A STUDY OF MUON RESPONSE IN THE INO-ICAL DETECTOR

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Introduction

The India-based Neutrino Observatory (INO) [1] - 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 at precise measurement of oscillation parameters [2], probing neutrino mass hierarchy as well as new physics

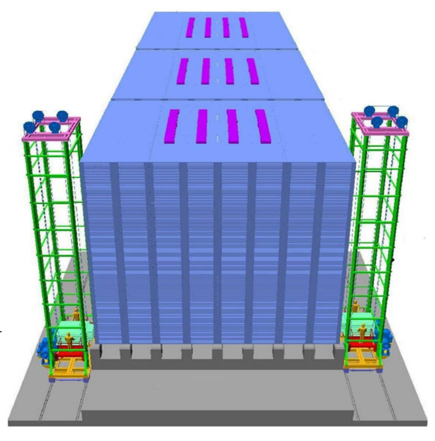

Fig 1: INO-ICAL Detector

ICAL (passive component)	
- No. of modules	3
- Module dimension	16m x 16m x 14.4m
- Detector dimension	48m x 16m x 14.4m
- No. of layers	150
- Iron plate thickness	~ 5.6 cm
- Gap for RPC trays	4 cm
- Magnetic field	1.3 T
RPC (active component)	
- RPC unit dimension	1.84 m x 1.84 m x 24 mm
- Read out strip width	3 cm
- No. of RPC units/Road/Layer	8
- No. of Roads/Layer/Module	8
- No. of RPC units/Layer	192
- Total no. of RPC units	~28800
- No. of electronic readout channels	3.6864 x 10^6

ICAL detector specifications

ICAL Detector Simulation – 1

Softwares used in this analysis are:
ROOT5.32 [3], CLHEP 2.1.0.1 [4], Geant4.9.4p02 [5], inoical0_20112011 [6]

Method:
- Curvature Method: The iron layers are sandwiched between the active detector material i.e., RPCs
- Whenever an atmospheric neutrino enters the detector from all zenith angles, will undergo weak interaction with the iron and forms muon and hadron [7]
- Muon 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 to central region; acceptance effects are an issue
- Peripheral Region: Changing magnetic field, smaller in magnitude but both B_x and B_y components; also acceptance effects

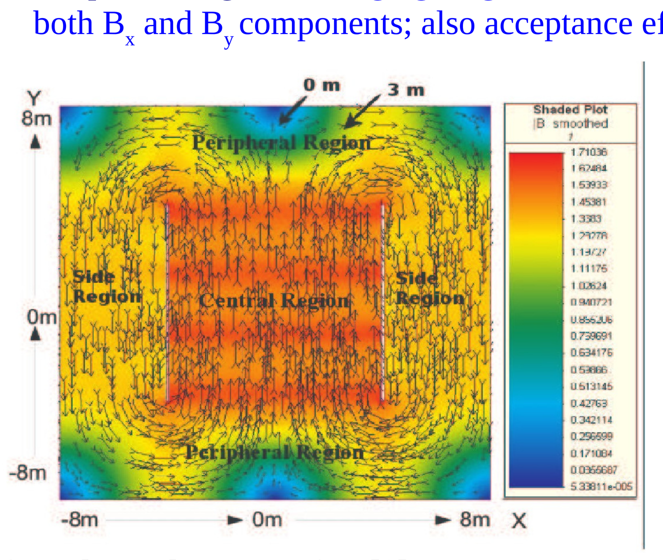

Fig 2: Magnetic field in ICAL Detector

Hit and Track Generation [8]:
- 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
- x and y 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

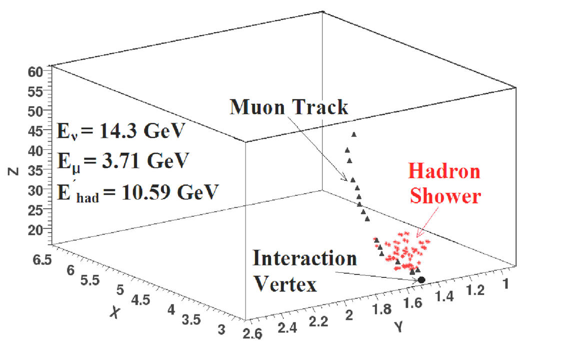

Fig 3: A sample event generated in ICAL showing muon track and hadron shower

Definitions:
- Reconstruction efficiency is the ratio of total no. of reconstructed μ^- or μ^+ (with cuts) to the total no. of incident μ^- or μ^+
- Where cuts applied are:
  - nhits>0, $\chi^2/(2*\text{nhits[0]}-5) < 10$, ntrkt==1
  - Position cut depending upon the region taken
  - 0 - 2P_{in} (P_{in} is input momentum)
  - Cosθ ± 0.15 (for cosθ resolution)
- If the sign of input and reconstructed momentum are same then it is called right charge identification (CID). Hence, CID efficiency is ratio of total no. of rightly identified μ^- or μ^+ to the total no. of reconstructed μ^- or μ^+
- Momentum resolution for μ^- is calculated at every energy and angle bin and is given by: Momentum resolution; $R_{mom} = \sigma/E$,
  (where σ is the standard deviation of gaussian fitted distribution of reconstructed momentum)

Results: Momentum Resolution

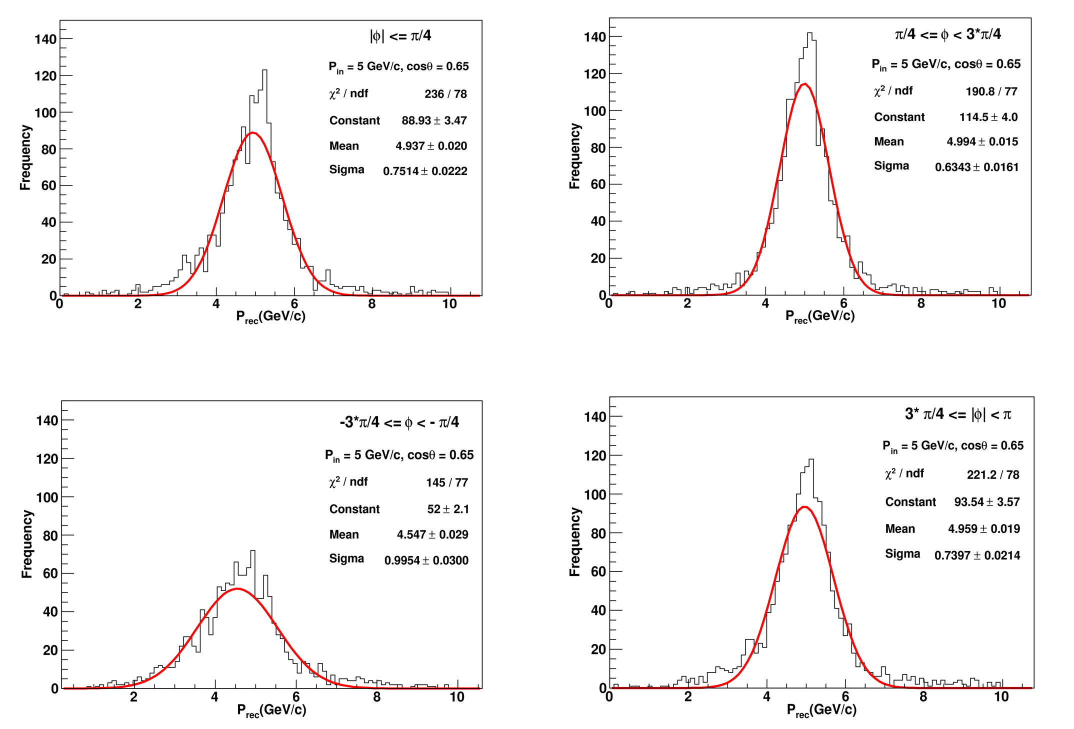

Fig. 4: Gaussian fits to reconstructed momentum distribution for muons with fixed energy (P_{in}, cosθ) = (5 GeV/c, 0.65) in four different bins of azimuthal angle in the peripheral region

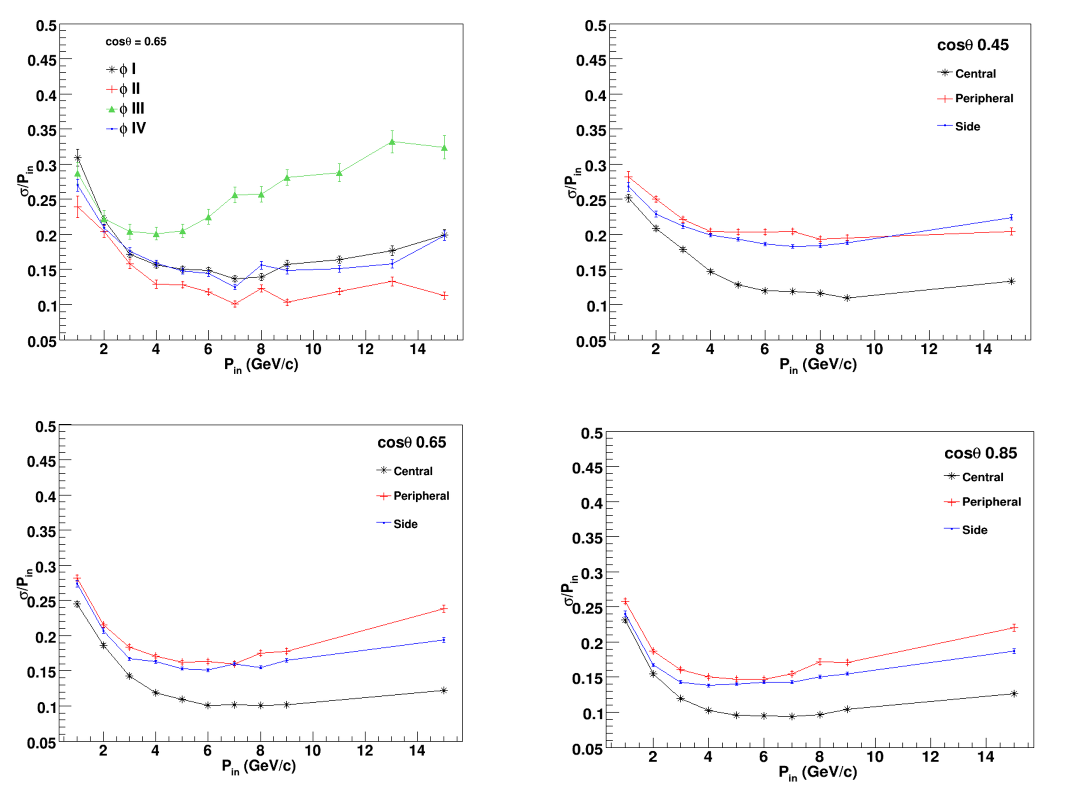

Fig. 5: Resolution in peripheral region (Top left).
A comparison of resolution in central, peripheral, side region as a function of input momentum P_{in} for the different values of cosθ = 0.45, 0.65, 0.85

Results: Efficiencies and cosθ Resolution

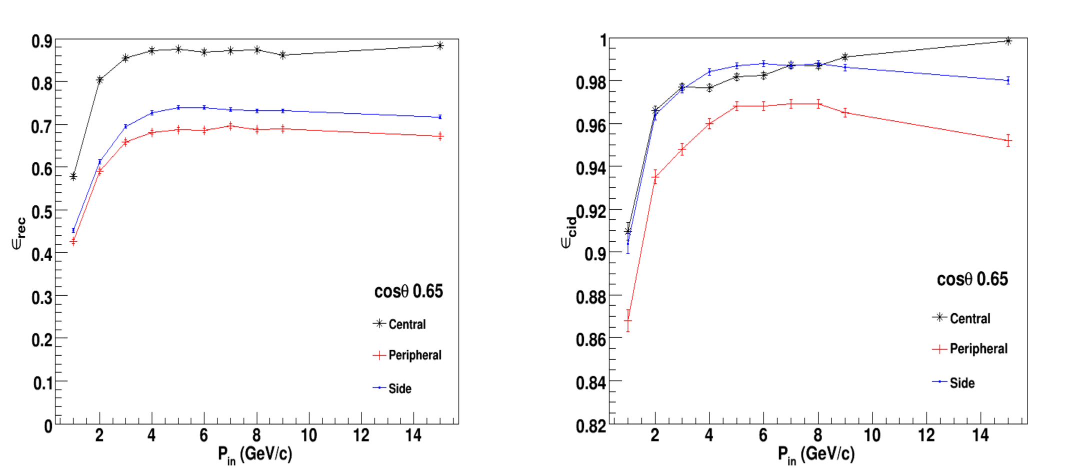

Fig. 6: A comparison of reconstruction (L) and CID efficiency (R) of central, peripheral, side region as a function of input momentum P_{in} for cosθ = 0.65

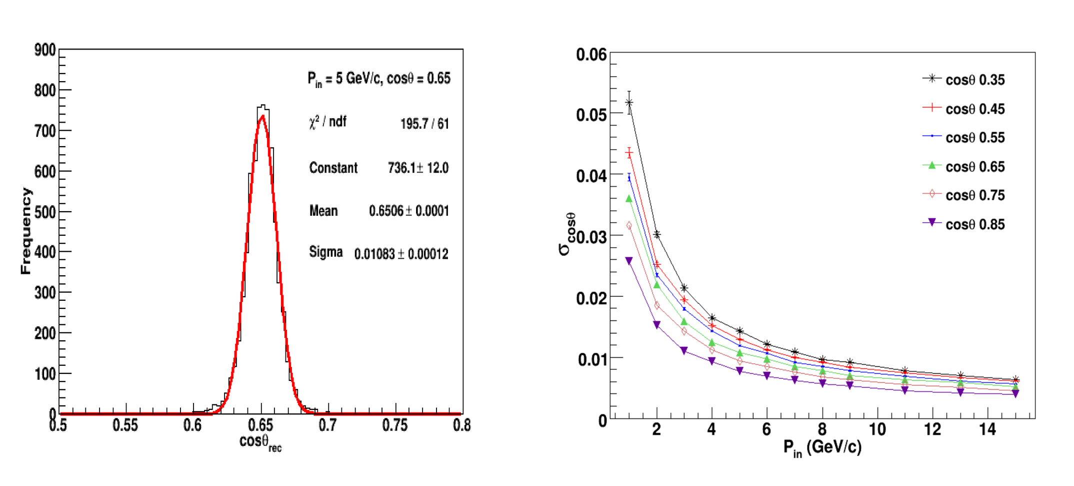

Fig. 7: Gauss fitted $\text{Cos}\theta_{rec}$ for $\cos\theta_{in}$ = 0.65 in the peripheral region (L).
Cosθ resolution as a function of input momentum P_{in} in the peripheral region.
(Cosθ resolution is almost same in all the regions)

Observations:
- Reconstructed momentum fitted with Gauss function in four different bins
- Resolution in different regions : II>IV>I>III (muons go out of detector from III)
- Central region gives the best resolution
- At horizontal angles and low energy, side region gives better resolution than peripheral region, at high energy peripheral region gives better resolution due to the presence of both magnetic field components B_x and B_y, which allow it to trasverse more iron layers
- At vertical angles, side region is always better then peripheral. As peripheral region has changing magnetic field giving worse resolution than side region
- At 6 GeV/c, cosθ = 0.85, central region gives best resolution i.e., 9% whereas side region gives 14% and peripheral region gives 15%
- Reconstruction and CID efficiencies are better in central region than side and peripheral region
- For input momenta upto 8 GeV/c, central and side region CID efficiencies are comparable
- Cosθ resolution is best in ICAL and is around 1° for all the 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 are 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 φ regions studied
- Central region gives the best resolution than peripheral and side region
- At 6 GeV/c, cosθ = 0.85, central region gives best resolution i.e., 9% 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 angular resolution of about a degree is obtained in all regions

References

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Acknowledgements

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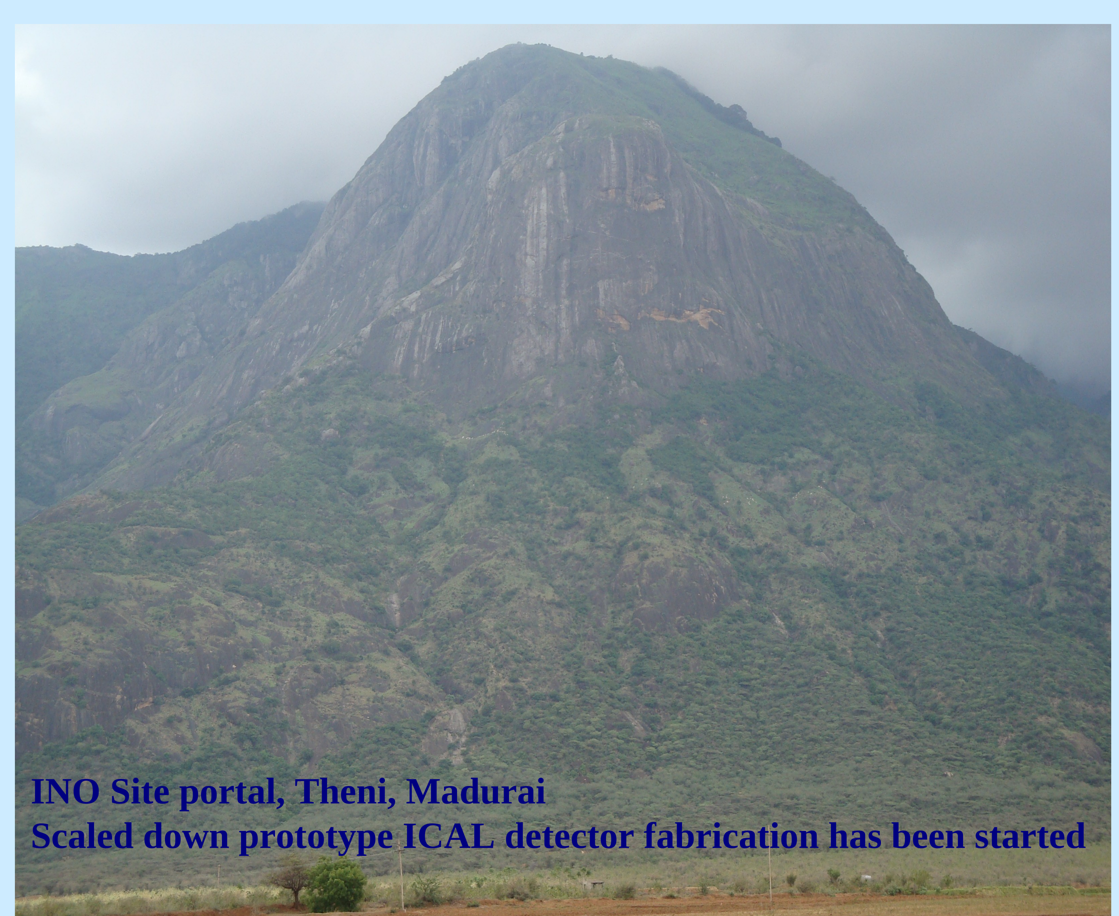

INO Site portal, Theni, Madurai
Scaled down prototype ICAL detector fabrication has been started