DUNE-PRISM: Data-driven Wrong Sign Background prediction

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on behalf of DUNE – PRISM working group

LBL Meeting

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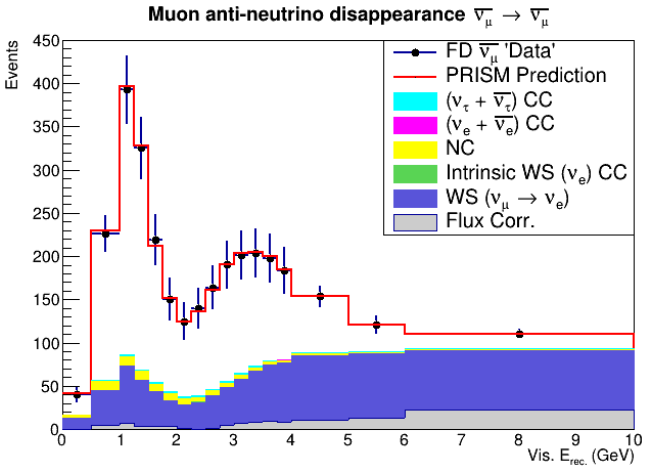
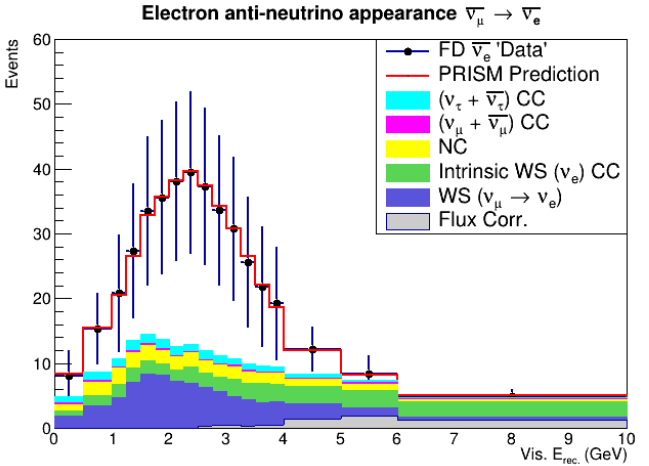
DUNE-PRISM

- DUNE-PRISM aims to be robust to cross section modeling → data-driven prediction of the FD oscillated spectrum
- Main cross section systematics enter the analysis via:
  - Efficiency correction (work in progress – see Wei's talk)
  - **FD background** (obtained from MC):
    - miss-identified $\overline{\nu}_\tau + \nu_\tau$
    - wrong lepton (i.e mu for appearance and e for disappearance channel)
    - neutral current
    - intrinsic $\overline{\nu}_e + \nu_e$ → right sign intrinsic ν_e predicted on a data-driven approach (Wei)
    - wrong sign background

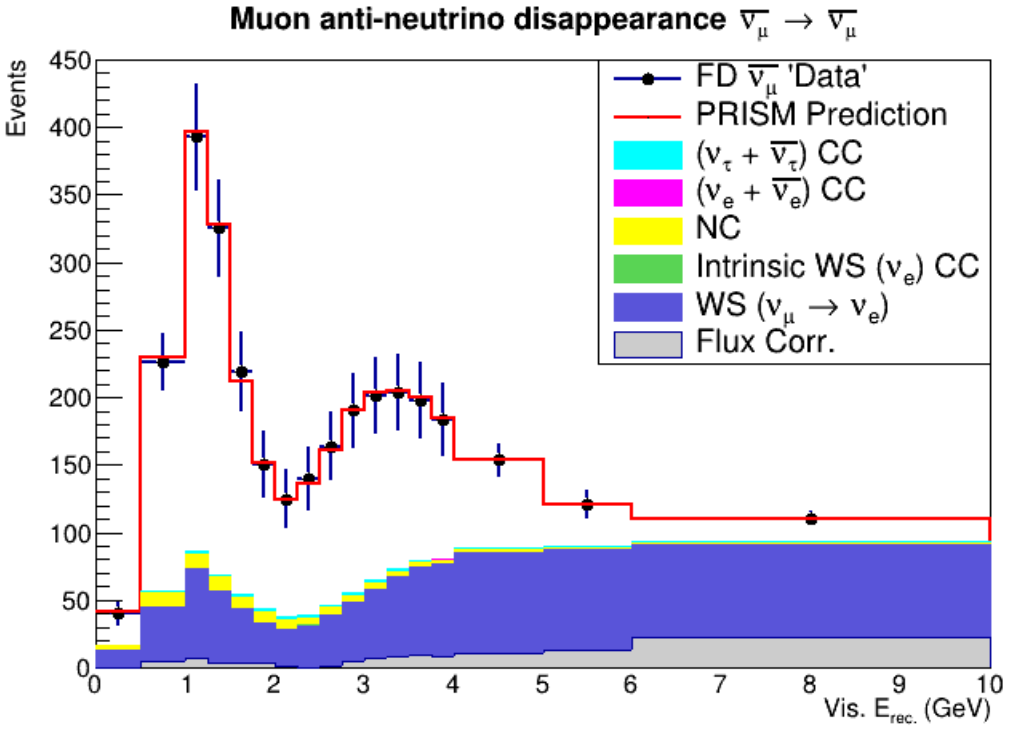




- **Wrong Sign (WS)** and **intrinsic WS** background dominate the background
  → predict these components on a data-driven approach → reduce cross section modeling dependency

PRISM Prediction – Wrong Sign Background (WSB) data driven approach

- Total WSB (intrinsic + WS from beam contamination) can be predicted on a data driven approach
  - example for $\overline{\nu}_\mu \rightarrow \overline{\nu}_\mu$ channel: WSB = intrinsic $\nu_e \rightarrow \nu_\mu$ + $\nu_\mu \rightarrow \nu_\mu$



- **use the FHC** (ν_μ mode) **ND data to predict the RHC** ($\overline{\nu}_\mu$ mode) **FD wrong sign background**

ND_FHC Fluxes × C_{WSB} = FD_{WSB}_RHC flux

→ WSB coefficients as a function of the off-axis position

→ PRISM Prediction for the wrong sign background (WSB)

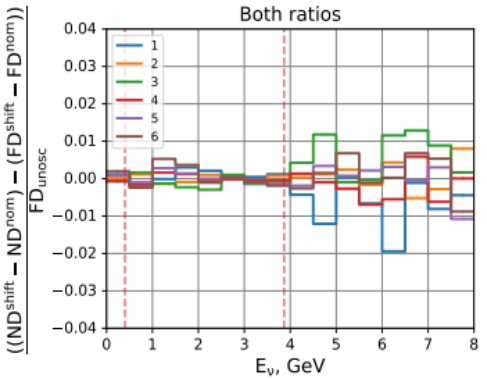
- PRISM Prediction WSB is then added to the FD background instead of the MC WS spectra

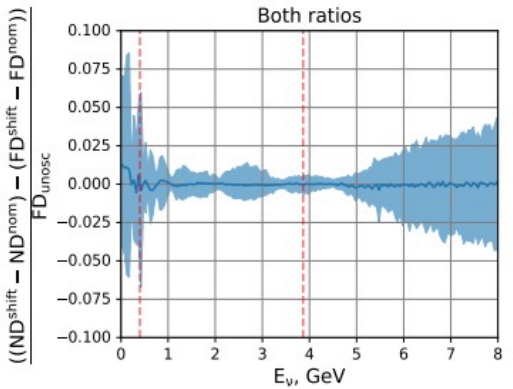
Wrong Sign Background (WSB) data driven – flux uncertainties

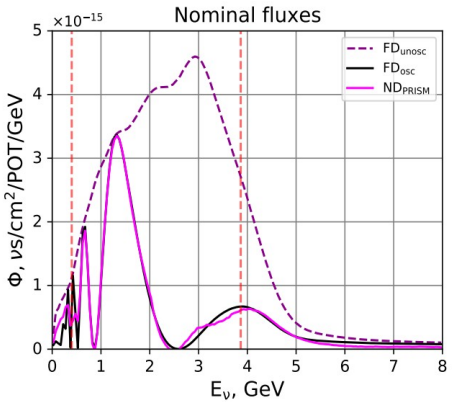
- Use the ND data from the opposite channel (**FHC** – ν_μ mode) to match the target FD WSB (intrinsic WS ν_e + WS ν_μ) flux (**RHC** – ν_μ mode)
- Main concern: flux uncertainties (graphs and study by Anna Stepanova)

Standard Target

(ND FHC → FD FHC)

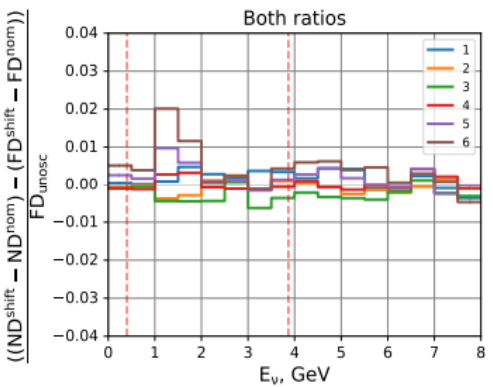


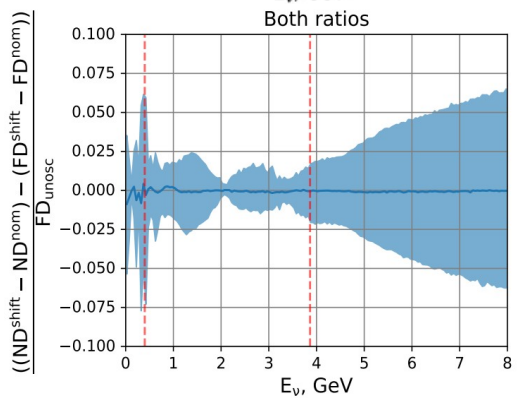


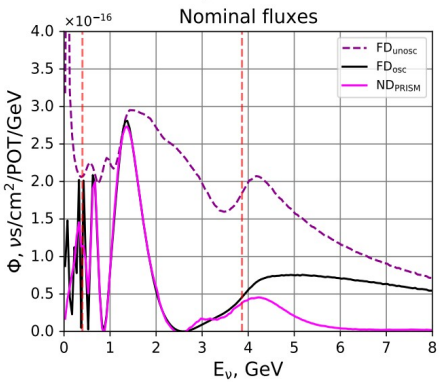


WS Target

(ND RHC → FD FHC)



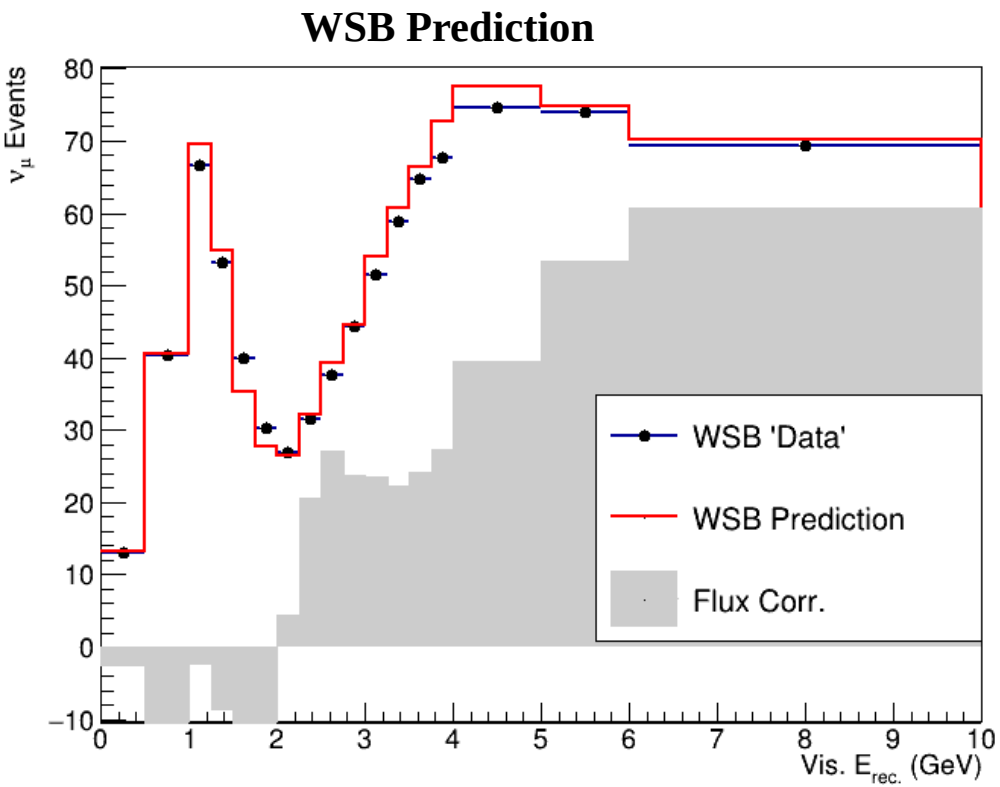


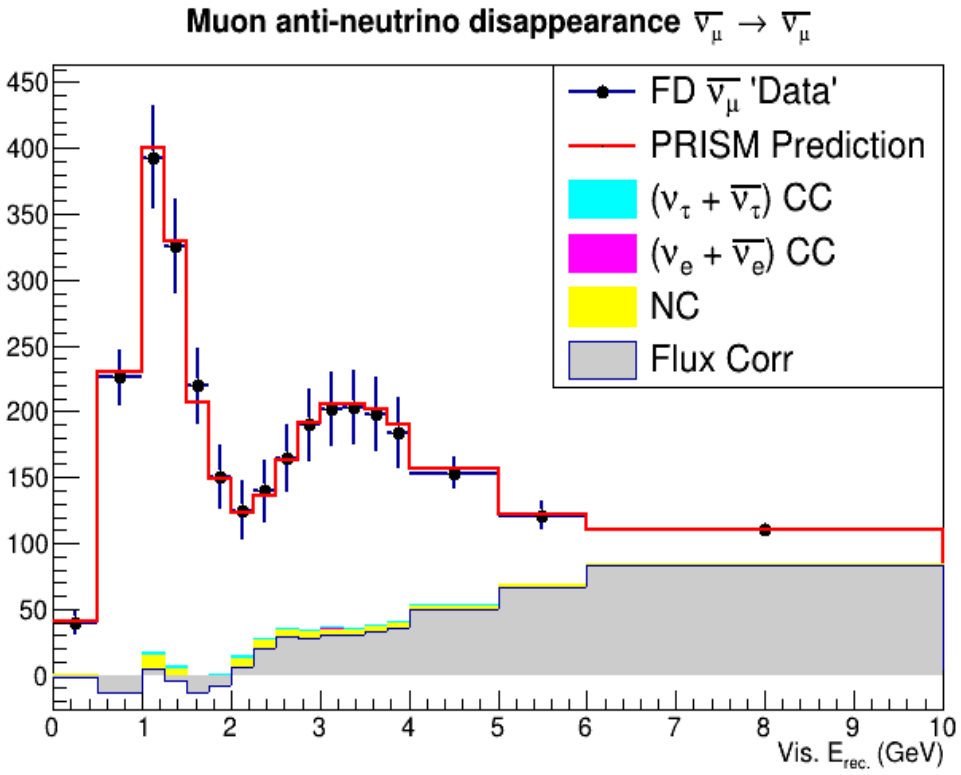


- Flux uncertainties less than 3% in the fitting area → similar to the standard case

Wrong Sign Background (WSB) data driven – Disappearance anti-neutrino channel

- WSB Prediction = $\nu_\mu \rightarrow \nu_\mu$ from beam contamination + intrinsic $\nu_e \rightarrow \nu_\mu$ beam contamination





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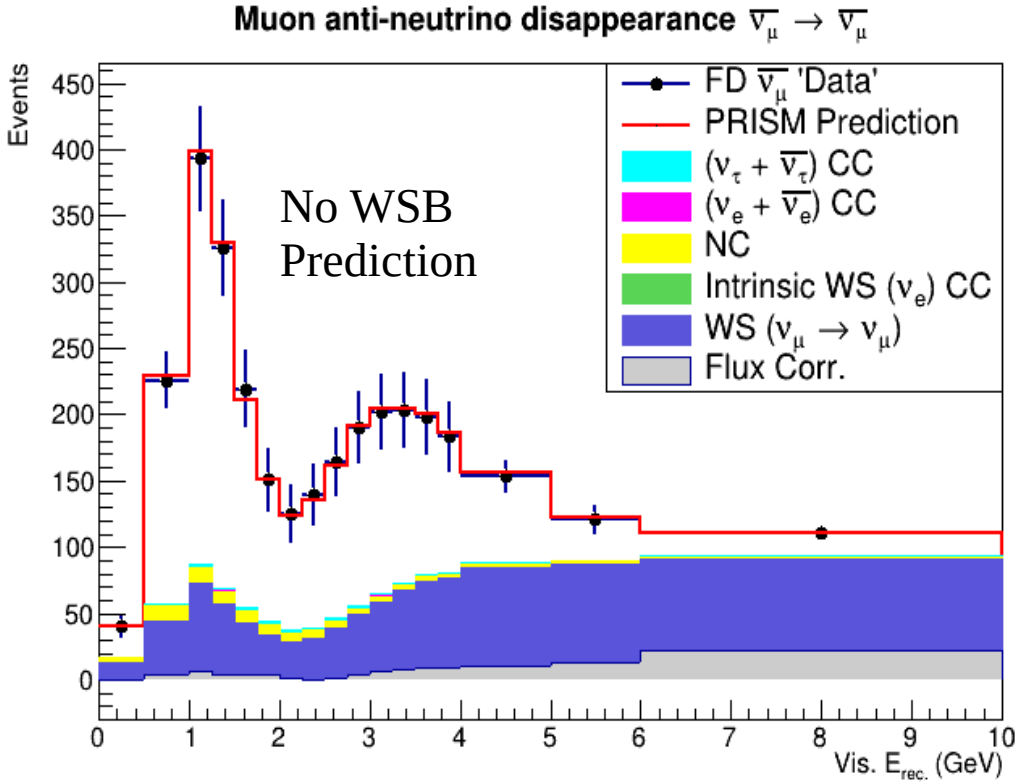

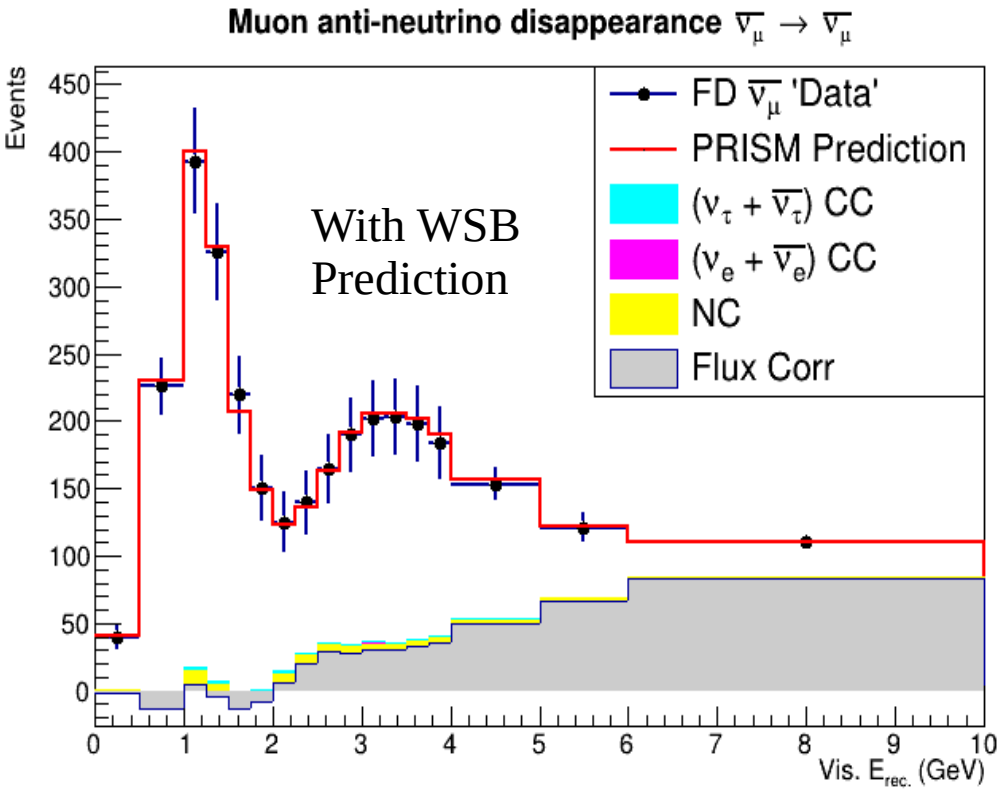

Wrong Sign Background (WSB) data driven – Appearance anti-neutrino channel

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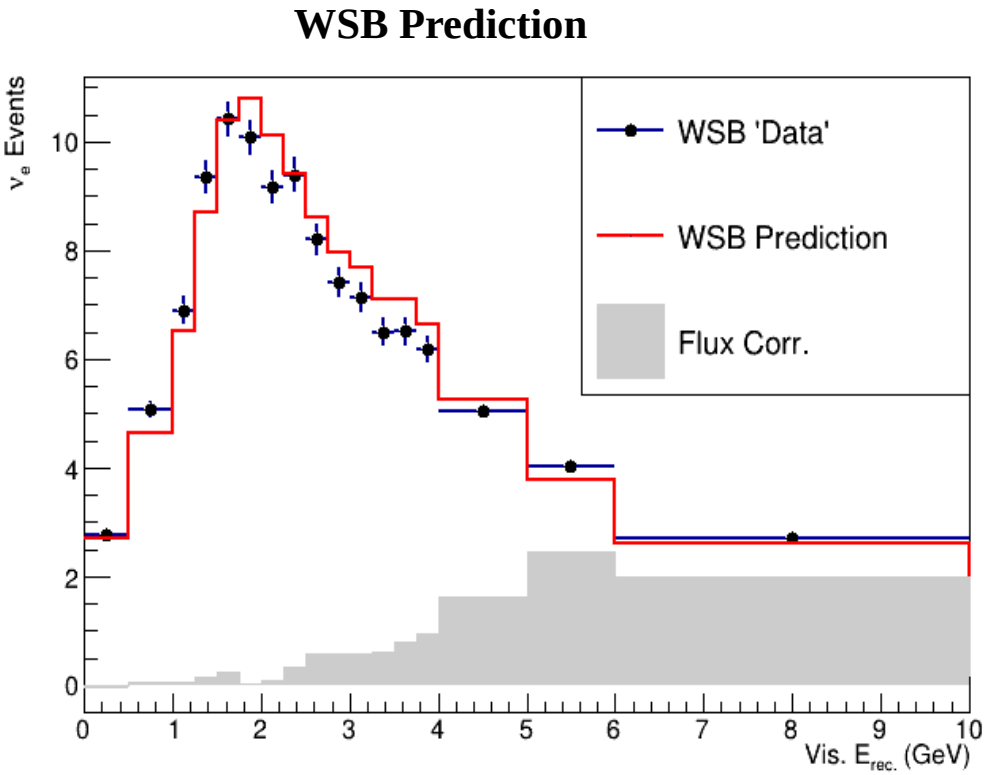

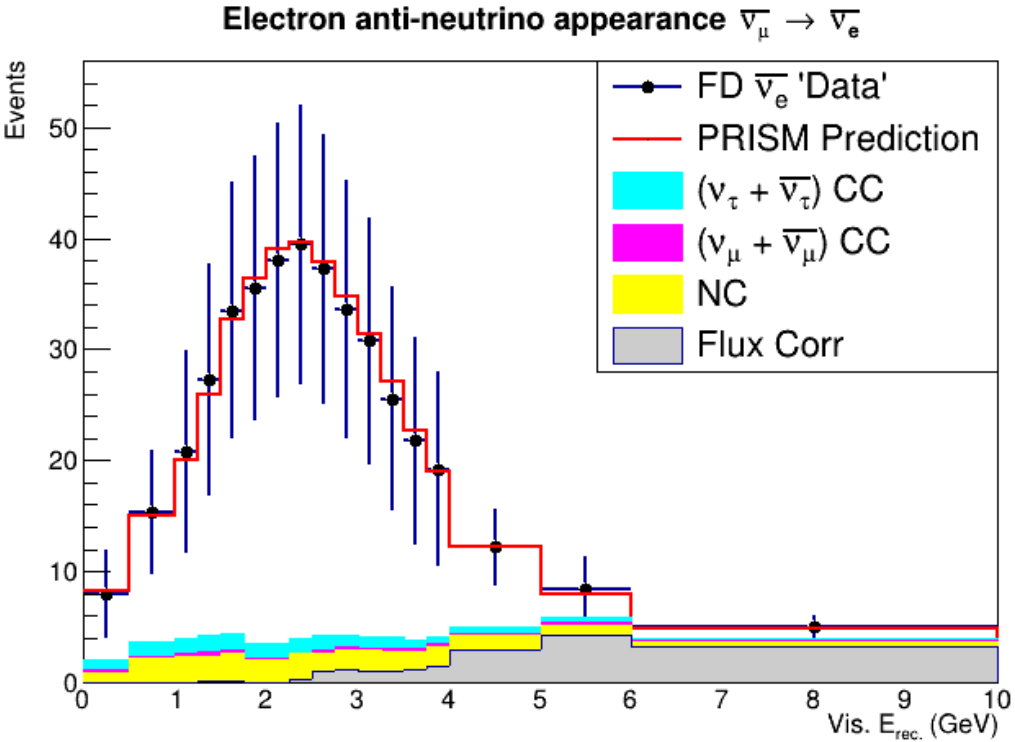

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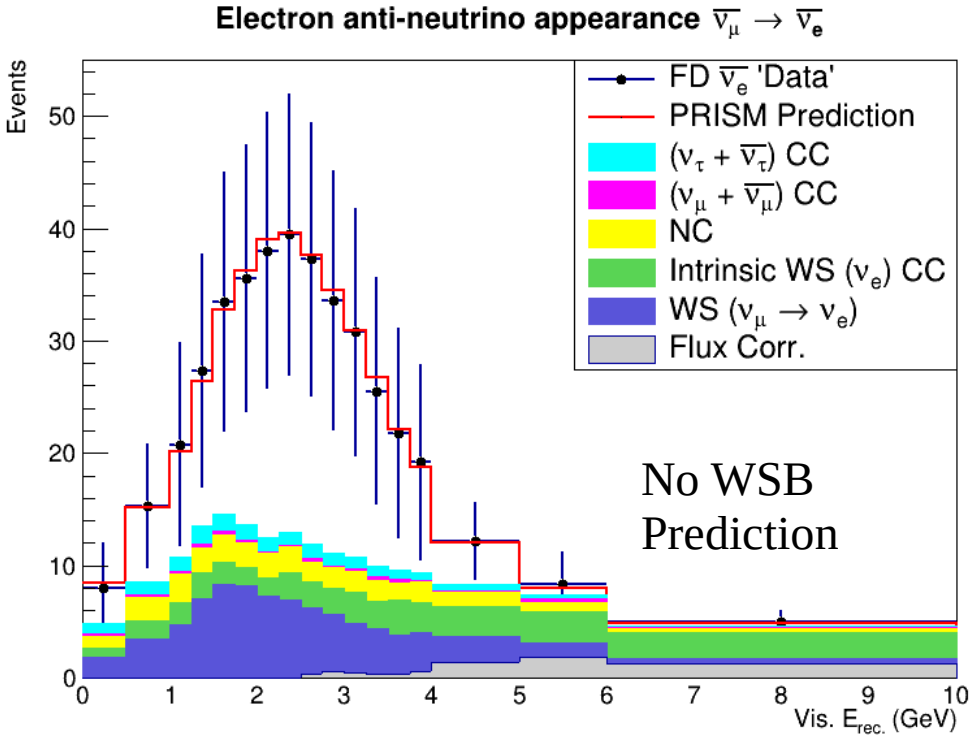
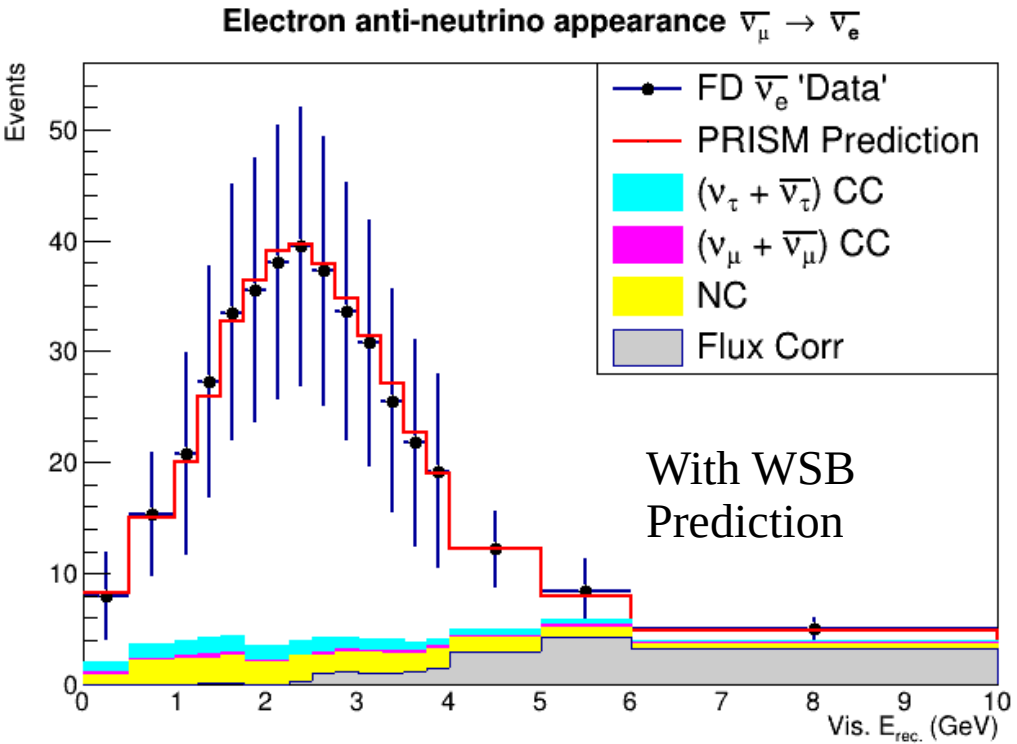
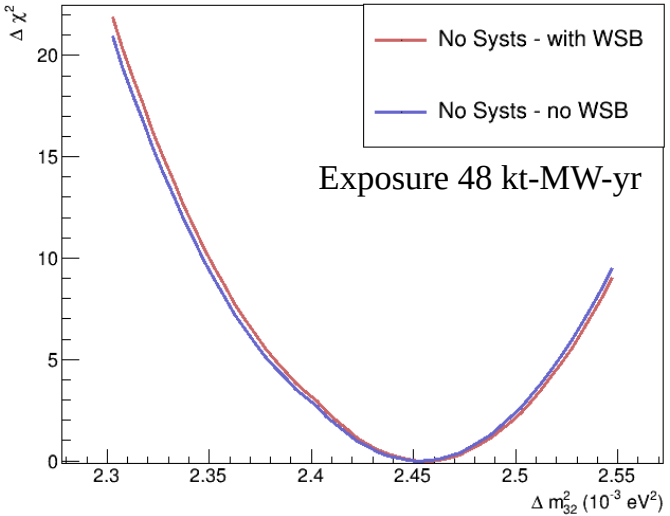
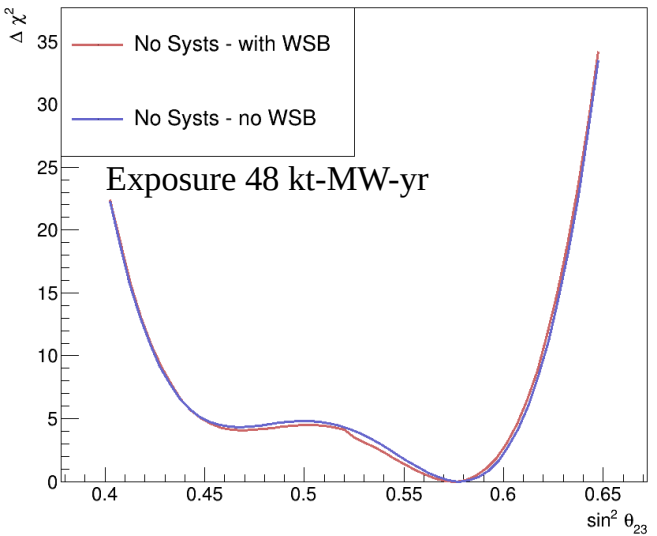


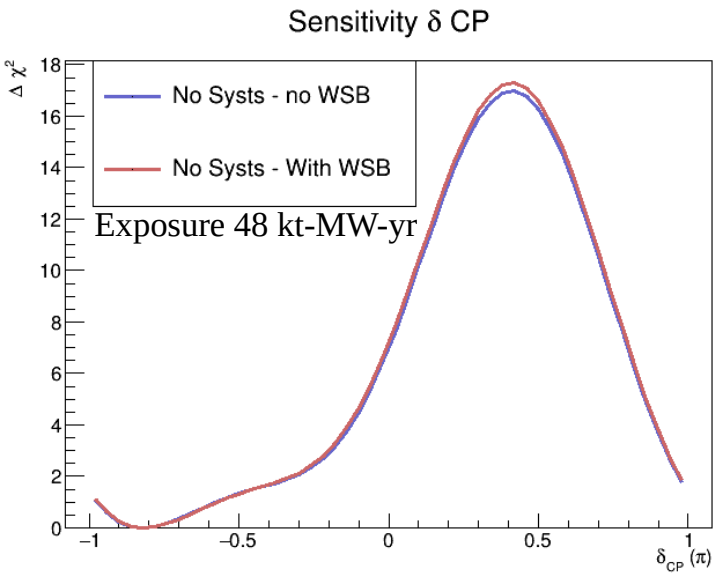


Wrong Sign Background (WSB) data driven – Oscillation fits

- Nominal – stats only
- 4 Flavours: $\nu_\mu + \nu_e + \overline{\nu}_\mu + \overline{\nu}_e$



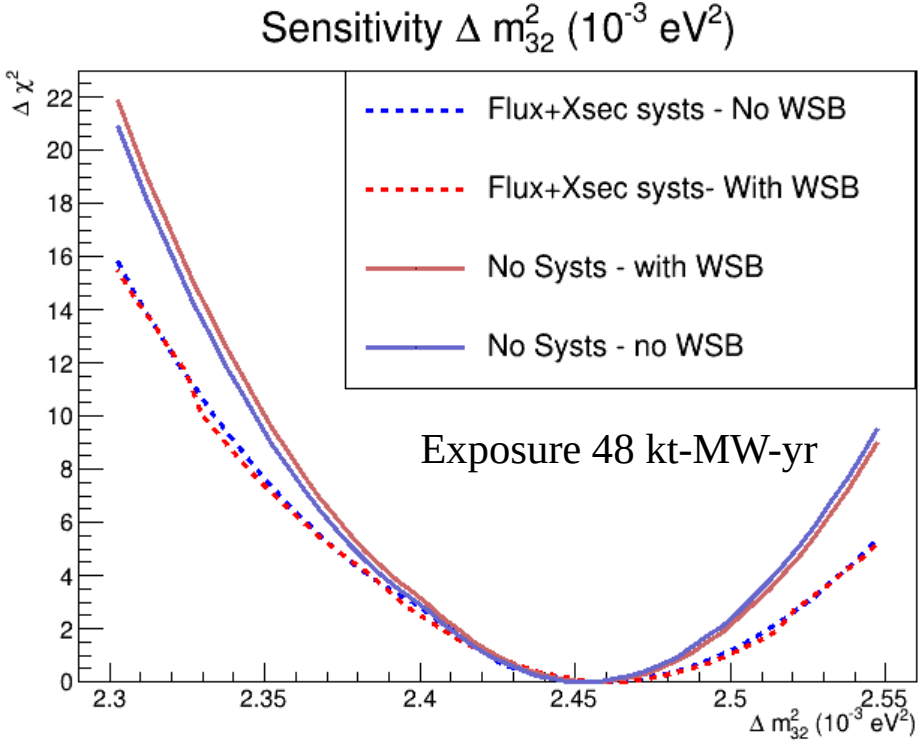


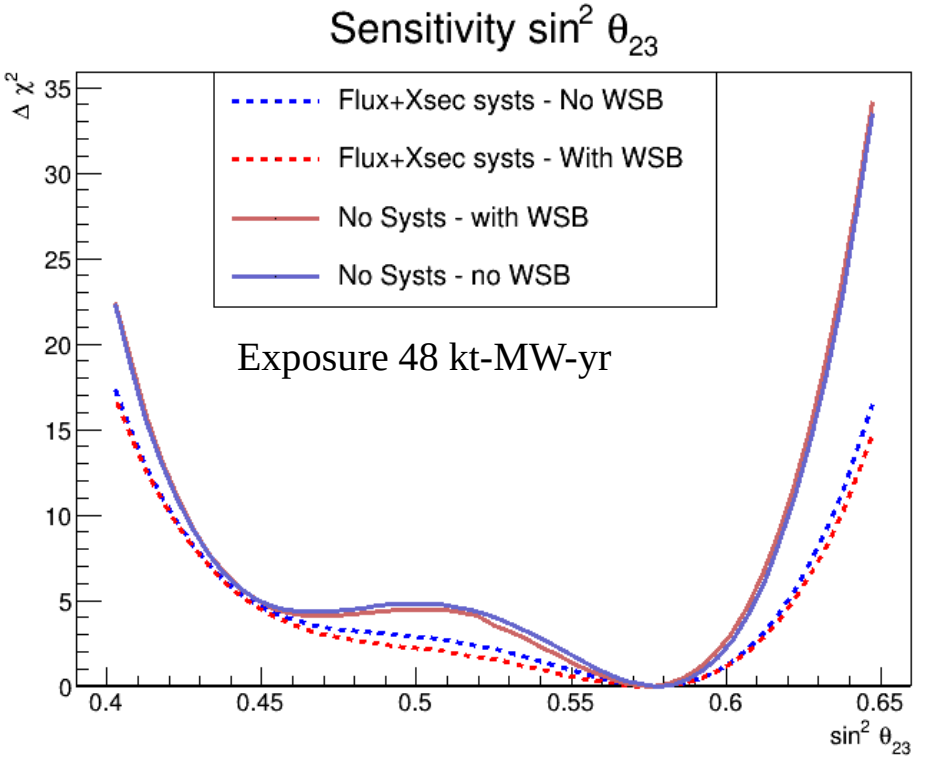


- No significant shift in the nominal case between the two different scenarios
  → no additional bias included

Wrong Sign Background (WSB) data driven – Oscillation fits

- Systematics included: flux + Xsec
- 4 Flavours: $\nu_\mu + \nu_e + \overline{\nu}_\mu + \overline{\nu}_e$



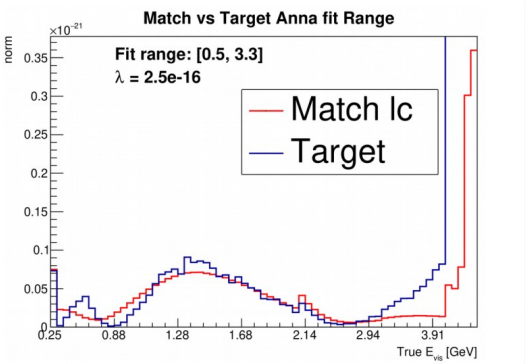


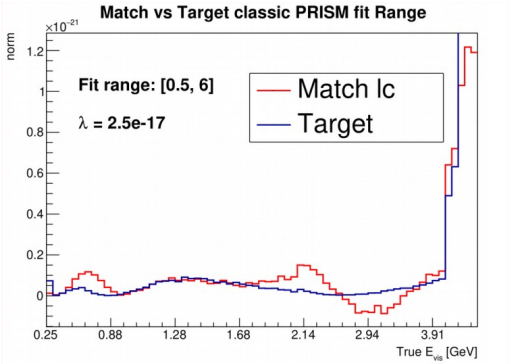
- **No significant improvement in Xsec systs when WSB is predicted on a data-driven approach**

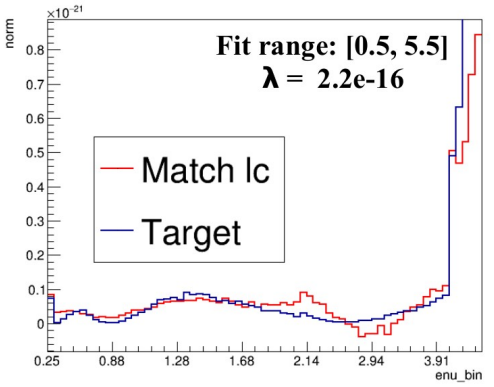
PRISM WSB Prediction – Flux correction

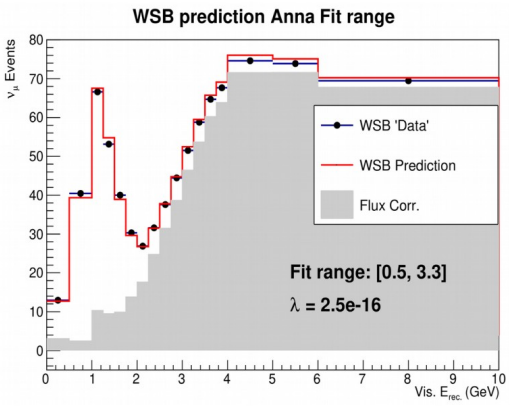
- Different fitting ranges and regularization parameters have a direct influence in the flux correction (MC component)
  → could this influence the oscillation fit..?

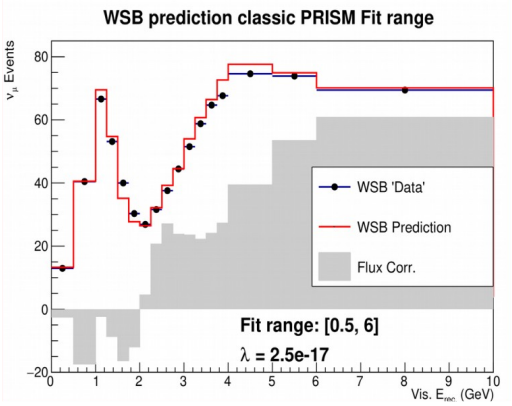
Anti muon neutrino disappearance channel ($\overline{\nu_\mu} \rightarrow \overline{\nu_\mu}$)

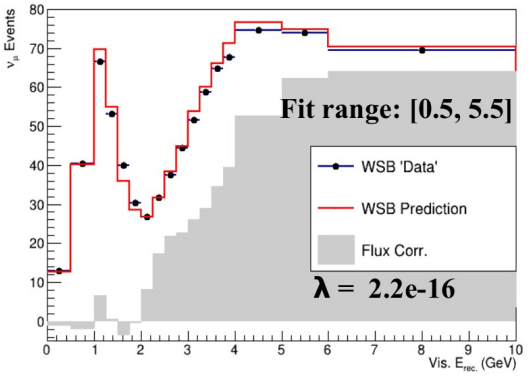












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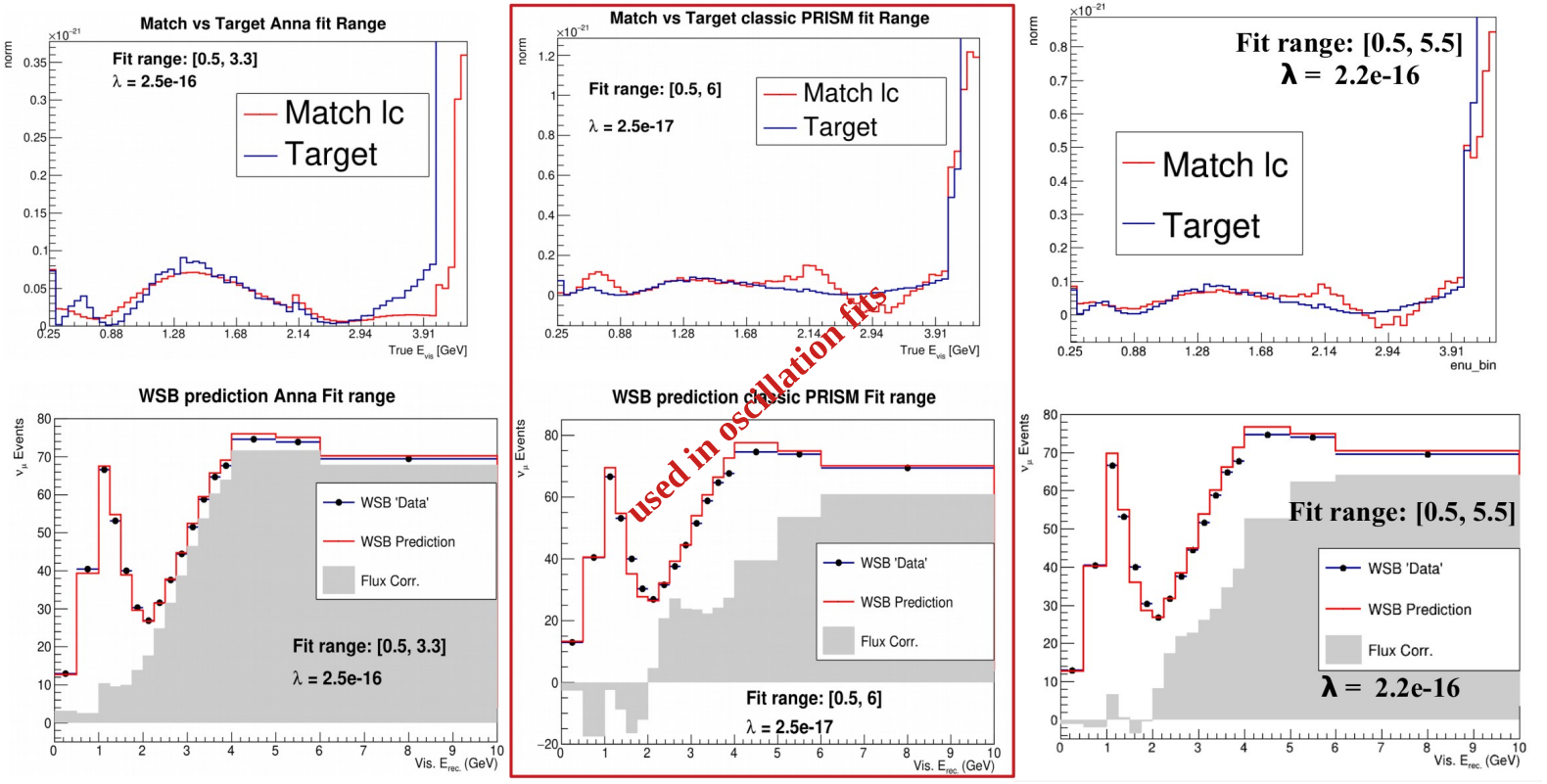

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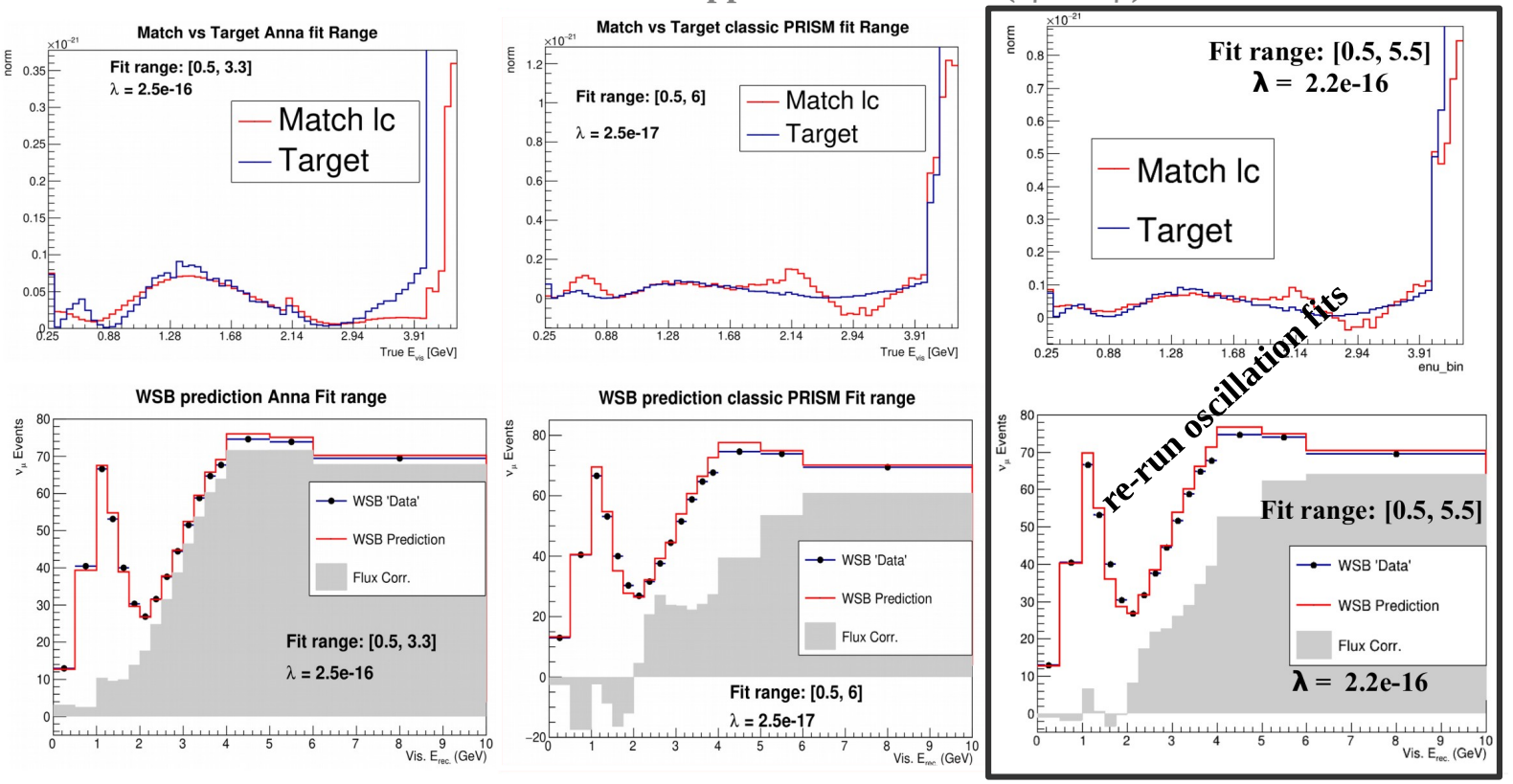
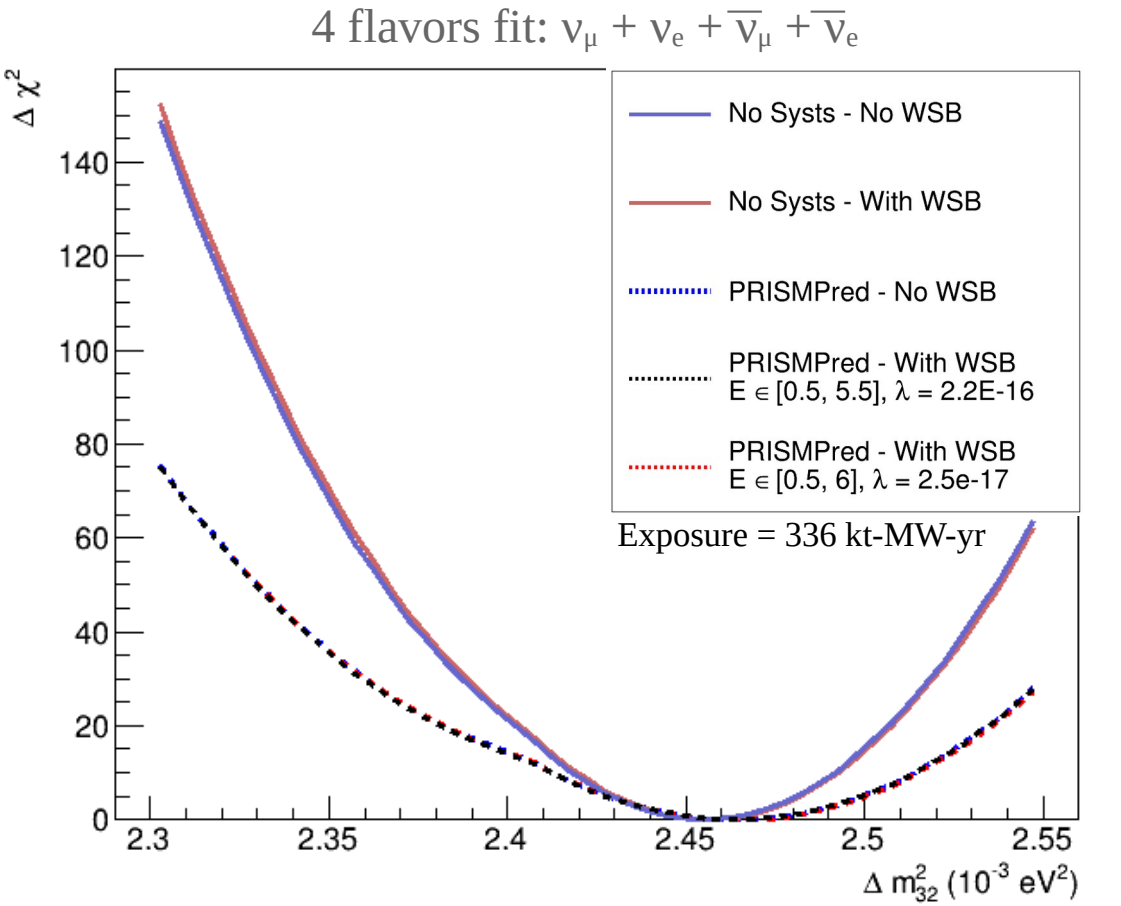


Oscillation fits with/without WSB – Xsec systematics

- **PRISM no WSB** prediction: WSB from MC with the corresponding systematic shift
- **PRISM with WSB**: WSB from data-driven approach (different fit ranges)

→ no significant difference when different flux corrections are used



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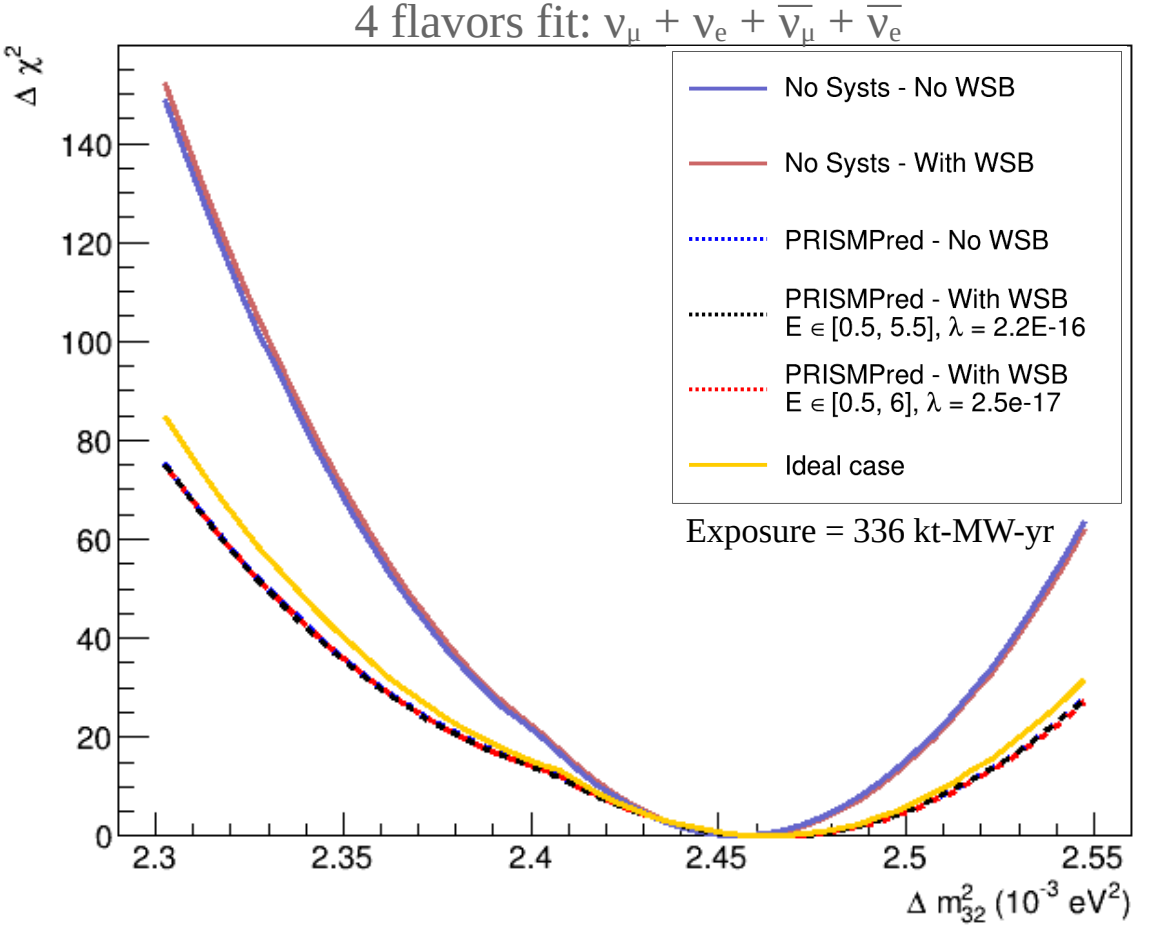
- **Ideal case**: no systematic shift in the WSB component (artificially turn off the syst shifts within the classic – WSB from MC PRISM prediction)



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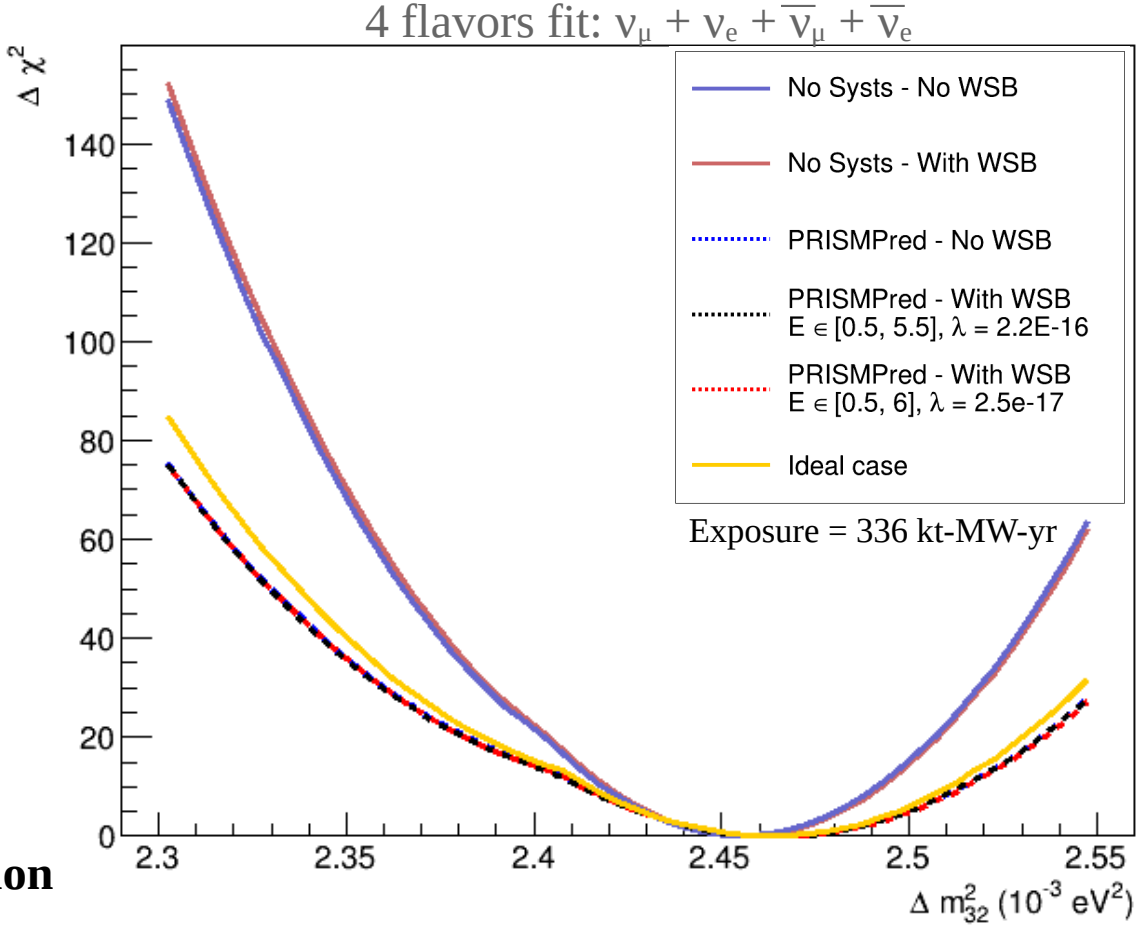
No significant difference between the resulting fits (with/without WSB) with Xsec systs → **maybe the flux correction is not the main source of systematics..**



Oscillation fits with/without WSB – Xsec systematics

→ Turn off the syst shift in the ND efficiency correction used for the WSB prediction on a data-driven approach

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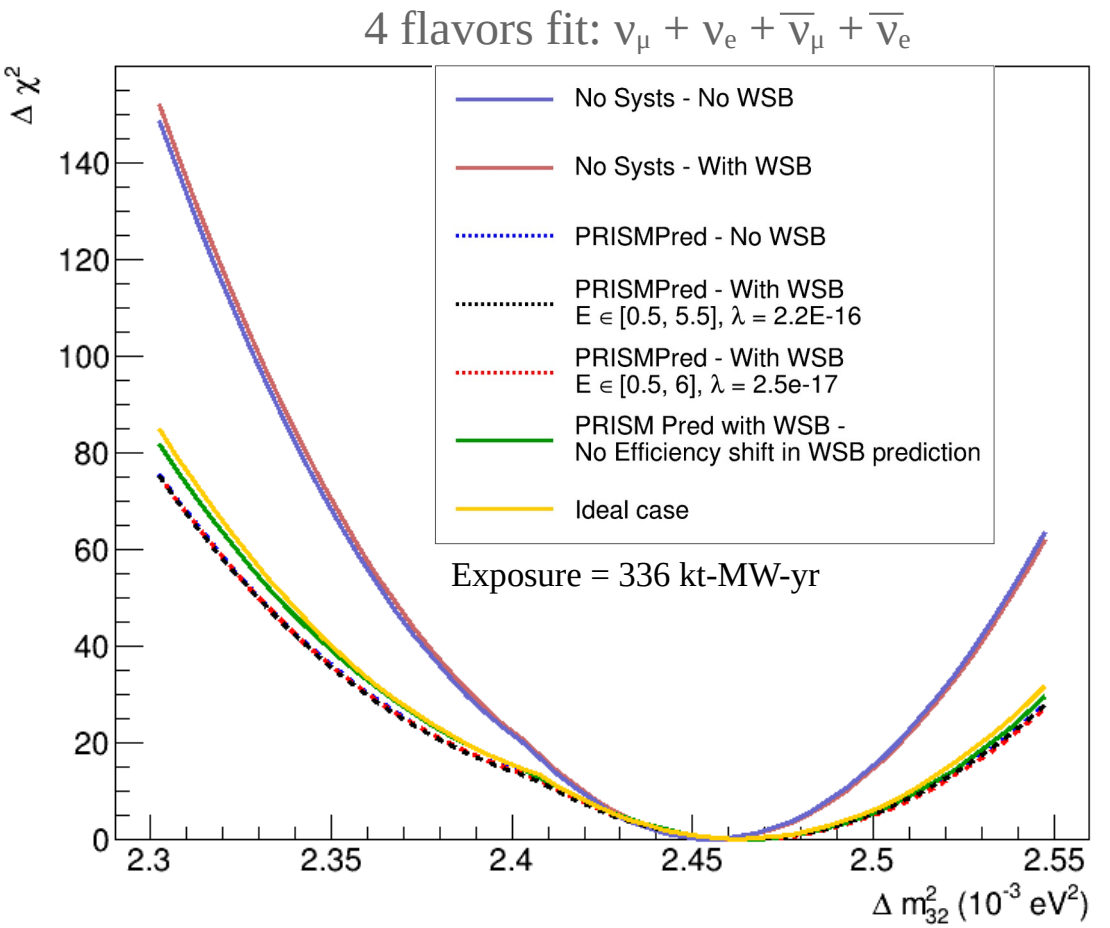
- **PRISM with WSB**: WSB from data-driven approach (different fit ranges)
- **Ideal case**: no systematic shift in the WSB component (artificially turn off the syst shifts within the classic – WSB from MC PRISM prediction)
- **PRISM with WSB no syst shift in WSB ND efficiency calculation:** WSB from data-driven approach no shift in ND efficiency

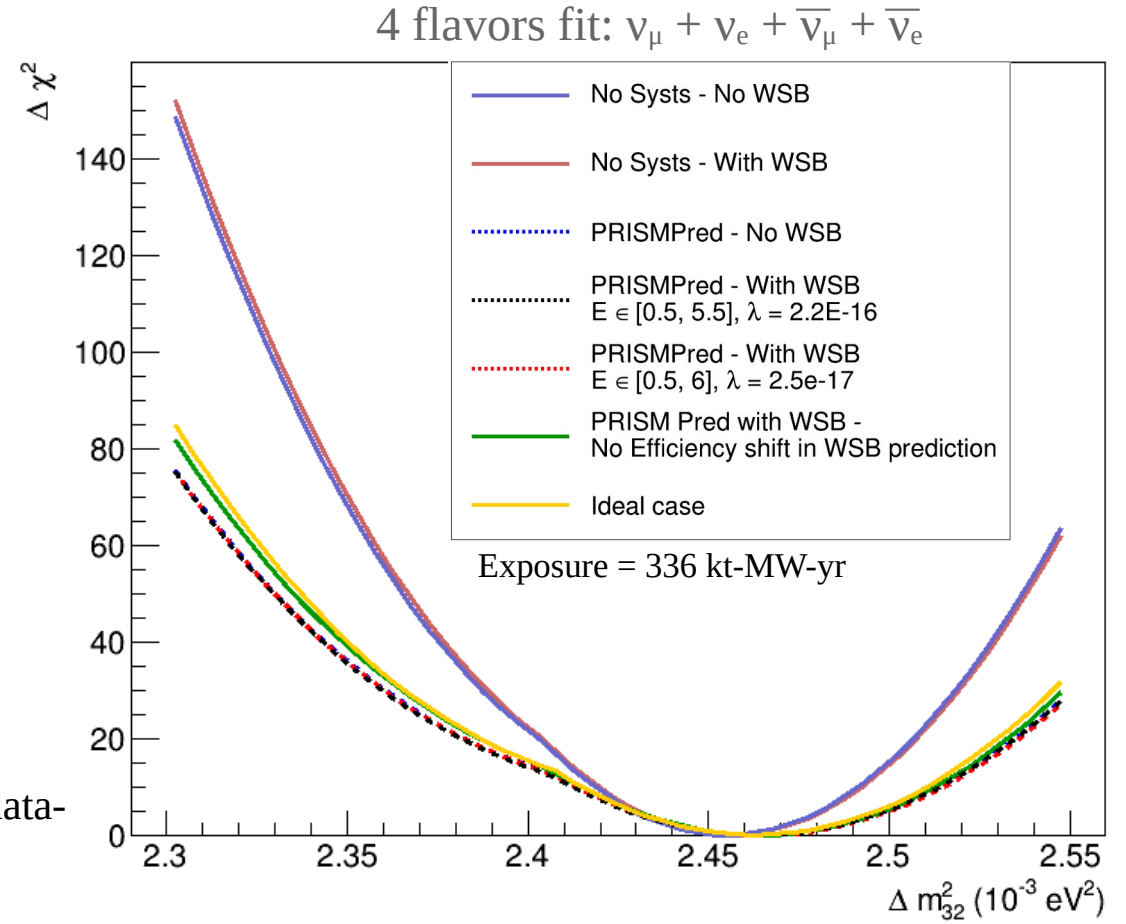


Oscillation fits with/without WSB – Xsec systematics

- **The main source of systematics comes from the efficiency calculation:** for the WSB prediction the efficiency calculation enters the analysis individually (I.e we use the efficiency calculation two times: once for the classic PRISM prediction of the oscillated spectrum + once for the WSB prediction)

  → the improvement in using the WSB prediction is canceled by the additional Xsec dependence introduced via the efficiency calculation

- This should not be a problem once the ND efficiency correction is implemented on a data-driven approach (work in progress by Wei)



PRISM Prediction with a WSB data-driven approach: Conclusions

- The WSB prediction on a data-driven approach is fully implemented (code has been pushed on github some time ago) and works as desired

- Once the efficiency correction (data-driven) is implemented, **the improvement obtained in the oscillation fits is very close to the ideal case of a "no-syst" WSB**

- The data-driven wrong sign background plays a **crucial role in the fake data PRISM analysis** and bias reduction (see Ciaran's talk next week)
    - a separate individual study (extreme case of lower/higher cross sections by 1 order of magnitude) has been performed and shows how significantly lower biases are obtained when the WSB is obtained in a data-driven way

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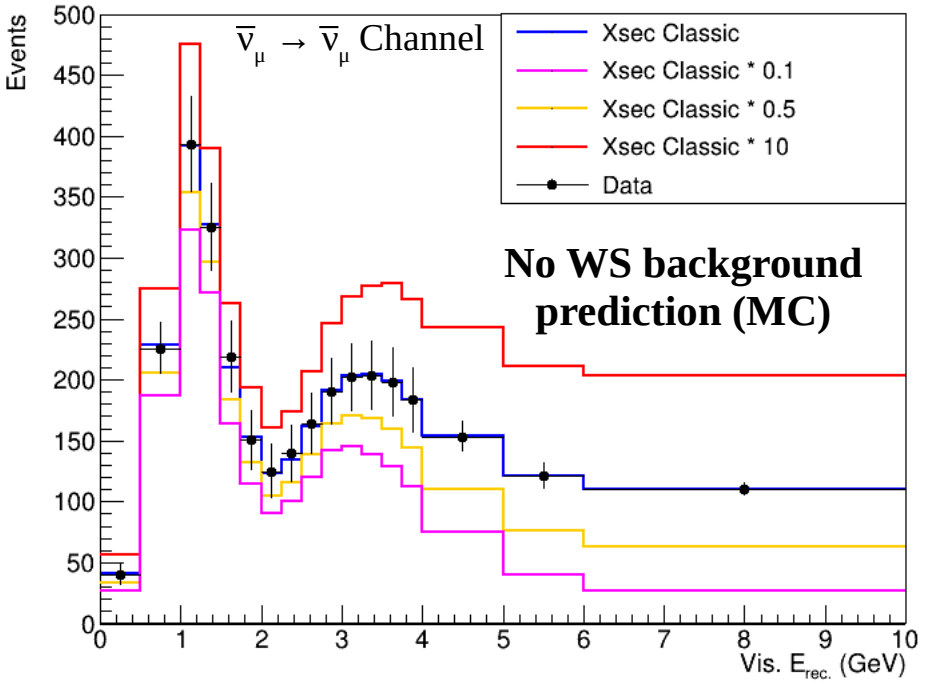
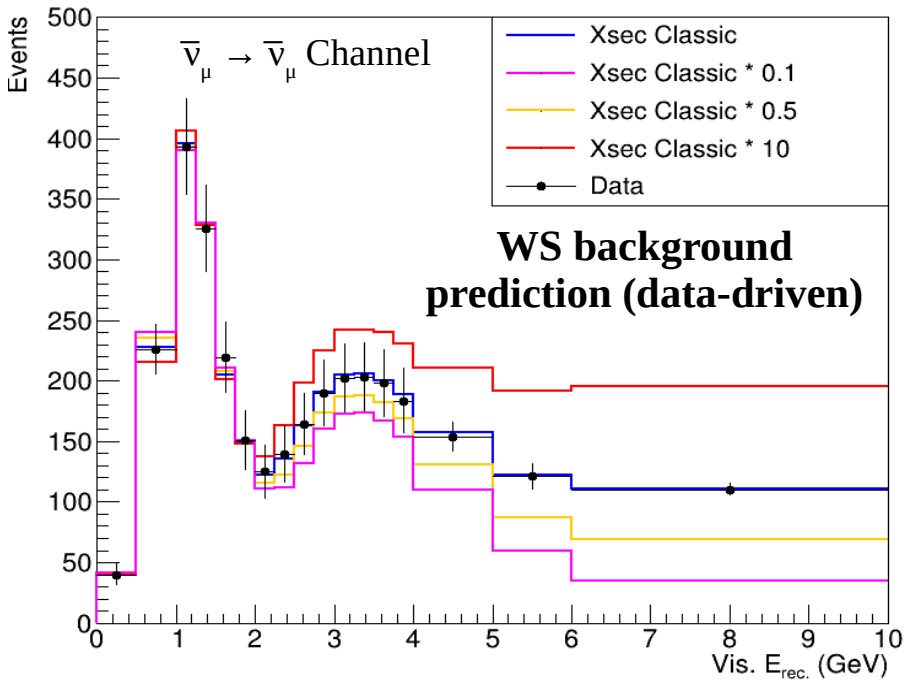
Thank you!

BACKUP

Wrong Sign Background (WSB) data driven – Study case

- Shift the cross section (FrInelPi) by a given weight → see how does this influence the PRISM prediction and oscillation fits within the two scenarios: WSB from MC vs WSB data-driven
- Include only FrInelPi cross section systematics and apply +1 σ shift





→ **Significantly smaller shifts when the WS background is predicted on a data-driven approach**

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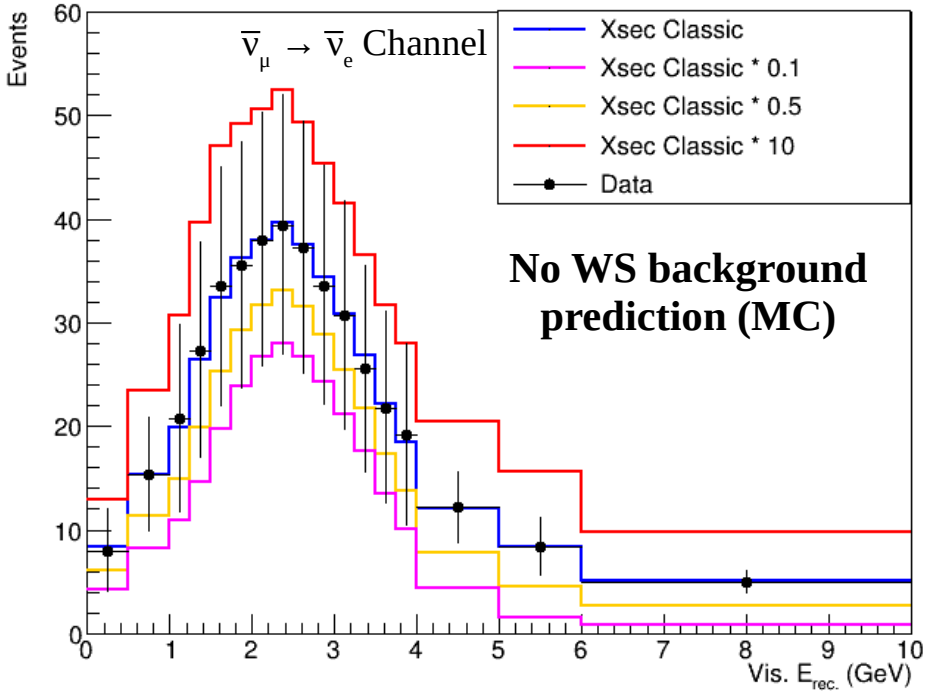

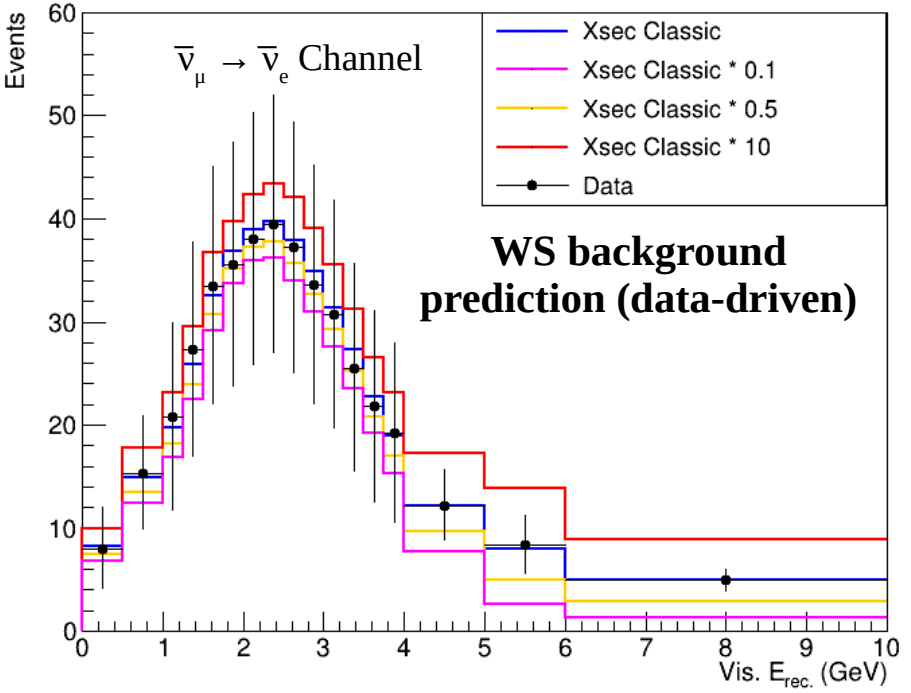

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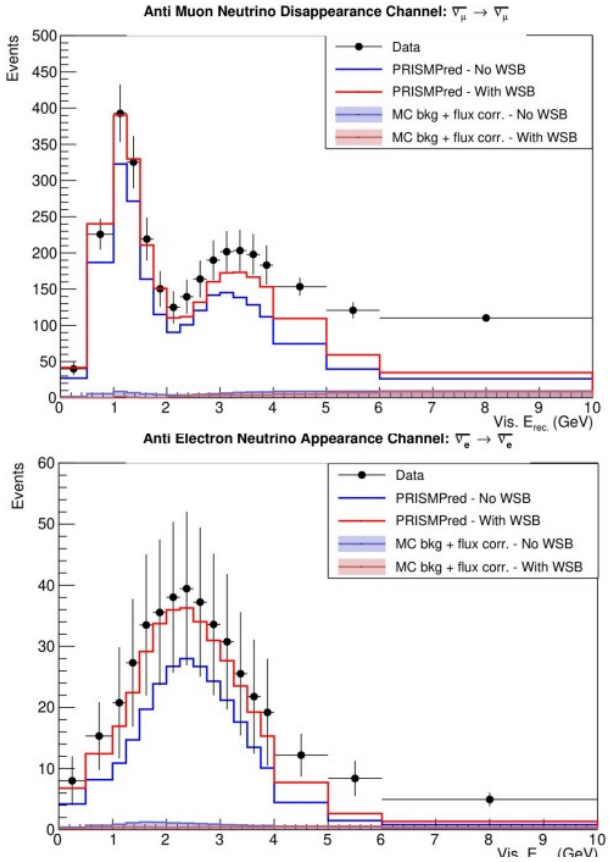
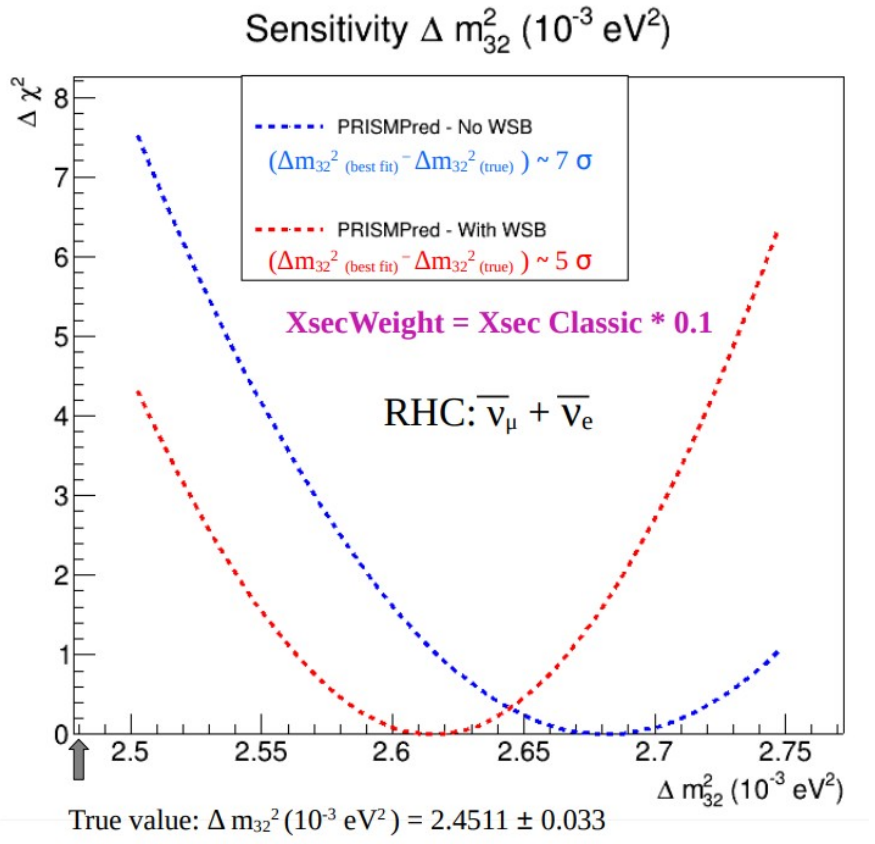
Wrong Sign Background (WSB) data driven – Study case Oscillation fits





→ Much better agreement (2 σ) of the resulted Δm_{32}^2 with the true value in the case of WSB obtained from a data-driven approach

PRISM Prediction – Wrong Sign Background (WSB) data driven approach

- Total WSB (intrinsic + WS from beam contamination) can be predicted on a data driven approach
  - example for $\overline{\nu}_\mu \rightarrow \overline{\nu}_\mu$ channel: WSB = intrinsic $\nu_e \rightarrow \nu_\mu$ + $\nu_\mu \rightarrow \nu_\mu$
- **use the ND data from the opposite channel** (RHC – $\overline{\nu}_\mu$ mode) **to match the target FD WSB** (intrinsic WS ν_e + WS ν_μ) flux (FHC – ν_μ mode)

ND_RHC Fluxes × C_{WSB} = FD_{WSB}_FHC flux

WSB coefficients as a function of the off-axis position

START

NDData RHC mode (OffAxis vs visErec)

Subtract ND background

NDData No Bkg – RHC mode (OffAxis vs visErec)

Correct for different efficiencies at ND and FD

Correct for nu/numu x-sec ratio (in case of appearance)

FINISH

PRISM Prediction WSB

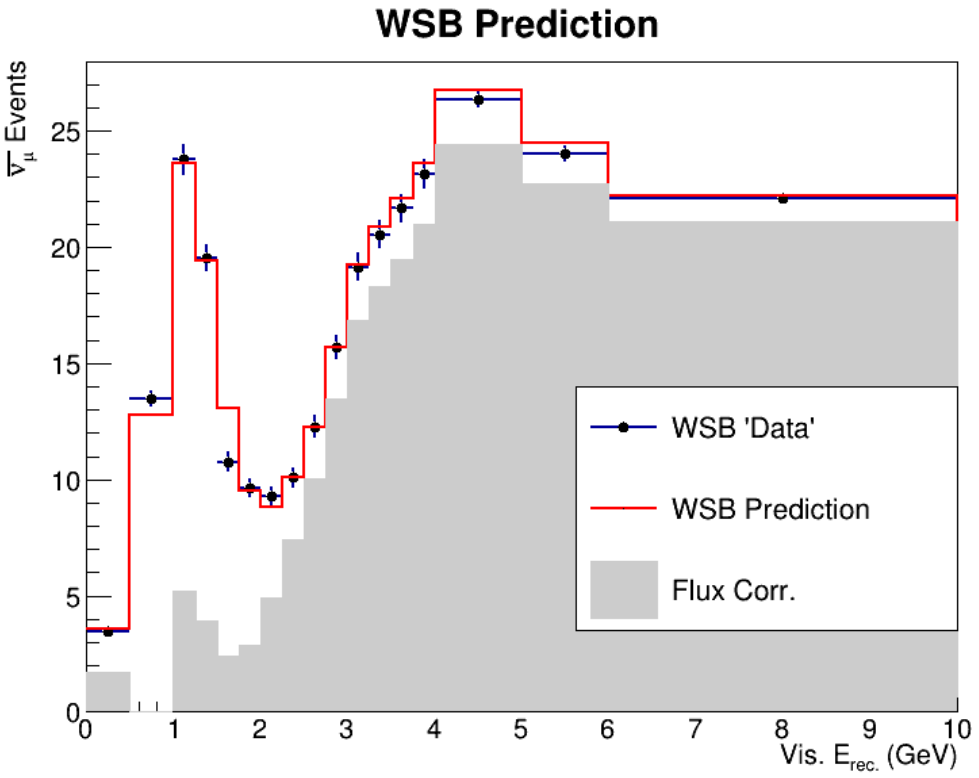
Add flux correction (MC)

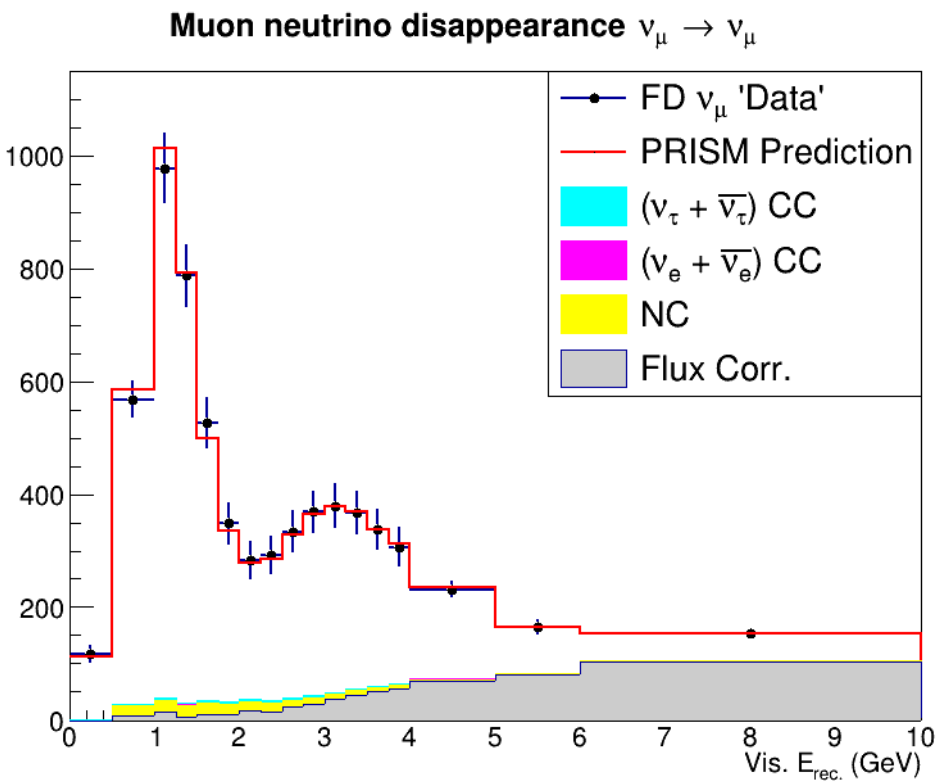
Perform linear combination (Coefficients WSB)

- PRISM Prediction WSB is then added to the FD background instead of the MC WS spectra

Wrong Sign Background (WSB) data driven – Disappearance neutrino channel

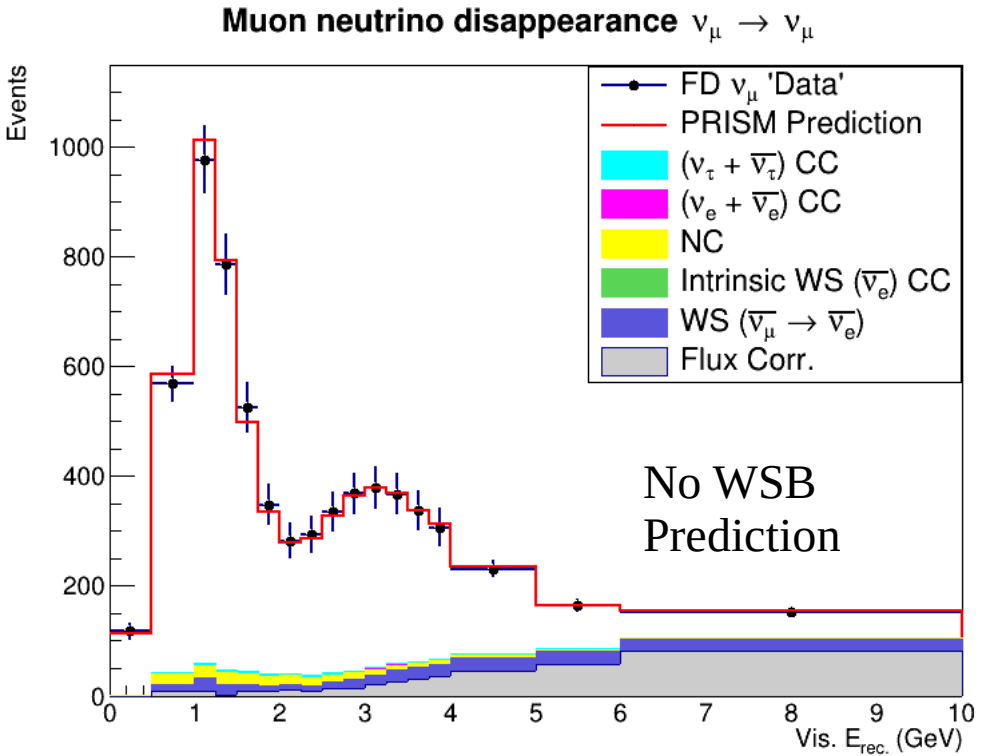
- WSB Prediction = $\overline{\nu}_\mu \rightarrow \overline{\nu}_\mu$ from beam contamination + intrinsic $\overline{\nu}_e \rightarrow \overline{\nu}_\mu$ beam contamination

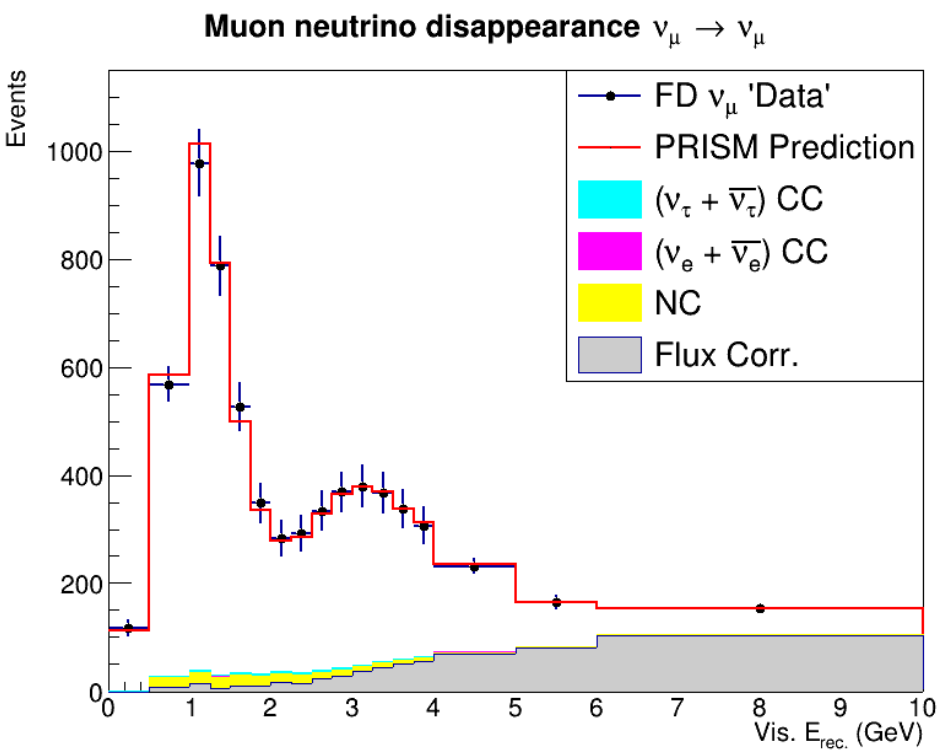




Wrong Sign Background (WSB) data driven – Disappearance neutrino channel

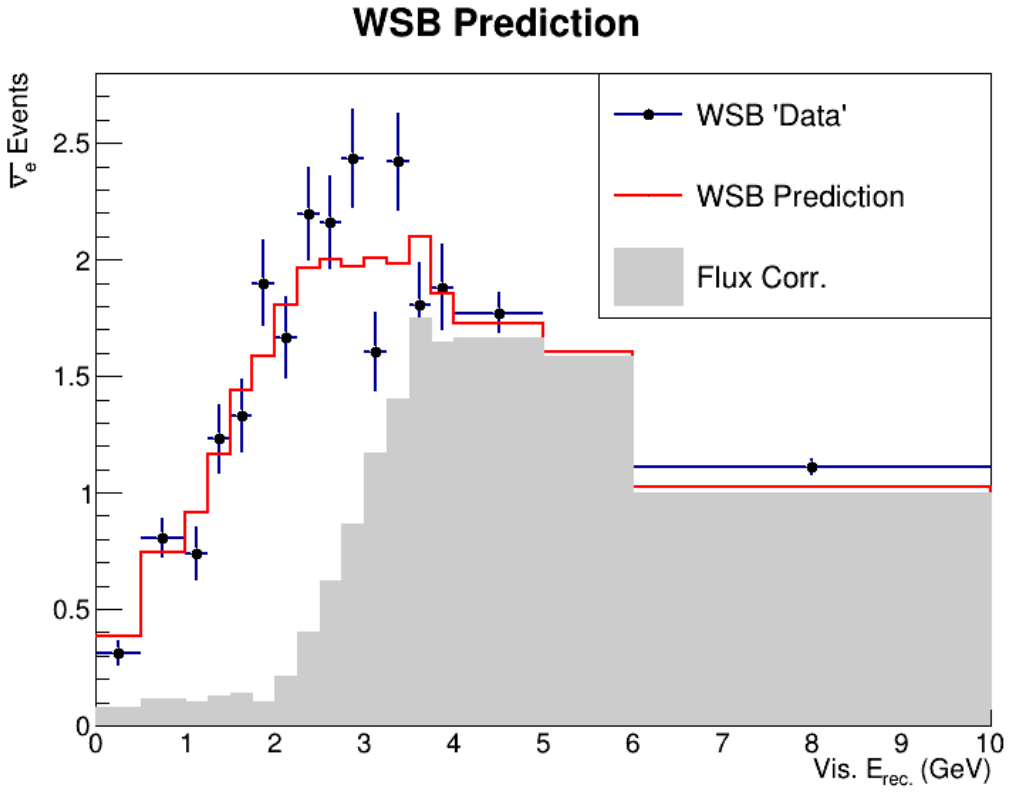
- WSB Prediction = $\overline{\nu}_\mu \rightarrow \overline{\nu}_\mu$ from beam contamination + intrinsic $\overline{\nu}_e \rightarrow \overline{\nu}_\mu$ beam contamination

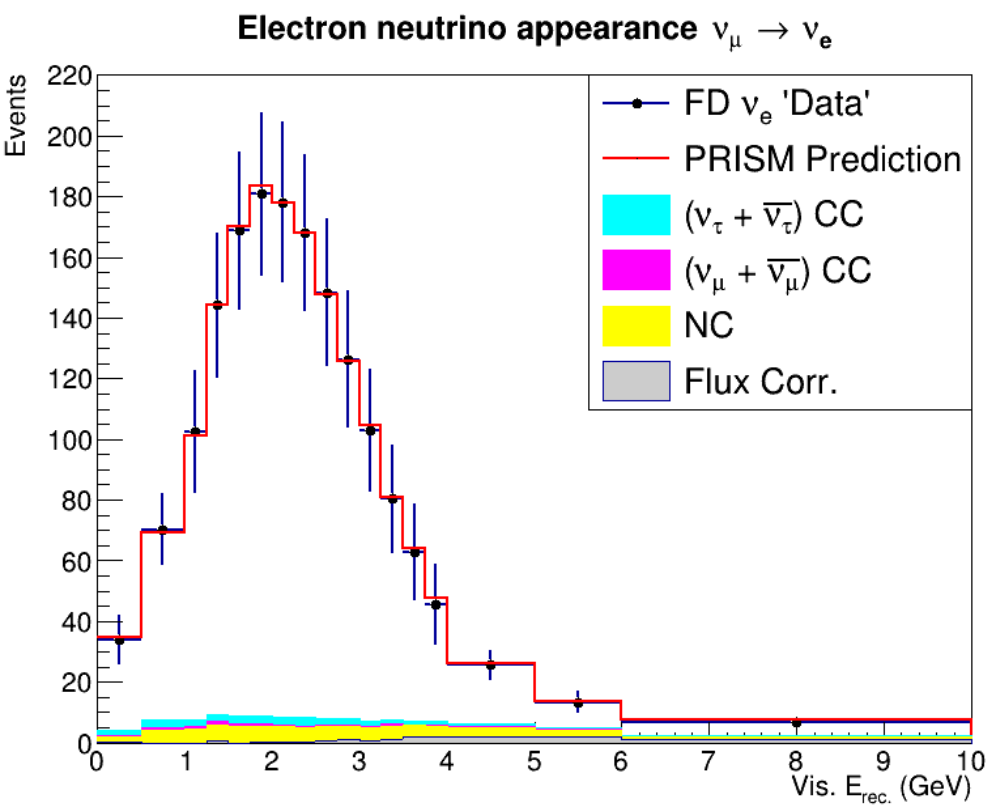




Wrong Sign Background (WSB) data driven – Appearance neutrino channel

- WSB Prediction = $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ from beam contamination + intrinsic $\overline{\nu}_e$ beam contamination





Wrong Sign Background (WSB) data driven – Disappearance neutrino channel

- WSB Prediction = $\nu_\mu \rightarrow \nu_\mu$ from beam contamination + intrinsic $\nu_e \rightarrow \nu_\mu$ beam contamination