DUNE-PRISM Update

DUNE LBL Physics
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DUNE DEEP UNDERGROUND
NEUTRINO EXPERIMENT

This Update

- Status
- Non-disappearance flux fits
- Flux fit interpolation
- Immediate plans

Brief Recap: Flux fitting

- Make flux predictions through small flux windows at off-axis positions in a proposed near detector cavern.

- Find coefficients in a linear combination of off-axis flux predictions that match some target

- Have traditionally shown fits to far detector disappearance or gaussian spectra: **but can in principle try to fit anything**.
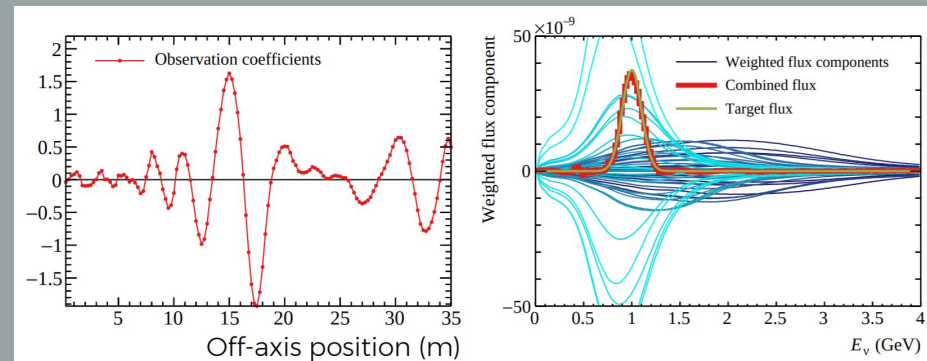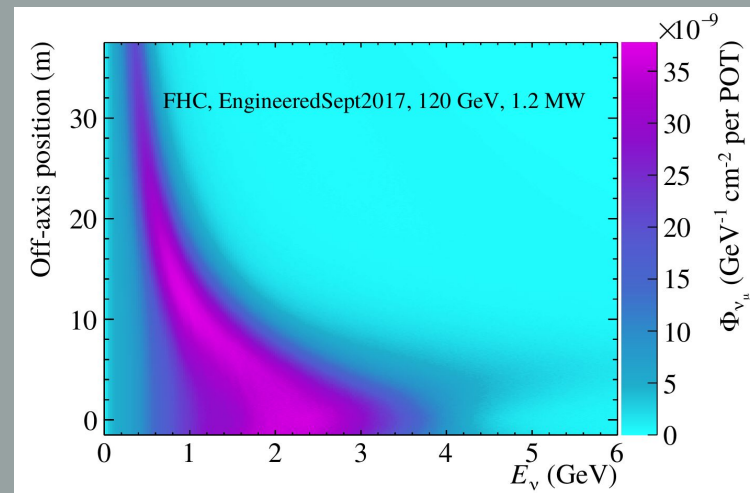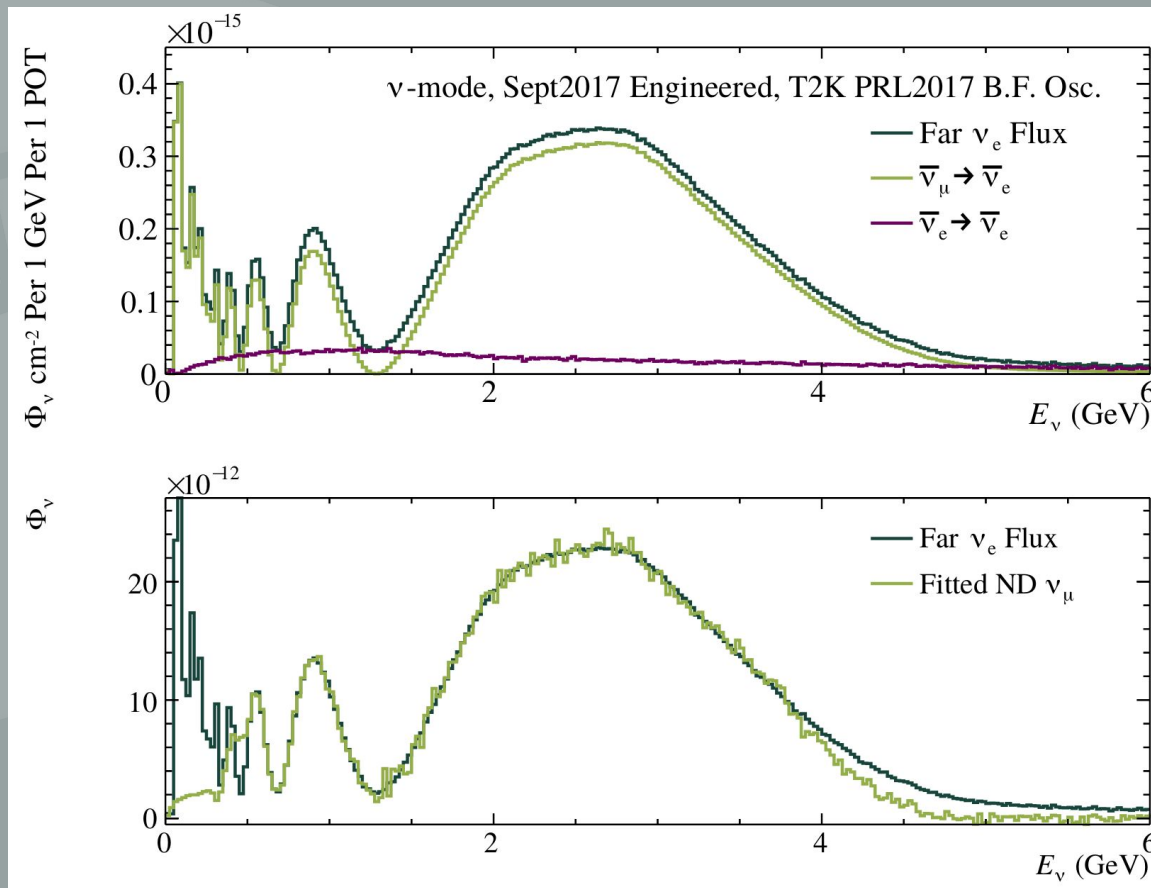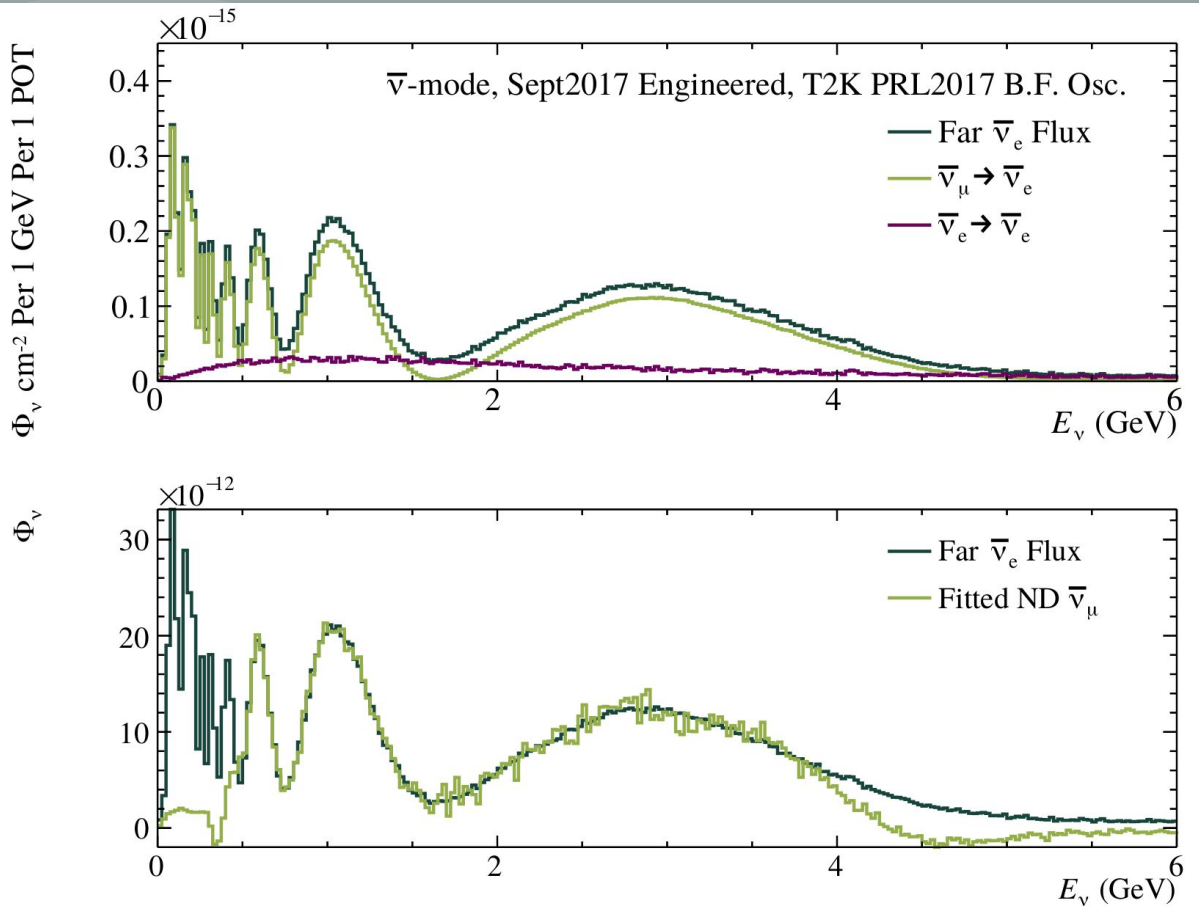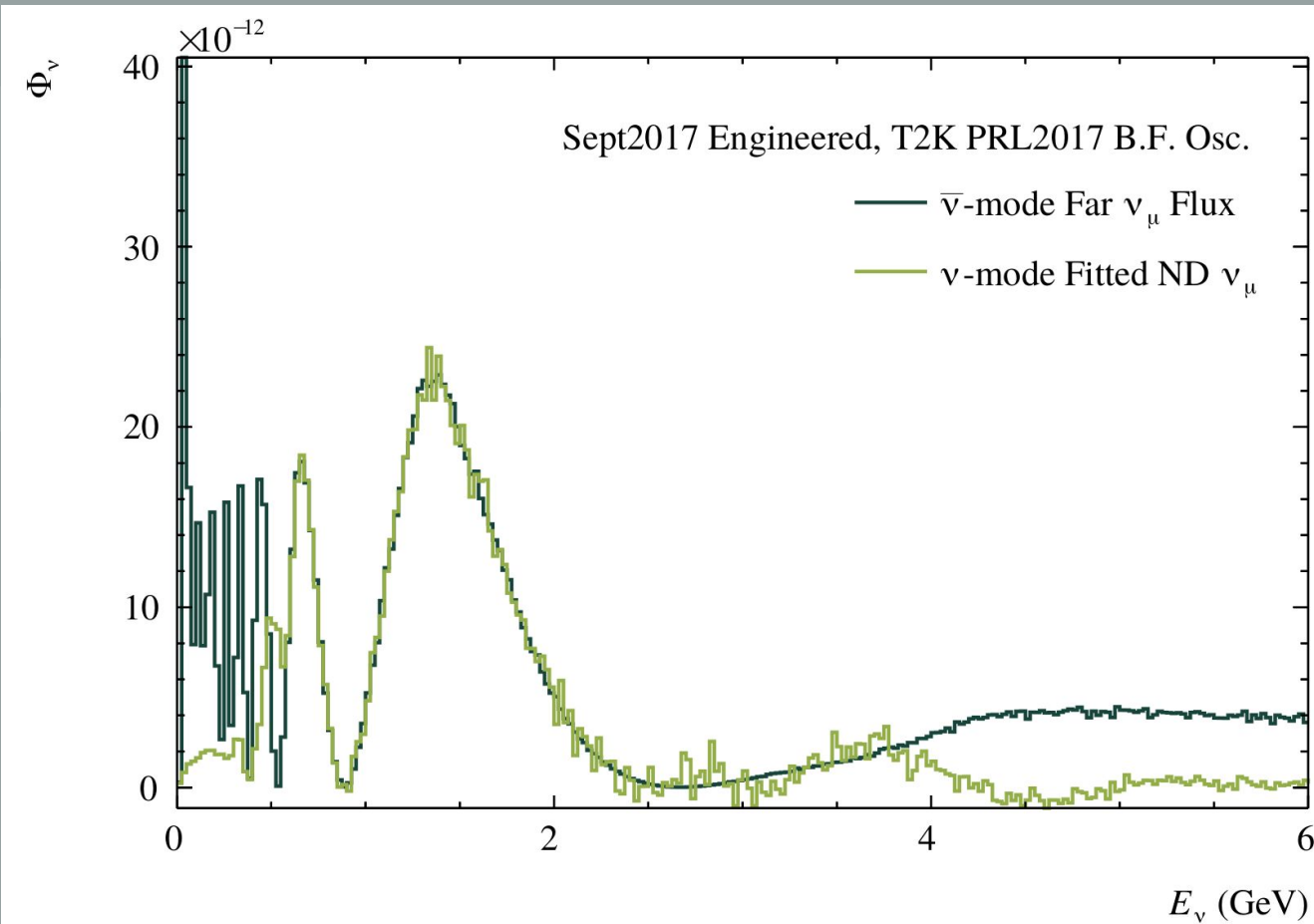
Other Flux Fits

- We can use this to think up a number of other interesting linear combinations:
  - Far detector nue(bar) appearance spectra fit with ND numu(bar).
  - Far detector WSB numu(bar) fit with other-HC ND numu(bar).
  - Near detector nue(bar) fit with ND numu(bar).

- Can be used to calibrate:
  - WSB prediction at the FD
  - numu<->nue energy reconstruction mapping

- What follows is a first pass attempt at doing some of these fits: there is a quite a bit of leeway in getting better fit quality with regularization (as seen for the disappearance spectra) so these might improve in the future.

- FHC ND numu fit to FD FHC numu
- FHC ND numu fit to FD FHC nue (intrinsic + oscillated)
- RHC ND numubar fit to FD RHC numubar
- RHC ND numubar fit to FD RHC nuebar
- FHC ND numu fit to FD RHC wrong-sign numu
- FHC ND numu fit to FD RHC wrong-sign nue
- FHC ND numu fit to ND FHC nue
- RHC ND numubar fit to ND RHC nuebar

The M. Wilking list

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$\times 10^{-12}$

Φ_ν

ν-mode, Sept2017 Engineered, T2K PRL2017 B.F. Osc.

Near ν_e Flux 16.5--33 m

Fitted ND ν_μ

E_ν (GeV)

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dp_FitFluxes

```
3   FluxInputs_FHC: {
4     InputFluxFile: @local::FHC_NearDet_FluxFile
5     # InputFluxName: ""
6     # MergeOffAxisBins: 0
7     # MergeNeutrinoEnergyBins: 0
8     FluxSliceDescriptor: "0_33:0.5"
9   }
```
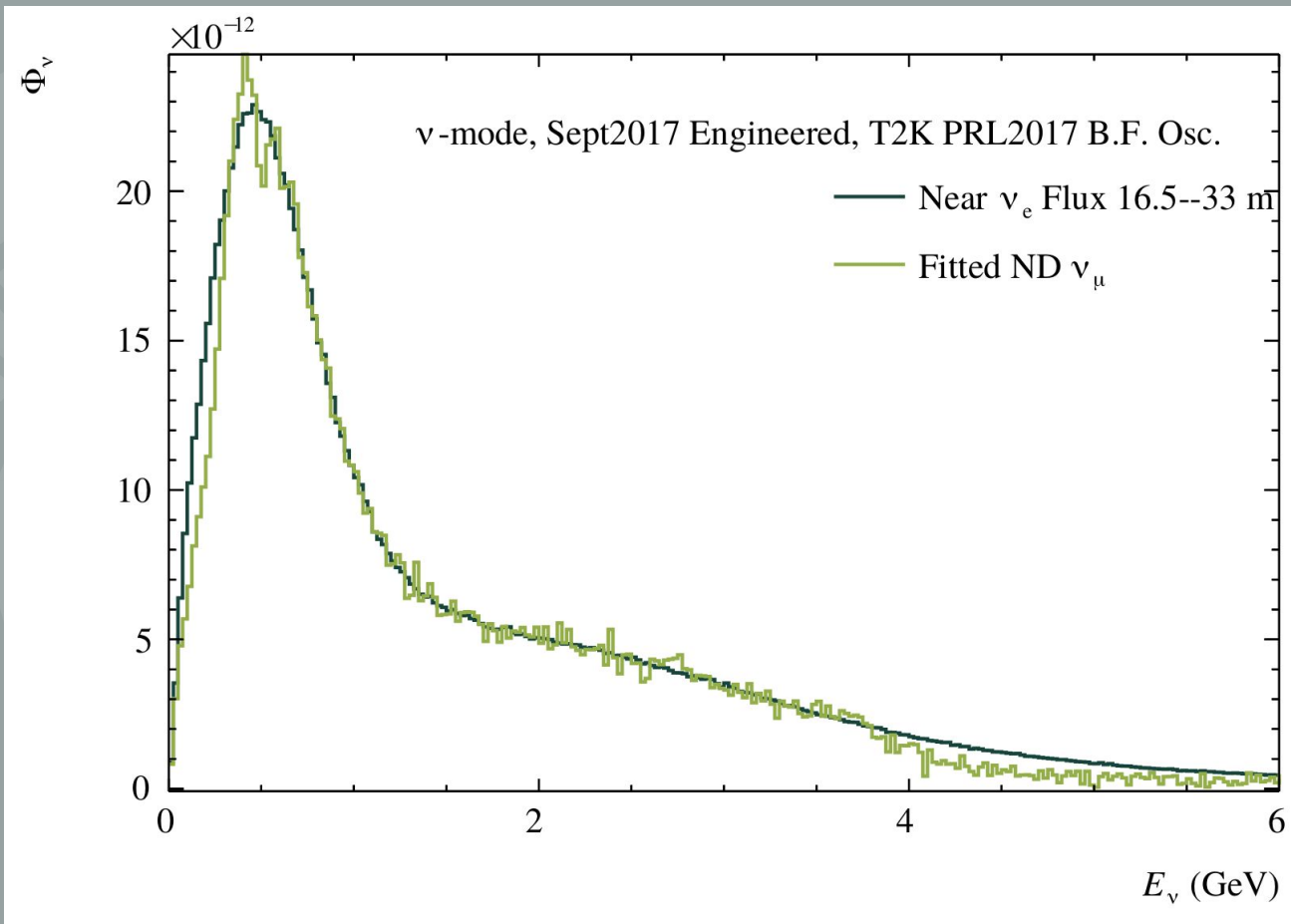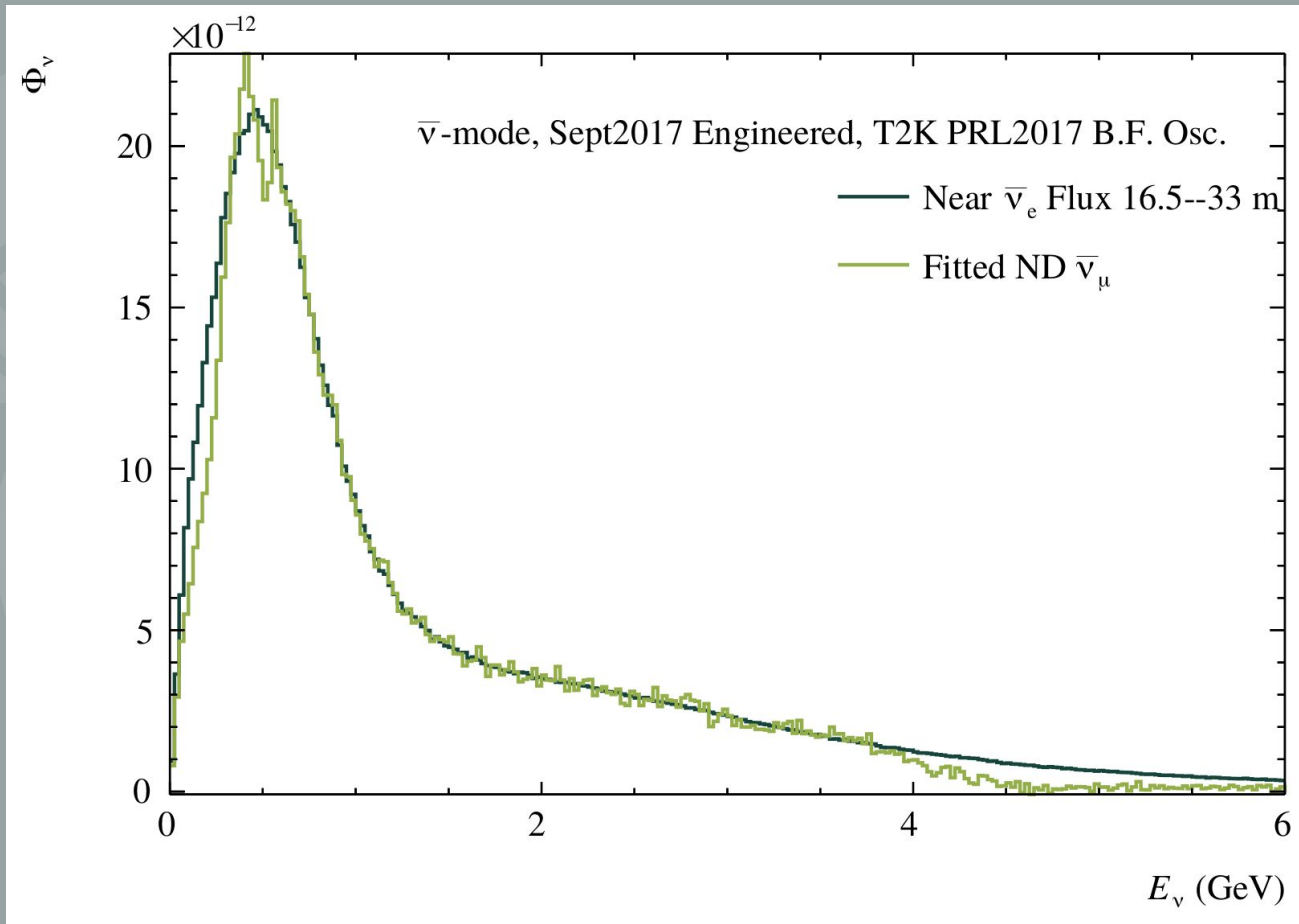**Input flux**
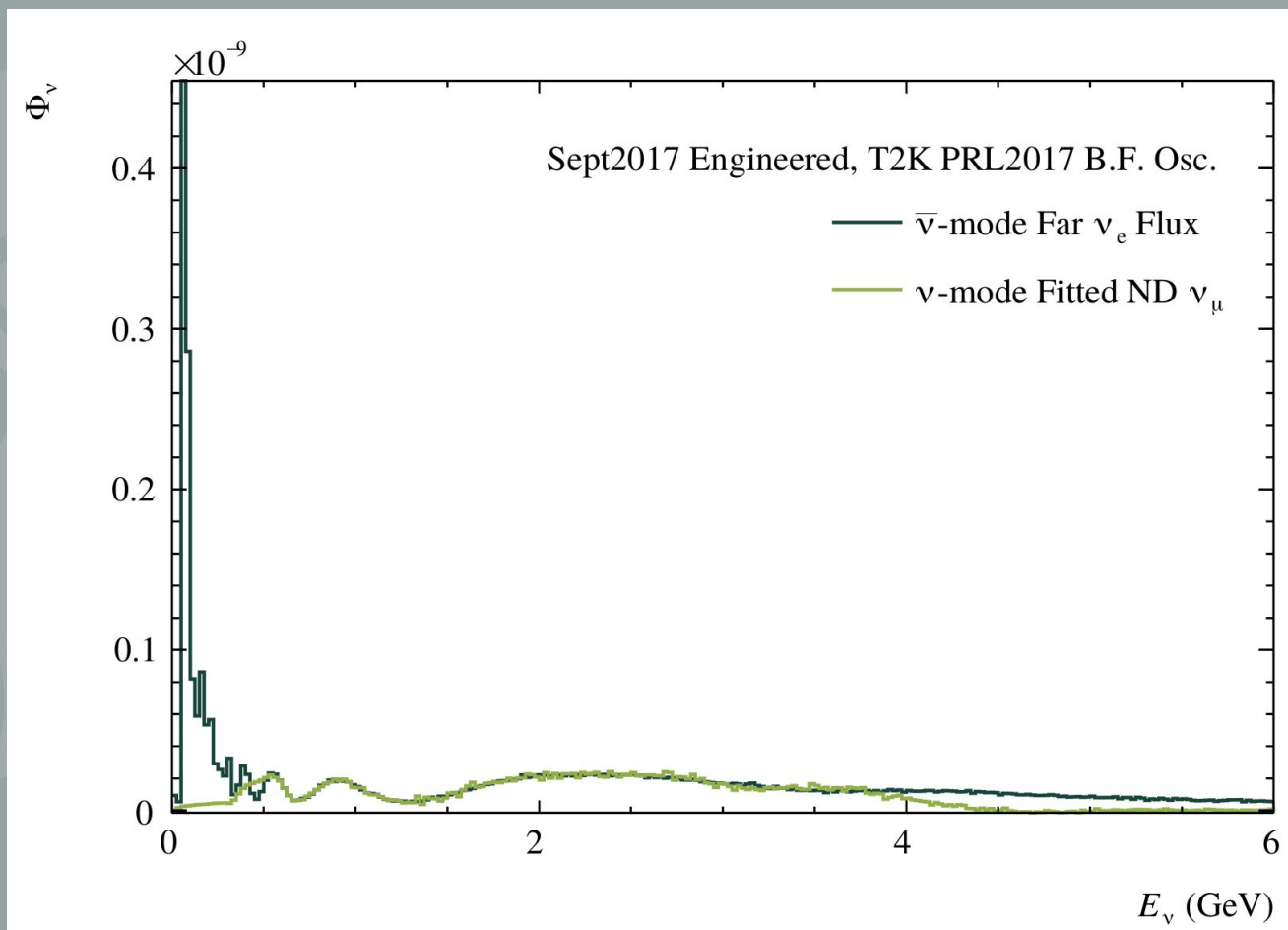
- For the purposes of these and future studies, I modified my previous monolithic fitting app into something controlled by a FHiCL file.

```
OscillationParameters_T2K2017: {
  S2Th12: 0.297
  S2Th13: 0.0214
  S2Th23: 0.534

  Dm2_21: 7.37E-5
  Dm2_Atm: 2.539E-3
  dcp: 0
}

Baseline_DUNE: {
  dip_angle: 5.8
}

Oscillation_T2K2017_DUNE: {
  OscillationParameters: @local::OscillationParameters_T2K2017
  Baseline: @local::Baseline_DUNE
}
```
Oscillations

```
FHC_FD_nue: {
  InputFluxFile: @local::FHC_FarDet_FluxFile

  Name: "FHC_FD_nue"
  Fluxes: [
    { # Intrinsic nue survival
    InputHistogram: LBNF_nue_flux
    Oscillate: [12,12]
    },
    { # Intrinsic numu -> nue
    InputHistogram: LBNF_numu_flux
    Oscillate: [14,12]
    }
```
Target flux construction

- Requires input flux files (not public so cannot include), email me for some recent inputs (from next week I will host some blessed inputs on /pnfs/.

- Aim to add reg/fit region/osc param scanning features soon.

Code: Standalone, just requires ROOT:
github.com/luketpickering/DUNEPrismTools

```
OutputFile: test.fit.root
RecreateOutputFile: true

Fits: [
  @local::Fit_FD_FHC_numu_disp,
  @local::Fit_FD_FHC_nue_app,
  @local::Fit_FD_RHC_numubar_disp,
  @local::Fit_FD_RHC_nuebar_app,
  @local::Fit_FD_RHC_numu_disp_WSB,
  @local::Fit_FD_RHC_nue_disp_WSB,
  @local::Fit_ND_FHC_nue_intrinsic,
  @local::Fit_ND_RHC_nue_intrinsic
]
```
Run some fits

```
Fit_FD_RHC_nuebar_app: {
  @table::Fit_Base
  FitRange: [0.5, 4]

  FluxInputs: @local::FluxInputs_RHC_numubar

  BuildTargetFlux: true
  FluxDescription: {
    @table::RHC_FD_nuebar
    Oscillation: @local::Oscillation_T2K2017_DUNE
  }

  OutputDirectory: "RHC_nuebar_app"
}
```
Fit config

Flux Fit Interpolation

- Flux fit from scratch takes O(1 min): Infeasible to run at fit time
  - Previous demo analyses have not 'fit' to extract oscillation parameters, but instead performed DeltaChi2 scans with pre-marginalized systematics.
- Previous studies suggest with adequate regularization, individual linear sum coefficients vary quite smoothly in disappearance parameter space:
  - Need to extend to 4D oscillation parameter space.
  - Interpolate coefficients and build far detector flux prediction, compare to from-scratch fit.
  - Other possibility: If interpolation is not good enough, but close, can seed on-the-fly flux fits with interpolated coefficients and fits should finish *much* faster.
- Studies on-going...

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A word on Cheating (1)

- We have identified a few DUNE-PRISM analysis components that we will likely 'cheat' in the proposed linear-combination analysis, but need to discuss what is acceptable for TDR:
  - Ignore WSB in FHC.
  - ND<->FD Efficiency correction
    - Hope to perform data-driven, geometric efficiency corrections in future analyses, but do not have time/person-power to build these studies yet.
    - Aim is to define regions of some interaction-relevant phase space that we will be able to correct at the near detector and limit the effect on xsec systematics on events here. Events outside this space will get the full xsec uncertainty.

A word on Cheating (2)

- We have identified a few DUNE-PRISM analysis components that we will likely 'cheat' in the proposed linear-combination analysis, but need to discuss what is acceptable for TDR:
  - ND (cheated) <->FD (CVN) ERec differences:
    - PRISM analysis power comes from apples-to-apples comparison between near and far observables, any differences need to be corrected for (c.f. nue appearance spectra).
    - Practically for the TDR analysis, may need extra FD variables that are cheated in a similar way to the ND, other strategies available for real data.

Immediate Plans

- Guang will continue getting the ND off-axis samples generated and then move on to adapting CAFAna-DUNE for DUNE-PRISM analysis.
- I am going to get the flux uncertainties produced:
  - Previously only calculated alignment uncertainties:
    - Don't gain anything by using an uncertainty matrix in enu energy/species as there's only a few parameters.
  - Hadron production uncertainties add a very large number of 'parameters'
    - Gain a lot by building and diagonalizing an uncertainty matrix: 700+ parameters become only a few important principle components.
  - Preliminary DUNE-PRISM linear sum disappearance analysis used O(70) flux windows, previous Near/Far matrix had 208 'bins', proposed Near*70/Far matrix would have O(7600) 'bins'.
    - Plan to perform PCA and distribute fully correlated uncertainties as just the EVal/EVects that contain most of the variance -- Fitters do this decomposition on the fly, but inversion of 7500x7500 matrix may need special attention and there is no reason to perform it on the fly.
  - Hopefully get this done this coming week.

L. Pickering

Thanks for listening

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Status

- Guang has been throwing ND events at off-axis stops:
  - Need to validate that they look as expected and then ramp up statistics.
  - ~On track.

- Would be ideal to do the 'DUNE-PRISM' fake data study:
  - Remove some % energy from protons and give to neutrons
  - Find event-by-event reweights to make ND fake data look like ND nominal in many analysis projections (Solved ML problem).
  - Project weights to model variables (Q2, W, …) and propagate ML-made model to far detector.
  - Taking energy from protons is only a complete study if re-run from detsim stage.
  - Requires altering GHep events before being passed to GEANT:
    - I know how to do this for ND sim
    - C. Backhouse and A. Himmel, suggest writing ART module for FD should be easy (similar approach used by NOvA).
  - Other fake data studies should also show the power of DUNE-PRISM, but this is being kept as a stretch goal.