Impact of nuclear effects on the DUNE long-baseline oscillation analysis

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Introduction

The next generation neutrino oscillation experiments aim to measure the already measured neutrino oscillation parameters with utmost precision. At the present level of precision achieved, we need to constrain the systematic uncertainities in an attempt to make the predictions more accurate. Use of heavier nuclear targets like Argon in the detector implies a large smearing in the reconstructed neutrino energy due to the presence of nuclear effects in both the inital and final state interactions. Additionally in the energy range most sensitive to the oscillation, the nuclear smearing is maximal. Hence we must try to impose constraints on the systematic uncertainities arising due to nuclear effects. Therefore, in our work we study the impact of this nuclear smearing on the oscillation analysis and possible ways to reduce the corresponding systematic uncertainties. The systematic uncertainities are constrained using the novel concept of DUNE PRISM which helps in the prediction of events with minimal cross section model dependence and using GiBUU which helps in imposing constraints on nuclear effects.

DUNE-ND PRISM

As long-baseline neutrino experiments move into the high precision era, one of the most difficult challenges will be to control systematic uncertainties due to neutrino interaction modeling. Detector effects like cross-sectional uncertainities and flux cannot be factorised. The goal of DUNE PRISM[1] is to use the flux model to predict the far detector event rates with minimal cross section model dependence. This can be achieved by collecting data at several off axis angles i.e. by exposing the detector to different fluxes at different positions. Moving the LAr near detector horizontally in a direction transverse to the neutrino beam would result in a PRISM.

Calorimetric Neutrino Energy Reconstruction

Neutrino energy estimation depends on the interaction model in two ways[2]. Firstly, undetected pions lead to missing energy by an amount of pion's mass, secondly the detector response of a the neutron re-interactions is not well correlated to the kinetic energy carried by the primary neutron emerging from the argon nucleus. Calorimetric neutrino energy reconstruction is a more reliable method as compared to the muon kinematic neutrino energy reconstruction method.

$$E_\nu = E_l + \Sigma_i T_i^N + \epsilon_n + \Sigma_j E_j \qquad (1)$$

- where- E_l is charged lepton's energy
- T_i^N is kinetic energy of knocked out nucleons
- ϵ_n is the corresponding separation energy (34 MeV)
- E_j is the total energy of any other particle produced

Simulation and details

For performing the calorimetric neutrino energy reconstruction for ν_μ-Argon (Resonance Interaction including DELTA and

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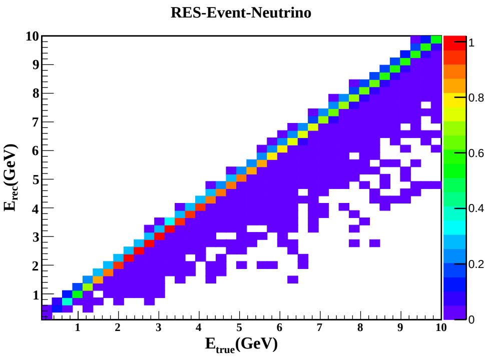

FIG. 1: Calorimetric Neutrino energy reconstruction for ν_μ-Argon Resonance interactions.

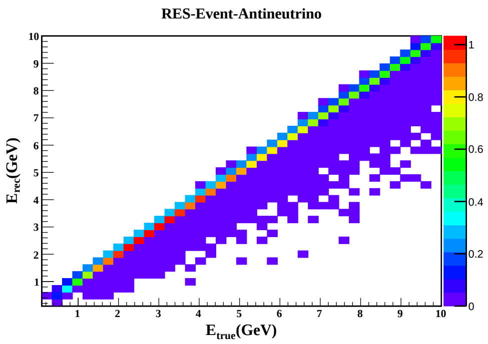

FIG. 2: Calorimetric Neutrino energy reconstruction for $\bar{\nu}_\mu$-Argon Resonance interactions.

Higher resonance processes), an event sample size of approximately 100,000 events using GiBUU-2019 is generated. Uniform Flux in the energy Range 0.1-10GeV is selected to generate the migration matrices.

Result and Discussion

Constraining neutrino interaction uncertainties is particularly difficult, since no complete model of neutrino interactions is available. Observing the neutrino interactions at different off-axis angles will provide an independent handle on neutrino energy. The DUNE-PRISM near detector concept can provide a data-driven determination of the relationship between true and reconstructed energy that is significantly less sensitive to neutrino interaction models. The next steps consist of a full oscillation analysis with far detector predictions produced directly from linear combinations of DUNE-PRISM off-axis measurements.

Acknowledgments

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References

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