Current Status and Future Progess of DUNE ND studies

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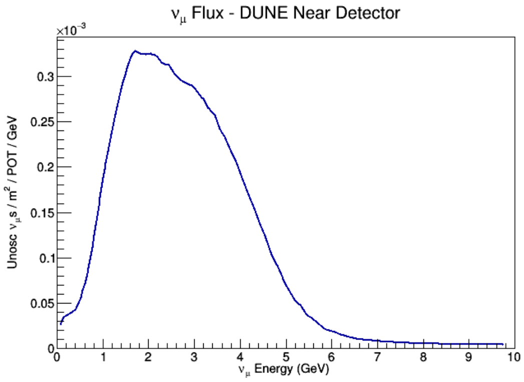
1 Overview

(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 Motivation, Methods, and Results

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 GENIE[1](REFERENCE), NEUT[2](REFERENCE), and NuWro[3](REFERENCE) according to the 2015 DUNE CDR fluxes. The various data sets are passed through the NUISANCE(REFERENCE TO NUISANCE PAPER) 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 are applied for the GAr[4] and LAr ND and FD[5].

[1] GENIE version 2.10, RFG
[2] 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
[4] 100 MeV/c proton momentum, FIND OTHER EFFICIENCIES
[5] 200 MeV/c proton momentum, FIND OTHER EFFICIENCIES



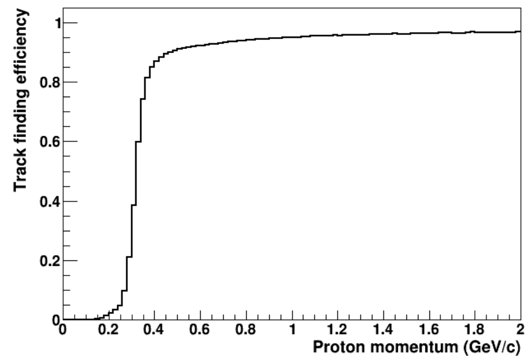


Figure 1: Left: ν_μ flux at DUNE ND used to generate events, Right: Tracking efficiency for protons in FGT.

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 (all neutrons are assumed undetectable). This is achieved by using the NUISANCE software package to reduce the output from various Monte Carlo neutrino event generators (including GENIE, NEUT, NUWRO, as well as the nuclear reaction and transport simulation software, GiBuu) 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 information for the FGT is available, but the inclusion of the LAr or GAr TPCs will be easily implemented.

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. This will be highlighted in conjunction with the variations in the difference between Ereco and Enu. Additionally, investigations in the ability for errors in GENIE to cover the differences between models have been started.

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 pions along with detector thresholds can enlighten the ability of the detectors reconstruction capabilities.

4 Parameterization

4.1 Q^2 studies

The first study to be considered is the sufficiency of a purely 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).

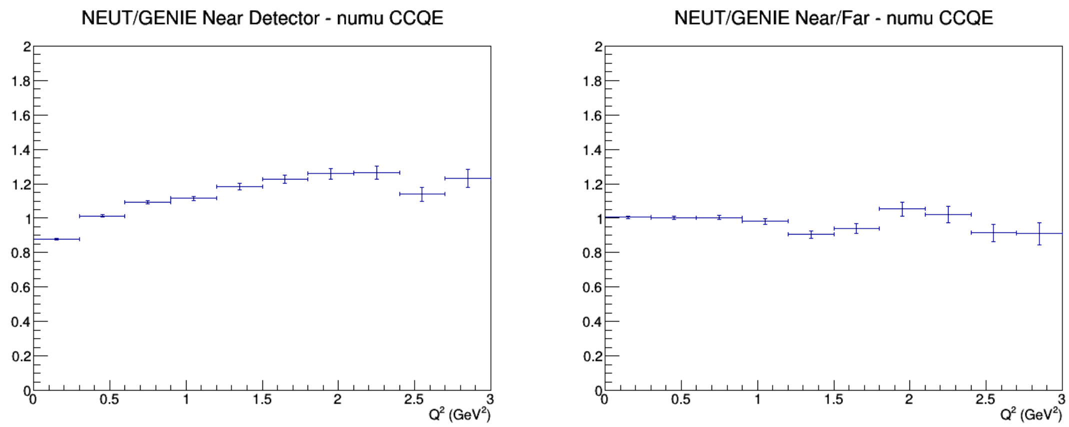


Figure 2: Q^2 distributed events using DUNE flux, no efficiencies applied. Left: Ratio of NEUT to GENIE output at ND, Right: Double ratio of NEUT to GENIE, Near to Far. Of note is the relative flatness in the low-Q^2 region in the double ratio, becoming less flat toward the higher end.

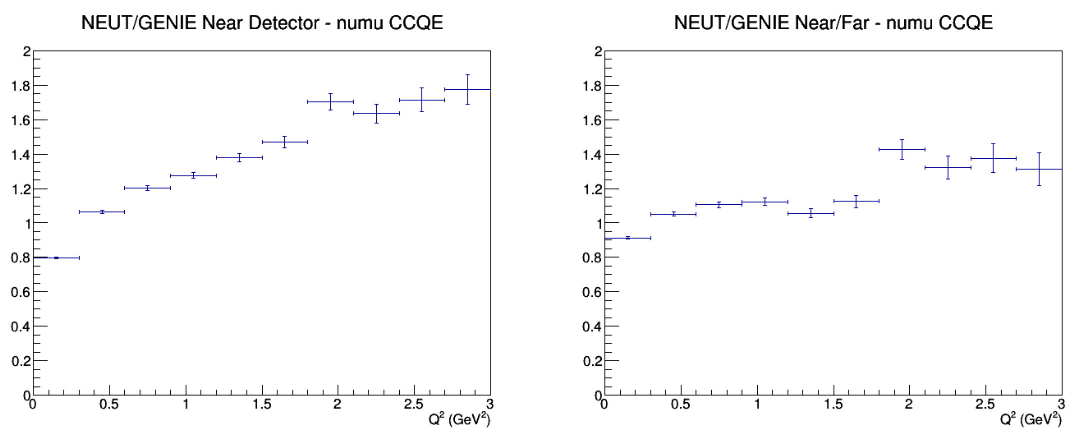


Figure 3: Q^2 distributed events using DUNE flux, no efficiencies applied. Left: Ratio of NEUT to GENIE output at ND (high Q^2 region out of bounds of plot), Right: Double ratio of NEUT to GENIE, Near to Far. Flatness is generally lost throughout double ratio, particularly made worse in higher end.

4.2 $q_0 vs. q_3$ studies

In comparison to the purely Q^2 parameterization, a simple $q_0 vs. q_3$ parameterization was also considered. One concern is the possibility of inconsistency between the two parameterizations in variations between models.

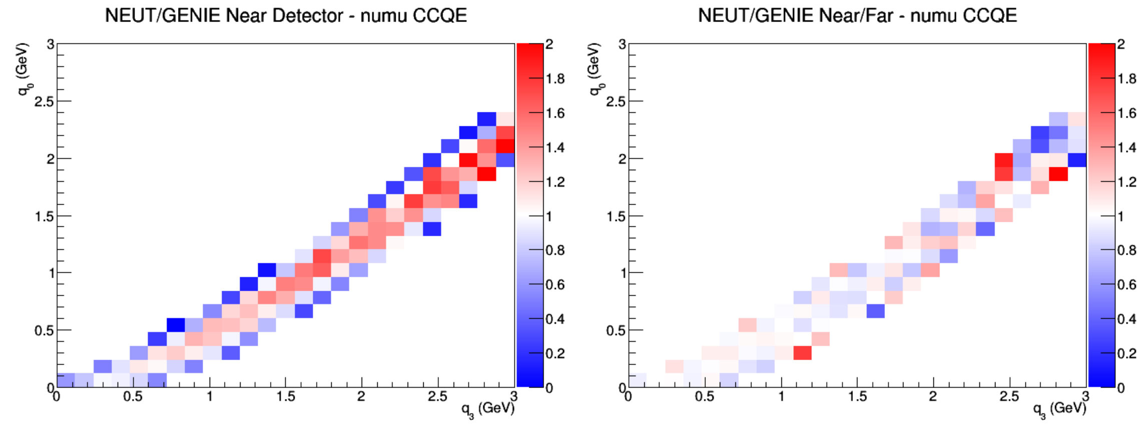


Figure 4: q3 vs. q0 distributed events using DUNE flux. Left: Ratio of NEUT to GENIE output at ND, Right: Double ratio of NEUT to GENIE, Near to Far

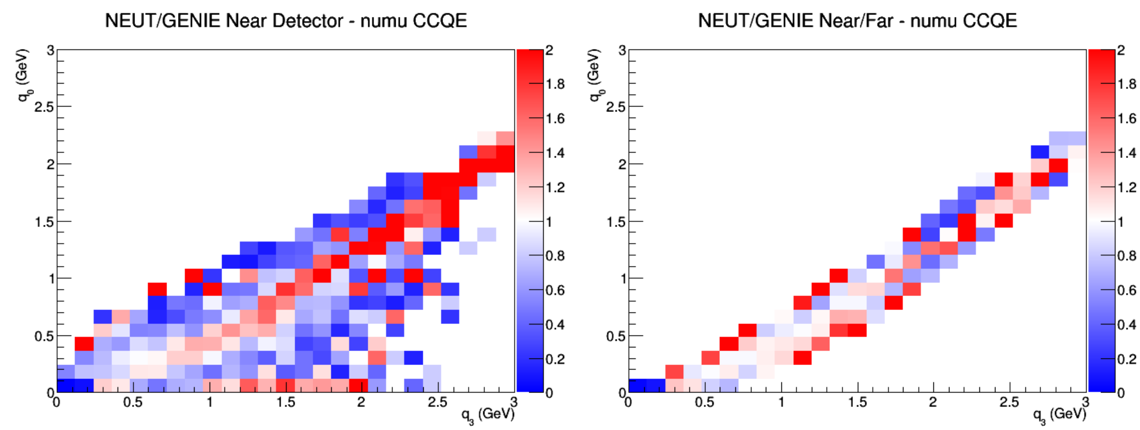


Figure 5: q3 vs. q0 distributed events using DUNE flux. Left: Ratio of NEUT to GENIE output at ND, Right: Double ratio of NEUT to GENIE, Near to Far. Much of the FD has a tighter phase space due to being generator-level truth information, so a good deal of the ND-with-efficiency phase space is lost. 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 Ereco, yreco

An additional study to be commenced is the mapping from Ereco & yreco into other kinematic variables (i.e. Q^2, q_0 vs. q_3), and the ability to similarly map model variations.

4.4 Nucleon multiplicty vs. W

Differences in mapping from Ereco to true variables can arise from shape differences in Nucleon multiplicites 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 arive at useful conclusions on ND configuration choice.

- Extend studies to include LAr and GAr efficiency information when available
- Map from Ereco, yreco into true variables and investigate differences between configurations