Semi-Inclusive Charged-Current Neutrino-Nucleus Reactions: Analysis of Data in the Relativistic Plane-Wave Impulse Approximation

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Abstract

Semi-inclusive neutrino-nucleus cross sections within the plane-wave impulse approximation (PWIA) for three nuclear models: relativistic Fermi gas (RFG), independent-particle shell model (IPSM) and natural orbitals shell model (NO) are compared with the available CC0π measurements from the T2K[1], MINERvA[2] and MicroBooNE[3] collaborations where a muon and at least one proton were detected in the final state. Results are presented as a function of the momenta and angles of the final particles, as well as in terms of the imbalances between proton and muon kinematics. The analysis reveals that contributions beyond PWIA are crucial to explain the experimental measurements and that the study of correlations between final-state proton and muon kinematics can provide valuable information on relevant nuclear effects such as initial state dynamics and final state interactions.

Semi-inclusive neutrino-nuclei reactions in the PWIA

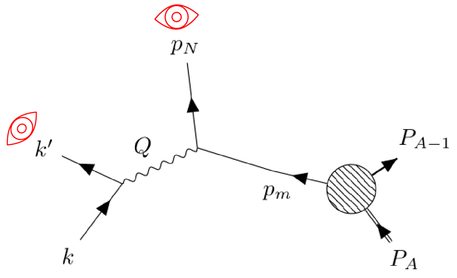

Figure 1. Schematic representation of the process in the PWIA. The final lepton (k') and proton (p_N) are detected in coincidence.

In PWIA, the neutrino-nucleus fifth-differential cross section[4,5] factorizes into two terms: one corresponds to the weak interaction of the neutrino with a single nucleon of the nucleus and the other is the nuclear spectral function that contains information about the nuclear dynamics.

$$\frac{d\sigma}{dk' d\cos\theta_l dp_N d\cos\theta_N^L d\phi_N^L} = \frac{(G_F \cos\theta_c k' p_N)^2 m_N}{8k\varepsilon' E_N (2\pi)^5} \mathcal{V}_0 \mathcal{F}_\chi^2 S(p_m, \mathcal{E}_m)$$

Instead of defining the cross section as function of the final muon and proton momentum and angles, we could use another set of variables, like the transverse kinematic imbalances[6] (TKI), that are especially designed to enhance some nuclear effects and require the detection in coincidence of the final muon and an ejected nucleon.

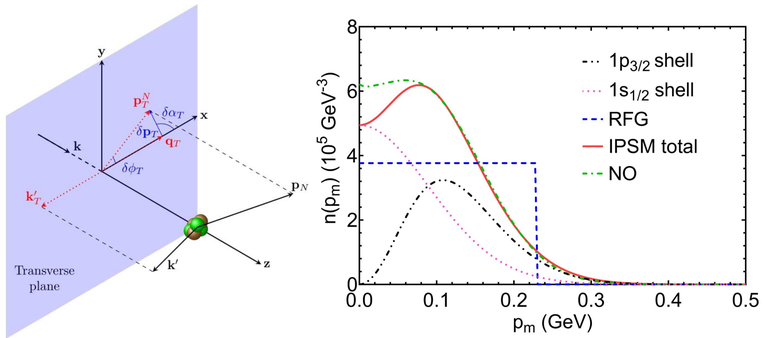

Figure 2. Definition of the TKI as function of final lepton and proton kinematics (left) and momentum distribution of neutrons in ^{12}C for different nuclear models (right).

Results

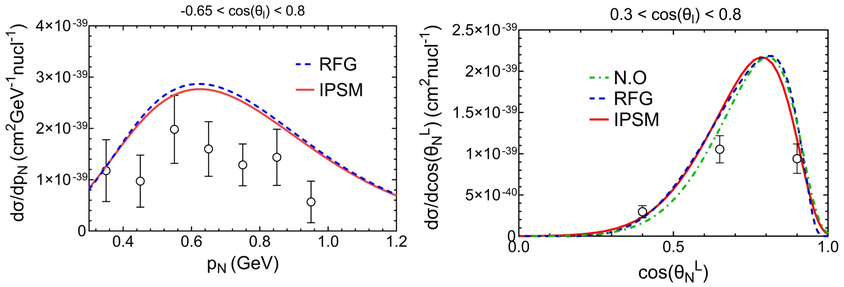

Figure 3. MicroBooNE (^{40}Ar left) and T2K (^{12}C right) semi-inclusive cross sections as function of muon and proton kinematics for different nuclear models.

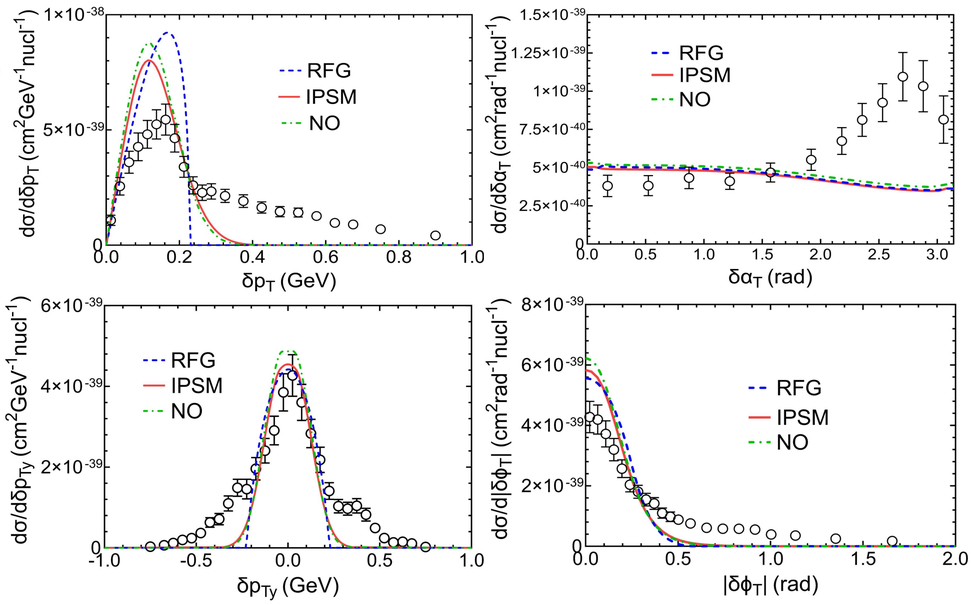

Figure 4. MINERvA semi-inclusive cross sections as function of the TKI.

Summary and outlook

- Theoretical predictions for the cross sections as function of the muon and proton momenta and angles show very little dependence on the nuclear model in PWIA.
- Variables that measure correlations between the final muon and proton like δp_T or $\delta\alpha_T$ can help to identify relevant nuclear effects like initial state dynamics and final state interactions.
- Work in progress to analyze final state interactions based on the Relativistic Mean Field approach.

Acknowledgments

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