Single Transverse Variables in MicroBooNE

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Outline

1. **INTRODUCTION**
2. **BACKGROUND**

- Cross-section Measurements
- Signal definition
- Single Transverse Variables (STVs)

3. **METHOD**

- Simulation procedure
- Smearing matrix calculation

4. **RESULTS**

INTRODUCTION

1. **Study neutrino scattering cross-sections on an argon target**
- Monte Carlo simulation
- Reconstruction of Single Transverse Variables (STVs)

2. **Single Transverse Variables: probe nuclear effects**

STVs have been studied for neutrino-carbon interactions
→ apply technique to argon nuclei

3. **Goal**

1. Examine reconstruction methods
2. Examine current analysis process

} Study neutrino-nucleus interactions

BACKGROUND: Cross-section measurements

$$N(\Theta) \propto \Phi(E_\nu) \cdot \sigma(E_\nu) \cdot P_{\nu\alpha \rightarrow \nu\beta} \cdot \epsilon(E_\nu)$$

$N(\Theta)$	$\Phi(E_\nu)$	$\sigma(E_\nu)$	$P_{\nu\alpha \rightarrow \nu\beta}$	$\epsilon(E_\nu)$
Event rate	Neutrino flux	Cross section	Oscillation probability	Detector efficiency

- Neutrino cross-section measurements
  - Improved precision in oscillation analyses
  - Constrain theoretical models of neutrino-nucleus scattering

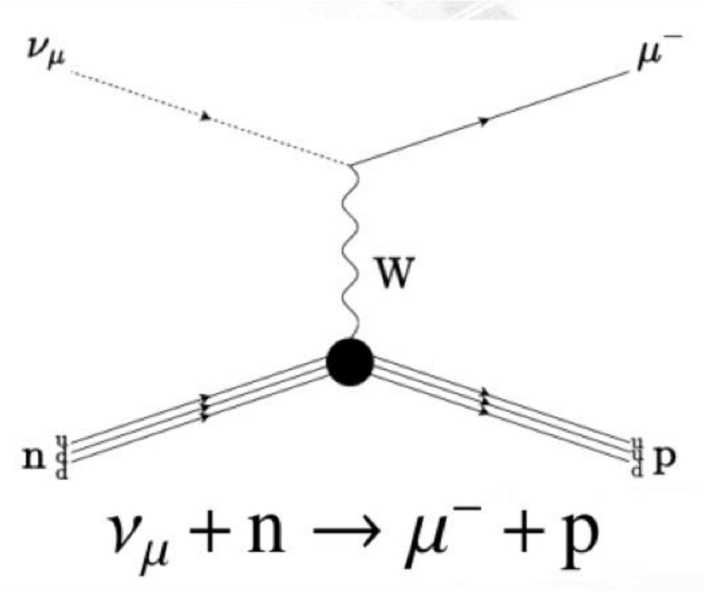
BACKGROUND: Signal definition

CC0πNp → 1 muon, zero pions, and at least 1 proton in the final state.

Charge-Current Quasi-Elastic (CCQE)

- Dominant interaction mode at neutrino energies relevant for MicroBooNE (between 0.1 and 1.5 GeV)

- Neutrino exchanges a W boson with a nucleon in the nucleus → a charged lepton is produced and the nucleon's isospin is altered



BACKGROUND: Single Transverse Variables

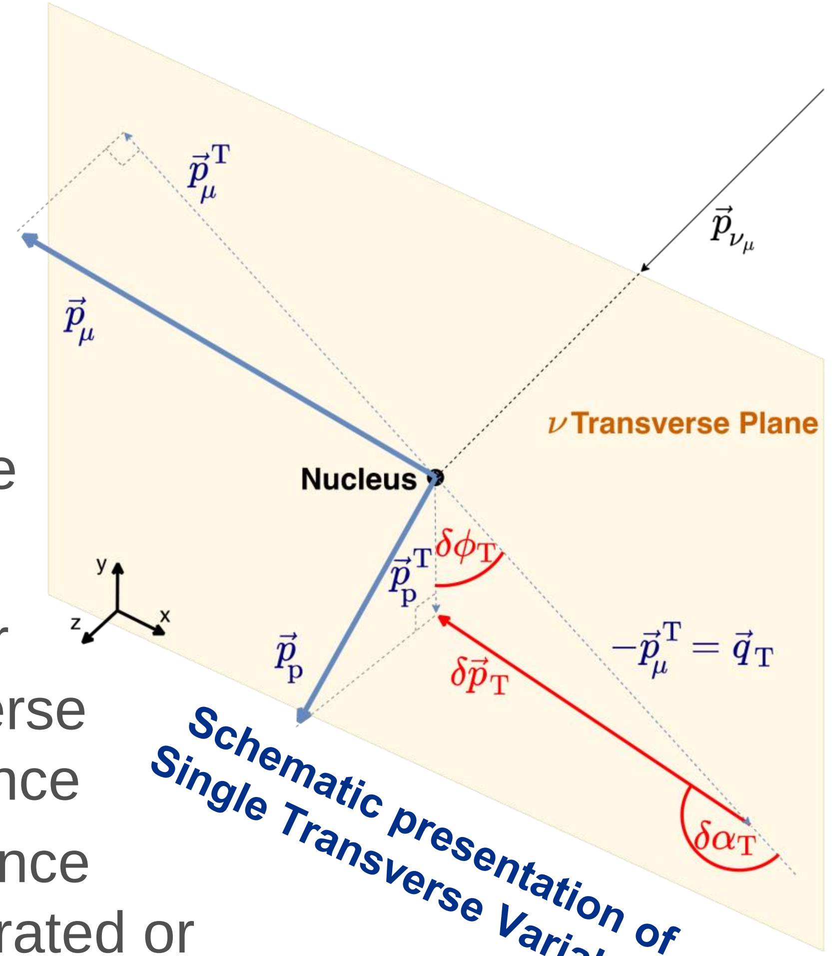
Three observables:

- Quantify the momentum imbalance between the **final muon** and **leading proton**.
- Defined on the transverse plane.

$$\delta p_T = |\delta \vec{p}_T| \equiv |\vec{p}_\mu^{\,T} + \vec{p}_{\mathrm{p}}^{\,T}|$$ ⟵ magnitude

$$\delta\phi_T \equiv \arccos\left(\frac{-\vec{p}_\mu^{\,T}\cdot\vec{p}_{\mathrm{p}}^{\,T}}{p_\mu^T\, p_{\mathrm{p}}^T}\right)$$ ⟵ angular transverse imbalance

$$\delta\alpha_T \equiv \arccos\left(\frac{-\vec{p}_\mu^{\,T}\cdot\delta\vec{p}_T}{p_\mu^T\,\delta p_T}\right)$$ ⟵ imbalance accelerated or decelerated?



Schematic presentation of Single Transverse Variables

→ Sensitive probe of nuclear effects

METHOD: Simulation procedure

GENIE v3.0.6 : Theory Events

- Tune G18_10a_02_11a: default model
- Tune G00_00b_00_000: alternate model

Uboonecode : Reconstructed Events

- Default model
- Alternate model

Cross-section Extraction

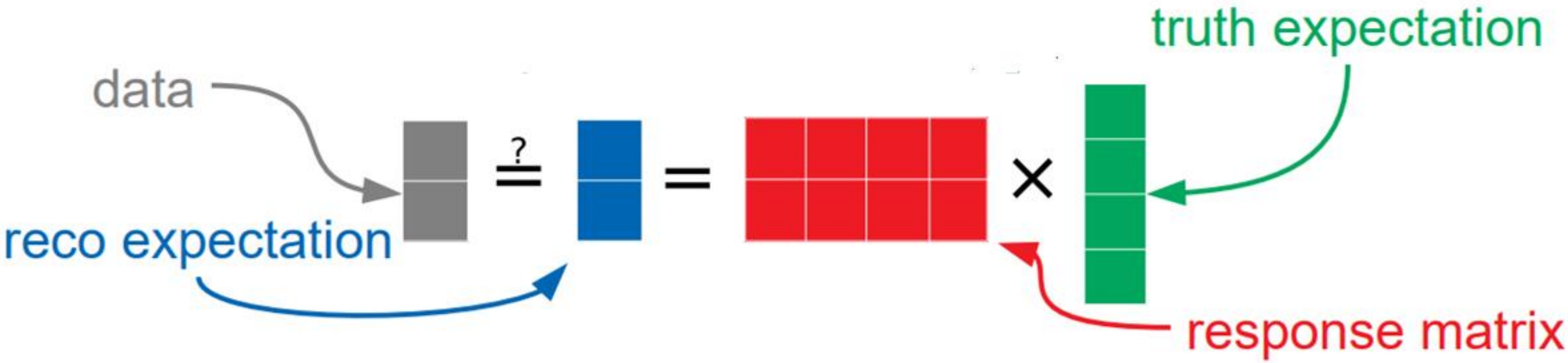
$$\left(\frac{d\sigma}{dx}\right)_i = \frac{N_i - B_i}{\tilde{\epsilon} \cdot N_{target} \cdot \Phi_{\nu_\mu} \cdot (\Delta x)_i}$$

Macro files to analyze simulated events → ROOT

METHOD: Smearing matrix calculation

Forward-folding Process

- Apply detector effect to theory event sets→ smearing matrix



- Smearing matrix is built from uboonecode default model.

$$S_{ij} = \frac{N_{ij}^{sel}}{N_{j}^{sel}}$$

True bin *j*
Reco bin *i*

METHOD: Analysis of reconstruction performance

Smear true cross-sections calculated using both sets of GENIE theory events

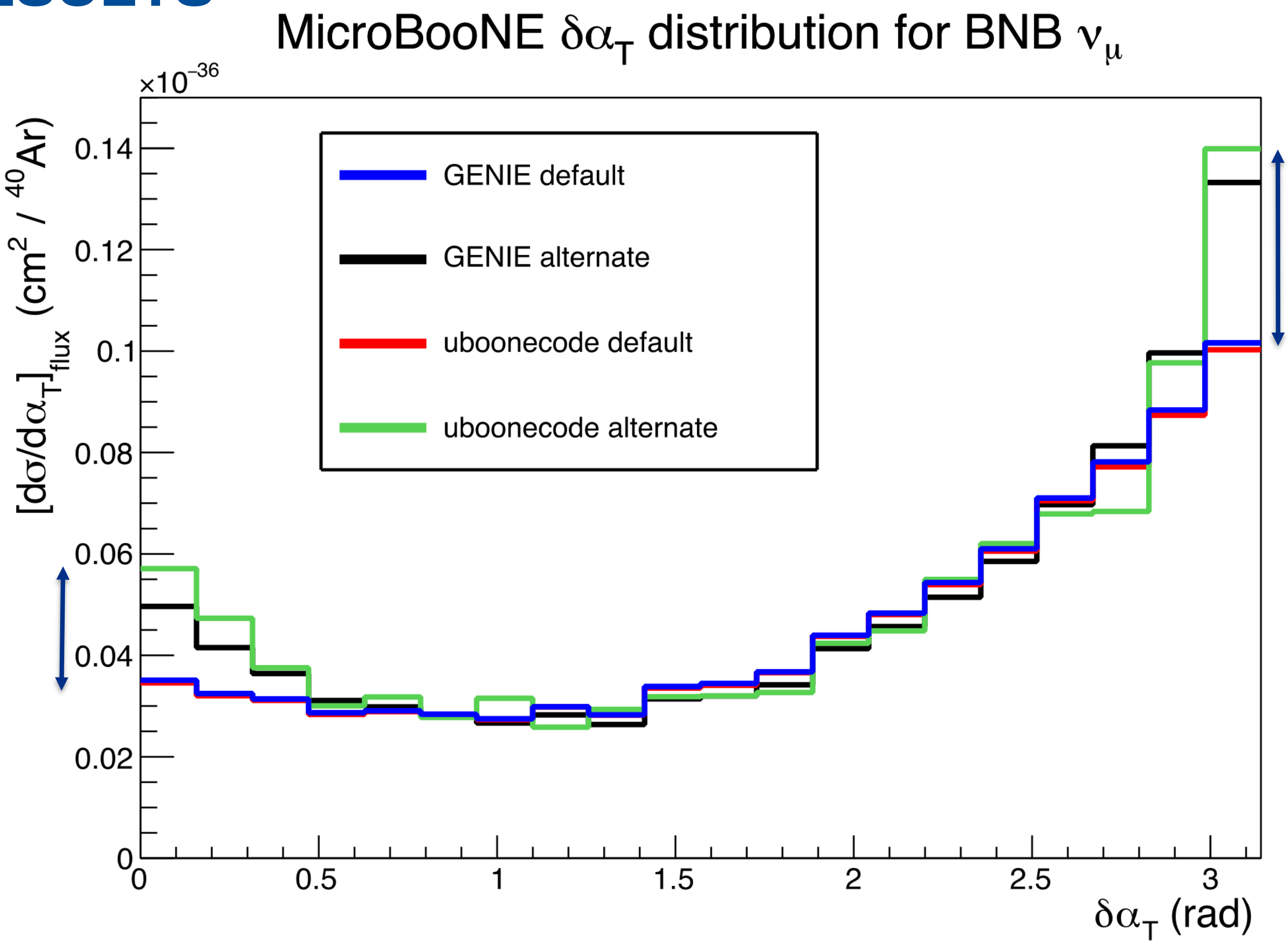
After cross-sections are obtained from the 4 samples:

1. Closure check: smeared-GENIE default = uboonecode default

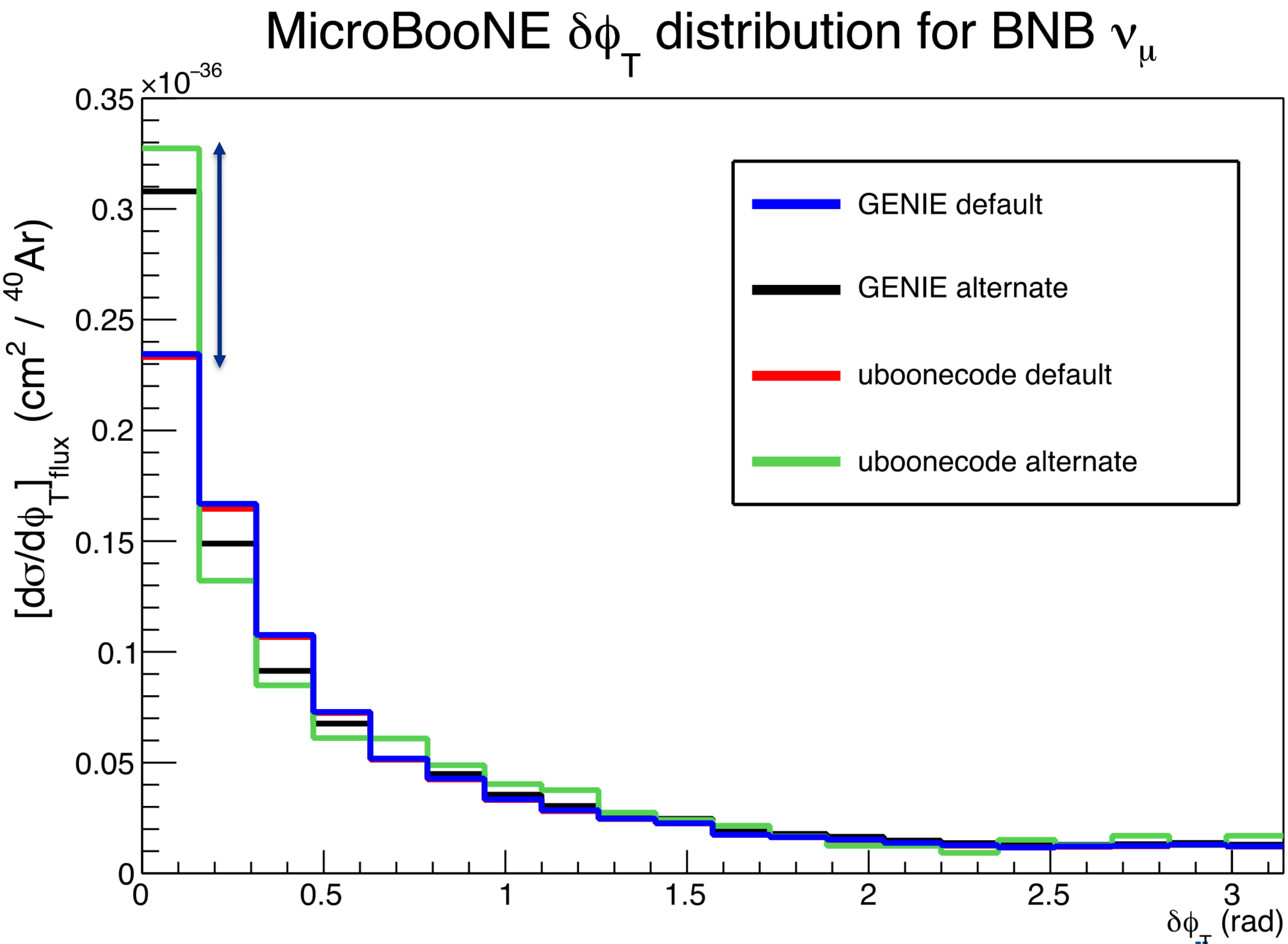
2. Main questions:

- Are the “smeared GENIE default” and “smeared GENIE alternate” results distinguishable after applying the smearing matrix?
- Does the “smeared GENIE alternate” cross section match the reconstructed “uboonecode alternate” one?

RESULTS

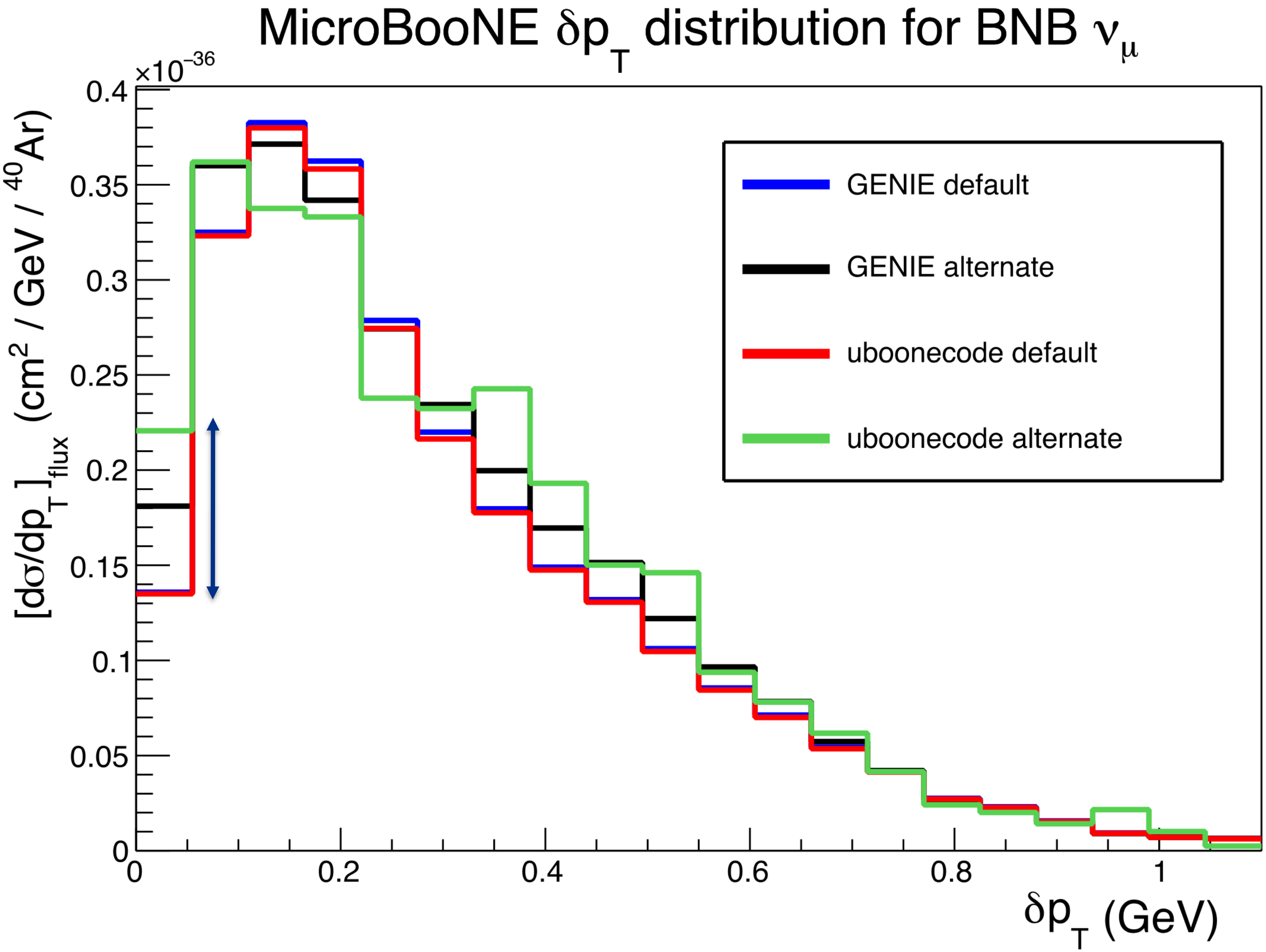

MicroBooNE $\delta\alpha_T$ distribution for BNB ν_μ
$\times 10^{-36}$
$[d\sigma/d\alpha_T]_{flux}$ (cm^2 / ^{40}Ar)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
GENIE default
GENIE alternate
uboonecode default
uboonecode alternate
0
0.5
1
1.5
2
2.5
3
$\delta\alpha_T$ (rad)

RESULTS



MicroBooNE δφ_T distribution for BNB ν_μ
×10^-36
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
[dσ/dφ_T]_flux (cm^2 / 40Ar)
0
0.5
1
1.5
2
2.5
3
δφ_T (rad)
GENIE default
GENIE alternate
uboonecode default
uboonecode alternate

RESULTS



MicroBooNE δp_T distribution for BNB ν_μ
×10^−36
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
[dσ/dp_T]_flux (cm^2 / GeV / ^40Ar)
0
0.2
0.4
0.6
0.8
1
δp_T (GeV)
GENIE default
GENIE alternate
uboonecode default
uboonecode alternate

CONCLUSION & FUTURE WORK

CONCLUSION

- This is the first "fake data" study for an emerging STV cross section analysis for MicroBooNE
- The smearing matrix shows some dependence on the default model. Nevertheless, opportunities still exist to differentiate between the two GENIE cross-section models for the angular STVs.
- Improvements in the reconstruction are needed for more reliable reconstruction of δp_T and to reduce the model-dependence of the smearing matrix.

FUTURE WORK

- Possible improvements to the analysis will be studied in the future using the tools developed here
- A combination of refinements to the event selection, cross section binning, signal definition, and reconstruction methods will be pursued

THANK YOU

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- And friends. !

REFERENCES

- T2K collaboration, *Probing Nuclear Effects at the T2K Near Detector Using Transverse Kinematic Imbalance,* in *Prospects in Neutrino Physics,* 4, 2016, 1605.00179
- MicroBooNE collaboration, *Recent Neutrino Cross Section Measurements from MicroBooNE, PoS* **LeptonPhoton2019** (2019) 065.

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