Neutrino Interaction Modeling with Electron Scattering in LDMX

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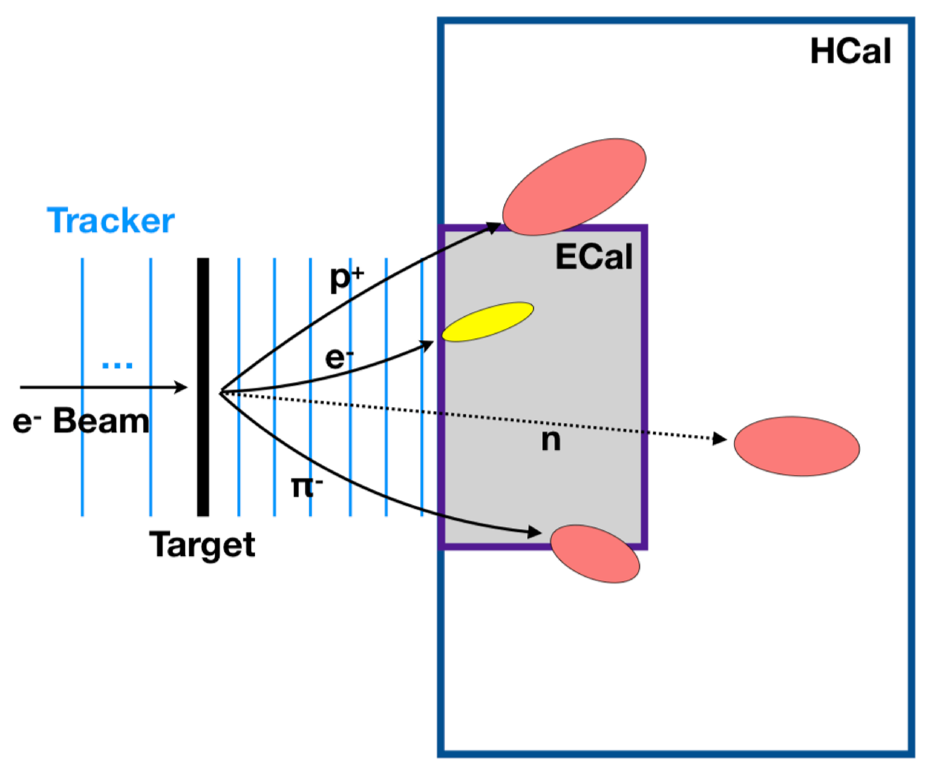
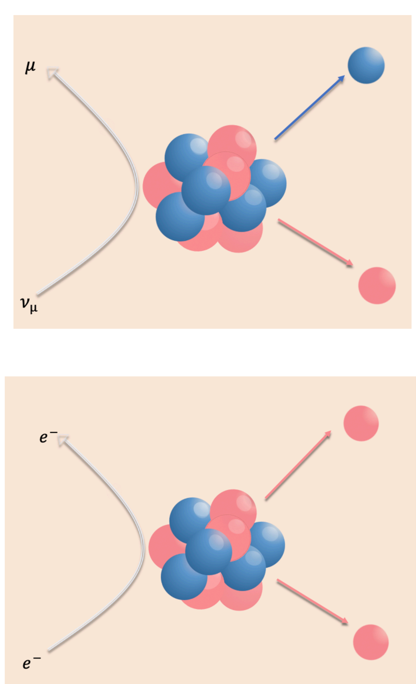
Introduction

Long-baseline neutrino experiments (like DUNE) focus on understanding neutrino oscillations by detecting neutrino interactions on heavy nuclei, which are complicated to model and need input from data. Studying analogous processes in electron-nucleus scattering strengthens understanding of neutrino-nucleus interactions.



Conceptual drawing of the LDMX detector



Neutrino nucleus and electron nucleus interaction

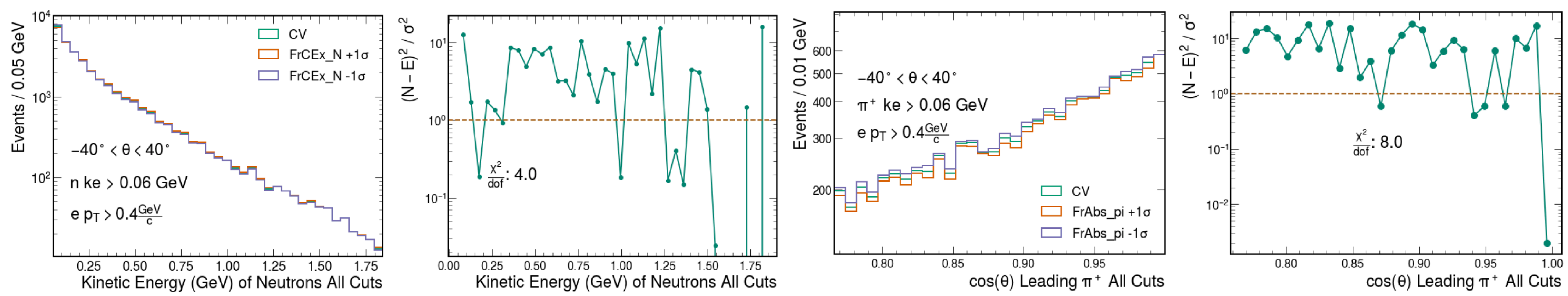
Methods

LDMX [1], a proposed small-scale fixed-target experiment designed to search for dark matter, is also capable of making measurements of electron-nucleus scattering in a similar kinematic region of neutrino interactions in DUNE [2]. We simulate 4 GeV electrons impacting a titanium target using the GENIE neutrino event generator [3] and use GENIE's event-reweighting utilities [4] to study how measurements of the outgoing lepton and hadron kinematics in LDMX could be sensitive to hadronic final state interactions (FSI), which are of particular interest in neutrino interactions due to their impact on neutrino energy reconstruction.

To model an inclusive electron scattering trigger, we require the outgoing electron pT be greater than 400 MeV/c. We require outgoing hadron kinetic energy > 60 MeV and angle, θ, < 40 degrees to mimic detector acceptance. We use a chi-square metric with an assumed uncertainty of 1% to quantify differences between a central value (CV) model and FSI-varied models.

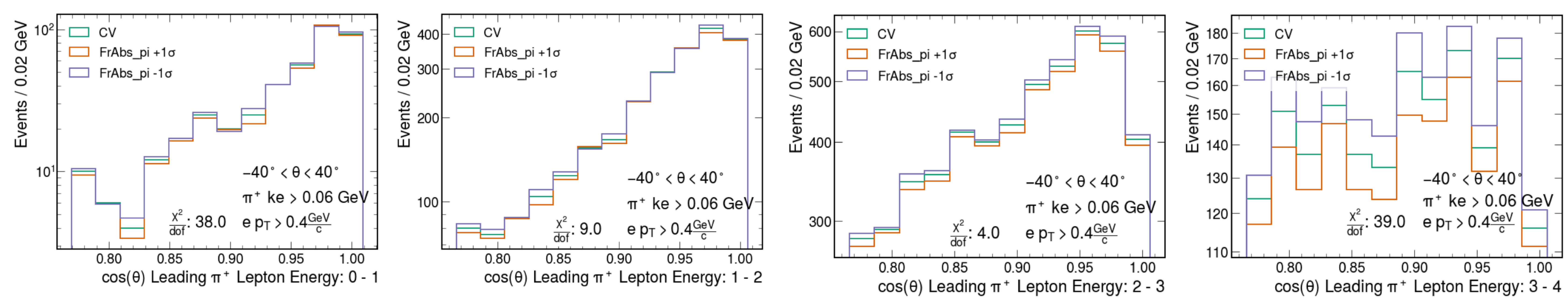
Results

We find outgoing hadron kinematics of kinetic energy, leading kinetic energy, multiplicity, and angle could prove as effective observables for the FSI parameters of charge exchange, inelastic collisions, pion production and absorption for neutrons or pions. Neutrons with KE in the 400-600 MeV and charged pions with KE in the 200-500 MeV range are particularly sensitive. However, no reasonable observable was determined for pion production on neutrons. Sums of kinematic quantities, total energy or per event, and solely lepton kinematics also proved ineffective for constraining FSI model uncertainties.



Neutron kinetic energy for fractional neutron charge exchange and leading positive pion angle for fractional pion absorption with specified cuts and chi squared analysis

We also investigate hadron kinematics with cuts on outgoing lepton energy, probing different interaction types. We find sensitivity to FSI parameters persists across different energy transfer, allowing for later constraint.



Leading positive pion angle for fractional pion absorption with chi squared for specified cuts and division based on outgoing lepton energy

Conclusion

We show that LDMX is capable of effectively measuring lepton and hadron kinematics with sensitivity to various FSI uncertainties in GENIE, showing LDMX's potential to constrain important uncertainties in neutrino interactions, and ultimately improve the sensitivity of neutrino experiments.

Acknowledgements

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References

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