DUNE-PRISM Analysis Update

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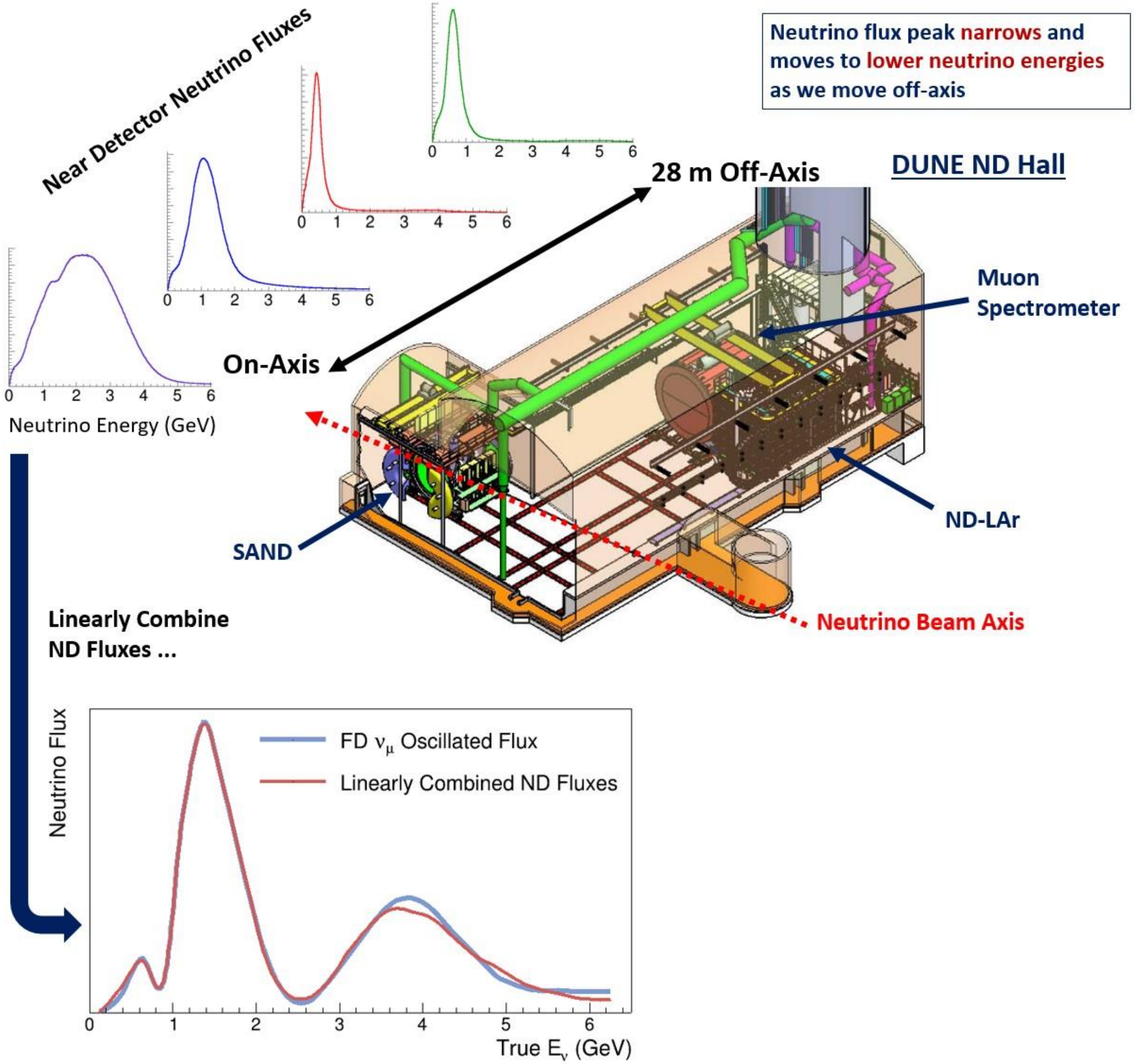
LBL Meeting
11th July 2022

Outline

- The PRISM analysis linearly combines off-axis measurements at the ND to predict the FD data
- In this update:
  - Flux uncertainties
  - Missing proton fake data



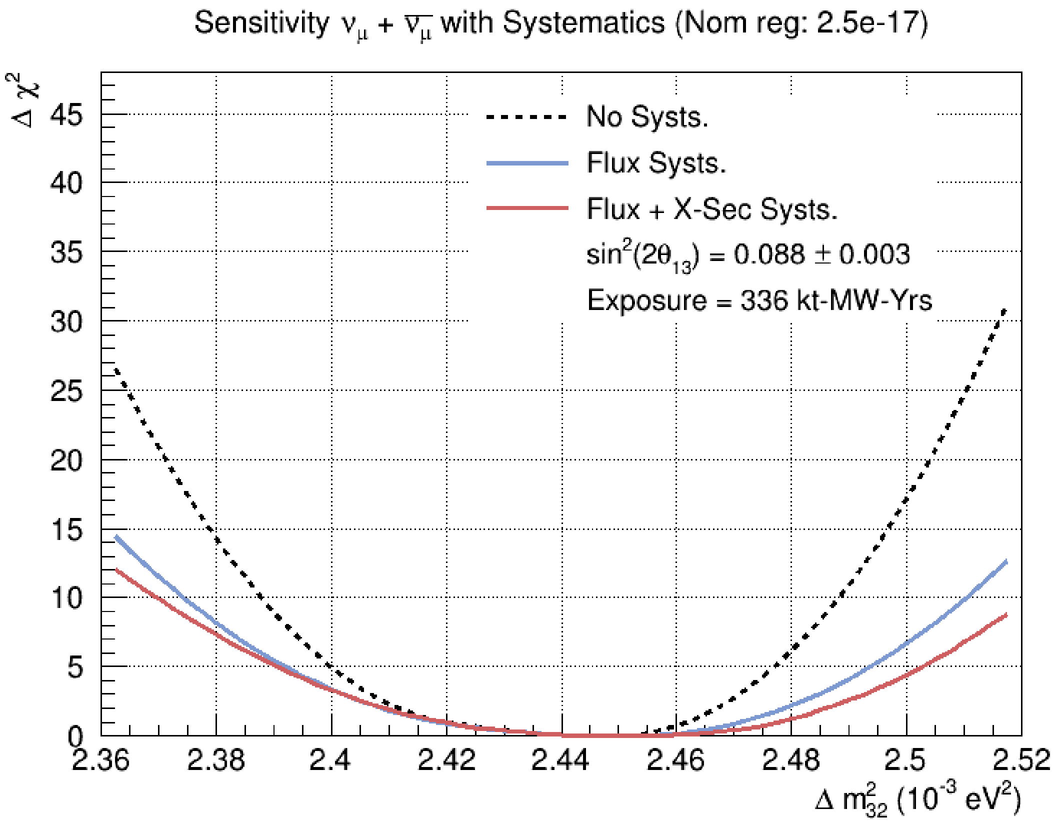
Flux Uncertainties

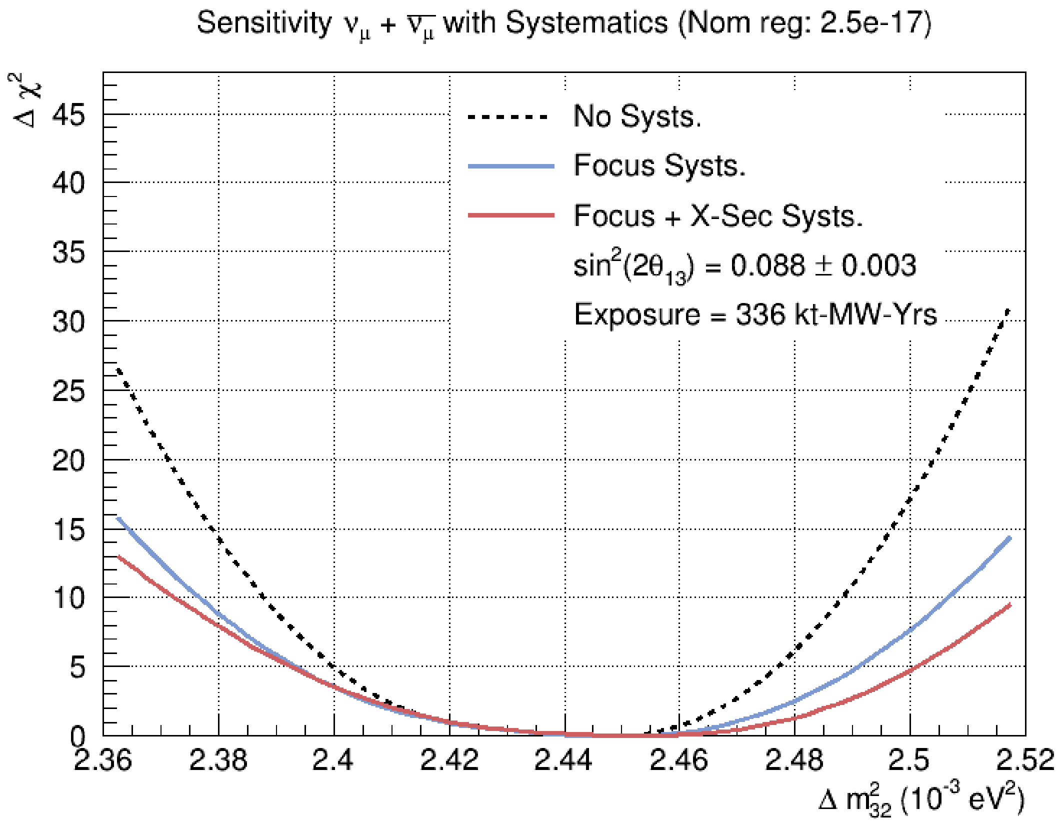
Name	Category	Variations
PPFX	Hadron production	100 throws about PPFX CV tune
DecayPipeRadius	Focussing	+10 cm
WaterLayer	Focussing	+0.5 mm
HornCurrent	Focussing	+3, -3 kA
TargetDensity	Focussing	+1.8, -1.8 %
Horn1XShift	Horn Alignment	+3,+0.5, -0.5, -3 mm
Horn2XShift	Horn Alignment	+0.5, -0.5 mm
Horn1YShift	Horn Alignment	+0.5, -0.5 mm
Horn2YShift	Horn Alignment	+0.5, -0.5 mm
BeamTheta	Beam Alignment	0.07 mrad tilt
BeamThetaPhi	Beam Alignment	0.07 mrad tilt and 90° rotation about $\hat{z}$
BeamSigma	Beam Alignment	+0.1, -0.1 mm
BeamOffsetX	Beam Alignment	+0.45, -0.45 mm

Table 1: The systematic variations used in this analysis.

Flux Uncertainties

- The **focusing uncertainties** (not hadron production) have the **largest impact on contours**
- "Flux" = focusing + hadron production





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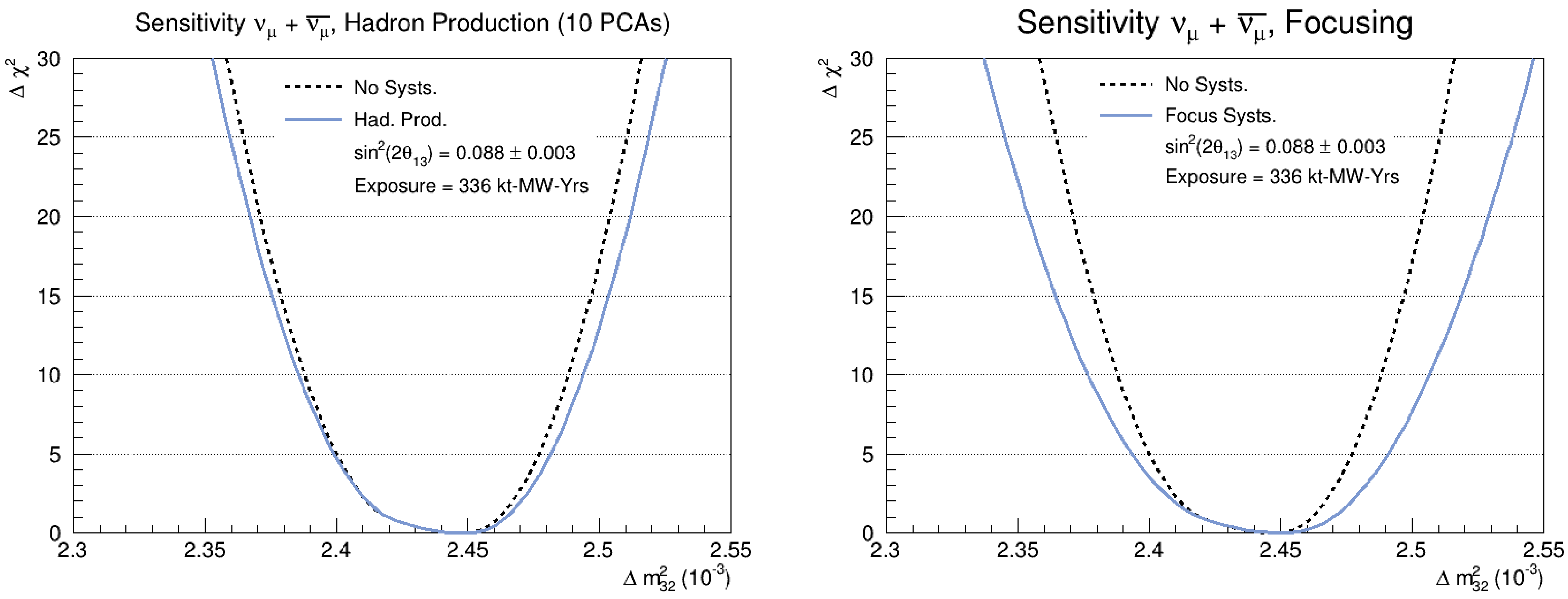

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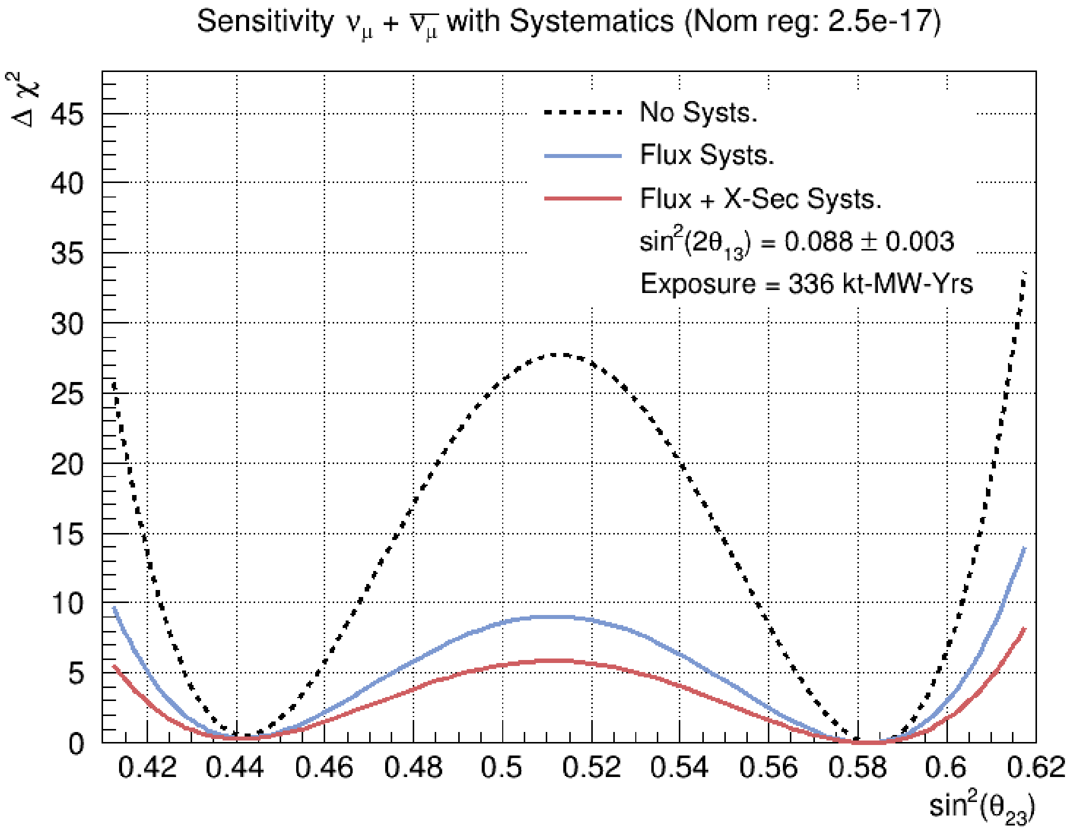
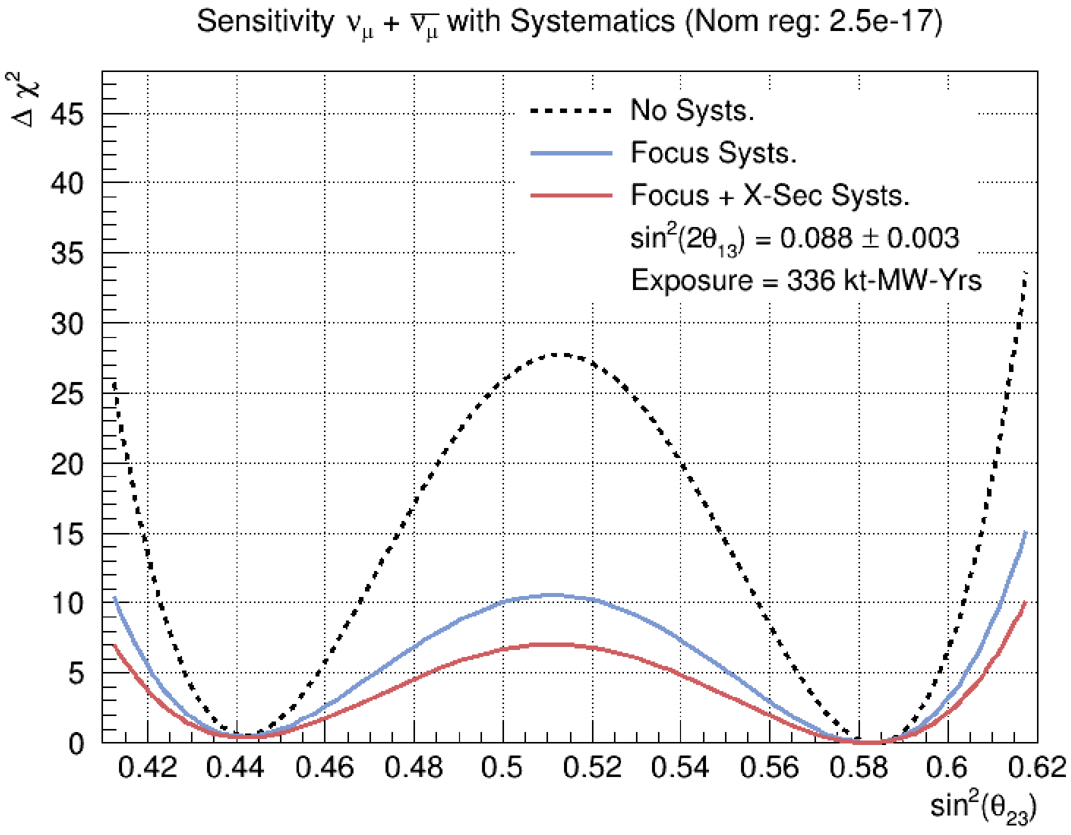
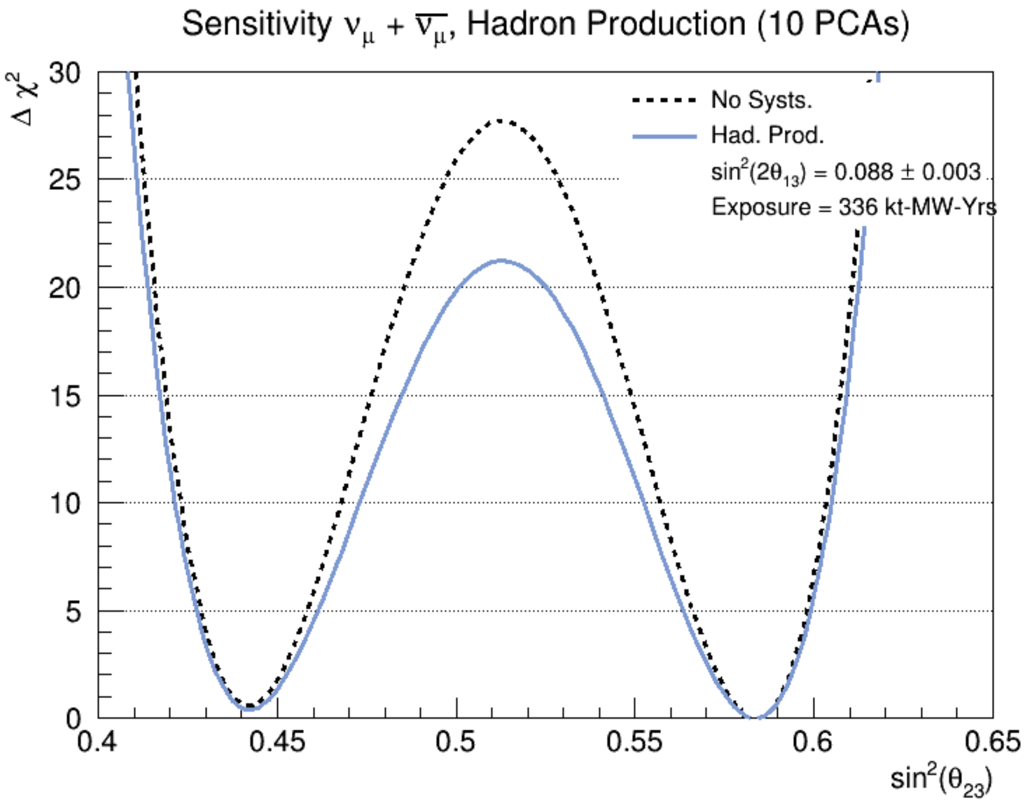
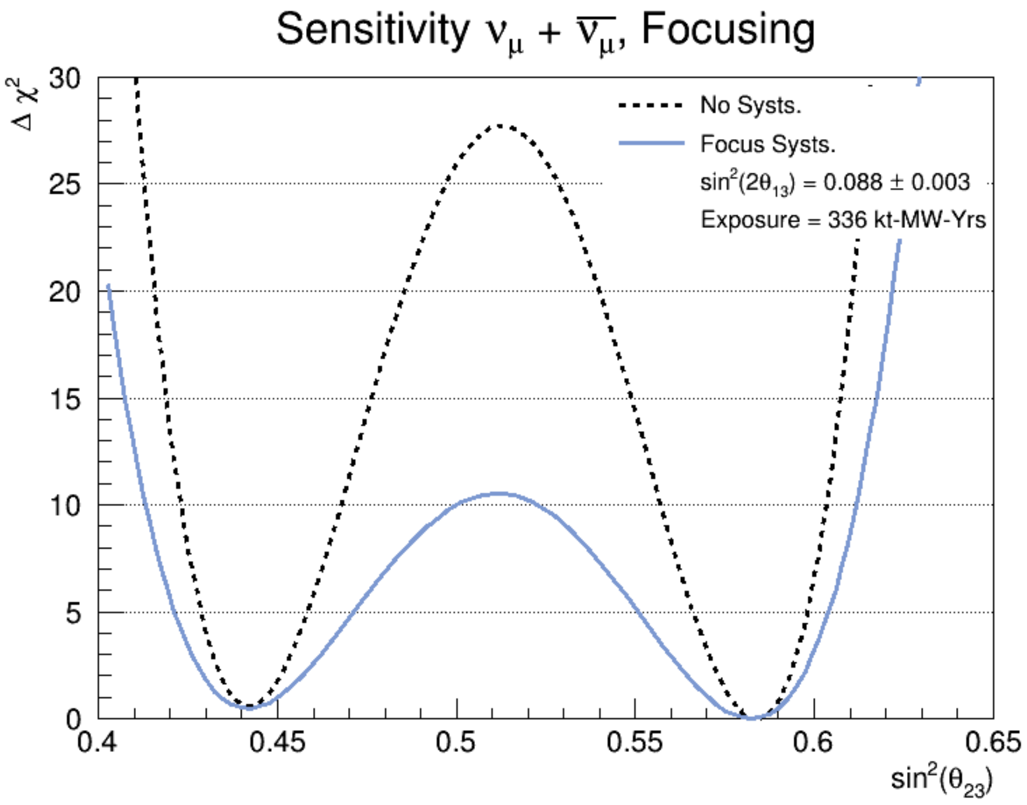




Flux Uncertainties

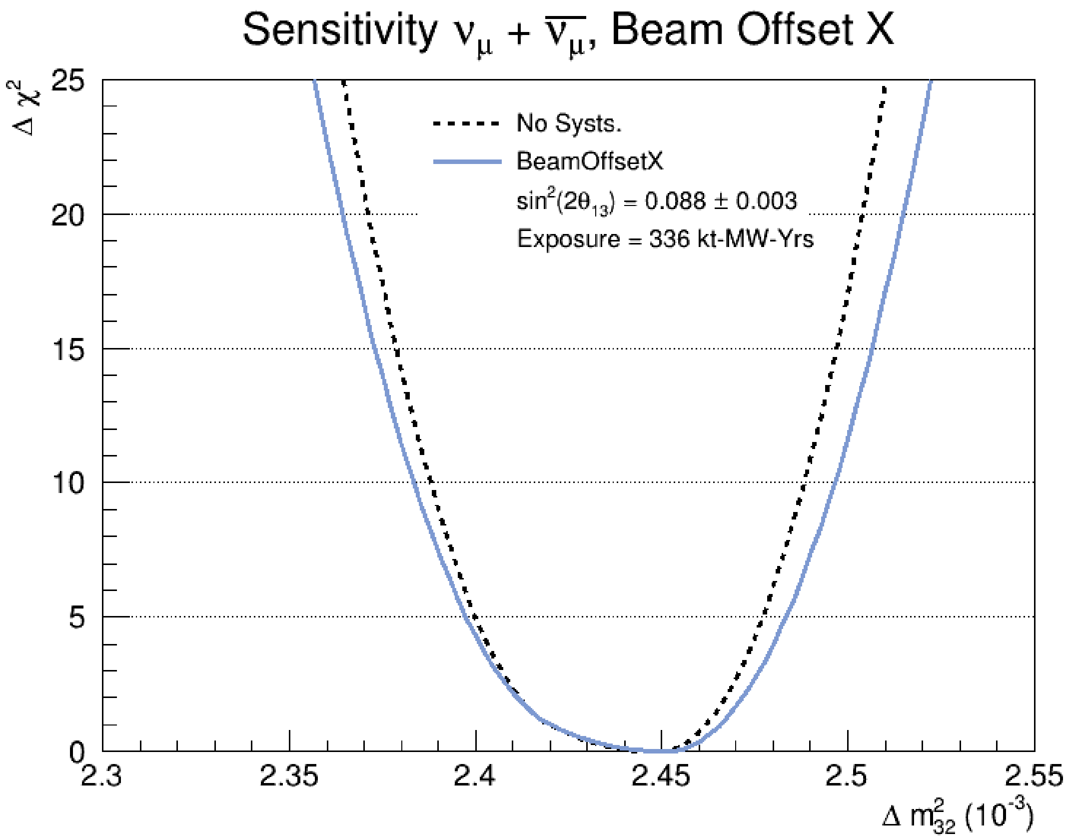
- The **focusing uncertainties** (not hadron production) have the **largest impact on contours**
- Following slides show the important focusing parameters

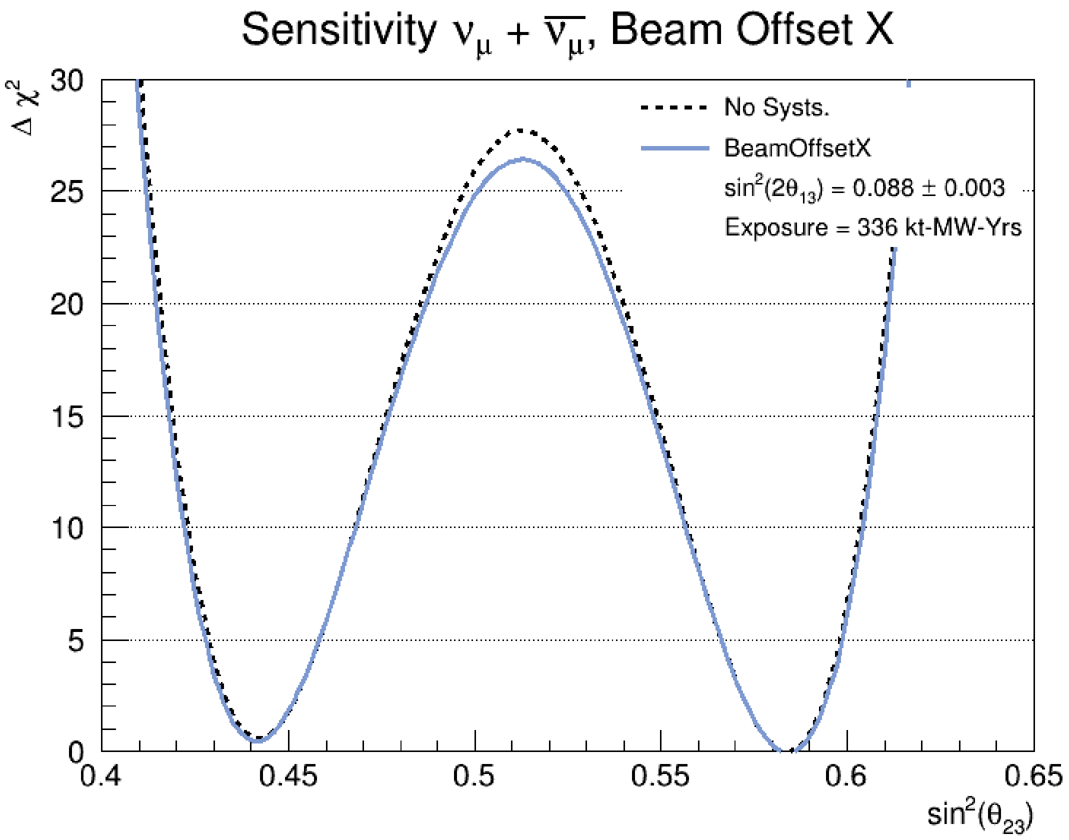




Beam Offset X

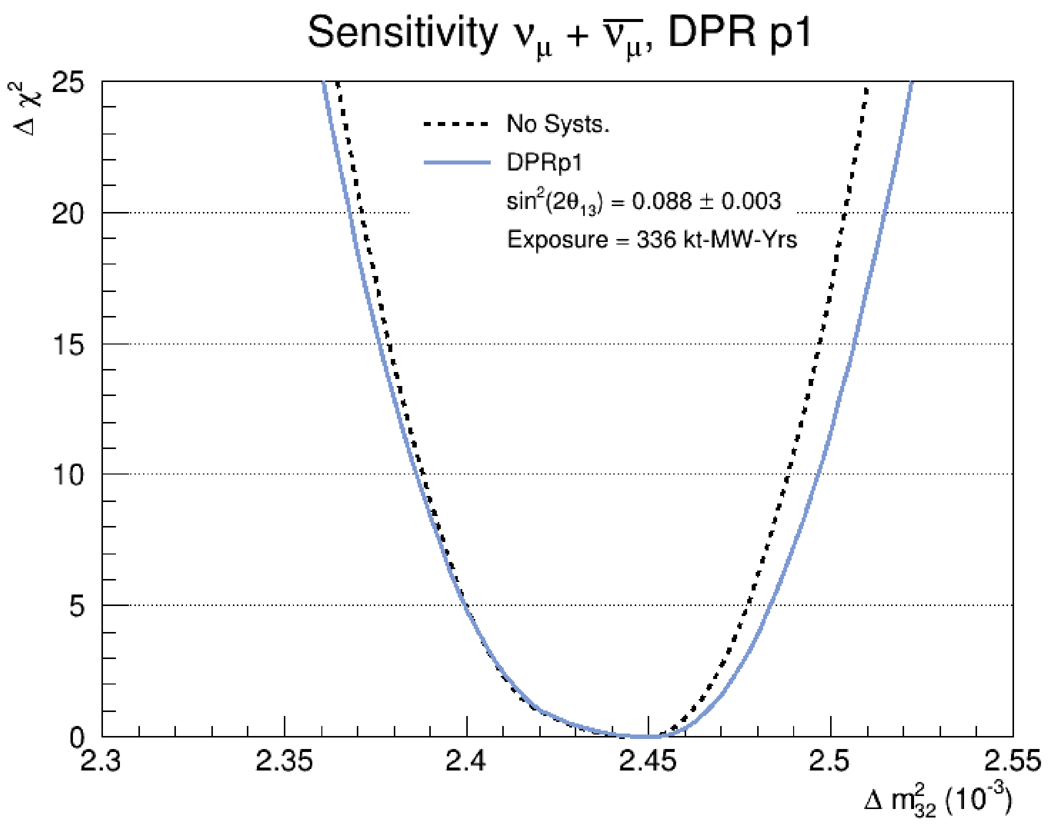
- Focusing parameters that affect the flux in the x-direction (the direction we move the detector) tend to be more important

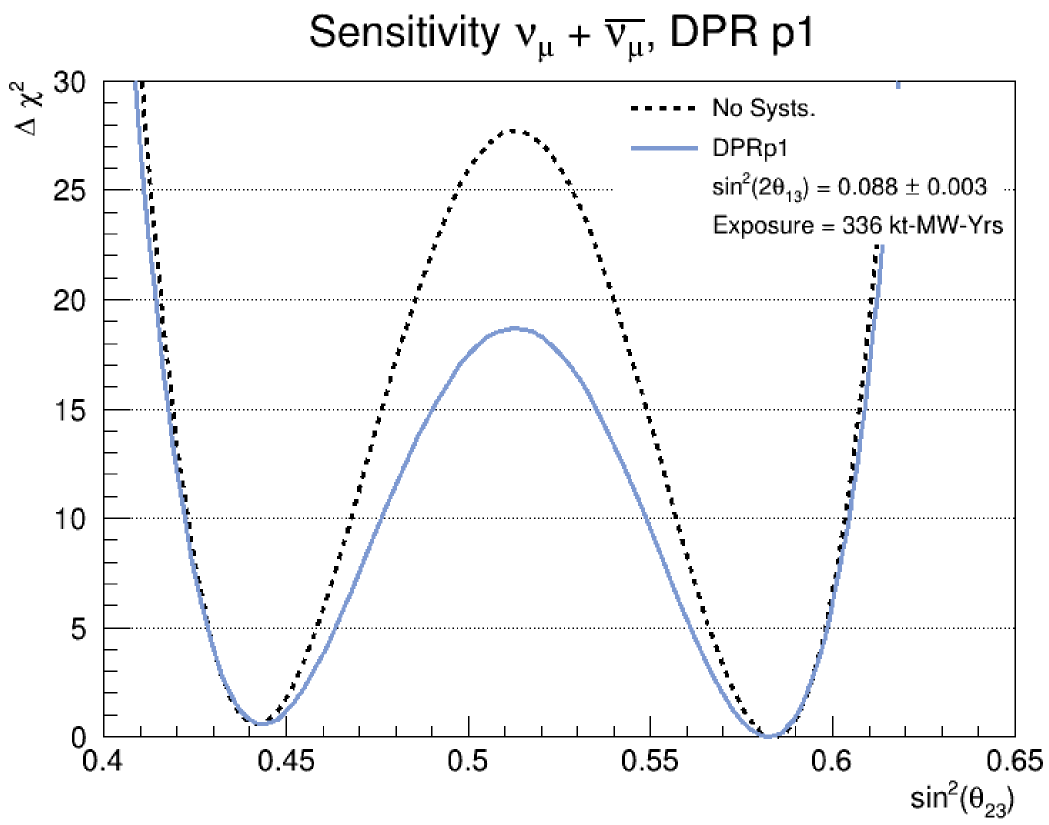




Decay Pipe Radius

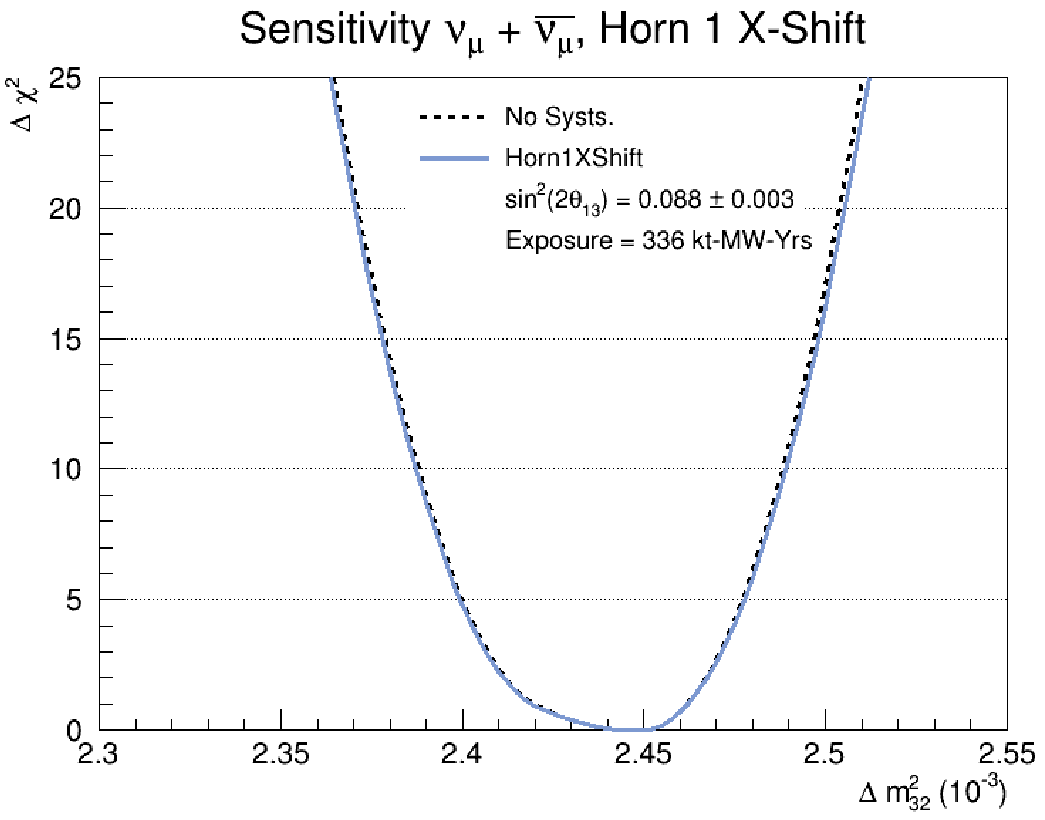
- The 1-sigma uncertainty on the DPR is 10 cm
- New flux simulation has a DPR uncertainty of 2 cm – not likely to be important in the future

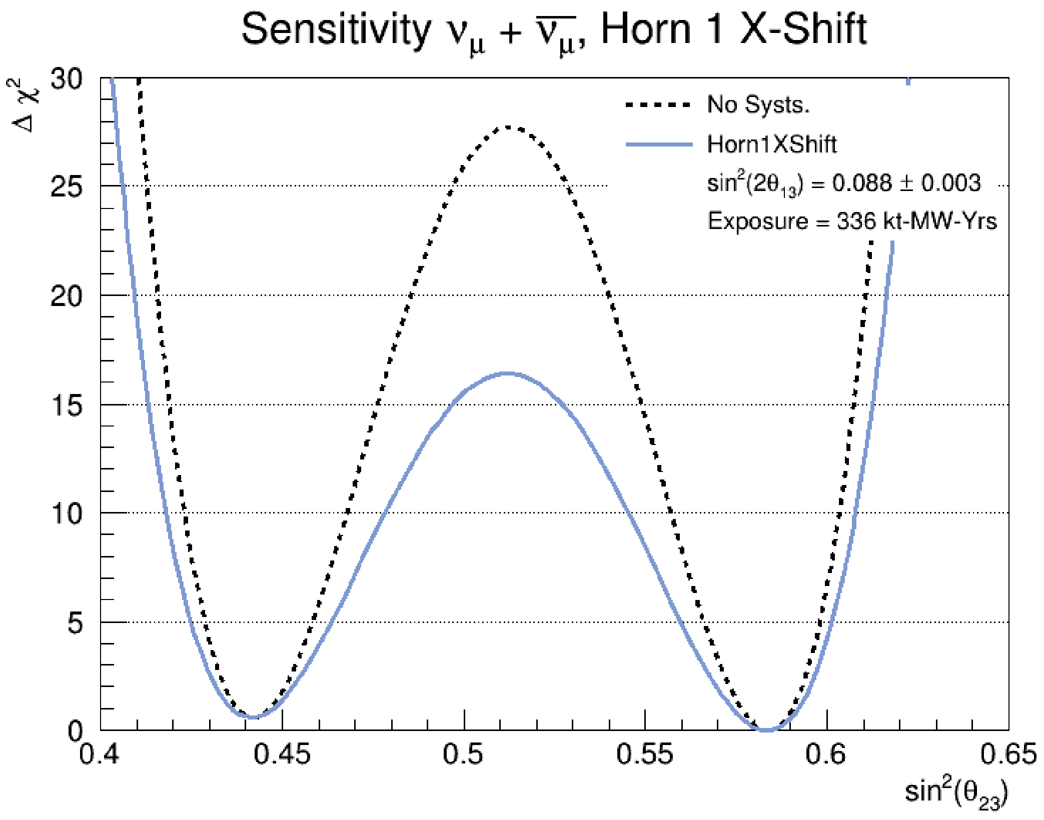




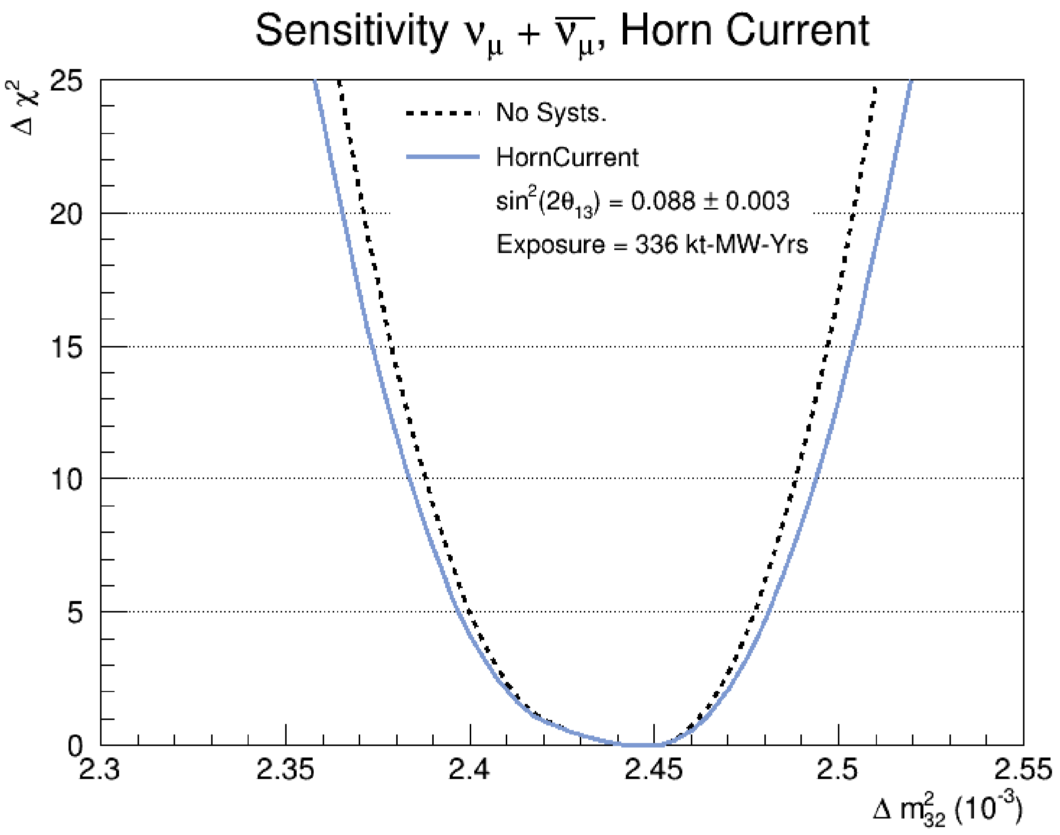
Horn 1 X-Shift

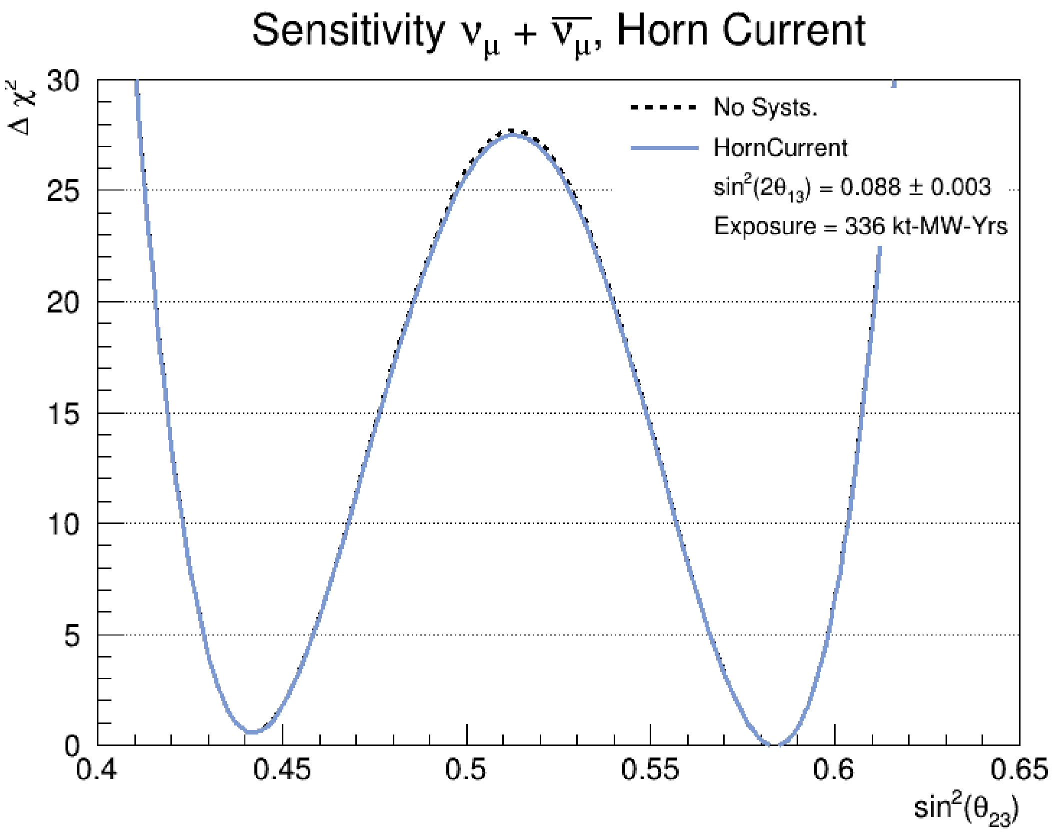
- Focusing parameters that affect the flux in the x-direction (the direction we move the detector) tend to be more important





Horn Current



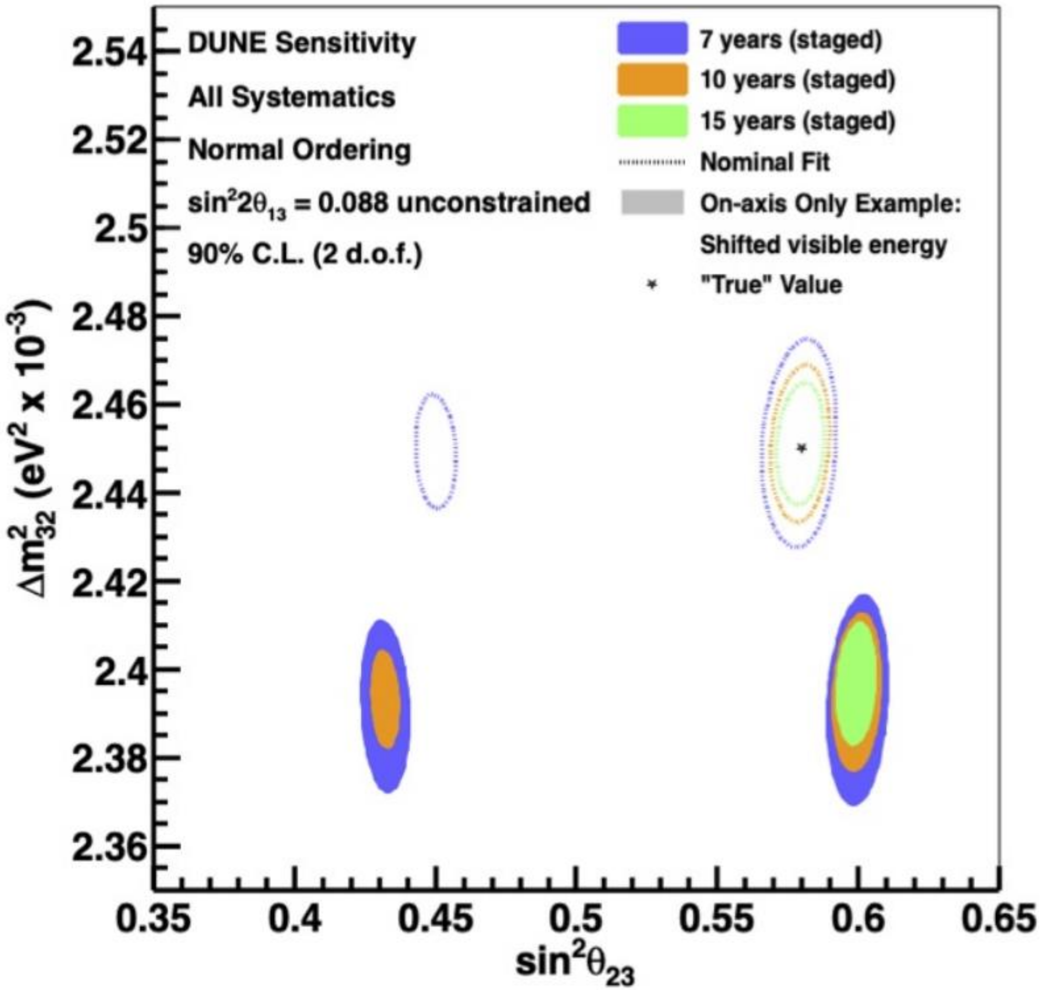


Implementing New Flux Uncertainties

- New flux uncertainties have been produced by the beam group for off-axis fluxes (thank you Pierce Weatherly)
- Expanded set of **focusing uncertainties** and changes to current uncertainties
    - Reduced **DPR uncertainty**, reduced impact from **horn 2 position** – hopefully see a reduction in total impact of focusing uncertainties
- Still expect the same pattern of **flux shifts in the x-direction** to be the most important
    - Explore feasibility of additional horn position monitoring or using TMS to monitor these effects

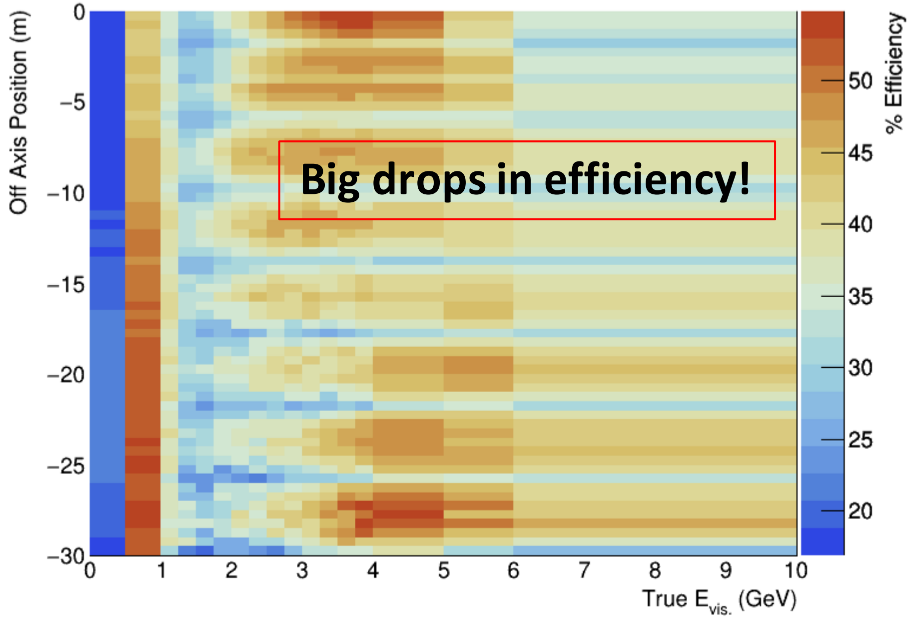
Missing Proton Fake Data Bias

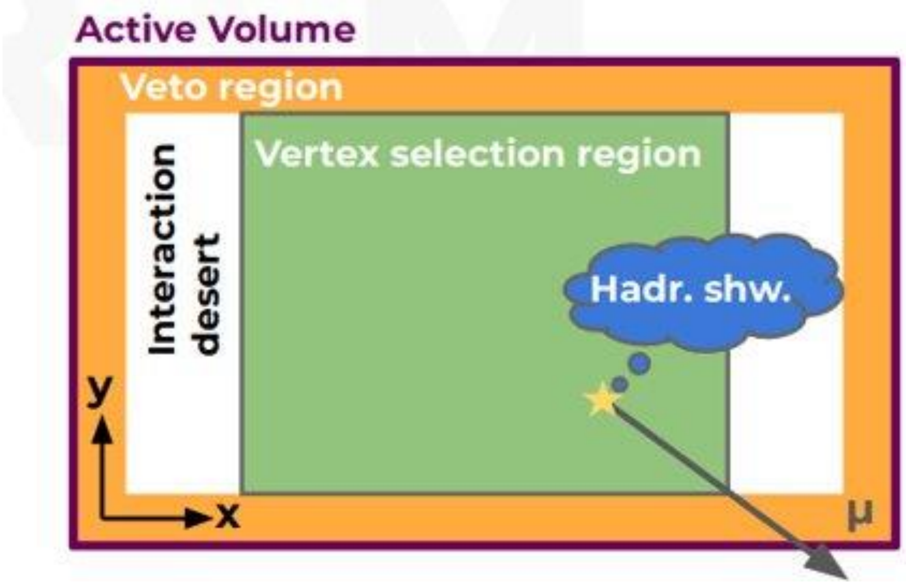
- PRISM analysis aims to be **robust** against **cross-section modelling errors**
- Poorly modelled cross-section effects should be **naturally included** in our measurement
- Focus on **missing proton fake data** – **20% of proton energy taken away** and given to neutrons
- Current challenge: Introduced model dependence to correct for **detector effects**



Missing Proton Fake Data Bias

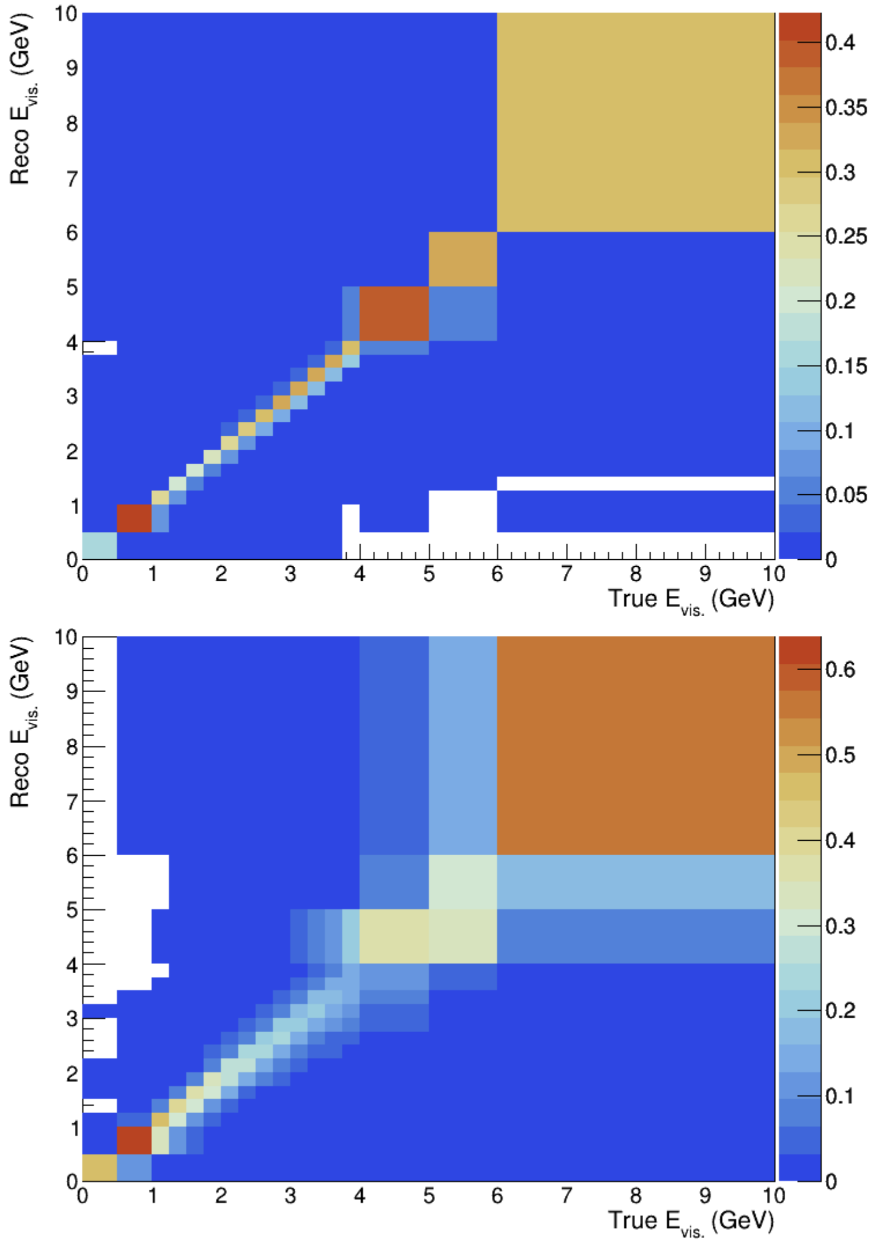
- The **efficiency** in the **ND** corrected for using the MC – **Entirely model dependent!**
- Current **standard efficiency** correction the primary way **cross-section uncertainties** enter PRISM analysis currently
- Data-driven **geometric efficiency correction**
  - Replace MC-based efficiency correction
  - Event-by-event efficiency correction based on detector geometries
  - See talk by Cris Vilela





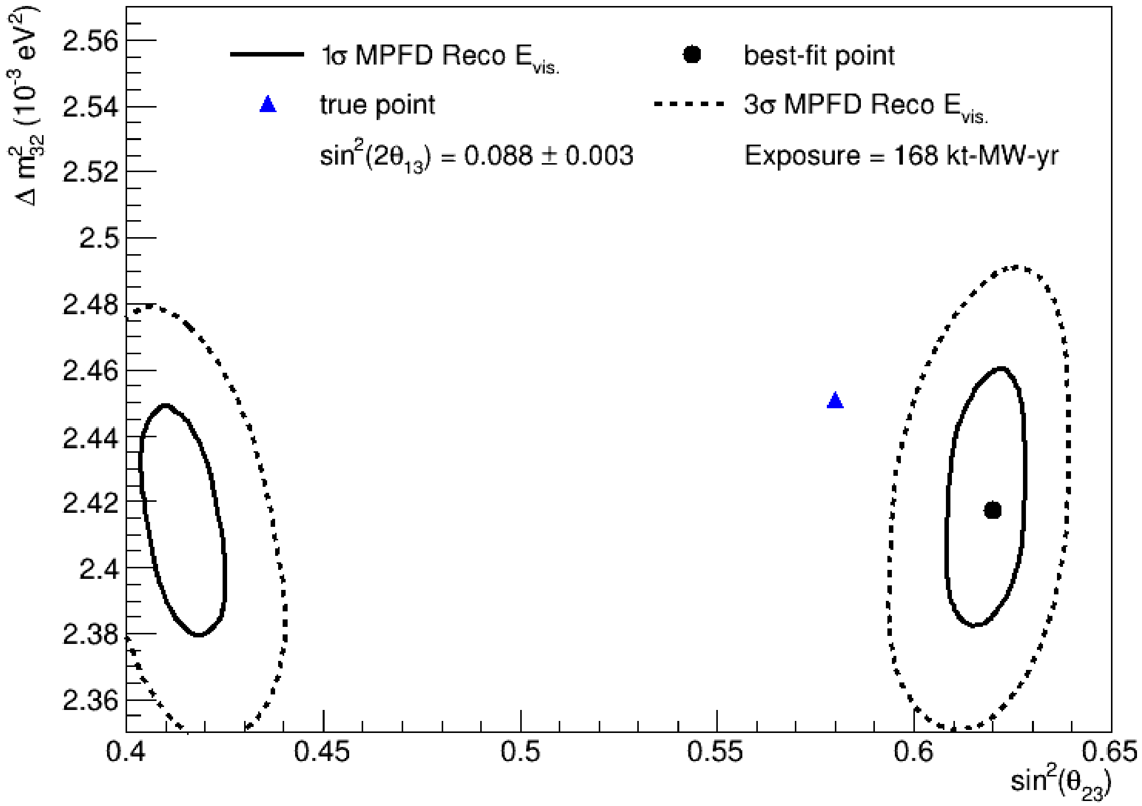
Missing Proton Fake Data Bias

- Current method for correcting for ND/FD detector differences uses **MC to unfold and smear ND data**
- Proposal for a **ML-based ND to FD translation**
  - See talk by [H. Tanaka]() for detailed plan
  - R. Radev and C. Vilela exploring use of an image-to-image translation model to project ND pixels to the collection plane of the FD
- I.e., no more smearing matrices or unfolding



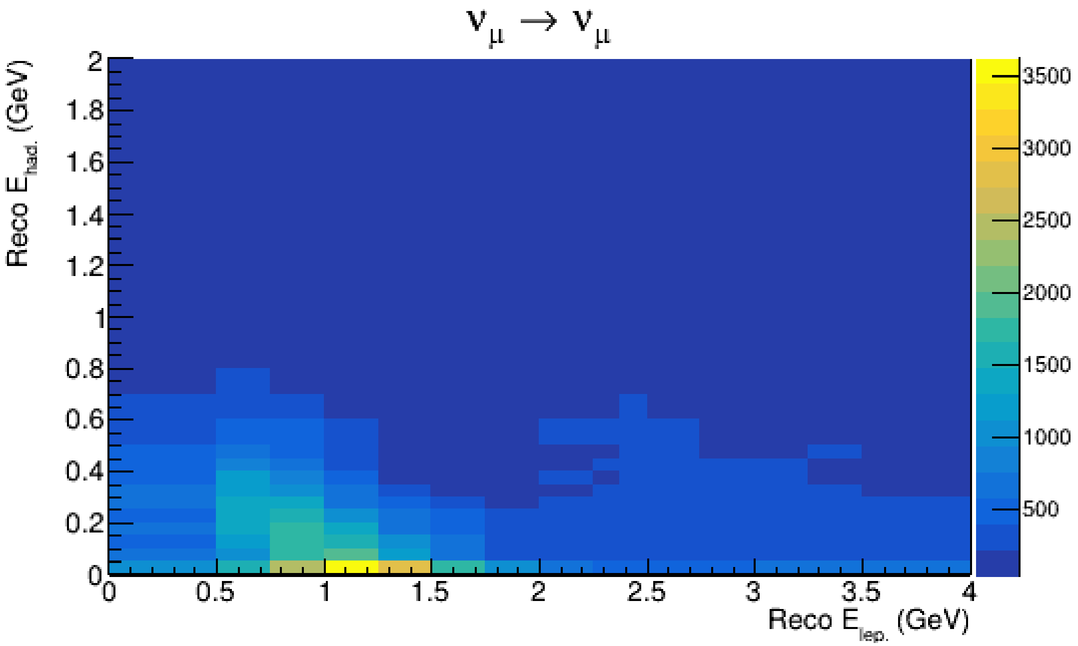
Missing Proton Fake Data Bias

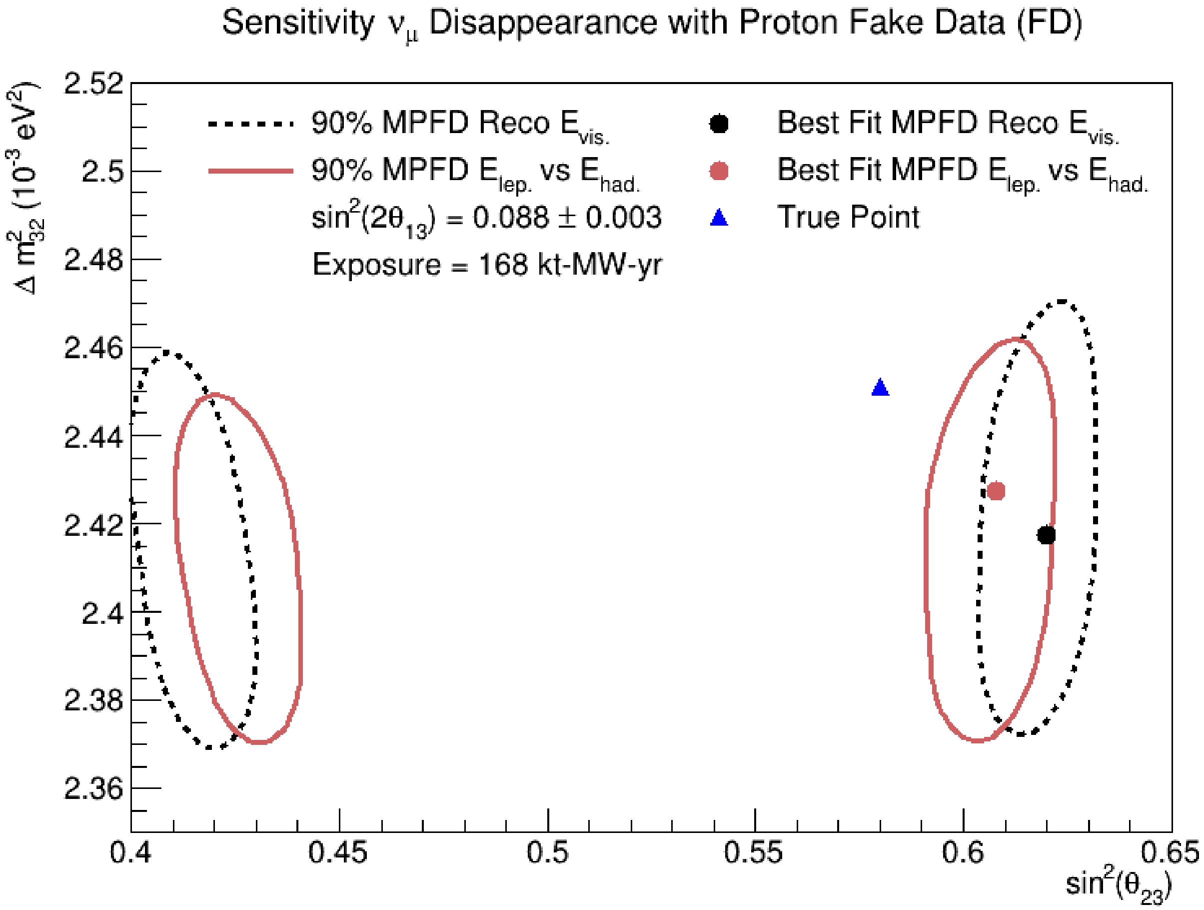
- Fit our **1D PRISM prediction** to our **FD 'biased fake data'**
- Our ND data has the same bias, but our oscillation contours are wrong
- This is **entirely due** to correcting for **detector effects using MC**



Missing Proton Fake Data Bias

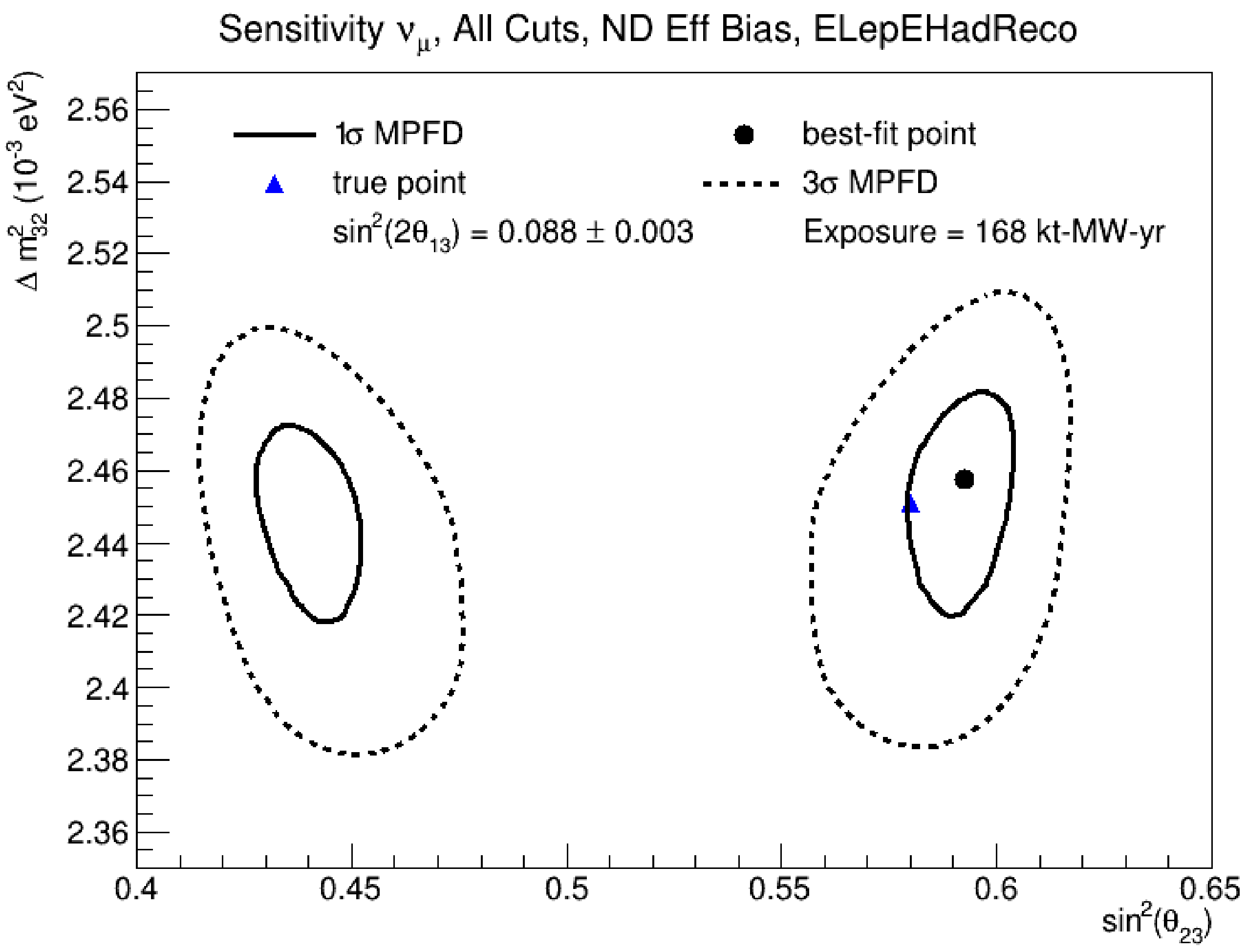
- Moving from a **1D Ereco prediction** to a **2D ELep vs EHad prediction** helps
- Better separation between events of high ELep and low EHad and vice versa, which can have very different efficiencies





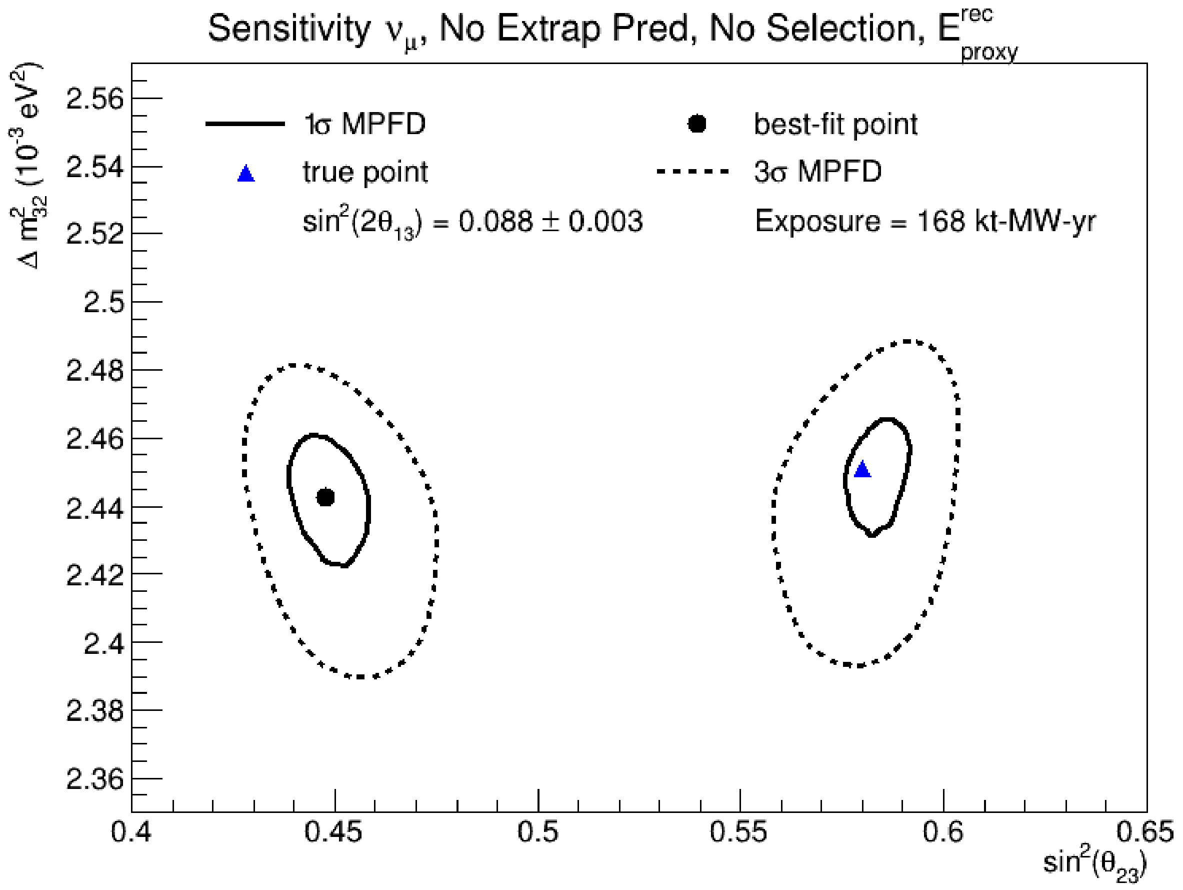
Missing Proton Fake Data Bias

- Shift the **ND MC efficiency correction** by the same "missing proton fake data" shift
- ND efficiency correction **'knows'** about the real physics
- Bias reduced to 1-sigma effect
- Remaining bias explained by the **smearing matrices** and a small bias in theta23 inherent to the current analysis (currently hunting the source of this)



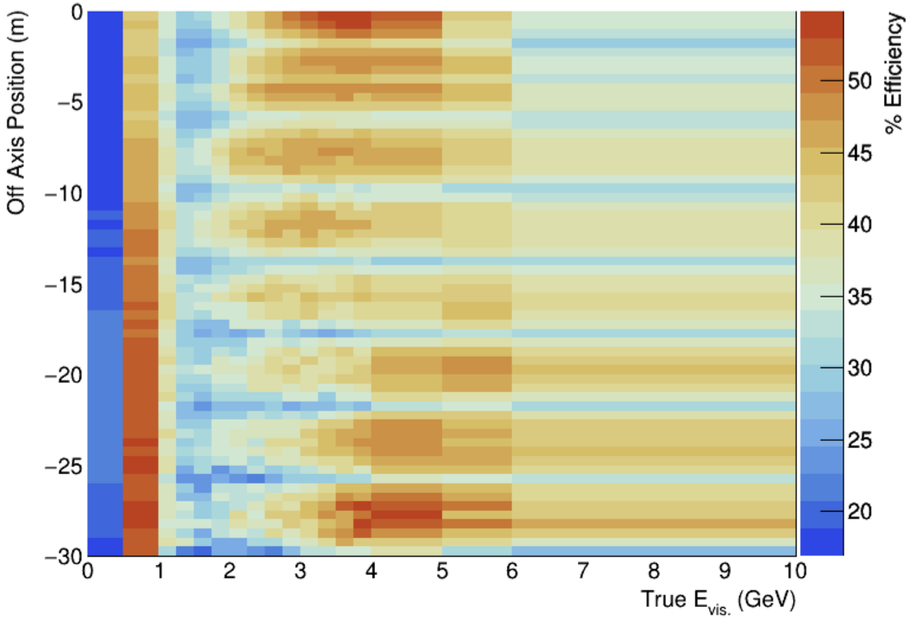
Missing Proton Fake Data Bias – Ideal Case

- Want to **remove MC dependence** in the correction for detector effects
- Shown is using **"Proxy EReco"** (sum of true energy in final state) variable and only selecting **true numu CC** events
- No unfolding, smearing or efficiency correction needed
- No contour bias



Next Steps

- Implement **new flux uncertainties** in the PRISM analysis
- The source of the contour bias in fake data fits has been isolated to the **MC correction of detector effects**
- Alex Booth has kindly produced **new MC at "half stops"** - this will help fill-in some of the big drops in selection efficiency



Thank you for listening!

Backup

Disappearance Analysis Procedure

FINISH

1. **Subtract backgrounds** from each ND off axis slice

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

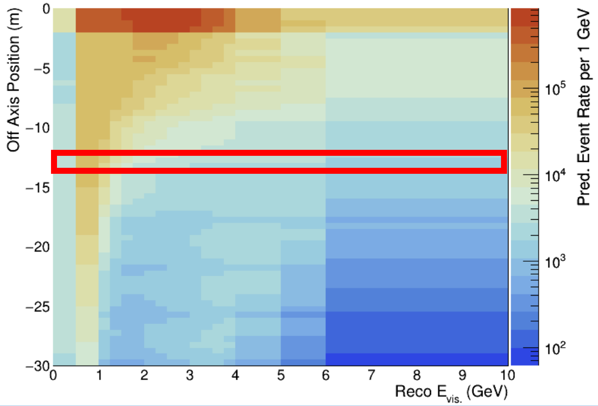
3. **Unfold** each slice of ND data to **true** variable, correct for efficiency in ND slice (**ND detector systematics**)

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

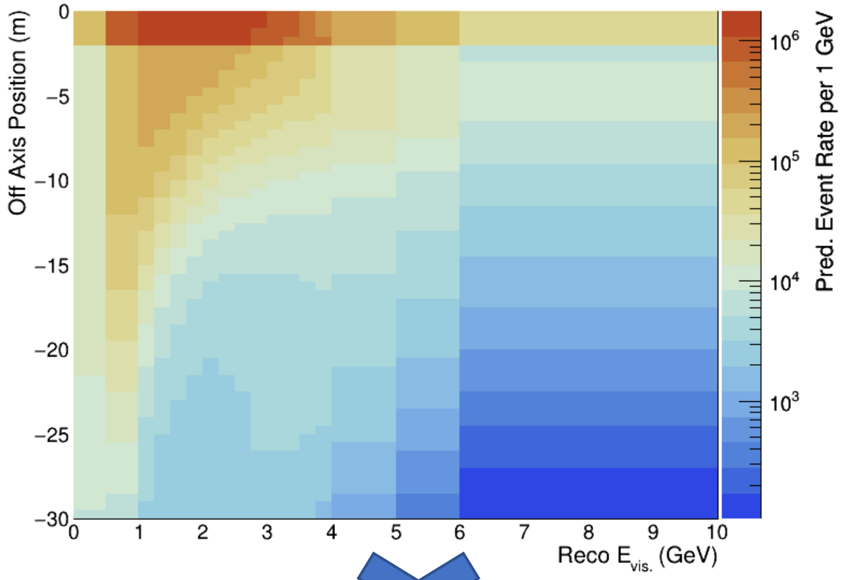
5. **Perform linear combination of extrapolated ND off-axis data**

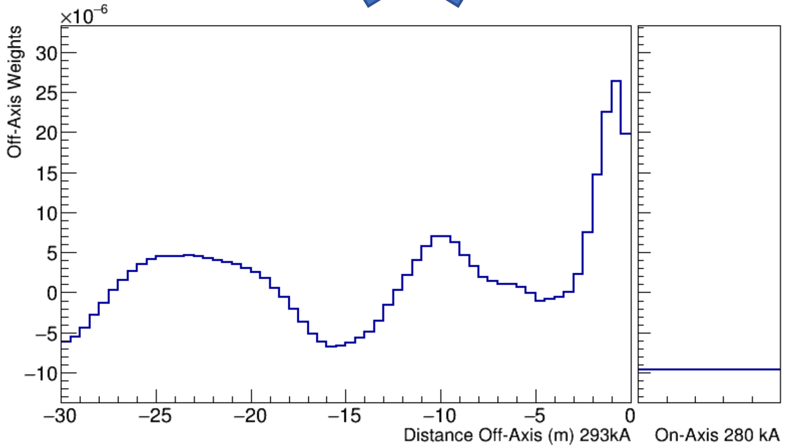
6. Add FD backgrounds to get **Extrapolated PRISM Prediction** in reconstructed visible energy

START

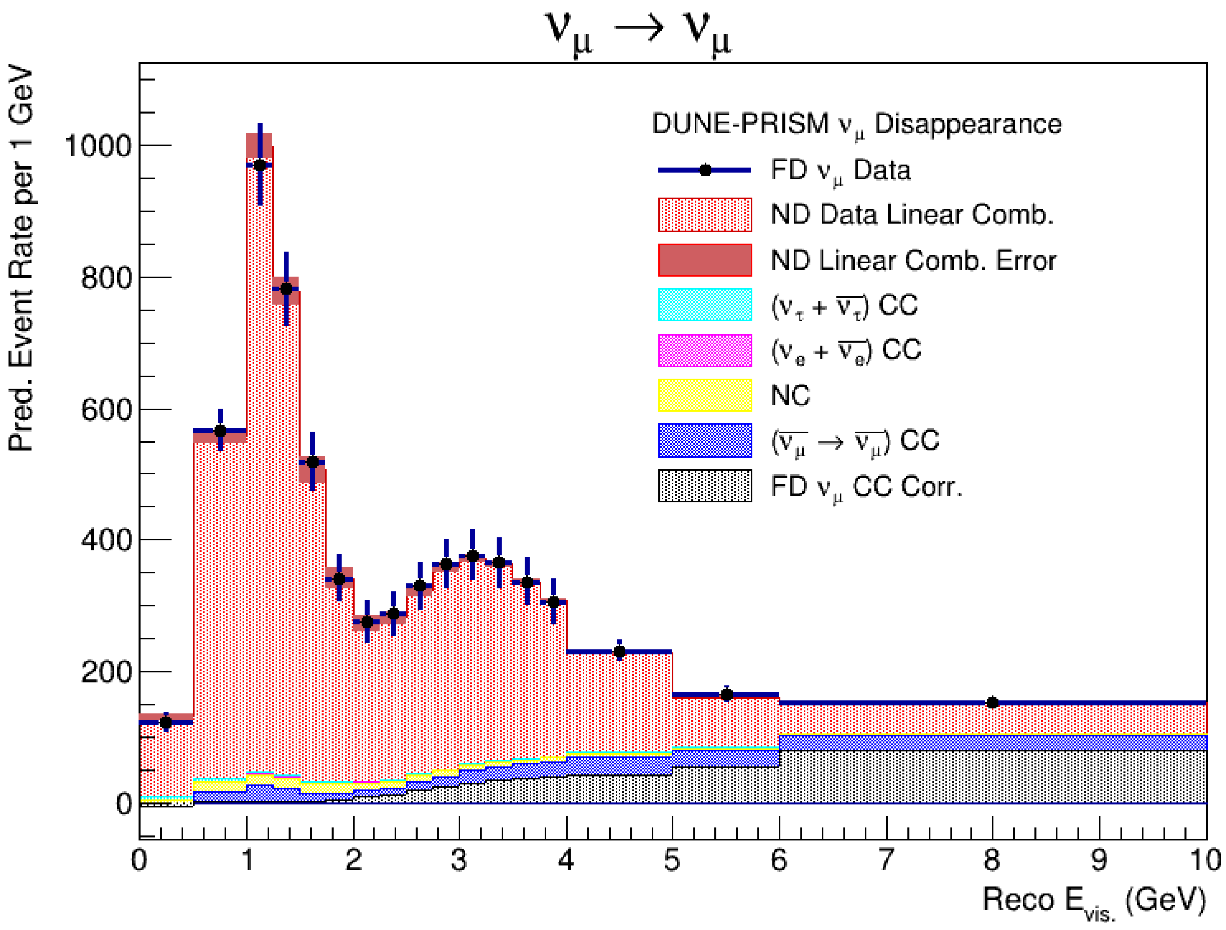


FHC Disappearance Prediction





Just the RED



Appearance Analysis Procedure

FINISH

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

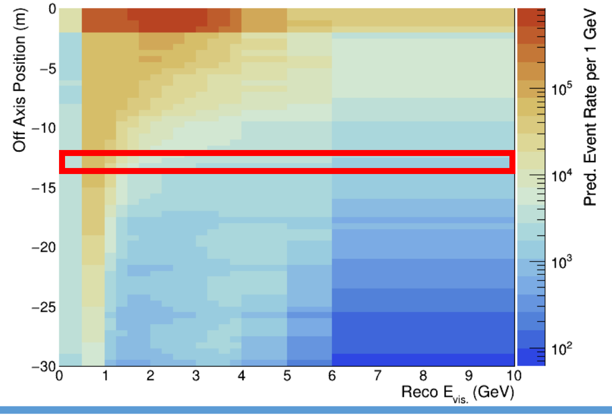
3. **Unfold** each slice of ND data to **true** variable, correct for efficiency in ND slice (**ND detector systematics**)

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

1. **Subtract backgrounds** from each ND off axis slice

4. Correct for nue/numu x-section ratio as a function of true variable

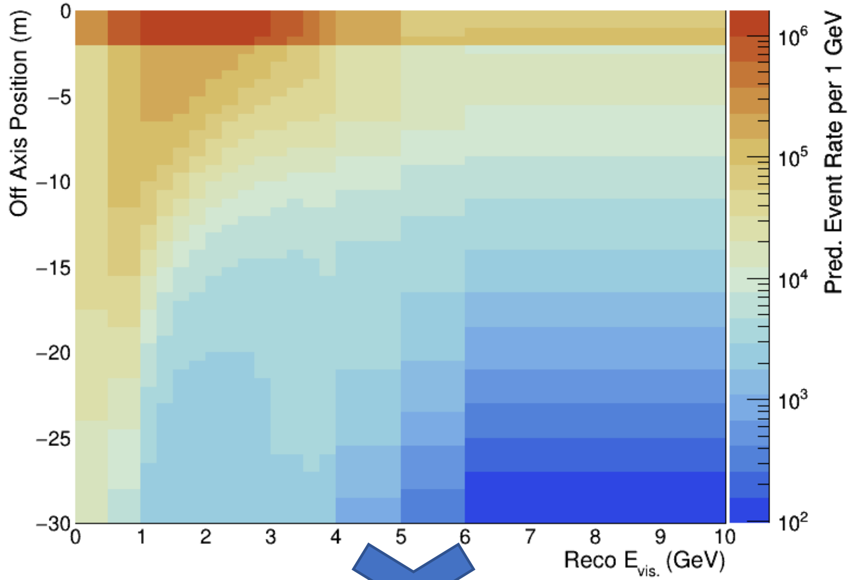
START

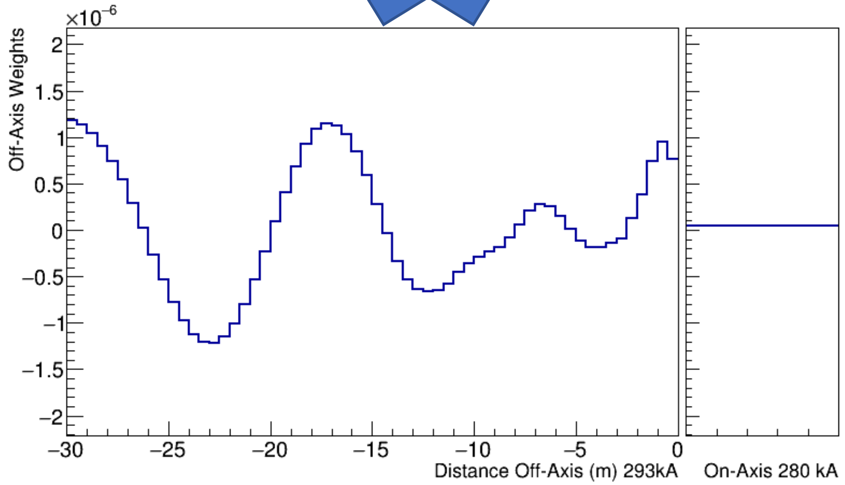


5. **Smear true variable** in each slice to **FD reco**, correct for FD efficiency (**FD detector systematics**)

6. **Perform linear combination of extrapolated ND off-axis data**

FHC Appearance Prediction





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