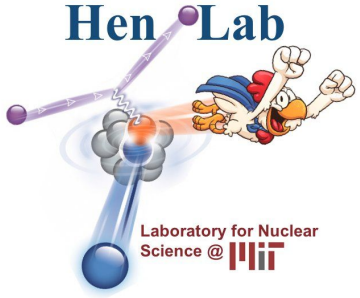
Towards The First Measurement Of Differential ν_μ-Argon Charged Current Single Transverse Variable Scattering Cross Sections

A. Papadopoulou for the μBooNE Collaboration

apapadop@mit.edu



New Perspectives, June 16-20 2021

FERMILAB-SLIDES-21-062-ND
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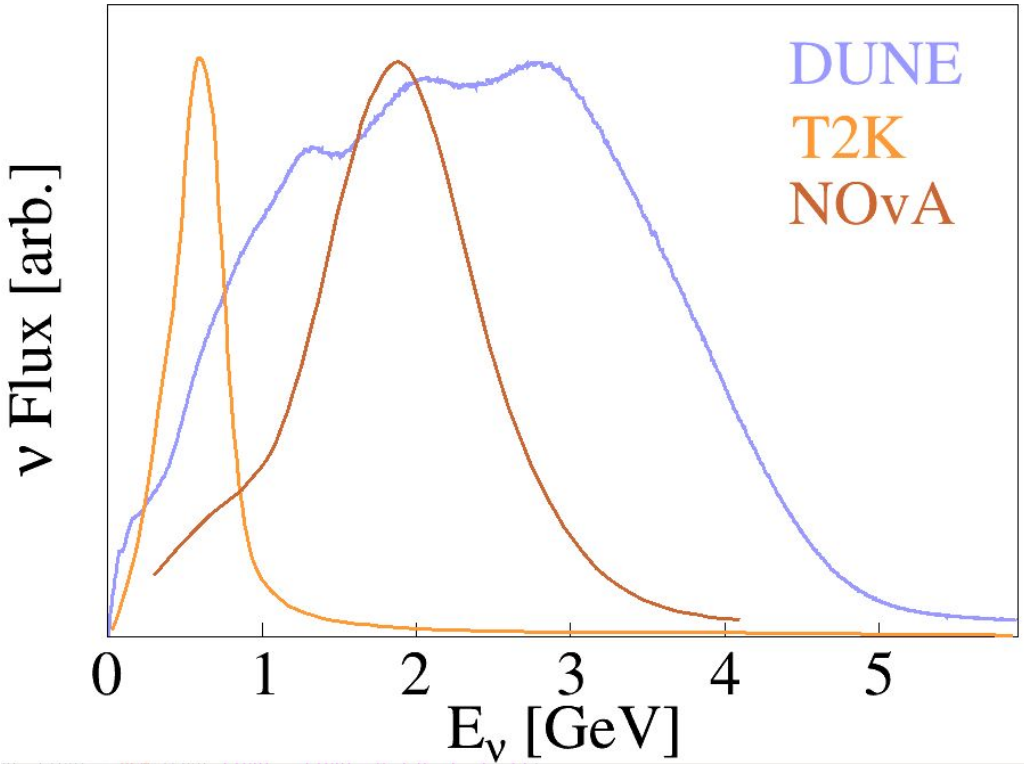
Why Precision Cross Sections Measurements?

Oscillation measurements rely on unprecedented understanding of ν-nucleus scattering



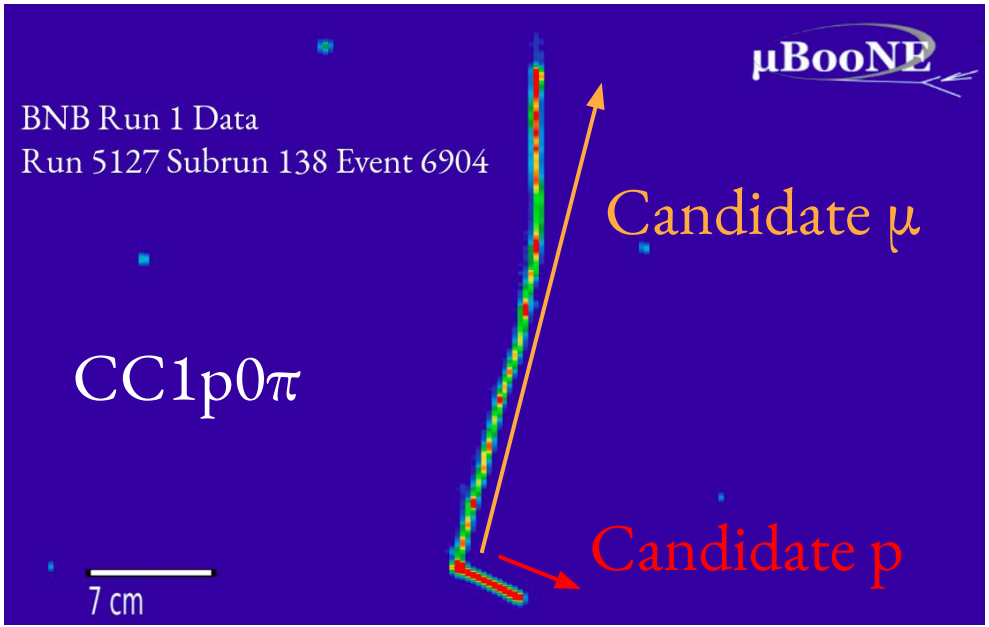
BUT … many known unknowns

- Wide ν energy spectra
- Fermi motion
- Multi-nucleon effects
- Final state interactions (FSI)
- .....

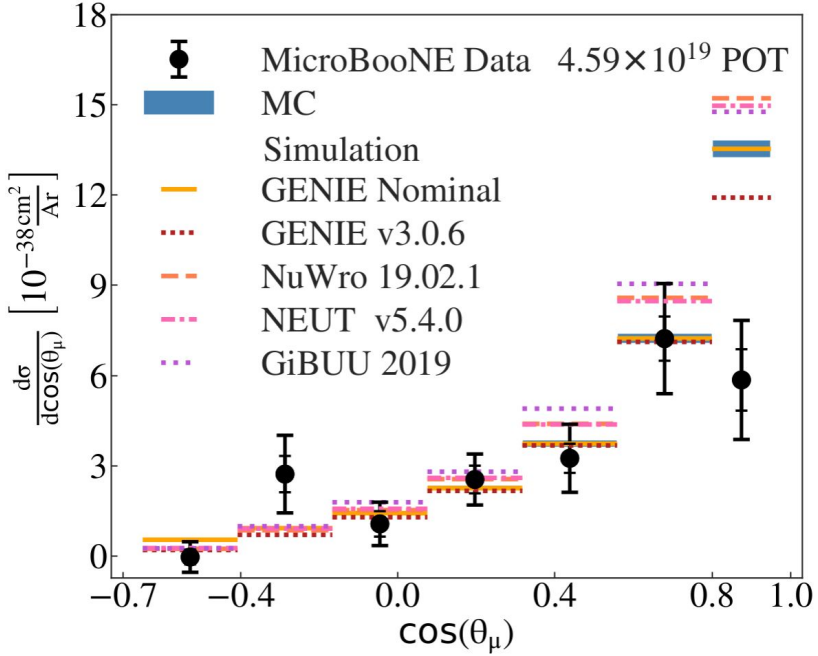
CC1p0π Interaction Channel

Simple topology, dominant at energies relevant for MicroBooNE

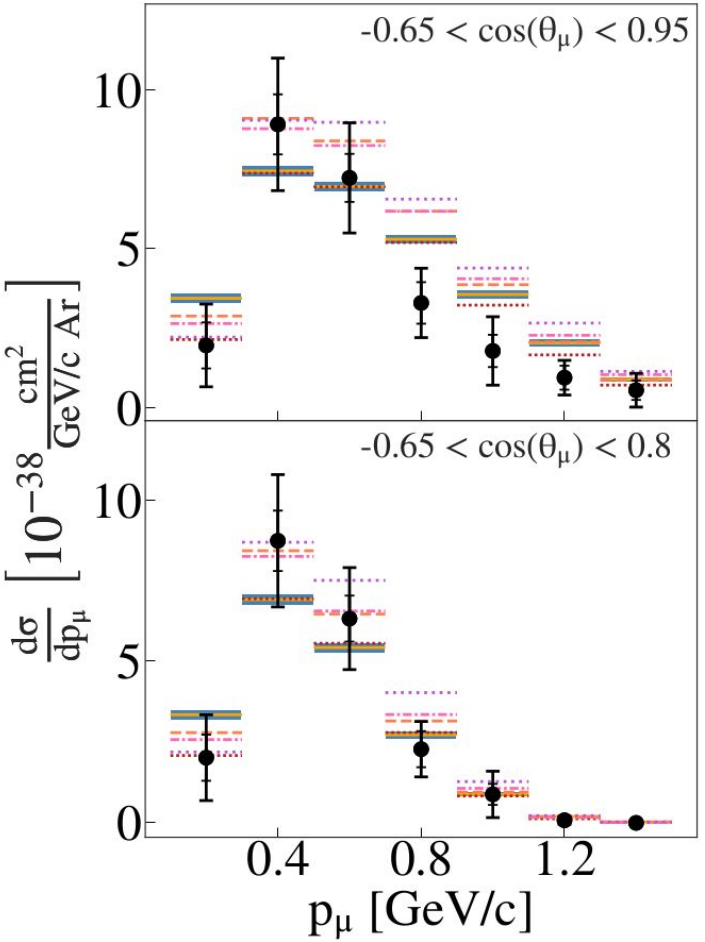
- Single muon $P_{\mu} > 100$ MeV/c
- Single proton $P_{p} > 300$ MeV/c
- No neutral pions
- No charged pions with $P_{\pi} > 70$ MeV/c



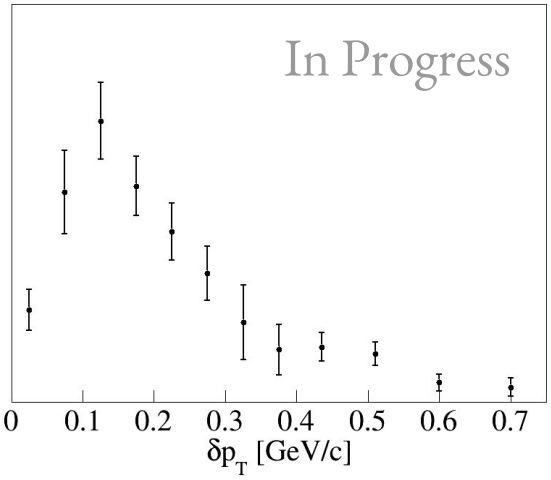
First Analysis Identified Regions Where Improvement Is Required

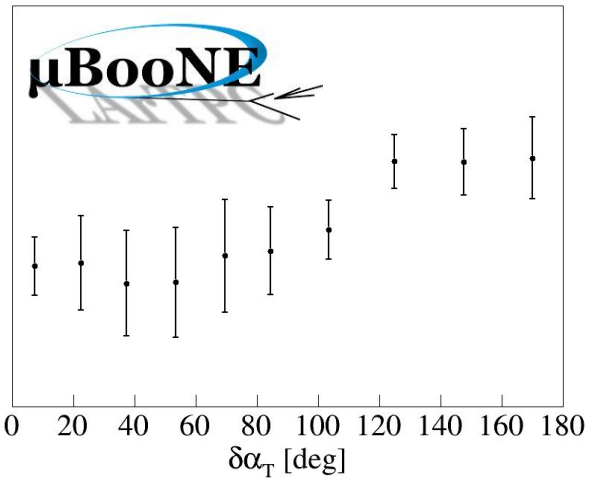


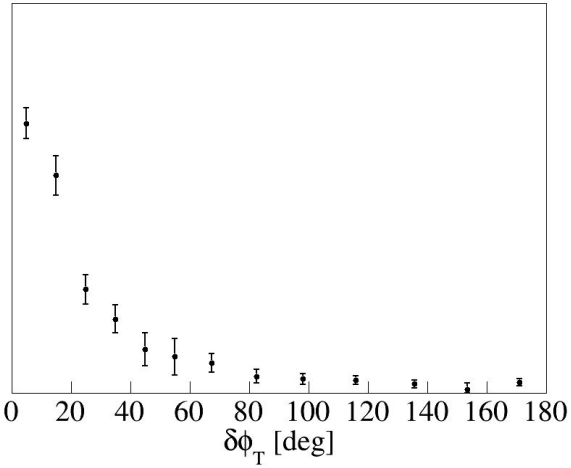
Phys. Rev. Lett. 125, 201803 (2020)



Current Analysis With Much Higher Statistics & Improved Modeling

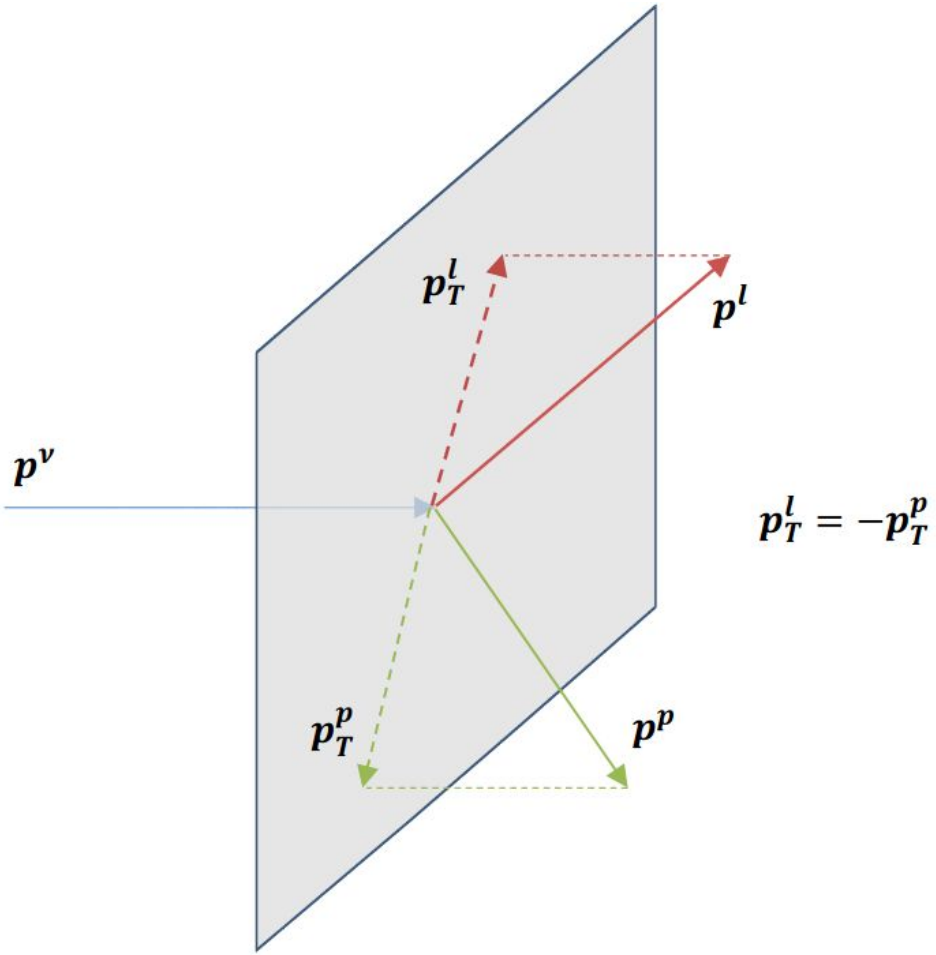






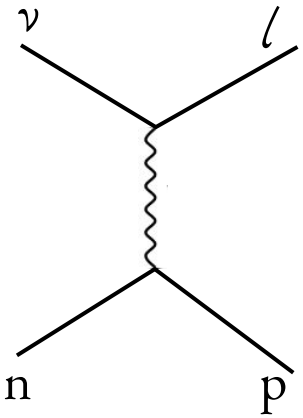
- Largest ν_μ-^{40}Ar dataset to date
- Latest version of GENIE Event Generator
  arXiv:2106.09381,
  MICROBOONE-NOTE-1074-PUB
- Currently finalizing central values & uncertainties
- Also longitudinal variables
- Today, discussion on MC sensitivities

Transverse Components Cancel Out In Absence Of Nuclear Effects

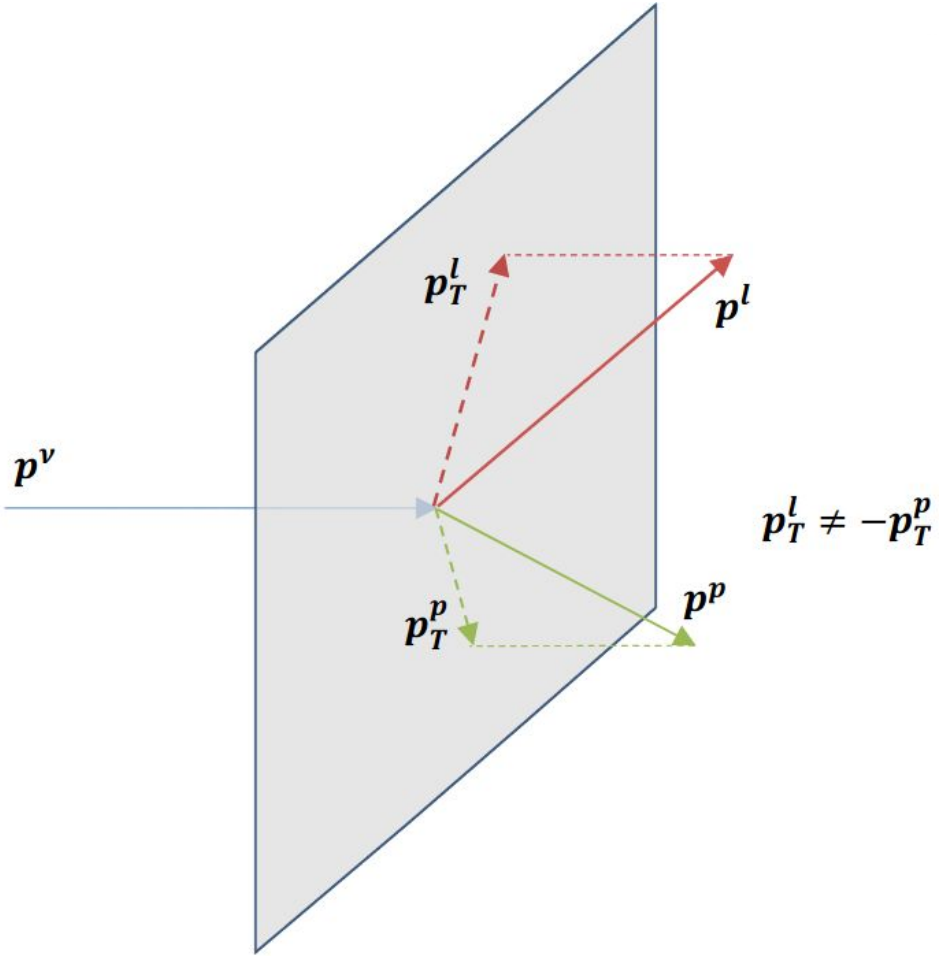


$p_T^l = -p_T^p$

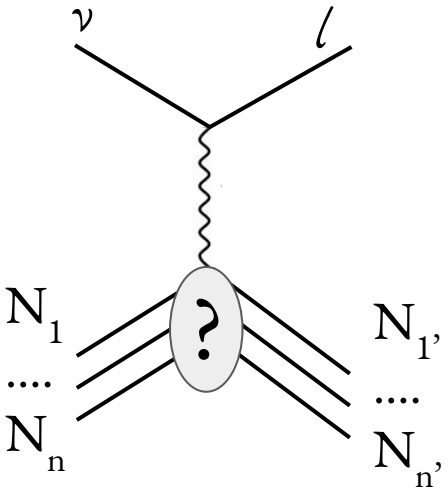
- $\delta p_T = | \mathbf{p_T}^{l} + \mathbf{p_T}^{p} | = 0$



Imbalance In The Presence Of Nuclear Effects

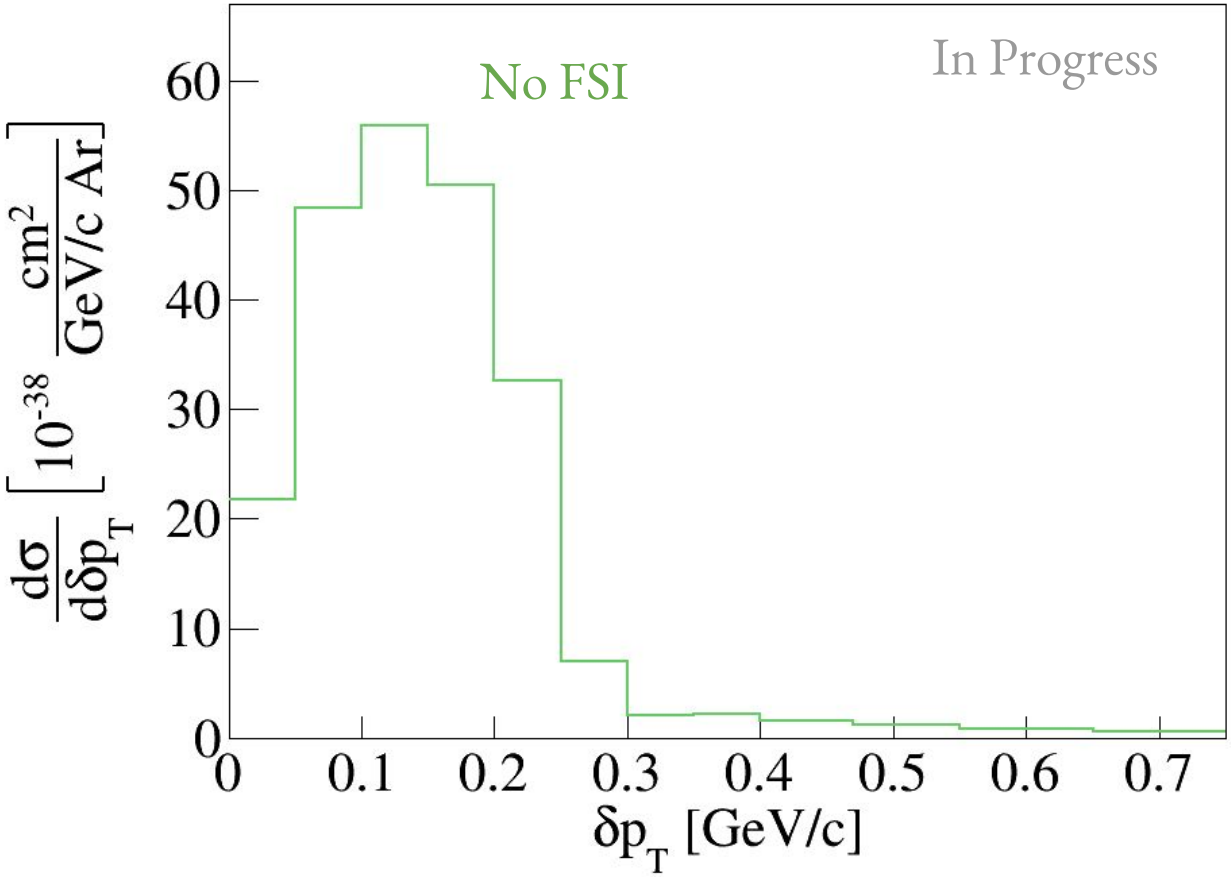


- $\delta p_T = | \mathbf{p_T}^{\ell} + \mathbf{p_T}^{p} | > 0$
  proxy for Fermi motion

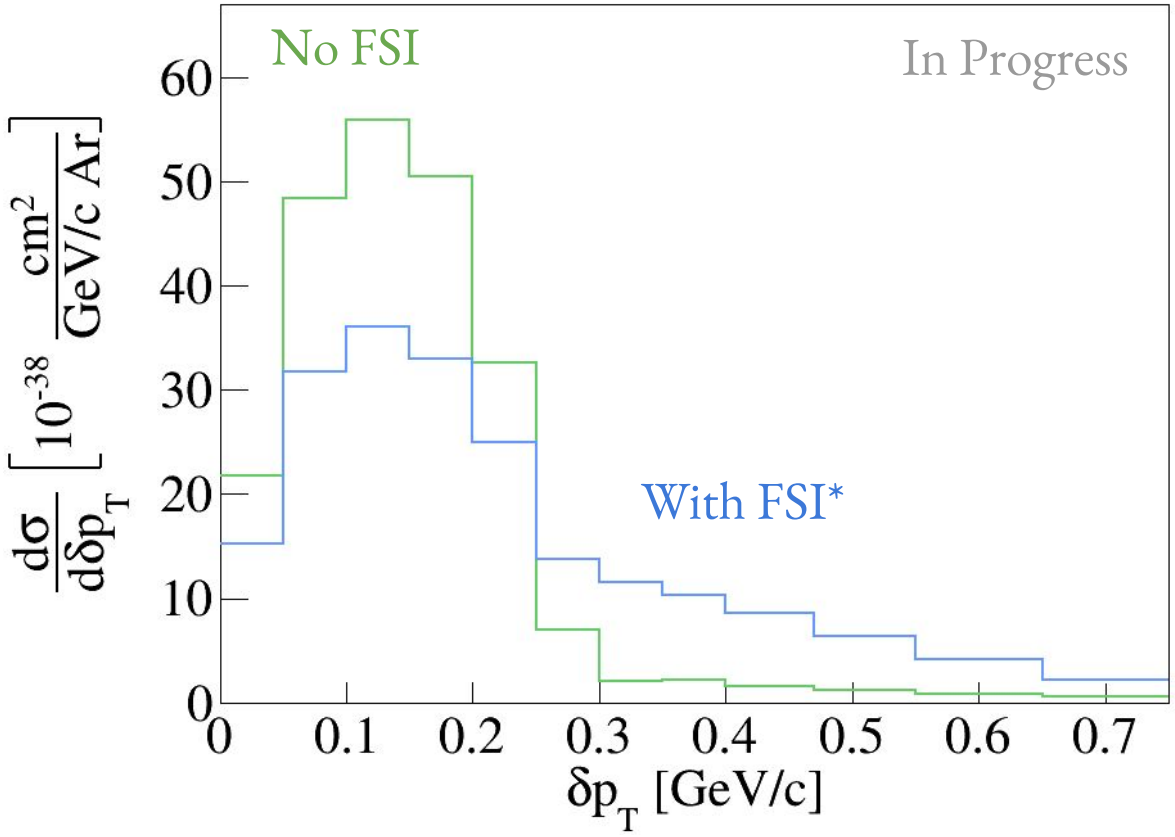


δp_T Probes Fermi Motion

MC uses Local Fermi Gas for ground state

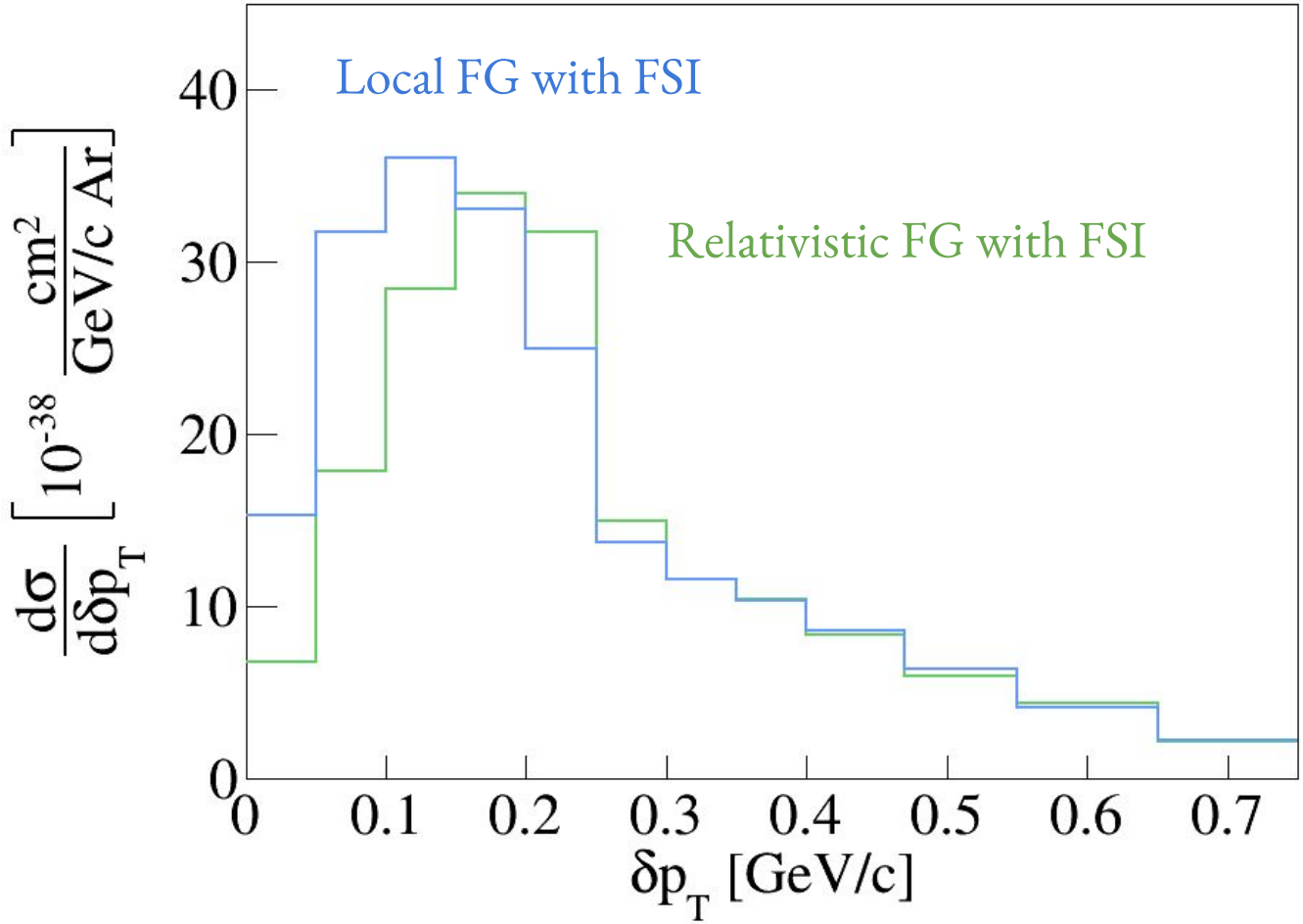


Adding FSI Gives Rise To High Momentum Tail

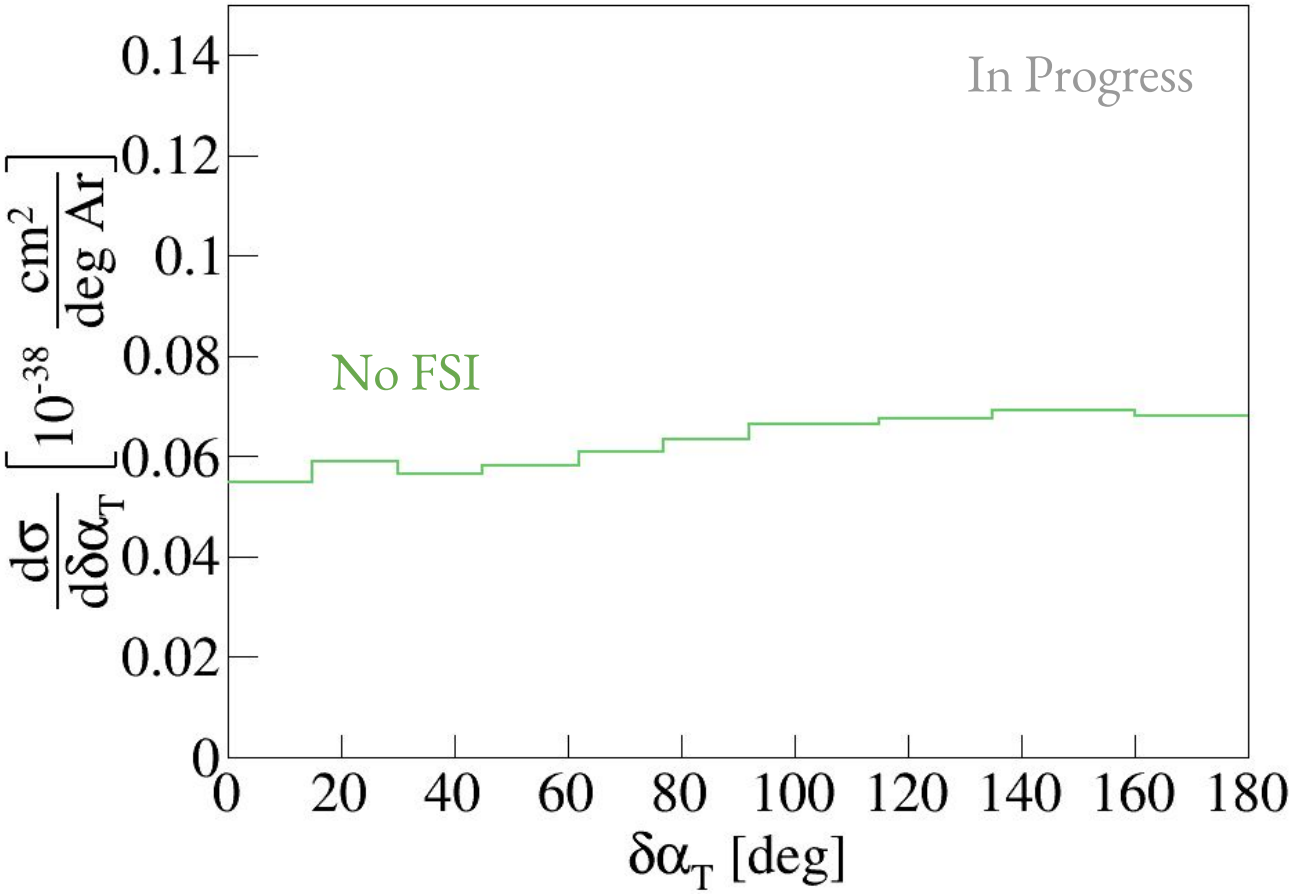


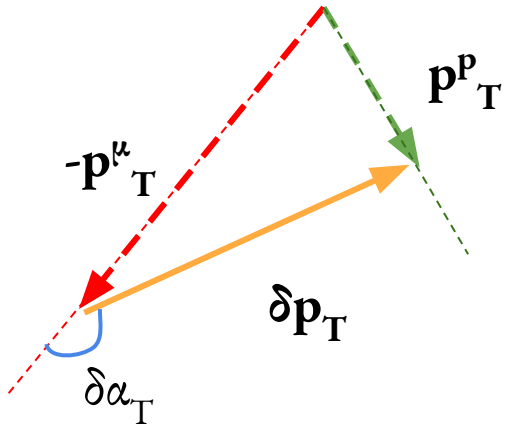
* Used as the nominal MC by the MicroBooNE Collaboration arXiv:2106.09381, MICROBOONE-NOTE-1074-PUB

Nuclear Model Shifts Peak Location

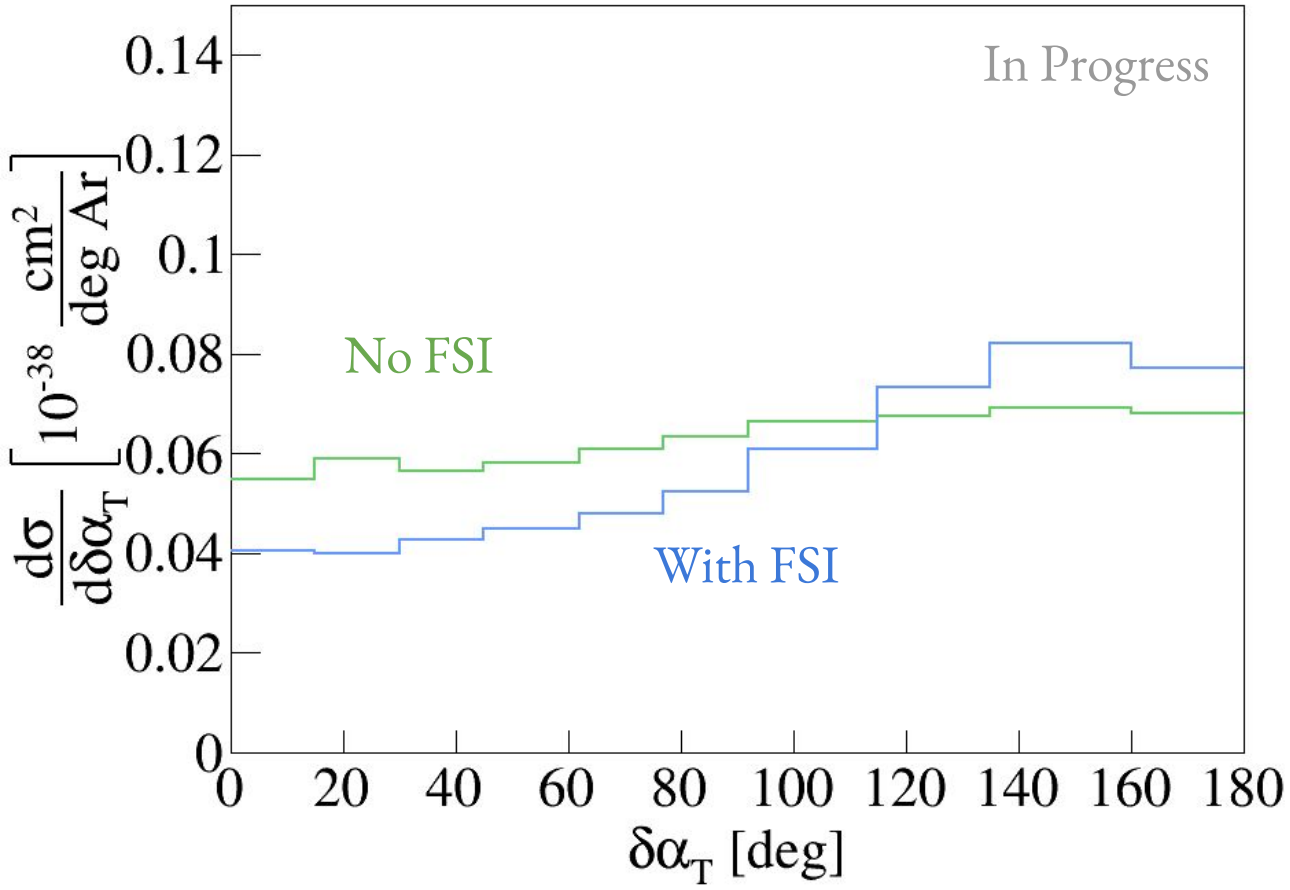


No Preferred $\delta\alpha_T$ Direction Without FSI and $\delta p_T \sim 0$

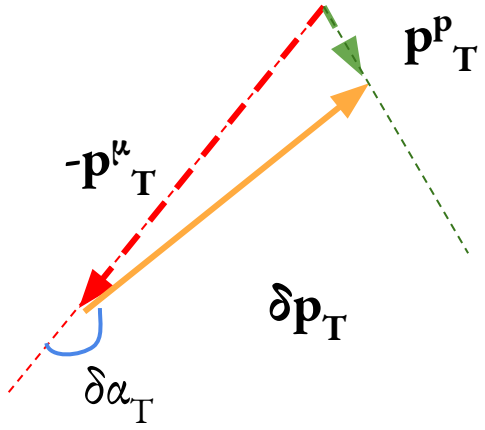




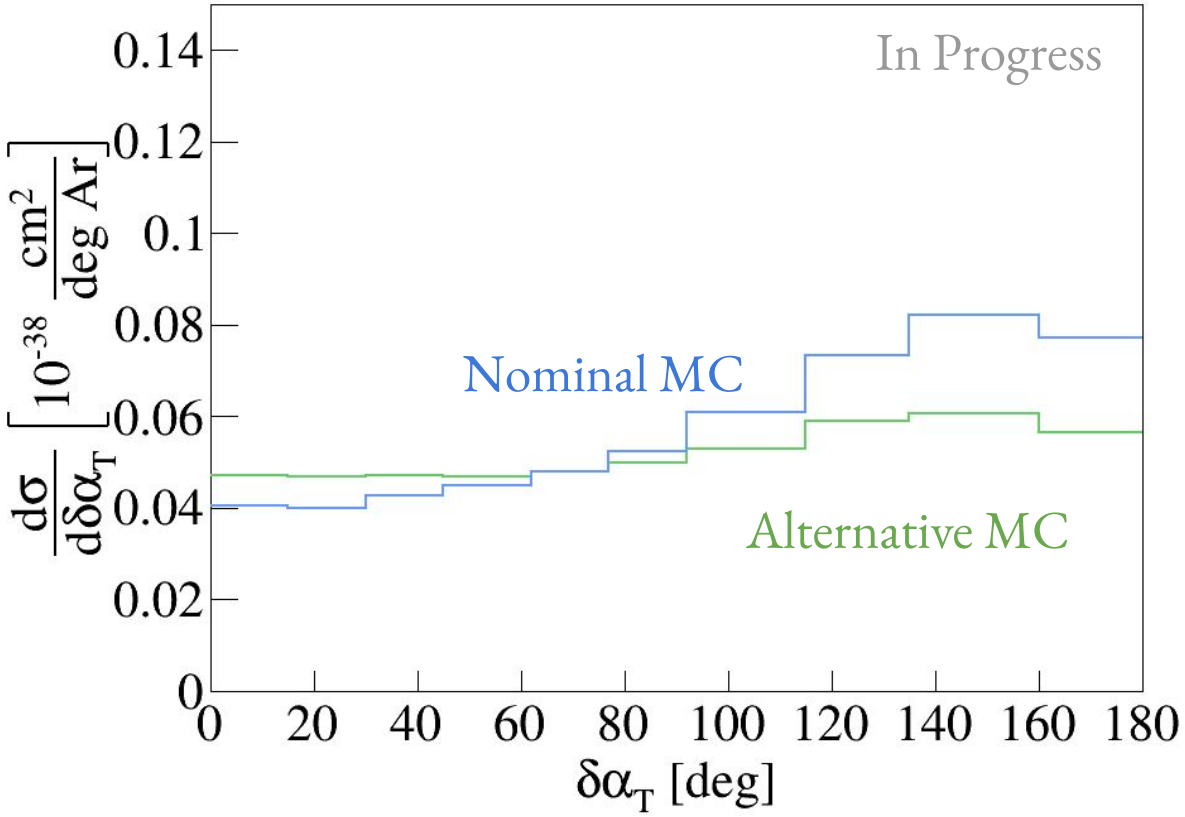
Adding FSI Causes $\delta\alpha_T$ To Rise



Proton "deceleration" due to FSI



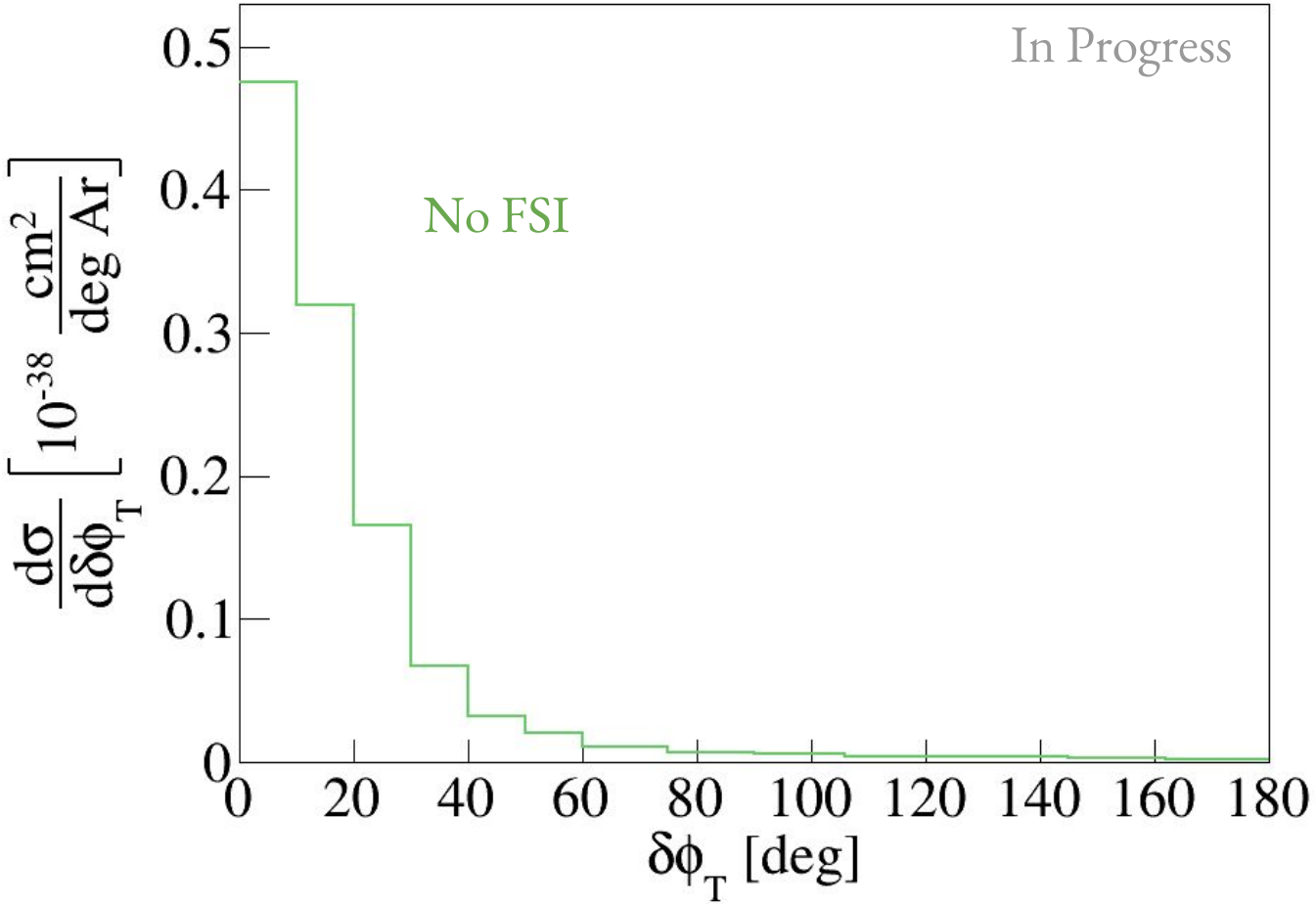
Alternative MC Doesn't Show "FSI Deceleration"

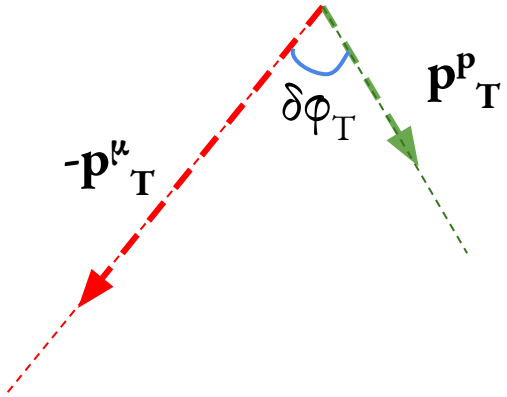


Nominal MC = GENIE v3.0.6 with MicroBooNE Tune arXiv:2106.09381

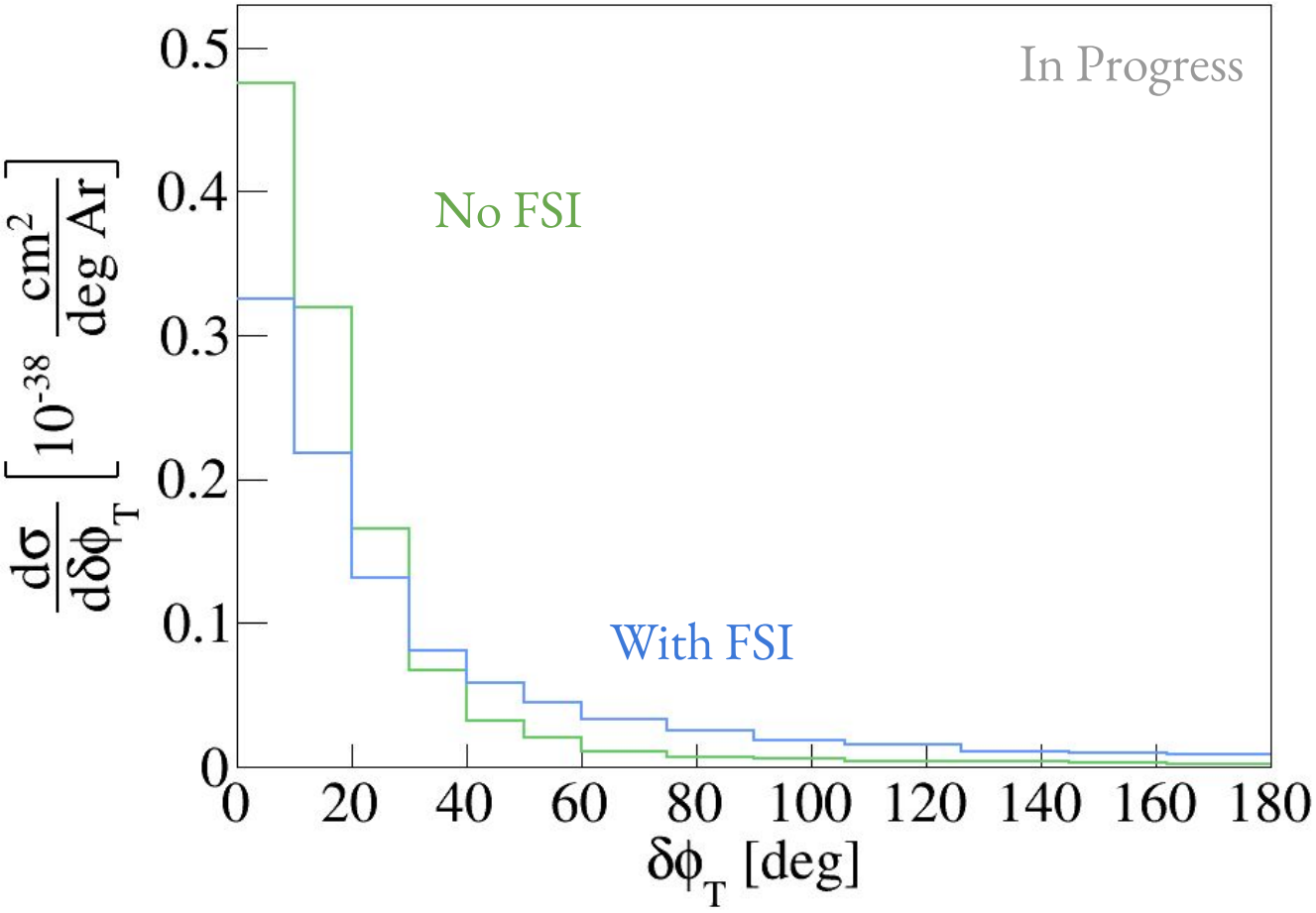
Alternative MC = NuWro Nucl.Phys.Proc.Suppl. 229-232 (2012) 499

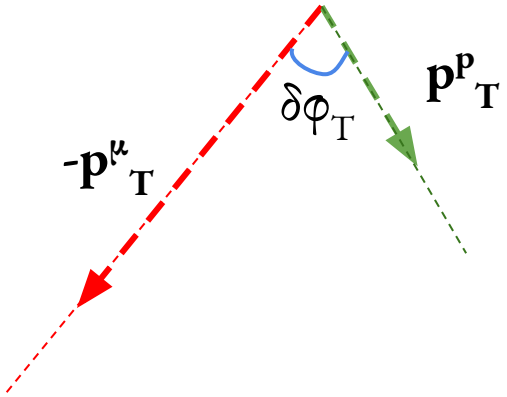
$\delta\varphi_T$ Is Small In The Absence Of FSI



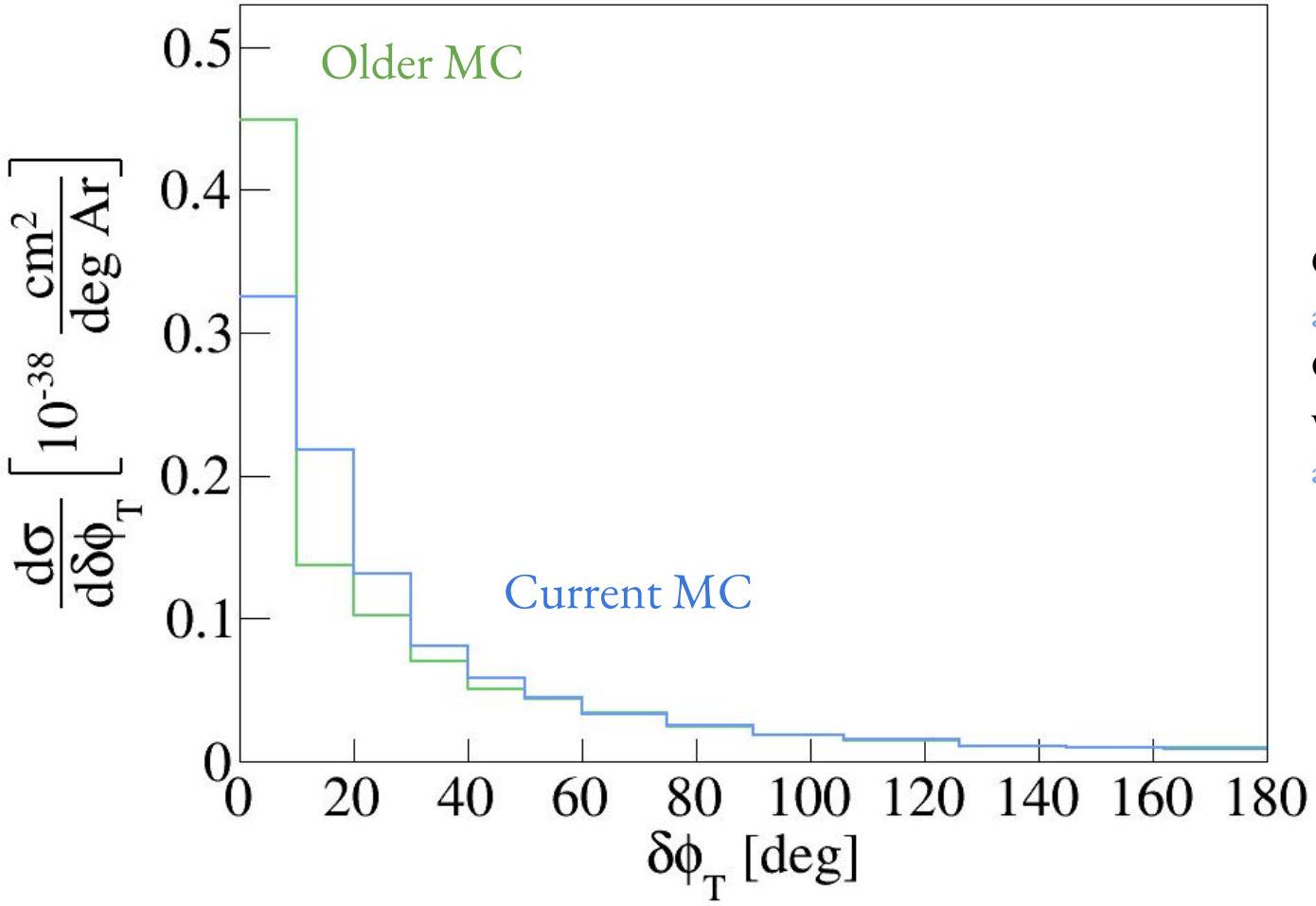


Adding FSI Gives Rise To High Angles Tail





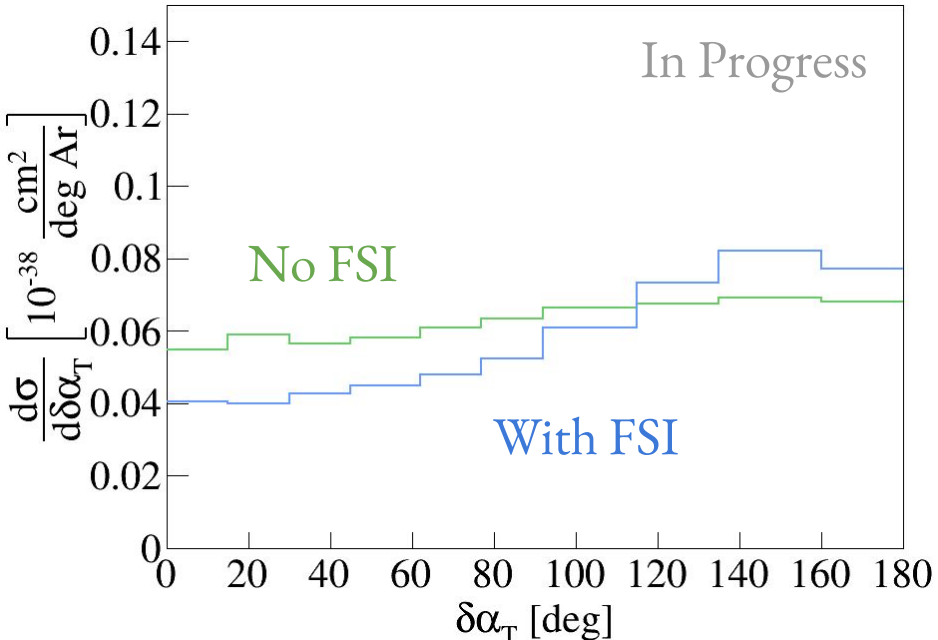
MC Versions Show Differences At Small Angles



Older MC = GENIE v2.12.10
arXiv:1510.05494
Current MC = GENIE v3.0.6
with MicroBooNE tune
arXiv:2106.09381

Wrap Up

- Single transverse variable sensitivity to nuclear models, FSI and multi-nucleon effects
- Powerful tools to reduce cross section uncertainties
- Performed the first CC1p0π analysis studying these variables on MicroBooNE



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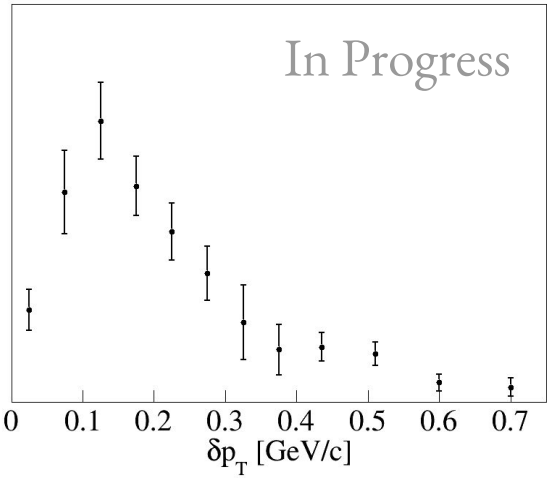

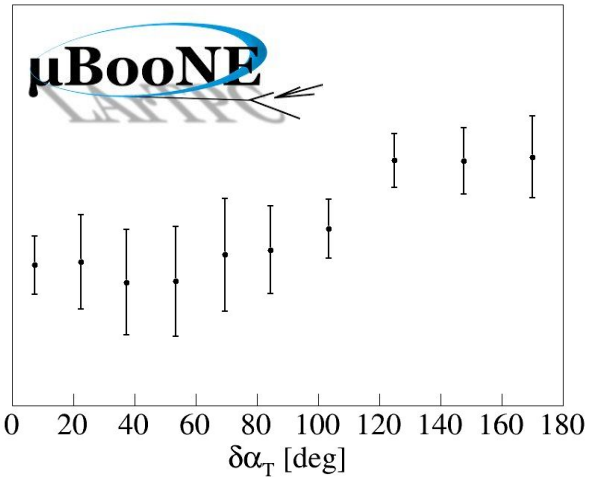

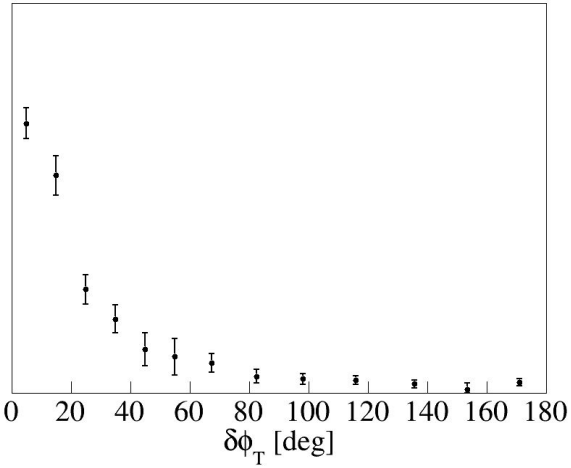

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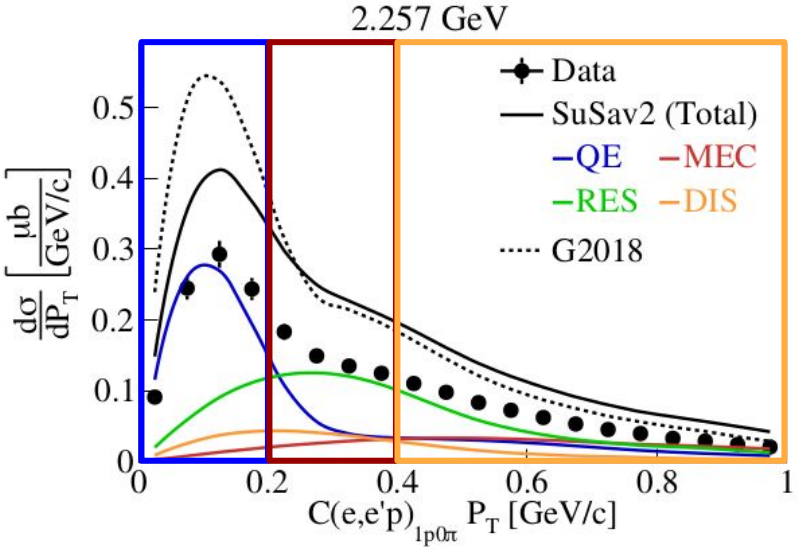
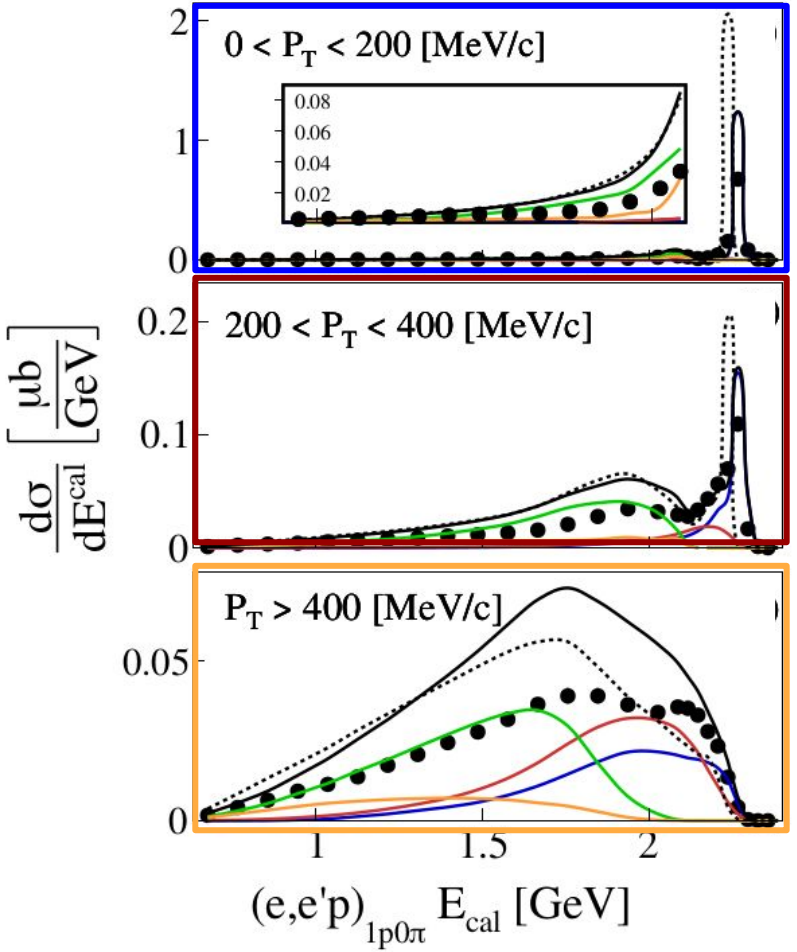
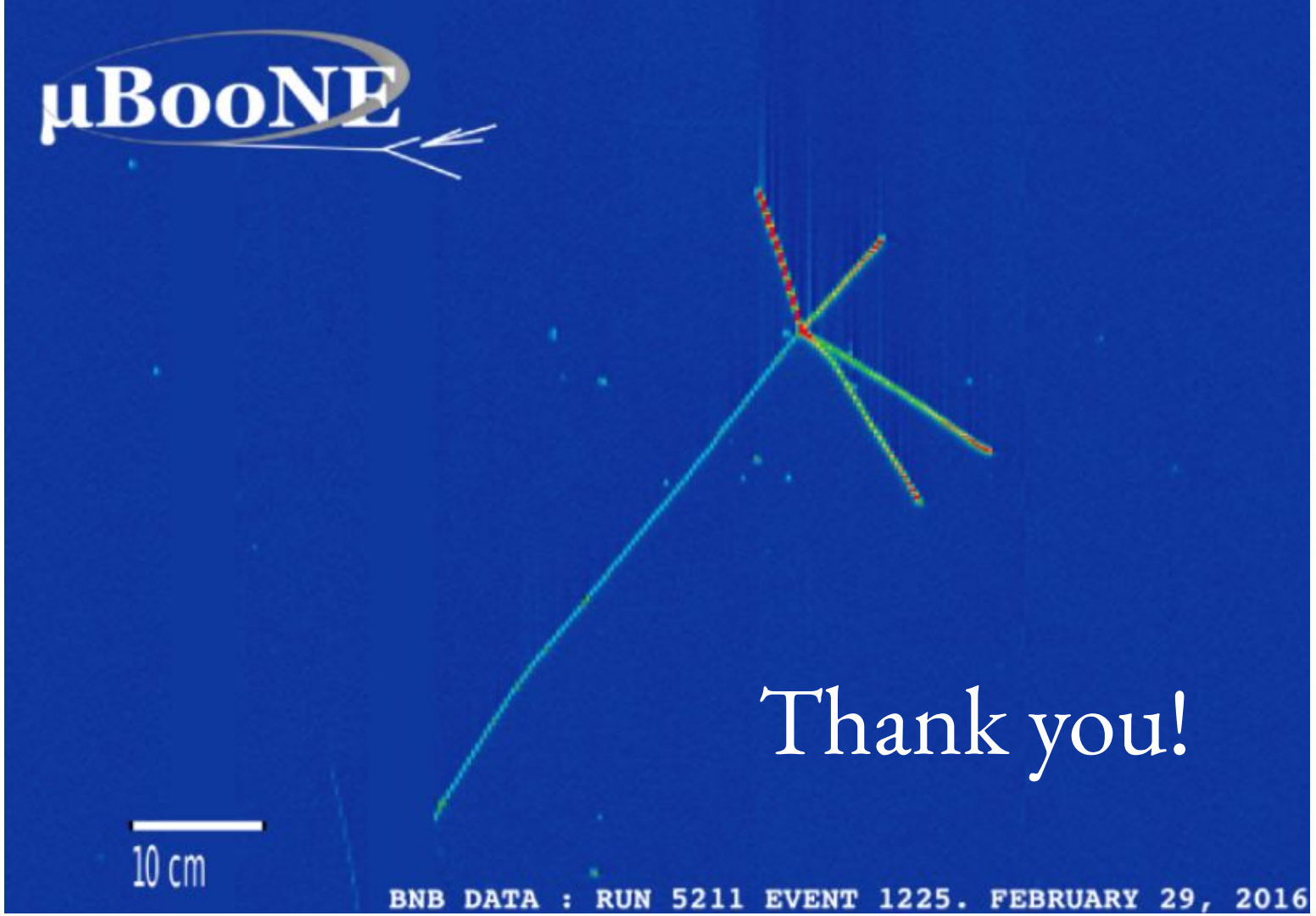
- Currently finalizing central values & uncertainties
- Today, discussion on MC sensitivities

Connections To Electron Scattering





Khachatryan and Papadopoulou et al.
Nature, in process (2021)


μBooNE
Thank you!
10 cm
BNB DATA : RUN 5211 EVENT 1225. FEBRUARY 29, 2016

Backup Slides

Largest ν_μ-Ar Dataset!

Combined Runs	Number of Events	Beam–On Equivalent
BeamOn	10952.00 ± 104.65	10952.00 ± 104.65
MC	36592.00 ± 191.29	6971.48 ± 83.50
CC1p0π MC	26953.00 ± 164.17	5135.07 ± 71.66
ExtBNB	2396.00 ± 48.95	681.35 ± 26.10
Dirt	184.00 ± 13.56	143.23 ± 11.97

Run 1	Purity (%)	Overall Efficiency (%)	Contained Part Efficiency (%)
CC1p0π	69.10 ± 0.48	10.70 ± 0.06	28.62 ± 0.17

Single Transverse Variables

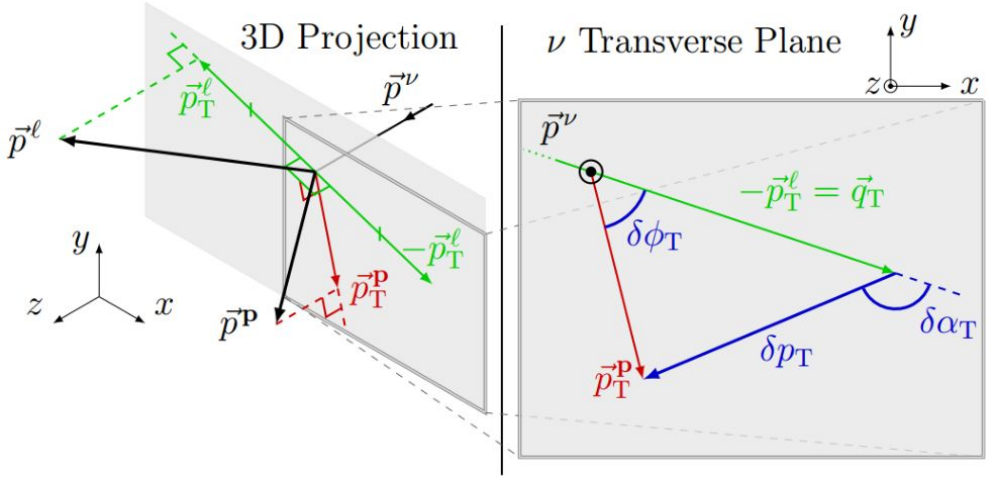
Transverse direction characterized by magnitude & 2 angles

Transverse missing momentum

$$\delta\vec{p}_{\mathrm{T}} = \vec{p}_{\mathrm{T}}^{\,\ell} + \vec{p}_{\mathrm{T}}^{\,p}$$

$$\delta\phi_{\mathrm{T}} = \arccos\frac{-\vec{p}_{T}^{\,\ell}\cdot\vec{p}_{\mathrm{T}}^{\,N}}{p_{\mathrm{T}}^{\ell}p_{\mathrm{T}}^{N}}$$

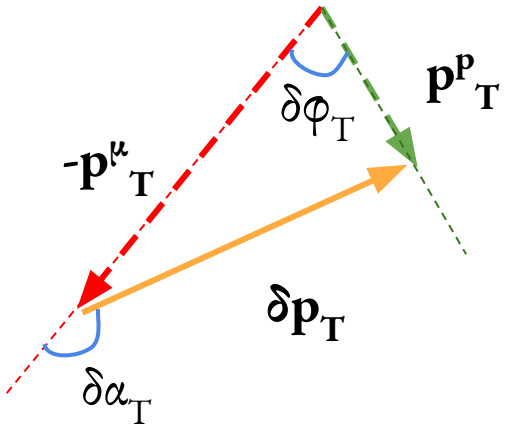
$$\delta\alpha_{\mathrm{T}} = \arccos\frac{-\vec{p}_{T}^{\,\ell}\cdot\delta\vec{p}_{\mathrm{T}}}{p_{\mathrm{T}}^{\ell}\delta p_{\mathrm{T}}}$$



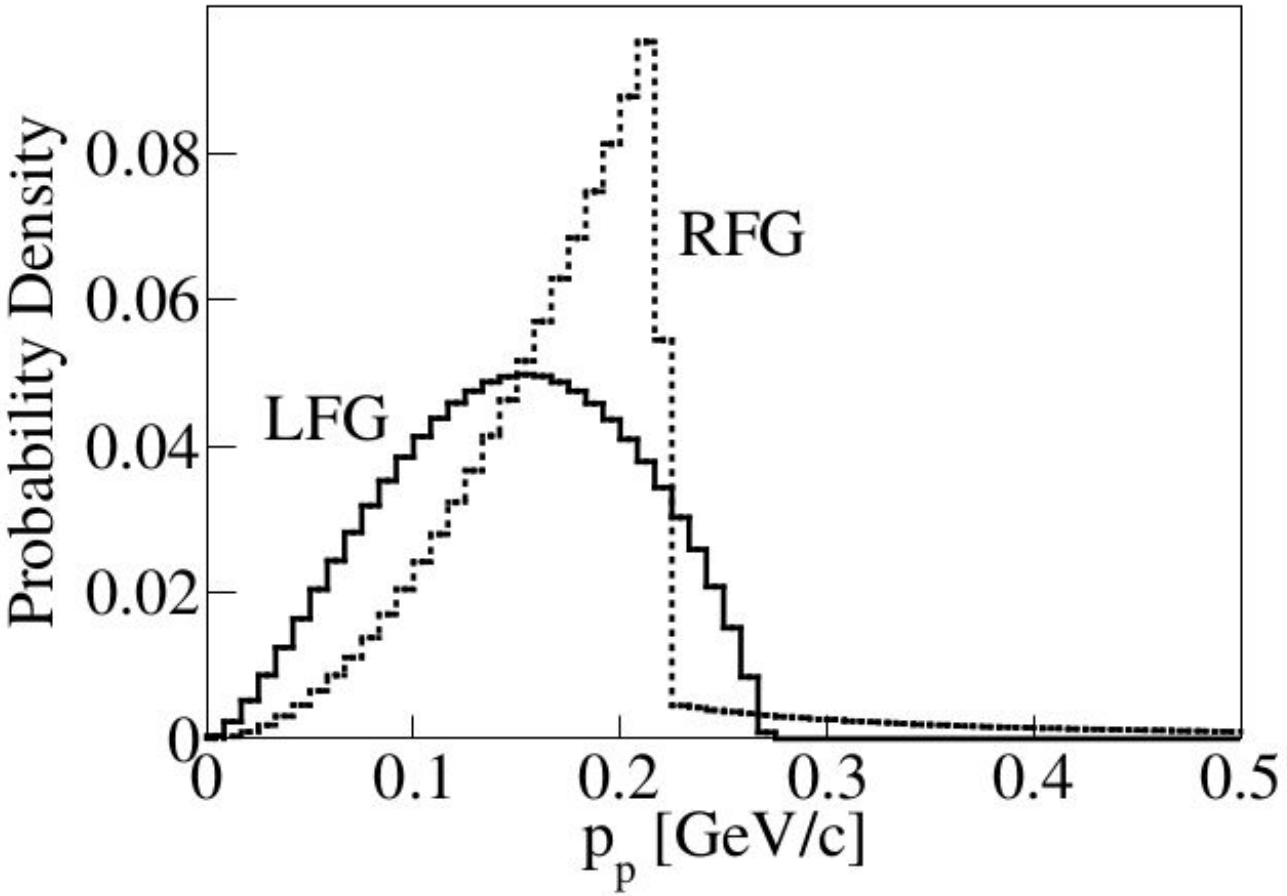
Phys. Rev. C 94, 015503 (2016)

Phys. Rev. Lett. 121, 022504

Single Transverse Variables



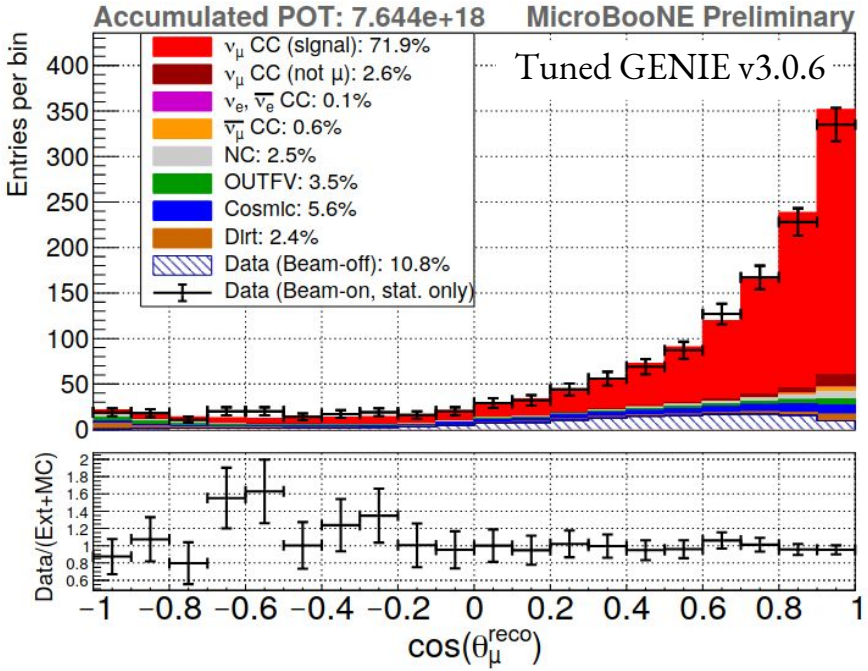
Nuclear Models In The GENIE Event Generator



Better Data/Simulation Agreement From Improved Modeling

- GENIE v2.12.2 → GENIE v3.0.6
- Tuned CCQE and CCMEC models to T2K ν_μ CC0π data
- T2K data is on a carbon target
  → Tuning seems to give good agreement with MicroBooNE's argon-target data

MICROBOONE-NOTE-1074-PUB

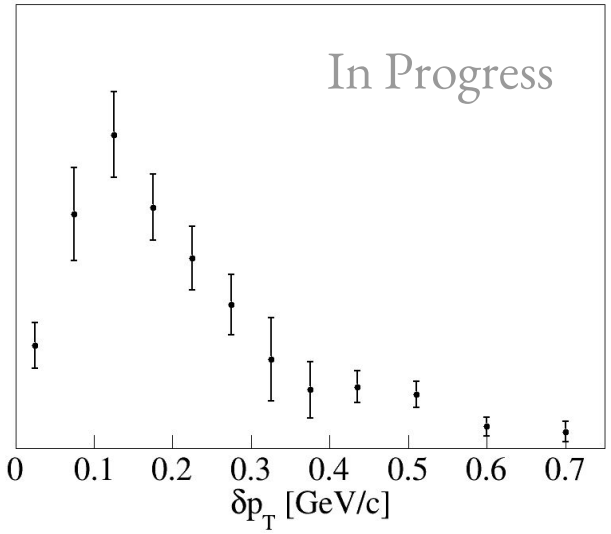


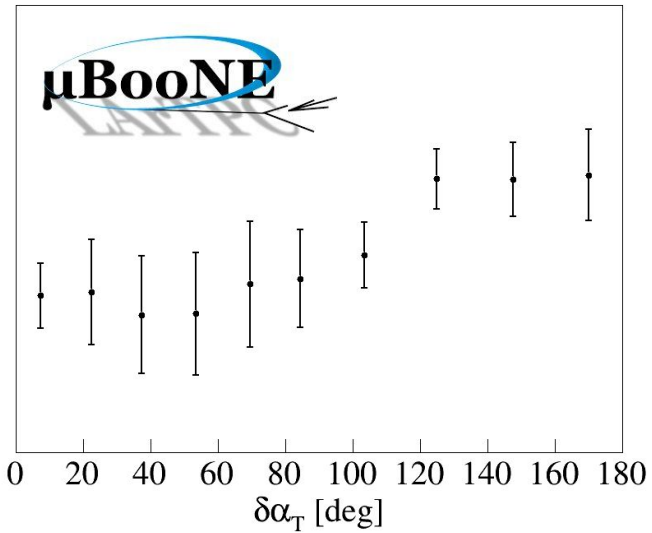
Current measurement

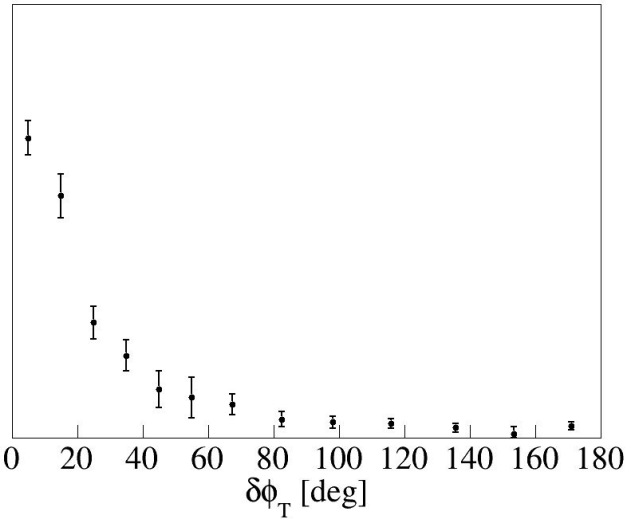
MICROBOONE-NOTE-1069-PUB

GENIE v3.0.6 G18_10a_02_11a

GENIE v3.0.6 models used:
QE/MEC → **J. Nieves, J.E. Amaro, M. Valverde** Phys. Rev. C 70, 055503 (2004) and
R. Gran, J. Nieves, F. Sanchez. M. Vicente-Vacas Phys. Rev. D 88, 113007 (2013)
RES/COH → **C. Berger, L. Sehgal** Phys. Rev. D 76, 113004 (2007), Phys. Rev. D 79, 053003 (2009)
FSI → work by **L. Salcedo, E. Oset, M. Vicente-Vacas, C. Garcia-Recio**
Nucl. Phys. A 484, 557-592 (1988) and **V. Pandharipande, S.C. Pieper** Phys. Rev. C 45, 791-798 (1992)







- High statistics & fine binning
- Currently finalizing central values & uncertainties
- Excellent handle to study known unknowns
- Today discussion on MC sensitivities