Directionality study of cosmic muons using INO-ICAL prototype detector

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As part of INO-ICAL R&D program, a prototype detector stack comprising of 12 layers of RPCs of (1 m $\times$ 1 m) in area has been running for last three years and collecting data using cosmic muon trigger. Passage of a muon through this muon telescope is obtained from position and timing informations in each layer and those are later on analysed to get zenith angle distribution of muons and also their directionality. Muon detection efficiency in these RPC detectors are $\sim 95 \pm 2\%$ with time resolution $\sim$ 1.5 ns, while operating in the avalanche mode at an applied voltage of 9.9 kV. Straight line tracks are fitted through selected muon hits (rejecting noise events) where the calibrating layer is excluded from fitting. Fit parameters are used to estimate tracking efficiencies pixel by pixel (3cm $\times$ 3cm) and position resolution. These are used to simulate muon tracks in Monte Carlo (MC) analysis considering all types of fluctuations. In MC, muon tracks are simulated assuming $dN/d\theta \sim cos^{2.15}\theta$.

Timing informations in each layer are then analysed to study the direction of incoming muons. Linear fitting of the time vs. track length is performed to study this directionality of muons. Depending up on their incoming direction, slope of time vs. track length fitting will have different signs. Pixel wise timing efficiencies, correlation among timing signals of different layers and strip wise time offset and resolution are studied and these are again used in MC study to simulate muon timing informations. Up-coming muons are defined as those coming from the Earth's surface and down-going muons are those coming from the atmosphere. A less than of 0.1% events though identified as up-going events but they are well reproduced in MC simulation with down-going muons. This study is important in view of understanding various sources of time-offsets and their effects in defining the direction of muons.

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