Investigating Neutrino-Nucleus Scattering in MicroBooNE

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Methodology

We generate one proton knockout events,

$$\nu_\mu + {}^{40}Ar \;\rightarrow\; \mu + p + X \qquad (1)$$

where X is the residual system, according to a fully differential unfactorized cross-section calculation in the Relativistic Distorted Wave Impulse Approximation (RDWIA)

$$\left\langle \frac{d^6\sigma}{d\vec{k}_l d\vec{p}_N} \right\rangle = f_x \int dE\, \varphi(E)\rho(E_m) L_{\mu\nu} H^{\mu\nu}. \qquad (2)$$

Here f_x is a pre-factor, $\rho(E_m)$ is a realistic energy density, $\varphi(E)$ is the neutrino flux. $L_{\mu\nu}$ is the lepton tensor, and $H^{\mu\nu}$ is the hadron tensor which includes high-momentum components from short-range correlations [1]. We make use of the Energy-Dependent Relativistic Mean Field (EDRMF) model which employs a mean-field potential multiplied by an energy-dependent factor [1]. We also use a Relativistic Optical Potential (ROP) of which, the imaginary part removes the inelastic final-state interactions. The latter describes the cross-section when rescattered protons do not contribute to the experimental signal [2]. In the absence of distortion, we have the Relativistic Plane Wave Impulse Approximation (RPWIA).

To explicitly account for inelastic Final-State Interactions (FSI), we use the intranuclear cascade model from the NEUT event generator [3].

Results with MicroBooNE data

MicroBooNE is the first experiment to measure double-differential cross-sections in terms of transverse kinematic imbalance on ^{40}Ar [4]. The missing transverse momentum is defined as

$$\delta\vec{p}_T \equiv \vec{p}_T^{\,\mu} + \vec{p}_T^{\,p} \qquad (3)$$

were superscripts μ and p indicate the muon and proton, respectively and 'T' denotes components of the momentum transverse to the direction of the beam. Its angle with respect to $\vec{p}_T^{\,\mu}$ is

$$\delta\alpha_T \equiv \cos^{-1}\frac{-\vec{p}_T^{\,\mu}\cdot\delta\vec{p}_T}{|p_T^\mu||\delta p_T|}\,. \qquad (4)$$

We can see in Fig.1, the RPWIA and the EDRMF models over-predict the data in the small δp_T region and are under-predicting at higher values. This is because FSI shifts the cross-section towards higher δp_T and $\delta\alpha_T$. We can see that once the NEUT cascade is applied, the models with NEUT predict the correct shape of the distribution. The ROP underpredicts because it removes all strength from inelastic FSI.

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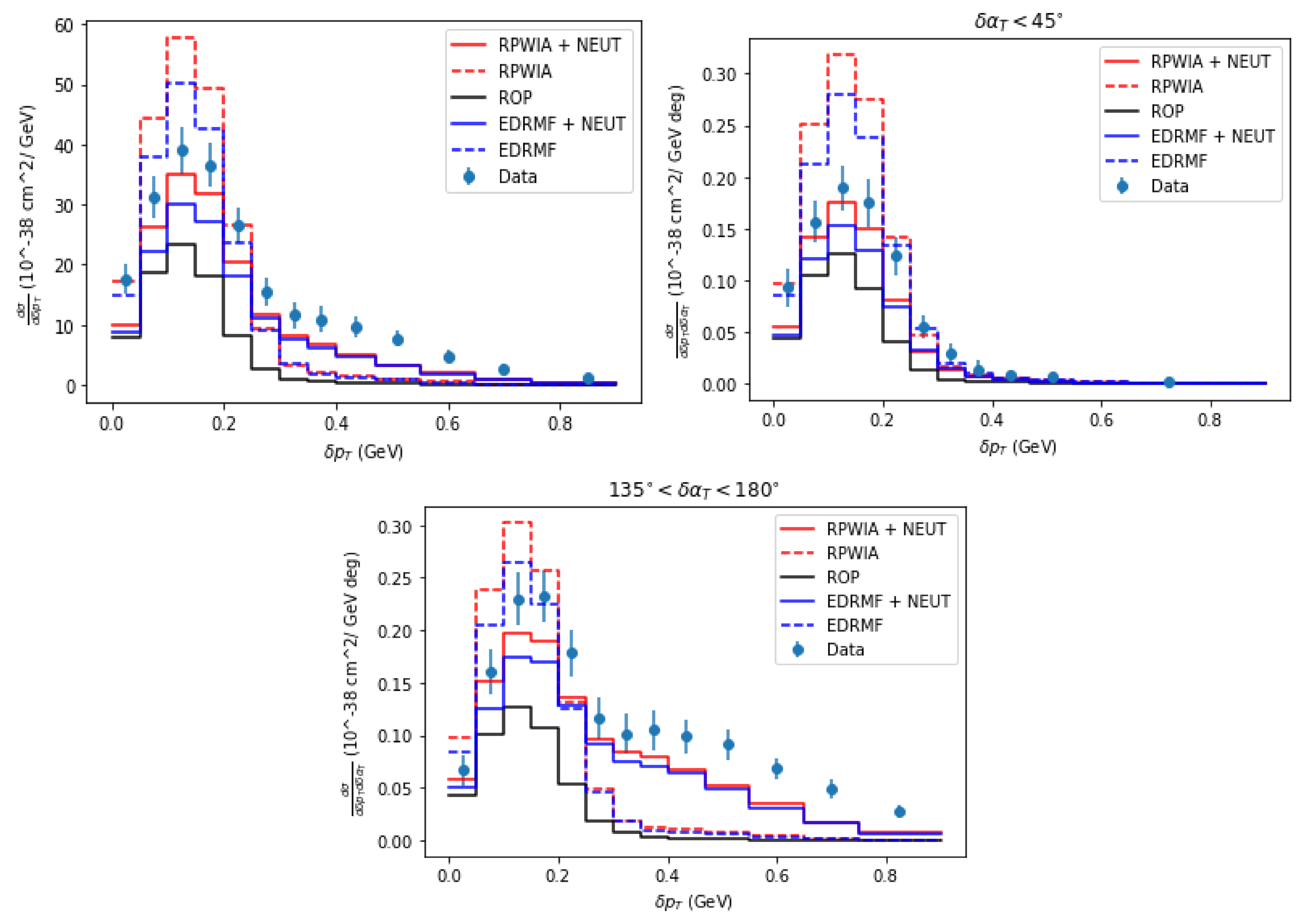

Fig.1: The flux-averaged single- (top-left) and double-differential cross-sections as functions of δpT and δαT, compared to MicroBooNE data [4].

A-Dependence of Observables

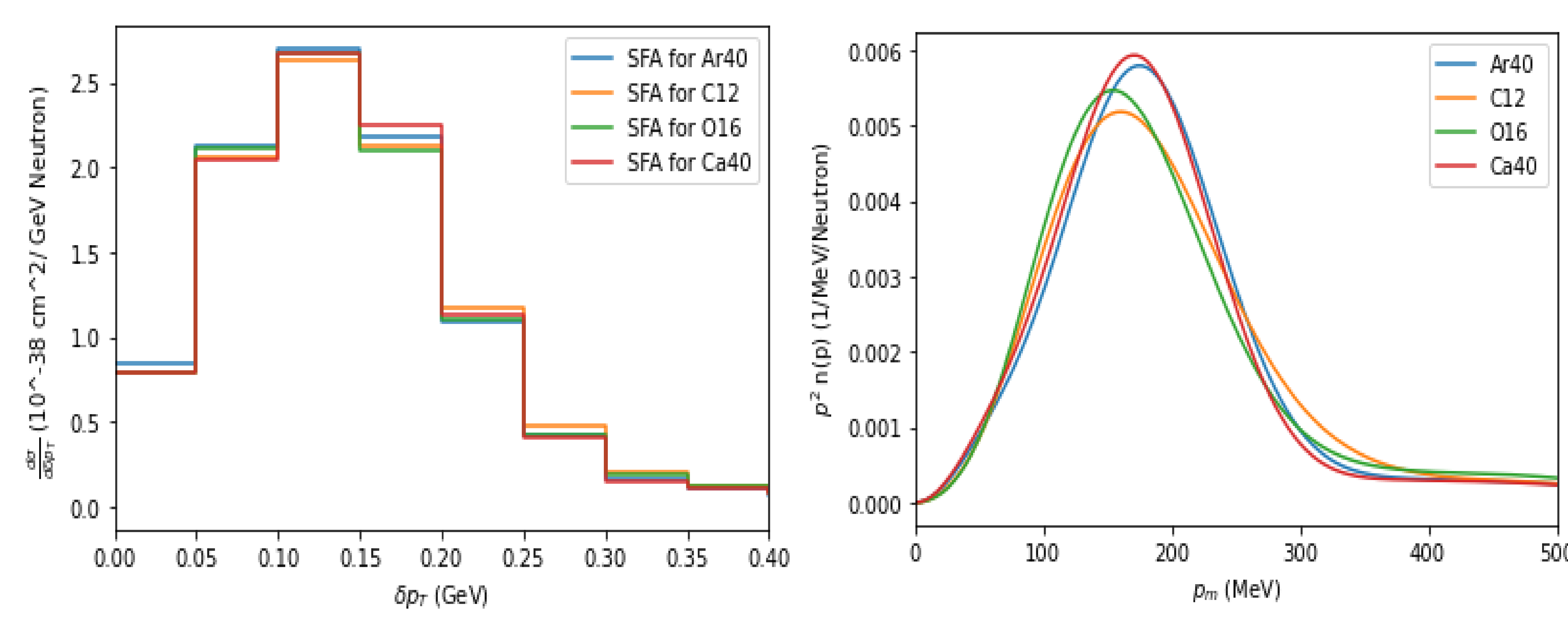

Fig.2: (left) MicroBooNE flux-integrated cross-section as a function of δp_T obtained with spectral functions for different nuclei, binned according to the experimental resolution. (right) Momentum distributions from the different nuclear spectral functions.

To assess the sensitivity of the data to the nuclear spectral function we compare PWIA calculations that use realistic spectral functions for ^{12}C, ^{16}O, ^{40}Ca, and ^{40}Ar [5]. When normalized per neutron, we find that the calculations for different nuclei are indistinguishable with current experimental resolution. An example of δp_T is shown in Fig.2.

Conclusion

We find that for (R)PWIA calculations of single-nucleon knockout, the experimental observables of [4] are insensitive to variations in realistic nuclear spectral functions. Including distortion, we see a significant reduction of the cross-section compared to plane-wave calculations. Events that undergo inelastic FSI provide a significant contribution even at $\delta p_T < 200$ and for small $\delta\alpha_T$. The description of the data might be improved by including scattering mechanisms beyond proton knockout.

References

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