DUNE Near to Far Neutrino Beam Correlations For DUNE Experiment

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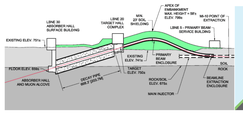
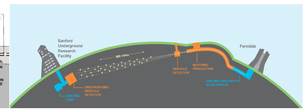
Introduction

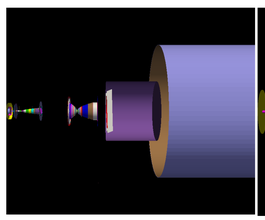
The DUNE near detector will be used to characterize the LBNF neutrino beam and to predict the neutrino fluxes at the DUNE far detector. Because of the different detector locations with respect to the beam-line, energy spectra at the two detectors will be slightly different, even in the absence of oscillations. A method known as the beam matrix method attempts to improve on the simple near/far ratio method of flux extrapolation by using a two dimensional map of near detector energy to far detector energy. I will show the impact of this method on neutrino flux predictions at the DUNE far detector.



DUNE Beamline [1]

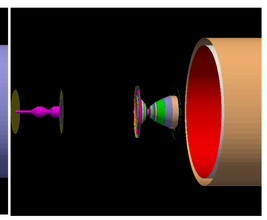


DUNE Near and Far Detector [1]



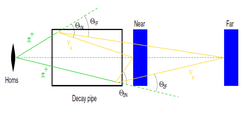
Current Reference Beam Design

- 1m Target
- Numi Like horn
- 80 GeV Proton



Current Optimized Beam Design

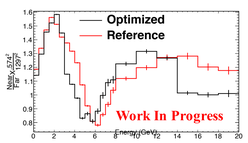
- 2m Target
- LBNO style horn
- 60 GeV Proton



Neutrino event as seen by near and far detector [2]

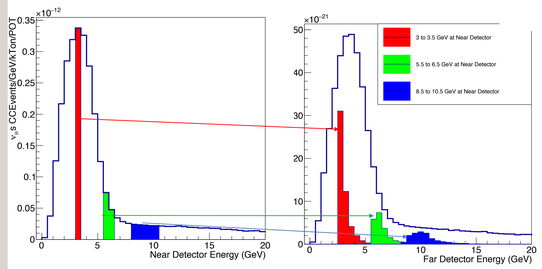
$$E_\nu = \frac{0.43\,E_\pi}{1+\gamma^2\theta^2}$$

$$\phi_\nu = \left[\frac{2\gamma}{1+\gamma^2\theta^2}\right]^2 \frac{A}{4\pi z^2}$$



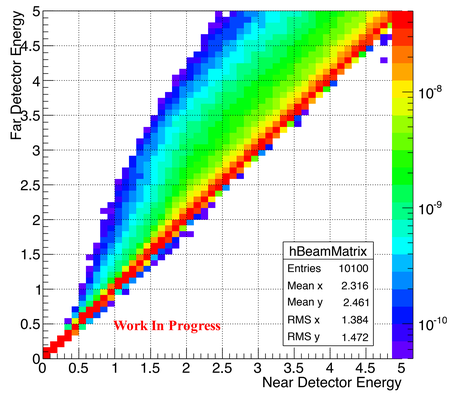
Near to Far Ratio after cancelling the detector location effect

- Near and Far detector spectra are correlated since they come from same hadron source.
- Hadrons creating neutrinos in a particular bin of near detector energy will create a slightly different spectrum at the far detector.

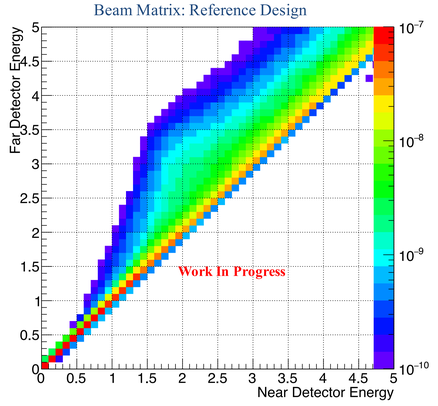


Illustrations of how near detector neutrino energies map to far detector energies.

Beam Matrix to Represent this correlation



Beam Matrix: Reference Design



Beam Matrix: Optimized Beam

Extrapolation of Far Detector Flux using Ratio and Beam Matrix Methods

Uncertainties in Neutrino Flux

- Uncertainties arise from limited knowledge of production spectra of hadrons from e.g. pp $\rightarrow \pi^{\pm}$ interactions
- LBNF will use a long (>1 m) target, which leads to:
  - Neutrinos from multiple interactions
  - Absorption and re interactions of particles contribute further uncertainties
- More than 20% variation of neutrino flux using different Geant4 physics model [2]

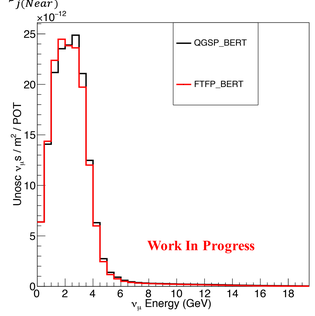
- I looked at the performance of ratio and matrix methods using near and far detector fluxes simulated with two different hadron production models
- Two Geant4 Physics List:
  - QGSP_BERT (Assumed "Simulated")
  - FTFP_BERT (Assumed "Real")

- Extrapolate "real" far detector flux from "real" near detector flux using a ratio and matrix computed using the "simulated" flux. The extrapolated far neutrino flux in the i^{th} bin is :

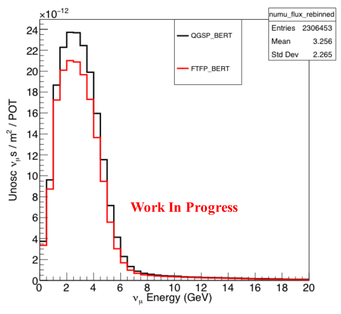
- $\emptyset_{\nu\,i(Far)}^{FTFP} = \frac{\emptyset_{\nu(Far)}^{QGSP}}{\emptyset_{\nu(Near)}^{QGSP}}\,\emptyset_{\nu(Near)}^{FTFP}$ (Ratio Method)

- $\emptyset_{\nu\,i(Far)}^{FTFP} = \Sigma_j\, M_{ji}\emptyset_{\nu(Near)}^{FTFP}$ (Matrix Method)

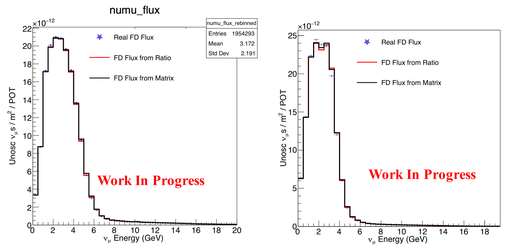
  - $M_{ji} = \frac{\emptyset_{ji(Far)}^{QGSP}}{\emptyset_{j(Near)}^{QGSP}}$



Neutrino Flux at Far Detector For Optimized Beam Design

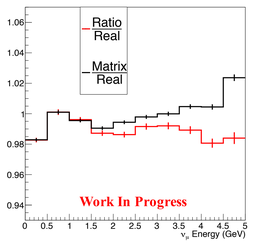


Neutrino Flux at Far Detector For Reference Beam Design

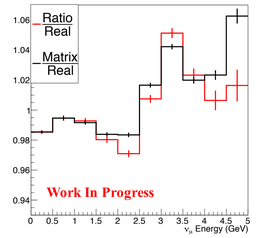


Reference Beam: "Real" and Extrapolated Neutrino flux at Far Detector

Optimized Beam: "Real" and Extrapolated Neutrino Flux at Far Detector



Reference Beam: Predicted/Real at Far Detector



Optimized Beam: Predicted/Real at Far Detector

Conclusions

- Neutrino flux from conventional neutrino beams have large uncertainties originating from models used to simulate hadrons produced in the target.
- Near and Far detector neutrino flux are correlated, allowing measurements in the near detector to constrain uncertainties on the far flux.
- Near and far detector spectra are different
  - Hadrons creating a fixed energy of neutrinos in the near detector will result a broader spectrum of events at the far detector.
- Ratio and Matrix methods can be used to extrapolate flux measured in the near detector to the far detector.

References

[1]. Dune Collaboration, 2016, Conceptual Design Report, *arXiv:1606.09550.*

[2].M.Szleper,A.Para,2001,Neutrino Spectrum at the Far Detector Systematic Errors, *arXiv:hep-ex/0110001.*

[2]. MINOS Collaboration,, Study of Muon Neutrino Disappearance in Fermilab MainInjector Neutrino Beam, *Phys. Rev. D77 (2008)072002*