

Nov2017 Engineered Flux Uncertainties

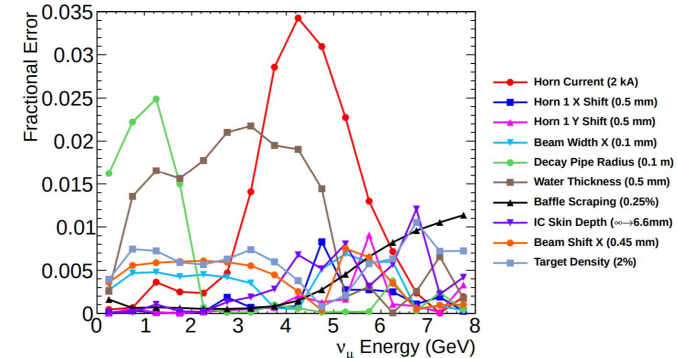
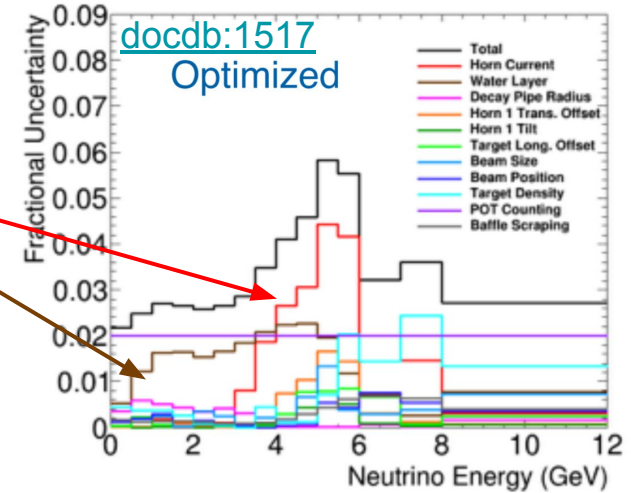
Luke Pickering
2019-01-23

Set Up

- Current g4lbnf:
 - v3r5p5
 - GEANT v4_10_3_p03
 - Use `OptimizedEngineered0ct/Nov2017Review.mac`
- ‘Nominal’ 5E8 POT thrown per beam mode:
 - Same decay parents used for each off-axis stop and for the far detector
 - Each parent comes with 100 ppfx universe weights.
- Discrete tweaks 2.5E8 POT thrown per beam mode:
 - Horn current +/- 3 kA
 - Decay pipe radius +10 cm
 - Water layer thickness +0.5 mm
 - Horn 1&2 X shift +/- 0.5 mm
 - Horn 1&2 Y shift + 0.5 mm
- All choices informed by [docdb:1486](#), and [LBNE docdb:8410](#)

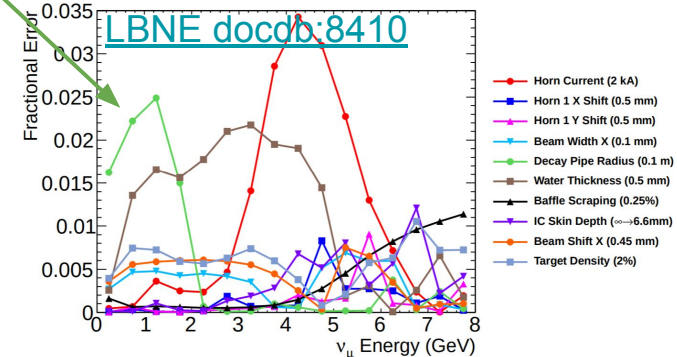
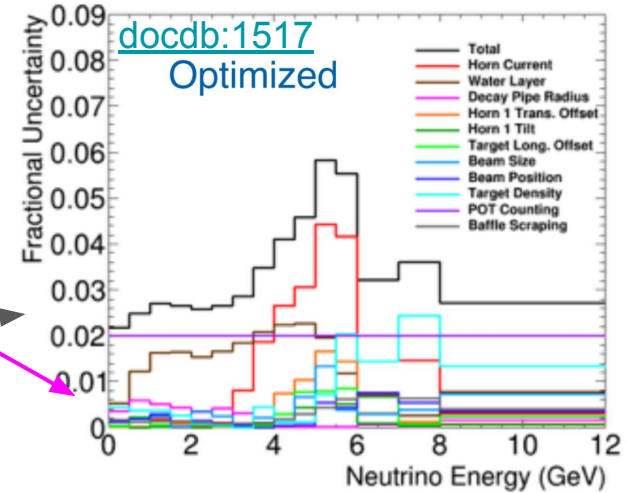
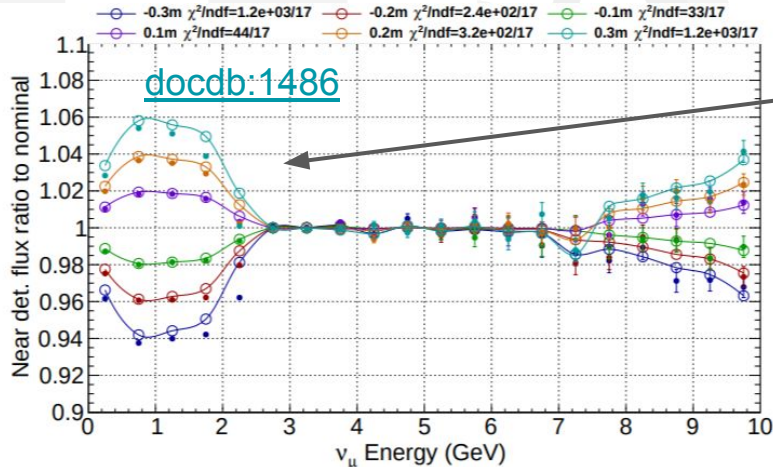
Discrete Tweaks

- Focussing:
 - The three tweaks used here were the most important in the last two iterations of this study:
 - Should do **Target Density**...
 - But has sub % effect in [docdb:1486](#)
- Alignment:
 - Validated that Horn 1 X translation produces similar effect as previous study, will now repeat with Y, Horn 2 and (3?).
 - Anything else? Target Z?
 - Seem to have sub % effect in [docdb:1486](#)



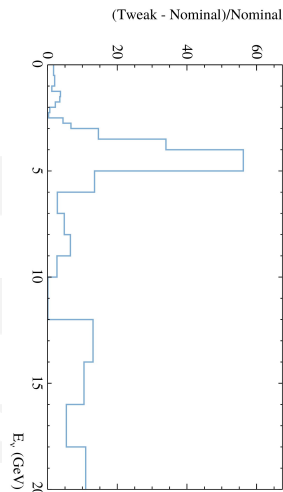
Discrete Tweaks: Decay Pipe Radius

- What happened to Decay Pipe Radius?

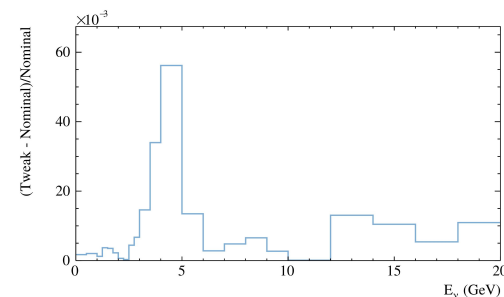


Discrete Tweaks: Method

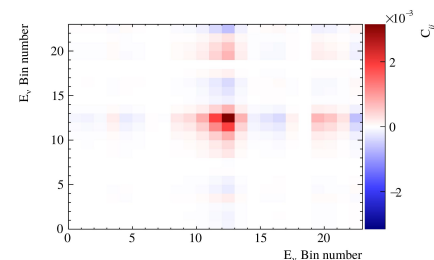
- If only have a single shift calculated as:
 - Covariance component built from $(\text{Shifted} - \text{Nominal}) \times (\text{Shifted} - \text{Nominal})^T$
- For Horn Current and X Shift interpolate +/- shifts and take gaussian throws of the response:
 - Similar to previous iterations, but here only fit to 2 varied points.
 - Could easily increase, just takes disk space.
 - Y shift should be symmetric so only used one-sided variation.



Horn current +3 kA
Effect on ND numu in nu-mode

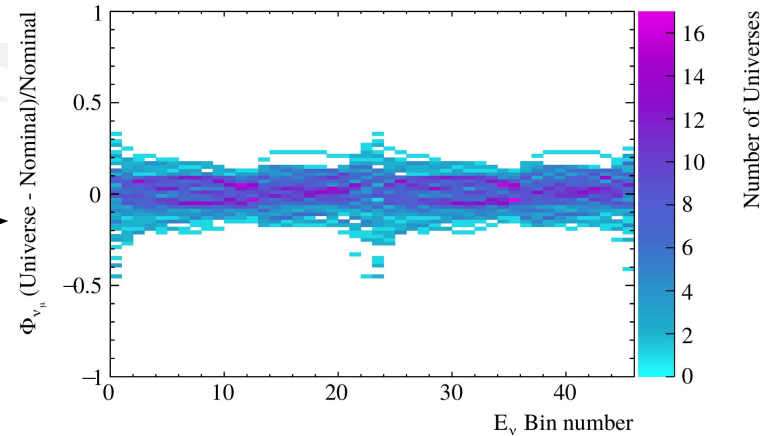
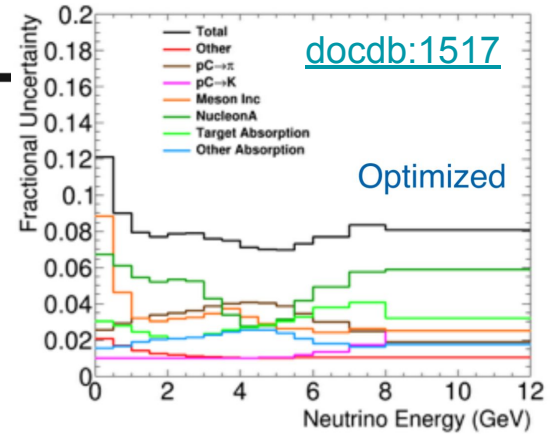


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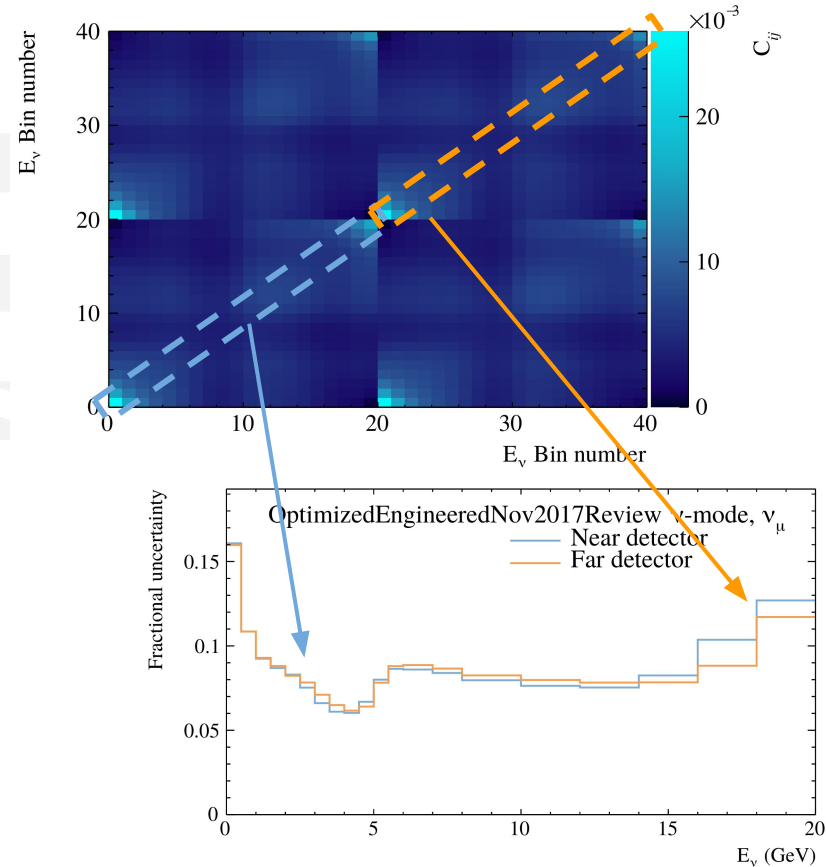
PPFX

- Repeated as before, but using the latest geometry:
 - For file-size reasons, do not keep weights for individual components and so can only compare the total hadron-production uncertainty with previous studies.
- 100 universes were used again, may be interesting to try using more, but binned energy response seems fairly gaussian already.



PPFX: Method

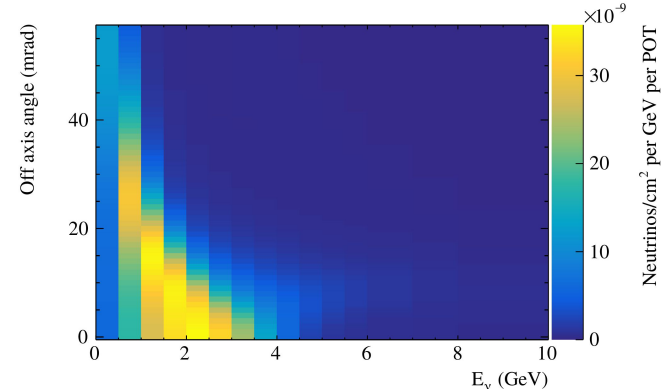
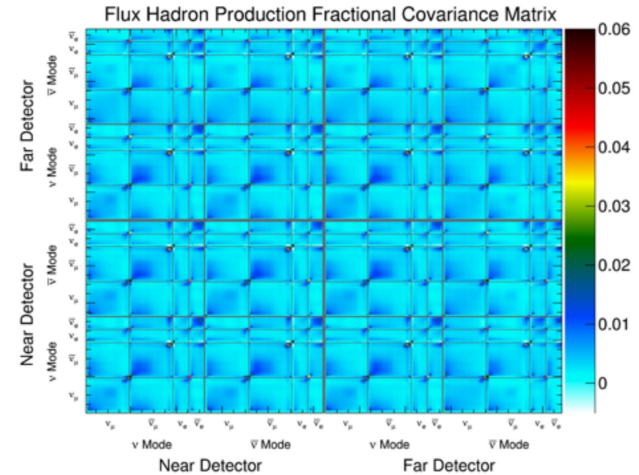
- Build covariance component for each PPFX universe as for discrete tweaks, total hadron production covariance:
 - $C_{ij} = 1/N \text{ Sum}_{ij} (\text{Univ}_i - \text{CV}_i) \times (\text{Univ}_j - \text{CV}_j)$
 - Standard error matrix statistics
- Then extract statistical properties under a gaussian assumption from the covariance matrix, *i.e.* 1D fractional uncertainty from sqrt of diagonal elements.



Error Propagation: Problem

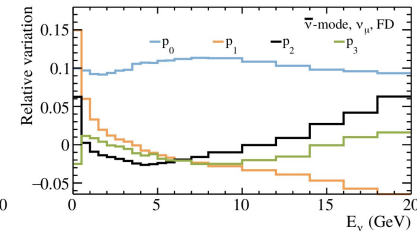
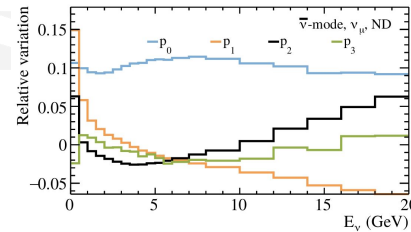
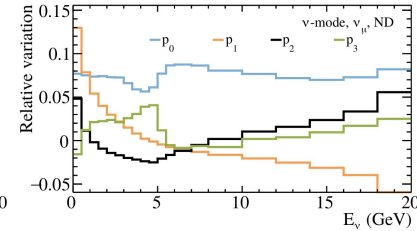
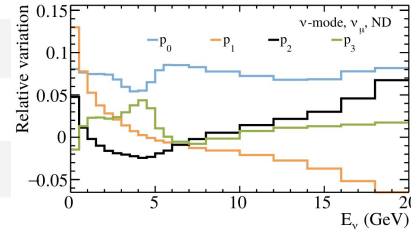
[docdb:1517](#)

- Previously had: $(\nu, \bar{\nu}) \times (\nu_{\mu}, \nu_{e}, \nu_{\mu\bar{e}}, \nu_{e\bar{e}}) \times (ND, FD)$ matrix.
- Variation as a function of off-axis angle non-trivial, want to bin ~finely.
- For a few off axis stops, flux error matrix becomes $O(1k \times 1k)$
 - Large file to disseminate
 - Either adds $O(1k)$ parameters to any analysis or requires time-consuming decomposition at analysis time.

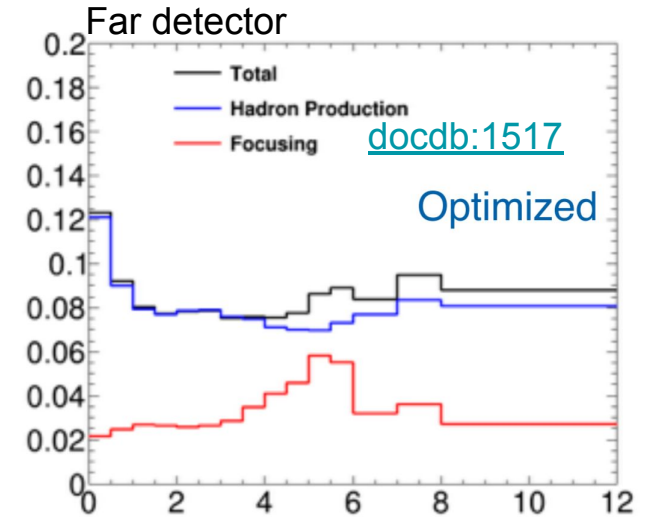
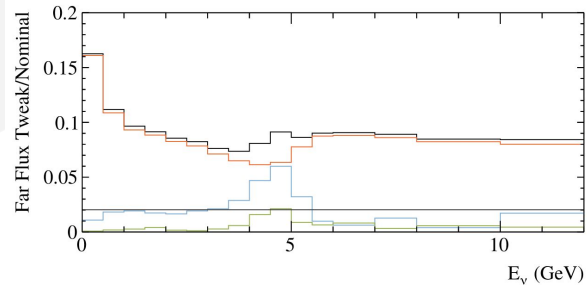
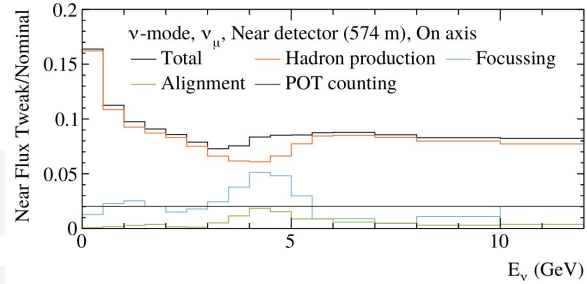


Error Propagation: Pre-decomposed

- DUNE LBL analysis tools use pre-decomposed inputs:
 - Get most important N eigenvectors and eigenvalues of the total error matrix.
 - These become effective, linearly independent variations across all species, beam modes, flux plane definitions.
- Error propagation is then done with uncorrelated gaussian distributed throws of the decomposed variations.

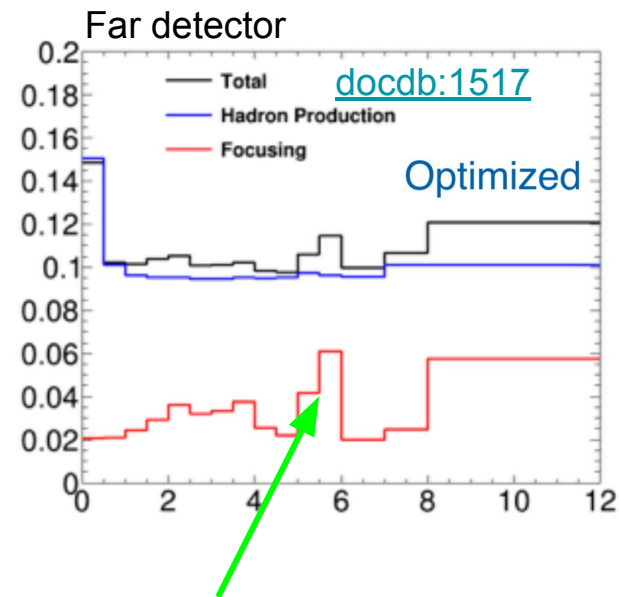
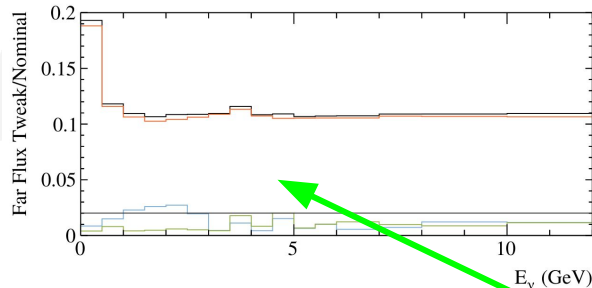
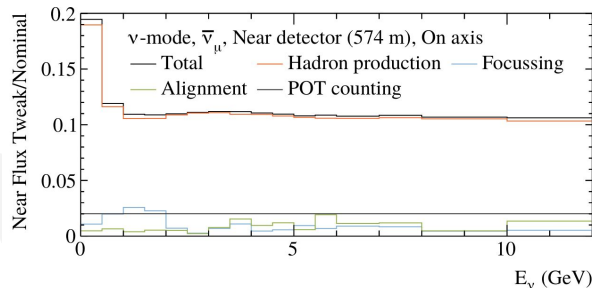


Comparison to the 2016 Analysis: numu, nu-mode



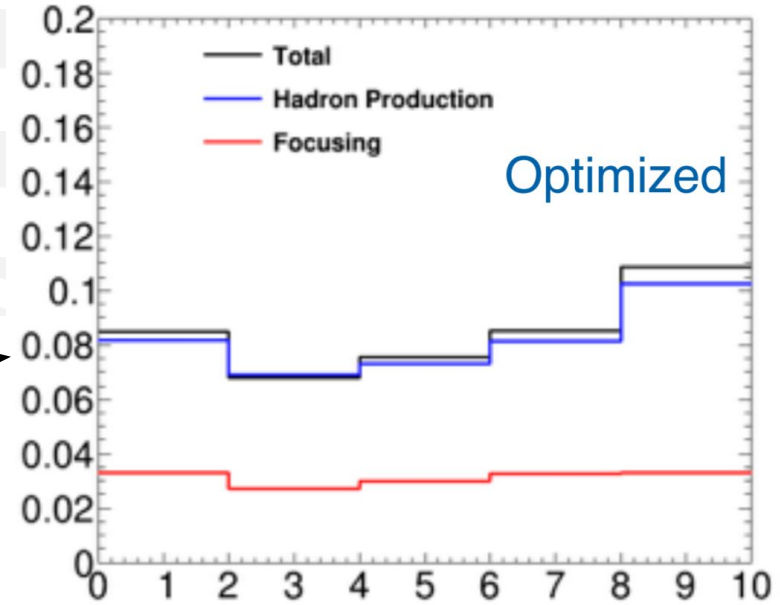
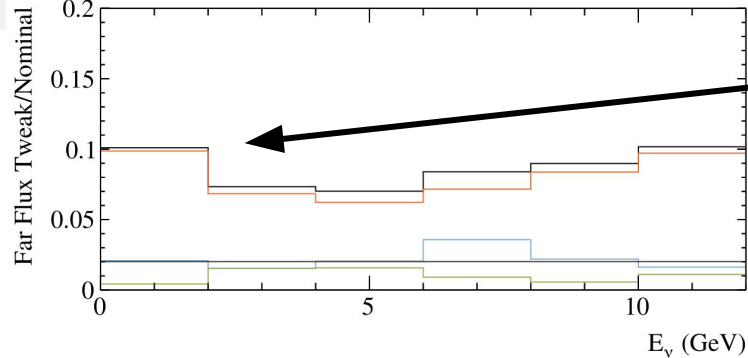
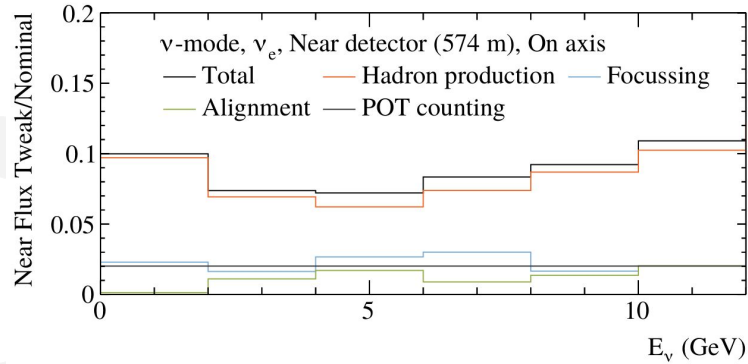
- Lowest few bins are more uncertain in my studies...
- Missing feature at ~ 8 GeV, from Target Density.

Comparison to the 2016 Analysis: numub nu-mode

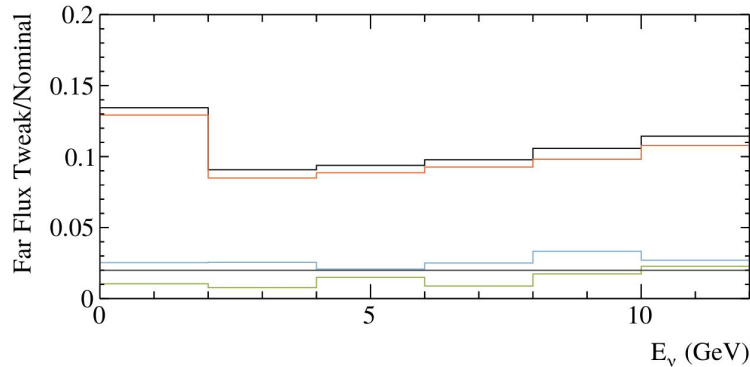
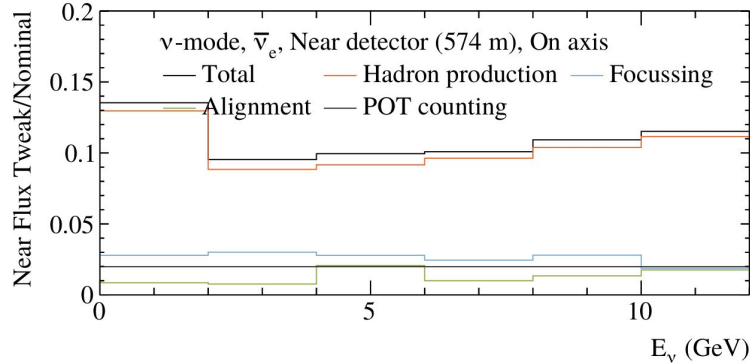


- Hadron production looks ~good, though larger in the lowest bin again
- Focussing **missing feature** at 5 GeV. Not sure of source.

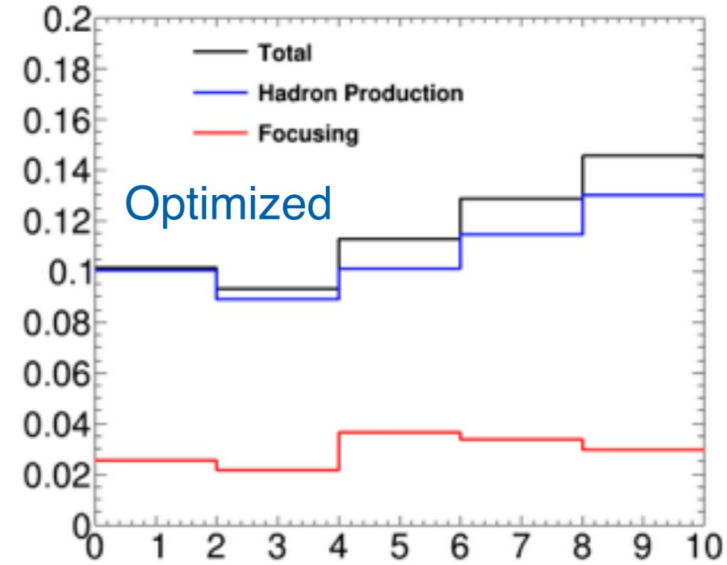
Comparison to the 2016 Analysis: ν_e ν -mode



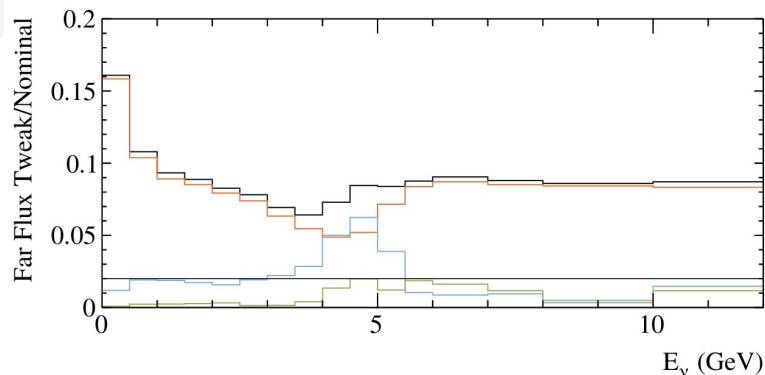
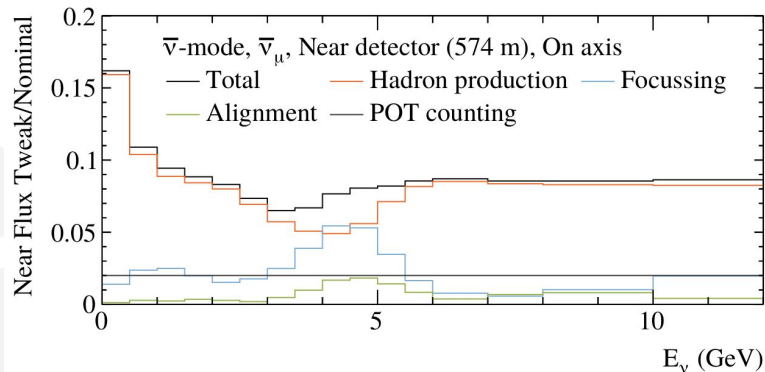
Comparison to the 2016 Analysis: nueb nu-mode



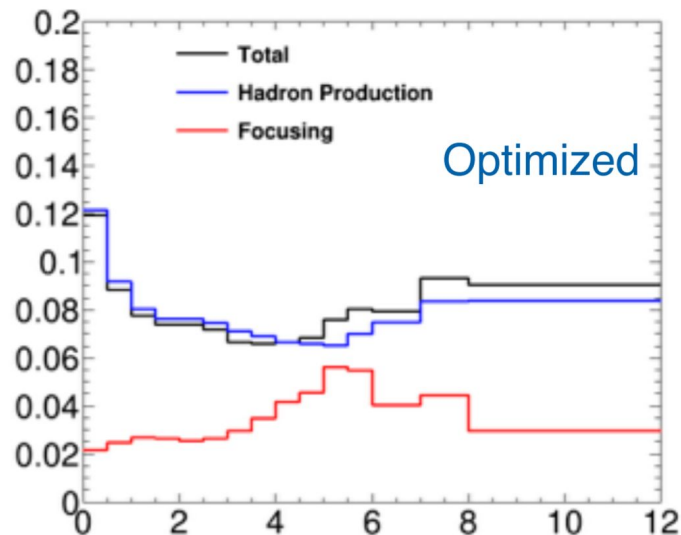
Far detector

docdb:1517

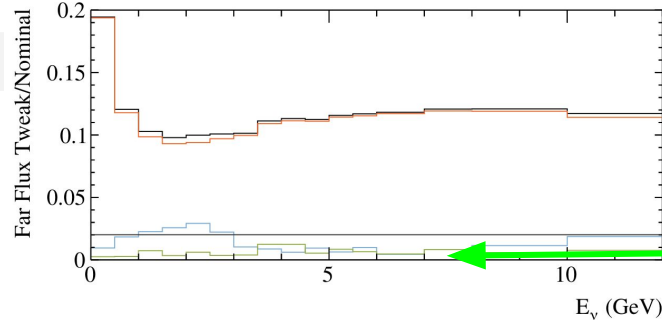
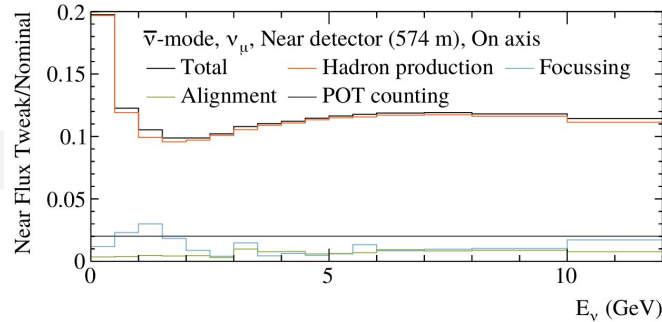
Comparison to the 2016 Analysis: numub nub-mode



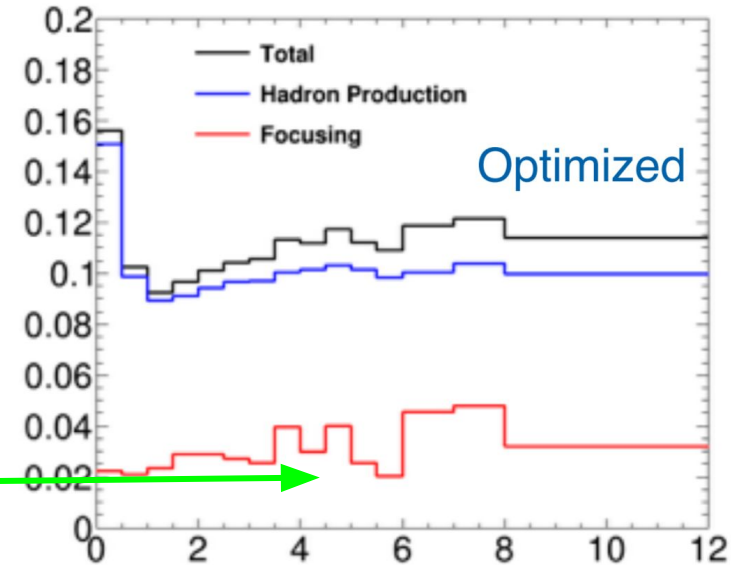
Far detector

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Comparison to the 2016 Analysis: numu nub-mode

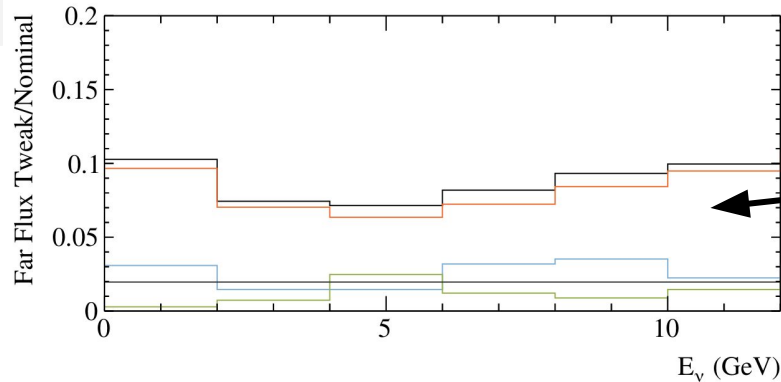
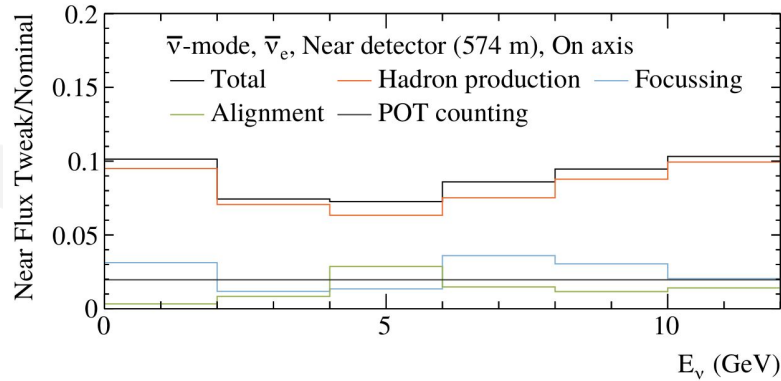


Far detector

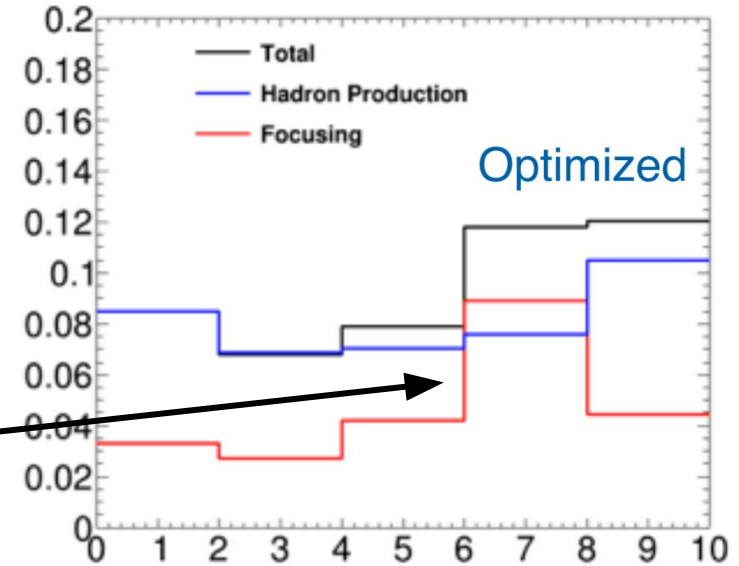
[docdb:1517](https://docdb.1517)

- Similar to WSB in nu-mode, missing features around 4-6 GeV

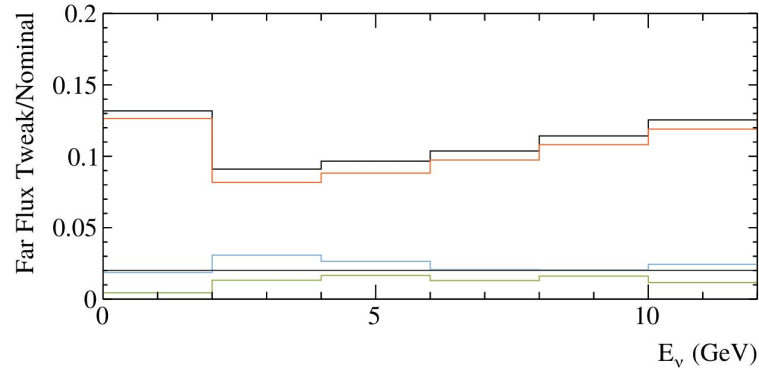
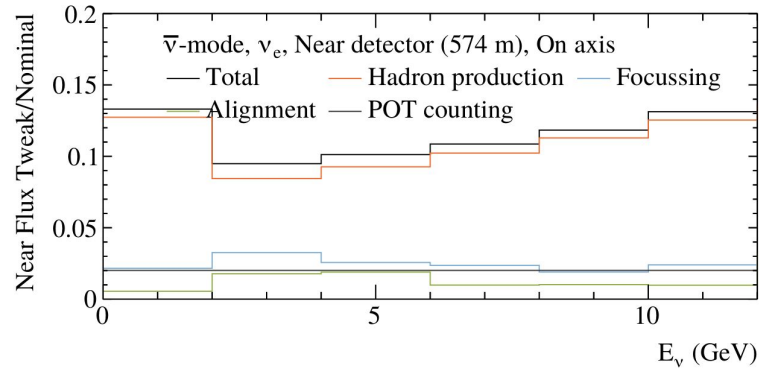
Comparison to the 2016 Analysis: nueb nub-mode



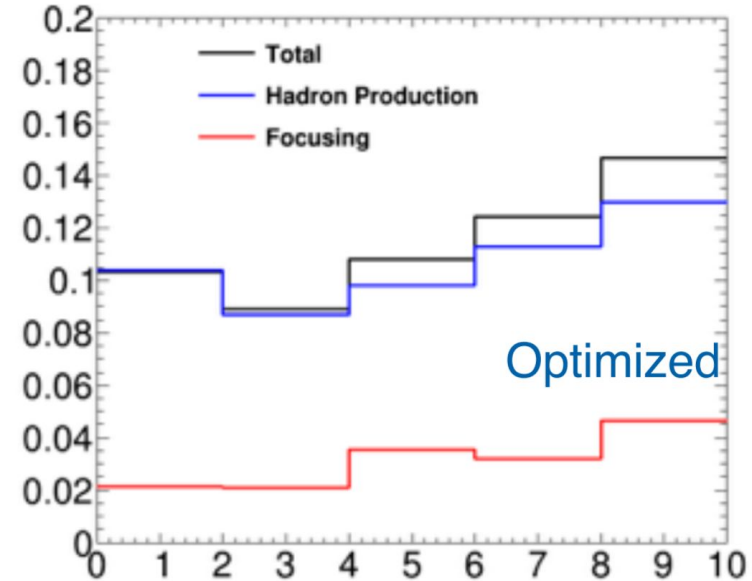
Far detector

[docdb:1517](https://docdb.fnal.gov/docdb/1517)

Comparison to the 2016 Analysis: nue nub-mode



Far detector

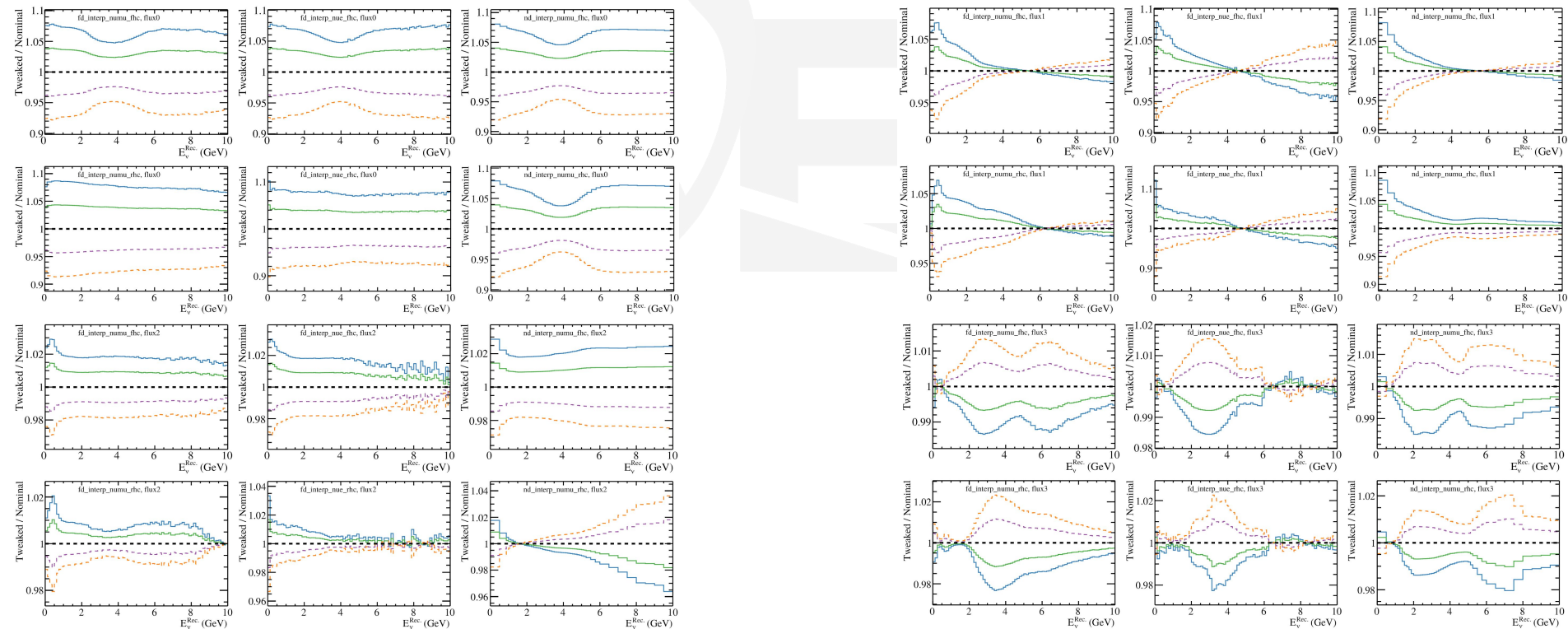
[docdb:1517](https://docdb.1517)

Comparison Summary

- Broadly similar results seen:
 - As should be the case, not much has changed.
- Some missing features in focussing error on the wrong-sign muon content in each beam mode, not clear where these come from.
 - Previous documents don't appear to have breakdown of wrong-sign errors so cannot easily determine which tweak is missing.

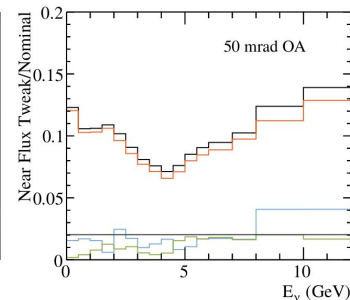
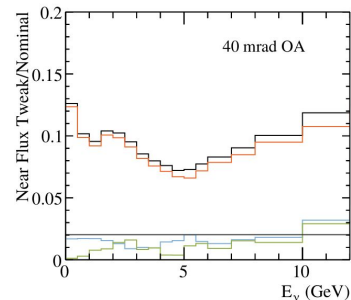
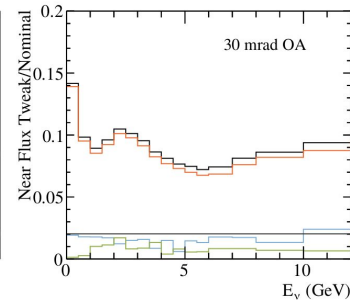
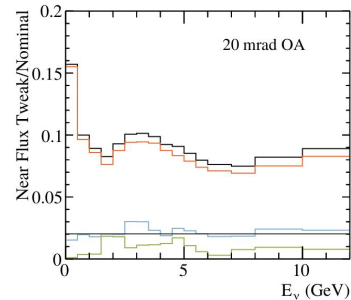
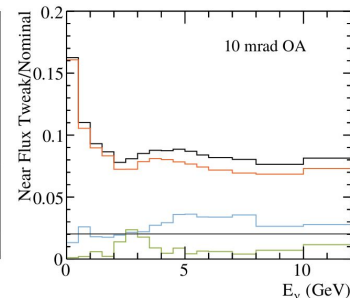
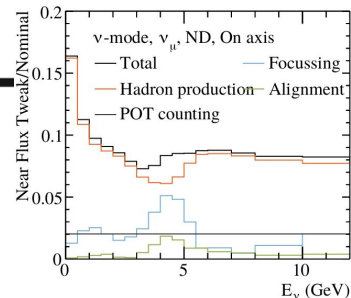
In The LBL Analysis

- Effective flux parameters produced by this analysis can/are/will be used in the CAFAna OA sensitivity. Example effect on analysis spectra



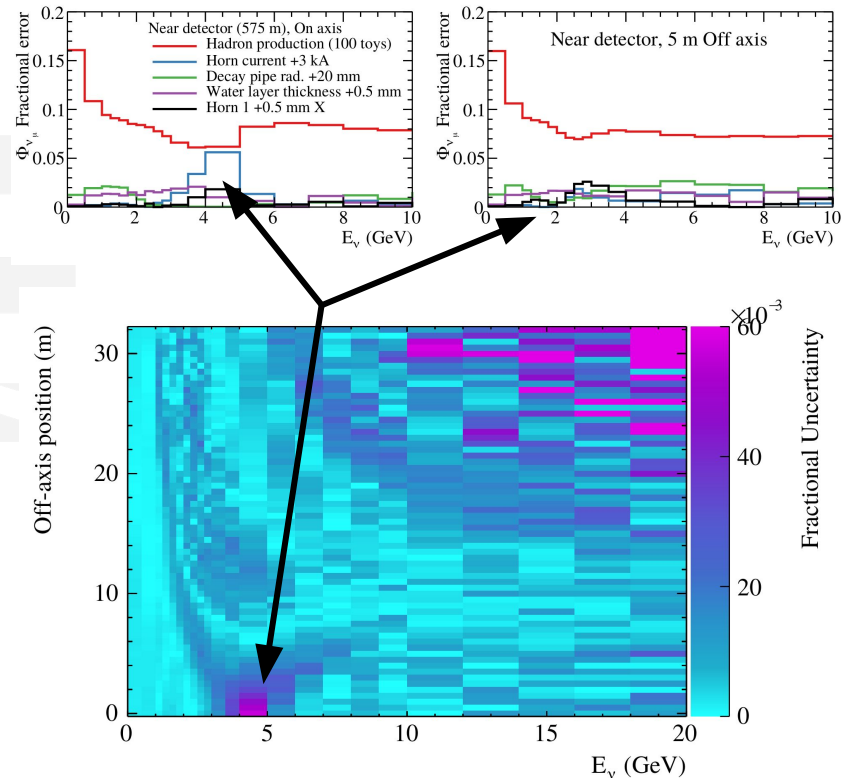
Off Axis at the near detector

- My involvement in running this was to get correlated uncertainties as a function of off-axis position/angle at the near detector for use in PRISM analyses and predictions.
- This is done as before, but includes multiple near detector predictions in addition to the standard near and far flux windows.
- Still need time to digest, but initial results broadly make sense.



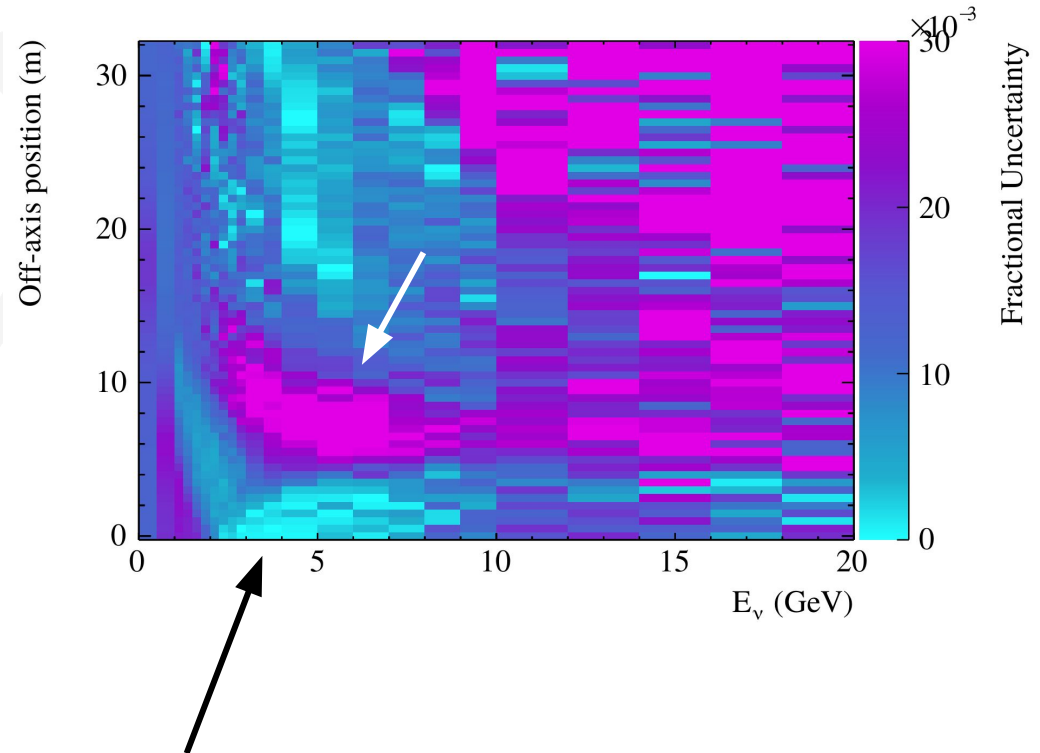
Off Axis at the near detector: Horn Current

- One notable feature is that the horn current error is apparently only really a feature on-axis.
 - Is this expected?
- Can also have a look in 2D, not sure this enlightens me any more. Possibly need more stats as this comparison is quite noisy.
 - Could also rethink energy binning.



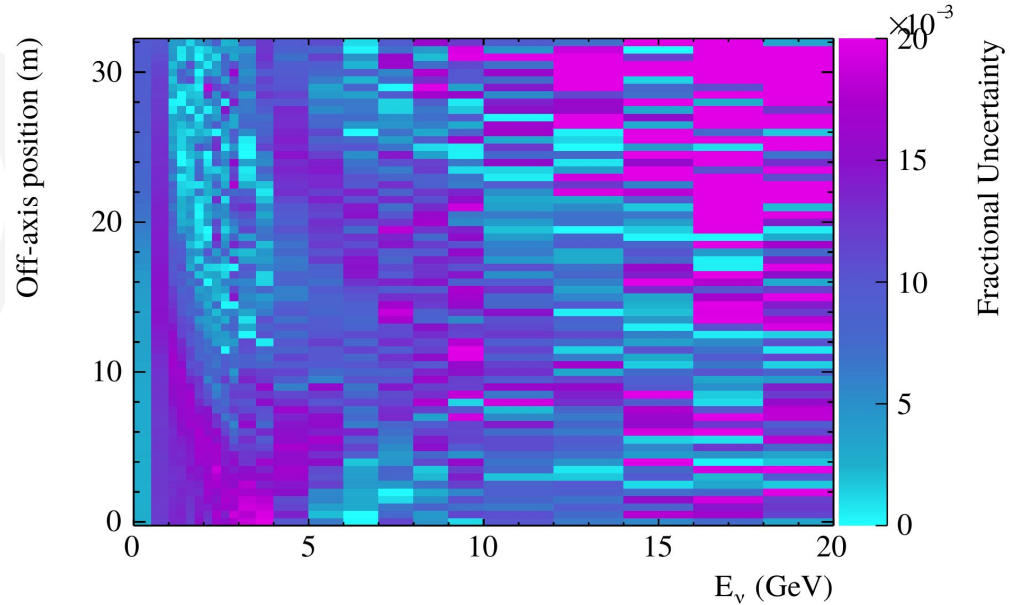
Off Axis at the near detector: Decay Pipe Radius

- On-axis feature appears to move to **higher energy** at low off-axis angle, in defiance of every other feature that I've seen.
- Dominated after about 5 m by **features moving down** in energy.



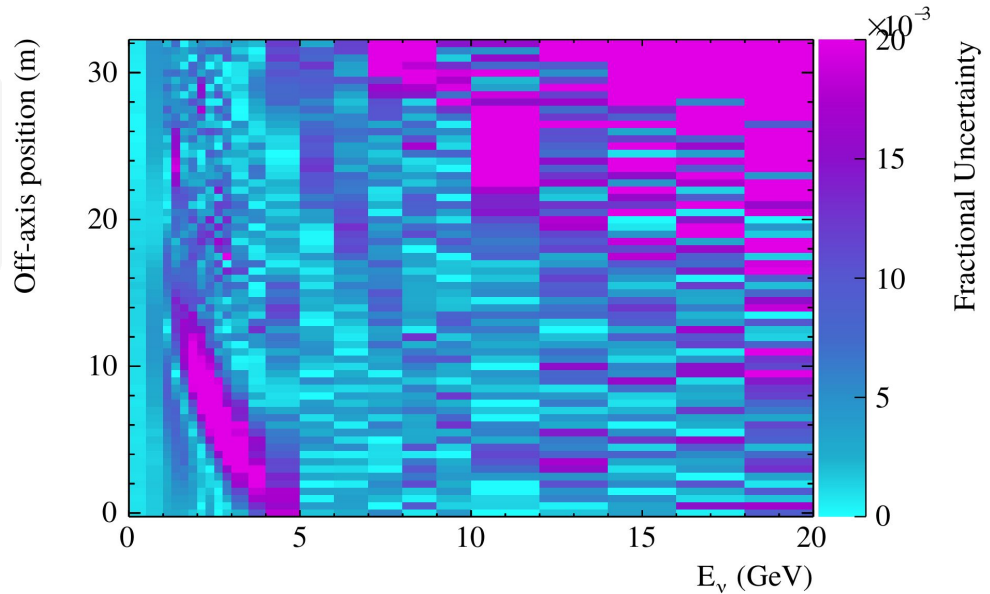
Off Axis at the near detector: Water Layer Thickness

- Minimal effect above a few GeV.
- Otherwise, response as a function of off-axis position \sim as expected based on naive decay kinematic expectations.



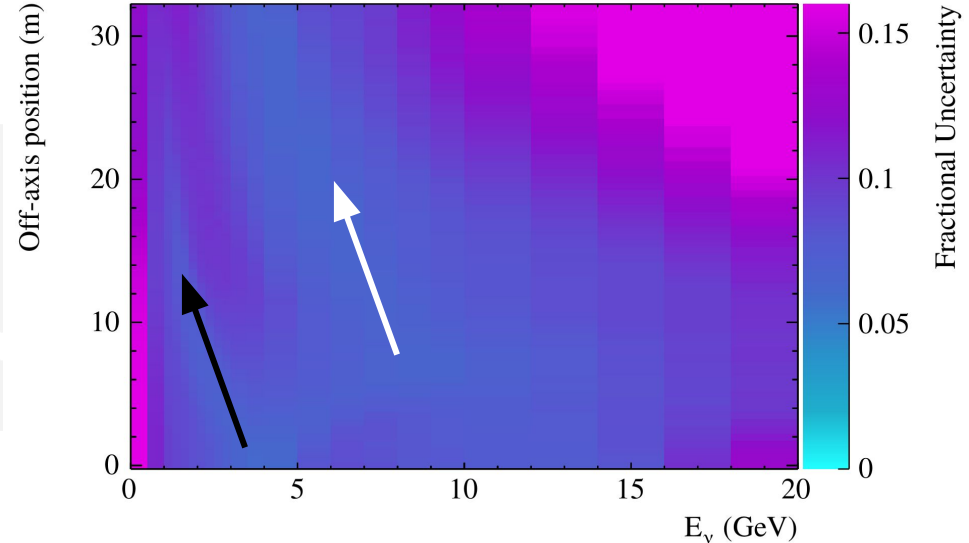
Off Axis at the near detector: Horn 1 X shift + 0.5 mm

- Included directly as a single shift in one direction away from nominal.
 - In the same plane as increasing off-axis angle, should probably include both directions.
 - For each beam mode and each horn, increases required CPU time by 1/3 again (2 beam modes, 3 horns, 2 displacements + target Z and decay pipe).



Off Axis at the near detector: PPFX

- Ratio here is average effect of universe weights, rather than separately thrown predictions, hence smoothness.
- Can see separate effect on **Pion** and **Kaon** peaks



Off-axis study Summary

- Probably worth being careful with the prediction errors to determine regions where the variation is significantly above MC stats error.
 - This will be worse for non-dominant muon species in a given beam mode.
 - Adjust binning or throw more stats accordingly.
- Is it worrying that I use the same set of decay parents to calculate the flux at each off-axis position? (and near and far)
 - If I can't do this, then the CPU time requirements shoot up (say an order of magnitude and a bit), or the signal/noise of the error estimates tanks...

Next

- Consider re-binning
- Consider upping stats of both nominal (currently $5E8$ POT) and tweaked ($2.5E8$ POT)
- Digest/discuss Off-axis plots
- Write TDR section, What do we want? Plots similar to?
- Write updated TN?

Thanks for listening