Monte Carlo simulations of a first prototype micropattern gas detector system used for muon tomography

J. B. Locke, K. Gnanvo, and M. Hohlmann
Florida Institute of Technology
Melbourne, Florida

FIT SPS Chapter
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FIT High Energy Physics (FIT HEP) Research Group

Pictures from FIT HEP archives, National SPS, Florida Institute of Technology, and the US Census Bureau.
High Energy Physics Research at FIT

CMS at LHC Experiment

Search for the Z’ Boson

Muon Tomography Simulation

Quarknet

Particle Detector Construction

Open Science Grid Computing Cluster

Pictures from the FIT HEP archives.
What are Muons?

• Muons are leptons.

• Symbols:
  – Muon = \( \mu^- \)
  – Antimuon = \( \mu^+ \)

• Similar to electrons, but 200 times more massive:
  – Muon mass = \( 0.106 \text{ GeV/c}^2 \)
  – Electron mass = \( 0.000501 \text{ GeV/c}^2 \)
  – Muon charge = \(-1 \text{ e}\)

• Interact weakly with matter.
Where Do Muons Come From?

Nuclear reaction (not chemical)

Nucleus

Energy and other particles

$p^+$ (or other high-energy cosmic ray)

*Not to scale.*
Important Numbers

• Average muon energy at sea level: 4 GeV

• Modal muon energy at sea level: 1 GeV

• Muon flux at sea level: 10,000 muons/m²/min

• Smallest prime number: 2
Micropattern Gas Electron Multiplier (GEM) Detector

1. A high-energy muon ionizes the gas in the detector.
2. The free electrons are channeled through the microperforations (~50 μm) due to the electric field.
3. A readout plane gathers the electrons.

Pictures from the FIT HEP archive, CERN Courier, and DESY Labs.
Muon Tomography Concept

Muon Detector

Scattering Point

$\mu^-$

$\theta = \text{Scattering Angle}$

$\text{High } \theta \Rightarrow \text{High-Z Material}$

$(x,y)$ of detector hits

$(x,y,z)$ of detector hits

Data Analysis

Pictures from Microsoft Clipart.
Muon Tomography Applications

• Investigate trucks with the drivers inside.

• Easily locate high-Z contraband (Uranium, Plutonium, etc.).

• Maybe medical applications when technology improves.
Monte Carlo Simulations

Targets (U, Pb, etc.)

Position (x,y,z) [mm]

Scattering Angle [degrees]

Pictures from the FIT HEP archives.
Prototype Muon Tomography System

30x30 cm²
GEM Detectors
(Only 5x5 cm² Used)

3x3x2 cm³
Pb Block

Target Support

GEM Detectors

Picture from the FIT HEP archives.
Pb Box Simulation Results

24 hours exposure to natural muon flux.
No points are cut from the data.

Position
(x, y, z)
[mm]

Scattering Angle
[degrees]

Picture from the FIT HEP archives.
“Empty” Detector Simulation Results

24 hours exposure to natural muon flux.
Pb Box Simulation Results

24 hours exposure to natural muon flux. Scattering angles less than 0.12° are cut from the data.
Pb Box Simulation Results

$5 \text{ mm} \leq z \leq 15 \text{ mm}$

Mean Scattering Angle in Voxel [degrees]

Picture from the FIT HEP archives.
Pb Box Simulation Results

-5 mm ≤ z ≤ 5 mm

Mean Scattering Angle in Voxel [degrees]
Simulation Results

$75 \text{ mm} \leq z \leq 85 \text{ mm}$

Mean Scattering Angle in Voxel [degrees]

Picture from the FIT HEP archives.
Simulation Results

-85 mm ≤ z ≤ -75 mm

Mean Scattering Angle in Voxel [degrees]
Current and Future Work

• Analyze data from the GEM detector system prototype.

• Construct a GEM detector system with a more efficient geometry and 8 to 12 detectors.

• Continue Monte Carlo simulations for various GEM detector system geometries.

Picture from FIT HEP Archives (Lenny Grasso).
Pictures from National SPS, Florida Institute of Technology, LucasArts, NASA Goddard Space Flight Center, and the FIT Ortega Telescope.