Muon Flux Variance from Severe Atmospheric Conditions

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Background

Atmospheric muon showers are the direct result of high energy cosmic rays (typically p^+) entering upper Earth atmosphere and interacting electromagnetically with atomic nuclei. These interactions create short-lived pions that almost instantly decay to muons with a lifetime of 2.2 μs at rest. Lorentz boosted muons then travel through the atmosphere and reach the surface of the Earth where they can be detected.

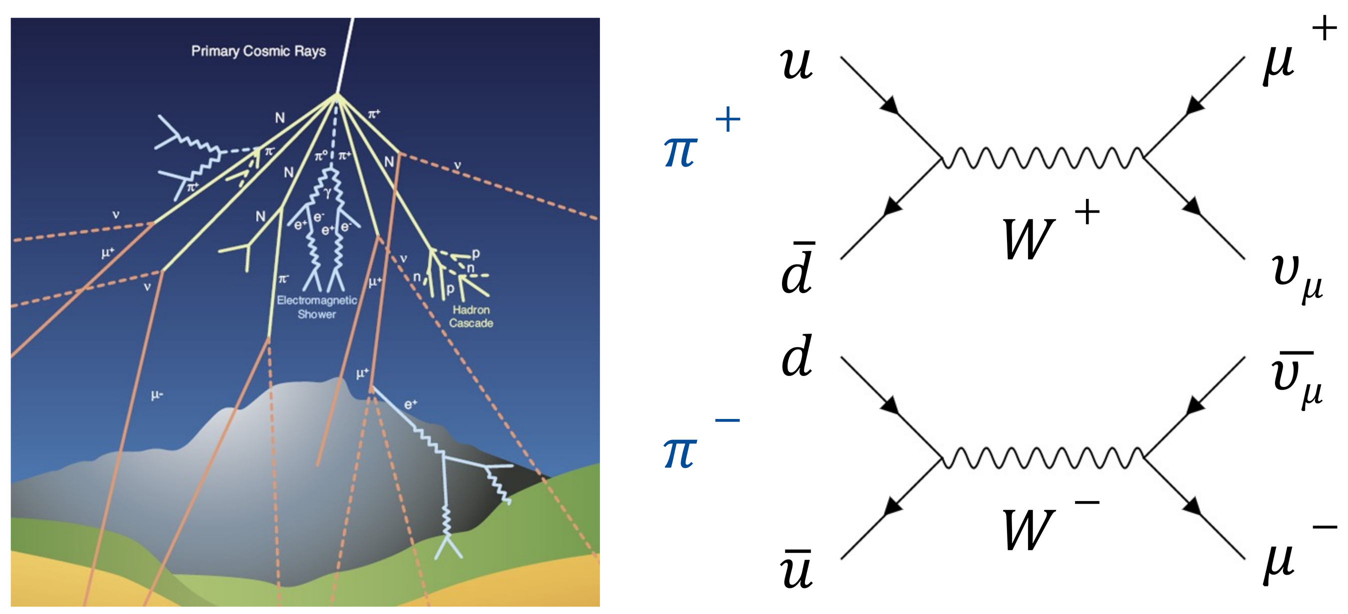

Figure 1: Typical atmospheric shower (left) and simplified Feynman diagrams for π^+ and π^- decay (right)

The first part of this project aims to find correlations between severe weather phenomena and muon flux rates. We use muon flux data collected by the QuarkNet Research Group [1] and weather data from ECMWF [2]. A preliminary study was performed to understand the typical properties of muonic showers from the atmosphere. A simulation tool, CORSIKA [3], was employed to perform this analysis and shower reconstruction for particles that are created during 10,000 showers from an initial cosmic p^+ in the 10^4-10^7 GeV range.

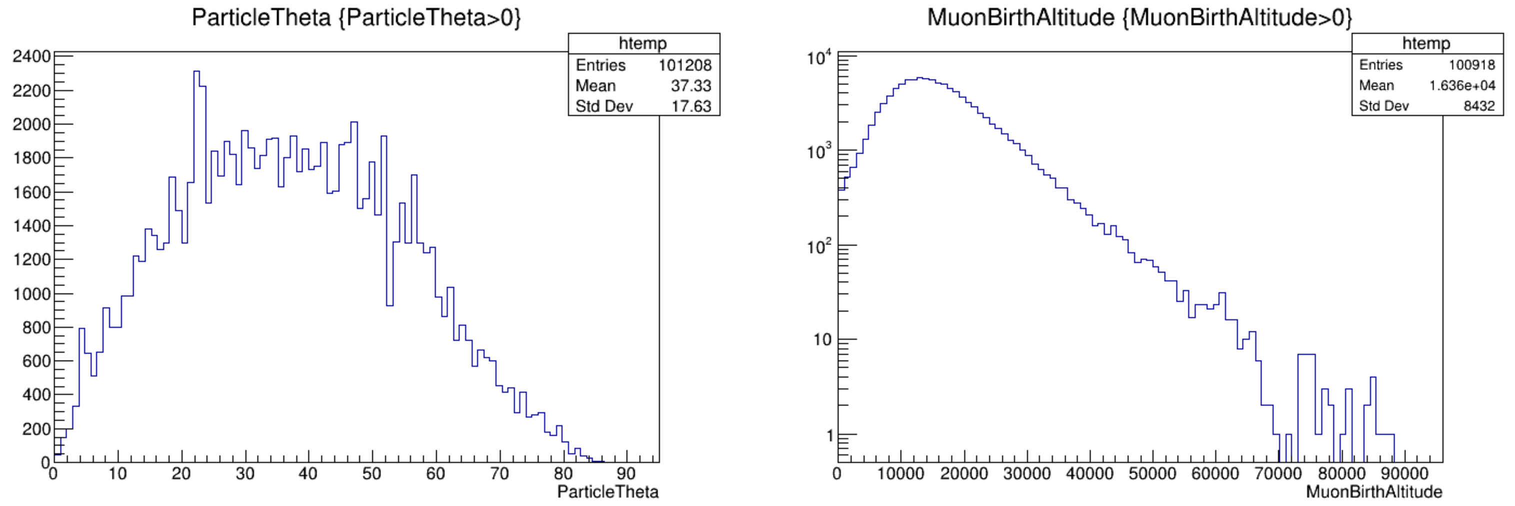

Figure 2: Angular distribution of muons detected at the surface of the Earth (left) and distribution of muon birth altitudes in the atmosphere in metres (right) both with cuts at null values to ignore killed particles – These were simulated using the QGSJET-II simulation model for hadronic showers involving higher order quark-gluon interactions

Analysis

This analysis considered temperature and pressure anomalies as a proxy for severe weather conditions. Temperature and pressure gradients were extracted from the ECMWF 2024 database. Cuts were made using pressure gradients to isolate our analysis to heights where the QuarkNet muon detectors were placed. The temperature data was then plotted and combed through to find anomalous values.

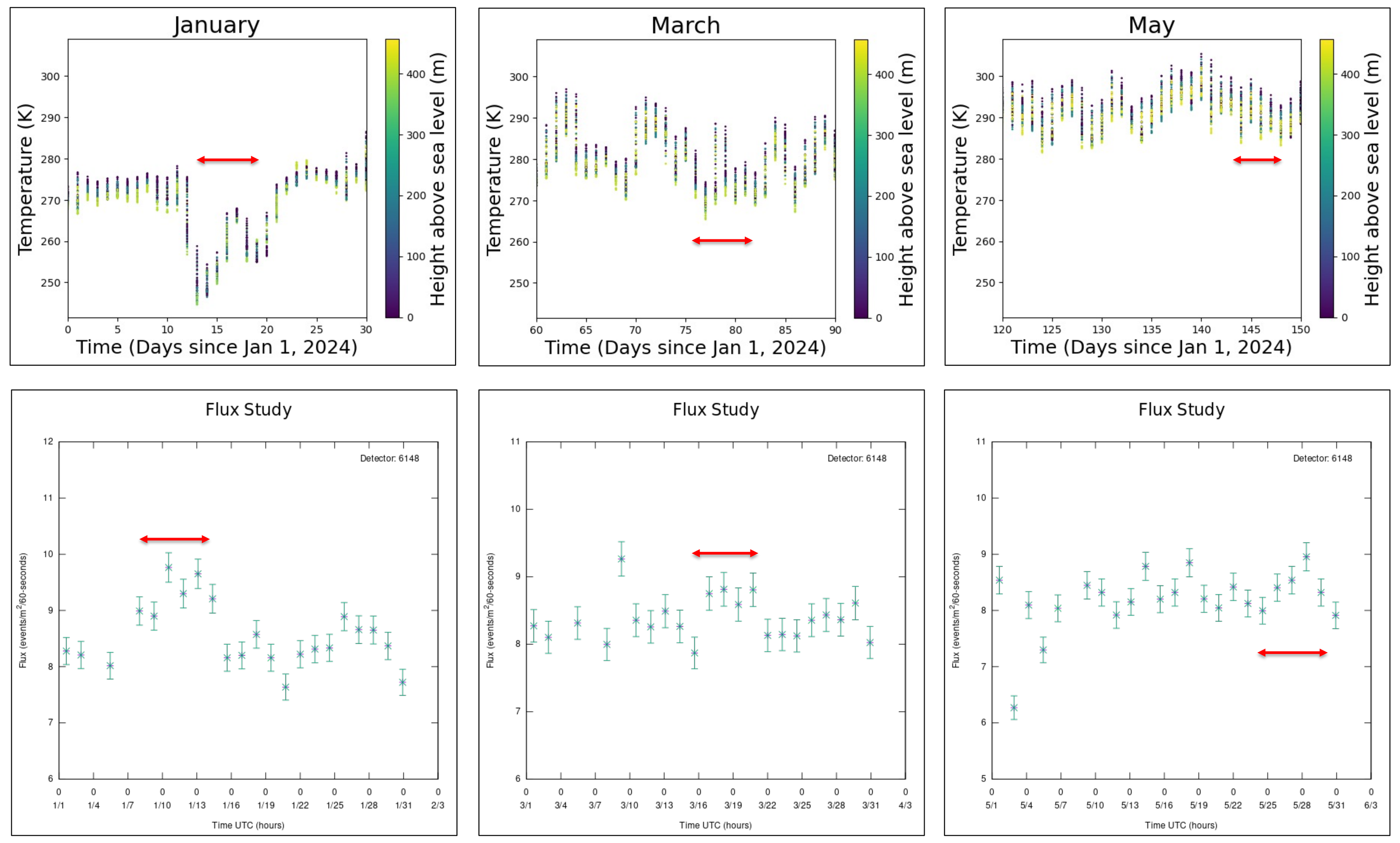

Figure 3: Qualitative analysis of temperature data correlation to muon flux data at the height of ~200m above sea level over 3 seasons in 2024 – The spread of the localized anomalies are indicated with red arrows in both temperature and muon flux plots

We considered anomalous events over the Winter, Spring and Summer. The most significant storm-related temperature variation in each season was considered for analysis.

Variance in	Winter	Spring	Summer
Muon Flux	~125%	~110%	~105%
Temperature	~20 K drop	~15 K drop	~5 K drop

Winter storms had the most drastic drop in temperature and a corresponding spike in muon flux. As expected, an inverse relationship between temperature and muon flux was observed. Further, since temperature and pressure have a near-linear dependance in lower atmosphere, this also implies an inverse relationship between atmospheric pressure and muon flux.

CosmicWatch Detectors

The latter part of this project involved the assembly of CosmicWatch [4] muon detectors. These are inexpensive and scalable muon detectors with built-in logic circuitry. It is a self-contained apparatus that uses scintillators for detection and SiPMs (Silicon Photomultipliers) for light collection.

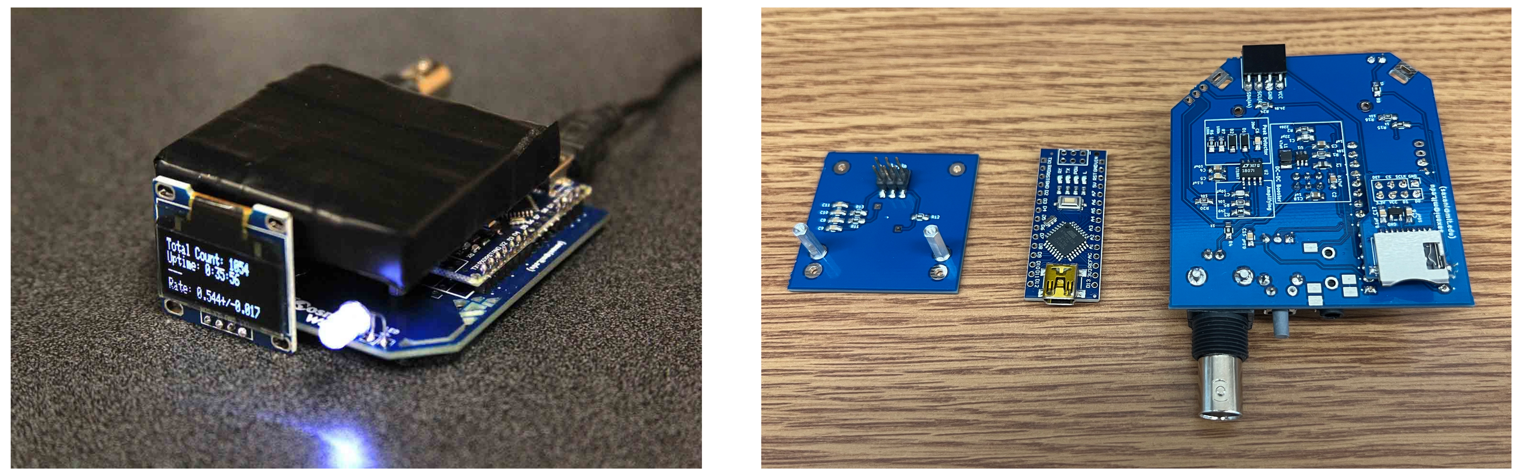

Figure 4: Built and functional single unit CosmicWatch detector (left) and piece by piece breakdown of the PCB and Arduino setup (right)

The scalability of these detectors makes them an ideal candidate for use in tests for the MMBC/MAMBA Bubble Chamber. Using a Raspberry Pi connection, a simple pair of these CosmicWatch detectors can be used to trigger on muons, providing extremely precise and inexpensive tracking granularity in the form of a muon telescope.

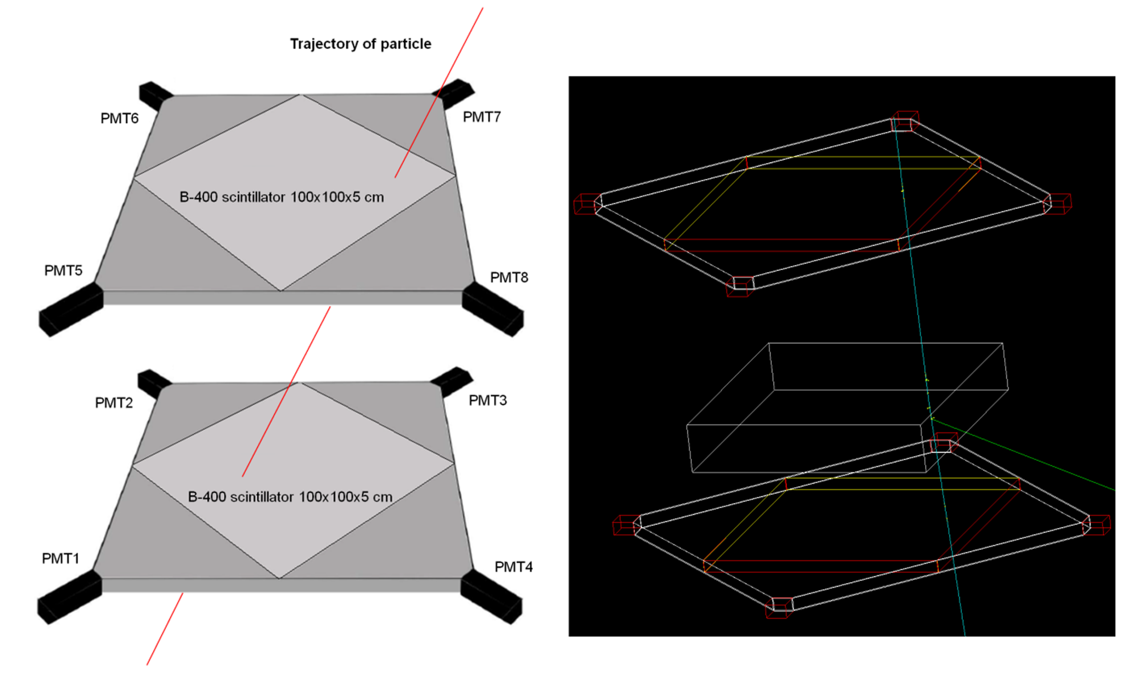

Figure 5: Muon telescope experiment with light guides and scintillators depicting trajectory through the Muon Impact Tracer and Observer (MITO) concept design [5]

References

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