Application and Utilization of the GEM Detector in Security and Agriculture Fields

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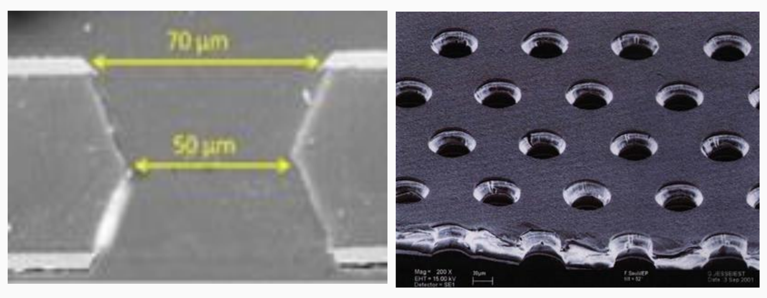
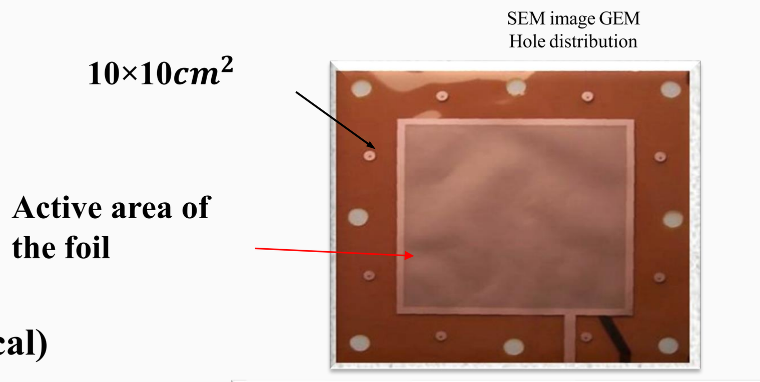
Introduction of GEM detector

Introduction

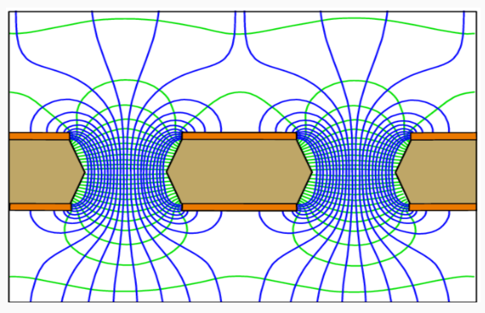
- Gas Electron Multiplier (GEM) is a gaseous charge amplification structure with wide application in high energy physics and other active research fields due to its excellent features
- Feature of triple-GEM
  - Higher Radiation rate handling capability up to ~10 MHz/cm²
  - Excellent spatial resolution (~100μm)
  - Good Timing resolution (~10ns)
  - Muon detection efficiency (~98%) for single chamber
  - Can be designed in various hole sizes and shapes
  - Low aging effect

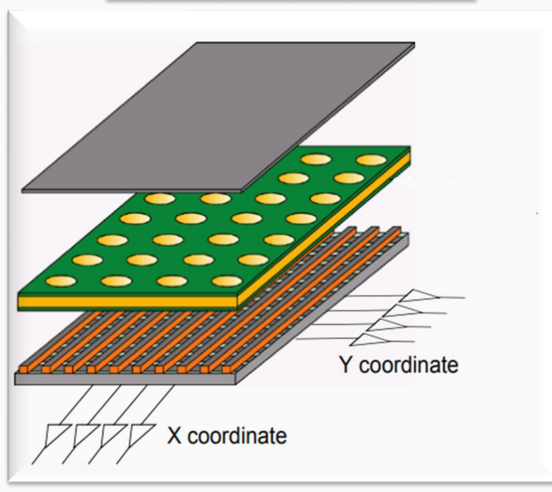




GEM Foil/Hole Design

- GEM foils consist of a 50 μm thin polyamide (Kapton/Apical) coated with a 5 μm thin layer of copper on both sides
  - Bi-conical holes:
    - Inner diameter(polyamide): ~50μm
    - Outer diameter (copper): ~70μm
    - Pitch: ~140μm
    - Holes density: 6000/cm²





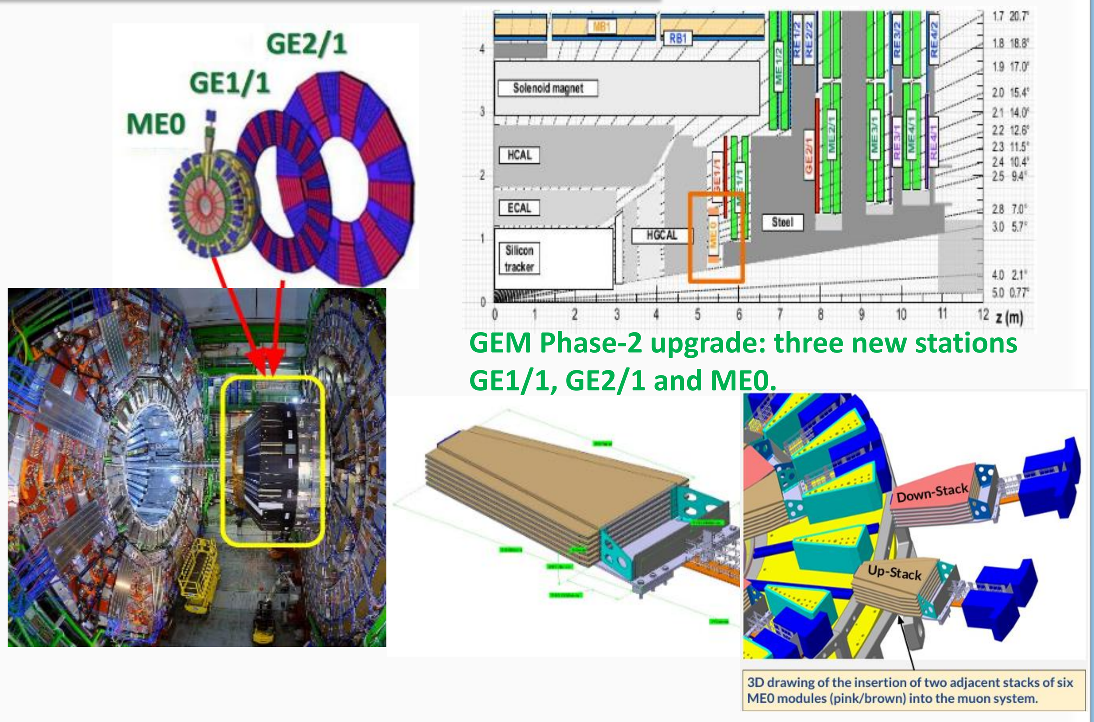
Operating principle

- Low operating voltage (300-400 V)
- Each hole acts as a proportional counter.
- Multiple foils can be used for desired charge amplification.
- High charge gain makes it compatible with even less sensitive signal-processing electronics chain

Application in HEP

CMS (Compact Muon Solenoid) Detector

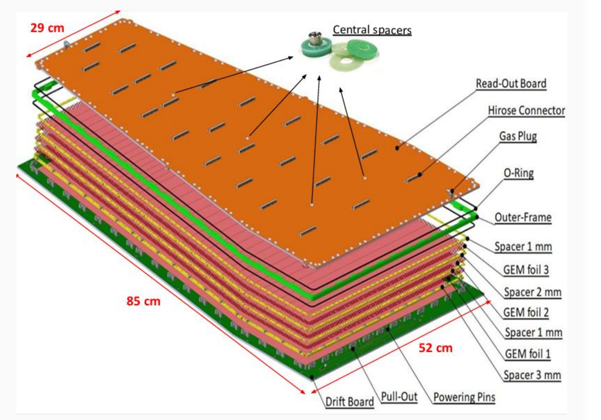
- A general-purpose experiment measuring proton-proton and heavy-ion collisions at the Large Hadron Collider (LHC) at CERN.
- LHC is currently running at p-p energies 13.6 TeV, with luminosity exceeding ~ 1034 cm-2 s-1. For the HL-LHC (High Luminosity LHC) period-Integrated luminosity will increase tenfold w.r.t. LHC's design value.
- GEM detectors in CMS- To improve the forward muon triggering and reconstruction.
- In Phase-2 upgrade- ME0 GEM detectors will extend the acceptance of the muon system, which will improve muon identification



GEM Phase-2 upgrade: three new stations GE1/1, GE2/1 and ME0.

Description of the new ME0 stations

- The ME0 detector station comprises 36 ME0 stacks (18 per endcap).
- Each stack consists 6 ME0 triple GEM detectors; total 216 ME0 modules required.
- Install behind the new Endcap HGCAL.
- Coverage extends from |η | = 2.0 to 2.8. Each stack covers $\delta\varphi$ = 20°.
- Radial distance from beam line: 63 cm.



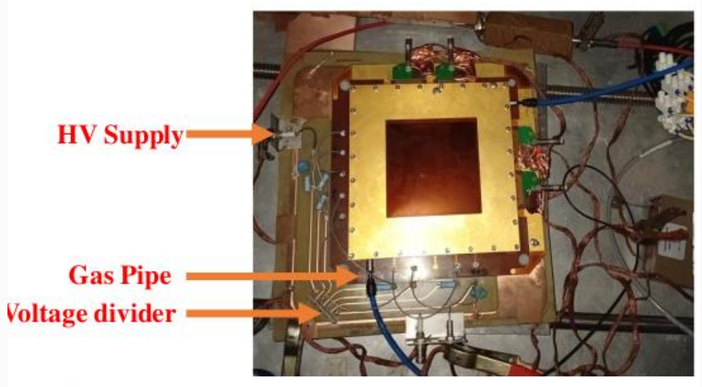
Imaging with GEM

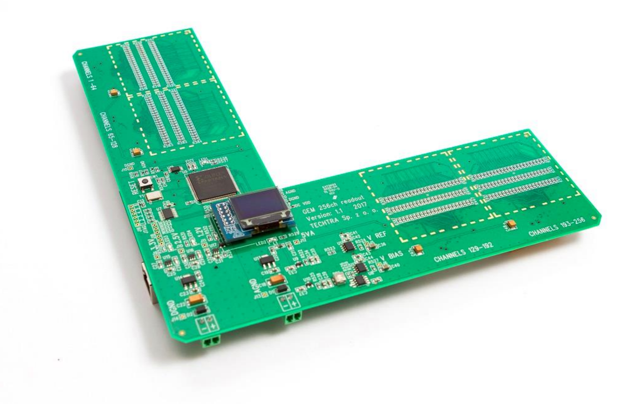
Motivation

- GEM detectors provide excellent spatial and time resolutions
- Capable of handling high particle flux
- Suitable for imaging applications
- Aim: detailed evaluation of imaging capability using in-house GEM detector

Experimental Setup

- Tested GEM detector with well-characterized parameters
- 2D readout board: 256 strips with 0.39 mm pitch (X & Y axes)
- Signals readout via 4 Panasonic male connectors (128 channels each)
- Charge collection at 6k samples/s using 256-channel Techtra GEM board
- Readout made compatible by pairing successive strips
- GEM readout electronics: 4 DDC24 ADCs, 20-bit, 64-channel each



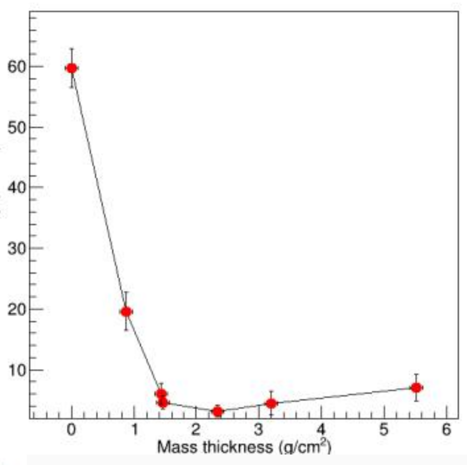


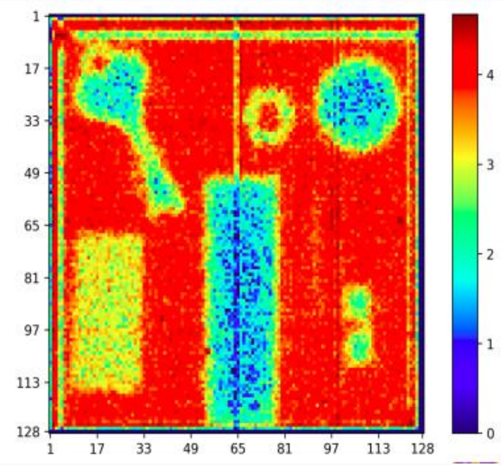
Experimental Setup

- 64 channel 20 bit ADC(DDC24)
- Charge information per strip is stored (6k sample/s)
- Xilinx Spartan-3 FPGA to control various electronics components and connect to a computer (100 Mbps)
- Algorithm finds cluster, and the Gaussian fit mean is taken as the hit position

Image Reconstruction & Results

- Detector gain set to **~10k**, X-ray operated at **5 kHz**
- Data stored in **raw format** → processed for image reconstruction
- **Basic cuts** applied on the energy spectrum & time for quality improvement
- Images successfully reconstructed for **copper, steel, alloys, FR4**
- Example: **20k events (~10.24M sub-events)** used for image reconstruction
- **Limitations:**
  - X-ray source overheats after a few minutes → interrupts data taking
  - Slow readout electronics limit statistics
- **Future upgrades:** higher stability X-ray source & **fast** readout system





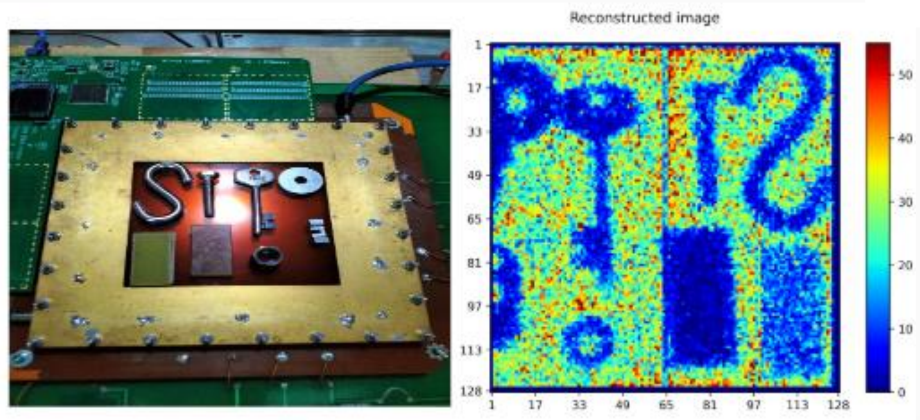


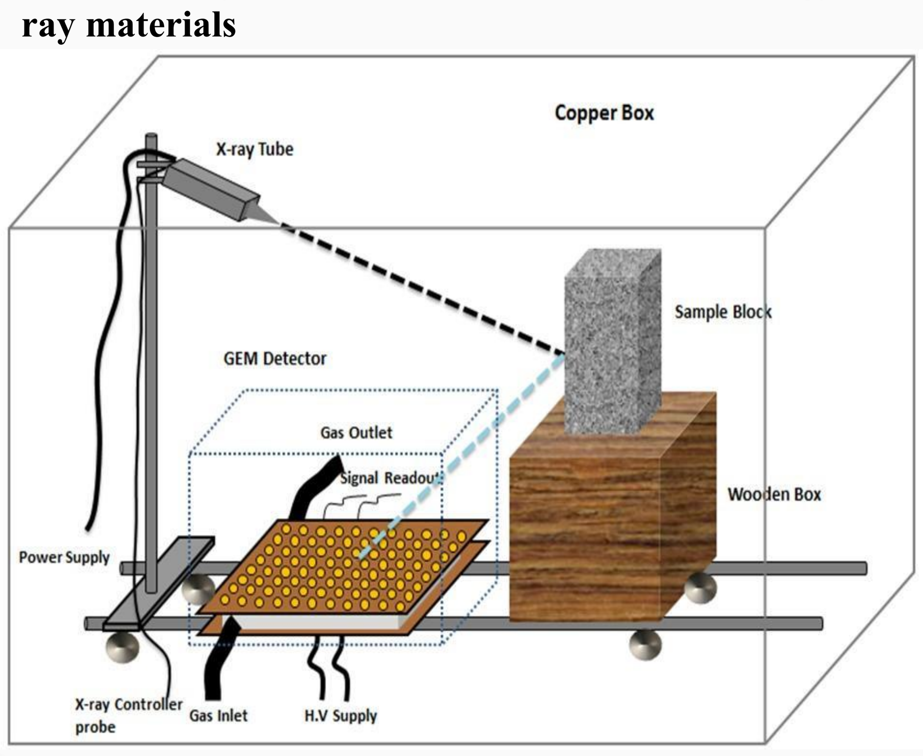
Image reconstruction

- Exponential attenuation law: $I/I_0 = e^{-(\frac{\mu}{\rho}x)}$
- Hit density below each object is calculated
- The plot clearly reveals the identification of the object based on the mass thickness
- Object dimensions are measured within 1% of tolerance

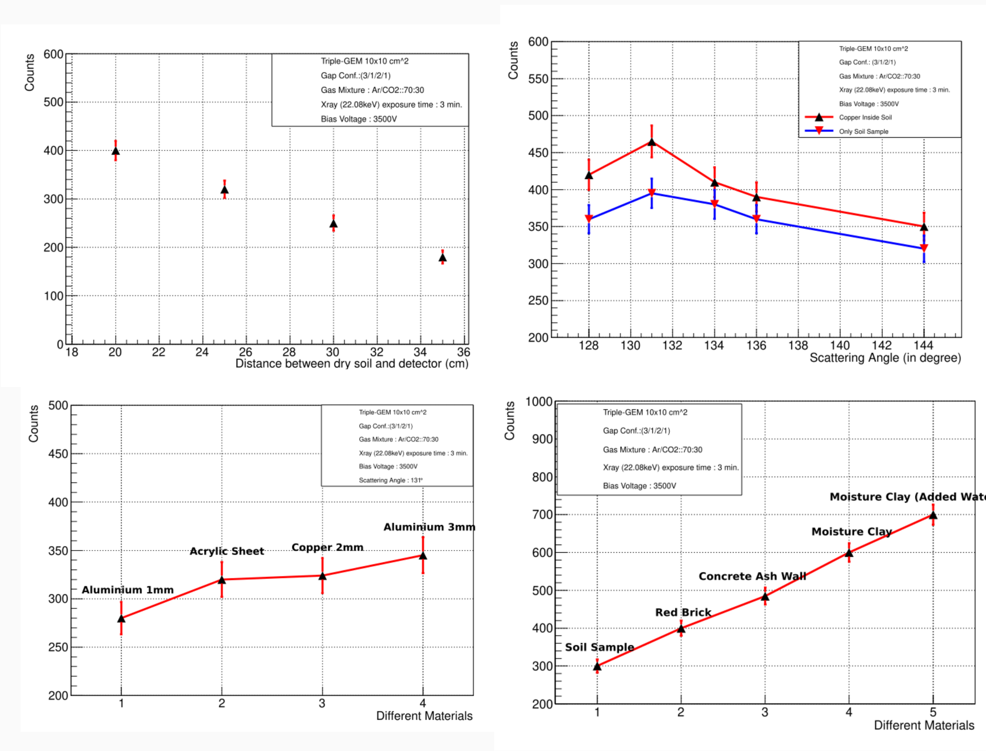
Agriculture Application of GEM

Motivation: To detect underground land mines and hidden metallic and non-metallic objects

- We utilized GEM to detect the metallic or non-metallic objects buried under the soil/mud.
- Setup was created using the x-ray and GEM detectors along with the required readout system.
- Different types of soils and material have been used for this study with the source of 22.08 keV energy X-ray materials



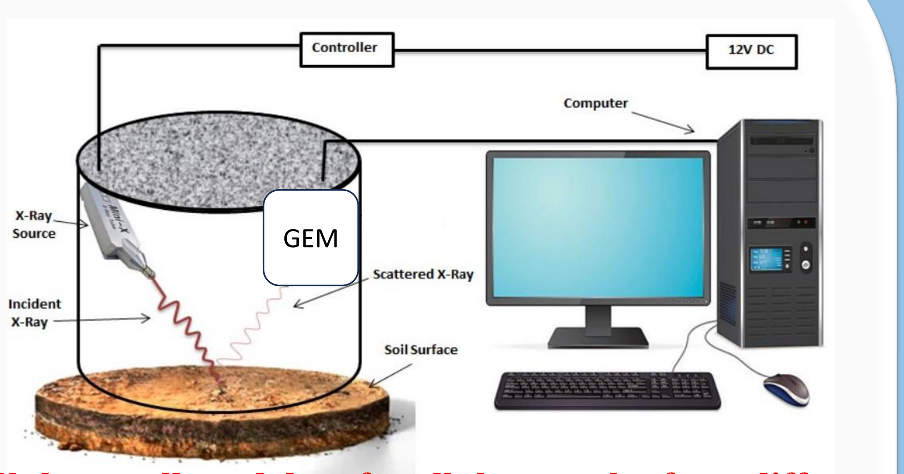
To determine the optimal scattering angle for the future study, we have conducted a thorough analysis of various scattering angles



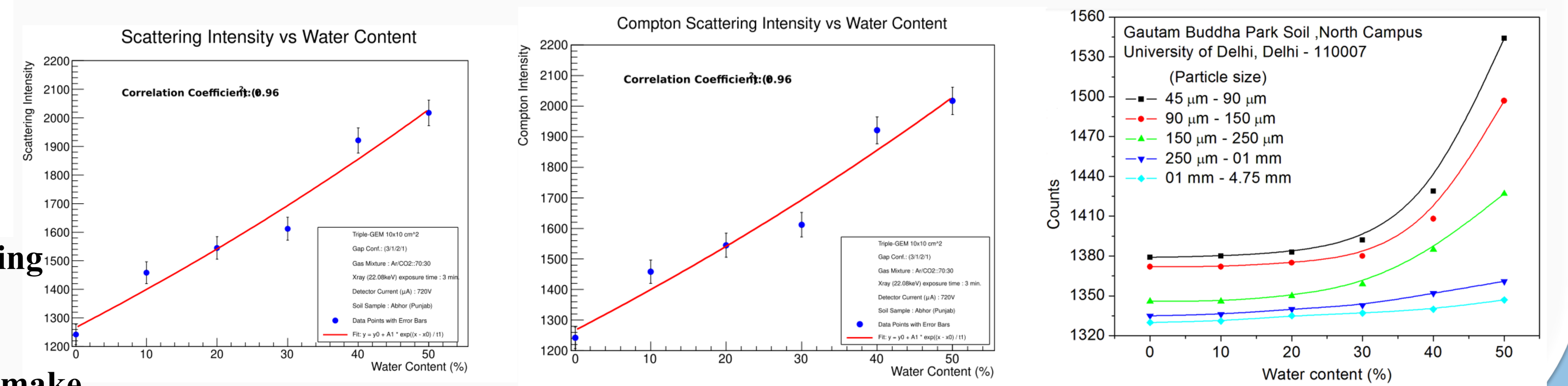
- Our studies show that GEM detectors are capable of detecting materials buried under the soil/mud.
- Our limitation is due to the use of soft X-rays.
- Initial results are quite promising, but need hard X-rays to make a prototype that can detect objects hidden deep inside the soil

Motivation: The study of grain size and water content of soil is important because these properties directly affect plant growth and crop yield

- Grain size affects water, air, and nutrient holding capacity
- Water content shows how much water plants can use
- Helps decide which crops grow best in the soil
- Guides efficient irrigation planning
- Supports sustainable soil management & higher yields
- We can study these soil changes using **Scattering Technique**.



We have collected data for all the samples from different locations, with variations in the water content. These plots allow for a clear visualization of the relation between water content.



Conclusions

- We have made efforts to identify objects inside the soil. Primary results are satisfactory. But we require a high-energy X-ray source. We are trying to improve the results.
- We have clearly seen the effect of water content in the soil, the density of the soil, and the particle size of the soil. which proves valuable in agriculture
- An attempt at imaging with a GEM detector showed a promising outlook and is capable of distinguishing materials of different densities.

Acknowledgements

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