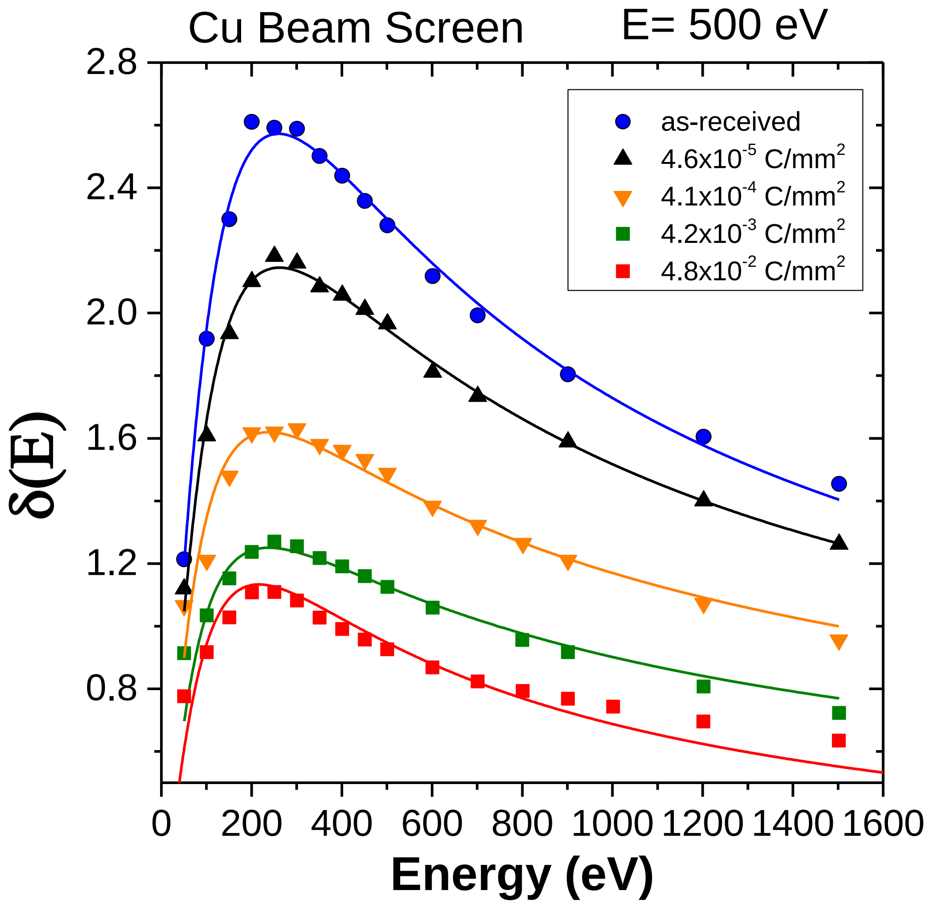


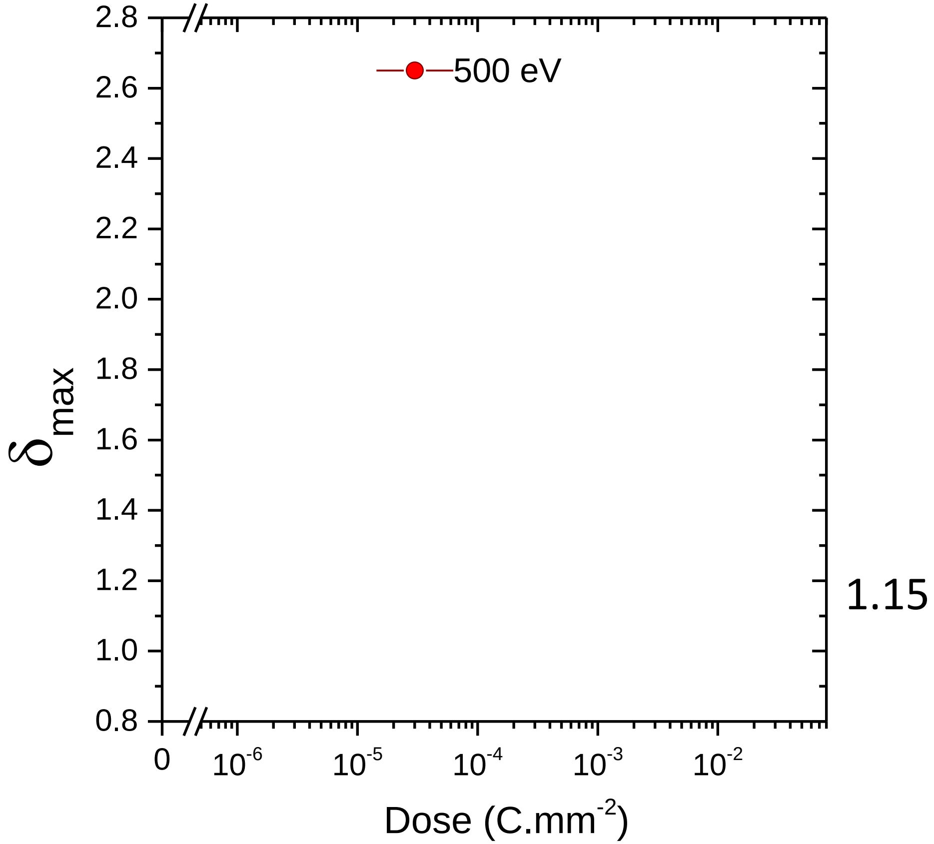
$$\delta(E) = \delta_{max} \frac{s * \left(\frac{E}{E_{max}}\right)}{s - 1 + \left(\frac{E}{E_{max}}\right)^{s}}$$

[Scholtz et al J of Research, 1996]

Suheyla Bilgen PhD Thesis (IJCLab 2020)

SEY measurements : copper beam screen



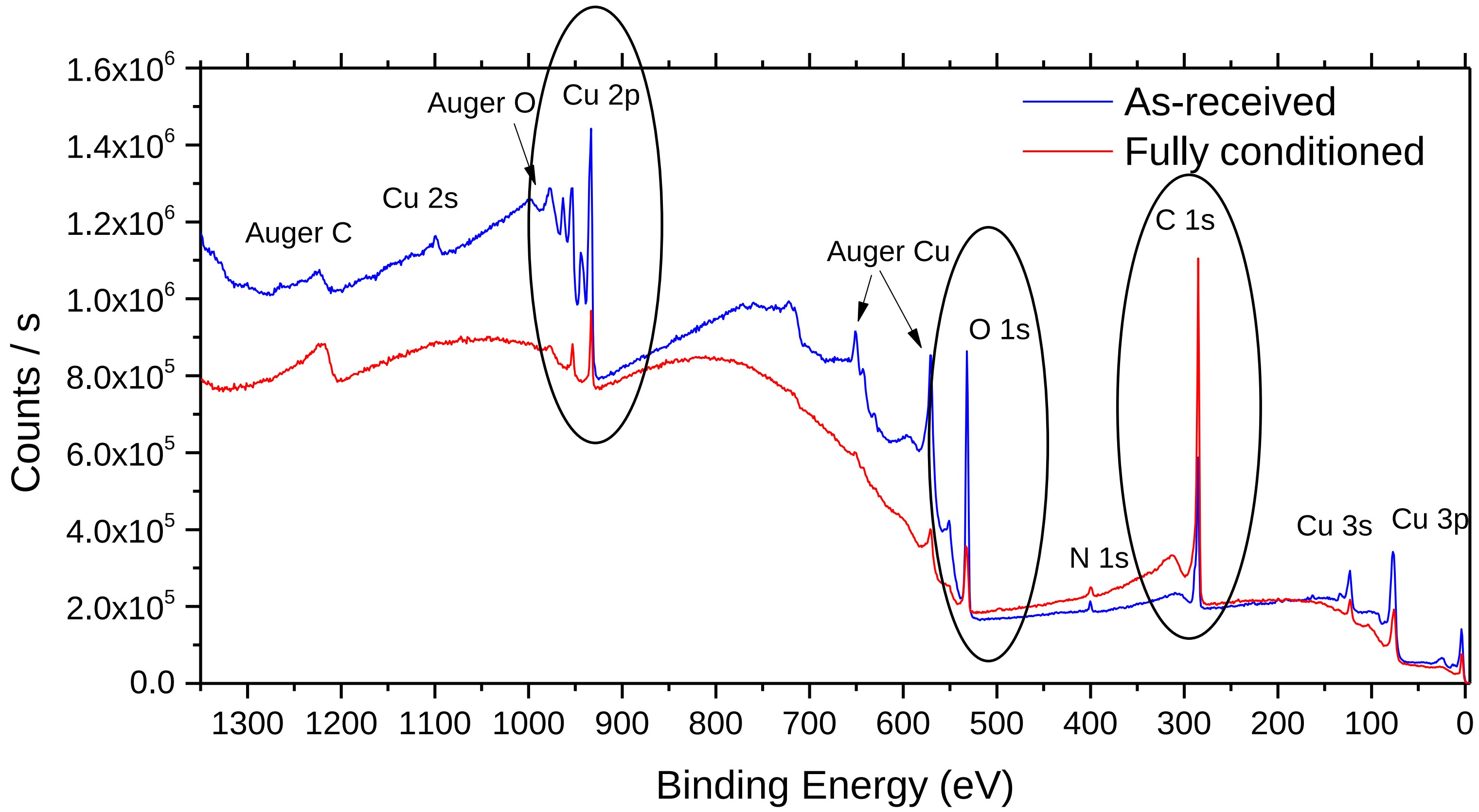


δ(E) decreases with increasing electron dose

in agreement with the literature e.g *[R. Cimino et al J. of Electron Spectr. Related Phenomena, 2020]*

XPS analysis

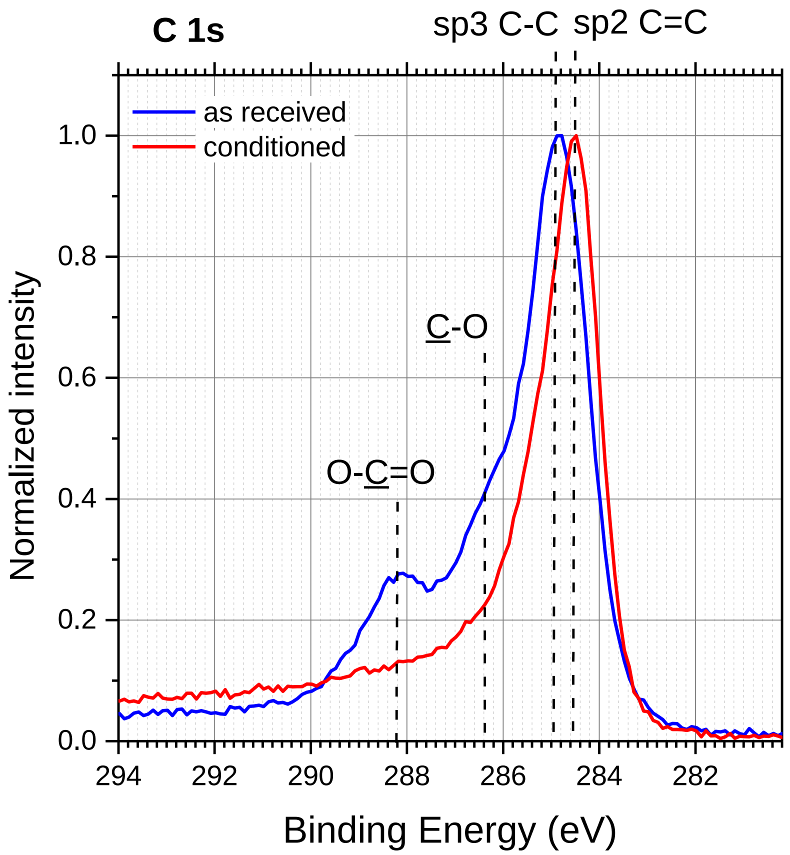
X-ray Photoelectron Spectroscopy



We are mainly interested in the chemical modifications of Cu, O and C induced by e- irradiation (main elements detected on the copper surface).

Carbon evolution?

XPS



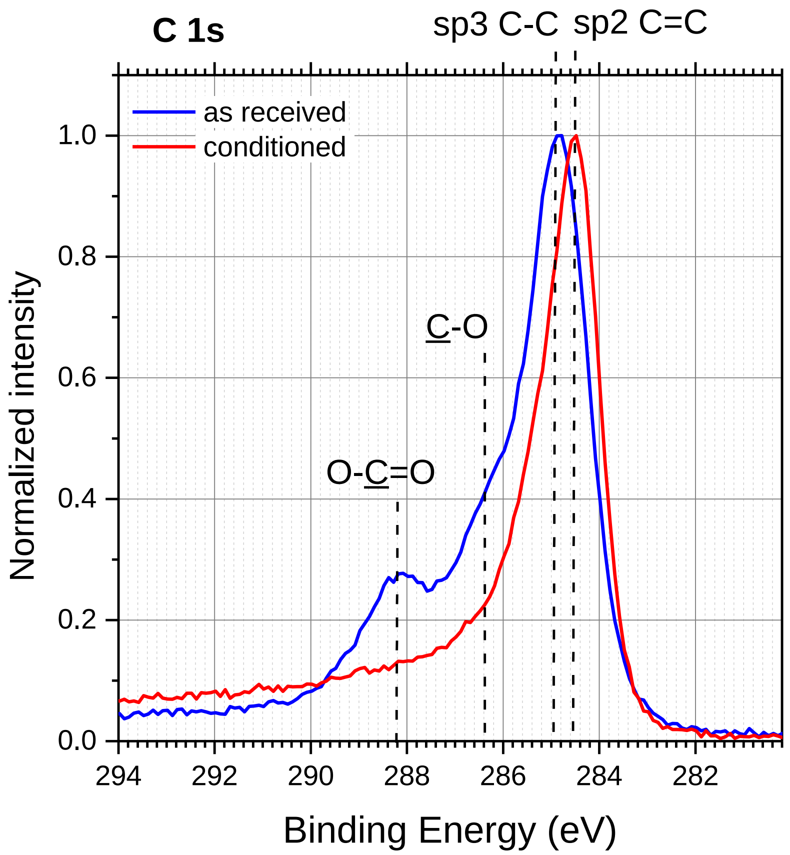
Adventitious carbon (C-O, O-C=O) is removed by electron irradiation

Modification of the C hybridization induced by electron irradiation
Shift from C-C bonds (sp3) to C=C bonds (sp2)
→ in agreement with the literature *[R. Cimino et al, 2020]*

→ For the first time, this phenomenon was investigated by TOF-SIMS (plateform ANDROMEDE/IJClab)

Carbon evolution?

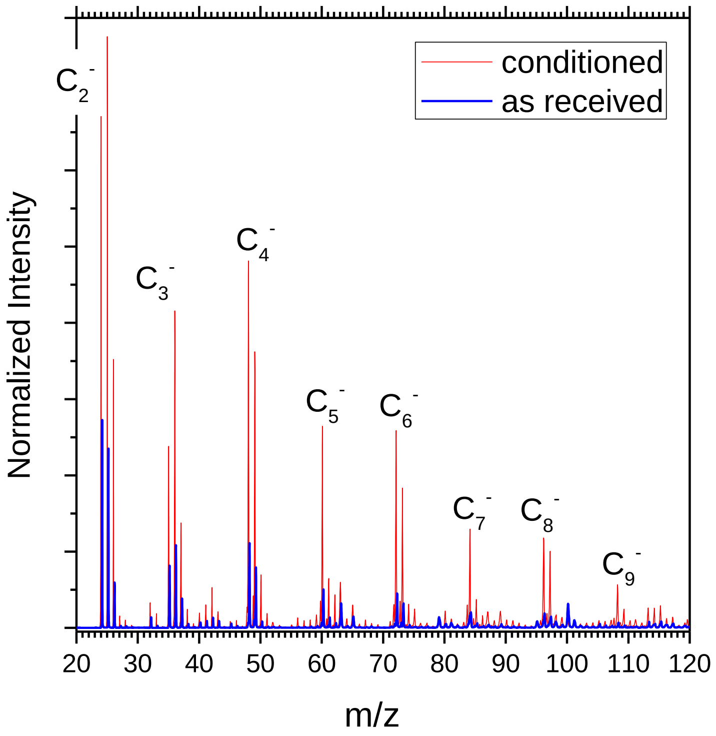
XPS



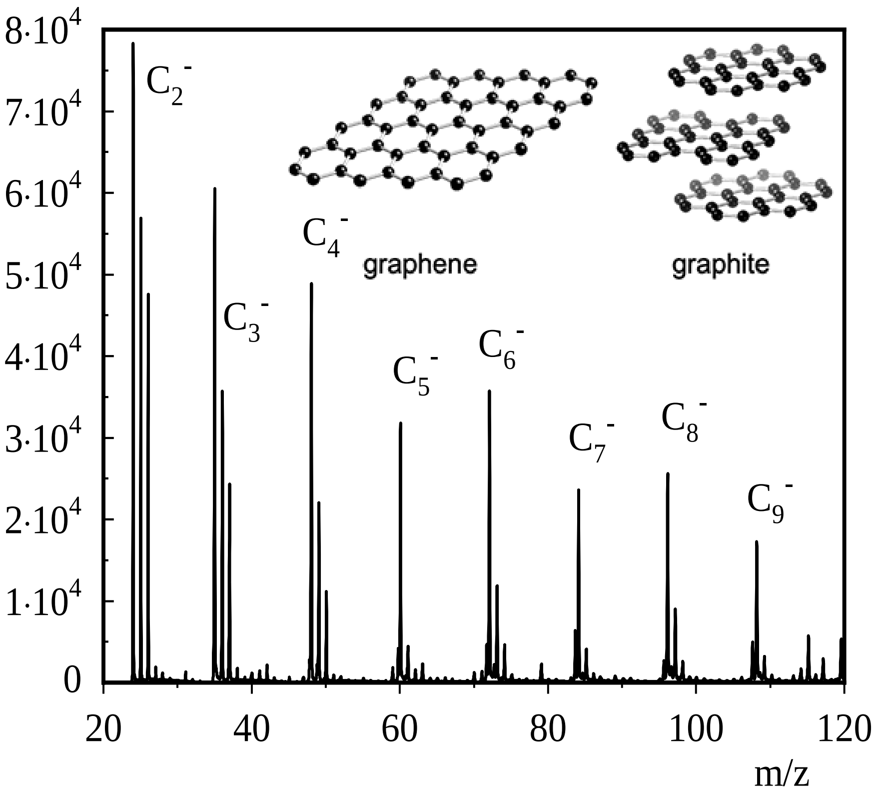
XPS : Modification of the C hybridization : from C-C bonds (sp3) to C=C bonds (sp2) compatible with a graphite structure.

MeV-TOF-SIMS

Carbon on the surface of a fully conditioned Cu



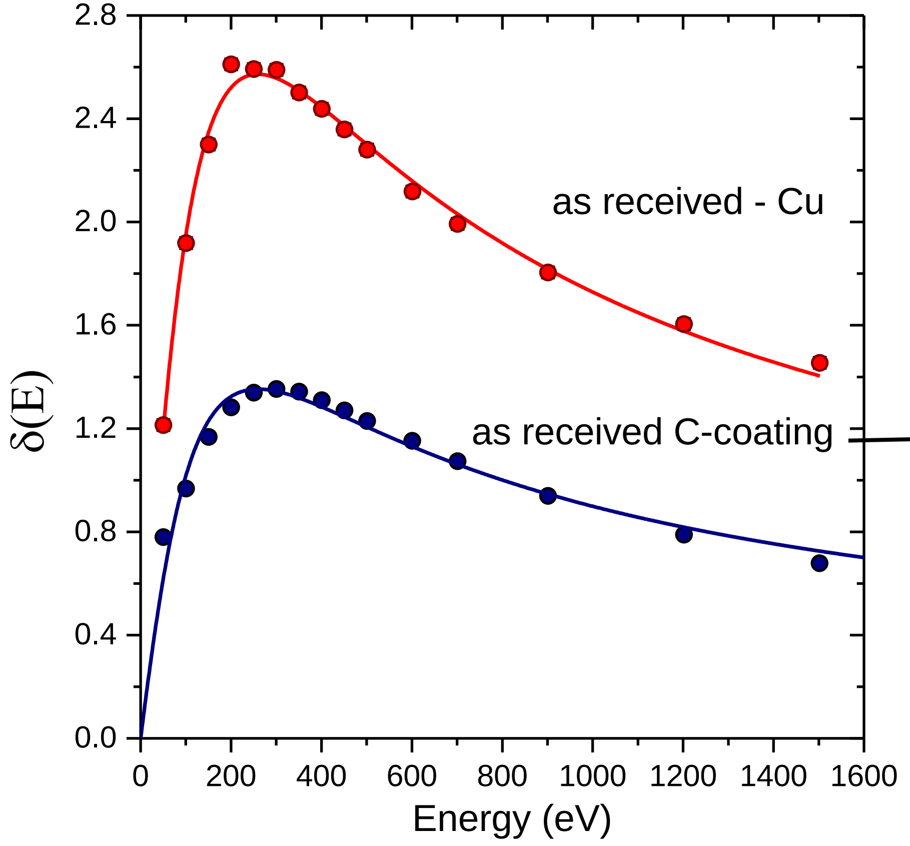
Graphene reference sample

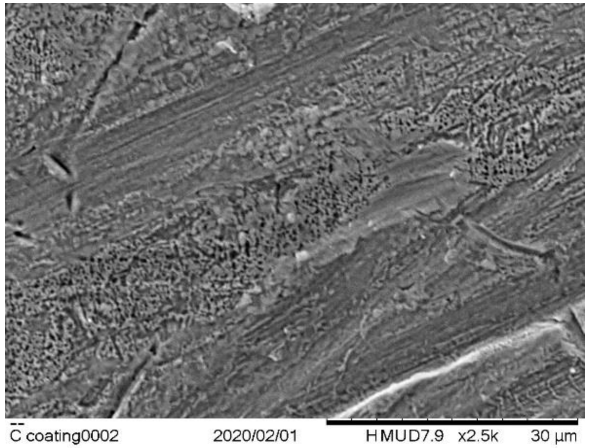


TOF-SIMS : a graphitic (graphene) carbon layer is formed on the surface of the fully conditioned sample (with a large amount of H).

→ Carbon from organic compounds initially present on the surface is transformed into a graphite layer (0.5 nm) by e- irradiation.

Why does the presence of a carbon layer reduces the Cu-SEY?





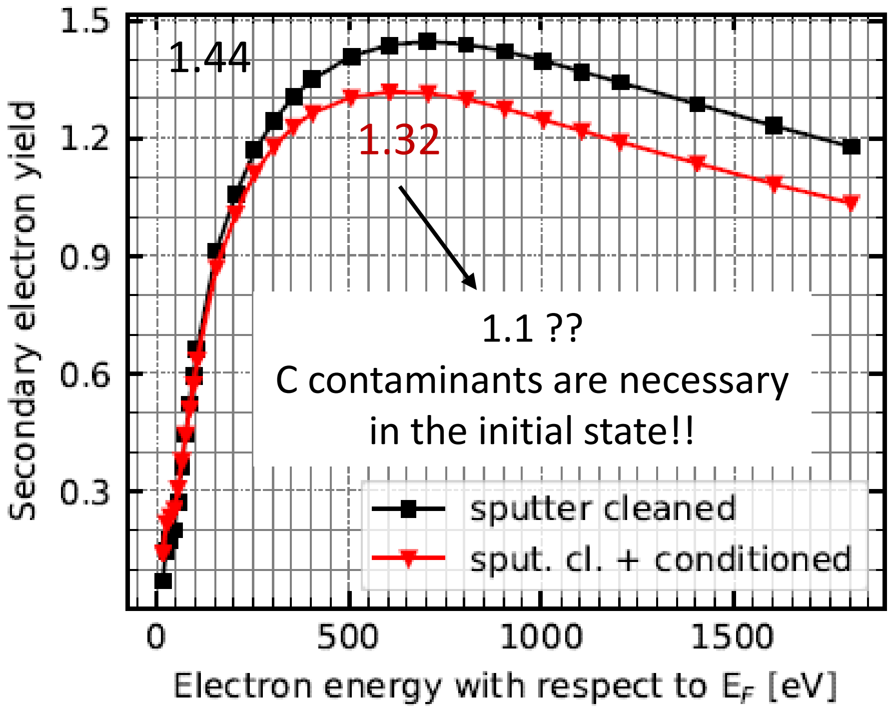
SEM image of C-coating

→ SEY of carbon is intrinsically lower than the one of copper

→ Carbon thin film deposited on Cu beam pipe walls is a solution to mitigate the electron cloud build up in the LHC *[P. Pinto Costa, IPAC2014]*

Valentine Petit PhD Thesis (CERN 2020)

pure Cu (cleaned, without pollutants)

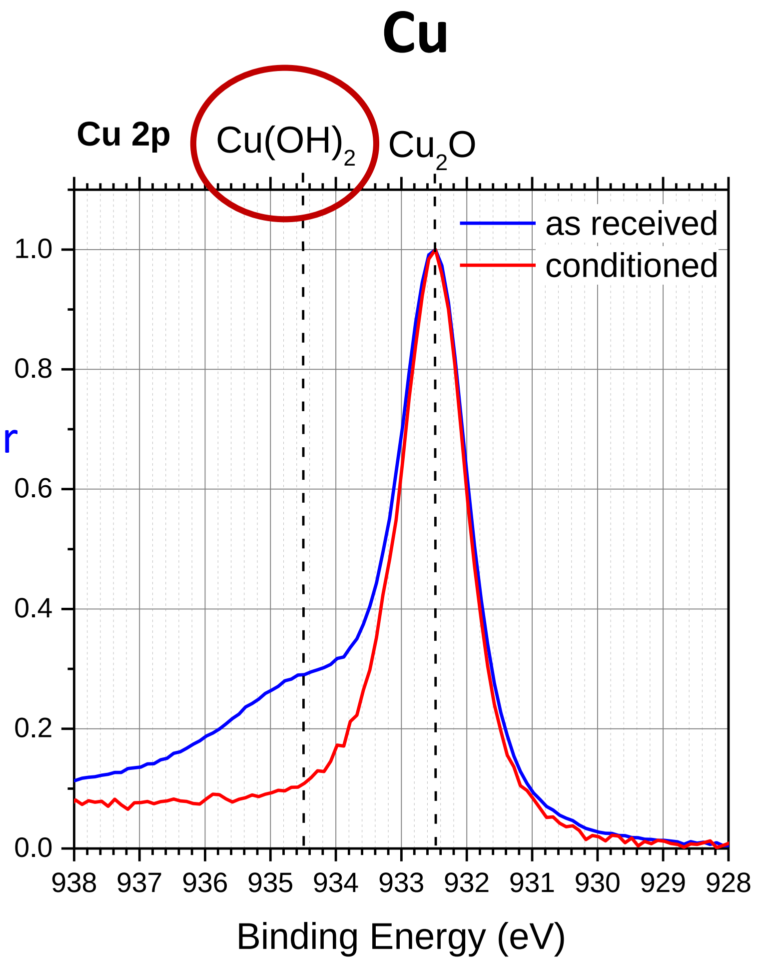


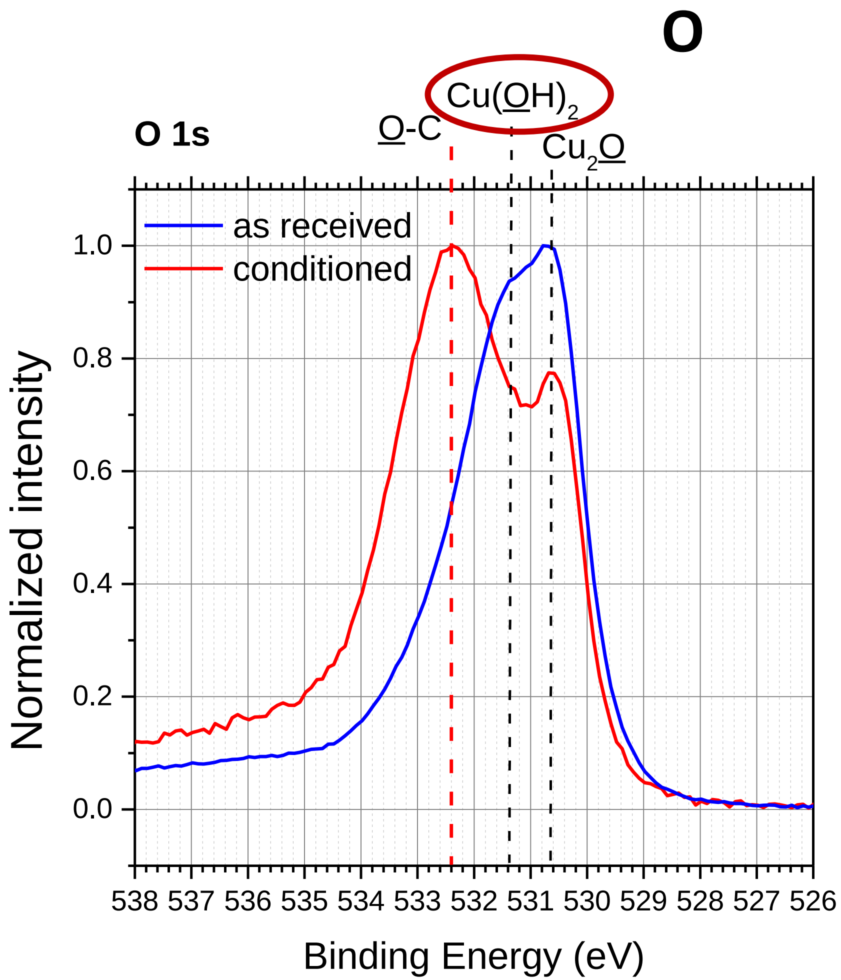
The conditioning of a sputter-cleaned copper sample results in a δ_{max} decrease from 1.44 to 1.32 and only a small amount of carbon is observed on the surface after conditioning

The ultimate δ_{max} of the cleaned sample after conditioning (1.32) remains still much higher than the one obtained for the conditioning of an air exposed sample (1.1).

The formation of graphitic carbon appears to be necessary to decrease δ_{max} down to the ultimate value observed on an as received sample

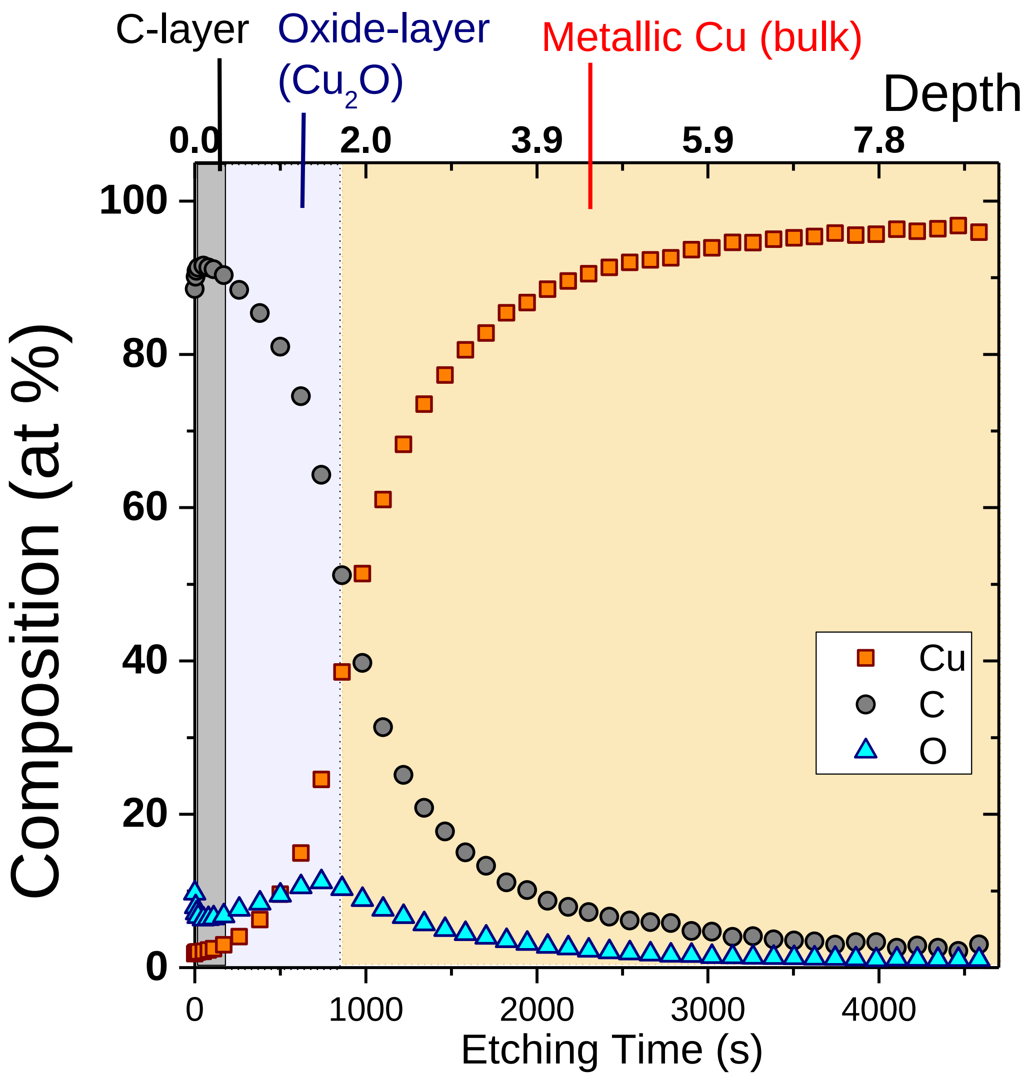
The native oxide layer
$Cu_2O + Cu(OH)_2$





Modification of Copper oxides after electron bombardment: Cu hydroxide↘

Depth profiles of elements in a fully conditioned Cu by XPS analysis



Depth (nm) estimation from the etching time

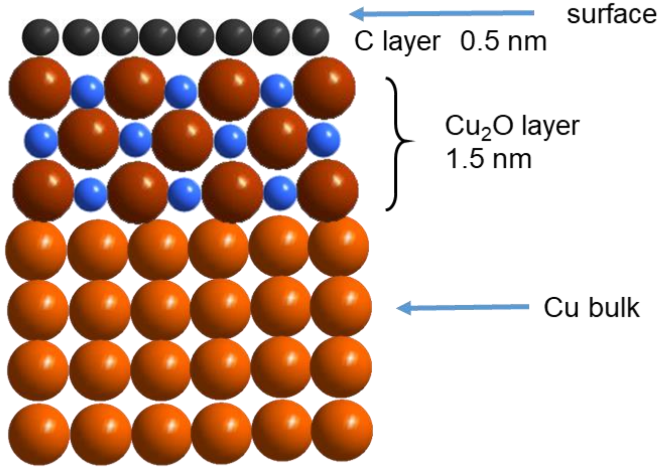
1) A graphitic carbon layer is first detected at the extreme surface. The graphitic C layer contains O and H of ≈ 0.5 nm thick .

2) At a larger depth, the oxide layer (Cu_2O) is observed of ≈1.4 nm thick.

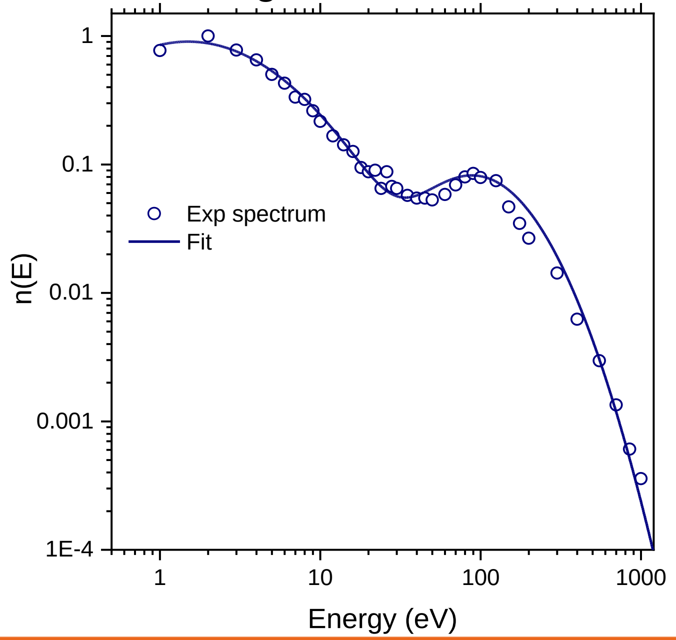
3) The copper oxide disappeared and the metallic Cu is detected at a depth larger than 2 nm, and finally metallic Cu is present.

→ Does the presence of the oxide layer influence the SEY of Cu?

The SEY : contribution of the extreme surface

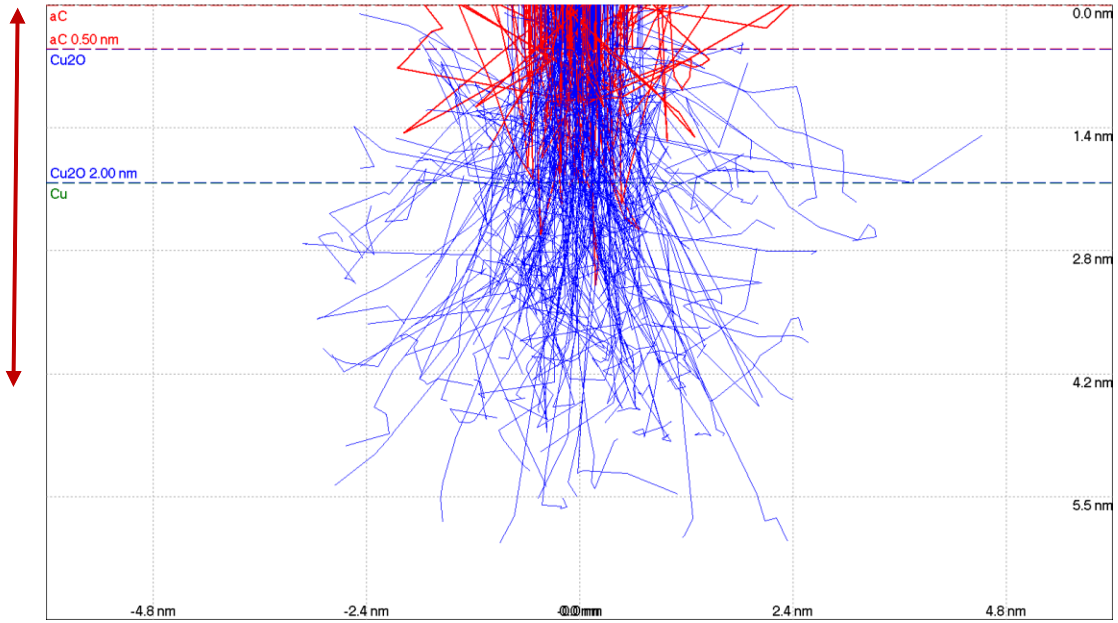


Distribution en énergie des électrons dans le VPS du LHC



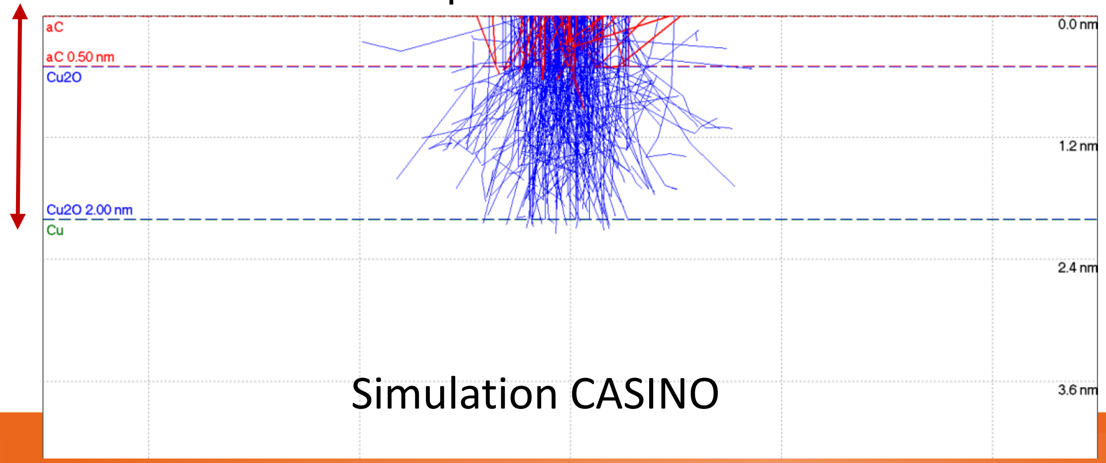
Penetration depth of 500 eV-electrons

≈4 nm



Penetration depth of 200 eV-electrons

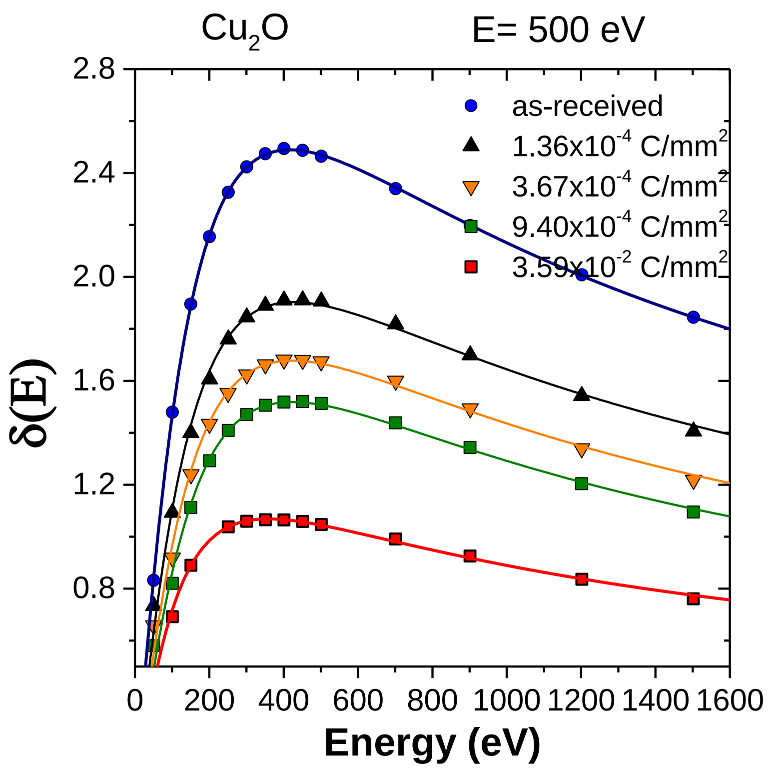
≈2 nm



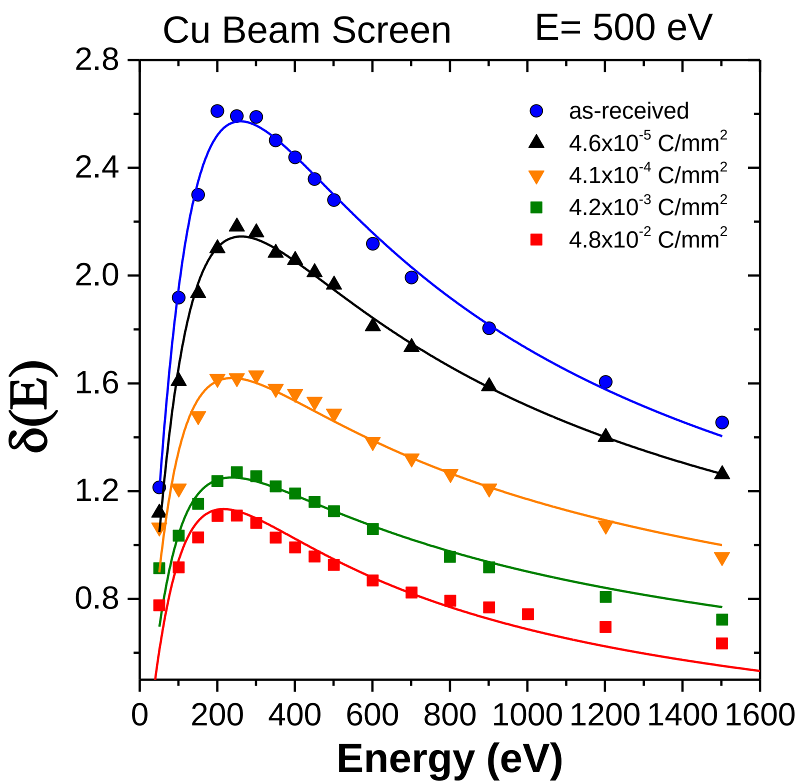
Simulation CASINO

Influence of the Cu oxide layer on SEY?

Pure Cu_2O

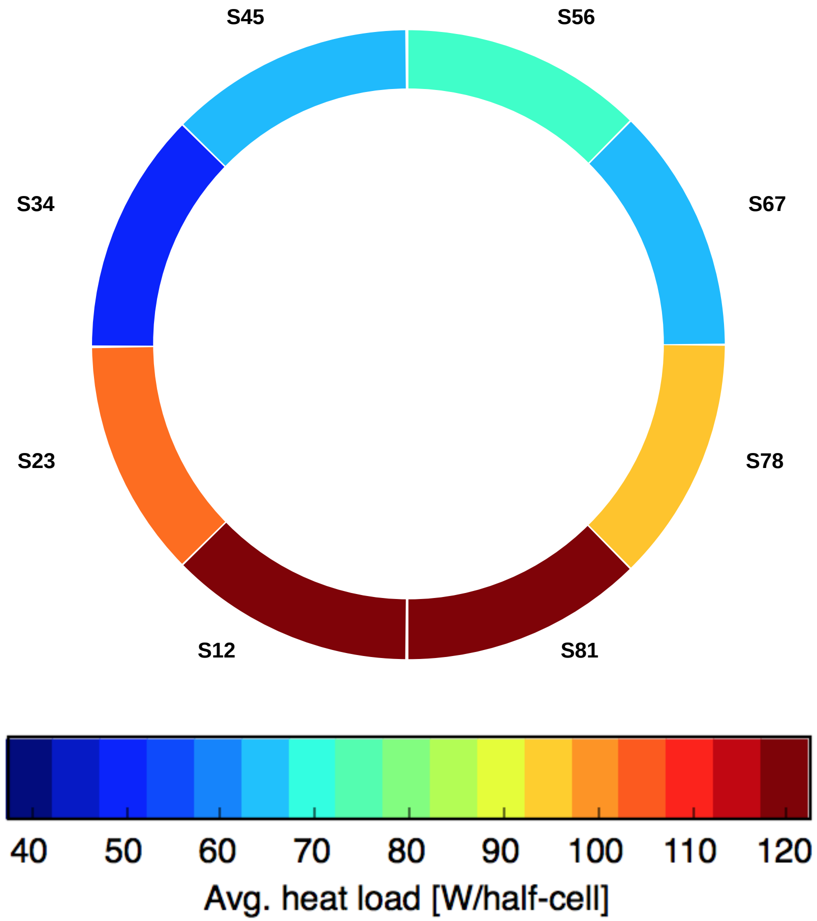


Cu Beam screen



- The SEY curve for Cu_2O has a different shape as the one of Cu Beam screen
- Cu_2O oxide can be conditioned by e- irradiation

Heat load from the e-cloud in the LHC

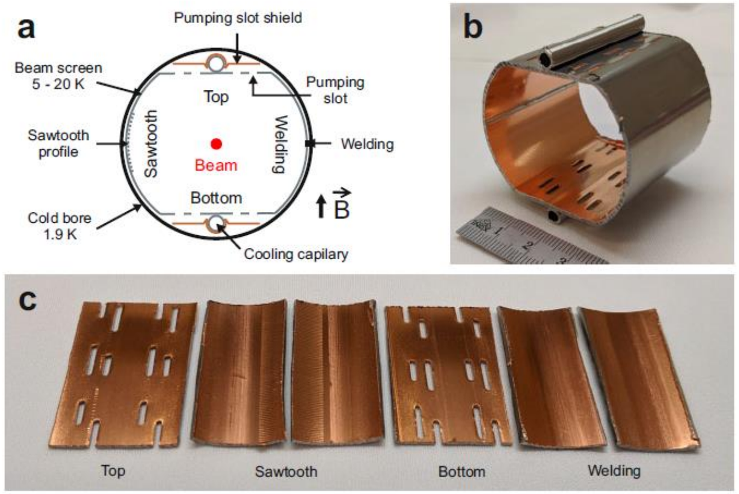


Giovanni Iadarola, CERN
E-CLOUD workshop 2018

- heat load is inhomogeneous along the ring
- machine appears to be splitted into two parts: arcs 34, 45, 56 and 67 have an average heat load lower that for arcs 12, 23, 78 and 81

Why is the E-cloud more intense in some parts of the LHC ?

Valentine Petit PhD Thesis (CERN, 2020) / V. Petit COMMUNICATIONS PHYSICS | https://doi.org/10.1038/s42005-021-00698-x



- Beam screen extracted from the LHC beam pipe

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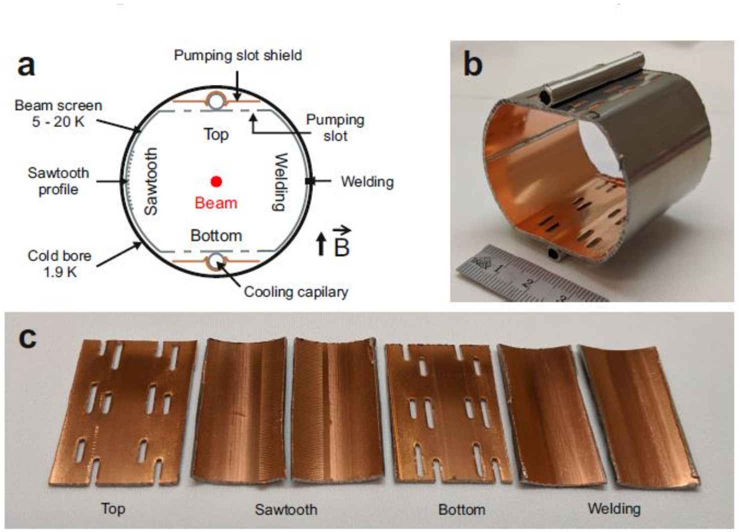

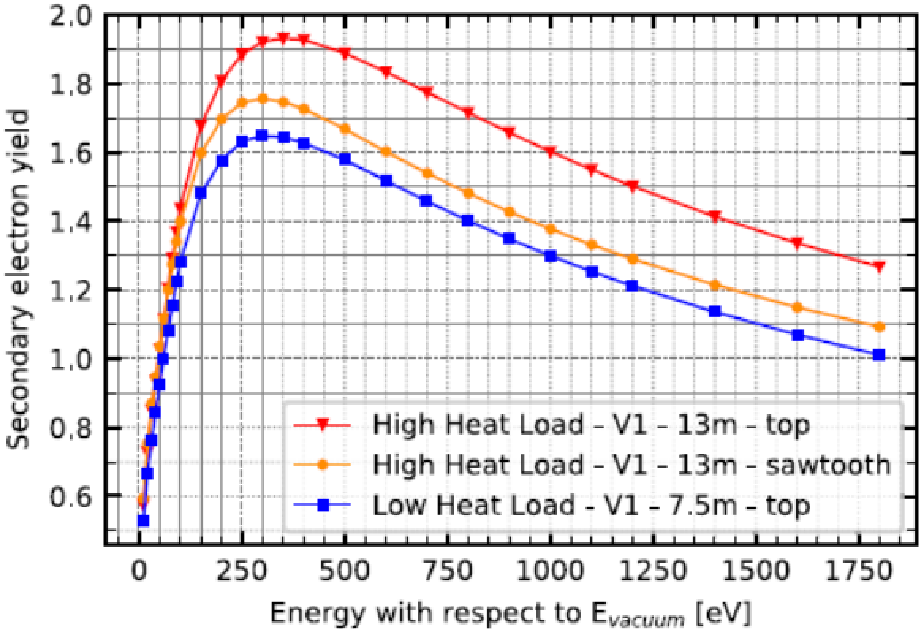

- Beam screen extracted from the LHC beam pipe
- High Heat Load parts exhibit a higher SEY than the Low Load parts

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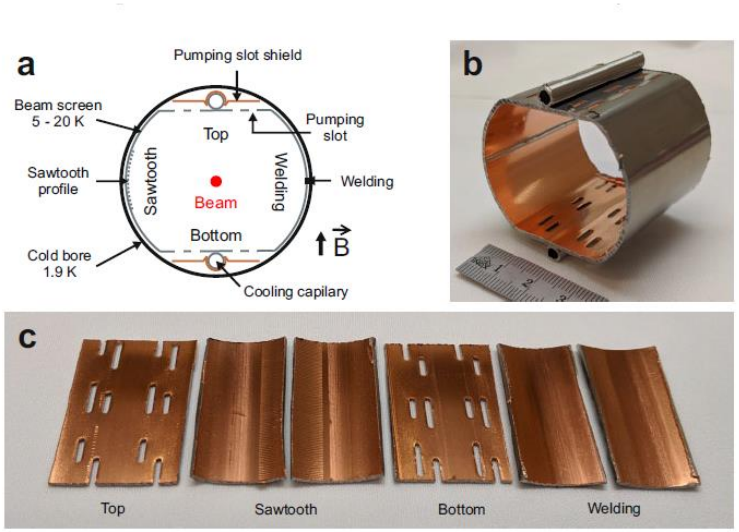
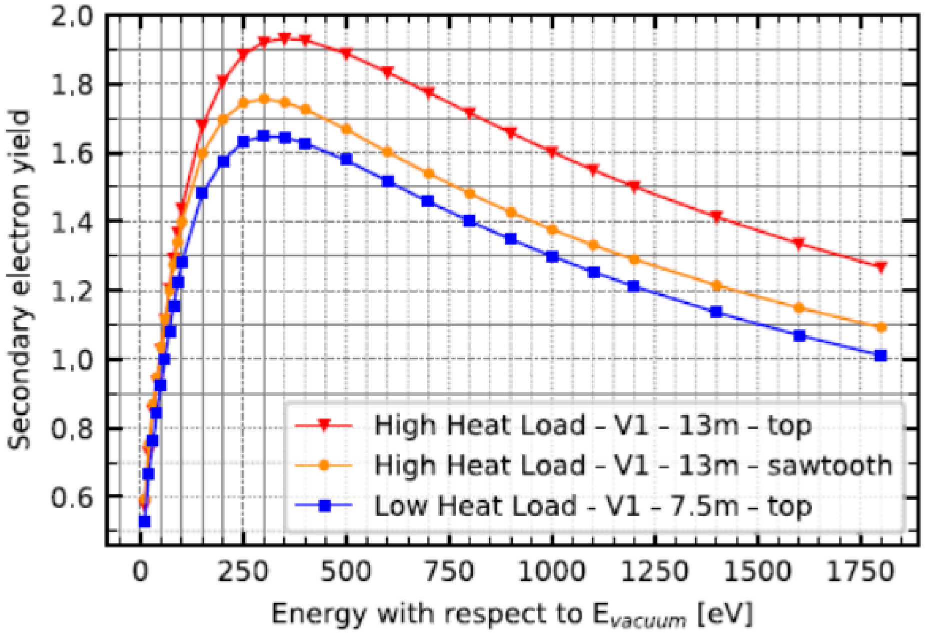
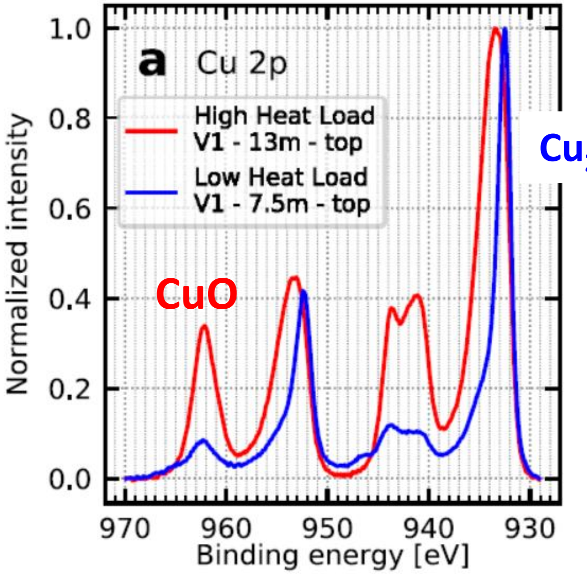


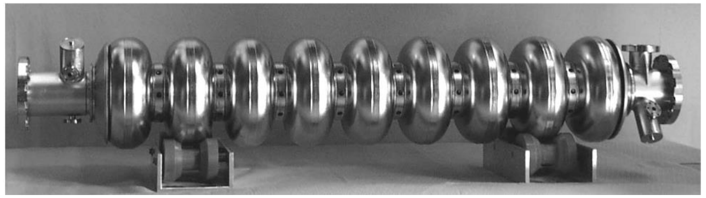




- Beam screen extracted from the LHC beam pipe
- High Heat Load parts exhibit a higher SEY than the Low Load parts
- **CuO was detected (and not the native oxide Cu_2O) in High Heat Load parts !**

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

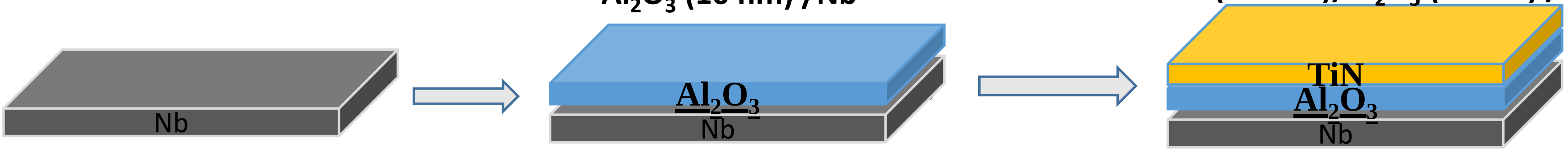
The influence of copper oxides on the conditioning is an important issue for the LHC

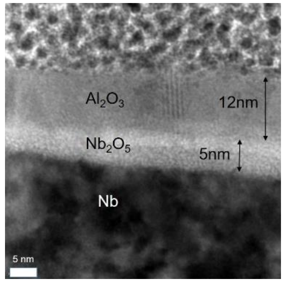


Thèse Sarra Bira (IJCLab)
Collab. Dépôts ALD Thomas Proslier / Yasmine Kalboussi

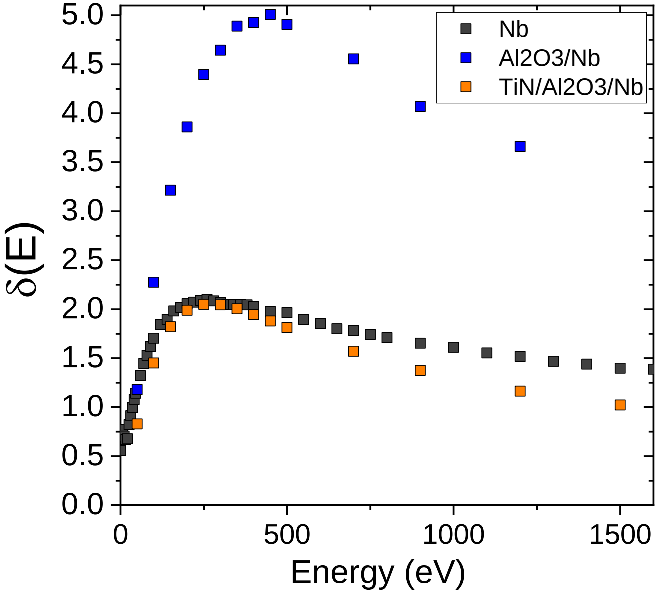
Al_2O_3 (10 nm) /Nb

TiN (5.5 nm)/Al_2O_3 (10 nm) /Nb

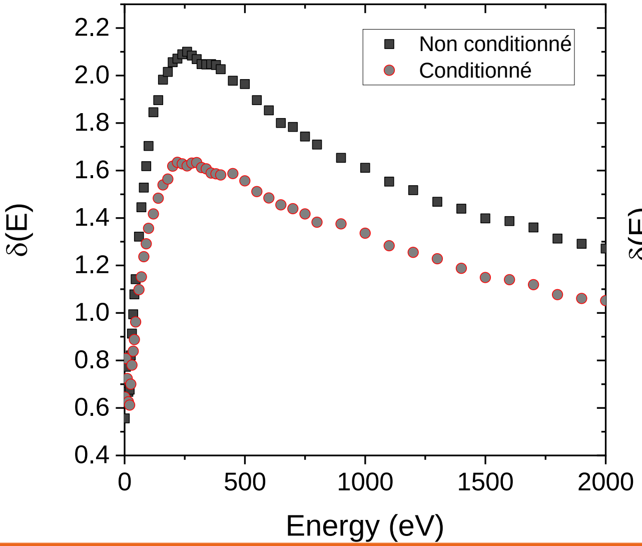


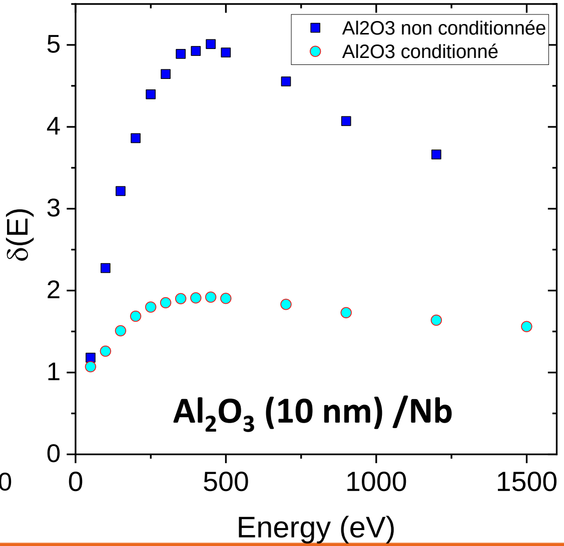


Comparaison SEY
Matériaux non conditionnés

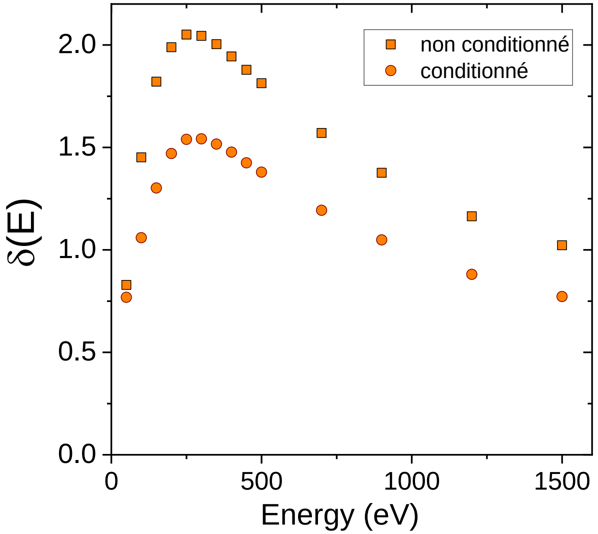


Nb





TiN (5.5 nm)/Al_2O_3 (10 nm) /Nb



Conclusion et perspectives

- **Importance des analyses de surface pour comprendre la relation entre la chimie de surface** et :
  (i) la pression dynamique dans les accélérateurs (conditionnement)
  (ii) le processus d'émission d'électrons secondaires (multipacting dans les cavités SRF et lignes de faisceau)

- Une modification sur quelques nm de profondeur peut avoir des conséquences extrêmement importantes sur les propriétés de surface

- Il est important de développer des bâtis d'analyses en laboratoire adaptés pour répondre à ces problématiques

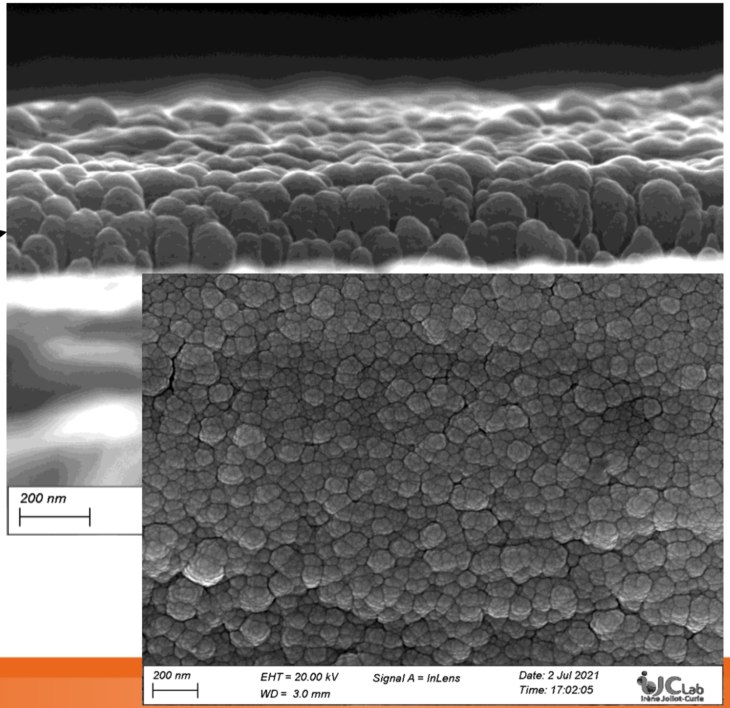
- **Perspectives R&D**:

  (i) Influence de l'épaisseur de dépôt (dépôt C) + rôle de CuO sur le SEY du Cu (LHC)

  (ii) Nature/épaisseur de dépôts ALD : études exploratoires pour identifier d'autres matériaux antimultipacting que TiN (nitrures métalliques ou carbure): thèse en collaboration avec le SIMAP/LPSC (Grenoble)

  (iii) Influence de l'épaisseur et la microstructure de **dépôts NEG** sur son efficacité (pompage distribué et antimultipacting/WP Vacuum pour FCC-ee)

  (iv) Acquisition de bâtis d'analyses multitechniques (EQUIPEX PACIFICS) pour renforcer les équipements de la plateforme Vide&Surfaces de IJCLab



Thanks for your attention