A Data-Driven Extrapolation Technique for the DUNE-PRISM Oscillation Analysis

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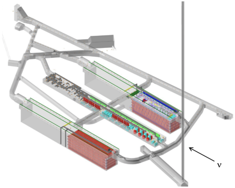
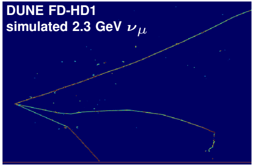
DUNE Oscillation Analysis

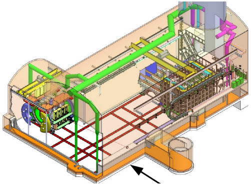
$$N_\nu\left(E_{rec}\right) = \int dE_\nu \underbrace{P_{osc}\left(E_\nu, L; \theta\right)} \times \underbrace{\Phi\left(E_\nu\right) \times \sigma_{\nu\text{-Ar}}\left(E_\nu\right)} \times \mathbf{D}\left(E_\nu, E_{rec}\right)$$

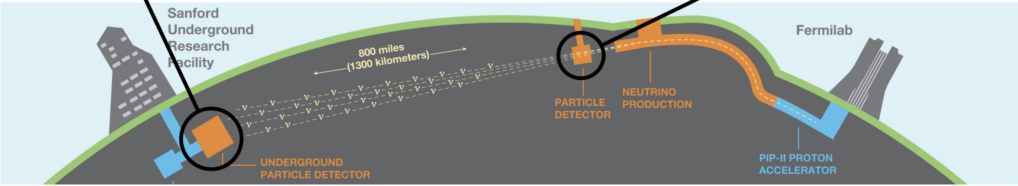
Far Detector fits for oscillation probability

Near Detector constrains flux & cross section model params



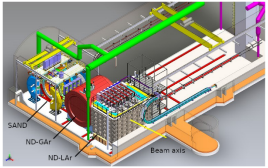


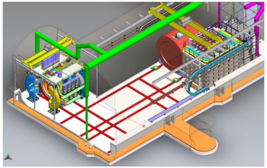


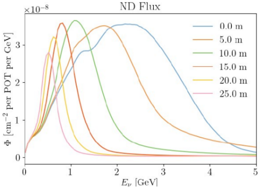


DUNE-PRISM

- Constraining neutrino-nucleus interaction model parameters using ND can introduce bias if the model is not correct
  - → Reconstructed energy depends on the final state of the ν-Ar interaction, so model needs to be correct for exclusive cross sections too - really hard!
- The Precision Reaction Independent Spectrum Measurement (PRISM) technique can help
  - → The ND moves perpendicular to the neutrino beam ("off-axis") up to 30m
  - → Beam energy spectrum changes with off-axis position
- Sampling many energy spectra provides strong verification on the cross section model adjustments used to make ND MC match data
  - → Harder to introduce bias with a bad model correction

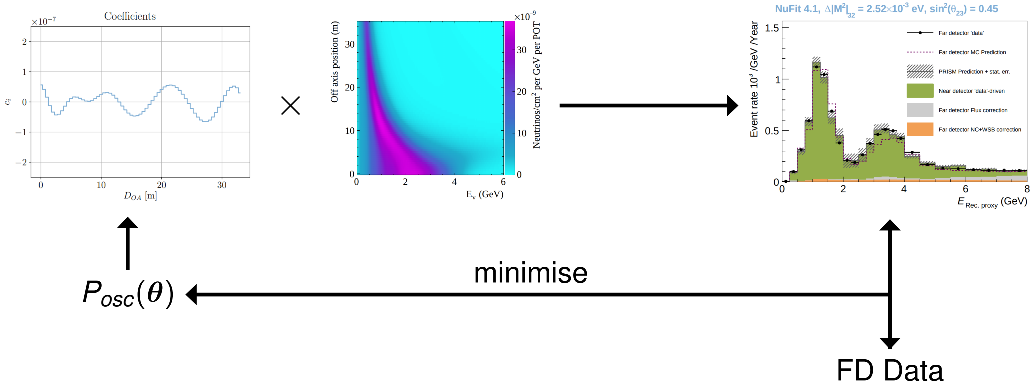






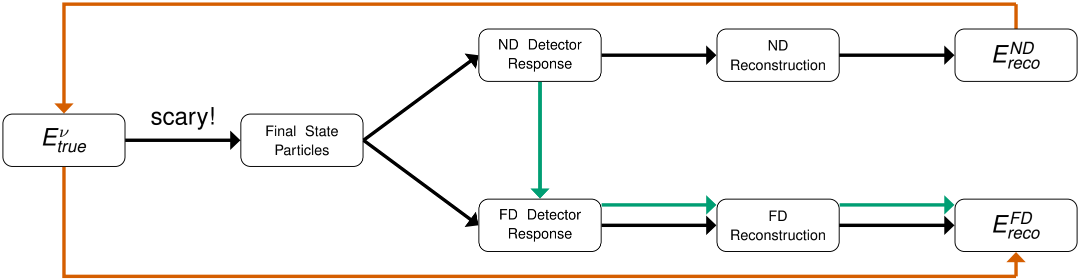
Model-Insensitive Analysis with PRISM

- PRISM enables an oscillation analysis that compares ND data to FD data directly through linear combination of off-axis fluxes
  - → Any unknown cross section effects get directly incorporated into a FD spectrum prediction



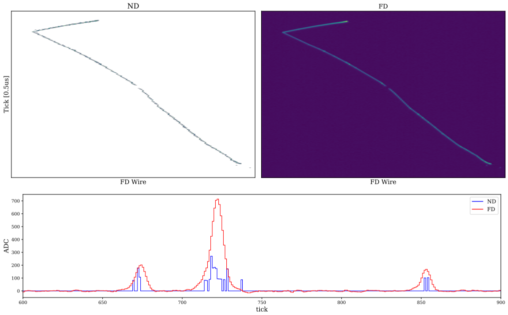
Near to Far Detector Extrapolation

- Completing the extrapolation of off-axis ND measurements to the FD requires correcting different detector effects
  - → Using MC response matrices to unfold and smear introduces interaction model dependence
  - → Directly translating detector response from ND to FD would be much better

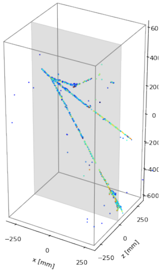


Translating from Near to Far Detector

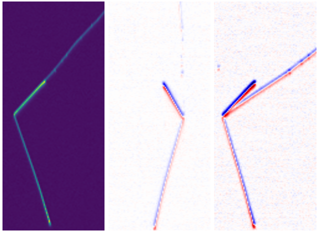
- Apply machine learning to translate ND response to the equivalent FD response
- Focus on the primary difference between detectors — charge readout
  - → Single 3d view from self-triggering pixel planes vs multiple 2d views from wire planes
- Generate a paired dataset by simulating the same charge depositions at both detectors



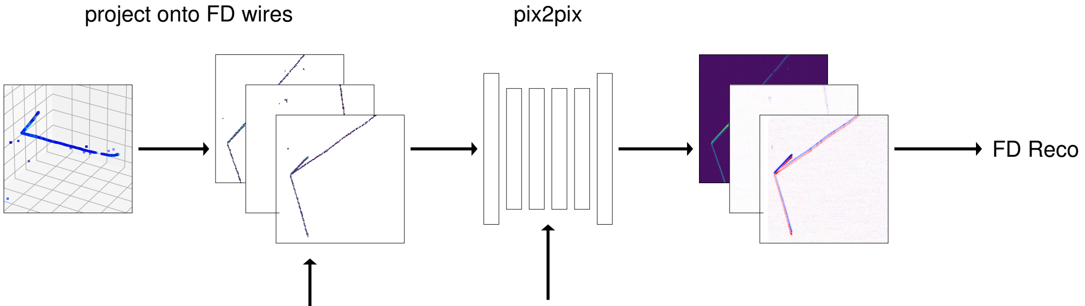
Near Detector



Far Detector



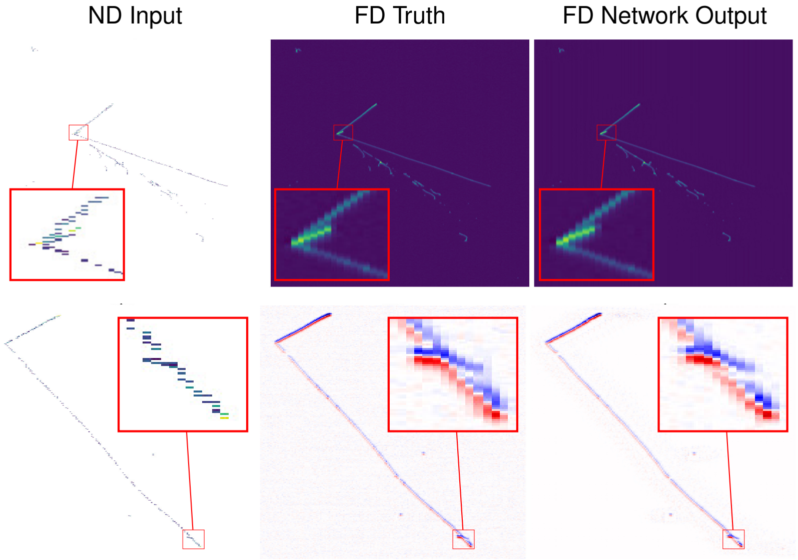
Translation with pix2pix



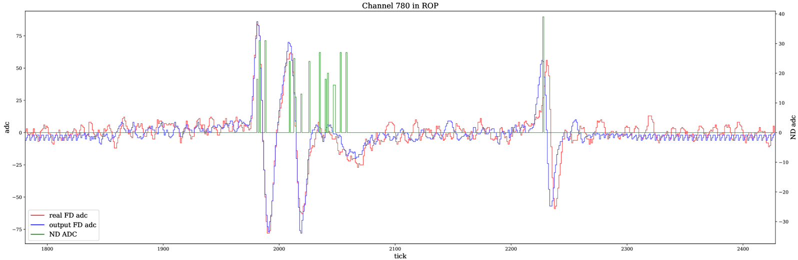
- Full FD resolution projection
- Input channels include ADC, wire projection info, ND + FD drift distances

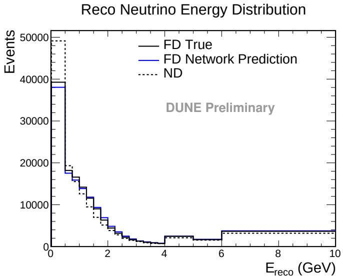
- Conditional GAN architecture
- 9-block ResNet generator with up/downsampling layers
- PatchGAN discriminator
- L1 loss applied in signal region only

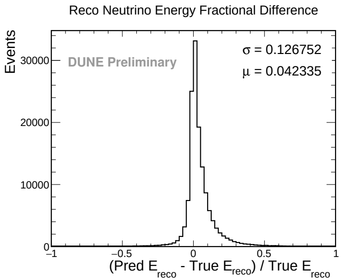
Results - Image Translation



Results - Wire Trace and Reco





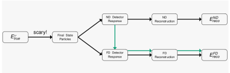


Cross Section Systematics

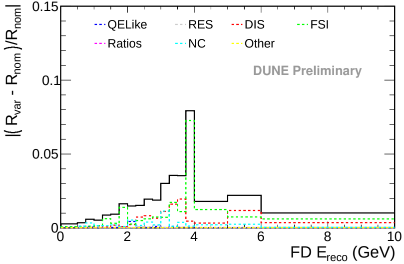
- Study interaction model dependence of extrapolation method using cross section systematic event reweights
- Look at the ratio of predicted FD spectrum with true FD spectrum under reweights

  → No change in ratio after reweight means no interaction model dependence is introduced by extrapolation

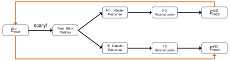
ML Translation



Network Pred+Smear/True variation from all xsec dials (2 σ)



Unfold + Smear



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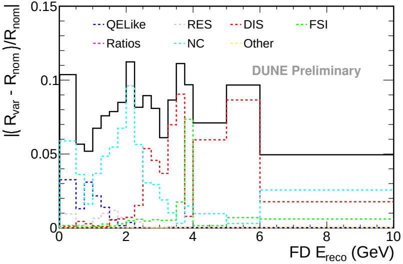


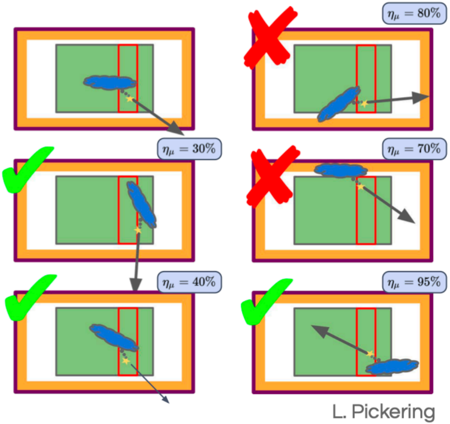
Summary

- PRISM capability of near detector enables an oscillation analysis that is largely independent of cross section modelling by making FD predictions directly from ND data
  - $\rightarrow$ Detector effects correction can compromise this
- Machine learning is applied to correct for detector effects by translating detector response
  - $\rightarrow$ Accurate prediction of FD response
  - $\rightarrow$ Robust to mismodelling of cross sections
- Working on extending model to correct for all ND-FD differences
  - $\rightarrow$ Different detector dead regions
  - $\rightarrow$ Muon spectrometer ND component

Backup

Geometric Efficiency Correction

- Correct each event by combining leptonic and hadronic efficiency factors for each throw and averaging over all throws

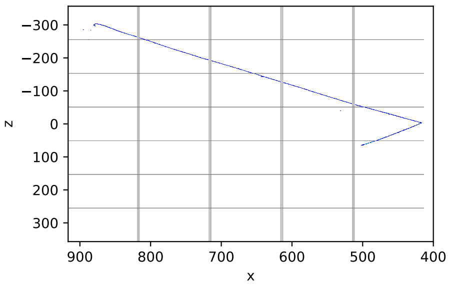


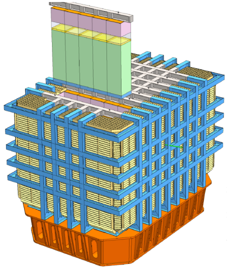
$$\eta = \frac{0\times0.8+1\times0.3+0\times0.7+1\times0.4+1\times0.95}{5} = 0.33$$

$$\rightarrow \text{reweight event by } \frac{1}{0.33}$$

Dead Region Infill

- Need to predict FD detector response in the non-active ND regions between drift modules to correctly translate
- Difficult to do this after wire projections since positions of gaps are not well defined in this projection
- Attempt to infill gaps between drift modules at the 3D pixel response level





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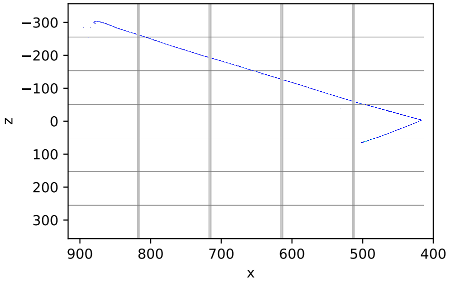
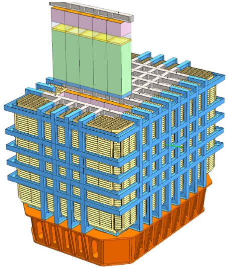
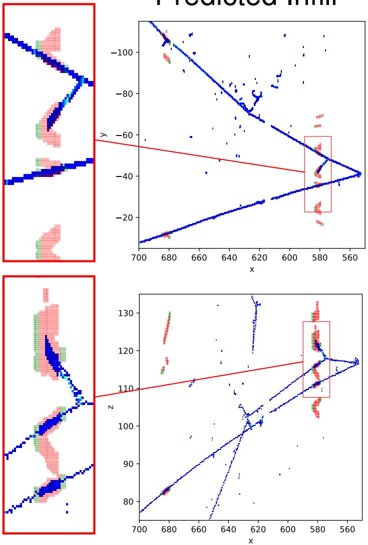




Dead Region Infill

Predicted Infill



Target Infill