INL/CON-24-81916-Revision-0

Using Cosmic Ray Muons to Assess Geological Characteristics in the Subsurface

November 2022

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Using Cosmic Ray Muons to Assess Geological Characteristics in the Subsurface

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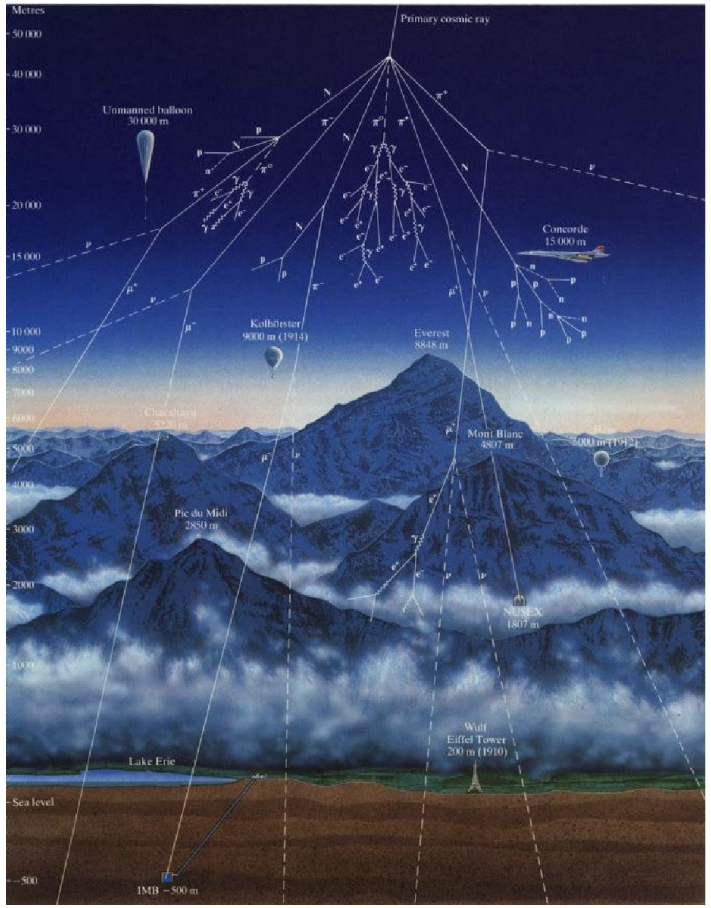
Outline

- Cosmic Ray Muons
- Goals and Methodology
- Detection System
- Detector Simulation
- Conclusions and Path Forward

Cosmic Ray Muons

- Cosmogenic charged particles:
  - 207 times heavier than electron
  - ~4 GeV at sea-level
  - Naturally occurring
  - ~2.2μsec mean-life
- Cos^2 distribution
- 10,000 muons m^{-2} min^{-1} at sea-level
- Few km sub-surface range
  - Orders of magnitude greater compared to conventional radiation



(https://sites.google.com/site/diaphanemuontomography/Home/diaphane-home-of-the-english-pages/cosmic-ray-muon-tomography)

Goals and Methodology

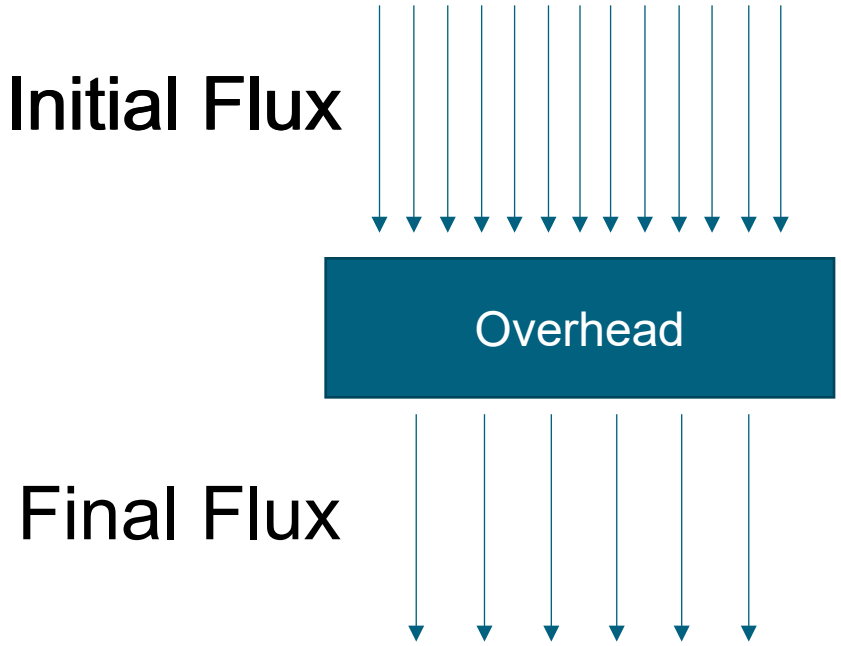
Flux
- Measure cosmic ray muon flux

Overhead
- Overhead estimation (reduction in muon flux)

Tomography
- Design modifications (tomography)

Goals and Methodology (cont.)

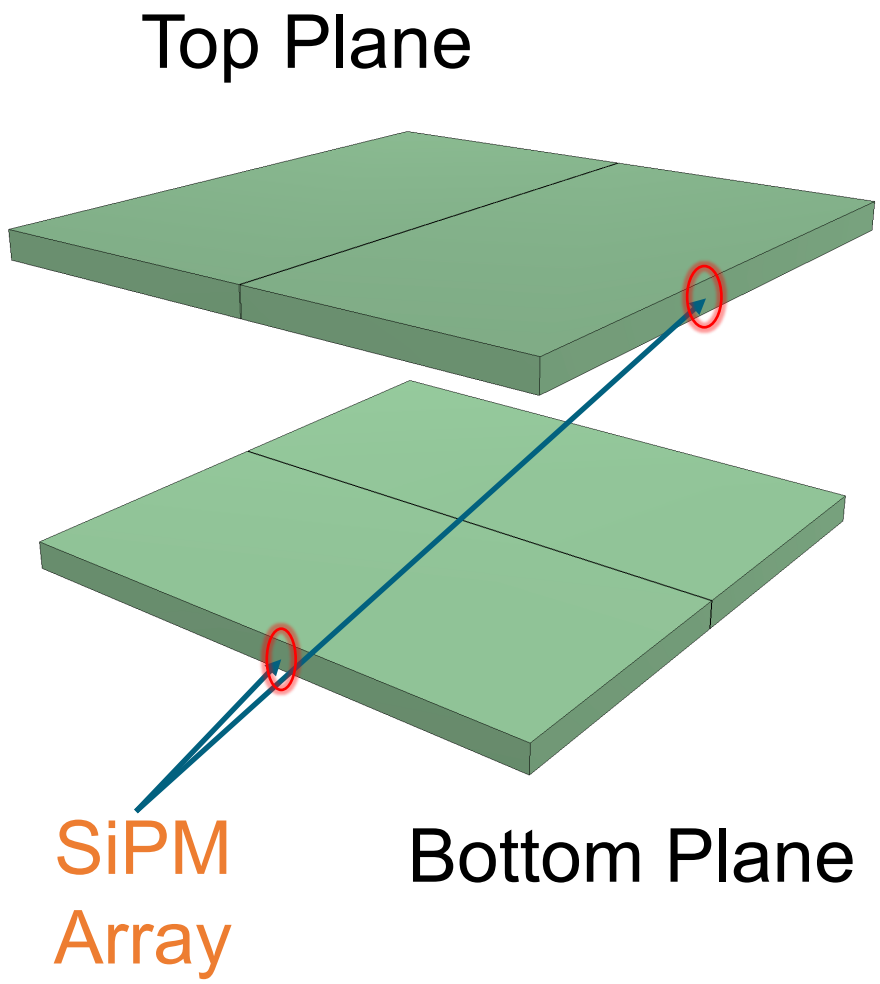
- Flux Measurement:
  - Plastic scintillators
  - Estimate cosmic ray muon background
- Overhead Estimation:
  - Depth → density OR density → depth
  - Benchmarking at facilities with known characteristics
- Tomography:
  - Preliminary effort towards muon geo-tomography



↑ Overhead; ↓ Final Flux

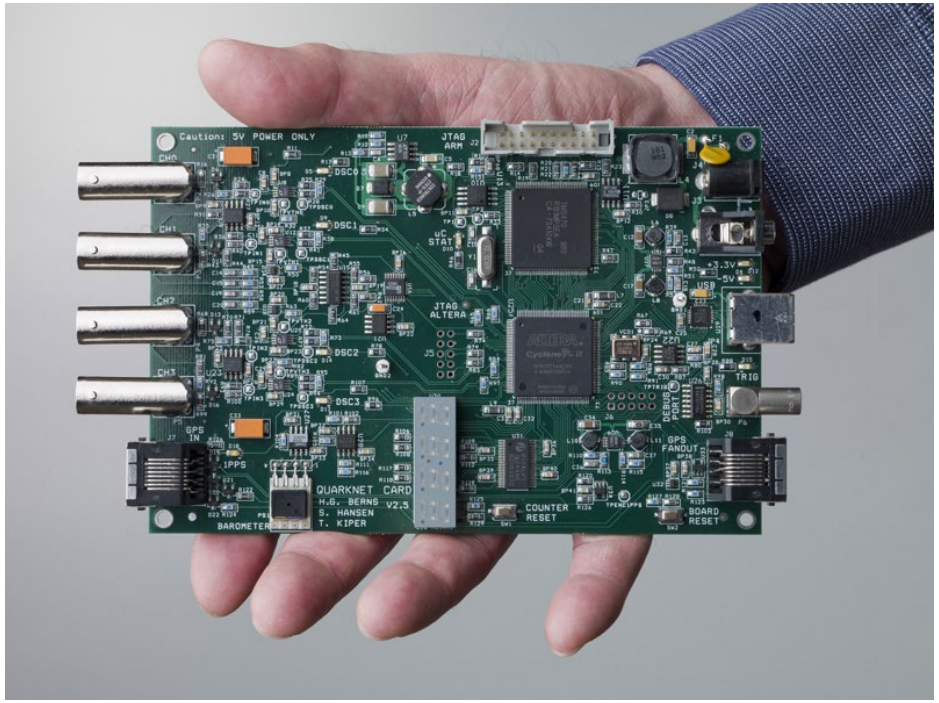
Detection System

- Plastic Scintillators (Saint Gobain):
  - 2 planes (~10,000 cm^2 each)
  - Orthogonal placement → tomography
  - 102 cm × 51 cm × 5 cm
- Optical photon yield > 1.11 x 10^5 per event
- Silicon Photomultipliers vs PMTs
- Teflon → Aluminum → Black Vinyl



Detection System (cont.)

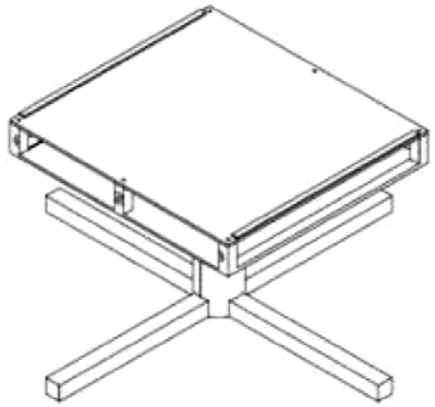
- Data Acquisition System (FNAL):
  - 4 channel system
  - Real-time coincidence identification
  - Negative sensitive (custom design)
  - 12 W DAQ
- Pulse digitization: time-over-threshold methodology → amplitude estimation
- User-adjustable signal amplifiers

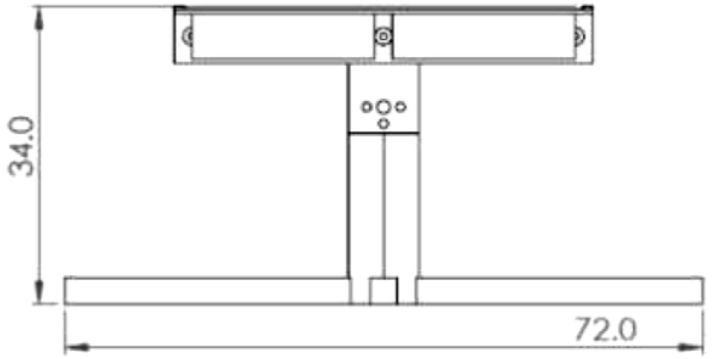


(https://news.fnal.gov/wp-content/uploads/2017/05/quarknet-daq-3000-09-0021-09D.jpg)

Detection System (cont.)

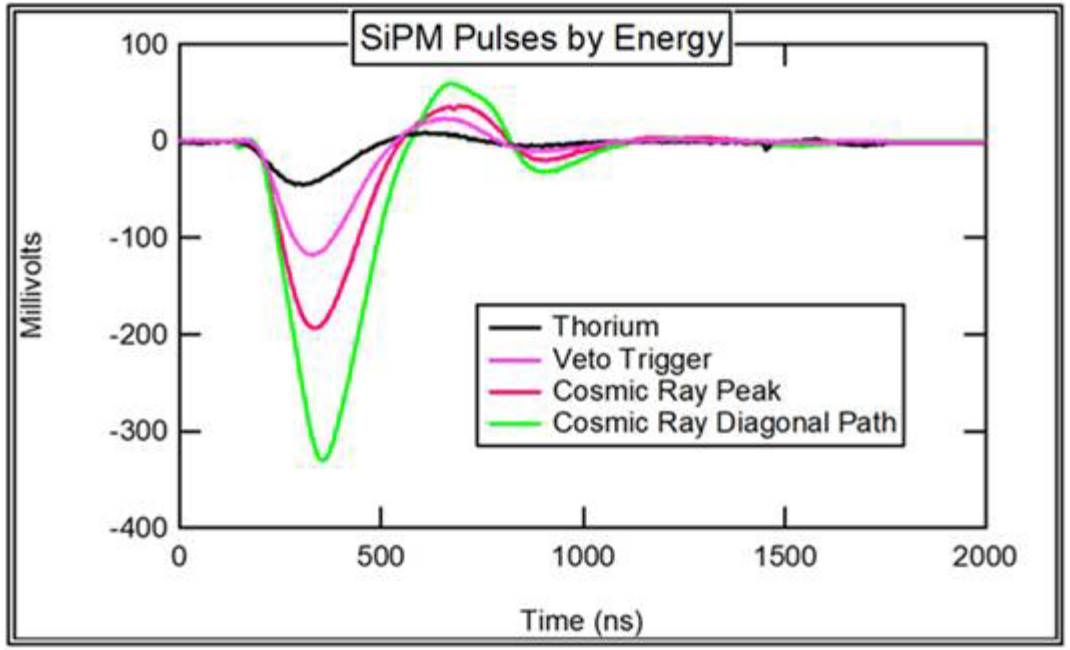
- Detector Frame:
  - Aluminum 6061
  - Variable plane distance → resolution
  - Zenith rotation: 0°, 15°, 30°, 45°, and 60°
- Additional Components:
  - User Interface: Raspberry Pi
  - Rechargeable batteries for remote locations





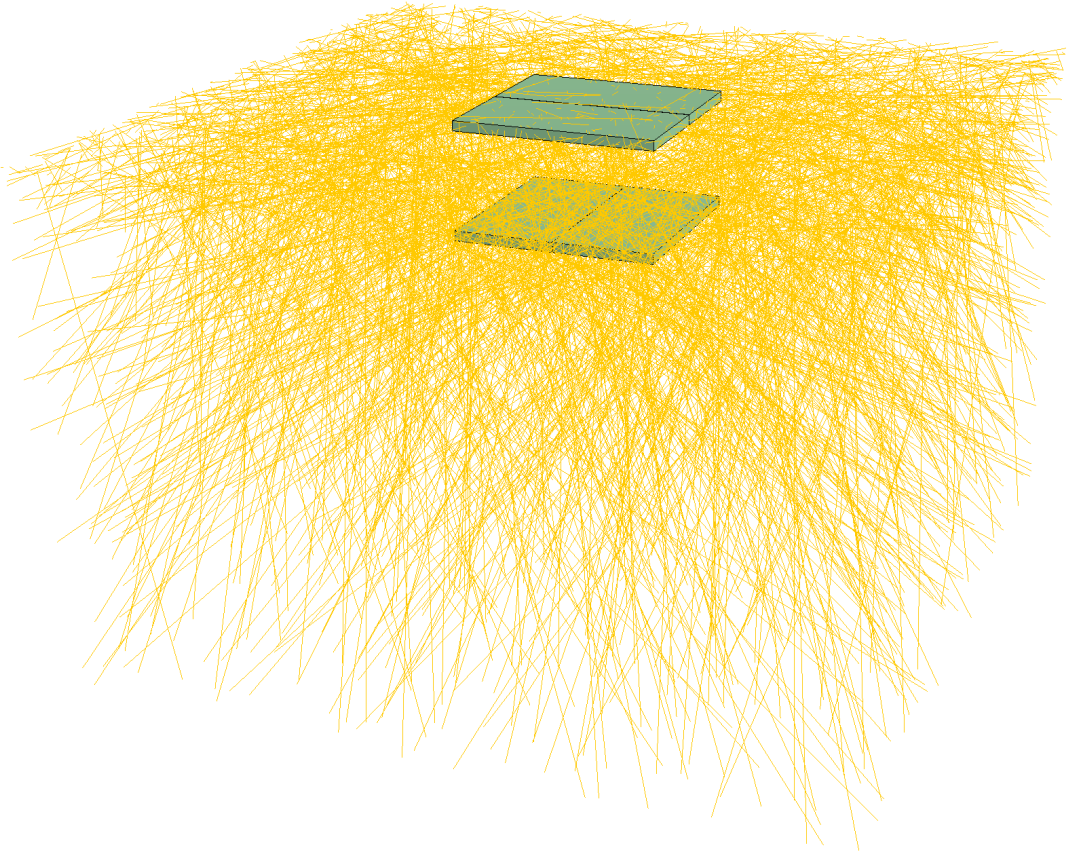
Detection System (cont.)

- Preliminary Results (SG):
  - Muon peak ~ 200 mV (10 MeV)
  - System Threshold ~125 mV (6 MeV)
  - 91 to 100 cps muon count rate from scintillator panel
- 25% far-end optical intensity drop



Detector Simulation

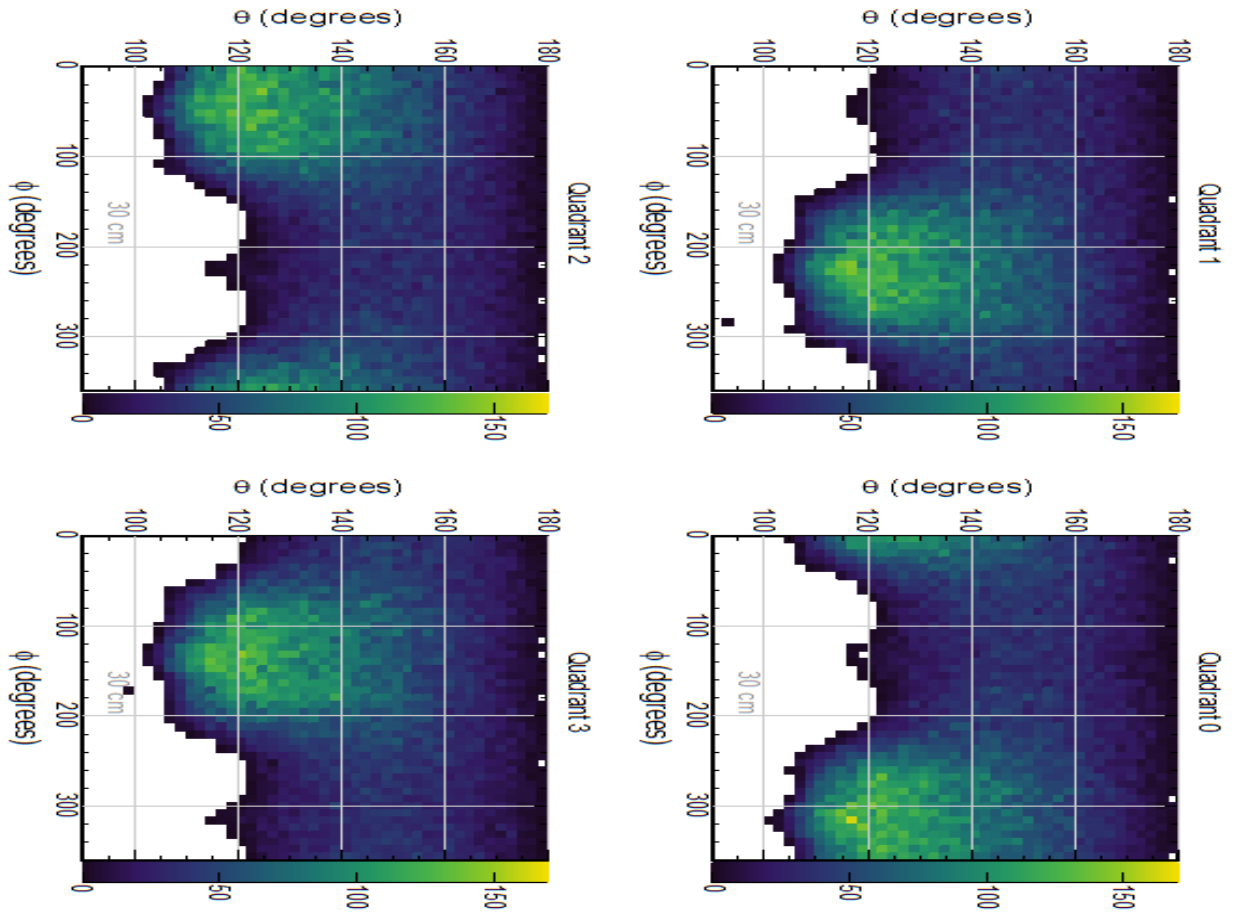
- Geant4 simulation toolkit used:
  - Geometry: PVT planes in vacuum
- ROOT for I/O and analysis
- Primary geometry optimized for testing – separation between panels
- Current implementation:
  - Fixed muon energy
  - Uniform zenith distribution



Detector Simulation (cont.)

Future Work

- Realistic energy and zenith profile
  - Accurate flux estimations
- Monte Carlo chain: Atmosphere → sea-level →sub-surface
- Flux and angular resolution as a function of plane distance



Conclusions and Path Forward

- A detection system for muon flux and overhead estimations is being developed
- System design complete and components are selected
- Preliminary detector results provided by Saint Gobain (scintillator fabricator)
- Monte Carlo simulations of the detection chain underway
- Calibration, experimentation, and benchmarking at sub-surface facility is planned this FY

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