Current Status and Future Progess of DUNE ND studies

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1 Overview

(Put in some general info about the DUNE experiment here) While the design of the Liquid Argon Far Detector has been finalized, there is still ongoing effort in deciding the configuration of the Near Detector. The main near detector design includes a Fine-Grained Tracker (FGT) with possible inclusion of an upstream detector being either a Liquid (LArTPC) or High Pressure Gaseous Argon TPC (GArTPC). The focus of the work described in this document is to quantify the ability of the standalone FGT detector to achieve the goals of DUNE, and whether the addition of a TPC would help achieve this goal. Additionally, the sufficiency of current kinematic parameterization to handle model variations is considered.

2 Methods

As the analysis techniques for DUNE are developed, checks on the cross section model are necessary. Variations arise in the different handling of Final State Interaction (FSI) effects by Monte Carlo event generators, as well as choice of Near Detector configuration. Sets of neutrino and antineutrino events on Argon-40 are produced with the GENIE¹[1], NEUT²[2], and NuWro³[3] according to the 2015 DUNE CDR fluxes. The various data sets are passed through the NUISANCE[4] software to reduce the various outputs to a common format, in turn saving all final state particle information for each event. Each particle is than randomly accepted or rejected according to efficiencies for each detector. Currently, only a robust description of the FGT efficiency is available, and simple thresholds for protons are applied for the GAr⁴ and LAr ND and FD⁵. Currently, we do not have the efficiencies for μ , $\pi^{+,-}$,

¹GENIE version 2.10, RFG

 $^{^2 \}rm NEUT$ version 5.3.6, Nieves et. al RPA+2p2h/MEC $M_A = 1.01$

 $^{^{3}}$ NuWro version (FIND THE VERSION) LFG + RPA + Nieves et. al

^{* 100} MeV/c

 $^{^5}$ 200 MeV/c

and π^0 in the LAr and GAr, and so the detectors are assumed to be perfectly efficient (no rejections) to these particles. π^0 efficiency information is also currently missing in the FGT configuration, and so are assumed fully accepted.

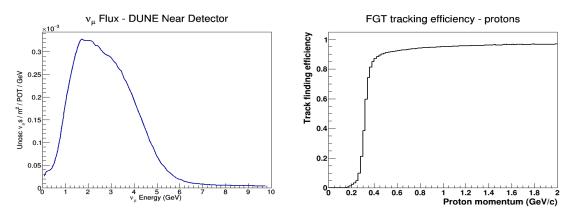


Figure 1: Left: ν_{μ} flux at DUNE ND used to generate events, Right: Tracking efficiency for protons in FGT.

3 Reconstructed Energy

A framework for investigating the differences in reconstructed energy calculations between different generators and ND configurations has been developed.

The current development of this work includes a calculation of the final state energy by summing the total energy from final state leptons and pions (all charges) and the kinetic energy of final state protons after passing efficiencies through the data sets. All neutrons are assumed undetectable. This can be summed up in Equation 1:

$$E_{reco} = \Sigma E_{lep} + \Sigma E_{\pi} + \Sigma (E_{prot} - M_{prot})$$
 (1)

where E_{lep} is the energy of the outgoing lepton, E_{pi} is the energy of the charged pion, and E_{prot} (M_{prot}) is the energy (momentum) of the proton. This is achieved by using the NUISANCE software package to reduce the output from various Monte Carlo neutrino event generators, including GENIE, NEUT, and NUWRO, into a common format that can easily be analyzed.

Work has begun to include tracking/PID efficiencies to accept or reject final state particles. So far, only the full information (barring π^0 efficiencies) for the FGT is available. Future studies intend to include both the efficiencies and acceptance of the LAr or GAr TPCs once this information become available.

3.1 Neutron Multiplicities & Energy

Differences between models in the number of final state neutrons and the total energy into FS neutrons can largely affect reconstruction of neutrino energy. Large variations in reconstructed energy can arise due to missing energy caused by the inability to detect neutrons in the various models.

3.2 Particle Multiplicity and Momentum

Nucleon multiplicity and momentum distributions offer similar information as do N vs. E distributions, while specifically looking at protons and charged pions along with detector thresholds can enlighten the ability of the detectors' reconstruction capabilities. For these studies, the 3-momentum of the final state (after efficiencies) protons or charged pions are summed. The magnitude is then plotted against the multiplicity for the specific particle type.

4 Parameterization

4.1 Q² studies

The first study to be considered is the sufficiency of a purely \mathbb{Q}^2 parameterization (a la VALOR) in treating the uncertainties for CCQE. To be considered is the relative change between the models (displayed as a single ratio of Other/GENIE separately at the near and far detectors) and this change as it is extrapolated between the near and far detector (as a double ratio of Other/GENIE,Near/Far).

Figure 5: \mathbb{Q}^2 distributed events using DUNE flux, no efficiencies applied. Left: Ratio of NEUT to GENIE output at ND, Right: Double ratio of NEUT to GENIE, Near to Far. Of note is the relative flatness in the low- \mathbb{Q}^2 region in the double ratio, becoming less flat toward the higher end.

$4.2 \quad q_0 vs. q_3 \text{ studies}$

In comparison to the purely Q^2 parameterization, a simple $q_0vs.q_3$ parameterization was also considered. One concern is the possibility of inconsistency between the two parameterizations in variations between models.

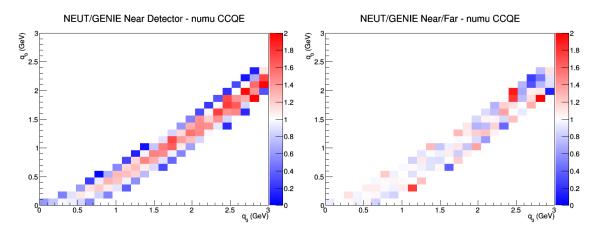


Figure 7: q3 vs. q0 distributed events using DUNE flux. Left: Ratio of NEUT to GENIE output at ND, Right: Double ratio of NEUT to GENIE, Near to Far

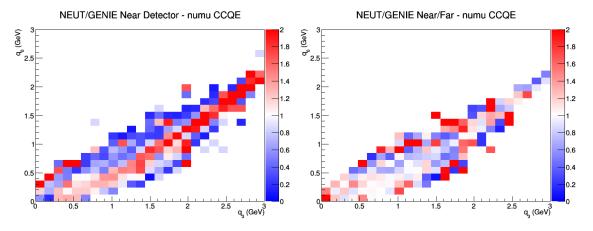


Figure 8: q3 vs. q0 distributed events using DUNE flux. Left: Ratio of NEUT to GENIE output at ND, Right: Double ratio of NEUT to GENIE, Near to Far. Much of the FD has a tighter phase space due to being generator-level truth information, so a good deal of the ND-with-efficiency phase space is lost. Within the FD-covered phase space in the double ratio, flatness seems to be lost in the lower region, and much more bin-to-bin variation is present in the upper region (possibly need more statistics?).

4.3 Nucleon multiplicity vs. W

Differences in mapping from Ereco to true variables can arise from shape differences in Nucleon multiplicities vs. W distributions. The first foray into these studies have

been started, and need to be fleshed out for meaningful results.

5 Future Work

The above studies need to be furthered and expanded upon to successfully arrive at useful conclusions on ND configuration choice.

- Extend studies to include LAr and GAr efficiency and acceptance information when available.
- Include a mapping of E_{true} to E_{reco} along with y_{true} to y_{reco} and investigate differences between configurations.

References

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- [4] P. Stowell, C. Wret, C. Wilkinson, L. Pickering, S. Cartwright, Y. Hayato, K. Mahn, K.S. McFarland, J. Sobczyk, R. Terri, L. Thompson, M.O. Wascko, Y. Uchida NUISANCE: a neutrino cross-section generator tuning and comparison framework arXiv:1612:07393v2