On-axis and off-axis neutrinos in the DUNE near detector

Jarrett Fein, Michigan State University – SULI Intern | Minerba Betancourt, Fermilab

Introduction

DUNE is a long baseline neutrino experiment that, when complete, will be the most advanced neutrino experiment in the world. It aims to make precision measurements of the neutrino mixing angles, CP violating phase, and the neutrino mass hierarchy. One of the critical components of the DUNE experiment is its near detector, which is used to measure the initial composition of the neutrino beam. One part of the near detector, ND-LAr, is a moveable LArTPC, which allows measurement of neutrinos that enter the detector off-axis from the beamline. Here, we run simulations of off-axis neutrino detections in ND-LAr using beams configured to produce either neutrinos or antineutrinos in forward or reverse horn current modes respectively (FHC, RHC) and analyze the projections to point future studies to likely areas of interest.

Methods

GENIE simulations were used to generate neutrino interaction events for various off-axis positions (0m, 8m, 16m, 24m) in both FHC and RHC. We examine the data through the lens of charged current interaction channels (QE, RES, DIS, MEC, COH).

Results: Muon neutrinos vs. electron neutrinos

When the detector is positioned on-axis and using FHC, DIS and RES events dominate the $\nu_\mu$ distribution at low energy. At off-axis positions, QE events become dominant at low energy, but DIS shifts to become more prominent at high energy.

The $\nu_e$ distribution is dominated by DIS at high energy on-axis and QE is the most dominant at low energy off-axis. This paradigm is similar for RHC, but there are substantially more matter interactions in RHC than there are antimatter interactions in FHC.

Across all channels, the ratio of electron neutrinos to muon neutrinos detected increases with off-axis detector position, permitting easier study of electron neutrino interactions. This comes with the caveat that significantly fewer total events are detected at further off-axis positions.

Results: Muon kinematics

In the on-axis position, muons resulting from neutrino interactions are primarily measured with very little angle relative to the beamline. As the off-axis position increases, there are more events detected at greater angles, and those events are most preferentially QE. Similarly to neutrino energy, $p_\mu$ is dominated by RES and DIS in the on-axis configuration and shifts in favor of QE at low energies in the off-axis configuration. Here we also see the prominence of matter interactions when the beam is set to RHC via the relatively pronounced $\mu^{-}$ QE, RES, and DIS distributions. The off-axis configurations provide data useful for constraining oscillation measurements, making cross-section measurements, and searching for physics beyond the standard model.

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