A measurement of integrated vertical flux intensity of cosmic-ray muons using angular distributions at surface laboratories

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Introduction

The study of the atmospheric cosmic muons flux is done for the estimation of background at the underground facilities for neutrino detection, dark matter studies and other rare-events experiments. In the present work, the integrated vertical flux intensity of cosmic-ray muons has been measured using the angular distribution at two different latitudes and altitudes in the surface laboratories of SINP, Kolkata, and UCIL, Jadugoda respectively. The measurement for cosmic muon background is done in the underground laboratory at JUSL also, but the cosmic muon flux intensity could not be produced due to very low statistics. The angular distribution of cosmic muons has been measured by counting the muons incident along various zenith angles (θ). The integrated vertical flux intensity ($I_\mu(0)$) of cosmic muons has been calculated by fitting the angular distribution data to the standard $cos^2(\theta)$ distribution. Finally, we have compared the experimental data (obtained at the surface) with the simulation results where standalone PYTHIA8 code has been augmented for Extensive Air Shower (EAS) environment [1]. The primary cosmic rays are more or less isotropic, but the cosmic-ray muon flux strongly varies with the zenith angle (θ), as depicted by the equation (1):

$$I_\mu(\theta) = I_\mu(0)cos^n(\theta) \qquad (1)$$

where $I_\mu(0)$ is the integrated vertical muon flux intensity, and n is an exponent [2, 3] respectively. The value of exponent n and the integrated vertical flux intensity $I_\mu(0)$ depends on several factors like; latitude, altitude and geomagnetic cut-off. At typical sea level altitudes, the integral vertical intensity is about 70 $\mathrm{m^{-2}\,s^{-1}\,sr^{-1}}$, and the expected value for exponent n is around 2 for muons with energies above 1 GeV [2, 4].

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Experiment & Results

The detection system comprises of plastic scintillator tiles where Silicon Photomultipliers (SiPM) are coupled with it. The output signals from the SiPM are fed to the Coincidence Module, which provides us the coincidence counts of the muons passing through the top and bottom detectors. Telescope Mechanics is used for changing the zenith angles (θ) with precision during the experiment. The plastic scintillator is a Polystyrene-based tile with a length and breadth of 15 cm each, and a thickness of 1 cm. The SiPM has the dimensions 4×4 mm^2, and a Photon Detection Efficiency of 43%. The flux of cosmic ray muons was calculated using the solid angle of the equipment and the coincidence counts [1]. The experimental data was collected at two different altitudes from the sea level (SINP, Kolkata and UCIL, Jadugoda).

A. Cosmic Muon Flux:

The data taking was done for each zenith angle in a duration 12 hours. The angular distribution of calculated cosmic muon flux measured at two laboratories are compared with PYTHIA8 simulation results and shown in FIG.1 & 2 respectively. The values of integrated vertical flux ($I_\mu(0)$) and the exponent term (n) for the measurements have been given in Table I.

TABLE I: Values of exponent (n) and Integrated vertical flux ($I_\mu(0)$) for the two laboratories.

Laboratories	**n**	$\mathbf{I_\mu(0)(m^{-2}s^{-1}sr^{-1})}$
Kolkata	1.705	$49.75 \pm 0.042(stat) \pm 0.036(syst)$
UCIL	1.9	$58.6 \pm 0.046(stat) \pm 0.042(syst)$

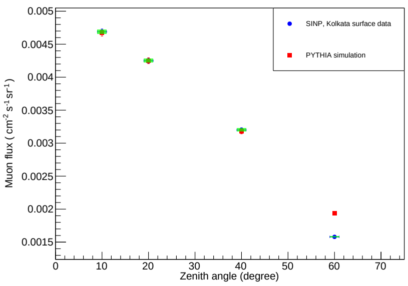

FIG. 1: The comparison of PYTHIA8 simulation results with measured cosmic muon flux as a function of zenith angles (θ) at SINP (Kolkata).

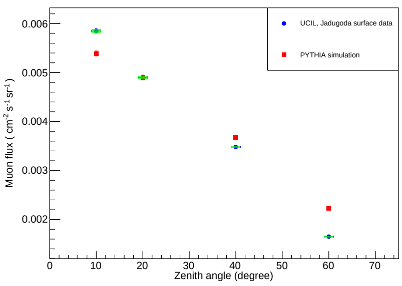

FIG. 2: The comparison of PYTHIA8 simulation results with measured cosmic muon flux as a function of zenith angles (θ) at UCIL (Jadugoda).

B. Geant4 Simulation:

The visualization of the scintillation process in the plastic scintillator is simulated in Geant4, and is illustrated in FIG. 3. The angular distribution of cosmic muons and the efficiencies of detectors could be calculated incorporating detector geometry and construction in Geant4 software package. A preliminary simulation result is showing a visualization of the scintillation process in the plastic scintillator. Here, the outer box represents the world volume, and the smaller blocks inside represent the plastic scintillators. A muon (μ^-) is represented by a red track, which upon striking the scintillator plates, causes them to glow in green via scintillation process.

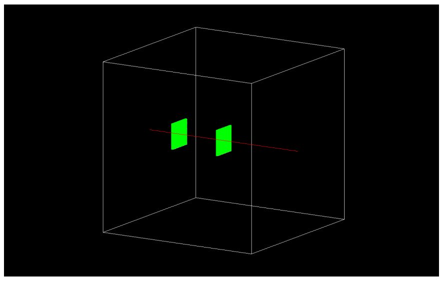

FIG. 3: Geant4 visualization of scintillation process as the muon strikes the scintillator plates.

Summary

The measurement of angular distribution of cosmic ray muons provides us with the information of the integrated vertical muon flux intensity ($I_\mu(0)$) and the exponent (n). This information can be utilized to scan the interiors of volcanoes, ancient monuments and can also be used for nuclear waste imaging. The study of underground flux of cosmic ray muons is necessary in neutrino and dark matter related experiments. The good statistics of cosmic muon counts could be obtained if data taking is done for a long time ($\sim$ the period of one month) for each zenith angle (θ) in the underground at JUSL laboratory.

References

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