Angular distributions of atmospheric cosmic muons at the Earth: A study with Pythia8 and CORSIKA

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INTRODUCTION

Muons observed at the surface of the earth and underground sites are mainly produced in the decay of pions and kaons which are generated due to the interaction of primary cosmic-rays, with the Earth's atmosphere at altitudes, typically of the order of 15 km. At the sea level muons are the most abundant charged particles in cosmic rays, reaching the ground with an average energy of approximately 4 GeV. The primary cosmic rays are more or less isotropic but the observed cosmic muon angular distribution at various altitudes and latitudes follows the expression $I(\theta) = I(\theta^0)cos^n(\theta)$, where $I(\theta^0)$ is the integrated vertical muon flux intensity, and n is an exponent [1]. The value of exponent n and the integrated vertical flux intensity $I(\theta^0)$ depends on several factors like; latitude, altitude and momentum cut off.

ANGULAR DISTRIBUTION OF COSMIC MUONS

Cosmic ray flux is more or less symmetric but the muons reaching the ground have an angular distribution of flux. The intensity of the atmospheric muons is related to the zenith angle by the relation;

$$I(\theta) = I(\theta^0)cos^n(\theta)$$

The exponent n lies around a value of 2 for the measurements conducted on the ground.
Atmospheric muons lose their energy through ionization at a fairly constant rate of about 2 MeV per g/cm^2. Here the variation is measured in terms of interaction depth X, with units g/cm^2, and is given by:

$$X = \int \rho \, dh$$

where ρ and h are air density and altitude respectively.

RESULTS: PYTHIA8 & CORSIKA

It is possible to simulate cosmic ray cascades using PYTHIA8 event generator along with standalone CORSIKA shower generator. Hence we can model the primary cosmic ray collisions, as well as subsequent secondary particle production and their collisions. We have augmented the PYTHIA8 code for the constituents of atmosphere adding Oxygen (22%) with the 78% Nitrogen which is close to the actual composition of atmosphere. We simulated 100 events of high-energy cosmic ray interactions taking the components of earth's atmosphere, and calculated the flux of cosmic muons at the surface of earth in different zenith angles (θ). Top of the atmosphere is taken as an altitude of 100 km (Karman Line). Fitting our normalized data against the $cos^n\theta$ distribution, we found the value of exponent $n \approx 1.4 \pm 0.1(stat)$. Similarly, we simulated 100 events in CORSIKA, where we can also control various azimuthal angles, in addition to zenith angles. Thus we can study the flux of muons along different directions(North, South, East and West).

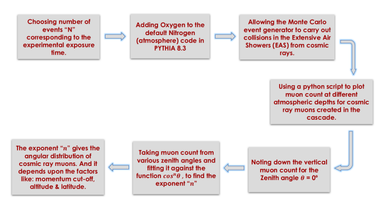

FIG. 1. Flowchart for PYTHIA8 simulation.

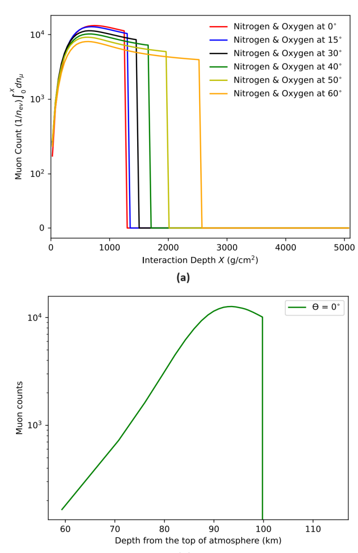

FIG. 2. The variation of cosmic muon flux as a function of interaction depth (a) and altitude from ground (b).

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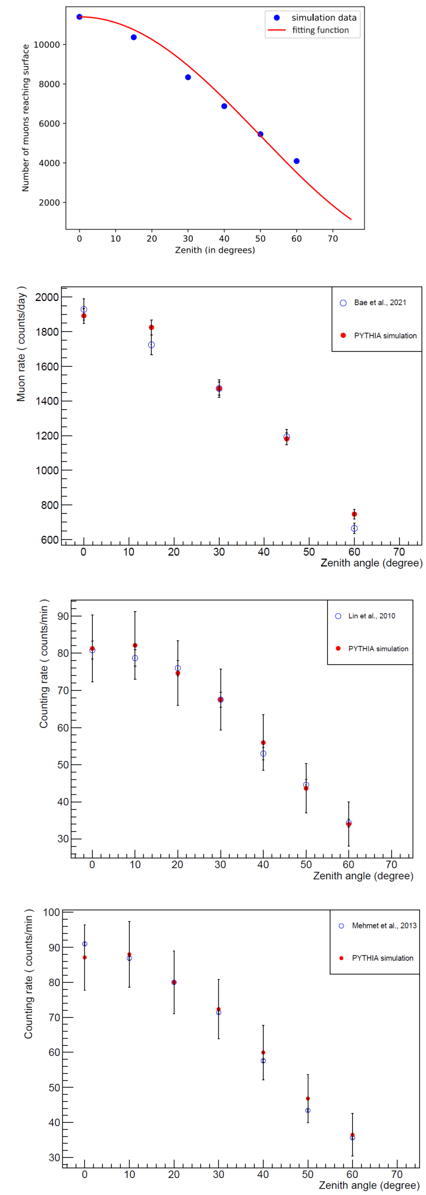

FIG. 3. Comparing PYTHIA results with experimental data.

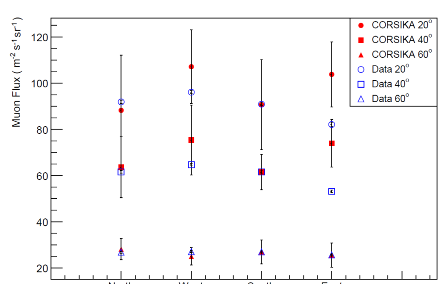

FIG. 4. Comparing CORSIKA results with experimental data.

The flowchart for PYTHIA8 simulation, the variation of cosmic muon flux in atmosphere, the comparison of PYTHIA8 results to experimental data, and the CORSIKA results are shown in figures 1, 2, 3, and 4 respectively [2–5].

SUMMARY

This paper presented a study of the angular distribution of atmospheric cosmic muons using the PYTHIA8 & CORSIKA simulation frameworks. By simulating cosmic muon production and propagation, we obtained a clear angular distribution pattern that matched well with experimental data. Thus, PYTHIA8 can be considered as a candidate for simulating cosmic ray air showers in addition to its conventional uses of simulating single particle collision events. The Future work may involve refining the simulation framework to better match the experimental results.

Also, in future studies, we will employ Geant4 to further incorporate the geometry of our detector to study muon flux at SINP (9.14 m above sea level, 22.5726^0 N, 88.3639^0 E), JUSL (115 m above sea level, $22^0 39' 21.6540''$ N and $86^0 21' 10.3752''$ E) and also at JUSL underground lab (555 meter).

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