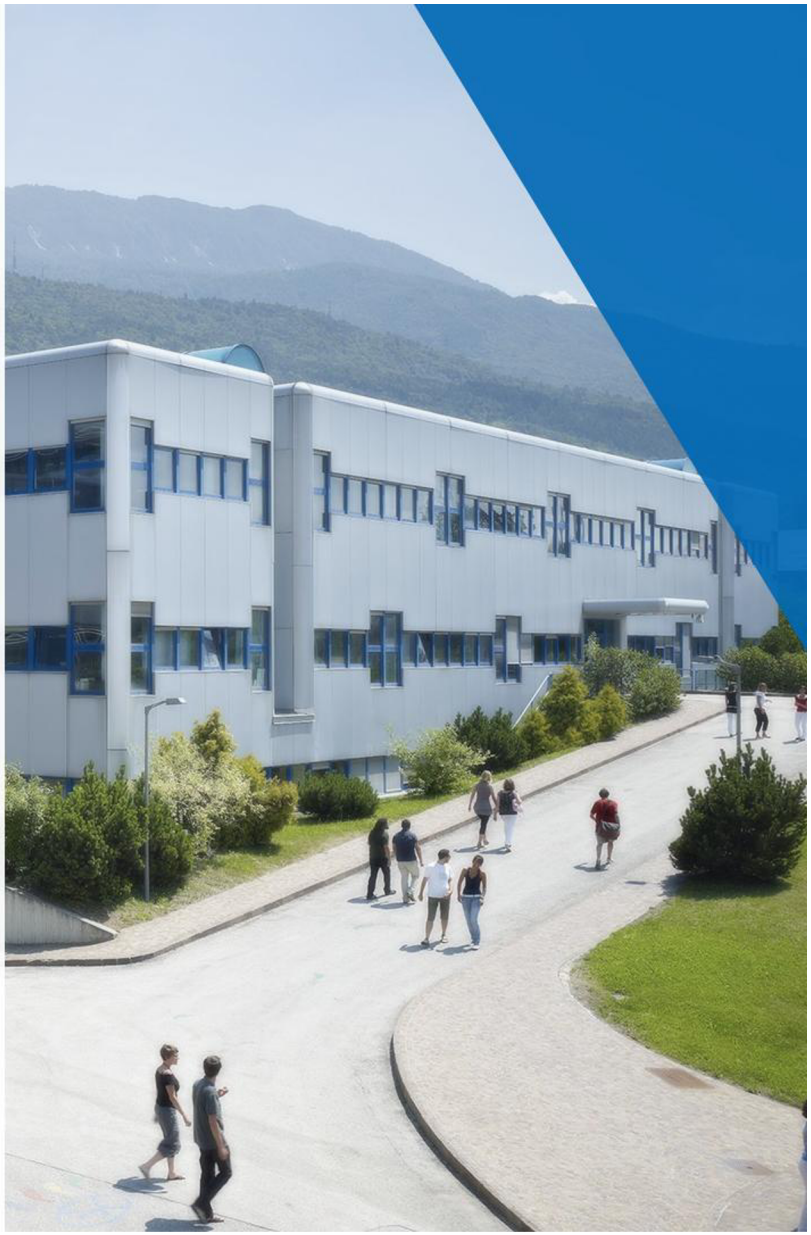
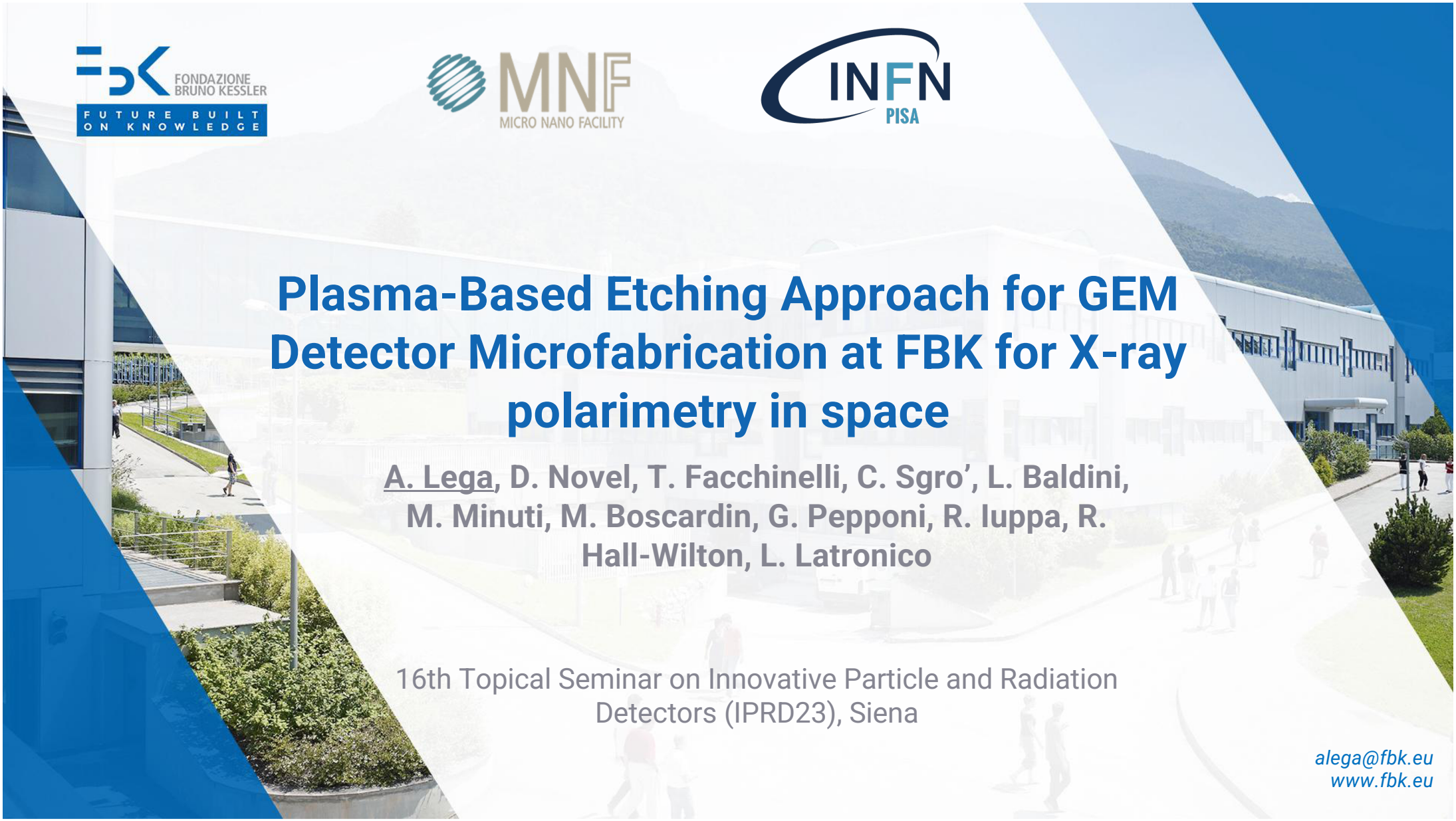
FONDAZIONE
BRUNO KESSLER

FUTURE BUILT
ON KNOWLEDGE





Plasma-Based Etching Approach for GEM Detector Microfabrication at FBK for X-ray polarimetry in space

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16th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD23), Siena

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Presentation outline

- 1 GEMs in HEP
- 2 GEMs in astronomical X-ray polarimetry
- 3 R&D of GEMs microfabrication at FBK
- 4 Preliminary results

Performed in the framework of FBK and INFN MiNaTAP agreement

GEMs in HEP

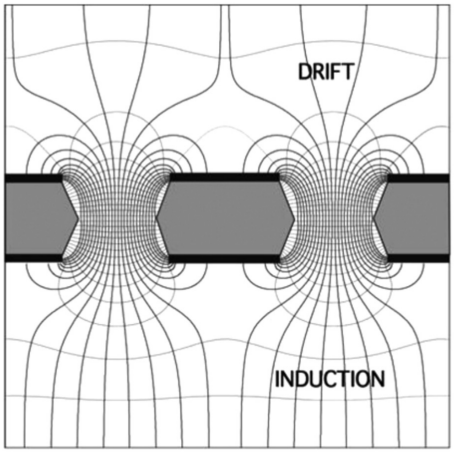


Fig. 2. Electric field in the region of the holes of a GEM electrode.

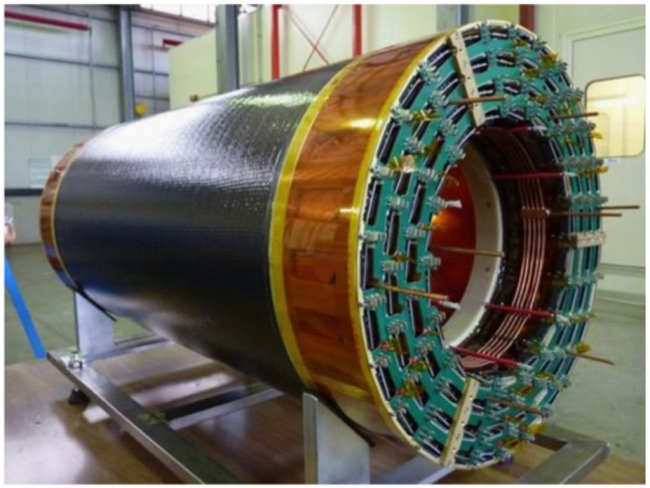


Fig. 37. The Triple-GEM tracker for the KLOE experiment, 70 cm long.

Fig. 34. A large GEM prototype for the CMS forward muon upgrade. The detector is about one meter high.

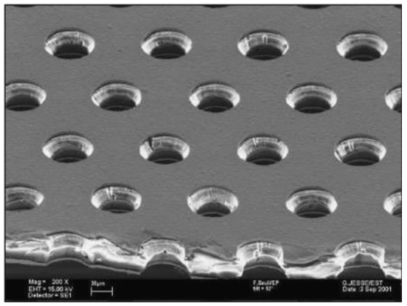
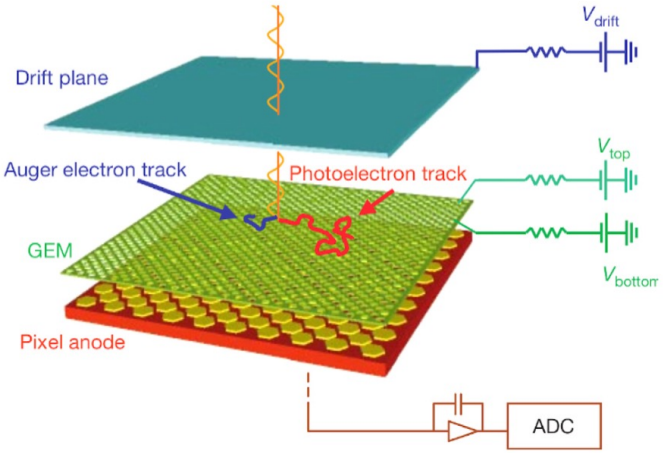
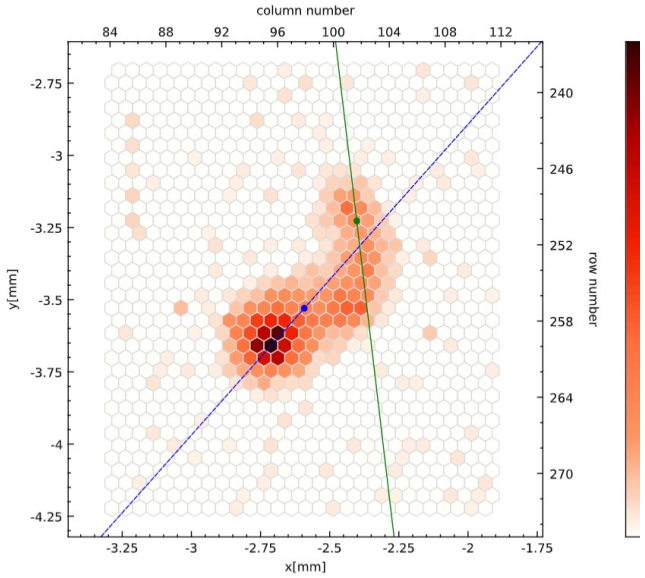


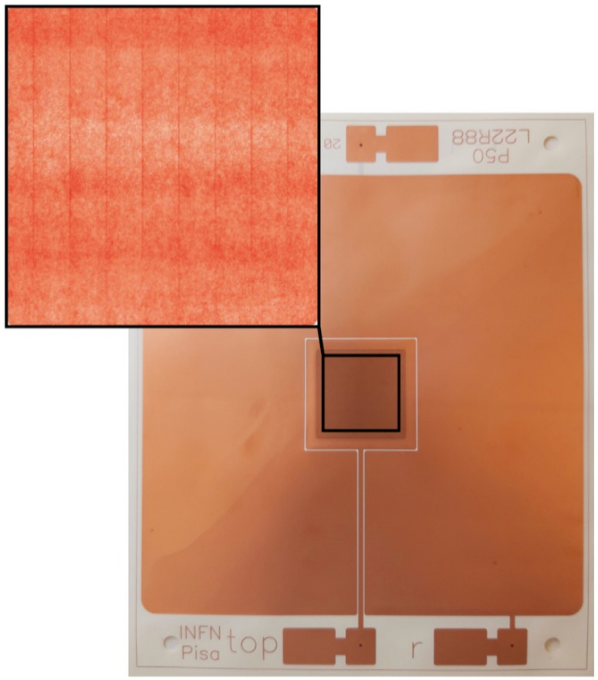
Fig. 1. Electron microscope picture of a section of typical GEM electrode, 50 μm thick. The holes pitch and diameter are 140 and 70 μm, respectively.

- Fabricated with standard PCB technology.
- Large area (m^2).
- Very established technology in HEP.

GEMs in astronomical X-ray polarimetry







$$\frac{d\sigma_C^K}{d\Omega} \propto Z^5 E^{-\frac{7}{2}} \frac{\sin^2\theta\cos^2\phi}{(1+\beta\cos\theta)^4}$$

- Fabricated with innovative technology (CO_2 laser drill).
- Small area (1.5x1.5 cm^2).
- Technology developed for the IXPE experiment.
- Very difficult to obtain good polarimetry measurements due to the **necessity of high microfabrication quality**.

Facilities @ FBK

4 Clean Rooms & Other laboratories

- CRD (Production of silicon radiation detectors)
- CR3D (Wafer level 3D integration, wafer thinning & bonding)
- CRM (MEMS, multiple metals compatibility)
- CRP (Chip level packaging @ small scale)
- Gas Sensing Laboratory (Testing chambers)
- Electrical Testing Lab (Wafer level probing)
- Integration Lab (Prototype system integration @ small scale)
- Material Characterization Laboratories (Chips & material science)

R&D of GEMs microfabrication at FBK

X-ray polarimetry experts

David Novel
Alessandro Lega
Tiziano Facchinelli

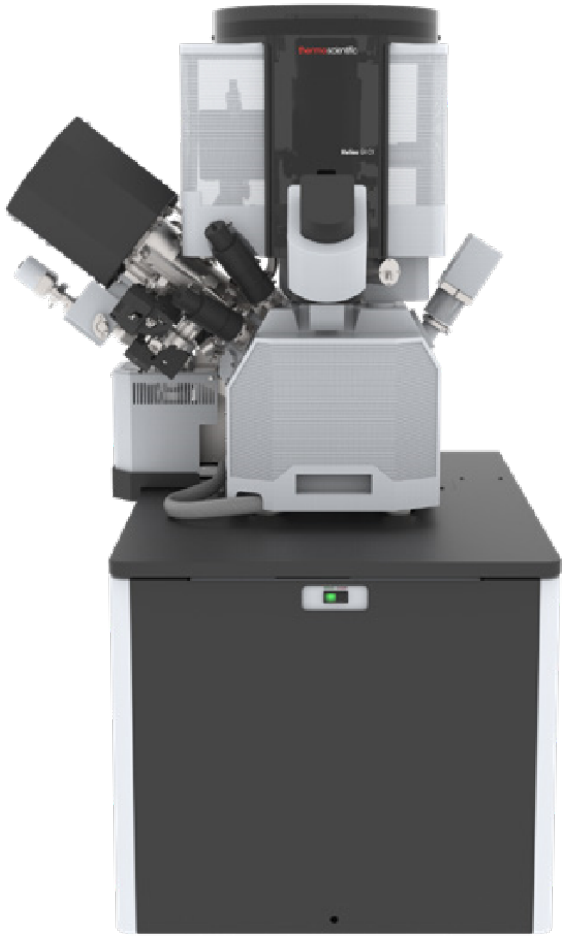
Microfabrication experts

Explore GEM microfabrication plasma techniques that has high uniformity (on small areas).
Pros: high geometrical precision, aspect ratio and less defects than standard production techniques

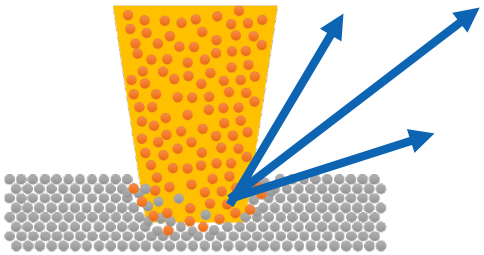
CSN2 Project (XRO GEM RIE) + MiNaTAP agreement
Phase 1 (Single side GEM) – Phase 2 (Double side GEM)

Performed in the framework of FBK and INFN MiNaTAP agreement

Plasma Focused Ion Beam (PFIB)
Technique overview



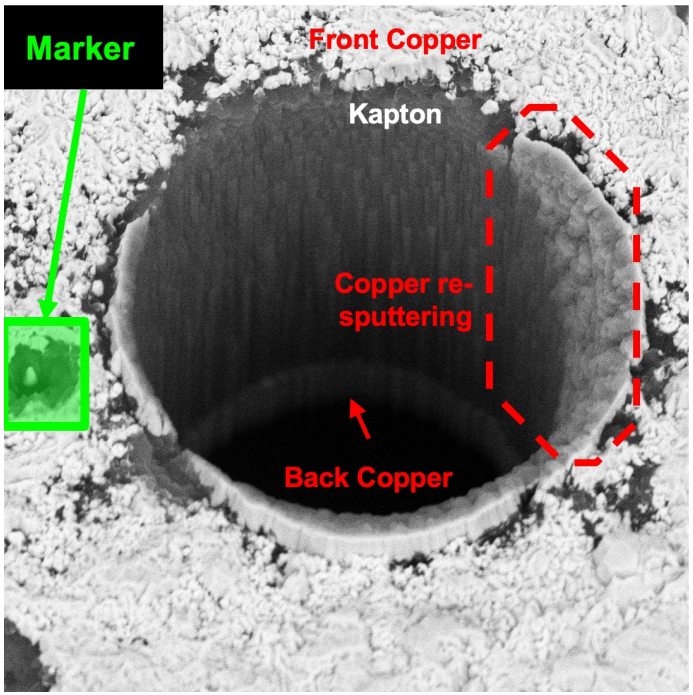
Xe ion beam
Material milling

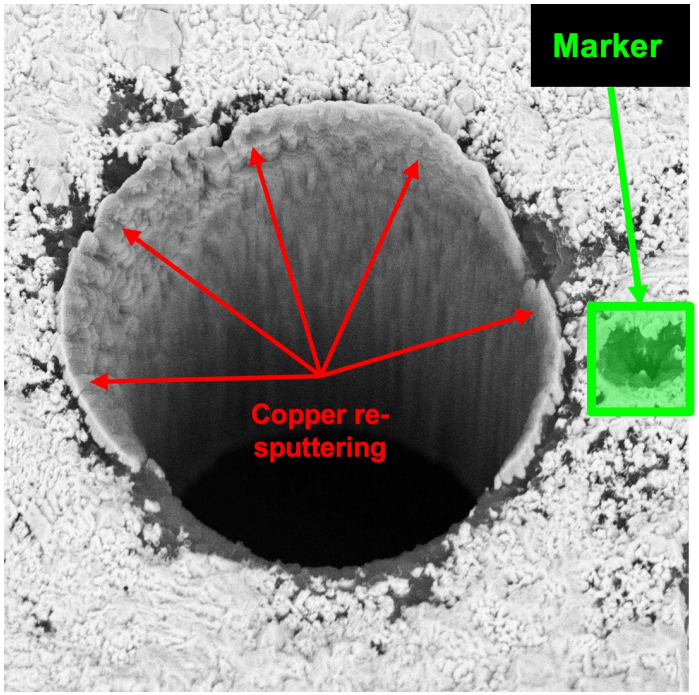


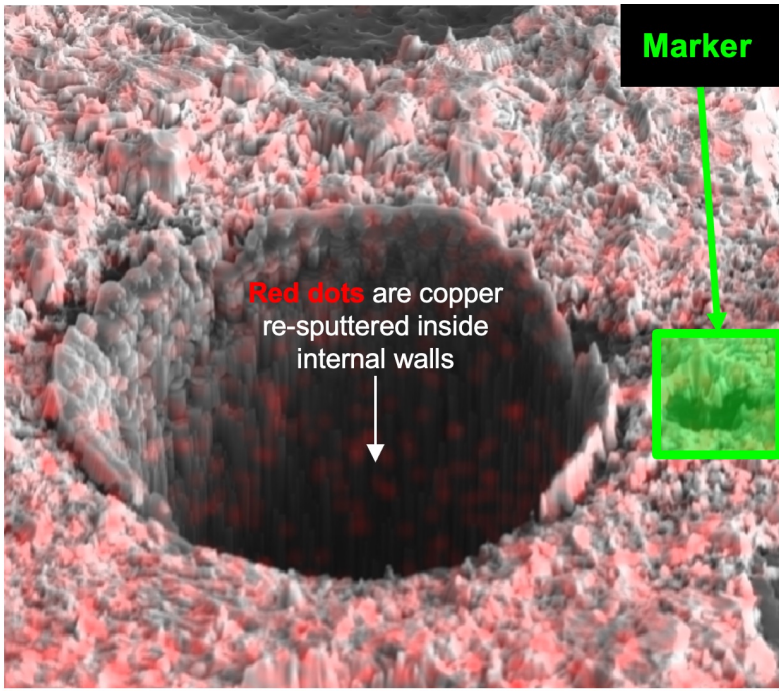
Live milling imaging with secondary electrons

High performance PFIB column with ICP Xe^+ Plasma
Ion beam current range: 1.5 pA to 2.5 µA
Accelerating voltage range: 500 V - 30 kV
XY repeatability: 3 µm
Compatible with 6-inch wafers (15 cm diameter)
Nano-pattering capabilities & several detectors
Wide characterization capabilities & fast chip reworking times

Single hole GEM with PFIB
Limitations







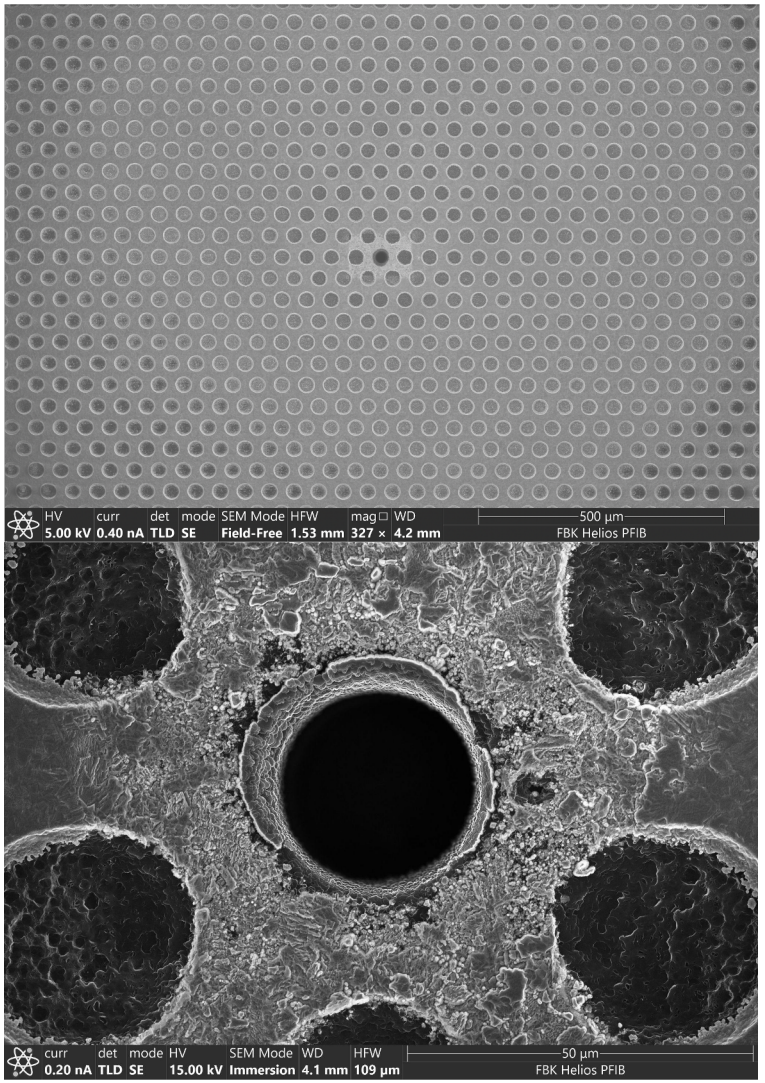
Single hole GEM with PFIB

Mixed results => difficulties & successes

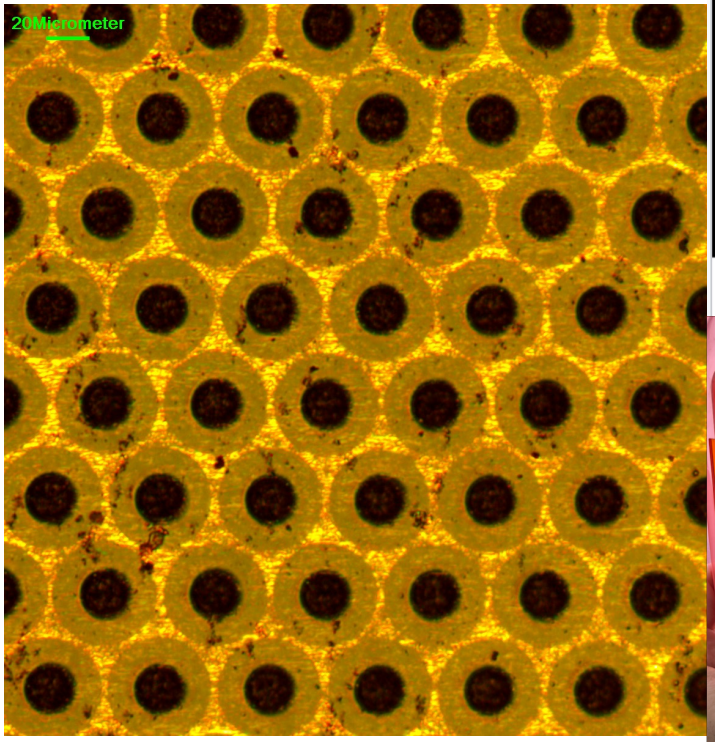
Advantages:
- very vertical walls
- each hole can be machined separately
- process can be automated
- in-situ correction to open holes with defects

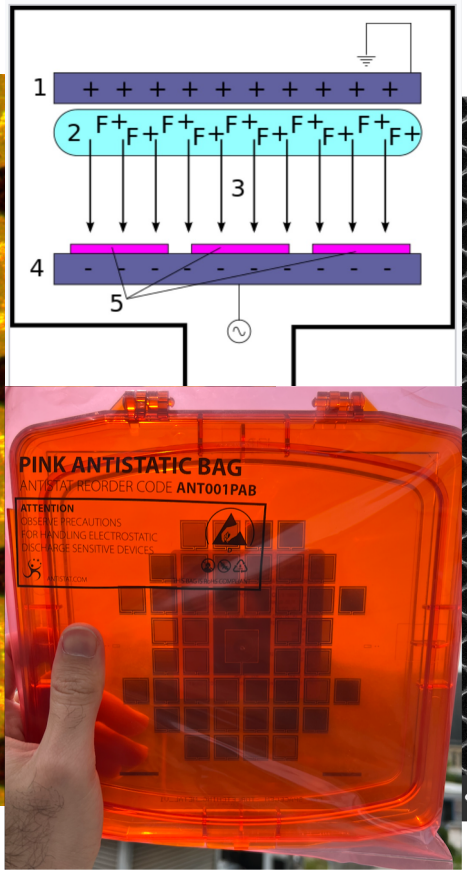
Disadvantages:
- copper re-sputtering inside the hole (can be minimized)
- process is slow (works in series and not in parallel)
- few hours for a single hole (it could be improved)
- Not scalable for 100k holes => 10k days

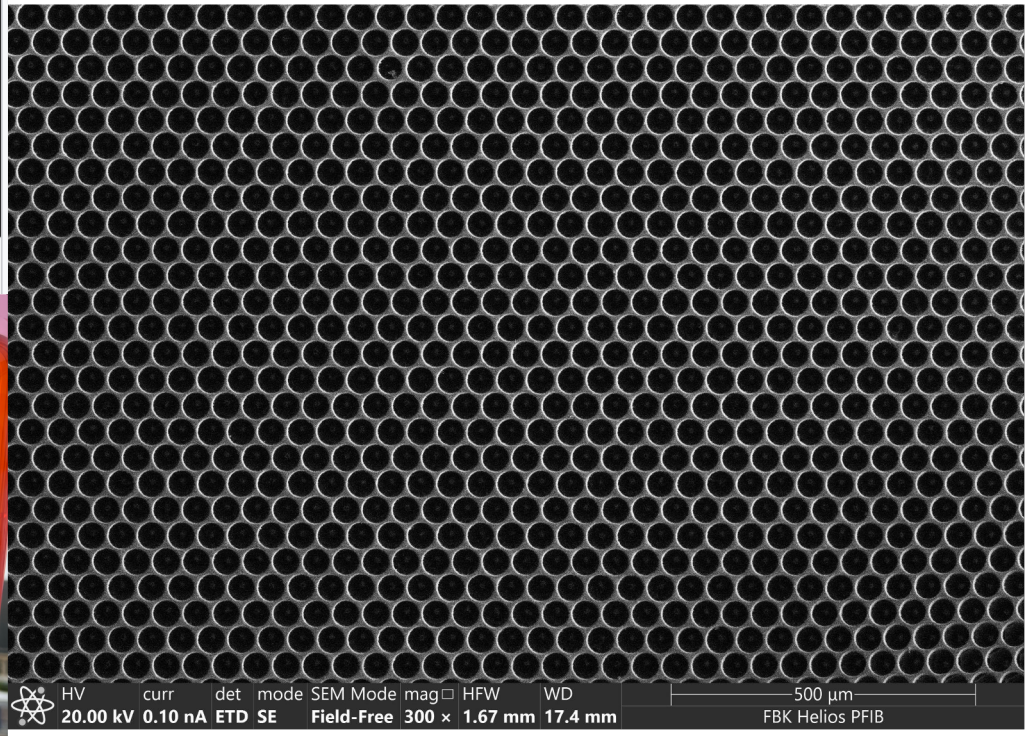
Microfabrication is the most suitable technique that we have at hand



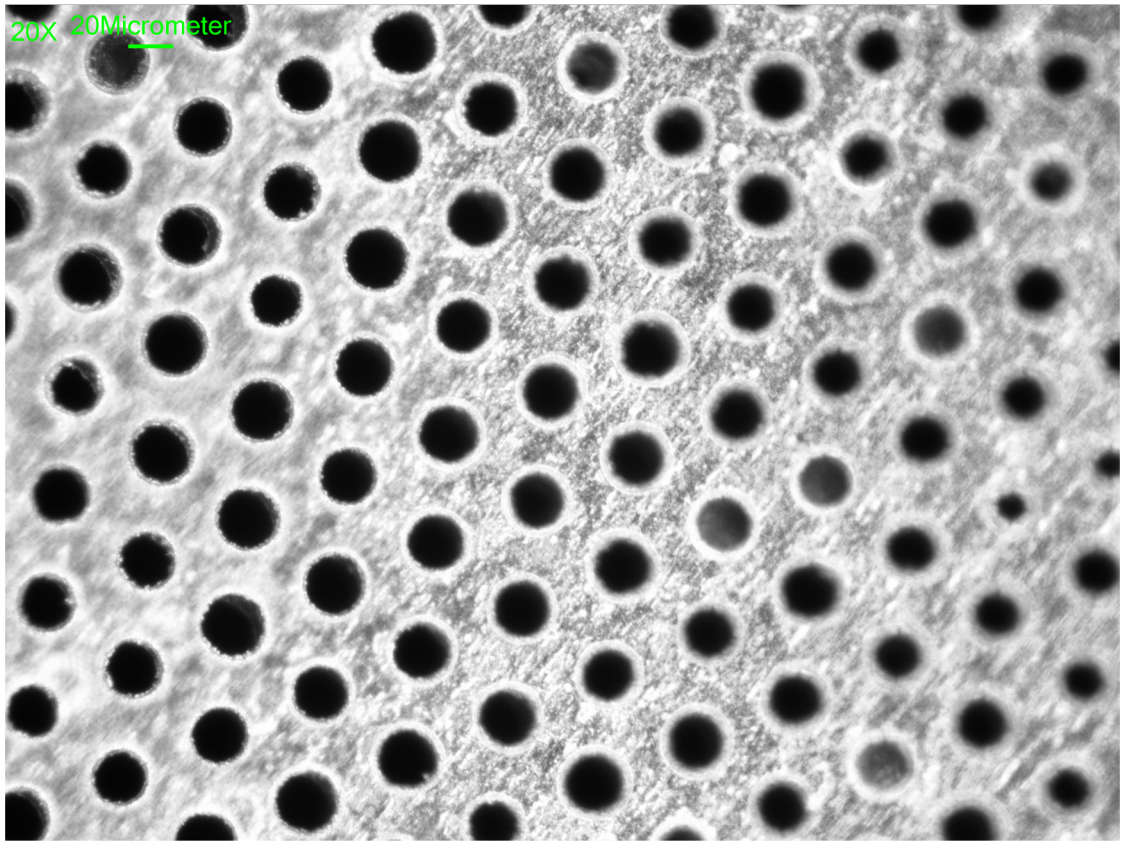
GEM with Reactive Ion Etching (RIE)



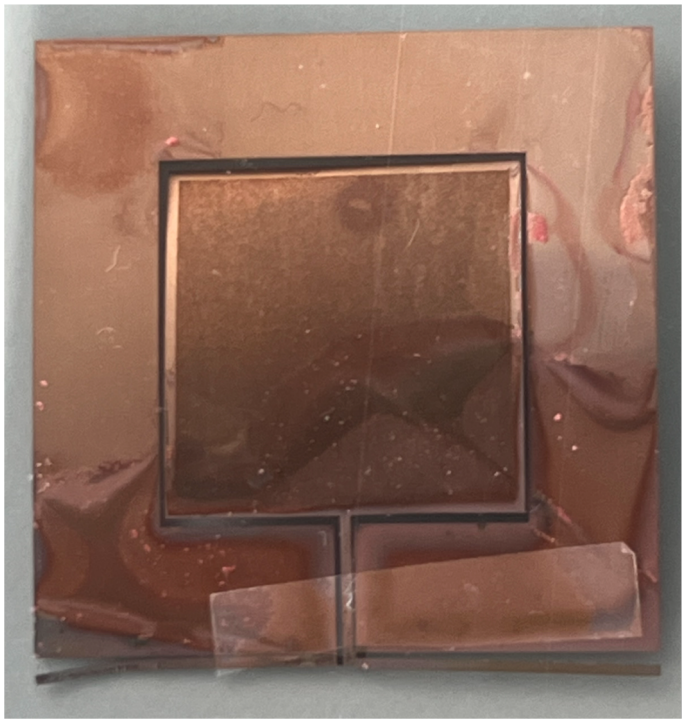




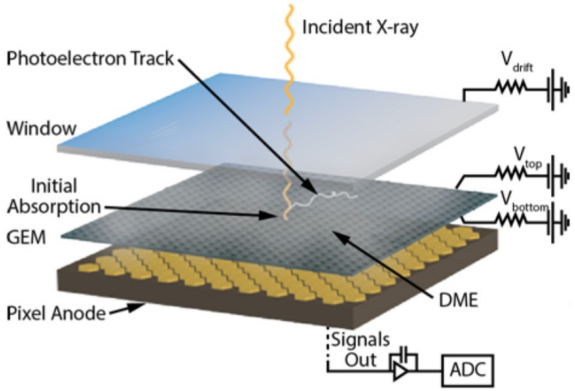
GEM patterned on both sides
With good alignment

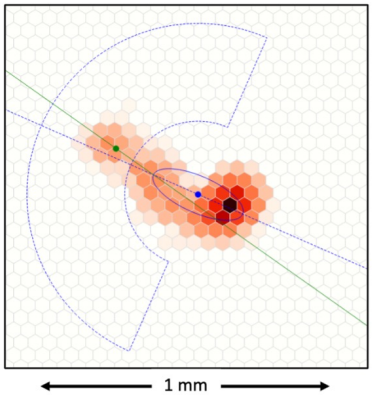


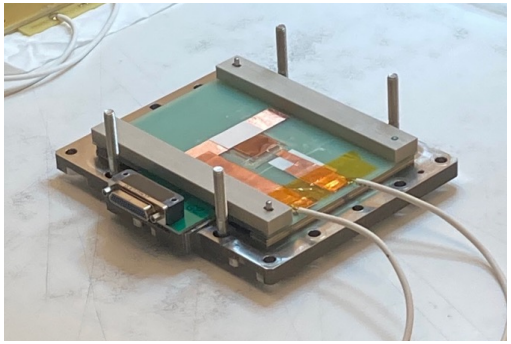
FRESH NEW RESULT!
First GEM double sided
Hole 20 µm-Pitch 50 µm



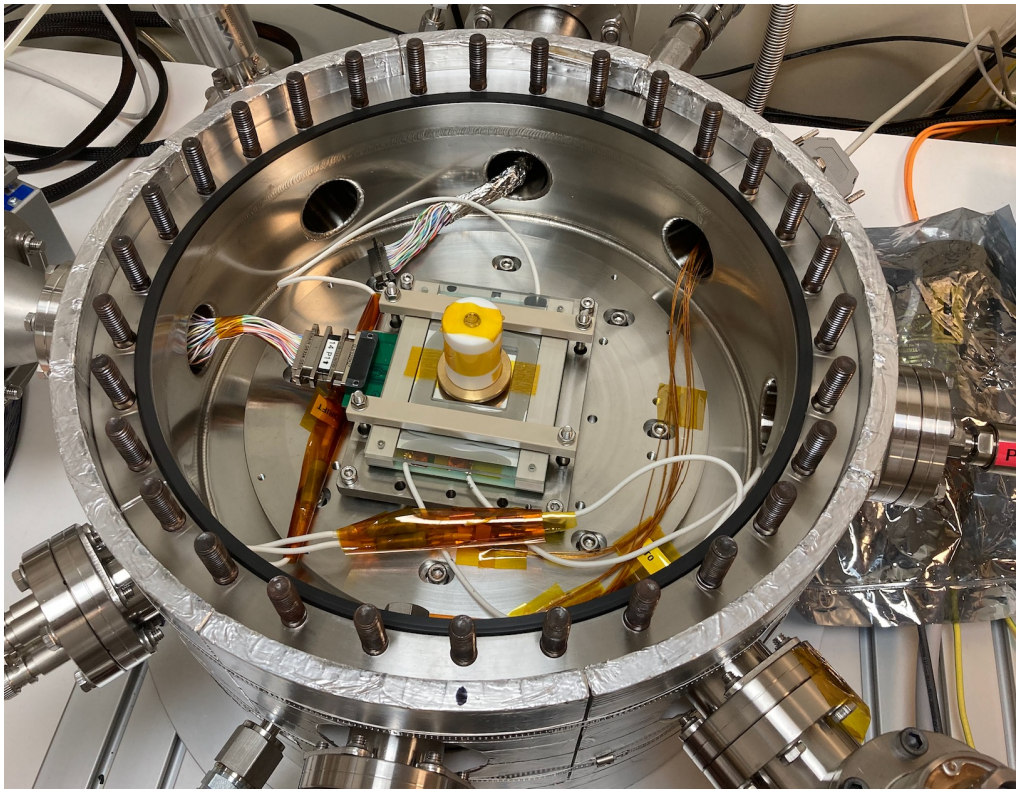
Functional testing setup at INFN Pisa with Fe^{55}





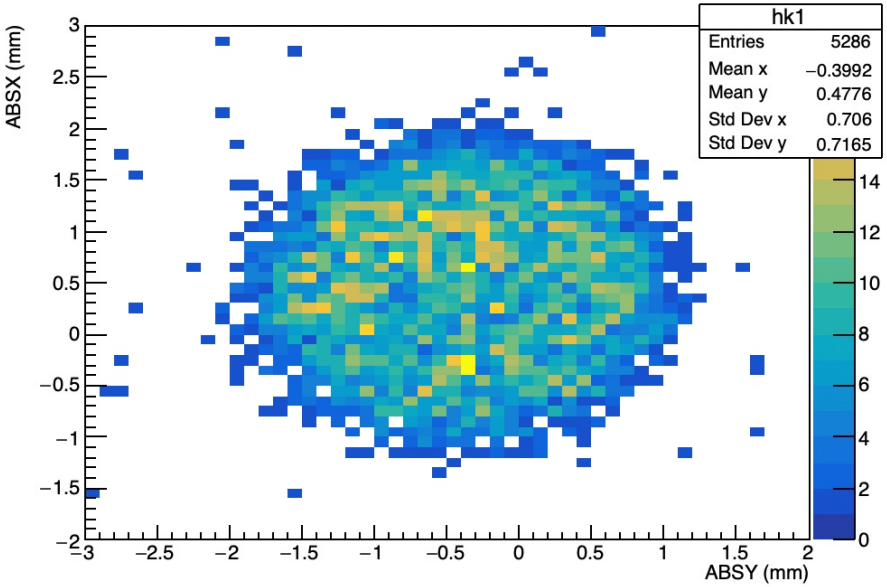


- 5.9 keV from Fe^{55}
- Collimator of 1 mm
- 70/30 Ar & CO_2 at 1 bar



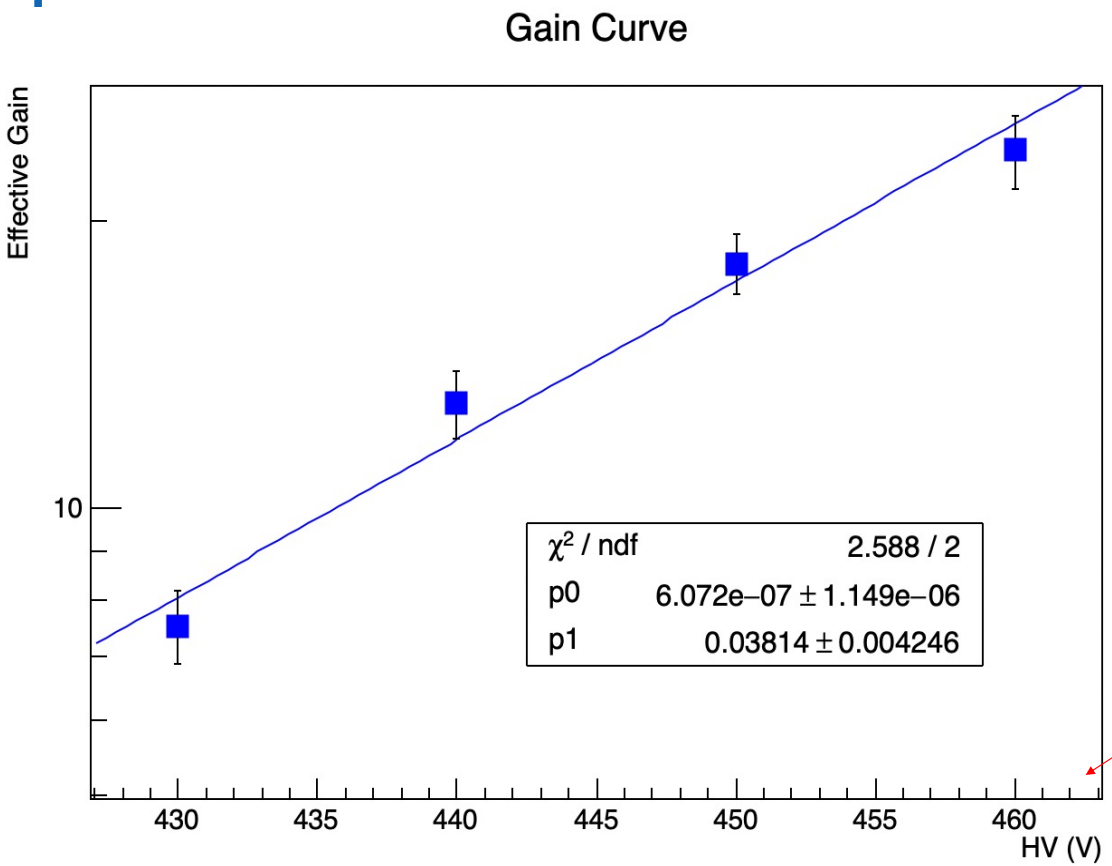
Functional testing setup at INFN Pisa with Fe^{55}

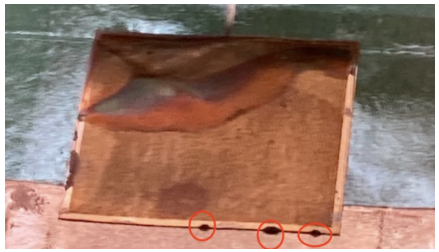
It works! First track observed. This was not obvious, it was our first attempt.



Projection in the ASIC of the 1 mm collimated source.

Gain curve





Discharge due to a problem during the mounting. It is now understood and does not represent a game stopper. No discharge in the patterned area.

$$(V_{2*Gain})_{IXPE} = 25V$$

$$(V_{2*Gain})_{FBK} = 20V$$

Conclusions

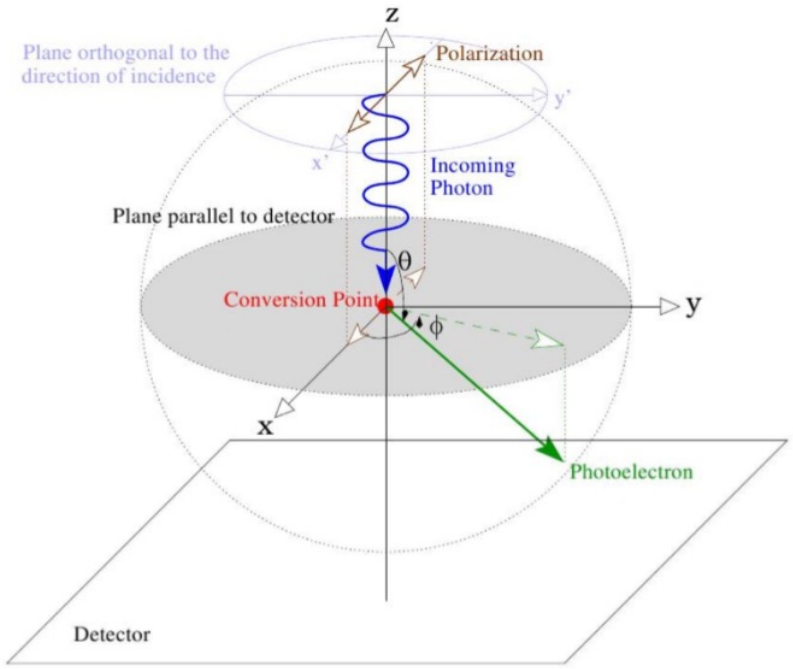
- 1 FBK learned how to fabricate small pitch GEM with plasma etching.
- 2 The geometrical properties are well controlled and homogeneous.
- 3 The gain curve is really promising
- 4 We had discharges due to (known) issues in the mechanical mounting rather than discharges in the active area of the detector

Future perspectives

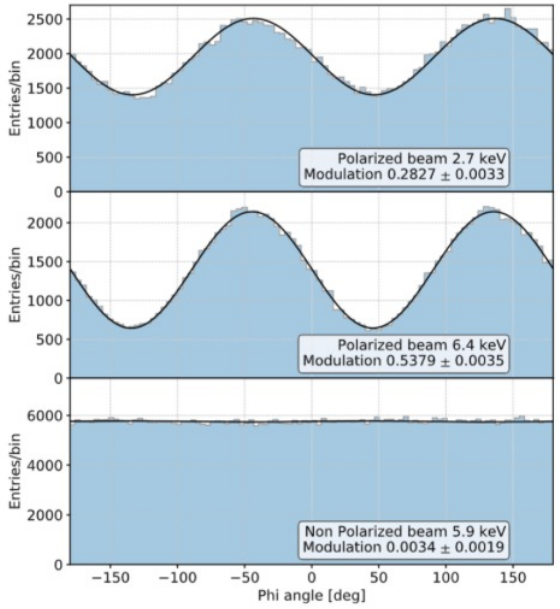
- 1 Perform a complete gain curve.
- 2 Study the performances in extensive experimental campaigns.
- 3 Perform space qualification tests.
- 4 Explore new materials.


THANKS FOR THE
ATTENTION!

Backup



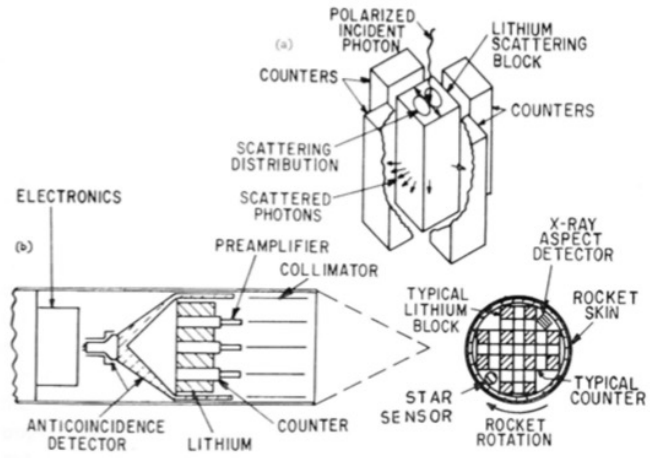
$$\frac{d\sigma_C^K}{d\Omega} \propto Z^5 E^{-\frac{7}{2}} \frac{\sin^2\theta\cos^2\phi}{(1+\beta\cos\theta)^4}$$

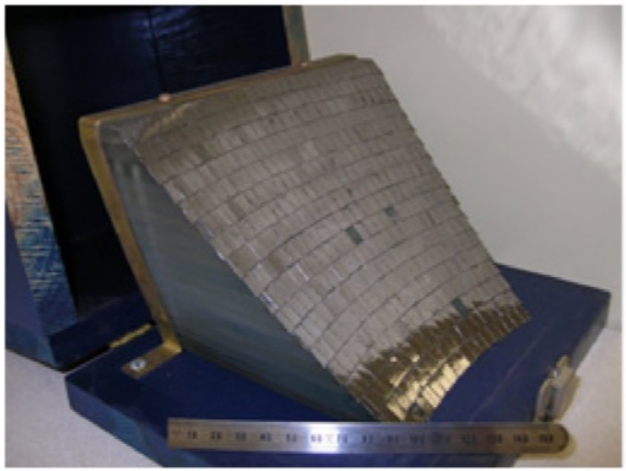


Backup

Orbiting Solar Observatory (OSO-8)

1970-80





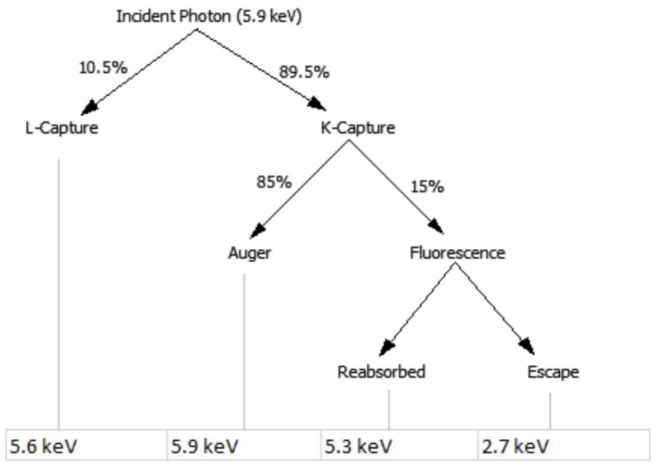
Crab $p = 19 \pm 1\%$

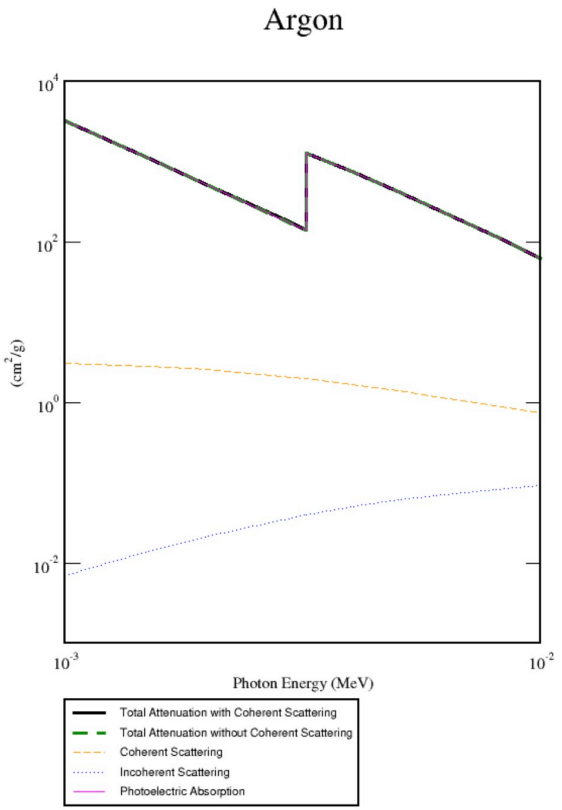
Backup

$$Effective_{Gain} = \frac{PHA_{MediaGaussiana} * 3.7}{235}$$

$1ADC = 3.7e^{-}$ $\quad E_{thr} = 25eV$ $\quad Starting_{electrons} = \frac{5900eV}{25eV} = 235$

$$\Delta V_{2*Gain} = \frac{log(2)}{p_1}$$





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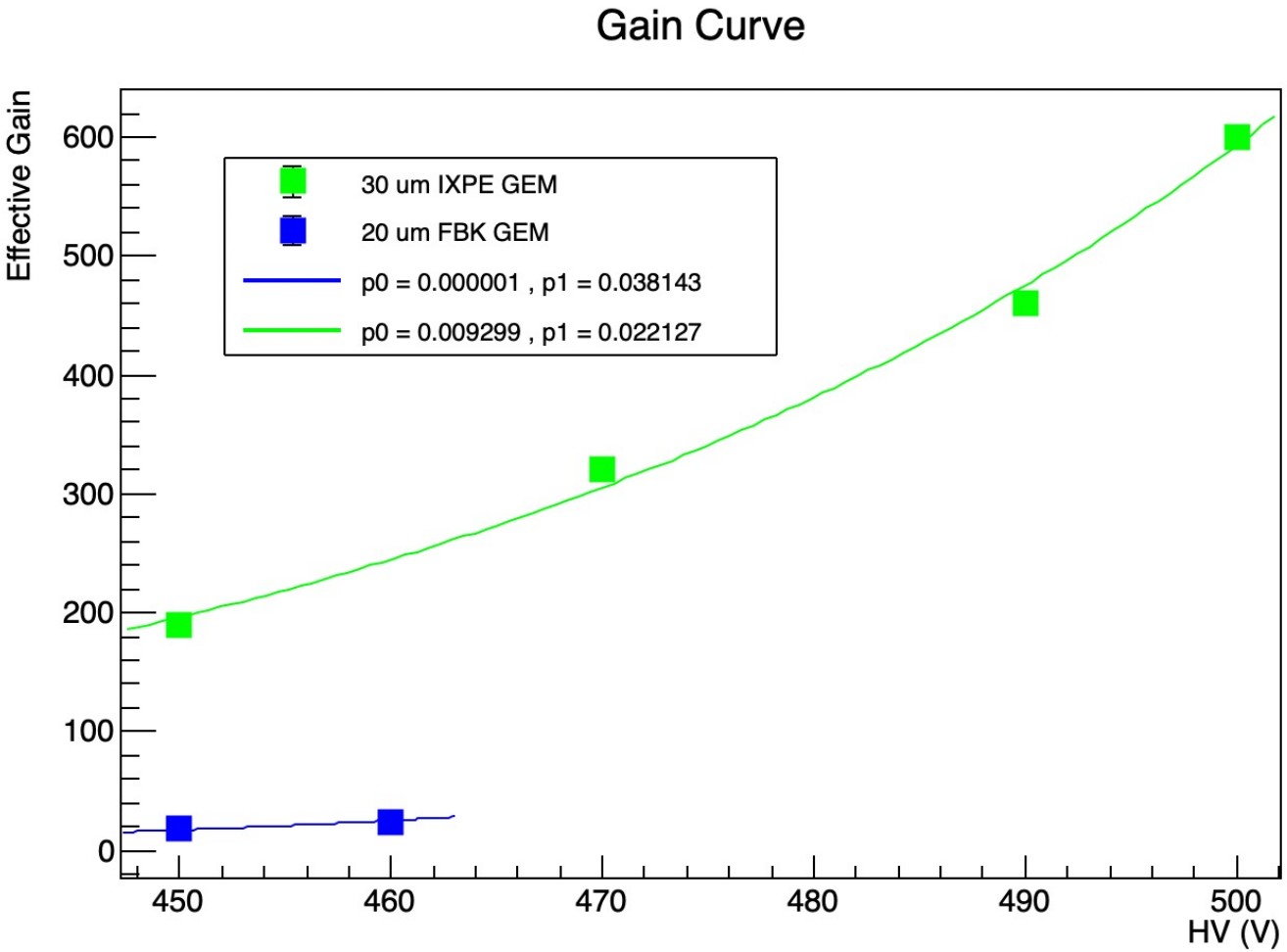
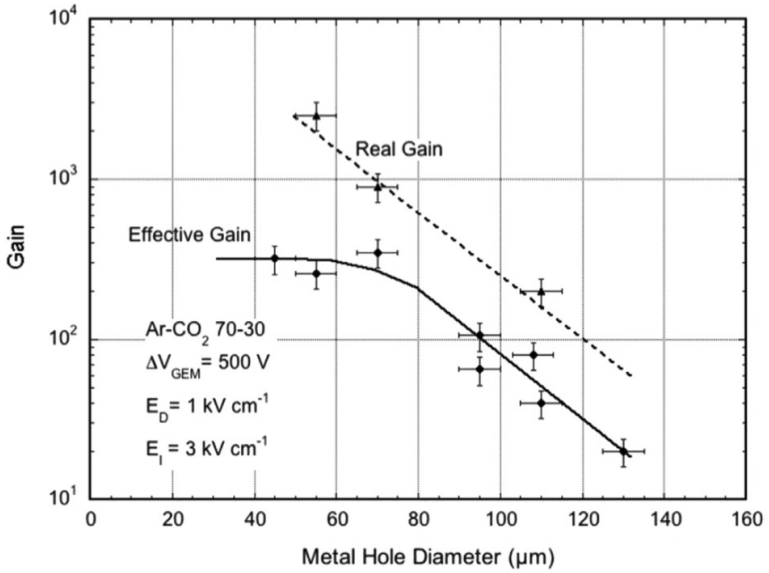
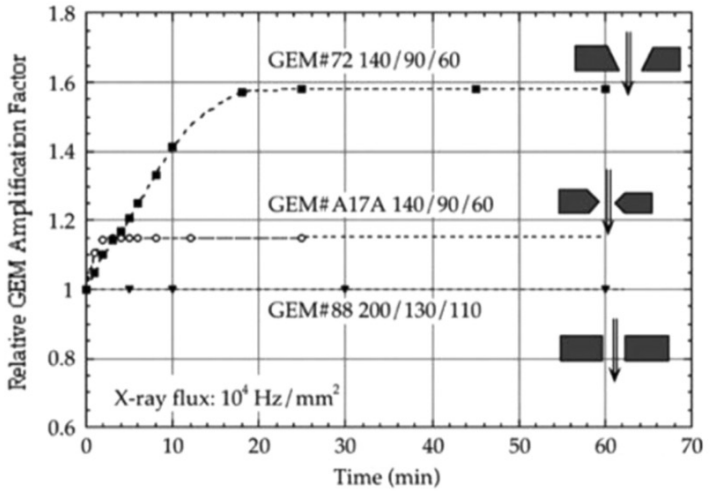
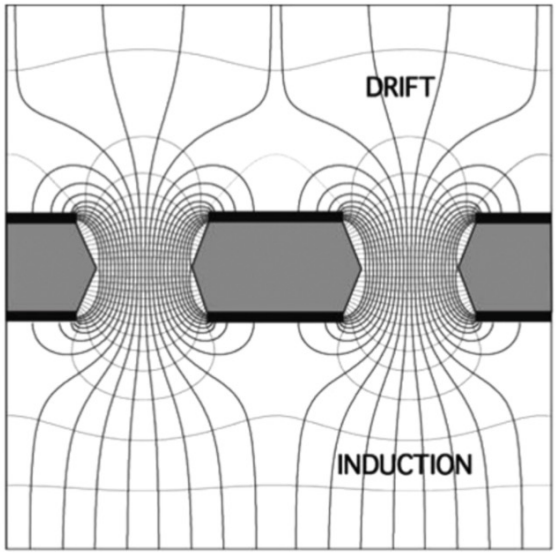

Gain Curve
Effective Gain
600
500
400
300
200
100
0
450
460
470
480
490
500
HV (V)
30 um IXPE GEM
20 um FBK GEM
p0 = 0.000001 , p1 = 0.038143
p0 = 0.009299 , p1 = 0.022127

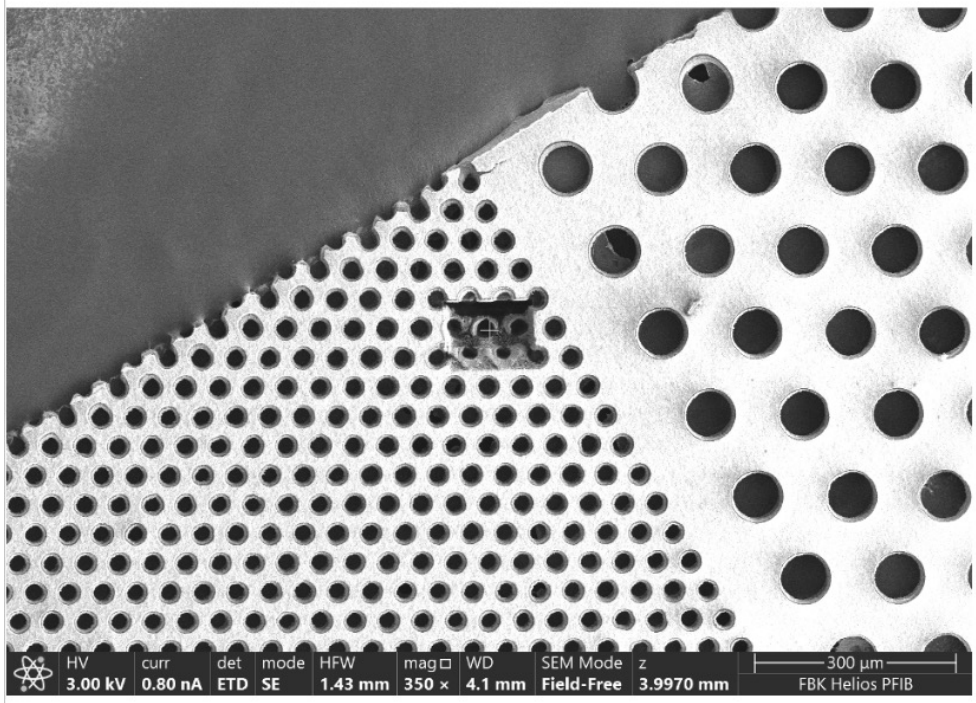
Backup

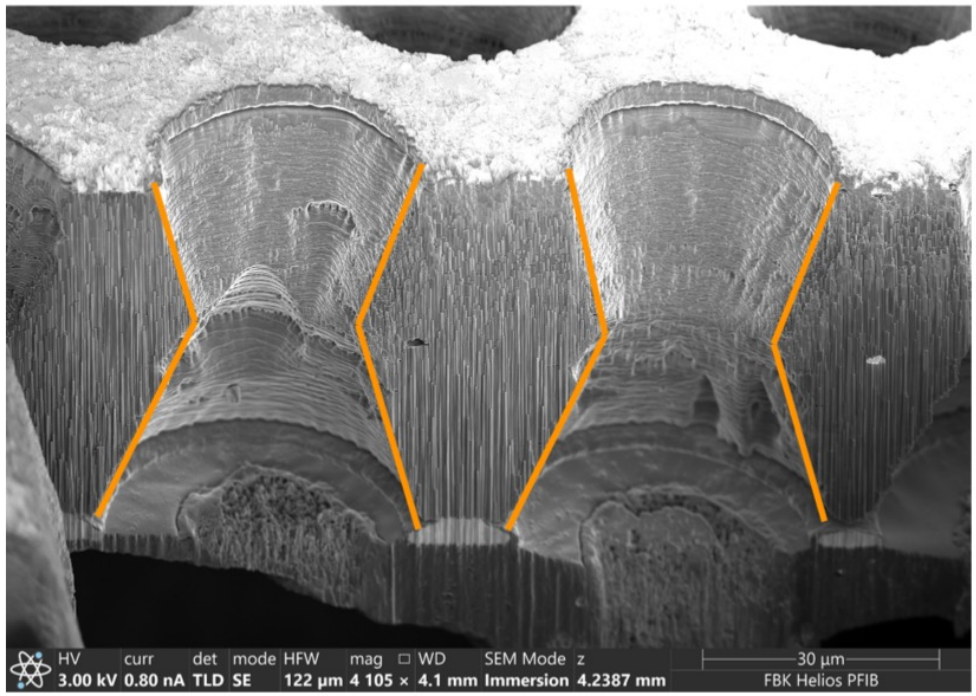

Gain
Metal Hole Diameter (μm)
Real Gain
Effective Gain
Ar-CO2 70-30
ΔVGEM = 500 V
ED = 1 kV cm-1
EI = 3 kV cm-1


Relative GEM Amplification Factor
Time (min)
GEM#72 140/90/60
GEM#A17A 140/90/60
GEM#88 200/130/110
X-ray flux: 10⁴ Hz/mm²


DRIFT
INDUCTION

Backup


HV curr det mode HFW mag WD SEM Mode z
3.00 kV 0.80 nA ETD SE 1.43 mm 350 x 4.1 mm Field-Free 3.9970 mm
300 µm
FBK Helios PFIB


HV curr det mode HFW mag WD SEM Mode z
3.00 kV 0.80 nA TLD SE 122 µm 4 105 x 4.1 mm Immersion 4.2387 mm
30 µm
FBK Helios PFIB