The ArduSiPM Muon Detector

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ABSTRACT

This paper describes the fabrication of a portable muon detector and data acquisition system. The muon detector functions by the means of two plastic scintillators as the detection medium and a silicon photomultiplier for light collection. The silicon photomultipliers (SiPMs) are used because they are small, inexpensive, and have good dynamic range. The SiPM is coupled with the scintillators to build an efficient and small single photon detector. Detector readout is possible by utilizing the ArduSiPM, an inexpensive and easily replicable module for a hardware-software system. The ArduSiPM is either battery powered or connected via USB to another source, and it is comprised of two components: an Arduino DUE processor board and a custom designed top board (ArduSiPM Shield). The Shield monitors and acquiresa the SiPM signals. The future experiments and measurements to be performed with the detector are also outlined.

*K*eywords Ultra-high energy cosmic rays · Muons · Silicon Photomultiplier · Scintillation

1 Introduction

At any moment, a type of radiation, known as cosmic rays, shower onto the Earth's atmosphere. These high energy, charged particles are comprised of protons or light nuclei and travel nearly at the speed of light. Ultra-high energy cosmic rays (UHECRs) are categorized as having an energy of about 10^{18} eV or greater. These particles were discovered over a century ago, however their origins and the astrophysical process that accelerates them remain unknown. The flux of these ultra-high energy particles is extremely low at one particle per square kilometer per century. In addition to being incredibly rare events, UHECRs are also difficult to detect because they do not travel in a straight path from their origins. Charged particles are deflected in magnetic fields, causing difficulty in determining their true origins. When such cosmic rays collide with the Earth's upper atmosphere, they disperse and produce secondary particles of lower energies as shown below in Fig. 1. One of these particles is the muon — a charged subatomic particle from the same family as electrons and positrons but are 200 times heavier. Stationary muons have an average lifetime of 2.2 microseconds, which might mean they won't make it down very far despite traveling at 0.98c, however, during their fleeting lifespan they can be found through every layer of the Earth's atmosphere. Some of these muons of higher energies can depenetrate the surface of the Earth and reach deep into layers of rock and ice. Einstein's theory of time dilation explains this; the faster something travels through space the slower it travels through time therefore a lifetime depends on the frame of reference instead of the frame of the observer. When we detect muons or other secondary particles, we can determine the nature of the primary particles that produced them, such as their arrival direction, mass composition, and energy spectrum.

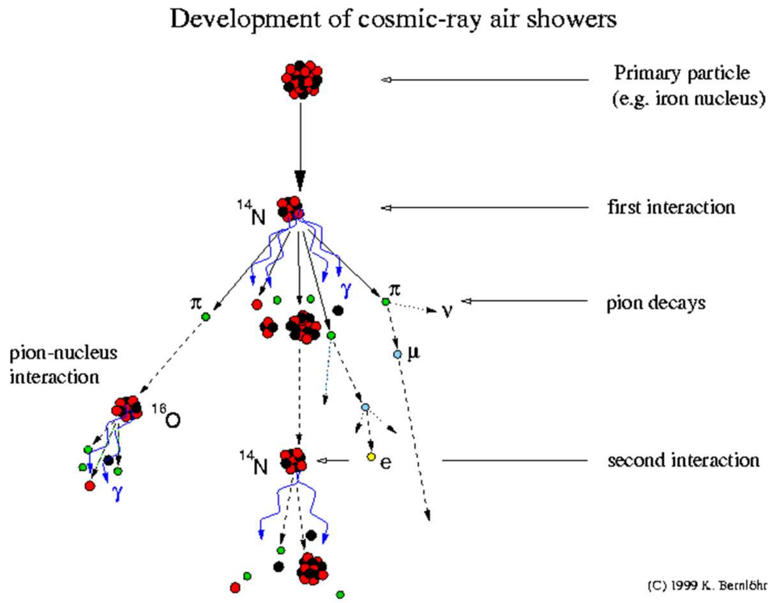

Figure 1 Diagram of CRs entering the atmosphere and dispersing into extensive air showers[1]

One of the main facilities that actively detects and measures cosmic rays above energies 10^{17} eV to study the origins and characteristics of these particles is the Pierre Auger Observatory in Mendoza, Argentina. It is the world's largest cosmic ray observatory, covering 3000 square kilometers, which is about the size of Rhode Island because, as previously mentioned, UHECR events are incredibly rare so a large area is needed to detect enough for a substantial data set. The observatory functions using two detection techniques: detecting the particles through interactions with water in surface detector tanks and the air showers through ultraviolet light emissions. Over the last decade, the results from the Pierre Auger Observatory have greatly advanced our understanding of the highest-energy cosmic rays. Despite this fact, several fundamental questions remain to be tackled by the upgrades of current experiments or by the next generation of experiments. The researchers working in the Privitera Lab in the Kavli Institute of Cosmological Physics have designed a single-photon detector based off the work at the Auger Observatory that's main function is to observe muons. The detector was designed to be inexpensive and easily portable, allowing it to be carried around to measure muon rates in virtually any environment.

2 Detector Components

The goal of this project was to develop a low-cost, portable muon particle detector and data acquisition system. This project was engineering focused, so there the tasks include creating CADs for components to be 3D printed, constructing parts in the on-campus machine shop, and testing different components. To explain some of the components involved, we make use of:

- Plastic Scintillator (Fig. 2)
- Silicon Photomultiplier (Fig. 3)
- Arduino DUE boards
- Custom top boards called Shields

2.1 Scintillator and Silicon Photomultiplier Coupling

As previously mentioned, the detection and collection method are through the principle of scintillation. Scintillation can be described as certain particles or radiation passing through matter and exciting the atoms and molecules in the target material. This causes light emission. Those photons are then detected by the silicon photomultipliers which produces a corresponding electronic trigger signal to be read on our oscilloscope.

The plastic scintillators were wrapped in a layer of foil, which acts as a reflector thus improving the optical properties of the detector. In addition, a layer what is known as optical grease was thinly applied between the scintillator and the SiPM coupling, in order to improve photon transmission.

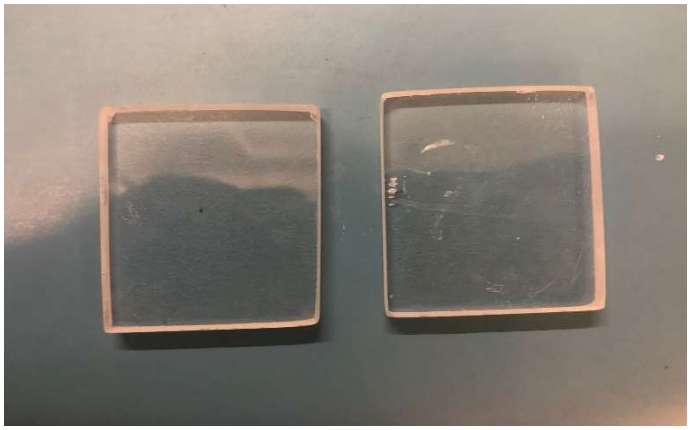

Figure 2 Two unwrapped plastic scintillators

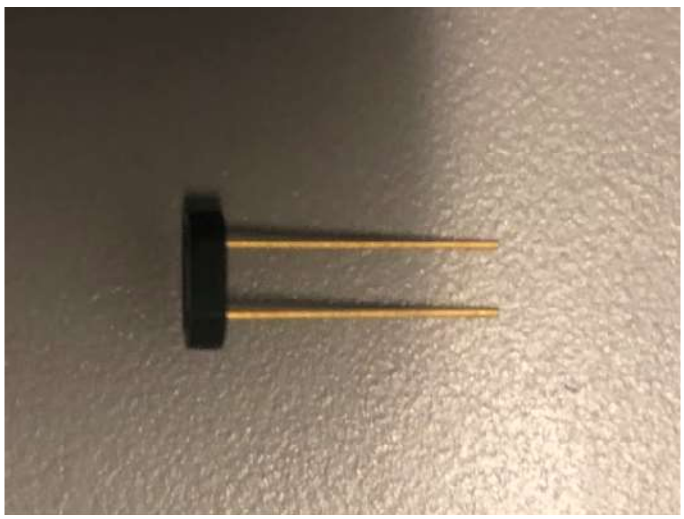

Figure 3 A single unattached silicon photomultiplier (SiPM)

2.1.1 Electronics

Arduino technology provides an open hardware and software system. The Arduino DUE is based on the Atmel SAM3X8E ARM Cortex-M3 central processing unit[2]. The ArduSiPM Shield (Fig. 4) is our custom designed board with all electronics interface from Arduino DUE and a SiPM photodetector. The Shield and Arduino DUE coupling creates a system that can be easily transported, including Front end electronics and data acquisition system. The global architecture of the system is in Fig. 5. The shield that we use was custom designed to monitor, set, and acquire the signals that come from the SiPM, allowing them to be read out. In terms of monitoring, it allows us to monitor parameters such as arrival time, signal amplitude, and number of muon counts within a specific time window.

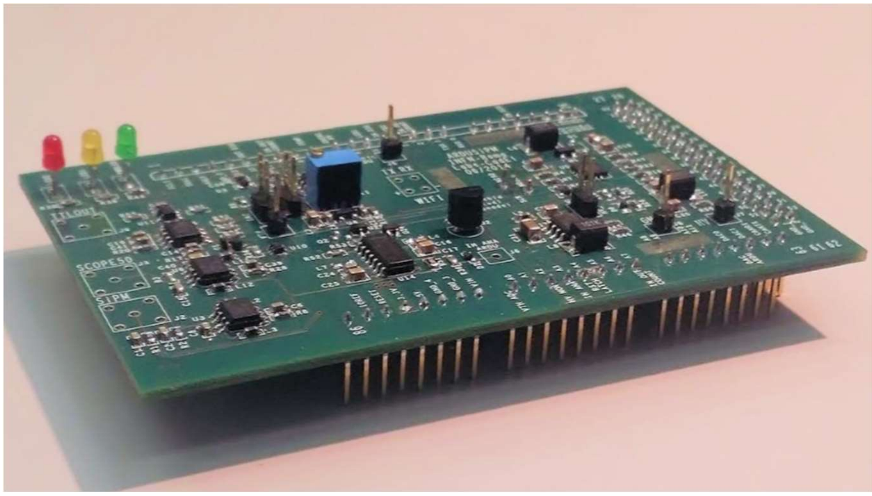

Figure 4 Custom ArduSiPM Shield[2]

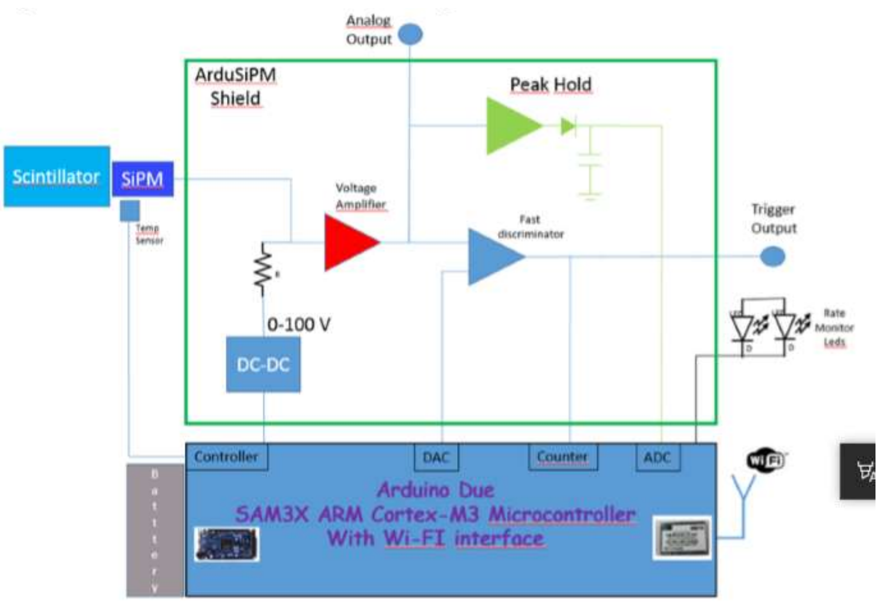

Figure 5 Block Diagram of ArduSiPM Shield system[2]

3 Mechanical Support

The group has designed and built a mechanical support system that secures the Arduino board and attached shield to an aluminum plate while keeping the scintillators in parallel. When the scintillators are parallel, we can detect muons by looking for coincidences in the trigger signals, shown in Fig. 6. We know it is muons that are being detected because of set threshold value in the photomultipliers and the threshold to trigger on the oscilloscope. Now that we have a way to secure the components, the design needs to allow for altering the angle orientation to determine the muon rate as a function of polar angle.

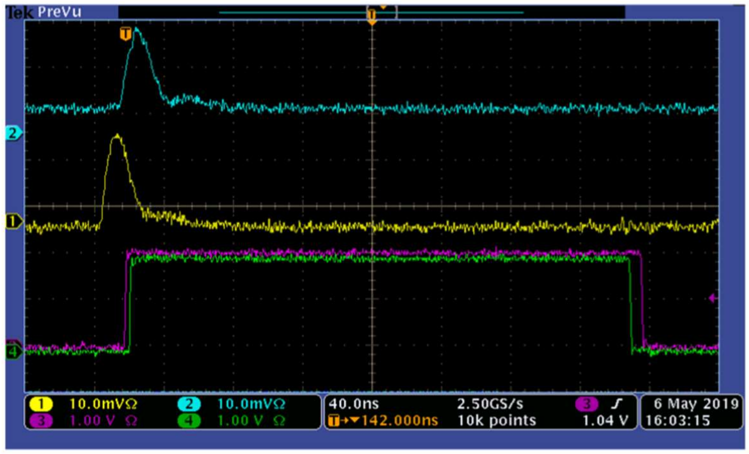

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Figure 6 Scope trace of a signal passing through two scintillators and their corresponding triggers[3]

4 Troubleshooting and Future Work

The next steps after completing the mechanics is to attach a GPS pin to the shields to correct timing windows. The acquisition windows on the two boards need to be synched to ensure that coincidences being measured are accurate. A GPS unit can be used to send a pulse per signal to pins on both boards simultaneously. Since the acquisition windows are supposed to begin at the same time, then a muon that passes through both scintillators would show up as a signal on both boards. Another thing we plan to observe is how using different scintillator sizes affects the ability to absorb and detect certain radiation emissions. We have prepared scintillators of various thicknesses so we will implement both and compare rates of detection. Finally, the last step with the muon detector once data has been collected in the lab would be to move to external locations and measure muon counts from various altitudes.

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