Measurement of muon zenith angle distribution at sea level using a setup of liquid scintillator bars

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Introduction

Muons are the most abundant energetic charged particles with a mean energy of about 2 GeV at Sea level [1]. We report here the measurement of the zenith angle distribution of muons at BARC, Mumbai (19° N, 72.9° E) using setup of liquid scintillator (EJ301) bars readout from both sides.

Experimental Setup

To measure the muon flux at sea level, a setup of four liquid scintillator bars placed in the same vertical plane is used. Each detector bar is one 1.02 meter long and with cross section 4.9 cm × 5.6 cm. The gate width for the trigger was 7 ns.

Analysis

A. Position calibration

For obtaining position time relation two detectors were placed in cross geometry with respect to the other two detectors, which restricts the muon overlap region within 5.6 cm × 5.6 cm. Figure 1 shows the measured time plotted with position of muon in scintillator bar. The measured θ resolutions for 0°, 30° and 45° are 2°, 1.5° and 1° respectively.

B. Acceptance and Efficiencies

Muon events are generated using Monte Carlo method at the lower face of top detector using $\cos^2\theta$ distribution and only those events are selected which fall on the top surface of the bottom detector. The zenith angle distribution can be safely assumed as $\cos^2\theta$ for angles $< 70°$ [2]. Out of such selected events only those muons are accepted which have minimum energy deposition (corresponding to the energy cut) in both detectors. For our geometry case the value of acceptance is 0.0213 corresponding to energy deposition cut 6.88 MeV.

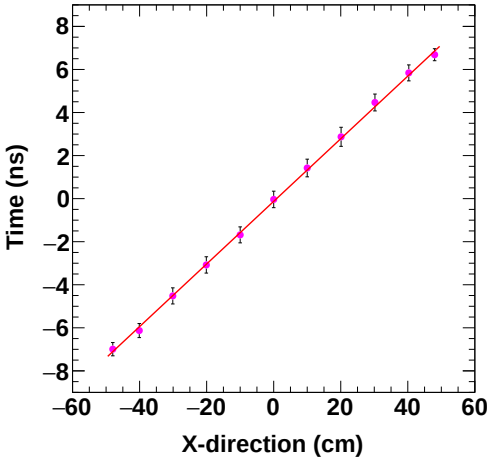

FIG. 1: Time and position relation obtained using vertical muons.

Efficiency of energy deposition in a detector was obtained using close geometry in which 4 detectors are placed each with separation of nominal distance of 3 cm. We obtained the efficiency of one of the middle detectors by using coincidence technique in other 3 detectors with stringent track quality. Efficiencies of top to bottom detectors for energy deposition cut 6.88 MeV are 0.991, 0.996, 0.998 and 0.997 respectively.

C. Track quality parameters

1. χ^2/NDF obtained by fitting a straight line to the 4 measured data points.
2. Δt is obtained using the measured time dif-

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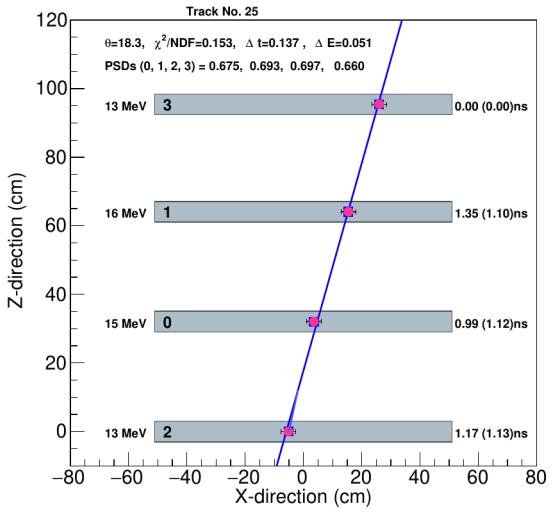

FIG. 2: A muon track reconstructed in the setup along with the track parameters explained in the text.

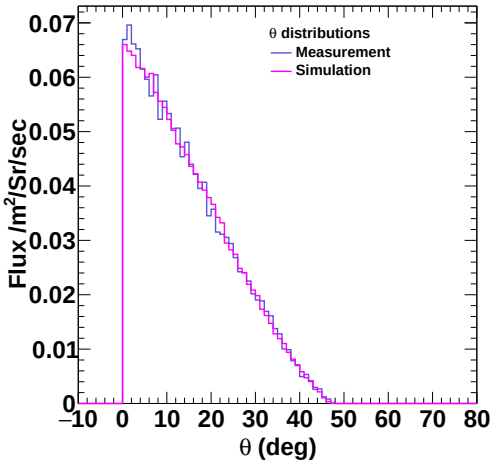

FIG. 3: Theta distribution.

ference between the two consecutive detectors scaled by expected time which is denoted by Δt_i with mean t_m

$$\Delta t = \sqrt{\frac{1}{3}\sum_{i=1}^{3}\left(\frac{\Delta t_i - t_m}{\Delta t_i}\right)^2} \qquad (1)$$

3. ΔE (dimensionless) is obtained using the energy deposition $E_i's$ in the detectors and their mean E_m as follows

$$\Delta E = \sqrt{\frac{1}{4}\sum_{i=0}^{3}\left(\frac{E_i - E_m}{E_i}\right)^2} \qquad (2)$$

Results and discussions

Figure 2 shows a muon track reconstructed in the setup along with the corresponding track quality parameters. To measure the efficiency of track quality parameter under study, the other 2 parameters and energy deposition cuts were kept stringent. Efficiency of track quality parameters are 0.988, 0.966 and 0.996 for cuts $\chi^2/\mathrm{NDF} = 4.5$, $\Delta t = 0.75$ and $\Delta E = 0.25$ respectively. Fig. 3 shows the measured and simulated $\cos^2\theta$ distribution of cosmic rays muons for $0° < \theta < 45°$. Measured theta distribution matches well with simulated theta distribution. The data for this figure corresponds to an acquisition time 113455 sec on the dates 5,6,7 and 8 July 2021.

Summary

In this work, we report the measurement of zenith angle distribution using setup of 4 liquid scintillator bars for one of the geometry. The muon track is reconstructed by measuring the positions of the muons obtained using time signal measured at the two ends of each bar. Track quality parameters are devised to reject background and obtain clean muon spectrum. We have measured the zenith angle distributions using many geometries the details of which will be presented.

References

[1] P.K.F. Grieder, Cosmic rays at earth: Researcher's refrence manual and data book, Elsevier (2001).

[2] P. Shukla and S. Sankrith, Int. J. Mod. Phys. A **33**, 1850175 (2018).