Large Area GEM Detectors for Muon Tomography: Application to Nuclear Material Contraband Detection

Kondo Gnanvo, Leonard Grasso III, Marcus Hohlmann, Nick Leioatts, Debasis Mitra, Amilkar Quintero

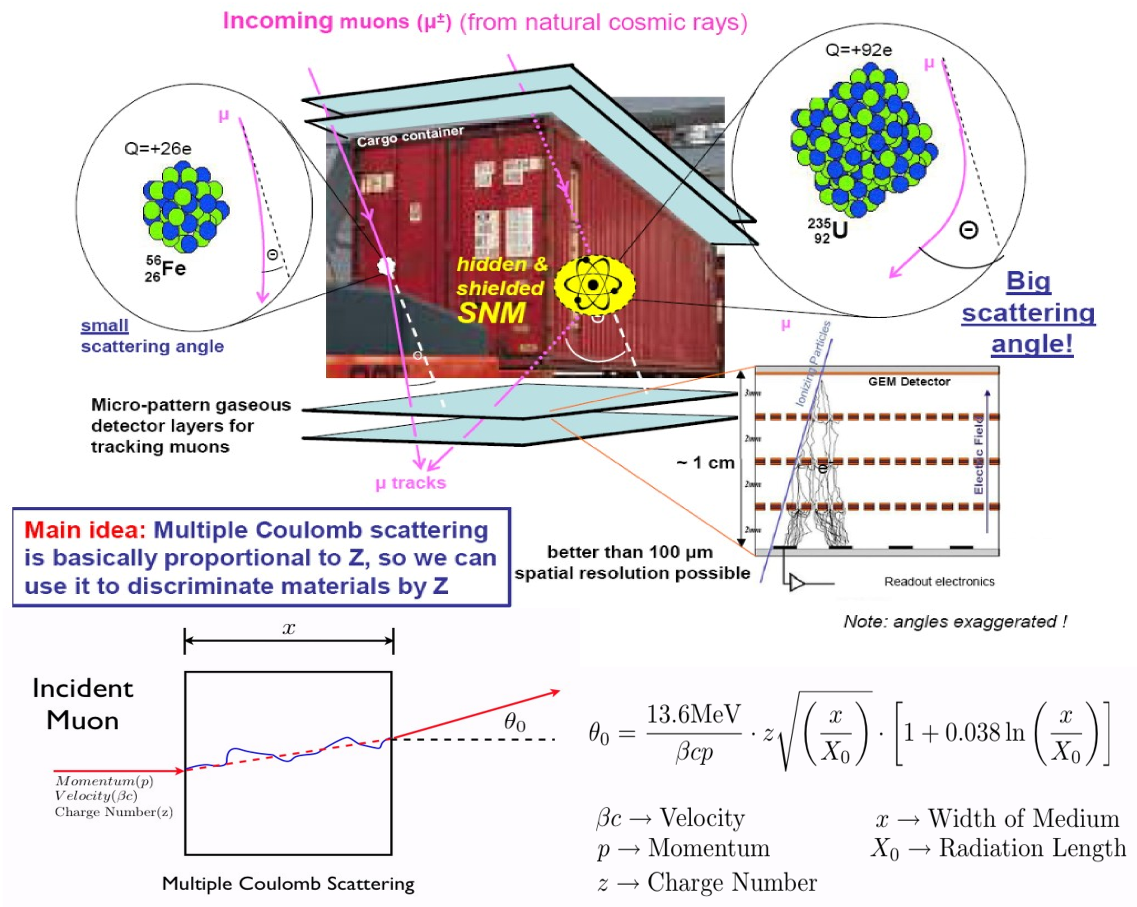
Florida Institute of Technology, Melbourne, FL 32901, USA

Abstract

Standard radiation detection techniques currently employed by portal monitors at international borders and ports are not very sensitive to high-Z radioactive material (U, Pu) if the material is well shielded to absorb the emanating radiation. Muon Tomography (MT) based on the measurement of multiple scattering of atmospheric cosmic ray muons traversing cargo or vehicles is a promising technique for solving this problem. Various groups propose to use the Drift Tube (DT) chambers as tracking detectors for Muon Tomography Station for cargo inspection. The relatively poor spatial resolution (400 μm) as well as additional scattering of the incident muons by the chambers both strongly affects the precision of the scattering angle measurement and therefore affect the performance of the MT station in detecting high-Z material. We propose to use low mass, high spatial resolution (~50 μm) large area Gas Electron Multiplier (GEM) detectors for the tracking of the cosmic muons MT to overcome the intrinsic limitations of drift tubes chambers. After a brief overview of simulation results on the compared performances of Drift Tube and GEM based MT station. We then talk about the ongoing effort to build the first prototype of MT station based 30 cm × 30 cm GEM detectors. The assembly of 10 chambers in collaboration with CERN is presented and we discuss the challenges on the electronic and readout system. We finally, discuss our plan to design and build large area GEM detectors (1m × 1m) for the final MT prototype.

Muon Tomography based on scattering of cosmic ray muons

Muons are created in the upper atmosphere by cosmic rays. A muon is an elementary particle with a mass of 105.7 MeV c^{-2}. The muon flux at sea level is 10^4 s^{-1} m^{-2} at an average energy of 4 GeV. Muons interact with matter and are deflected at an angle which has a dependence on their atomic number Z. Due to their penetrating nature, muons are good candidates for detecting shielded high-Z materials. By placing a set of detectors on top of the volume to be probed and another set of detectors at the bottom, one can measure the tracks of the incoming and outgoing muons and therefore the deviation angle due to scattering of whichever material inside the volume and we could perform 3D tomography of the volume.



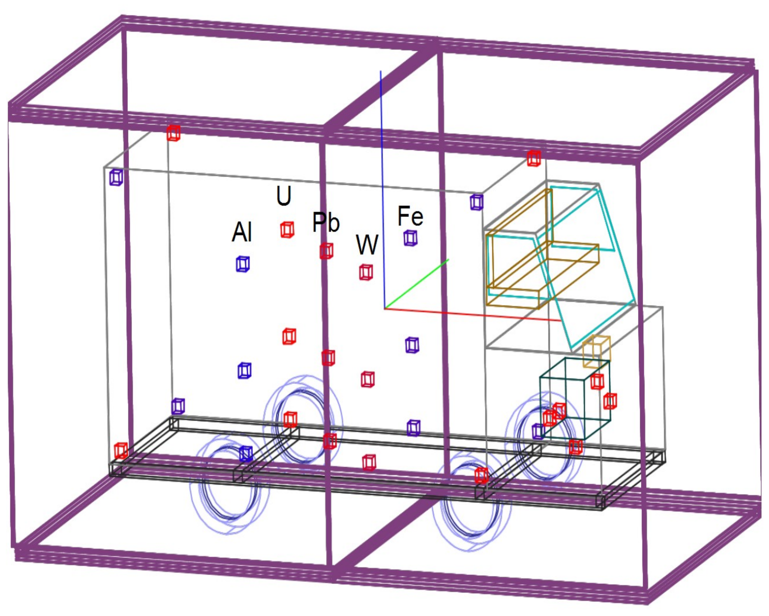
Principle of Muon Tomography using cosmic rays nuons

Gas Electron Multiplier for Muon Tomography

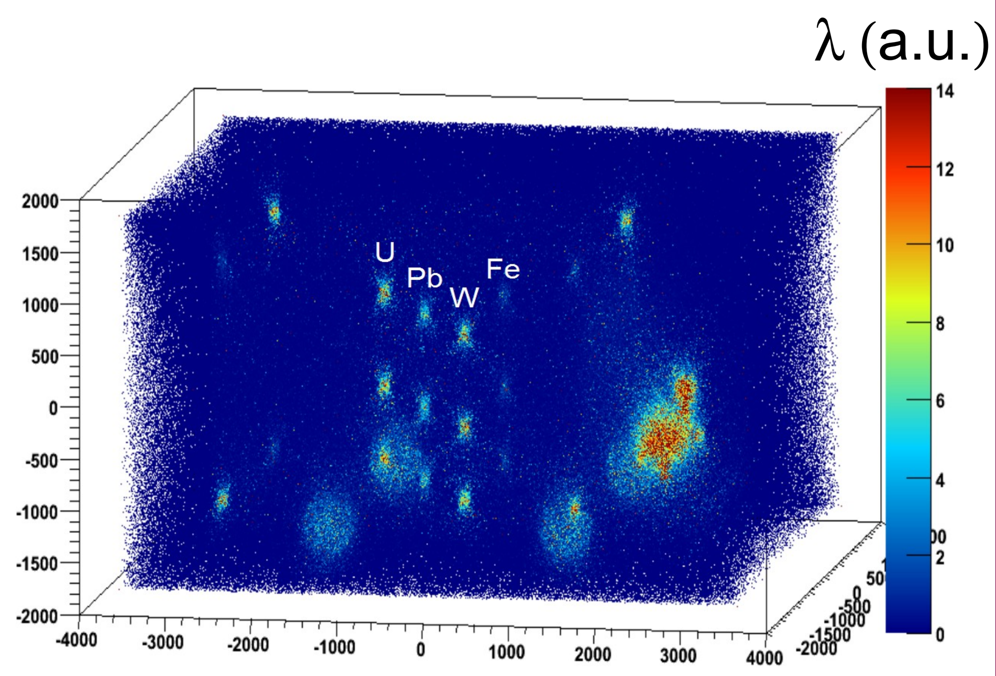
Many research groups worldwide involved in Muon Tomography technique use Drift Tube chambers as the tracking detectors. We propose to use large area Gas Electron Multiplier (GEM) detectors instead. With the excellent spatial resolution (about 50 μm) of GEM detectors, we expect to achieve higher z-discrimination performance than with conventional drift tube (typically 400 μm). Moreover the geometry of the GEM detectors ensure a compact station.

Simulation of Muon Tomography Station

We ran simulation based on GEANT4 tool kit interfaced with CRY Monte Carlo cosmic ray muons generator to study the performances of Muon Tomography stations (MTS) with drift tube vs MTS with large GEM detectors as tracking station and with a realistic van containing multiple targets ranging from low Z aluminium to high Z uranium. The Point Of Closest Approach (POCA) algorithm combined with the scattering density λ is used for 3D reconstruction of the scenario.



The scenario



The reconstruction

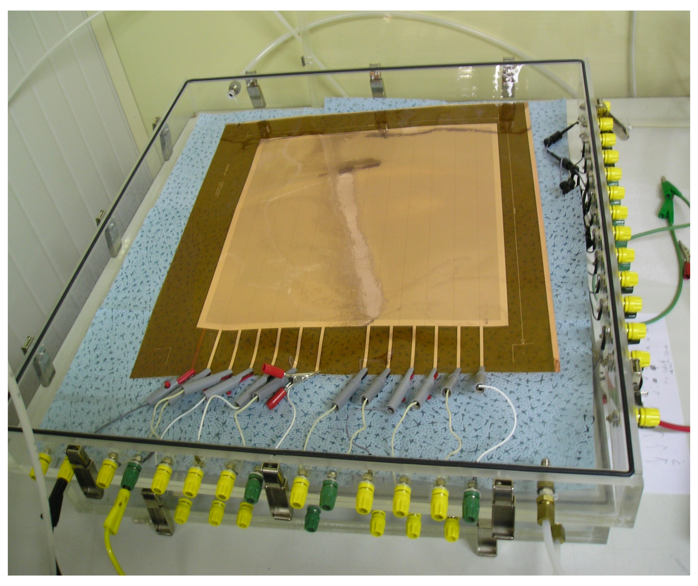
We are also actively working on a Maximum Likelihood method, i.e. an Expectation Maximization (EM) algorithm, developed in Los Alamos (L. Shultz et al.) which combines the lateral displacement of each muon with the scattering angle information in the calculation of the scattering density.

GEM based MT prototype: Proof Of Concept

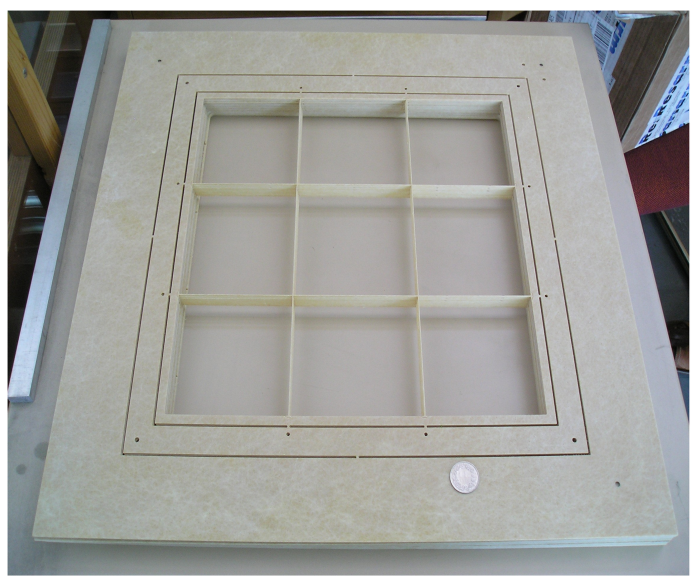
We are building the first prototype of a Muon Tomography Station with 30 cm × 30 cm active area triple-GEM detectors. Initially, the station will consist of two tracking units, one on the top and another one at the bottom of the MT volume we want to investigate. Each tracking unit will have 3 to 5 GEM detectors with adjustable gap between them. Later we are planning to add detectors on the side to test a fully efficient MT station. This first prototype is aimed at studying the feasibility of GEM-based MTS as well as parameters to optimize the performances of such technology like geometrical configuration of the station and minimum numbers of detectors required for maximum efficiency. The experimental results will be compared to the simulation data we obtained earlier.

GEM detectors assembly

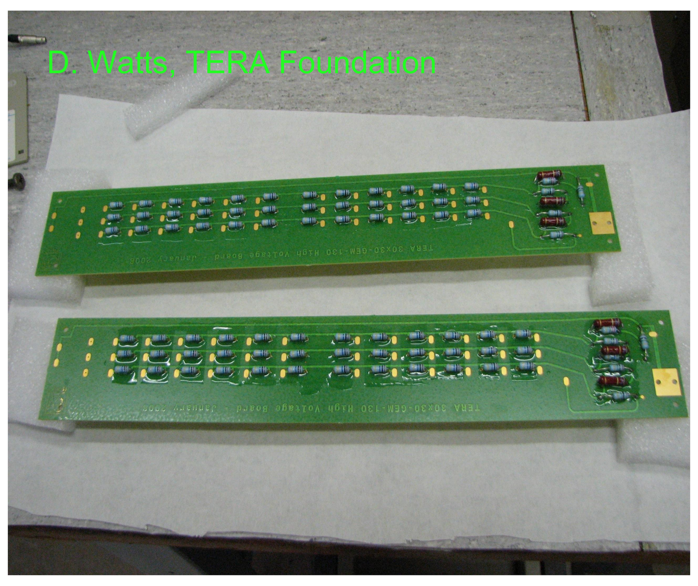
10 triple-GEM detectors that we are building are based on an upgraded version of the original COMPASS GEMs (without beam killer). This upgraded design was made by Fabio Sauli et al. for TERA foundation with significant modification of the XY readout board with respect to the original COMPASS GEM detectors. We added some new modifications to the frame and spacer design to make the stretching and framing of the GEM foils easier during the assembly procedure. The chambers are currently being assembled at CERN with help of the GDD group (L. Ropelewski et al.), the EST/PCB workshop group (R. de Oliveira et al.), and the RD51 collaboration.



GEM foil under HV test



Spacers and frames for the GEM foil



HV board

XY readout foil mounted on a honeycomb board

Front-end electronic and Readout system

We currently are investigating different options for the front-end amplifier chip and readout electronics suitable for our small size MT prototype. Ideally we would like to read out a minimum of 6 complete chambers, equivalent to around 10k channels. The possible candidates are:

- APV chip with COMPASS PixelGEM readout system (Tech. Univ. Munich)
- APV chip with Forward GEM Tracker (FGT) readout system (MIT)
- Gassiplex chip with Micromegas readout system (CEA Saclay)
- VFAT chip with TOTEM readout system (CERN)

Large MT station

The next step is to build a large-area GEM-based MT station prototype to be tested under realistic conditions for vehicle or container scanning. To do so we need larger-area GEM detectors (~ 100 cm × 100 cm) as the base unit for our tracking station. Efforts are being made by RD51 collaboration for various HEP applications to build GEM detectors of this large area. We intend to fully participate in different aspects of this R&D of large GEM ranging from the framing and testing of the large GEM foils to the challenges associated with the electronic readout system needed for this detectors.

Conclusion

Muon tomography (MT) based on Multiple Coulomb Scattering of cosmic ray muons appears as a promising way to distinguish high-Z threat materials such as U or Pu from low-Z and medium-Z background with high statistical significance. Spatial resolution of the tracking detectors is a critical parameter for the expected MT performance. High-resolution Micro Pattern Gaseous Detectors, e.g. Gas Electron Multiplier (GEMs), as proposed here would improve overall MT performance. After an extensive simulation study of the performances of MT technique, we are building a first MT station prototype with 30 cm × 30 cm large GEMs to demonstrate the validity of using MPGDs in the tracking station for muon tomography. We plan to get the first data from the MT station by the end of year 2009. The next phase will be the development of large GEM detectors (~100 cm × 100 cm) in order to build a cubic-meter size MT station prototype as the basis of a full-size MT system that could be deployed in realistic environment for cargo scanning.

Acknowledgement & Disclaimer

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