

PRISM Analysis Status

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LBL Meeting
26th July 2021

Talk Outline

- 1. Disappearance analysis procedure**
- 2. Cross section and flux systematics in a disappearance analysis**
- 3. Disappearance fits**
- 4. PRISM appearance analysis**

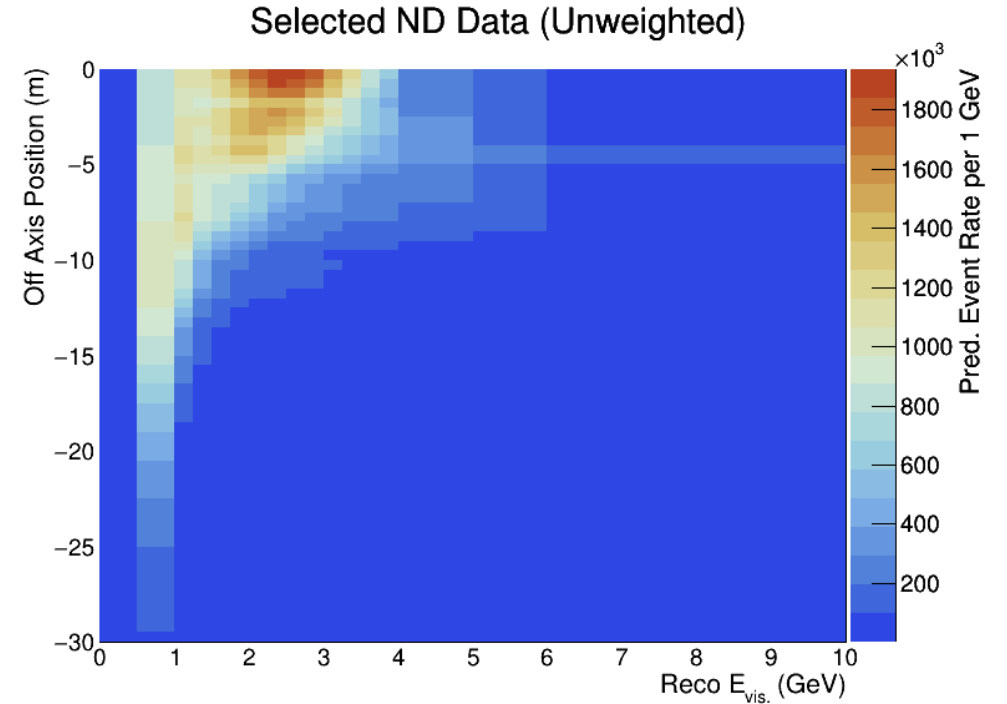
Data and Event Selection

- Collect data at the ND and apply a **selection**:
 - $\text{reco_numu} = 0$ or 1 (muon reconstructed)
 - $\text{EHad_veto} < 30$ MeV (hadronic energy veto cut)
 - Muon either contained in ND-LAr or makes it into ND-GAr
- Selection applied in the FD data using **CVN** from FD TDR
- Use $E_{vis, reco}$ and analogous true variable $E_{vis, true}$

$$E_{vis, reco} = E_{lep, reco} + E_{p, reco} + E_{\pi^{\pm}, reco} + E_{\pi^0, reco} + E_{other, reco}$$

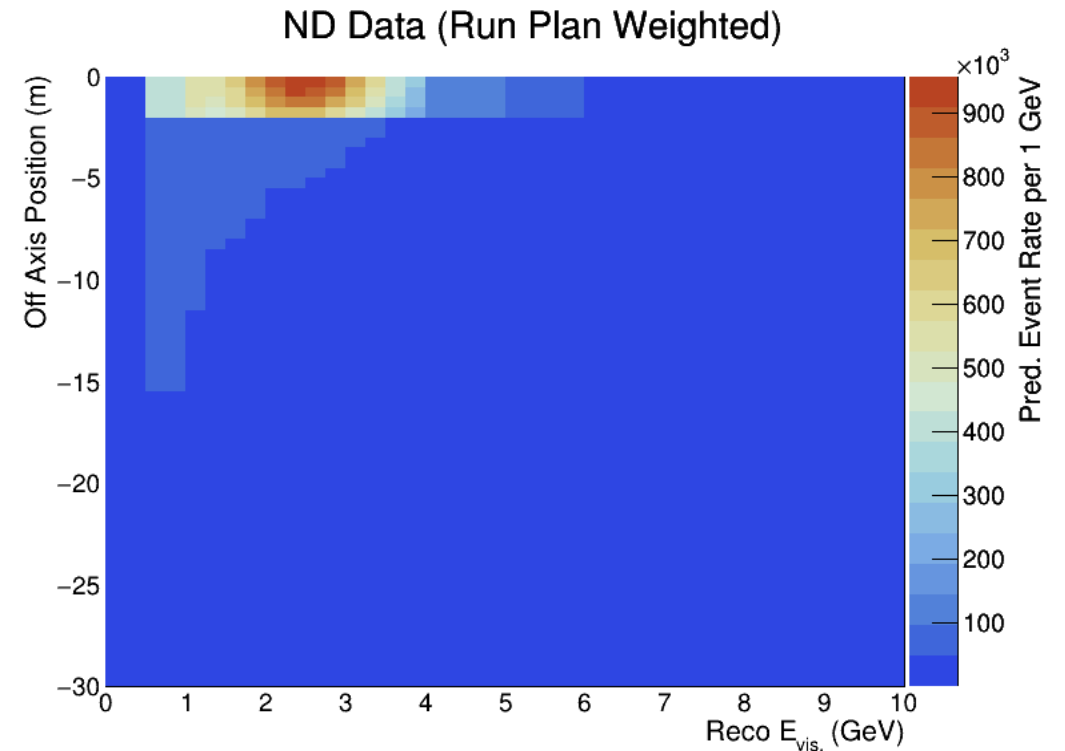
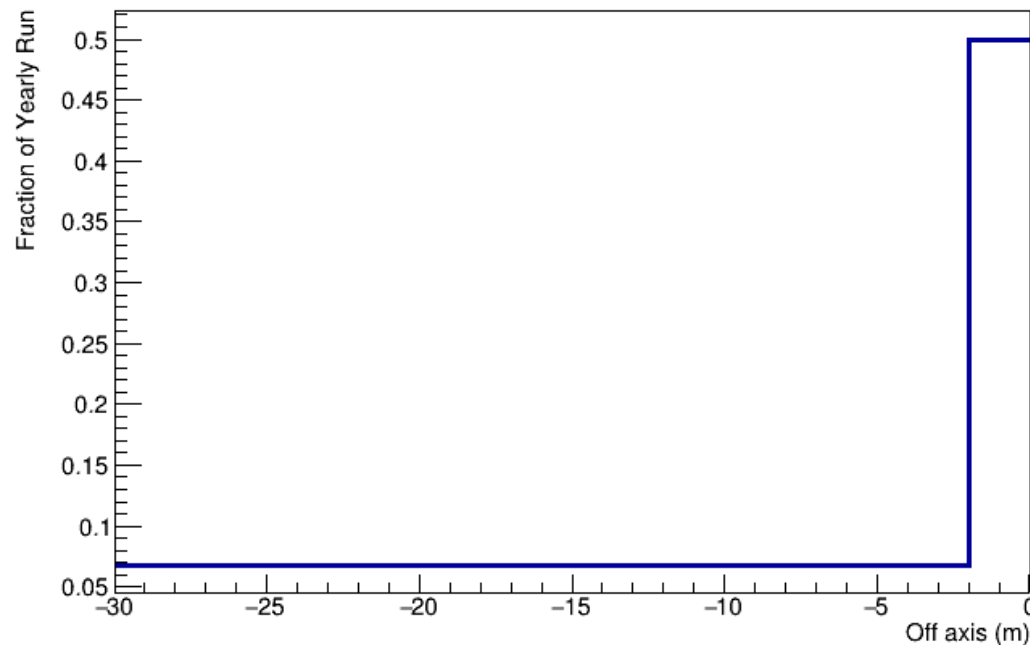
$$E_{vis, true} = E_{lep, true} + T_{p, true} + T_{\pi^{\pm}, true} + T_{\pi^0, true} + (M_{\pi^0} \times N_{\pi^0}) + T_{other, true}$$

- Variables are the sum of the **visible energy** in the detector



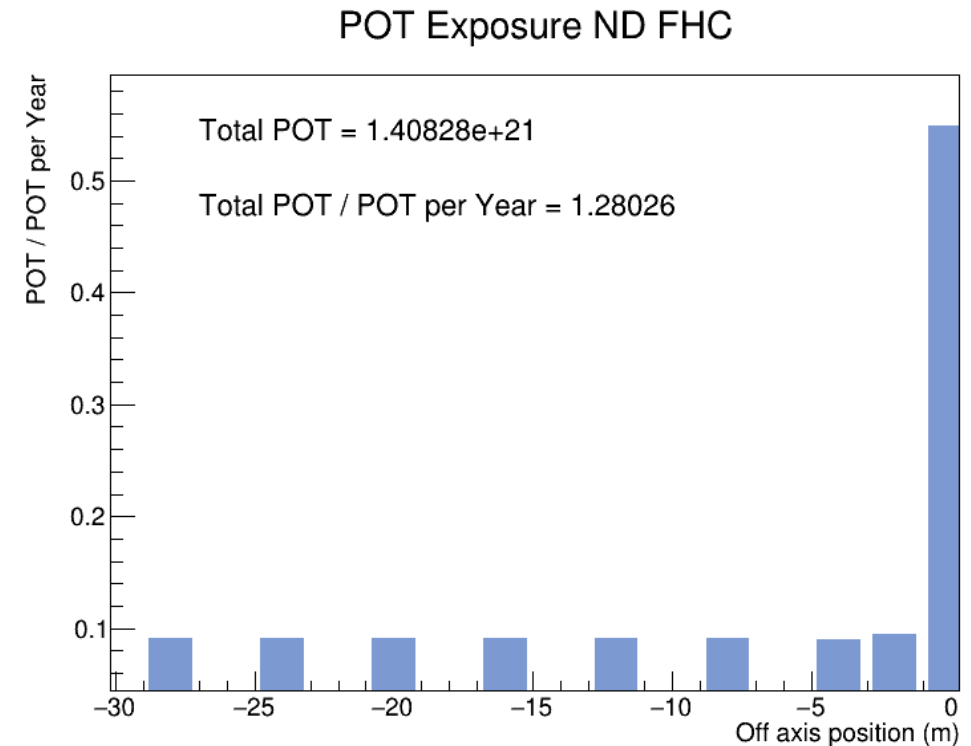
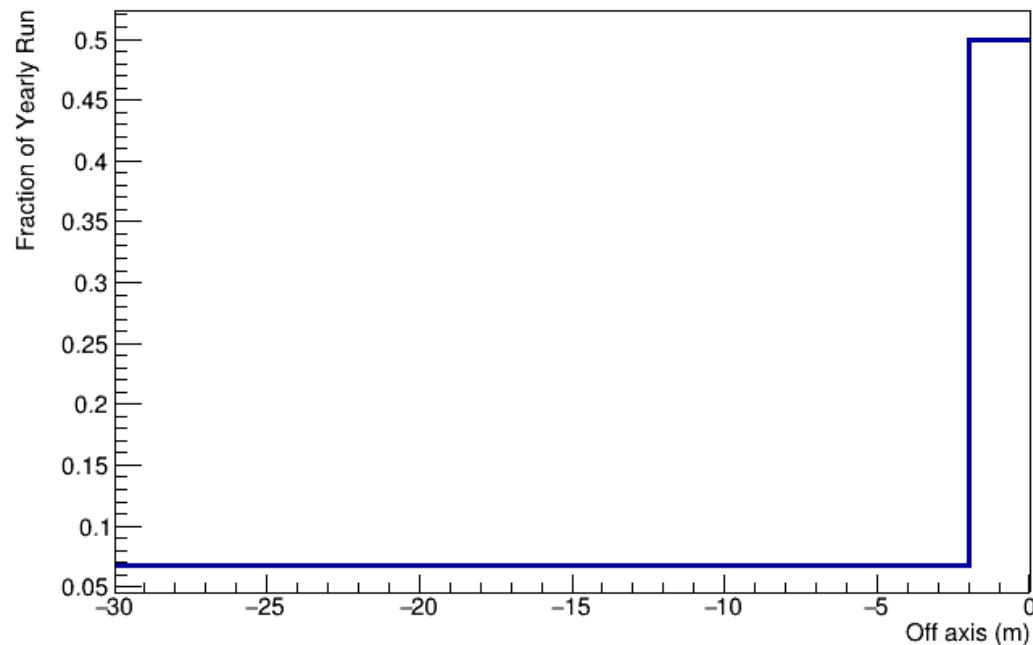
Data and Event Selection

- Take data at the ND according to a **1-year run plan**
- In the **CDR run plan**, most data is taken in the **on-axis position**
- Set the statistical uncertainty in each bin to be \sqrt{N} → mocks-up the uncertainty in a **real analysis**



Data and Event Selection

- Bottom **right**: actual exposure in our **ND FHC CAF file**
- Bit over a year of exposure (1.28 POT-years) in MC file – restrict current analysis to **1 year**



Signal Extrapolation Procedure

FINISH

1. Subtract backgrounds from each ND off axis slice

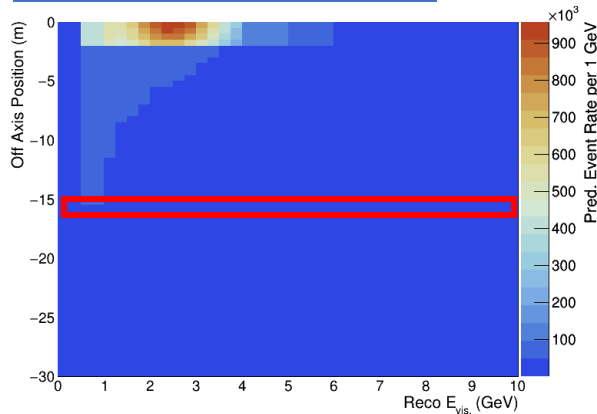
2. Construct **smearing matrices** for the ND and FD

3. **Unfold** each slice of ND data to **true variable**, correct for efficiency in ND slice (ND detector systematics)

6. Add FD backgrounds to get **Extrapolated PRISM Prediction** in reconstructed visible energy

4. **Smear true variable** in each slice to FD reco, correct for FD efficiency (FD detector systematics)

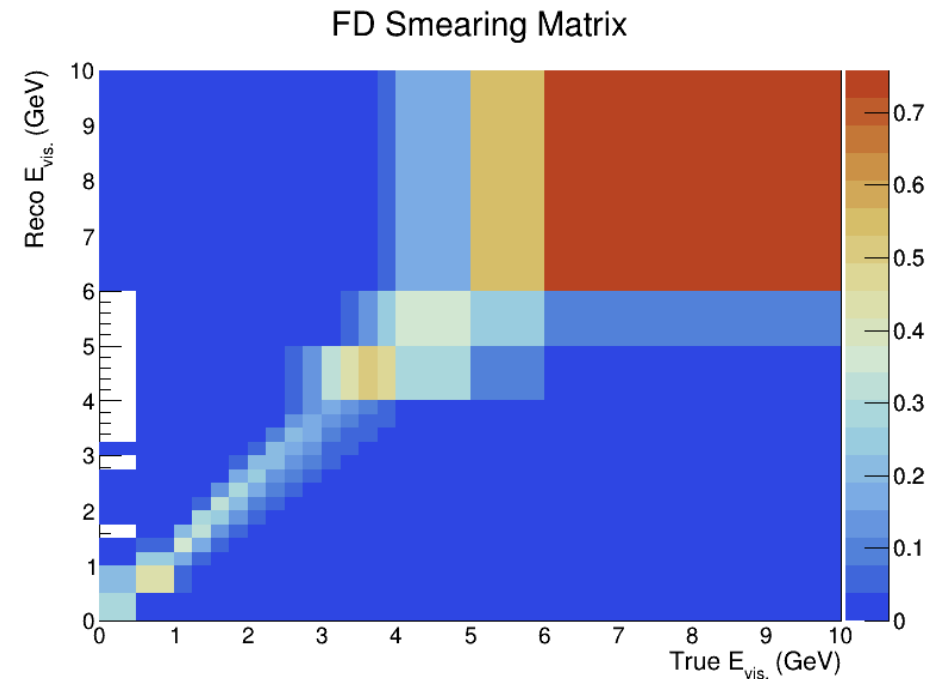
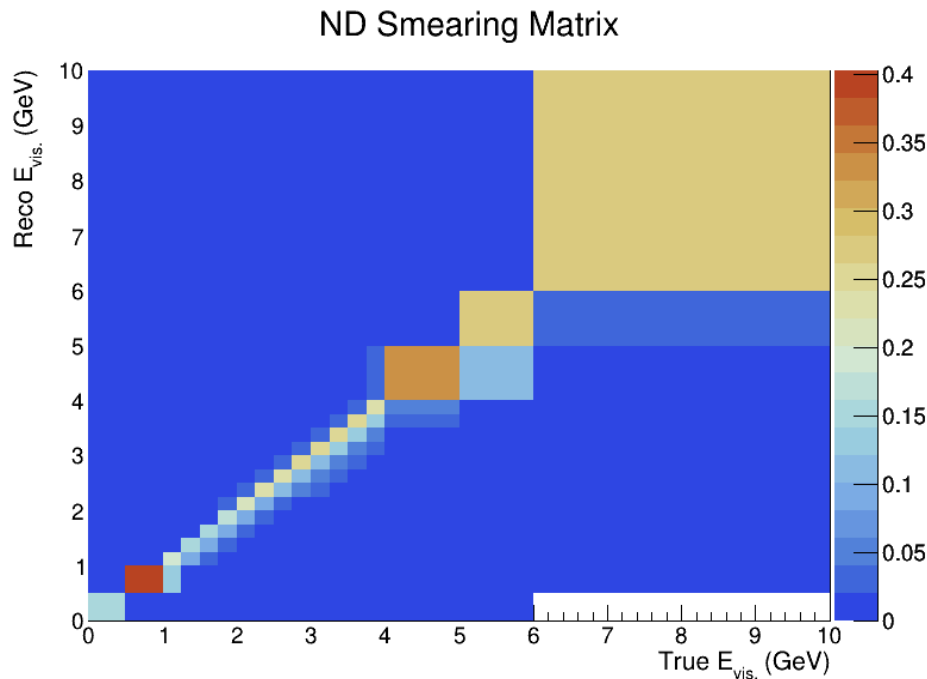
5. Perform linear combination of extrapolated ND off-axis data



START

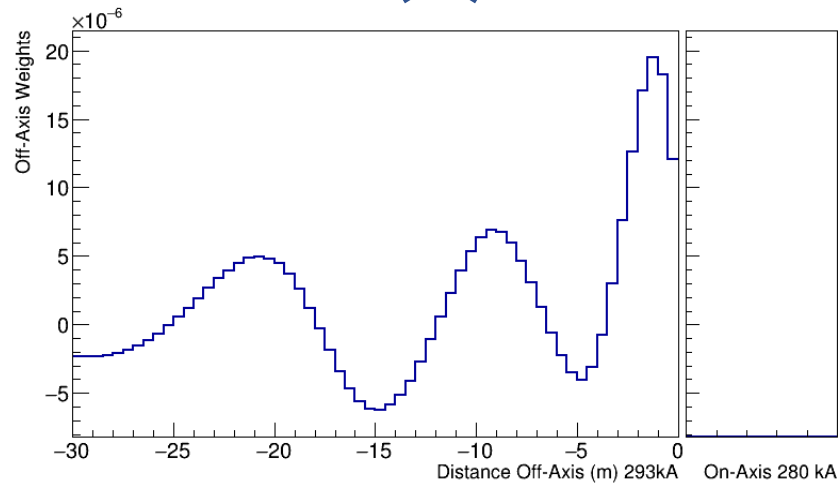
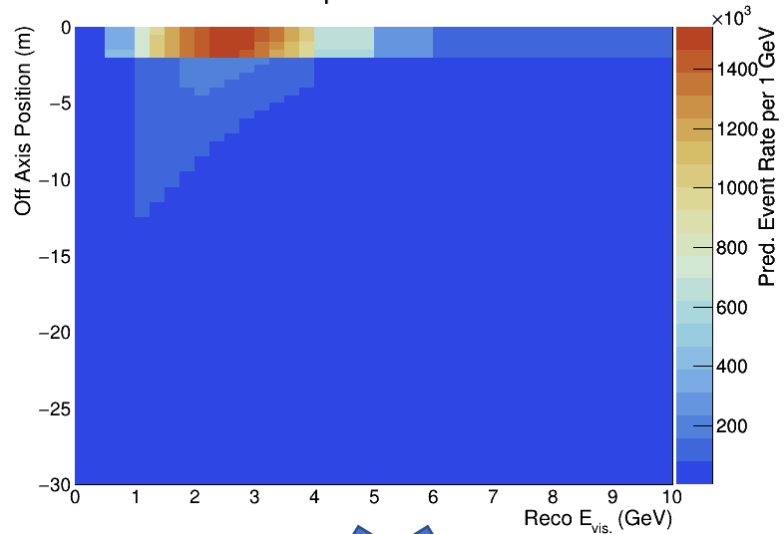
Signal Extrapolation Procedure

- Each matrix is the relationship between **E_{vis, reco}** and **E_{vis, true}** in the ND and FD
- Normalise the integral of each true energy bin to the **selection efficiency** at that energy
- ND smearing matrix normalised to the efficiency at the **particular off-axis position**

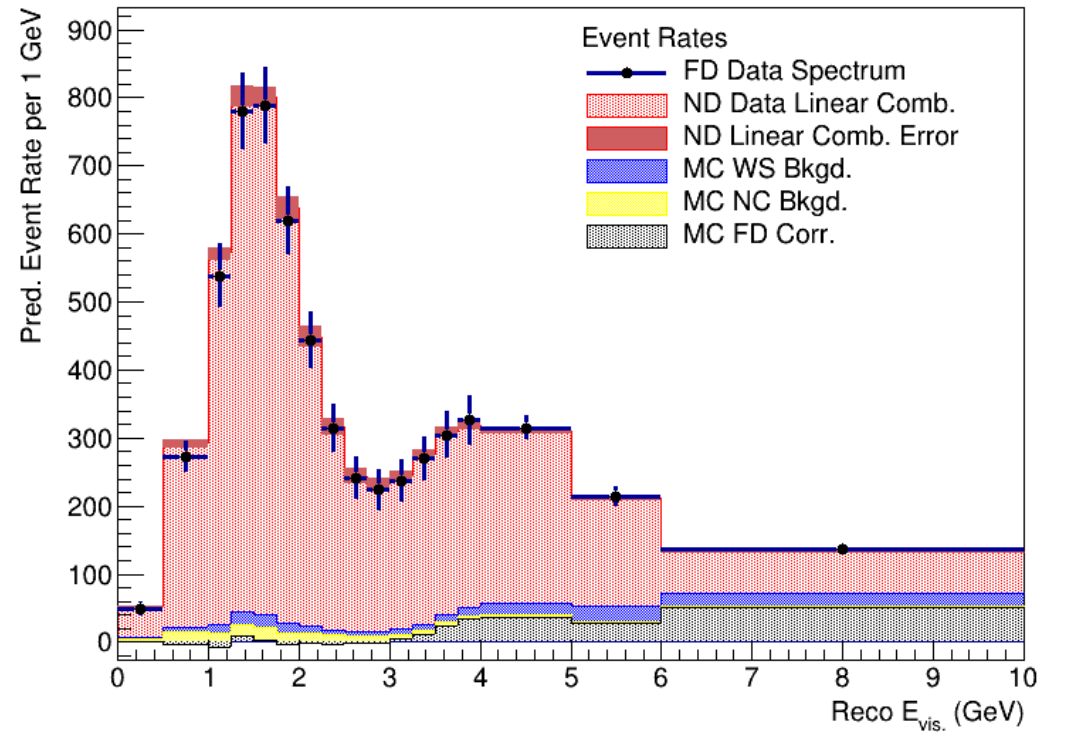


FD Disappearance Prediction

Extrapolated ND Data

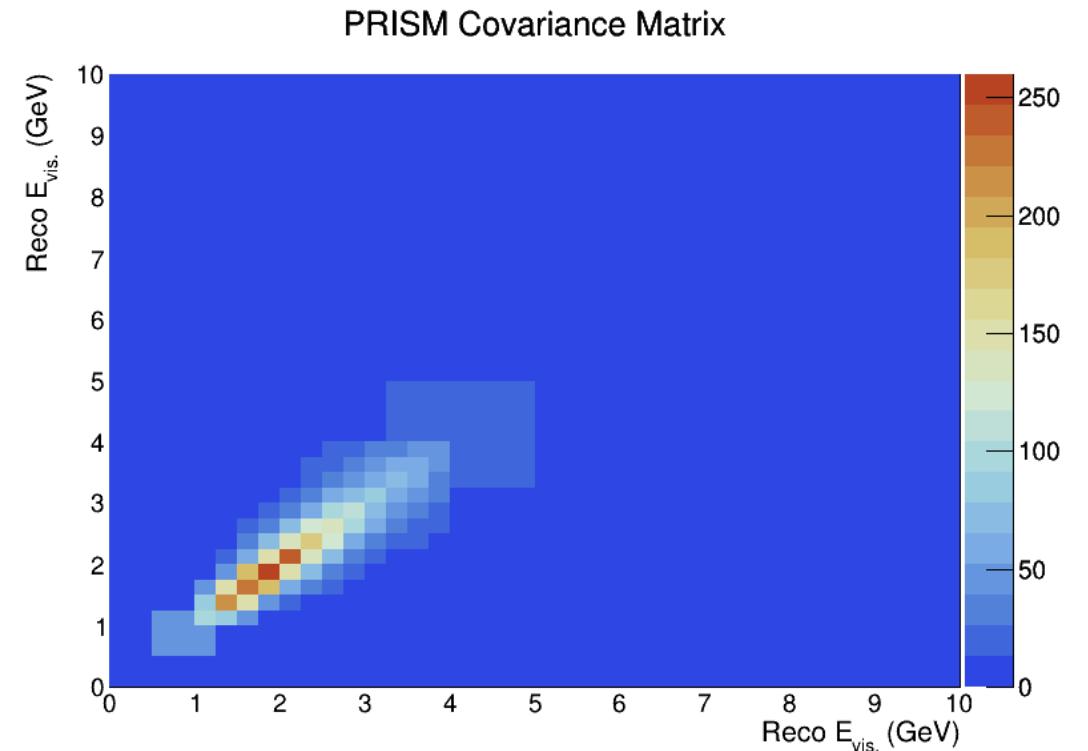
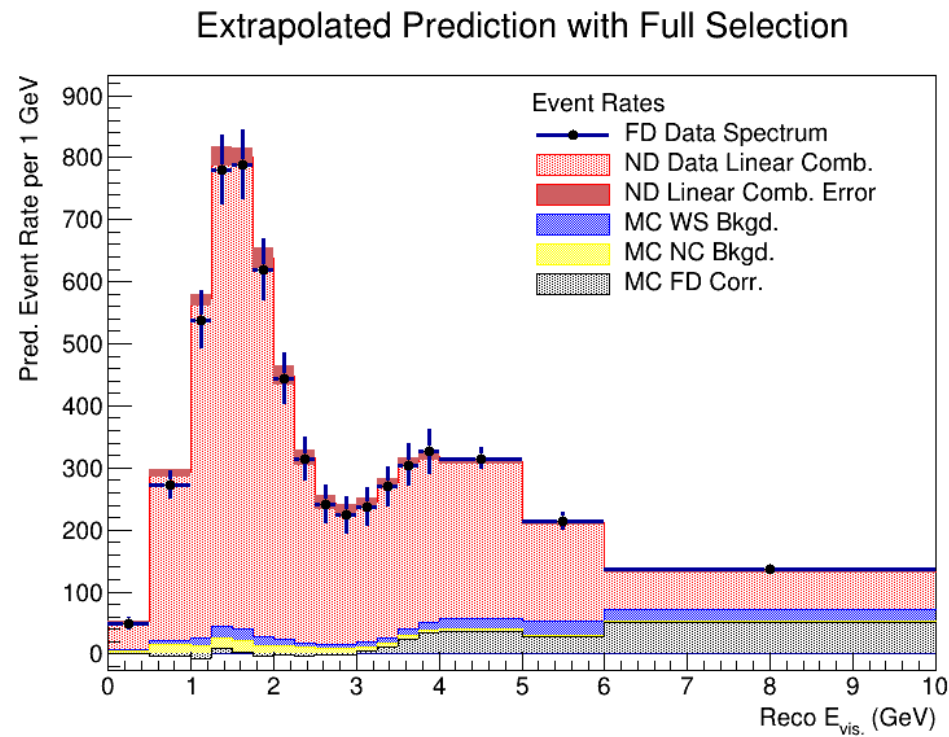


Extrapolated Prediction with Full Selection



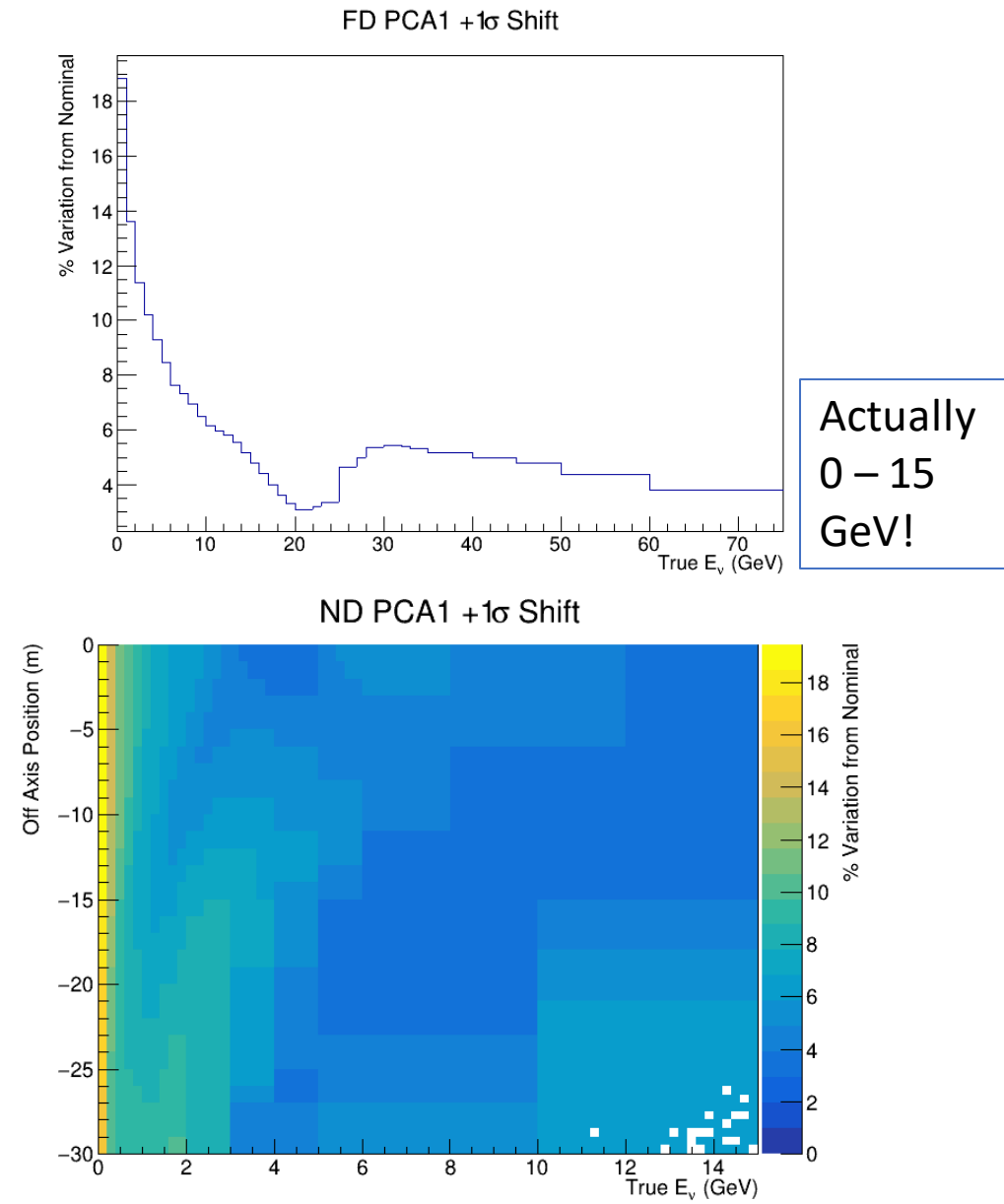
FD Disappearance Prediction

- Statistical uncertainty on PRISM Prediction given by a **covariance matrix**
- Covariances arise from the **unfolding** of each slice of ND data
- Diagonal of final covariance matrix **exactly matches** bin errors in 1D prediction plot



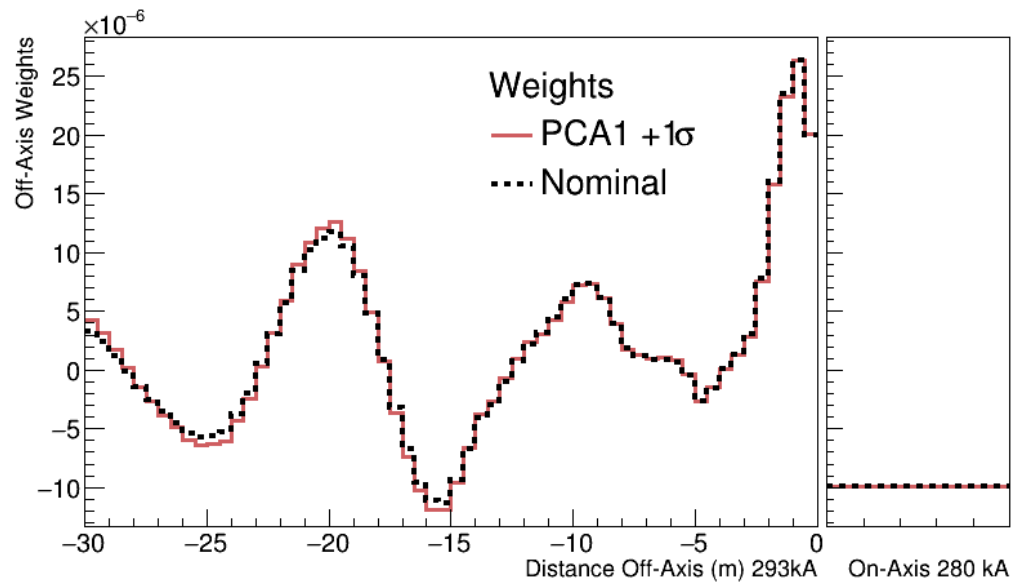
Flux Systematics

- Flux systematic parameters can shift:
 - Flux prediction used to calculate the **weights**
 - Backgrounds **subtracted** from ND data
 - Backgrounds and MC flux correction **added** to FD prediction
 - Calculation of **efficiency**
 - ND and FD **smearing matrices**
- Shown: shift in unselected event rate due to **hadron production** PCA component 1

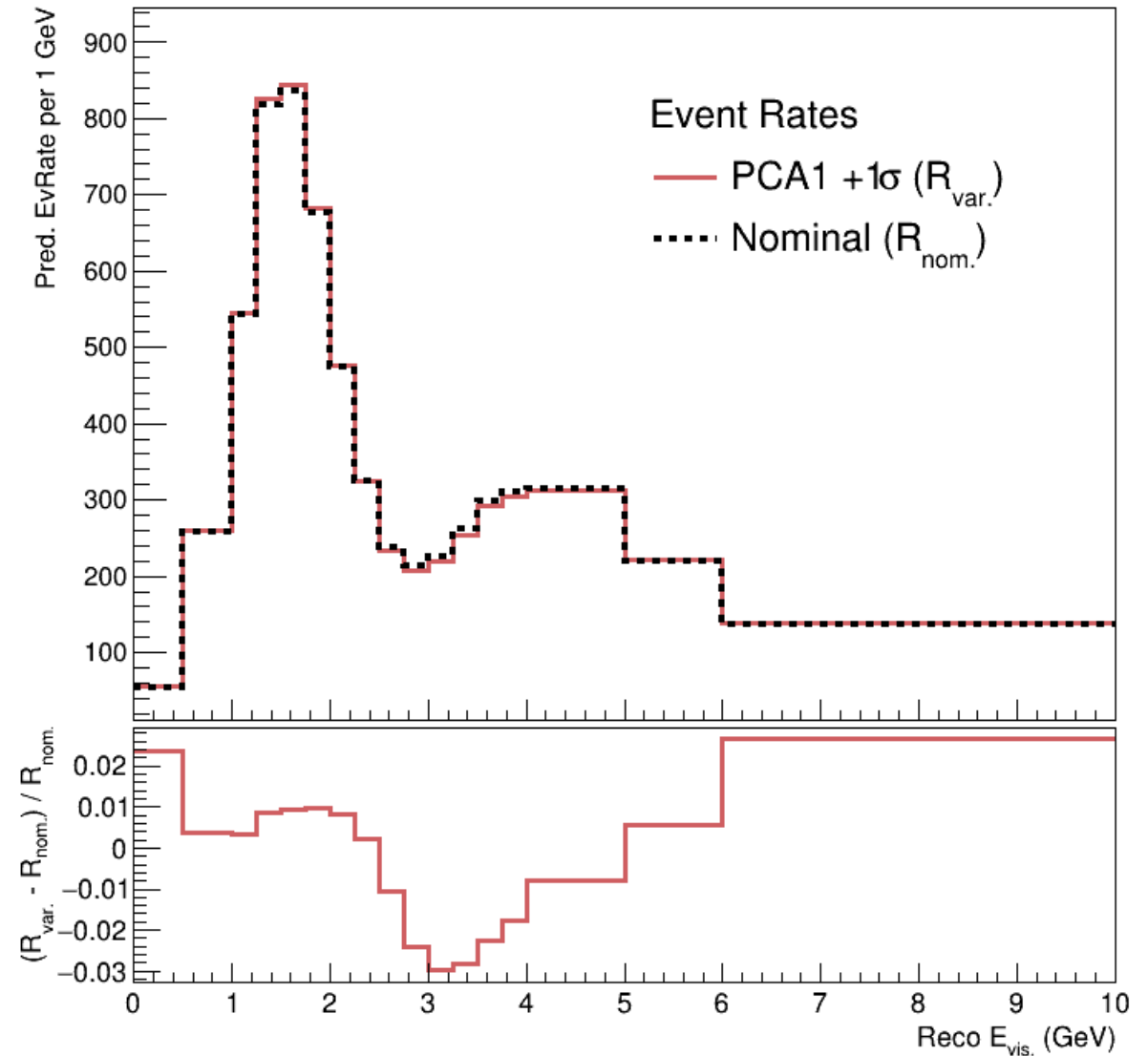


Flux Systematics

- Shift in the flux prediction shifts the coefficients
- Certain flux systematics can affect on and off-axis ND flux differently
 - leads to imperfect systematic cancellation



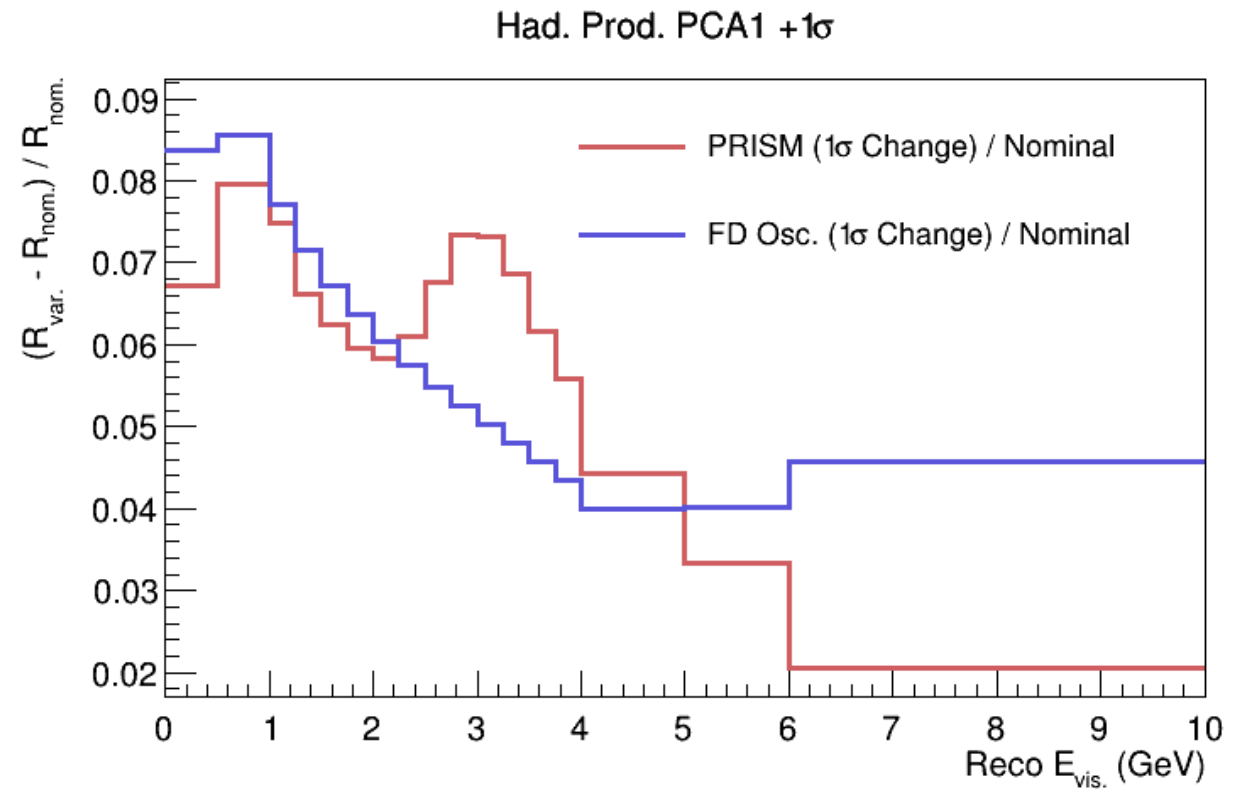
PRISM Pred. PCA1 +1 σ Shift



Flux Systematics – 'Fake Data' Shift

- The analysis applies shifts to the MC – the 'data' is fixed
- Alternatively, do a 'fake data' study: all the **MC components are nominal** and **shift the 'data'**
- See how the PRISM prediction tracks the FD spectrum
- Total systematic uncertainty is the difference
- For more of these plots

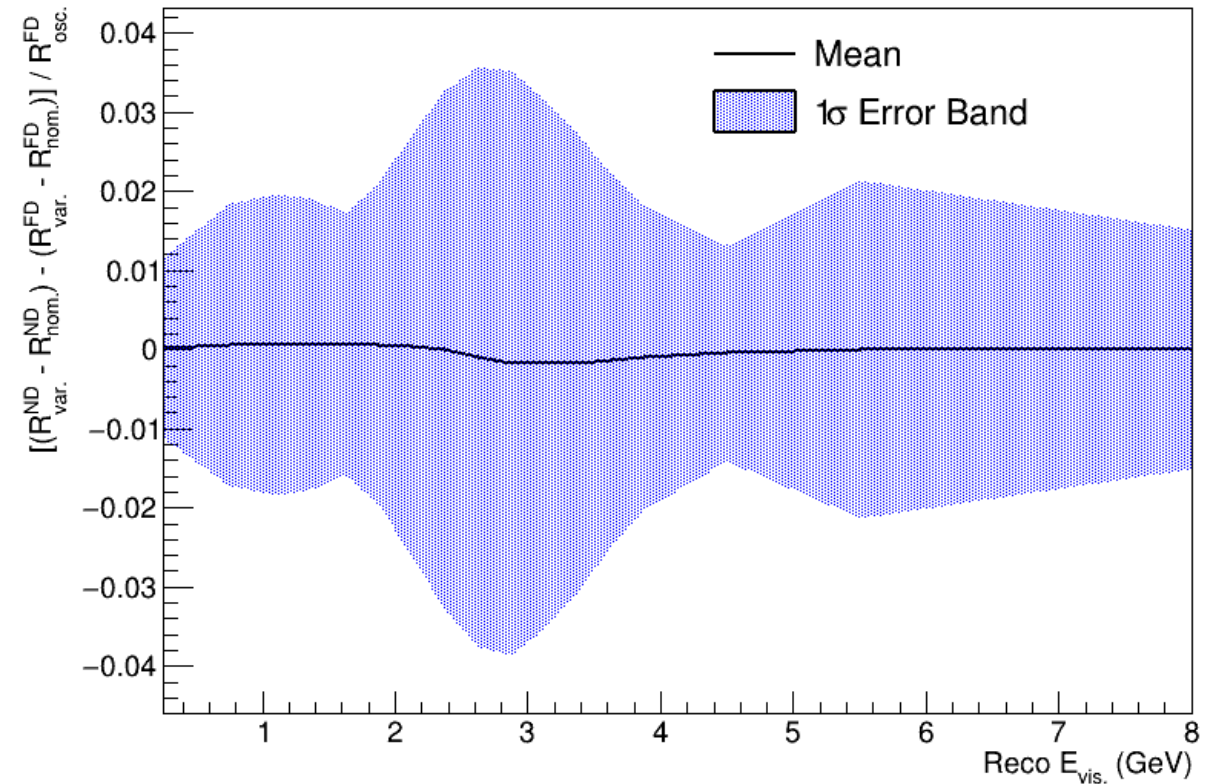
see: https://indico.fnal.gov/event/49755/contributions/218685/attachments/144905/184274/PRISMGroup_CAFAnaUpdate_1July21.pdf



Flux Systematics - 'Fake Data' Shift

- Do many 'fake-data' random **systematic throws**
- Take the difference between the ND and FD shift
- Plot 1 sigma **error band** (covariance matrix also available)

All Flux Systematic Throws (FDOsc norm.)

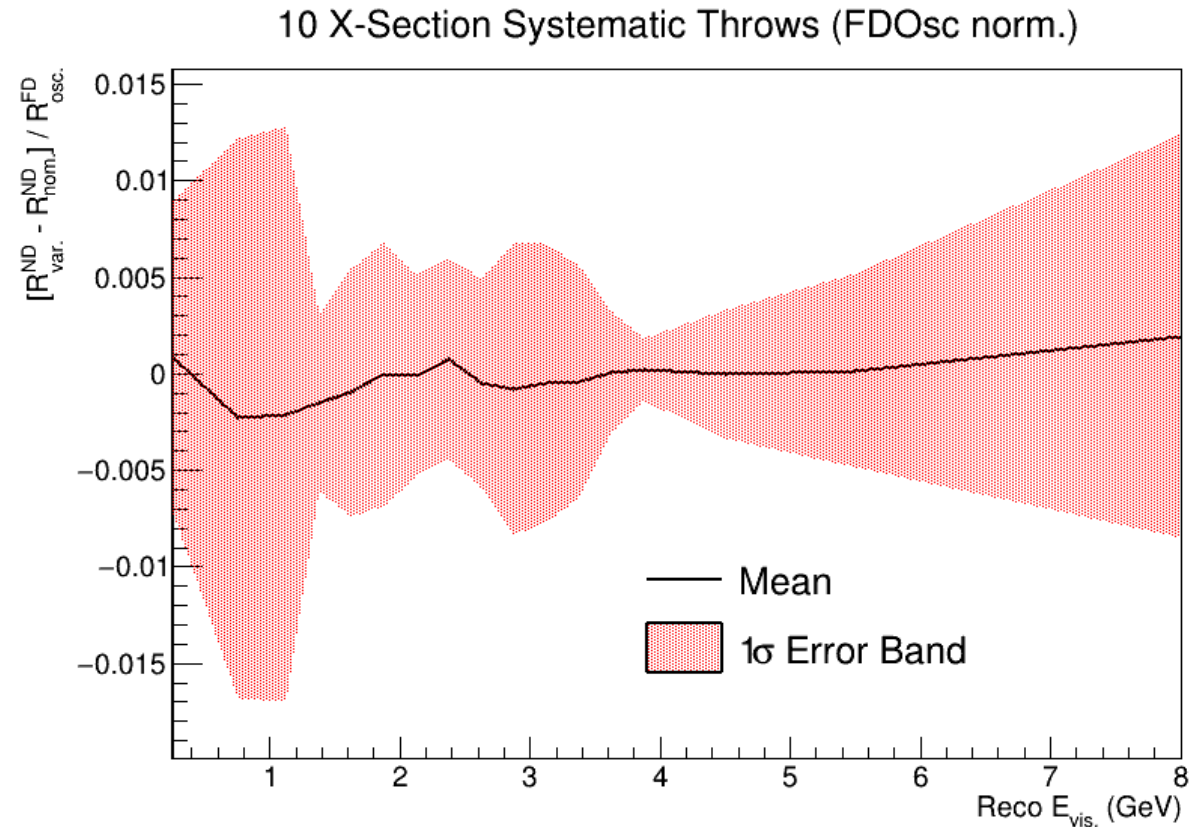


Parameters thrown: 12 'focusing' parameters + first 10 hadron production PCAs

Cross Section Systematics

'Data' fixed here, only vary MC components

- Cross section systematic parameters affect:
 - Backgrounds **subtracted** from ND data
 - Backgrounds and MC flux correction **added** to FD prediction
 - Calculation of **efficiency**
 - ND and FD **smearing matrices**



Parameters thrown: *MaCCQE, MaCCRES, MvCCRES, AhtBY, BhtBY, CV1uBY, CV2uBY, BeRPA_A, BeRPA_B, BeRPA_D*

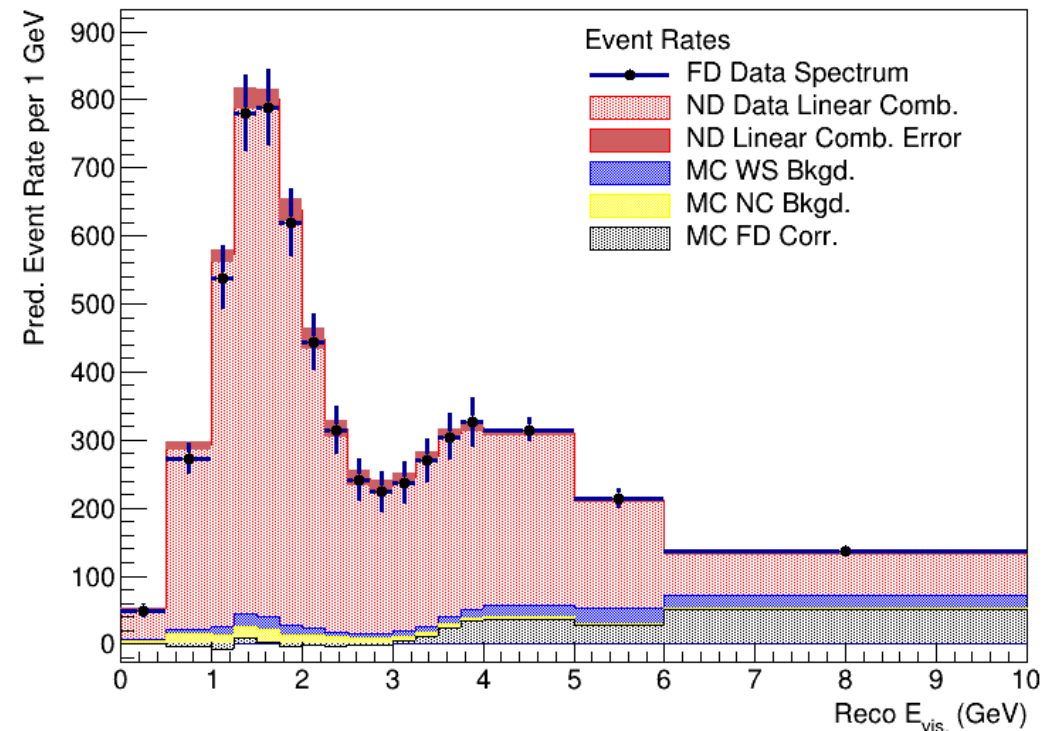
Disappearance Fits with PRISM

- Fit the **PRISM Prediction** to the **FD "data"** (using MINUIT)
- Use a Chi2 function which includes covariance:

$$\chi^2 = (P - D)^T V_{prism}^{-1} (P - D)$$

- Include flux and cross section systematics as nuisance parameters in fit

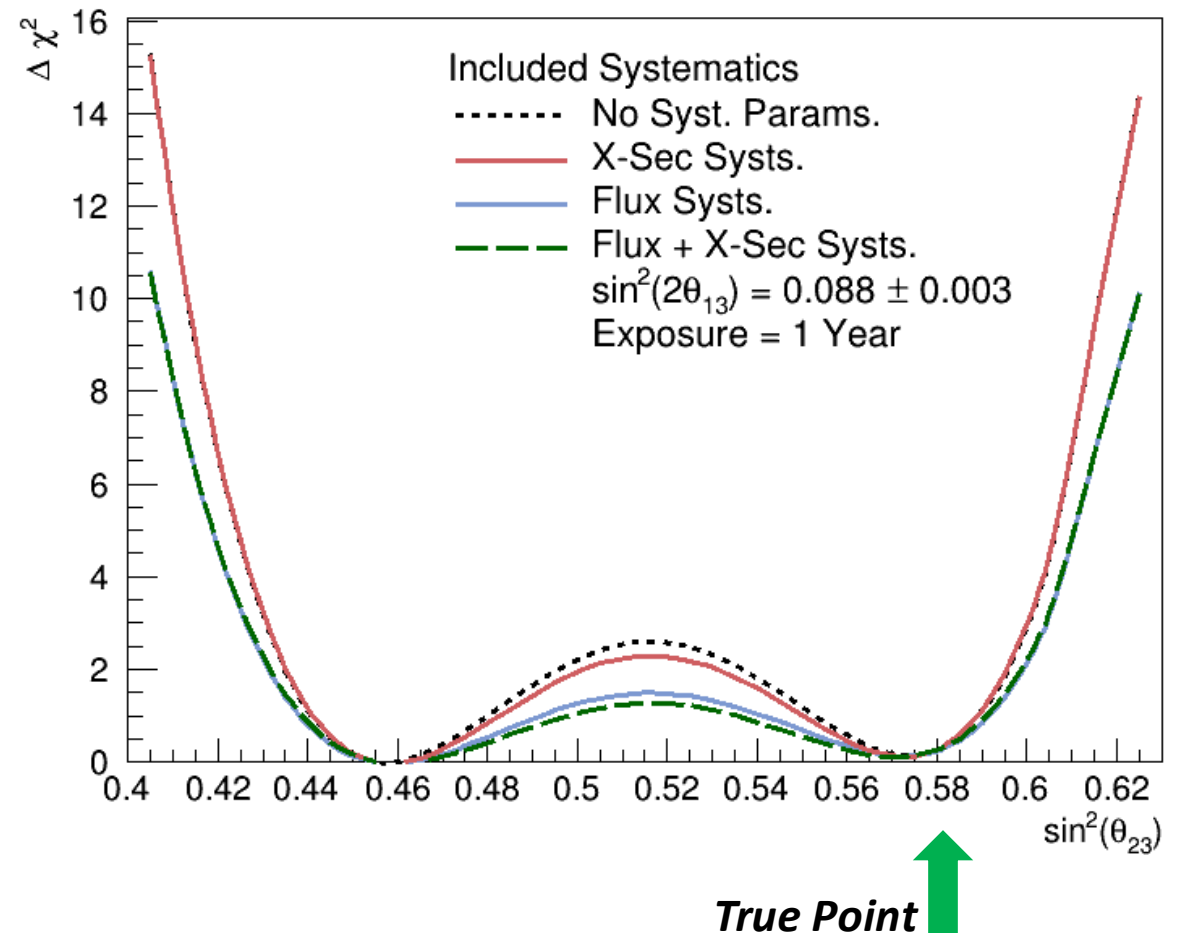
Extrapolated Prediction with Full Selection



Disappearance Fits with PRISM

- Fit for **ssth23** with **1 year** of exposure
- 4 fits:
 - Stats only
 - All x-section
 - All flux
 - All flux and x-section
- "All x-section" = all parameters used in TDR analysis
- "All flux" = 12 'focusing' parameters and first 10 hadron production PCAs

Flux & X-Section Systematics with Osc Params Profiled

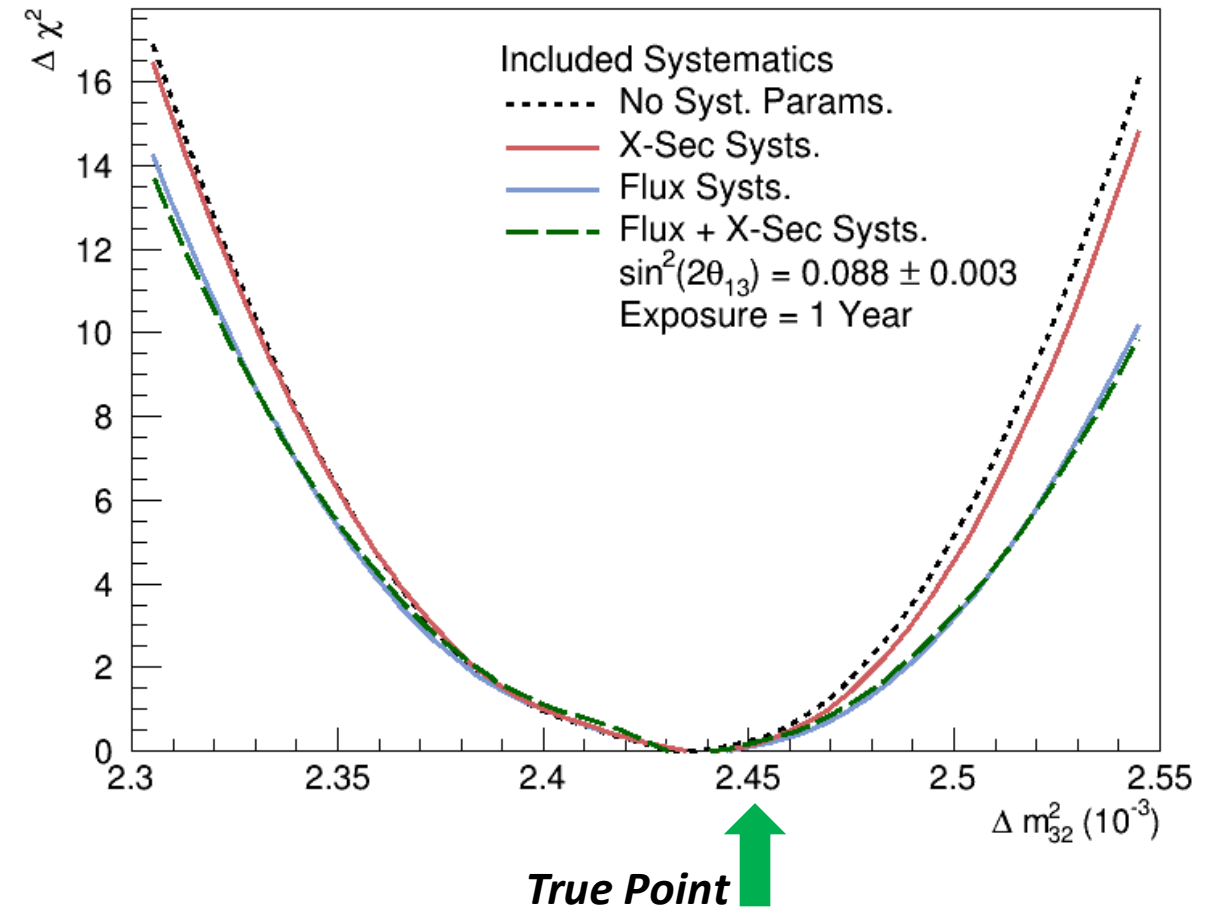


Disappearance Fits with PRISM

Warning: failed fit point in flux + x-section fit (WIP)

- Fit for **dmsq32** with **1 year** of exposure
- 4 fits:
 - Stats only
 - All x-section
 - All flux
 - All flux and x-section
- "All x-section" = all parameters used in TDR analysis
- "All flux" = 12 'focusing' parameters and first 10 hadron production PCAs

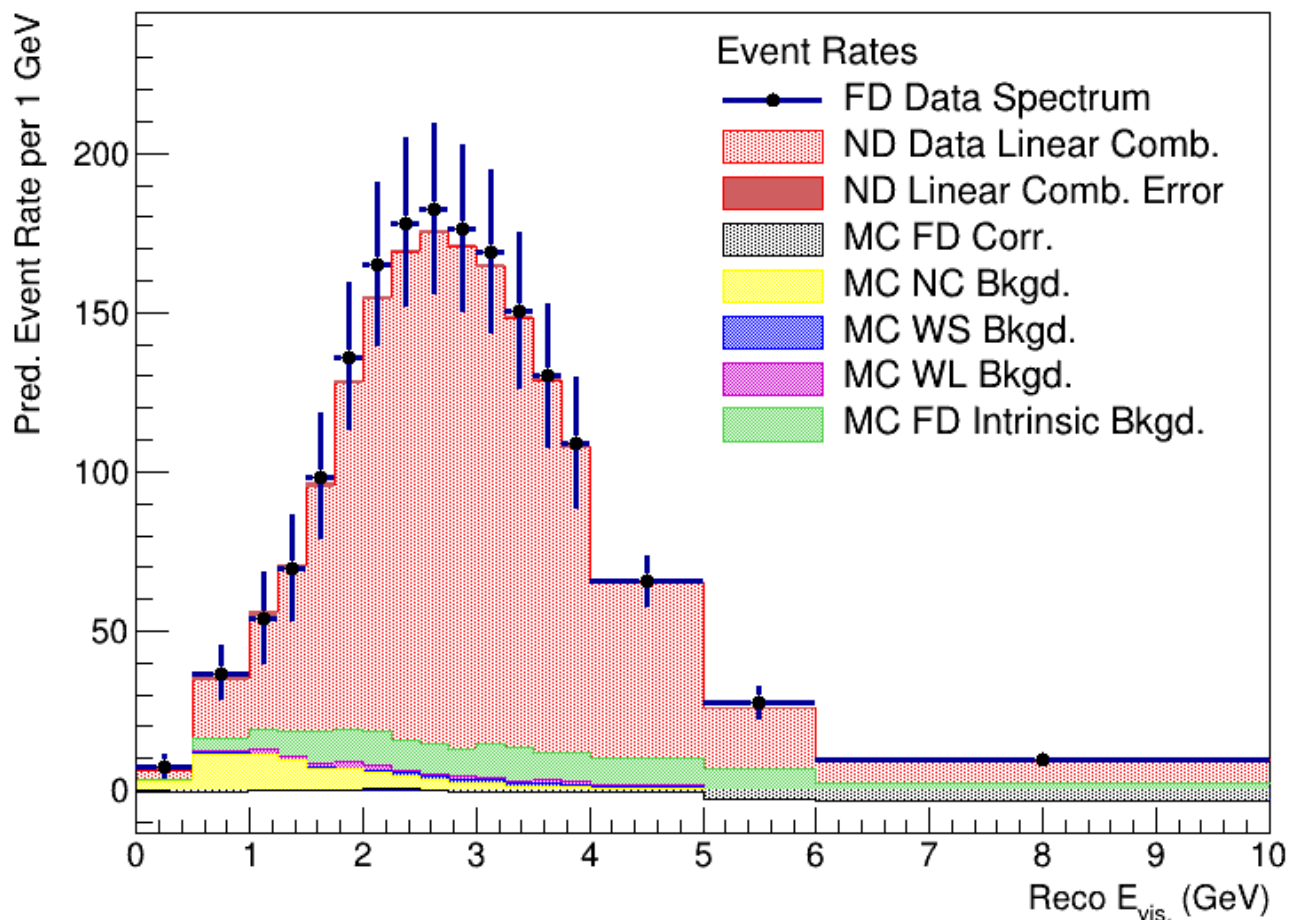
Flux & X-Section Systematics with Osc Params Profiled



PRISM Appearance Analysis (WIP)

- Match **ND numus** to **FD nues**
- Use the same extrapolation procedure as for disappearance
- Correct for ν_e/ν_{μ} **cross section differences**
- Several details still to work out – but more of this coming soon!

Extrapolated ν_e Prediction with Selection

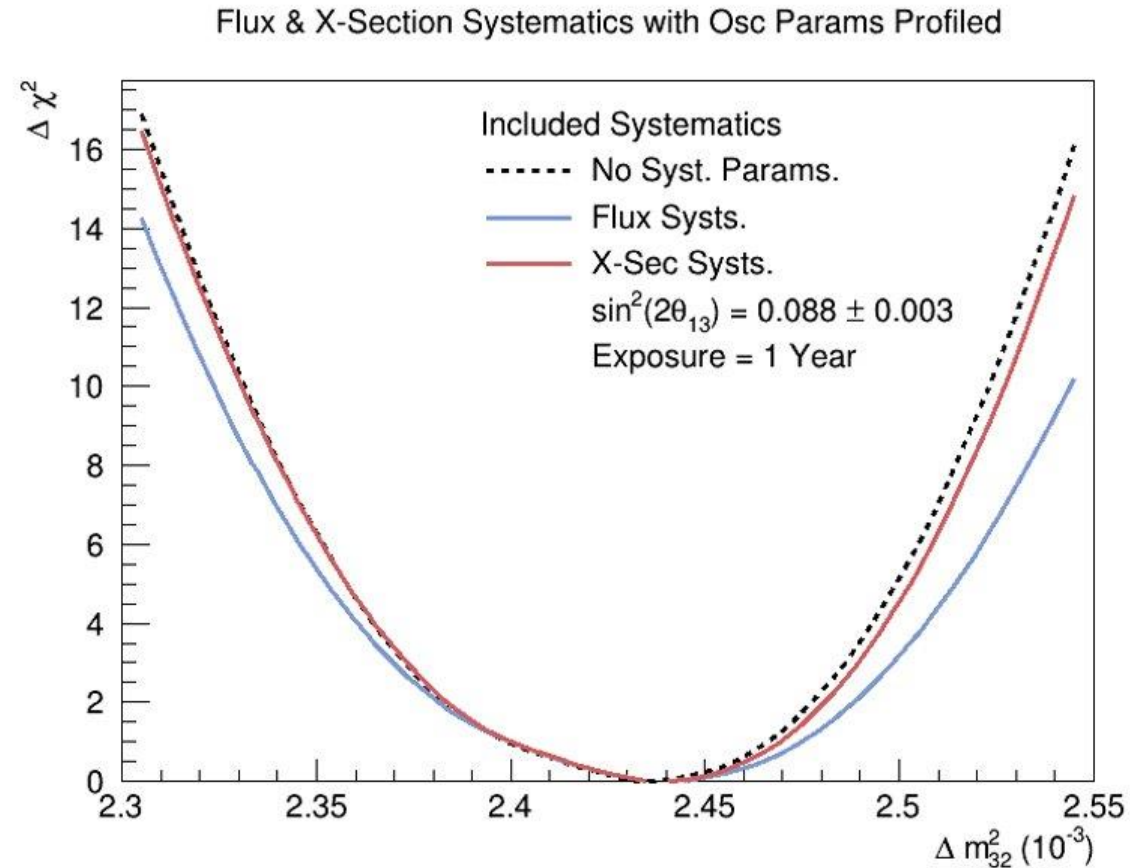


Conclusions & Next Steps

- Disappearance analysis is working with the ability to include flux cross section and detector systematics
- Disappearance FHC fits so far show the effect of cross section systematics are small, but flux systematics do matter (as expected)
- Appearance analysis has made good progress, but details still need to be worked out – more on this to come

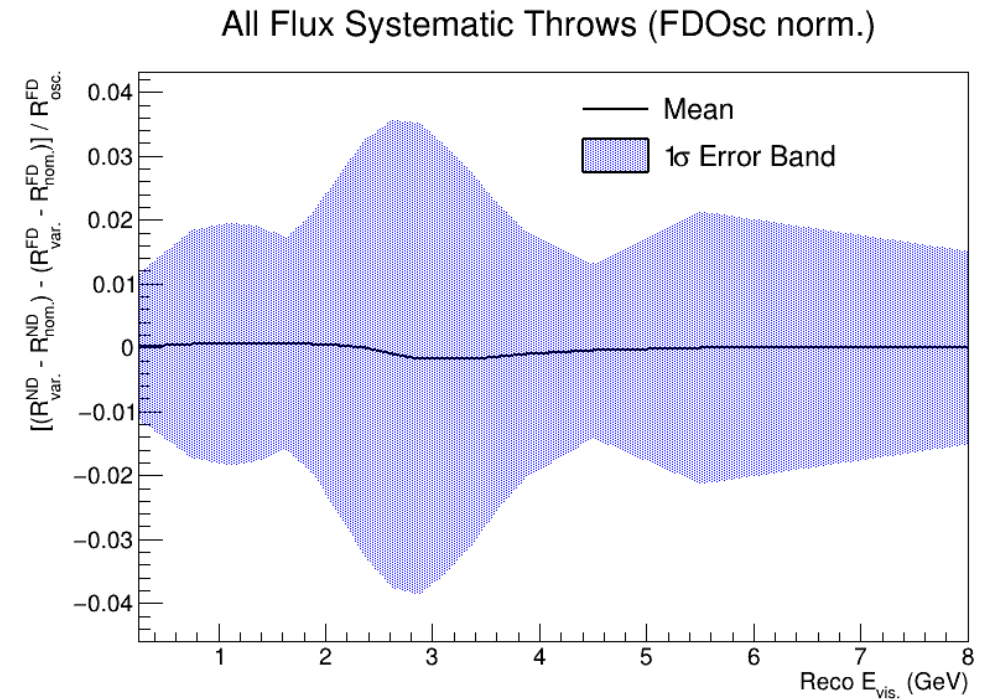
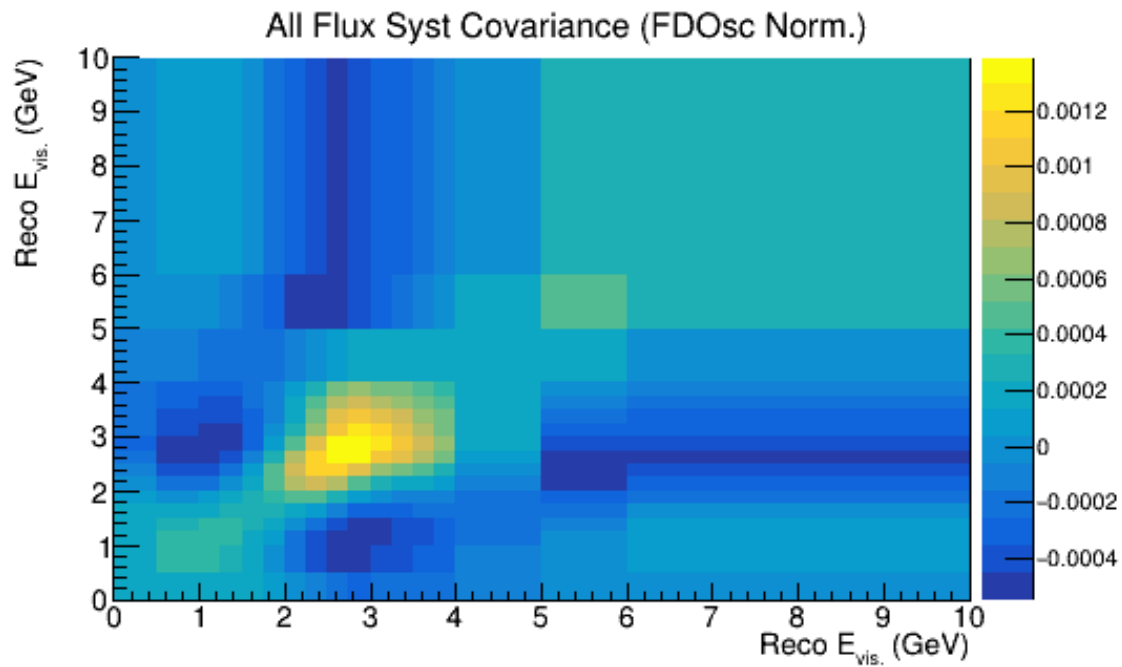
Backup

- Fit with just flux and cross-section systematics separately
- No failed fit point



Backup

- Error band plots are easier to interpret, but are only the diagonal of a covariance matrix



Backup

- Selection efficiency in the ND and FD

