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Simulations for the India based Neutrino Observatory (INO)

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About the INO Experiment

The India-based Neutrino Observatory(INO) is a proposed experiment designed to study neutrino oscillation parameters using atmospheric neutrinos as the source. The proposed location of the experiment is Theni in Southern India. The experimental setup consists of 150 alternate iron blocks and the Resistive Plate Chambers (RPCs) stacked vertically. The total mass of the detector is 50 kt. This setup is optimized primarily to measure the muon momentum with a high efficiency. The detector is magnetized with a field of 1.5 Tesla to identify the charge of the muons. It is also possible to calibrate the hadron energy and direction using the hadron shower hits in order to reconstruct the neutrino momentum. The primary goals of the experiment are to make precision measurement of the atmospheric oscillation parameters ($sin^2 2\theta_{23}$, $|\Delta m^2_{32}|$) and to determine the neutrino mass hierarchy.

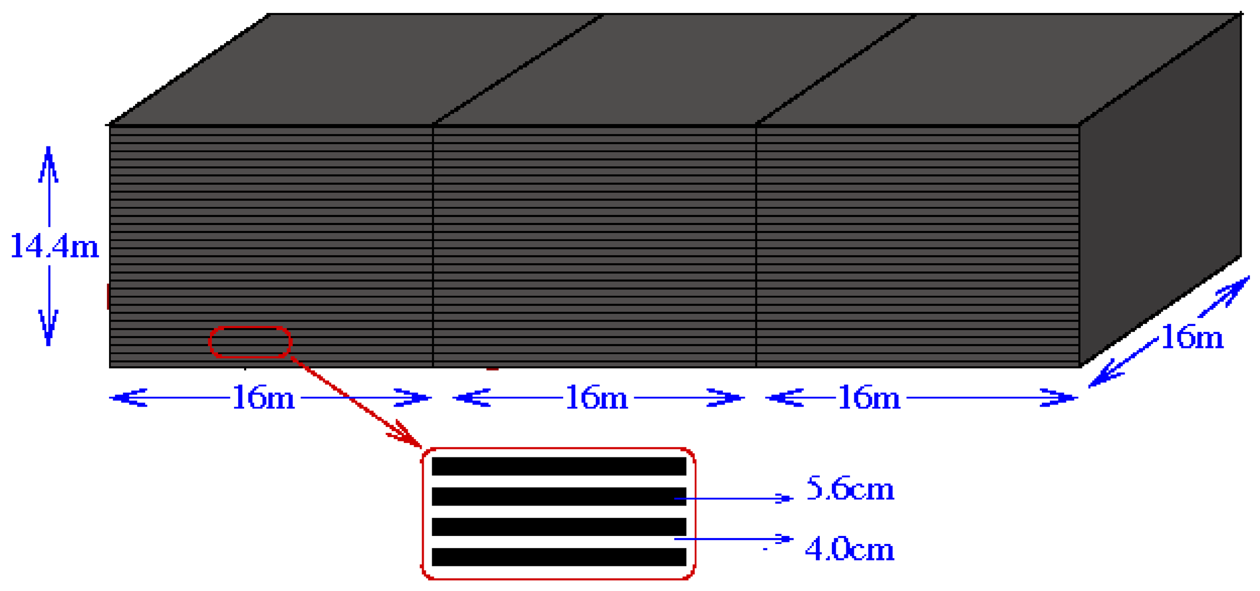

Figure: Schematic layout of the INO detector

Here we present some **PRELIMINARY** simulation results for the muon reconstruction and the sensitivity to neutrino oscillation parameters and the mass hierarchy with the muon energy and zenith angle as the observables.

Muon Reconstruction Simulation

A GEANT4 based detector simulation package for INO is used for the reconstruction of the muons. The momentum can be determined by using the curvature method or the path length method. The muon momentum is reconstructed in two steps.

1. Track Finder (the topology of the hits is analyzed to find the hits for a possible muon track.)
2. Track Fitter (Kalman filter is used to reconstruct the energy and the direction of the muon.)

The following plots show the muon energy and direction resolutions and the reconstruction and charge identification efficiencies for some directions.

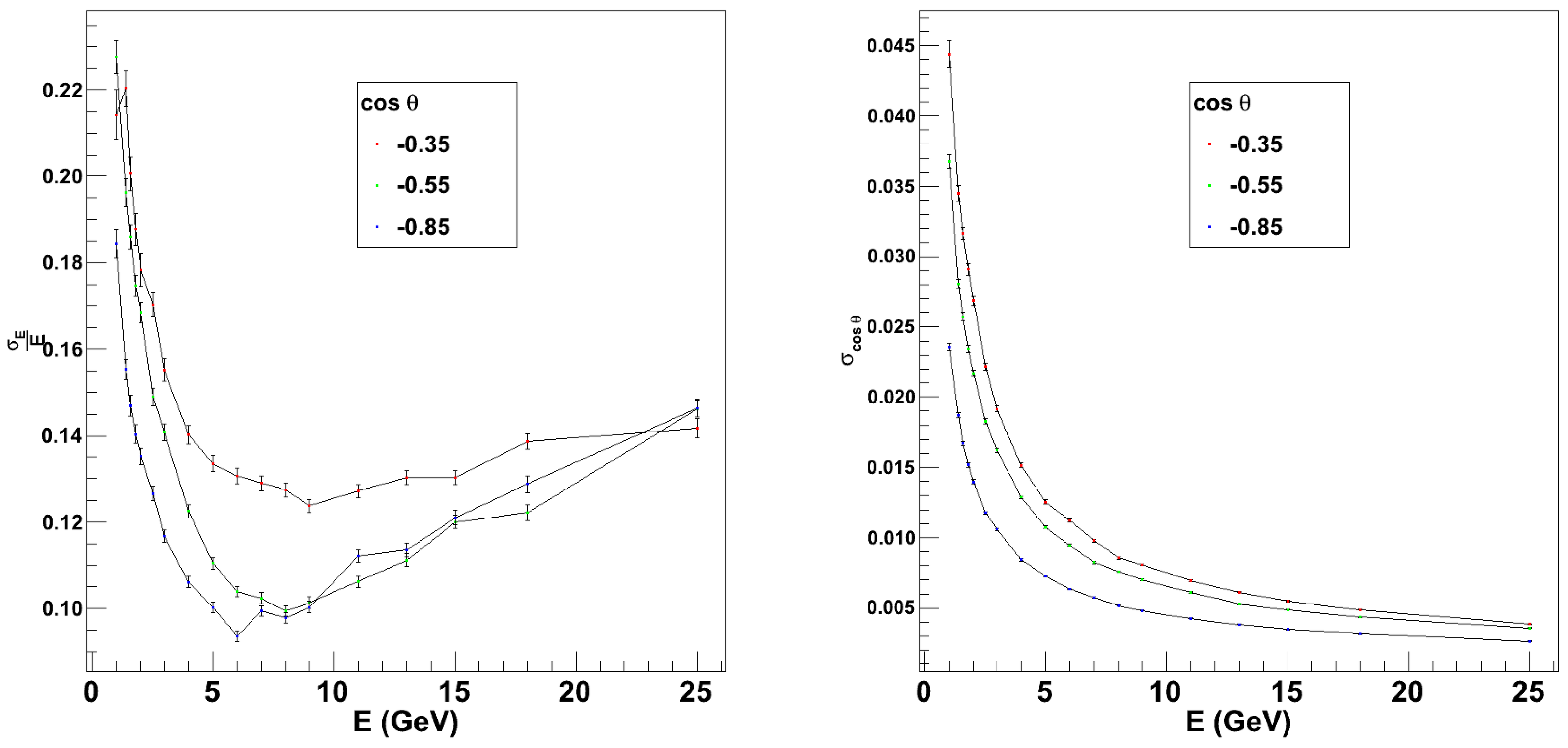

Figure: Energy and cos θ Resolutions of μ^-

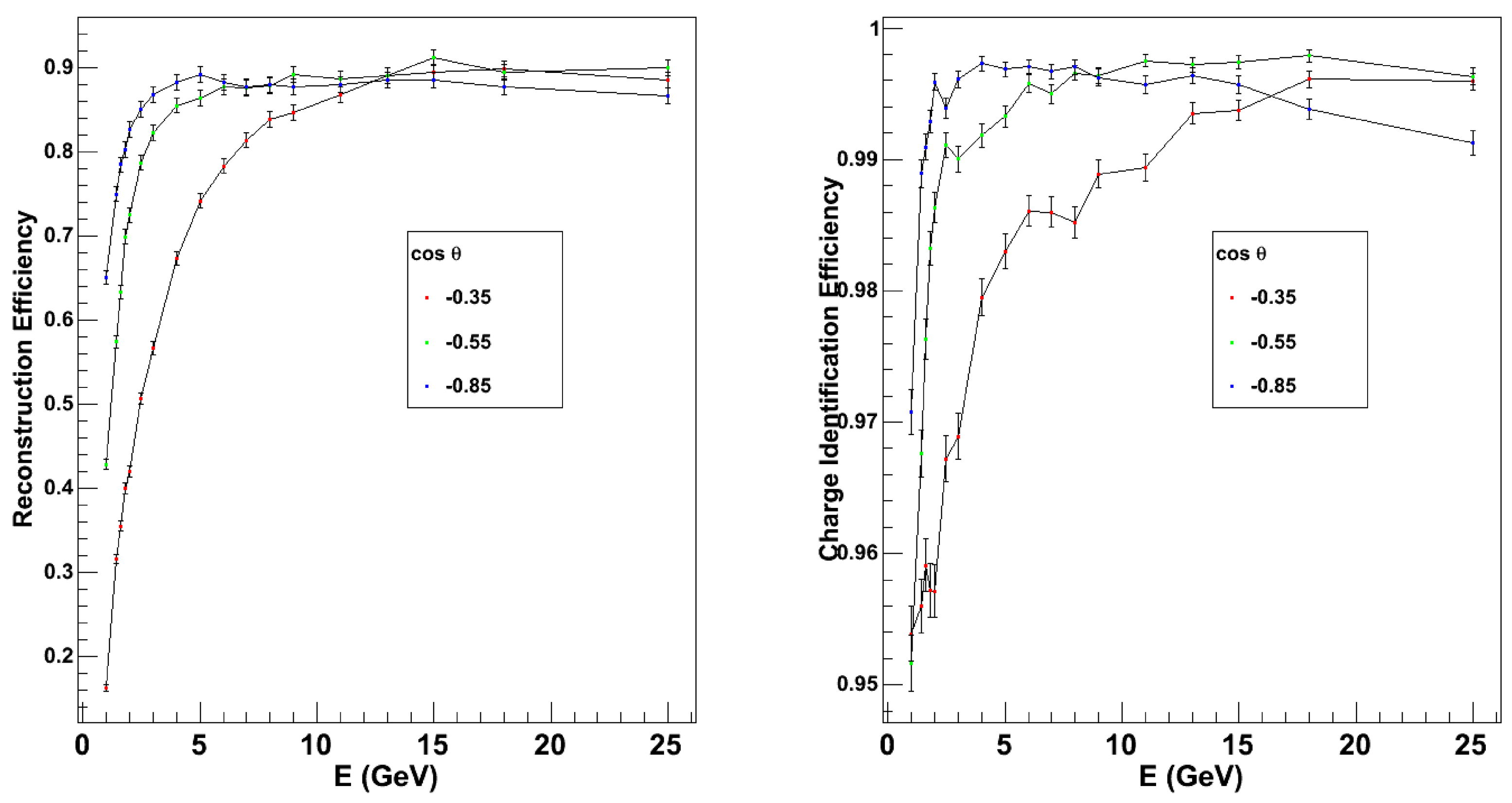

Figure: Reconstruction and Charge Identification Efficiencies of μ^-

Methodology for the Oscillation Analysis Simulation

A package written in C++ using the CERN ROOT libraries has been developed to carry out the neutrino oscillation simulations. This code can simulate the analysis using the true/reconstructed muon momentum or the neutrino momentum or the combination of the two. The present analysis is carried out using the reconstructed muon momentum as follows.

1. Unoscillated $\nu_\mu(\overline{\nu}_\mu)$ interactions are generated from the neutrino event generator NUANCE. The HONDA3D atmospheric neutrino flux at the SK location is used. A data set is generated for 50 kt $\times$ 1000 years. This data set is scaled down to the desired exposure in order to reduce the stastical fluctuations.
2. Oscillations are applied to these events using the MC accept/reject method with the 3 flavor oscillation probability with matter effects. This gives the true muon (E, cos θ) distribution. The current best fit oscillation parameters are taken with $sin^2 2\theta_{13} = 0.113$.
3. The reconstruction and charge identification efficiencies and the energy and the direction resolutions are applied to smear the events. At this stage we get the measured muon (E, cos θ) distribution.
4. A χ^2 analysis is carried out to get the precision measurement and mass hierarchy sensitivity. Systematics on the flux normalization and cross-section are considered using the method of pulls. A poisson χ^2 function is used. The muon events are binned in 10 bins in the energy range 1-10 GeV and 20 cos θ bins in the range -1 to +1.
5. For the precision measurement of the parameters ($sin^2 2\theta_{23}$,$|\Delta m^2_{32}|$), a prior on $sin^2 2\theta_{13}$ is added.
6. For the mass hierarchy sensitivity, the normal hierarchy(NH) is considered to be the true hierarchy and an inverted hierarchy(IH) is fitted. We calculate $\Delta\chi^2 = \chi^2_{IH} - \chi^2_{NH}$. Priors are added for $sin^2 2\theta_{23}$, $|\Delta m^2_{32}|$ and $sin^2 2\theta_{13}$.
7. The χ^2 function is marginalized over $sin^2 2\theta_{23}$, $|\Delta m^2_{32}|$ and $sin^2 2\theta_{13}$ and δ_{CP}.

In order to gauge the discovery potential of the experiment, we have produced the sentivity plots without the statistical fluctuations in the total number of observed events. Work is underway to make the sensitivity plots with the statistical fluctuations in the observed data.

Precision Measurement of the Parameters

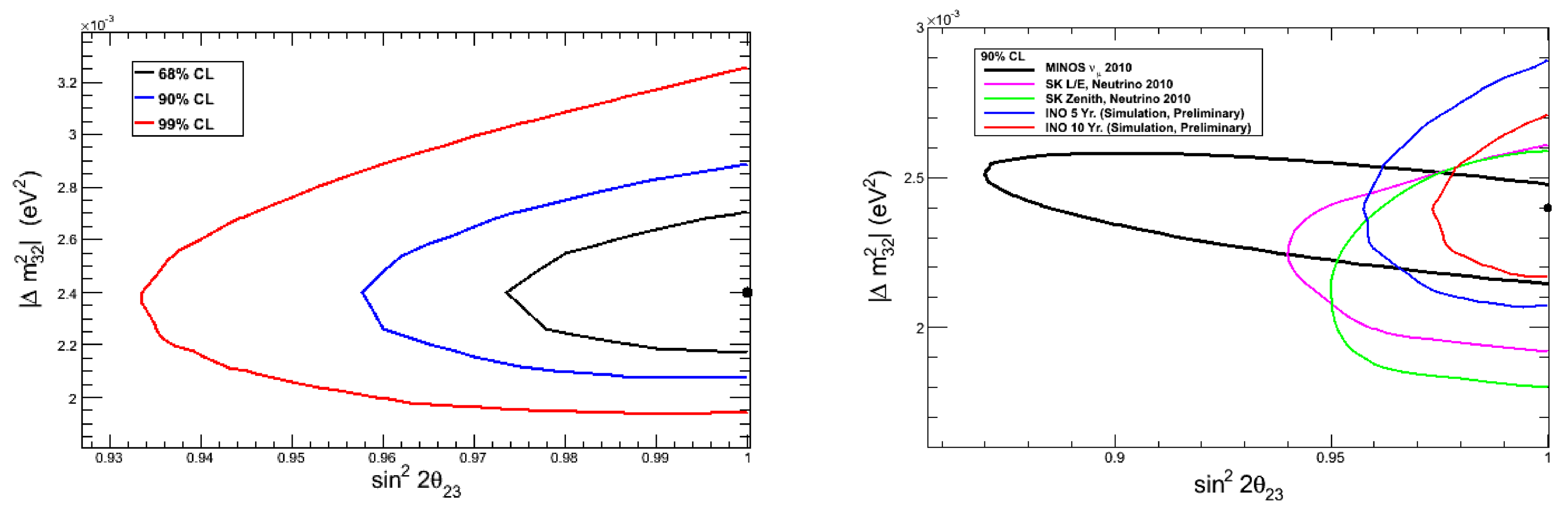

Figure: Left : χ^2 contours for INO 5 years $\times$ 50 kt exposure, Right : INO 5 and 10 year χ^2 contours compared with other experiments

Sensitivity to the Neutrino Mass Hierarchy

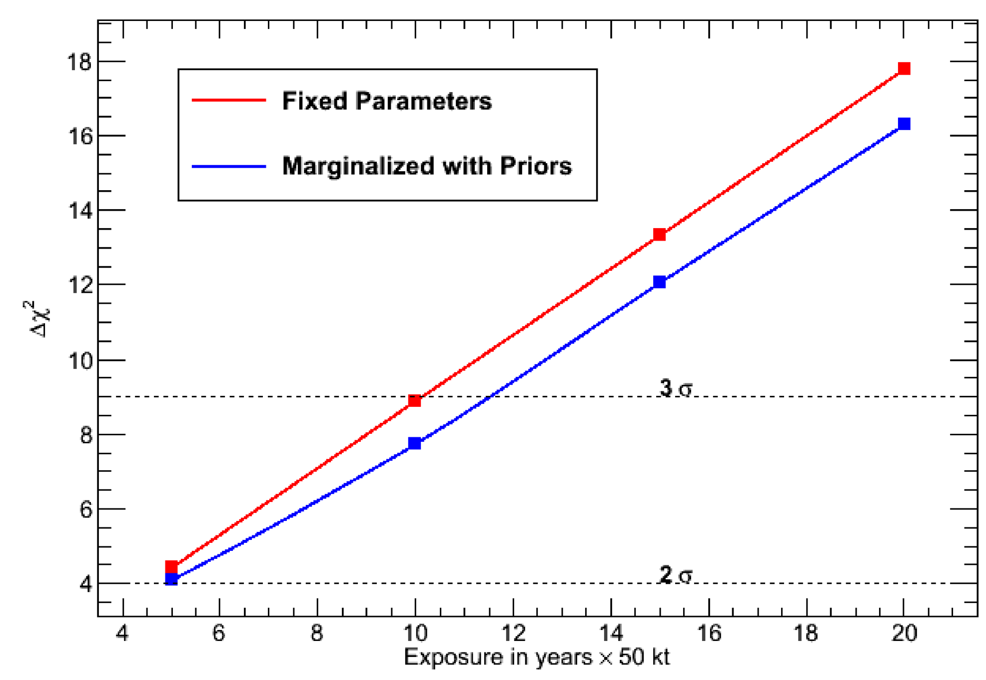

Figure: $\Delta\chi^2 = \chi^2_{IH} - \chi^2_{NH}$ for NH as the true hierarchy, $sin^2 2\theta_{13} = 0.113$, marginalized with the current prior values

We can rule out the inverted mass hierarchy with a significance $n\sigma$. ($\Delta\chi^2 = n^2$)

Acknowledgements

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[2]More information at www.ino.tifr.res.in