Implementation of new beam focusing systematics within the PRISM Analysis

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on behalf of DUNE – PRISM working group

DUNE Collaboration Meeting

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Incorporation of beam focusing uncertainties (v3r5p9 release of G4LBNE) within PRISM Analysis

- Focusing uncertainties:
  - the position, geometry, and composition of the beamline components (horns, target, decay pipe, etc)
  - the current or water layer in each horn
  - the geometry of the incident proton beam

- Previous flux focusing systematics (Nov 17) are incomplete and include only 2 horns

- New (not present in the previous releases) uncertainties:
  - tilt of target, horns, decay pipe
  - horns' inner conductor deformations
  - major updates to the decay pipe geometry and positioning

Parameter	1 σ Shift	Notes
Proton Beam Transverse X	0.5 mm	Interaction Position.
Proton Beam Transverse Y	0.5 mm	Updated to 0.5 mm from 4.5 mm in TDR
Proton Beam Angle X	$\delta\theta$ = 70 μrad Φ = 0, π	Proton Beam Angle on target Target Interaction Point fixed to center of target
Proton Beam Angle Y	$\delta\theta$ = 70 μrad Φ =$\pm\pi/2$	
Proton Beam Radius	10% (0.27 mm)	Updated from 1% in the TDR. Change X&Y sigmoid simultaneously
Target Density	2% (0.0356 g/cm^3)	Approximate target degredation
Upstream Target Degredation	5 mm loss	Assume complete loss of target on upstream end; basically a shorter target (by dz) shifted downstream by the loss dz
Target Displace Transverse X	0.5 mm	
Target Displace Transverse Y	0.5 mm	
Target Tilt Transverse X	0.5 mm	
Target Tilt Transverse Y	0.5 mm	
Target Length	1.5 mm (0.01%)	Arbitrarily assumed tolerance
Horn Currents	1% (3 kA)	Simoultaneously change to all 3 Horns; nominal = 300 kA
Horn Water Layer Thickness	0.5 mm	Simultaneous change to all 3 Horns; nominal = 1 mm. Cannot go below 0
Horn A Displace Transverse X	0.5 mm	
Horn A Displace Transverse Y	0.5 mm	
Horn A Displace Longitudinal Z	2.0 mm	
Horn A Tilt Transverse X	0.5 mm	Upstream and downstream ends shifted in opposite directions by tolerance value
Horn A Tilt Transverse Y	0.5 mm	
Horn A Eccentricity X Induced B Field	0.035 mm	Horn A Inner conductor eccentrictiy: Eccentric (off aixs) deformation of inner conductor; induced dipole field in y in field-free region. NuMI Horn 1 tolerance assumed
Horn A Ellipticity X Induced B Field	0.120mm	Elliptical deformation of inner conductor; induced quadrupole field in x-y in field-free region; NuMI Horn1 tolerance assumed
Horn B Displace Transverse X	0.5 mm	
Horn B Displace Transverse Y	0.5 mm	
Horn B Displace Longitudinal Z	3.0 mm	
Horn B Tilt Transverse X	0.5 mm	Upstream and downstream ends shifted in opposite directions by tolerance value
Horn B Tilt Transverse Y	0.5 mm	
Horn B Ellipticity X Induced B Field	0.180 mm	NuMI Horn 2 tolerance assumed
Horn C Displace Transverse X	0.5 mm	
Horn C Displace Transverse Y	0.5 mm	
Horn C Displace Longitudinal Z	3.0 mm	
Horn C Tilt Transverse X	0.5 mm	
Horn C Tilt Transverse Y	0.5 mm	
Horn C Eccentricity X Induced B Field	0.07 mm	NuMI horn 2 tolerance assumed
Horn C Ellipticity X Induced B Field	0.180 mm	NuMI horn 2 tolerance assumed
Decay Pipe Radius	2.0 cm	Changed from 10 cm; nominal = 2 m
Decay Pipe Length	2.5 cm	Same as elongating, since the distance between decay pipe upstream is fixed
Decay Pipe Displace Transverse X	2.5 cm	
Decay Pipe Displace Transverse Y	2.5 cm	
Decay Pipe Tilt X _ DSOA	2.5 cm	Downstream (DS) end fixed to remain on axis
Decay Pipe Tilt Y _ DSOA	2.5 cm	
Decay Pipe Elliptical Cross section X (A)	2.5 cm	Ellipse with A (X-axis) or B (y-axis) varied by tolerance, while other dimension fixed to nominal radius
Decay Pipe Elliptical Cross section Y (B)	2.5 cm	
Decay Pipe Geo B Field	1	Scale-factor value to 1 is 1σ tolerance. Mapped from NuMI decay pipe geo B-field measurements
Decay Pipe Segmented Bowing X	2.5 cm	Decay Pipe segmented in 3 equal pieces; central piece transverse shifted by tolerance
Decay Pipe Segmented Bowing X	2.5 cm	

Incorporation of beam focusing uncertainties (v3r5p9 release of G4LBNE) within PRISM Analysis

- Use flux systematics provided by P. Weatherly (/pnfs/dune/persistent/users/pweather/fluxfiles/g4lbne/v3r5p9/QGSP_BERT/)
  - nominal: OfficialEngDesignSept2021/neutrino/flux
  - shift: OEDS21_HornADisplaceTransverseX_pos_1_sigma/neutrino/flux

- **ND files – Flux vs Off Axis vs Neutrino Energy**

Rebin for PRISM Analysis needs (diff E binning for diff OA bins)

Apply the systematics to ND data
– Check how the **fractional shift** (1σ Shift– Nominal) /Nominal looks in **ND data** as a function of **Off-axis position vs True E_ν**

Linearly combine nominal ND data and nσ shifted ND data

Fractional shift (Lin. Comb. 1σ Shifted ND data – Lin. Comb Nominal ND data) / Nominal **of PRISM Prediction vs energy**

- **FD files – Flux vs Neutrino energy**

Rebin in E for PRISM Analysis needs

Apply the systematics to FD data
– Check how the **fractional shift** (1σ Shift– Nominal) /Nominal looks in **FD data vs energy**

1. **Compare FD Fractional and PRISM Fractional**:

if different → flux parameter expected to have high impact on the PRISM sensitivity (IMPORTANT parameter)

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Linearly combine nominal ND data and nσ shifted ND data

PRISM linear combination (@nσ) energy

- **FD files – Flux vs Neutrino energy**

Rebin in E for PRISM Analysis needs

Apply the systematics to FD data
– Check how the **fractional shift** (1σ Shift– Nominal) /Nominal looks in **FD data vs energy**

2. **Apply corresponding systematics** (each parameter at a time) to the PRISM Analysis and evaluate the **oscillation parameter sensitivity**

New Flux Systematics – September 2021

September 2021: 45 flux parameters (beam systs)

→ Investigate the effect each individual parameter has on the PRISM oscillation analysis

10 IMPORTANT (influence the sensitivity significantly)

8 SEMI (influence the oscillation fit much less)

27 NEGLIGIBLE (negligible effect on the oscillation fit)

- Analysis variable **is reconstructed neutrino energy:** EnuReco

→ all of the presented results are obtained by using EnuReco unless stated otherwise

September 2021 flux focusing parameters

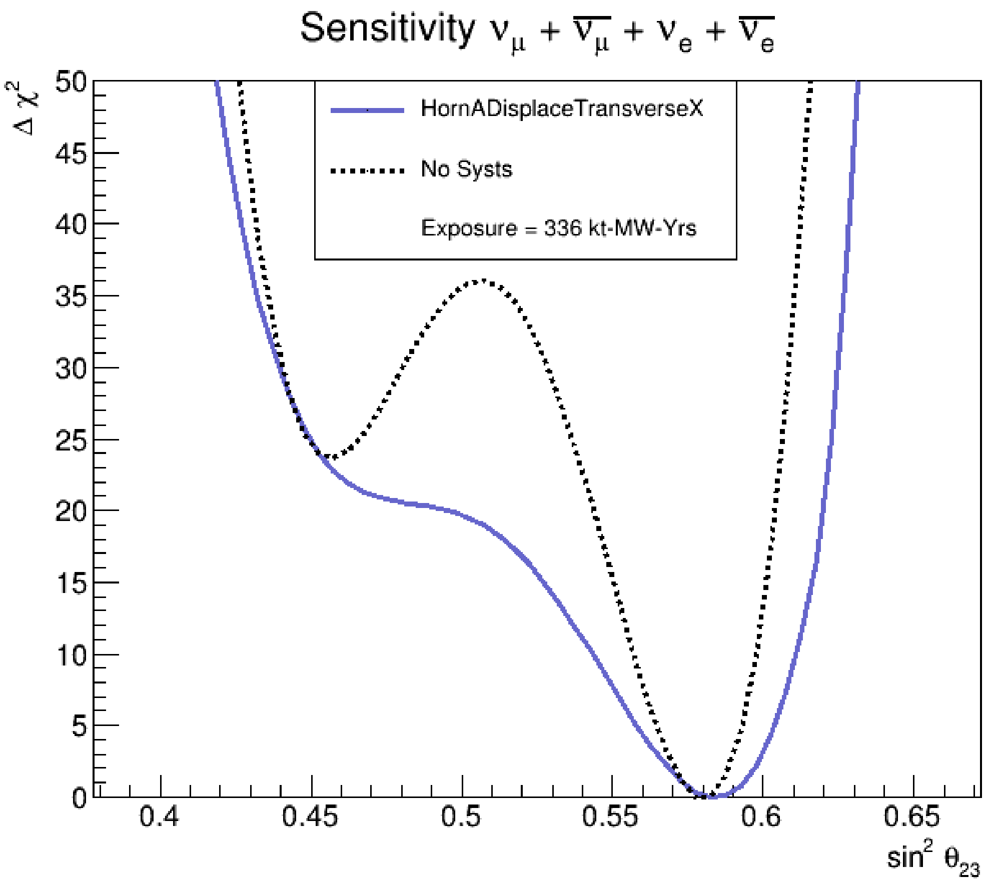
" HornADisplaceTransverseX ",
" HornBDisplaceTransverseX ",
" HornCDisplaceTransverseX ",
" HornADisplaceTransverseY ",
" HornBDisplaceTransverseY ",
" HornCDisplaceTransverseY ",
" DecayPipe3SegmentBowingX ",
" DecayPipe3SegmentBowingY ",
" DecayPipeDisplaceTransverseX ",
" DecayPipeDisplaceTransverseY ",
" DecayPipeEllipticalCrossSectionXA ",
" DecayPipeEllipticalCrossSectionYB ",
" DecayPipeGeoBField ",
" DecayPipeLength ",
" DecayPipeRadius ",
" DecayPipeTiltX_DSOA ",
" DecayPipeTiltY_DSOA ",
" HornADisplaceLongitudinalZ ",
" HornAEccentricityXInducedBField ",
" HornAEllipticityXInducedBField ",
" HornATiltTransverseX ",
" HornATiltTransverseY ",
" HornBDisplaceLongitudinalZ ",
" HornBEllipticityXInducedBField ",
" HornBTiltTransverseX ",
" HornBTiltTransverseY ",
" HornCDisplaceLongitudinalZ ",
" HornCEccentricityXInducedBField ",
" HornCEllipticityXInducedBField ",
" HornCTiltTransverseX ",
" HornCTiltTransverseY ",
" HornCurrent ",
" HornWaterLayerThickness ",
" ProtonBeamAngleX ",
" ProtonBeamAngleY ",
" ProtonBeamRadius ",
" ProtonBeamTransverseX ",
" ProtonBeamTransverseY ",
" TargetDensity ",
" TargetDisplaceTransverseX ",
" TargetDisplaceTransverseY ",
" TargetLength ",
" TargetTiltTransverseX ",
" TargetTiltTransverseY ",
" TargetUpstreamDegredation "

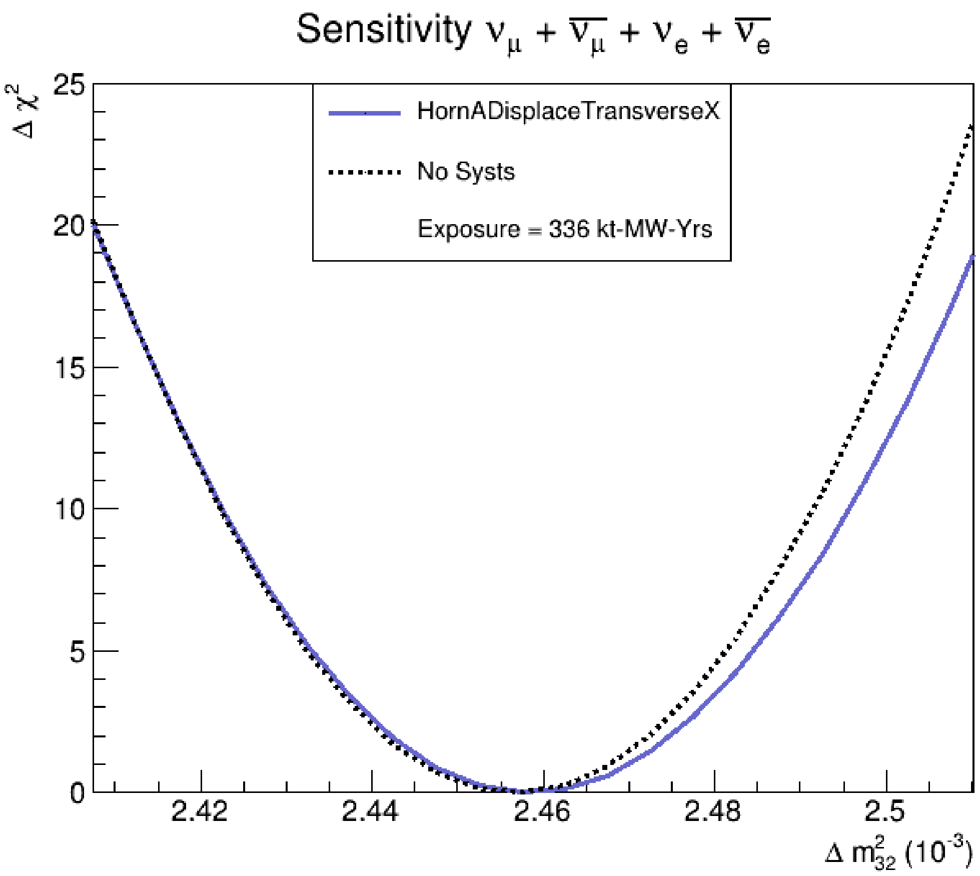
* temporary classification (some of important parameters might be considered semi in the end)

Horn A Displace Transverse X

IMPORTANT

- 1σ shift = 0.5 mm

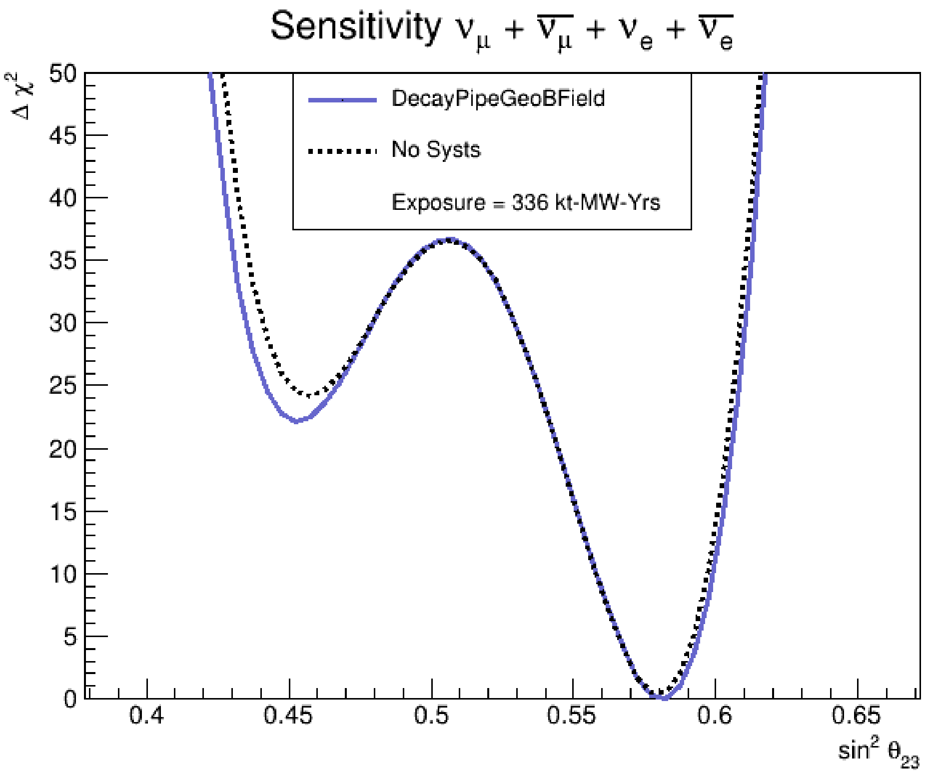


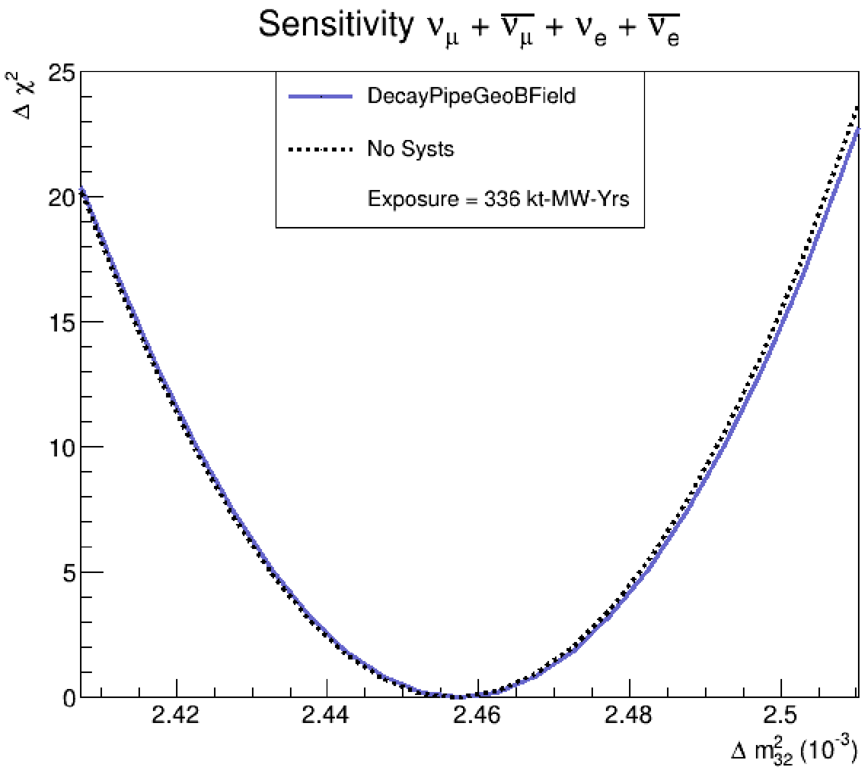


Decay Pipe Geo BField

SEMI

- 1σ shift = 1: scale factor value of 1 is 1σ tolerance
(mapped from NuMI Decay Pipe Geo Bfield measurements)

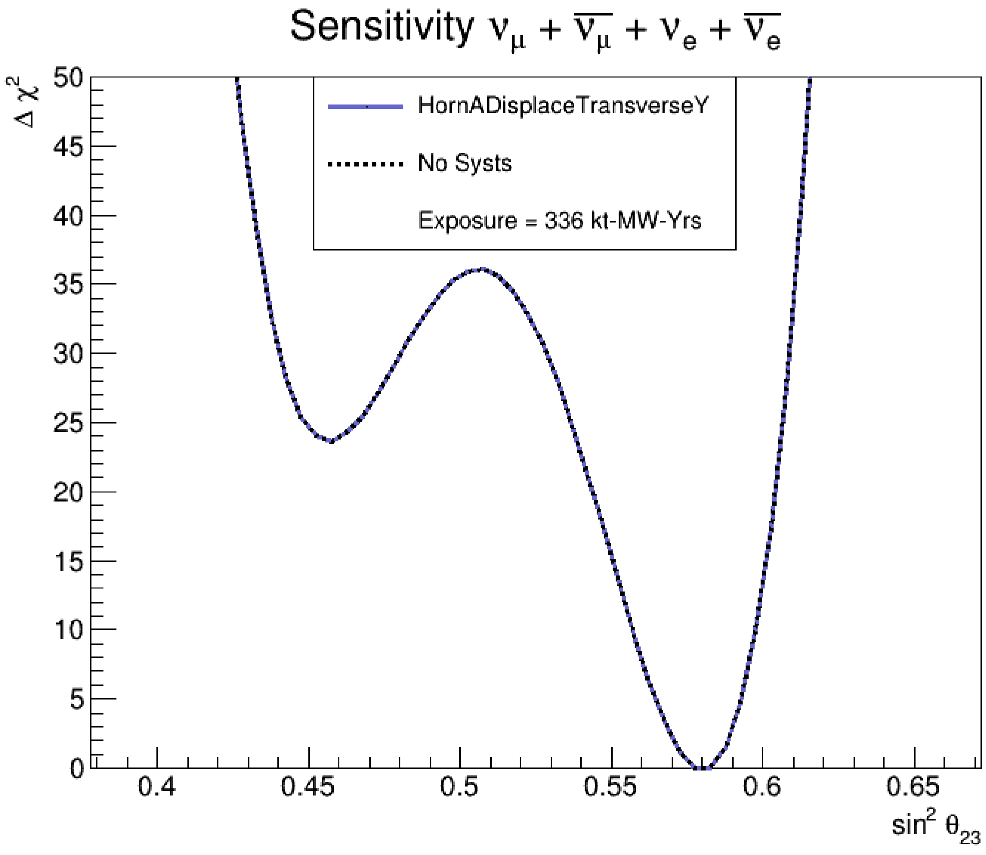


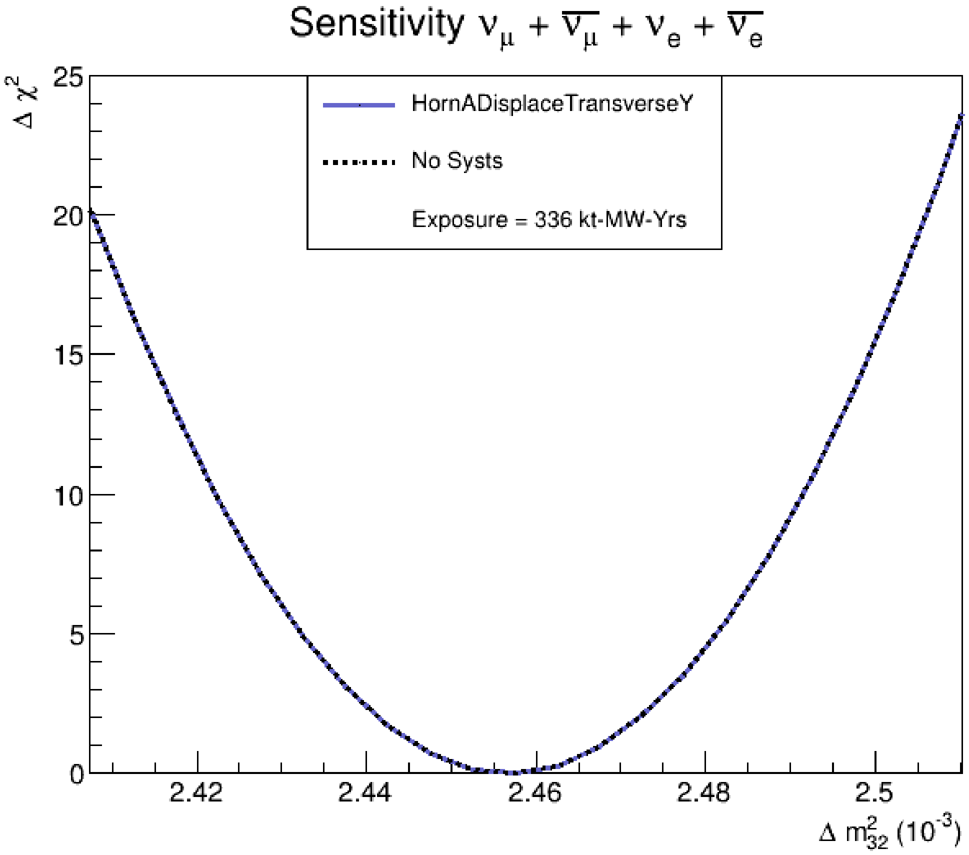


Horn A Displace Transverse Y

NEGLIGIBLE

- 1σ shift = 0.5 mm





New Flux Systematics (Sept 21) – Important parameters

10 IMPORTANT parameters: influence the sensitivity significantly

- HornADisplaceTransverseX → 1 σ shift = 0.5 mm
- HornBDisplaceTransverseX → 1 σ shift = 0.5 mm
- HornCDisplaceTransverseX → 1 σ shift = 0.5 mm
- HornAEccentricityXInducedBField → 1 σ shift = 0.035 mm
- HornATiltTransverseX → 1 σ shift = 0.5mm
- HornCEccentricityXInducedBField → 1 σ shift = 0.07 mm
- HornCurrent → 1 σ shift = 3 kA (1%)
- HornWaterLayerThickness → 1 σ shift = 0.5 mm
- ProtonBeamTransverseX → 1 σ shift = 0.5 mm
- TargetUpstreamDegredation → 1 σ shift = 5 mm

- New uncertainties (not present in TDR): Horn C Displace Transverse, Eccentricity X (both A and C), Horn Tilt (horn A), target upstream degredation

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- HornWaterLayerThickness → 1 σ shift = 0.5 mm
- ProtonBeamTransverseX → 1 σ shift = 0.5 mm
- **TargetUpstreamDegredation → 1 σ shift = 5 mm**

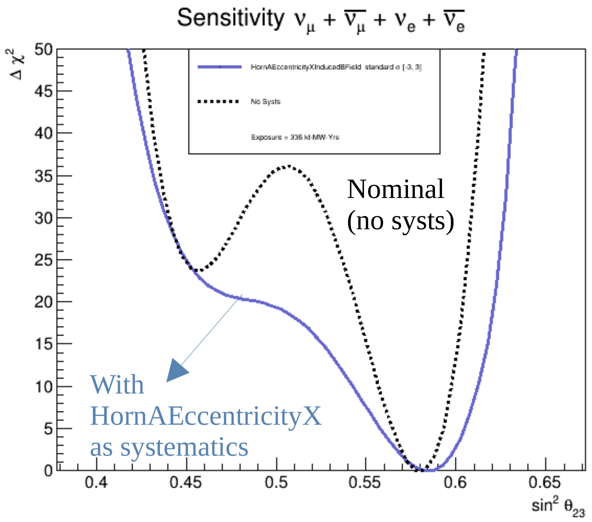
Need further discussion

- New uncertainties (not present in TDR): Horn C Displace Transverse, Eccentricity X (both A and C), Horn Tilt (horn A), target upstream degredation

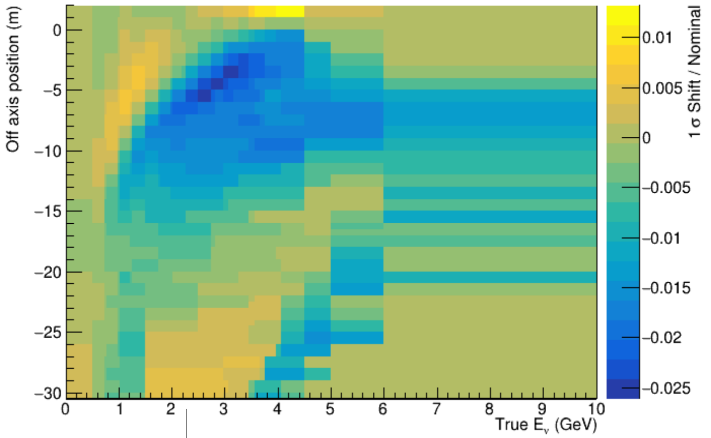
Horn A Eccentricity X Induced Bfield

IMPORTANT

- **1σ shift = 0.035 mm**: NuMi Horn 1 tolerance assumed (off axis deformation of inner conductor) → **significant influence on the sensitivity**

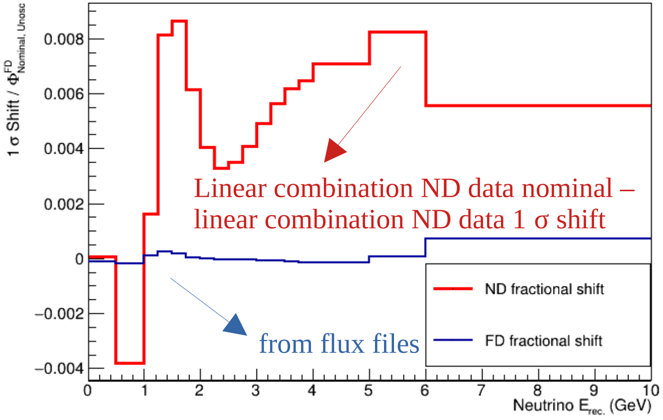


Fractional shift effect (+1σ) on the ND vs OA vs True E_ν



Obtained from existent flux files

Fractional shift effect on linear combination vs FD



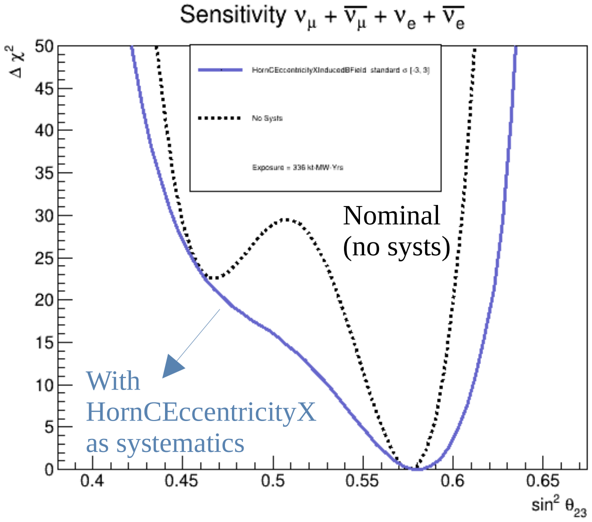
- Very low uncertainties for on-axis data → uncertainties start to become significant for data at several off-axis positions; maximum shift around 5m off-axis and neutrino energies ~ 3GeV

→ Does it make sense that a **tolerance of 35 μm** in the off axis deformation of the inner conductor results in **uncertainties up to 2.5%** in the ND fluxes? - if it does.. can we do better than **35 μm** ?

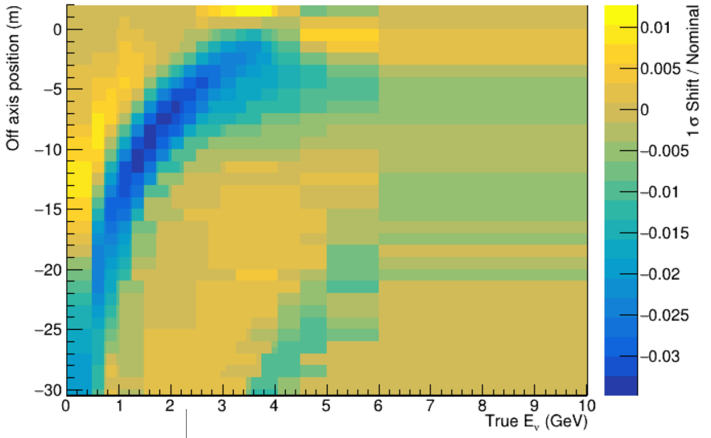
Horn C Eccentricity X Induced Bfield

IMPORTANT

- **1σ shift = 0.07 mm**: NuMi Horn 2 tolerance assumed (off axis deformation of inner conductor) → **significant influence on the sensitivity**

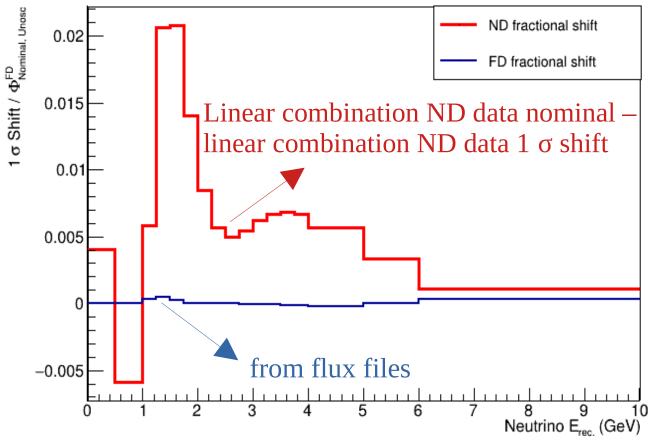


Fractional shift effect (+1σ) on the ND vs OA vs True E_ν



Obtained from existent flux files

Fractional shift effect on linear combination vs FD



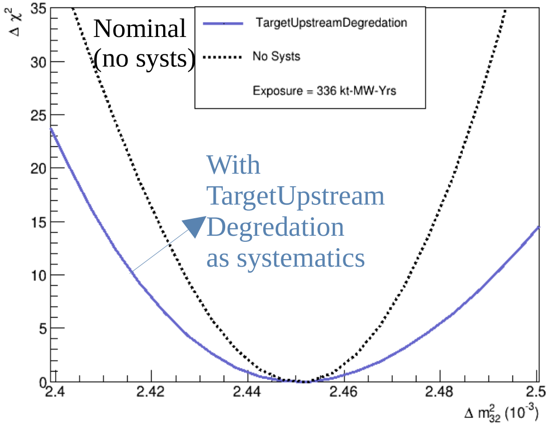
- Very low uncertainties for on-axis data → uncertainties start to become significant for data at several off-axis positions; maximum shift around 10m off-axis and neutrino energies ~ 1.5 GeV
  – high uncertainties 3 % (compared to HornAEccentrictity X) for all off-axis positions

→ Does it make sense that a **tolerance of 70 μm** in the off axis deformation of the inner conductor results in **uncertainties up to 3.5%** in the ND fluxes? - if it does.. can we do better than **70 μm** ?

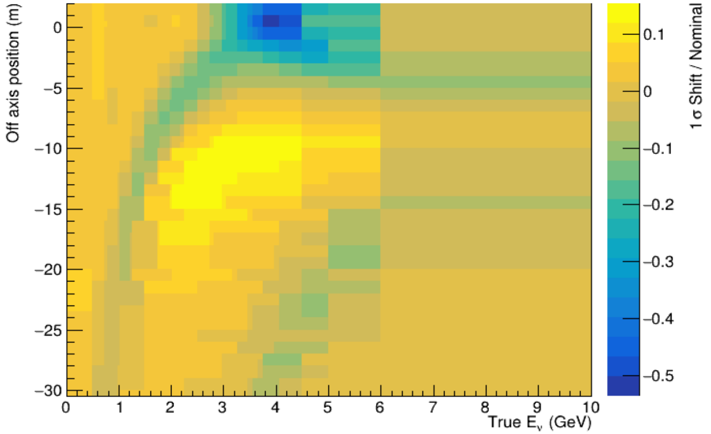
Target Upstream Degredation

IMPORTANT

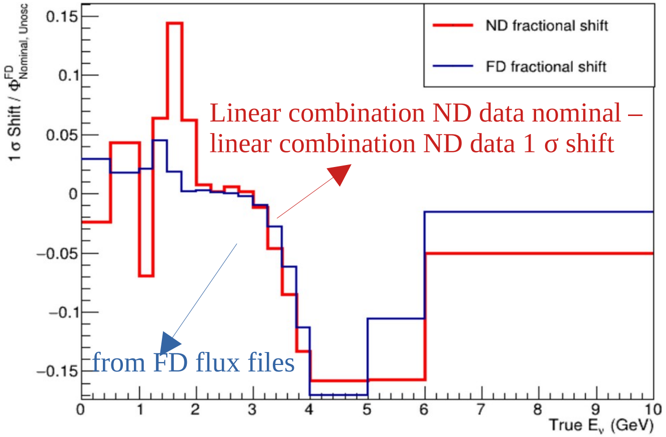
- **1σ shift = 5 mm loss**: assume complete loss of target on upstream end
(a shorter target by dz shifted downstream by the loss dz) → **significant influence on the sensitivity**



Fractional shift effect (+1σ) on the ND vs OA vs True E_ν



Fractional shift effect on linear combination vs FD



- Very high uncertainties for ND **on-axis** data (up to **50% at E_ν ~ 4 GeV**) + off-axis uncertainties also high: ~15%
- High uncertainties (up to 15%) for FD as well

→ Do we expect 50% uncertainties from a 5 mm target loss? Why so high uncertainties for this parameter?

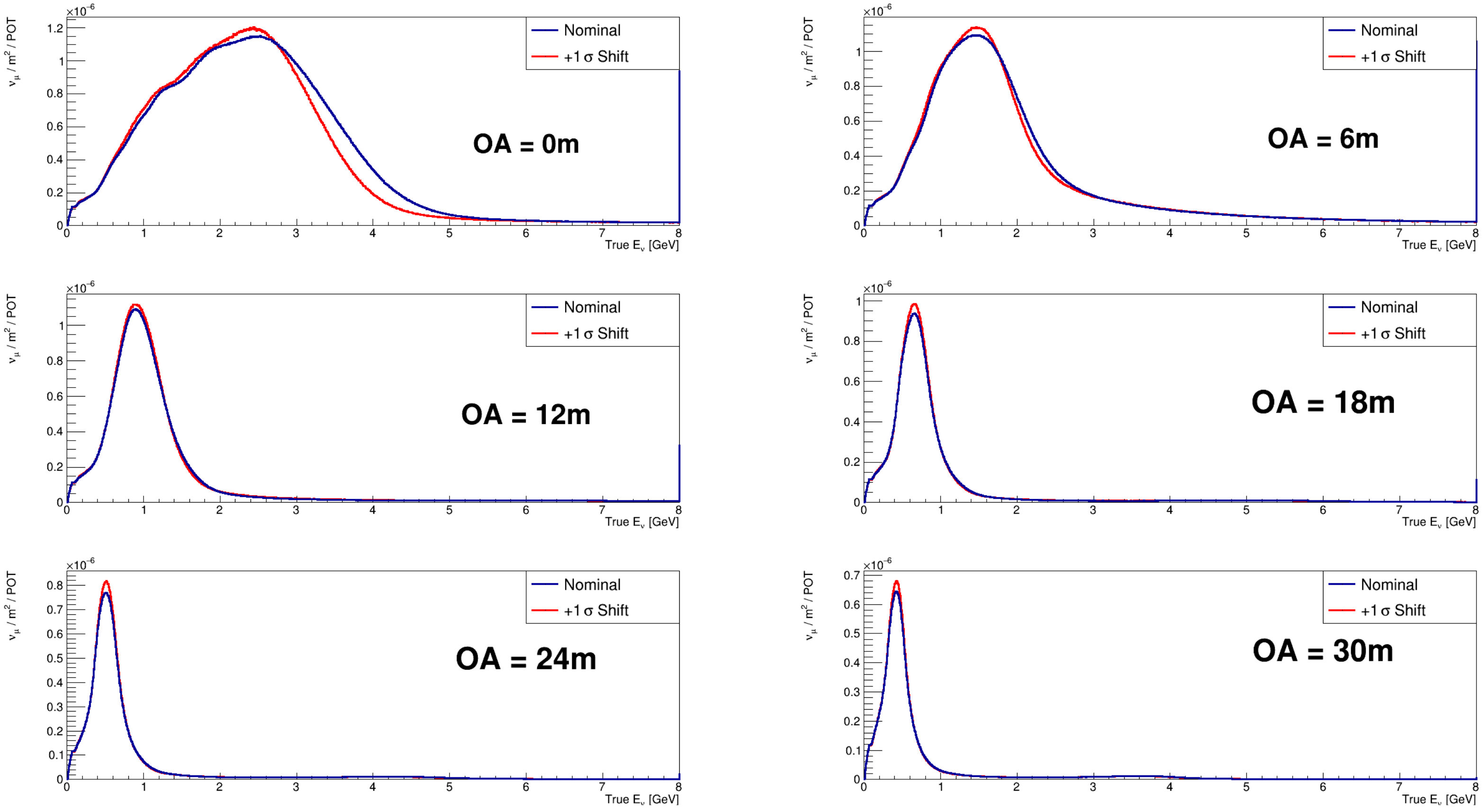
- is a tolerance of 5 mm feasible? Could we do better?

Target Upstream Degradation

IMPORTANT

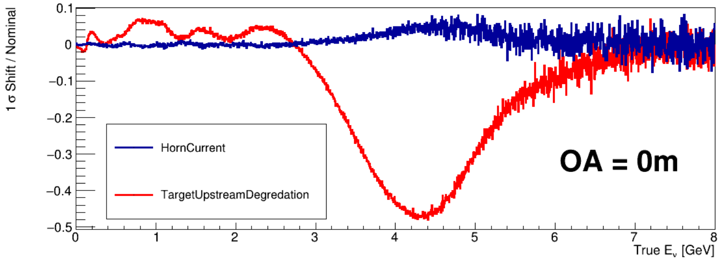
- 1σ shift = 5 mm loss: assume complete loss of target on upstream end

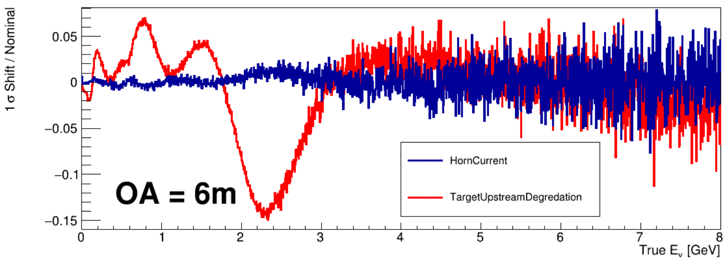
→ cross check with fluxes from the provided root files: visible difference in the shifted flux

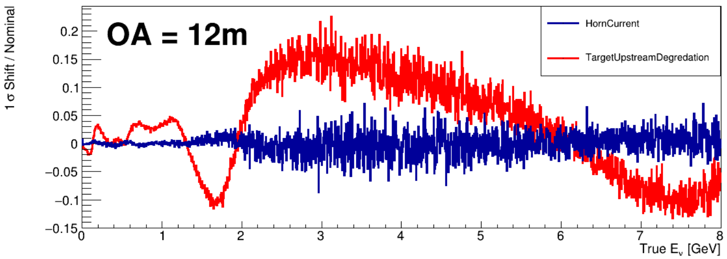


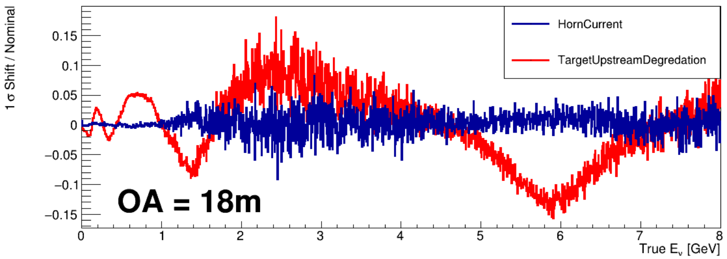
Target Upstream Degradation vs HornCurrent

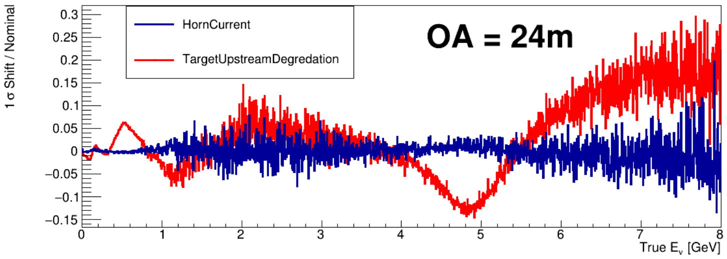
→ fractional error obtained from the flux files (original energy binning)

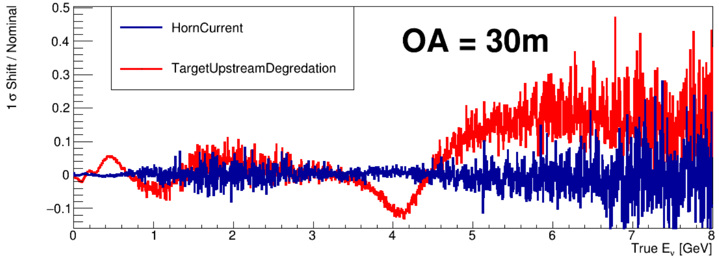












High fractional uncertainties **(up to 50%)** for **TargetUpstreamDegradation** parameter are coming from the original root files (not a re-binning issue)

Open questions:

- **Horn Eccentricity X Induced Bfield** (off axis deformation of inner conductor)
  → why so high uncertainty values (1 sigma shift = 0.035 mm resp. 0.07 mm) up to 3%?

- **Target Upstream Degredation** (5 mm loss at 1 σ)
  → why are the uncertainties so high? (up to 50% for on-axis at E ≈ 4GeV)

- **Decay Pipe Geomagnetic field** (1 σ shift = 1: nominal – 0 no Earth magnetic filed, 1 – NuMi value)
  → what is the assumption for the uncertainty calculation?
  → relatively high values for the uncertainties: 1.5%

- **Could we cross check (i.e reproduce the *worrying* systematics..?)**
  → do we have access to Pierce's code?
  → do we have anyone (manpower..) who could help with this.. → how difficult would it be?

Slide dedicated to path of files and histograms used from Pierce's files

- ND files:
  - – nominal:/pnfs/dune/persistent/users/pweather/fluxfiles/g4lbne/v3r5p9/QGSP_BERT/OfficialEngDesignSept2021/**neutrino**/flux/histos_g4lbne_v3r5p9_QGSP_BERT_OfficialEngDesignSept2021_neutrino_LAr_center.root
    - Nominal Flux histogram: Unosc_**numu**_flux_DUNEPRISM_LAr_center – TH2D histogram neutrino flux vs energy vs off-axis positions (neutrino energy on x-axis, off-axis position on y-axis and neutrino fluxes on z-axis)
      - Energy binning: E [0, 8GeV] – 0.005 GeV bin width
        E (8, 114 GeV] – 0.25 GeV bin width
      - OA binning: OA [-4.0, 36.925 m] – 0.05 m bin width
  - – shift: /pnfs/dune/persistent/users/pweather/fluxfiles/g4lbne/v3r5p9/QGSP_BERT/OEDS21_**HornADisplaceTransverseX**_pos_1_sigma/**neutrino**/flux/histos_g4lbne_v3r5p9_QGSP_BERT_OEDS21_HornADisplaceTransverseX_pos_1_sigma_neutrino_LAr_center.root
    - Shifted flux histogram: Unosc_**numu**_flux_DUNEPRISM_LAr_center – TH2D histogram neutrino flux vs energy vs off-axis positions (neutrino energy on x-axis, off-axis position on y-axis and neutrino fluxes on z-axis)
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- FD files:
  - – nominal: /pnfs/dune/persistent/users/pweather/fluxfiles/g4lbne/v3r5p9/QGSP_BERT/OfficialEngDesignSept2021/**neutrino**/flux/histos_g4lbne_v3r5p9_QGSP_BERT_OfficialEngDesignSept2021_neutrino_finemc.root
    - Nominal flux histogram: Unosc_flux_**numu**_finemc_DUNEFD – TH1D hisotgram neutrino flux vs energy
      - Energy binning: E [0, 8GeV] – 0.005 GeV bin width
        E (8, 114 GeV] – 0.25 GeV bin width
  - – shift: /pnfs/dune/persistent/users/pweather/fluxfiles/g4lbne/v3r5p9/QGSP_BERT/OEDS21_**HornADisplaceTransverseX**_pos_1_sigma/**neutrino**/flux/histos_g4lbne_v3r5p9_QGSP_BERT_OEDS21_HornADisplaceTransverseX_pos_1_sigma_neutrino_finemc.root
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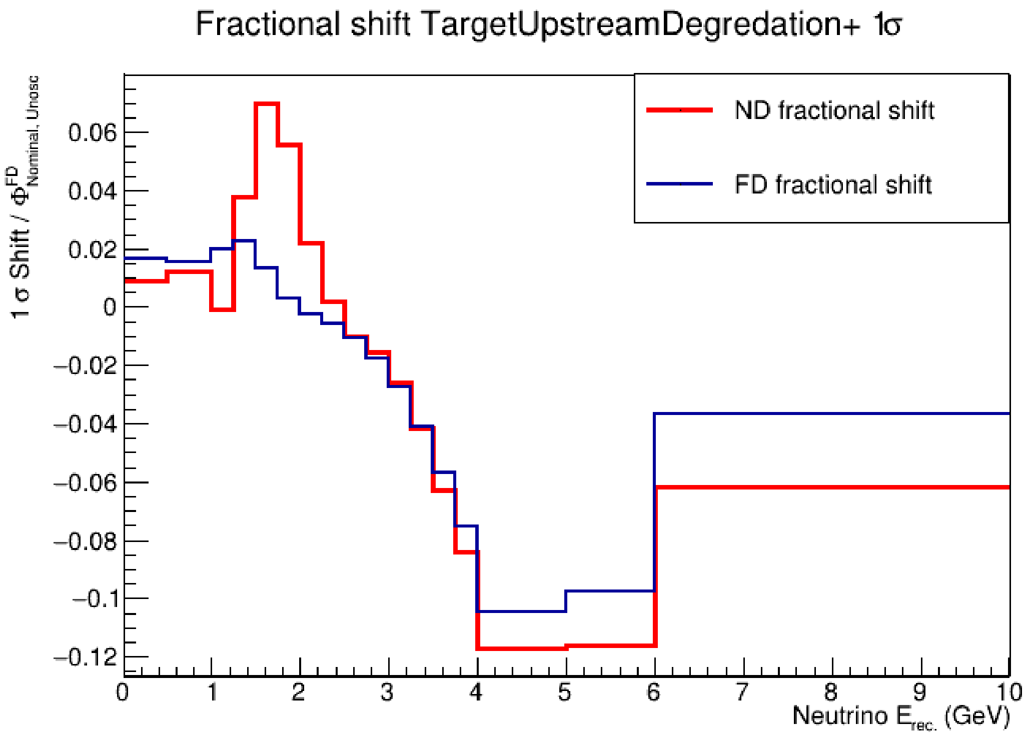
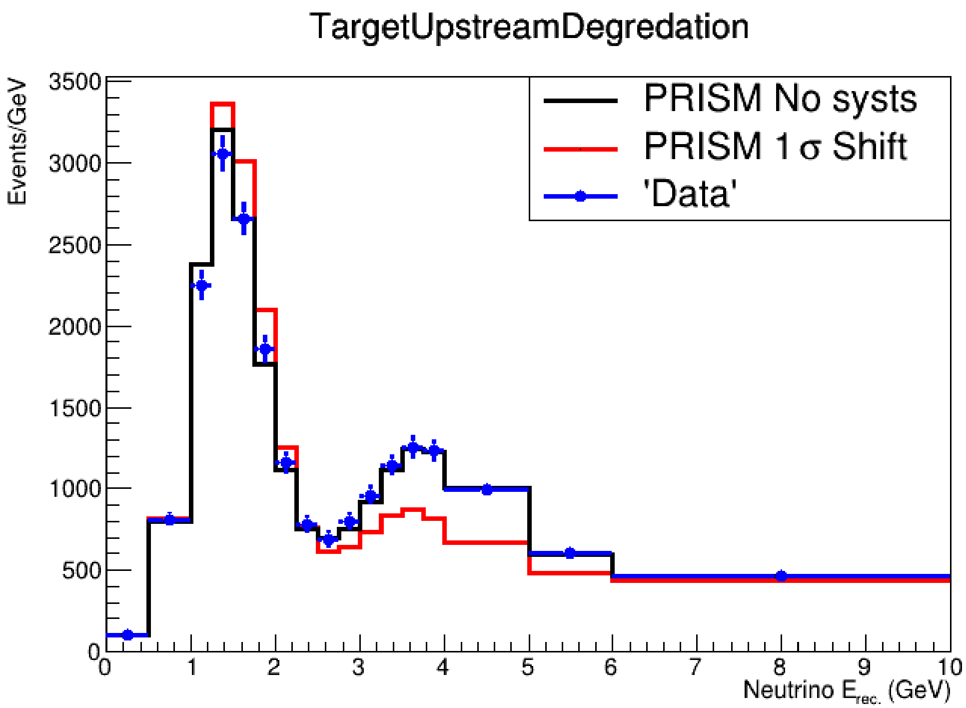
BACKUP

Target Upstream Degredation

IMPORTANT

- 1σ shift = 5 mm loss: assume complete loss of target on upstream end
(a shorter target by dz shifted downstream by the loss dz)



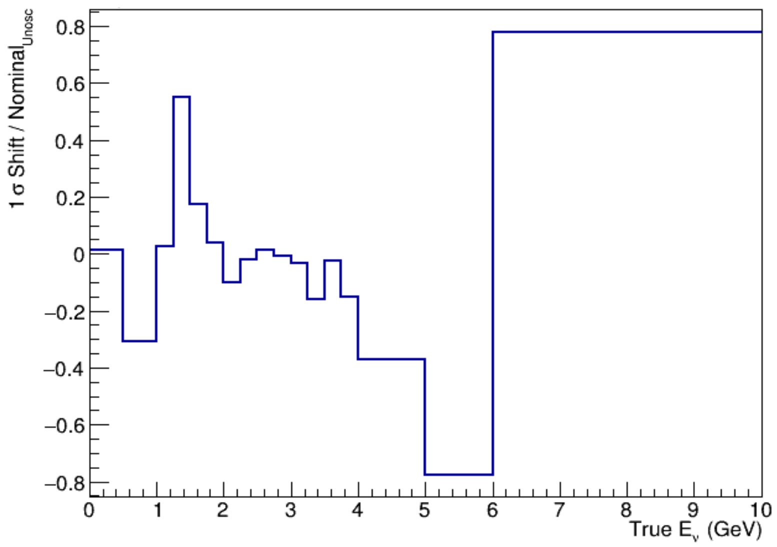


Horn A Eccentricity X Induced Bfield

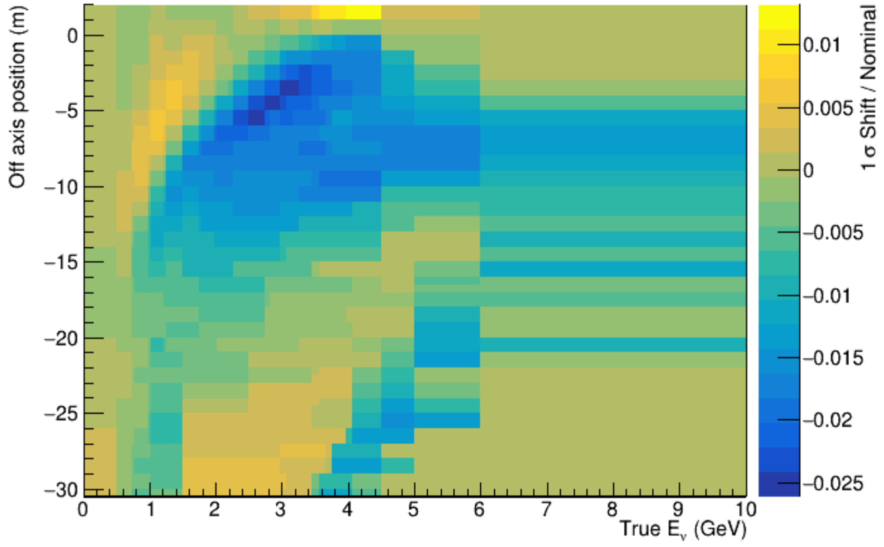
IMPORTANT

- 1σ shift = 0.035 mm: NuMi Horn 1 tolerance assumed (off axis deformation of inner conductor)

Fractional shift effect (+1σ) on the FD



Fractional shift effect (+1σ) on the ND



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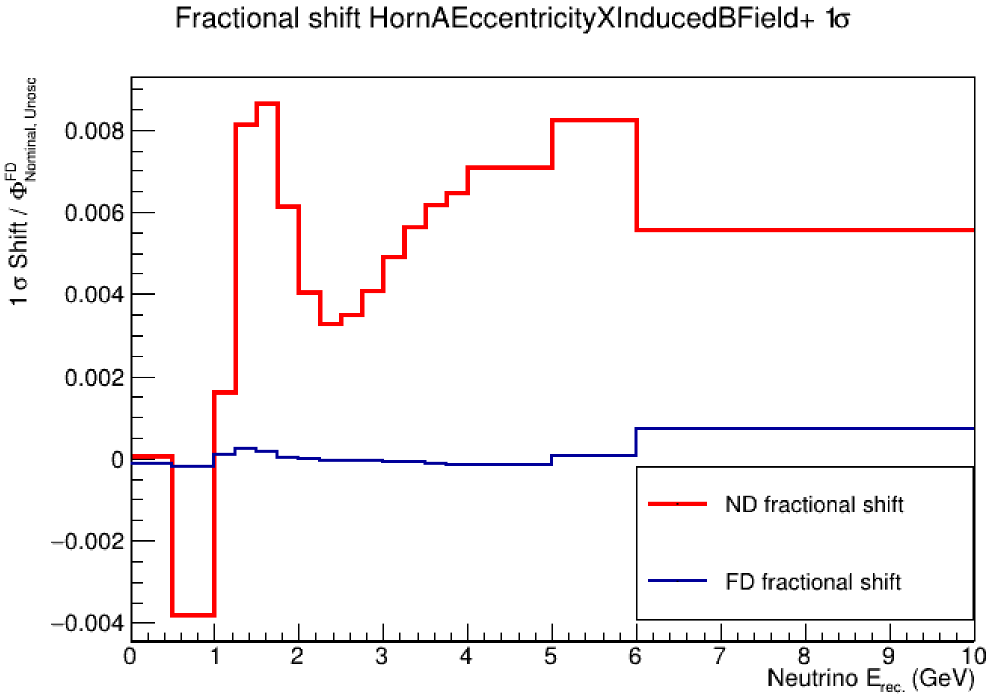
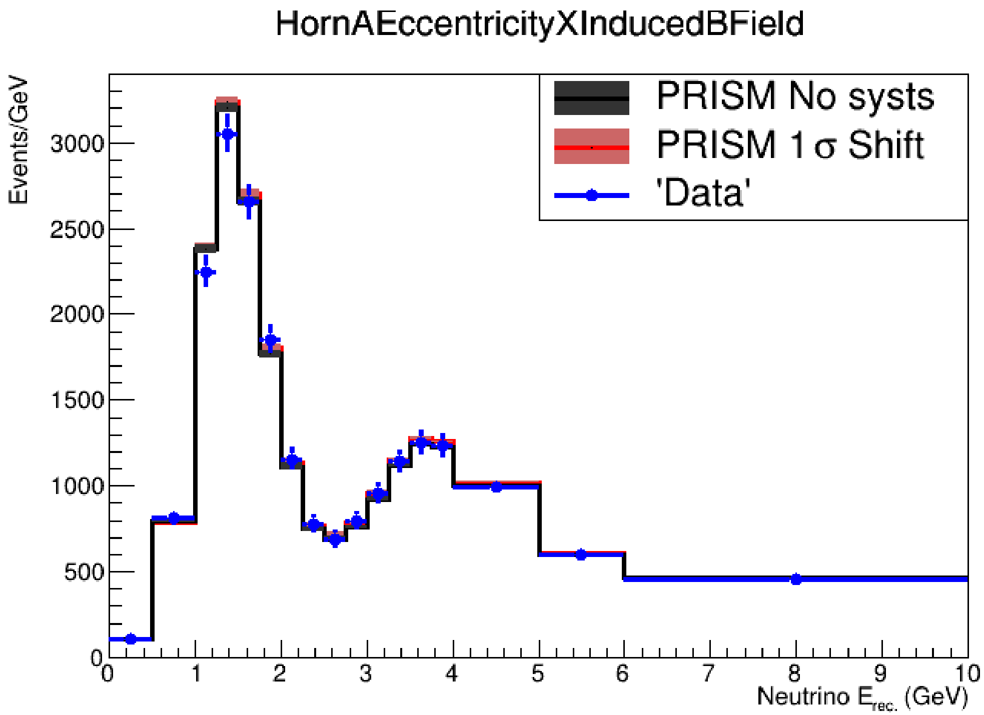
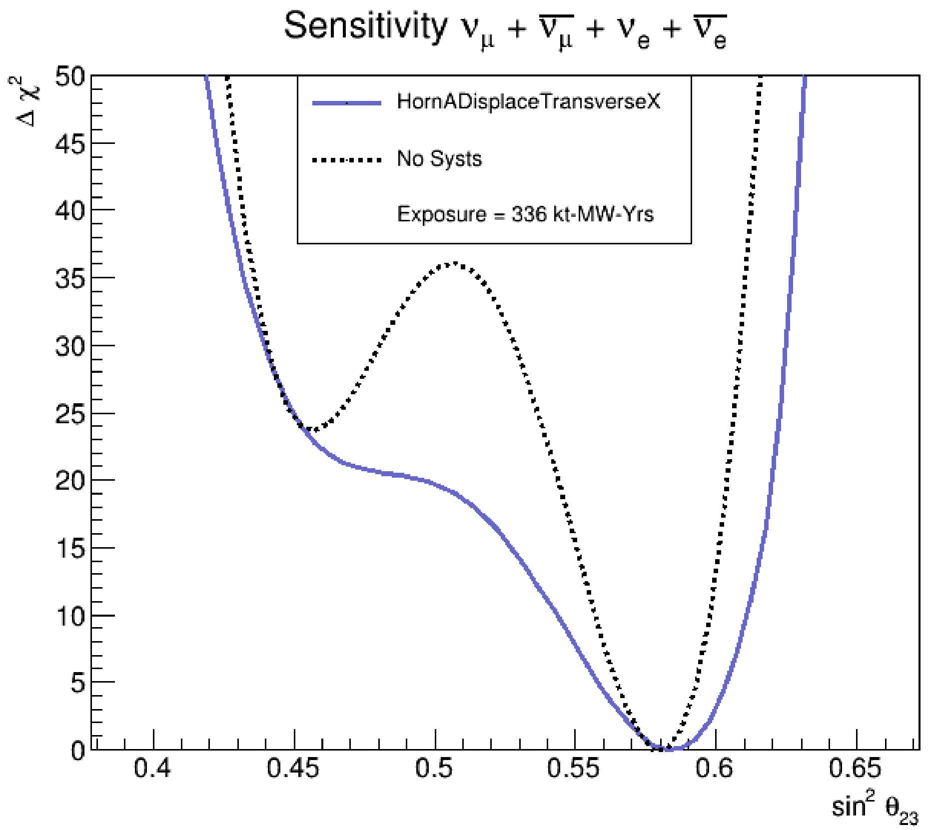


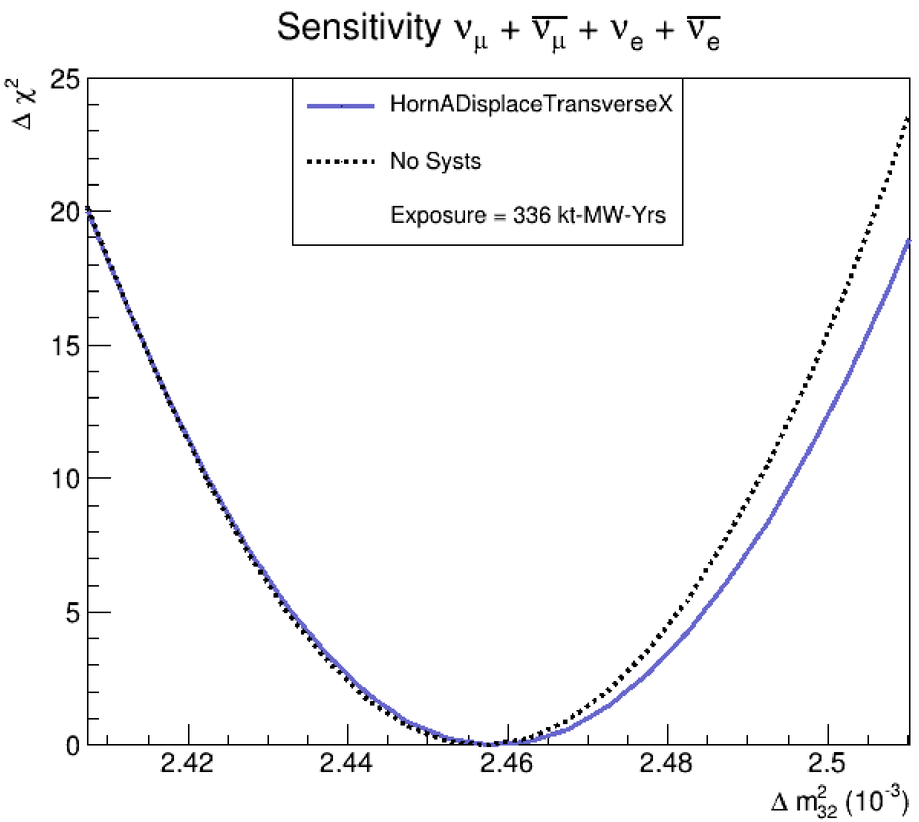


- PRISM linear combination (ND) fractional shift is much higher than the oscillated FD one + different energy dependence between ND and FD → high impact on the oscillation parameters sensitivity

Horn A Displace Transverse X

- 1σ shift = 0.5 mm





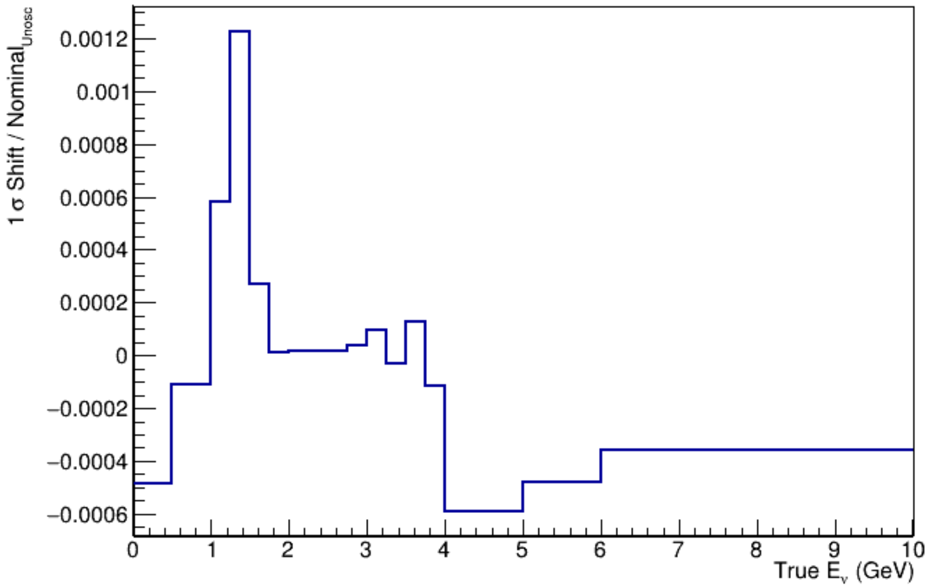
- Significant sensitivity reduction → where does this comes from?

Horn A Displace Transverse X

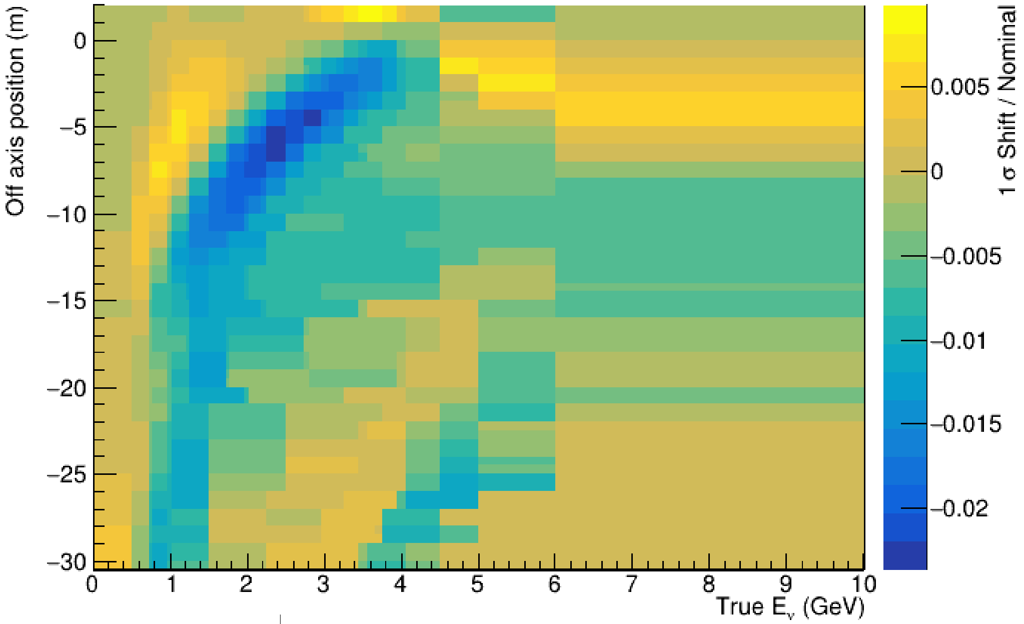
IMPORTANT

- 1σ shift = 0.5 mm
- look at both FD and ND fractional ratios versus energy when the the flux parameter of interest is shifted by 1 σ

Fractional shift effect (+1σ) on the FD



Fractional shift effect (+1σ) on the ND

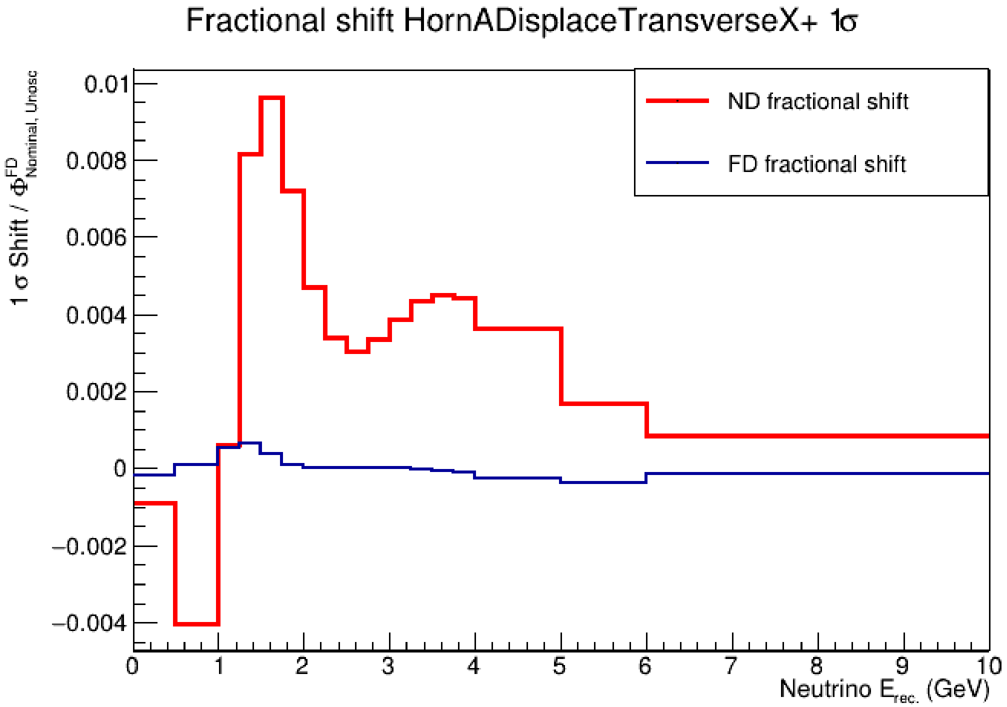


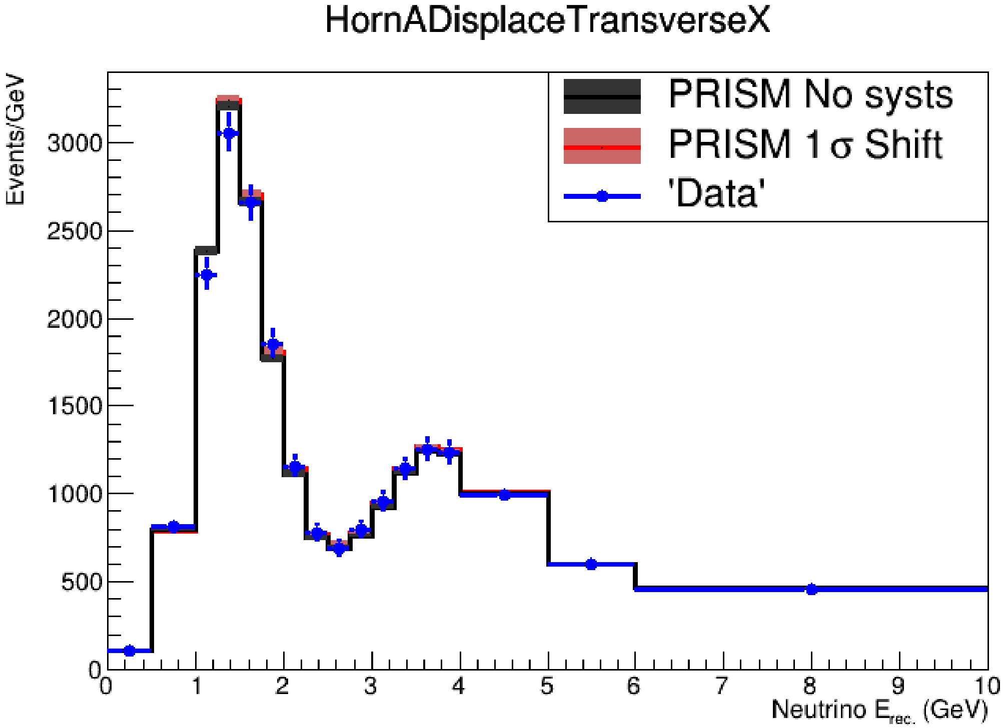
Linearly combine to get the PRISM fractional uncertainty

Horn A Displace Transverse X

IMPORTANT

- 1σ shift = 0.5 mm

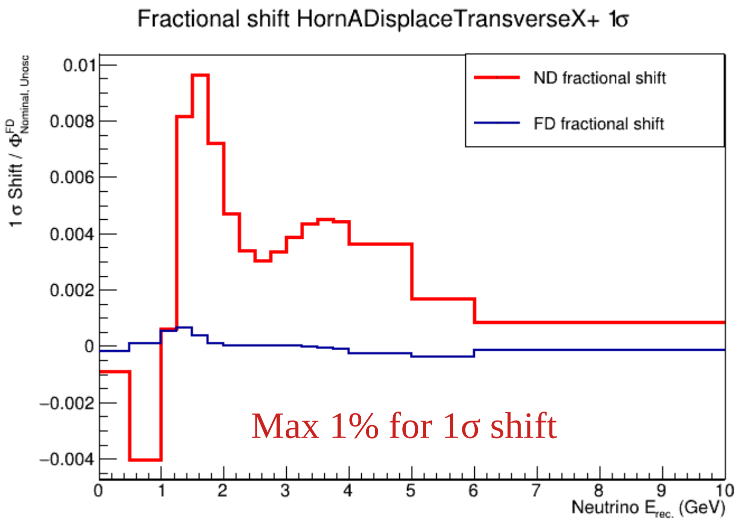


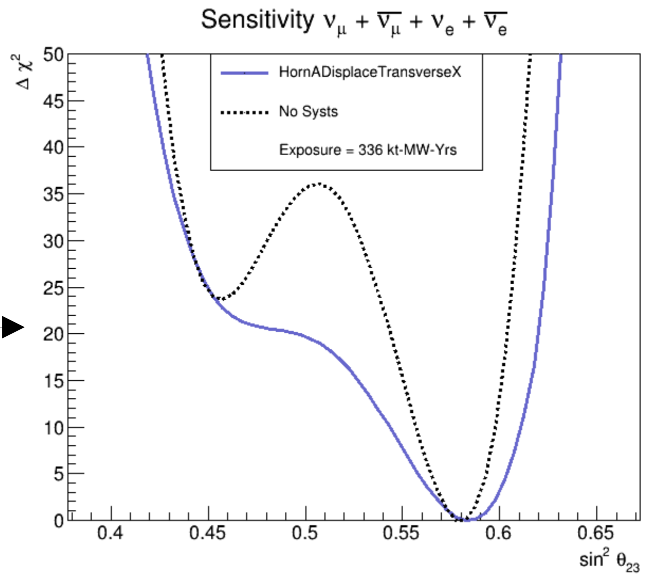


- PRISM linear combination (ND) fractional shift is much higher than the oscillated FD one + different energy dependence between ND and FD → high impact on the oscillation parameters sensitivity

Horn A Displace Transverse X

IMPORTANT



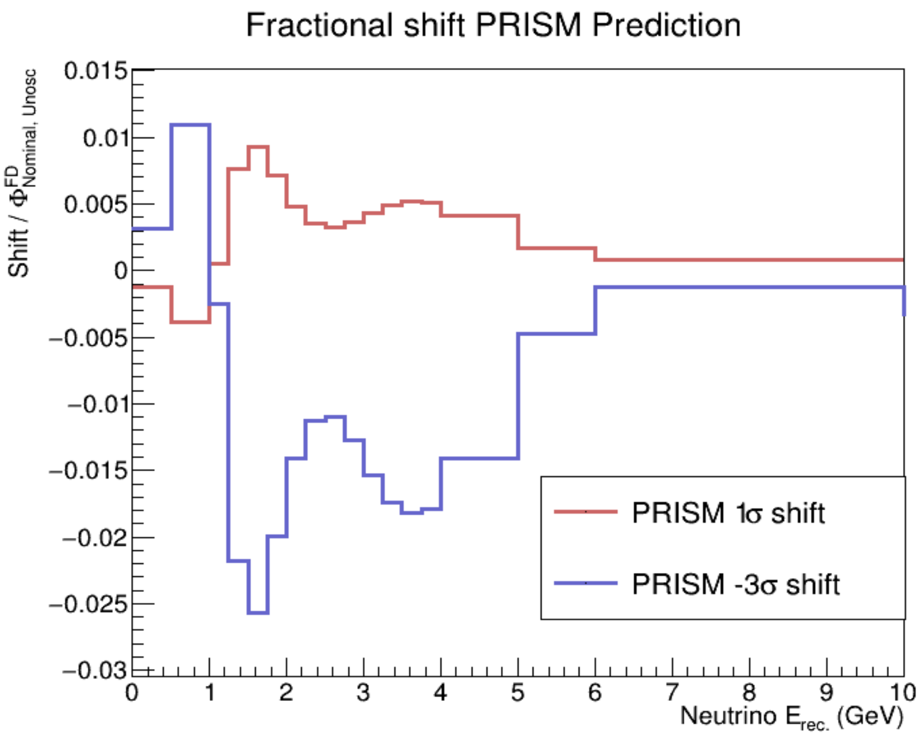


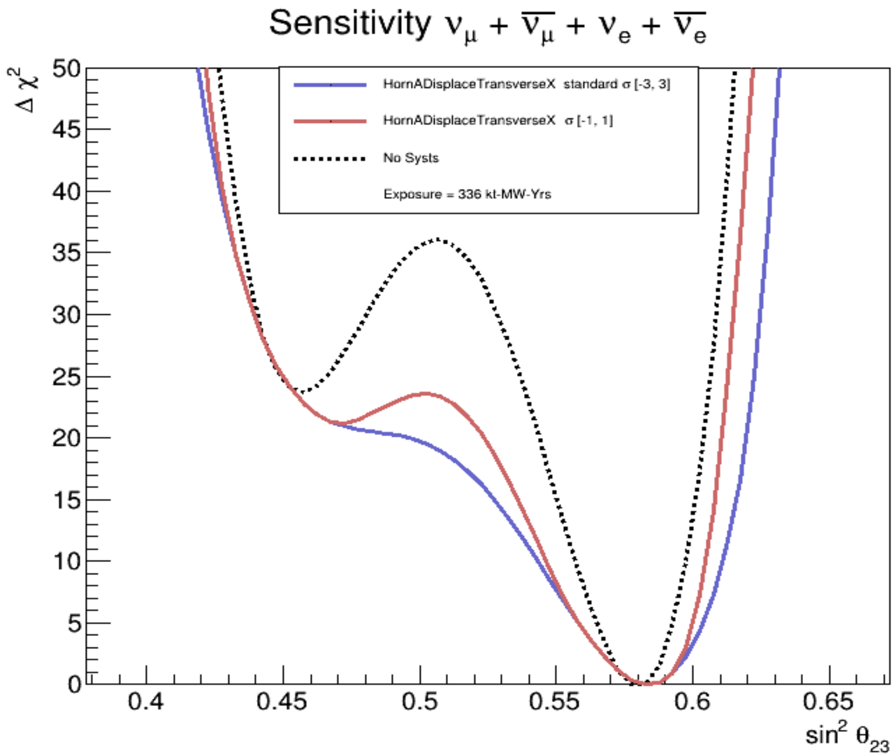
Why such a big sensitivity reduction?

- Systematics allowed to vary in a +/- 3 σ range
- χ^2 calculation is using Asimov data (PRISM Pred – Asimov data) → nominal PRISM prediction for different scan parameters has a poor agreement with the Asimov data → for certain parameters a maximum systematics shift (+/- 3 σ) results in a better match
- Limit maximum systematics shift to +/- 1 σ and re-evaluate the PRISM sensitivity

Horn A Displace Transverse X

IMPORTANT





- Better sensitivity with a maximum +/-1 σ (< 1%) systematics shift

  - highest sensitivity reduction correspond to +/- 3 σ shift (< 3%)

Updates to the Decay Pipe

Parameter	1 σ Shift	Notes
Decay Pipe Radius	2.0 cm	Changed from 10 cm; nominal = 2 m
Decay Pipe Length	2.5 cm	Same as elongating, since the distance between decay pipe upstream is fixed
Decay Pipe Displace Transverse X	2.5 cm	
Decay Pipe Displace Transverse Y	2.5 cm	
Decay Pipe Tilt X _ DSOA	2.5 cm	Downstream (DS) end fixed to remain on axis
Decay Pipe Tilt Y _ DSOA	2.5 cm	
Decay Pipe Elliptical Cross section X (A)	2.5 cm	Ellipse with A (X-axis) or B (y-axis) varied by tolerance, while other dimension fixed to nominal radius
Decay Pipe Elliptical Cross section Y (B)	2.5 cm	
Decay Pipe Geo B Field	1	Scale-factor value to 1 is 1σ tolerance. Mapped from NuMI decay pipe geo B-field measurements
Decay Pipe Segmented Bowing X	2.5 cm	Decay Pipe segmented in 3 equal pieces; central piece transverse shifted by tolerance
Decay Pipe Segmented Bowing Y	2.5 cm	

Geometry and positioning

- before (1 parameter):
  - vary radius by large tolerance (10 cm)

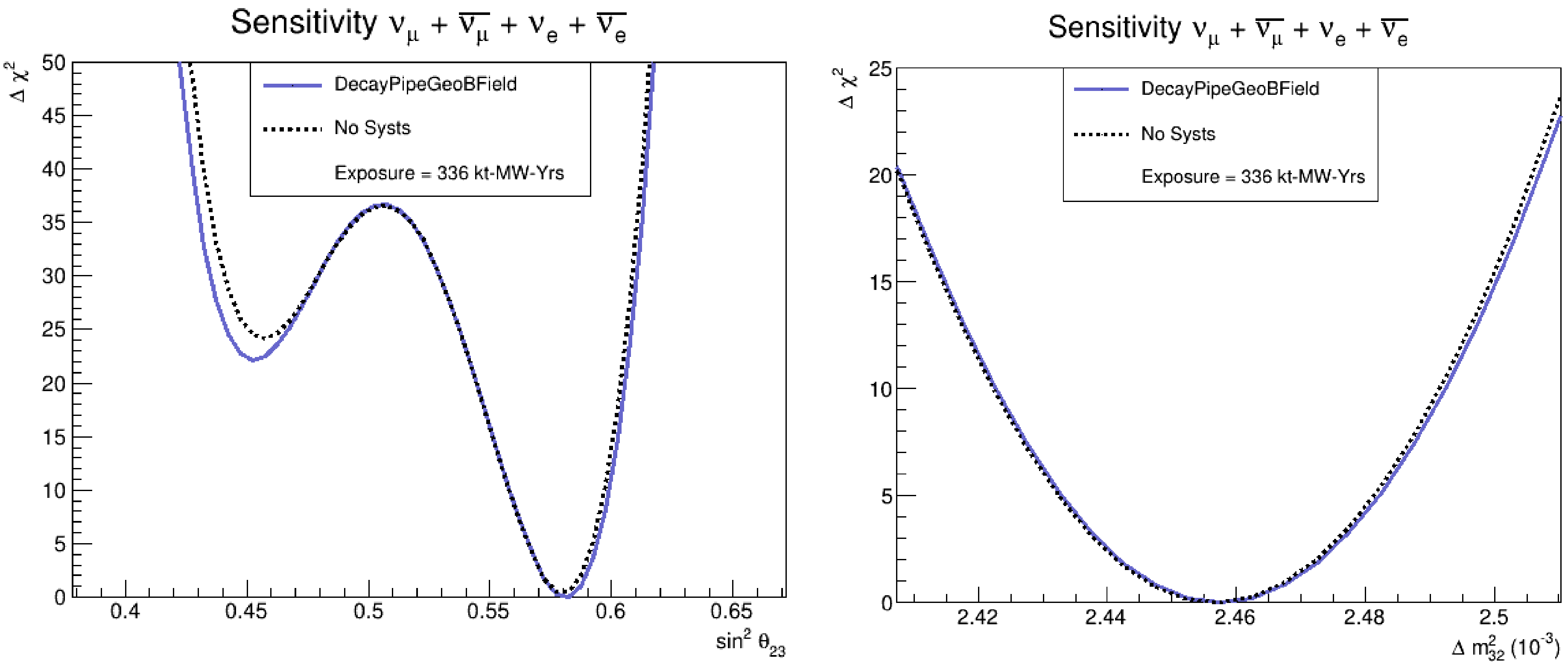
→ dominant uncertainty in the region of interest (E < 4.5 GeV)

- now: (11 parameters)
  - tolerance of 2 cm in the **decay pipe radius**
  - length of the pipe expected to change 1σ = 2.5 cm @ 1.2 MW
  - **transverse offset** of the decay pipe in X, Y by 2.5 cm
  - transverse tilt of the upstream end of decay pipe by 2.5 cm
  - **elliptical cross section** of the decay pipe: expectation the decay pipe will come out of round as it settles (2.5 cm tolerance in both X(A) and Y(B))
  - possibility the pipe can be bowed along the beamline
  - uncertainty due to the effect of the Earth's geomagnetic field: geomagnetic field measured in NuMI decay pipe was mapped into DUNE decay pipe, and a scale factor of 1 is used to tune the strength of the B-field vector. (0 – nominal, 1-NuMI)

Decay Pipe Geo BField

SEMI

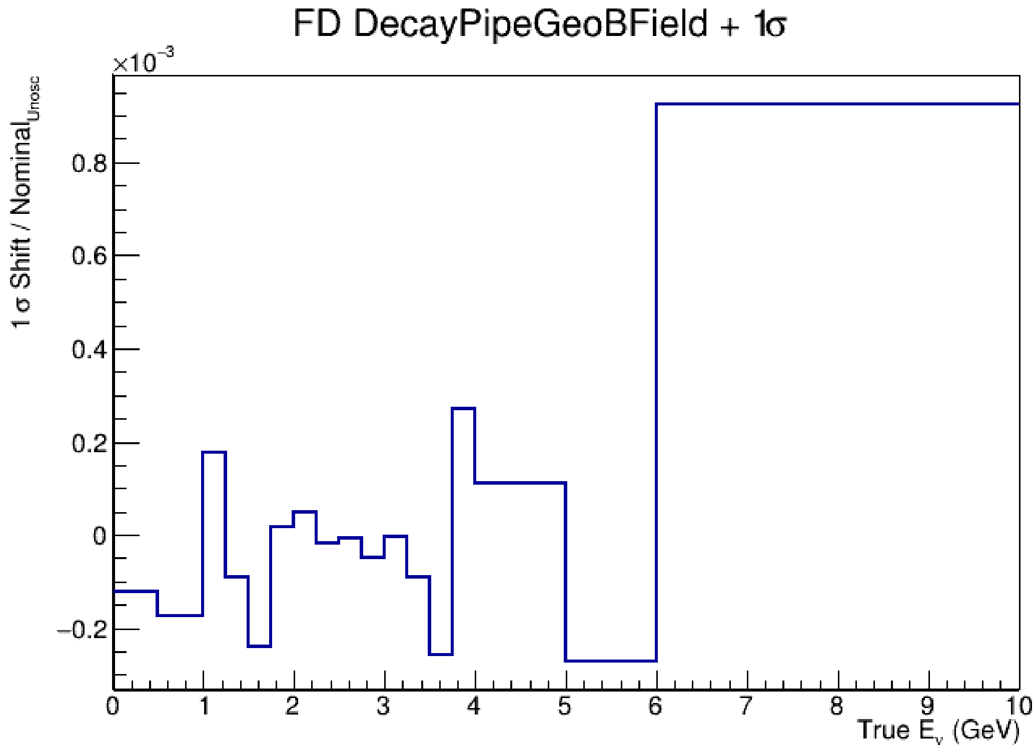
- 1σ shift = 1: scale factor value of 1 is 1σ tolerance
(mapped from NuMI Decay Pipe Geo Bfield measurements)

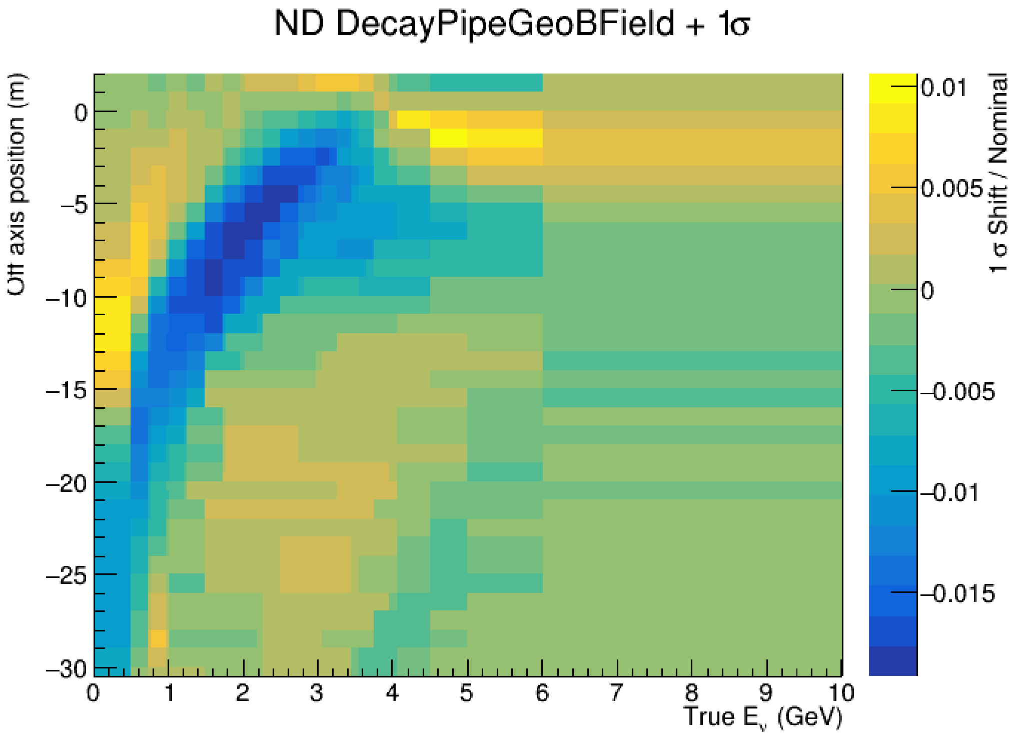


Decay Pipe Geo BField

SEMI

- 1σ shift = 1: scale factor value of 1 is 1σ tolerance
(mapped from NuMI Decay Pipe Geo Bfield measurements)

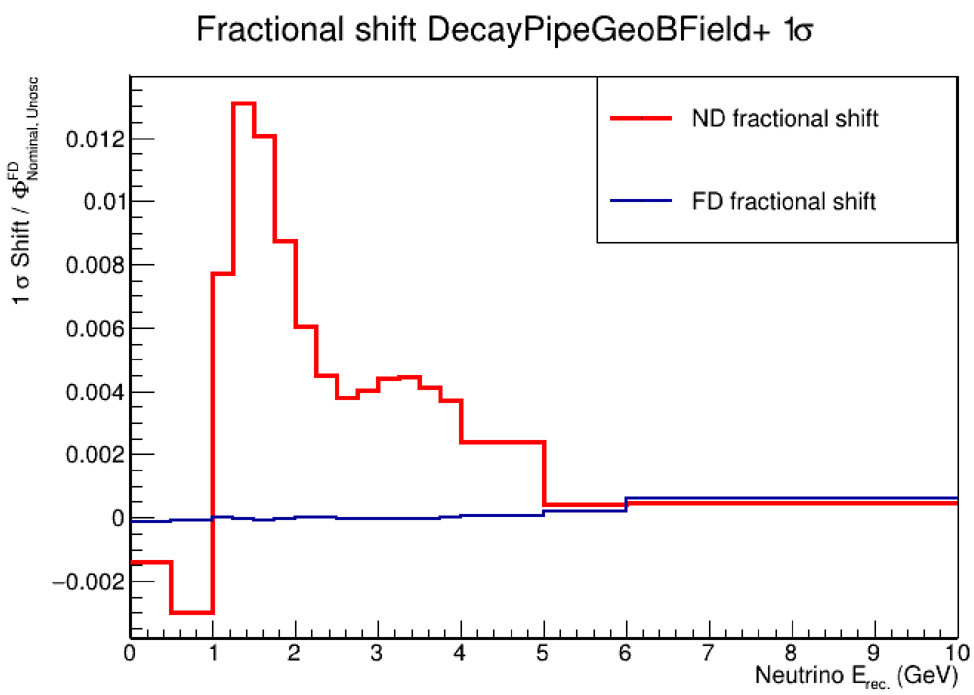


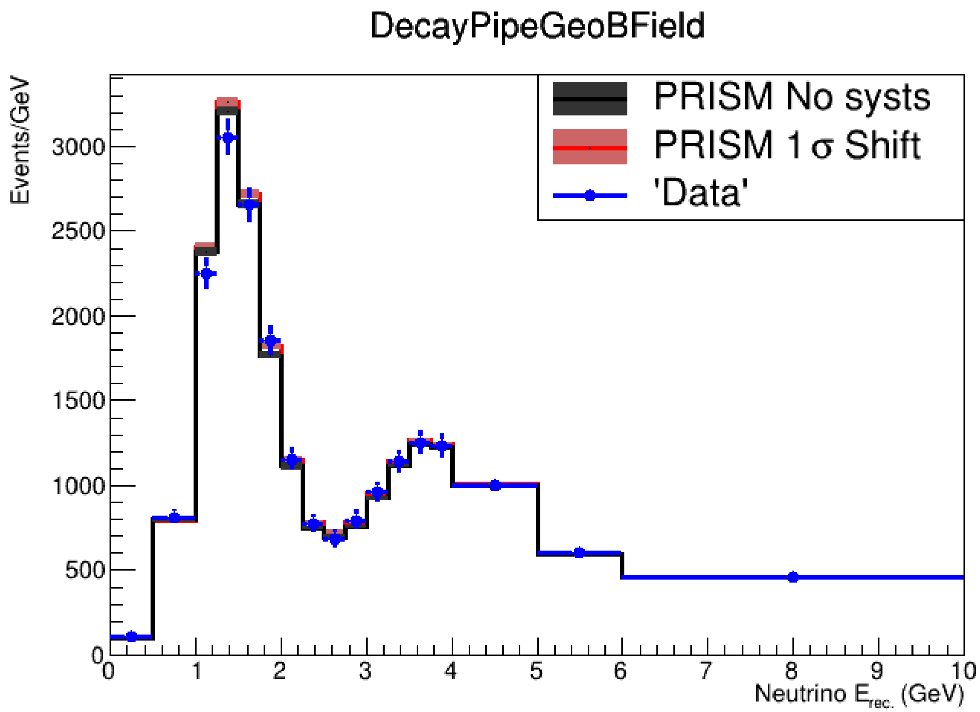


Decay Pipe Geo Bfield

SEMI

- 1σ shift = 1: scale factor value of 1 is 1σ tolerance (mapped from NuMI Decay Pipe Geo Bfield measurements)



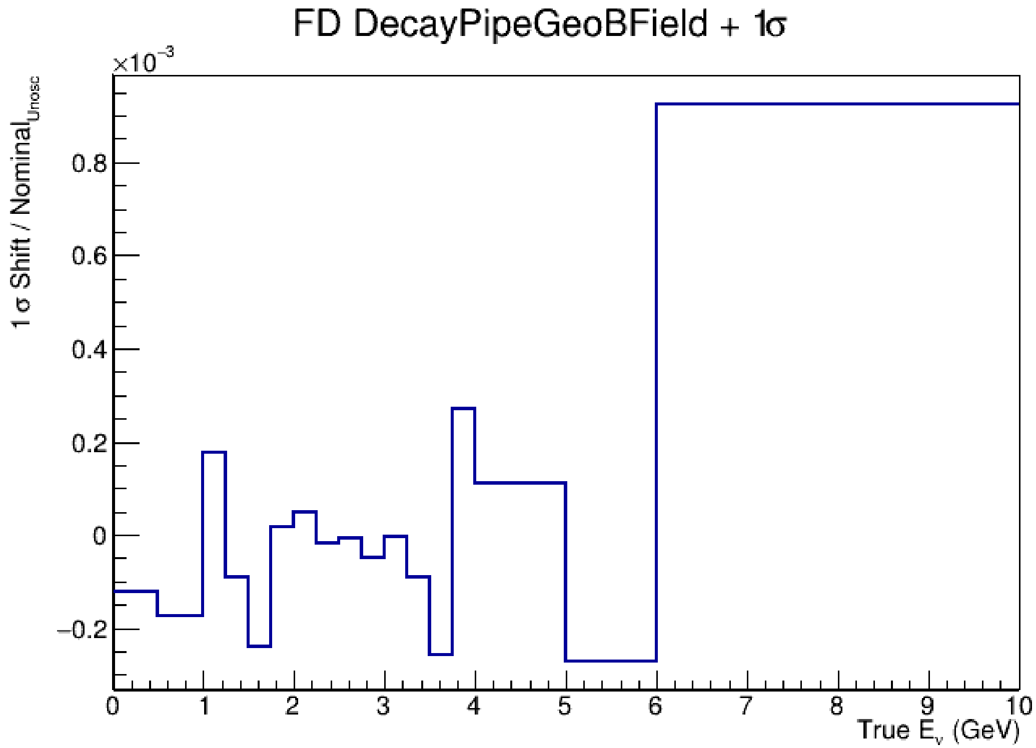


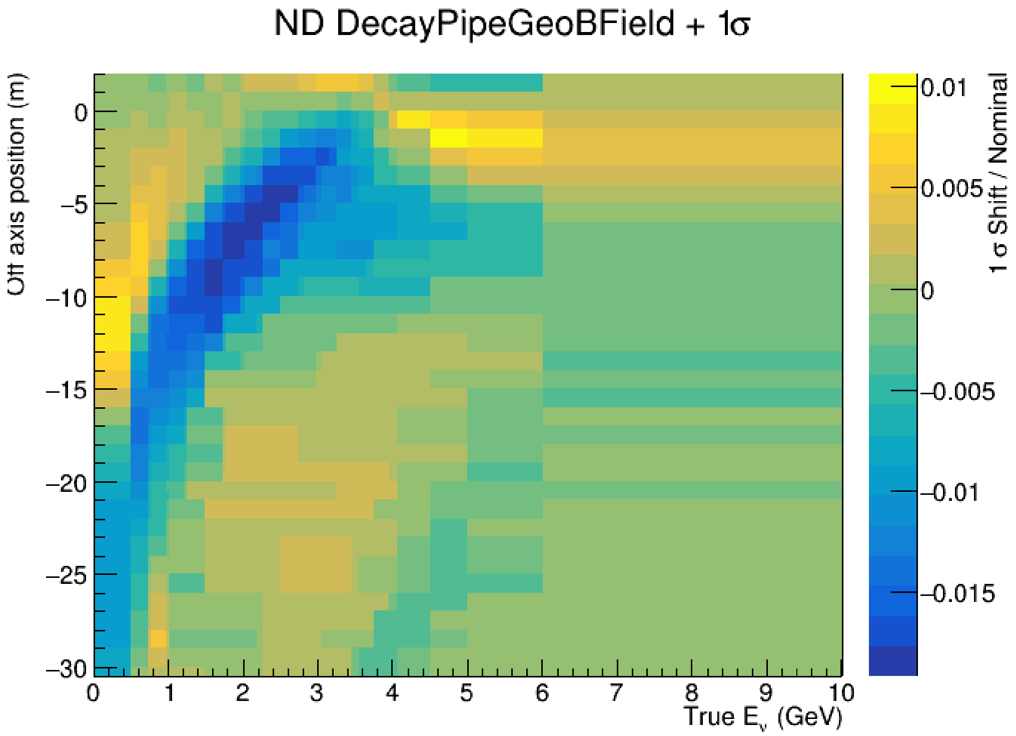
- high uncertainty values for this parameter, BUT partially canceled out by the antineutrino channel (not a significant influence on the oscillation parameter sensitivity)

BACKUP: Decay Pipe Geo Bfield: neutrino channel $\nu_\mu \rightarrow \nu_\mu$

SEMI

- 1σ shift = 1: scale factor value of 1 is 1σ tolerance
(mapped from NuMI Decay Pipe Geo Bfield measurements)

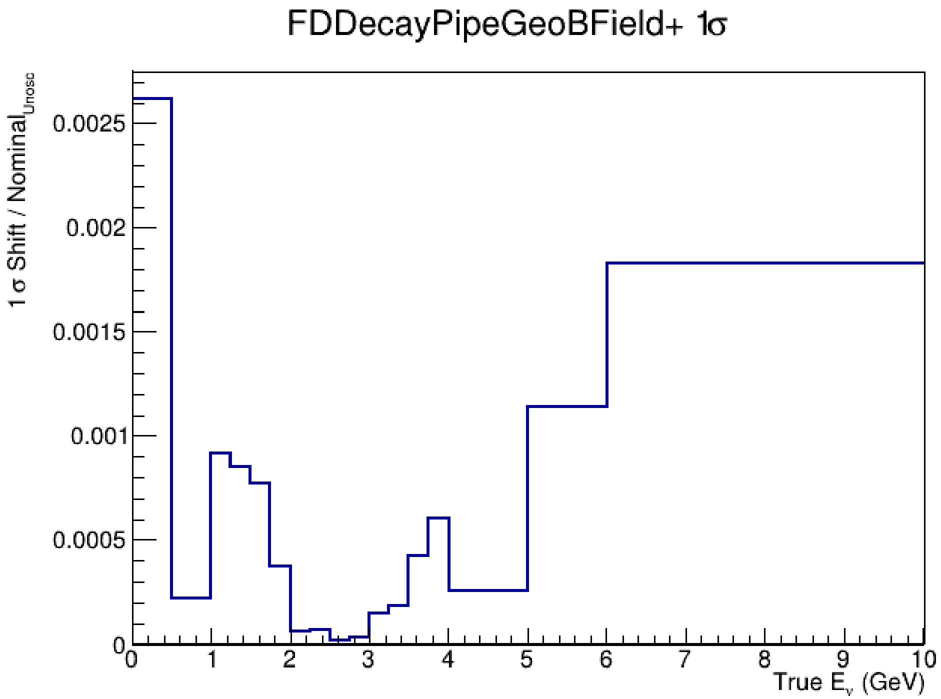


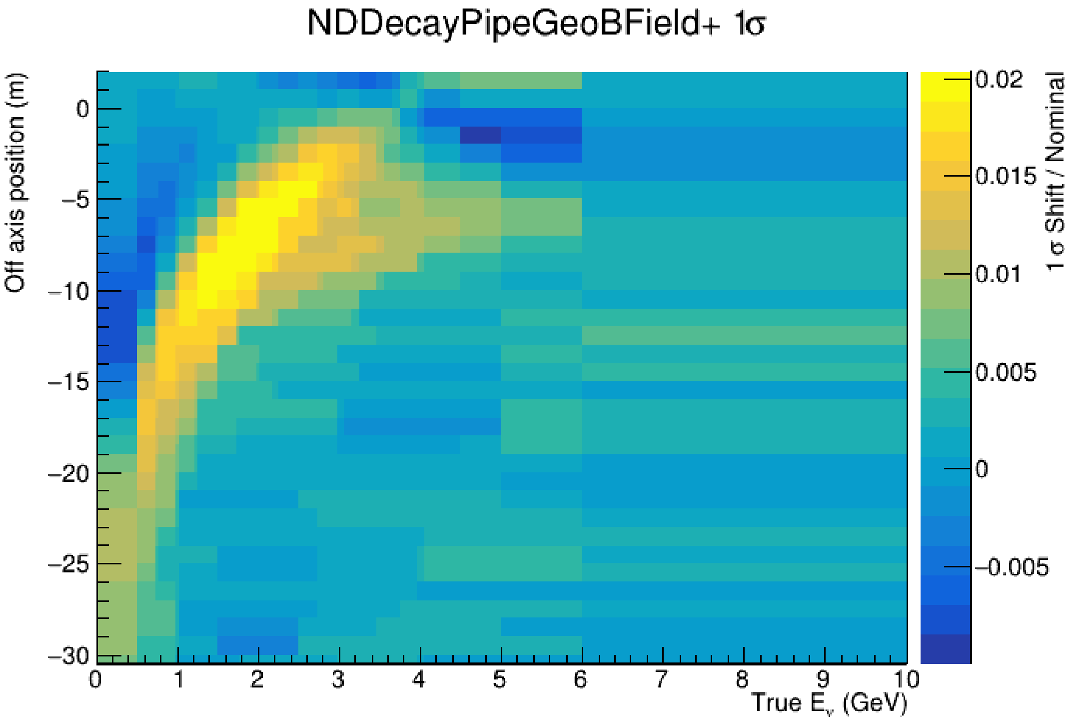


BACKUP

Decay Pipe Geo BField: antineutrino channel $\overline{\nu_\mu} \rightarrow \overline{\nu_\mu}$

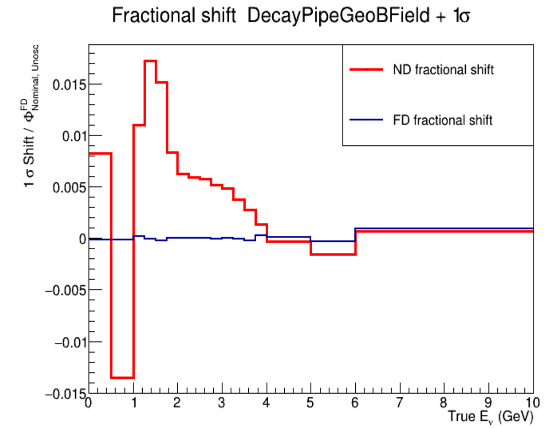
SEMI



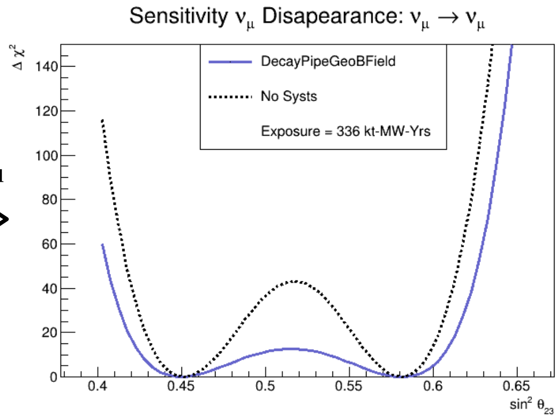


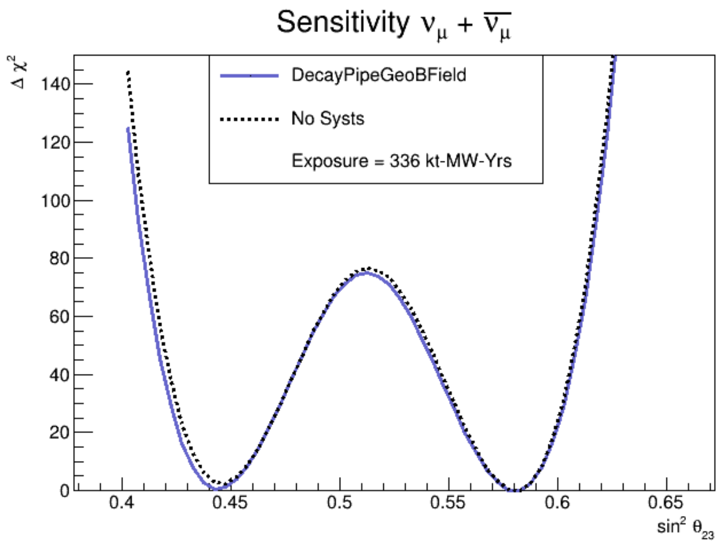
BACKUP: Decay Pipe Geo BField

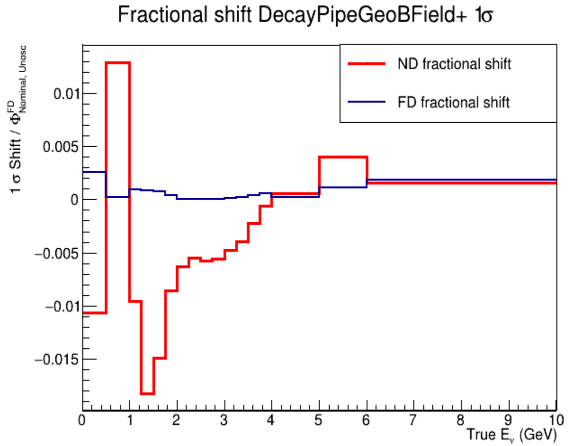
SEMI



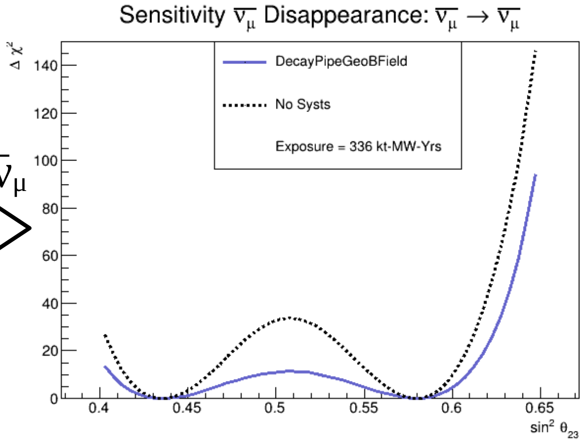
$\nu_\mu \rightarrow \nu_\mu$







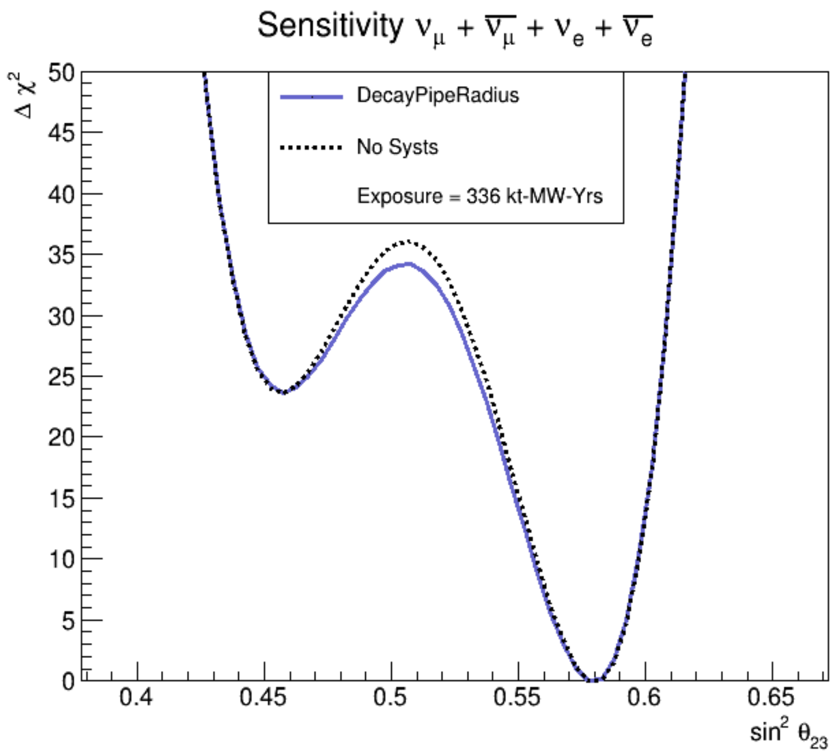
$\overline{\nu}_\mu \rightarrow \overline{\nu}_\mu$

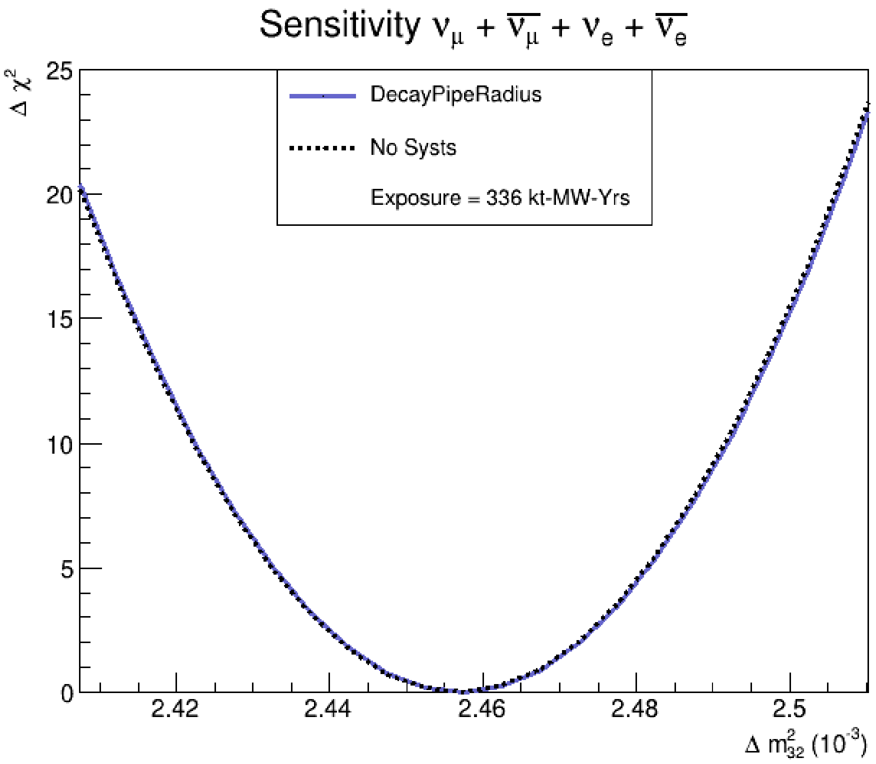


Decay Pipe Radius

SEMI

- 1σ shift = 2cm: changed from 10 cm (nominal = 2m)



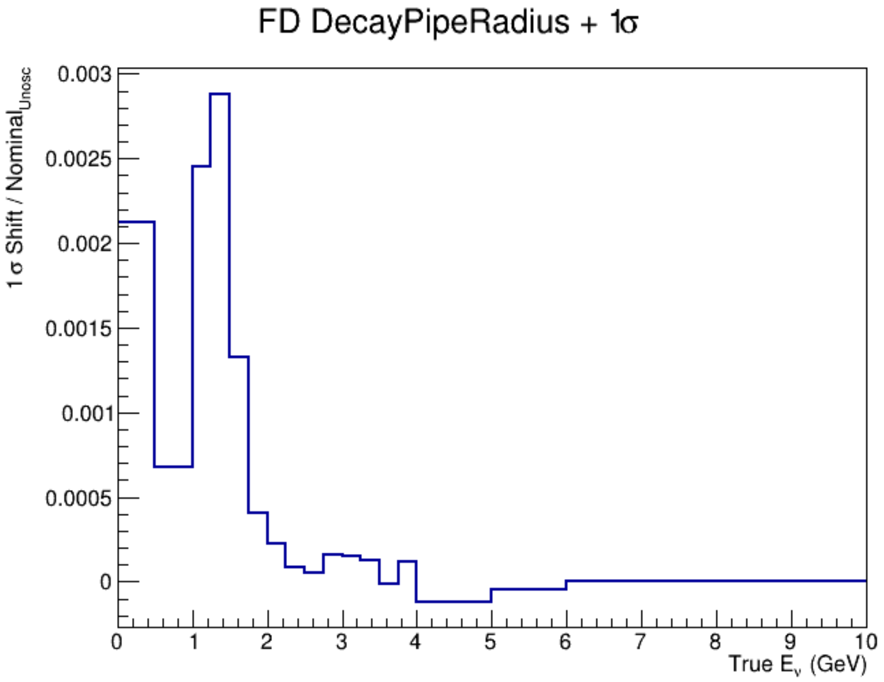


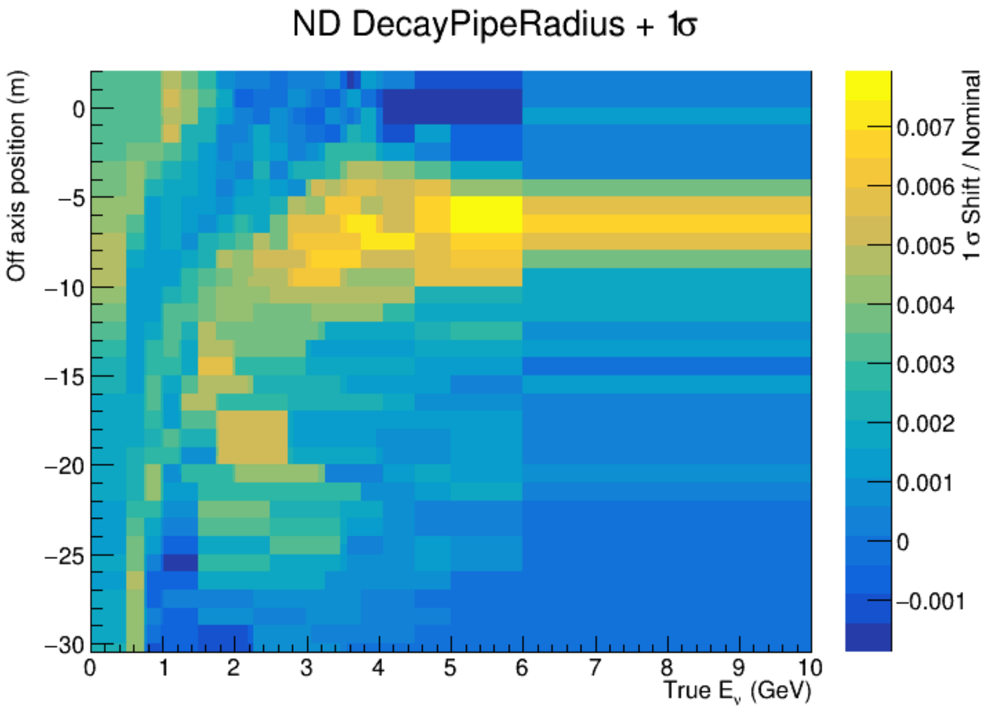
Used to be IMPORTANT in the old (Nov17) systematics!

Decay Pipe Radius

SEMI

- 1σ shift = 2cm: changed from 10 cm (nominal = 2m)



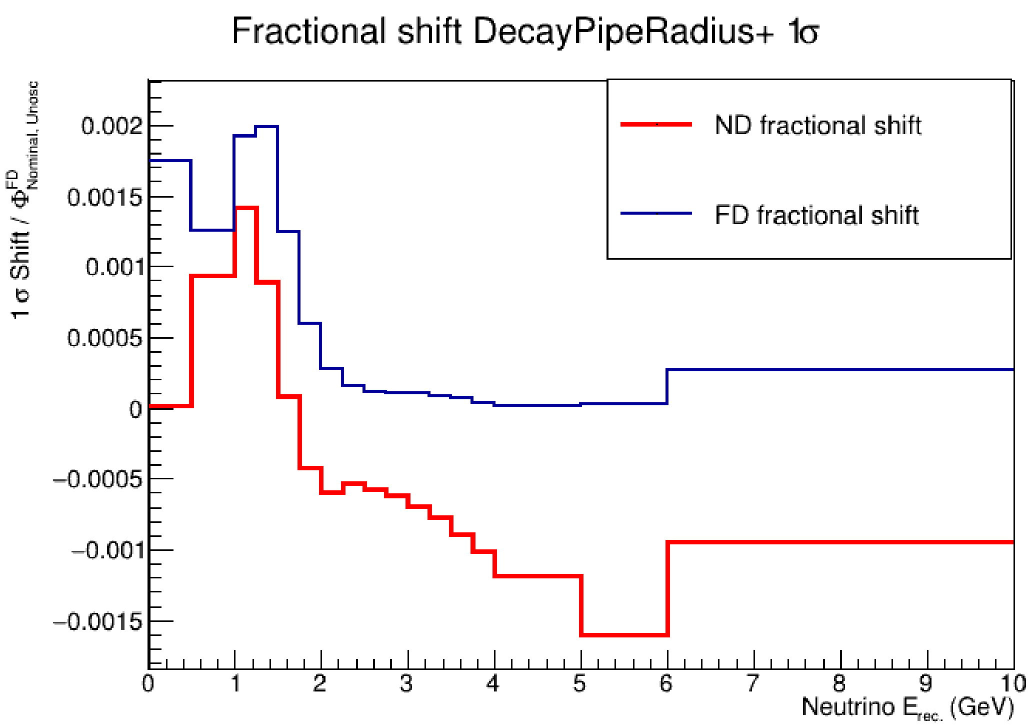


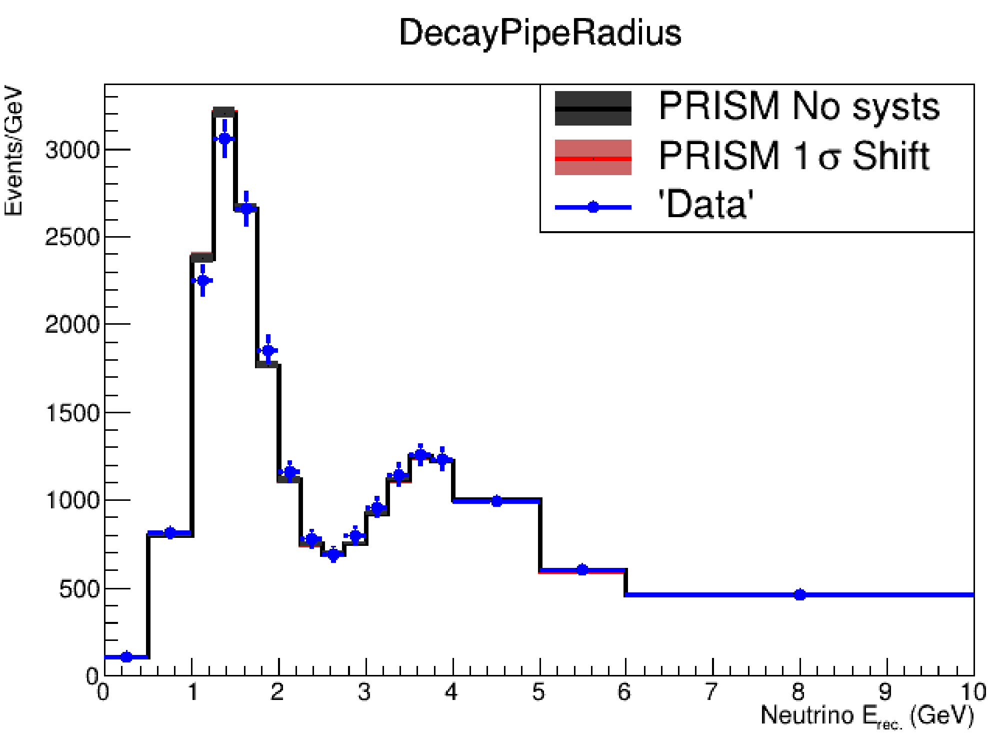
- Comparable ND and FD uncertainties: max. of 0.8%

Decay Pipe Radius

SEMI

- 1σ shift = 2cm: changed from 10 cm (nominal = 2m)



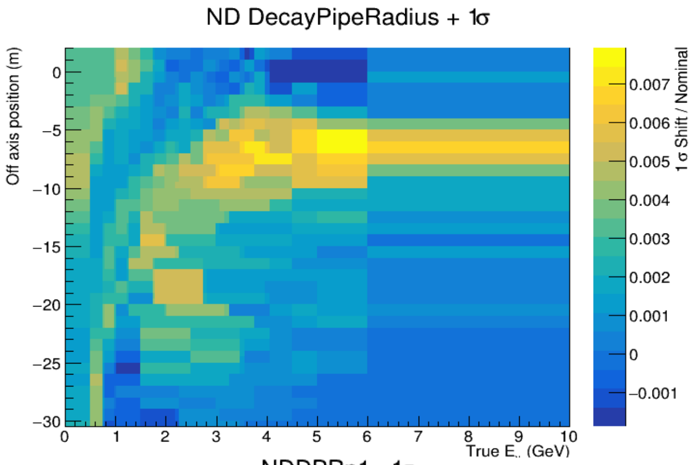


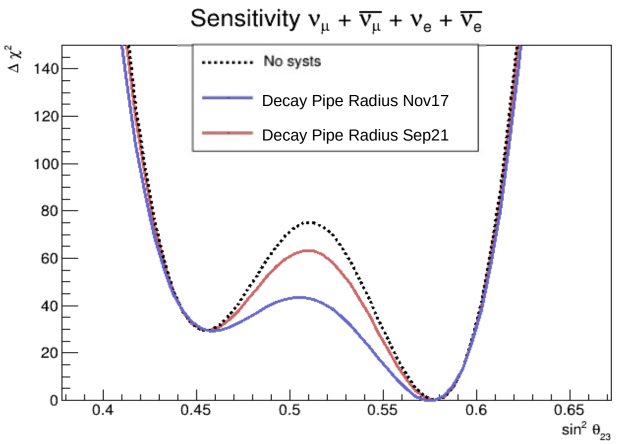
- Maximum difference between PRISM prediction (ND) and FD of ≈ 0.15%

Decay Pipe Radius → Comparison to Nov17 systematics

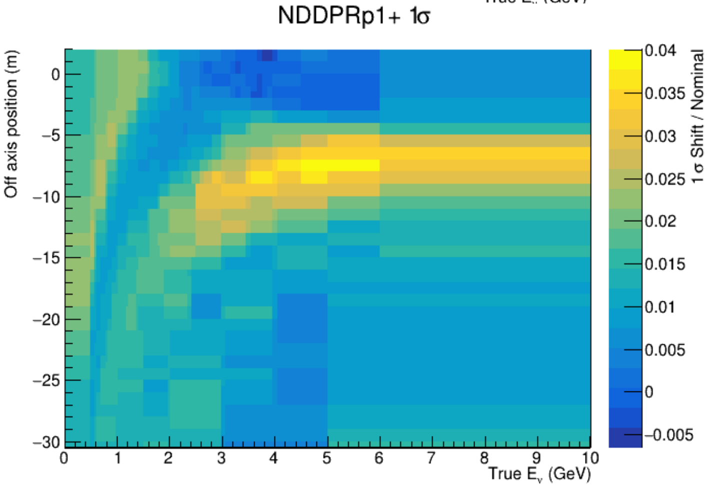
SEMI

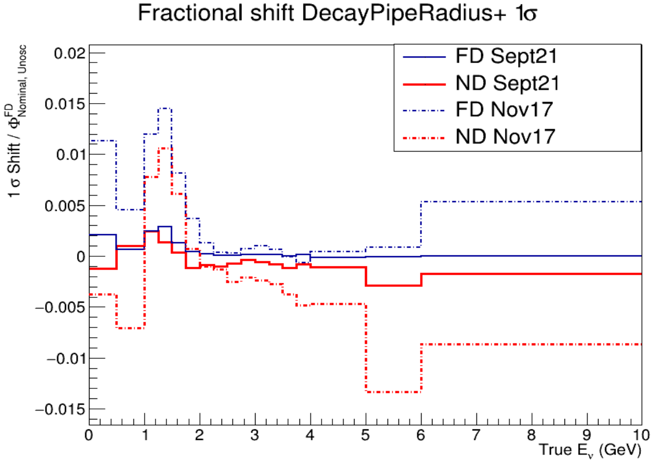
Sept 21:
1σ = 2 cm





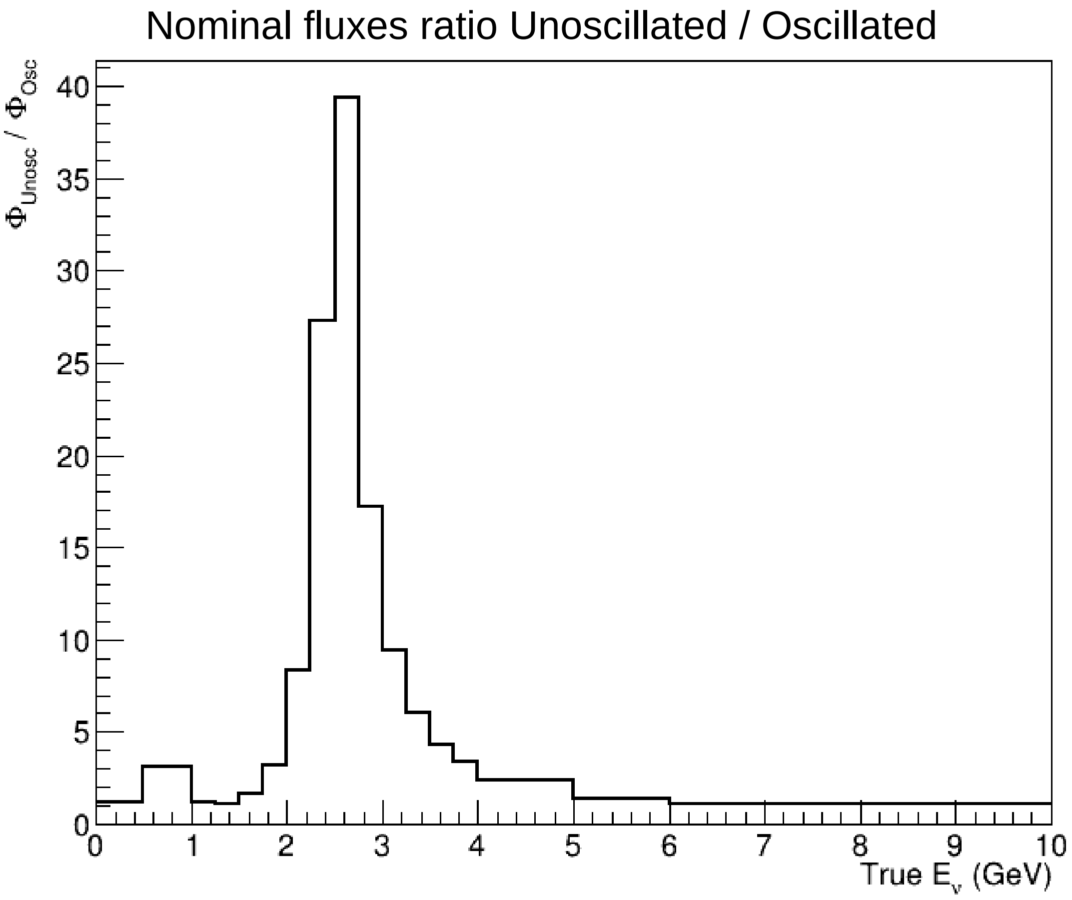
Nov 17:
1σ = 10 cm





Much smaller uncertainties with the new (Sep 21) systematics → increased sensitivity

Flux normalization: Unoscillated versus Oscillated



→ if the oscillated flux is chosen as the normalization factor:

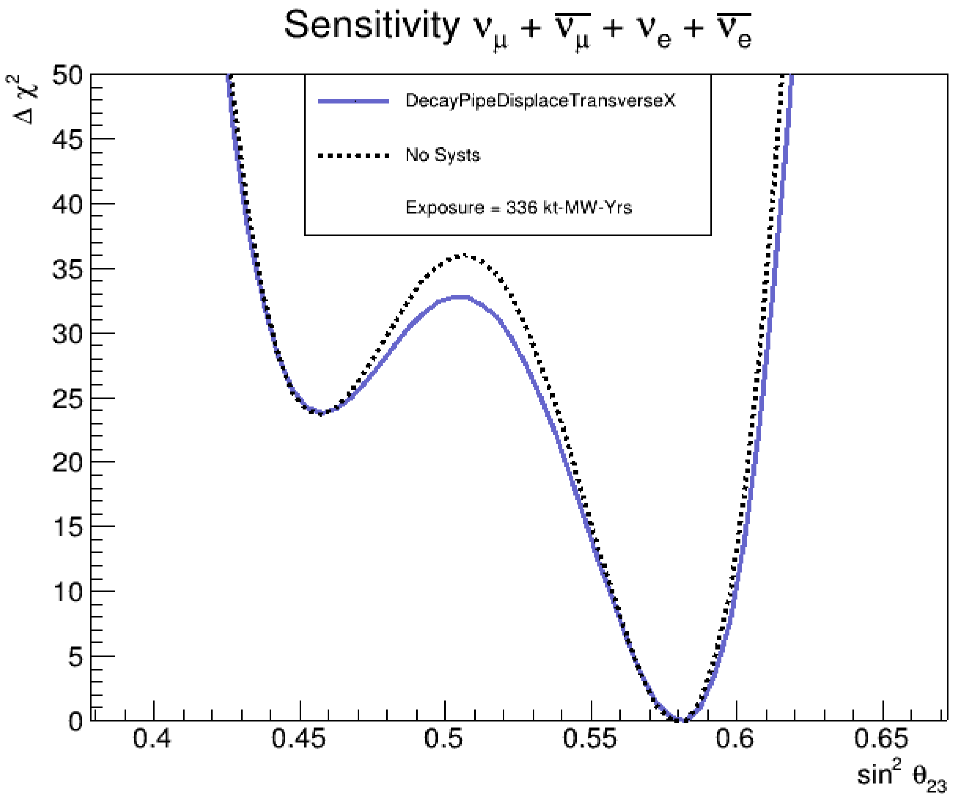
- fractional error a factor of ~ 40 larger
- peak structure @ ~2.6 GeV

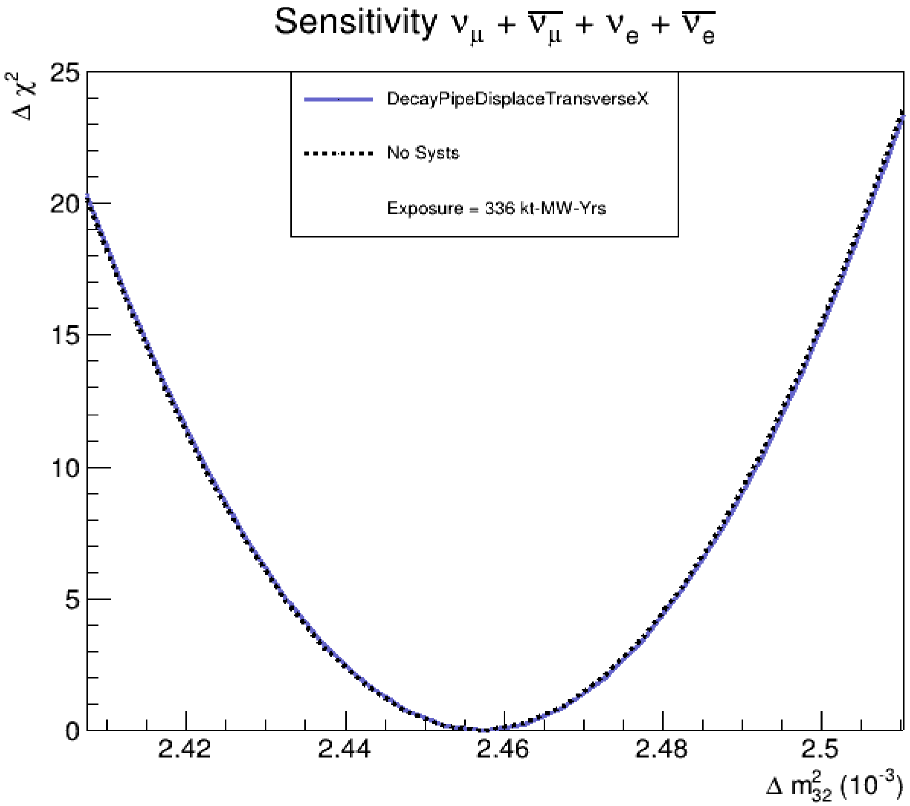
→ FD **unoscillated flux** is used as **normalization factor**

Decay Pipe Displace Transverse X

SEMI

- 1σ shift = 2.5 cm

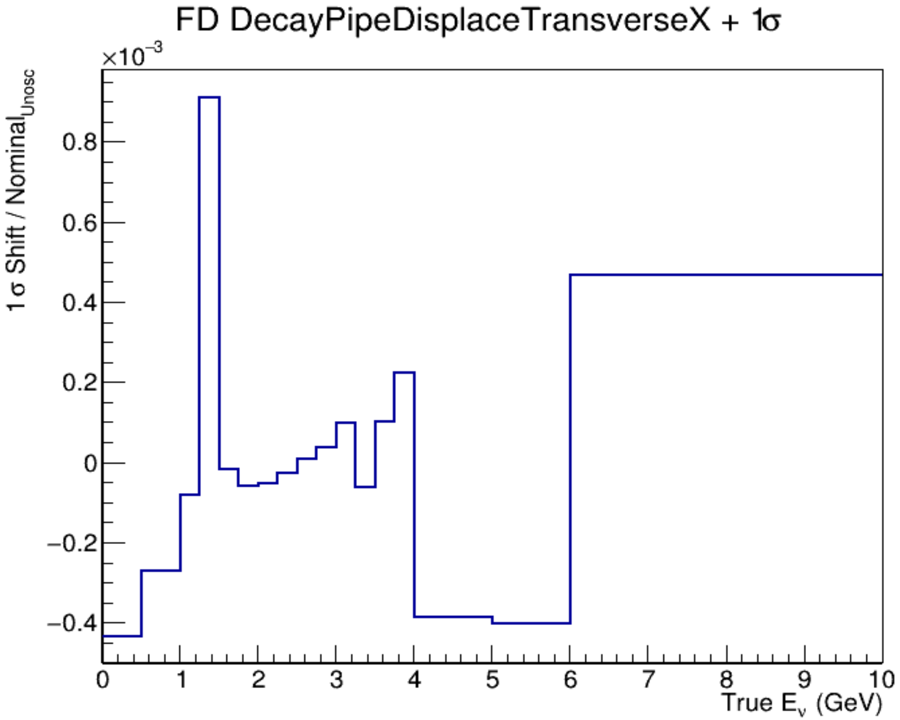


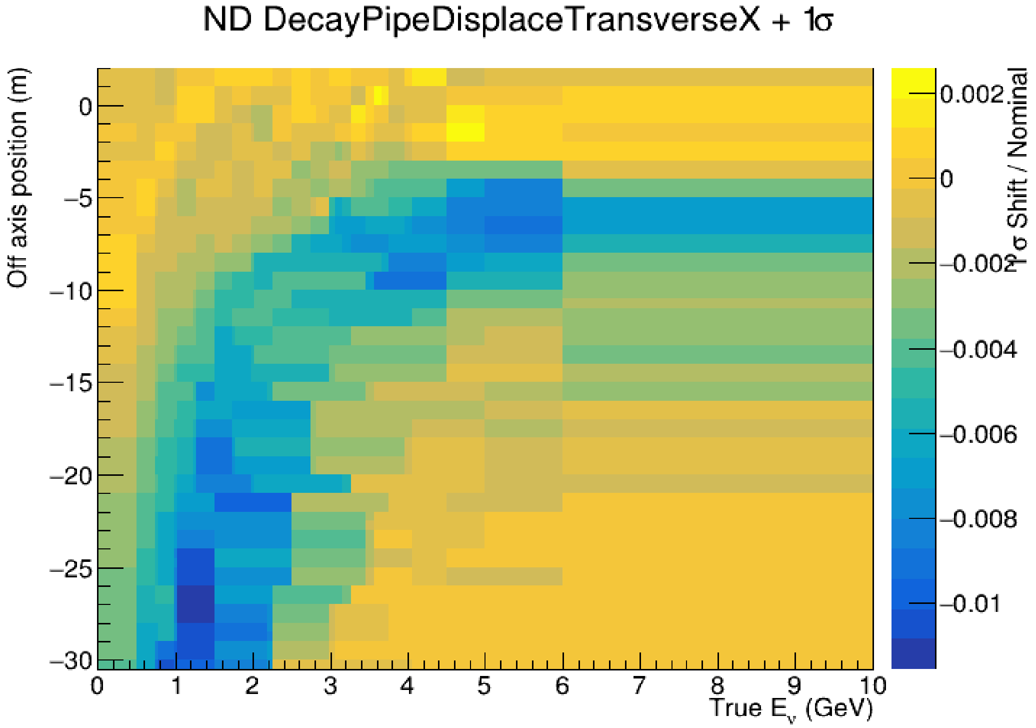


Decay Pipe Displace Transverse X

SEMI

- 1σ shift = 2.5 cm

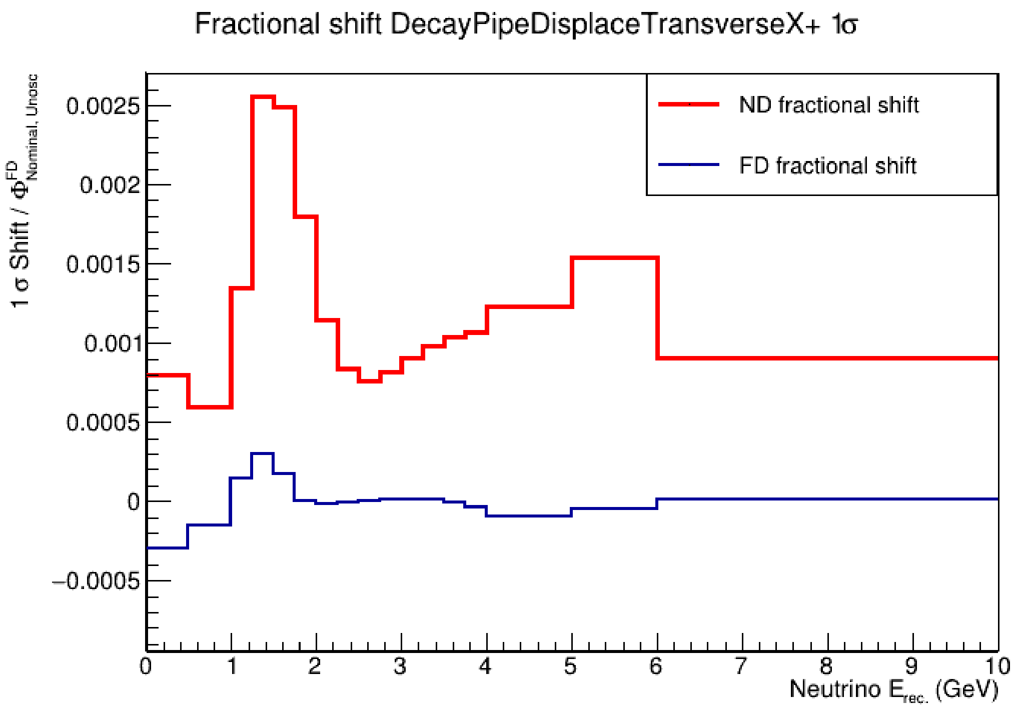


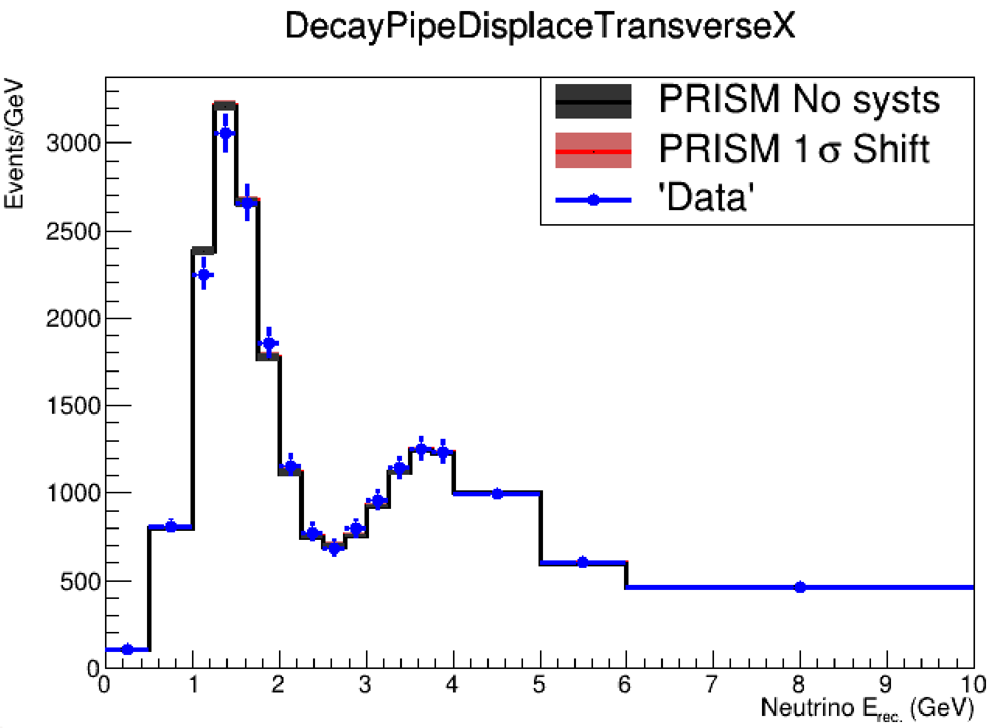


Decay Pipe Displace Transverse X

SEMI

- 1σ shift = 2.5 cm



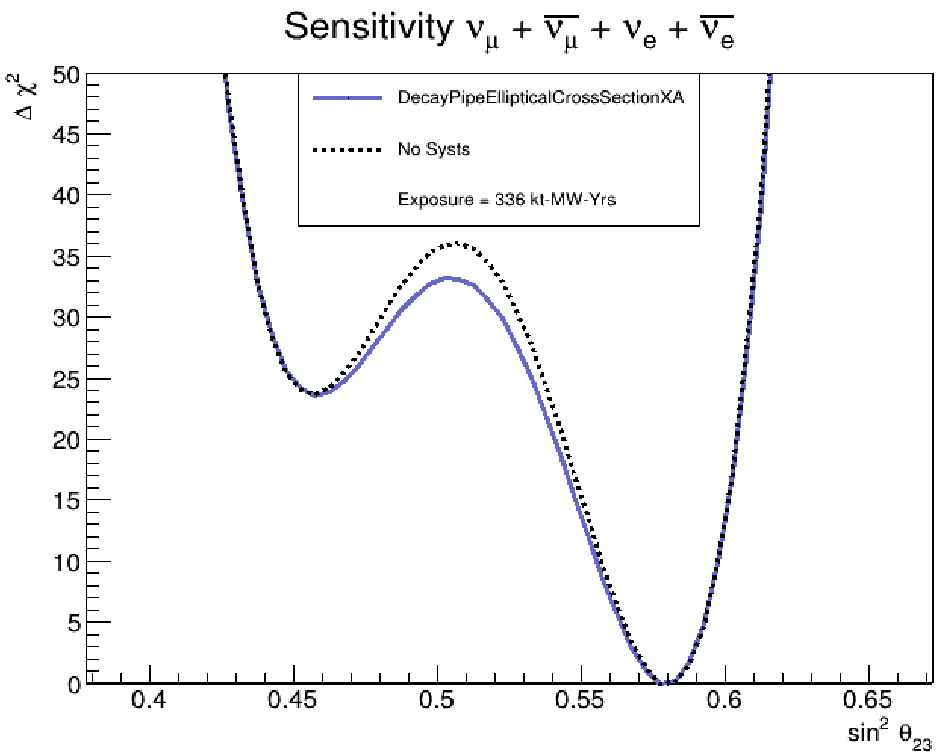


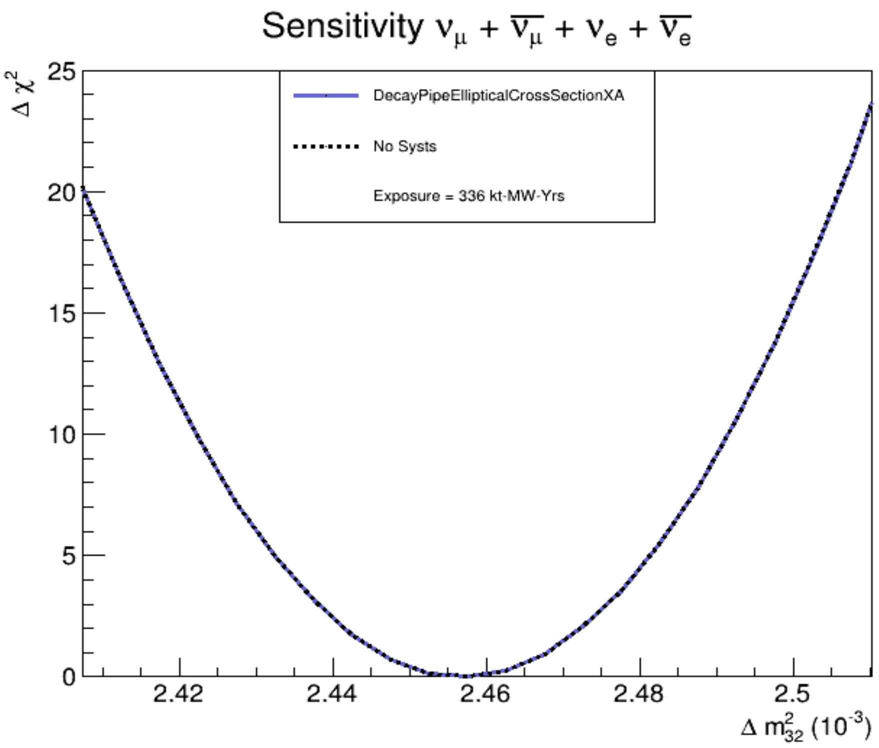
- Maximum difference between PRISM prediction (ND) and FD of ≈ 0.25% (larger than in the case of decay pipe radius → stronger sensitivity reduction)

Decay Pipe Elliptical Cross Section X A

SEMI

- 1σ shift = 2.5 cm: ellipse with A (x-axis) varied while the other dimension fixed to nominal radius

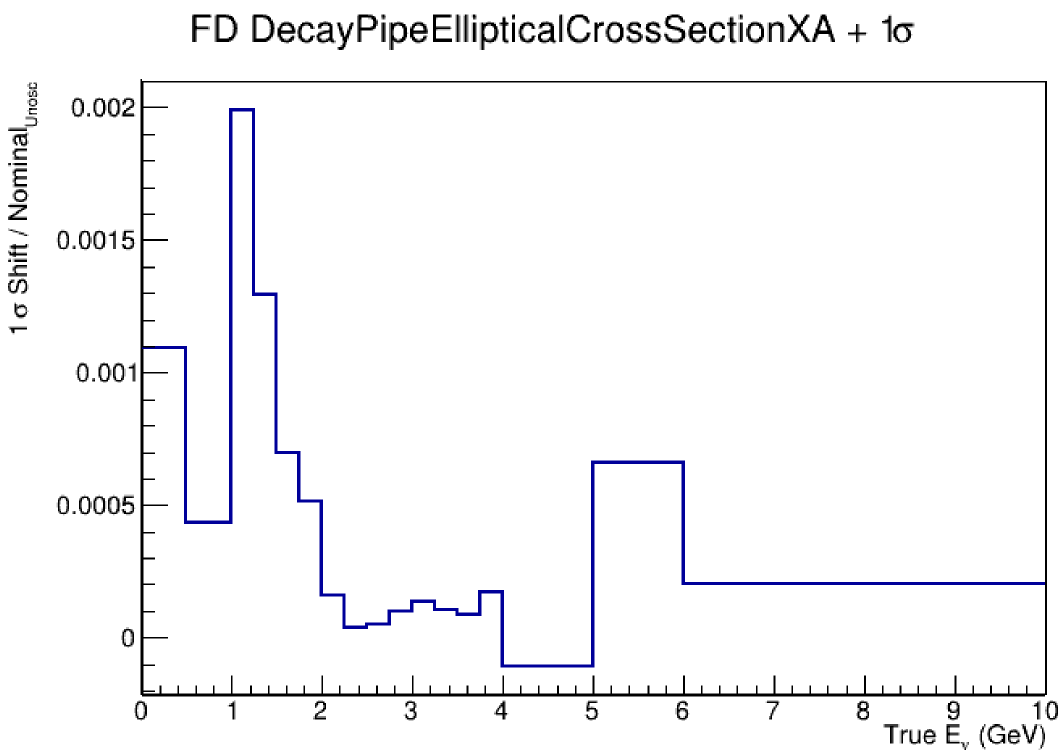


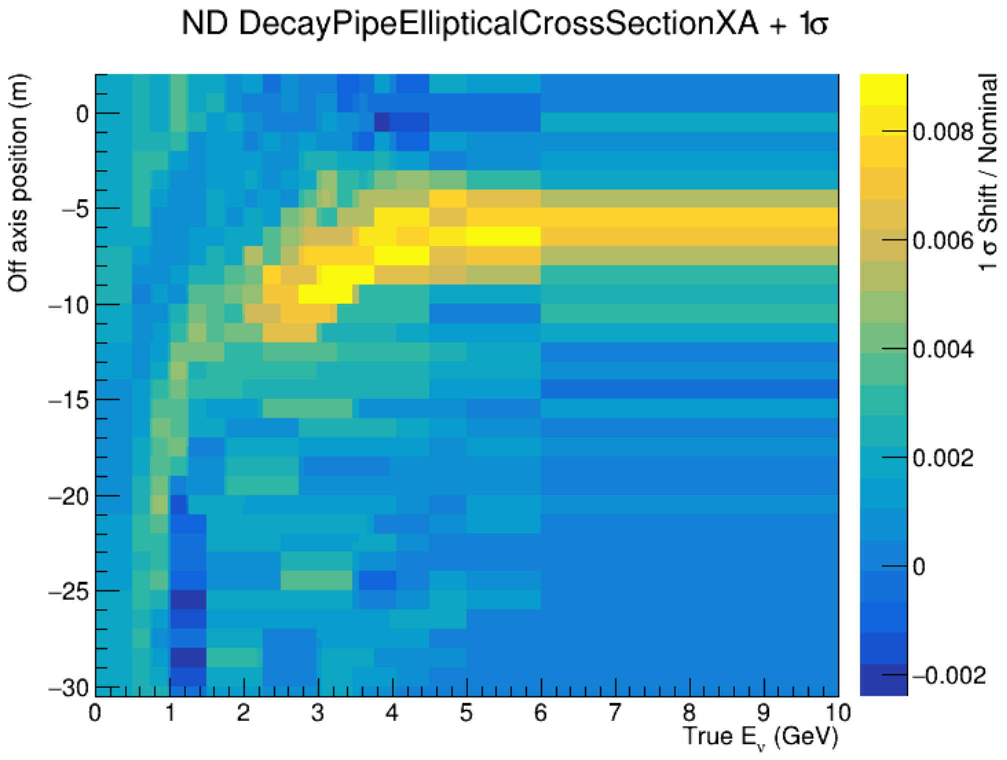


Decay Pipe Elliptical Cross Section X A

SEMI

- 1σ shift = 2.5 cm: ellipse with A (x-axis) varied while the other dimension fixed to nominal radius

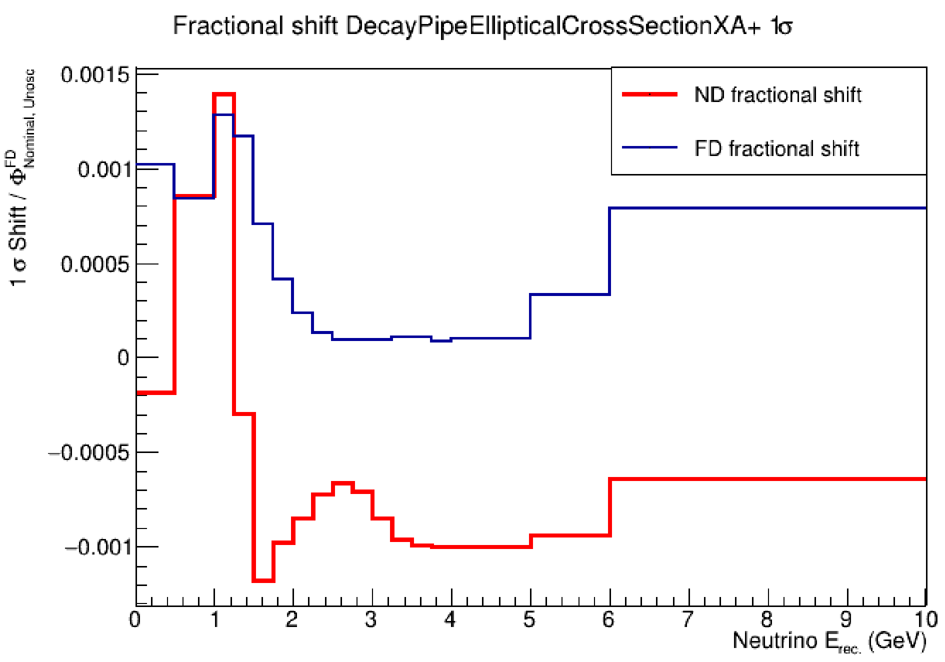


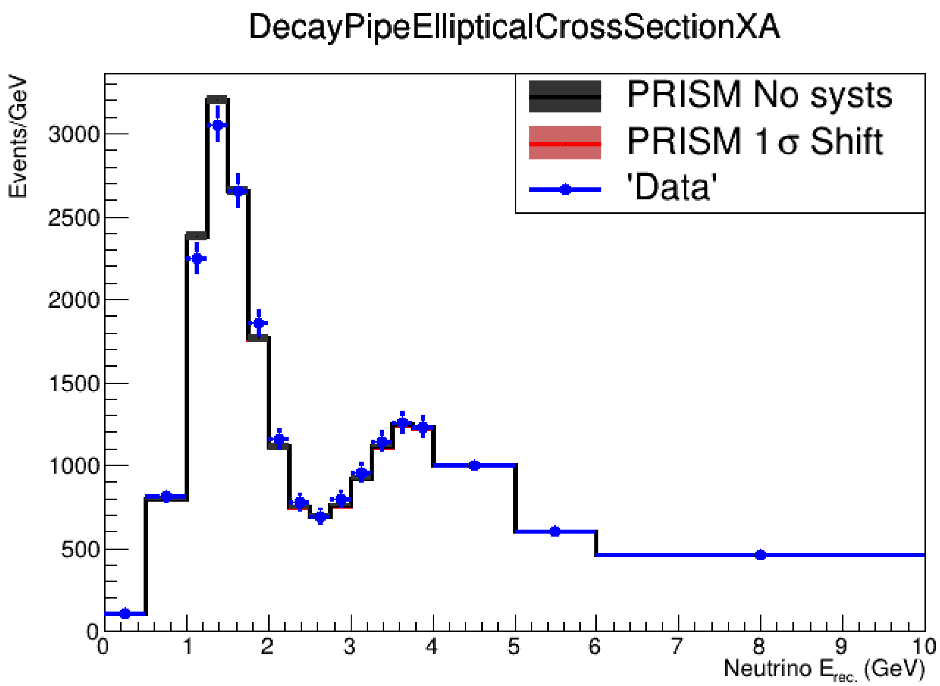


Decay Pipe Elliptical Cross Section X A

SEMI

- 1σ shift = 2.5 cm: ellipse with A (x-axis) varied while the other dimension fixed to nominal radius

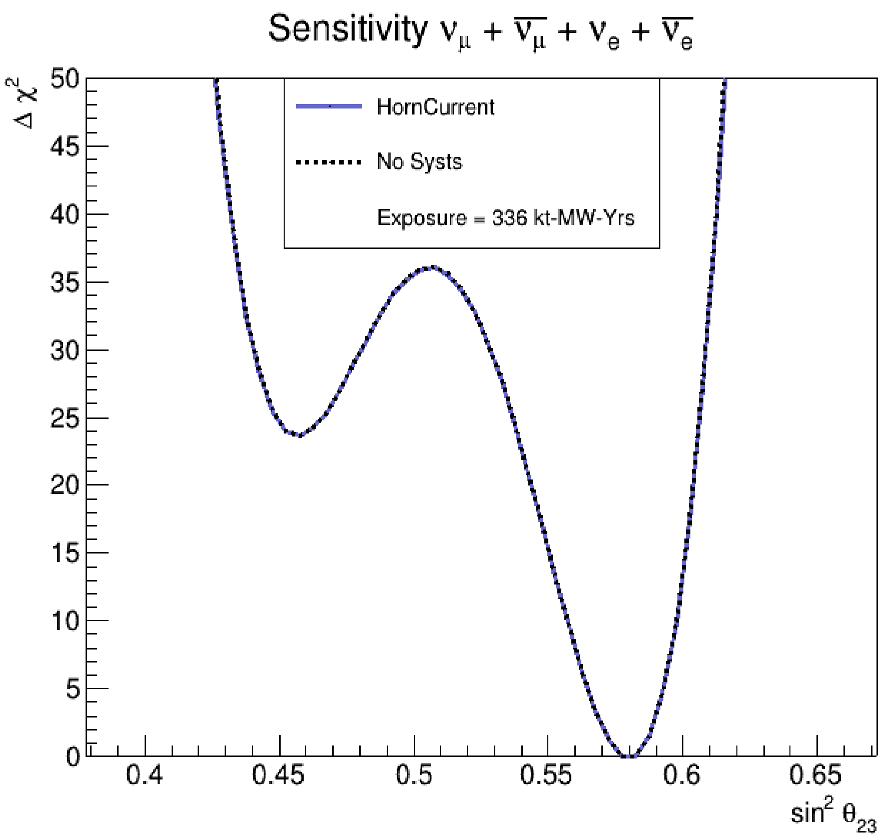


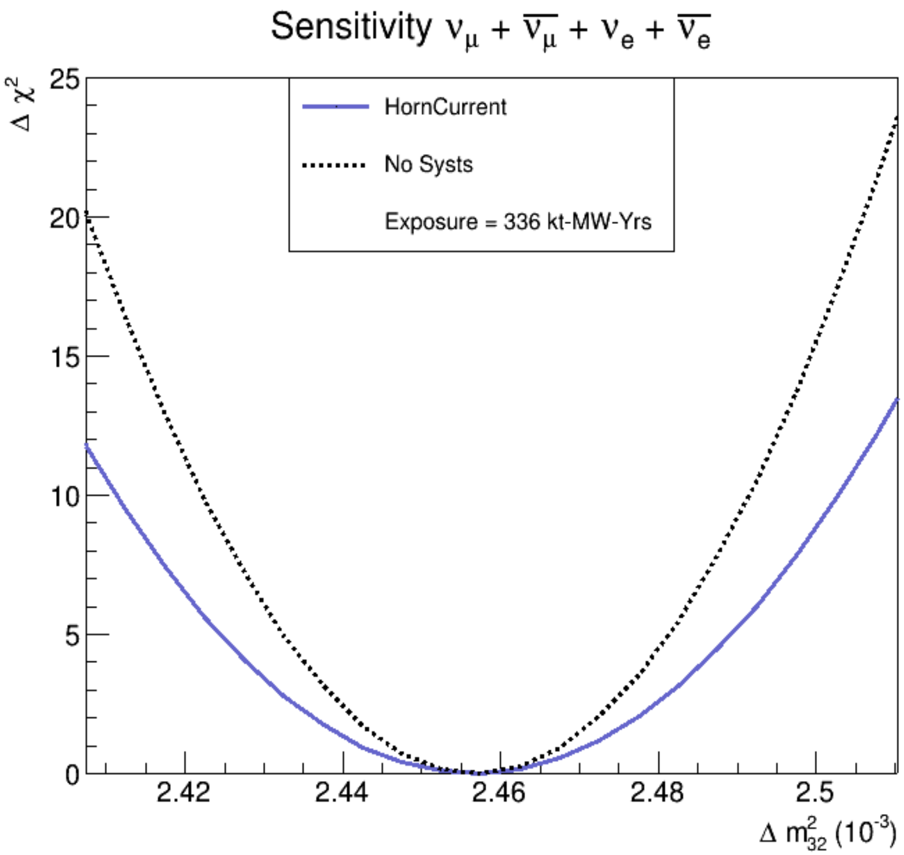


Horn Current

IMPORTANT

- 1σ shift = 1% (3kA): simultaneous change to all 3 horns





Horn Current

IMPORTANT

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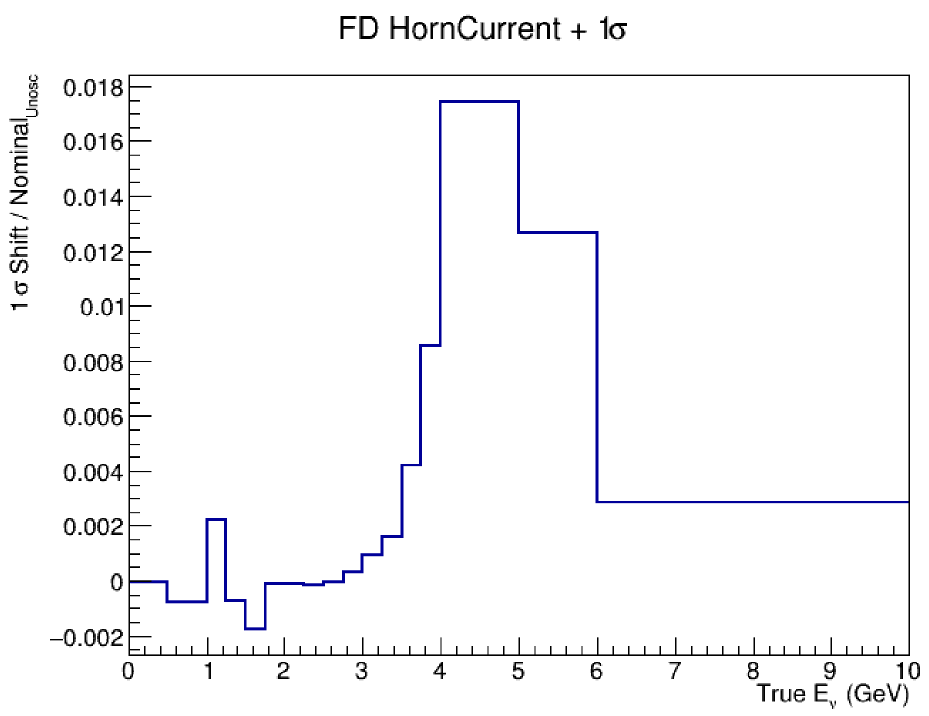
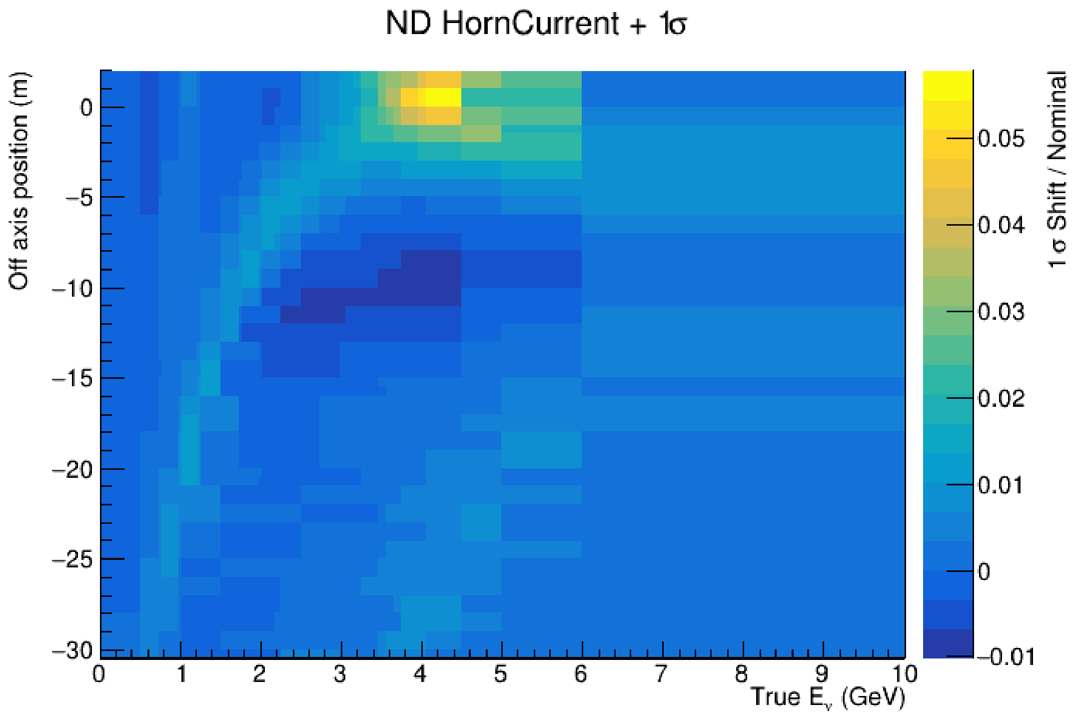
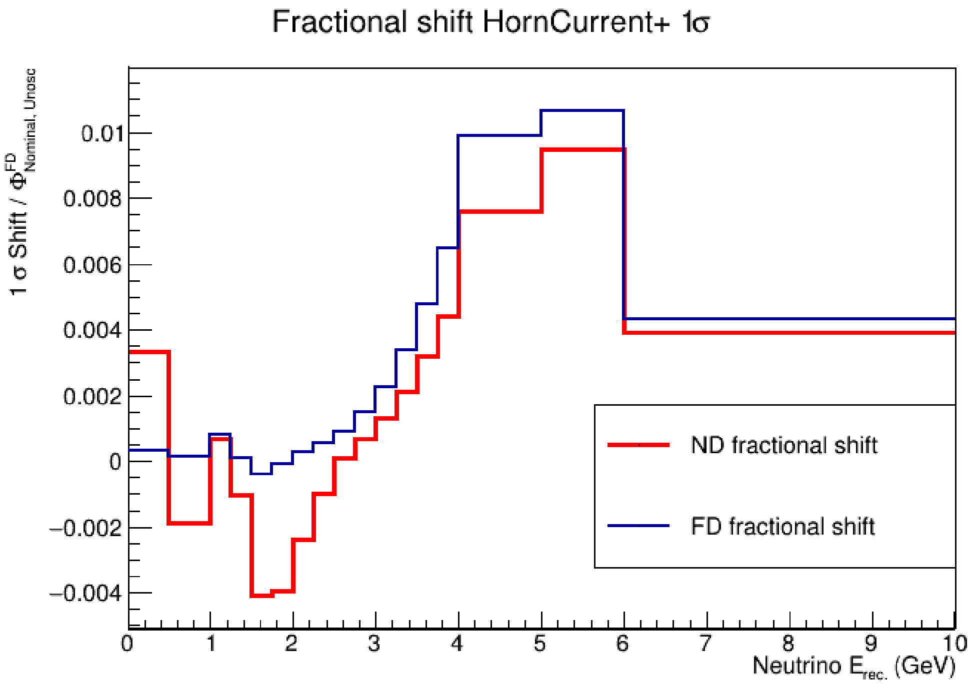


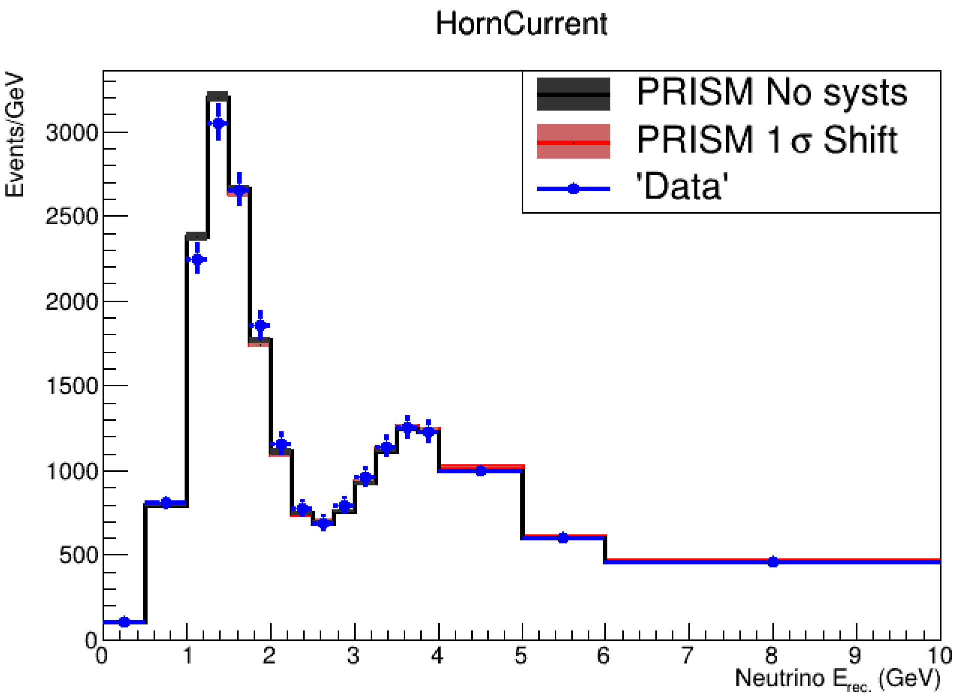


Horn Current

IMPORTANT

- 1σ shift = 1% (3kA): simultaneous change to all 3 horns

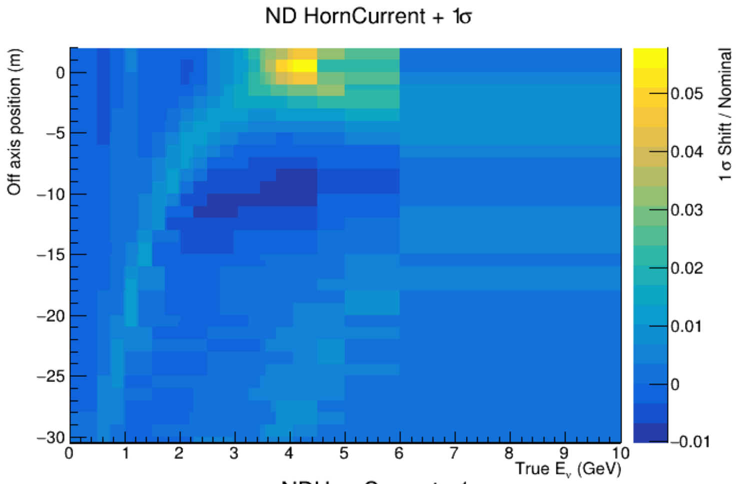




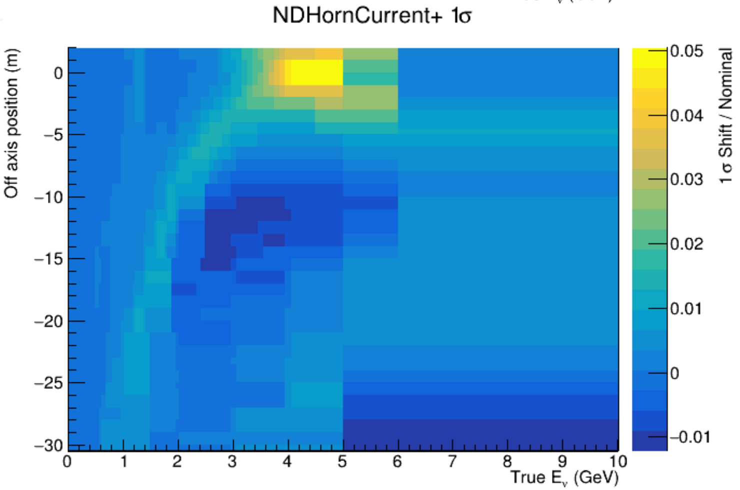
Horn Current → Comparison to Nov17 systematics

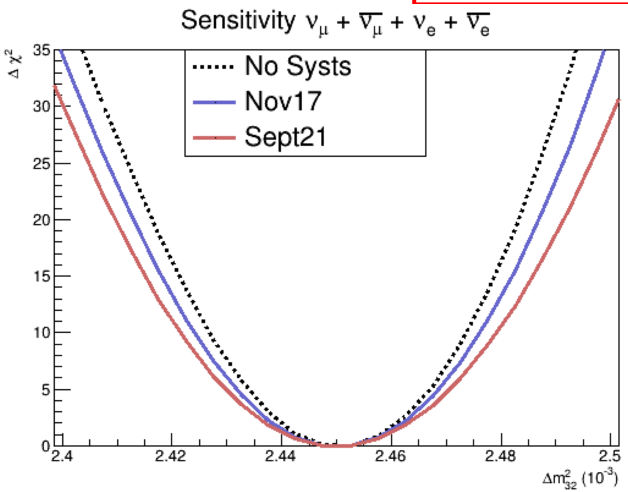
IMPORTANT

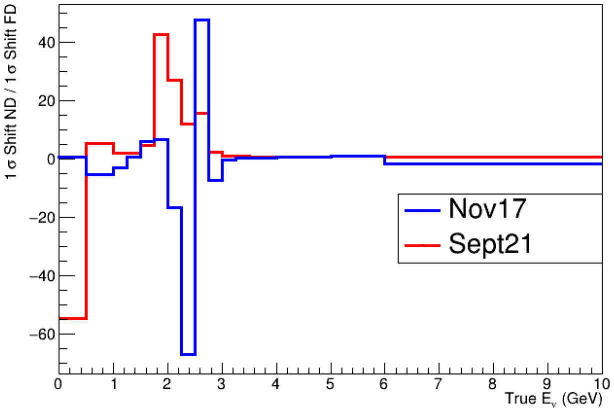
Sept21:
1σ shift = 3kA



Nov17:
1σ shift = 2.93kA



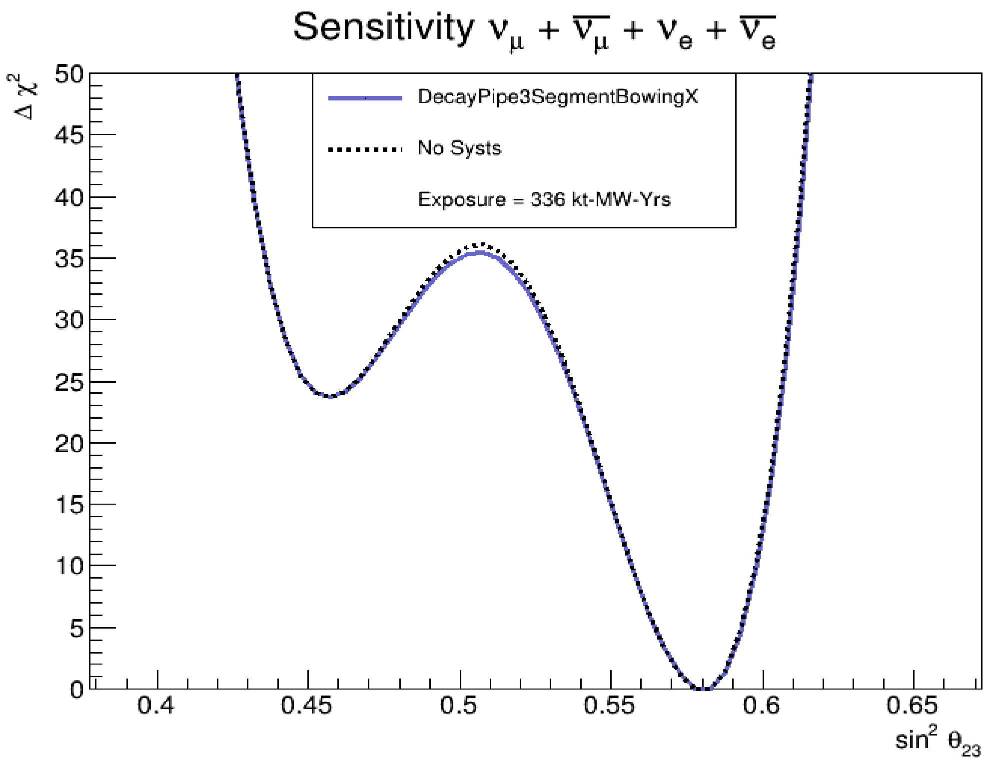


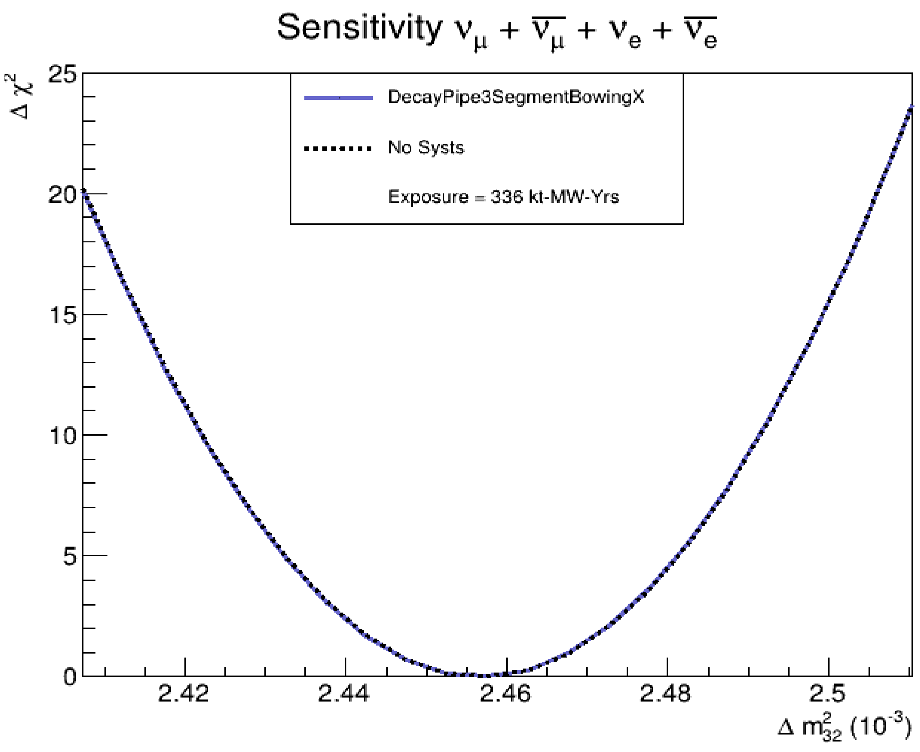


Decay Pipe 3 Segment Bowing X

SEMI

- 1σ shift = 2.5cm: decay pipe segmented into 3 equal pieces; the central piece is transverse shifted by tolerance

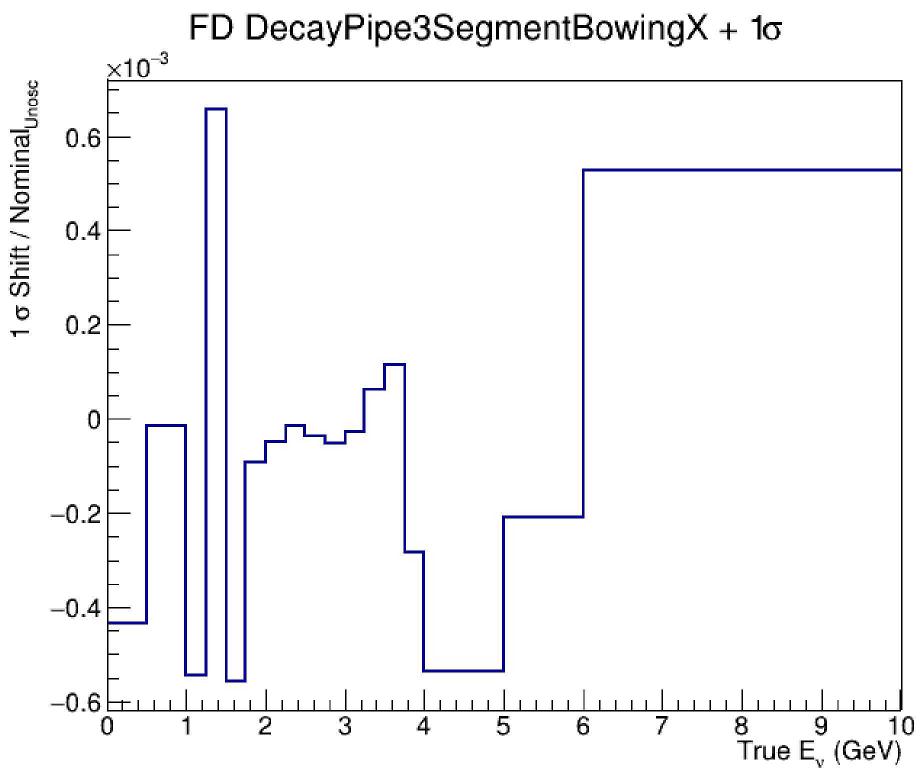


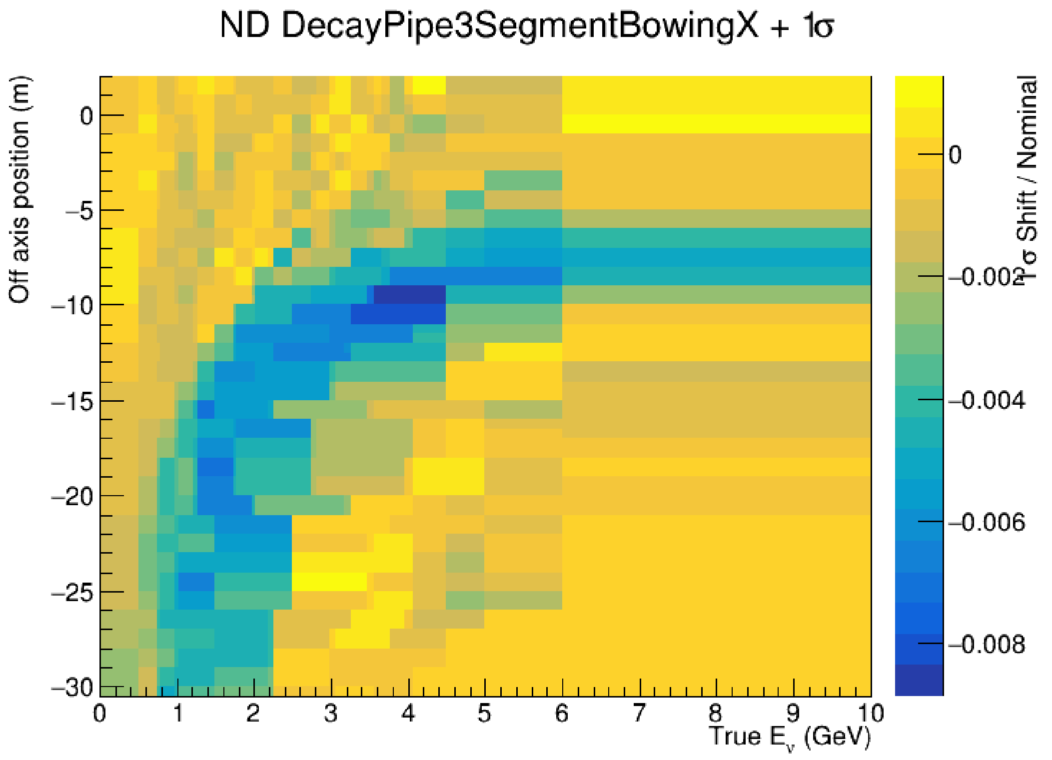


Decay Pipe 3 Segment Bowing X

SEMI

- 1σ shift = 2.5cm: decay pipe segmented into 3 equal pieces; the central piece is transverse shifted by tolerance

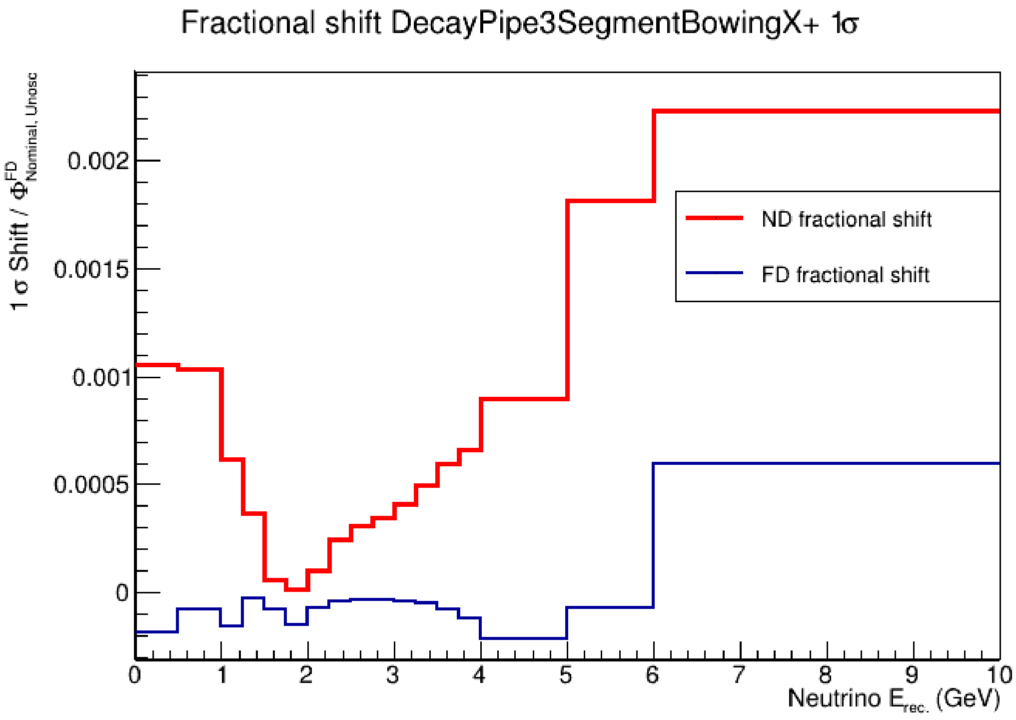


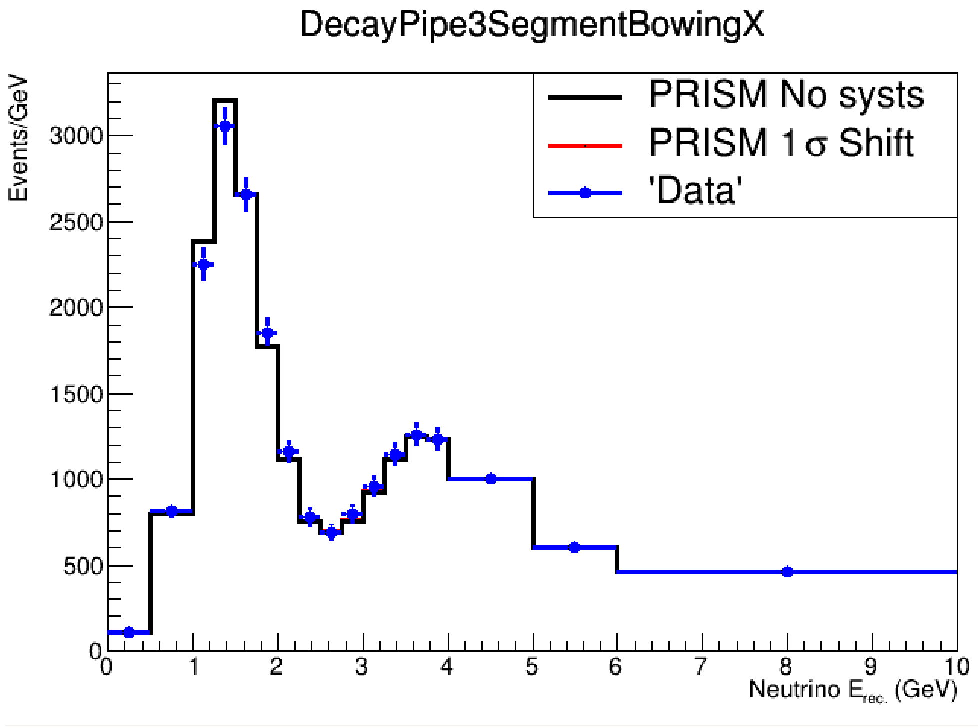


Decay Pipe 3 Segment Bowing X

SEMI

- 1σ shift = 2.5cm: decay pipe segmented into 3 equal pieces; the central piece is transverse shifted by tolerance

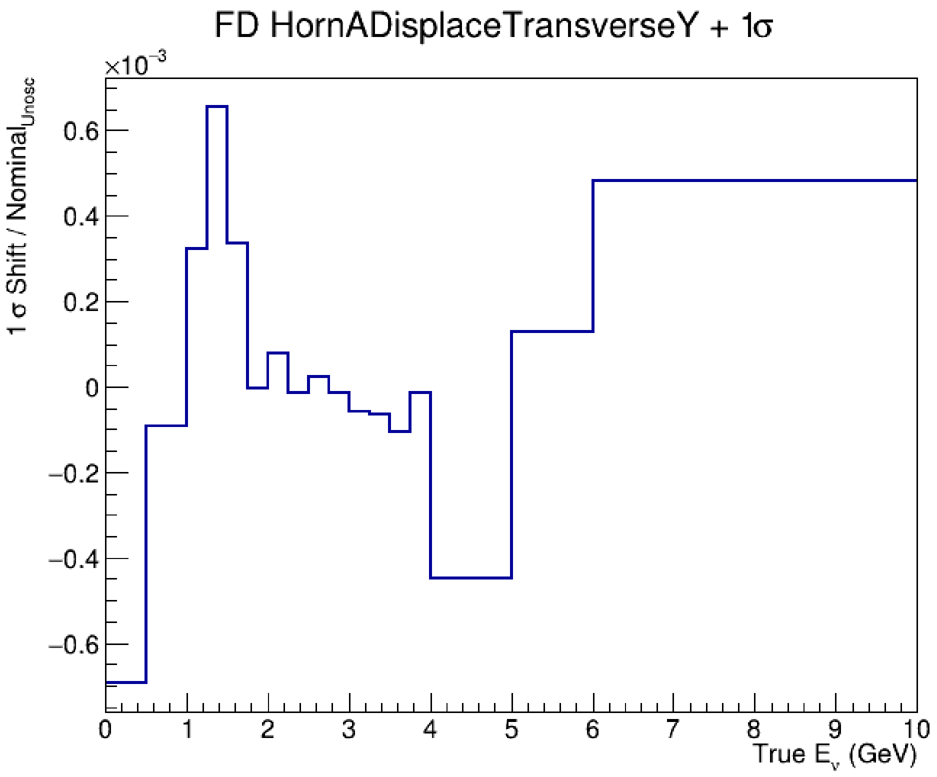


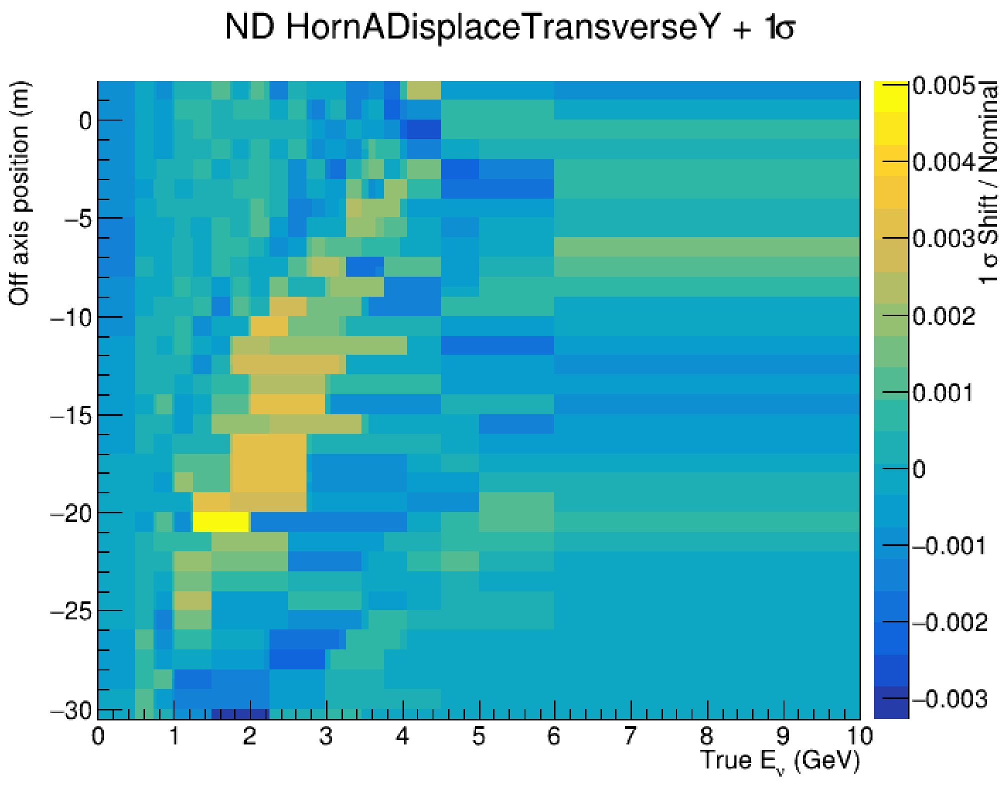


Horn A Displace Transverse Y

NEGLIGIBLE

- 1σ shift = 0.5 mm

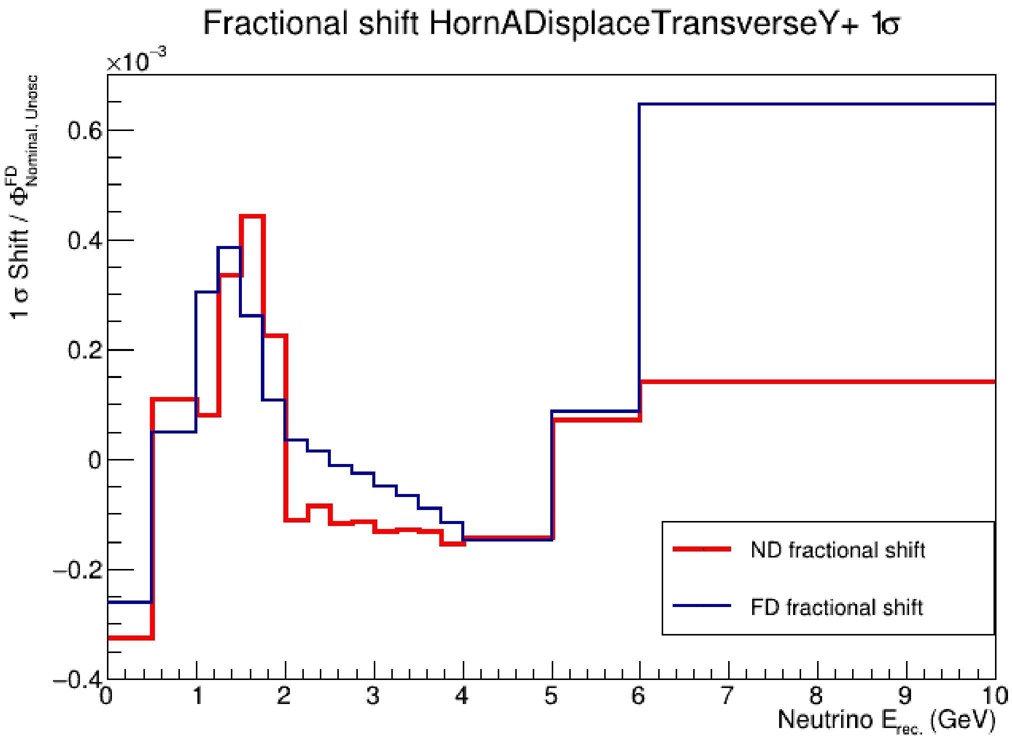


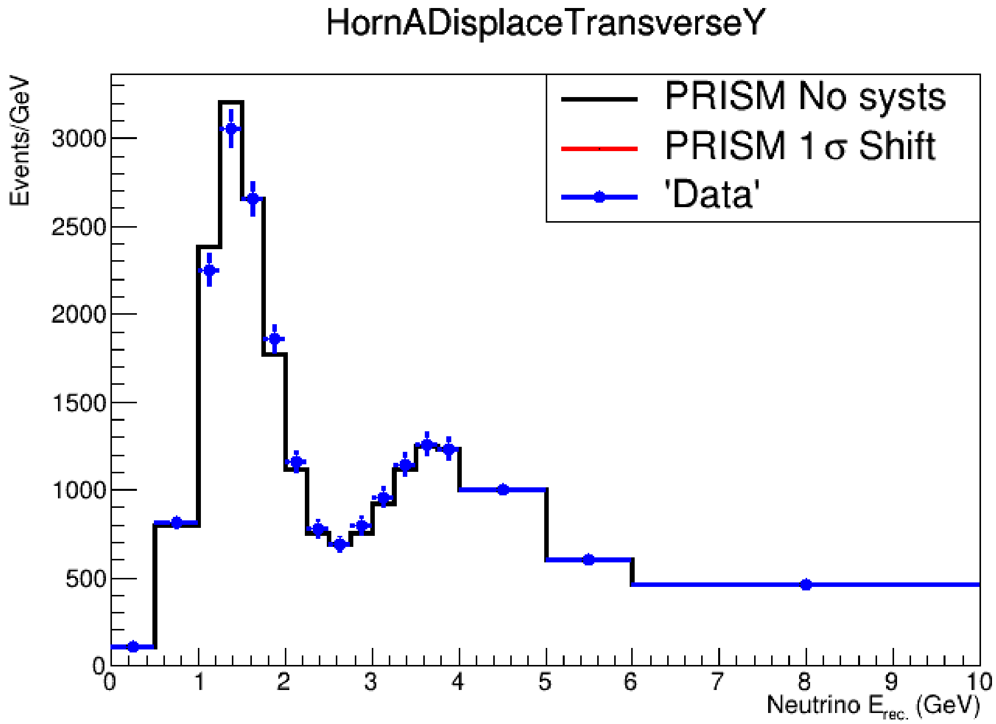


Horn A Displace Transverse Y

NEGLIGIBLE

- 1σ shift = 0.5 mm

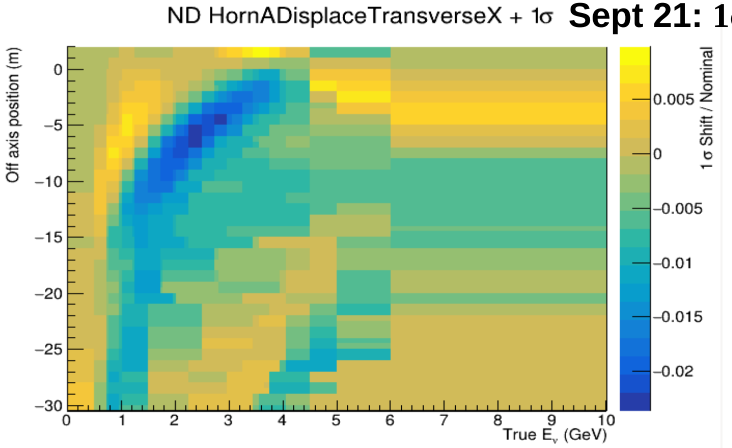


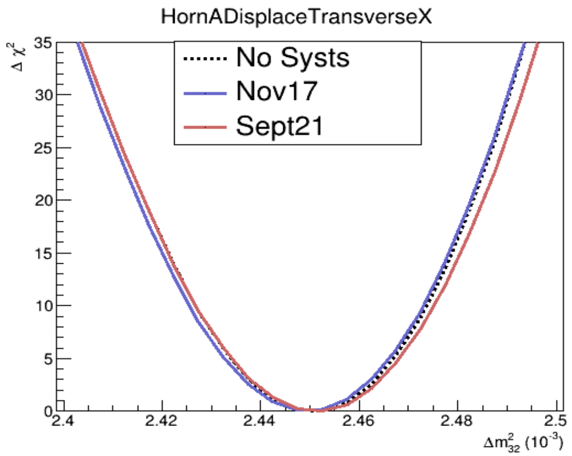


Horn A Displace Transverse X → comparison to Nov17 systs

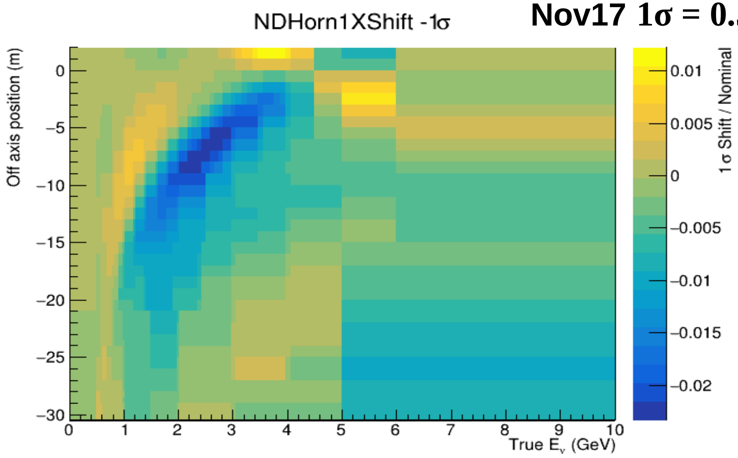
IMPORTANT

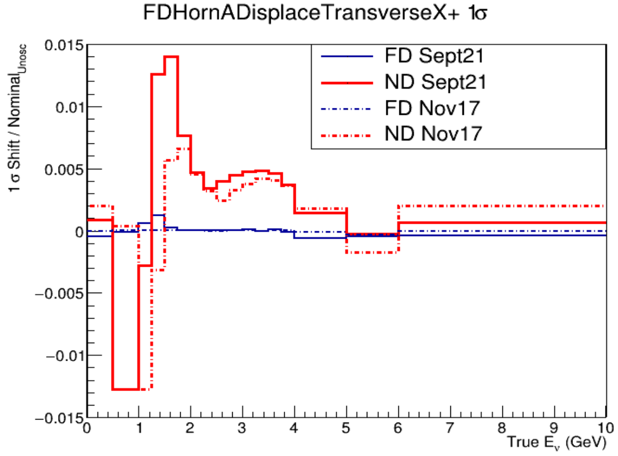
Sept 21: 1σ = 0.5mm





Nov17 1σ = 0.5mm

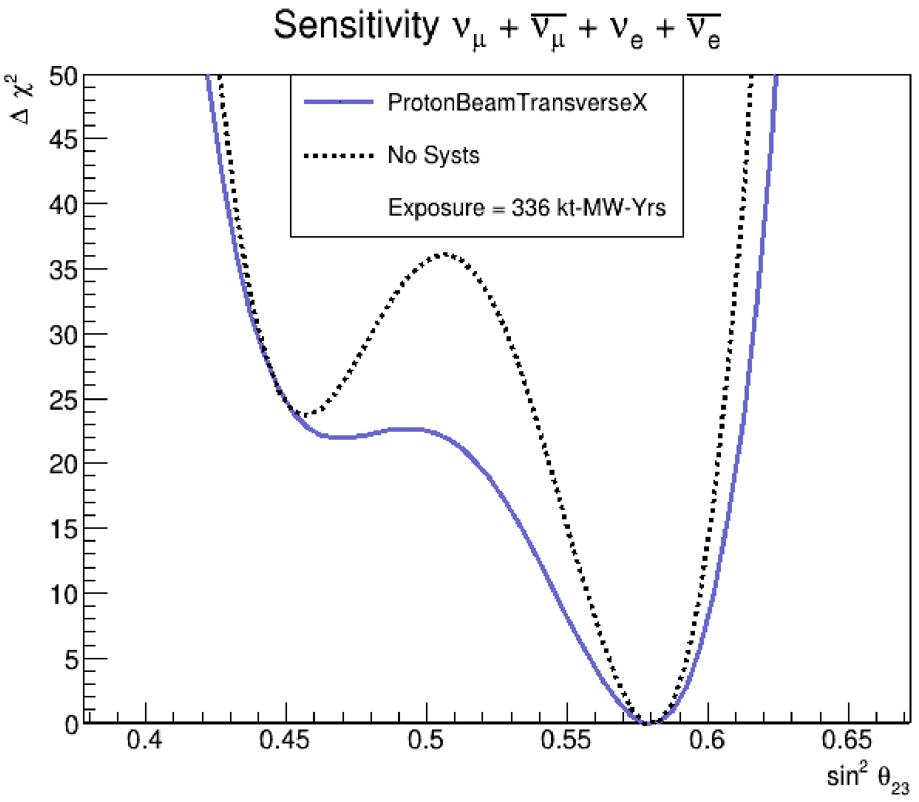


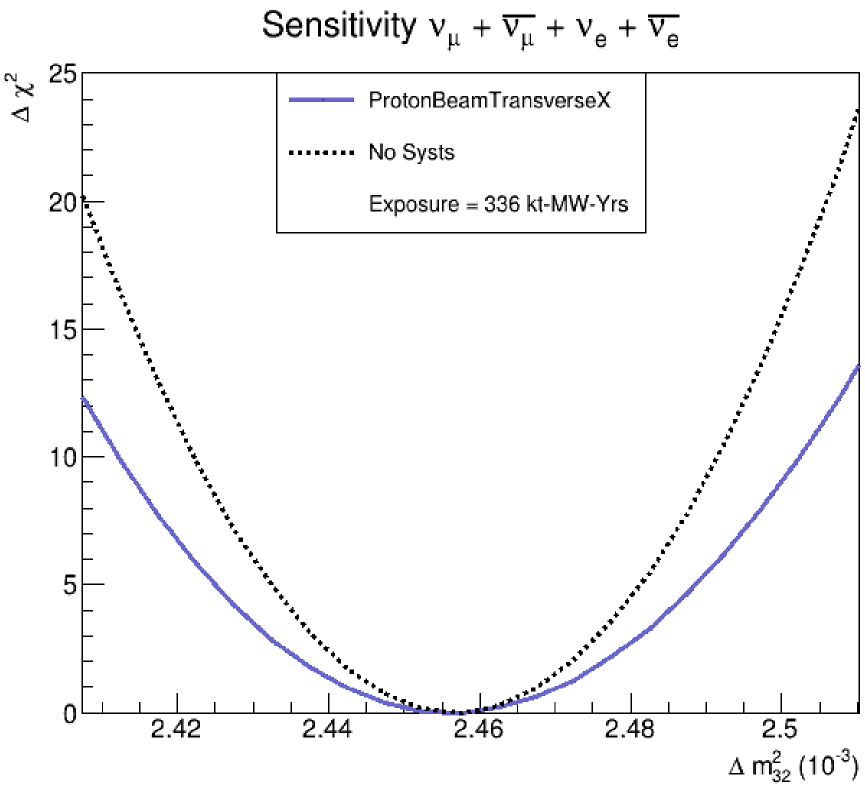


Proton Beam Transverse X

IMPORTANT

- 1 σ shift = 0.5 mm (updated from 4.5 mm in TDR)

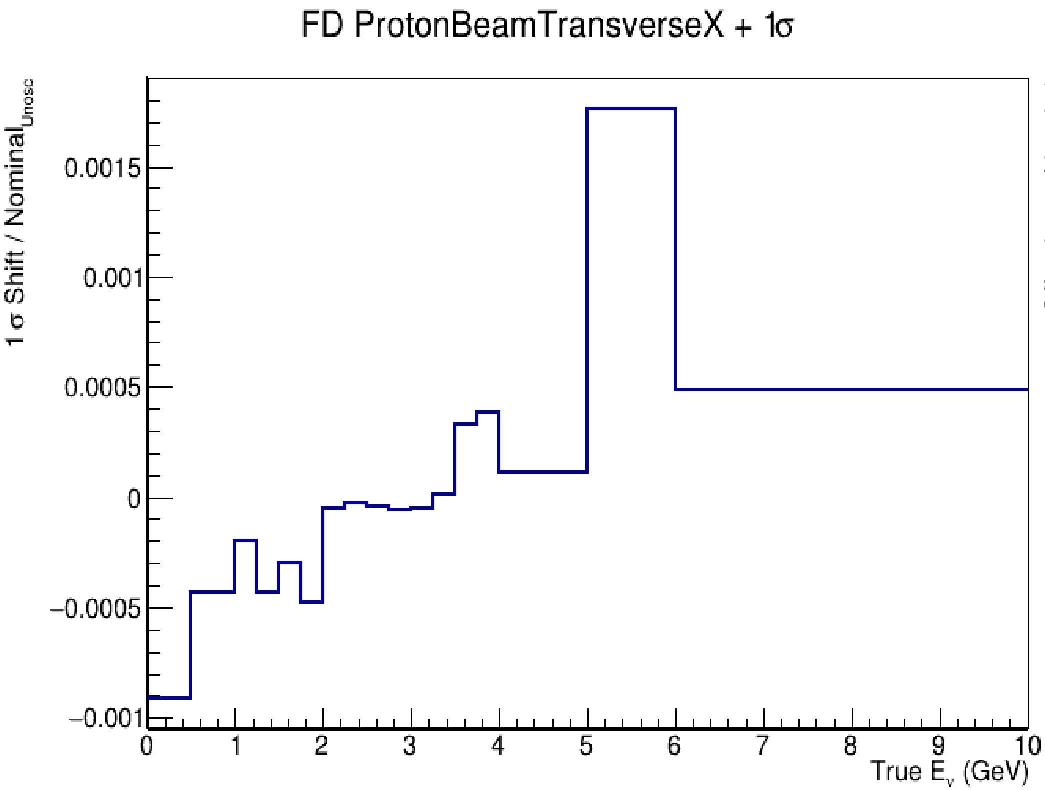


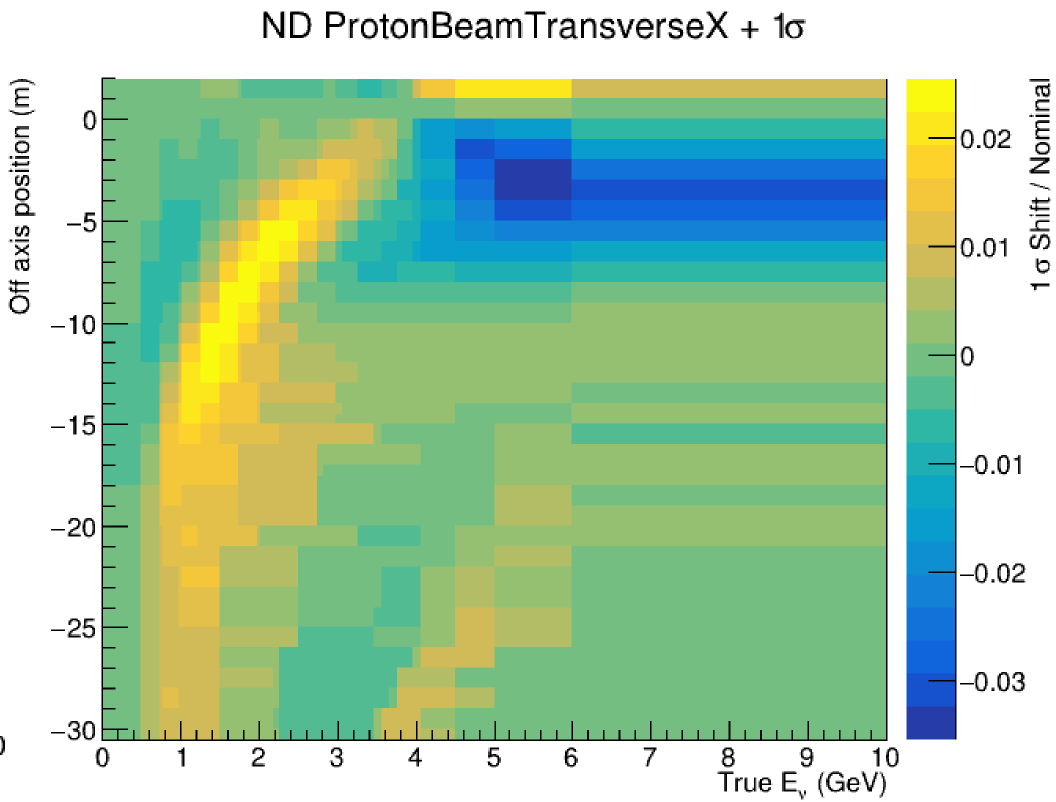


Proton Beam Transverse X

IMPORTANT

- 1 σ shift = 0.5 mm (updated from 4.5 mm in TDR)

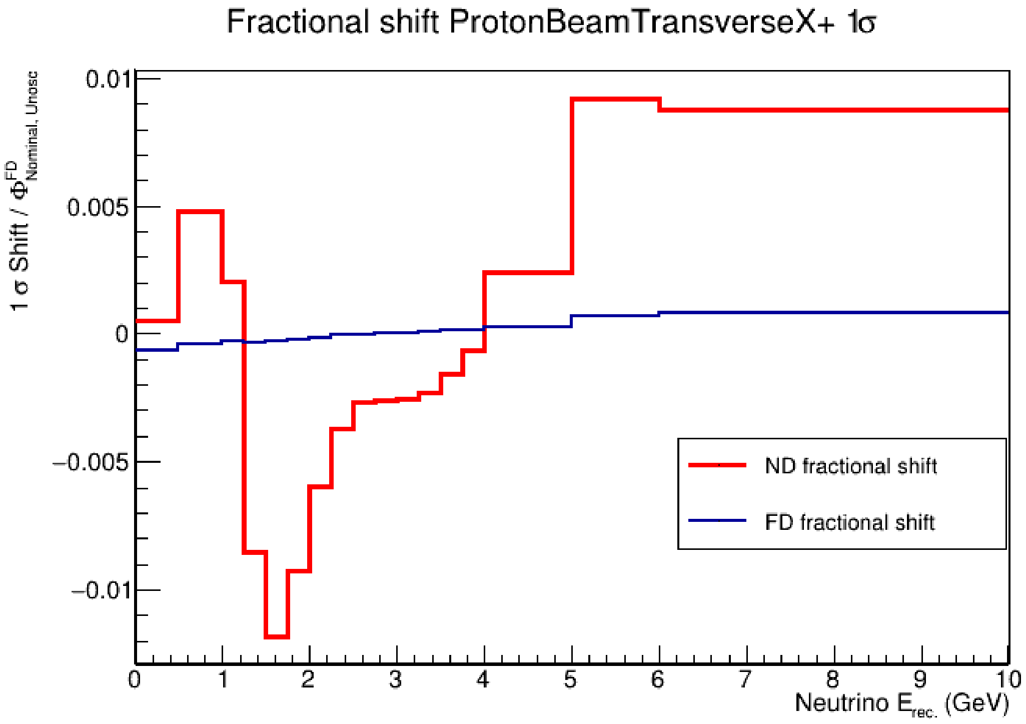


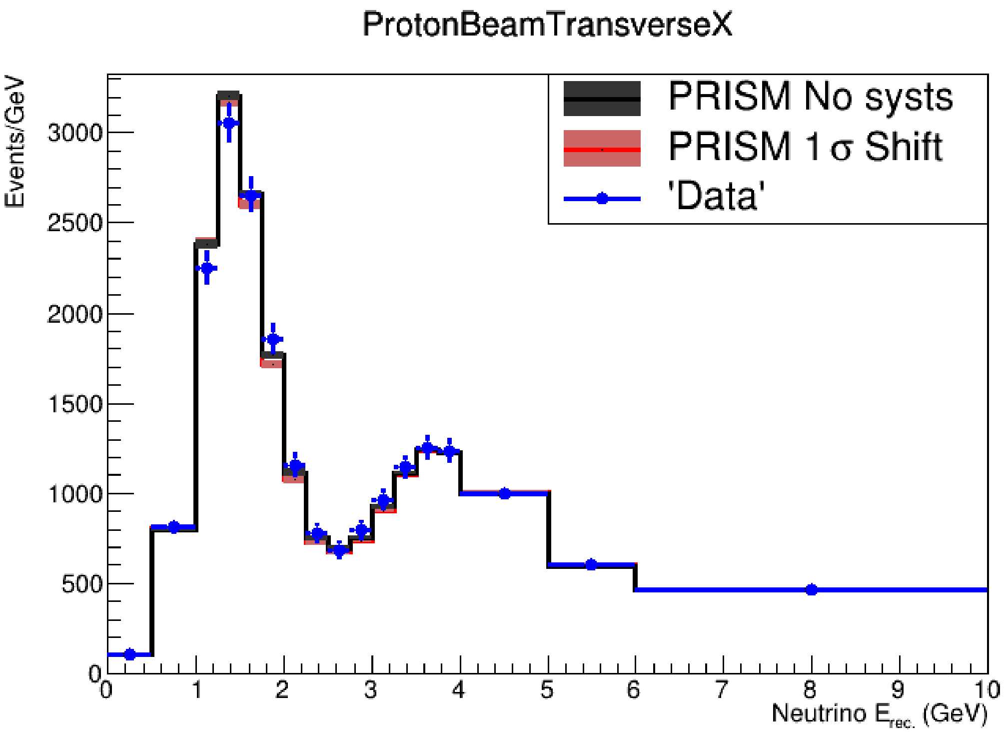


Proton Beam Transverse X

IMPORTANT

- 1 σ shift = 0.5 mm (updated from 4.5 mm in TDR)

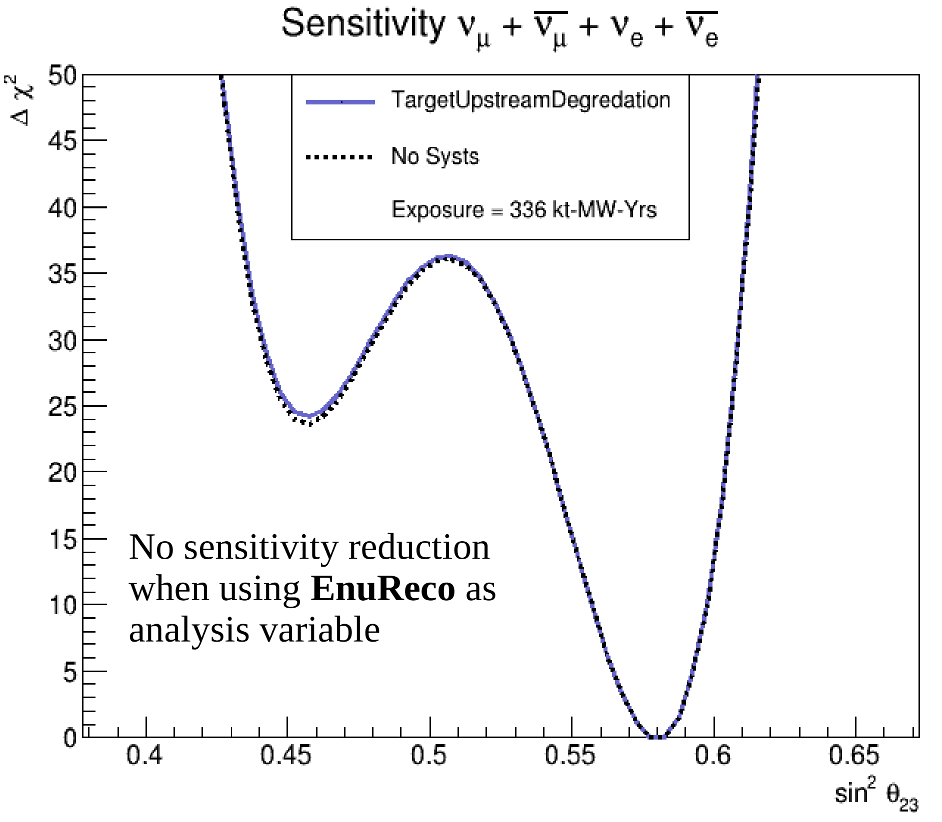


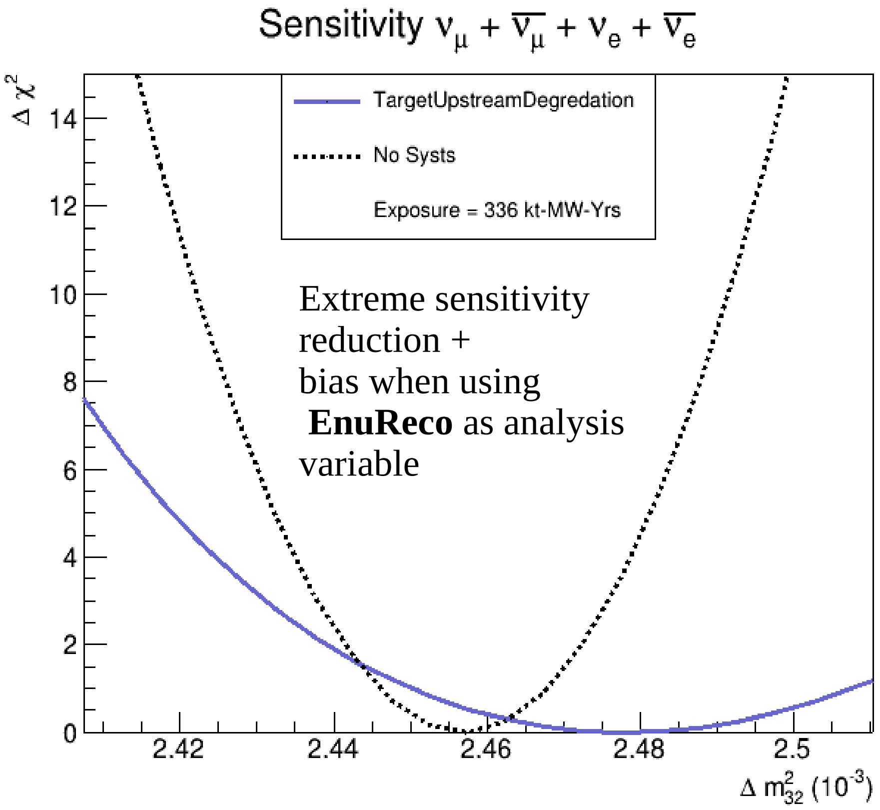


Target Upstream Degradation

IMPORTANT

- 1σ shift = 5 mm loss: assume complete loss of target on upstream end (a shorter target by dz shifted downstream by the loss dz)

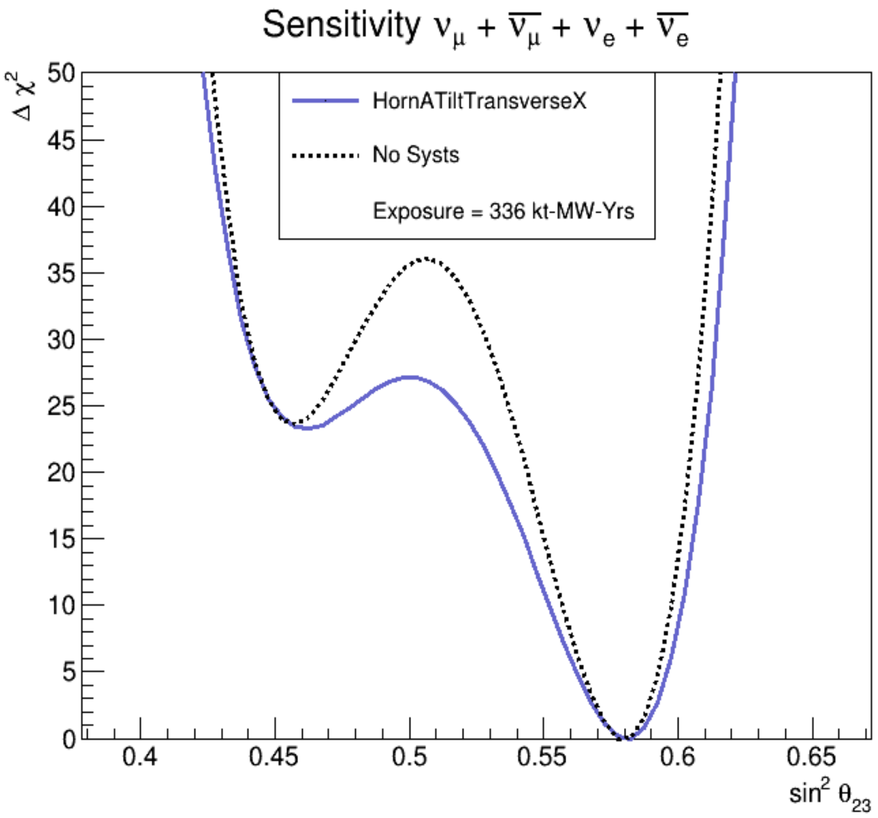


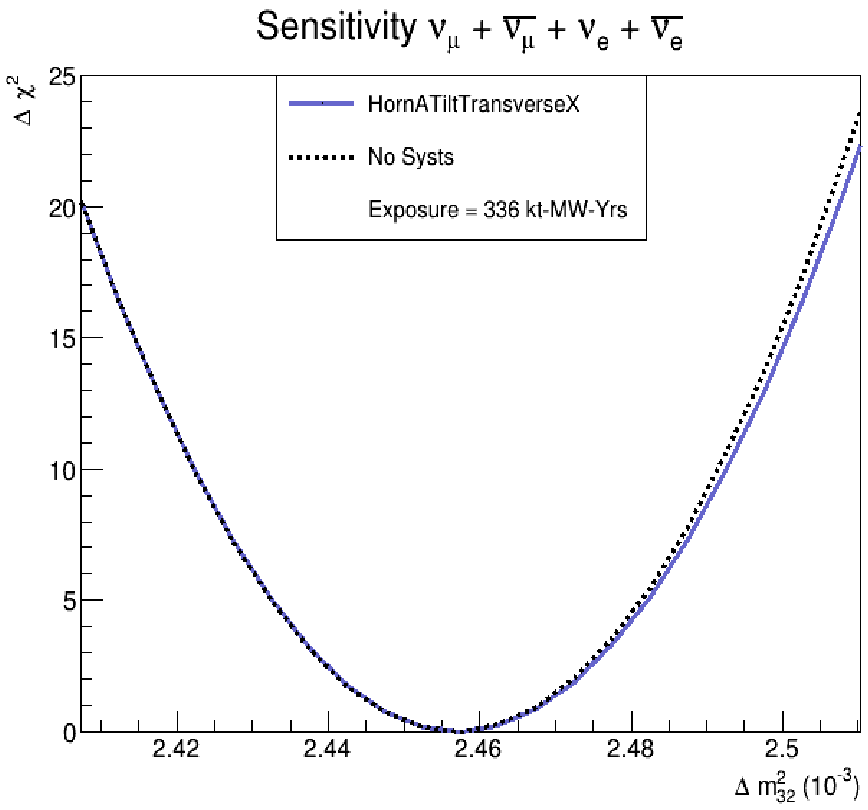


Horn A Tilt Transverse X

IMPORTANT

- 1σ shift = 0.5 mm

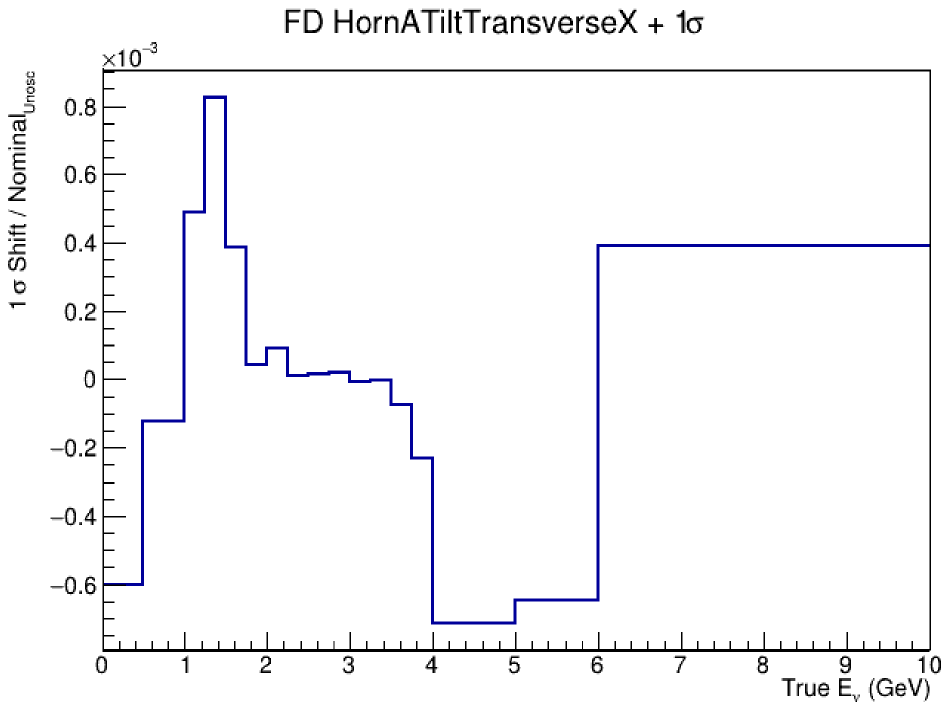


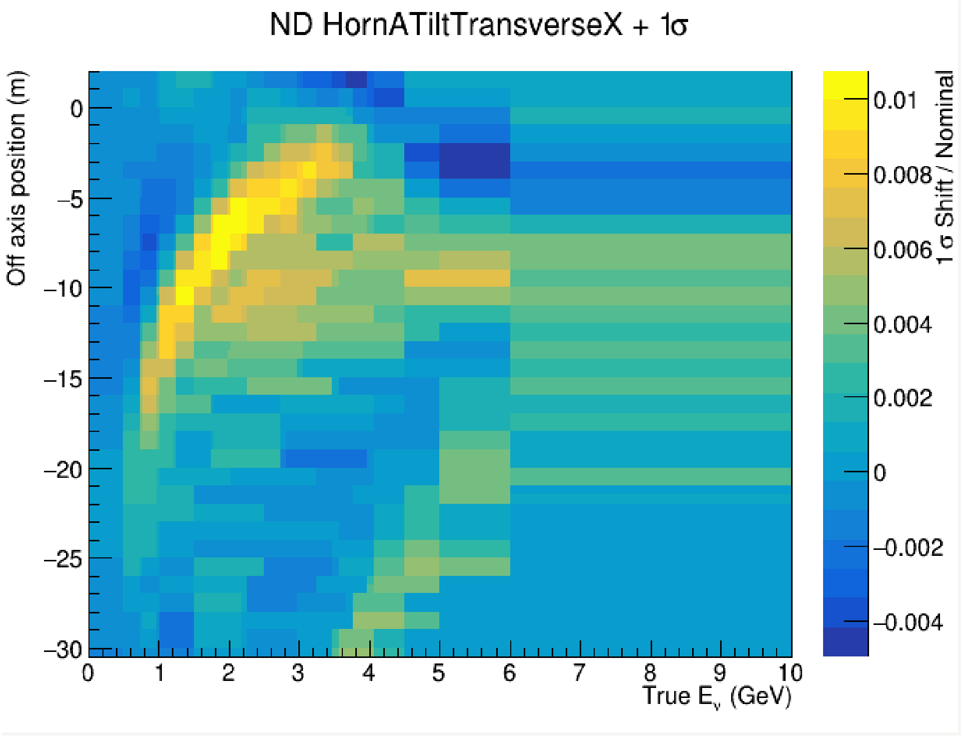


Horn A Tilt Transverse X

IMPORTANT

- 1σ shift = 0.5 mm

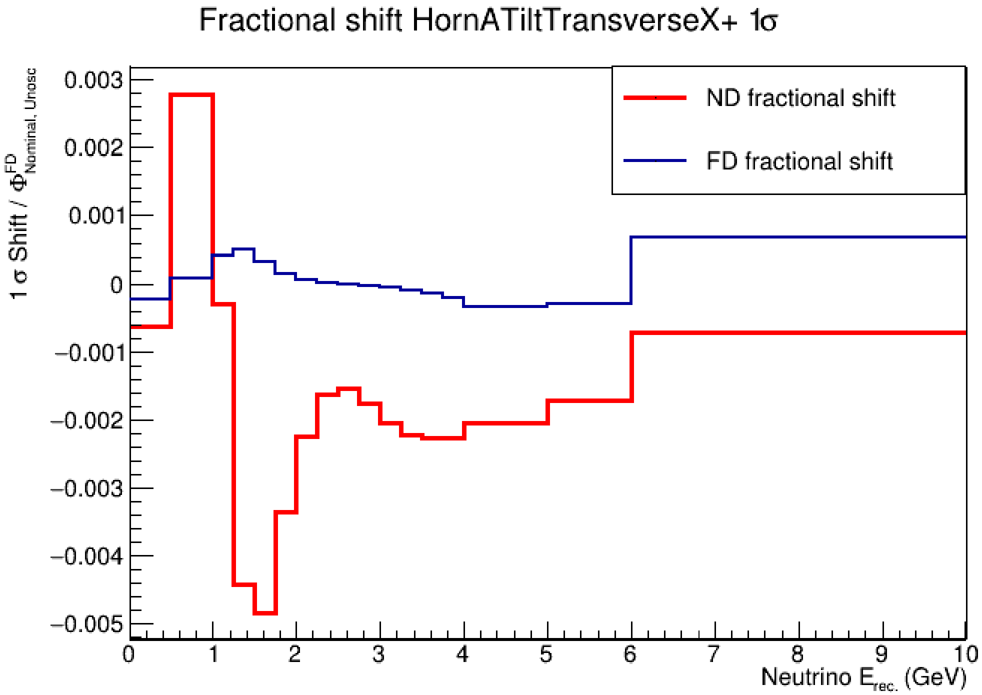


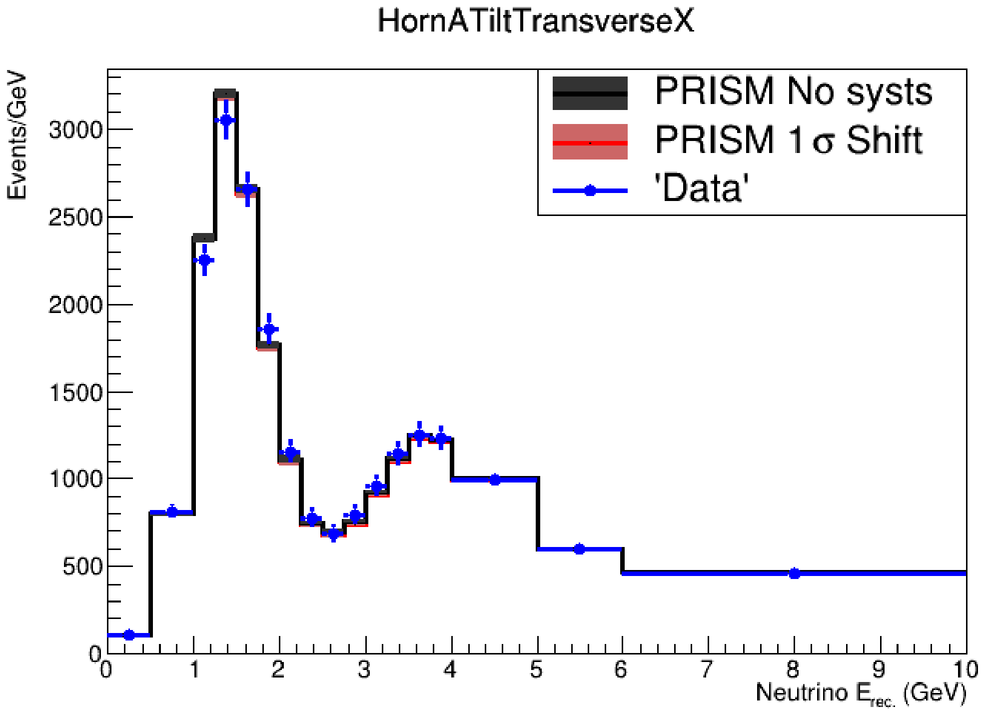


Horn A Tilt Transverse X

IMPORTANT

- 1σ shift = 0.5 mm

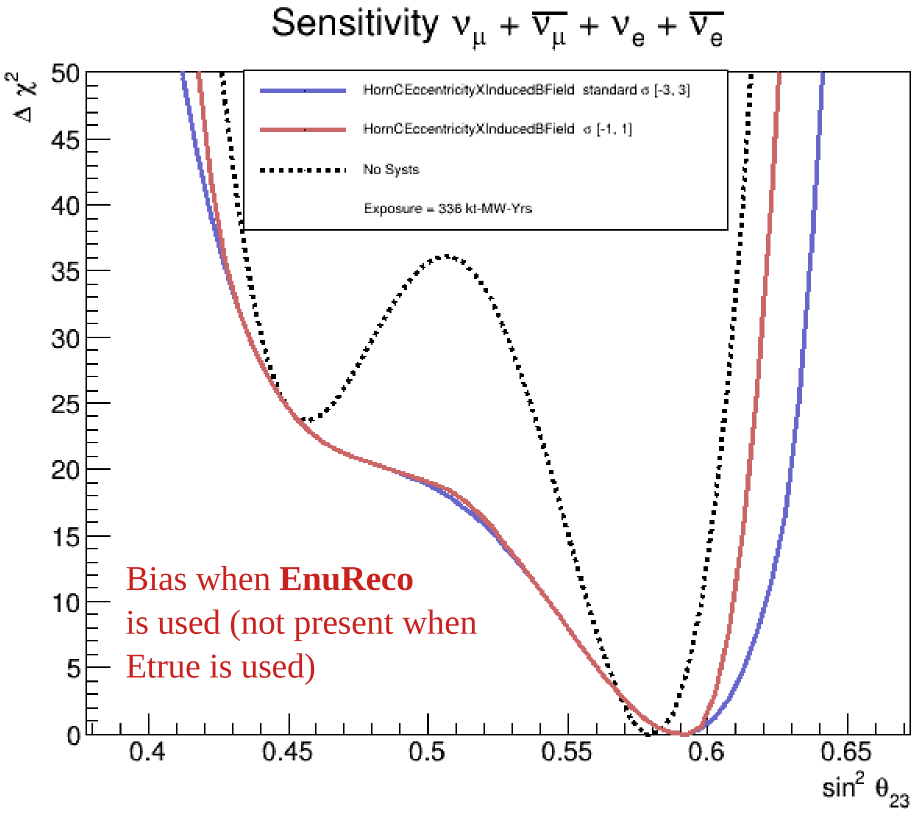




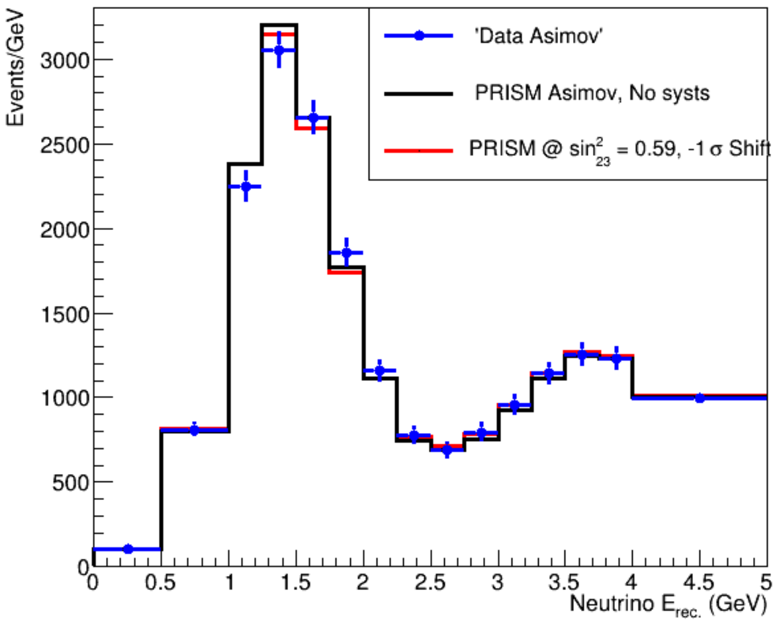
Horn C Eccentricity X Induced Bfield

IMPORTANT

- 1σ shift = 0.07 mm: NuMi Horn 2 tolerance assumed (off axis deformation of inner conductor)



- PRISM prediction works well, but it is not a perfect match → mismatch comes from smearing + efficiency correction (perfect match for E_{true})



Horn C Eccentricity X Induced Bfield

IMPORTANT

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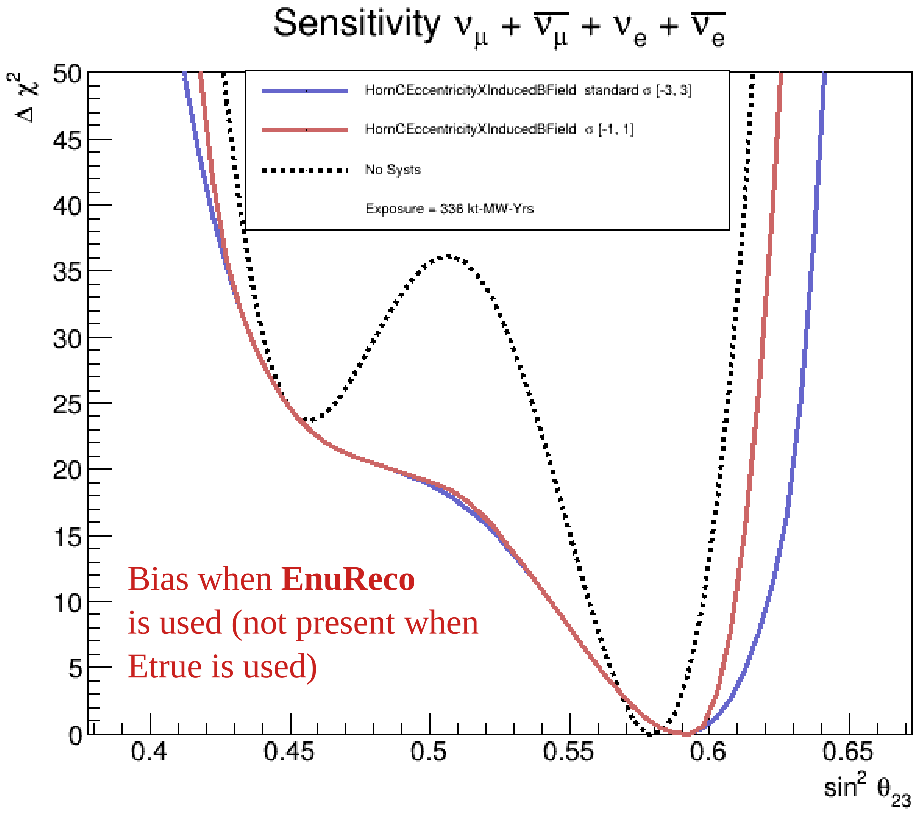
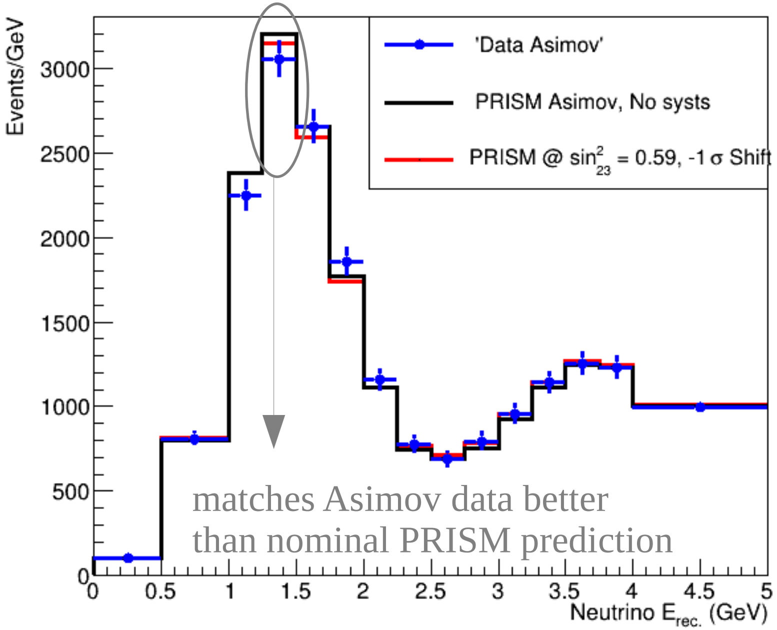
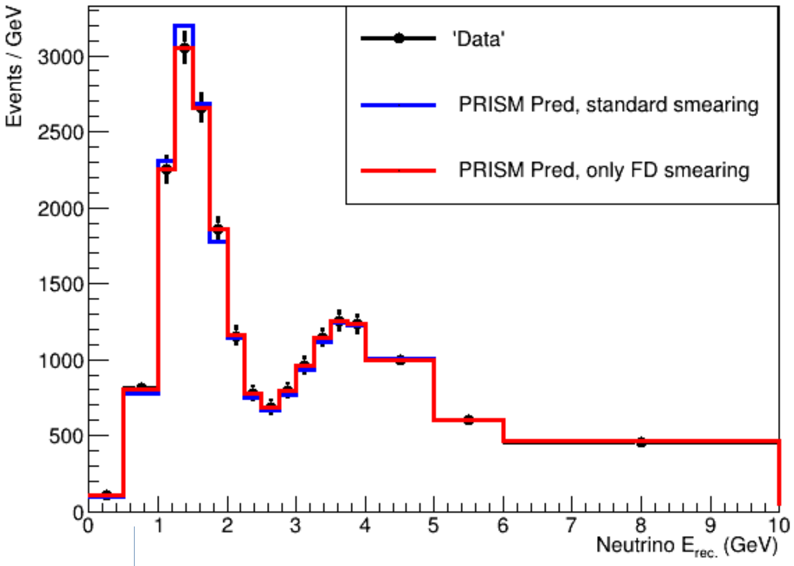


- PRISM prediction works well, but it is not a perfect match → mismatch comes from smearing + efficiency correction (perfect match for E_{true})



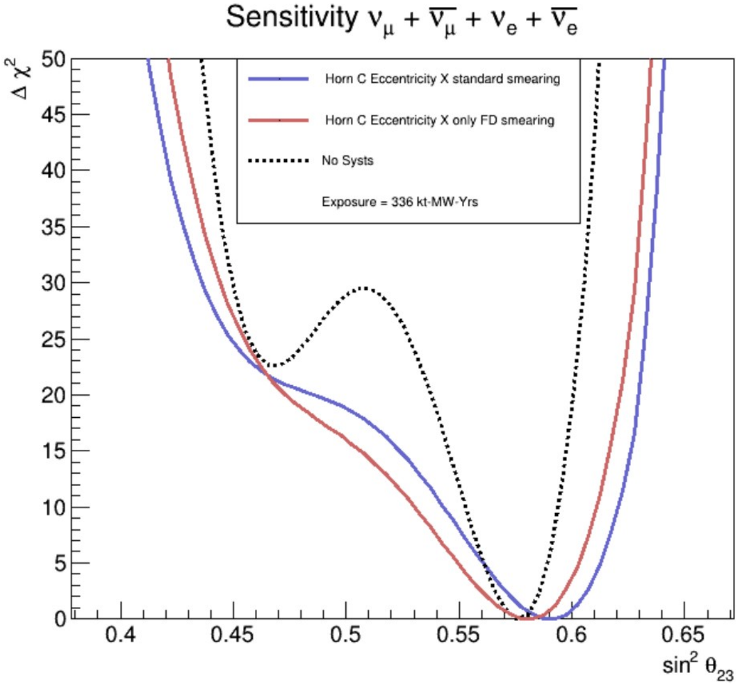
Horn C Eccentricity X Induced Bfield – perfect PRISM match

- PRISM mismatch comes from smearing + efficiency correction (perfect match for E_{true})
  → disentangle FD + ND smearing: no ND smearing (work with Etrue in ND)



mismatch comes from ND smearing + efficiency correction

No bias with → PRISM perfect match

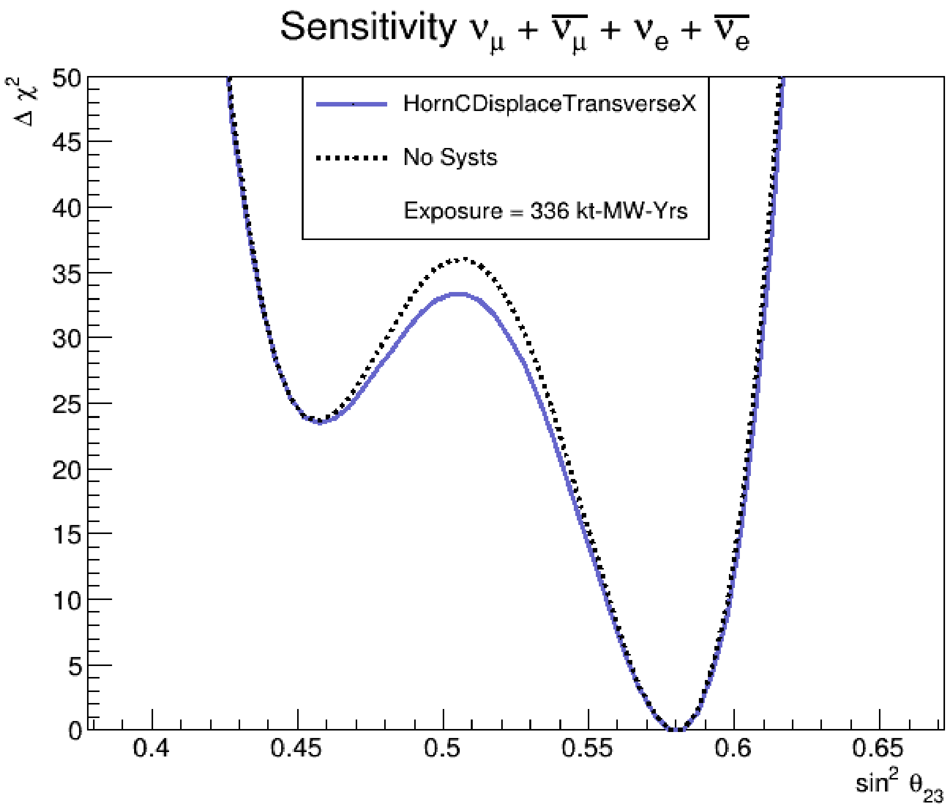


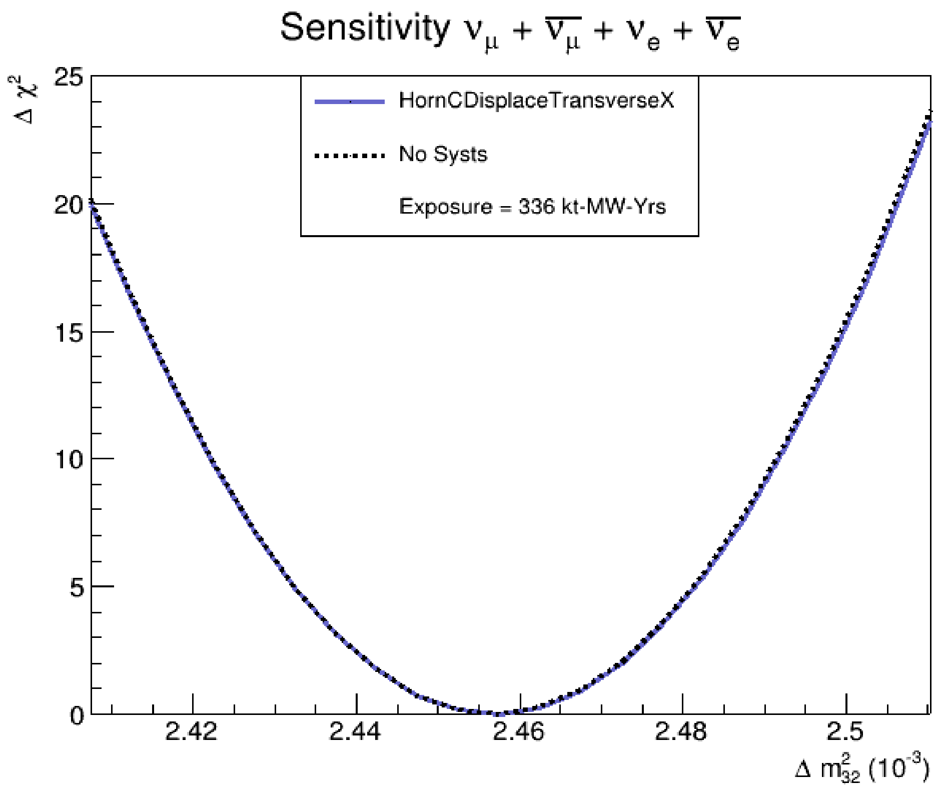
- **There is no additional bias when PRISM prediction results in a perfect data match → sensitivity is still significantly reduced due to this focusing parameter**

Horn C Displace Transverse X

IMPORTANT

- 1σ shift = 0.5 mm





Horn C Displace Transverse X

IMPORTANT

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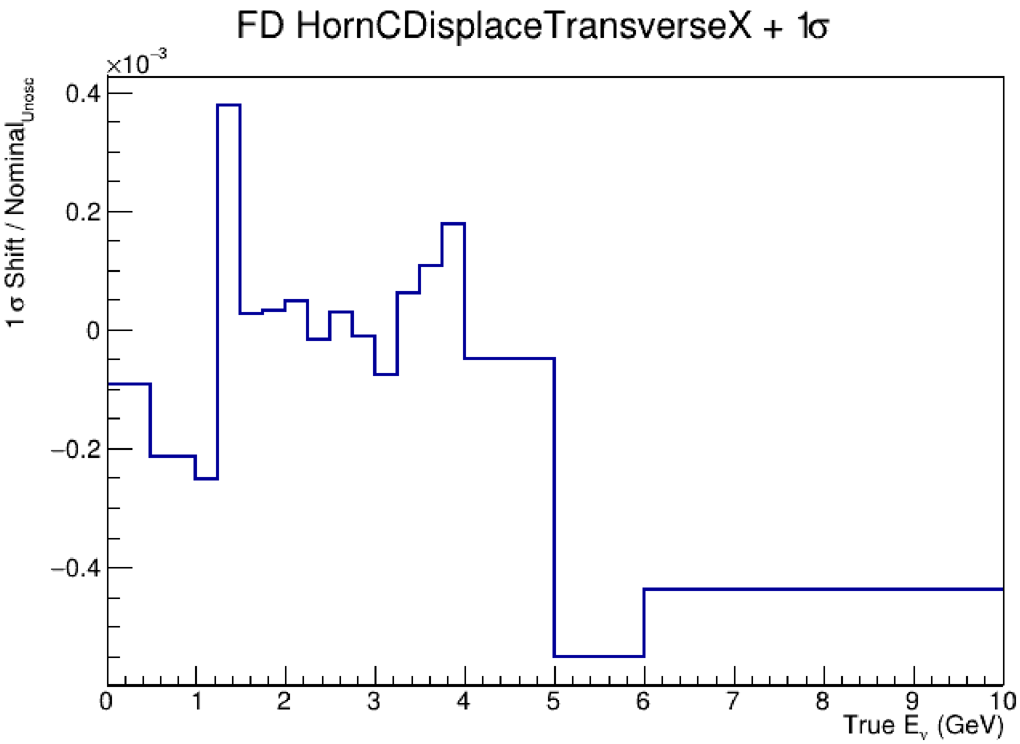
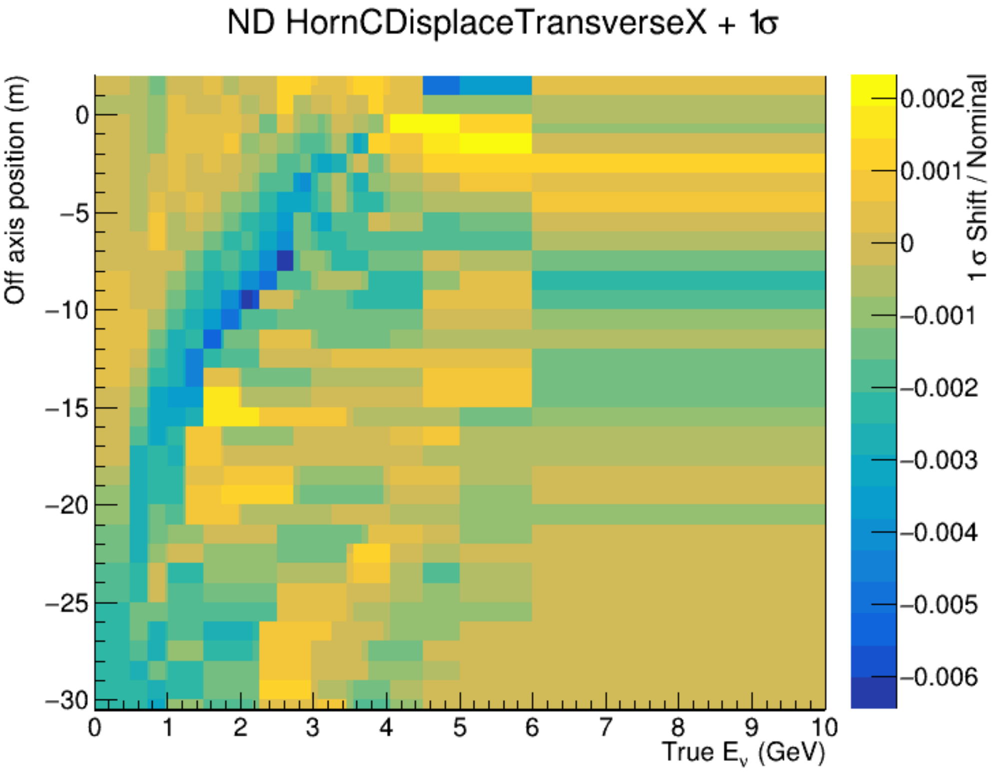
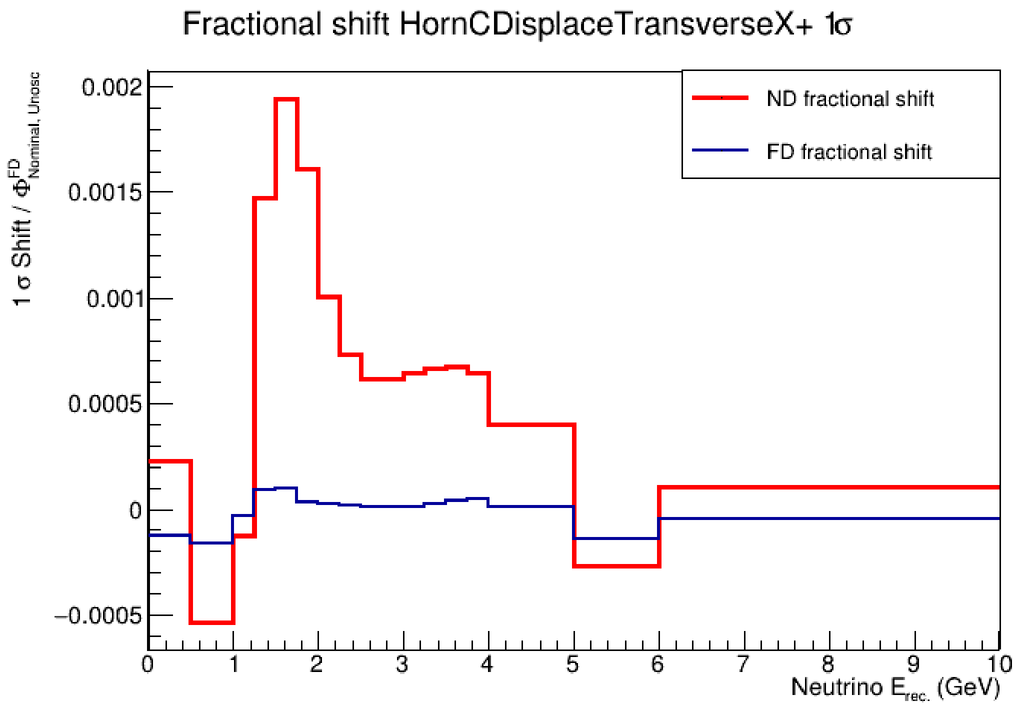


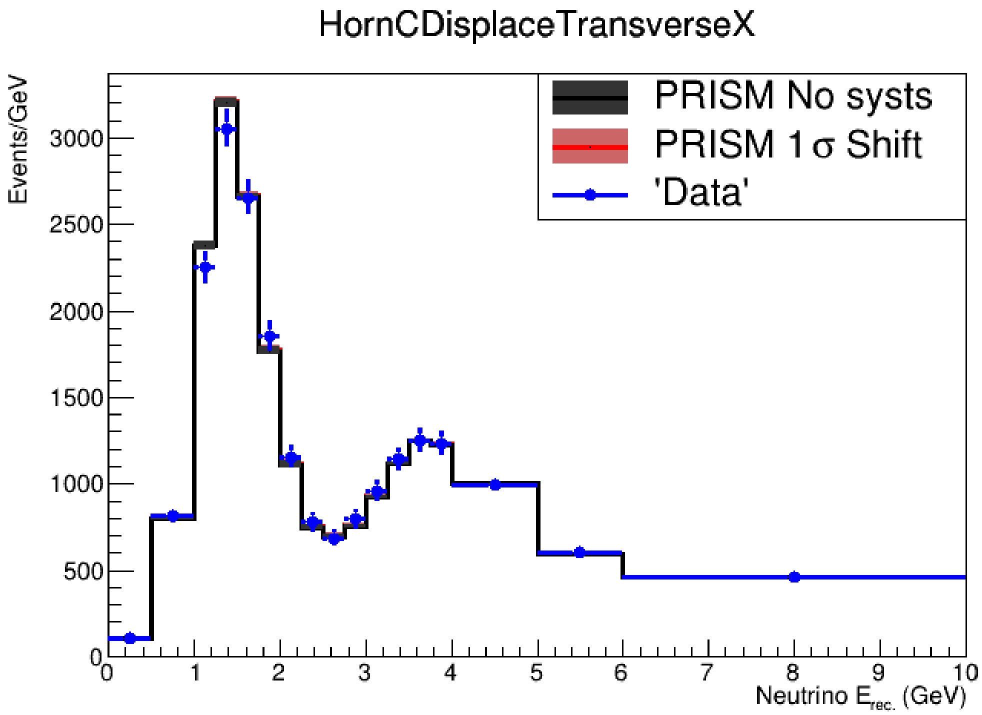


Horn C Displace Transverse X

IMPORTANT

- 1σ shift = 0.5 mm

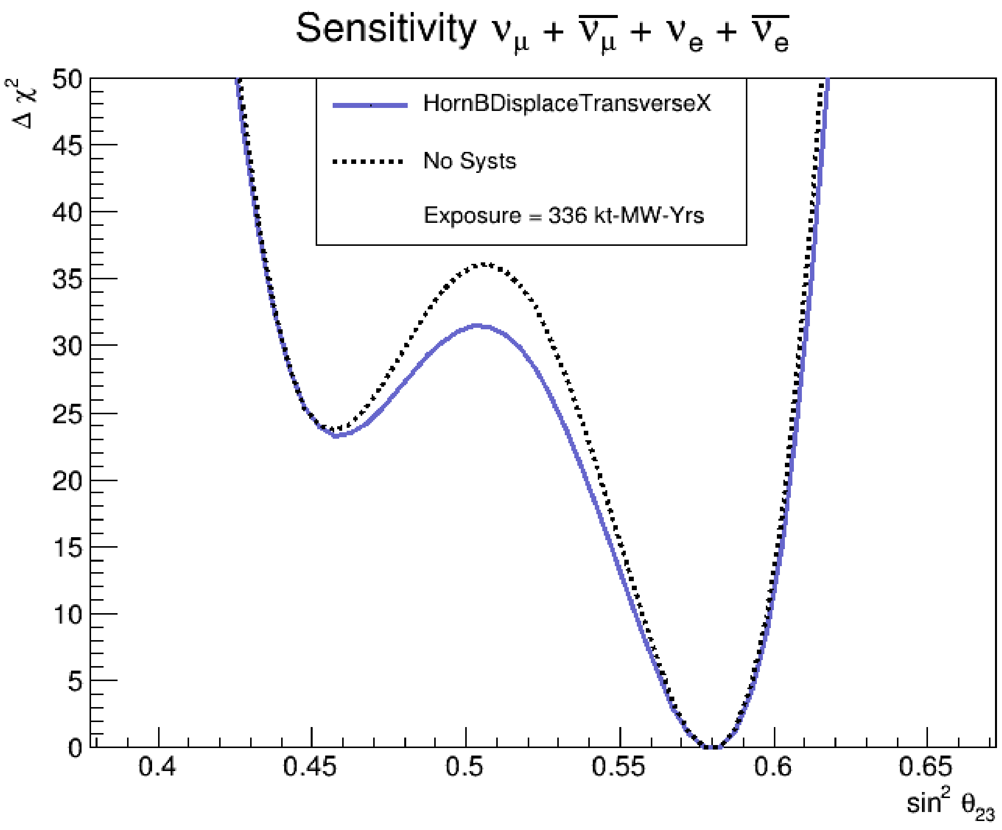


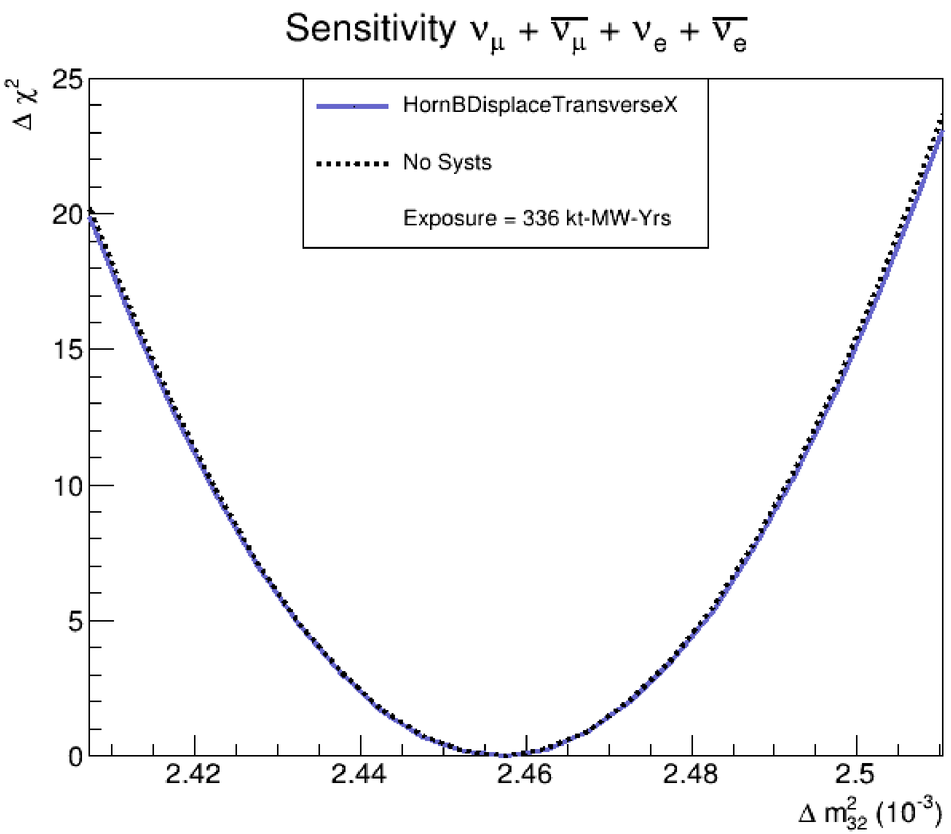


Horn B Displace Transverse X

IMPORTANT

- 1σ shift = 0.5 mm

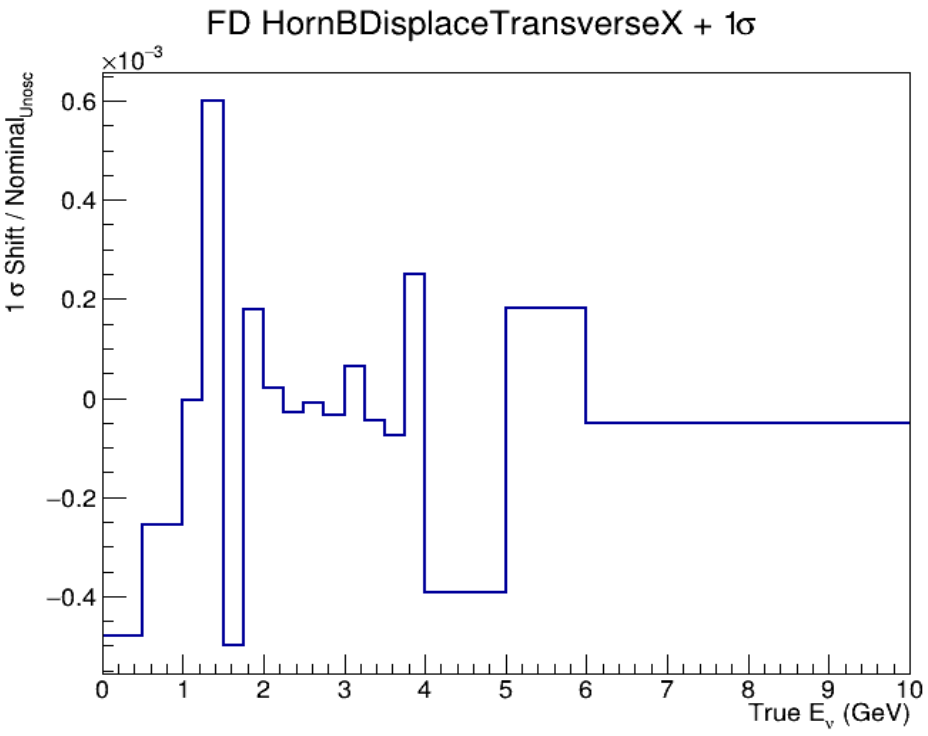


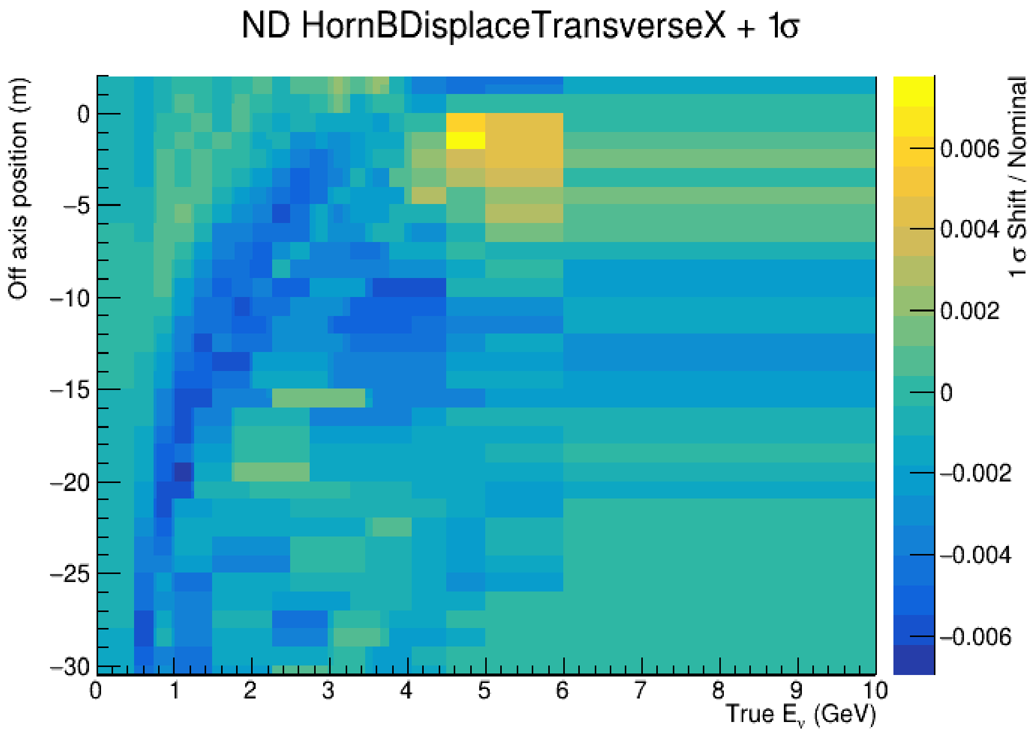


Horn B Displace Transverse X

IMPORTANT

- 1σ shift = 0.5 mm

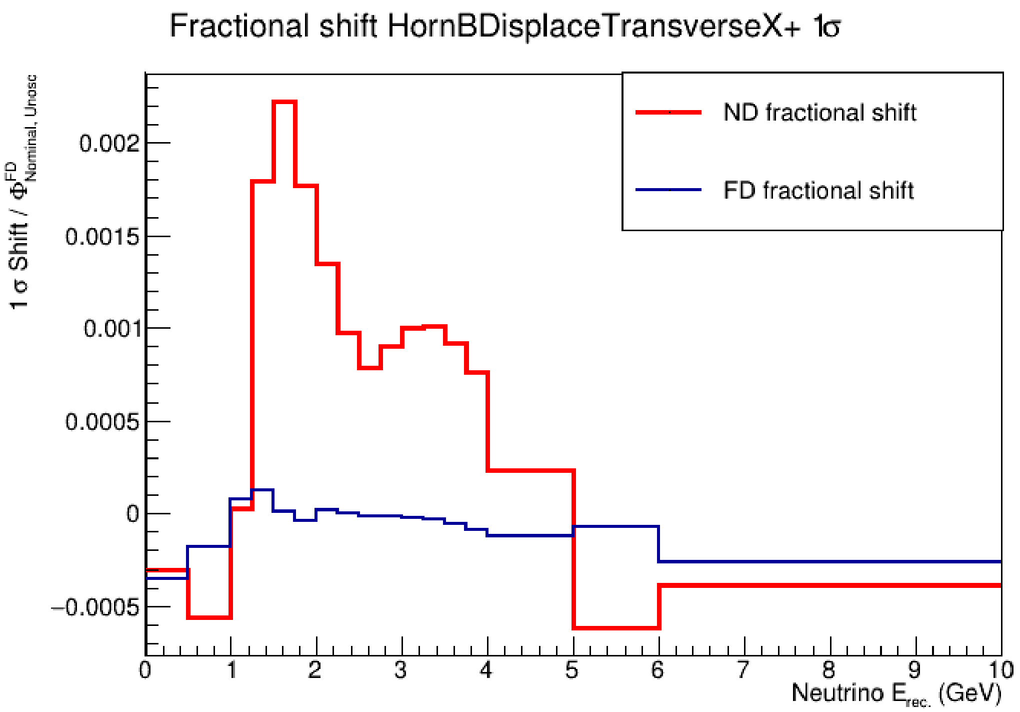


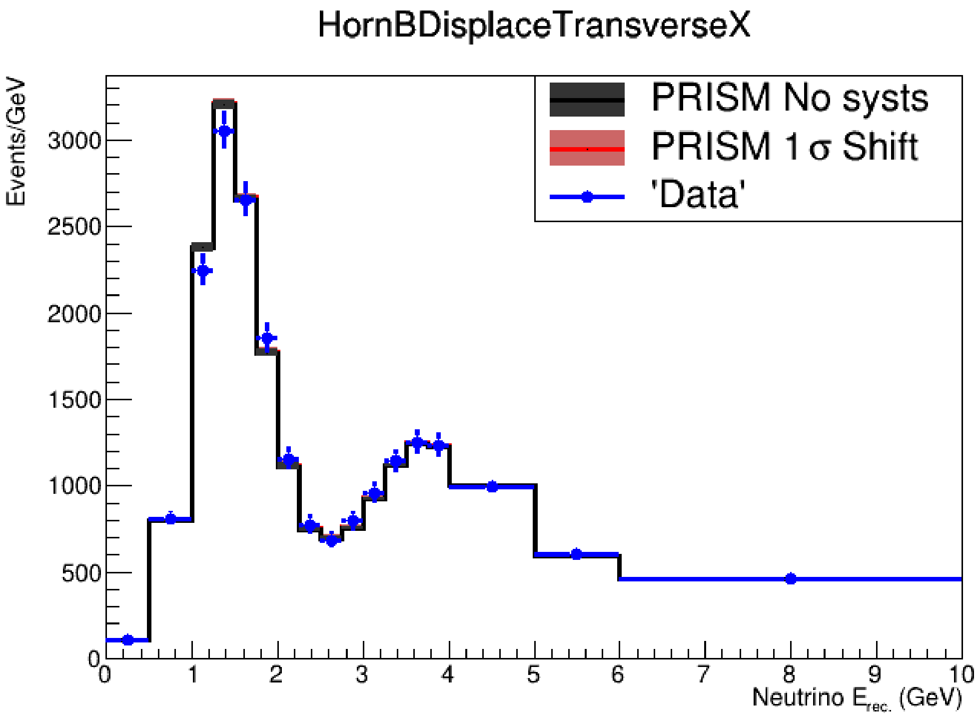


Horn B Displace Transverse X

IMPORTANT

- 1σ shift = 0.5 mm

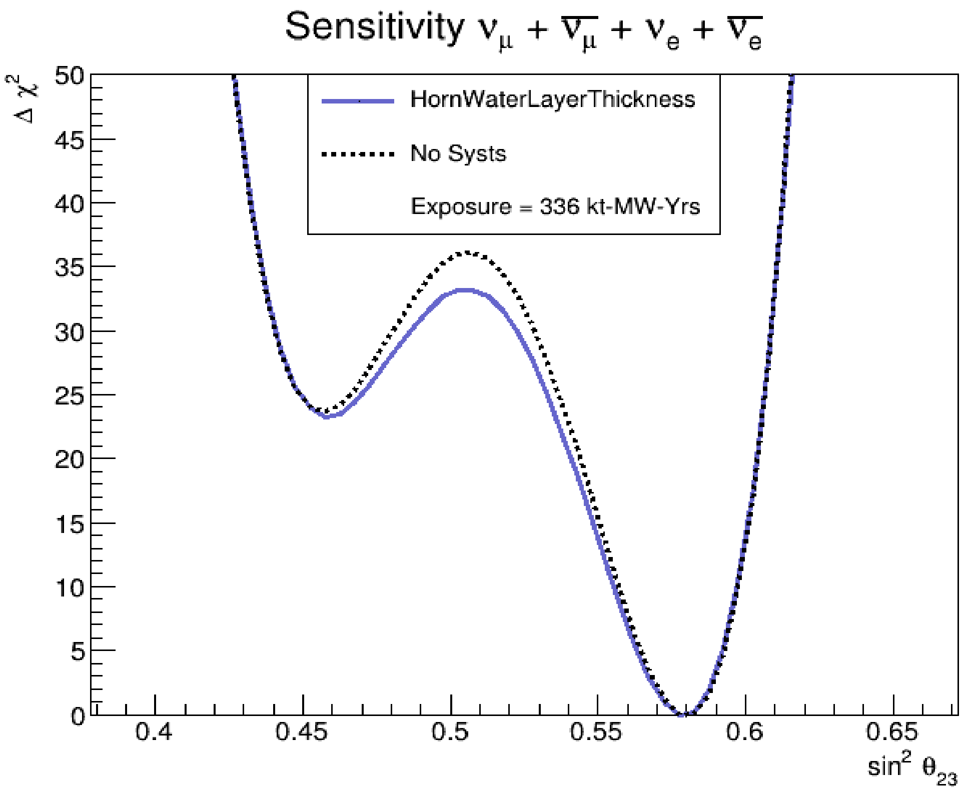


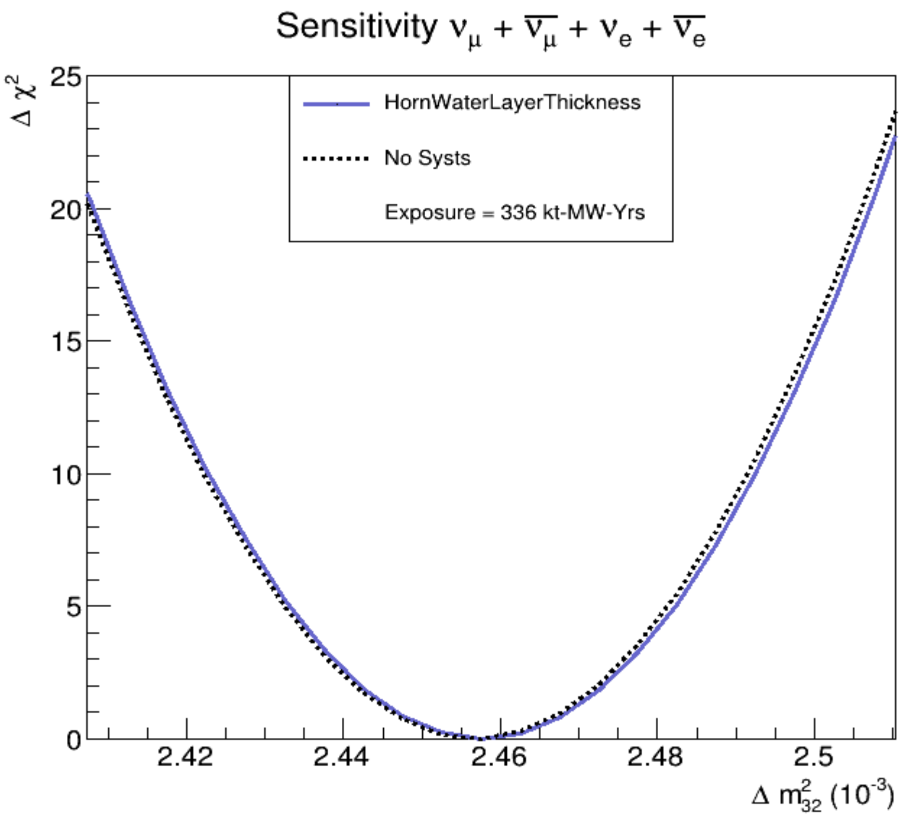


Horn Water Layer Thickness

IMPORTANT

- 1σ shift = 0.5 mm: nominal = 1mm; simultaneous change to all 3 horns





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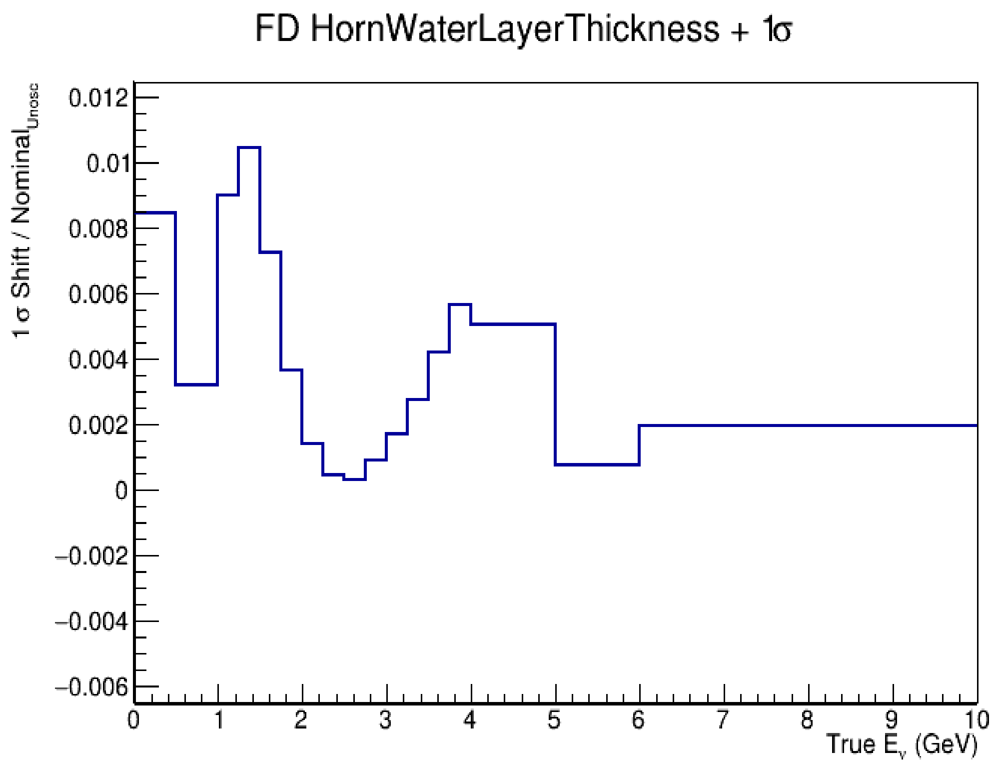

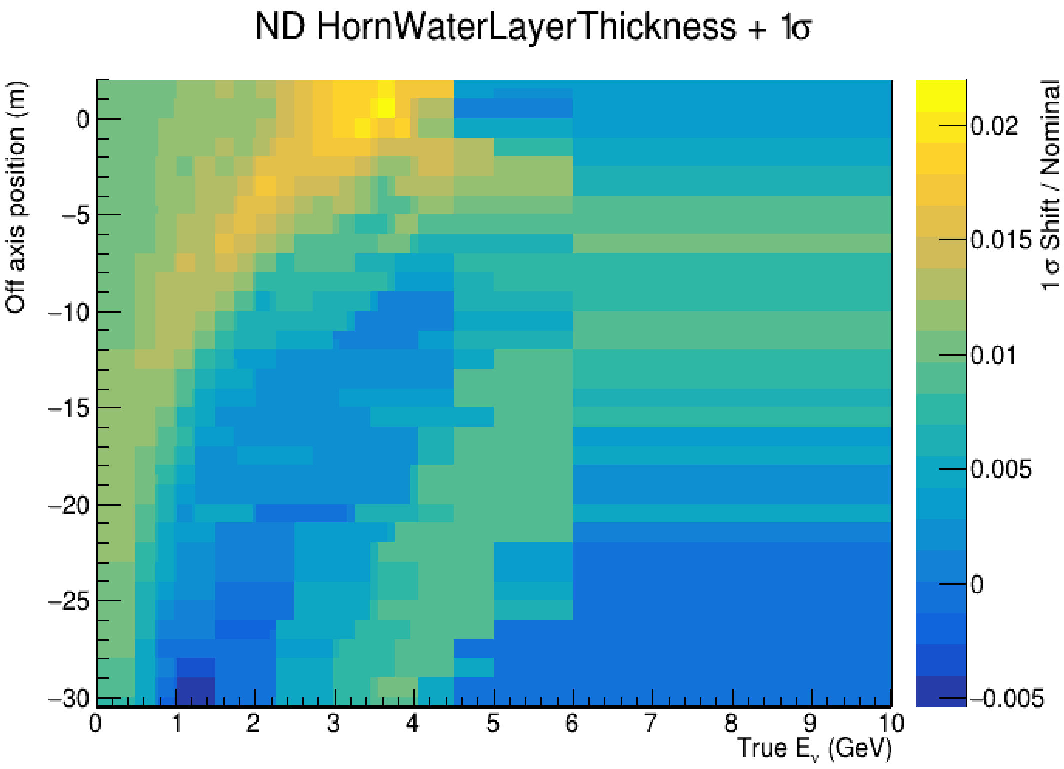

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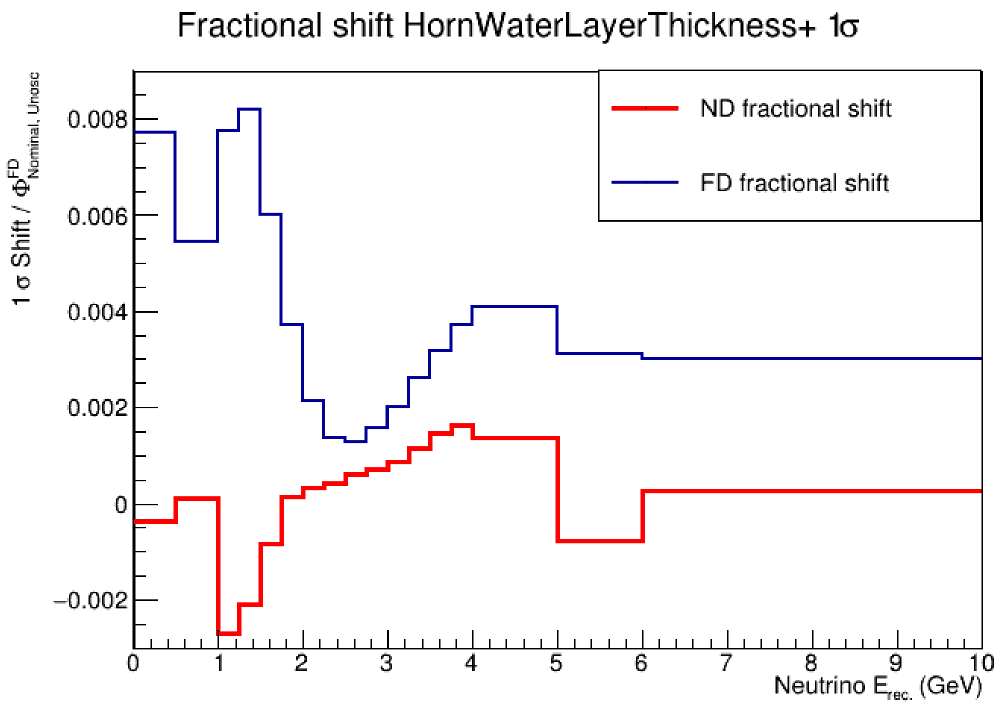

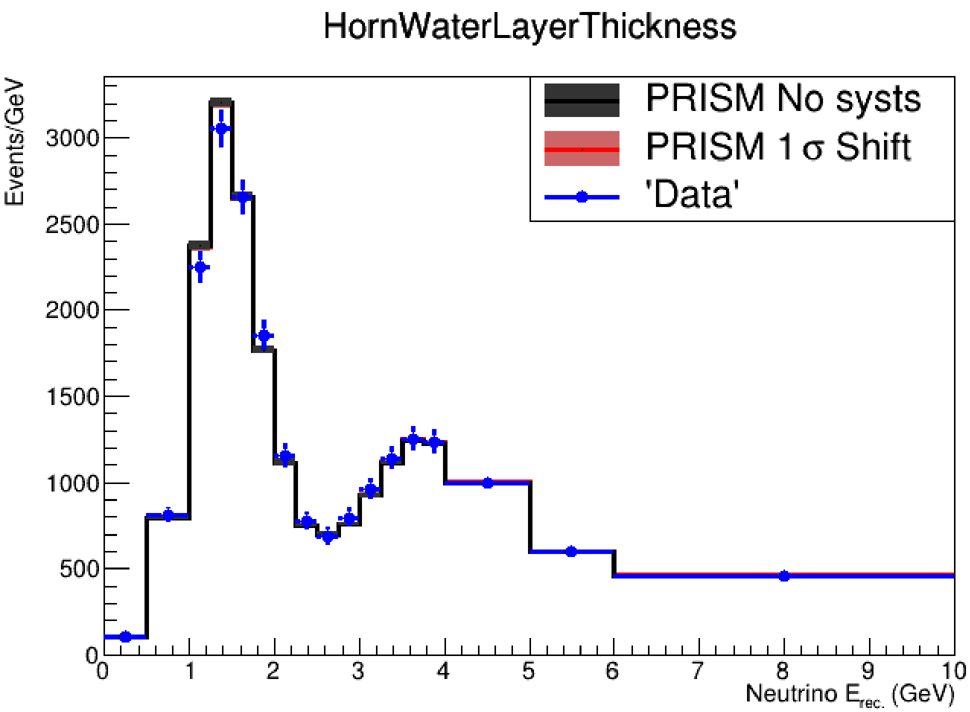

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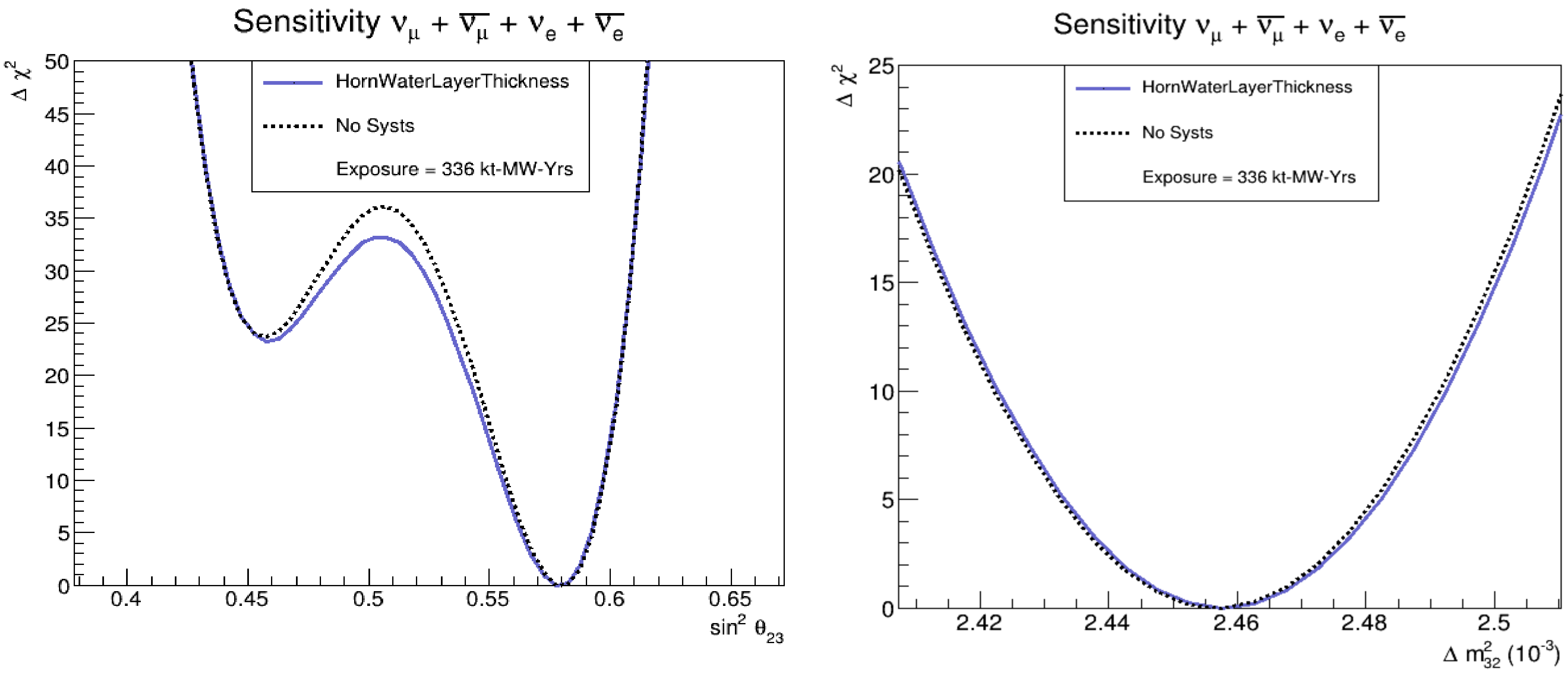

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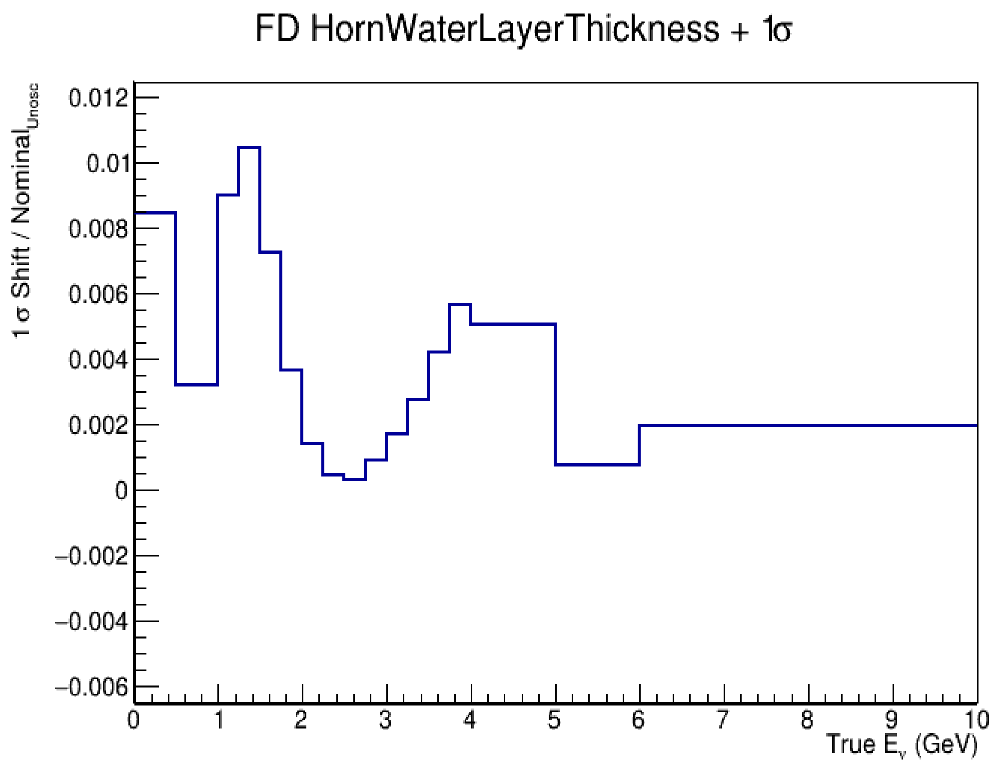

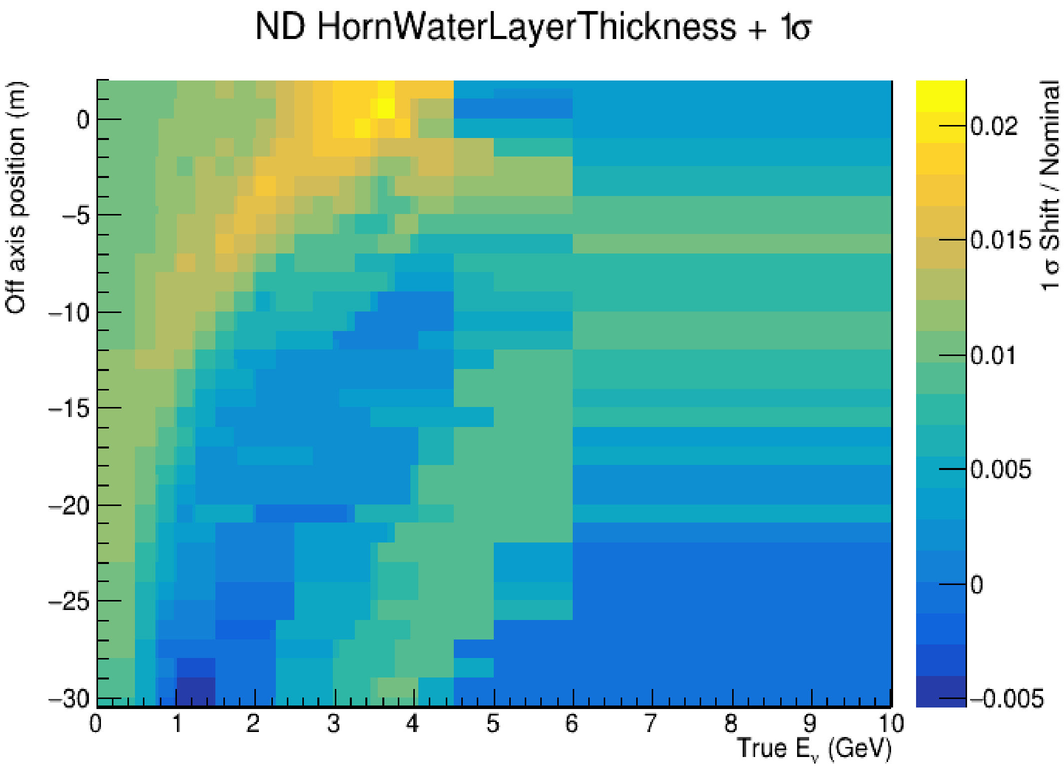

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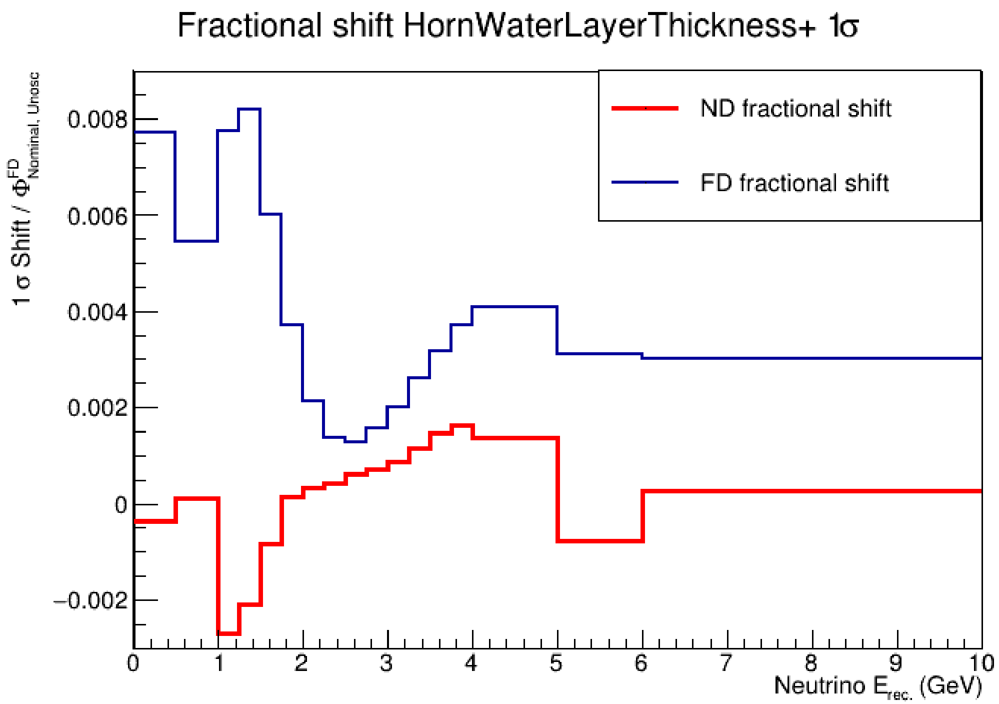
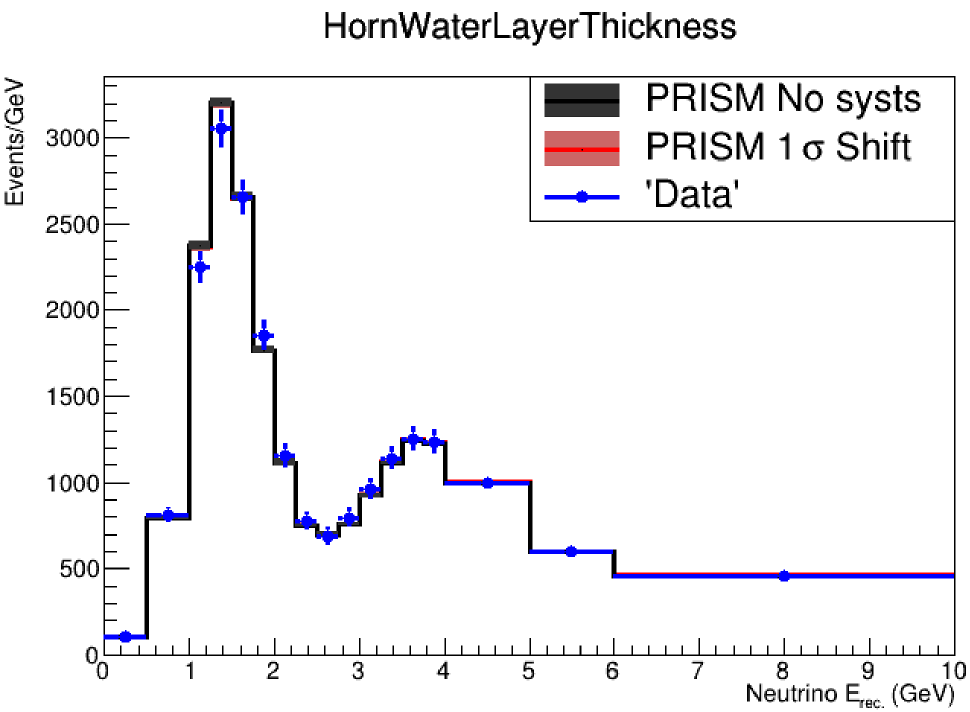
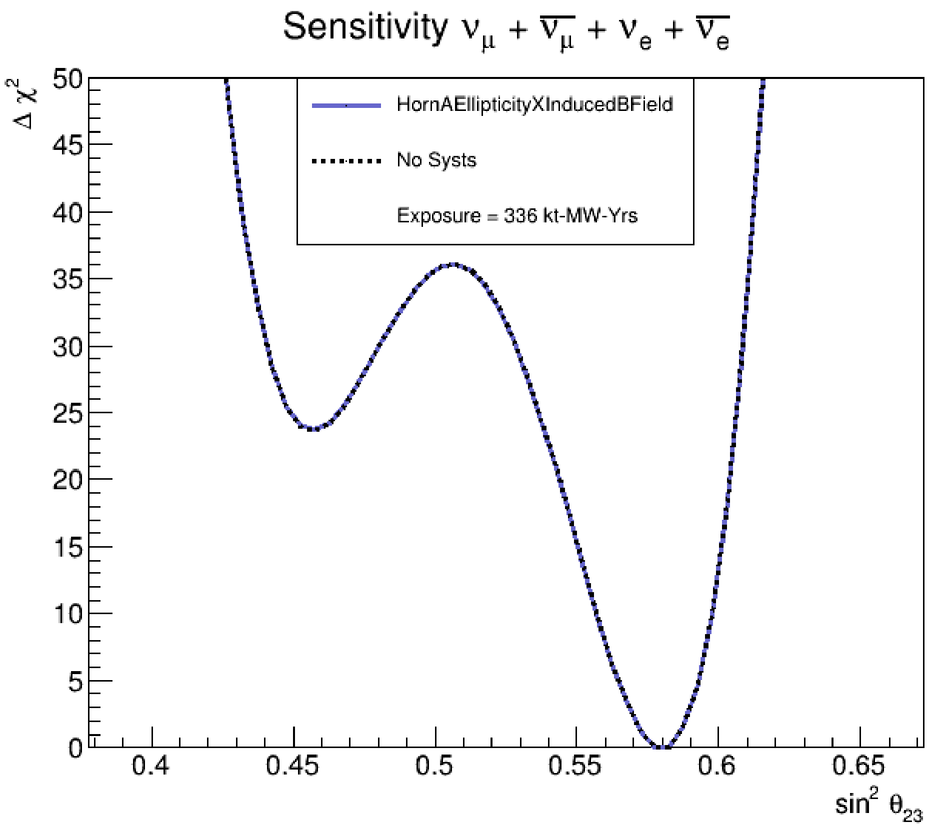


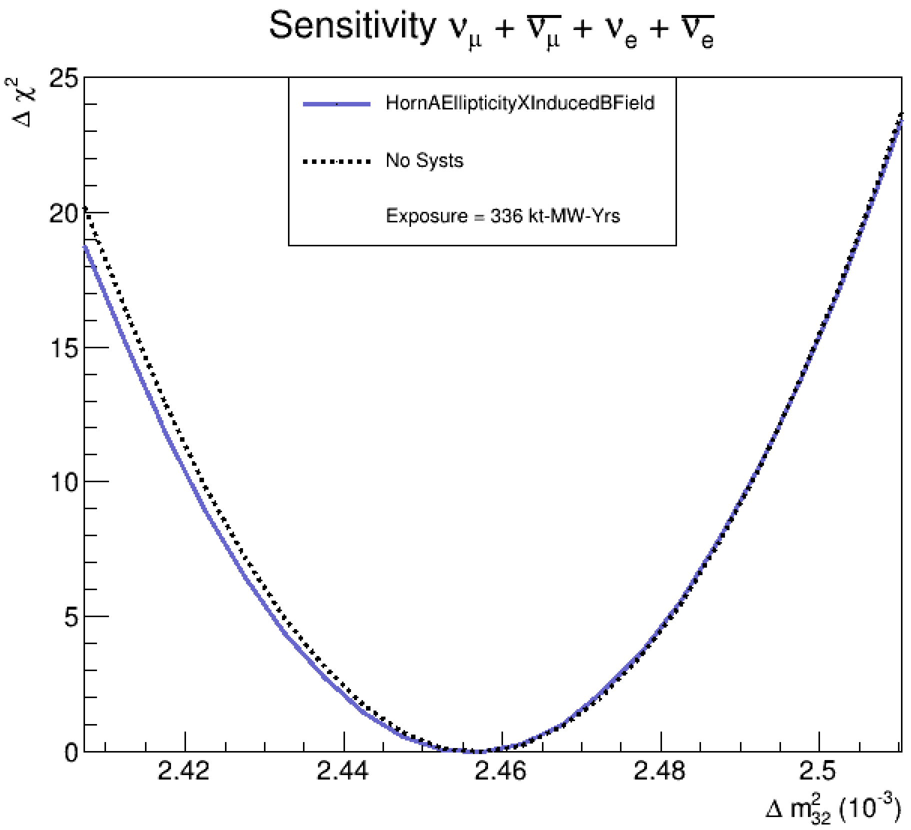


Horn A Ellipticity X Induced Bfield

SEMI

- 1σ shift = 0.120 mm: NuMi Horn 1 tolerance assumed (eliptical deformation of inner conductor)





Horn A Ellipticity X Induced Bfield

SEMI

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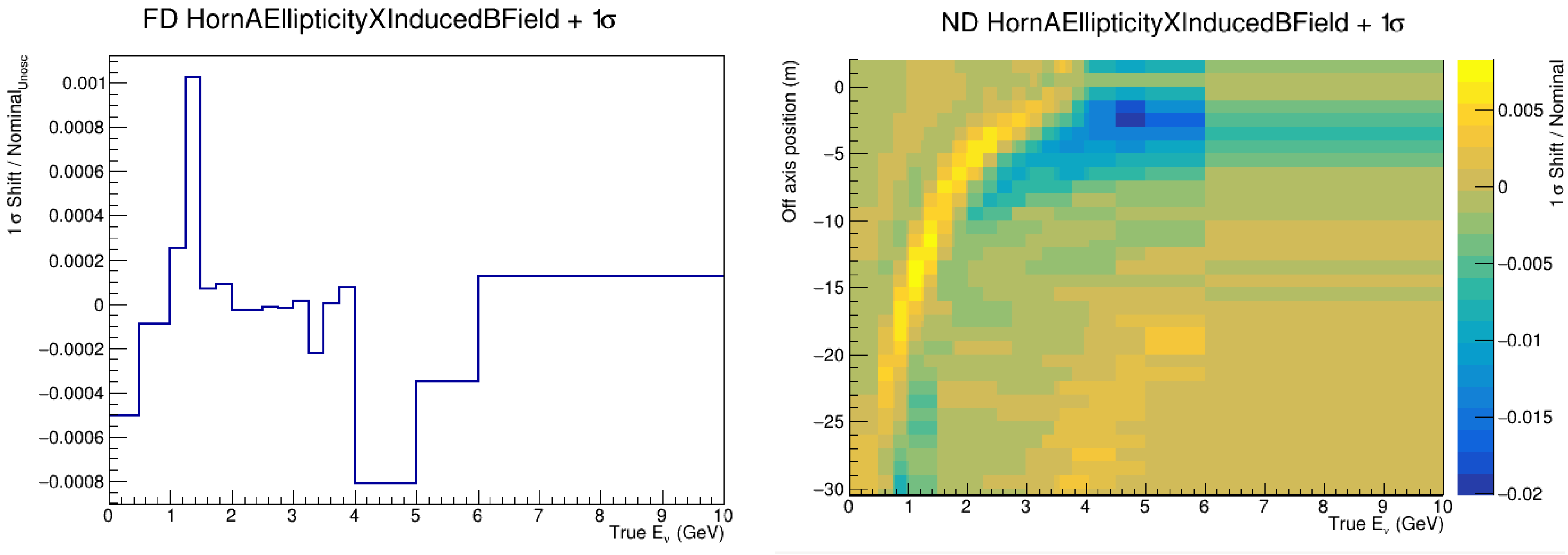
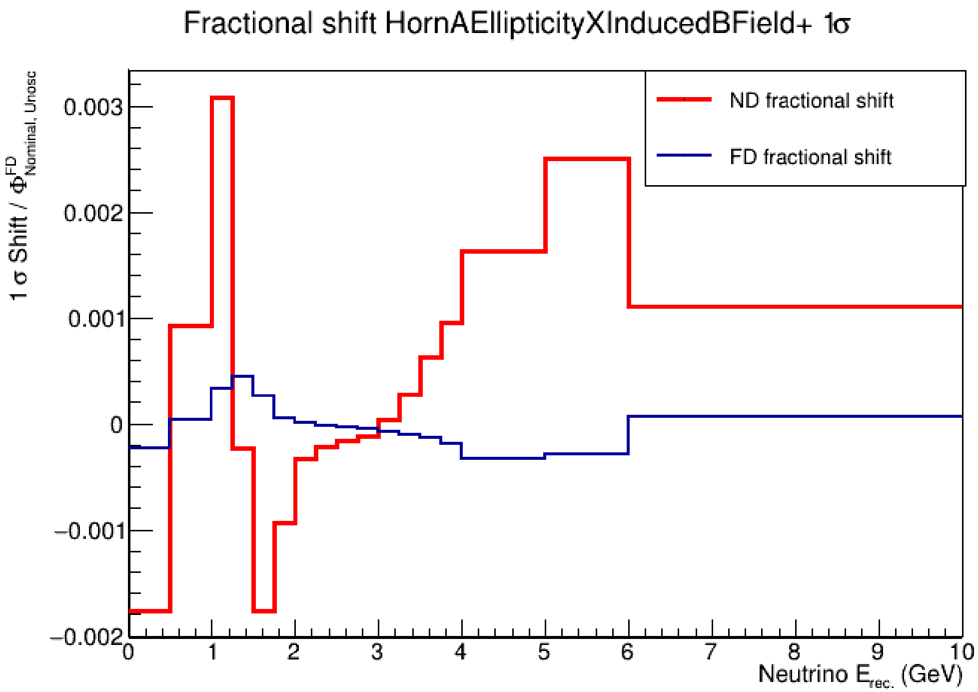
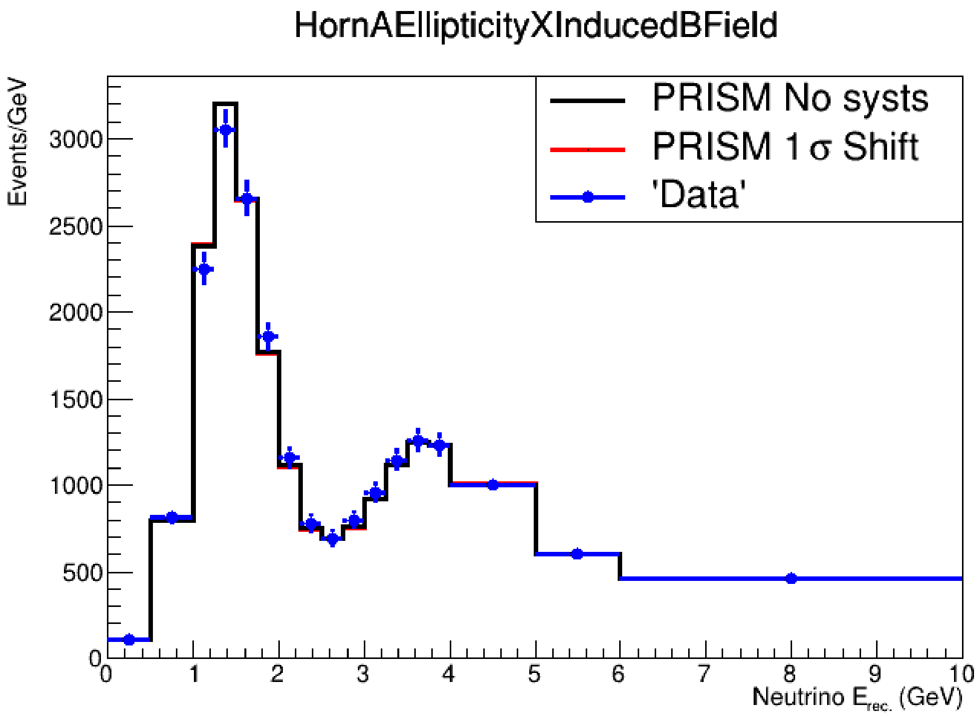


Horn A Ellipticity X Induced Bfield

SEMI

- 1σ shift = 0.120 mm: NuMi Horn 1 tolerance assumed (eliptical deformation of inner conductor)

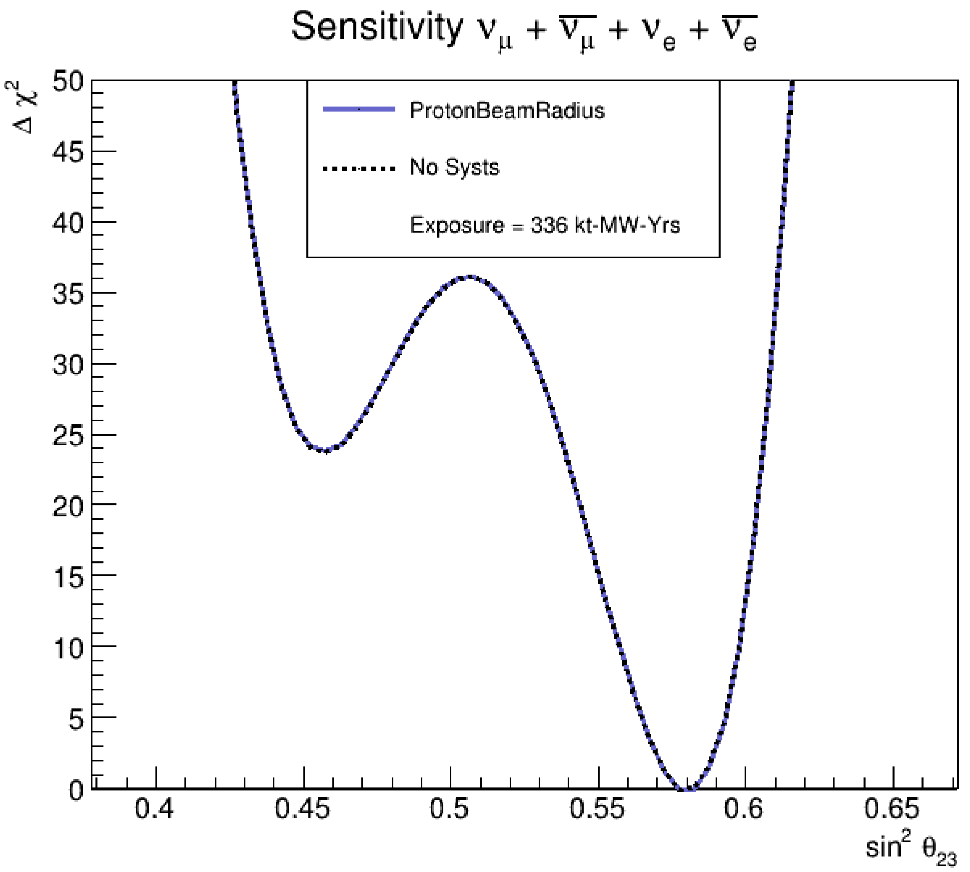


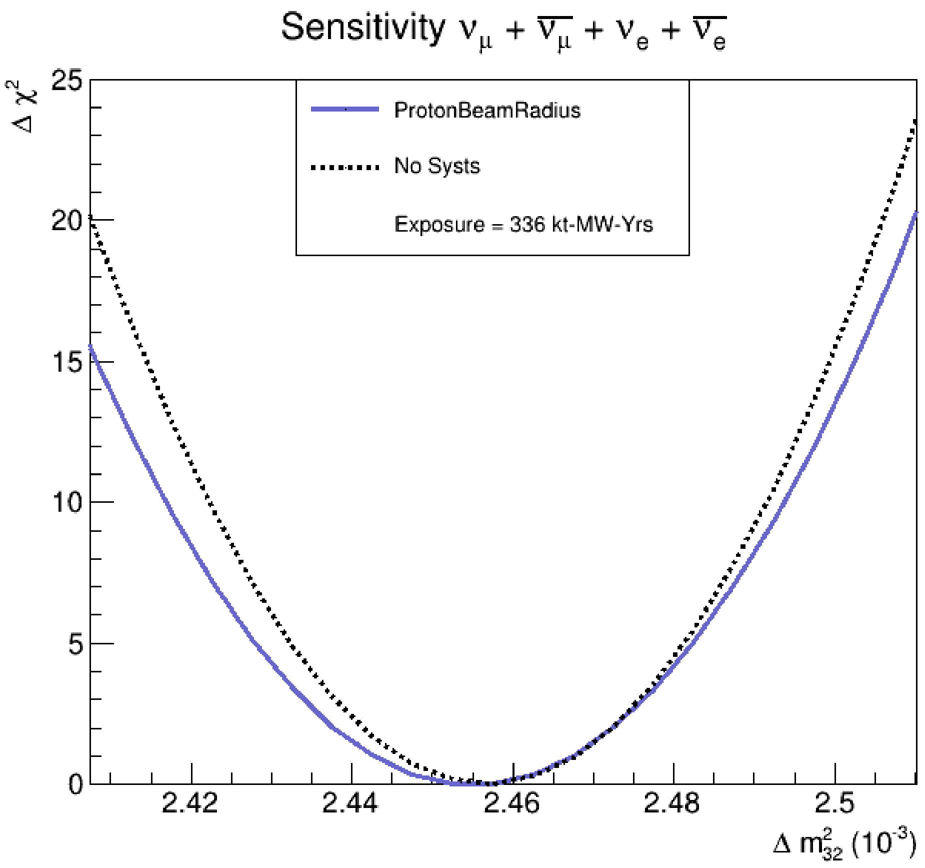


Proton Beam Radius

SEMI

- 1σ shift = 10% (0.27 mm): updated from 1% in TDR





Proton Beam Radius

SEMI

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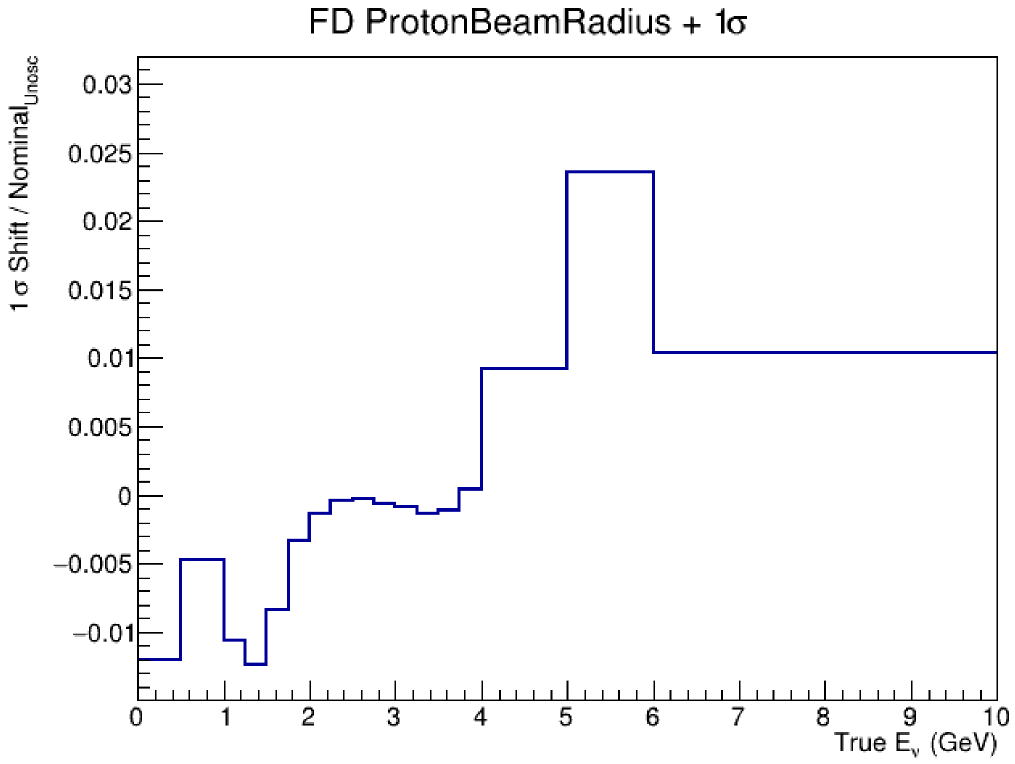

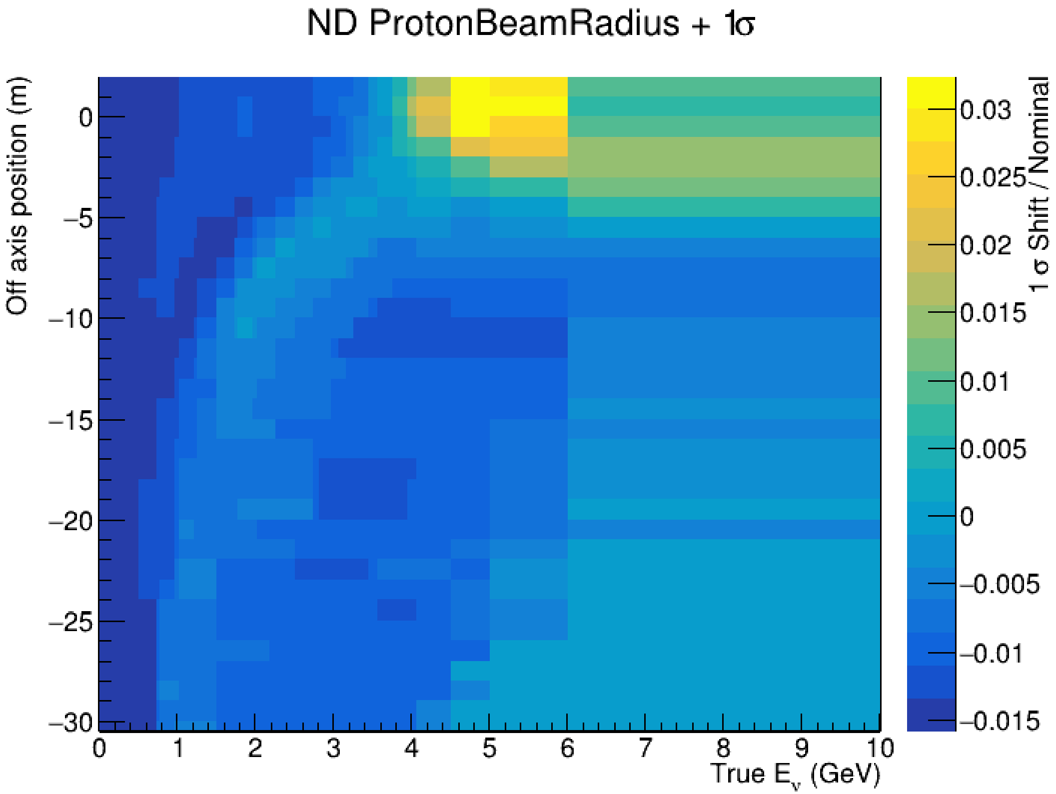

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