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Muon telescope: An experimental observation of leptonbased on coincidence technique

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Muon telescope: An experimental observation of leptonbased on coincidence technique

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Abstract. Cosmic rays are high energy radiation originating in the cosmos, consisting of nucleonic fragments that rain down on the earth from outside the solar system in the form of Extensive Air Shower (EAS). There are several secondaries generated in these showers. The most common fundamental particles to reach the Earth's surface are muons, electrons, neutrinos, and gamma rays. The easiest way to extract information from these particles is by keeping the detector on earth's surface. By requiring coincidence in several detectors, background radiation will automatically be sorted out. A muon telescope consisting of two polystyrene plastic scintillation detectors has been set up in our laboratory. In this paper, secondary flux has been observed by increasing the distance between the detectors, horizontally as well as vertically. This study has been extended for observing the flux on keeping the detector inside, outside and on the top (4.5 meters) of the laboratory building. Horizontal separation, vertical separation, data inside, outside and at the roof of the laboratory building, are five measurements performed using Muon Telescope at constant threshold of discriminator. In this process, one detector was kept at the fixed position and the other detector has been moved with respect to the first one. SEASA (Stockholm Educational Air Shower Array) in Alba Nova Physics Centre in Stockholm, has performed this detector separation study with three detectors and it has been observed that the count rate decreases with the separation between the detectors because the telescope loses the sensitivity to lower energy shower.

Keywords—Cosmic rays, Count rate, Muon Telescope, Detector.

1.Introduction

Cosmic rays are basicallyhigh energetic particle which travels to us from our galaxy and outer galaxy but their actual source of origin is a question mark. It consists of proton, pion, kaon, muon, electron, positron, gamma rays and neutrinos. The detectable cosmic rays begin at energies of about 1 GeV. The highest energy cosmic ray so far detected had energy of 51J [1]. Cosmic ray energy spectrum can be explained by power-law with a detectable steepening at a little below 10^{16} eV called knee and a flattening above 10^{18} eV called ankle as shown in figure 1.

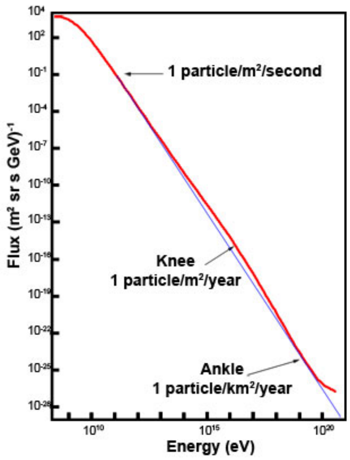

Figure 1: Cosmic Ray Energy Spectrum [2].

The power-law form is believed to be the result from cosmic ray acceleration processes involving progressive acceleration in magnetic fields such as in supernova shells and astrophysical wave shock. High energy cosmic rays interact with Earth's atmosphere and produce a shower of secondary particles in which many particles are produced from a single primary particle but because of coulomb scattering and momentum distribution, these secondary particles deviate from their track. This shower is called Extensive Air Shower (EAS) or cosmic ray showers.

Interaction of primary particle with the atmospheric nuclei produce pions (charged and neutral) and the charged pions interact again and decay into muons, as muon is weakly interactingparticle, so it usually continues its path to the sea level. Neutral pions immediately decay into pairs of gamma-rays which initiate the electromagnetic shower and produce electrons and positrons by bremsstrahlung process and further produce gamma-rays [3]. The electromagnetic shower develops until the energy losses due to photoelectric and ionization becomes dominant. At sea, there are mainly three components: first, the muon component which is a highly penetrating particle and produced in the atmosphere; second, the electromagnetic component in which electrons, positrons and gamma-rays are produced; and third is a hadronic component [4]. These particles are directly associated with the primary particle of cosmic shower. Many muons are produced by quite low energy primary particles whose electromagnetic components die in the atmosphere. The result is that there is a large ground level flux [5]. Their flux at sea level is about one particle per square cm per minute. The sum of the total energy deposited by the total number of particles in a shower is approximately equal to the energy of the primary particle which can be expressed in GeV. A single primary particle of shower involves approximately 10 billion of particles. These numbers of particles are then spread across an area of km^2[6]. Primary cosmic rays interact with the atmosphere so no primary cosmic rays can be detected on the earth’s surface. To detect the primary before the interaction takes place, the satellite and balloon experiments have been used. This is called direct detection method. At the ground level these particles are detected using large detector arrays and these arrays detect many secondary particles at the same time. For this mainly two methods are used,the detection of air fluorescence, in which charged particles in the shower cause excitation (ionization) of air molecules which emit light of a characteristic wavelength. The intensity of fluorescence gives information about the primary energy. This method is used to locate the shower energy and the type of the primary particle.

The other method is detection of muons, electrons and photons using scintillation detectors.From this secondaries particle’s data is collected and that data is used to reconstruct the primary parameters. These are called indirect detection methods because in these methods the primary particles have not been detected directly but by the reconstruction. Muon telescope is the base of many advanced studies effecting our lives. The outline of its applications has been summarized in the Figure 2.

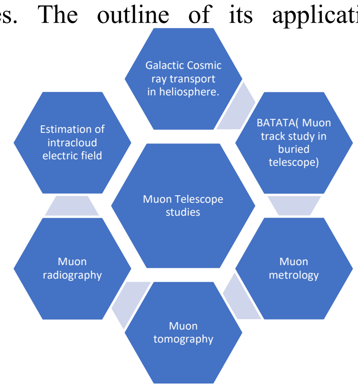

Figure 2.Applications of muon telescope to real life.

The galactic cosmic ray solar diurnal anisotropy data from the Nagoya muon telescope made way to calculate the detail parameters of particle rigidities through interplanetary magnetic fields. Another important application of muon's absorption or scattering results in imaging methods. The muon detector measures its incoming flux, whereas absorption-based muon radiography depends on the rate of muon absorbed by a given target along the given direction. Two- and three-dimensional imaging is done along with Monte carlo simulation. In fact, the author has recently completed calculations of high energy muons with the nuclear waste containers in our country [7].The muons from cosmic rays have several applications, are a forever source with no radiological side effects, identified on some known detectors and being studied for a long period in Astroparticle physics. The following figure 3 outlines some very interesting experimental studies involving the muon detectors. The first diagram [8] describesmuon radiography explained in different scenarios as a cargo check, nuclear radiation check, underground digging and open structurescanning's.The SEVAN resembles our muon telescope in detector specifications, is using the time series of count rates to observe effects of electric fielddisturbances [9].

Figure 3: Muon telescopes at work.

In the above figure, the EEE Collaboration is studying the EAS using muon telescopes of resistive plate chambers [10]. They are studying solar flares and its correlation to muons from EAS. In our telescope the detector is plastic scintillator. Scintillation detectors are used due to its quality to convert the kinetic energy of the charged particle into a detectable light pulse of withlarge scintillation efficiency and good optical quality [11]. For these studies organic scintillators are used over inorganic scintillators due to their fast response time and cheap price.In inorganic scintillators, the scintillation arises due to the structure of the crystal lattice. But in organic scintillators, scintillations arise from transitions in the energy levels by a single molecule so from there the fluorescence can be observed [5].

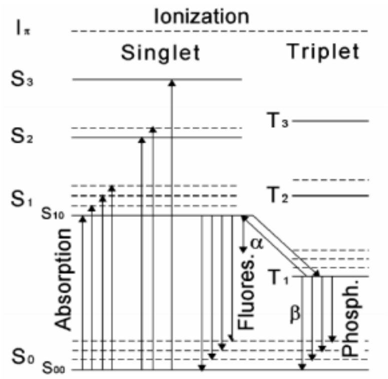

Figure 4: Energy Level Diagram for the Organic Scintillators [5].

Figure4 shows the energy level diagram for the organic scintillators. As observed in the figure, the energy from a charged particle is absorbed by the electron which jumps into the various excited states; the singlet states which has spin 0 are labeled as S_1, S_2, S_3, the spacing between ground state S_0 and S_1 is 3 - 4 eV for organic scintillators and this space goes on decreasing on going to S_1-S_2, S_2-S_3 and so on. Each of the S levels is subdivided into a series of levels with much finer structure that shows the vibrational states of molecules. The spacing between these series is typically 0.15 eV. S_2, S_3 etc. are considered as higher states and from here the molecule de-excite in (psec) to the S_1 state. States S_{11}, S_{12} have extra vibrational energy so these states are not in thermal equilibrium hence from thesestates the molecule loses its energy very quickly. Scintillation light, prompt fluorescence is emitted in transitions between S_{10} and the ground state. Fluorescence decay time in organic scintillators is of the order of nsec, leading to a fast response time of organic scintillators [12]. Transition from T_1 to S_0 gives the phosphorescence which is also known as delayed light emission and wavelength of the phosphorescence is larger than the fluorescence. When the charged particle hits the detector, it excites the electron of the material and these electrons emit energy in the form of photon which are in UV (10 nm to 400 nm) range. This can be seen from our eyes on holding the scintillator slab in our hand and observe it from its edges, it will be in blue colorbecause of production of scintillation by the charged particle passing through it. Once this photon is created it is randomly oriented and may or may not move towards the photo-multiplier tube (PMT) [13]. To catch the maximum number of photons,wavelength shifting fibers are used which not only catch the photon but also shift the wavelength of the absorbed photons to the wavelength for which the PMT has the maximum efficiency. The plastic scintillator is being polished and wrapped in black Tyvek sheet so that no unwanted photon (from the background) can enter the system.

2.Experimetal setup and methodology

Muon Telescope (μT) has been setup in Nuclear Electronics laboratory, Dayalbagh Educational Institute, Agra with latitude of 27.1767° N and longitude of 78.0081° E at an altitude of 171 m. It consists of two plastic scintillation detectors of dimensions 23.5x24x2 cm^3, which has been kept together and with the help of coincidence technique muons are being filtered from its background. These scintillators are connected to the photo-multiplier tubes (PMT) via light guides and generate electronic pulses which are being measured using NIM (Nuclear Instrumentation Module) electronics. The signal from PMT, goes into discriminator (Phillips Scientific, model 704, Quad 300 MHz) which setup a threshold for that signal and convert the analog pulse into digital pulse. Figure 5 is showing the analog pulse from the PMT and its corresponding pulse from the discriminator after getting converted into digital pulse. The amplitude of the pulse coming from double fiber detector is ~250 mV and from the single fiber detector it is of ~220 mV.Discriminators threshold is fixed at the value -150 mV which convertsthe analog pulse into digital pulse with the pulse width of 60 nsec. After getting converted into digital pulse, the signal is wired to the logic unit (Phillips Scientific, model 756, Quad Four – Fold),using AND logic a coincidence between the detector within 60 nsec is produced. Whenever a particle will pass through both the detectors within 60 nsec the system will trigger,and the coincidence count increments. From the discriminator and logic unit the counts are observed,feeding their output into the scalar (CAEN, Model N1145, Quad Scalar andPreset Counter/Timer). The coincidence counts are mostly muons because only muon has the property to penetrate through both the detectors without getting absorbed. Figure 6 shows the muon telescope setup in our laboratory, in which on the left side there are two detectors (wrapped in black cover) one above the other and right side shows the Data Acquisition System (Nuclear Instrumentation Modules electronics). This muon system detects coincidence for every 5-minute interval.

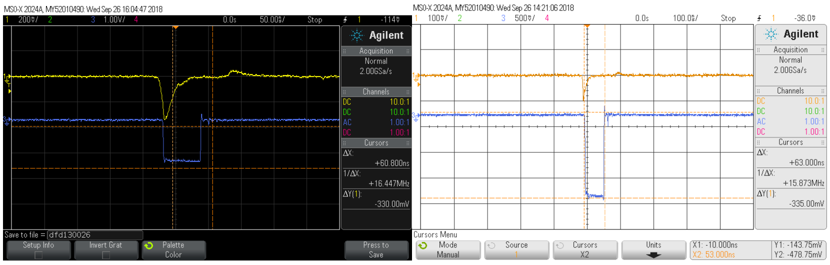

Figure 5 Double Fiber Detector Pulse and single fiber detector pulse from PMT and Discriminator.

Figure 6:Data Acquisition System in Nuclear Electronics Laboratory

For a better understanding, variation of cosmic muon flux has been analyzed with increasing the distance between the detectors, horizontally as well as vertically and by placing the telescope inside, outside and on the top (4.5 meter) of the laboratory building. As a solar timevariation, the cosmic ray daily variation is often being referred to as a local time phenomenon. It is not possible to assume the same variation in all altitude regions as besides a diurnal variation the pressure displays a semidiurnal wave as well as still harmonics dependence on the climate region concerned. The data is being analyzed from 2016. The earlier studies have been reported in [6], [7]. These studies were further extended in 2016 to 2018.

3.Result and discussion

Muon count rate has been observed at different places in the laboratory: inside, outside and at the roof of the laboratory i.e. at 4.5 m height. This observation is important to study many applications like low background measurements, count rate variation with the atmospheric parameter etc. Figure 6, 7 and 8 are showing the variation in count rate with the different placement of detectors and it can be observed from the Figure 6 that single detector counts are high when measuring inside the laboratory; this is due to the high probability of secondaries to decay inside the laboratory from the wall of the laboratory. The graph has been plotted on a logarithmic scale and x-axis denote the date on which the counts has been taken. The other important factor to note here is the change in coincidence rate with respect to the placement of the detector and it can be observed form the figure 6 and 7 that coincidence count rate does not change by placing the detector inside or outside the laboratory but it does change on changing the altitude or height of the placement of detectoras shown in figure 8.

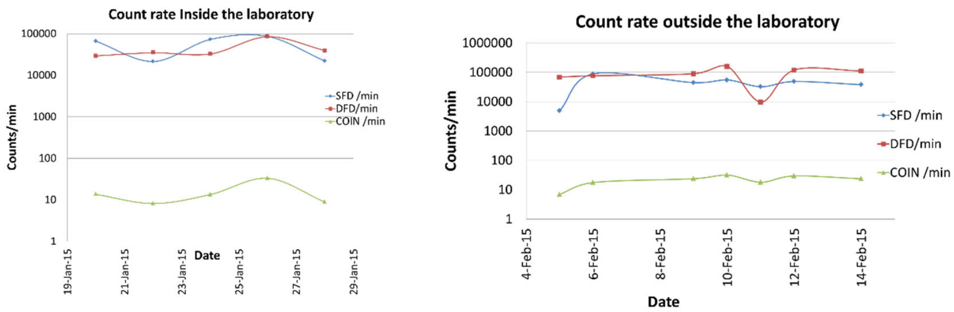

Figure 7: Count rate variation of the detectorsinside and outside the laboratory

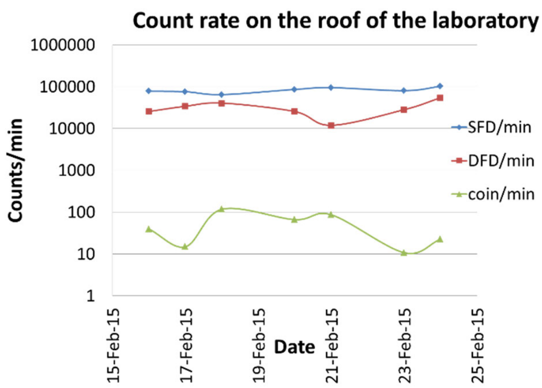

Figure 8: Count rate variation of the detectors at the roof of the laboratory.

On keeping the detector at 4.5 m above, the coincidence count rate increased by a factor of 10 which shows that ongoing above the sea level the probability of getting large number of muons increases which is confirmed in other experiments too which are running at higher altitude such as GRAPES-3 experiment in Ooty. The probability of getting muon is directly proportional to the altitude i.e. as we go to the higher altitude the more muon,we'll be able to detect. Second study that has been carried out here is the variation in muon count rate (coincidence count rate) with the separation between the detectors (vertically and horizontally).

Table 1: Count rate variation on increasing the distance between the detectors vertically and on the roof.

Distance (cm)	**Outside Counts/sec**	**Inside Counts/sec**	**Distance (cm)**	**Roof Counts/sec**	**Ground Counts/sec**
0	21.49	15.5	0	0.66	0.29
30	13.71	12.27	30.48	0.21	0.10
60	13.57	12.32	60.96	0.096	0.07
90	10.98	10.80	91.44	0.064	0.05
120	9.92	10.73	121.92	0.038	0.02
150	9.92	10.32	152.4	0.012	0.002

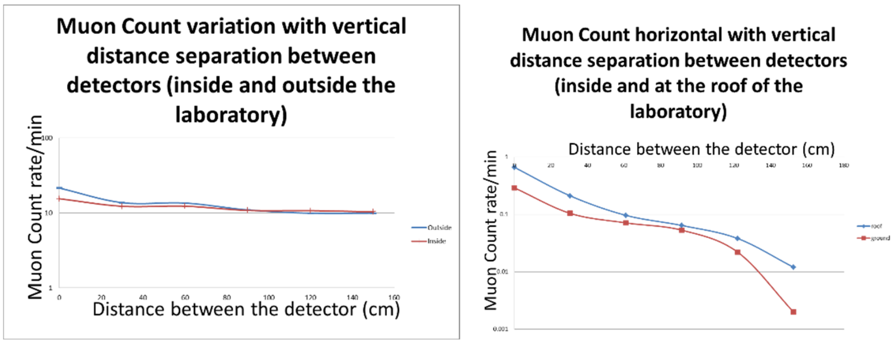

Figure 9: Count rate variation

It has been observed that the count rate decreases while increasing the separation between the detectors because of less probability of existing of vertical slant muons while passing through both the detectors. Here the detector separation gives a possible approach to collect single muons and the detected coincidences from related air shower particles. Table 1 is showing the muon count rate variation on increasing the separation between the detectors vertically when the detectors are placed inside and outside the laboratory. It has been observed from the table 1 and figure 9 that the counts rate does not change much on placing the detectors outside and inside the laboratory. The muon rates inside and outside the building showa slight variationin the studies done by the students in the Physics Department of Genova University [14] but the other experimental muon rates are comparable. In this work, they have designed the AstrO telescopeusing plastic scintillator, SiPMs and FPGA based DAQ in the INFN Genova Unit. This is since the muon absorption factor is more in their case due to the presence of surrounding materials.

The count rate decreases on increasing the distance between the detectors.Table 1 is showing the count rate variation on increasing the separation between the detectors horizontally when the detectors were placed at the ground and at the roof of the laboratory. Figure 9 shows that the muon count rates are larger on placing the detectors on the roof as compare to the ground. This is because of the probability of getting muon increases at higher altitudes while coincidence count rate decreases on increasing the distance horizontally. The number of vertical muons is much more than the number of horizontal muons i.e. most muons come vertically to the ground. We can interpret this as the muons are produced from the shower only, so muon gives the information about the primary particles.

These studies have been done by using NIM electronics after successfully setting up the muon telescope, the DAQ has been setup to study energy and time of flight experiments. Finally, the DEASA (Dayalbagh Educational Air Shower Array) is being setup in the Department of Physics and Computer Science, Dayalbagh Educational Institute, Agra.

4.Acknowledgment

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