Evolution of beam screen surface conditioning upon particle irradiation for vacuum studies

Role played by surface chemistry on the Secondary Electron Yield

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Collaboration :
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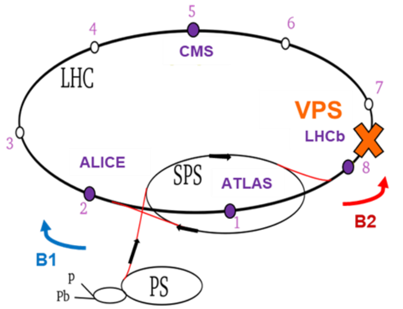
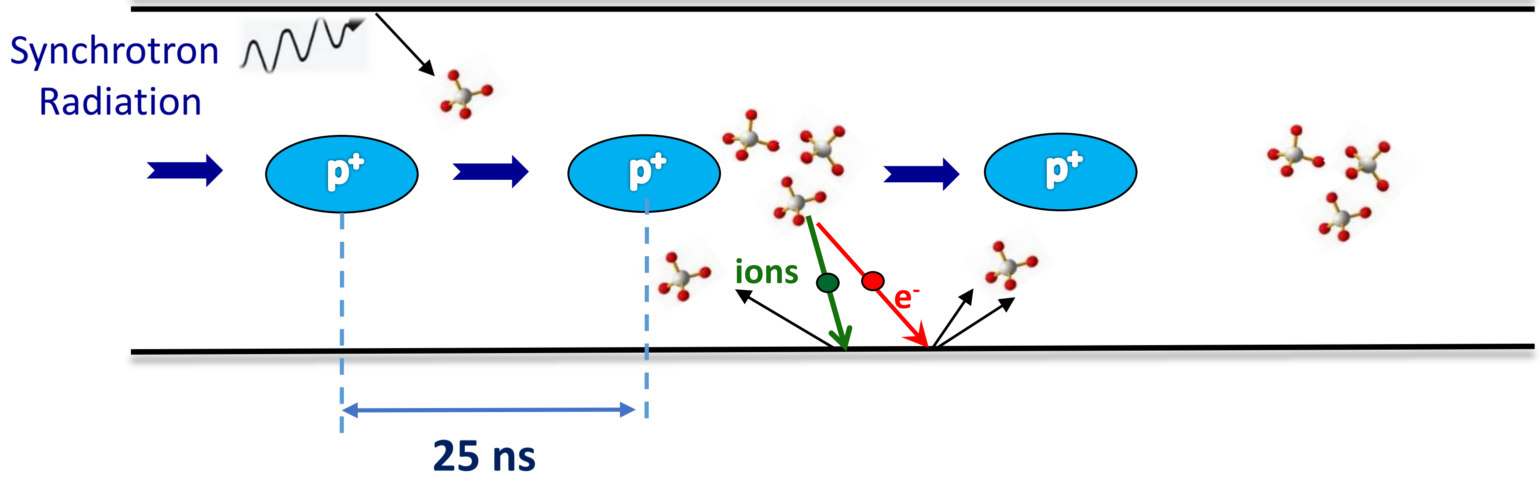
Context :vacuum in the LHC

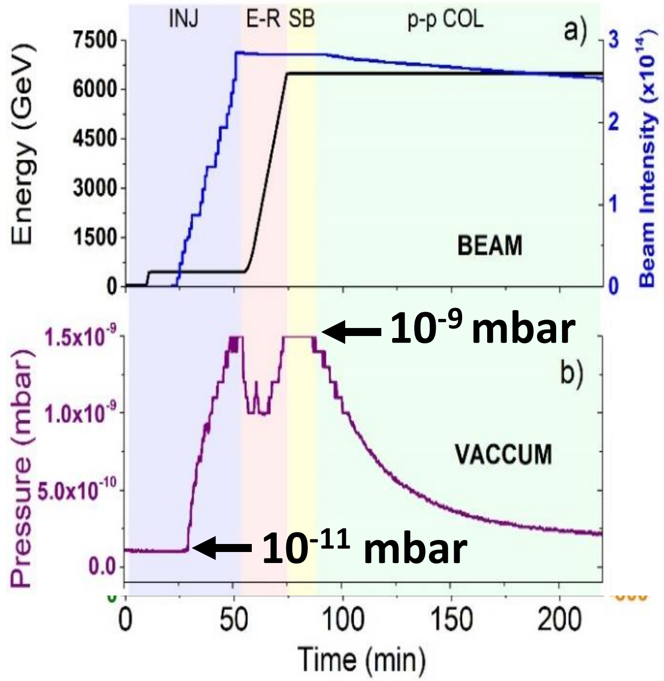


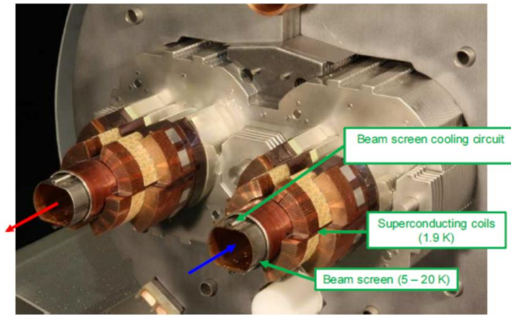
Vacuum studies constitute an essential field for all accelerator community, and high energy physics field.

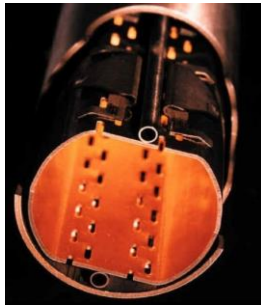
Stimulated Desorption



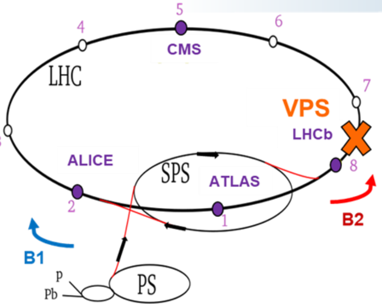
Dynamic pressure in the LHC (Vacuum Pilot Sector Station 4)



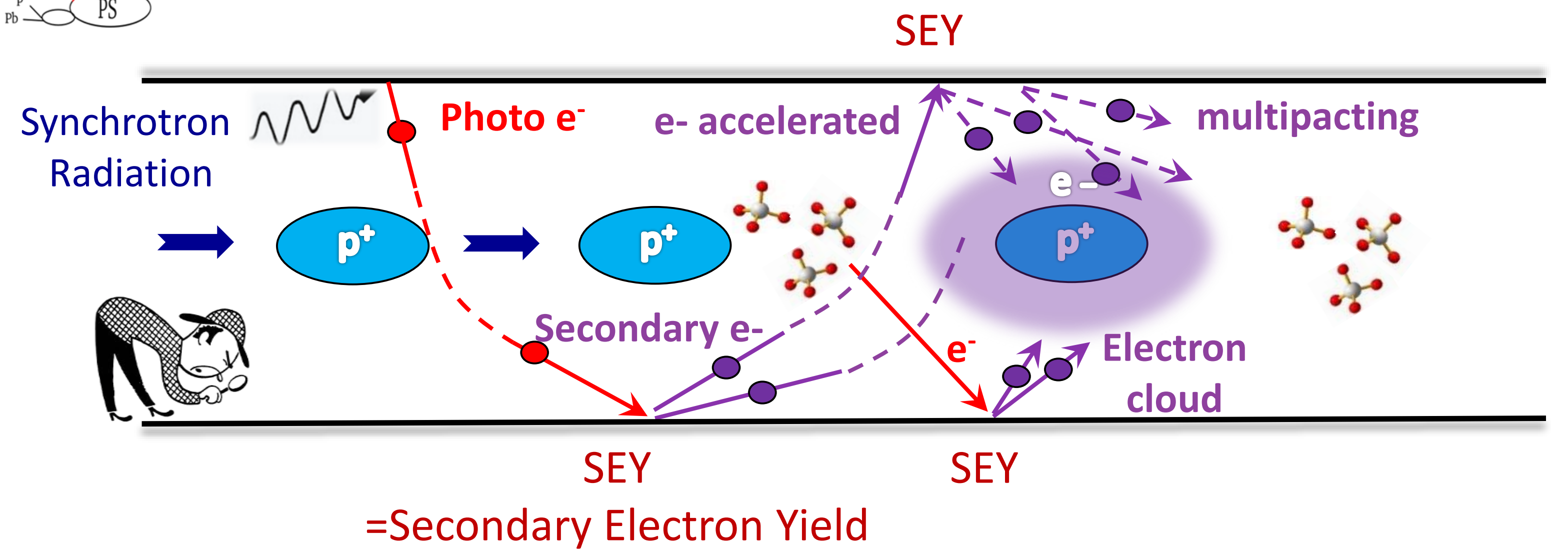




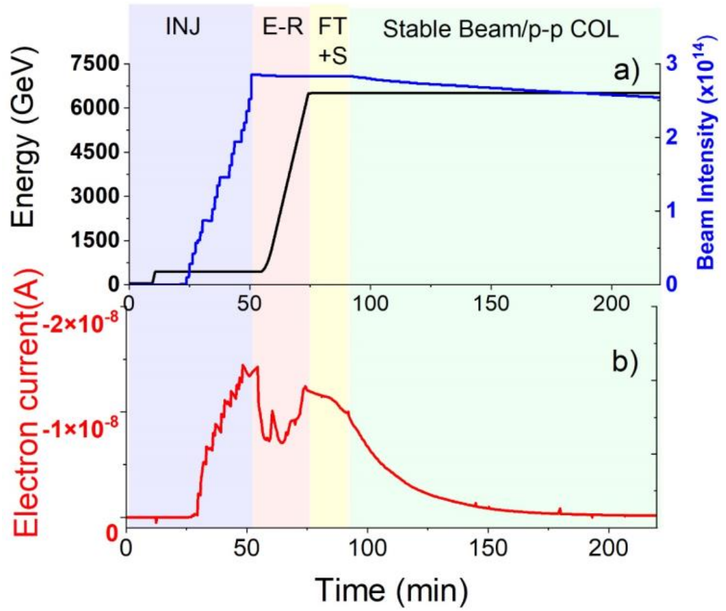
Context :vacuum in the LHC



Secondary particles creation



Electron current evolution in the LHC (Vacuum Pilot Sector Station 4)



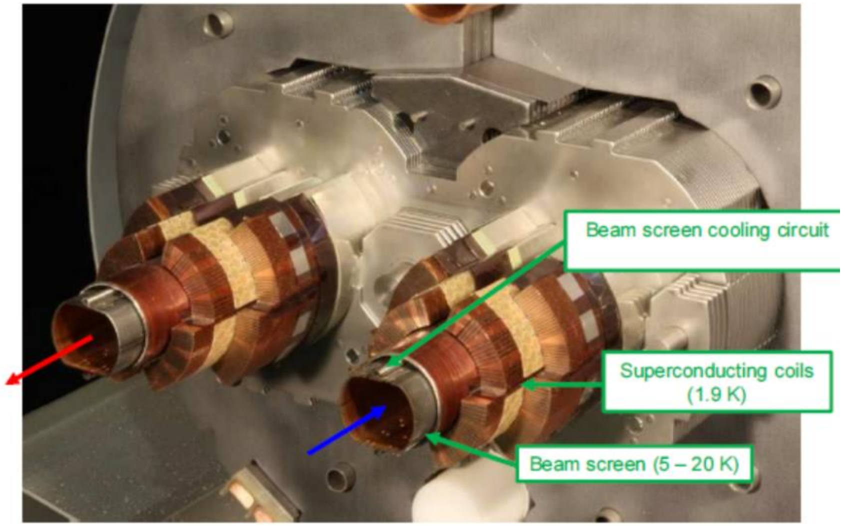
All of these phenomena may limit the performance of the LHC : **2018 LHC RUN 2** **13 TeV, 2556 b, 1.1x10^{11} ppb** ***vs*** **NOMINAL PARAMETERS LHC** **14 TeV, 2808 b, 1.2x10^{11} ppb**

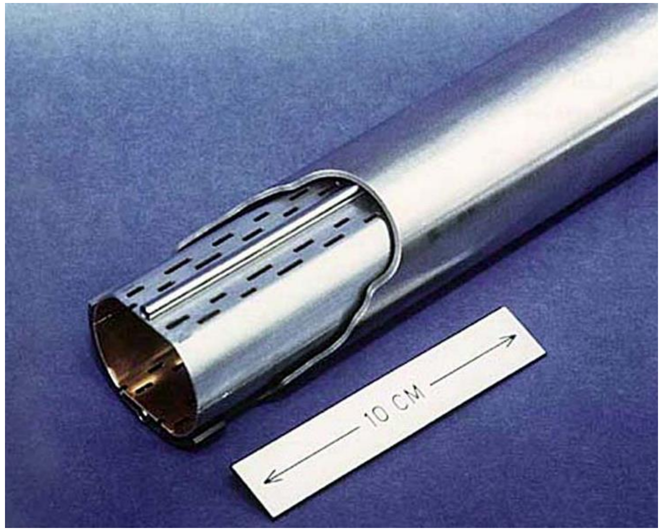
Main objectives

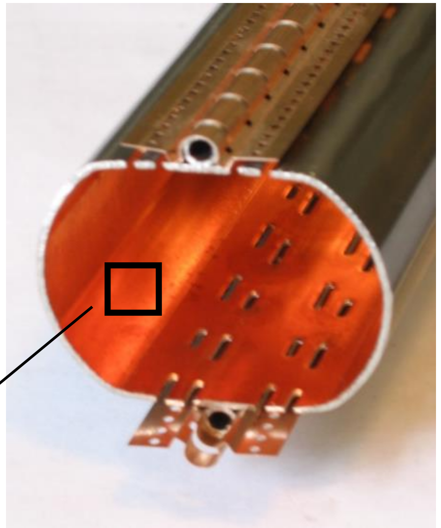
→ Mitigation of detrimental collective effects inside the beam lines

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

LHC beam screen samples







Oxygen-Free Electronic **copper colaminated onto stainless steel**.

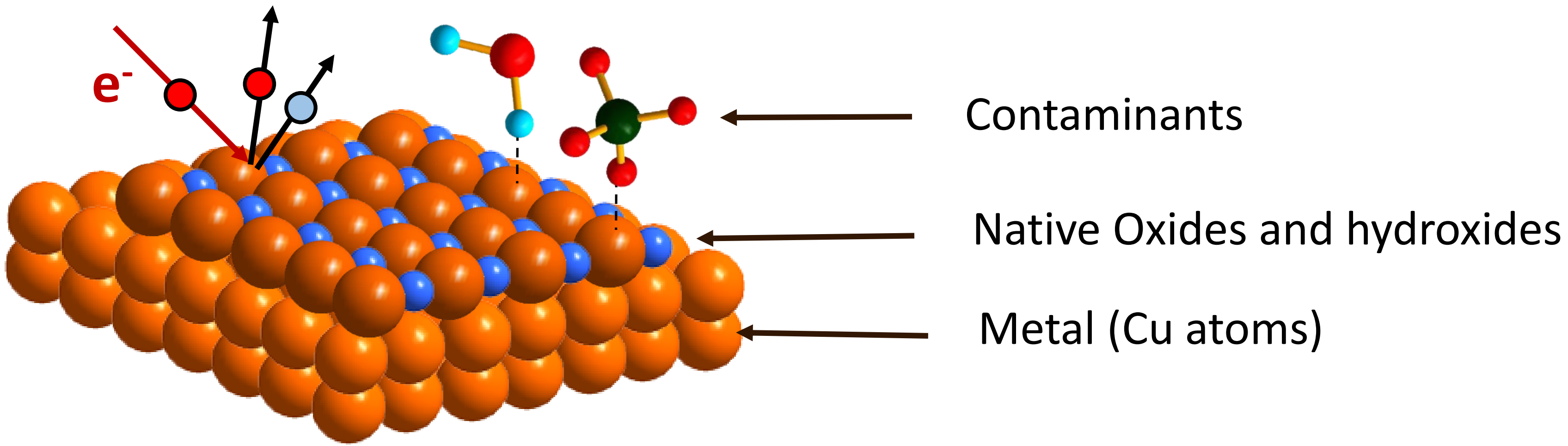
OFE copper = 99.99% pure copper with 0.0005% oxygen content to avoid undesirable chemical reactions with other materials

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.

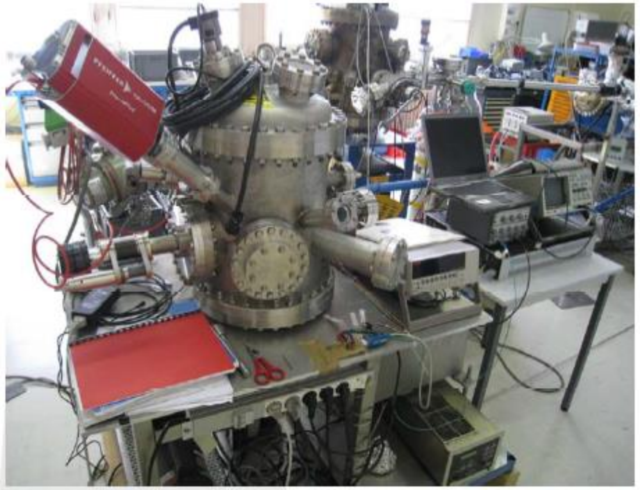
What is a “real surface”?



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

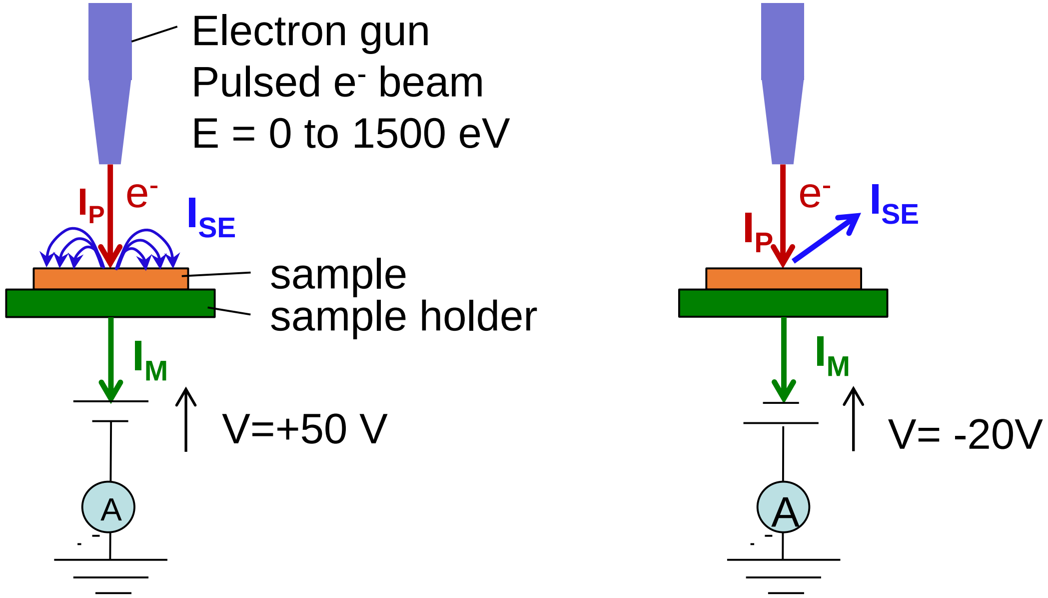
- ➢ role played by the C of the hydrocarbon molecules found on the surface of this beam screen ?
- ➢ role played by the native oxides of the metal?

} **On the SEY**



- base pressure: 5×10^{-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

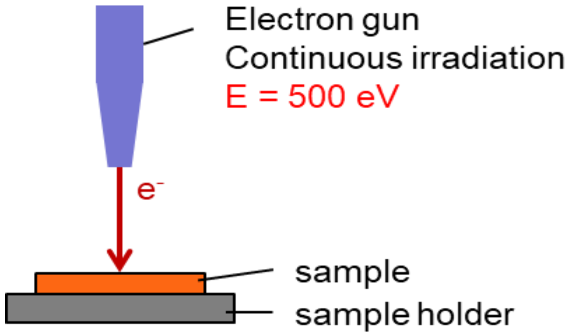


$I_M(+50V) = I_P$

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

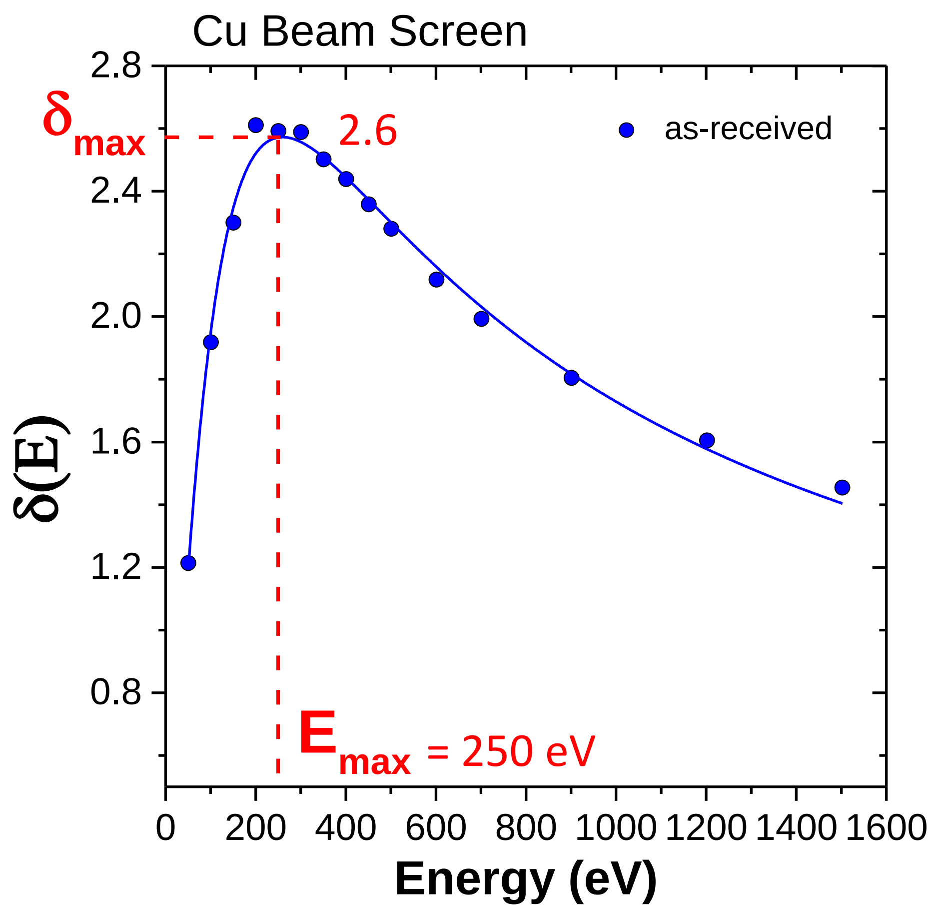
$$SEY: \quad \delta = 1 - \frac{I_M(-20V)}{I_M(+50V)}$$

Conditioning by e- irradiation



Characteristic evolution of the SEY of a copper beam screen

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



Phenomenological model used for the ***fit***

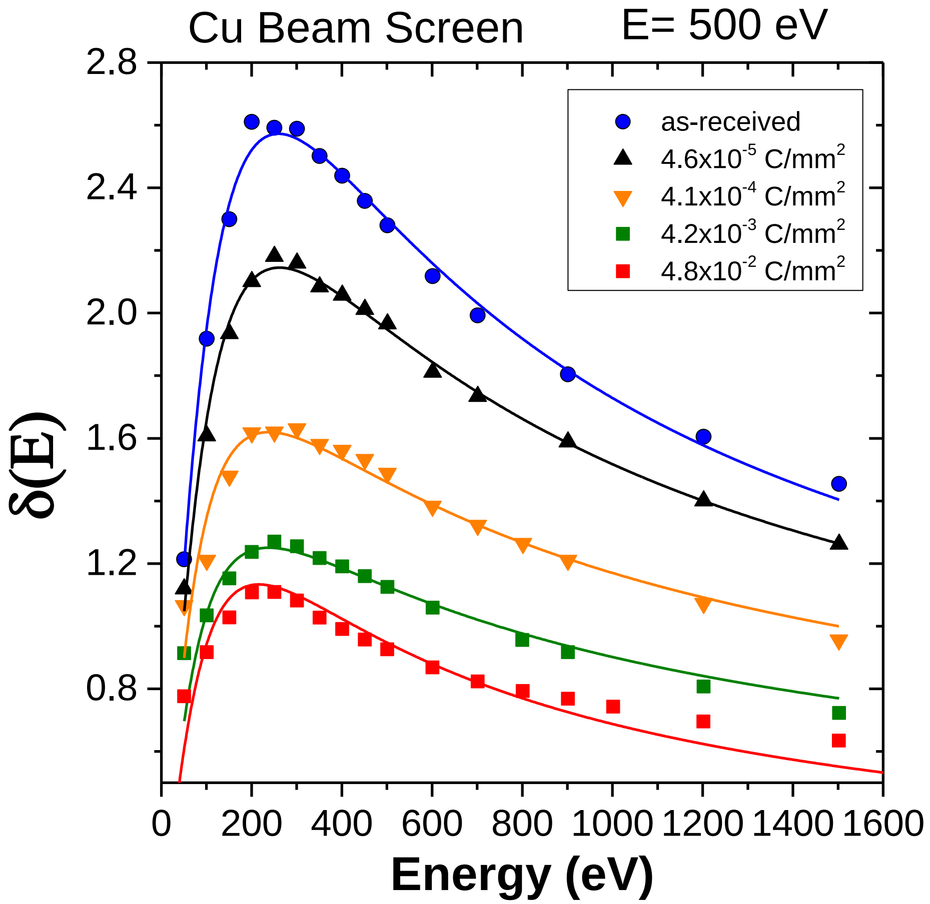
$$\delta(\mathrm{E}) = \delta_{max} \frac{s * \left(\frac{E}{E_{max}}\right)}{s - 1 + \left(\frac{E}{E_{max}}\right)^{s}}$$

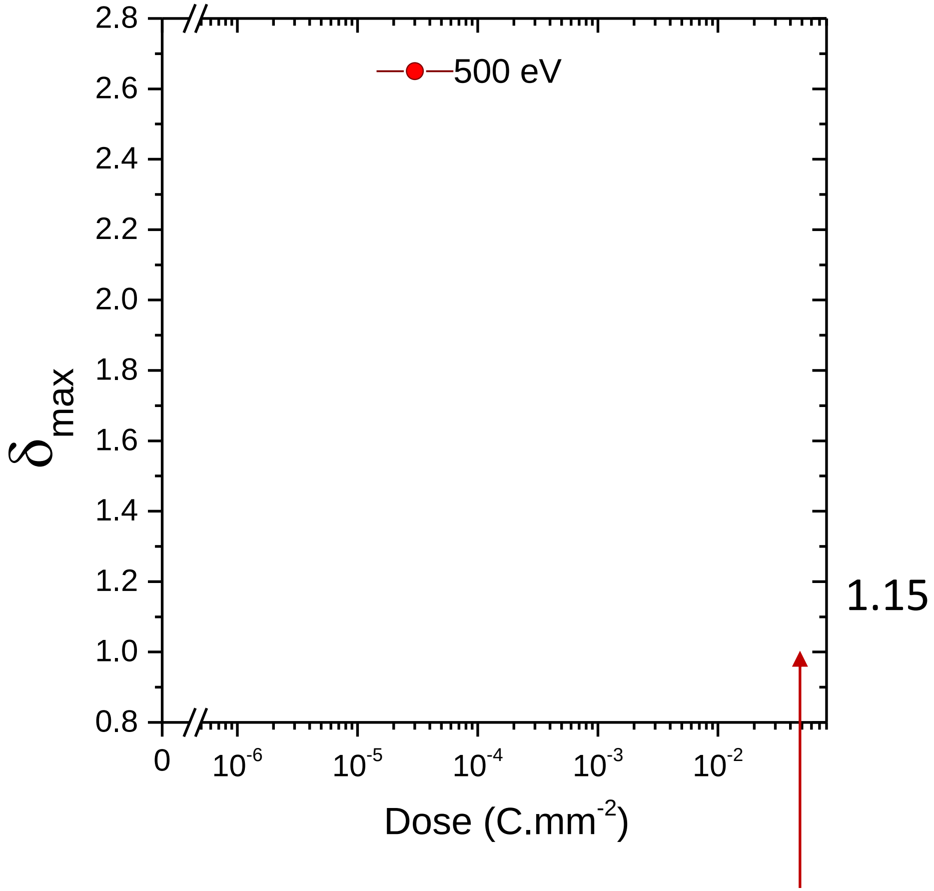
[Scholtz et al J of Research, 1996]

Suheyla Bilgen PhD Thesis (IJCLab 2020)

Conditioning of copper beam screen using e- of 500 eV

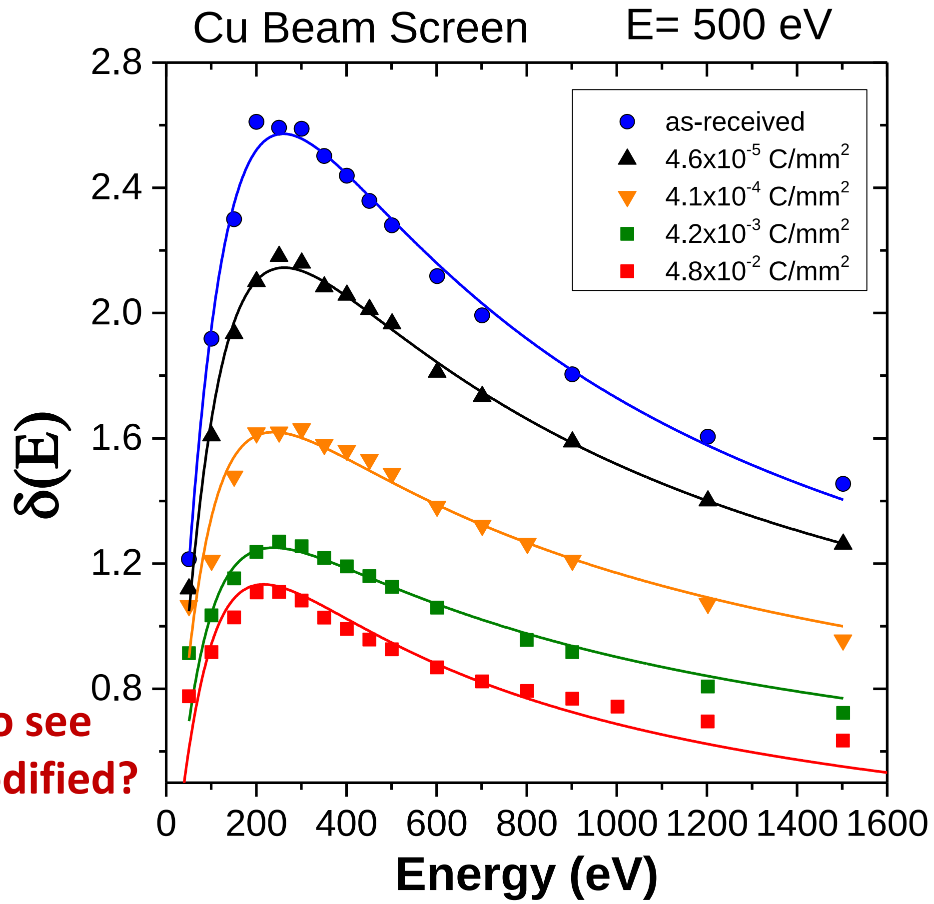
SEY measurement for different dose of e- received by the surface

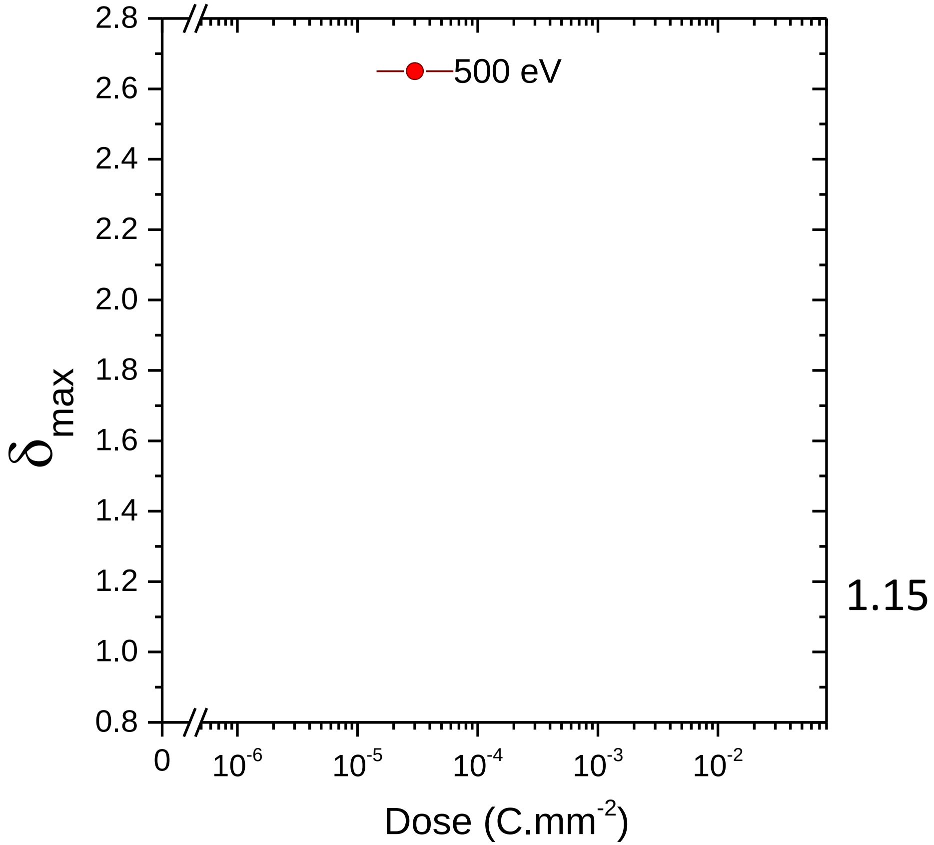




δ(E) decreases with increasing electron dose

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





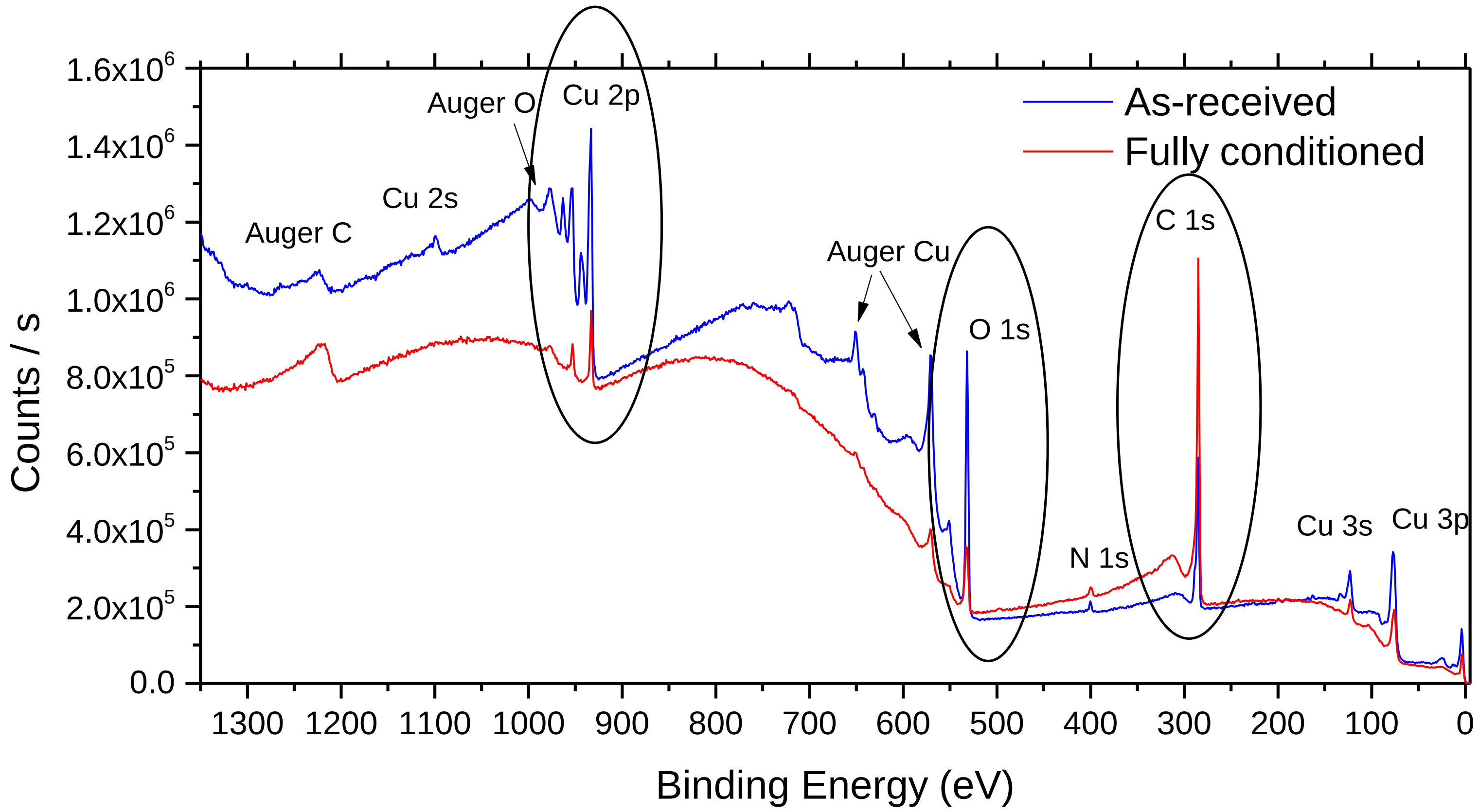
"surface conditioning" what does it mean?

study the surface chemistry to see how the chemistry has been modified?

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]*

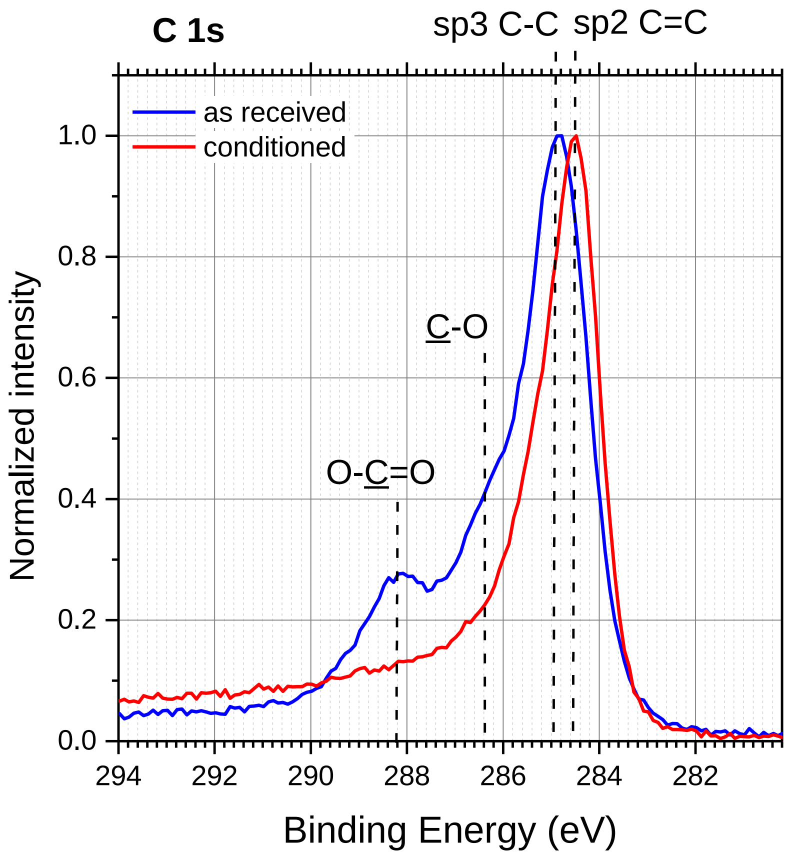
X-ray Photoelectron Spectroscopy



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:

Specific peaks associated with organic molecules on the surface, disappear after the surface cleaning by the e- bombardment.

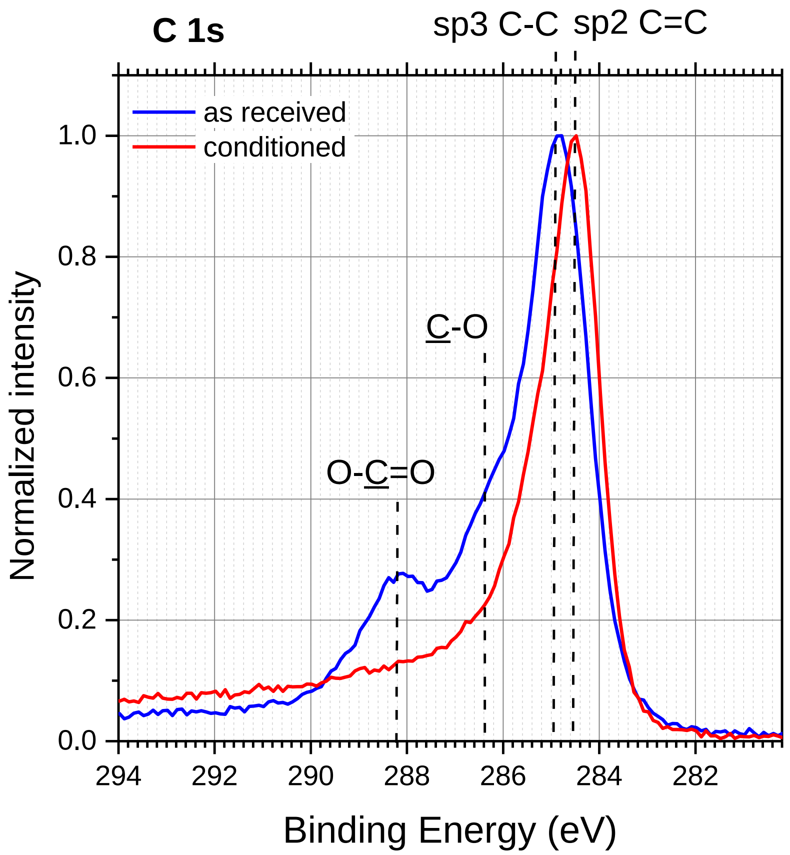
Modification of the **C hybridization** induced by electron irradiation:

Shift of the max of the peak towards low energies: 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]*

Nature of C present on the conditioned sample? TOF-SIMS analysis

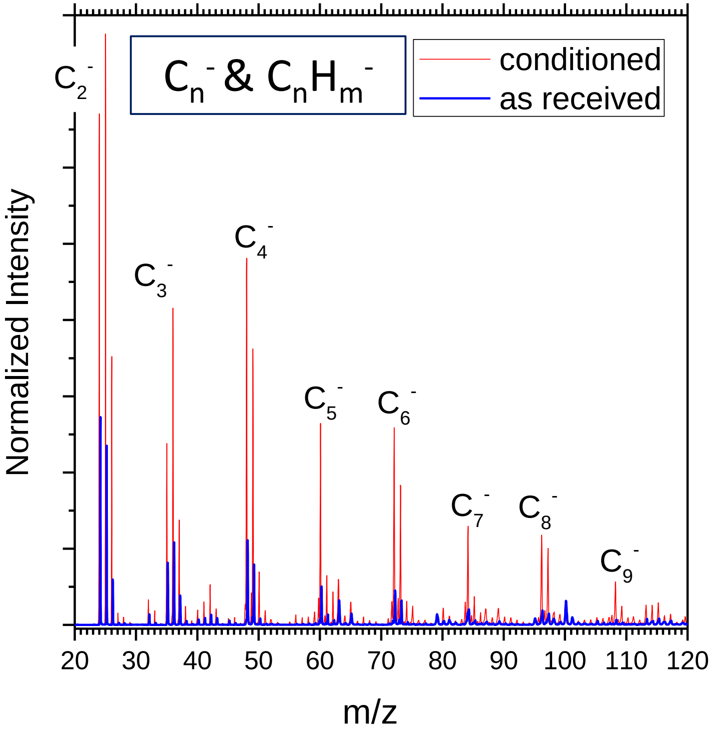
XPS



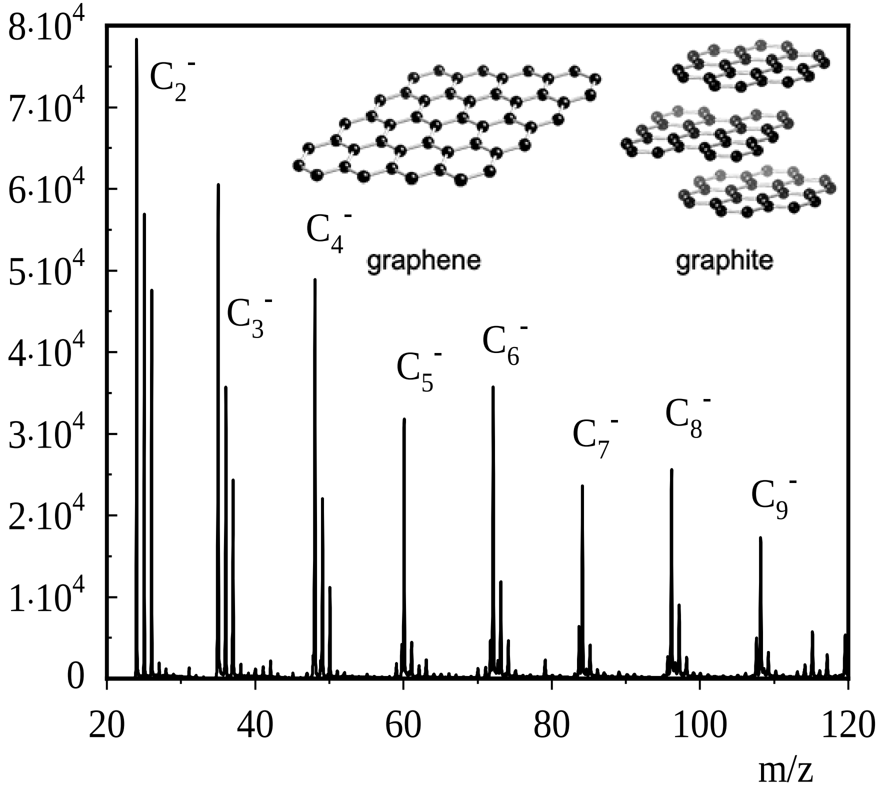
XPS : Modification of the C hybridization : from C-C bonds (sp3) to C=C bonds (sp2) compatible with a graphite structure.

MeV-Time Of Flight –Spectrometry – ANDROMEDE Platform

Carbon on the surface of a fully conditioned Cu



Graphene reference sample

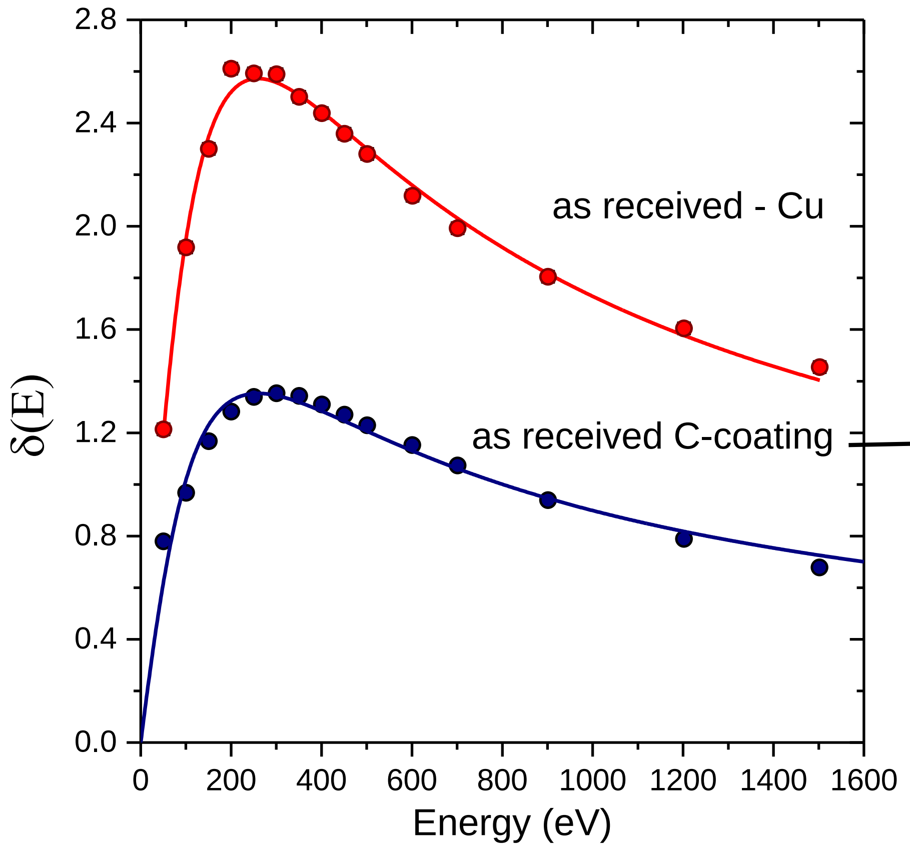


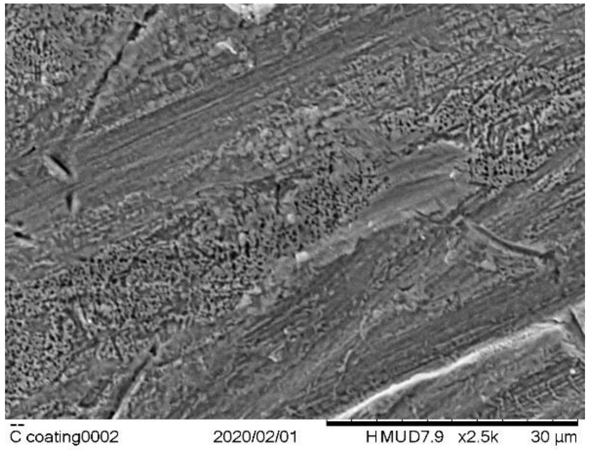
TOF-SIMS : a graphitic (graphene) carbon layer is formed on the surface of the fully conditioned sample (with a large amount of H).

→ 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 SEY of the beam screen?

Comparison of two unconditioned materials





SEM image of C-coating

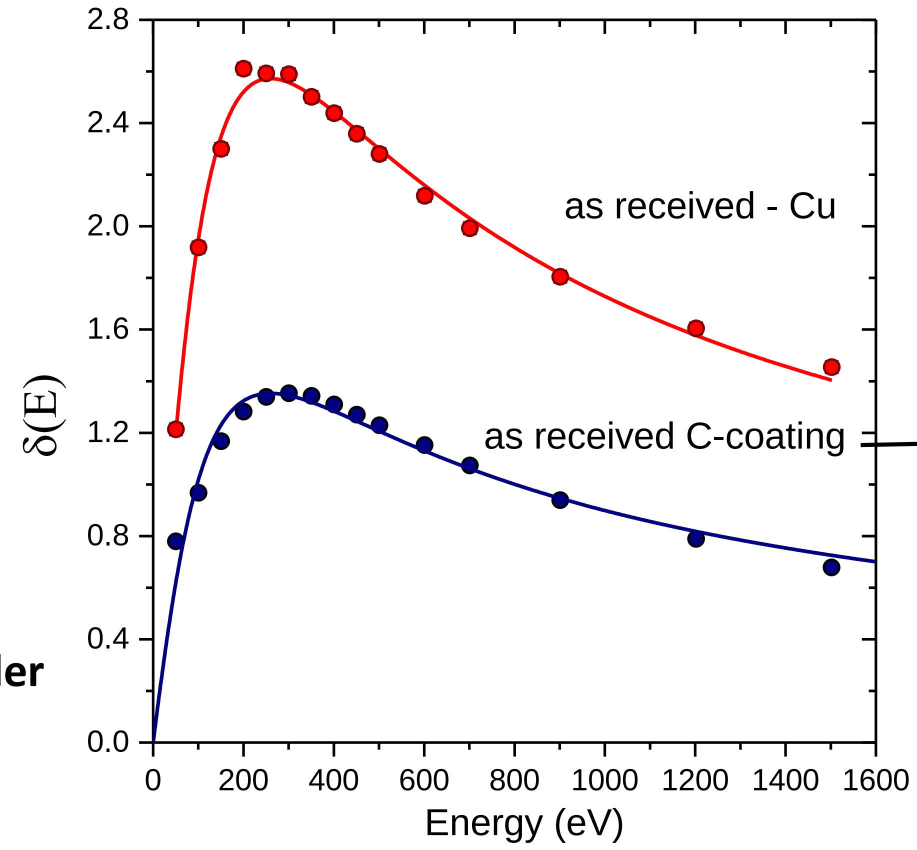
→ **SEY of carbon is intrinsically lower than the beam screen one**

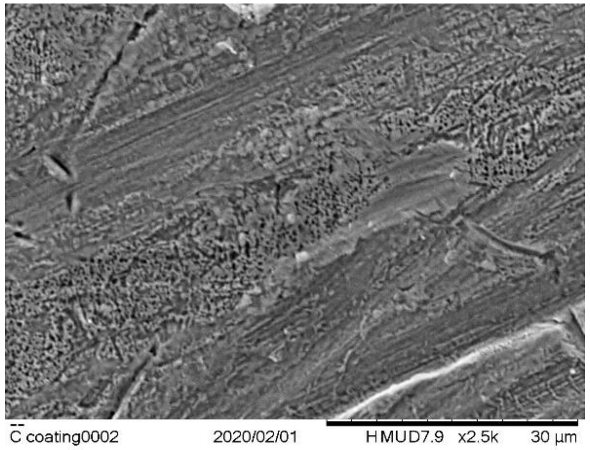
→ Carbon thin film deposited on Cu beam pipe walls is a solution to mitigate the electron cloud build up in the LHC *[P. Pinto Costa, IPAC2014]*

Why does the presence of a carbon layer reduces the SEY of the beam screen?

So, molecules of pollutants initially present on the beam screen are cracked under an e- bombardment to create a carbon layer which finally made it possible to reduce the SEY and therefore limit the EC in the collider

Comparison of two unconditioned materials





SEM image of C-coating

Conclusion and perspectives

- **Importance of surface chemistry analysis for a better understanding of dynamic pressure phenomena** :
  (i) such as EC formation in accelerators
  (ii) And the evolution of these surfaces submitted to different type of irradiation

- Finally we saw that the first few nm of a material has a major influence on surface properties such as the SEY

- All of these surface analysis are essential to investigate dynamic vacuum in accelerators and to improve colliders performances

- **Perspectives R&D**:

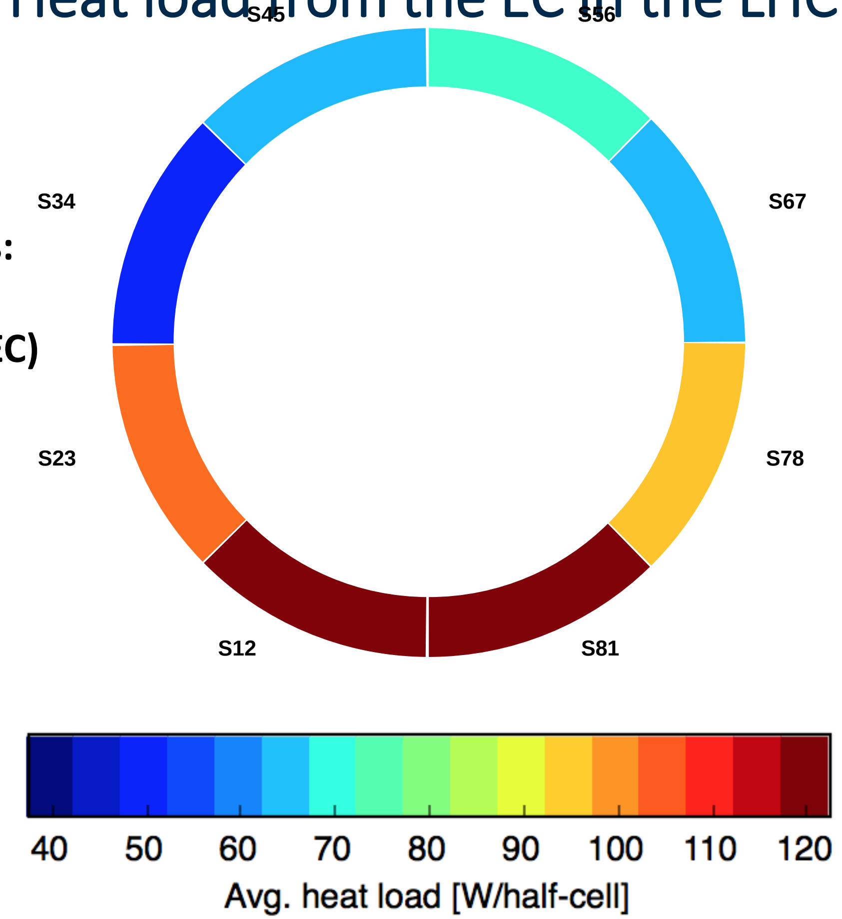
  Study of the evolution of copper oxides under electron irradiation using **Andromede** Facility

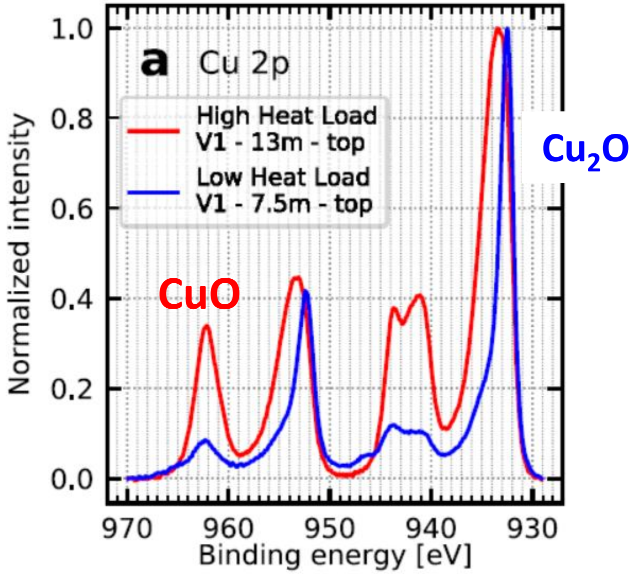
Heat load from the EC in the LHC

- 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)

Giovanni Iadarola, CERN
E-CLOUD workshop 2018





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)
Where does CuO come from?? Hypothesis: $Cu(OH)_2$ could be transform into CuO under e- bombardment

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

Thanks for your attention