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Cosmic Ray Detection By Plastic Scintillator and SiPM

Aryan Bharti

Delhi Public School, RK Puram

Abstract

Cosmic rays are charged particles which on entering the earth's upper atmosphere react and form muons. Muons have varying energies and can be a very potent particles. We can detect muons through a basic photodetector and scintillator combination. As most muon detectors are expensive and not easily accessible, we develop the design of a detector which is cheap and can be easily assembled by high school students. The detector can also be used to measure the flux and direction of muons, and the interaction of muons with different materials around us.

cosmic rays

Cosmic rays are charged particles, moving through space at nearly the speed of light ($c = 3 * 10^8 m/s$), raining onto the earth from each point in the universe. Most cosmic rays are atomic nuclei stripped of their electrons. The vast majority are hydrogen nuclei, or protons, but heavier elements are also observed. [1] The emission of cosmic rays is isotropic (within 1%), and no particular source of emission of these particles has been identified yet. The energies of these particles vary enormously, from 10^9eV to 10^{20}eV, and can be much higher than anything we can make in an accelerator.

Although there are several cosmic particles, we mostly receive **muons** on the Earth's surface. When a cosmic ray proton impacts atomic nuclei in the upper atmosphere, nuclear reactions occur which sometimes result in the creation of pions $\pi^{\pm,0}$(a type of meson). These pions decay extremely quickly into so-called "secondary muons" and muon neutrinos/antineutrinos. The "secondary muons" continue in about the same direction as the original cosmic ray proton at a velocity near the speed of light, and can be detected on the ground.[2] The muon mean life (τ) is $2 * 10^{-6} s$,and in theory they should only be able to travel around $c * t = 600m$ before decaying. But in reality, many muons manage to cross the Earth atmosphere, which is about 8 km thick, before decaying. This is due to time dilation $T = t/\sqrt{[1-v^2/c^2]}$, where 'T'=dilated time, 't'=stationary time, 'v'=speed of the particle and 'c' is the speed of light (this is an effect of the theory of special relativity which states that the passage of time is distorted for objects that move at high speed).

Scintillators and SiPM

What is a scintillator ?

A scintillator is a device which emits light when a high energy radiation goes through it. It can detect both charged particles and photons. Scintillators can be gaseous, liquid or solid. After a charged particle enters the scintillator material, it excites a molecule of the scintillator. When the molecule deexcites, it emits light.

What is a Photodetector ?

A photodetector is a device which converts incident light into electrical signals.

What is a Silicon Photomultiplier (SiPM) ?

Silicon photomultipliers (SiPMs) are highly sensitive, solid-state, versatile and high-performance photodetectors. They are made by arrays of multiple single-photon avalanche diodes (SPADs). Each cell (i.e. SPAD + resistor) is sensitive to single photons and provides a defined charge at the SiPM output when an avalanche is triggered. SiPMs have obtained growing attention as an cheap alternative to traditional photomultiplier tubes (PMTs) thanks to many advantages typical of solid-state detectors, such as compactness, ruggedness, ease of use, low operational voltage and insensitivity to magnetic fields. [3]

Cosmic Muon Detector (CMD)

We propose the design of a device that is cheap and easy to assemble, yet capable of producing important measurements of the cosmic rays flux. The detector is modular, consisting of 12 repetitions of a basic photosensor unit. The photosensor consists of a square block of plastic scintillator (5cm×5cm×1cm), which when crossed by a muon emits visible light - the emission spectrum peaks around 425nm. The block is wrapped in reflective foil to contain the photons and prevent cross-talk to other units. On the lower edge of the block, however, contact is made with a SiPM (6 mm×6 mm), which gets illuminated by the scintillation light and converts it into an electric signal; these electric pulses constitute the detection message to be processed by the electronic and logical modules. The twelve units are arranged in three horizontal layers (top, middle, and bottom); each layer hosts 4 units (as shown in figure A), side by side. The twelve channels are read independently and can be combined to form time coincidence.

In the simplest operation mode, the three layers are separated by the same vertical distance, so the detector volume is segmented into twelve cells. A perfectly vertical muon would activate three units lying on its path and produce a three-fold coincidence within 10ns; this signal can be easily identified by the electronics; the three points characterize the trajectory of the muon and the rate of such signals indicate the cosmic muons flux. Slanted trajectories will also activate three cells, which however do not lie on the same vertical line, so the rate for different incoming directions can also be reconstructed.

The top and middle layers of the detector can be raised or lowered together through a pulley with counterweights in the four angular posts, while the bottom layer is fixed in position; thus empty space can be created between the layers and filled with targets of choice: this allows studying the interaction of muons with other systems. For instance, a classical experience is having a heave (lead) target between the scintillators and measuring the muon decay. In this configuration, a cosmic muon entering from the top would cross two layers (giving two signals in coincidence) and then stop in the target; after slowing down and losing its relativistic boost, the muon will decay with a mean life of 2.2 microseconds and release an electron, which will subsequently produce a third signal in the detector. Thus one can look for a two-fold (but not three-fold) time coincidence (the stopping muon) and then open a trigger to look for a third delayed hit within a few microseconds (the emitted electron); the distribution of delay times between muon and electrons will follow an exponential curve and provide a direct measurement of the muon mean life. The detector is also mounted on wheels which allows for easy transportation.

Materials and costs

Item	Name	Require	Price(total)	Description
1	Plastic Scintillator	12	$120	5cm×5cm×1cm Plastic scintillator(peak emission at 425nm)
2	SiPM	12	$576	6x6mm SiPM MicroFC-60035-SMT
3	Arduino Nano	12	$27	ATmega328 CH340G
4	Alumunium foil	1	$2	10x10cm of Aluminium foil for wrapping the Plastic scintilaltor
5	Other components	_	≈$150	Coincidence Cable,detector enclosure, PCBs etc.
		Total:	≈$875	

Discussion

Through this paper we have developed the design of a cheap and easy to assemble muon detector which can be built in schools and can be operated by students. The detector allows us to measure the flux and the direction of the muon. The behavior of different materials on contact with muons can also be studied by placing the material between the layers of the detector. The detector is mounted on wheels, which means we can study the absorption of muons by different materials (an example experiment could be placing the detector on different floors of a building and observing the count of muons). This detector can be easily accessible for high school students and provide them with a glimpse of the wonderful world of cosmic rays.

Figures

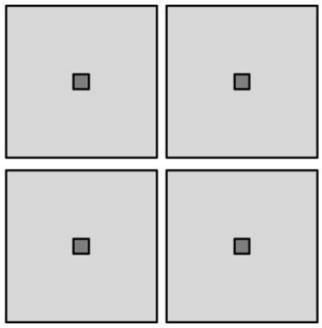

Figure A: Top view of the detector (single unit)

Figure B: Side view of the detector

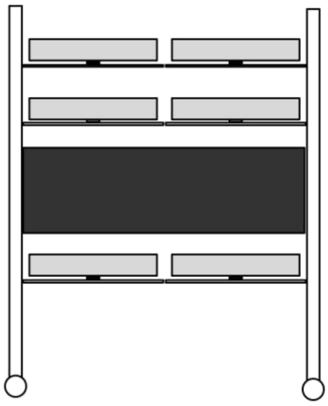

Figure C: Complete detector with lead block in between

References

1] “High Energy Cosmic Rays”, T. Stanev. Berlin, Heidelberg: Springer Berlin Heidelberg, 2010.

[2] “Muon Basics”, Universidad Nacional de La Plata, http://www2.fisica.unlp.edu.ar/veiga/experiments.html. Retrieved April 25th, 2014.

[3] “Lifetime of the Muon”, NP08, Oxford Physics, Particle Physics Projects Manual, revised MGB Oct 2006.

[4] “Determination of the Muon Lifetime”, The University of California, Physics 122 course, Experiment Manual. Retrieved Winter 2014.

[5] “The Speed and Lifetime of Cosmic Ray Muons”, Liu, Lulu, Solis, Pablo, MIT Undergraduate Experiment report. Retrieved Nov 18, 2007.