A simulation study on the hadronic response of the INO-ICAL detector

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Introduction

The India-based Neutrino Observatory (INO) is a proposed underground neutrino laboratory with the long term goal of conducting decisive experiments in neutrino physics and also other experiments which require an underground facility. The magnetized Iron calorimeter (ICAL) detector at INO will study the oscillation pattern of atmospheric neutrinos (both down going and up-going) and will try to improve the existing bound on the oscillation parameters Δm^2_{23} and θ_{23}. Since INO-ICAL is capable of charge identification of the leptons produced in the interaction of the neutrinos with the absorber (iron plates), it may also be able to probe the neutrino mass hierarchy.

Neutrino Interaction in The Detector

INO-ICAL is most sensitive to muon neutrinos. The neutrinos undergo CC and NC interactions in the detector. QECC inteactions produce associated leptons. Deep inelastic scatering (DIS) interactions produce a number of hadrons. Resonance events produce pions. Produced muons give hits (i.e. the interaction points in the detector) that follows a distinct track, whereas hadron produces shower. the muon momentum is reconstructed using Kalman filter techniques. In case of hadrons, the energy needs to be estimated from the hit pattern.

Importance of hadronic response

The precision in reconstructing the neutrino energy (E_ν) depends on how precisely the muon energy and hadron shower energy are measured.

$$E_\nu = E_\mu + E_{had}. \qquad (1)$$

For $E_\nu > 5GeV$, a large fraction of neutrino energy is carried by the hadrons. The direction of the incident neutrino can be reconstructed from the directions of the produced muon and the hadron shower. For the hadron shower, fluctuation in energy loss is much larger than the electromagnetic process. A part of the hadron energy (approximately 20-30%) remains invisible, which worsens the energy resolution. So it is very important to study the hadronic response of INO-ICAL.

Simulation Details

The INO-ICAL detector simulated in GEANT4 package has been used. The simulation framework is in the following.

1. Neutrino event generation (using NUANCE) - Particles that result from a random interaction of a neutrino with matter using theoretical models are generated. Reaction channels, vertex information, energy and momentum of the partices are the outputs.
2. Event Simulation (GEANT4) - Propagation of the particles through the detector are simulated. The outputs are position and time informations of the particles at the interaction point, the energy deposited and the momentum information.
3. Event digitisation (GEANT4) - The detector efficiency and noise are added. The output of simulation is digitised in this step.
4. Event reconstruction (GEANT4) - Track finding and track fitting are done. The output are the energy/momentum and direction of the incident neutrino obtained from the muon and hadron data.

The analysis, plotting and fitting of the simulation output are done using ROOT. For this study, atmospheric neutrino events generated using NUANCE have been used.

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The hadron energy resolution

The hadron hit patterns in INO-ICAL follow Vavilov distribution. Average number of hits by a hadron is proportional to its initial energy. The energy resolutions are found for different neutrino interaction events (both without and with oscillation), an example of which is shown in fig.1.

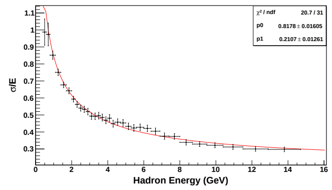


FIG. 1: The energy resolution vs energy plot for CC events without oscillation.

The energy resolutions are tabulated below.

Events	$\frac{\sigma}{E}$(No-oscillation)	$\frac{\sigma}{E}$(With-oscillation)
CC	$\sqrt{[\frac{0.818}{\sqrt{E}}]^2 + (0.211)^2}$	$\sqrt{[\frac{0.927}{\sqrt{E}}]^2 + (0.165)^2}$
All	$\sqrt{[\frac{0.831}{\sqrt{E}}]^2 + (0.029)^2}$	$\sqrt{[\frac{0.952}{\sqrt{E}}]^2 + (0.146)^2}$

TABLE I: Energy resolution for different type of neutrino events.

The shower direction resolution

The centroid of the hadron shower is formed by summing over the positions of the hits in each event.The direction vector of the centroid w.r.t. the vertex gives the reconstructed direction of the shower. The angle ($\Delta\theta$) between the reconstructed shower direction and the true shower direction is calculated. The distribution of $\Delta\theta$ is fitted using the function $f(\Delta\theta) = A * \Delta\theta \exp(-B * \Delta\theta)$.

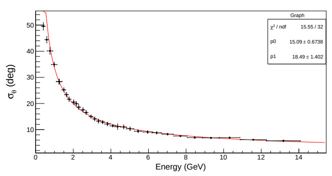


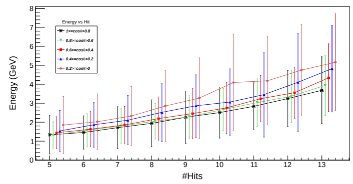
FIG. 2: Direction resolution vs energy.

We define the direction resolution σ_θ as, $\sigma_\theta = \sqrt{< (\Delta\theta)^2 > - < \Delta\theta >^2}$. Fig.2 shows the direction resolution vs energy plot. The resolution can be parametrized over the energy range by,

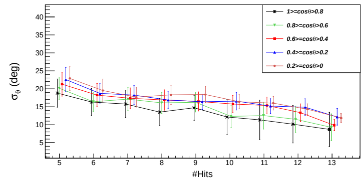
$$\sigma_\theta(deg) = \frac{15.09 \pm 0.67}{\sqrt{E}(GeV)} + \frac{18.49 \pm 1.40}{E(GeV)}. \quad (2)$$

Calibration of hadron energy and shower direction from the hit pattern

The simulated data are divided into some (reconstructed hadron direction, number of hits) bins and for each bin, calibration plots (examples are shown in fig.3) are obtained for hadron energy and direction resolution.



(a) Energy vs hit



(b) Direction Resolution vs hit

FIG. 3: The calibration plots for the $\cos\theta$ bins [1,0.8), [0.8,0.6), [0.6,0.4), [0.4,0.2), [0.2,0).

Now from the hit information of any event in INO-ICAL, we can estimate the hadron energy and shower direction using these plots.

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References

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