vPRISM Linear Combination Fits

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Linear Combination Review

- The way we are currently using nuPRISM is to reproduce a flux for which we want to measure final state observables with a linear combination of the nuPRISM off-axis fluxes

$$\Phi^{meas}(E_\nu) = \sum_{i=1}^{N_{OA}} c_i \Phi_i^{\nu P}(E_\nu)$$

- In the case of the disappearance analysis, the linear combination reproduces the surviving numu flux at SK:

$$\Phi_{\nu_\mu}^{SK}(E_\nu) P_{\nu_\mu \to \nu_\mu}(E_\nu | \Delta m^2, \theta) = \sum_{i=1}^{N_{OA}} c_i(\Delta m^2, \theta) \Phi_i^{\nu P}(E_\nu)$$

Linear Combination for RHC Neutrino Background

- There are additional linear combinations we may want to make:

- For the antineutrino mode (RHC) nuPRISM analysis we can model the wrong sign neutrino flux with the right sign neutrino flux from neutrino mode (FHC):

$$\Phi_{\nu_\mu}^{\nu P, RHC}(E_\nu, \theta_{OA}) = \sum_{i=1}^{N_{OA}} c_i(\theta_{OA}) \Phi_{\nu_\mu, i}^{\nu P, FHC}(E_\nu)$$

- In Leila's analysis, she will use this type of linear combination to predict the RHC wrong sign background and subtract it for each off-axis angle bin

Linear Combinations for Nue Appearance Analysis

- In the nue appearance analysis we will begin by making the linear combination that reproduced the SK beam+oscillated nue with the nuPRISM numu fluxes:

$$\Phi_{\nu_e}^{SK} + \Phi_{\nu_\mu}^{SK}(E_\nu) P_{\nu_\mu \to \nu_e}(E_\nu | \Delta m_{32}^2, \theta_{13} ...) = \sum_{i=1}^{N_{OA}} c_i(\Delta m_{32}^2, \theta_{13}, ...) \Phi_{\nu_\mu, i}^{\nu P}(E_\nu)$$

- If the numu and nue cross sections were the same, this could be used to predict the event rate in the far detector

- Since they aren't the same, we need to make a correction by the nue/numu cross section ratio

Linear Combinations for Nue Appearance Analysis, Cont.

- We can't measure the nue/numu cross section ratio for mono-energetic beams or the SK total nue flux, but we can measure it for the nuPRISM intrinsic nue flux

- We reproduce shape of the intrinsic nue flux with the off-axis numu fluxes to the cross section ratio is produced with identical fluxes in the numerator and denominator

$$\Phi_{\nu_e}^{\nu P}(E_\nu) = \sum_{i=1}^{N_{OA}} c_i \Phi_{\nu_\mu, i}^{\nu P}(E_\nu)$$

- In practice, it may be best to make this measurement with the more off-axis beam nue in nuPRISM since the average energy is a bit lower and the spectrum is more similar to the SK nue spectrum

What I will Show in this Talk

- Leila and Asher are now working on the analyses that will use these new linear combination techniques

- I did some preliminary feasibility studies for the linear combination fits for the EOI

- I added some scripts to the macros directory to make these fits

- I will show the results of the preliminary linear combination fits

Wrong Sign Numu Fit

- This can be run with the fit_spectrum_WrongSign.cc macro

  - The function/arguments are:
    fit_spectrum(double elo = 0.4, double ehi = 3.0, int nbins = 30,
    double oamin = 3.0, double oamax = 4.0)

- I run the fit over the 0.4-1.5 energy range for the 3.0-4.0 degree off-axis range

- Fits at larger off-axis angle ranges work better since the energy is lower

- To produce fits in fine off-axis binning, I should make more flux statistics

Wrong Sign Numu Fit Results
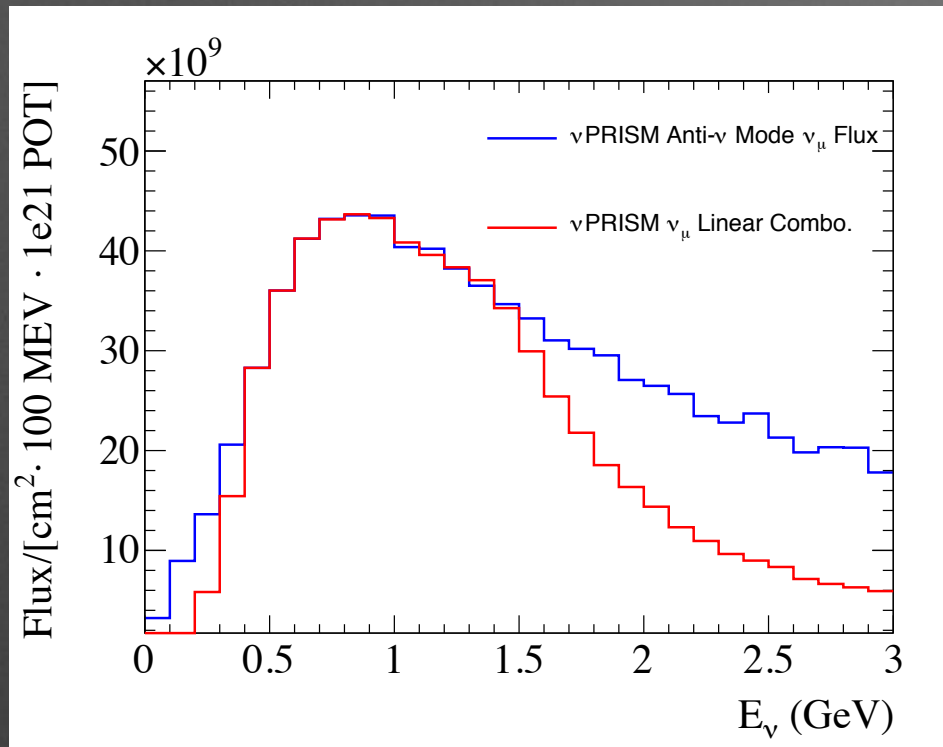
- The wrong sign flux can be fitted well in the 0.4-1.5 GeV range

- Expect that this region is where the nuPRISM reconstruction efficiency is high

- The coefficients are relatively smooth

 - Have not check the statistical errors for the selected samples
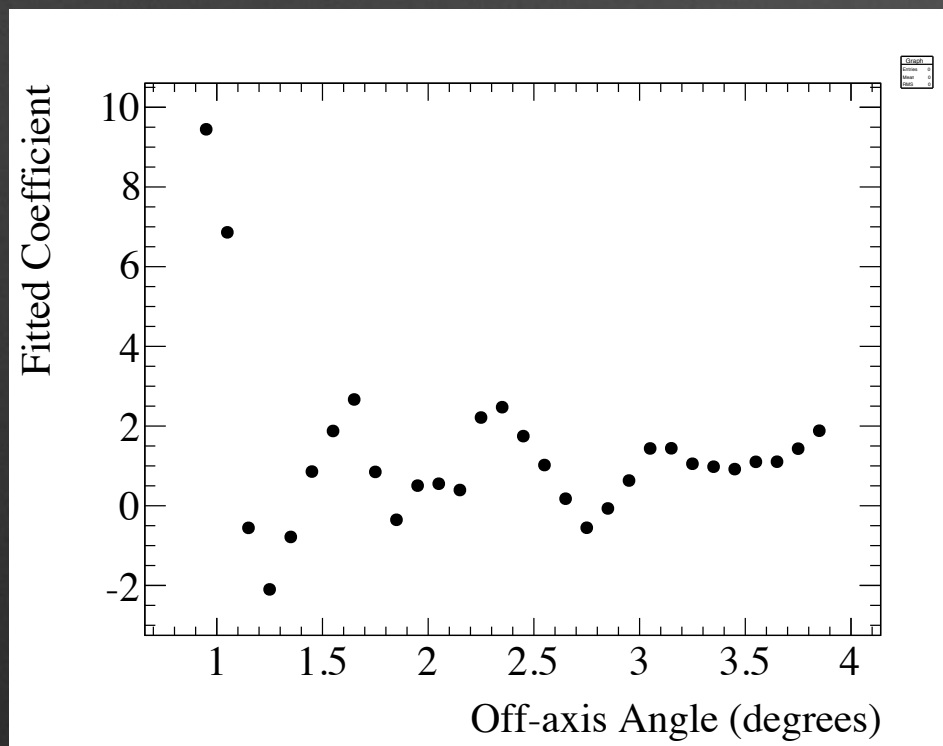
SK Beam+Oscillation Nue Fit

- This can be run with the fit_spectrum_SKNue.cc macro

  - The function/arguments are:
    fit_spectrum(double theta23, double dm2, double theta13,
    double delta, double elo = 0.4, double ehi = 3.0)

  - Here the angles are $\sin^2\theta$

- I ran the fit with theta23=0.5, dm2=0.0024, theta13=0.0241, elo=0.4, ehi=1.5

SK Beam+Oscillation Nue Results
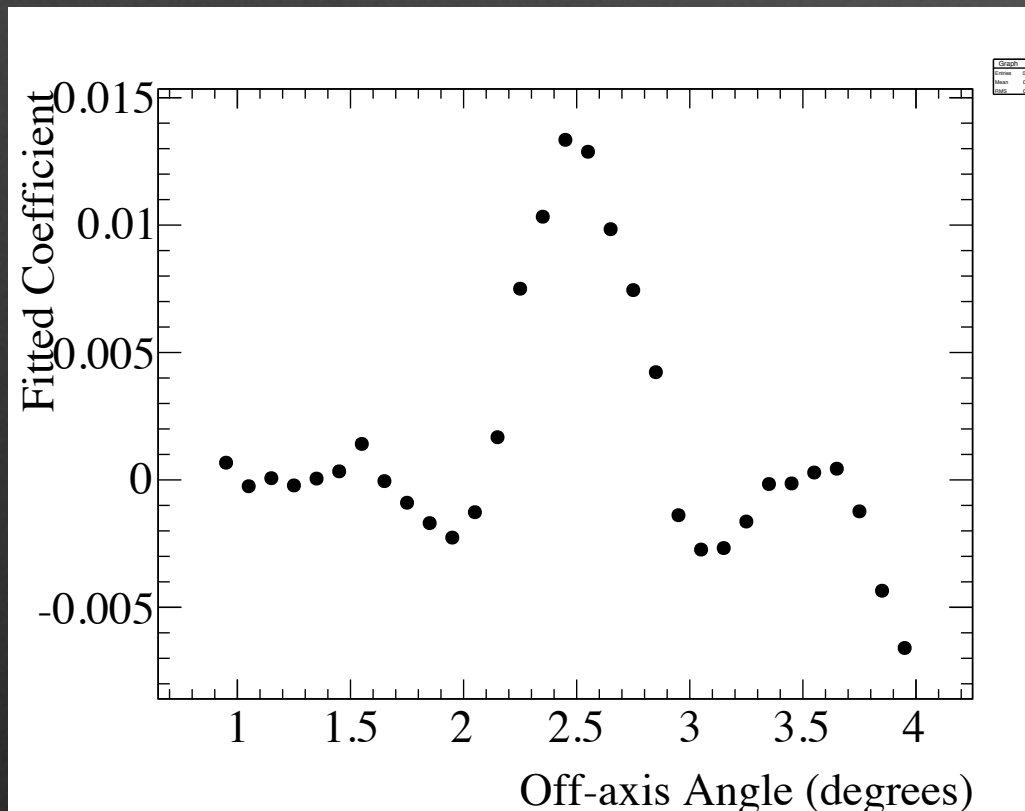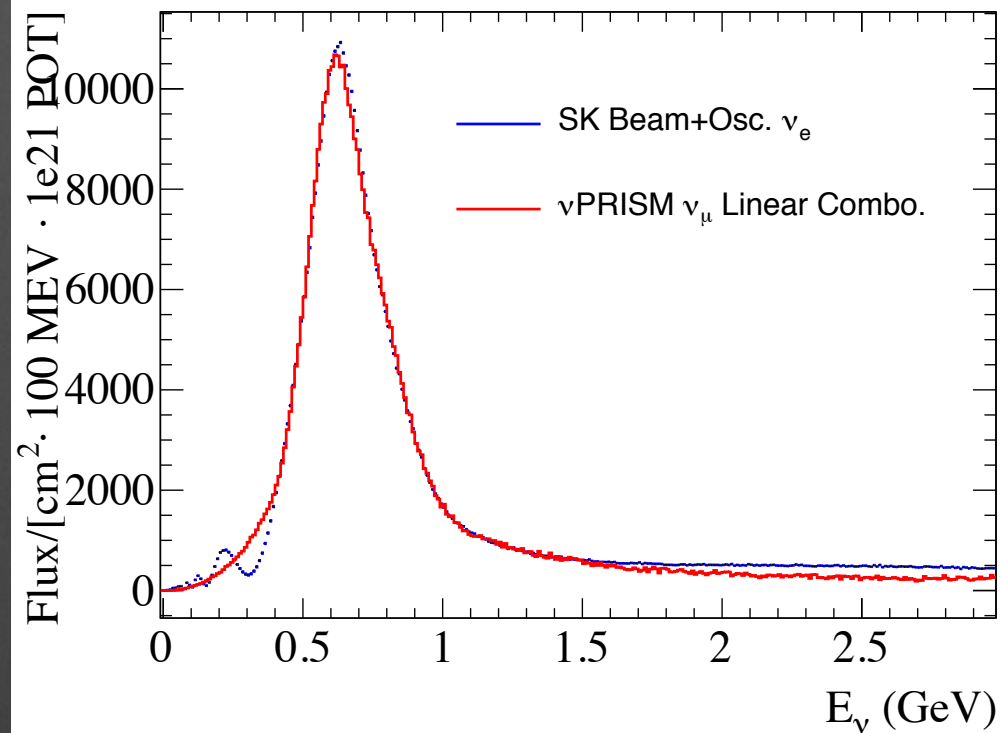
- The SK total nue flux can be reproduced well with the nuPRISM off-axis fluxes

- Haven't yet tried other assumptions the oscillation parameters

- The coefficients mostly around 0 with a peak near 2.5 degrees

- Coefficents are relatively smooth with the default macro settings

nuPRISM Beam Nue Fit

- This can be run with the fit_spectrum_BeamNue.cc macro

  - The function/arguments are:
    fit_spectrum(double elo = 0.4, double ehi = 3.0, int nbins = 30,
        double oamin = 3.0, double oamax = 4.0)

- I run the fit over the 0.4-1.5 energy range for the 2.5-4.0 degree off-axis range

- Fits at larger off-axis angle ranges work better since the energy is lower

- Larger off-axis bins also cover a lower energy range that is more consistent with the total SK Nue flux

nuPRISM Beam Nue Results
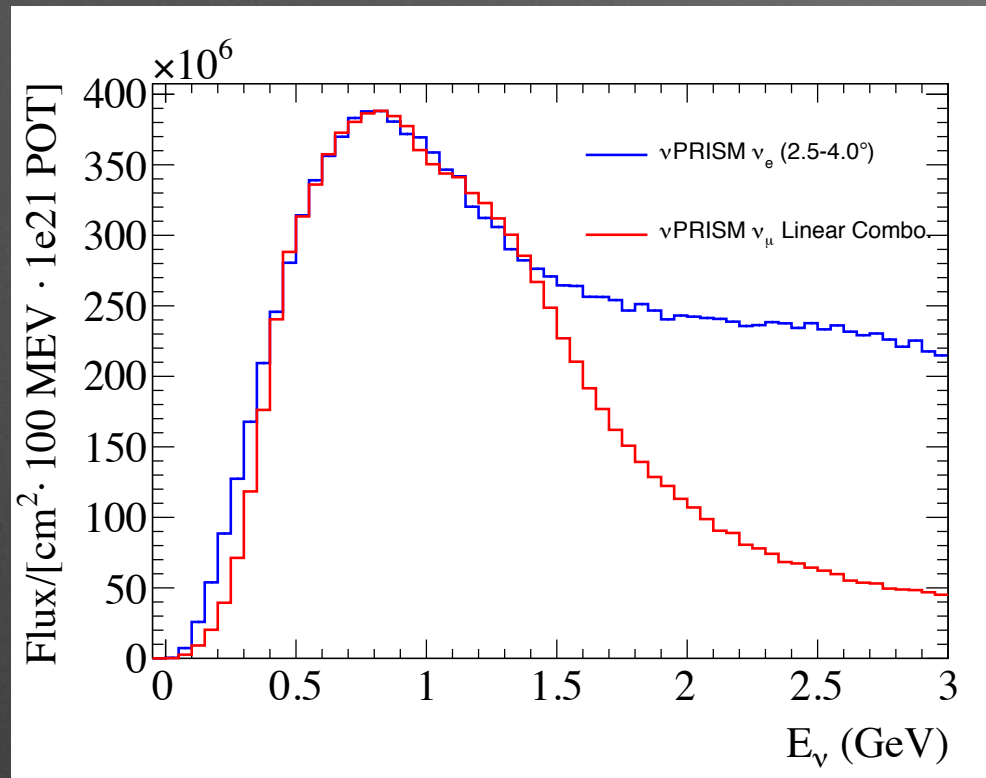
- Once again, the flux in the 0.4-1.5 GeV range can be reasonably reproduced

- The coefficients are largely selecting the most on-axis numu flux with some corrections from the more off-axis fluxes
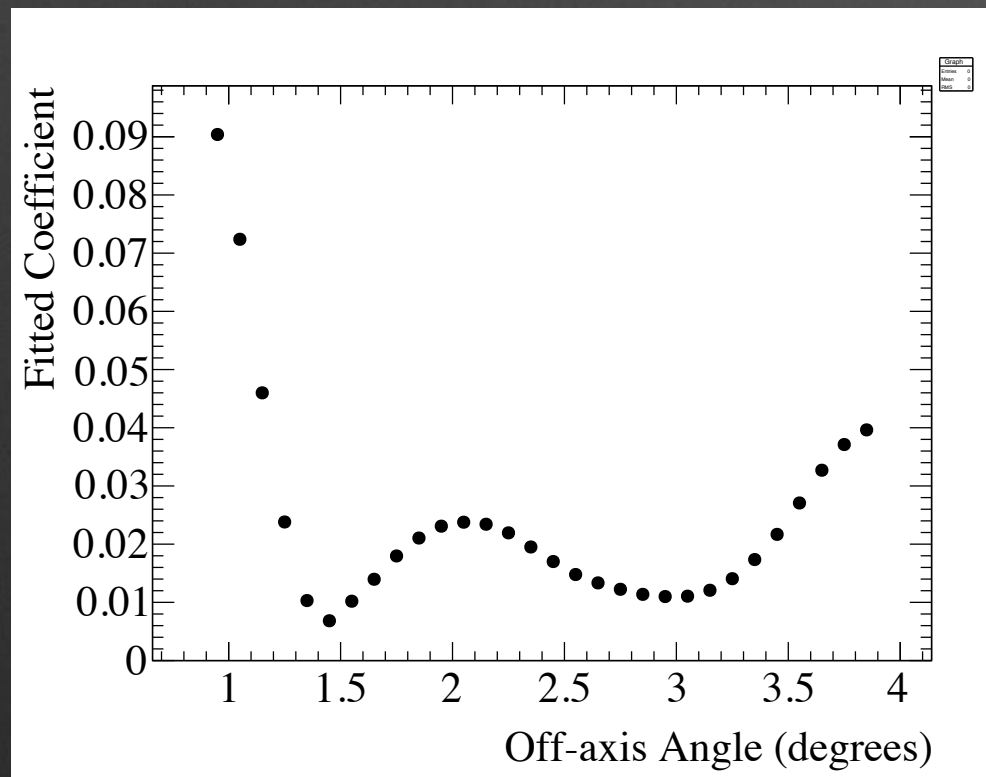
Conclusions

- We can use the linear combination method to model the nuPRISM wrong sign antineutrino mode background, and nue fluxes for the appearance analysis

- I have check macros for doing the flux fits into the repository

- In all three cases, the flux fits work reasonably well

- This work will be continued by Leila and Asher