High Resolution Muon Tomography using a Portable Prototype Muon Telescope

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Outline

- Cosmic Ray Showers and Muon Particles
- Muon Tomography
- Muon Detection System
- Muon Telescope
    - Assembly and Components
    - Data Acquisition System (DAQ)
- Experiment: Water Tower Image
- Monte Carlo Simulation for Experiment
- Results and Analysis
- Looking Forward

Cosmic Ray Showers and Muon Particles

- Cosmic Ray Shower – High energy protons interacting with the upper atmosphere to create muons.
- Muon Flux - 10,000 muons per minute per square meter at Sea Level
- Muon Particles:
  - leptons
  - same charge as an e-
  - 207 times the mass of an e-
  - mean lifetime of 2.2 microseconds

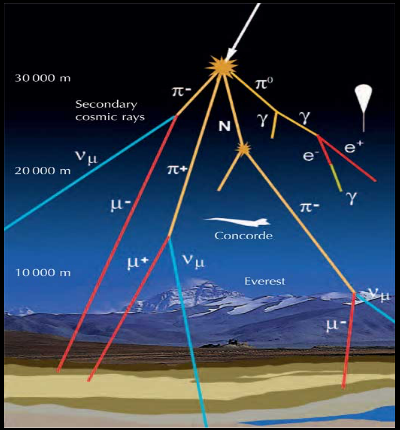

Fig 1. Cosmic Ray-Shower

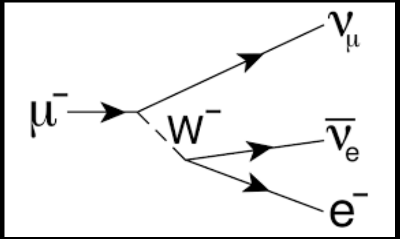

Fig 2. Muon Decay Products

Muon Tomography

- Muon Tomography – Technique that utilizes muon scattering and muon absorption to generate images of large objects such as buildings, volcanoes, and ancient archaeological structures
- Muon images contain both density and shape information of objects
- Non-invasive way of imaging using a natural source

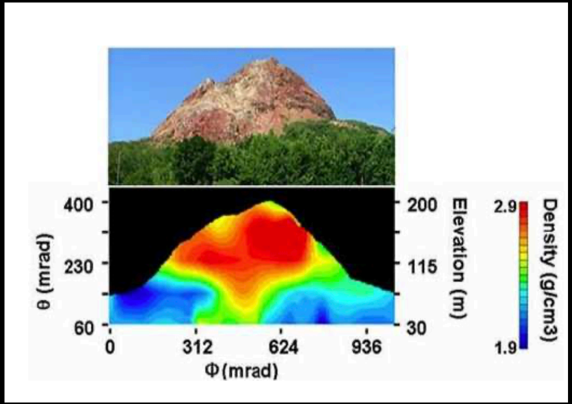

Fig 1. Top: Showa-Shinzan Lava Dome. Bottom: Density Distribution

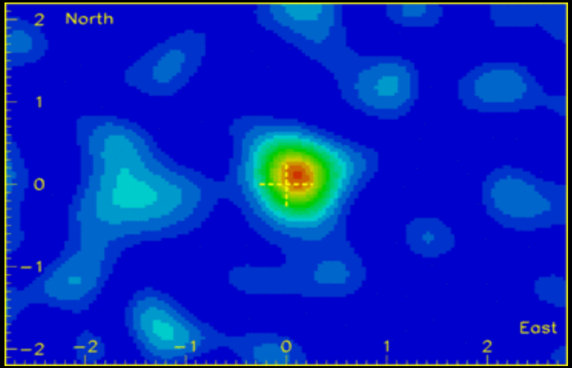

Fig 2. The Moon's Cosmic Ray Shadow detected by the Soudan II detector

Muon Detection System

- The muons are generated in cosmic ray showers
- When they pass through scintillators, the create scintillation photons
- These photons are detected by PMTs or SiPMs and converted into electrons
- The DAQ system comprises a readout electronics circuit that determines muon hits

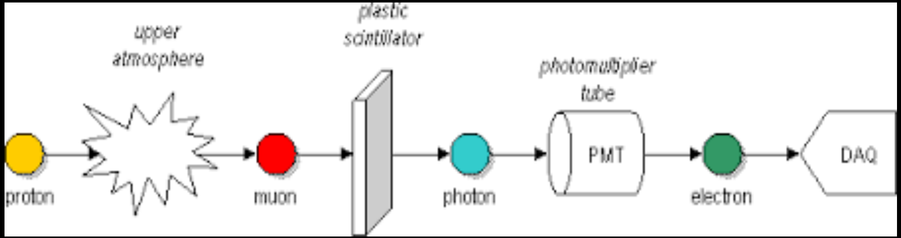

Fig 1. Schematic summarizing the muon detection process

Fig 2. EJ – 200 Scintillator Bars

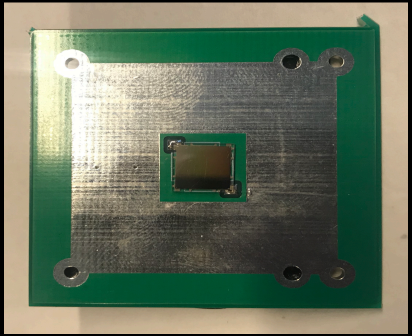

Fig 3. Silicon Photo Multiplier (SiPM)

Muon Telescope:
Assembly and Components

- Telescope - 2 layered system with each tray containing the following components
- Scintillator bars (5 x 5 x 60 cm^3), silicon photomultipliers (SiPM), Winston Cone light collectors, Readout Electronics and a network of Arduinos (DAQ).
- Size: 90 cm by 180 cm

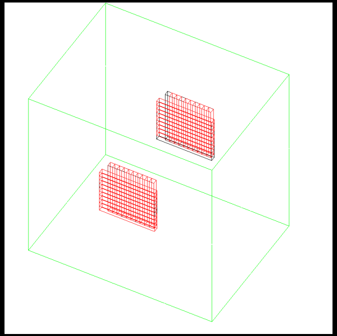

Fig 1. 2 Layers of Scintillator Bars

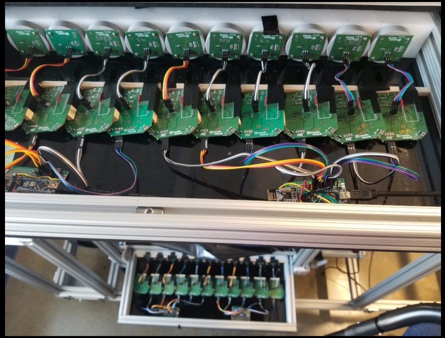

Fig 2. SiPMs and the DAQ

Fig 3. Muon Telescope

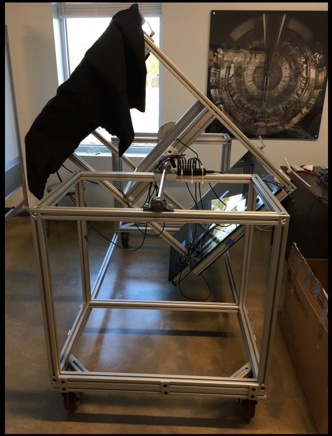

Fig 4. Muon Telescope rotated 45 degrees

Muon Telescope: Data Acquisition System (DAQ)

- DAQ – Communication system that allows us to efficiently transfer data from the start to finish via wireless communication.

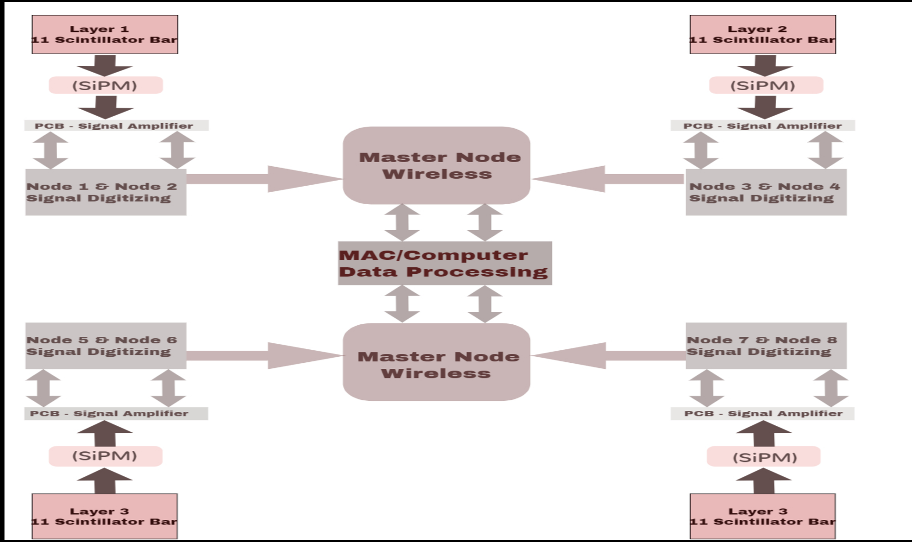

Fig 1. The Communications Flowchart.

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  - Working Philosophy
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- Experiment: Water Tower Image
- Monte Carlo Simulation for Experiment
- Results and Analysis
- Conclusion

The Experiment

- Currently being used to detect muons being absorbed and scattered by the water tank to create images of the water tank's shape and contents.
- Height – 44 meters

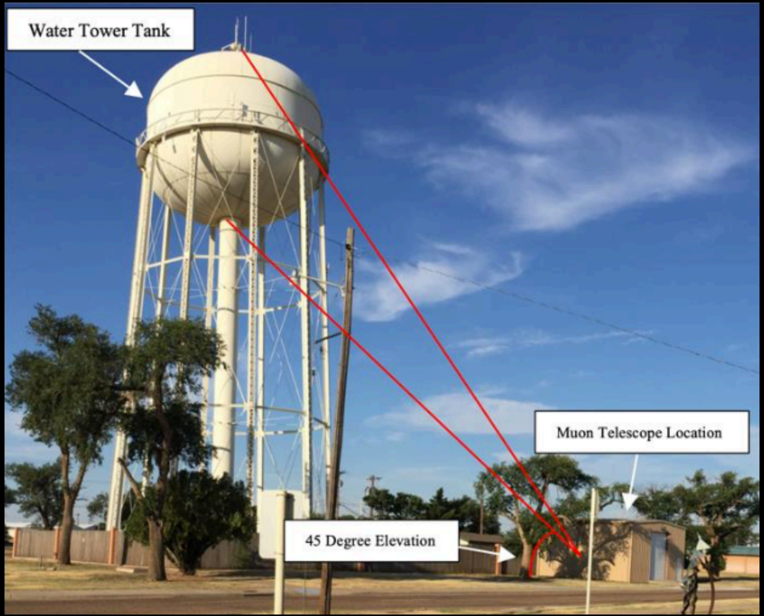


Fig 1. Water Tower at Reese Technology Center

Monte Carlo Simulation

- Geant4 – Toolkit to simulate the passage of particles through matter. Used to create the world we run the simulation in.
- Cosmic Ray-Shower Library (CRY) – Program for generating particle showers. Gives the particle ID and energy.
- ROOT – Framework for data processing. Allows us to create histograms from collected data to compare to experimental data.

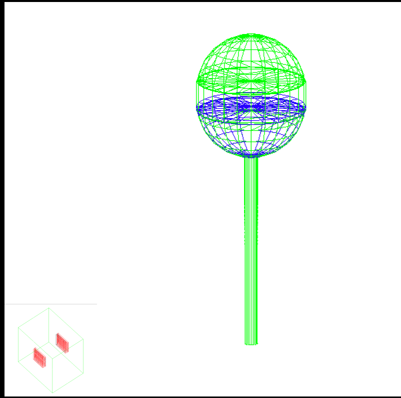


Fig 1. Simulation of water tower and detector.

Fig 2. Water Tower at Reese Technology Center.

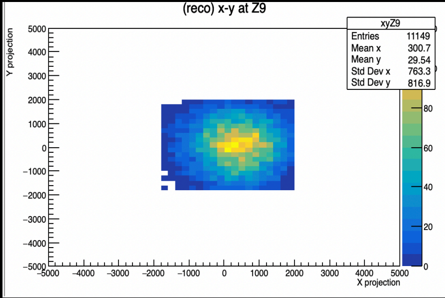
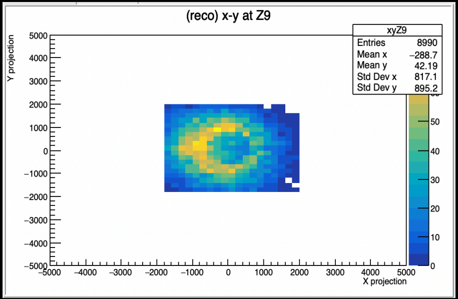


Fig 3. Frequency of muon hits [telescope looking at sky]



Frequency of muon hits [telescope looking at the water tower]

Results

- We were able to observe the shadow of the water tank using muon and the prototype detector
- The data indicate that there is ~15% loss of muons due to the presence of the filled water tower
- 5.2% of all detected muons go through all four layers in Prototype-I detector.
- Angular resolution of 50 milliradians at an operating efficiency of 89%

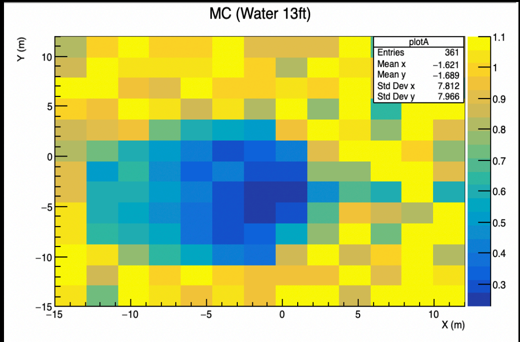


Fig 3. Water Tower Shadow Image from MC

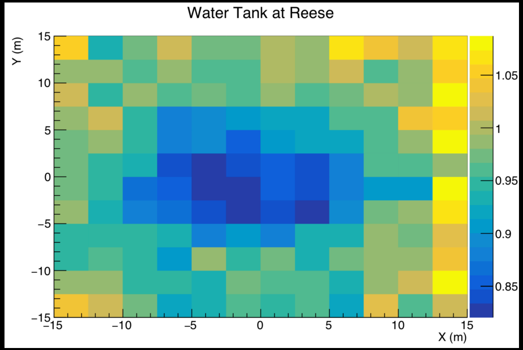


Fig 4. Water Tower Shadow Image from data

Looking Forward

- Use of WLS scintillation fibers
- Use of triangular scintillators
- Development of faster DAQ using multithreading processes
- Development of custom readout electronics
- Monte Carlo Simulation experiments of mountains in Limyra
- Prototype 2.0 for Texas Department of Transportation (0.5 milliradians)

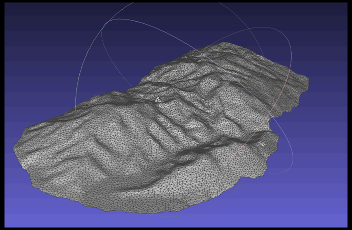


Fig 1. MC of Limyra

Fig 2. Mountains of Limyra

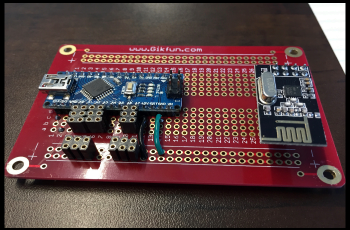


Fig 3. Prototype Readout Electronics

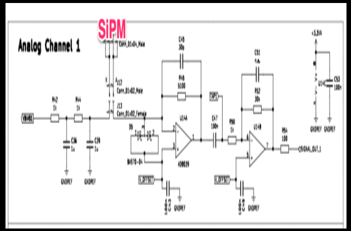


Fig 4. SiPM, Amplifier and Pulse Shaper Circuit

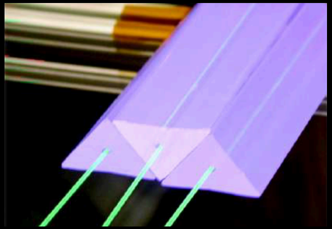


Fig 5. Triangular scintillators

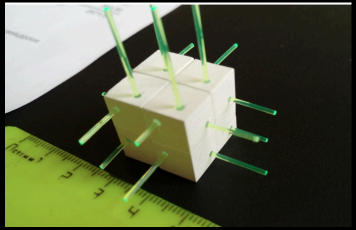


Fig 6. WLS scintillators

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