Large-area Gas Electron Multiplier Detectors for a Muon Tomography Station and its Application for Shielded Nuclear Contraband Detection

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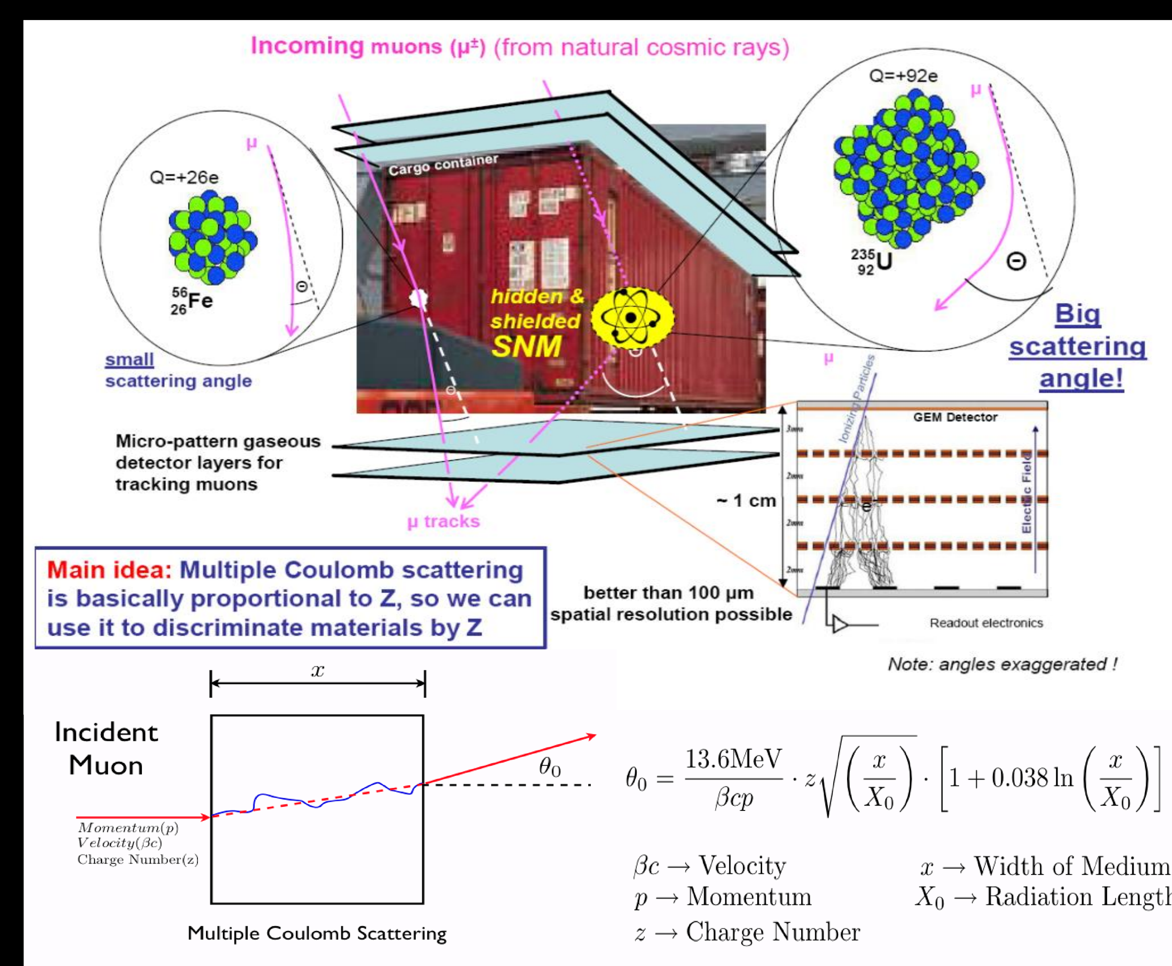
Abstract

Standard radiation detection techniques currently employed by portal monitors at international borders and ports are not very sensitive to detecting emanating radiation from shielded nuclear materials (SNM) like high-Z radioactive materials (U, Pu). Muon Tomography based on the measurement of multiple scattering of atmospheric cosmic ray muons traversing cargo or vehicles is a promising technique for solving this problem. The technique uses the information on the angle deviation of the cosmic ray muons to perform a 3D tomography reconstruction of the high Z material inside the probed volume. A Muon Tomography Station (MTS) requires large-area position-sensitive detectors with excellent spatial resolution for the tracking of incoming and outgoing cosmic ray muons. Large-area Micro Pattern Gaseous Detector (MPGD) technology such as the Gas Electron Multiplier (GEM) detectors are the perfect candidate for this application. We have built a first MTS prototype based on medium-size GEM detectors and took cosmic data for targets with various Z values inside the MTS volume. We discuss construction and commissioning of the GEM detectors and report preliminary results for target detection and imaging from cosmic data taken with the MTS prototype. We also discuss plans to build large- area high-performance GEM detector to be mounted in a 1m × 1m MTS prototype and the current development by the RD51 collaboration of final electronics for a full MTS readout based on the APV25 chip.

Muon Tomography Principle



Muons: created in the upper atmosphere by cosmic rays

Flux: ~ 1 muon min^{-1}cm^{-2} for horizontal detectors

Average energy: 4 GeV

Interaction: Multiple Coulomb Scattering

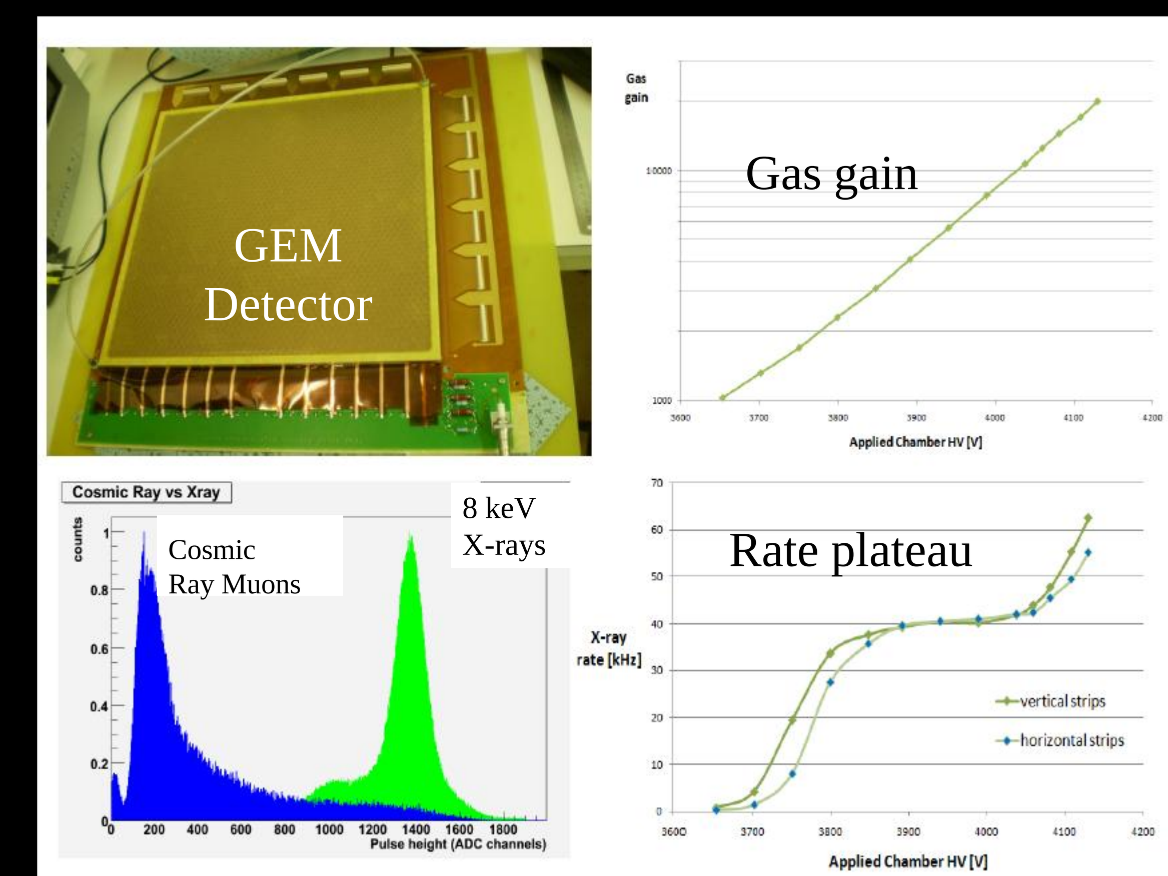
GEM Detectors Commissioning

Detectors: Eight 30cm × 30cm 30 Triple GEMs

Readout: 2D x-y cartesian strip readout

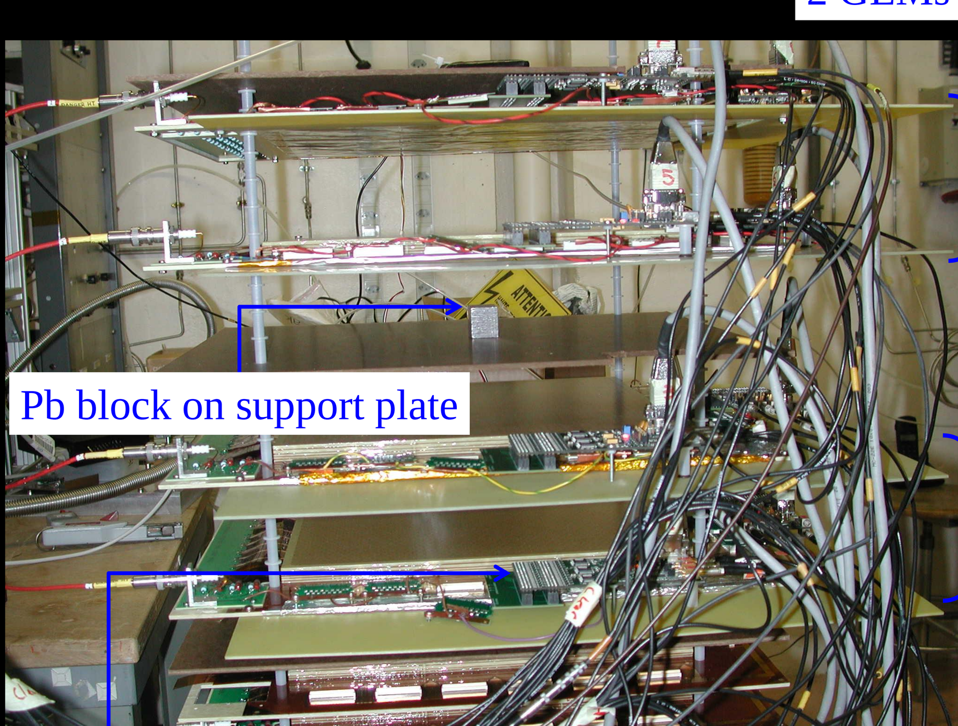
Gas: Argon/CO2 70:30

HV divider board



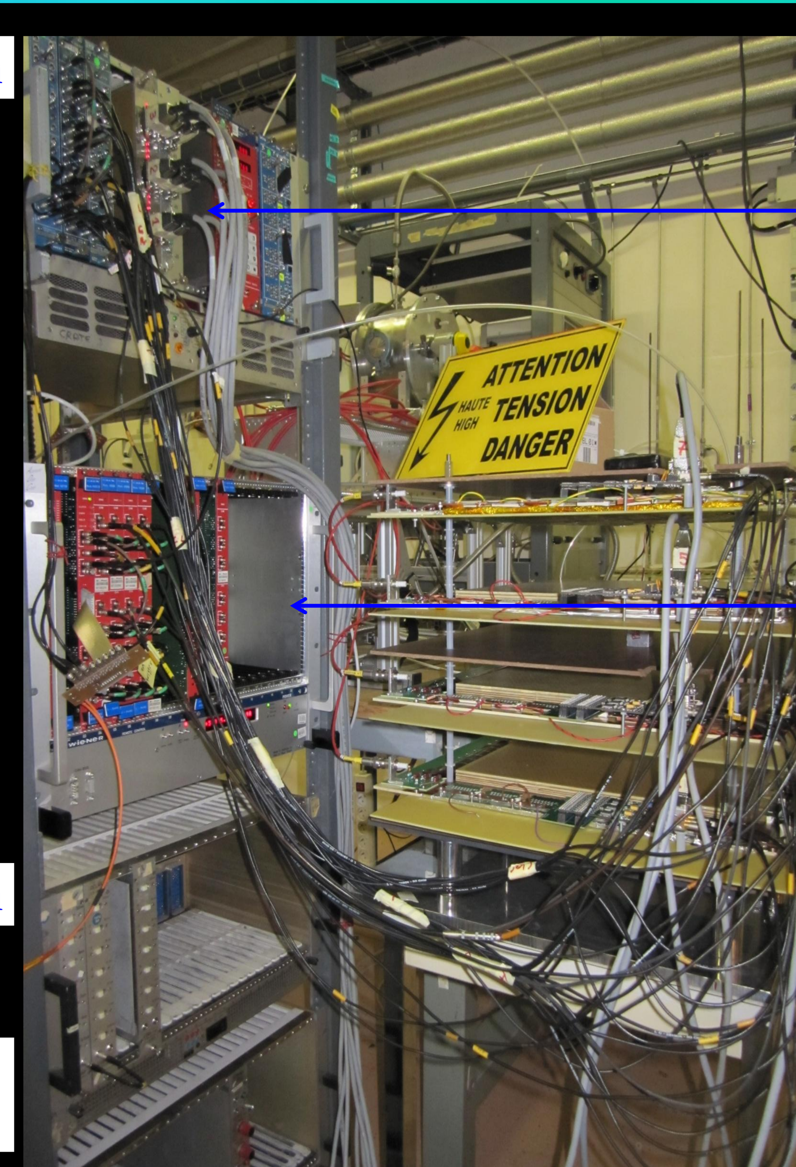
Standard test results of one of our Triple GEM detector

Muon Tomography Station (MTS)




Close view of the MT station and the trigger counter

Data Acquisition System



MT station setup with its the data acquisition hardware

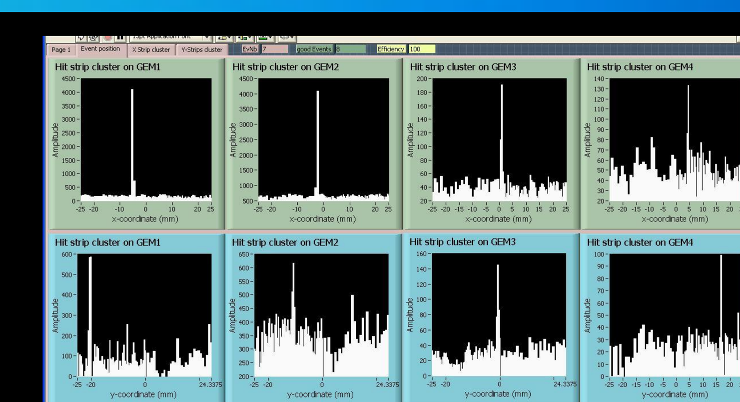
DAQ hardware:

- NIM crate:
  HV power for the GEMs, LV & control signals for the FE cards
- VME crate:
  - Sequencer (Caen V551) for trigger, FE & CRAMS control signals
  - 4 CRAMS (Caen V550 10-bit ADCs), Data signal from the Gassiplex FE

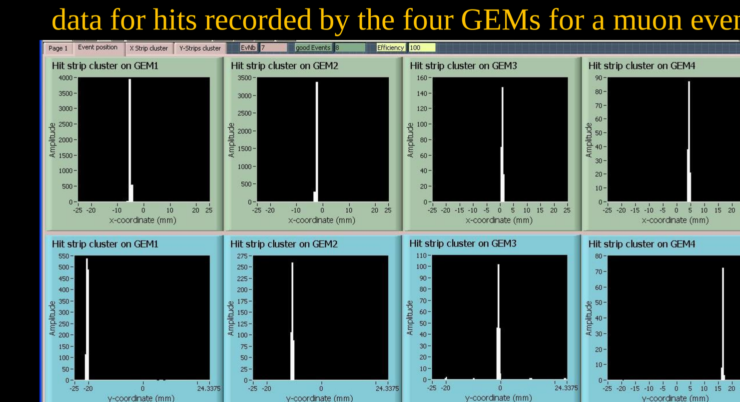
Labview DAQ Software

- Online:
  - DAQ VME hardware
  - Pedestal runs
- Offline:
  - Pedestal subtraction
  - Strip number correction
  - Performance analysis

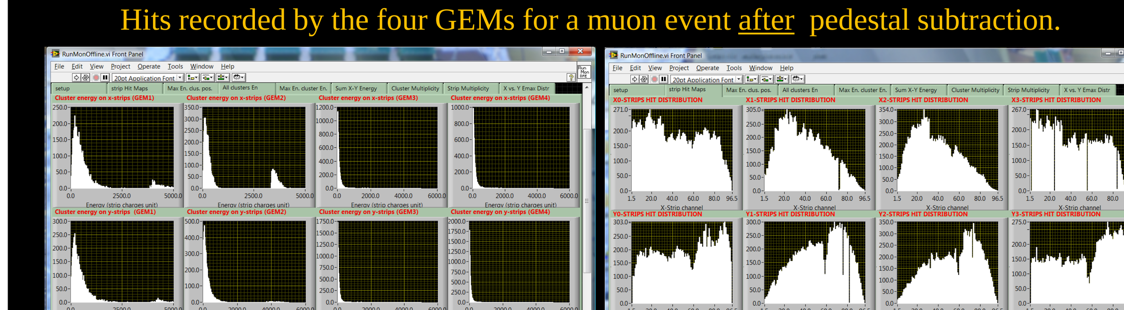
Performance of the MTS



data for hits recorded by the four GEMs for a muon event

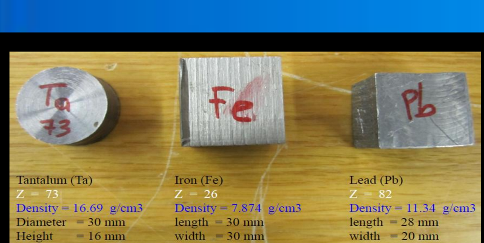


Hits recorded by the four GEMs for a muon event after pedestal subtraction.

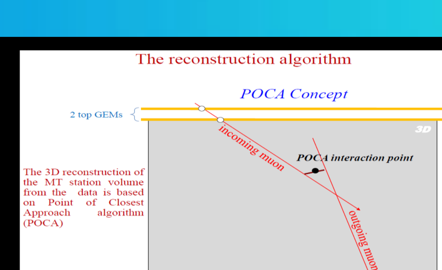


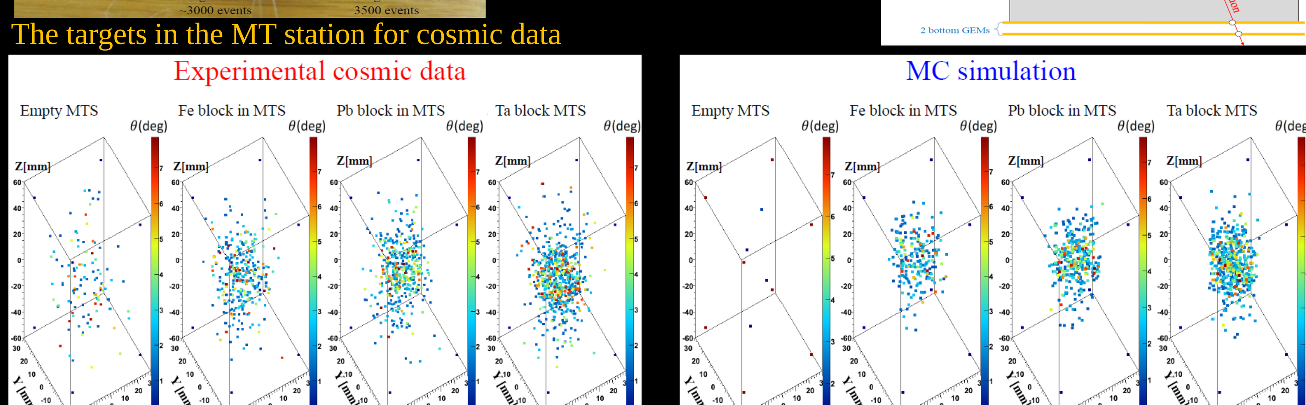
Hit charge (left) and hit position (right)distribution by the four GEMs.

Detection & Imaging from GEM-MTS



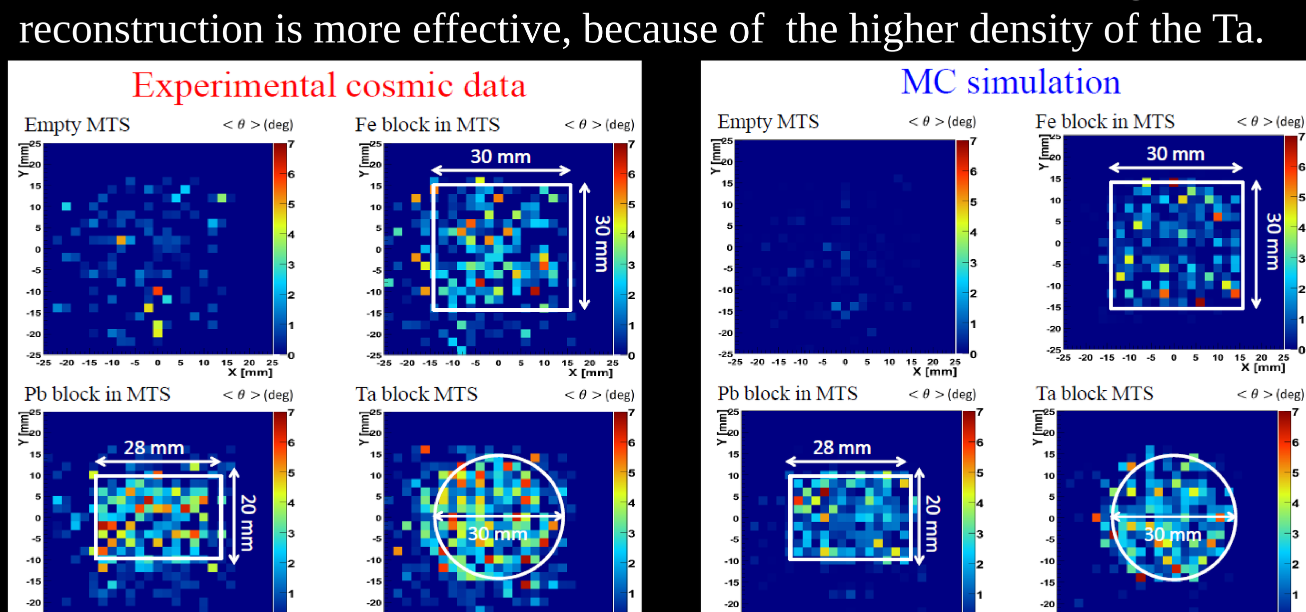
The targets in the MT station for cosmic data





3D POCA reconsruction of cosmic data runs with different targets in the MT station

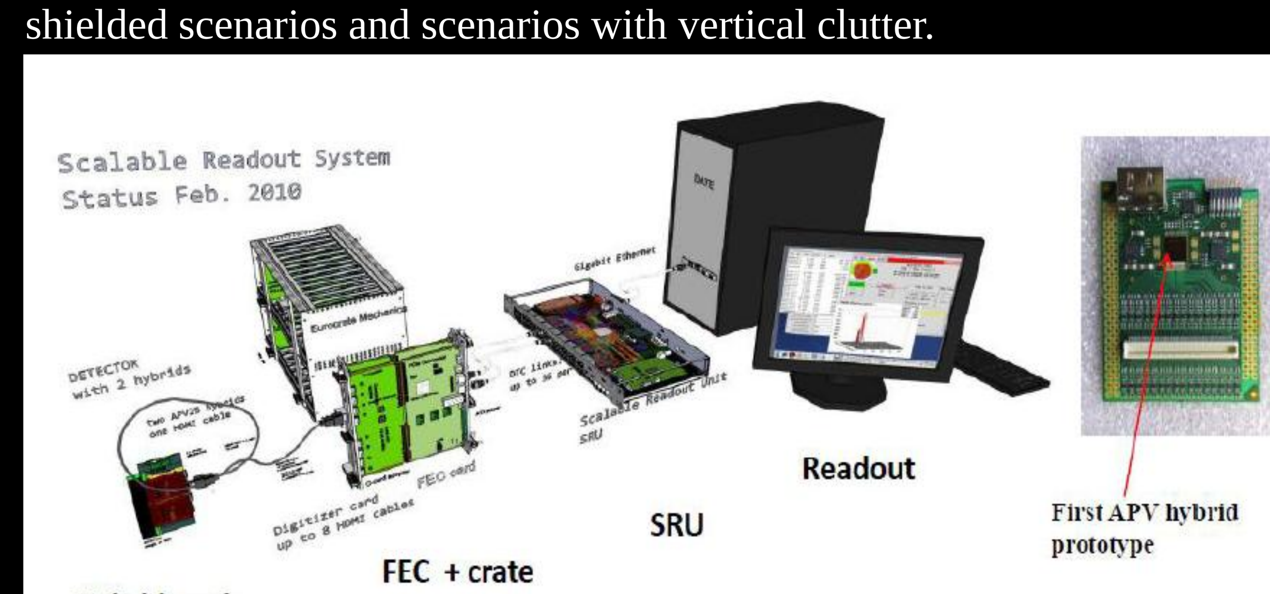
We clearly reconstruct and image the small targets Fe, Pb and Ta. We clearly imaged see the circular shape of the Ta target X-Y slice. Our Ta target has a lower Z value and a thickness twice as small as the Pb target, but the reconstruction is more effective, because of the higher density of the Ta.



20 mm X-Y slice of MTS volume at z = 0 where the targets are placed. Each voxel value represent the mean scattering angle of all the POCA points reconstructed in the voxel

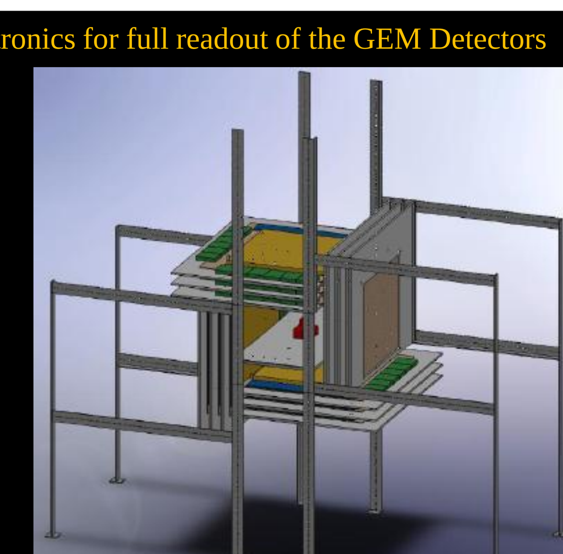
Future Planned Developments

The next step is to fully instrument all GEM detectors with the final electronics and mount them in a cubic-foot size MT station that also features side detectors. This will increase the rate of muons available for testing the MT station. We plan on constructing and operating such a station to experimentally investigate more advanced scenarios, e.g. shielded scenarios and scenarios with vertical clutter.



Schematics of the Scalable Readout System (SRS) electronics for full readout of the GEM Detectors

The final step in this project will be to build and test a cubic-meter size MT station under realistic condition. To do so, we need larger GEM detectors (~ 100cm 50cm) as the base unit for a tracking station. Efforts are being made by the RD51 collaboration for various HEP applications to build such large-area detectors. We plan to participate in different aspects of the R&D .



Design of the next mechanical stand for the MT station with also side detectors

Conclusions

We assembled a total of eight 30cm × 30cm GEM detectors at the GDD lab at CERN. Tests with X-rays and cosmic ray muons showed expected basic detector performance and similar behavior among the detectors. We have built and operated a first minimal MT station prototype using four of these GEM detectors and temporary electronics for reading out 1024 channels (of ~15k total) as a first demonstration of using GEM detectors for muon tomography. With a few thousand cosmic ray muons recorded with the station, we are able to detect and image several medium-Z and high-Z targets (Fe, Pb, Ta) with fairly small (~ cubic-inch) volumes using our simple point-of-closest-approach reconstruction algorithm. This demonstrates that GEM-based muon tomography is in principle possible.

Acknowledgments & Disclaimer

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