Detecting shielded nuclear contraband using muon tomography

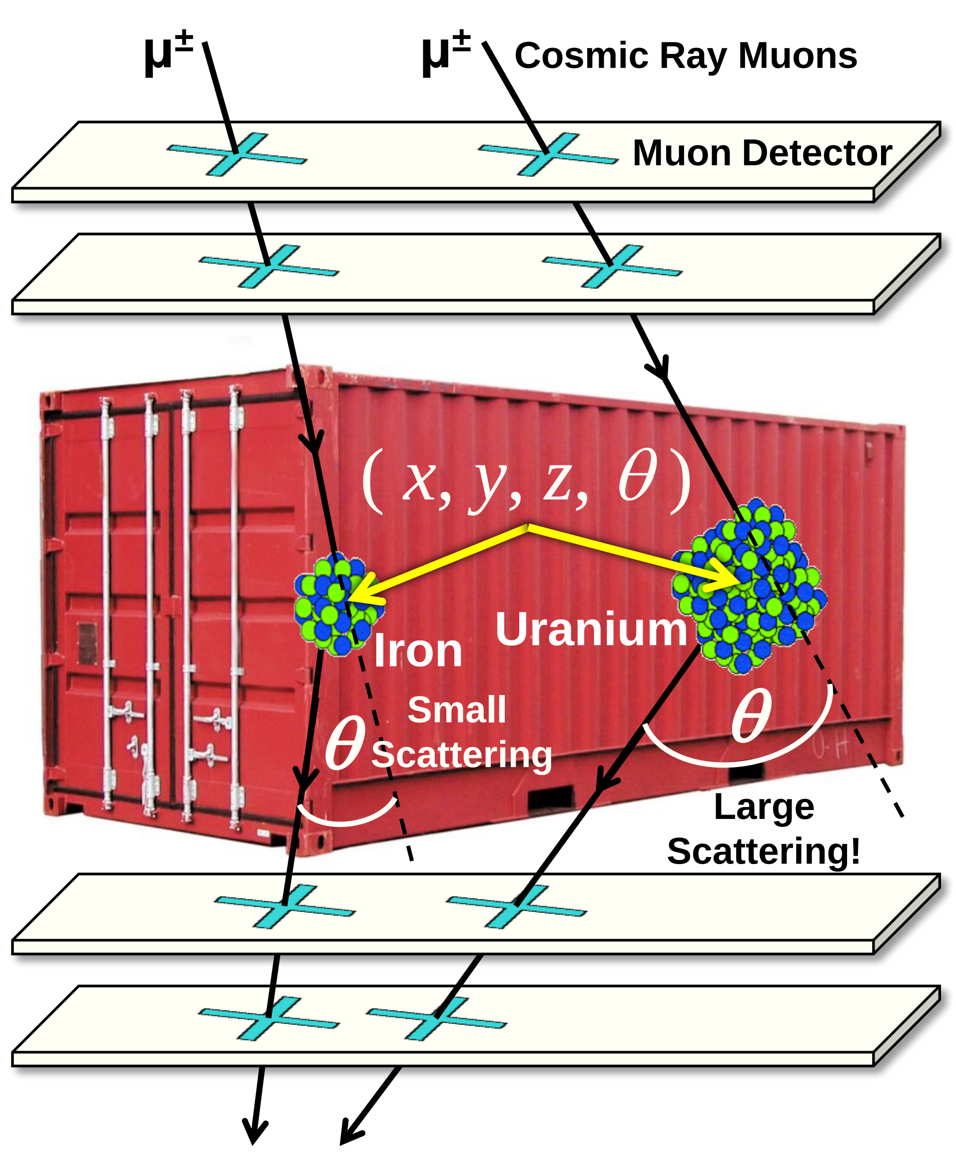
Judson Locke, William Bittner, Leonard Grasso, Dr. Kondo Gnanvo; Adviser: Dr. Marcus Hohlmann
Department of Physics and Space Sciences, Florida Institute of Technology

Background

There are ~800 points of entry in the US with radiation detection portals for locating nuclear contraband. These detection systems are triggered by gamma radiation emitted by nuclear material. However, only ~3.25 mm of lead shielding is needed to block 99% of gamma emissions from weapons-grade uranium-235. Therefore, a system for detecting *shielded* nuclear contraband is needed. For this reason, we seek to build a system using cosmic-ray muons to detect shielded nuclear contraband smuggled across borders in vehicles, shipping containers, etc. for terrorism or other malicious purposes.

Concept

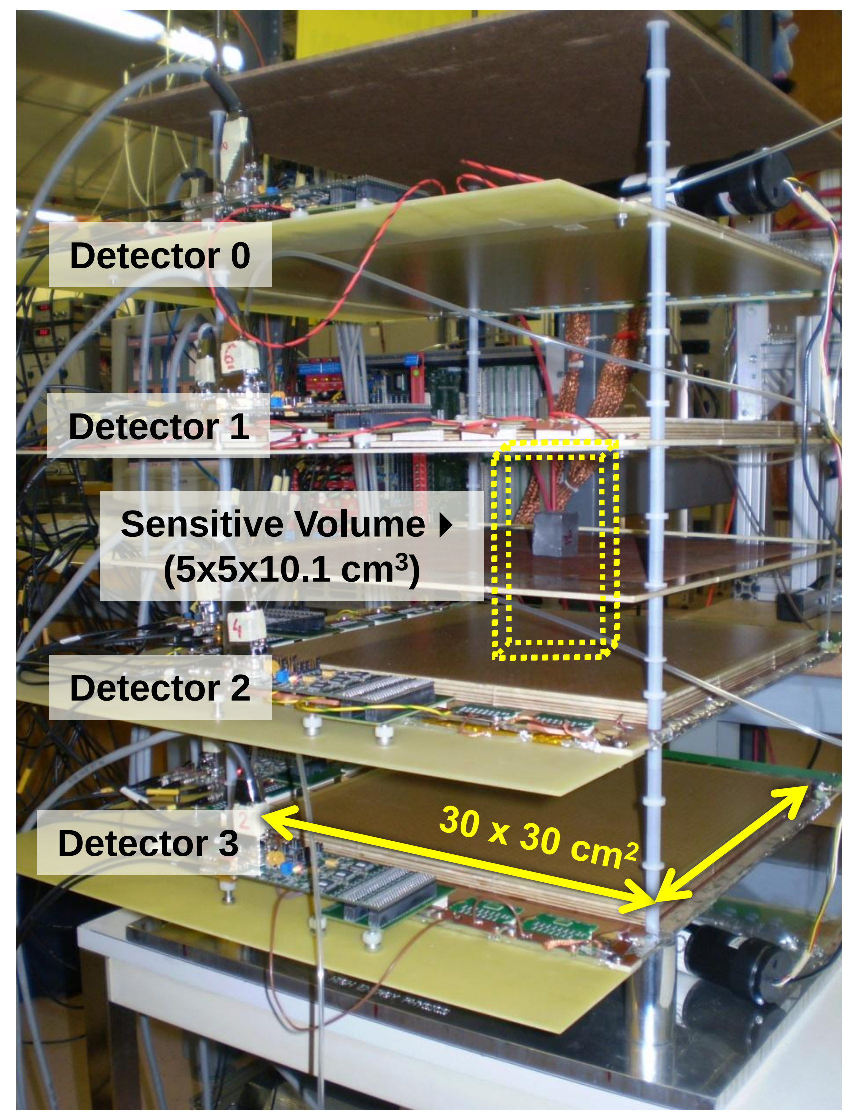
High-energy protons (cosmic rays) strike nuclei in the upper atmosphere, causing nuclear reactions resulting in showers of subatomic particles, including muons. The muons survive long enough to reach the Earth's surface with an average flux of ~10,000 muons/m^2/minute and an average energy of ~4 GeV. The muons are charged; therefore, they undergo Coulomb scattering with nuclei. Muons are scattered more by higher-Z materials (e.g. uranium) than by lower-Z materials (e.g. iron). Muons are tracked by a muon tomography station which provides incoming and outgoing trajectories. The point of closest approach (POCA) and angle between the trajectories are calculated to find the position and type of material which scattered the muon in the station. See Fig.1.



▲ **Figure 1 (above):**
Muon tomography concept in general. Cosmic-ray muons are tracked through a muon tomography station to find where and by how much they scattered: (x, y, z, θ). From this information, the types and locations of materials in the volume are found.

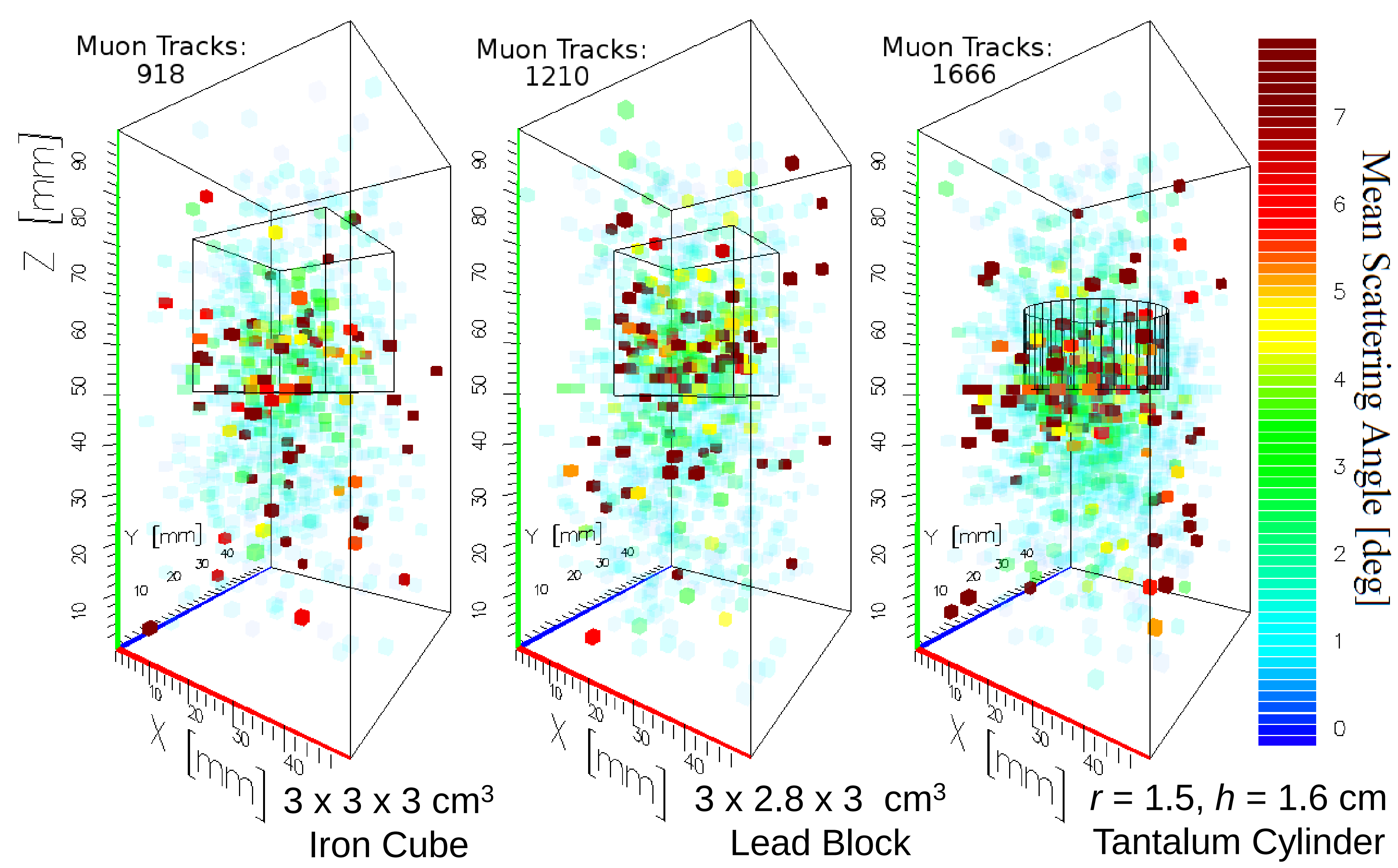
Minimal Prototype Muon Tomography Station

In summer/spring 2010, we constructed and tested a minimal prototype muon tomography station composed of 4 detectors with detection areas of 30x30 cm^2. See Fig. 2. We could only read out 5x5 cm^2 of the detectors due to electronics limitations. We imaged three targets: an iron cube, a lead block, and a tantalum cylinder. See Fig. 3.



The targets have different atomic numbers, densities, and geometries, all affecting the amount by which muons are scattered. Fig. 3 shows the three targets are *visually distinguishable* after several hours of data-taking. Such a long exposure time was necessary only because of the small size of the sensitive volume. Monte Carlo simulations using the GEANT4 utility predict the ability of a muon tomography station to detect nuclear material within a matter of minutes.

◀ **Figure 2 (left):**
Minimal prototype muon tomography station. The station is composed of 4 detectors: 2 on top, 2 on bottom. This is, essentially, a smaller version of the station shown in Fig. 1. Targets are placed in the sensitive volume (the cargo container, truck, etc. in a full-size station goes here). The iron cube target can be seen in the sensitive volume.

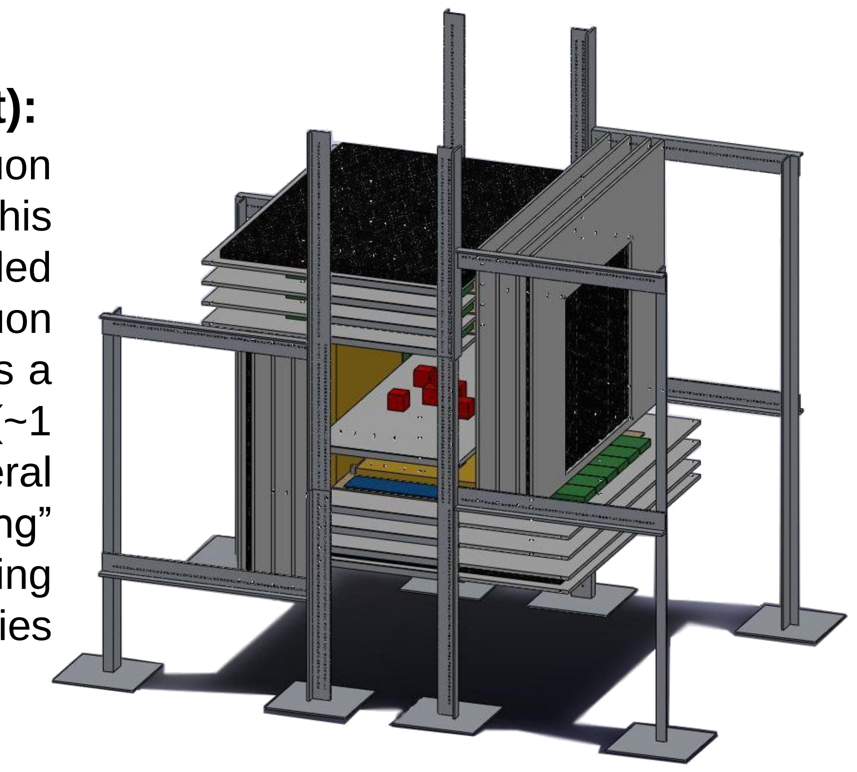


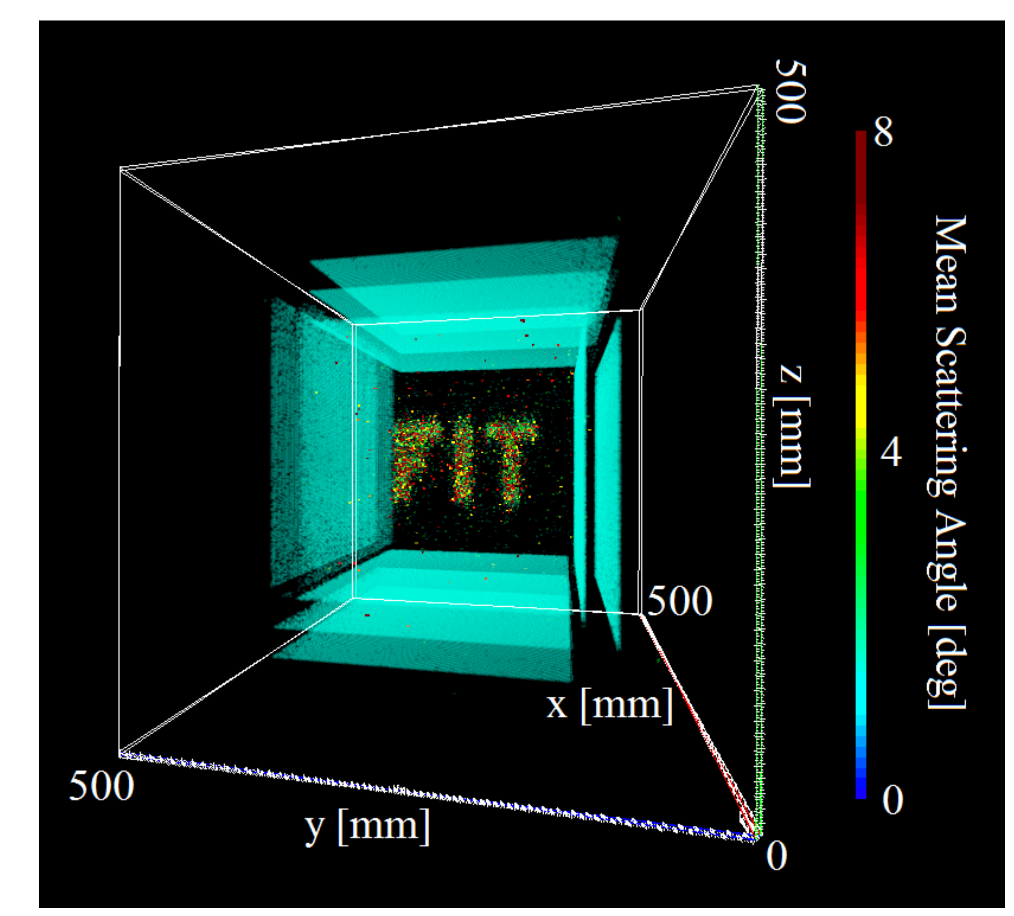
▲ **Figure 3 (above):**
Tomographic reconstructions of an iron cube, a lead block, and a tantalum cylinder using the minimal prototype muon tomography station. The volume of the plots corresponds to the sensitive volume shown in Fig. 2.

ft^3 Muon Tomography Station

In summer/fall 2010, we designed and built an upgraded muon tomography station with a sensitive volume of ~1 ft^3. See Fig. 4. The station is currently being assembled at CERN for testing. Tomography data is expected by early spring 2011. Monte Carlo simulations of the reconstruction abilities of the new station are presented in Fig. 5.

▶ **Figure 4 (right):**
The cubic foot muon tomography station. This station is an upgraded version of the minimal muon tomography station. It has a larger sensitive volume (~1 ft^3) for imaging and lateral detectors for "catching" more muons and improving reconstruction capabilities in the vertical direction.





▲ **Figure 5 (above):**
Tomographic reconstruction of the letters "**F I T**" made of uranium imaged with the ft^3 muon tomography station. Locations where muons struck the detectors are weighted with a mean scattering angle of 1.5. The detectors are clearly seen in this reconstruction and can be compared to Fig. 4.

Conclusion

Cosmic-ray muon tomography appears to be a promising technique for detecting shielded nuclear contraband. We successfully constructed and tested a muon tomography station using gas electron multiplier detectors. We imaged three targets of different dimensions, atomic numbers, and densities and were able to visually distinguish between the targets from the tomographic reconstructions.