Introduction

The India-based Neutrino Observatory (INO) [4] – a proposed underground facility to look for atmospheric neutrinos. The magnetized iron CALorimeter (ICAL) detector at INO with its charge identification capability will study the oscillation pattern of atmospheric neutrinos. It aims to precisely measure oscillation parameters [2], probing neutrino mass hierarchy as well as new physics.

ICAL Detector Simulation – 1

Softwares used in this analysis are:
- ROOT5.32 [1], CLHEP 2.1.0.1 [4], Geant4.9.4p02 [5]
- INO-ICAL simulation group (private communication)

Method:
- **Hadron energy response:**
  - Muons being minimum ionizing particles leave long, clean, tracks in the detector. Its momentum is determined from the curvature of its track as it propagates in the magnetized detector. Its momentum is determined from the curvature of its track as it propagates in the magnetized detector. The iron layers are sandwiched between the active detector material, ICAL.
  - Whenever an atmospheric neutrino enters the detector from all zenith angles, it undergoes weak interaction with the iron and forms muon and hadrons [1].
  - Muons will pass through the RPCs and will leave the footmarks by ionizing the gas inside the RPC.
  - These signals left by muon are picked up and we reconstruct back the muon track.

ICAL Detector Simulation – 2

Magnetic field:
- Central region: Uniform magnetic field
- Side Region: Uniform magnetic field but smaller (15% less) and opposite in central region; acceptance effects are an issue.
- Peripheral Region: Changing magnetic field, smaller in magnitude but both B_z and B_y components; also acceptance effects

Hit and Track Generation [3]:
- Mean and direction of incident particles leave long, clean, tracks in the detector. Its momentum is determined from the curvature of the track as it propagates in the magnetized detector.
- aanya and 4 hits in a plane are combined in all possible ways to form a cluster.
- Clusters are combined into a single longest possible track using a Kalman filter algorithm that accounts for the local magnetic field.
- In the case of multiple tracks, the reconstructed track closest to the vertex is considered as the muon track.

Results: Momentum Resolution

- Reconstruction efficiency is the ratio of total no. of reconstructed μ or p to the total no. of incident μ or p.
- Where cuts applied are:
  - offline μ/ p (2σ in |sinθ|): 0 - 10, mNarrated-1
  - Position cut depending upon the region taken
  - 0 – 2P0, P0 is input momentum
- Cost function (for cost resolution)
- If the sign of input and reconstructed momentum are same then it is called right charge identification (R) and vice versa (L), Cost function is ratio of total no. of rightly identified μ or p to the total no. of reconstructed μ or p.
- Momentum resolution for Lp or Lμ is calculated at every energy and angle bin and is given by Momentum resolution, Rrec = aσ/Lp, where σ is the standard deviation of gaussian fitted distribution of reconstructed momentum.

Results: Efficiencies and cosθ Resolution

- Central region gives the best resolution
- For input momenta above 4 GeV, central region gives best resolution i.e., 7% whereas side region gives 14% and peripheral region gives 15%.
- Reconstruction and CID efficiencies are better in central region than side and peripheral region.
- An angle resolution of about a degree is obtained in all regions.

Summary and Conclusions:

- The ICAL detector is mainly sensitive to charged current events from interactions of atmospheric neutrinos with detector material.
- The ICAL geometry is simulated using GEANT4 software and the response to muons is studied.
- Muons form a track and its momentum is determined from the curvature of the track, when it passes the magnetised ICAL.
- Muon response in different regions studied and further muons response in different p regions studied.
- Central region gives the best resolution than peripheral and side region.
- At 3 GeV, central region gives best resolution i.e., 7% whereas side region gives 14% and peripheral region gives 15%.
- Reconstruction and CID efficiencies are better in central region than side and peripheral region.
- A good angle resolution of about a degree is obtained in all regions.

Acknowledgements

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References

[1] INO PROJECT REPORT, INO-2006/01
[6] INO-ICAL simulation group (private communication)

Fig. 1: INO-ICAL Detector

Fig. 2: Magnetic field in ICAL Detector

Fig. 3: A sample event generated in ICAL showing muon track and hadron shower.

Fig. 4: Gaussian fits to reconstructed momentum distributions for muons with fixed energy (Eμ, cosθ) = (3 GeV, 0.65) in four different bins of incident angle in the peripheral region.

Fig. 5: Resolution in peripheral region (Top left).

Fig. 6: A comparison of reconstruction (L) and CID efficiency (R) of central, peripheral, side region as a function of input momentum Pμ for the different values of cosθ = 0.45, 0.65, 0.85.

Fig. 7: Gauss fitted Cosθ for cosθ = 0.65 in the peripheral region (L). Cosθ resolution as a function of input momentum Pμ in the peripheral region. (Cosθ resolution is almost same in all the regions)

Fig. 8: Resolution in different regions: II>IV>I>III (muons go out of detector from III)