Effects of LBNF Neutrino Beam Focusing Uncertainties on DUNE Neutrino Fluxes

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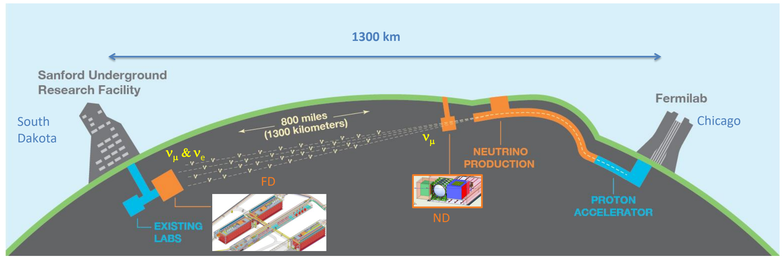
on behalf of the DUNE Collaboration

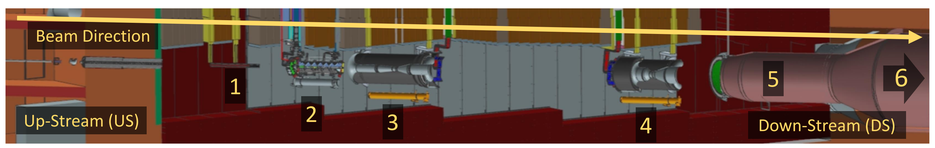
LBNF and DUNE



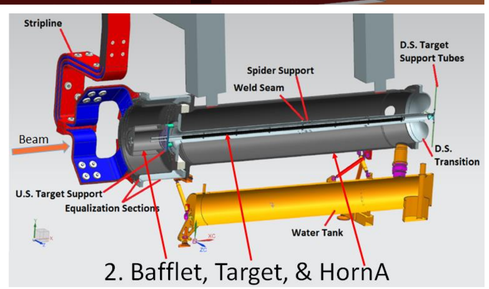
One of the physics drivers for the Deep Underground Neutrino Experiment (DUNE) is a precision measurement of δ_{CP} using the ν-beam produced by the Long Baseline Neutrino Facility (LBNF) at Fermilab. LBNF delivers a predictable ν and $\bar{\nu}$ flux to the DUNE Near (ND) and Far (FD) Detectors. The spectra of $\nu_\mu, \nu_e, \bar{\nu}_\mu$, & $\bar{\nu}_e$ are compared at the ND/FD for ν-flavor appearance, disappearance. Uncertainties in hadron production & the beam focusing can affect the fluxes and subsequent δ_{CP} measurement.

- The scope of the work presented here is over LBNF beam-focusing uncertainties
- Beam-focusing uncertainties incorporate effects from the components that comprise the "beamline," including engineering tolerances of component designs, component placement, and other physical considerations.

LBNF Beamline Components



1. Baffle
2. Bafflet, Target, & Magnetic Focusing Horn A (Right)
3. Horn B
4. Horn C
5. Decay Pipe
6. Not Shown: Hadron Absorber and Instrumentation



2. Bafflet, Target, & HornA

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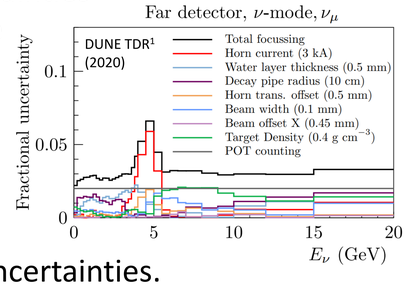
Citations: 1) arXiv:2002.03005 DUNE Collaboration

LBNF Simulation (Updates)

LBNF beam simulation is Geant4 based and uses GDML files and g4 C++ geometries for establishing beamline component placements/materials. The last round of focusing uncertainties were determined for the 2020 DUNE TDR[1] (right), which were limited in scope. Updates to the LBNF simulation and to the beamline design call for update to focusing uncertainties.



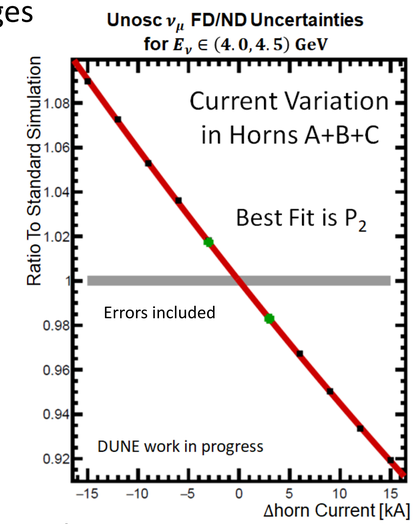
A more thorough assessment of uncertainties is also required. These updates include:

- Target: 2.2 m → 1.5 m RAL cantilevered target
- Engineering modifications to Horns
- Simulate tilting, displacement of target, horns
- B-field effects from Horn conductor deformations
- Include NuMI-style Muon Monitors & Alcoves, & Retention of μ-Monitor info for beam tracking studies
- I updated G4LBNF for fine control of output information retention: ~9x file-size reduction for flux determination.

Extraction of Uncertainties

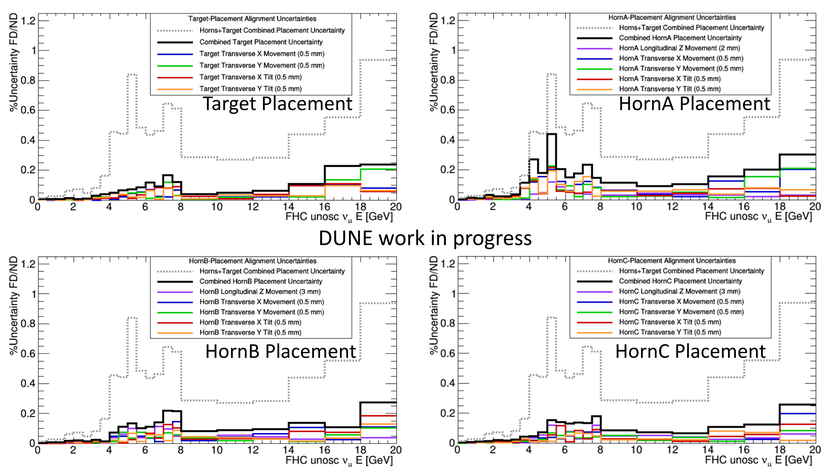
Simulate 1e9 Protons-on-Target (POT) for the standard simulation sample, and ≥25e7 POT with beam-focusing parameters varied by n standard deviations. The procedure for extracting uncertainties is as follows:

- Fit resulting flux changes for each energy bin
- The $\pm 1\sigma$ values are extracted from the best fit.
- The absolute value of their deviation from 1 is calculated averaged to obtain the uncertainty.
- Example for single energy bin (right) when horn currents are all varied simultaneously.
- Orthogonal alignment parameters, i.e. x, y tilts, are treated as independent uncertainties and added in quadrature



Results for ν-Beam Unoscillated ν_μ FD/ND Flux

Below: FD/ND focusing uncertainties from the target, horn placements
Right: FD/ND focusing uncertainties: Assorted & Combined Placement



Current Total Beam Focusing Uncertainties < 2%

~5 GeV structure due to edge of focusing system capture of ν-beam. Horn Current, Decay Pipe Radius, & Combined Target+Horns Placements are dominant uncertainties.