STUDY OF MUON RESOLUTION IN THE INO-ICAL DETECTOR

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1. 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, probing neutrino mass hierarchy as well as new physics

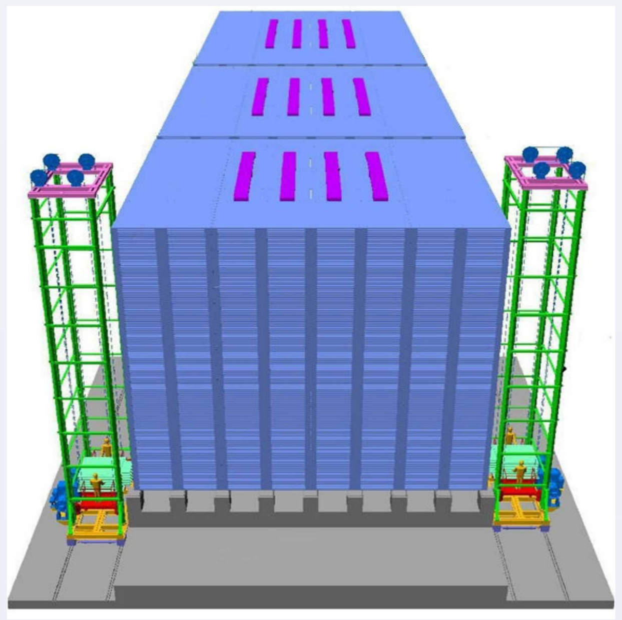

Fig 1: INO-ICAL Detector

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	4.0 cm
- Magnetic field	1.3 T
RPC (active component)	
- RPC unit dimension	1.84m x 1.84m x 24mm
- 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	3.6864×10^6

ICAL detector specifications

2. Neutrino Interactions

The different processes [2] are:

- Quasi-Elastic Charge Current (QECC) interactions: produces the associated leptons
- Deep Inelastic Scattering (DIS) interactions: produces associated leptons and hadrons
- Resonance Interactions (RI): produces single pion events

ICAL is most sensitive to muon neutrinos. Muon gives distinct track, and hadron produces shower
Hence, the neutrino energy is given by:

$$E_\nu = E_{muons} + E_{hadrons} \quad \text{(i)}$$

3. Method of Analysis

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
- 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

4. Inputs Used

Softwares used in this analysis are:

- ROOT5.32 [3]: stores the output
- CLHEP 2.1.0.1 [4]: Class libraries for High Energy Physics
- Geant4.9.4p02 [5]: a toolkit for the simulation of passage of particles
- inoical0_20112011 [6]: contains all the information of the INO-ICAL detector, the types of interactions that occurs and an inhomogeneous magnetic field

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Simulation Input

μ^- events generated	10000
Energy range (without smearing)	1 - 25 GeV
cosθ of μ^- (without smearing) θ is zenith angle	0.95, 0.85, 0.65, 0.45, 0.25
Azimuthal angle φ (smeared)	0 - 2π
Vertex taken (where magnetic field is non-uniform) (with smearing)	(0,600,0) cm with smearing of (800,100,600) cm
Selection criteria	- $P_{in} \pm 3*\sigma$, nhits[0]>0, $\chi^2/(2*nhits[0]-5) < 10$, ntrkt[0]>0 - 0 - $2P_{in}$ (P_{in} is input momentum) - Cosθ ± 0.15

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^+
- If the sign of input particle and reconstructed momentum are same then it is called right charge identification (Cid)
- 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; Rmom = σ/E, (where σ is the standard deviation of gaussian fitted distribution of abs(trkmm[0])), where 0th element represents muon and E is the corresponding energy
Fig. 2, 3, 4, 5 shows μ^- momentum resolution, reconstruction and Cid efficiencies, cosθ resolution respectively with E = 1 - 25 GeV and cosθ = 0.95, 0.85, 0.65, 0.45, 0.25

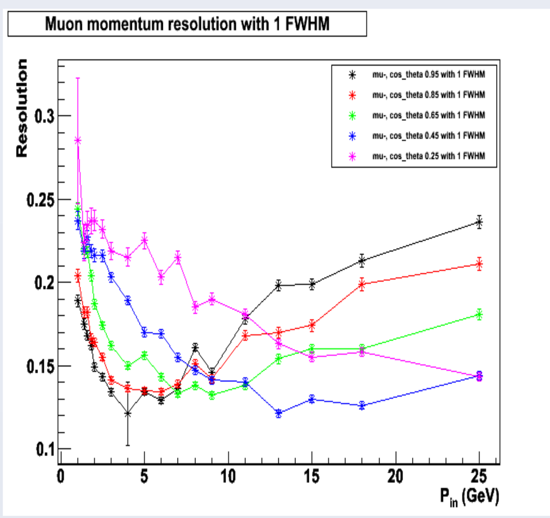

Fig 2. μ^- momentum resolution

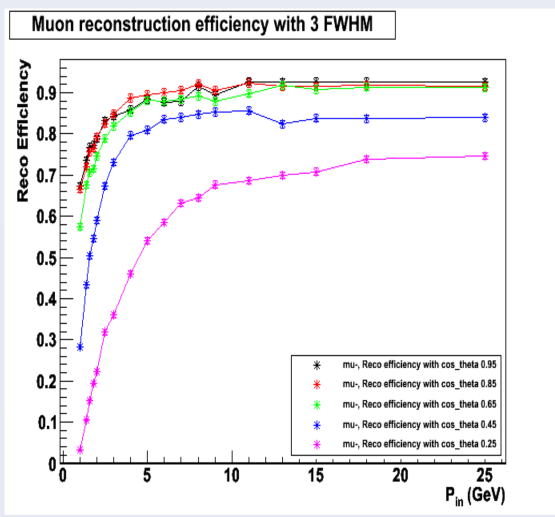

Fig 3. μ^- Reconstruction efficiency

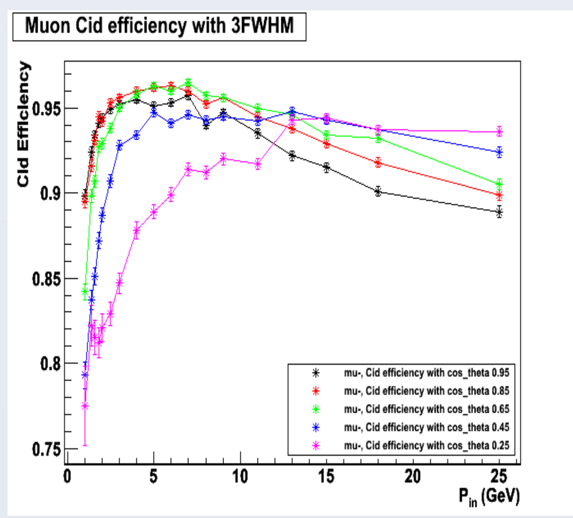

Fig 4. μ^- Cid efficiency

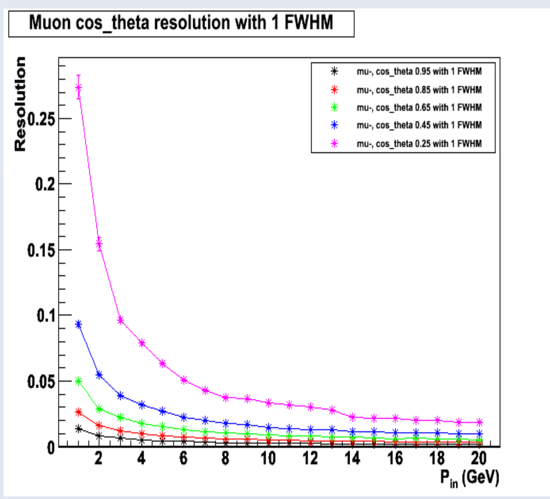

Fig 5. μ^- cosθ resolution

Energy range(GeV)	Resolution R_{mom} % (E,Cosθ)	Reco Efficiency % (E,Cosθ)	Cid Efficiency % (E,Cosθ)	Cosθ resolution %(E,Cosθ)
0-5	12(4, 0.95)	86(4,0.95)	96(4,0.85)	1(4,0.95)
5-10	13(9,0.65)	92(8,0.85)	96(9,0.65)	0.5(9,0.95)
10-15	12(13,0.45)	91(14,0.95)	95(13,0.45)	0.5(14,0.95)
15-20	13(18,0.45)	91(19,0.95)	95(15,0.25)	0.5(19,0.95)
20-25	14(25,0.45)	91(25,0.95)	94(25,0.25)	--

Table for maximum values of resolutions and efficiencies

7. Conclusions

- INO-ICAL: An Experiment to understand fundamental issues regarding the nature and interactions of neutrinos, determining the neutrino energy will be essential to accomplish the physics goals of the INO-ICAL experiment
- Both the hadron and muon energy is needed to reconstruct the neutrino energy
- Presented study, shows that the momentum/energy resolution of muon is found to be maximum at 12% with E = 4 GeV, cosθ = 0.95 and is better at lower angles. Reconstruction and Cid efficiency is found to be better at lower angles
- These resolutions and efficiencies will be used to calculate oscillation parameters with up-muons (muons generated from interaction of atmospheric neutrinos with rock material surrounding the detector)

References

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[6] INO-ICAL simulation group (private communication)

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