Investigating the Effect of Pollution on Muon Flux using a CosmicWatch Modular Detector

Finn Boyle, Mia Edmonson, Tiffany Hoang, Malaikah Khan, Daniel Ruiz, Joshua Sobajic
Mentor: Shreya Puranam
University of California, Berkeley Undergraduate Lab at Berkeley, Physics & Astronomy Division

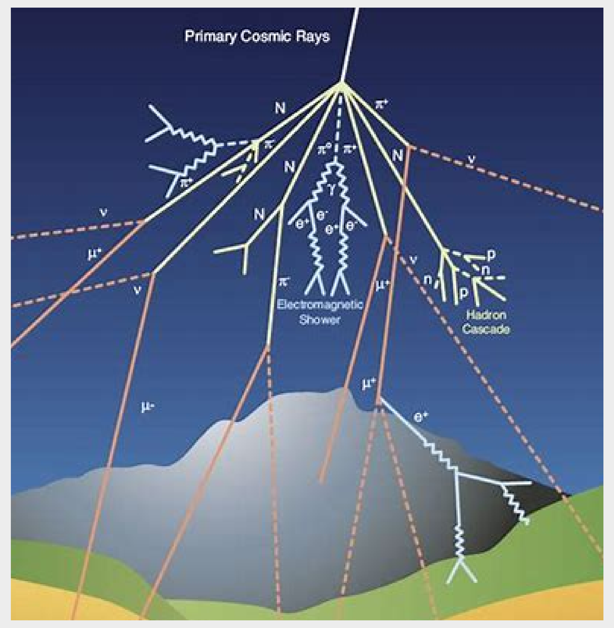
Muons

- Part of the lepton family with same charge as the electron, spin 1/2, and roughly 200 times more massive
- Unstable fundamental particles
- Lifetime of 2.2 microseconds

The muons we will be detecting come from cosmic rays, high-energy particles composed of protons and atomic nuclei, generated by the sun.

- As cosmic rays interact with our atmosphere, they produce pions
- Pions decay into muons as secondary or tertiary particles
- Muons then decay into an electron, a muon-type neutrino, and an electron-type anti-neutrino as is shown below:

$$\mu^- \rightarrow e^- + \nu_\mu + \overline{\nu_e}$$

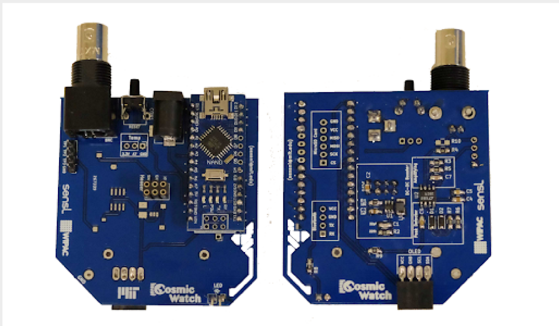


The image displays how cosmic rays interact with the atmosphere and produce muons. Image credit: CERN

Pollution

In an article, the High Energy Physics detector laboratory at Bose Institute, Kolkata studied muon flux before the COVID-19 lockdown and during the lockdown. They hypothesized that with more pollution in the atmosphere, muons would lose energy due to the particulate matter in pollution. Thus, more pollution would mean less muons and therefore, a decrease in muon flux. In this article, they were limited by their statistics and therefore were not able to come to a conclusive result. We wanted to test that theory by utilizing our own muon detector and creating pollution within a controlled environment.

Cosmic Watch



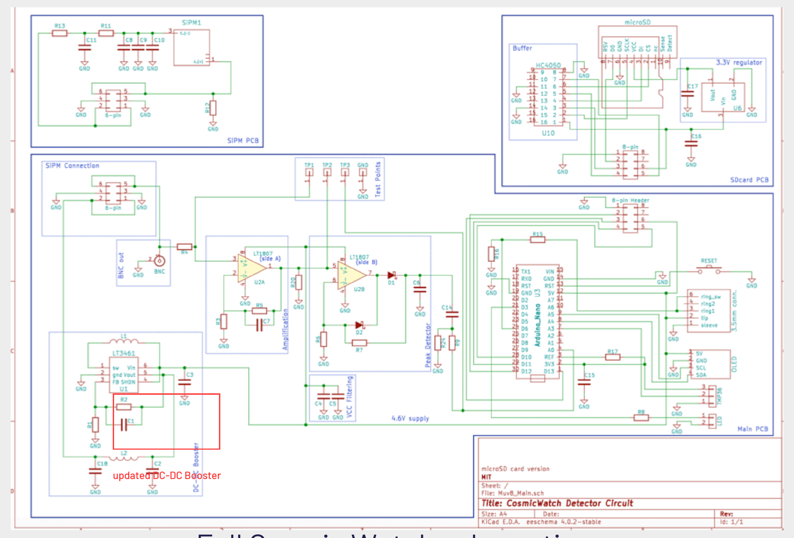
Detector PCB

The detector with the scintillator affixed on top of the PCB

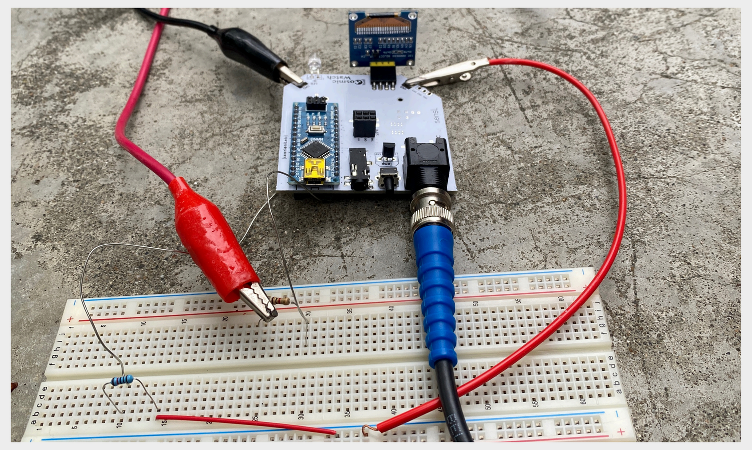
The Cosmic Watch is composed of a 5cmx5cmx1cm plastic scintillator used for the detection of muons and a silicon photomultiplier for light collection.

- **Scintillator**: A material that emits light when exposed to ionizing radiation. It undergoes a process called scintillation whereby absorbed radiation causes electrons to jump to an excited state and release energy returning to ground state
- **Silicon Photomultiplier**: A device that utilizes impact ionization to transform photon energy into a measurable output pulse. When a photon is absorbed in the active region of the SiPM's Avalanche Photodiodes, an electron hole pair is generated. An applied electric field causes electron-hole pairs to traverse and gain the energy to ionize other atoms.

With the help of a peak detector circuit, the APDs amplifies the signal of the charged carriers and generates a measurable output signal for the microcontroller (Arduino Nano) to detect



Full Cosmic Watch schematics



Above is a photo of our final detector set-up.

Research Question

What is the influence of different pollution mediums on muon flux?

Experimental Design

- On the CosmicWatch detector's L2 pads, solder wires to both ends (wire 1 and wire 2)
  - Wire 1 is closest to C2 on the PCB, ground it with a resistor
  - Connect Wire 2 to a resistor in series to a DC power supply.
- Using the power supply:
  - Connect ground cable to the ground on the detector
  - Connect positive cable to resistor in series with Wire 2.
- Connect Wire 1 to the ground on the detector through a resistor
- On the power supply, set voltage between +24.7V and +30V.
  - We decided to operate within a range of +28V to +29V to maximize SiPM output while minimizing risk of frying the circuit.

Depicted above is the L2 component being desoldered from its pad.

Depicted is the setup of the experiment, shown here is the power supply (left), oscilloscope (top), and closed-system (bottom).

- Connect the system via BNC Out to an oscilloscope.
- Configure the oscilloscope settings to 10mV and 5 microseconds.
  - On normal trigger mode, set the trigger level between 20mV and 40 mV (depending on if the voltage source is operating closer to 26V or 29V)
- Next, develop a closed-system to introduce pollutants into.
  - We made a box with openings for several cables and a feed through system.
  - Situate the detector inside the box
  - Place a protective covering over the the detector.
- Test each variation 3 times.
  - For every trial, count the number of passing muons by observing when the oscilloscope gets triggered.

Circuit Analysis

Damaged DC-DC Booster

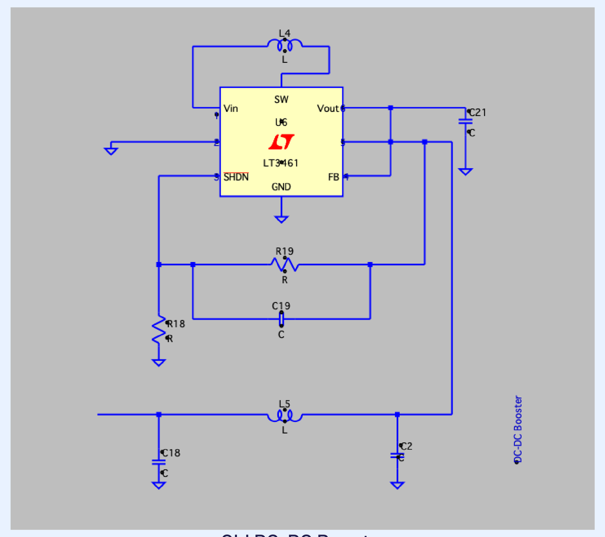
DC-DC Booster boosts +4.6V supplied by the USB connection through the Arduino to +29.5V.

- DC-DC Booster was damaged during soldering
  - SiPM became non-operational as the Arduino cannot supply enough voltage to meet the SiPM's minimum voltage intake.
- We replaced the L2 inductor with a DC power supply.
  - C2 was grounded
  - We thus didn't require an RC low pass filter through the C18 since the voltage supply was a DC source.

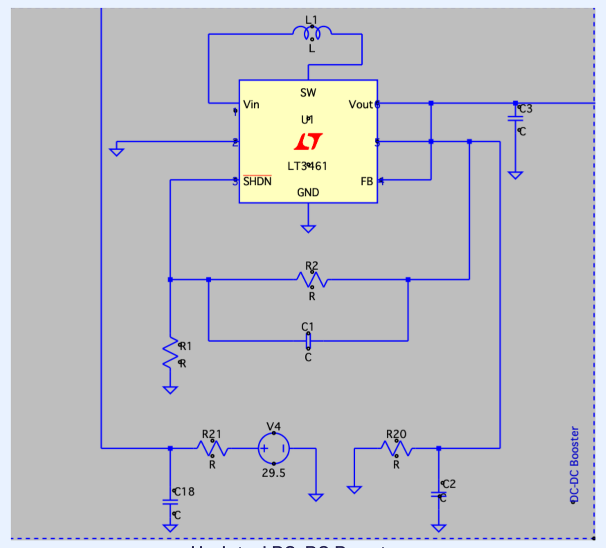
Overheating

The system overheated due to the new voltage source

- To remedy this, we added a resistor to limit the flow of current.
  - After some trial and error testing various resistor values, we settled on a 1 kΩ resistor connected to the the voltage supply.



Old DC-DC Booster



Updated DC-DC Booster

Results

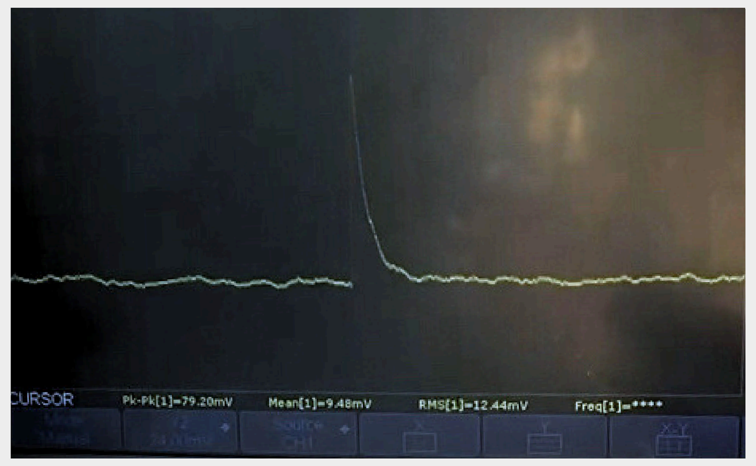
	No Aerosol	Low Aerosol	High Aerosol
Trial 1	23	20	26
Trial 2	31	39	43
Trial 3	37	40	57
Mean	30.33	33	42
Standard Deviation	7.0237691	11.269427	15.52417
Mean Ratio	1	1.08791208	1.384615385

Our table displays the data we found through our trials. Each number represents the amount of muons we counted per 4 minute intervals. Mean ratio is the various means divided by the mean of the normal (or no aerosol).

We counted the amount of muons that came in per 4 minute intervals for each trial.

- No aerosol is the detector in the environment without any aerosol added.
- Low aerosol was created by adding a spray of aerosol into the environment every 30 seconds.
- High aerosol was created by adding a spray of aerosol every 10 seconds.

The photo on the right shows our oscilloscope and a pulse of a muon that was detected by our muon detector.



Theoretical Calculations

$$-\frac{dE}{dx} = kz^2 \cdot \left(\frac{Z}{A}\right) \cdot \left(\frac{1}{\beta^2}\right) \cdot \left(\frac{1}{2}\ln\left(2m_ec^2\beta^2\gamma^2\frac{T_{max}}{I^2} - \beta^2 - \frac{\delta}{2}\right)\right)$$

Bethe-Bloch Formula

Describes the mean energy loss per distance travelled of swift charged particles traversing matter. For our purposes, we used Bethe-Bloch to estimate the average energy loss per unit path length by a charged particle due to ionization and atomic excitations in a medium

For 100% Air (No aerosol)

$K = 4\pi N_A r_e^2 m_e c^2 = 0.307075\ MeV\ \frac{cm^2}{g}$

$z = 1$ Charge Number of incident particle

$Z/A = 7.34/14.66\ \frac{g}{mol}$ Ratio of Average Atomic Number and Average Atomic Mass of Medium

$\beta = 1/\sqrt{1 - \frac{E}{mc^2}} = 0.995$ Velocity of particle relative to light

$T_{max} = \frac{(2m_ec^2\beta^2\gamma^2)}{1+2\gamma m_e/M + (m_e/M)^2} = 0.286\ MeV$ Maximum kinetic energy that can be transferred in a collision

$I = 85.7\ eV$ Mean excitation energy

δ is the density effect correction to ionization energy loss, which can often be negligible at lower energies.

$$\frac{dE}{dx} = 2.024\ MeV\ \frac{cm^2}{g} \cdot \rho = 0.00248\ \frac{MeV}{cm}$$

For 70% Air and 30% Aluminum Zirconium Tetrachlorohydrex GLY (AZTG)

Stopping power for air: $(\frac{dE}{dx})_{air} = 0.00248\ \frac{MeV}{cm}$

Stopping power for AZTG:

Aluminum $Z_{Al} = 13,\ A_{Al} = 26.98\ \frac{g}{mol}$

Zirconium $Z_{Zr} = 40,\ A_{Zr} = 91.22\ \frac{g}{mol}$

$Z_{AZTG} = 0.5 \cdot Z_{Al} + 0.5 \cdot Z_{Zr} = 26.5$

$A_{AZTG} = 0.5 \cdot A_{Al} + 0.5 \cdot A_{Zr} = 59.1$

$(\frac{dE}{dx})_{AZTG} = 0.00222\ \frac{MeV}{cm}$

$(\frac{dE}{dx})_{mixed_1} = f_{air}(\frac{dE}{dx})_{air} + f_{AZTG}(\frac{dE}{dx})_{AZTG}$

$$\frac{\left[\left(\frac{dE}{dx}\right)_{air} - \left(\frac{dE}{dx}\right)_{mixed_1}\right]}{\left(\frac{dE}{dx}\right)_{air}} = 0.0322$$

For 30% Air and 70% Aluminum Zirconium Tetrachlorohydrex GLY (AZTG)

$(\frac{dE}{dx})_{mixed_2} = f_{air}(\frac{dE}{dx})_{air} + f_{AZTG}(\frac{dE}{dx})_{AZTG}$

$$\frac{\left[\left(\frac{dE}{dx}\right)_{air} - \left(\frac{dE}{dx}\right)_{mixed_2}\right]}{\left(\frac{dE}{dx}\right)_{air}} = 0.073$$

Due to marginal differences in energy loss from ionization energies, the signal strength detection was not affected. Furthermore, the slight difference in stopping power in the aerosol conveys no attenuation of muon flux, meaning material absorption and particle interactions within the aerosol atmosphere did not play a significant role.

Conclusion

From our data and experiment, we found that is no decrease in muon flux when we added pollution, whether a little or a lot. Based on the fact that the average muon flux is 1 muon per square centimeter per minute and that the CosmicWatch is about 25 square centimeter, we expected to see about 25 muons for a 1 minute interval. This does not seem consistent with our data but would make sense given our limited statistics. In addition, we can neither confirm nor deny the hypothesis that pollution impacts muon flux given our limited statistics and lack of large experimental volume.

Next Steps

Our simulated environment was small and close to the detector. Due to this, the muons may not have had enough time to be affected by the pollution or sure to lose enough energy to not be detected by our detector. Our next steps from here would be to simulate a larger environment to take new data. This way, the muons have more time to lose energy and we could potentially see a decrease in muon flux. In addition, we would like to interface successfully with the oscilloscope so we can attain a much larger dataset.

References and Acknowledgements

Axani, Spencer N. "The physics behind the CosmicWatch desktop muon detectors." arXiv preprint arXiv:1908.00146 (2019).
Sen A, Chatterjee S, Roy S, Biswas R, Das S, Ghosh SK, Biswas S. Cosmic ray flux and lockdown due to COVID-19 in Kolkata - Any correlation? Pramana. 2021;95(2):64. doi: 10.1007/s12043-021-02106-z. Epub 2021 Apr 17. PMID: 33897090; PMCID: PMC8052198.

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