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Novel technique for large GEM-foils production the “Random Segmentation”; Simpler production method with higher GEM detector performances

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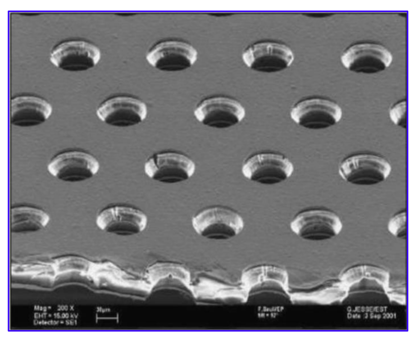
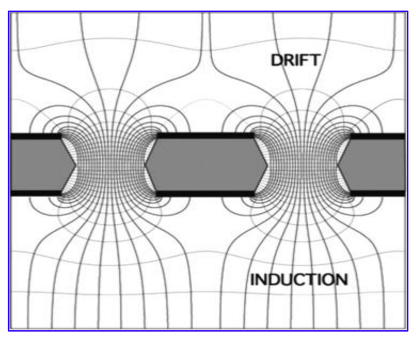
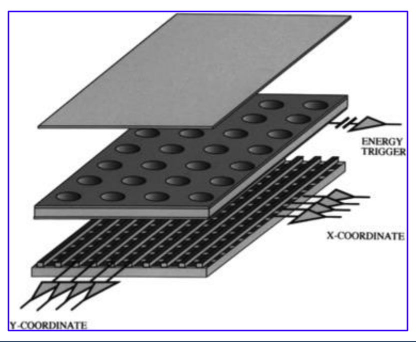
1. The Gas Electron Multipliers

Concept of **G**as **E**lectron **M**ultipliers

- **G**as **E**lectron **M**ultipliers (**GEM**) [1] was introduced by **Fabio Sauli** in 1996-97
- Gas Electron Multiplier electrode is a thin polymer foil, metal-coated on both sides and pierced with a high density of holes, typically 50–100 mm^{-2}
- Inserted between a drift and a charge collection electrode, and with the application of appropriate potentials, the GEM electrode develops near the holes field lines and equipotential
- The large difference of potential applied between the two sides of the foil creates a high field in the holes; electrons released in the upper region drift towards the holes and acquire sufficient energy to cause ionizing collisions with the molecules of the gas filling the structure
- A sizeable fraction of the electrons produced in the avalanche's front leave the multiplication region and transfer into the lower section of the structure, where they can be collected by an electrode, or injected into a second multiplying region, schematically a single GEM detector, with a two-dimensional patterned charge detection anode

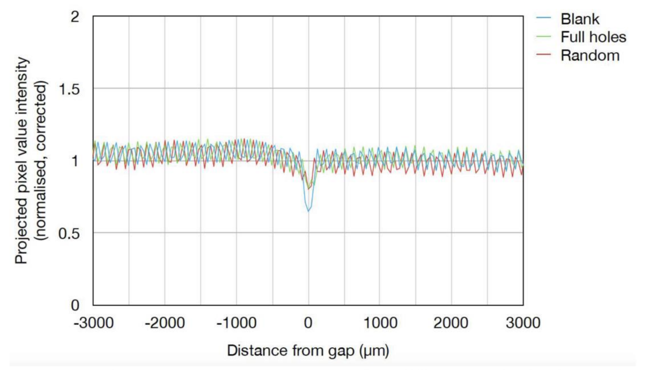




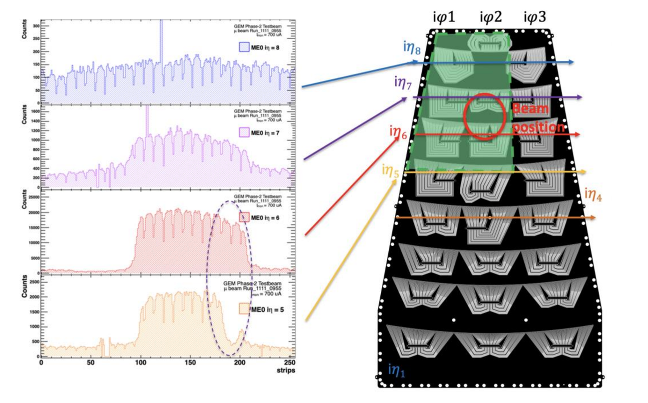


2. The Random segmentation: Motivation

- Simplification of large area GEM foils production
  - Removing GEM holes/Sectors alignment issue
- Possibility to design HV sectors of any possible shape, with reduced dead area between HV sectors
- Improve the GEM foils transparence [2], [3]
- Remove possible overlap between HV sectorization and readout strips/pad in detectors realized with HV sectors and readout pattern overlapping along the same coordinate
- Expect to improve efficiency and uniformity within the entire detector area covered by GEM foils
- Prove that the single mask technique allow to master GEM foils without any issue against HV distribution stability
  - In the past similar R&D based on GEM foils produced were abandoned due the GEM foils instability against HV distribution (Sparks) [4],[5]

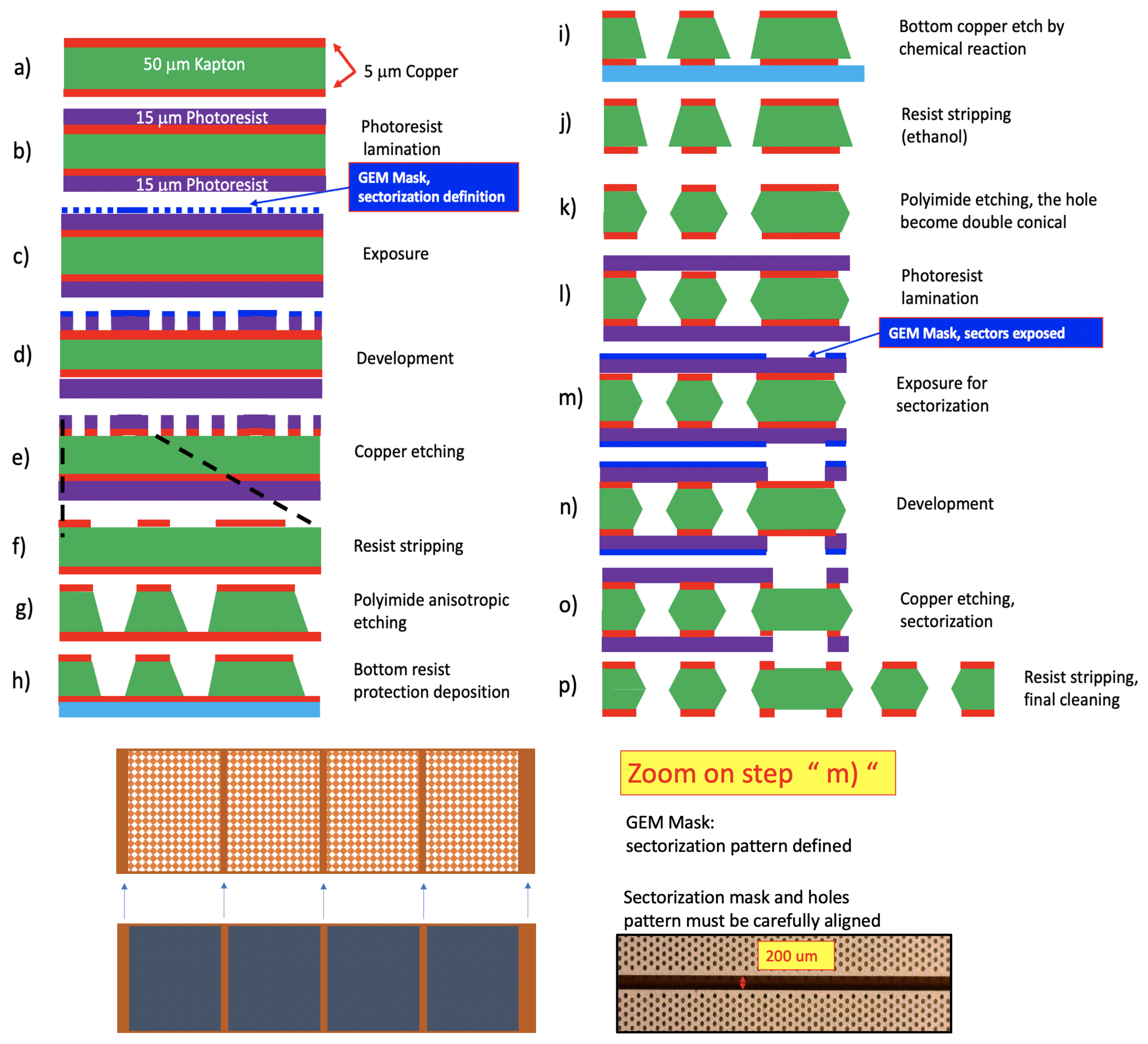


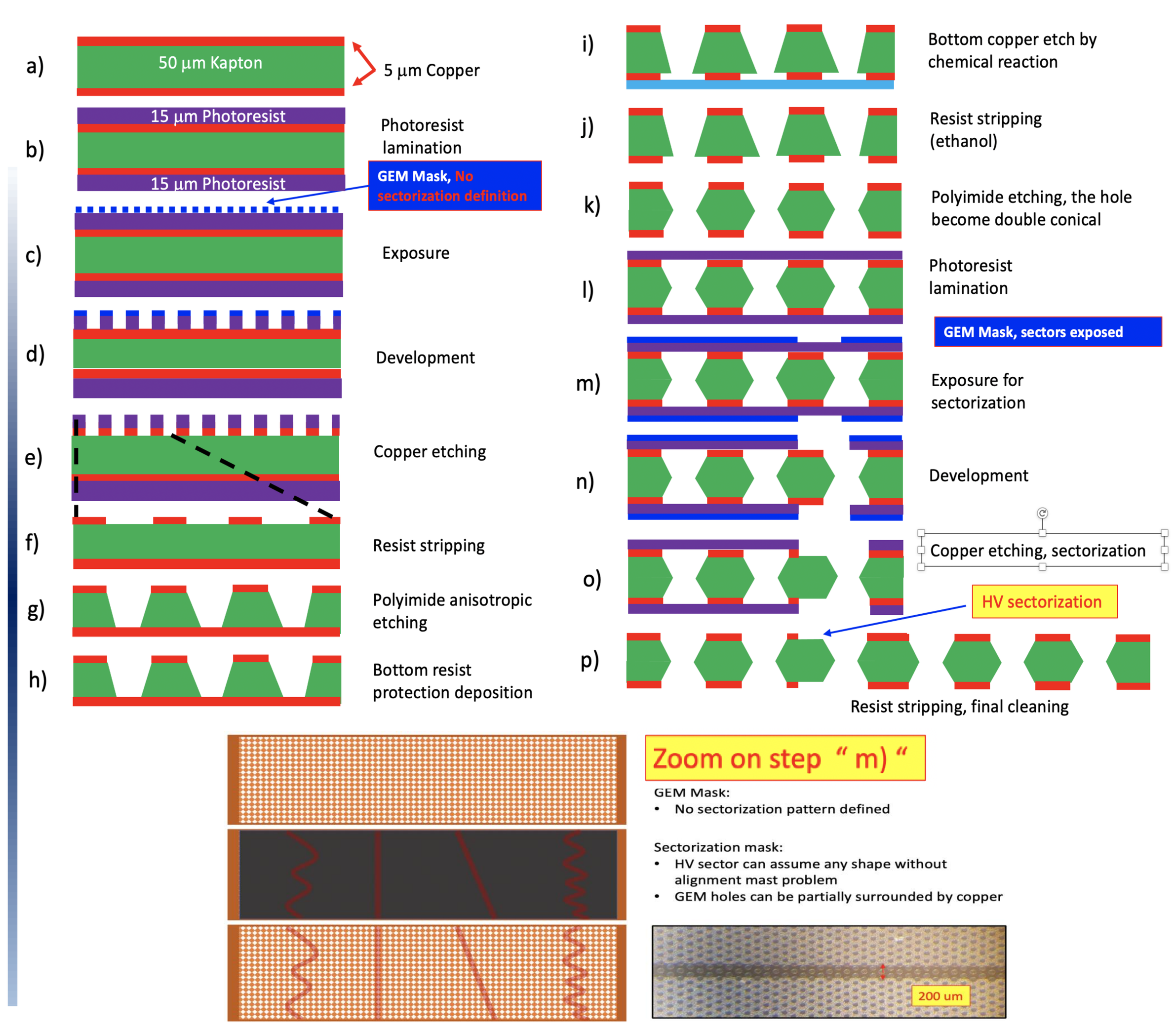
GEM Foils transparency at X-ray for different kind of sectorization, “Blank”, “Full holes”, “Random” [3]



CMS-ME0 Module, equipped with GEM foils “Blank” sectorized along the RO Strips. Longitudinal HV segmentation clearly observed in occupancy plot [6]

3. Manufacturing Process of GEM: Standard and Random Segmentation



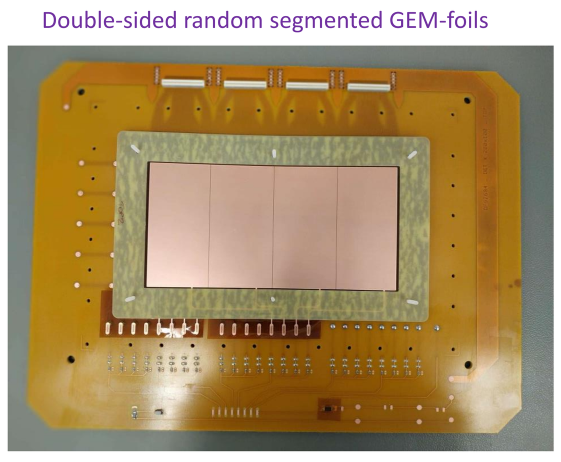


4. The 10x20 Chamber Prototype

Triple-GEM detector prototype

- ✓ active area: 10 cm × 20 cm
- ✓ gas configuration: 3/1/2/1 mm
- ✓ double-sided random segmented GEM-foils
- ✓ operating gas mixture: Ar/CO_2 (70/30) - 5 l/h
- → single-mask photolithography technique
- → 200 µm width copper free gaps produced at an angle of ~ 100 µm w.r.t. the hole pattern
- → 1MΩ prot. resist. on top, 100kΩ prot. resist. on bottom

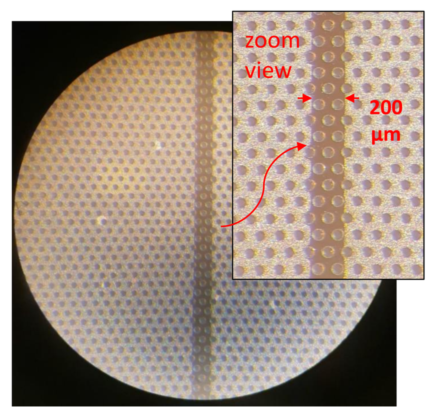
Double-sided random segmented GEM-foils



Optical inspection results:

- ✓optical inspection by backlight → good
- ✓holes uniformity → good
- ✓holes diameter → good

copper rings diameter: $\varnothing_{Cu}$ ~ 74 µm (required specs 70±5 µm)
polyimide rings diameter: $\varnothing_{PI}$ ~ 53 µm (required specs 50±5 µm)



Microscopie pictures of the random electrode sectorization

To be verified:

- ✓ Possible copper delamination risk in the vicinity of the insulating region between adjacent sectors
- ✓ Minimize the electric field distortion and recover the potential efficiency loss at the sector gaps

5. Performance of 10x20 prototype chamber

High Voltage and Linearity Test in pure N_2

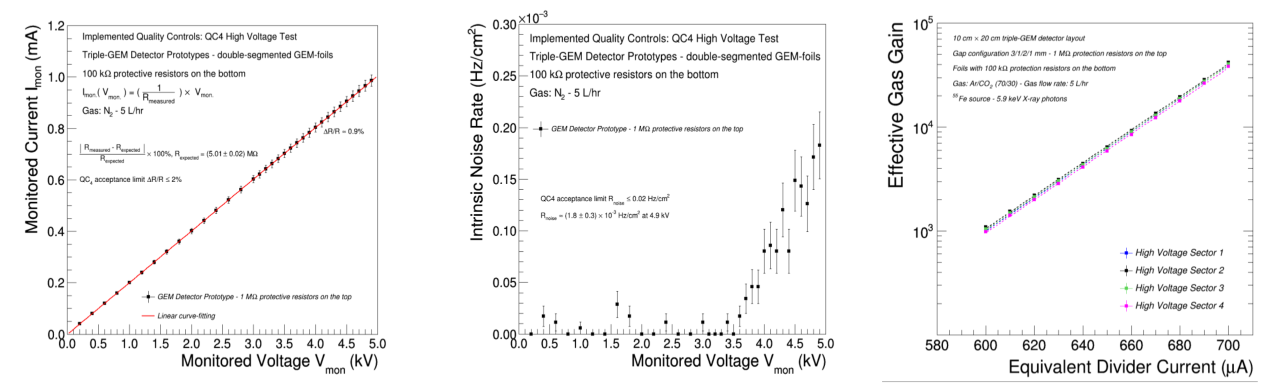
- ✓ High voltage and linearity test aims to determine the current voltage curve in order to identify possible malfunctions, defects in the HV circuit and intrinsic noise rate
- ✓ High voltage test includes the operating of the chamber at HV values leading to electric current values exceeding 40% the nominal ones as required by a final experiment

NO trips of the power supply or disruptive events were recorded

Measurement of the Effective Gas Gain in Ar/CO_2 (70/30)

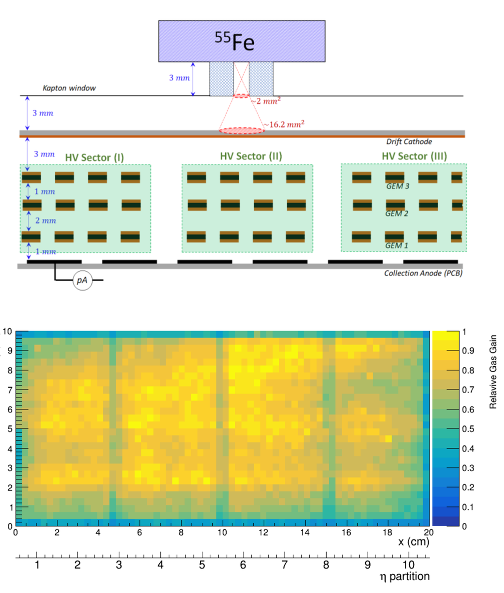
- ✓ Effective gas gain for the prototype with random electrode sectorization comparable to triple-GEM detector with standard sectorization

Effective gas gain in Ar/CO_2 (70/30) of about 2×10^4 at 680 µA of equivalent divider current (i.e. drift voltage 3.2 kV)



Gas Gain Uniformity

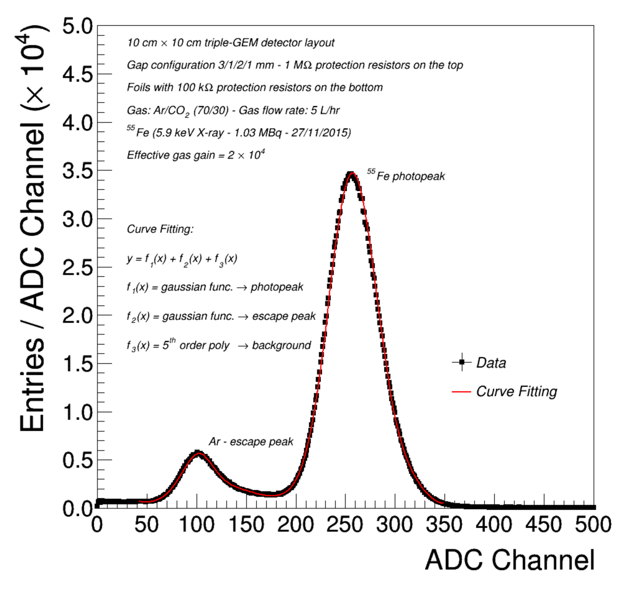
Gas gain map of the triple-GEM detector. Collimated 5.9 keV ^{55}Fe source (~ 2 mm^2) used to scan the 10 cm × 20 cm area at a 3 mm (x-coord.) × 4 mm (y-coord.) grid



6. Characterization and stability tests of 10x20 random segmented foils

Energy Spectrum in Ar/CO_2 (70/30)

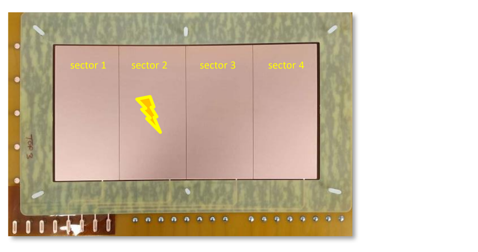
Typical energy spectrum of ^{55}Fe source: clean separation of the main photopeak and the Ar-escape peak is achieved



Energy resolution in Ar/CO_2 (70/30): FWHM/μ ~15%

High Voltage Stability in Ar/CO_2 (70/30)

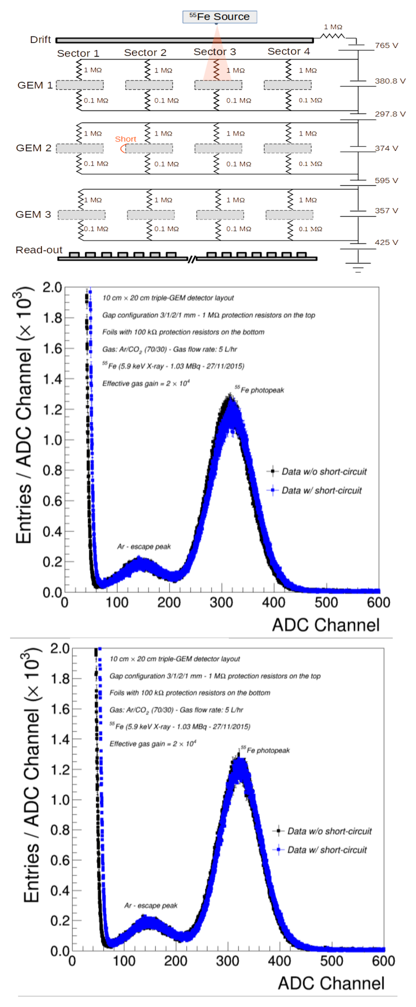
- ✓ If a sector of the GEM-foils is in short-circuit, the current flowing through the top and bottom side of the foil increases
- ✓ A short circuit is introduced in the sector 2 of GEM_1 (or GEM_2, or GEM_3)



- ✓ The current flowing through the other sectors and foils is proved to be stable. No abnormal leakage current or discharges were detected during several hours of measurement

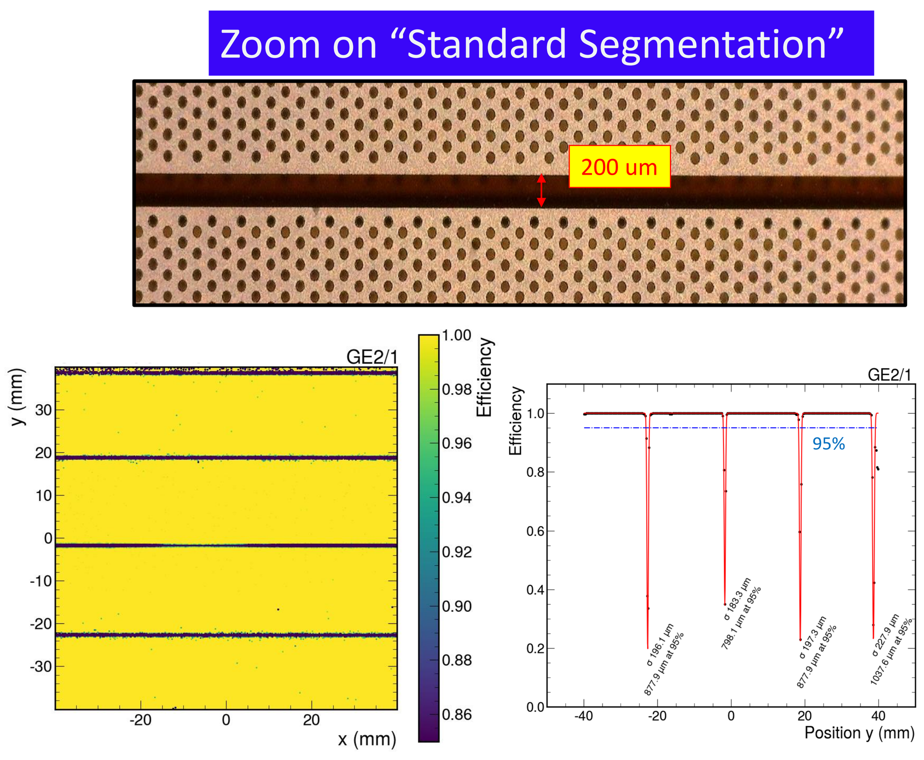
Energy Spectrum in Ar/CO_2 (70/30)

Energy spectra measured after positioning a ^{55}Fe source over a sectors adjacent to the short-circuited one are not affected by the presence of the short



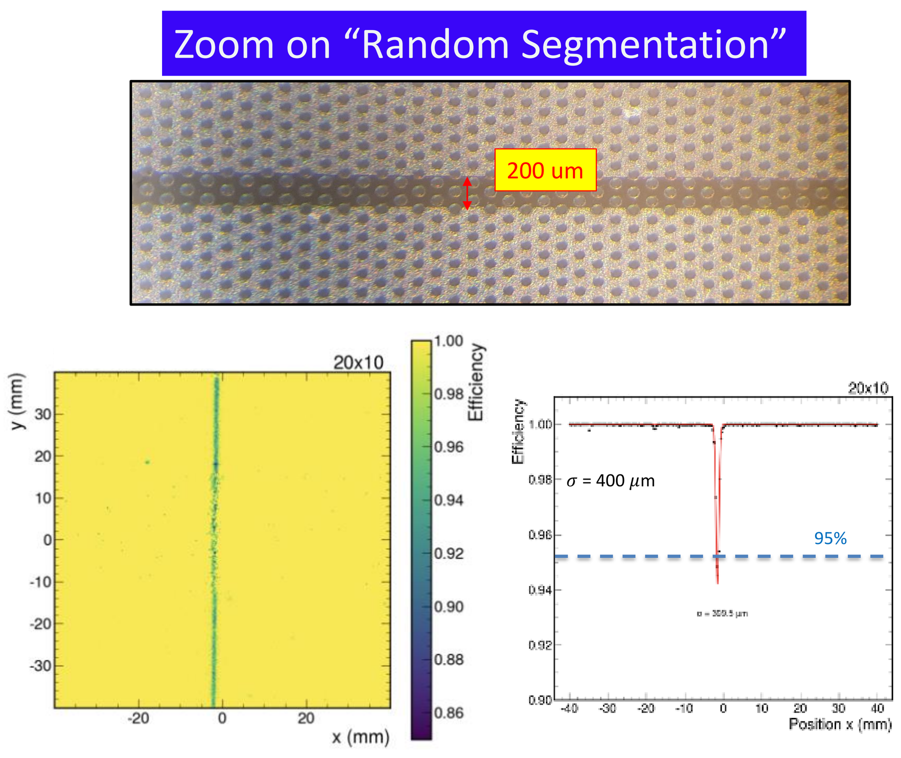
7. Efficiency measurements ad Test Beam of 10x20 prototype chamber

Zoom on “Standard Segmentation”



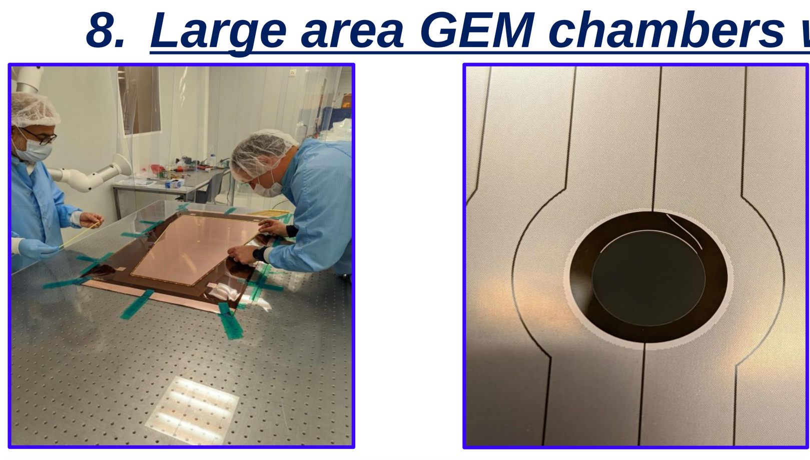
- Efficiency measured in CMS - GE2/1 chamber operated at GAIN: 2E4, instrumented with Standard Segmented GEM foils
- Sigma Efficiency dip due to the HV segmentation is 200 μm (Dip @ 95%: $w = 900 \pm 100\ \mu m$)
- Efficiency drop also up to ~20%

Zoom on “Random Segmentation”

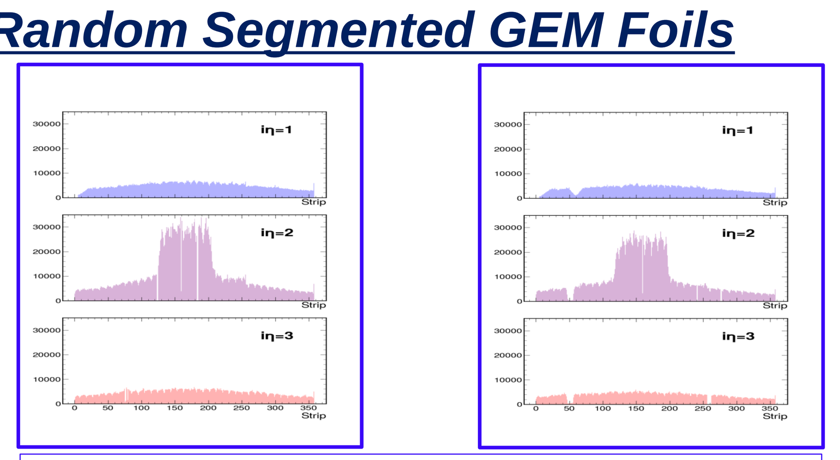


- Window of 9cm x 9cm, in 10x20 chamber with Random Segmented foils defined by the Tracker coverage
- Sigma Efficiency dip due to the HV segmentation is 400 μm (≪ width 95% efficiency)
- Efficiency drop very limited ~94%

8. Large area GEM chambers with Random Segmented GEM Foils



Large triple-GEM module (CMS-ME0 shape) assembled in March 2022 with “Random Segmented” foils



Strip profiles from CMS-ME0 modules assembled with blank (Left) and Random (right) segmented foils from June 2022 Test Beam

Conclusion

- ❖ **Random Sectorized GEM foils, mastered with single mask technique have been proved to be stable against HV distribution, to not suffer of discharge issues and be suitable for production of GEM detectors**
- ❖ **Small prototype chamber, 10x20 cm2, and large module having same shape of CMS-ME0 chambers have been assembled, tested and fully qualified.**
- ❖ **Test beam results shown that the detector efficiency is largerly improved, providing uniform efficiency amongst the whole detector, the efficiency drop measured with Random Segmented chambers, in correspondance of the secotrization is about 6%, while in Blank sectorized modules it reach the 70-80%**

[1] F. Sauli, **GEM: a new concept for electron amplification in gas detectors**, NIM A 386 (1997) 531
[2] F. Brunbaueret al, **The planispherical chamber: A parallax-free gaseous X-ray detector for imaging applications,** NIMA 875 (2017) 16
[3] F. Sauli, **Restoring Efficiency in GEM Sector Separation,** talk at RD51 Collaboration Meeting, 21-23 Oct 2019
[4] C. Altunbaset al, NIMA 490(2002)177
[5] M. Zigler, PhD Thesis, Development of a triple GEM detector for the LHCb Experiment, CERN-THESIS-2004-006
[6] A.Pellecchia et al, **Performance of triple-GEM detectors for the Phase-2 CMS upgrade and a high-resolution GEM telescope measured in a test beam,** Poster at 12th Pisa meeting on advanced detectors – May 22-28, 2022, Elba, Italy