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

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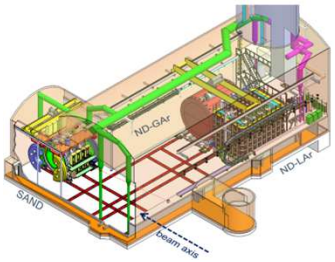
Introduction

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.

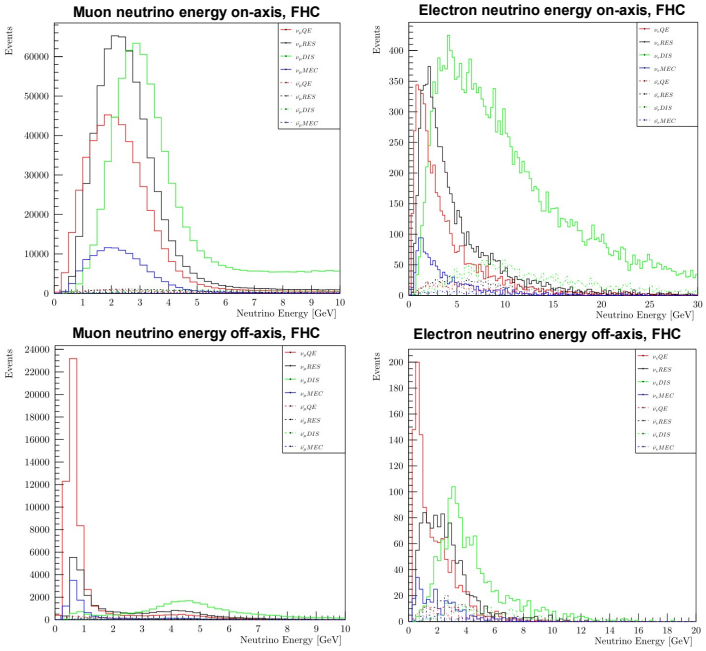
Methods

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).



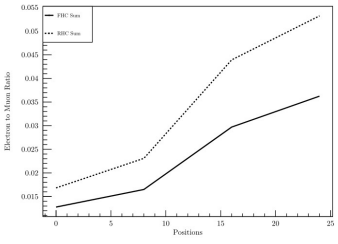
DUNE near detector, including ND-LAr

Results: Muon neutrinos vs. electron neutrinos



When the detector is positioned on-axis and using FHC, DIS and RES events dominate the ν_μ 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 ν_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.



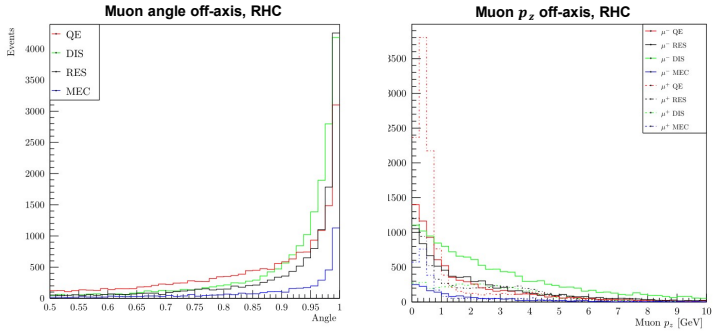
Electron neutrinos contribute a greater portion of total events detected as off-axis position increases.

Event projections for POT: 10^{19}

0m FHC	QE	RES	DIS	MEC	COH	Sum
$\nu_\mu + \overline{\nu_\mu}$	494500	655594	722291	124947	11576	2008908
$\nu_e + \overline{\nu_e}$	5094	6573	12522	1281	210	25680
Sum	499594	662167	734813	126228	11786	2034588
24m FHC	**QE**	**RES**	**DIS**	**MEC**	**COH**	**Sum**
$\nu_\mu + \overline{\nu_\mu}$	58198	28629	28071	10139	562	125599
$\nu_e + \overline{\nu_e}$	1380	1331	1504	309	28	4552
Sum	59578	29960	29575	10448	590	130151
0m RHC	**QE**	**RES**	**DIS**	**MEC**	**COH**	**Sum**
$\nu_\mu + \overline{\nu_\mu}$	222747	303875	258150	70278	10492	865542
$\nu_e + \overline{\nu_e}$	2772	3918	6888	854	136	14568
Sum	225519	307793	265038	71132	10628	880110
24m RHC	**QE**	**RES**	**DIS**	**MEC**	**COH**	**Sum**
$\nu_\mu + \overline{\nu_\mu}$	20960	14860	15873	4754	518	56965
$\nu_e + \overline{\nu_e}$	764	889	1125	220	34	3032
Sum	21724	15749	16998	4974	552	59997

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, muon p_z 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 μ^- 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.

Acknowledgements

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