



XVIII International Conference on Resistive Plate Chambers and Related Detectors

An integrated platform for fabrication, characterization and aging studies of micropattern gaseous detectors

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Marco Bregant, Alexandre A. P. Suaide, Marcelo G. Munhoz

Universidade de São Paulo, Brazil



High Energy Physics and Instrumentation Center at USP

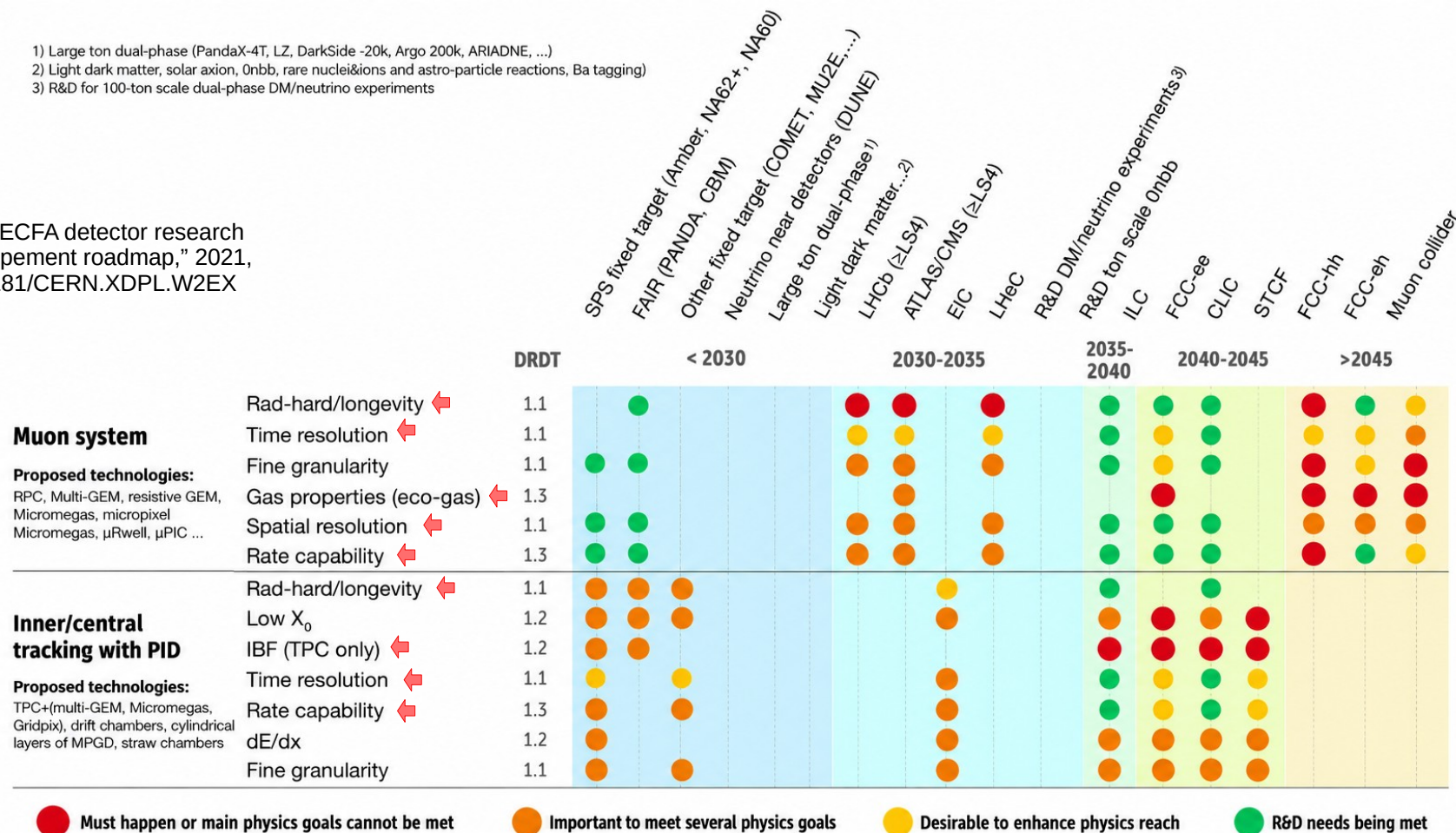
How the Gas Electron Multiplier works?

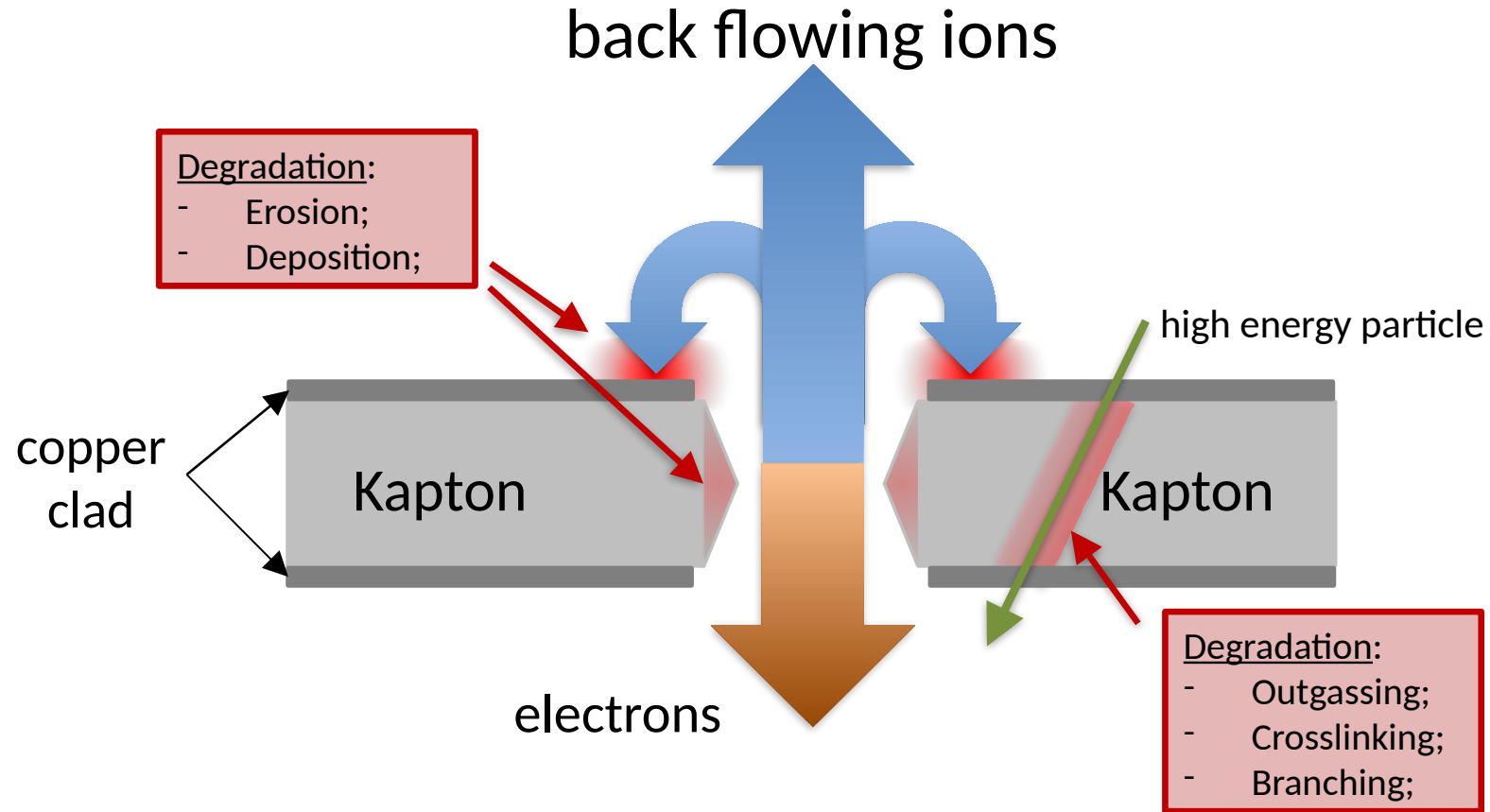


Aging and degradation models: why studying it?

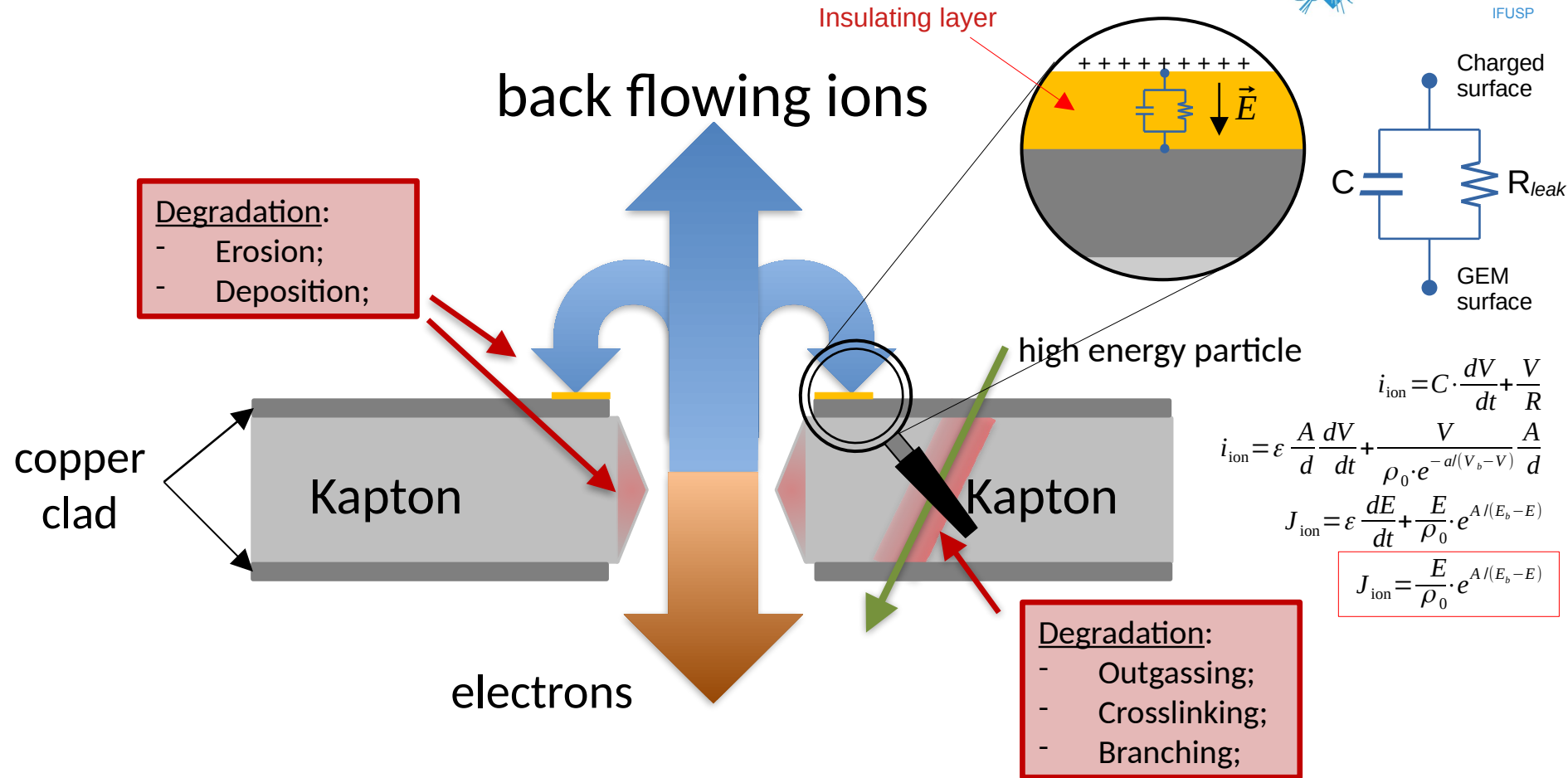
- 1) Large ton dual-phase (PandaX-4T, LZ, DarkSide -20k, Argo 200k, ARIADNE, ...)
- 2) Light dark matter, solar axion, Onbb, rare nuclei&ions and astro-particle reactions, Ba tagging)
- 3) R&D for 100-ton scale dual-phase DM/neutrino experiments

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



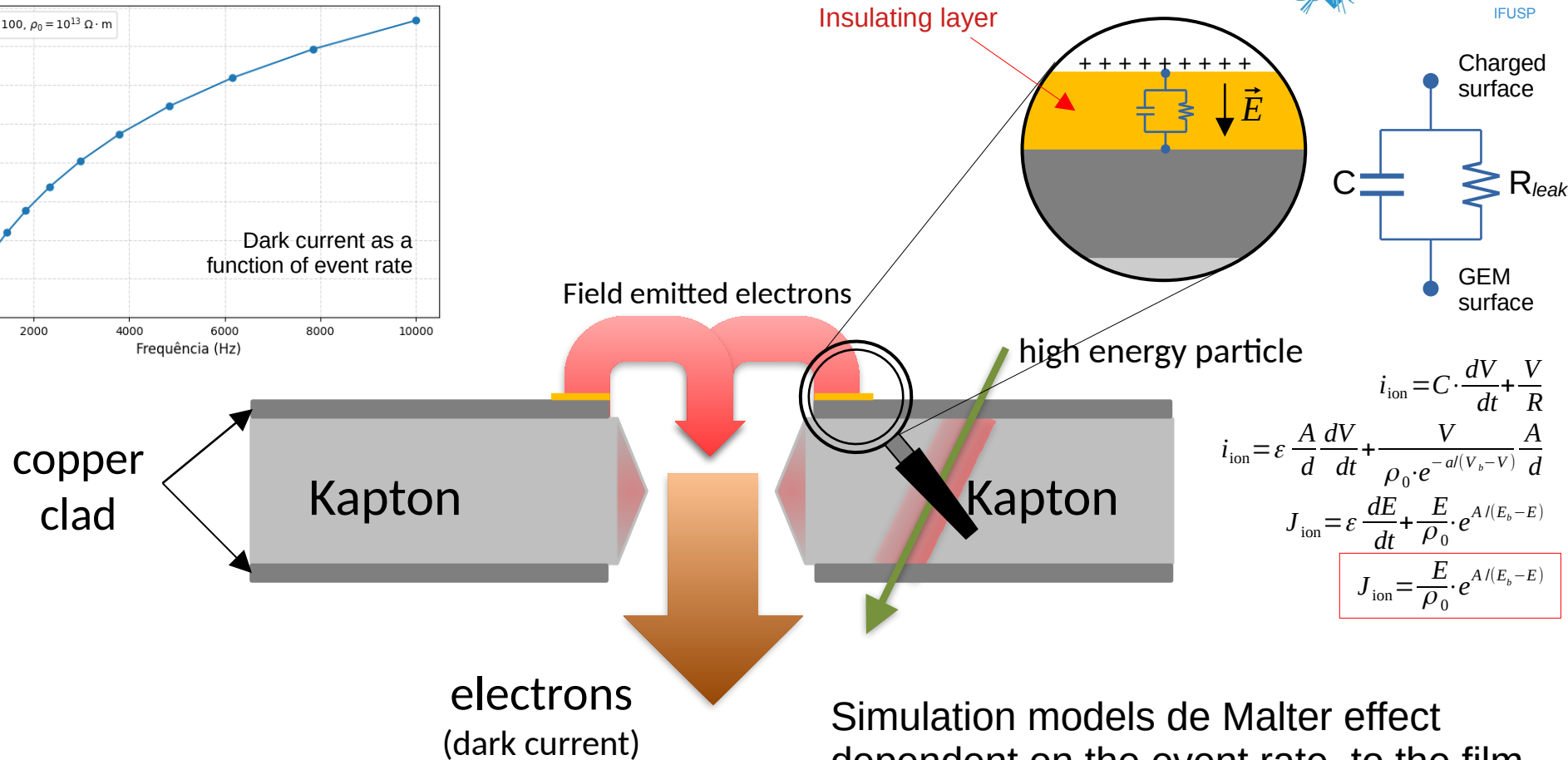
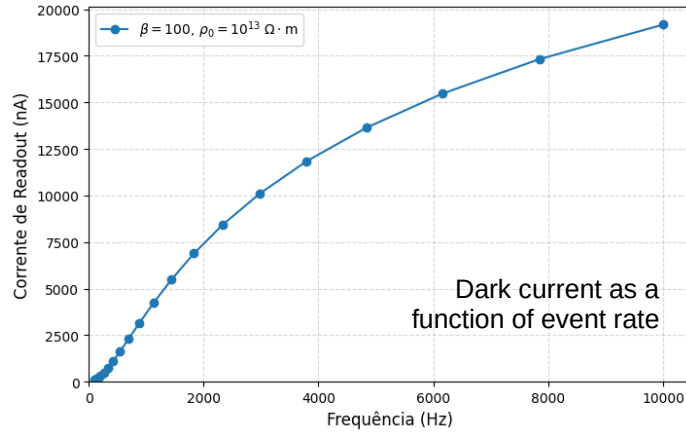


Aging and degradation models: the Malter effect



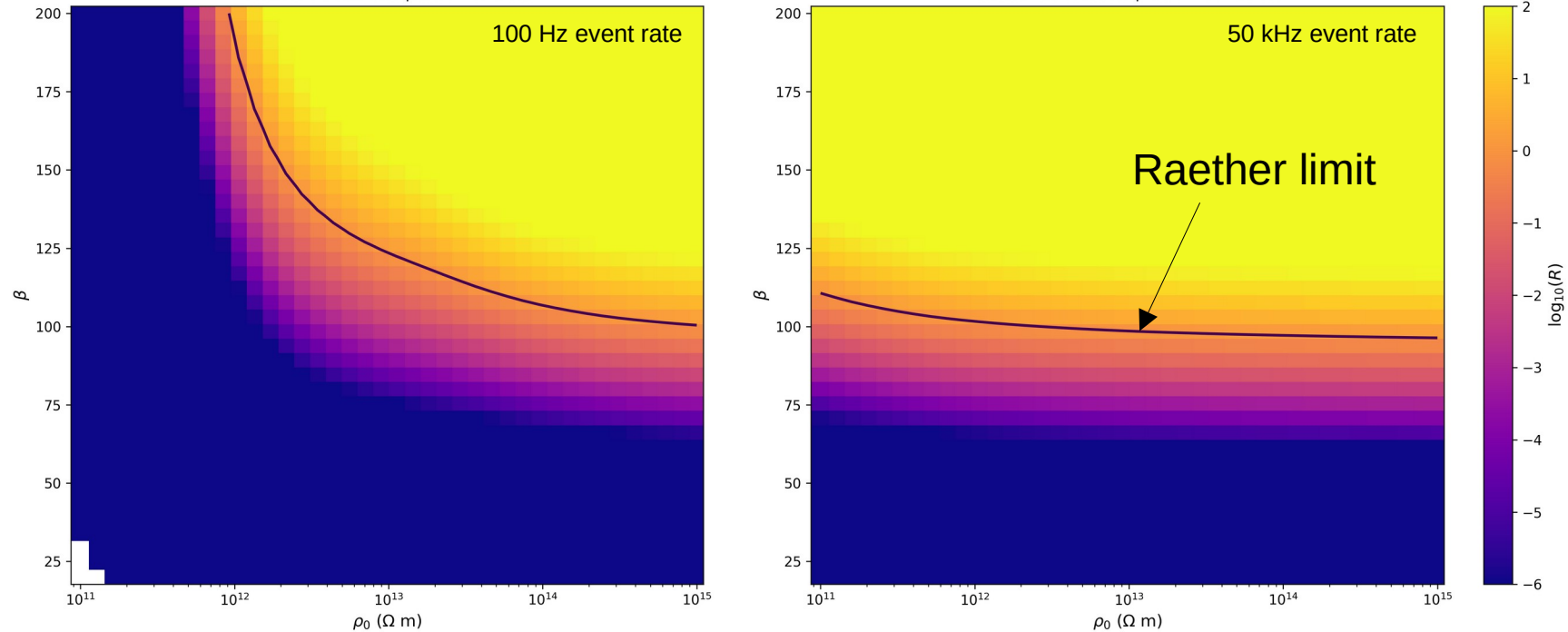
Work by:
Bruna B.T. Francisco (FAPESP)

Aging and degradation models: the Malter effect

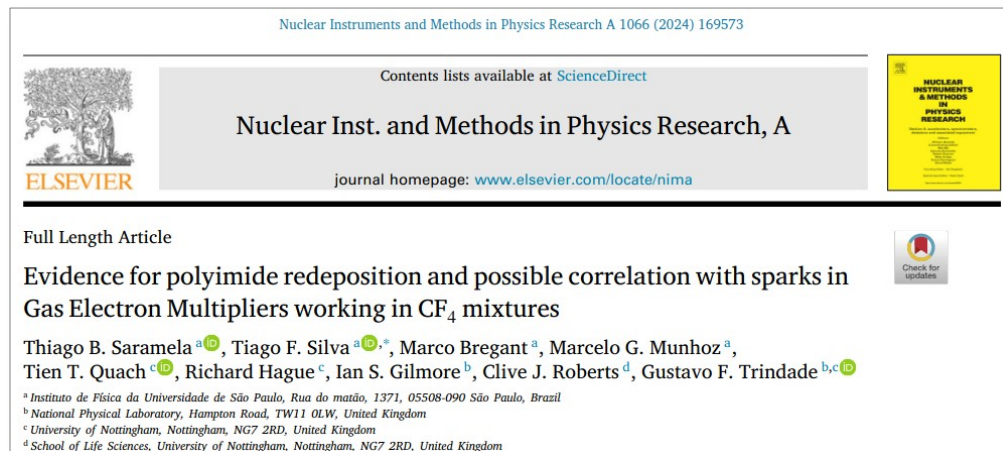


Work by:
Bruna B.T. Francisco (FAPESP)

The model shows that controlling micro-metric surface roughness is the most effective strategy for suppressing Malter discharges.



Work by:
Bruna B.T. Francisco (FAPESP)

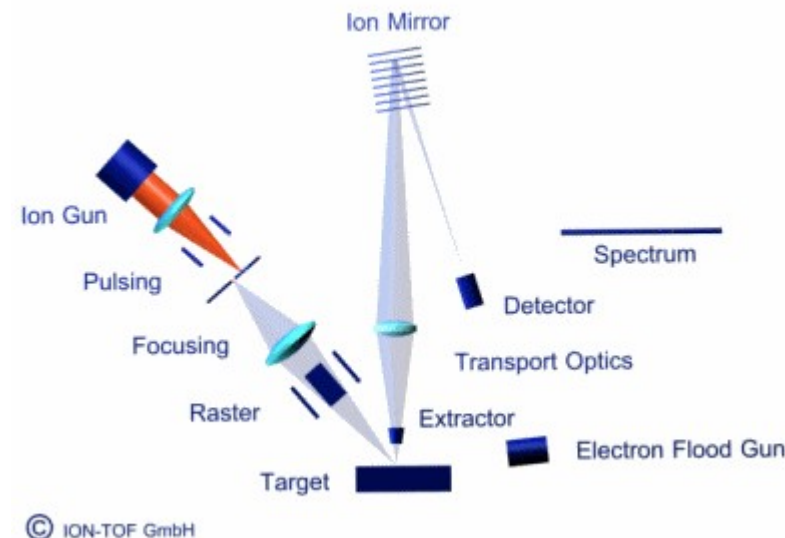


Collaboration with
National Physical
Laboratory (NPL)

ToF-SIMS is a ultra sensitive
surface analysis technique.

IonToF TOF.SIMS IV

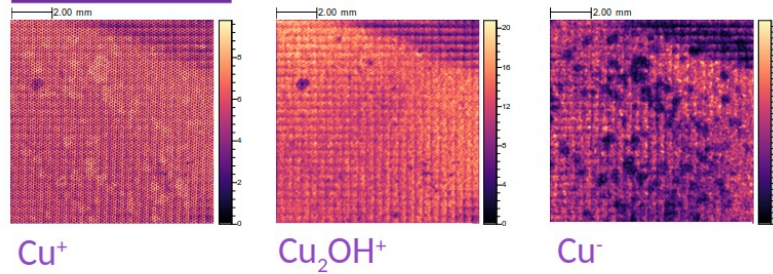
- Liquid metal primary ion source (Bi_n^+)
- Gas Cluster ion Beam source (Ar_n^+)
- Thermal sputtering ion Source (Cs^+)
- Single stage reflectron ToF analyser
- Nominal mass resolving power m/dm @ 29 u: 10,000



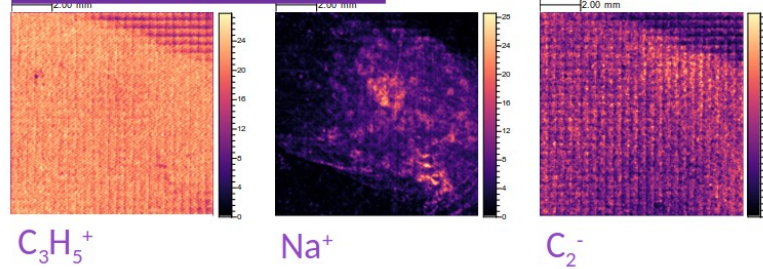
Work by:
Thiago B. Saramela (CAPES)

Studying the insulating film: surface analysis

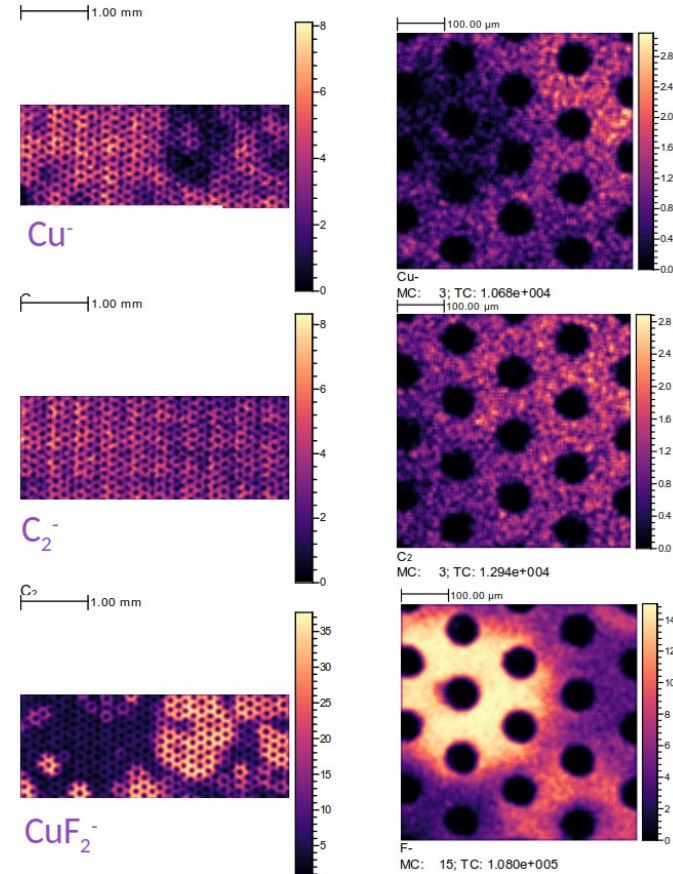
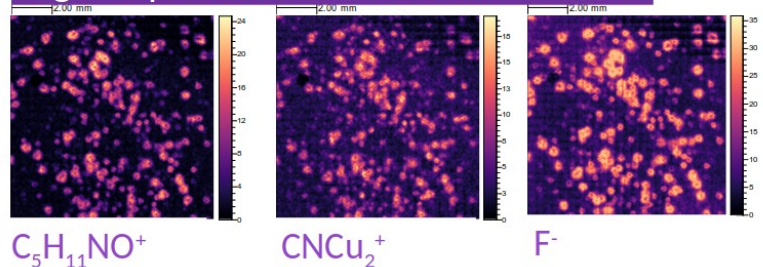
Cu oxide / Cu



Surface contamination

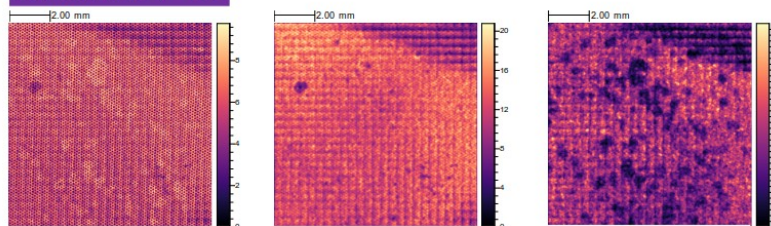


Organic pattern adsorbed onto surface



Studying the insulating film: surface analysis

Cu oxide / Cu

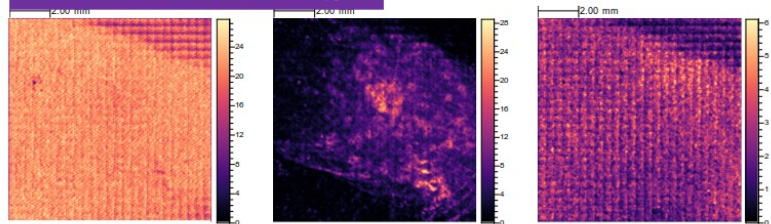


Cu^+

Cu_2OH^+

Cu^-

Surface contamination

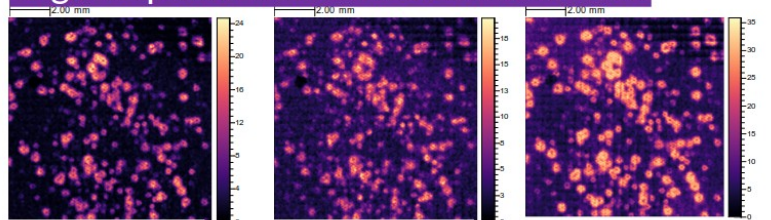


C_3H_5^+

Na^+

C_2^-

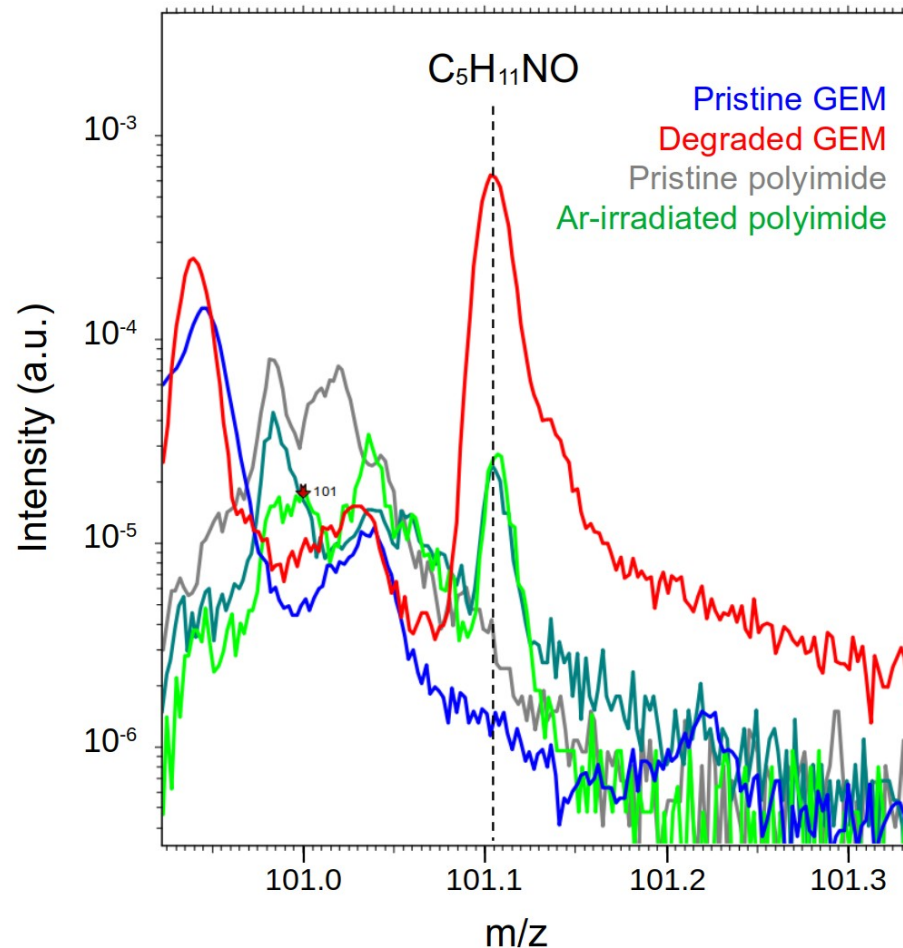
Organic pattern adsorbed onto surface



$\text{C}_5\text{H}_{11}\text{NO}^+$

CNCu_2^+

F^-



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 **Nuclear Inst. and Methods in Physics Research, A**

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

Full Length Article

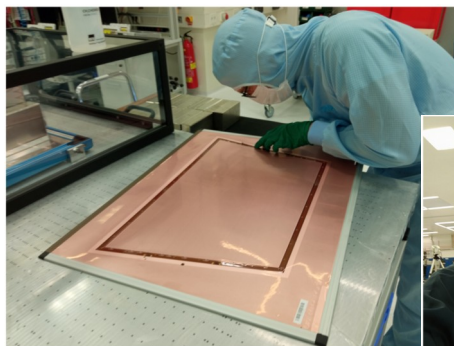
Surface mechanisms governing long-term stability of GEM detectors in CO₂-based gaseous mixtures

Tiago F. Silva^a, Thiago B. Saramela^a, Willian W.R.A. da Silva^a, Camilla de S. Codeço^b, Maria do C.M. Alves^c, Jonder Moraes^d, Niklaus U. Wetter^e, Anderson Z. de Freitas^e

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^d Instituto de Física da Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves, 9500, 91501-970, Rio Grande do Sul, Brazil
^e Instituto de Pesquisas Energéticas e Nucleares, Av. Prof. Lineu Prestes 2242, 05508-000 São Paulo, Brazil

Collaboration
with Brazilian
Center of
Physical
Research

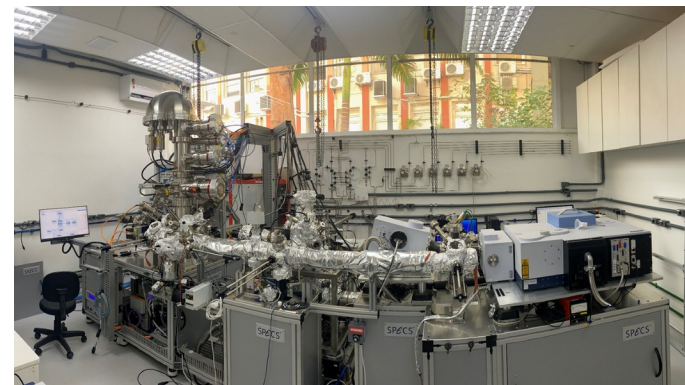
Sample preparation



ALICE-TPC
samples from
spare mounts



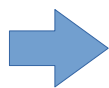
UHV system to NAP-XPS
Lab. de Fenômenos de Interface e Superfície do CBPF



Near-Ambient Pressure X-ray Photoelectron Spectroscopy (NAP-XPS) analysis used to monitor the adsorption and surface chemical reactions between copper and CO₂ (**FOR DIFFERENT CO₂ PRESSURES**) in a GEM foil produced at CERN workshop.

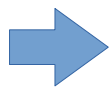
- Copper signal from the surface for different CO_2 partial pressures
- **Pristine surface is a mixture of Cu_2O (Cu^{+1}) and CuO (Cu^{+2})**

Sputter treated

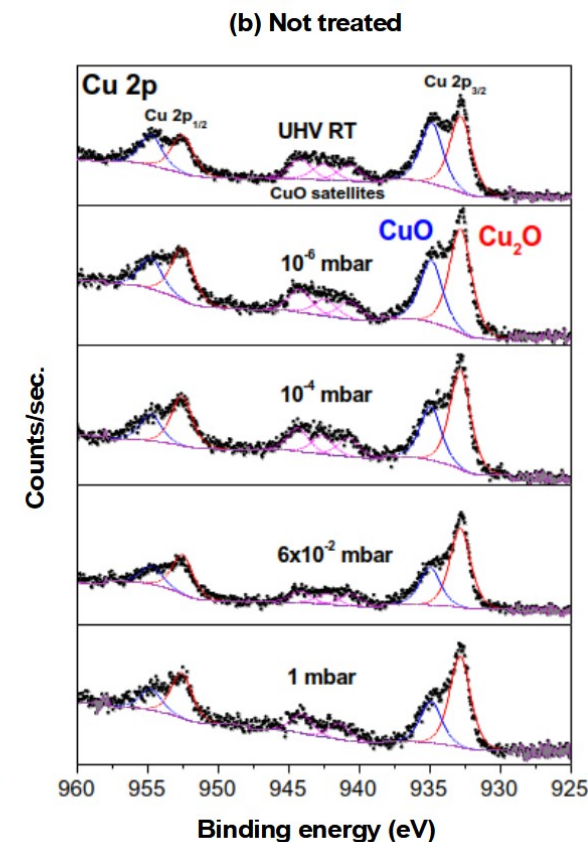
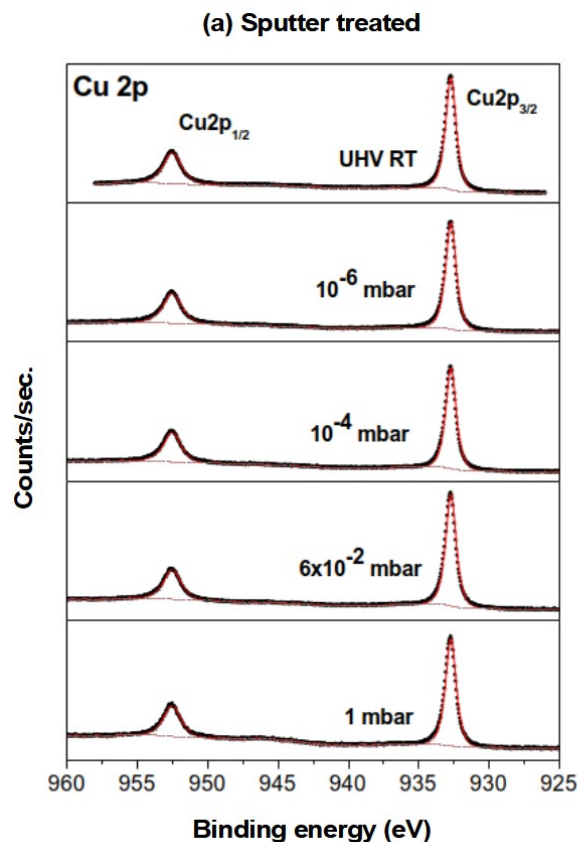


2 keV Ar beam
for cleaning by
sputtering

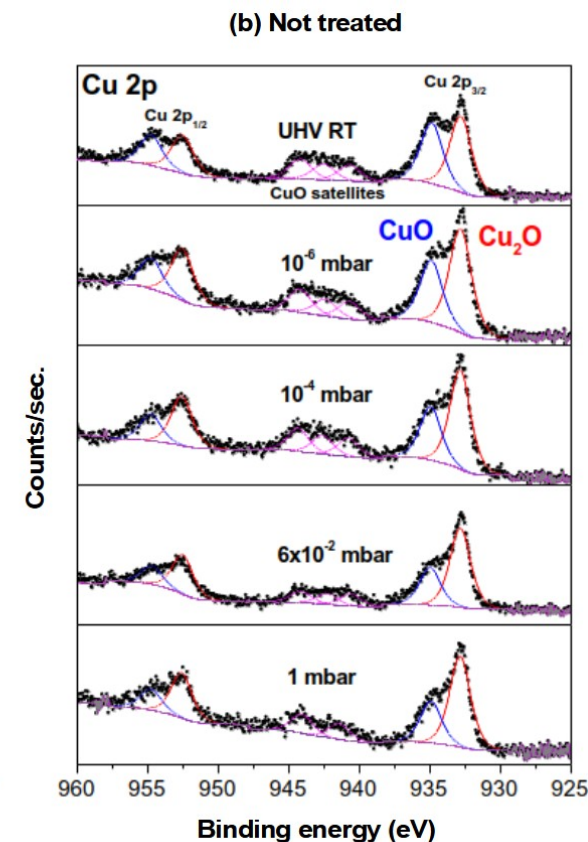
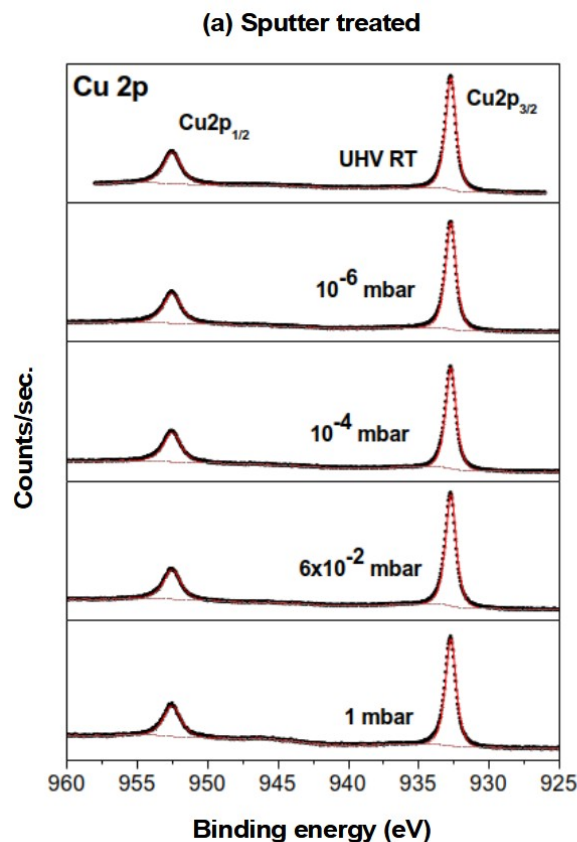
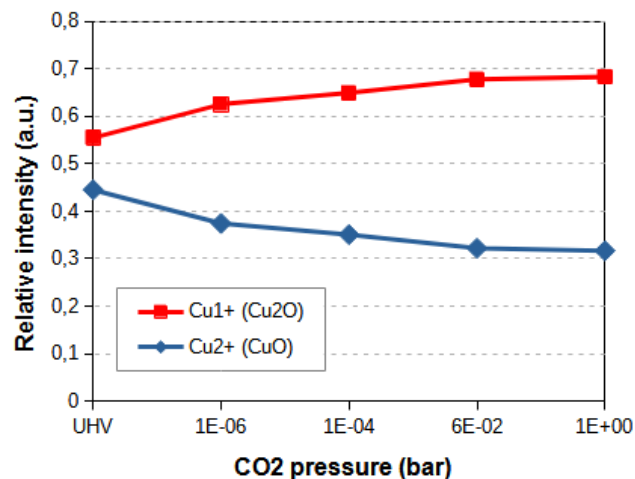
Not treated



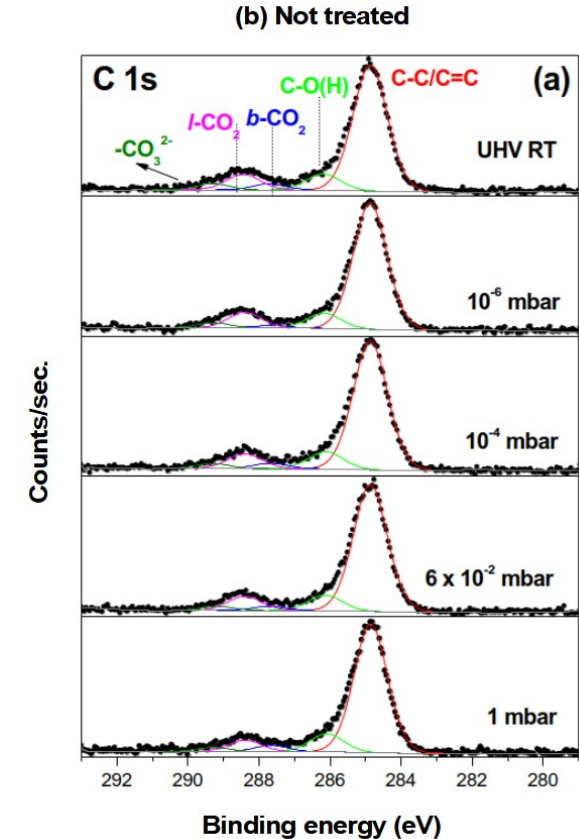
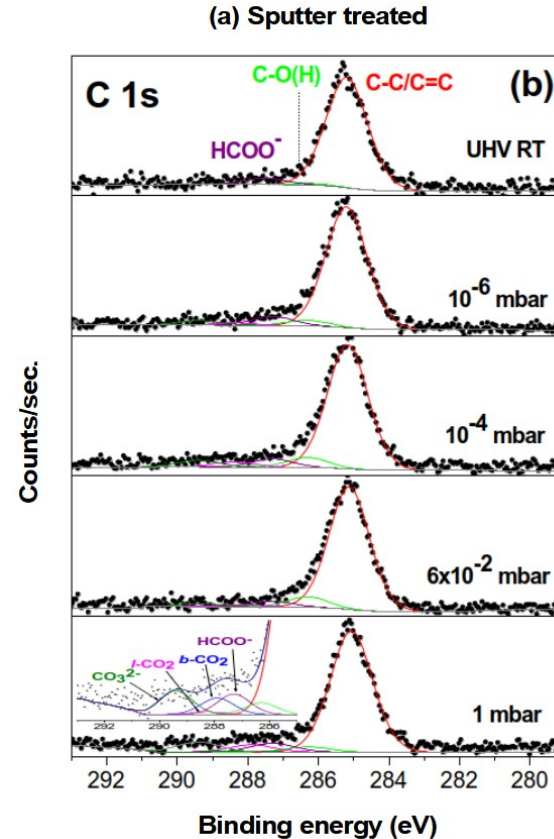
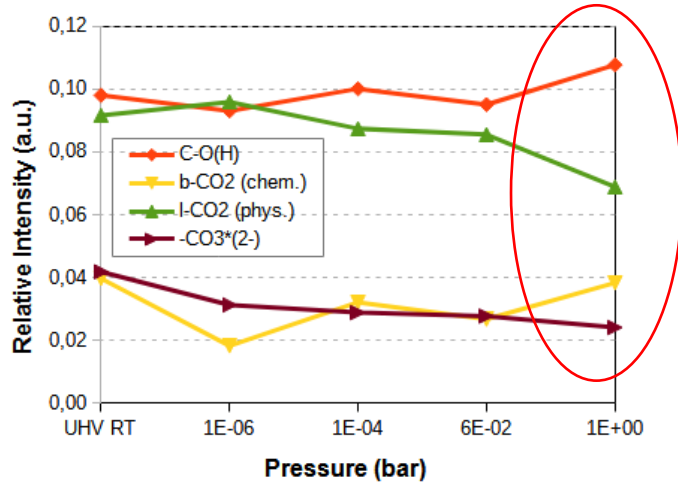
Samples as
produced by
CERN



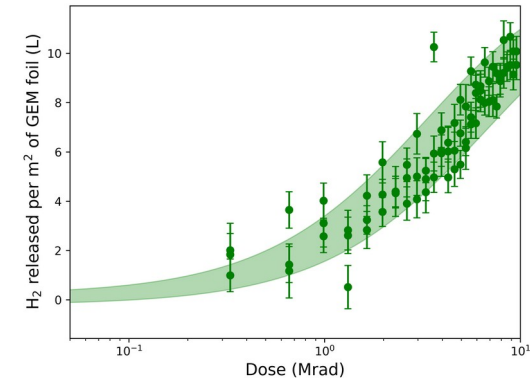
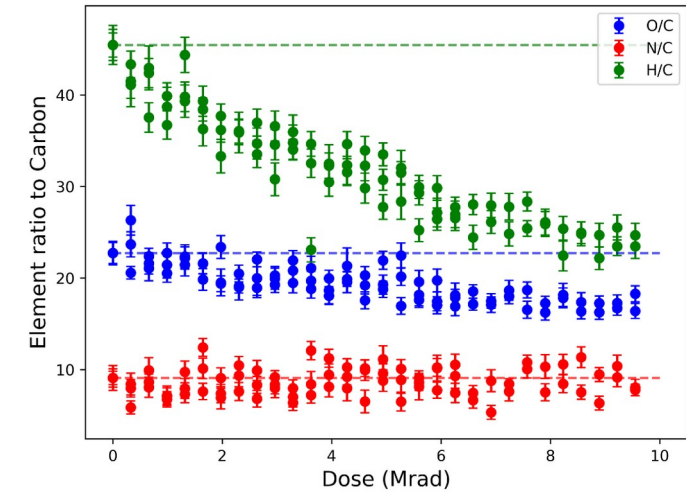
- Copper 2p signal from the surface for different CO_2 partial pressures
- **CuO is converted into Cu_2O for increasing pressure, but saturates**



- Carbon 1s signal from the surface for different CO₂ partial pressures
- After Cu₂O saturation, I-CO₂ converts to b-CO₂ and the hydroxyl increases**

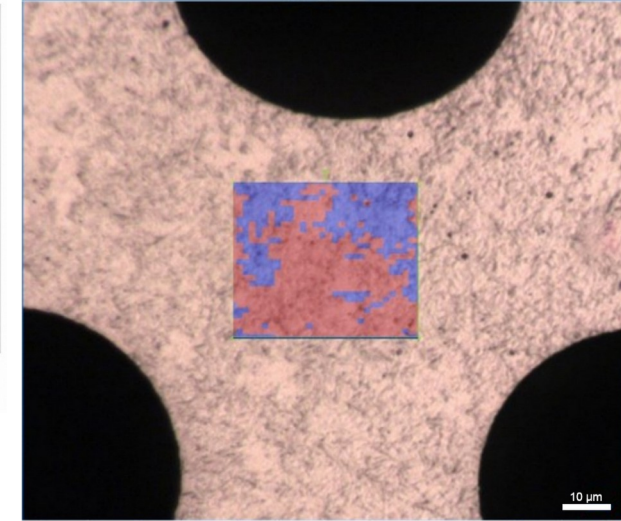
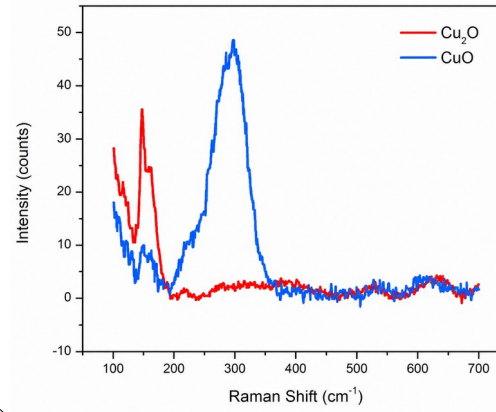
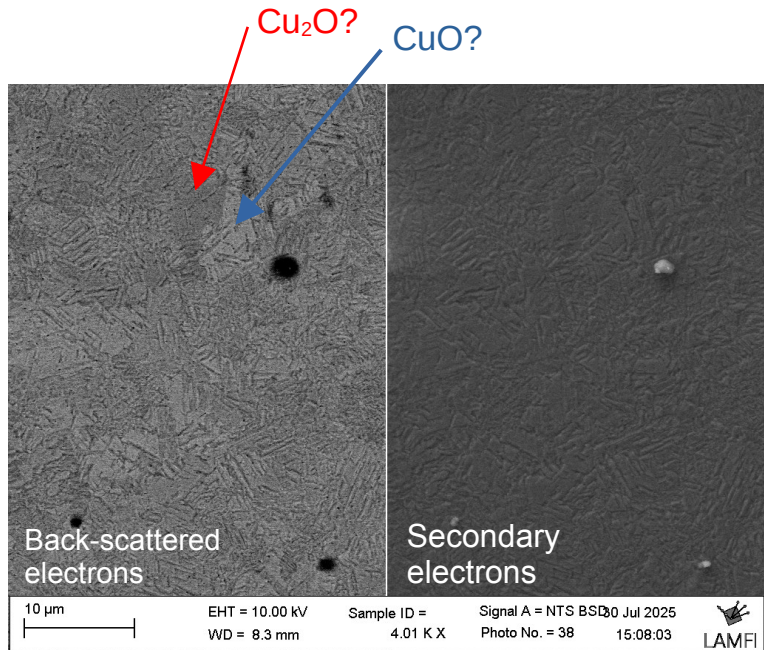


- Hydroxyl seeds the formation of complex polymers, and forms when H_2 is present
- H_2 become available when polyimide degrades
- Development of new material analysis techniques for polymer degradation studies
 - Time-resolved nuclear scattering combined with desorption mass spectroscopy
 - FAPESP funding for new equipments

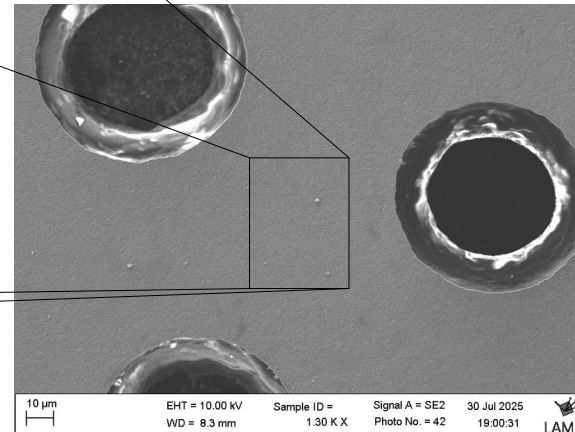


Work by:
Gabriela D. Santos (FAPESP)

Connections with production process:

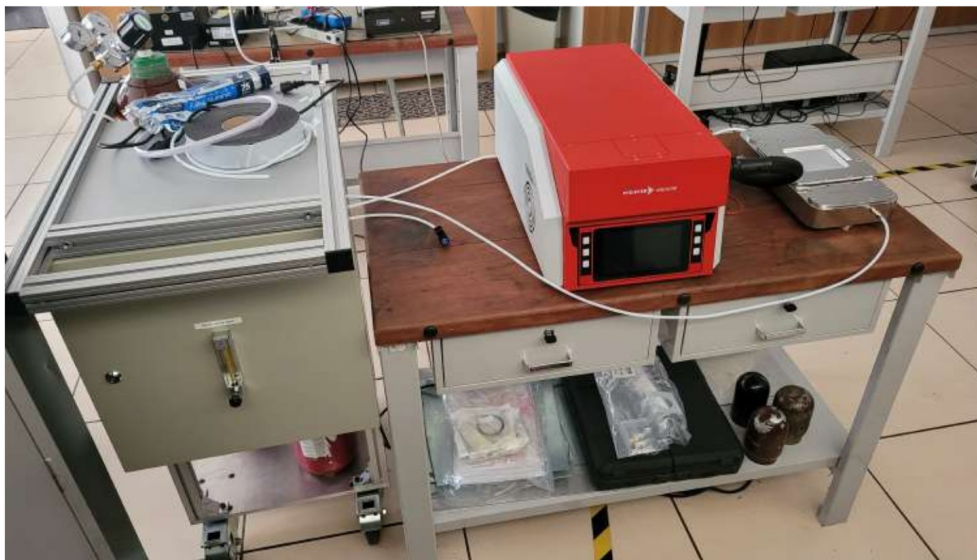


Raman microscopy results



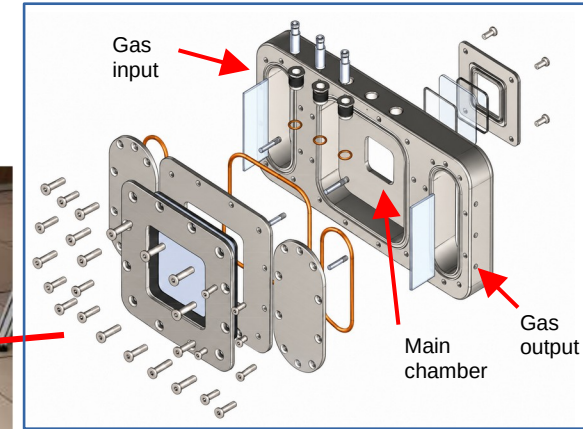
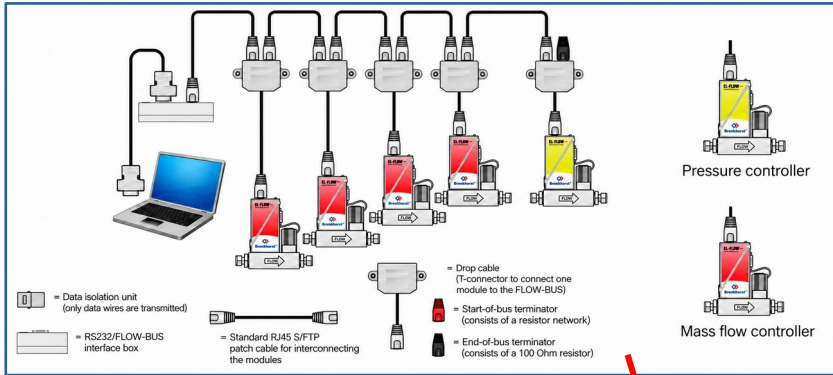
Electron microscopy results

Experiments for
controlled
degradation of
GEMs

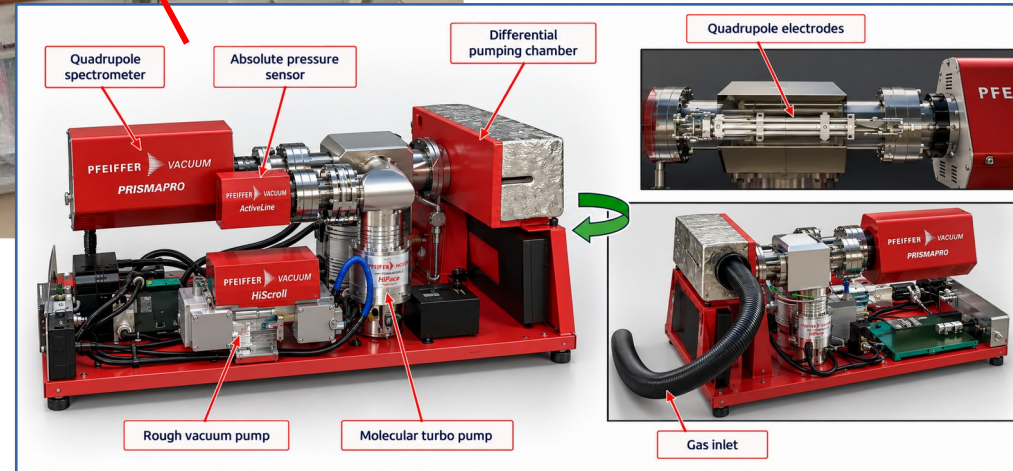
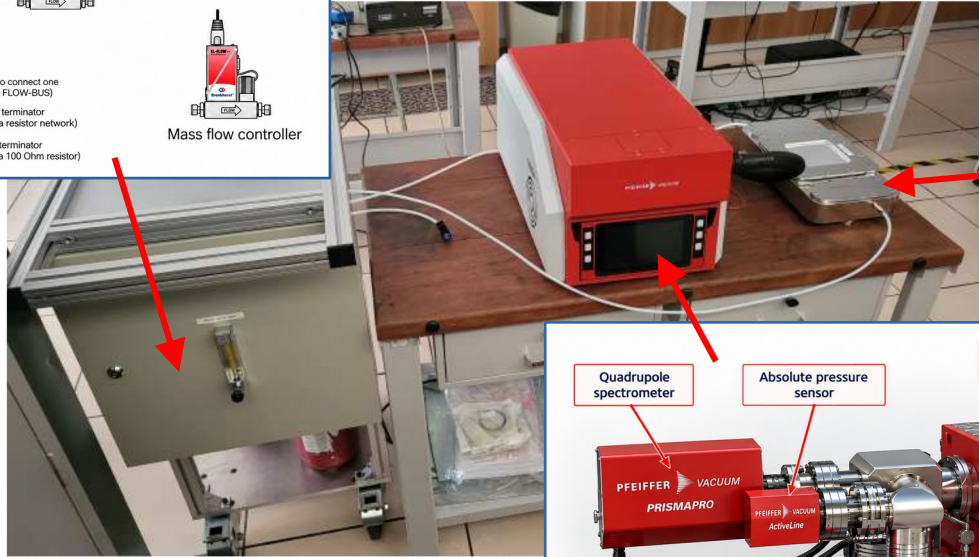


Work by:
Willian Wallace Ribeiro Alves da Silva (DR-FAPESP)
Thiago Badaró Saramela (DD-CNPq)
Eduardo dos Santos Palermo (MS-CNEN)
Daniel Neves Fachieri (DD-FAPESP)

Studying the gas environment: mass spectrometry

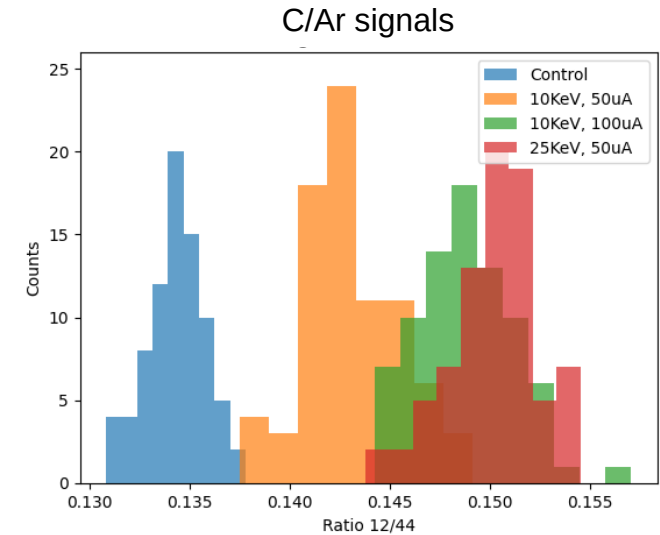
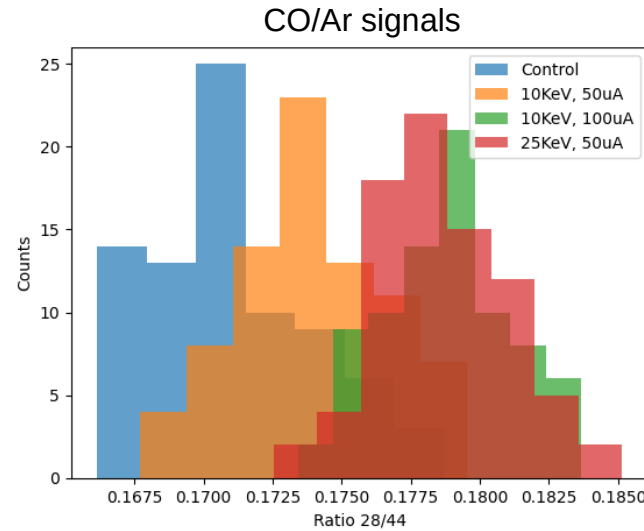
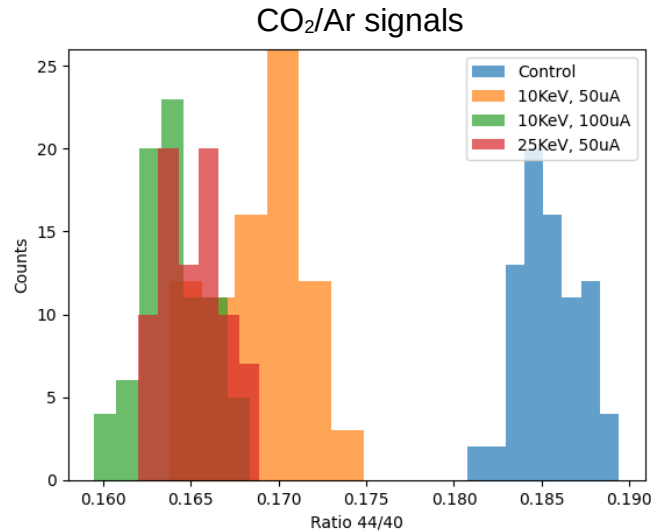


Experiments for controlled degradation of GEMs



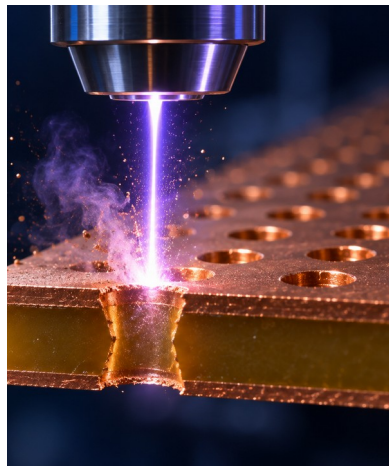
Work by:
Willian Wallace Ribeiro Alves da Silva (DR-FAPESP)
Thiago Badaró Saramela (DD-CNPq)
Eduardo dos Santos Palermo (MS-CNEN)
Daniel Neves Fachieri (DD-FAPESP)

Mass spectrometry of the gas mixture enables sensitive characterization of radiation induced molecular breakups and products reactions.



- We aim for a technique that enables flexibility to explore different geometries and concepts of GEMs
 - Quick and flexible prototyping
 - Geometries that optimize the electric field distribution presenting a positive impact on the detector's performances
 - Use insights from material and surface degradation studies to inform the development of new models.
- If possible, contribute to the advancement of MPGD technology
- Technology transfer to Brazilian companies to produce GEM for HEP experiments

Laser ablation is the process of removing material from the surface of a solid by irradiating it with an intense focused laser beam.



Goal: A strategic route toward fast prototyping, geometry freedom, cleaner processing, and local production capability.

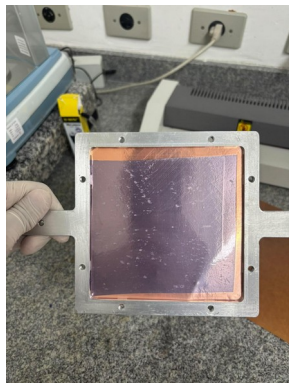
What laser ablation unlocks:

- ✓ **Rapid prototyping:** change pitch, diameter or segmentation directly from CAD design.
- ✓ **Material flexibility:** polyimide routes, LCP thick foils, PEN/PMMA GEM-like structures, and multilayer concepts.
- ✓ **Cleaner workflow:** Less dependence on wet chemistry, photomasks, mask alignment and chemical waste handling.
- ✓ **Local capability:** Shorter feedback loop between fabrication, microscopy, surface analysis and detector tests.



Class 1 laser
Laser wavelength: 355 nm
Diameter of focused beam: 20 μ m
Pulse freq.: 25-200 kHz

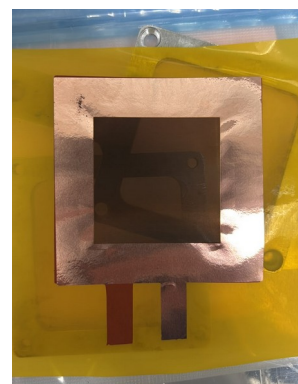
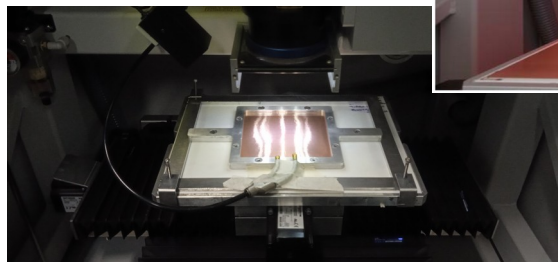




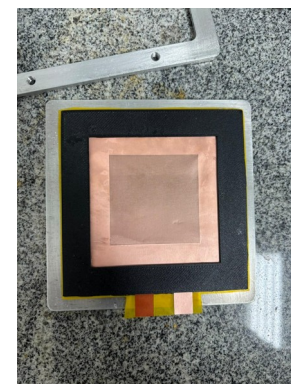
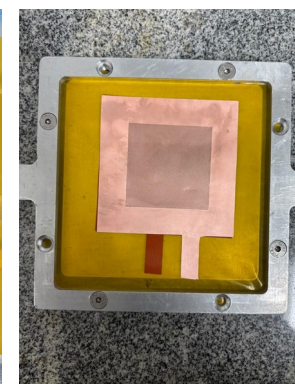
Lithography and chemical etching for preparation.



Laser ablation for micro-patterning



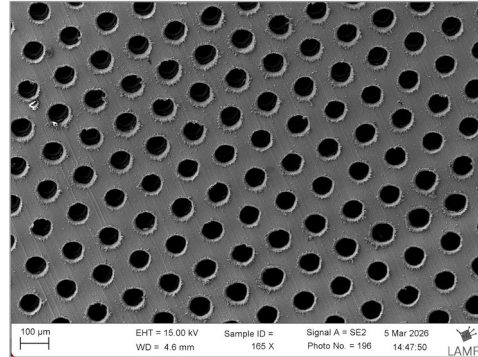
Cleaning and framing



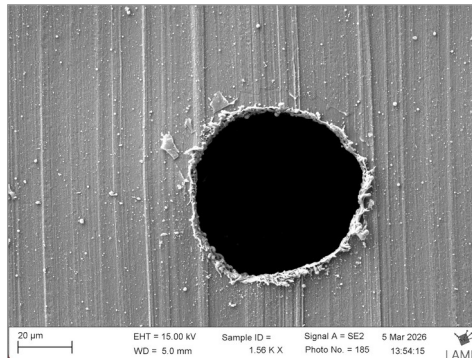
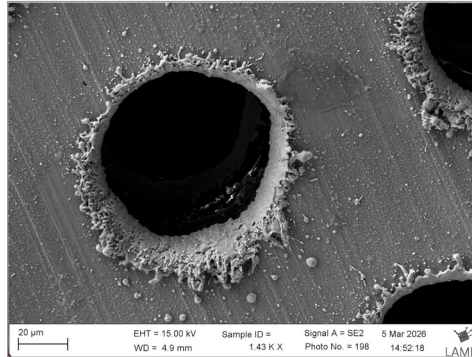
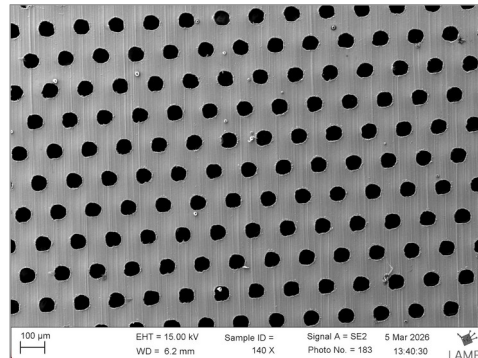
Work by:
Eduardo S Palermo (CNEN)
Daniel M. Estevão (FAPESP)

Microscopic morphology inspection

Laser
entrance
plane

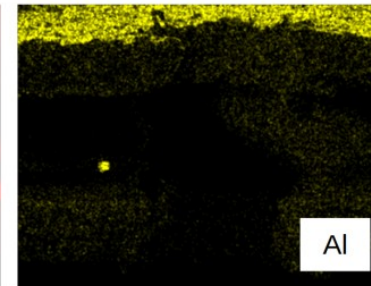
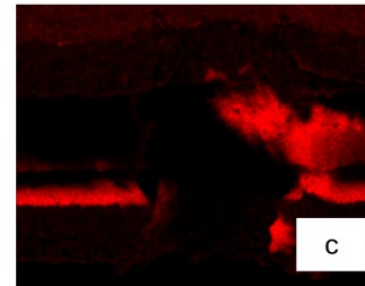
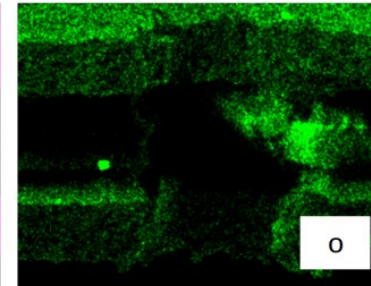
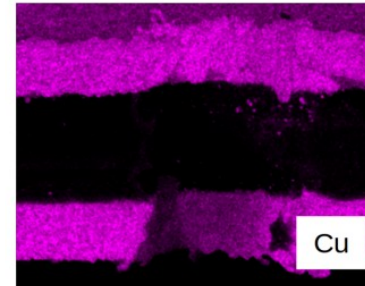
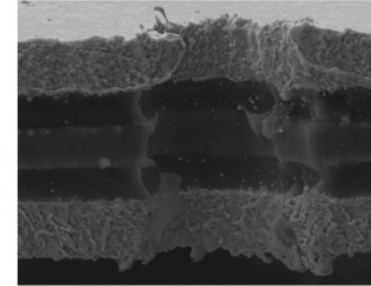


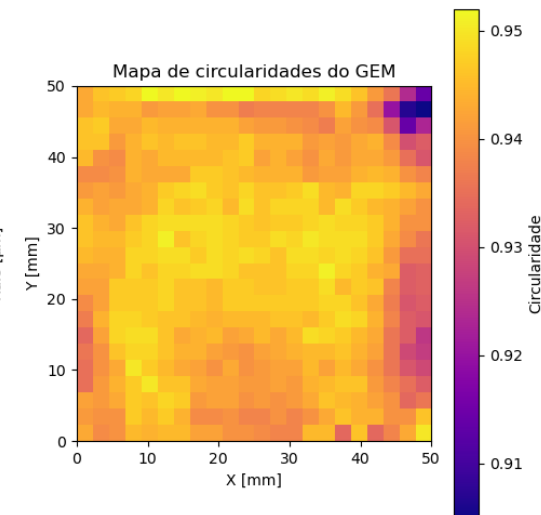
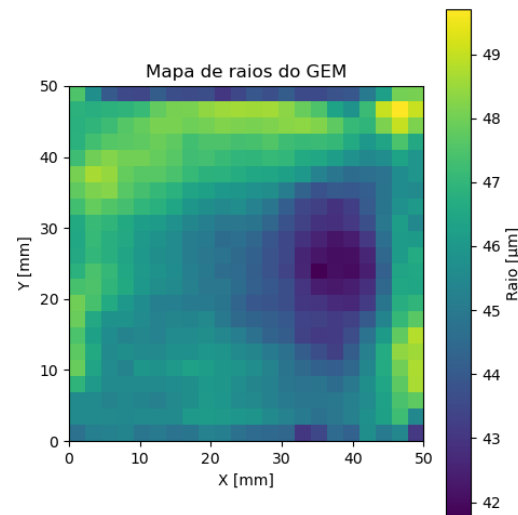
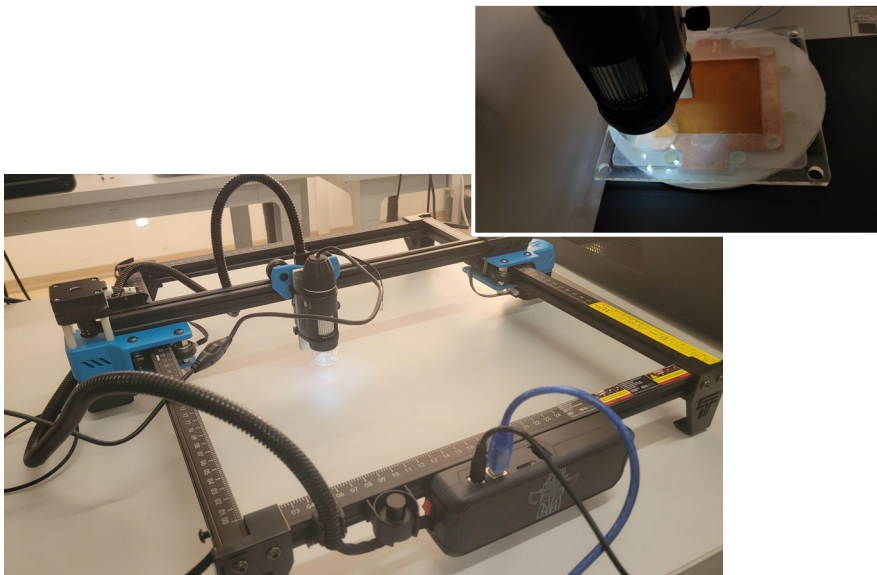
Laser
exit
plane



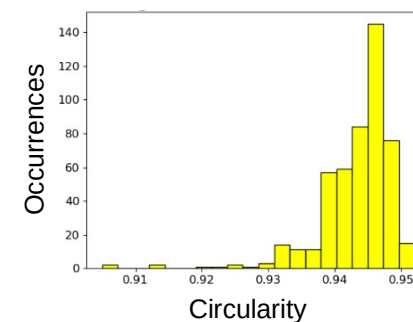
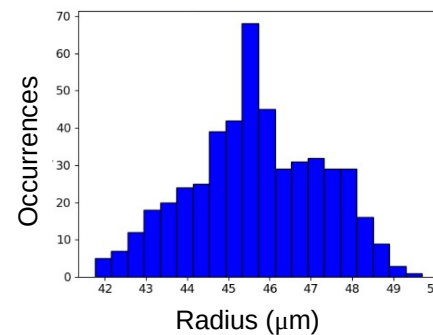
Contamination inspection

40 µm





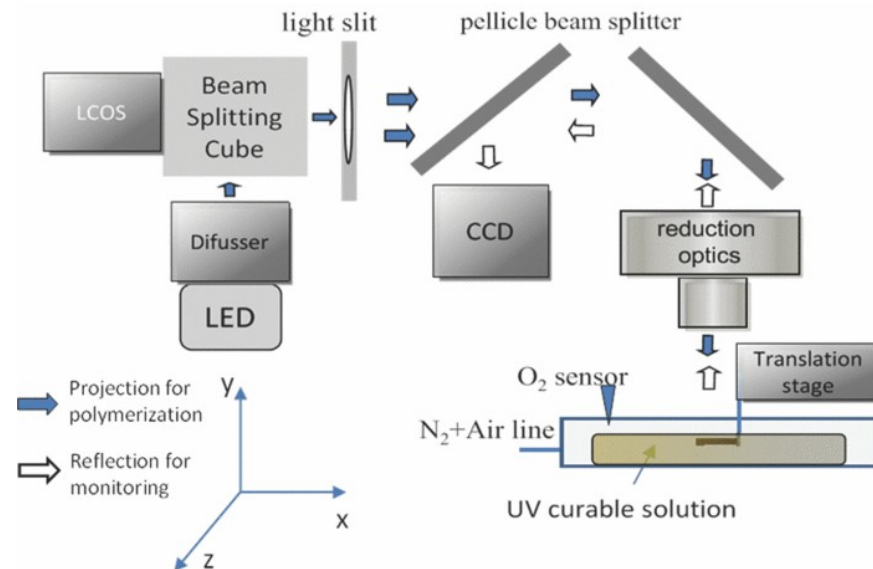
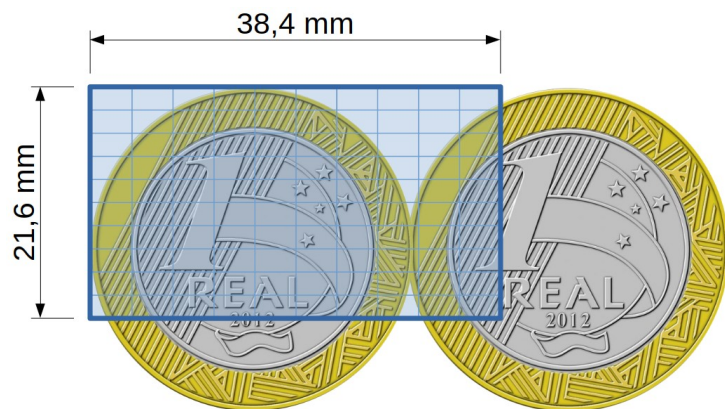
Super-resolution scanner
for GEM quality control



Work by:
Caio S. Ribeiro (FAPESP)

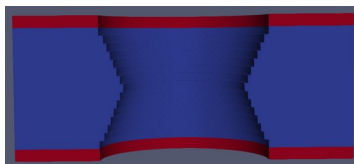
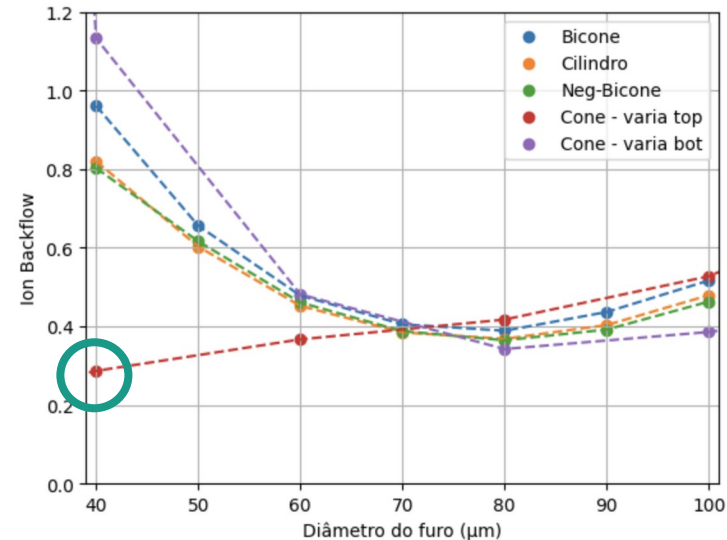
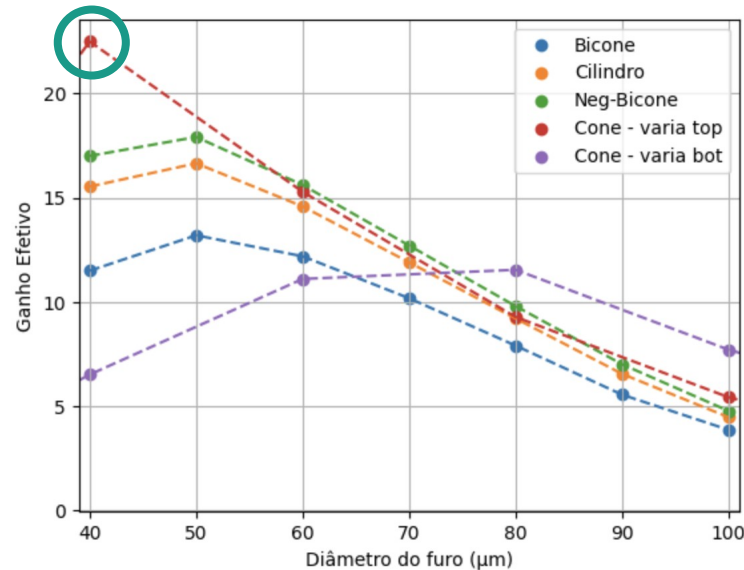
Enabling flexibility and speed to prototyping

- Projection micro stereolithography (collaboration with BMF3D):
 - Printing voxel resolution: 2-3 μm
 - Single exposure size:
3.84 mm (X) * 2.16 mm (Y) * 10 mm (Z)
 - Maximum product size:
38.4mm (X) * 21.6mm (Y) * 10 mm (Z)

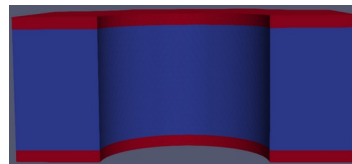


Zheng, X., Deotte, J., Alonso, M.P., Farquar, G.R., Weisgraber, T.H., Gemberling, S., Lee, H., Fang, N. and Spadaccini, C.M., 2012. Design and optimization of a light-emitting diode projection micro-stereolithography three-dimensional manufacturing system. *Review of Scientific Instruments*, 83(12), p.125001. [link]

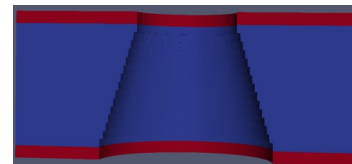
Goal: maximize effective gain and minimize ion backflow by exploring different hole shapes and diameters, leveraging the geometric flexibility enabled by additive manufacturing.



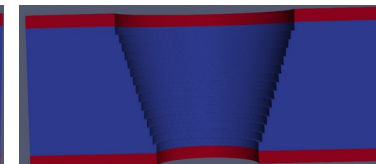
Biconical



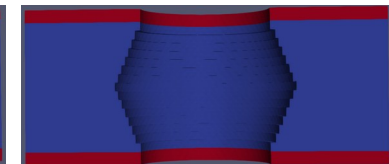
Cylinder



Conical
Narrow -> Wide

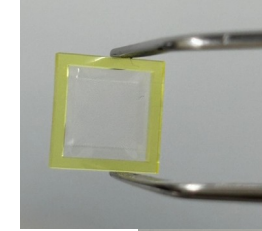
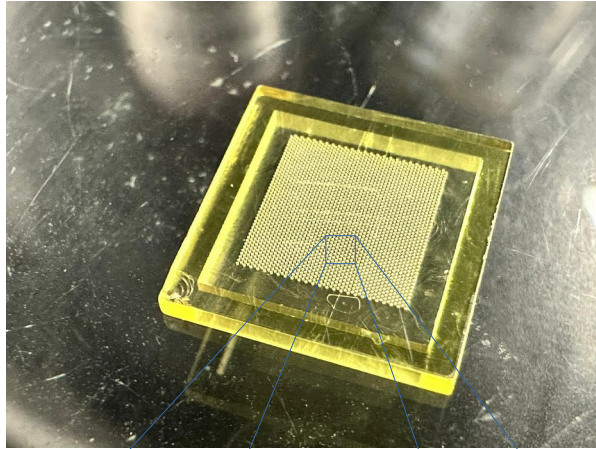


Conical
Wide -> Narrow

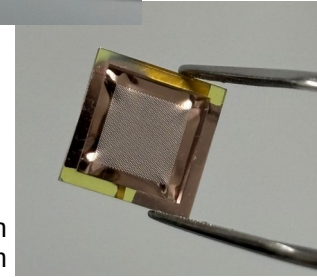


Inverse Biconical

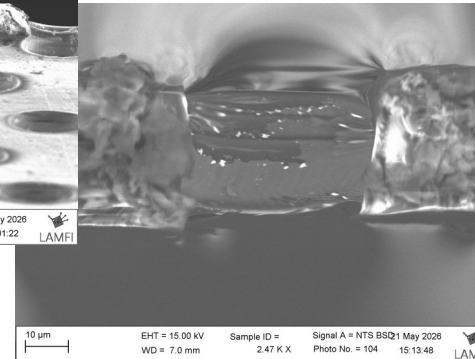
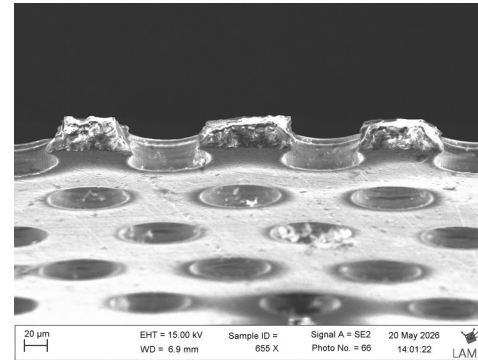
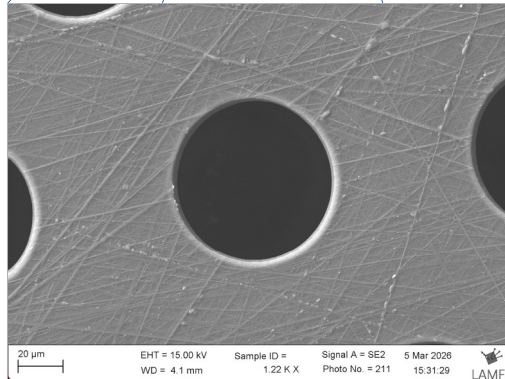
GEM production: State of art in additive manufacturing



As printed

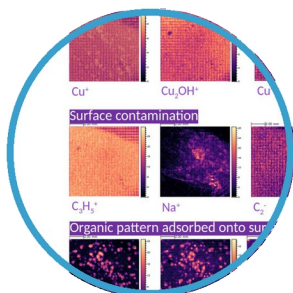
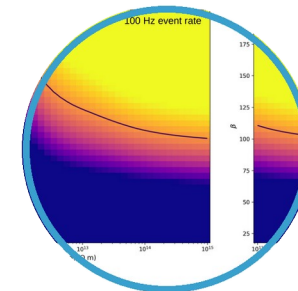


With
conductive film



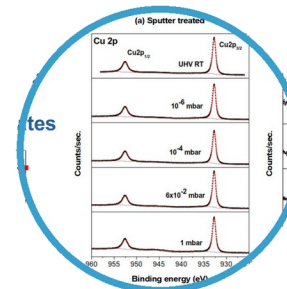
Challenge:
conductive film
deposition without
contamination of
internal walls of the
holes

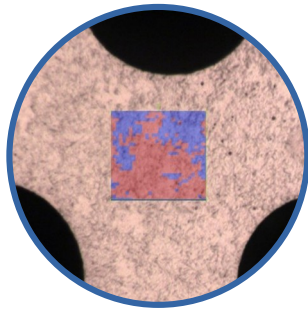
- Modeling the Malter effect points to a improved surface roughness and better surface characterization



- Our studies on the GEM surface revealed the importance of polyimide degradation

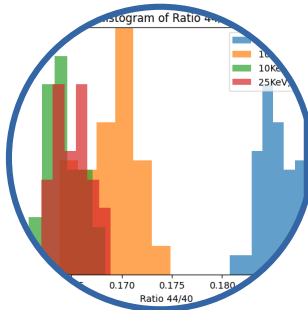
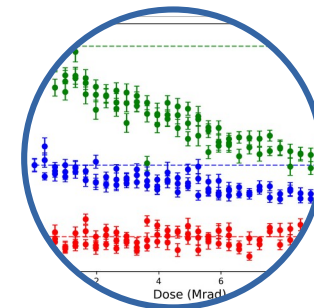
- In-situ analysis shows oxide conversion in favor of surface passivation





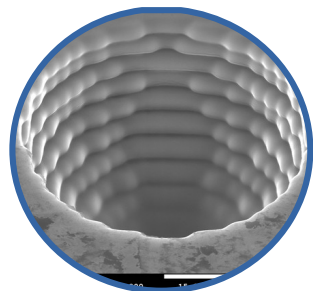
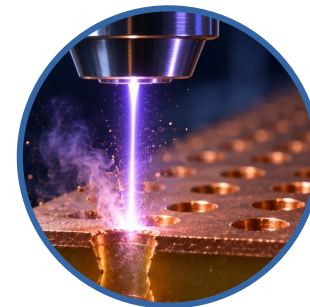
- Microscopic studies show possible connection with production process

- Hydrogen availability enables complex polymer formation and the polyimide may be a source during irradiation



- Degradation studies with gas mixture monitoring are essential for better insights on GEM degradation

- New routes for GEM production enable geometry and material flexibility
- A new generation of MPGDs requires new production routes



- Laser ablation and 3D printing are still not fully explored and can provide the necessary features for new developments

Acknowledgments:

