Updates on microfabrication techniques for local optimization of GEMs

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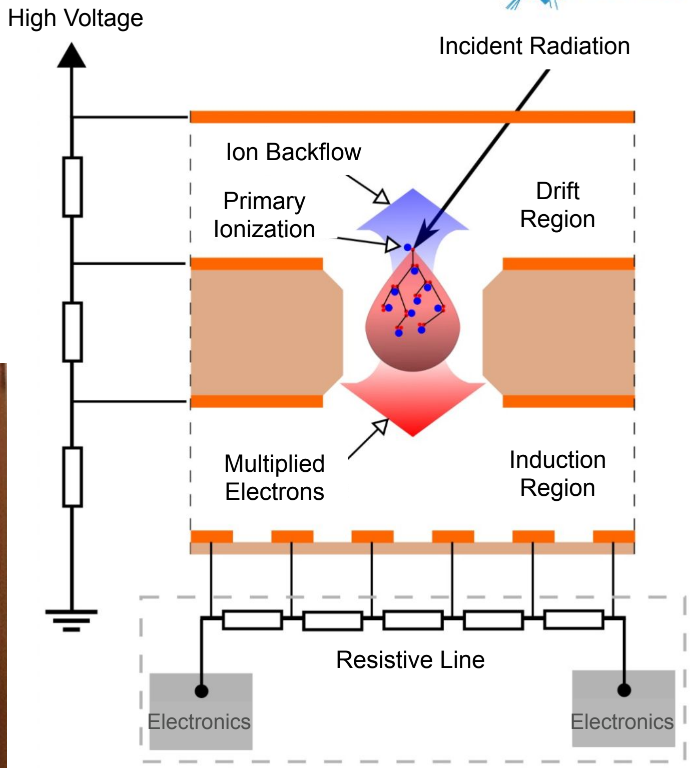
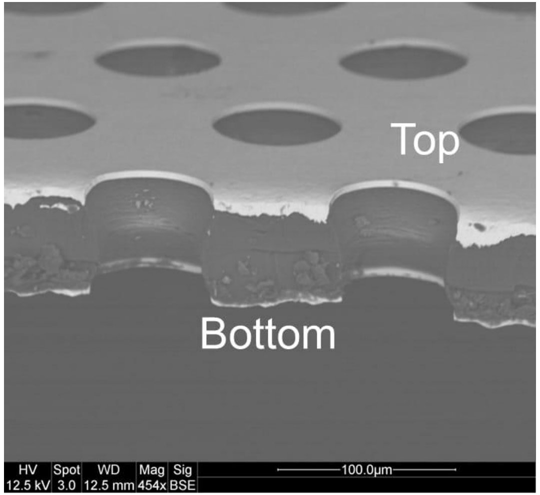
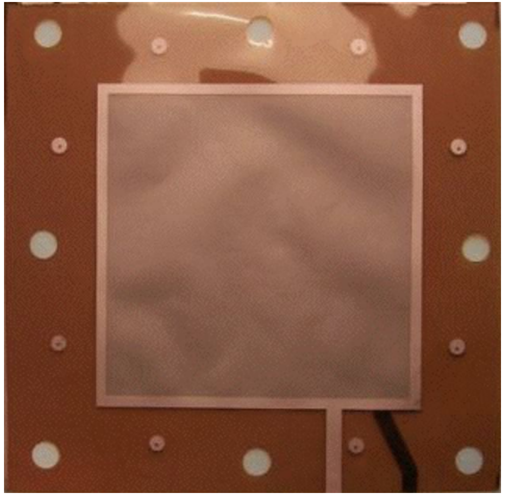
The Gas Electron Multiplier (GEM)

- The Gas Electron Multiplier belongs to a group of radiation detectors called Micro-Pattern Gas Detectors (MPGDs).
- Consists of a thin polymer foil metal-coated on both sides and pierced with a high density of micro holes.



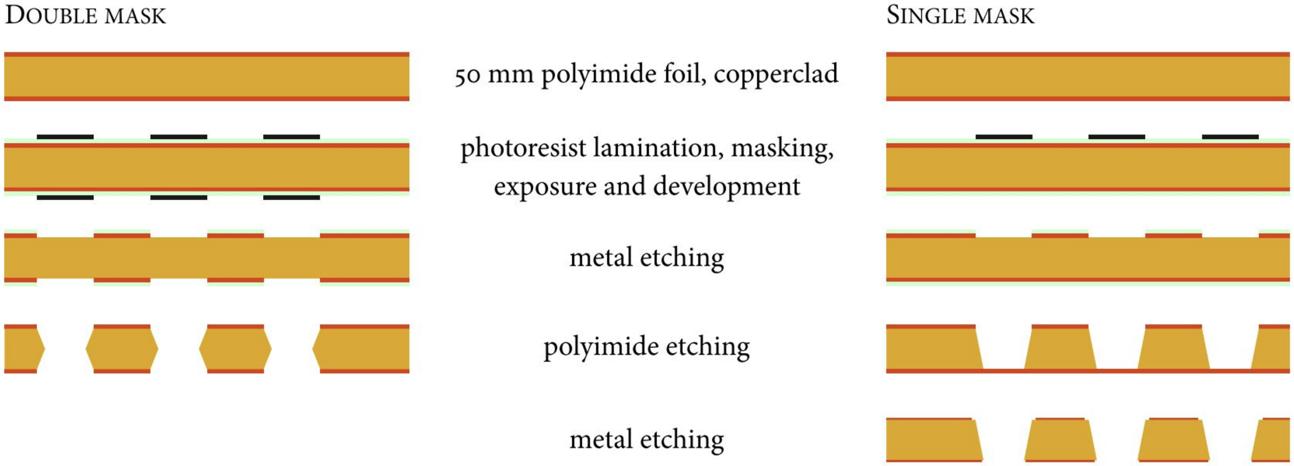




[1] F. Sauli. Gem: A new concept for electron amplification in gas detectors. Nuclear Instruments and Methods, A 386:531–534, 1997

GEM Manufacturing

- The current most used processes for fabricating GEMs are based on photolithographic and chemical etching techniques.



Double mask

Single mask

50 mm polyimide foil, copperclad

photoresist lamination, masking, exposure and development

metal etching

polyimide etching

metal etching

Image from [2]

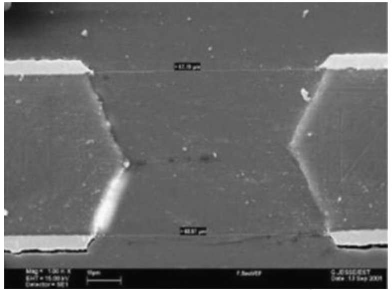


Image from [1]

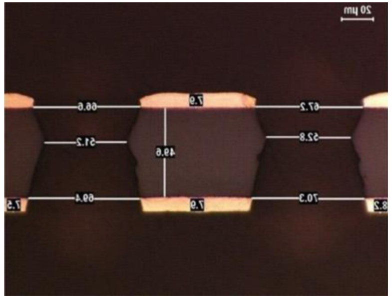


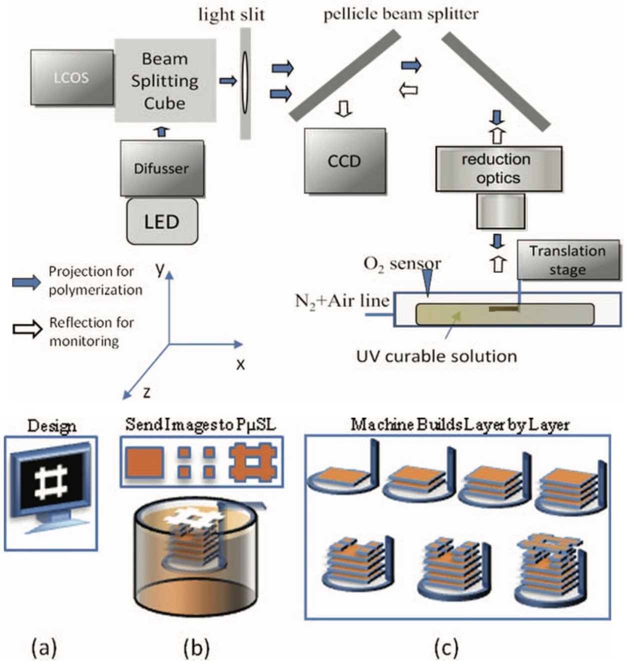
Image from [2]

- After producing the GEM foils they need to be stretched and glued to a frame.

[2] S Duarte Pinto et al, Progress on Large Area GEMs, 2009. JINST 4 P12009

Projection Micro-Stereolithography (pμSLA)

- 3D printing technique based on a layer by layer production process utilizing photopolymerization reaction

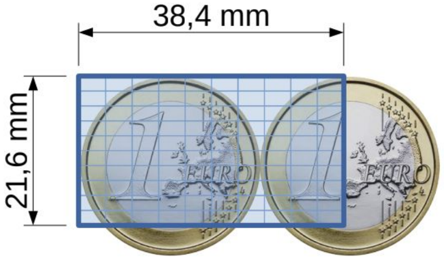


Schematic illustration of pμSLA system and its functioning [3]

[3] Xiaoyu Zheng, Joshua Deotte, Matthew P. Alonso, George R. Farquar, Todd H. Weisgraber, Steven Gemberling, Howon Lee, Nicholas Fang, and Christopher M. Spadaccini. Design and optimization of a light-emitting diode projection micro-stereolithography three-dimensional manufacturing system. Rev. Sci. Instrum., 83(12), 2012

Why this technique?

- ★ It has adequate spatial resolution for GEMs production (2-3 μm)
- ★ Adequate printing volume for prototyping: maximum size (38.4 x 21.6 x 10)mm

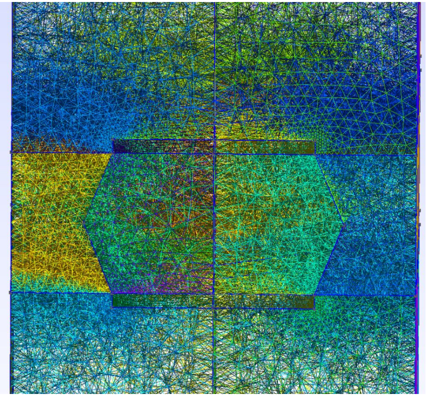


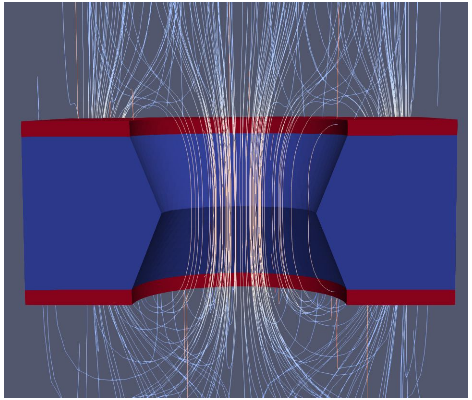
Computational simulations - exploring GEM geometries

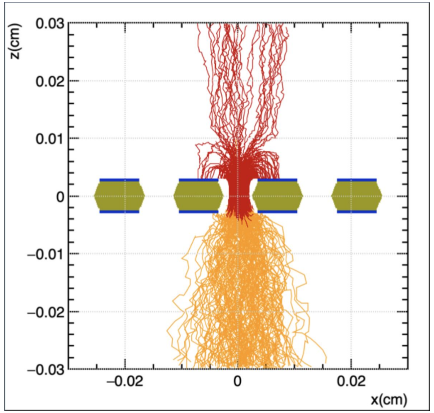
- Softwares:
    - GMSH: design of the geometry and discretization
    - ElmerSolver: electric field calculations
    - Garfield++: charged particles transport in gaseous medium (Monte Carlo)

- Evaluation of performance GEM parameters (effective gain and ion backflow) and mapping of the final destination of electrons and ions for differente hole geometries and across different diameters

- Exploring the addition of micro-sized decorations around the holes of the GEM foil that generate local alterations in the electric field that could generate some benefit

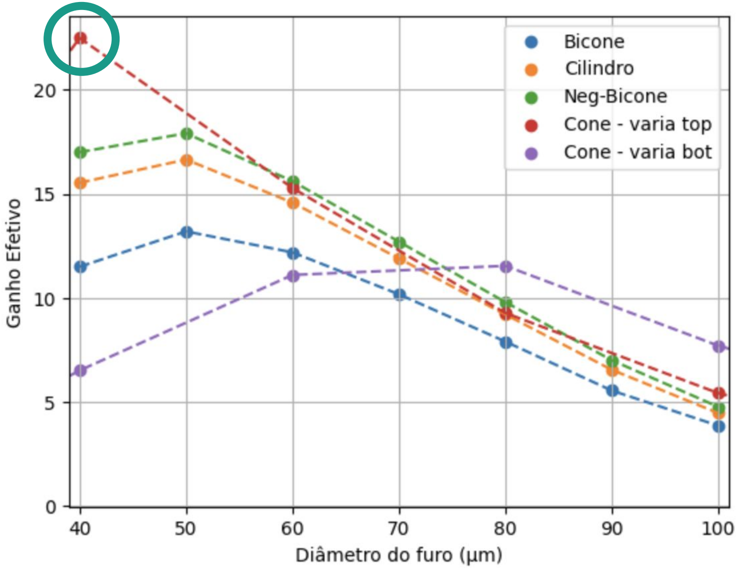


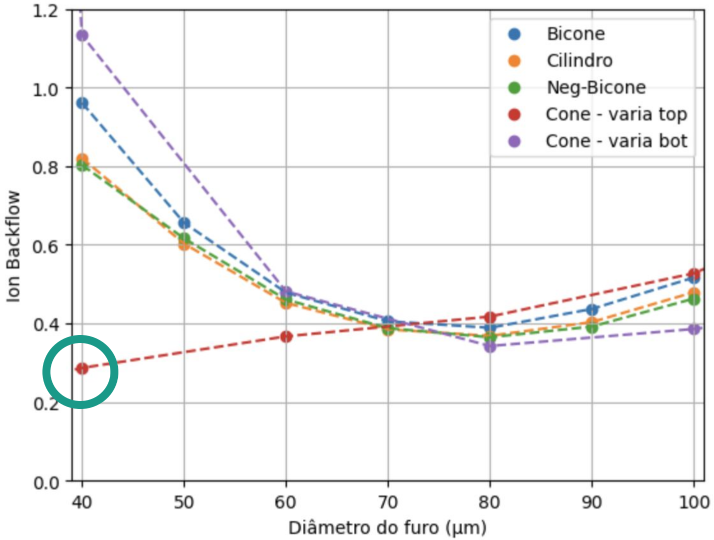


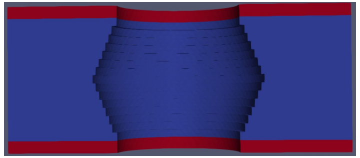


Exploring different hole geometries

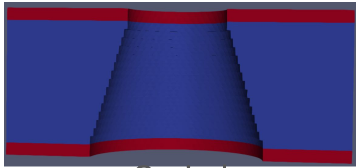
Goal: maximize the Effective Gain and minimize the Ion Backflow by varying the hole shape - since the additive manufacturing easily allows the flexibility of different holes - across different diameters

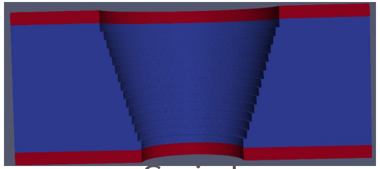


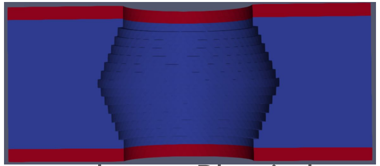



Biconical


Cylinder


Conical
Narrow -> Wide


Conical
Wide -> Narrow


Inverse BIconical

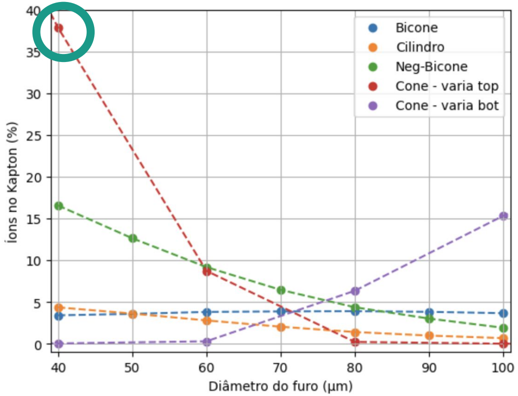
Exploring different hole geometries

Hole type (diameter in µm)	Effective Gain	Ion Backflow
Conical (40/70)	22.5	0.29
Biconical - CERN Standard(50/70)	10.2	0.41

❖ The geometry configuration with a conical hole with top diameter of 40µm and bottom diameter of 70µm shows an increase in more than 100% in the effective gain with a 30% reduction on Ion Backflow

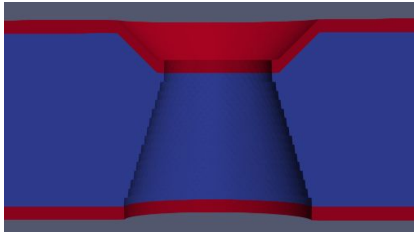
Possible disadvantage:

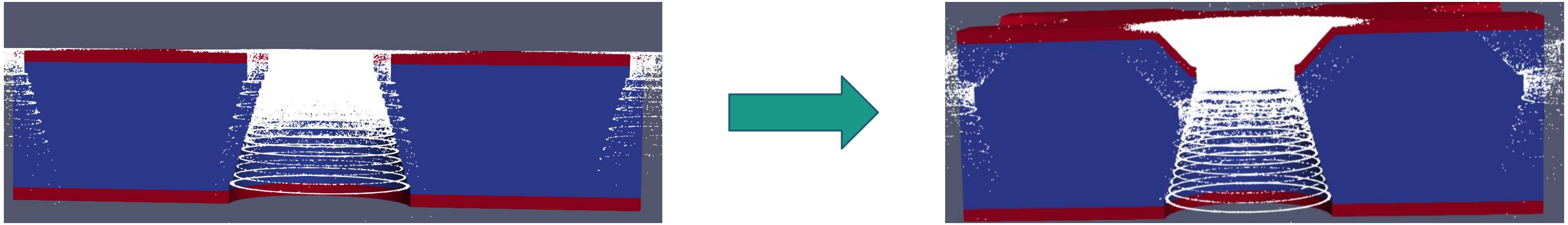
- Big increase in the Ions that hit the kapton, which could lead to:
  - Kapton degradation;
  - greater charge-up effects.



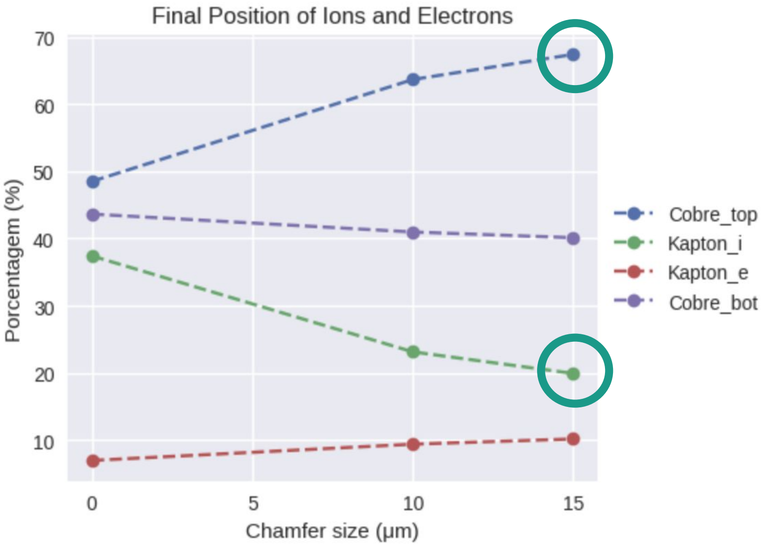
Exploring the addition of micro-sized decorations

- To overcome this feature, we can exploit the flexibility of 3D printing to add micro-sized decorations around the hole edges that can locally modify the electric field.
- Here, we simulated the conical hole with a chamfer covered by the conductor material on the top aperture to redirect part of the ions generated inside the hole to this structure





Exploring the addition of micro-sized decorations



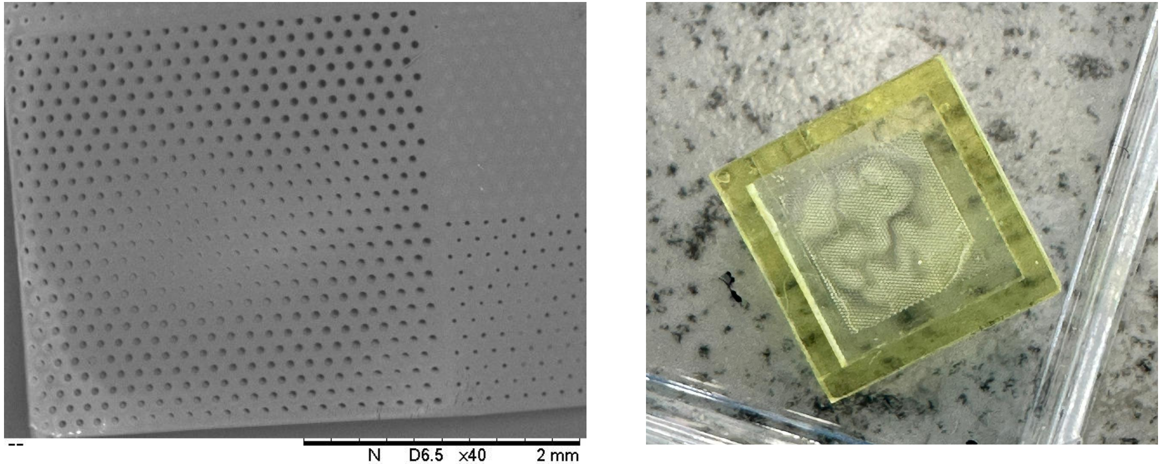
Hole Type (diameter in μm)	Eff Gain	IBF
Conical (40/70)	22.5	0.29
Conical + chamfer(40/70)	**19.5**	**0.26**
Biconical - standard (50/70)	10.2	0.41

First 3D printed GEM's insulator layer samples

- First tests performed on the nanoArch S130 printer by BMF Technology in Nottingham University
- During the time spent there:
  - learned how to operate the printer, including software controls, calibration and maintenance;
  - Printed several samples varying UV light intensity, exposure time, printing speed and other relevant parameters.

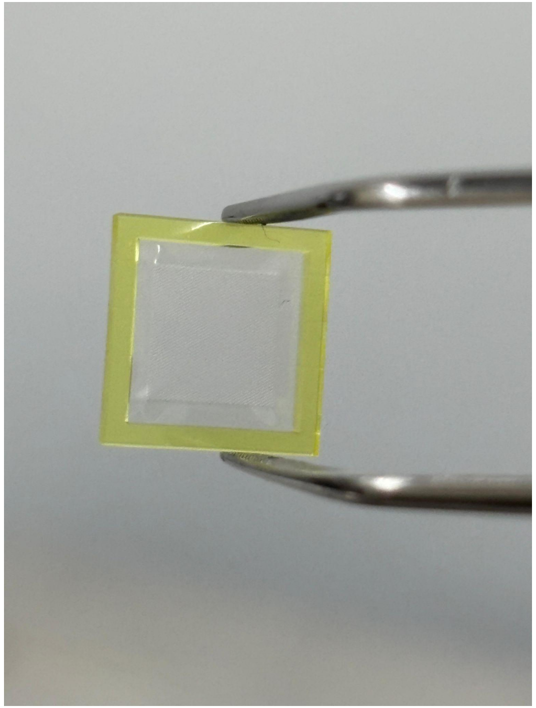
First 3D printed GEM's insulator layer samples

- Difficulties in printing holes completely open:
    - part of the resin was being half cured and closing partially or completely the holes independent of the parameters used.



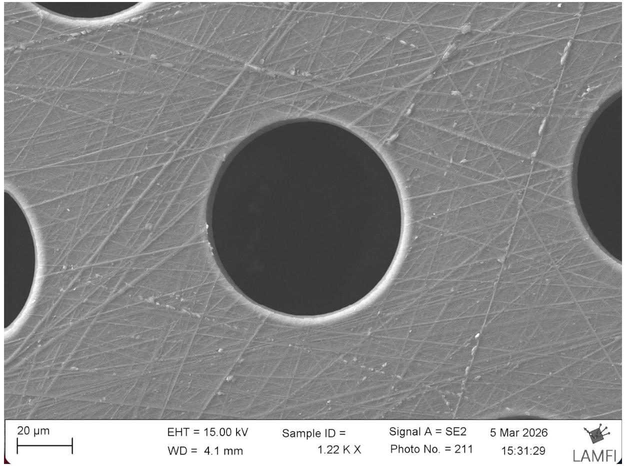
- This problem was later related to a contamination of the projection lens and, after technical visit by BMF, the printer is now already repaired.

First successfully 3D printed GEM insulator layer

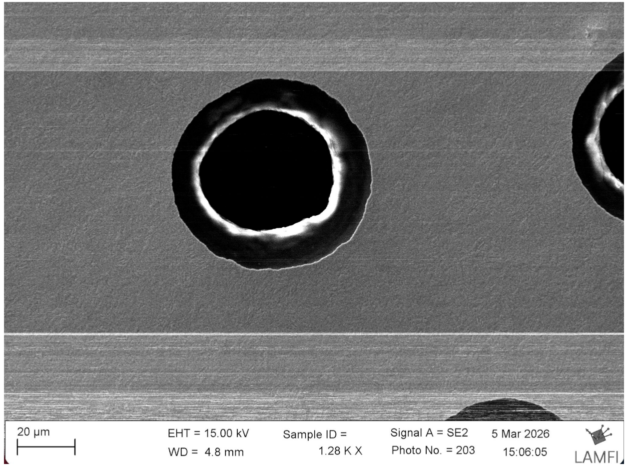


- BMF Technology printed samples

- The samples produced are:
  - 10x10 mm^2 total area
    - 6x6 mm^2 is the active detection - 50μm thickness
    - 2x2 mm^2 is a frame - 1mm thickness
  - Cylinder holes of 70 μm diameter with a 140 μm pitch.



3D print



CERN

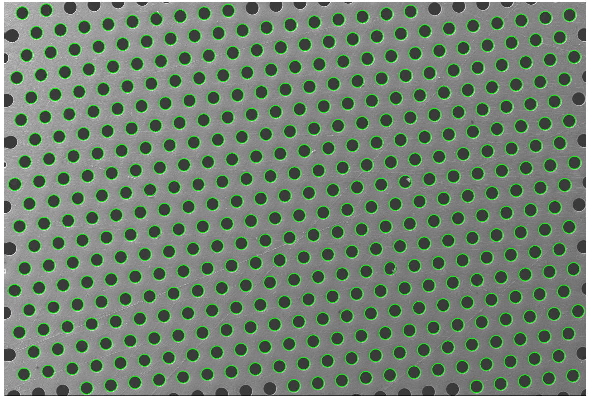
First successfully 3D printed GEM insulator layer

HEPIC
IFUSP

Quality Assurance procedure performed on the 3D printed samples

- Inspection of diameter and circularity of the holes, as well as pitch distances, by using SEM images and a python algorithm that identifies the holes and fits an ellipse to them, in a similar but simplified process of the one used in reference [4]

Sample	Diameter (μm)	Circularity	Pitch (μm)
CERN	67.5 +- 1.7	0.942+-0.021	137.8 +- 0.7
3D print	71.9 +- 0.7	0.982+- 0.011	141.7+-0.5



3D printed samples show:

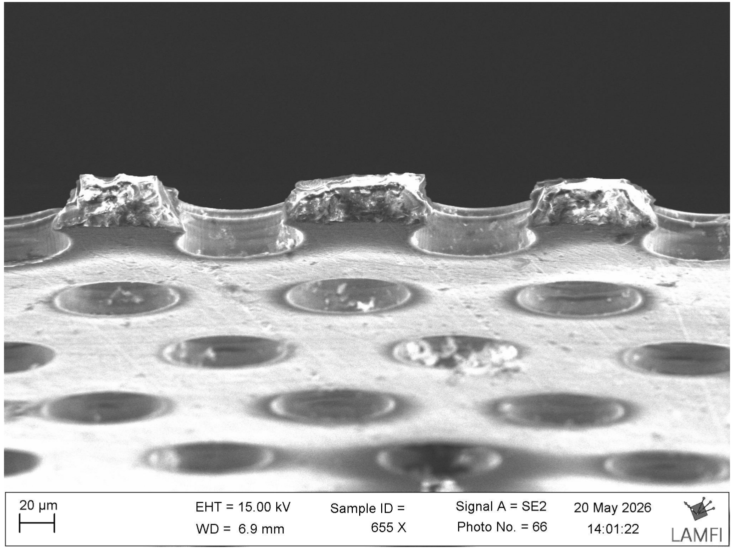
- Greater uniformity in holes diameters -> this can lead to a smaller variation in gain across the foil, as reported in [5] a variation of +- 5 μm lead to effective gain variations up to 18% across a GEM foil;
- Increase in circularity;
- Better conformity with targeted parameters.

[4] Hildén, T. et al, Optical quality assurance of GEM foils, 2015. Nuc. Inst and Methods, A.
[5] Supriya Das, Study of gain variation as a function of physical parameters of GEM foil, 2016. Nuc. Inst. and Methods, A.

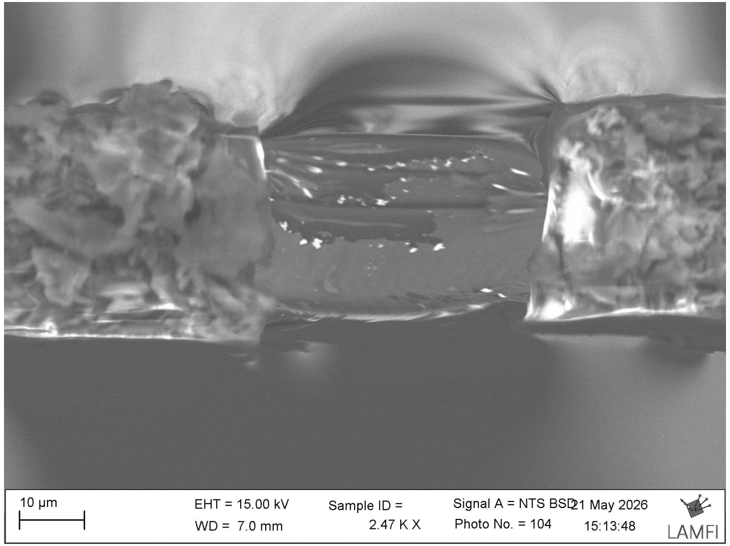
Deposition of the conductive layer

- **First tests:** deposition of gold layer by sputtering (estimate thickness of 500nm)

- Investigation of hole contamination by analyzing their cross section images:
  - Secondary Electrons: topography investigation of the inside of the holes ;
  - BackScattered Electrons + Energy-Dispersive X-ray Spectroscopy: investigation of gold contamination inside the holes;



SEM

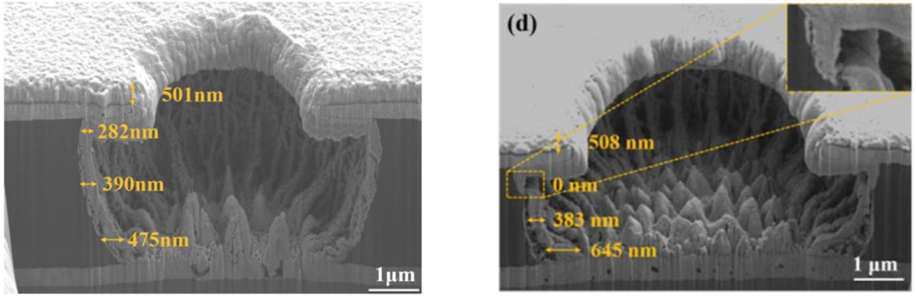


BSD

Deposition of the conductive layer

- In the latter images is possible to see a clear contamination of gold inside the holes, BUT the film is not continuous - we can see regions without any gold deposit (confirmed by local EDX) - as opposed to a continuous film on the top surface.

- This phenomena has been reported in studies such as [6] where the formation of films inside microvias by copper sputtering shows less thickness and poorer adhesion compared to the surface.



FIB-SEM image of copper sputtered micro-vias from [6]

[6] Zhendong Yin et al., Effect of sputtering process parameters on the uniformity of copper film deposited in micro-via, 2023. Journal of Materials Research and Technology, 25: 5249-5259

Deposition of the conductive layer

- **Current route:**
  - Work with the minimum thickness necessary to have the adequate conductive features;
  - Deposition of a copper layer by sputtering with a few times the superior thickness necessary and cleaning of the holes with chemical or plasma etching;
  - Have clean holes and a thin film leftover at the surface;

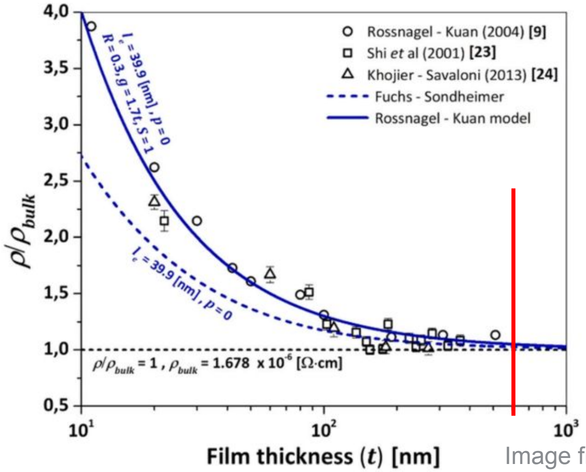
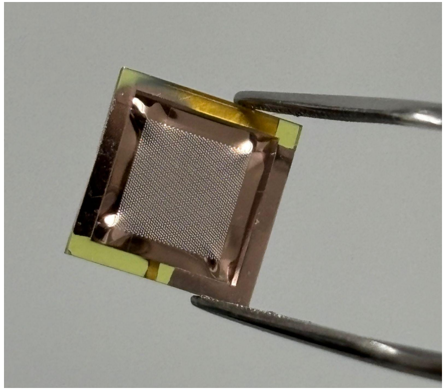


Image from [7]

- **Current status:** tests with copper thin film depositions in the Laboratório de Materiais Magnéticos.



[7] Simon Roa and Martín Sirena, Size effects on the optimization of the mechanical resistance and the electrical conductivity of Cu thin films, 2021. Materials Today Communications

Future steps

- Replicate BMF results in Nottingham
- Manufacturing of GEMs with decorations around the holes
- Testing different etching techniques inside the holes
- Electrical characterization of first complete samples

Thank you!