Looking at Cosmic Muons to verify Einstein's Special Relativity

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Abstract

In this paper we will be building a modified Geiger counter to detect cosmic muons and will be directly measuring the average muon density or flux on the earth's surface and at varying altitudes. This will give us a relationship between them and this in turn can be used to verify the time dilation concept of special relativity. The very high speed of the muons (essentially c, the speed of light) causes them to live longer and this enables them to travel a longer distance to reach the surface of the earth.

Introduction

Cosmic showers from high energy events in outer space reach earth's atmosphere and create a whole family of particles which rain down upon the surface at a very high rate. Out of these particles, muons are the most energetic ones and very interesting to study. Since their discovery in 1936 by Carl Anderson, muons have fascinated scientists and the scientific community alike that it prompted the very famous remark from Nobel Laureate I.I.Rabi " who ordered that?" There are a lot of ways of looking at muons and one of them is to have a modified Geiger counter consisting of two detectors and looking for a coincidence between the two. Natural terrestrial radiation will also trigger a detector but will get stopped because of their low energy. Muons on the other hand are highly energetic and pass through two of them quite easily without loosing much energy and give us a very accurate count.

Given below is the basic design of the experiment. In this we have many different types of detectors

1. Fluorescent light bulb
2.

Flat Vacuum chamber

3. Neon bulb detector

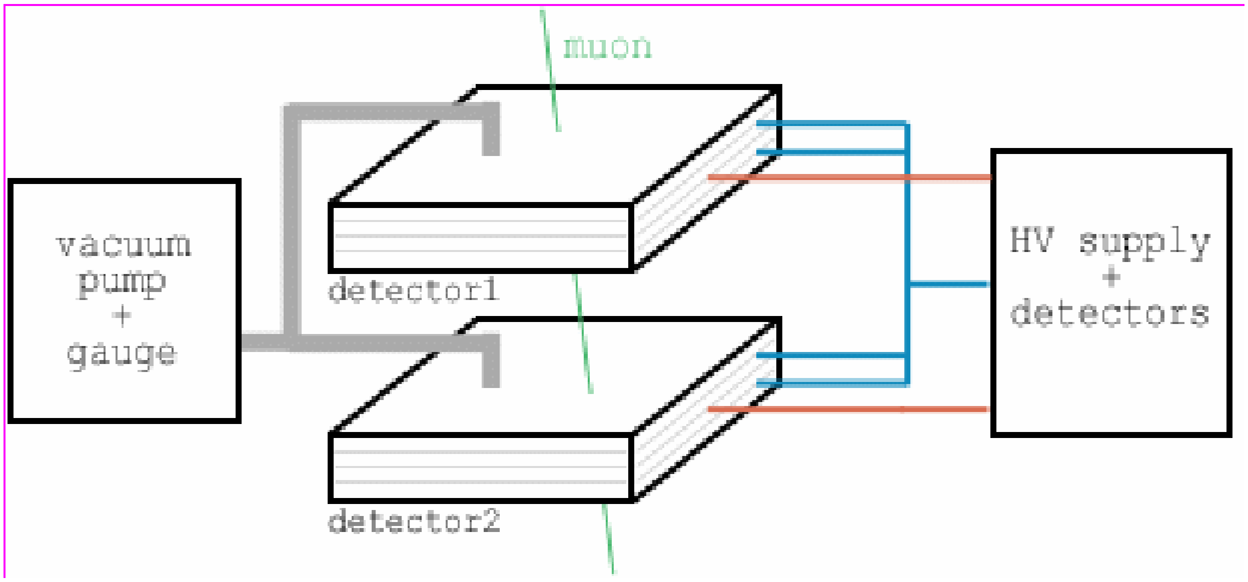


Figure 1 – Cosmicrays.org

Detector Designs

Design I

This design is a very low cost cosmic ray detector using common Fluorescent Tubes. It is based on variation of an experiment performed in 2000 by the CERN (European Organization for Nuclear Research) laboratories by Dr. Schmeling which uses a simple method for detecting and visualizing cosmic rays using everyday fluorescent tubes inside a wire mesh of feed with a high voltage. In our variation we have used copper tape on both sides of the tube to give it the high electric field.

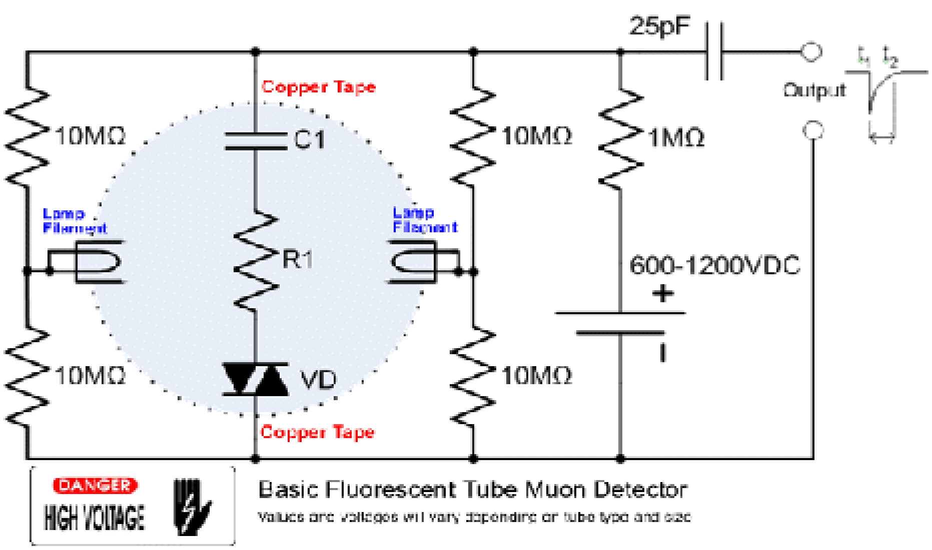


Figure 2 – Cosmicrays.org

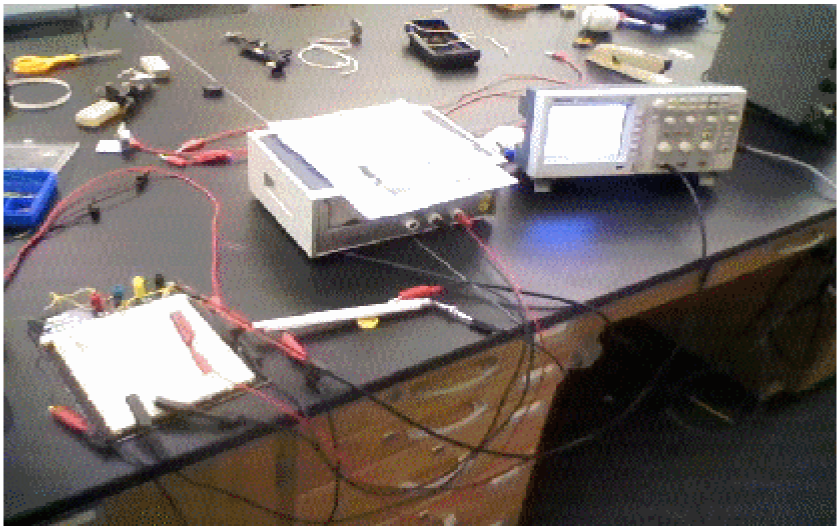


Figure 3.a

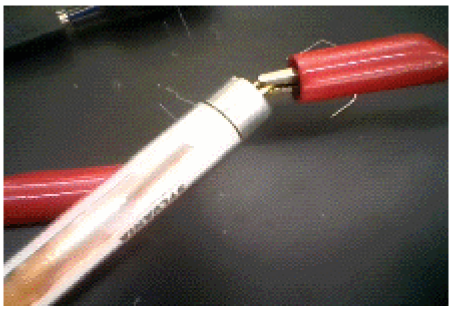


Figure 3.b

Problems with the detector:

1) Power supply requires good filtering and regulation
2) Tubes vary in voltage requirements from one tube to another even between the same make, model and age
3) Oscillation is a problem as the supply voltage and/or coupling plate surface area increase
4) Internal filament electrodes must be insulated, even loose coupling increases oscillation and spurious pulses
5) Oscillation occurs as the circuit forms a basic relaxation oscillator

Design II

I will be following the procedure given in the Scientific American (Feb 2001) article by Shawn Carlson. The basic design of a detector consists of four sheets of plexiglass one below the other and sealed to withhold a low pressure of about a tenth of an atmosphere. The picture below shows in layers how they are constructed.

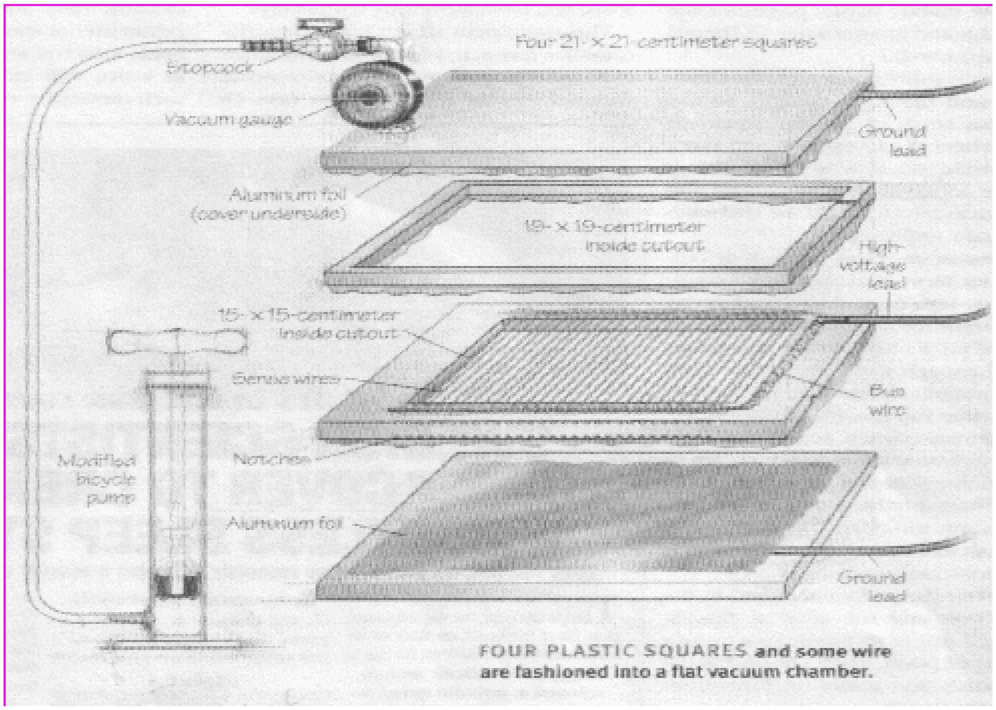


Figure 4. Sci-Am Feb 2001article

The aluminum foils on the inside of both the outer layers act as the ground and the assembly of thin wires in the middle are the high voltage. Here in the Sci-Am article, they have used four sheets of Plexiglas and I will be using five as I will be repeating the second layer in the bottom also to give it plenty of room in case the wires make contact with the aluminum foil and cause a short circuit.

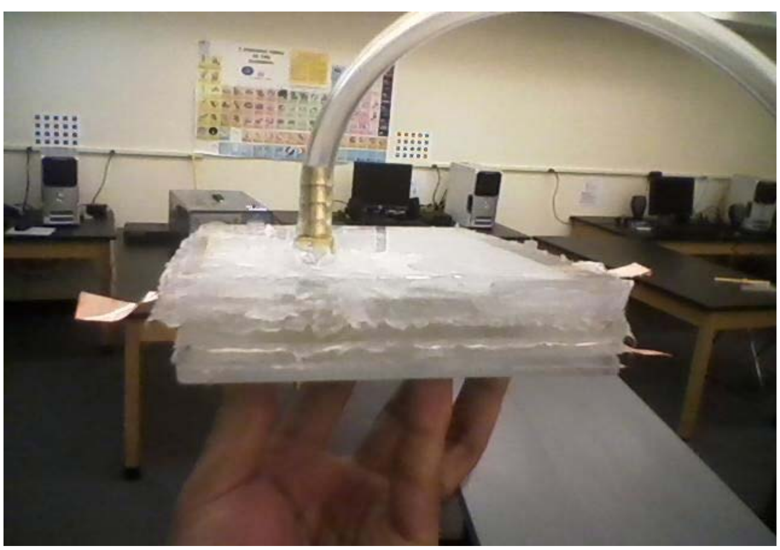


Figure 5

Other requirements

High voltage power supply: this detector requires a regulated high voltage supply which can be adjusted to have a range of about 600V to 1100V. This is very easily available in the market but to have one which we can run of a battery and is portable and cheap at the same time is needed. Hence we decided to build it from scratch and it was quite easy as the circuit was provided by the cosmicrays.org website.

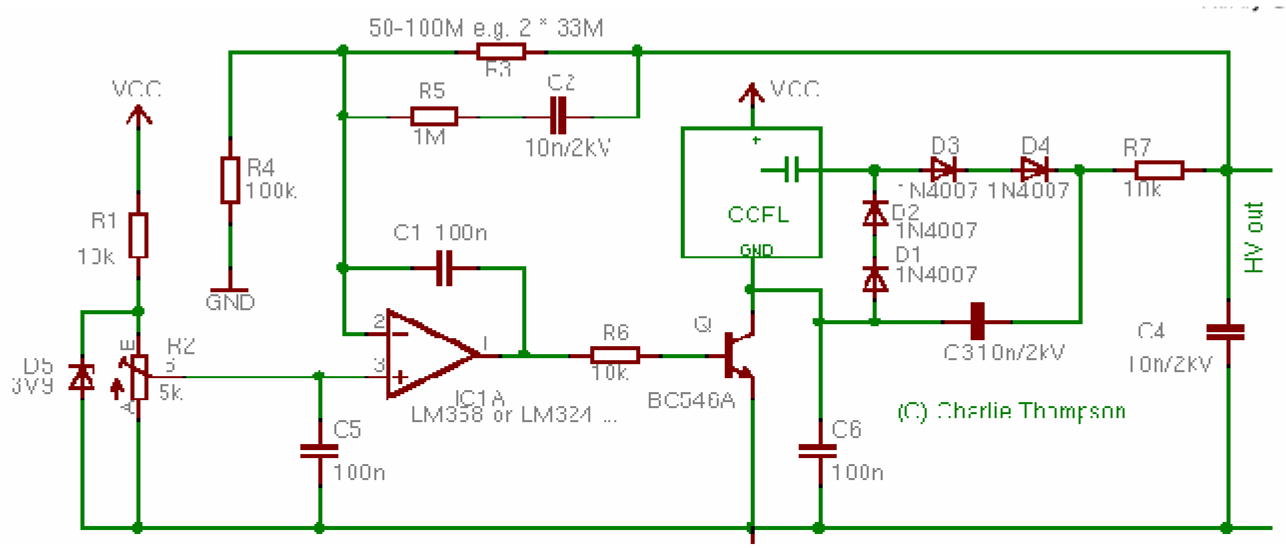


Figure 6.a

Figure 6.b

This regulated high voltage power supply is designed to be powered off a 6 volt battery to give up to about 900V and can also be varied using the 5K pot seen in the picture.

Design – III

The neon bulb detector has very much the same principle but the only difference being that the breakdown voltage is low (about 65.3V) compared to the other detectors. The circuit was provided by Peter Lay in his article in electronic design and we made a few modifications to it and ended up with a circuit which is shown below. All resistors are in ohms

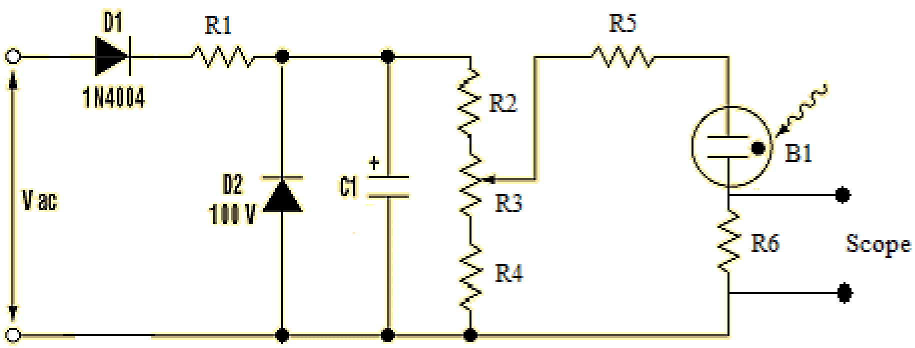


Figure 7

Vac = 120V, R1 = 25K, C1 = 1900 MF and 47 MF in parallel, R2 = 80K, R3 = 25K pot (offers the control on the voltage), R4 = 75K, R5 = 3M, R6 = 100K, B1 = Neon bulb

D1 = Diode, D2 = 100V Zener diode

This circuit provides a stable and variable power supply to the bulb and the voltage is adjusted so that its value is very close to the breakdown of the bulb. AC input is rectified by the diode and the capacitor is present just the reduce the ripples and provide a steady source of voltage. R1 is present to make the voltage drop across the zener diode around the sum of the resistors R2 to R4. Thus using the pot R3 we can change the voltage on the bulb.

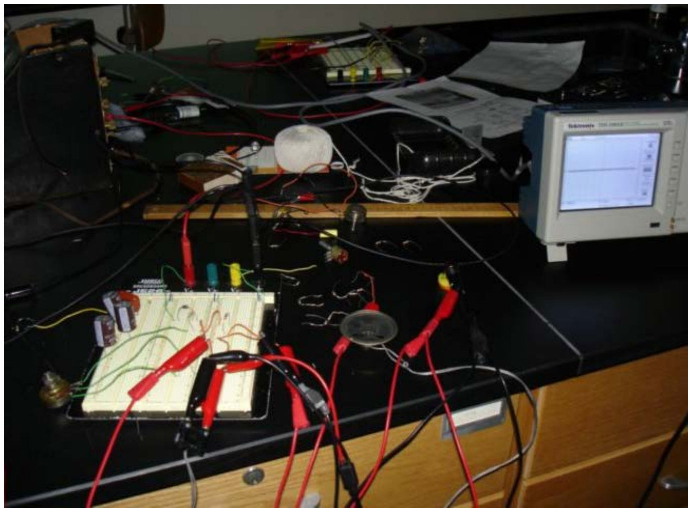


Figure 8

Physics of the detector

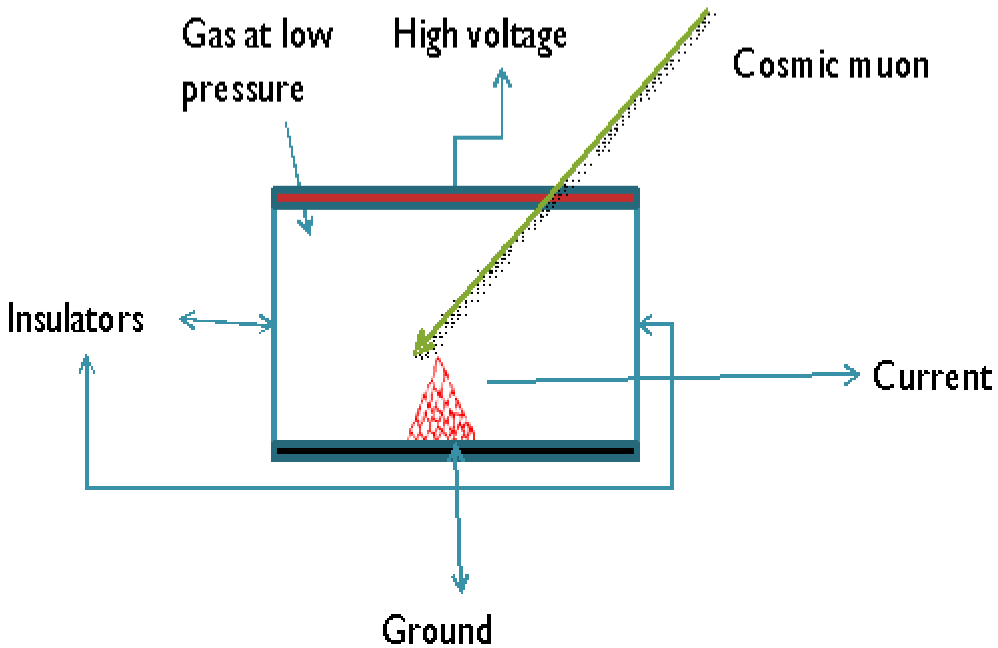


Figure 9

For all the designs, the physics is really the same. One end of the detector carries high voltage while the other end has ground. This potential difference creates an enormous electric field near each wire and in the gap between the plates. When a cosmic ray/muon enters the gap, it strips of some electrons of the atoms present in there and these electrons get accelerated towards the positive electrode. As it moves towards the positive electrode, it in turn strips more electrons of other atoms and starts a chain event.

Here there are two ways of detecting the current flowing between the two electrodes. One way is to make the high voltage really close to the breakdown value (when the system conducts) so that this chain of electrons continues and we get an avalanche of electrons which we can detect easily. Another way of detecting the small current amplitude is to send it through a trans-impedance amplifier followed by an op-amp with minimal gain (preferably unitary) and look at the voltage coming out of the follower amp.

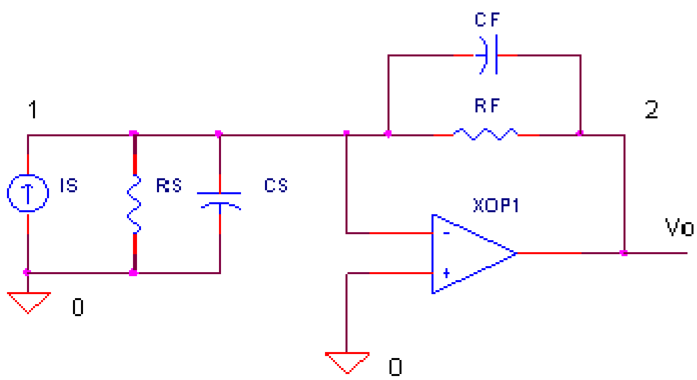


Figure 10 – Trans-impedance amplifier

The basic principle of this trans-impedance amplifier is that since the inverting input and the non inverting input are both kept at zero potential, no current flows through the amp. Thus any current pulse coming from the detector (IS – in this case) will be forced to go through the resistor RF and that voltage drop can be measured using a scope.

Connection to Special Relativity

The cosmic rays which strike the atmosphere create the muons and these muons have a typical lifetime of about 2.2 micro seconds. When they are created at approximately 15 km higher in the atmosphere and essentially travel at the speed of light we get that they should not travel more than

$$D = \text{speed x time} \quad (1)$$

$$D = (3 \times 10^{8}) \times (2.2 \times 10^{-6})$$

$$D = 660 \text{ m}$$

This is not really true since the muon flux measured on the surface of the earth is about 1 per minute per sq. cm. Here is where special relativity comes into the picture as for particles traveling close to the velocity of light, time slows down by a factor called as the Lorentz factor.

$$\Delta t = \Delta t_0 \, k(\textit{Lorentz Factor})$$

$$k = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$

(4)

We assume that muons are produced at a typical height of about 15km above ground level. If they travel at the speed of light then the time taken to travel the 15 km would be

T = x/c

$T = (15 \times 10^3)/(3 \times 10^8)$

$T = 5 \times 10^{-5}$ s.

If the mean lifetime of the particles is $t = 2.2 \times 10^{-6}$s then the fraction of

muons generated at 15km surviving to reach ground level should be:

$$N = N_0 e^{-\left(\frac{T}{t}\right)}$$

$$\frac{N}{N_0} = e^{-\left(\frac{5\times10^{-5}}{2.2\times10^{-6}}\right)}$$

$$\frac{N}{N_0} = 1.3\times10^{-10}$$

(5)

N = no of muons reaching the surface

N_0=no of muons created in the atmosphere

If we consider 20 Ge V muons then we can get k from the equation $E = mc^2$. This equation can be written in terms of the rest mass of the particle

$E = k\, m_0\, c^2$ (6)

so $k = E/m_0\, c^2$ – Lorentz factor

In energy terms, the rest mass of the muon is 106MeV so k = 20GeV/106MeV

k = 189.

The mean lifetime now becomes 189 x 2.2 x 10^{-6}s and so the fraction of muons now capable of reaching ground level becomes:

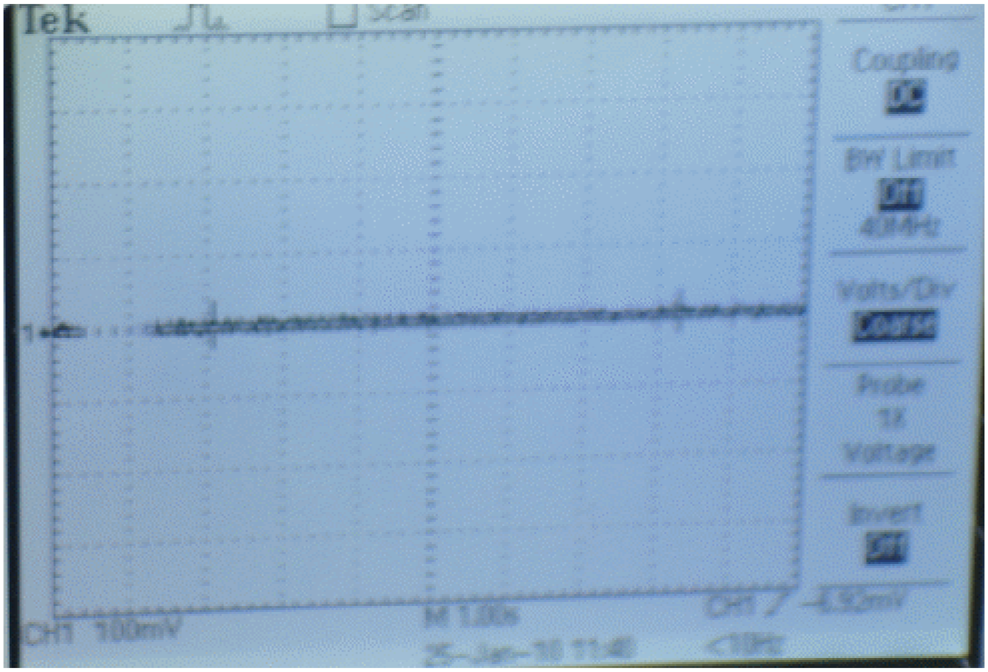
$$\frac{N}{N_0} = e^{\left(\frac{5\times10^{-5}}{189\times2.2\times10^{-6}}\right)}$$

$$\frac{N}{N_0} = \mathbf{0.89}$$

This ratio tells us that there is close to 90% chance that a muon created by a cosmic ray higher in the atmosphere (15 km) would reach the earth's surface. For our experiment, we would be testing this at varying altitudes and looking at the same ratio.

Results and Further Work

Even though the concept behind this detector is simple the calibration is very important to the detector. So for I have been able to calibrate only the neon bulb to a pretty good extent where in distinguishable difference between the radiation kept my us and the ambient terrestrial radiation was observed.



One of the problems which we encountered was that the AC line in had noise which was getting transferred to the bulb and which made it flicker thus sending a lot of spikes to the scope. This can be stopped by having a better regulated power supply.

The Plexiglas detector is the next closest to being completed but still a lot of calibration is required in the detector circuit. My next goal would be to complete this detector and set up a coincidence logic circuit. This is also given in the Sci-Am article and I would hope to get it done within the coming month.

References

Main detector designs - www.cosmicrays.org

High voltage power supply - www.hardhack.org.au/hv_reg_power

Scientific American - Shawn Carlson “Counting Particle from Space” February 2001

Electronic Design - Peter Lay “Simple Geiger Detector used Neon Glow lamp” March 2002

Trans-impedance Amplifier - www.ecircuitcenter.com/Circuits/opitov/opitov.htm