6rd DRD1 Meeting

Varsaw, Oct. 2025

Unveiling Surface Chemistry and Aging Pathways of GEMs through In-Situ Surface Spectroscopy

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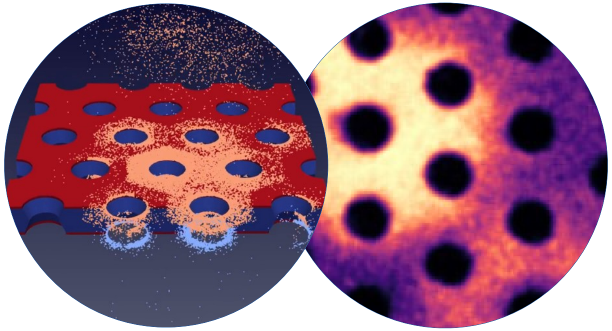
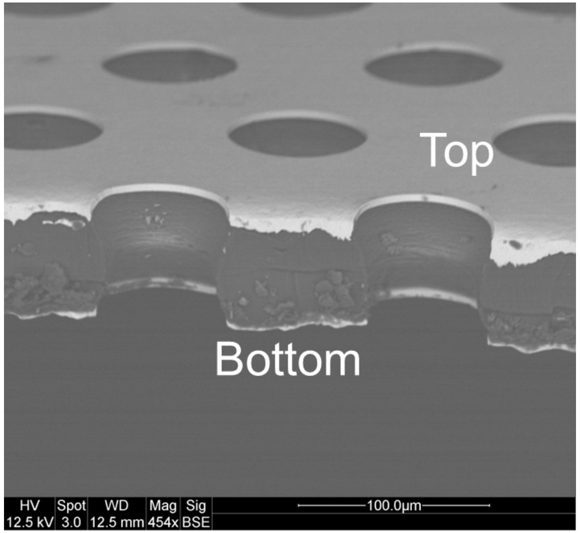
Aging and degradation models: why studying it?

- **Reliability & Stability:** Ensure long-term gain uniformity and tracking precision.
- **Predictive Maintenance:** Detect early degradation to prevent failures and reduce costs.
- **Radiation & Charge Effects:** Understand how ionization and charge buildup alter GEM performance.
- **Surface Chemistry:** Investigate gas–material interactions, contamination, and polymerization on GEM surfaces.
- **Ion Feedback & Discharges:** Mitigate micro-discharges and feedback under high-rate operation.
- **Design Optimization:** Guide material selection, cleaning, and fabrication for next-generation GEMs.





Aging and degradation models: why studying it?

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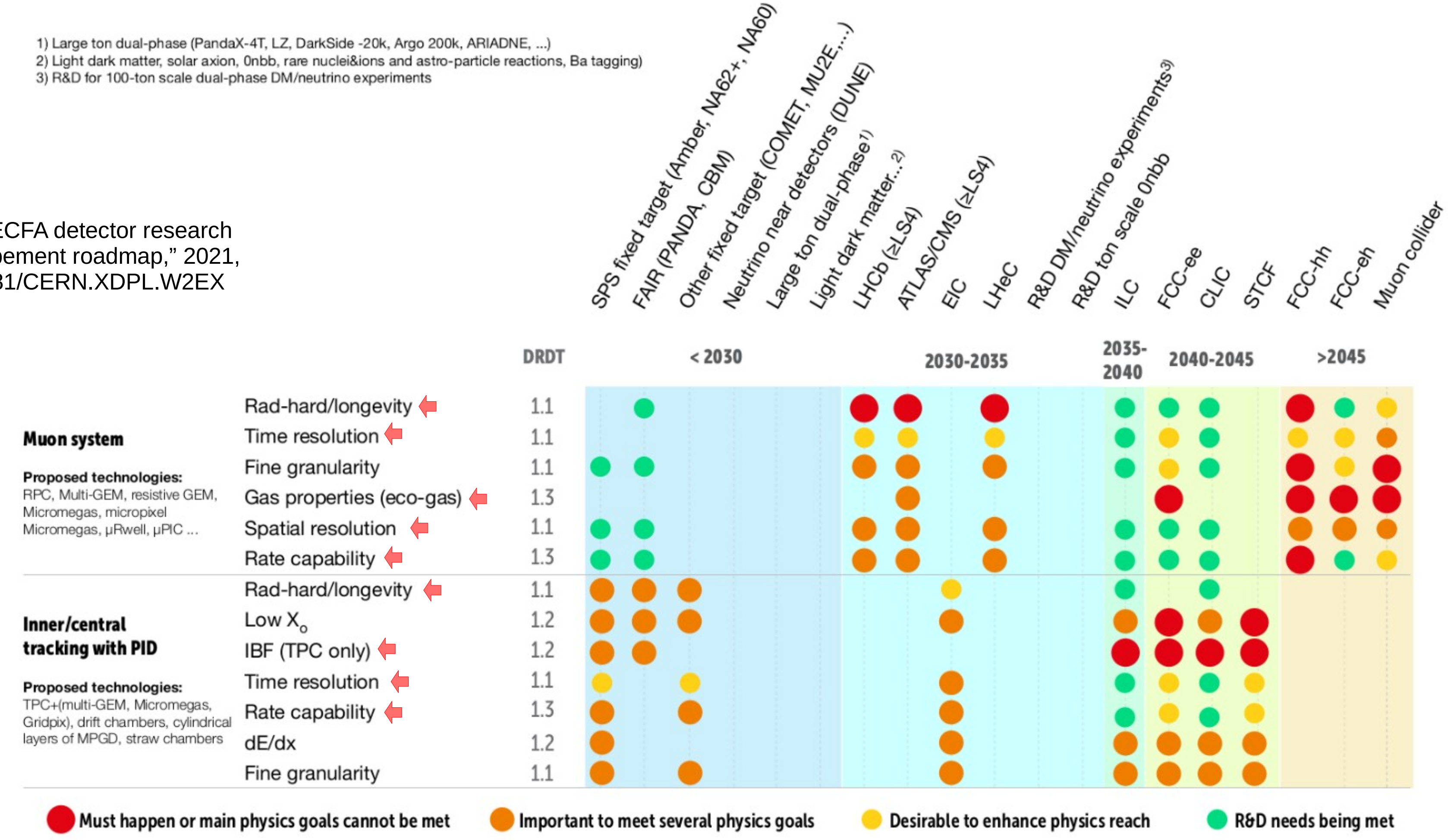
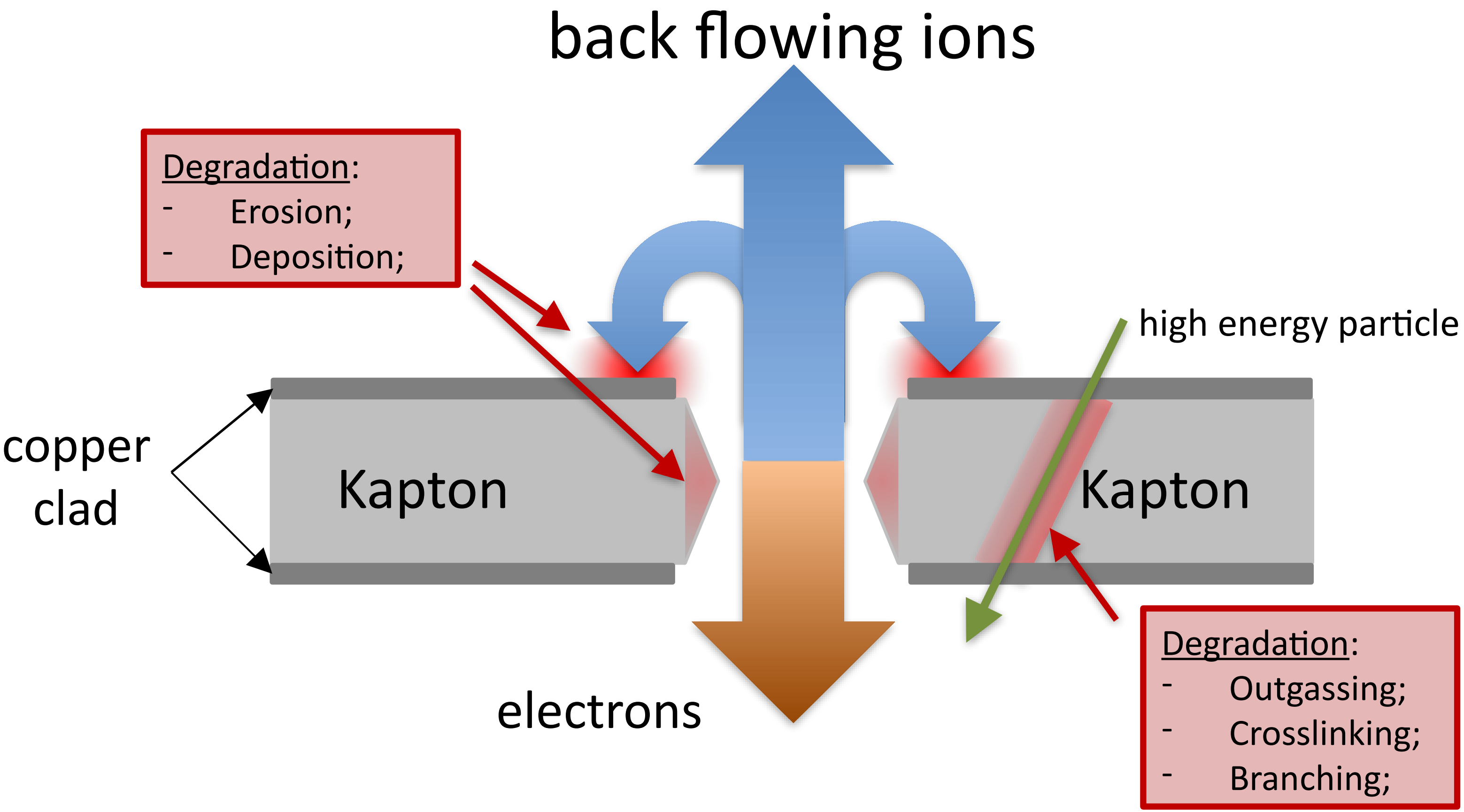
“The 2021 ECFA detector research and developement roadmap,” 2021, doi: 10.17181/CERN.XDPL.W2EX

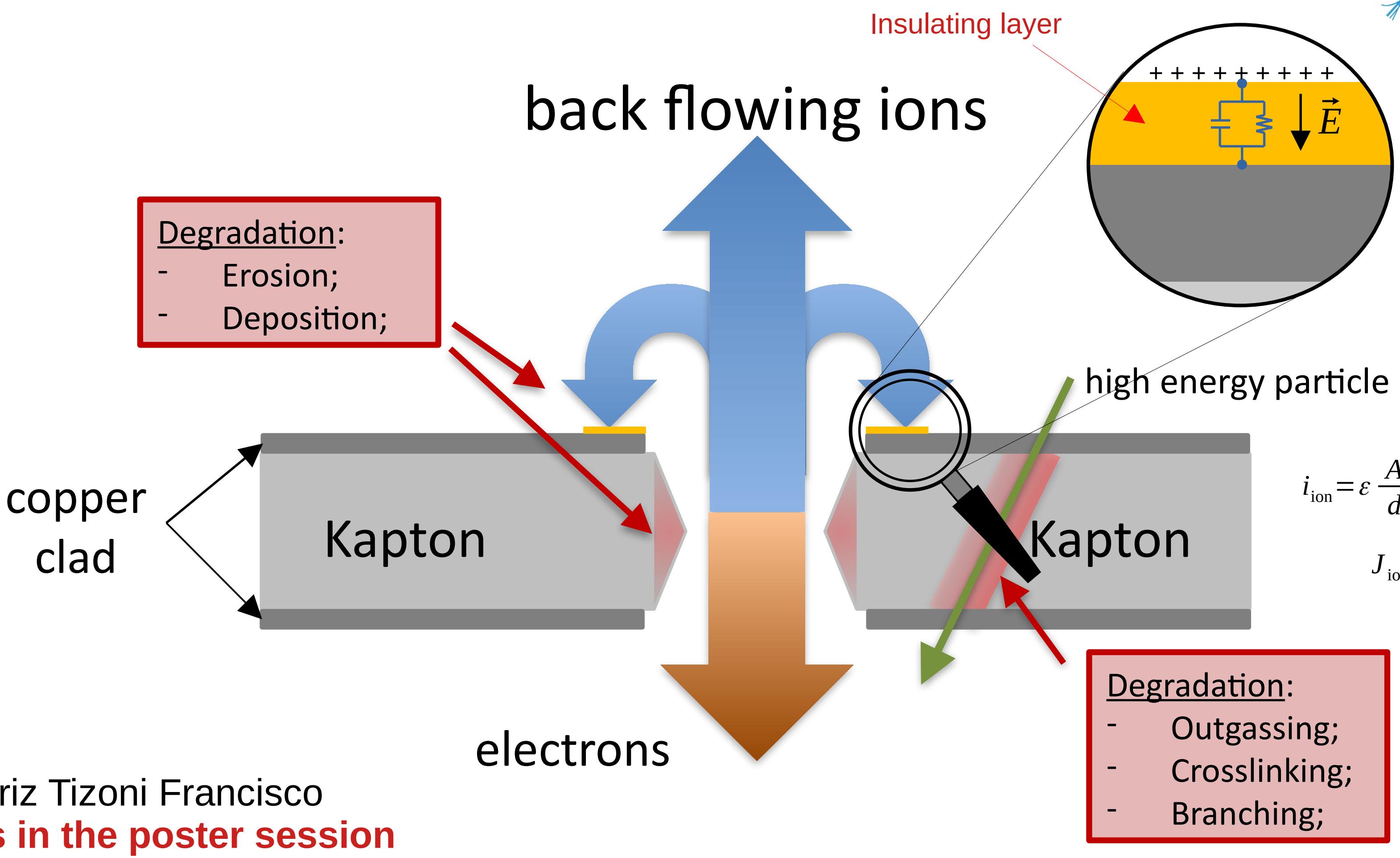


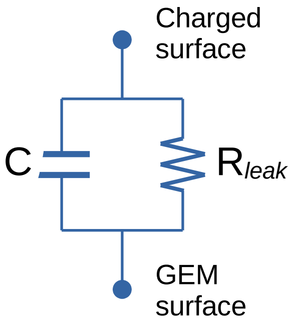
Aging and degradation models: what happens?



“Preliminary studies on GEM foil degradation in harsh radiation environments",
PoS, 2019, https://doi.org/10.22323/1.350.0036

Aging and degradation models: the Malter effect





$$i_{\text{ion}} = C\cdot\frac{dV}{dt} + \frac{V}{R}$$

$$i_{\text{ion}} = \varepsilon\,\frac{A}{d}\,\frac{dV}{dt} + \frac{V}{\rho_0\cdot e^{-a/(V_b - V)}}\,\frac{A}{d}$$

$$J_{\text{ion}} = \varepsilon\,\frac{dE}{dt} + \frac{E}{\rho_0}\cdot e^{A/(E_b - E)}$$

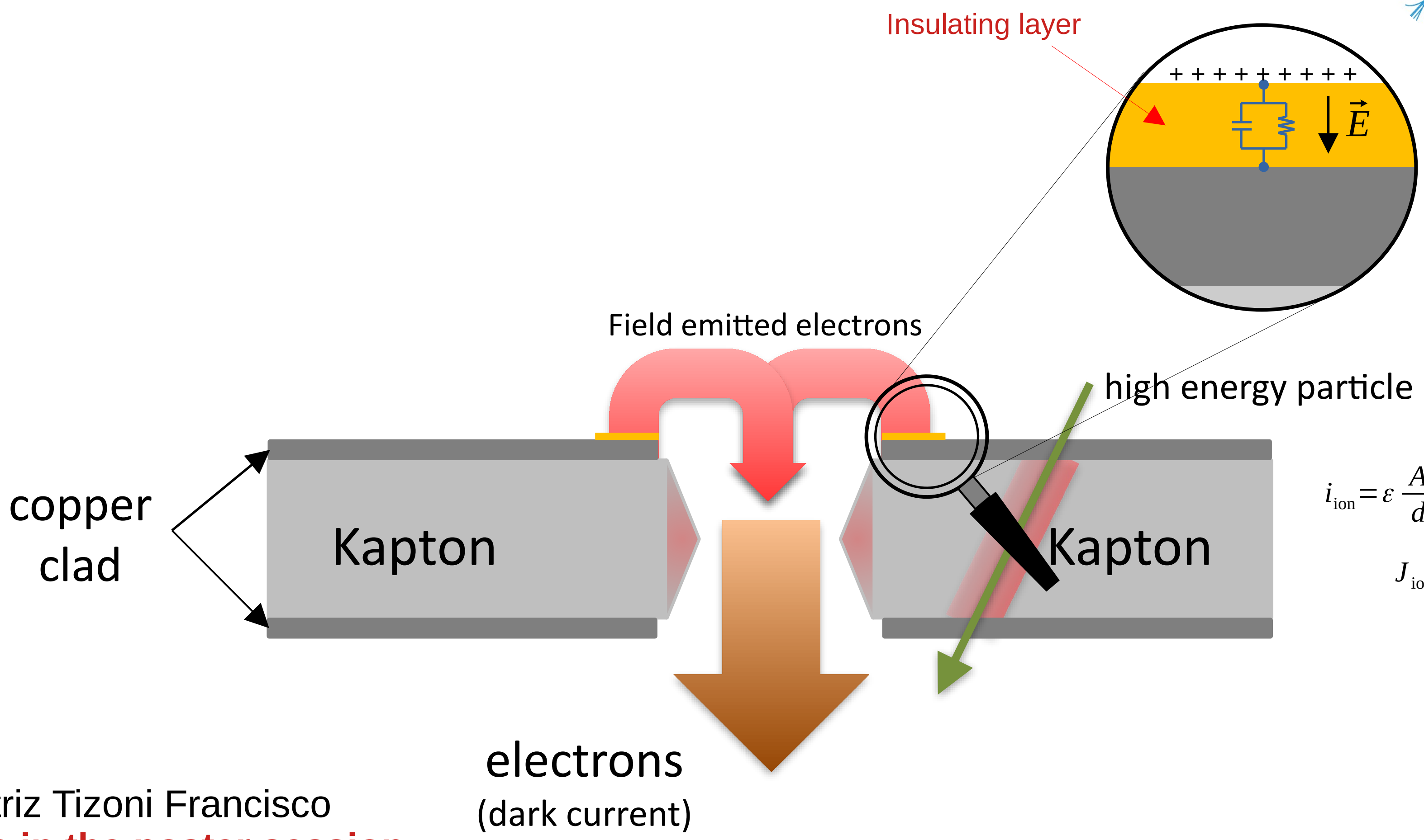
$$\boxed{J_{\text{ion}} = \frac{E}{\rho_0}\cdot e^{A/(E_b - E)}}$$

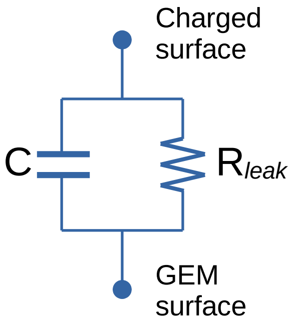
Bruna Beatriz Tizoni Francisco

See details in the poster session

“Understanding the dynamics of the Malter effect in GEMs through computer simulations”

Aging and degradation models: the Malter effect





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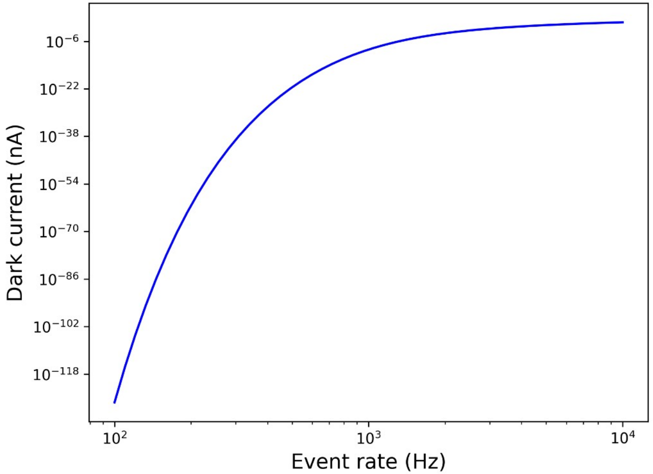
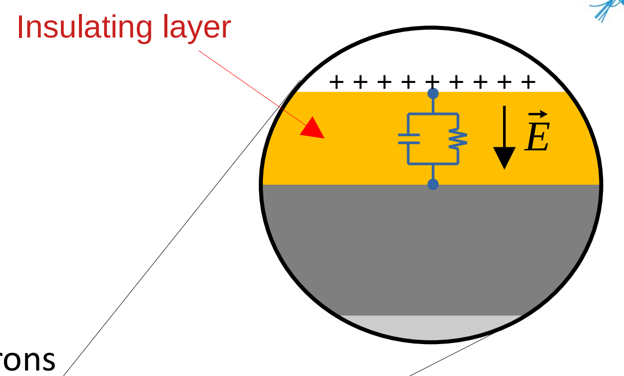
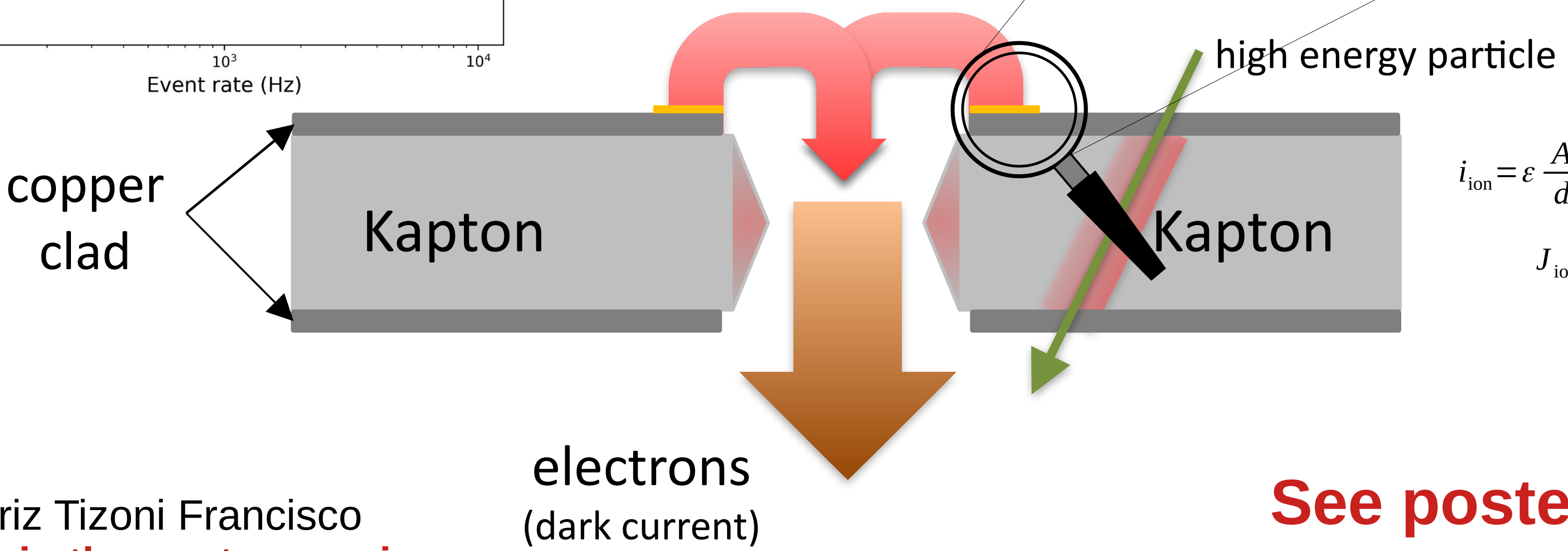
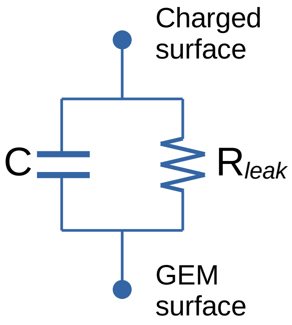
Aging and degradation models: the Malter effect









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Bruna Beatriz Tizoni Francisco

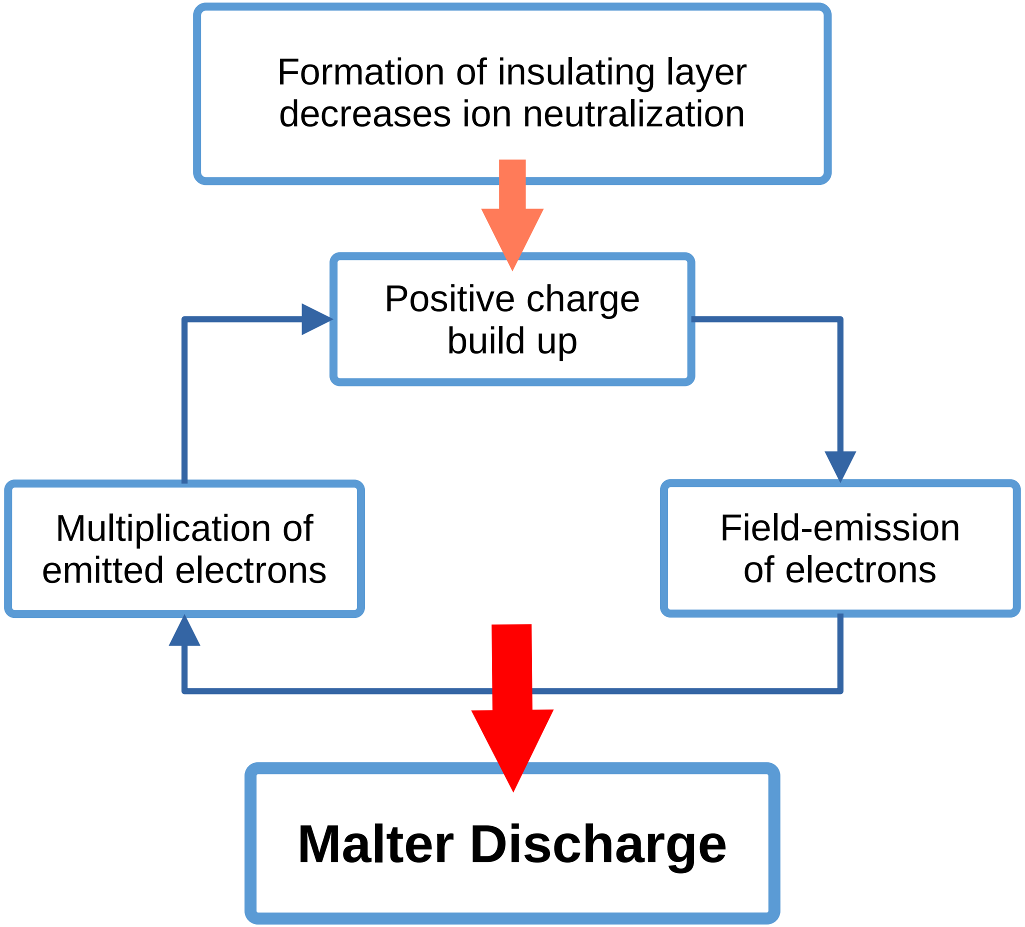
See details in the poster session

See poster 21!

“Understanding the dynamics of the Malter effect in GEMs through computer simulations”

Aging and degradation models: the insulating film

- **Discharge Behavior:** Films modify surface conductivity, increasing the risk of micro-discharges.
- **Surface Chemistry:** Understand oxidation, adsorption, and polymerization processes on copper.
- **Aging Mechanisms:** Identify how radiation, gas composition, and impurities drive film growth.
- **Material Optimization:** Guide cleaning, treatment, and coating methods to control surface passivation.



Aging and degradation models: the insulating film

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journal homepage: www.elsevier.com/locate/nima

Full Length Article

Evidence for polyimide redeposition and possible correlation with sparks in Gas Electron Multipliers working in CF_4 mixtures

Thiago B. Saramela [a], Tiago F. Silva [a,*], Marco Bregant [a], Marcelo G. Munhoz [a], Tien T. Quach [c], Richard Hague [c], Ian S. Gilmore [b], Clive J. Roberts [d], Gustavo F. Trindade [b,c]

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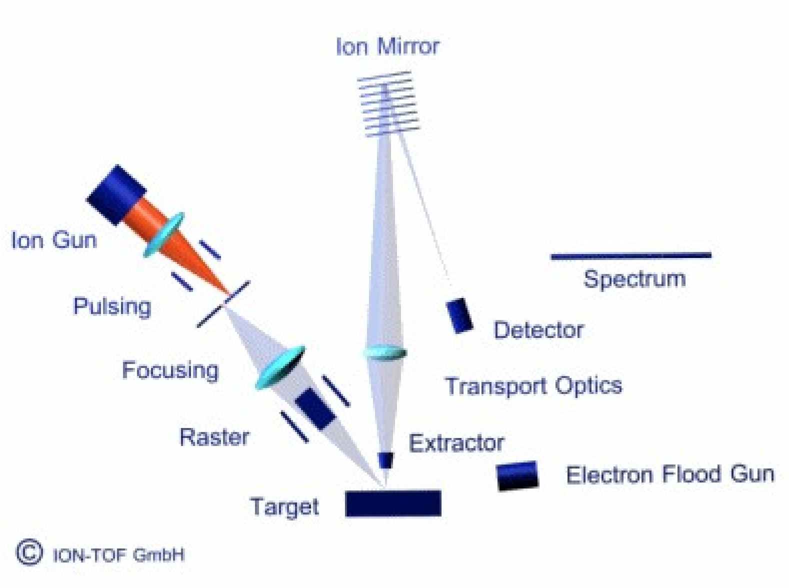
[b] National Physical Laboratory, Hampton Road, TW11 0LW, United Kingdom
[c] University of Nottingham, Nottingham, NG7 2RD, United Kingdom
[d] School of Life Sciences, University of Nottingham, Nottingham, NG7 2RD, United Kingdom

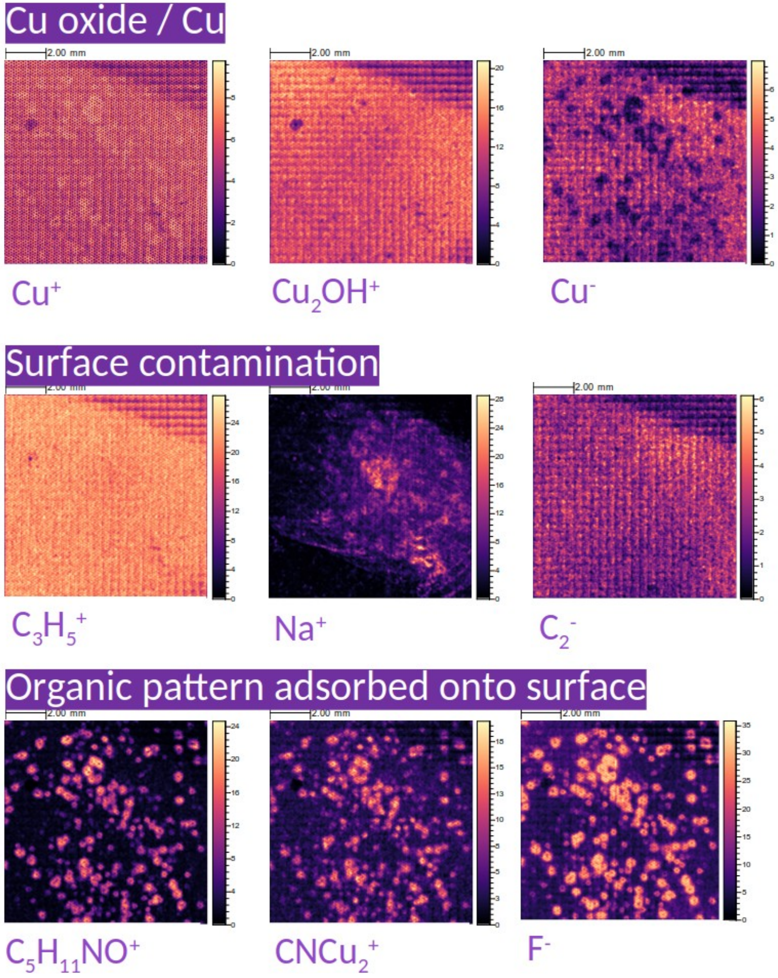
ToF-SIMS is a ultra sensitive surface analysis technique.

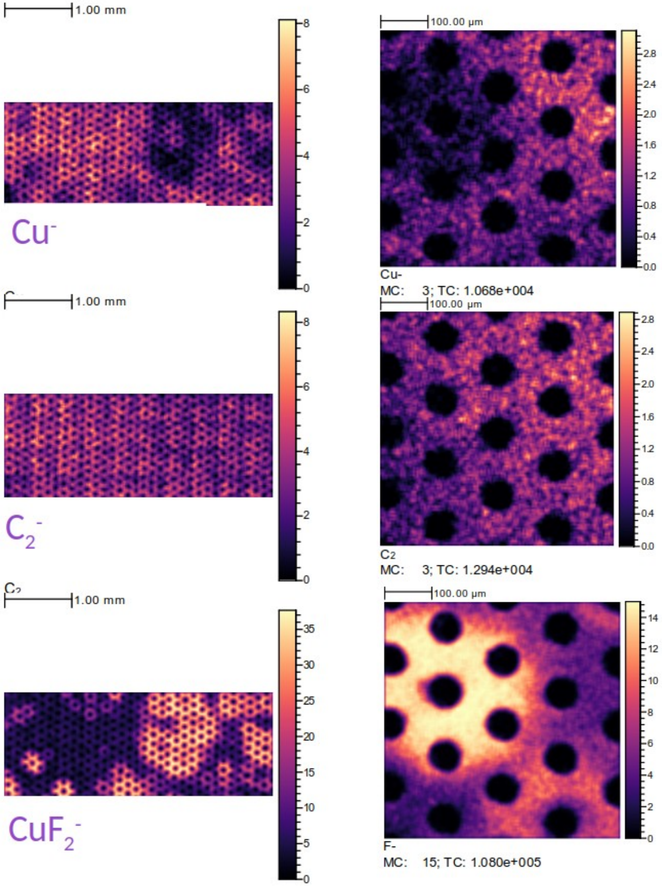
The University of Nottingham equipment

- Iontof TOF.SIMS IV
  - Liquid metal primary ion source (Bi_n^+)
  - Gas Cluster ion Beam source (Ar_n^+)
  - Thermal sputtering ion Source (Cs^+)
  - Single stage reflectron ToF analyser
  - Nominal mass resolving power m/dm @ 29 u: 10,000



ToF-SIMS as a surface analysis technique





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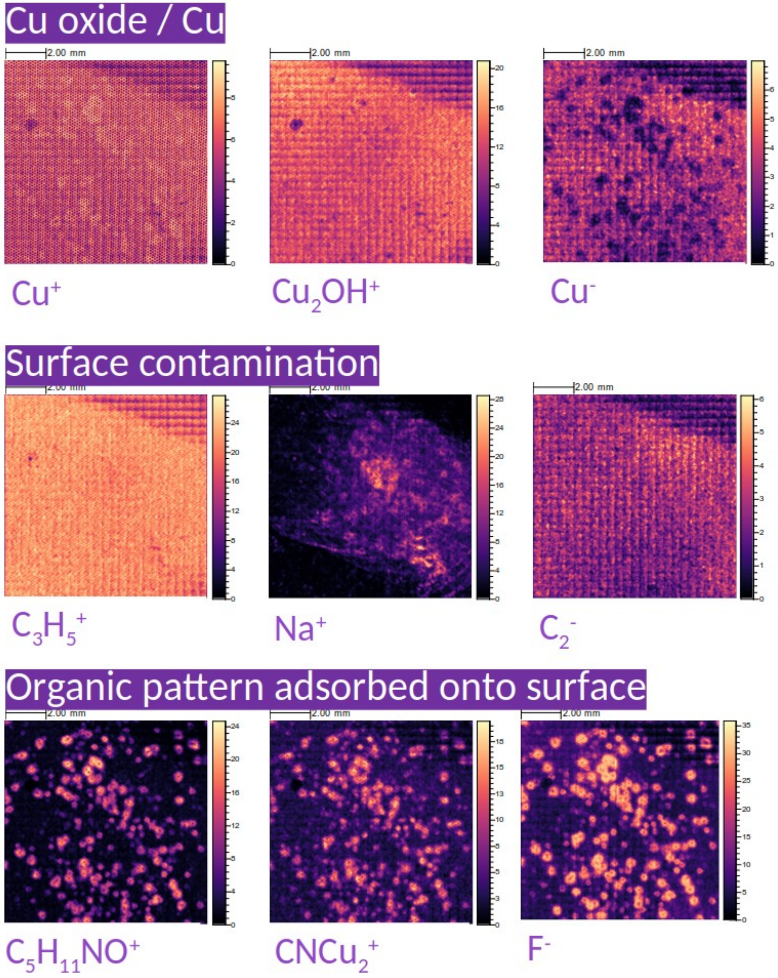
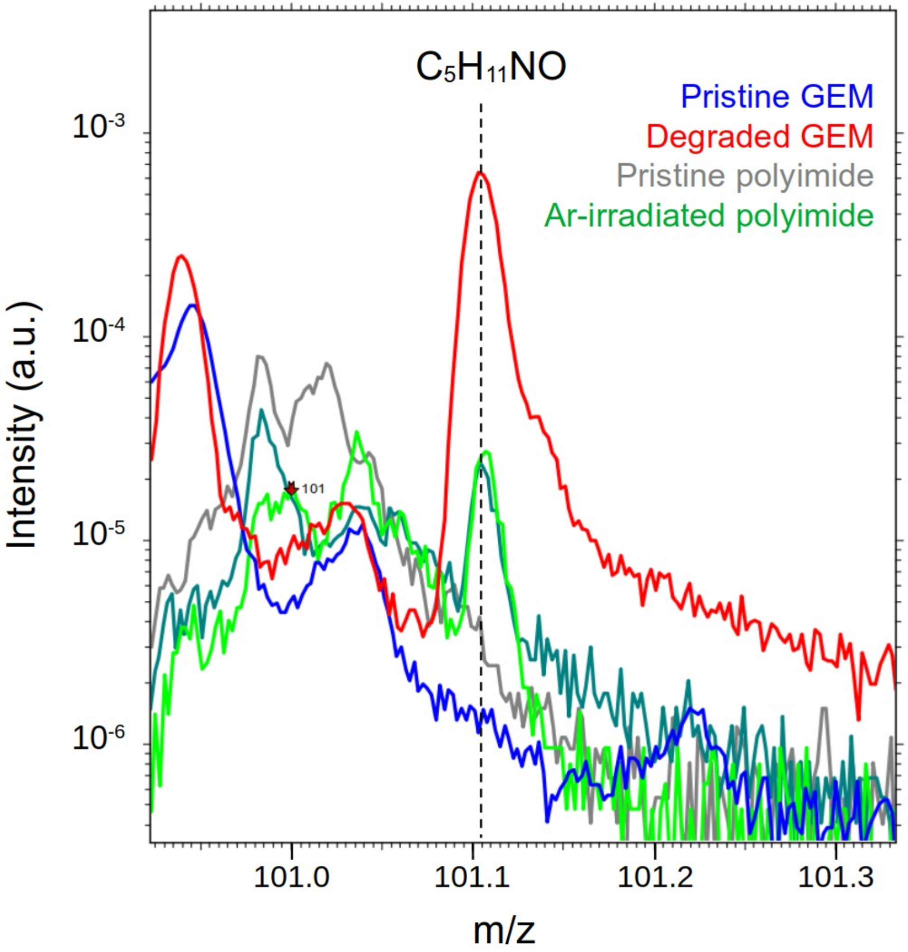
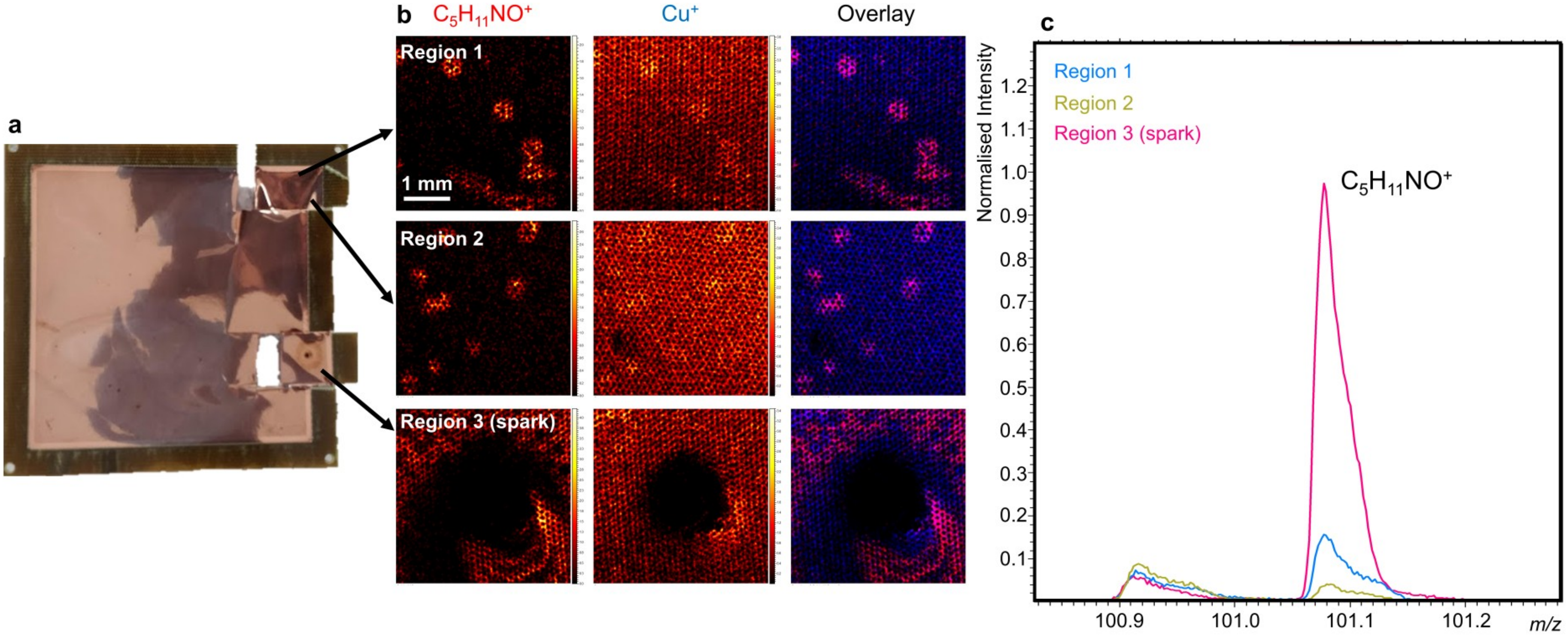




ToF-SIMS as a surface analysis technique

Possible connection with sparks!



XPS and NAP-XPS as surface analysis techniques

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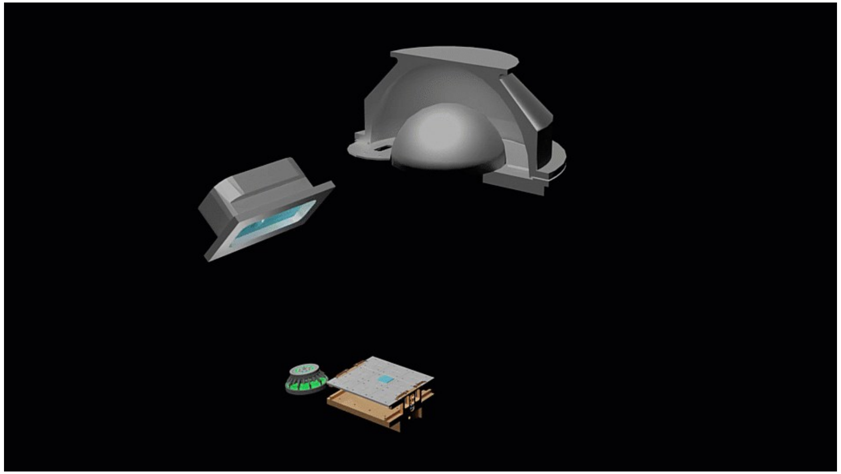
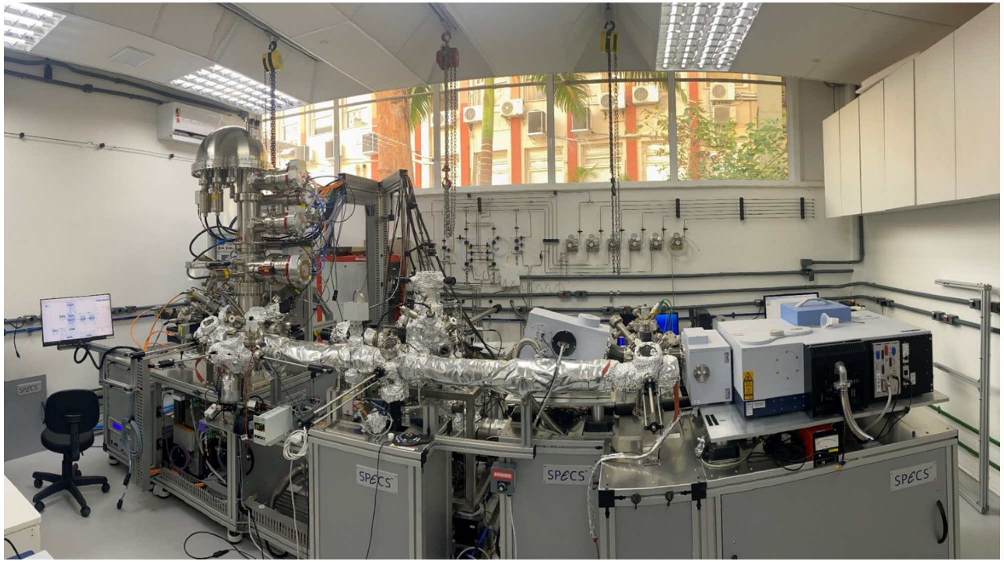
X-ray Photoelectron Spectroscopy (XPS) works by irradiating a material with X-rays and measuring the kinetic energy of emitted electrons to determine the elemental composition and chemical states of the surface.



https://ipgi.co.in/xps-x-ray-photoelectron-spectrometer/

UHV system to NAP-XPS
Lab. de Fenômenos de Interface e Superfície do CBPF



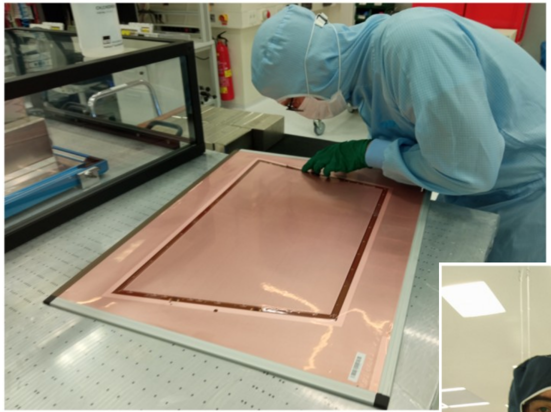
Near-Ambient Pressure X-ray Photoelectron Spectroscopy **(NAP-XPS)** analysis used to monitor the adsorption and surface chemical reactions between copper and CO_2 **(FOR DIFFERENT CO_2 PRESSURES)** in a GEM foil produced at CERN workshop.

Sample preparation: the type of copper surface matters

- **GEM samples produced by the CERN workshop**
  - For the ALICE TPC spare parts
  - Stored in same conditions as the GEMs used in the assembly

- **Why not samples of copper?**
  - Adsorption is highly dependent of the surface conditions
    - Cristalinity, oxidation states, roughness, etc.
  - Using GEM samples as produced in the CERN workshop is meaningful as GEM samples

Sample preparation



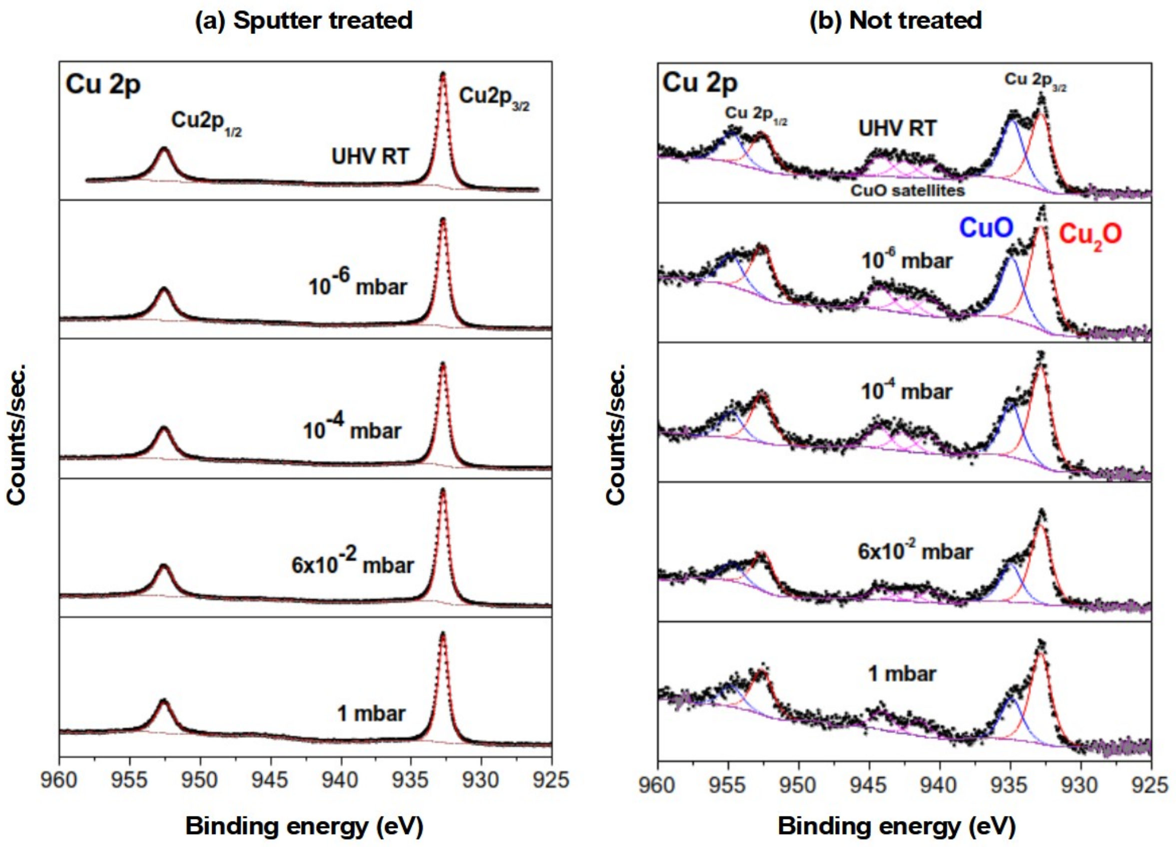
ALICE-TPC samples from spare mounts

T.B. Saramela at the GSI lab

Results: the pristine surface is not metallic copper

- Copper signal from the surface for different CO_2 partial pressures
- **Pristine surface is a mixture of Cu2O (Cu^{+1}) and CuO (Cu^{+2})**

Sputter treated	→	2 keV Ar beam for cleaning by sputtering
Not treated	→	Samples as produced by CERN



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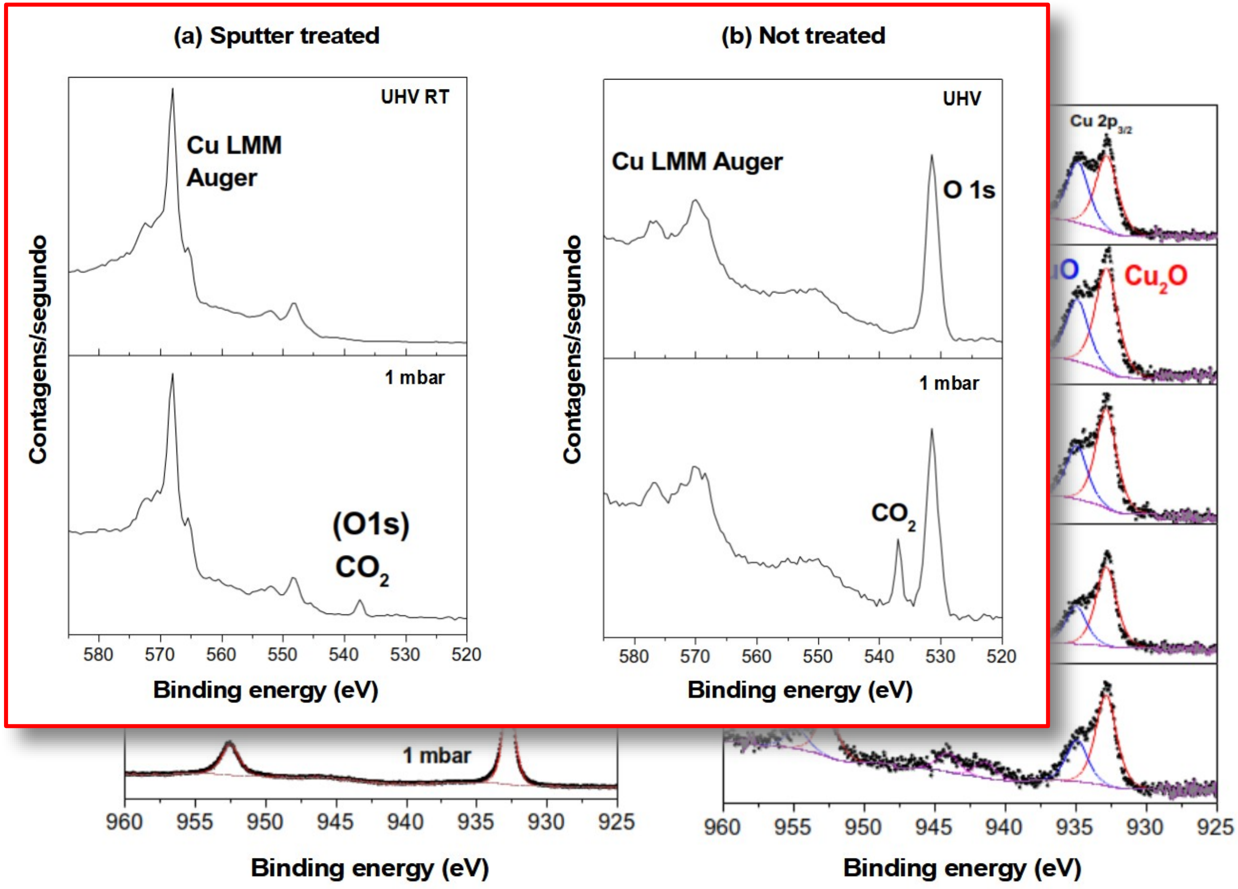

Sputter treated	→	2 keV Ar beam for cleaning by sputtering
Not treated	→	Samples as produced by CERN

Results: Cu_2O signal increases and saturates with pressure

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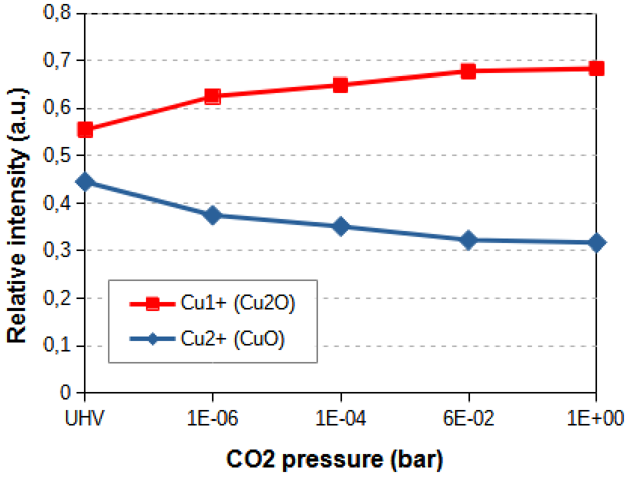
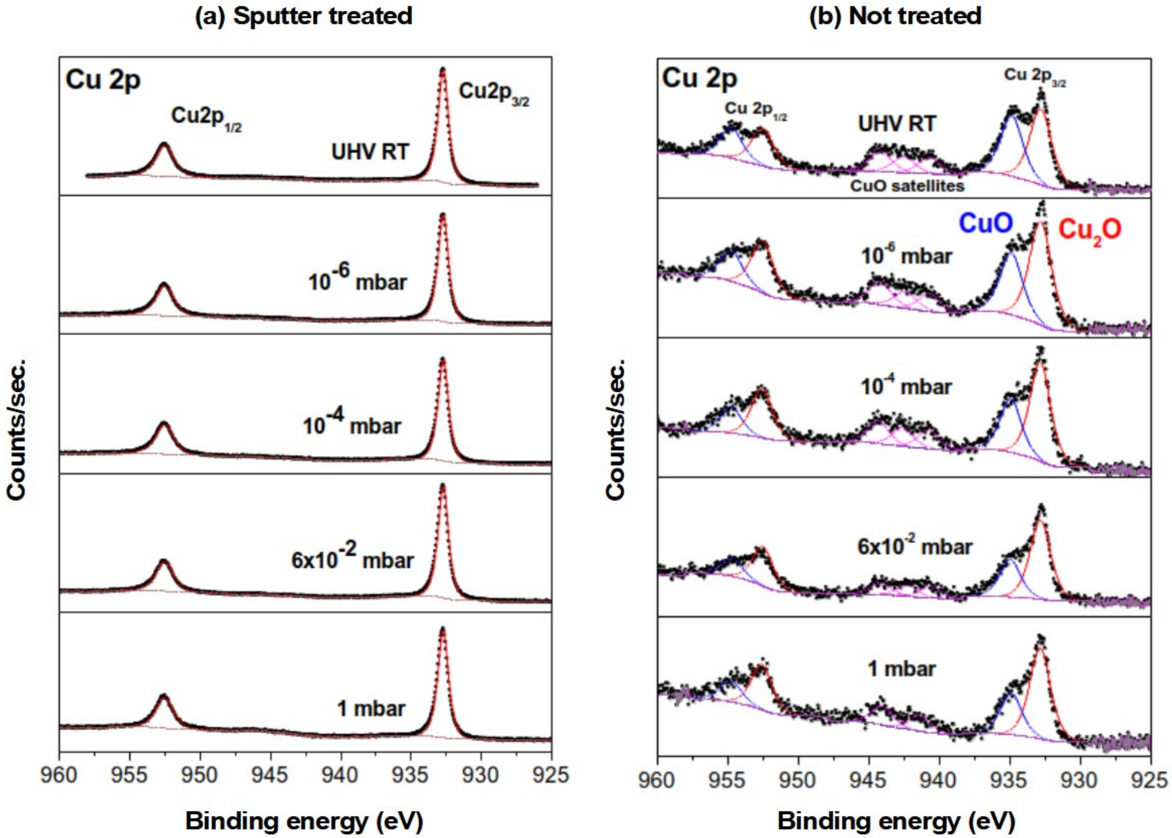
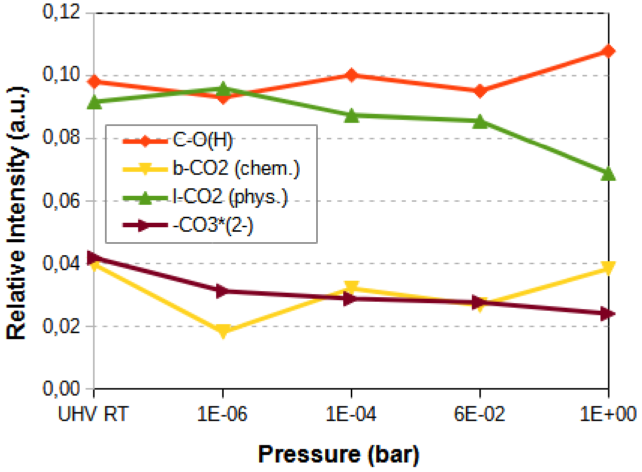
- Copper 2p signal from the surface for different CO_2 partial pressures
- **CuO is converted into Cu_2O for increasing pressure, but saturates**

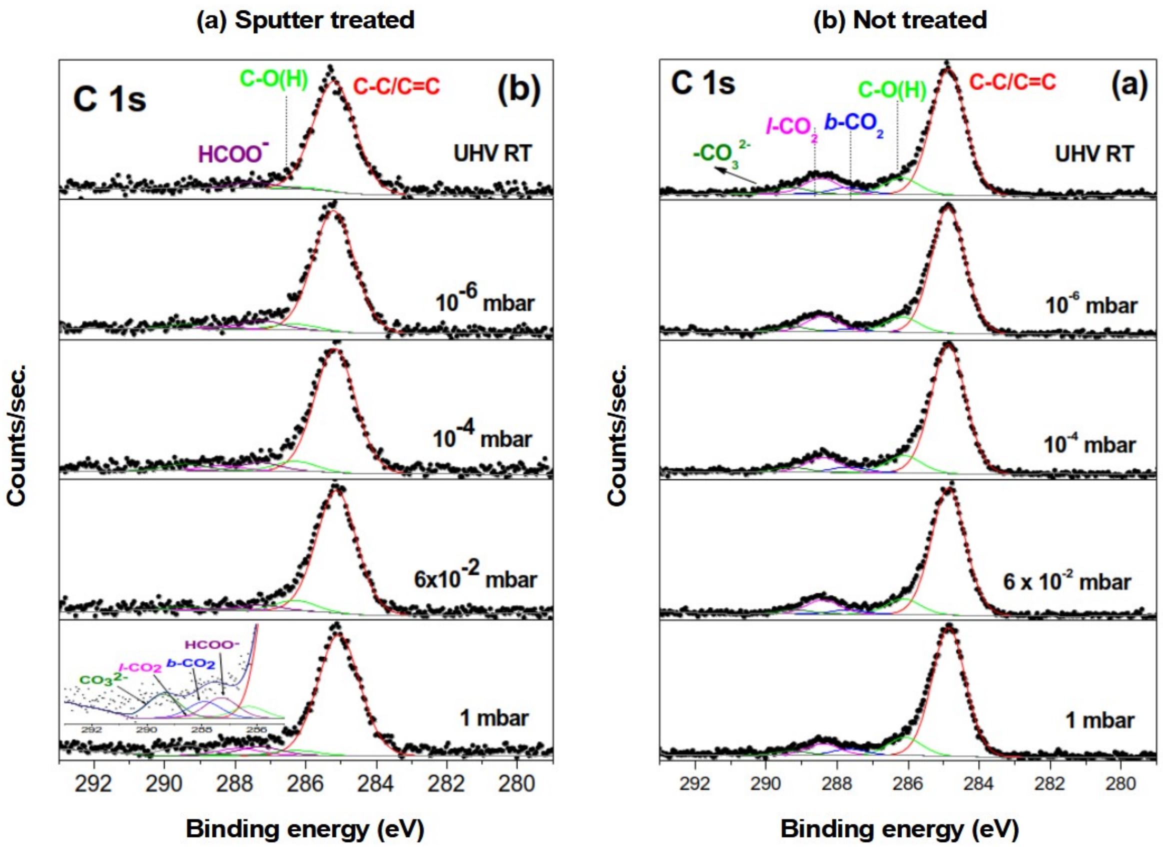




Results: Surface reactions on the pristine surface

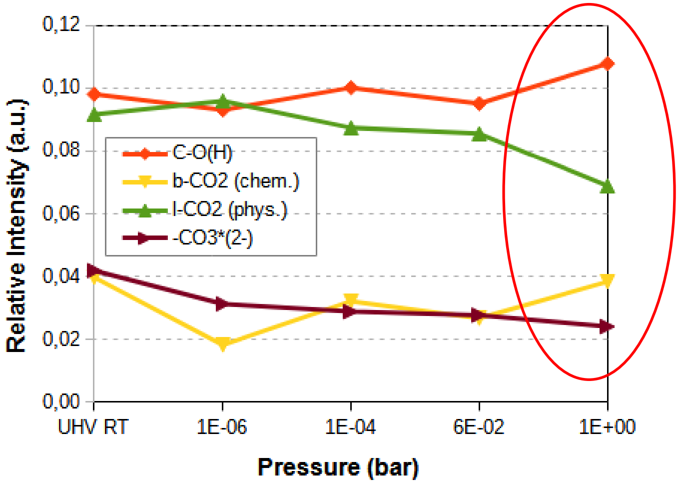
- Carbon 1s signal from the surface for different CO_2 partial pressures
- **Carbonate, hydroxyl, physisorbed, and chemisorbed species form <u>only on pristine samples.</u>**

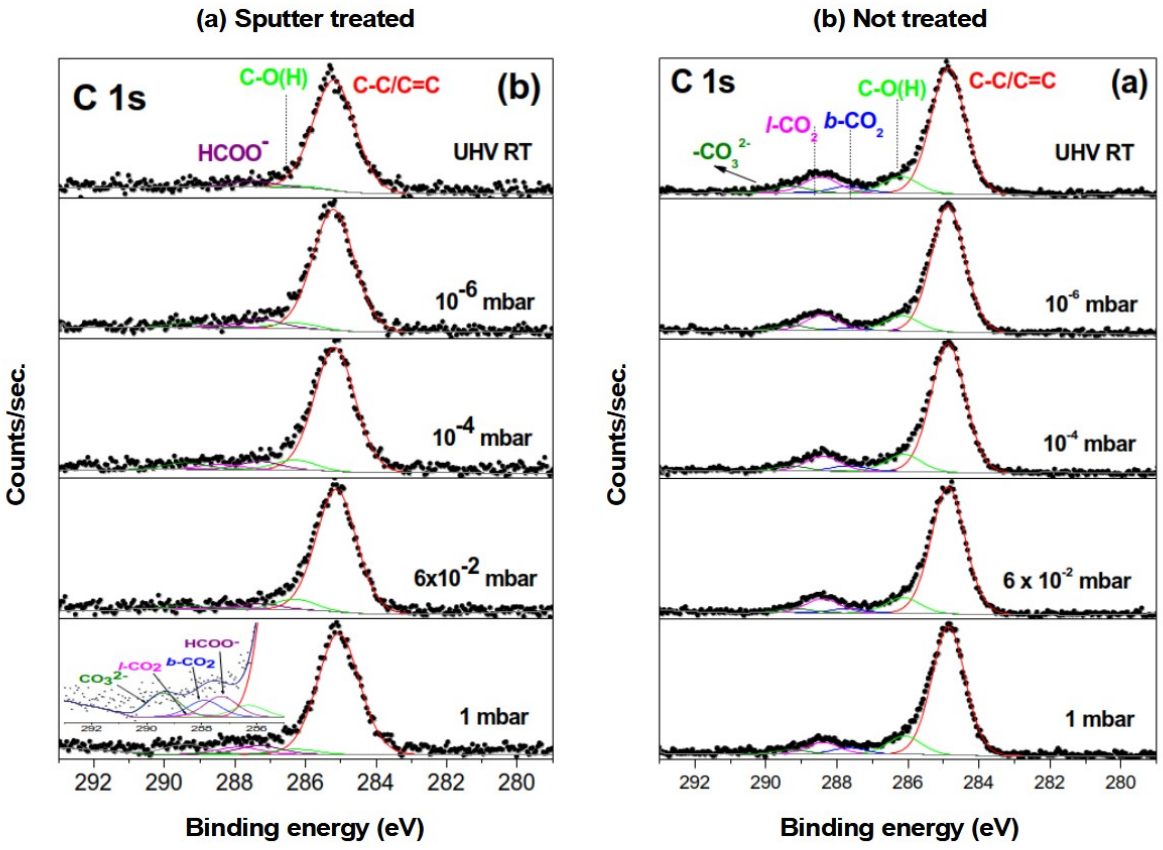




Results: Surface reactions on the pristine surface

- Carbon 1s signal from the surface for different CO_2 partial pressures
- **After Cu_2O saturation, I-CO_2 converts to b-CO_2 and the hydroxyl increses**





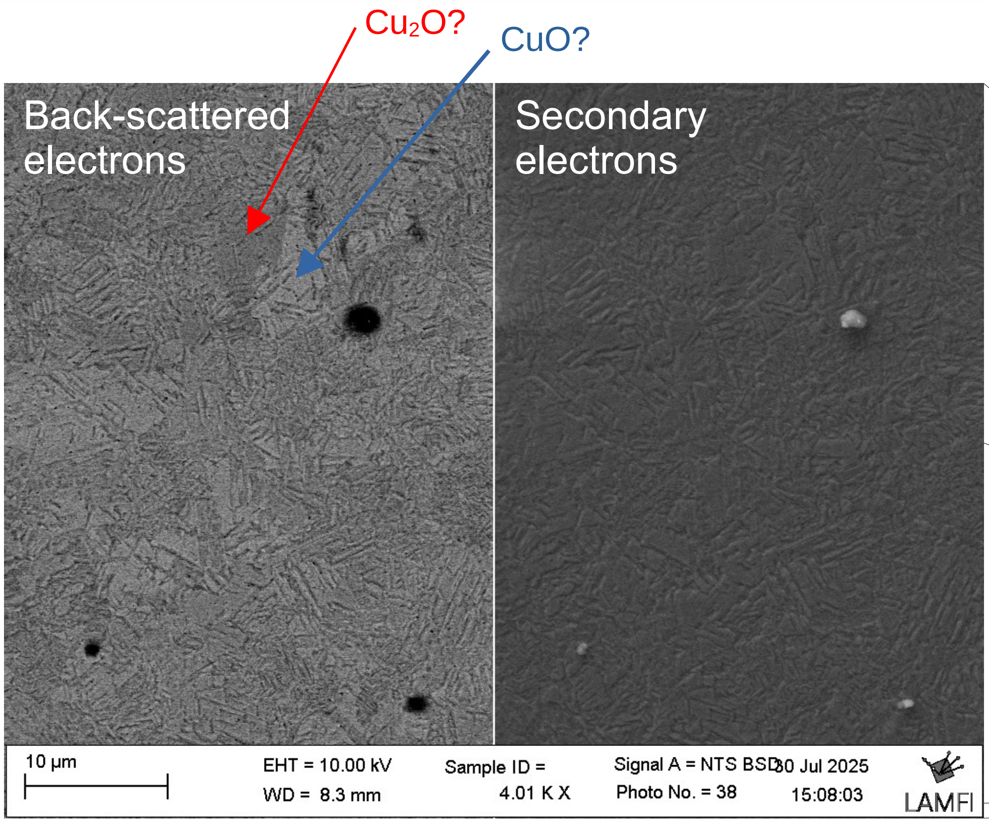
Conclusions

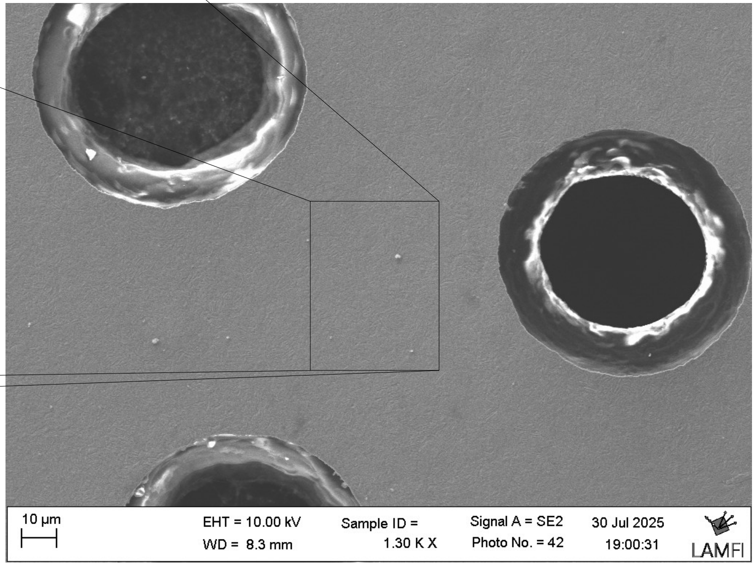
- **No metallic copper at pristine surface**
  - Metallic copper did not react with CO_2
- CuO converts into Cu_2O
  - CuO is not formed naturally (requires external energy)
  - May be **formed in chemical reactions** during production
- Both, CuO and Cu_2O are p-type semiconductors
  - 1.2 and 2.0 eV, respectively
  - **Not good insulators**, mainly in higher temperatures
  - Behave like conductors at 100 and 150 ^{o}C respectively
- Cu_2O presents **low interaction** with CO_2
  - Weak tendency to be an aging agent

Conclusions

- Both pristine and sputter treated surfaces present carbon signals
  - No carbon reaction observed in sputter treated samples (graphite trace contamination?)
- Carbonate, hydroxyl, physisorbed, and chemisorbed species observed only on pristine samples
  - Carbonate signal reduces systematically in pristine sample
  - Hydroxyl presented increment after Cu_2O saturation
    - Dependent on adsorbed water (which is present in pristine samples)
  - l-CO2 converts to b-CO2 after Cu2O saturation
    - Physisorbed CO_2 (Van-der-Walls bonding) become chemisorbed (covalent bonding)
    - Probably in the CuO residual region

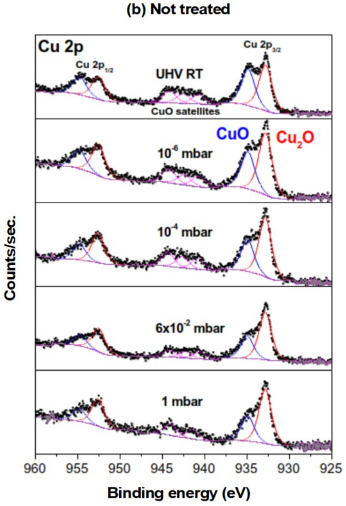
Next steps: determine Cu oxidation states distribution

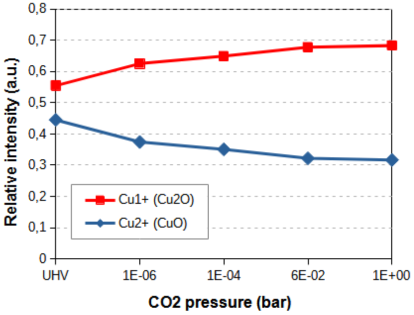


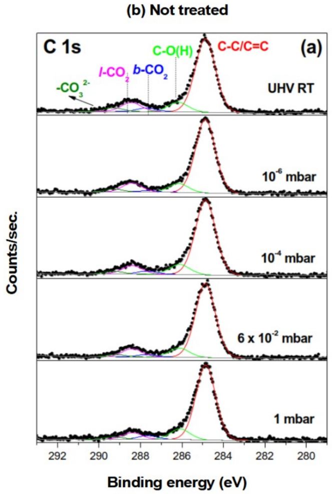


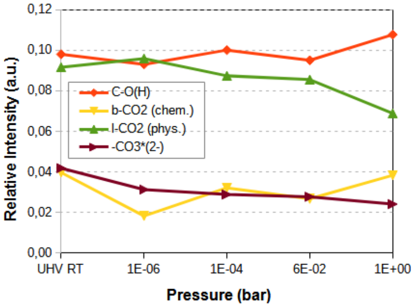
Unveiling Surface Chemistry and Ageing Pathways of GEMs through In-Situ Surface Spectroscopy

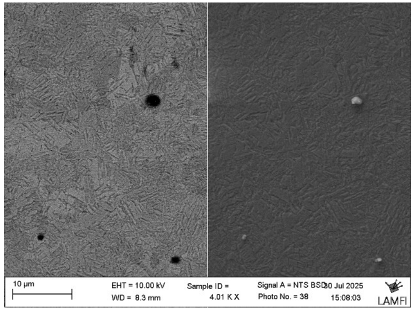
tfsilva@usp.br











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