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Mapping water on the Moon and Mars using GScan tracker system

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Outline

- Introduction
- Motivation
- Methodology
- Preliminary Results
- Summary & Outlook

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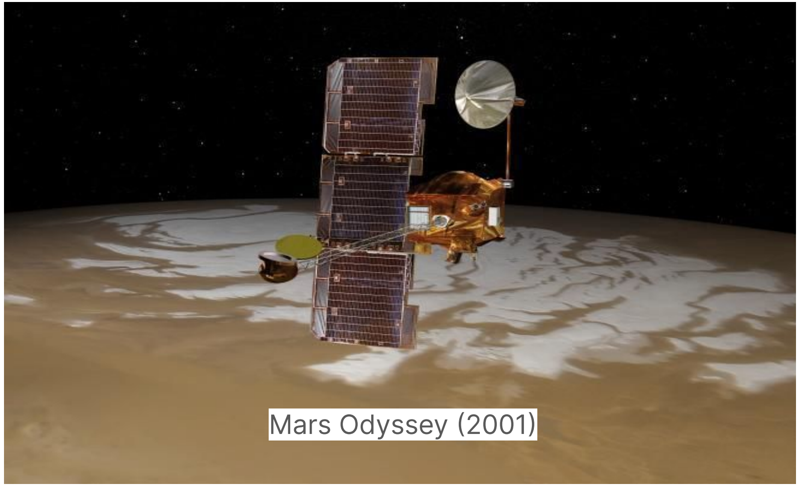
Introduction

- Lunar and Martian surfaces offer insights into celestial neighbors
- Water found on Moon and Mars — Lunar Prospector (1998) and Mars Odyssey (2001) first to find evidence

- Moon and Mars still a mystery
- Continued exploration will help understand place in universe and possibility of life beyond Earth

Lunar Prospector (1998)

nasa.gov/missions/lunar-prospector



Mars Odyssey (2001)

mars.nasa.gov/mars-exploration/missions/odyssey/

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Mission	Findings	Detectors
Lunar Prospector (1998)	Hydrogen in lunar soil, sign of water ice	Neutron spectrometer
Chandrayaan-1 (2008)	Confirmed presence of water ice in polar craters	Moon Mineralogy Mapper (M3)
LCROSS (2009)	Evidence of water ice in impact ejecta from Cabeus crater	Lyman-alpha spectrometer
Lunar Reconnaissance Orbiter (2009)	Water ice detected in various locations	Near-infrared spectrometer
Mars Odyssey (2001)	First detection of water ice on Mars	Gamma-ray spectrometer
Mars Express (2003)	Confirmed presence of water ice in polar craters	High-Resolution Stereo Camera (HRSC)
Mars Reconnaissance Orbiter (2005)	Detailed mapping and evidence of water ice	Compact Reconnaissance Imaging Spectrometer for Mars (CRISM)
Mars Phoenix Lander (2008)	Evidence of water ice in Martian soil	Thermal and Evolved Gas Analyzer (TEGA)
Mars Science Laboratory (2012)	Evidence of water in hydrated minerals and clays	Chemistry and Camera (ChemCam)
Perseverance Rover (2021)	Searching for signs of ancient life and collecting samples	Laser-Induced Breakdown Spectroscopy (LIBS)

Motivation

- Limited data and less precise measurements
- Existing methods fall short in accurate characterization
- Deeper insights crucial for future endeavors

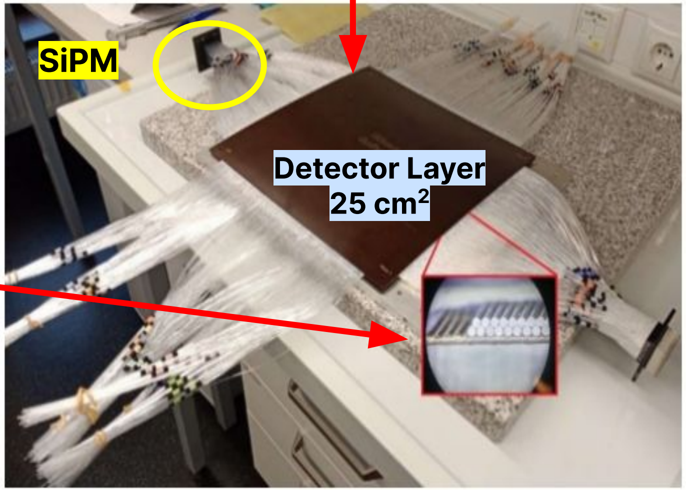
Benefit from muon tomography on the Moon and Mars?

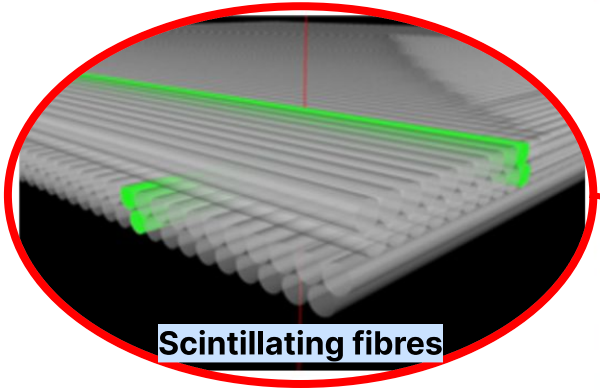
- **Natural Source:** Relies on cosmic-ray muons, no prior knowledge needed
- **Penetration Power:** High-energy muons can traverse subsurface water ice
- **Imaging:** Accurate mapping of object size, location, and density variability
- **Cost-Effective:** Low power, maintenance, and cost for efficient missions

Goal : To identify water-ice in lunar and martian surface using backscattered muons

GScan Technological Prototype

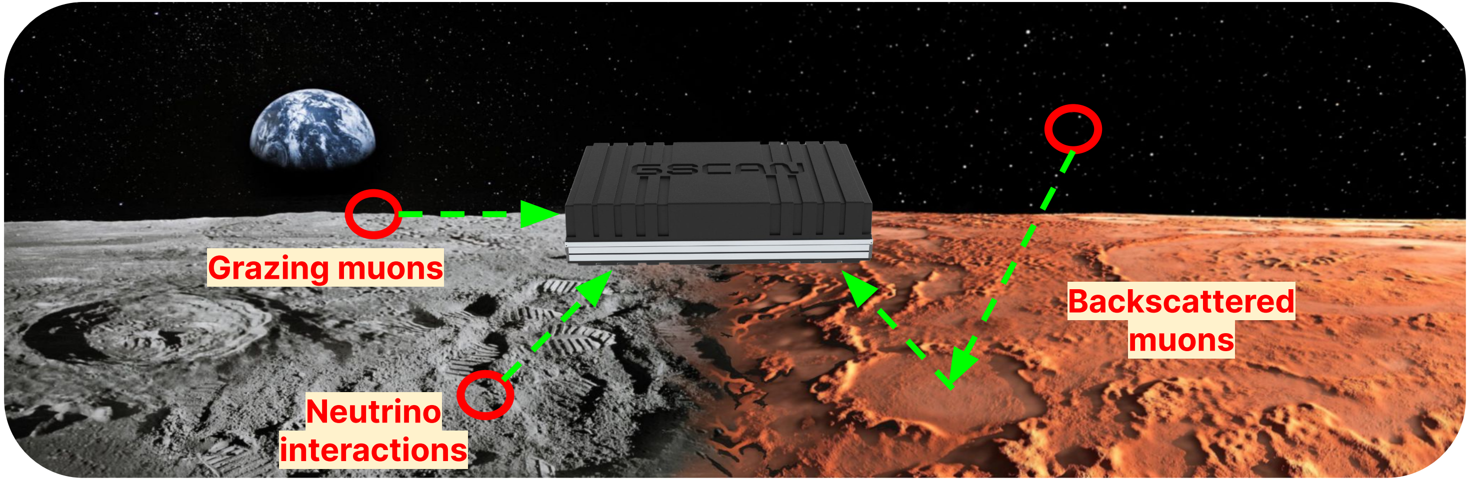
- Prototype consists of top hodoscope and a bottom detector layer
- Each hodoscope consists of the three position sensitive detector layers composed by plastic scintillator fibers
- arranged in orthogonal position coupled to SiPMs (resolution: spatial 120 μm and angular 1 mrad)





Methodology

- Utilize upward traveling muons to detect water-ice underground using a GScan tracker on the surface
- Reconfigure the GScan muon tracker (using top hodoscopes)
- Main source of backscattered particles are the grazing muons
- In order to obtain statistically significant data of the upward muon flux, used “large” detector as the size of lunar/martian surface



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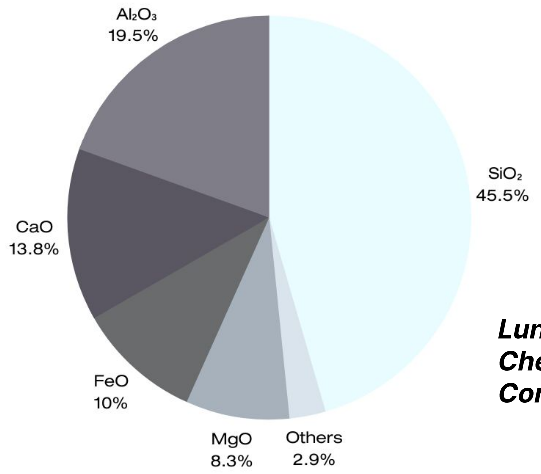
Simulation Dataset

- Simulated half-a-million events using GEANT4 (geant4-11-01-beta-01) QGSP_BERT and QBBC physics list

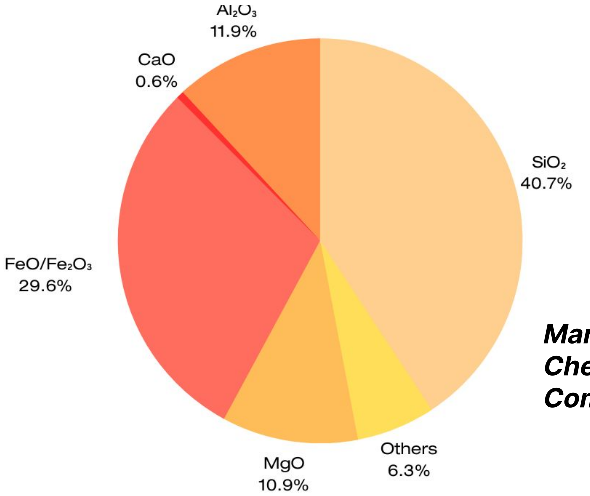
- Source:
  - Using EcoMug as cosmic ray source
  - Flux: 85% protons and remaining alpha particle
  - z-position : 2000 km above the surface
  - Energy: 1 GeV to 100 GeV
  - Zenith angle < 35°

- Detector size nearly the size of lunar surface to capture maximum backscattered muons

- Simulation of Lunar and Martian regolith obtained from past missions – main region of interest



Lunar Soil Chemical Composition



Martian Soil Chemical Composition

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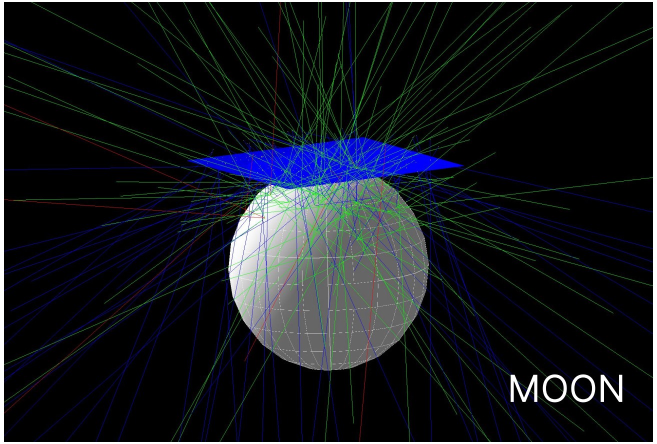
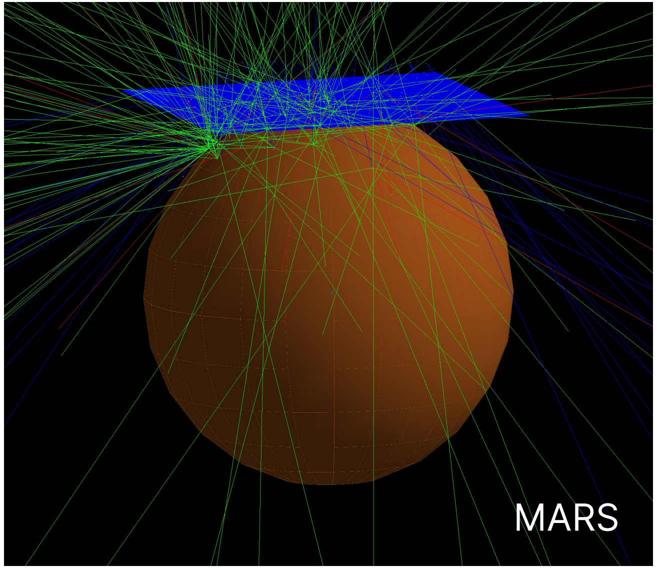
Event Selection

What defines a backscattered particle?

- p_z is in opposite direction
- Hits recorded from detector plates as: [3,2,1]
- Time: $t_3 - t_2 > 0$ and $t_2 - t_1 > 0$





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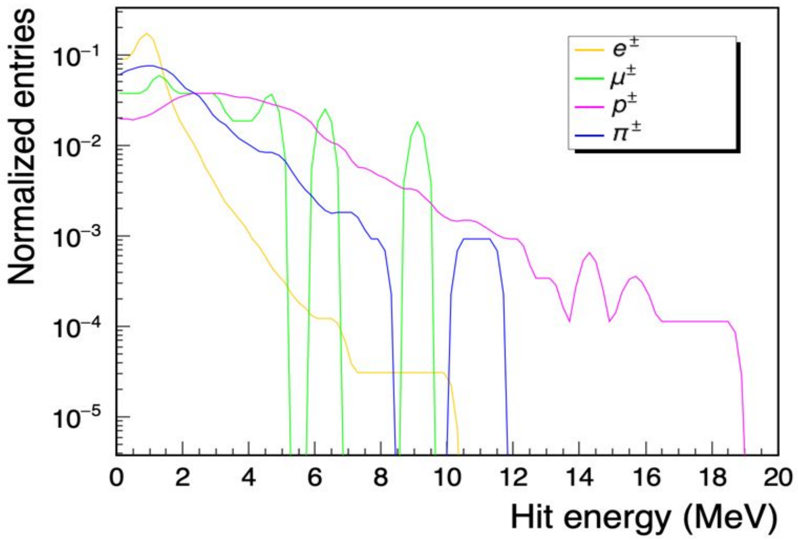
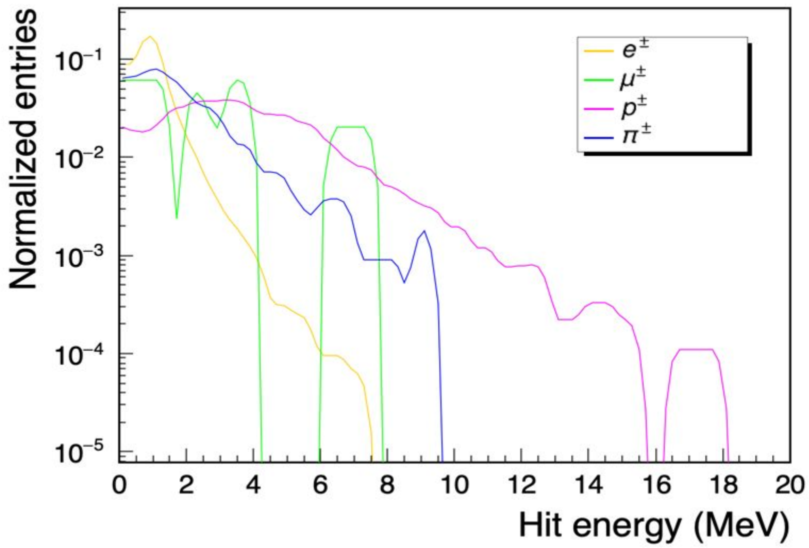
Lunar – Energy Distribution

Lunar surface



Dry Lunar rock: Anorthite rock (100%)



- Protons show broader energy distribution
- Muon energies remains consistent
- Electrons and Pions fall steeply after ~1 MeV

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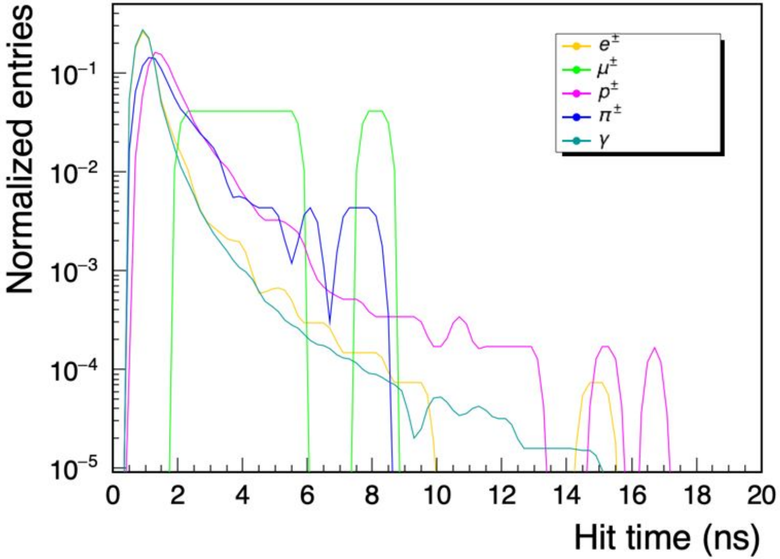
Lunar – Hit Time Distribution

Here the time difference t_3-t_2 and t_2 - t_1 is filled

Lunar surface



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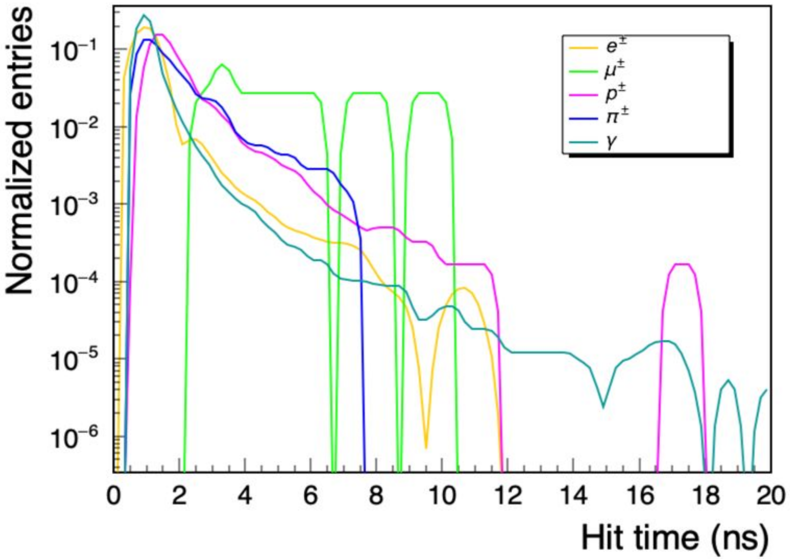

- The peak of the distributions show small differences
- Require excellent time resolution <5 ns

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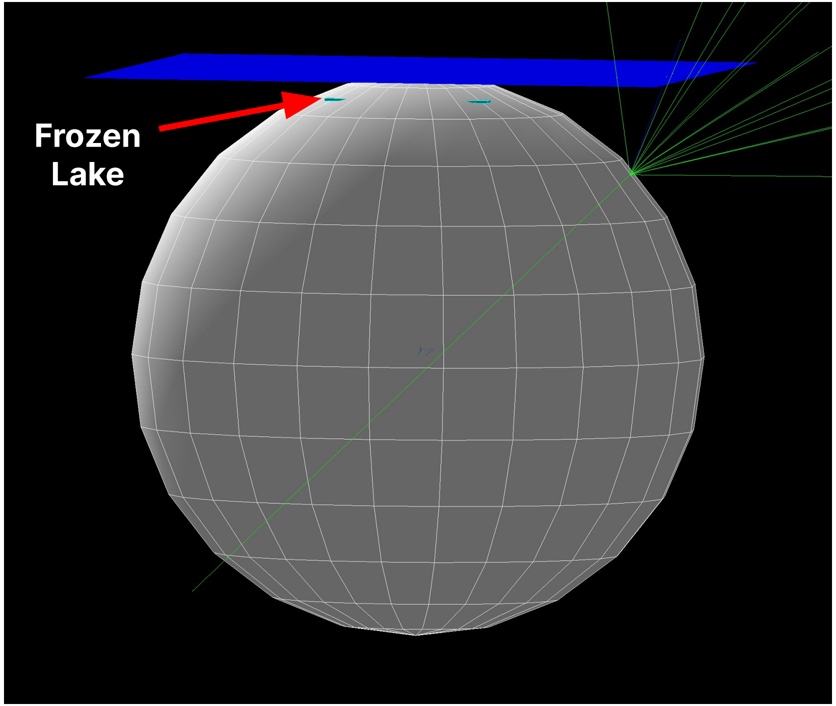
Comparison of Frozen Lake to Rock

- Comparison of total backscattered particles from a frozen ice (7 km deep) beneath the lunar surface and Anorthite rock
- The density ratio between the ice and rock: ~3
- The total flux of backscattered particle: ~1.95 → Reasonable to discriminate the backscattered flux

Frozen Lake
Total: 3425175
Backscattered: 1792191 : 52.3 %
Backscattered Photons: 1687650 : 94.2 %
Backscattered Electrons: 82362 : 4.6 %
Backscattered Muons: 75 : 0.0042 %
Backscattered Protons: 15090 : 0.8 %
Backscattered Pions: 1332 : 0.1 %

Anorthite rock
Total: 2512484
Backscattered: 1001379 : 39.9 %
Backscattered Photons: 948069 : 94.7 %
Backscattered Electrons: 40278 : 4.0 %
Backscattered Muons: 69 : 0.0069 %
Backscattered Protons: 9066 : 0.9 %
Backscattered Pions: 1149 : 0.1 %



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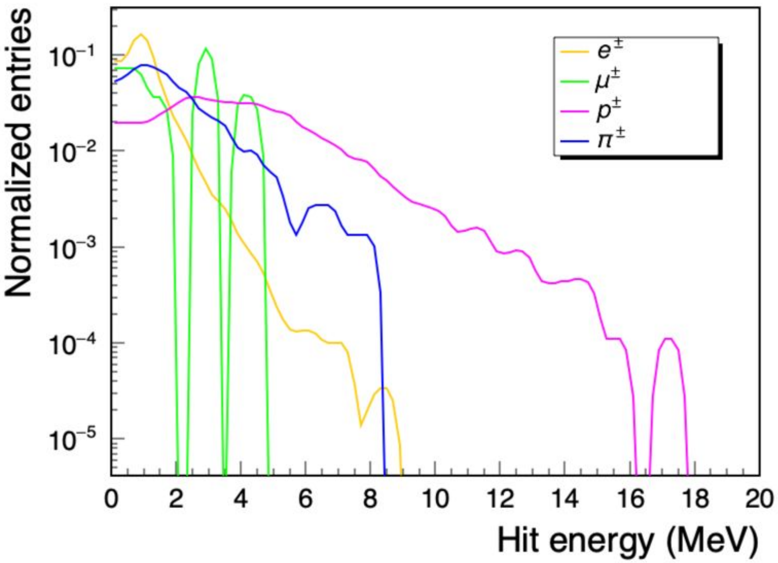
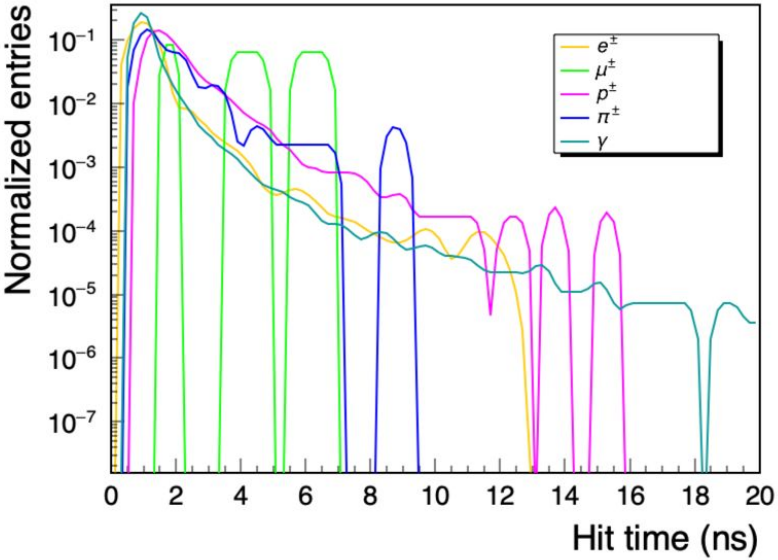
Martian – Energy and Time Distribution

Hit Energy



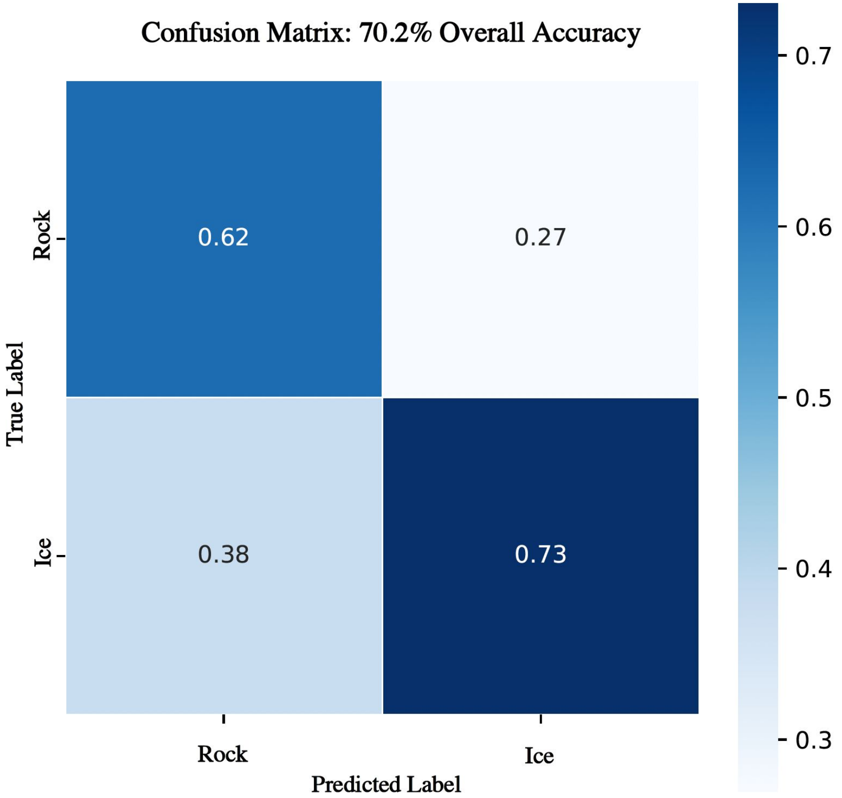
Hit Time



- The shape of the distributions are comparable to the lunar distribution
- Energy distribution more skewed in Mars compared to Lunar

Classifying Ice and Rock

- Included energy and time hits
- Distinctive characteristic for frozen-ice dataset
- Classify reasonably well between frozen-ice and rock
- Energy and time data is insufficient, requires to include backscattered angles as well



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Summary & Outlook

- Muon tomography presents a **powerful technique for space application**
- Detection of backscattered muons require a **timing <5 ns** (CERN achieves a time resolution between 30-50 ps)
- Reasonable **difference in flux density** is obtained between frozen Ice and the Anorthite rock
- Applying ML-binary classifier could easily classify frozen ice

- The study requires further simulation parameters involved – muon production depth, detector optimization using scintillating fibres
- Using realistic detector size
- Using more sophisticated Lunar and Martian models

Ideally aim at getting where the frozen lake would be visible like the hidden chambers in the pyramid.

Thank you!

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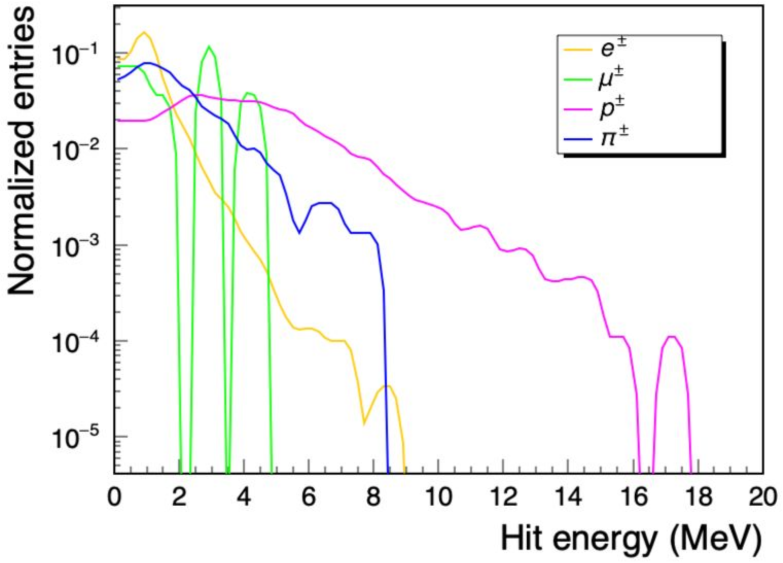
Energy Distribution

Martian surface



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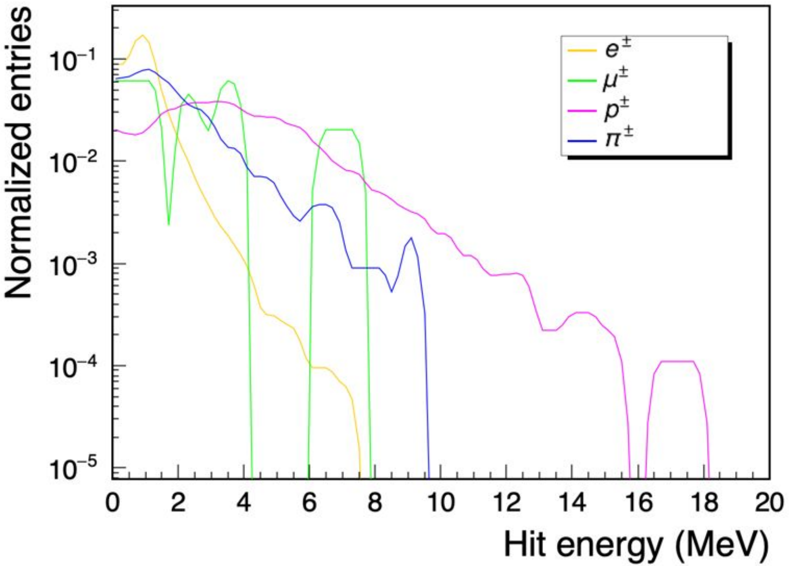

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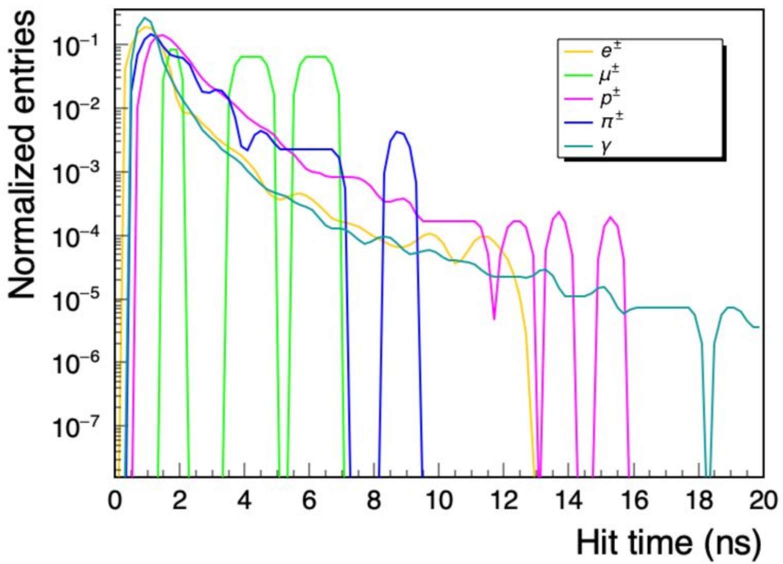
Time Distribution

Martian surface



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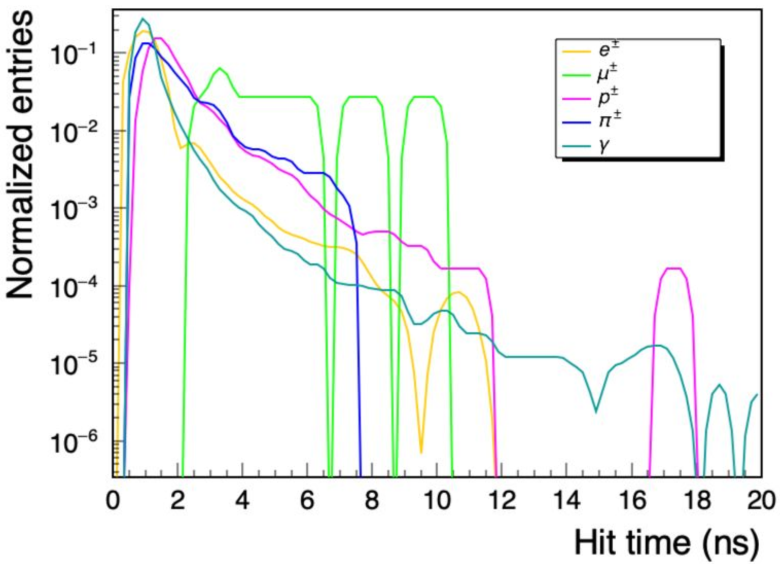

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