# Development of GEM detectors and their applications in security and agricultural fields


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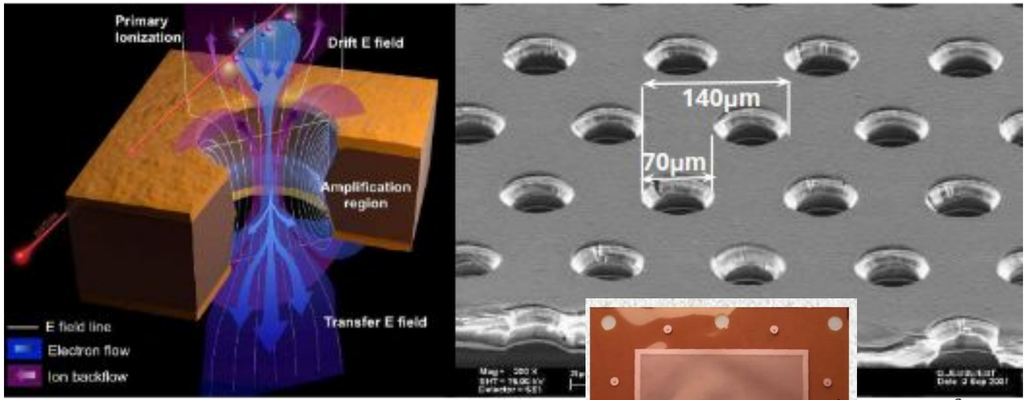
6th, DRD1 Collaboration Meeting 2025
06-10 October 2025
at
Warsaw, Poland

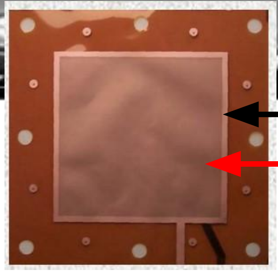
# Outline

- **Introduction of the GEM detector**
- **Application of the GEM detector**
  - **Imaging of the Objects and Identification**
  - **Underground Object detection with GEM**
  - **Soil Assessment for the Agriculture**
- **Summary**

# Introduction of GEM detector

- **Basis of GEM:** Standard GEM consists of polyimide (Kapton) of 50 um thickness coated with 5 um copper coated on both sides.
- Double conical holes with 70 um outer and 50 um inner diameter are etched into the active area of the foil in a honeycomb pattern of the 140 um pitch
- A 10x10 cm² foil has ~600,000 holes.



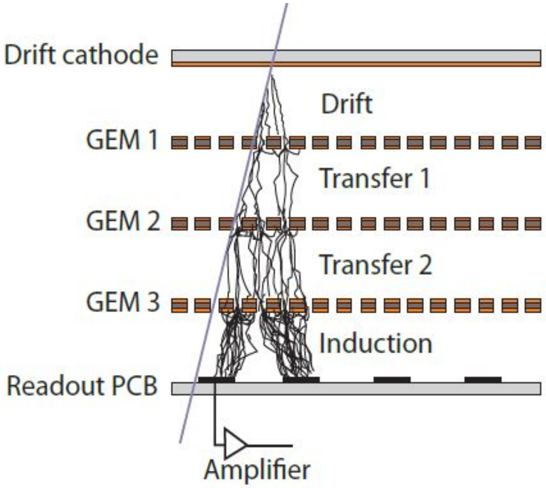
10×10$cm^2$

Active area of foil

**Gas Mixture: 70% Argon + 30% $CO_2$** for optimal operation.

**Performance Highlights:**

- **High Rate Capability:** ~MHz/cm² (handles intense particle flux).
- **Gain:** ~2 × $10^4$ (strong signal output).
- **Spatial Resolution:** ~100 μm (precise tracking).
- **Time Resolution:** ~8 ns (fast response).

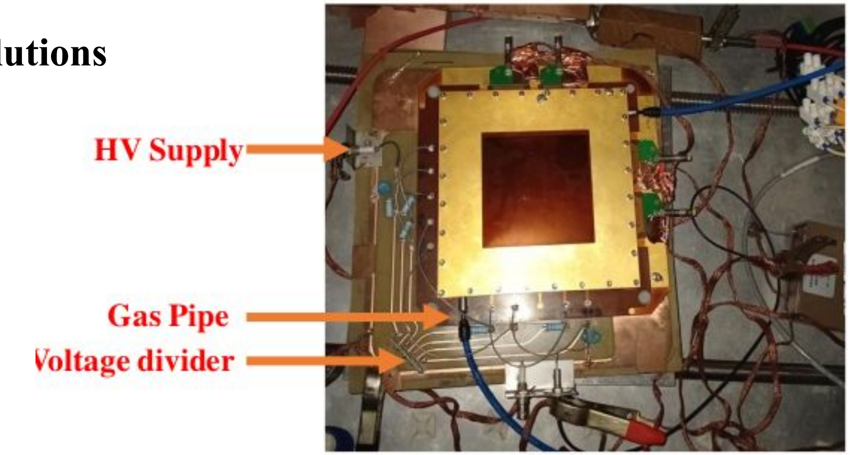



| GE1/1 Gap Sizes | Typical Potentials | Typical Voltages | Typical El. Fields [kV/cm] |
|---|---|---|---|
| 3 mm | 3200 V | 770 V | 2.6 |
| | 2430 V | 380 V | 64.0 |
| 1 mm | 2050 V | 300 V | 3.0 |
| | 1750 V | 370 V | 62.0 |
| 2 mm | 1380 V | 600 V | 3.0 |
| | 780 V | 350 V | 60.0 |
| 1 mm | 430 V | 430 V | 4.3 |
| | 0 V | | |

# Imaging Studies with GEM Detectors

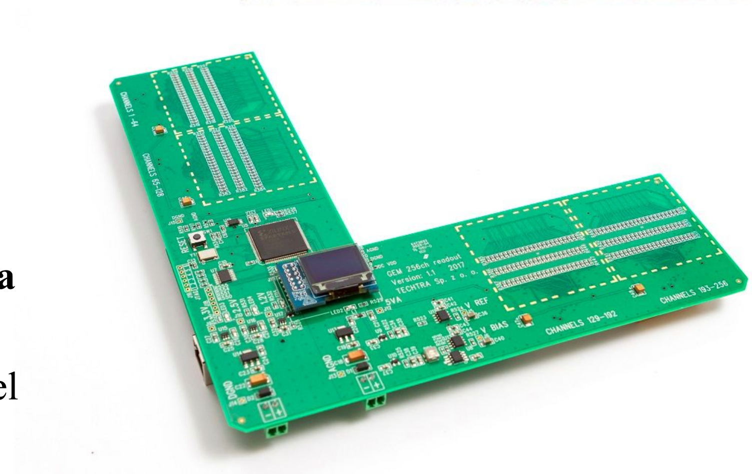
## Motivation

- 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  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**
- GEM readout electronics: **4 DDC24 ADCs**, 20-bit, 64-channel each

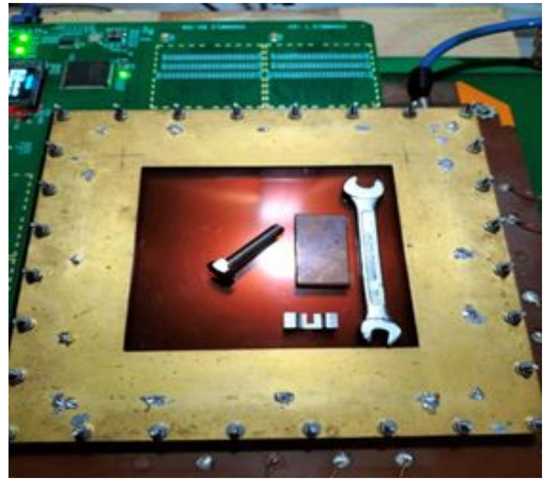


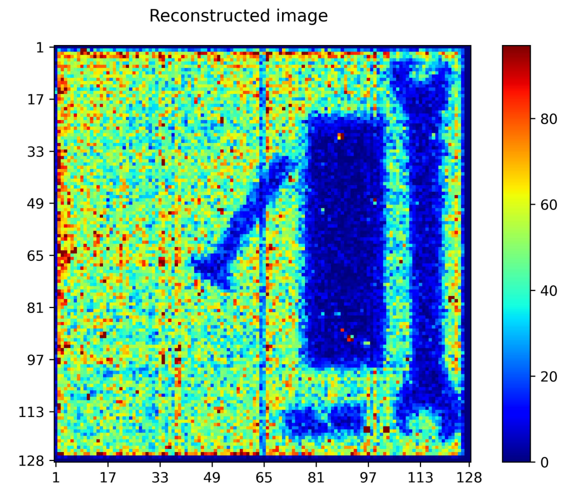
[Techtra GEM board, Techtra technology transfer agency.]()

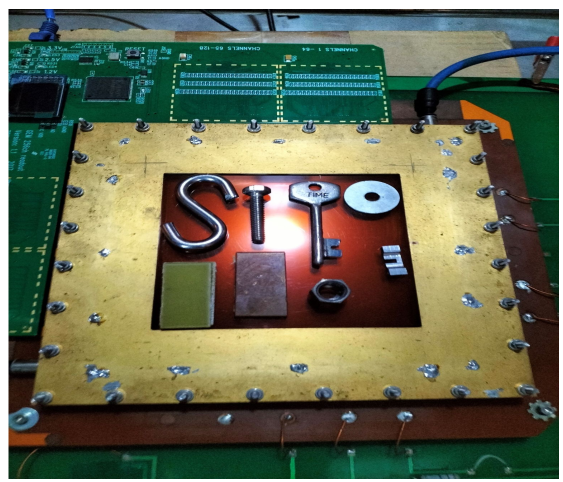
# Image Reconstruction: Results and Challenges

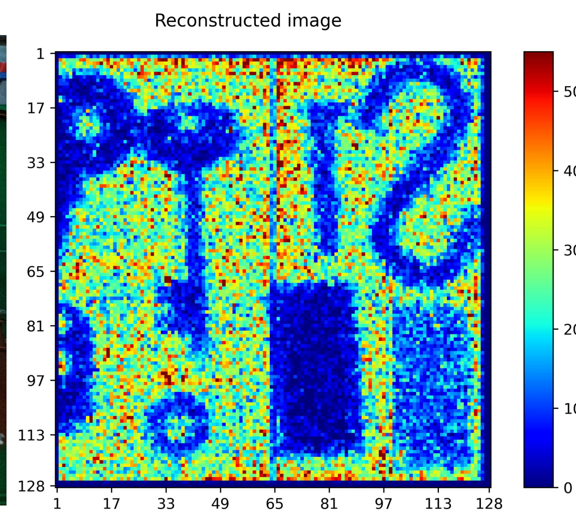
- Imaging of different-shaped materials
- X-ray as a source
- Ar-$CO_2$ gas mixture in ratio of 70:30
- Xilinx Spartan-3 FPGA to control various electronics components and connect to computer (100 Mbps)
- Charge information per strip is stored

**The primary image requires further processing, discussed on next slide**





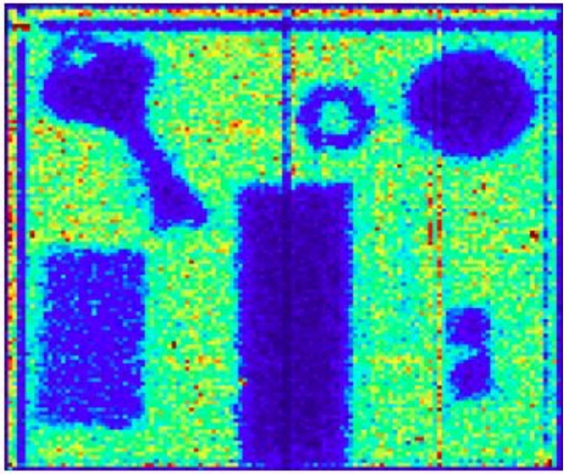



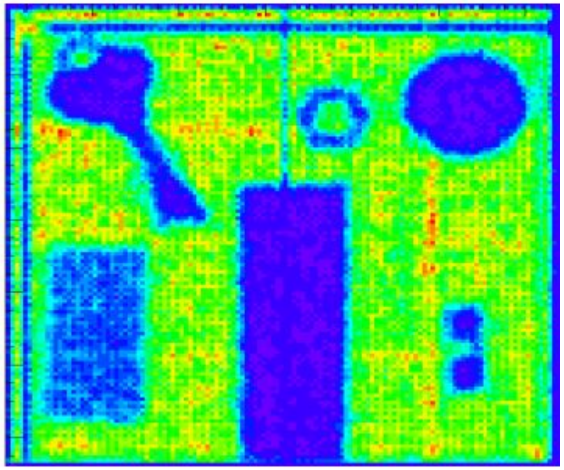


# Image Reconstruction: Results and Challenges

**Image Reconstruction & Results**

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



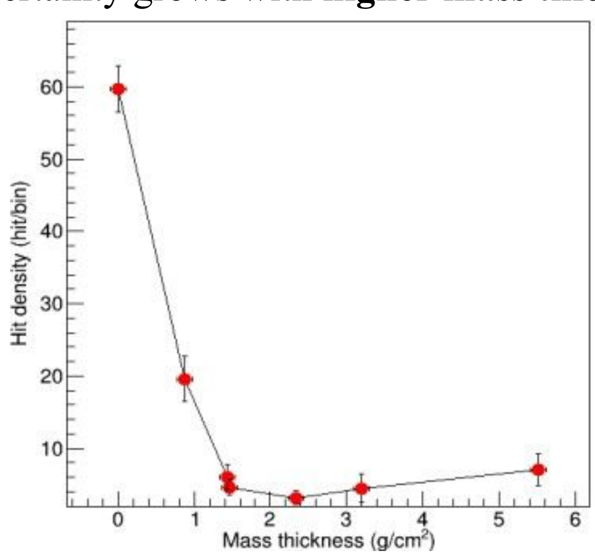


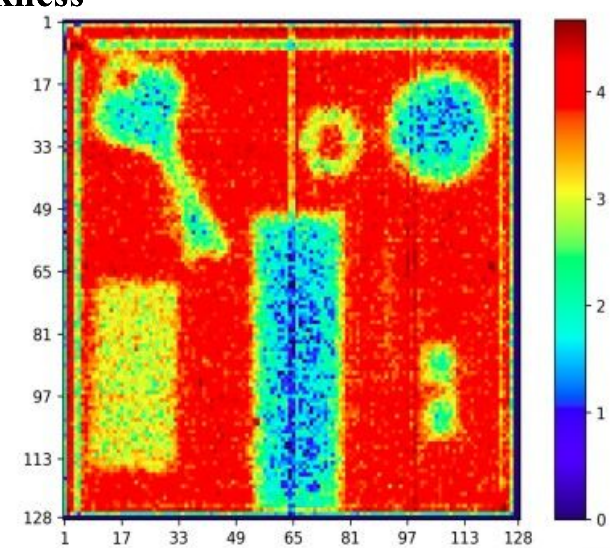
# Object Identification and Dimension Measurement

- Materials identified using **mass attenuation coefficient (μ/ρ)** via:

$$I/I_0 = e^{-(\mu/\rho)\cdot x}$$

  where $x$ = mass thickness, $\rho$ = density
- **$I/I_0$** calculated from reconstructed images at **22.8 keV X-ray**
- Hit density (I) extracted under each object → distinguishes **metallic vs non-metallic**
- Larger thickness → **higher uncertainty** due to increased scattering (coherent/Compton)
  Poor hit reconstruction for small/curved/thick objects (e.g., **Nut, Pullout**) with few events
- Reconstructed images also cast on **density scale** (color-coded distinction by density)
- Comparison with vernier caliper shows:
  - Imaging provides **good agreement** with actual dimensions
  - Uncertainty grows with **higher mass thickness**



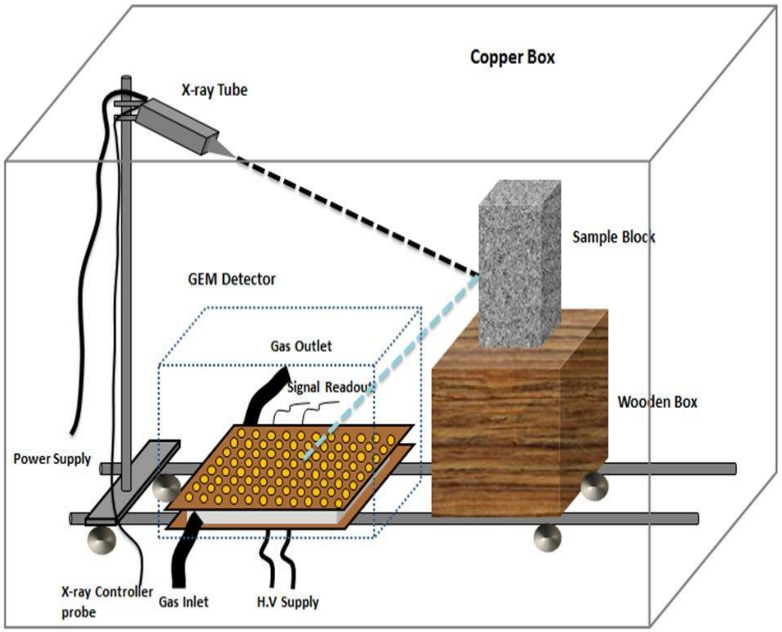
**Reconstructed image on logarithmic scale.**

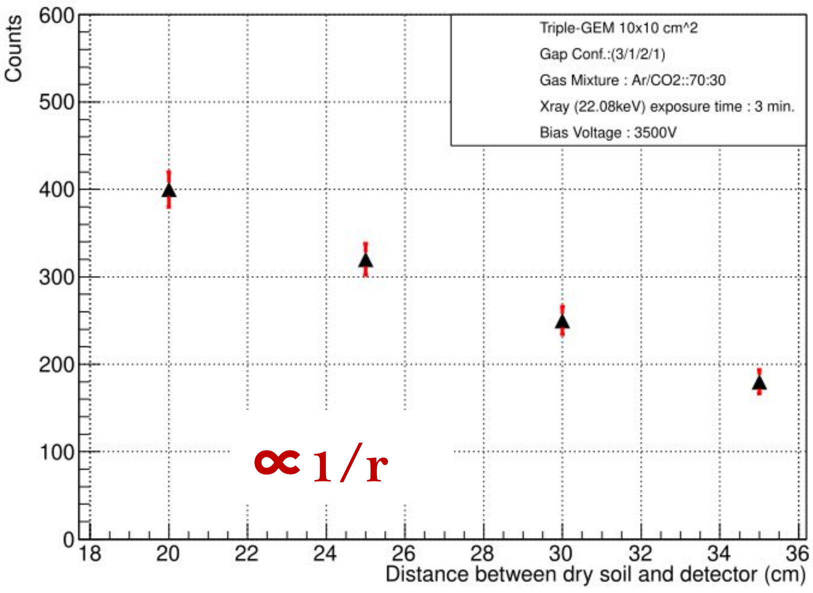
**Objects dimensions are measured within 1% of tolerance**

# GEM-Based Approach for Underground Object Detection

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

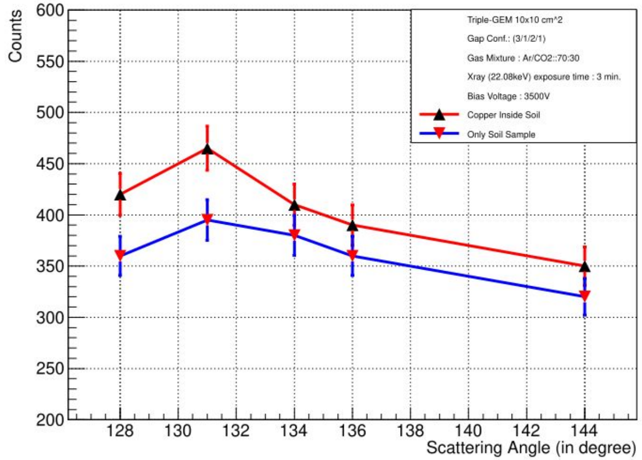
- ➢We utilized GEM to detect the metallic or non-metallic objects buried under the soil/mud.
- ➢The setup was created using the x-ray and GEM detectors along with the required readout system.
- ➢Different types of soils and material have been used for this study with the source of 22.08 keV energy X-ray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

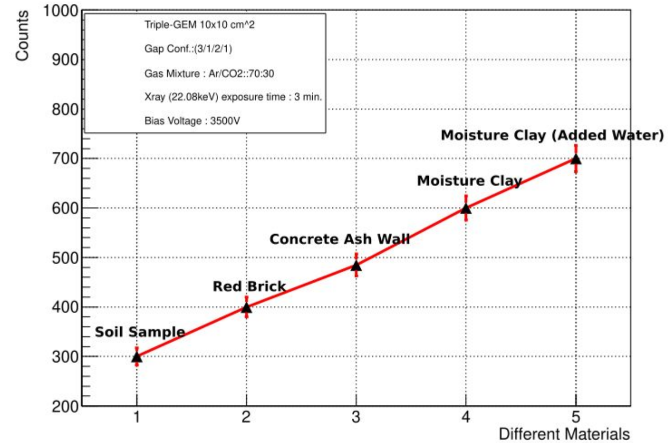


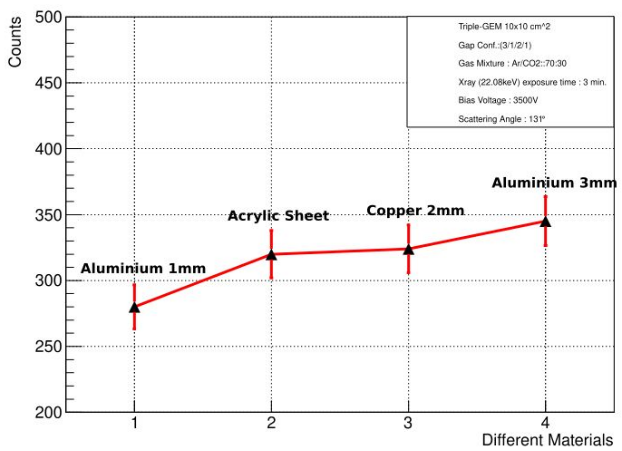



# Observations from GEM-Based Underground Object Study

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



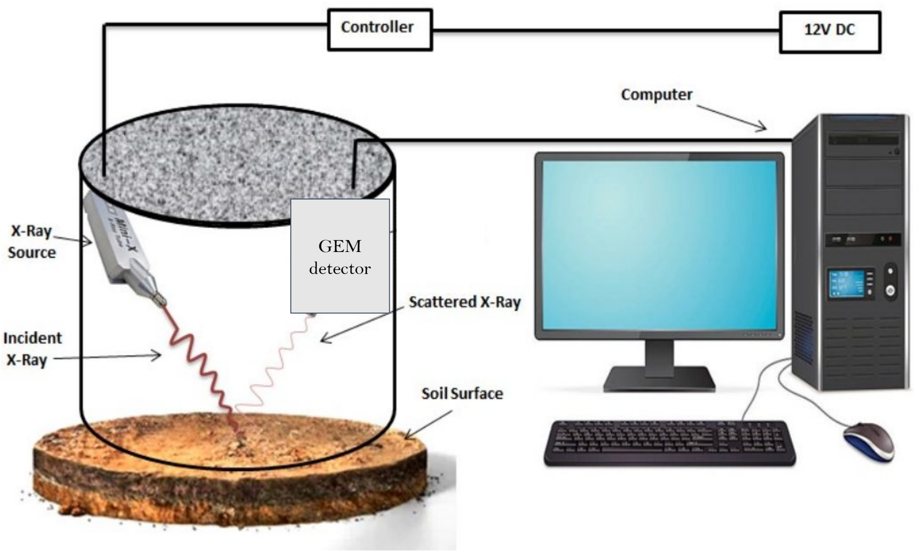




- **Our studies shows that GEM detectors are capable of detecting materials buried under the soil/mud.**
- **Our limitation is coming due to the use of soft x-rays.**
- **Initial results are quite promising but need hard x-rays to make a prototype which can detect objects hidden deep inside the soil**

# Understanding Soil Characteristics for Sustainable Agriculture

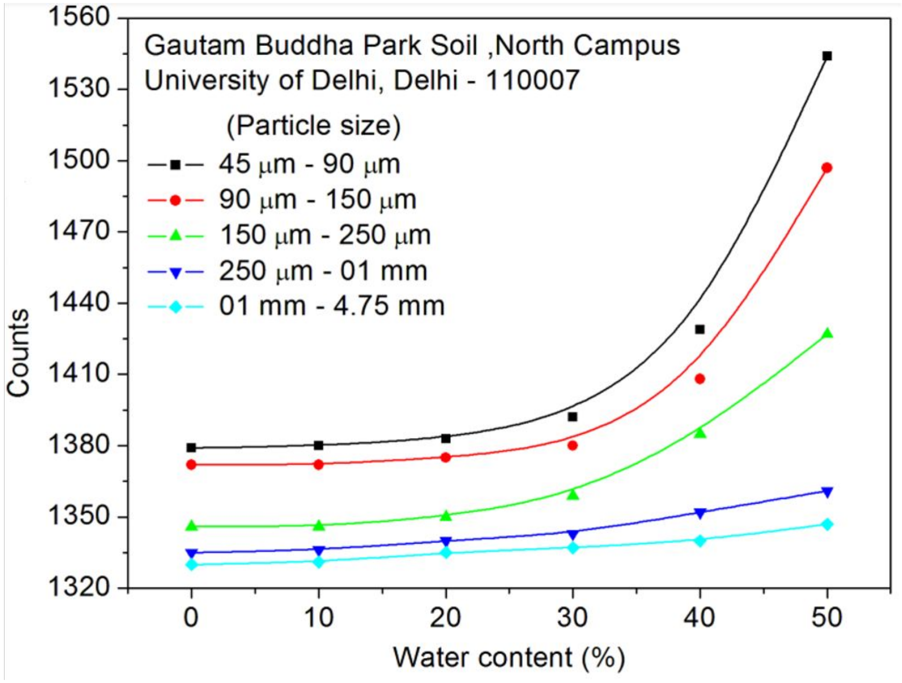
**Motivation : The study of grain size and water content of soil is important because these properties directly affect plant growth and crop yield**

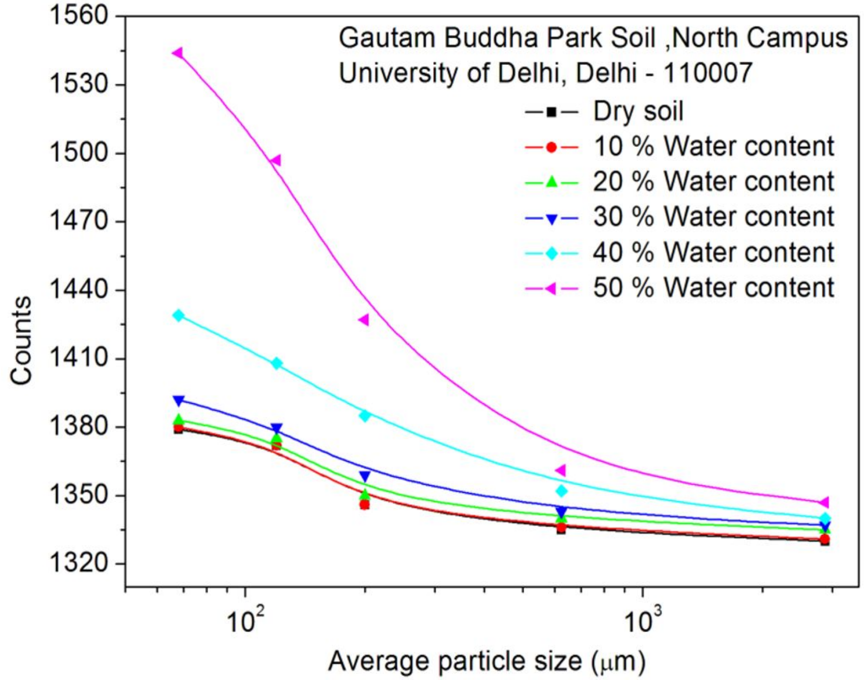
- Grain size affects water, air, and nutrient holding capacity
- Water content shows how much water plants can use
- Helps decide which crops grow best in the soil
- Guides efficient irrigation planning
- Supports sustainable soil management & higher yields
- We can study these soil changes using **Scattering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



# Soil Texture and Its Role in Agriculture

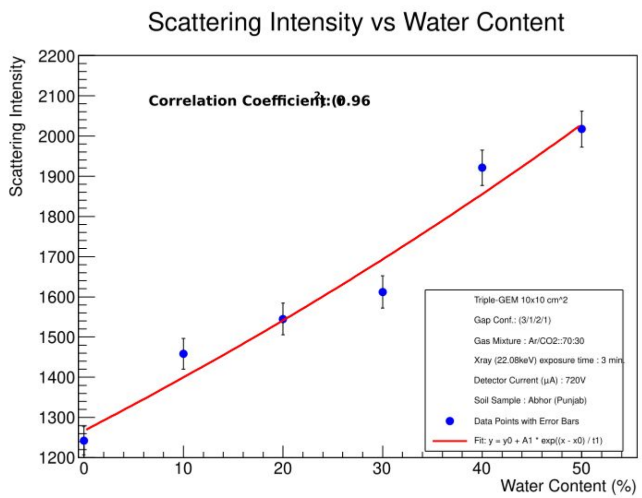
- **This investigation involved collecting data in two aspects:**
    - **Particle size distribution**
    - **Water content in the bricks**
- For the particle size analysis, we measured the counts of particles within each of the five different size ranges, and variable water content in the bricks
- This comprehensive approach allowed to us investigate the influence of both particle size distribution and water content on the properties of the bricks.

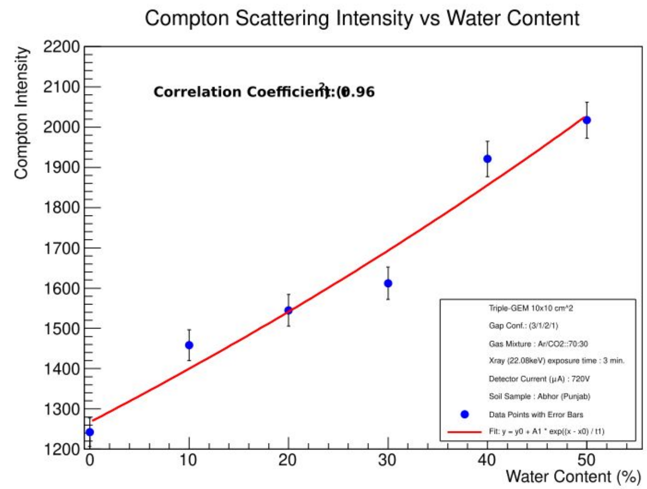


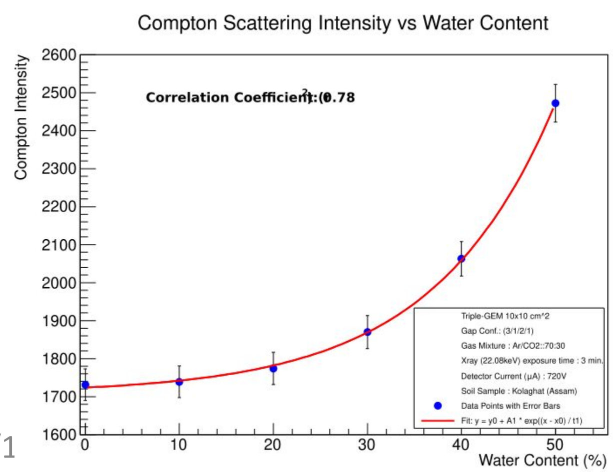



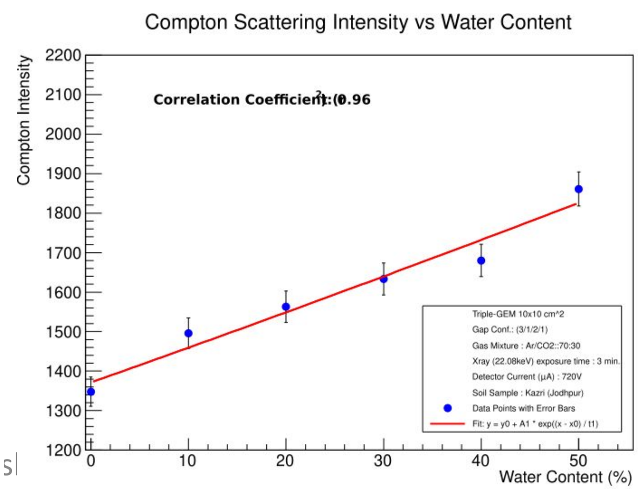
# Water Content Analysis of Soil

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



# Summary

- We have made efforts for the object identification 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 is 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.

**These primary results show that the GEM detector, renowned for its precision, and can play a vital role in both security and agriculture purpose**

**Thank you So much for your kind attention**

# Backup

| Material | Density ($gcm^{-3}$) | Thick. (cm) | Mass Thickness ($g/cm^2$) | Hit density $I$ (hit/bin) | $I/I_o$ |
|---|---|---|---|---|---|
| Kapton ($I_o$) | 1.42 | 0.005 | 0.007 | 59.70 | 1.000 |
| FR4 | 1.84 | 0.48 | 0.88 | 19.59 | 0.328 |
| Key (316) | 8.00 | 0.18 | 1.44 | 6.03 | 0.101 |
| Coin (FSS) | 7.70 | 0.19 | 1.46 | 4.57 | 0.077 |
| Copper | 8.96 | 0.26 | 2.33 | 3.16 | 0.053 |
| Pullout (316) | 8.00 | 0.40 | 3.20 | 4.45 | 0.075 |
| Nut (Iron) | 7.87 | 0.70 | 5.51 | 7.10 | 0.119 |

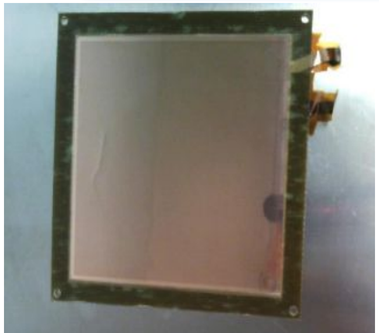
$$I/I_o = e^{-(\frac{\mu}{\rho}x)}$$

**where $x$ is the mass thickness and $\rho$ is the density of the material. $I/Io$ have been calculated from the reconstructed image of each object for 22.8 keV of X-ray.**

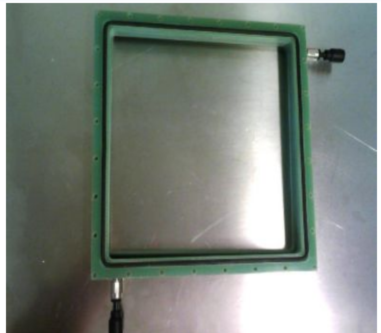
**Table 3.** Objects size measurements and percentage change from actual values.Where abbrevations used are, A.D.: actual dimension in mm, M.T.: massthickness in $g/cm^2$, B.C.: before corrections, A.C.: after corrections.

| Material | A.D. | M.T. | Meaured Dimension | | Change (%) | |
|---|---|---|---|---|---|---|
| | | | B.C. | A.C. | B.C. | A.C. |
| FR4 (L) | 38.63 | 0.88 | 38.81 | 38.28 | 1.42 | 0.91 |
| FR4 (W) | 20.49 | | 20.32 | 20.31 | 0.83 | 0.88 |
| Key (L) | 47.50 | 1.44 | 47.97 | 47.47 | 0.99 | 0.06 |
| Key (W) | 22.04 | | 22.31 | 22.15 | 1.23 | 0.49 |
| Coin (dia.) | 23.05 | 1.46 | 23.45 | 23.44 | 1.79 | 1.69 |
| Copper (L) | 61.41 | 2.33 | 61.53 | 61.49 | 0.20 | 0.13 |
| Copper (W) | 20.1 | | 20.61 | 20.09 | 2.53 | 0.05 |
| Pullout (L) | 19.03 | 3.20 | 19.49 | 19.14 | 2.42 | 0.58 |
| Pullout (W) | 7.15 | | 7.41 | 7.23 | 3.63 | 1.11 |
| Nut (Outer dia.) | 13.16 | 5.51 | 14.82 | 13.28 | 12.61 | 0.91 |
| Nut (Inner dia.) | 6.50 | | 4.80 | 6.25 | 26.15 | 3.85 |

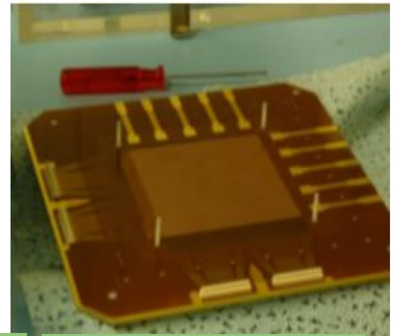
# Production of GEM prototype



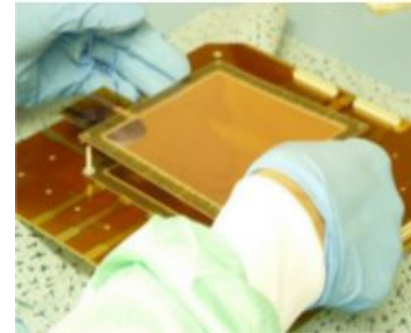
a.) GEM foil



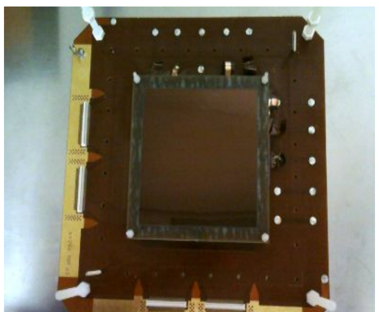
b.) Epoxy frame with gas inlets



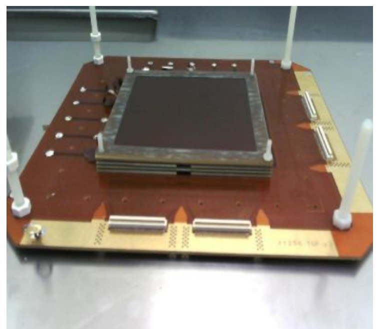
c.) 2D readout board



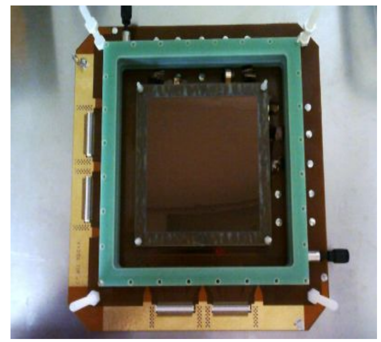
d.) Stack the foil one by one



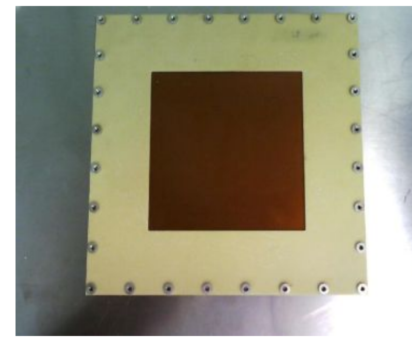
e.) Mounted GEM foils



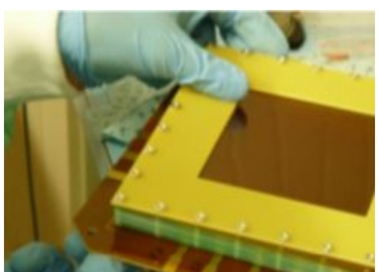
f.) Mounted GEM foils—side view with



g.) Mounted GEM foils with frame



h.) Kapton window to let radiation in



g.) Assembled detector with readout board


h.) 100-class clean room at Delhi University

- **Required 100-class clean room**
- **After assembly we need to perform some important quality control tests.**