Study of angular distribution and integrated vertical flux intensity of cosmic-ray muons at 555 meter depth using JUSL facility

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Introduction

In the present work, the angular distribution of cosmic-ray muons has been measured and the integrated vertical flux intensity has been calculated at the 555 meter depth level (1554 m w.e.) in the Jadugoda Underground Science Laboratory (JUSL), Jharkhand. The integrated vertical flux intensity of cosmic-ray muons has been calculated by fitting the collected data of angular distribution following the $cos^3(\theta)$ distribution. The standalone Geant4 code has been modified to augment the rock overburden for JUSL. The cosmic-ray muons incident on the rock are generated through PYTHIA8 event generator by simulating the Extensive Air Shower (EAS) from the atmosphere. This rock overburden assessment quantifies the background radiation for the sensitive experiment such as 'dark matter search', as the rock attenuates the muon flux. Although the primary cosmic rays are more or less isotropic, but the cosmic-ray muon flux strongly varies in the decreasing manner with the increasing of the zenith angles (θ), as depicted by the expression:

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

where $I_\mu(0)$ is the integrated vertical cosmic-ray muon flux intensity, and n is an exponent. The muon flux at underground decreases drastically with respect to the surface as the zenith angle increases since the rock density is much higher than that of air. At the JUSL, the measured vertical flux intensity of cosmic-ray muons ($I_\mu(0)$) are $5.02 \pm 0.8\,(\text{stat}) \pm 0.31\,(\text{sys}) \times 10^{-3}\,\text{cm}^{-2}\,\text{sec}^{-1}\,\text{sr}^{-1}$ at the surface (Jadugoda) and $2.79 \pm 0.13\,(\text{stat}) \pm 0.20\,(\text{sys}) \times 10^{-7}\,\text{cm}^{-2}\,\text{sec}^{-1}\,\text{sr}^{-1}$ at the underground respectively [1, 2]. This vertical flux intensity at the underground is four orders of magnitude lower than that at the surface.

Experimental Setup

The detection system comprises of two plastic scintillator tiles where Silicon Photomultipliers (SiPM) are coupled with it [3]. The output signals from the SiPM are fed to the Coincidence Module, which provides us the two-fold coincidence counts of the cosmic-ray muons passing through the two tiles. The telescope Mechanics is used for changing the zenith angles (θ) with precision of 1^0 during the experiment.

Geant4 Simulation

The rock overburden for JUSL underground lab has been simulated using augmented Geant4 software package to find the attenuation of muons due to rock while reaching the underground lab. The rock has been simulated, resembling the composition of typical Basalt rock along with the percentages of different elements such as Silicon (2%), Oxygen (50%), Aluminium (8%), Iron (7%), Calcium (5%), Magnesium (5%), Sodium (3%) and Titanium (2%) respectively. The rock density has been set as 2.8 g/cm^3 [2], and the illustration of cosmic-ray muons incident on the rock overburden is shown in FIG. 1. The red track represents a muon, and the green tracks are photons produced by electromagnetic processes.

Results

In FIG. 2, the simulated cosmic-ray muon counts as function of zenith angles (θ) obtained at the underground from the Geant4

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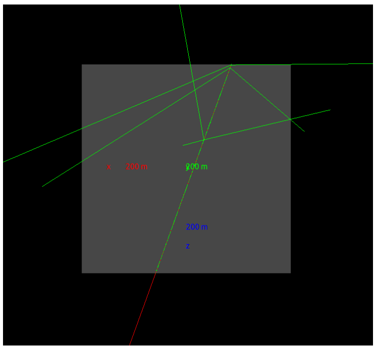

FIG. 1: Geant4 illustration of a muon passing through the rock overburden.

package where inclusion of rock overburden is present. This data is fitted against the $cos^n(\theta)$ distribution to obtain the value of $n = 1.823$. The value of the integrated vertical flux intensity $(I_\mu(0))$ of cosmic-ray muons from the simulation is found $9.295 \times 10^{-6}\ cm^{-2}s^{-1}sr^{-1}$. The experimental data was collected at JUSL

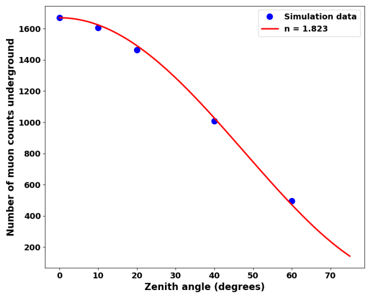

FIG. 2: Evaluation of integrated vertical flux intensity $(I_\mu(0))$ and the exponent n from Geant4 simulation including rock overburden.

underground laboratory using the coincidence counts from two scintillator tiles. FIG. 3 shows the collected experimental data for two-fold coincidence vs. zenith angles (θ) in JUSL and this data is fitted with $cos^n(\theta)$ distribution to obtain the value of exponent n = 1.755 also. The value of the integrated vertical flux intensity $(I_\mu(0))$ is found to be $1 \times 10^{-6}\ cm^{-2}s^{-1}sr^{-1}$. 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

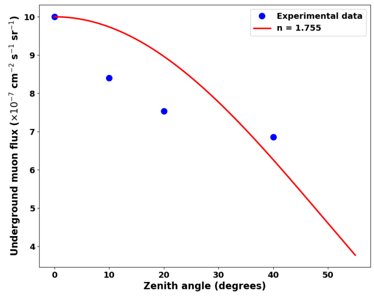

FIG. 3: Evaluation of integrated vertical flux intensity $(I_\mu(0))$ and the exponent n from JUSL experimental data with two-fold coincidence.

exponent n. The study of underground flux of cosmic-ray muons is necessary as a background study for the ongoing direct 'dark matter search experiment' [4]. It can be appraised that the data from the ongoing experiment with the three plastic scintillators where SiPM are embedded with it at JUSL, will provide us more improved results for the angular distribution of cosmic-ray muons.

References

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