Hadron Energy Resolution and Physics Analysis for INO-ICAL Detector

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Introduction

To explore the properties of neutrino, a large dimension massive magnetised Iron Calorimeter (ICAL) detector is proposed for India based Neutrino Observatory (INO). Determination of neutrino mass and mixing parameters is one of the important open challenge in today's physics. The ICAL detector is designed to address some of these problems. The detector will have a modular structure of total size 48m x 16m x 14.5m and consists of stack of 151 horizontal layers of 5.6 cm thick iron slab interleaved within 4 cm gap for the active detector element. Glass Resistive Plate Chambers (RPCs) of dimension 2m x 2m will be used as active part of the detector. The readout of the RPC's is through the external orthogonal copper pick up strips. This type of detector has good time resolution (1ns) and spatial resolution.
We present here our ongoing simulation studies and results on hadron energy resolution and preliminary results on two and three flavour neutrino physics analysis for INO-ICAL detector.

1. Hadron Energy Resolution

Atmospheric neutrinos interaction with detector produces associated leptons and hadronic shower. In order to get back the neutrino parameters we need to reconstruct the muons and hadrons.
Simulation study has been carried out for finding the hadron energy resolution of INO-ICAL detector with the help of GEANT based simulation code. Analysis has been done for Monte Carlo and NUANCE (Neutrino Generator) events generated for different direction and energy ranges. Hit distribution for various energy and angle bin has been obtained and fitted with Vavilov distribution function and found that hadron energy calibration is proportional to the number of hits in an event.An example of the fit can be seen in figure1. Resolution of the detector based on this proportionality behavior has been obtained and different fitting function has been applied to know the behavior of resolution as a function of energy.
The energy resolution is defined as

$$\frac{\delta E}{E} = \frac{\sigma}{E} \qquad (1)$$

the energy resolution $\frac{\sigma}{E}$ is plotted as a function of energy at varied angle bins and fitted with the functions given below

$$\frac{\sigma}{E} = \sqrt{(\frac{a_1}{\sqrt{E}})^2 + b_1^2}. \qquad (2)$$

and

$$\frac{\sigma}{E} = \frac{a_2}{\sqrt{E}} + b_2. \qquad (3)$$

Where fit parameters $a_1, b_1, a_2 and b_2$ shows the energy dependency of the resolution.

Plots and Results of Hadron energy Resolution

Resolution function for various energy and angle ranges has been calculated using the fitting parameters mentioned in section 1 for MonteCarlo and Nuance generated events. It was found that hadron energy resolution for INO-ICAL detector ranges from 40-45% for energy range 2-4 GeV for Monte Carlo fixed vertex data (fit parameters for different direction are shown in table 1) and it ranges from 70-80% for Nuance generated data in the same energy range. Resolution as function of incident particle energy for fixed vertex is shown in fig 2.

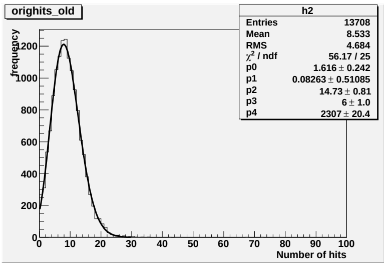

FIG. 1: Hit distribution for 2-3Gev Nuance generated pion fitted with vavilov distribution function

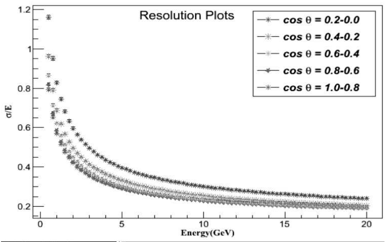

FIG. 2: Resolution curve for different angle bins for fixed vertex

Two and three flavour neutrino Analysis

Once we have the resolution functions for energy and direction, we wanted to perform the INO-ICAL physics sensitivity for oscillation parameters. It is well known from some recent experiments that neutrino oscillates and have some mass but the oscillation parameters are not measured precisely yet. The study of two and three flavour neutrino analysis with and without matter effect for INO-ICAL detector is therefore very important.

For two flavour neutrino analysis, we have studied $\nu_\mu - \nu_\tau$ oscillations using atmospheric neutrino events generated by Nuance generator and find the oscillation pattern and precisely measured the oscillation parameters.

A C++ based code has been written for two and three flavour neutrino analysis which differentiate between oscillated events and unoscillated events and hence confirm the oscillation based on oscillation survival probability in vacuum (eq4) and with matter effect. Further we calculate the minimum χ^2 for fine measurement of oscillation parameters using true neutrino events from Nuance and smeared neutrino events (which includes muon and hadron energy and angle resolution for INO-ICAL detector) for fixed and varied values of δ_{32} and θ_{23} for two generation analysis.

TABLE I: Table for the fit parameters of Monte-Carlo fixed vertex data

$\cos theta$	a_1	b_1	a_2	b_2
$1.0-0.8$	0.548 ± 0.005	0.161 ± 0.002	0.446 ± 0.007	0.098 ± 0.002
$0.8-0.6$	0.570 ± 0.005	0.141 ± 0.002	0.484 ± 0.007	0.078 ± 0.002
$0.6-0.4$	0.605 ± 0.006	0.135 ± 0.002	0.525 ± 0.008	0.070 ± 0.002
$0.4-0.2$	0.674 ± 0.006	0.137 ± 0.003	0.594 ± 0.008	0.067 ± 0.003
$0.2-0.0$	0.813 ± 0.008	0.156 ± 0.004	0.720 ± 0.012	0.074 ± 0.004

$$P_{\mu\mu} = \Bigg(1 - \sin^2 2\theta_{23} \cos^2\theta_{13} \sin^2(1.27\frac{\delta_{32}L}{E}) - \sin^4\theta_{23} \sin^2 2\theta_{13} \sin^2(1.27\frac{\delta_{32}L}{E})\Bigg) \quad (4)$$

In eq4 symbols have their usual meanings.

Conclusions

Hadron energy Resolution for INO-ICAL detector has been done using Monte Carlo and Nuance generated events for various energy and angle ranges. A detailed study on two and three generation neutrino analysis has been performed with and without resolution to confirm the oscillation and to measure the oscillation parameters very precisely.

References

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