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Velocity measurement of cosmic muons using the India-based Neutrino Observatory prototype detector

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ABSTRACT

The India-based Neutrino Observatory (INO) collaboration is planning to set up a magnetized 50 kton iron-calorimeter with resistive plate chambers (RPC) as active detectors to study neutrino oscillations. A prototype detector stack (without magnet) comprising 12 layers of RPCs of 1 m × 1 m in area has been set-up to track cosmic ray muons. To study its capability and the feasibility of distinguishing between up-going and down-going particles, the velocity of cosmic muons recorded in this stack has been measured. The measurement procedure, calibration and results are described here.

1. Introduction

A detailed description of the INO project can be found in other articles in these proceedings [1,2]. The prototype detector stack (without the magnet) for this project has been developed at the Tata Institute of Fundamental Research (TIFR). The detector consists of 12 layers of 1 m × 1 m RPCs with 32 strips on either readout electrodes labeled as X and Y, with the strips in the X plane orthogonal to the strips in the Y plane. The width of the strips is 2.8 cm and the gap between adjacent strips is 0.2 cm. The layers are stacked on top of each other, separated by a distance of 16 cm which amounts to a total stack height of 1.76 m. Fig. 1 shows the schematic diagram of the prototype stack. The RPCs are operated in avalanche mode and the efficiency of the layers is about 95% at an operating voltage of 9.9 kV. The time resolution of the chambers is ~ 1.5 ns. An overview of the detector set-up can be found in Refs. [3,4]. A short description of the detector signal processing units and the DAQ can be found in Ref. [5] in these proceedings.

2. Measurement procedure

The measurement of the velocity of the particles involves the estimation of the path length traversed by them in the detector and the time taken for the same. The estimation of these parameters is explained in the following sections.

2.1. Data received from the DAQ

The following informations are recorded by the DAQ system:

- Strip hit information, i.e., the strip-wise hit patterns in the X and Y planes in the layers through which the particle, satisfying the trigger condition (8/12 layer coincidence) has passed through.
- Timing information, measured by a multi-hit TDC (V1190B,CAEN) with 100 ps LSB.
- Noise rate of the strips, monitored at regular intervals.

2.2. Estimation of the path length

From strip hit information, the slope and the intercept are estimated by fitting a straight line to the respective hit pattern (cf. Fig. 2).

Although the average cluster size is around 1.6 strips, there are however outliers present in the hit pattern arising mainly due to correlated electronic noise. Therefore, data reduction becomes necessary before fitting. X-side and Y-side data are fit separately. The procedure for data reduction and fitting is described below:

(i) First, layers with no hits or with multiplicity greater than 2 are rejected (as in layers 3,5,6,7 and 8 in Fig. 2(a)).
(ii) If the multiplicity is 2, the layer is rejected if the hits are away by 2 strips (as in layer 11 in Fig. 2(a)). Otherwise, the average of the two hits is taken to be the hit position (as in layers 10 and 2 in Fig. 2(a)).
(iii) The event is rejected, if the number of layers is less than 4.
(iv) If the event is accepted, a linear fit is made to the hits.

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(v) If the residual (|Fit–Hit|) is greater than 2 strips, the layer is rejected.
(vi) The event is rejected if the number of layers is now less than 4. If accepted, another linear fit is made and the results are saved.

The above procedure results in rejection of approximately 5% of the events. The overall layer rejection is $\sim 8\%$. The error for the hit position is taken as ~ 0.8 cm assuming an uniform distribution of the hits along the strip width. This is also getting reflected in the residual distribution. The reduced χ^2 distribution and the residual distribution is shown in Fig. 3.

The total path length l between the plane of the top layer and the plane of the bottom layer is given by

$$l = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \quad (1)$$

where (x_1, y_1, z_1) are the coordinates in the plane of the bottom layer and (x_2, y_2, z_2) are the coordinates in the plane of the top layer which are estimated from the linear fit. The zenith angle θ of a track is given by

$$\theta = \cos^{-1}\left(\frac{h}{l}\right) \quad (2)$$

where h is the stack height. For this calculation only events with a reduced χ^2 in the range of 0–3 for both X and Y track fits are selected. This results in a further rejection of $\sim 8-12\%$ of the existing events.

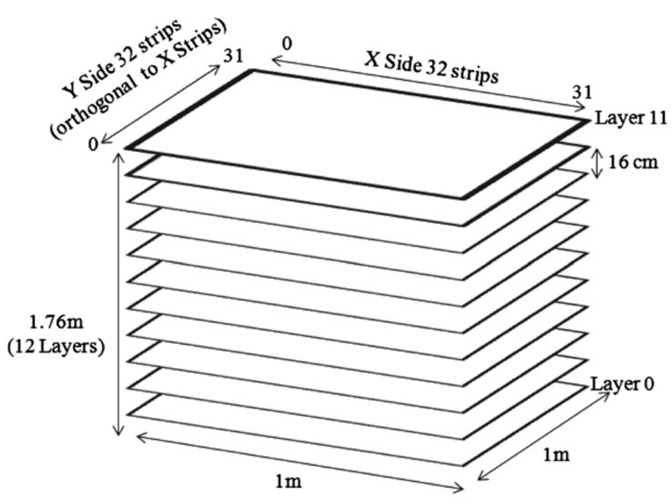

Fig. 1. Schematic diagram of the prototype stack with 12 RPCs.

2.3. Timing measurement

Before using the timing data for velocity estimation, a calibration is made so as to correct the differences in propagation delay from strip to strip due to the fact that each strip signal takes its own path to the TDC.

2.4. Time offset calibration

Since the RPCs operate in avalanche mode, the signals are amplified by pre-amplifiers with a gain factor of 80. These signals are further processed by analog front-ends (AFE) and digital front-ends (DFE) and finally reach the TDC and other measuring devices in the DAQ. In each plane (X and Y side separately), strips 0–3, 8–11, 16–19 and 24–27 are read by one AFE and strips 4–7, 12–15, 20–23 and 28–31 are read by another AFE. We have assumed that the effective contribution to the time delays come mainly from the electronics succeeding the pre-amplifier stage viz., the AFEs and the DFEs. The schematic for the time offset calibration is shown in Fig. 4. For this calibration, the bottom layer (0th Layer) is set as the reference. To calibrate the nth layer, one of the fan-out signal F_n from the pulse generator is connected to its respective AFE (AFE_n). Fan-out F_0 is connected to the AFE of the reference layer and F_t is connected to the trigger input of the TDC. If ΔC is the pulse propagation time from the pulse generator fan-out to AFE and Δt is the pulse propagation time from AFE to the respective TDC channel, then the pulse propagation time difference between the reference layer and the calibrated layer is given by

$$\Delta t = (\Delta C_n - \Delta C_0) + (\Delta t_n - \Delta t_0). \quad (3)$$

To minimize systematic errors, the fan-out channels are swapped at the AFE input and the measurement is repeated. The time

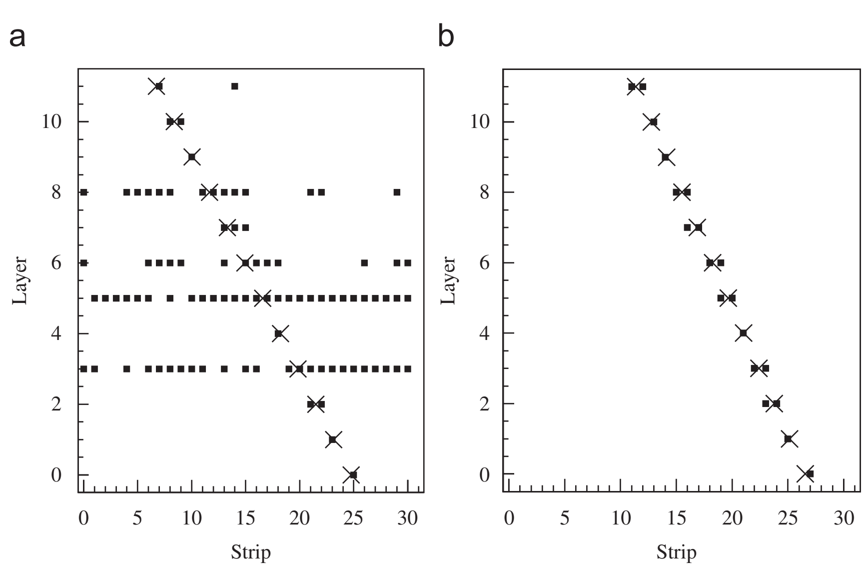

Fig. 2. (a) shows a typical noisy event and (b) shows a good event. The solid squares are the hits and the crosses are points from the straight line fit made using the algorithm discussed here.