Study of GEM detectors and their applications to Imaging

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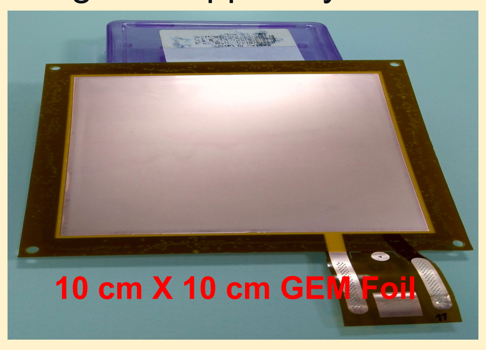
ABSTRACT

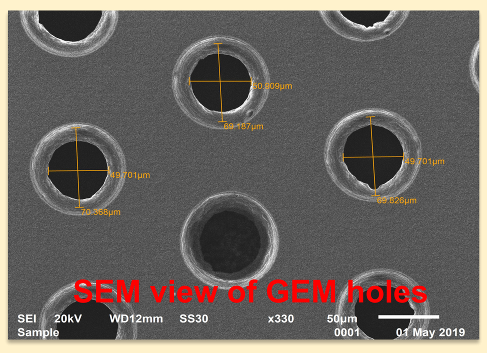
The Gas Electron Multiplier (GEM) Detector is being used extensively to handle a fairly large flux environment in high energy and other related experiments. Due to the ease of operation with environment friendly gases, this detector can be deployed to wider range of experiments as well as in applications to developing the instruments for humanitarian aid purposes. In this talk, we will present results from one such effort. We collaborated with the industry to produce the GEM foils of various specifications and then made an effort to use GEMs as an imaging detector for medical as well as security purposes. The key component of a GEM detector is the GEM foil which has very dense go-through holes on a 50 µm highly insulating foil (Kapton/Apical) coated on both sides with 5 µm layers of copper. Before these GEM foils can be used for assembling the GEM detector the foils electrical and optical properties have to be tested to find defects and correct it. We report on the development of techniques used to study the GEM foils electrically and optically. A feasibility study to utilize GEM detectors for imaging objects with varying densities with x-rays were carried out. The reconstructed images shows a good distinction between materials of different densities, which opens the possibility to further explore the applications of GEM detectors to medical imaging or cargo imaging.

GEM Foil & Characteristics

➢ ***Gas Electron Multiplier (GEM):*** F. Sauli in 1997 [1] introduced a new concept in gaseous detector with micro pattern foil called Gas Electron Multiplier (GEM). GEM foils consist of a 50 µm thin polyimide (Kapton/PI) foil coated with a thin layer of copper on both sides. Bi-conical holes with 50 - 60 µm inner and 70-80 µm outer diameters are chemically etched in the foil at a pitch of about 140 µm by using either a double mask or single mask technique. GEM foils are produced, using photo-lithographic techniques in which hole patterns are transferred to the copper-clad polyimide substrate using microscopic masks placed on the top and bottom of the substrate. A 15 µm thick photo-resistive layer is applied on both sides of the substrate and the mask is placed on top of the base material and engraved on the photoresist by UV-light exposure. The foil used has a 50 µm Kapton film with 5 µm copper foil on either side. Several solvents and acid baths are used to etch the copper layer to form the copper holes. The polyimide is then dissolved by chemical etching using the copper layer as a mask.



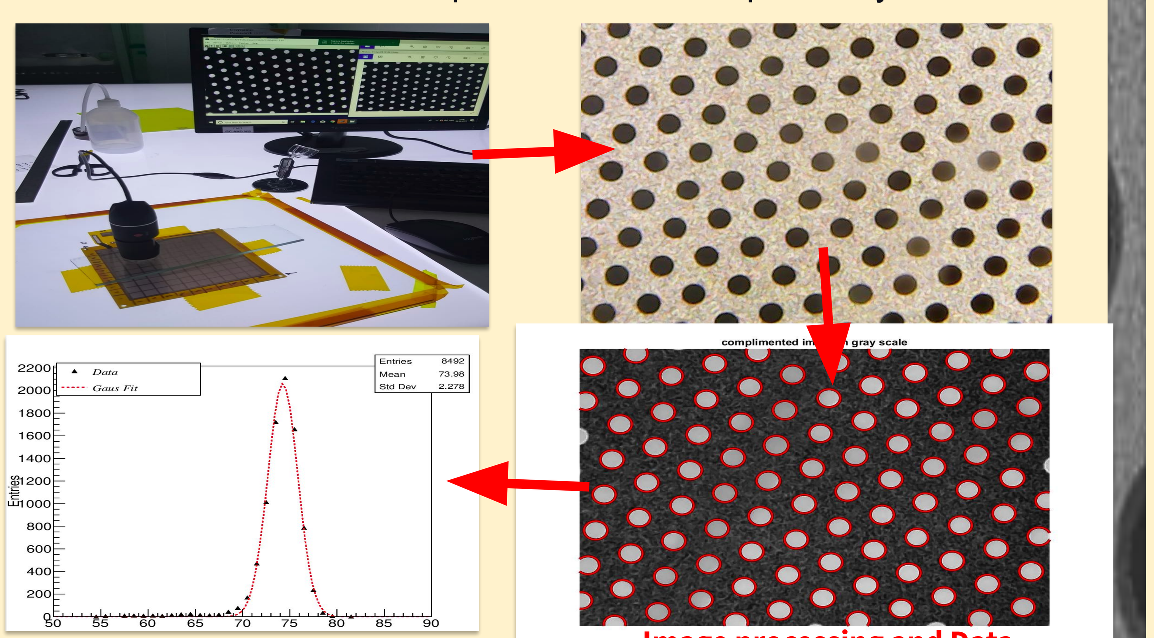
10 cm X 10 cm GEM Foil



SEM view of GEM holes

➢ ***Optical Inspection of GEM Foils:*** The GEM foil performance depends heavily on the hole geometry and its pattern. A GEM foil with a 140 µm pitch using a hexagonal hole pattern contains approximately 600,000 holes. Any irregularity or defect in the hole pattern or in its geometry can profoundly affect their performance. Therefore it's very important to study foil to locate every glitch and defects which could lead to foil failure.

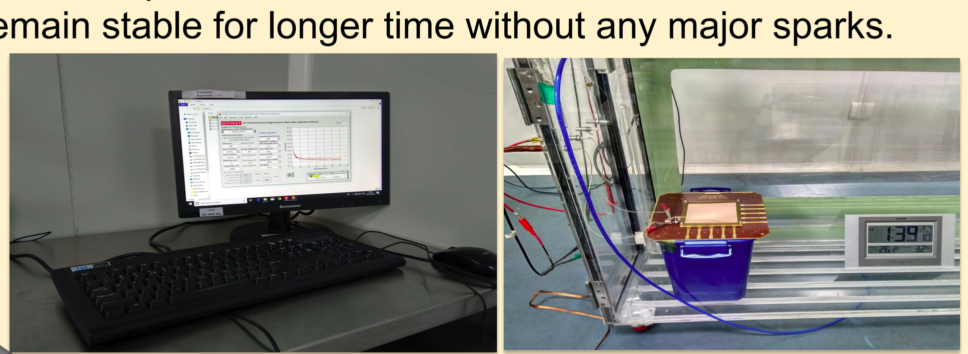
To study these holes, we opt for a digital image processing method, which can be effective and cost-effective. This technique uses a digital microscope to take images and then process them using MatLab [2] image processing algorithm to study holes defects, their diameter, and pitch. The setup is first calibrated using image data taken from SEM. A hundred of images of inner and outer holes were taken on each side of the foil with the random position, The analysis of all the pictures and their data for the top side is shown figure. The observed outer and inner hole mean diameter of 73.98 µm and 53.37 µm with a standard deviation of 2.78 µm and 1.415 respectively.



Data Processing using ROOT

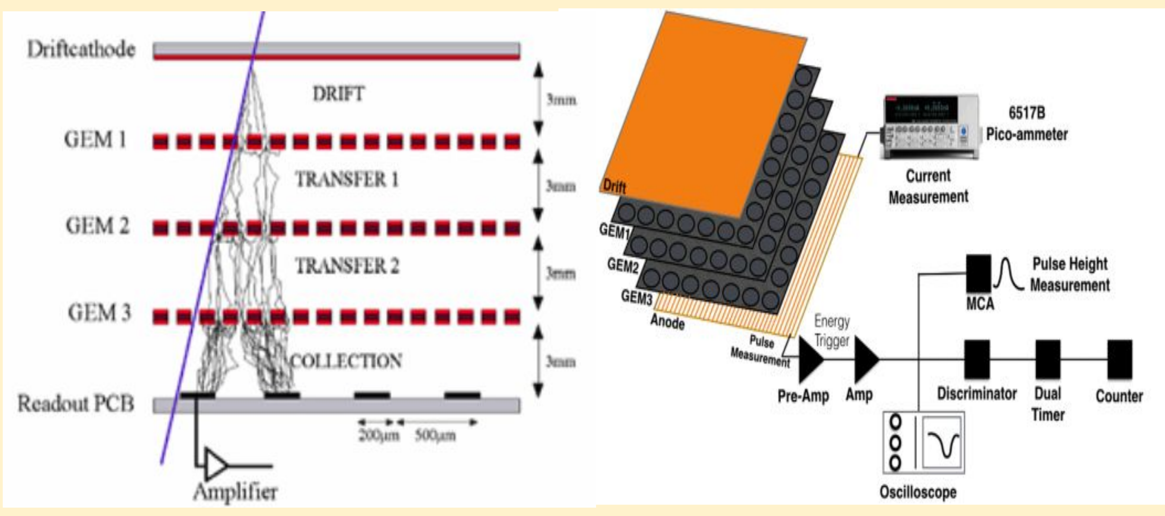
Image processing and Data Extraction in pixels using MatLab

➢ ***Electrical Behaviour:*** Electrical properties of the GEM foils were tested by measuring its leakage current extended over a period of time in well controlled environment after proper cleaning, at various voltages, temperature and humidity. The leakage current insures the proper cleaning, electrical defect and stability of the electric field inside holes. Foil has shown impedance of more then 100 Gohm over 550V and remain stable for longer time without any major sparks.



Detector Performance & Imaging

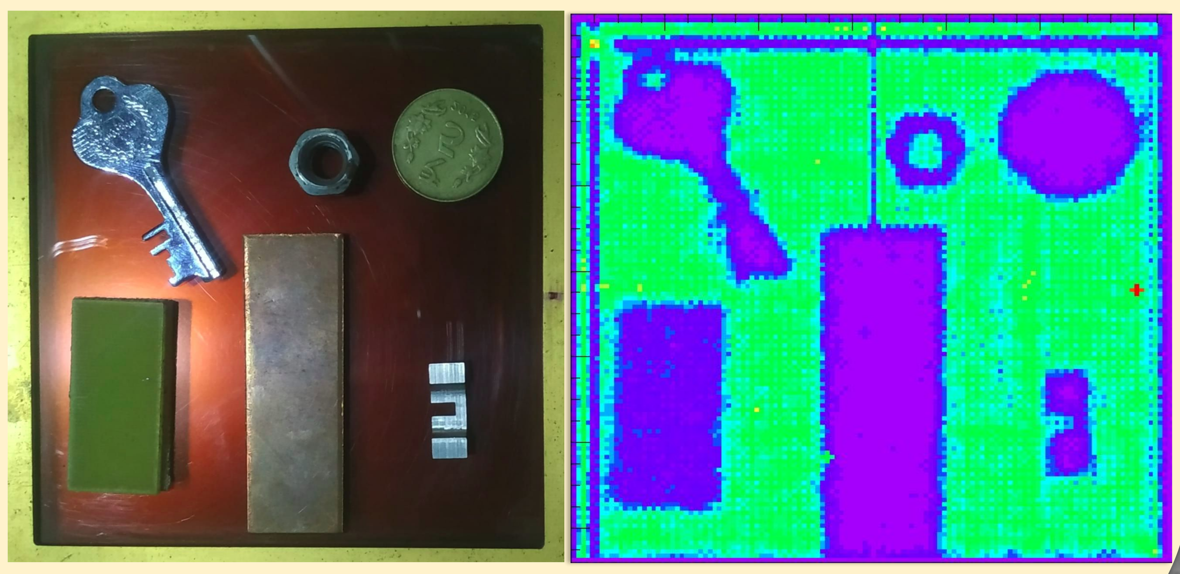
- **Detector Assembly & Performance:** 10cm X 10cm triple layered GEM detector with 3/1/2/1 gaps in mm was assembled and inspected its behaviour by performing following test[3].
  - High voltage stress test. This test is done in pure CO_2 flushing at 3 l/h and is a check to withstand high voltage without discharge/sparks or much noise.
  - Spurious rate measurement, which checks signal coming from detector without any actual charged particle or high energy photons interactions.
  - Gain of the detector in Ar/CO_2 (70:30) mixture (3 l/h). Here Ar is ionising gas, with which ionising particle interact and create e^-/ion pair, these primary electrons than drift towards three GEM foils, where they experience enough high electric field to create secondary electrons from ionising gas, three layer of GEM foils act as electron multiplier and the avalanche of electrons produced in this way are collected on readout plane where these charges passed through DAQ system to amplify, shape and count the signal. Detector was irradiated with X-ray source of 22.8 keV of energy for the gain measurement.



➢ **Imaging Using GEM Detector:**

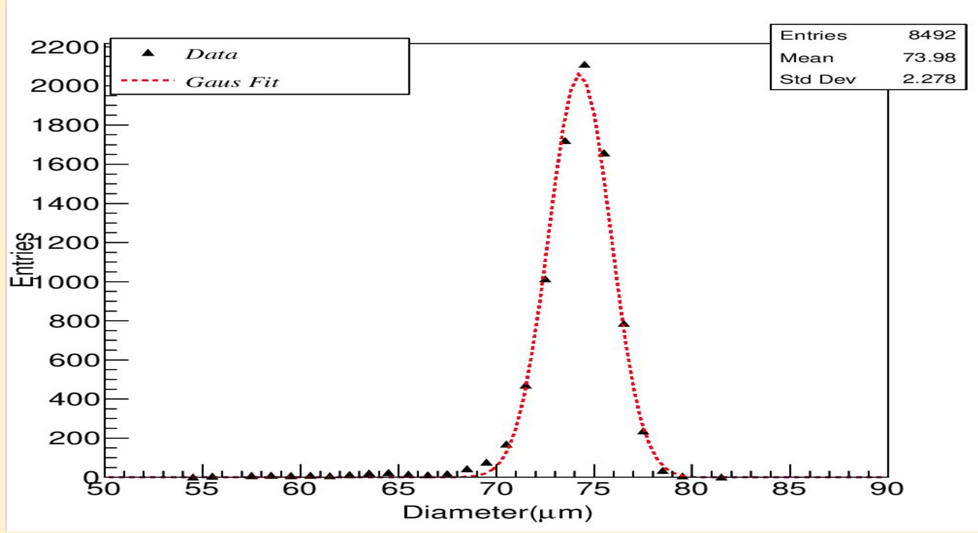
For imaging, we have used a 2D readout board to collect the charge and four DDC24 20 bit 64 channel current input analog to digital converter (ADC) data acquisition electronic board which is capable of taking data at a sampling frequency of 6 kHz and configured with Spartan-3 FPGA to control various components. The detector was flushed with Ar/CO2 gas mixture at 70:30 (3L/h).

The detector was then irradiated with an X-ray source (22.8 keV) [4] at a gain of ~10k. The data are saved in raw format, which requires further data processing and visualization to construct the image where the clustering algorithm takes seed as the maximum charge hit the strip and runs over 10 strips on both sides of the seed strip to find peak position. The peak position of the cluster is then filled in the 2D histogram to construct the image. A fitting algorithm is then run on a 2D histogram to sharpen the edges or boundary of the objects. Another image is constructed to identify the material based on the mass length of the materials which can be seen clearly in the result section.

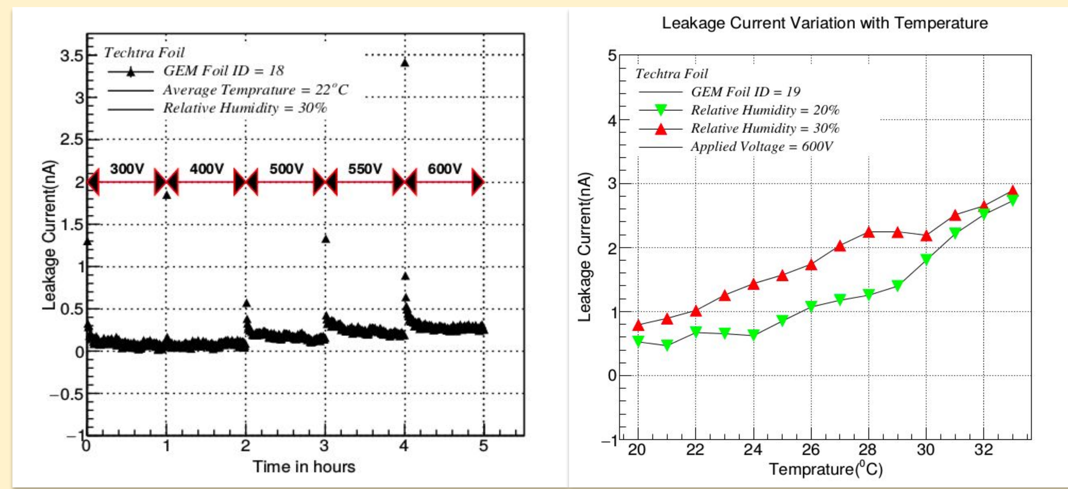


Objects under scan and reconstructed image

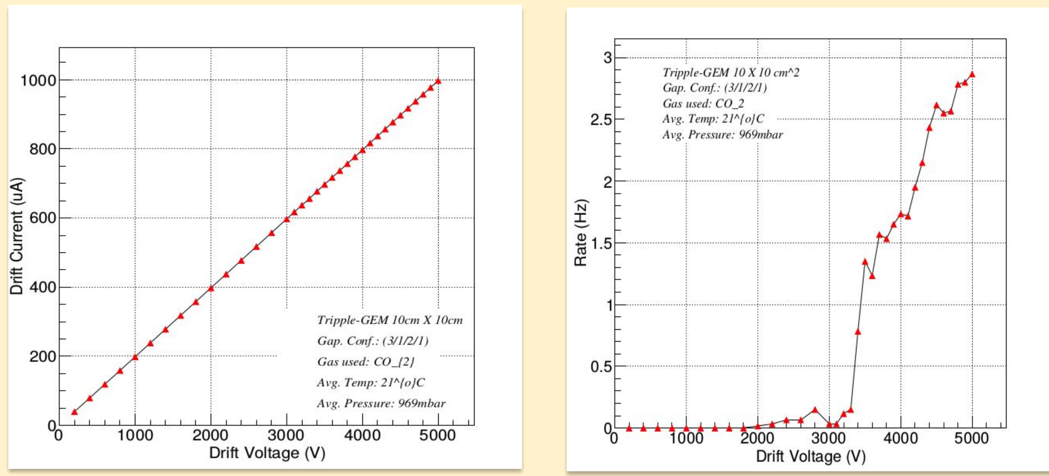
Results



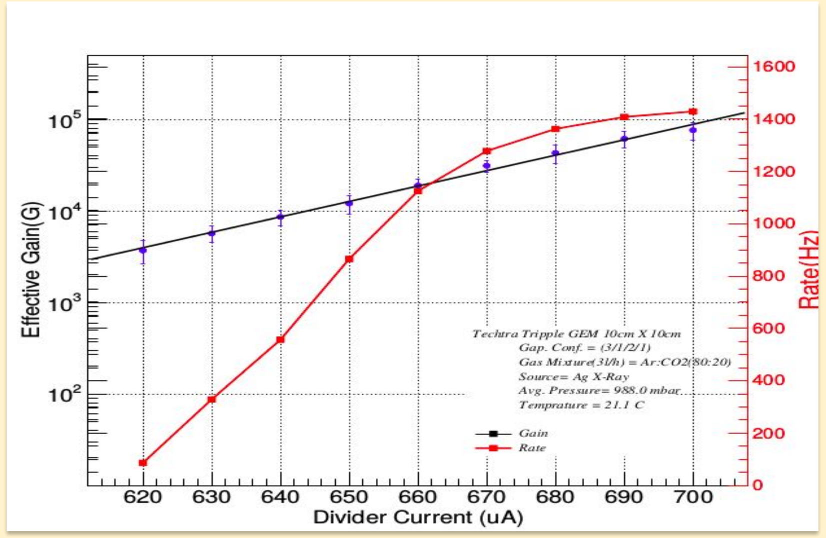
Top outer holes diameter distribution



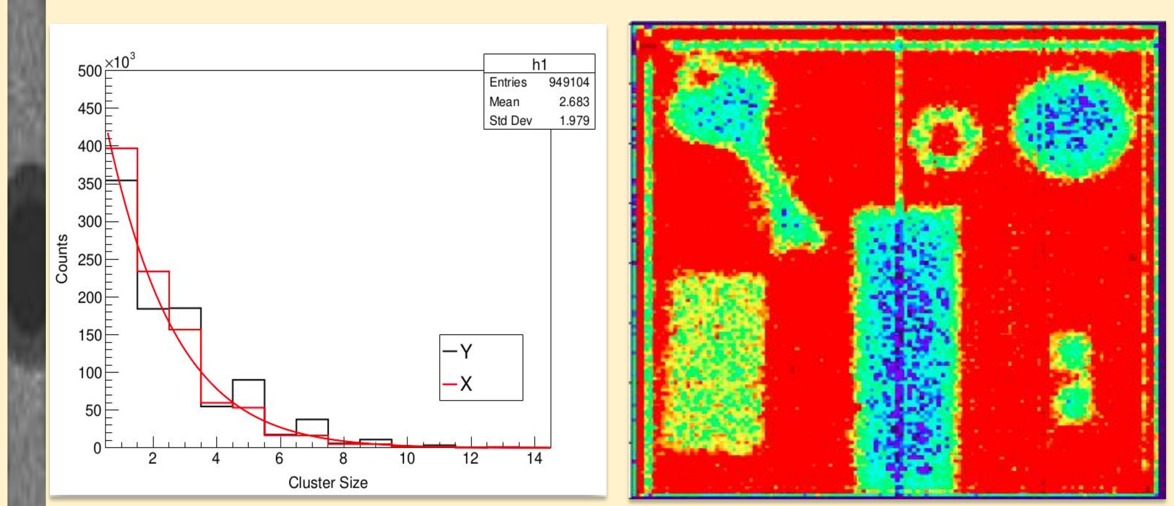
Leakage current at different Temp and RH%



HV stress test and Supirius rate



Rate and Gain Curve



Cluster size and reconstructed image as per mass length of the material

References

1. F. Sauli, GEM: A new concept for electron amplification in gas detectors, Nucl. nstrum. Methods A 386 (1997) 531,
2. https://www.mathworks.com/products/matlab.html
3. Mohit Gola, et al. Performance of the triple GEM detector built using commercially manufactured GEM foils in India.
4. https://www.amptek.com/products/x-ray-sources/mini-x2-ray-tube

CONCLUSIONS

➢ *The measured optical and electrical properties of Micropack foils were found to reflect the desired parameters.*

➢ *The detector has shown excellent performance towards HV, gain, uniformity, and gain stability.*

➢ *Attempt on imaging with GEM detector shown a promising outlook and is capable of distinguishing materials of different densities.*

ACKNOWLEDGEMENT

➢ *We would like to thank the Department of Science and Technology (DST) , Government of India for providing the financial support to work on this project.*

➢ *We also acknowledge the financial support received from DU R&D grant and University Grant Commission (UGC) for their help in making this project successful.*

Presented at : The 30th International Symposium on Lepton Photon Interactions at High Energies.

JAN 10-14, 2022 , The University of Manchester (UK).