Data Analysis of (e,e'p) Argon and Titanium Electron Scattering

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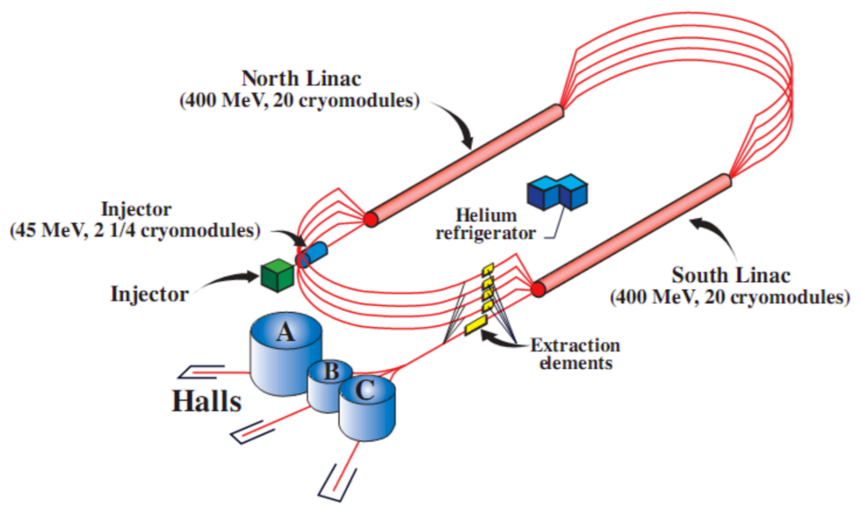
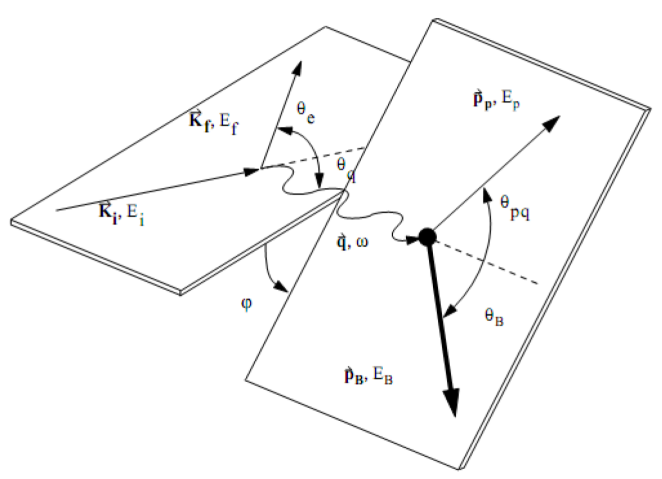
INTRODUCTION

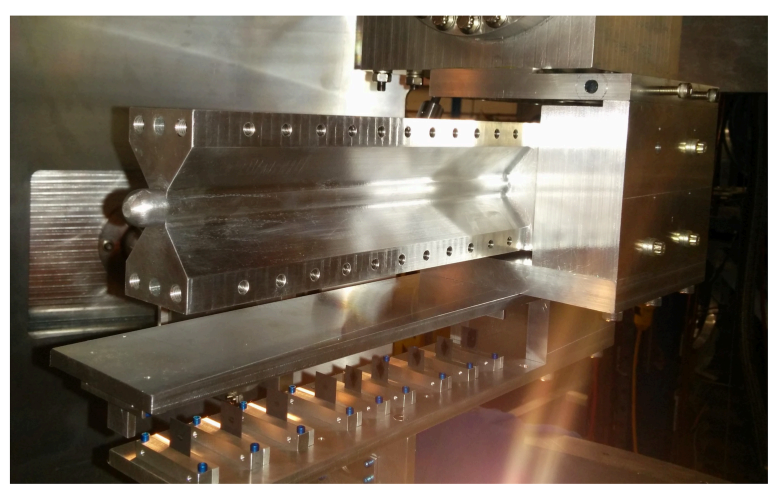
Current models of lepton-nucleus interactions involving complex nuclei are limited by systematic uncertainties. To address this, experiment E12-14-012 in Hall A of Jefferson Lab (JLab) was performed using electron scattering off of various nuclei using the continuous electron beam accelerator facility (CEBAF), shown below. The argon and titanium nuclei were of particular interest because of future long-baseline neutrino experiments investigating neutrino and anti-neutrino scattering, which will measure charge-parity symmetry violation, which will provide insight into matter-antimatter asymmetry.



BACKGROUND

The data we analyzed concerned the (e,e'p) reaction, wherein a single electron knocks off a single proton from the target nucleus (shown below on the left), and the electron and proton are detected in coincidence. The argon nucleus has Z=18, A=40. The inequality of protons and neutrons makes argon an isospin-asymmetric nucleus, so lepton-proton interactions would yield different results than lepton-neutron interactions. The titanium nucleus, with Z=22, A=48, has the same number of protons as argon has neutrons, so (e,e'p) in titanium serves as a useful proxy for neutron reactions in argon.

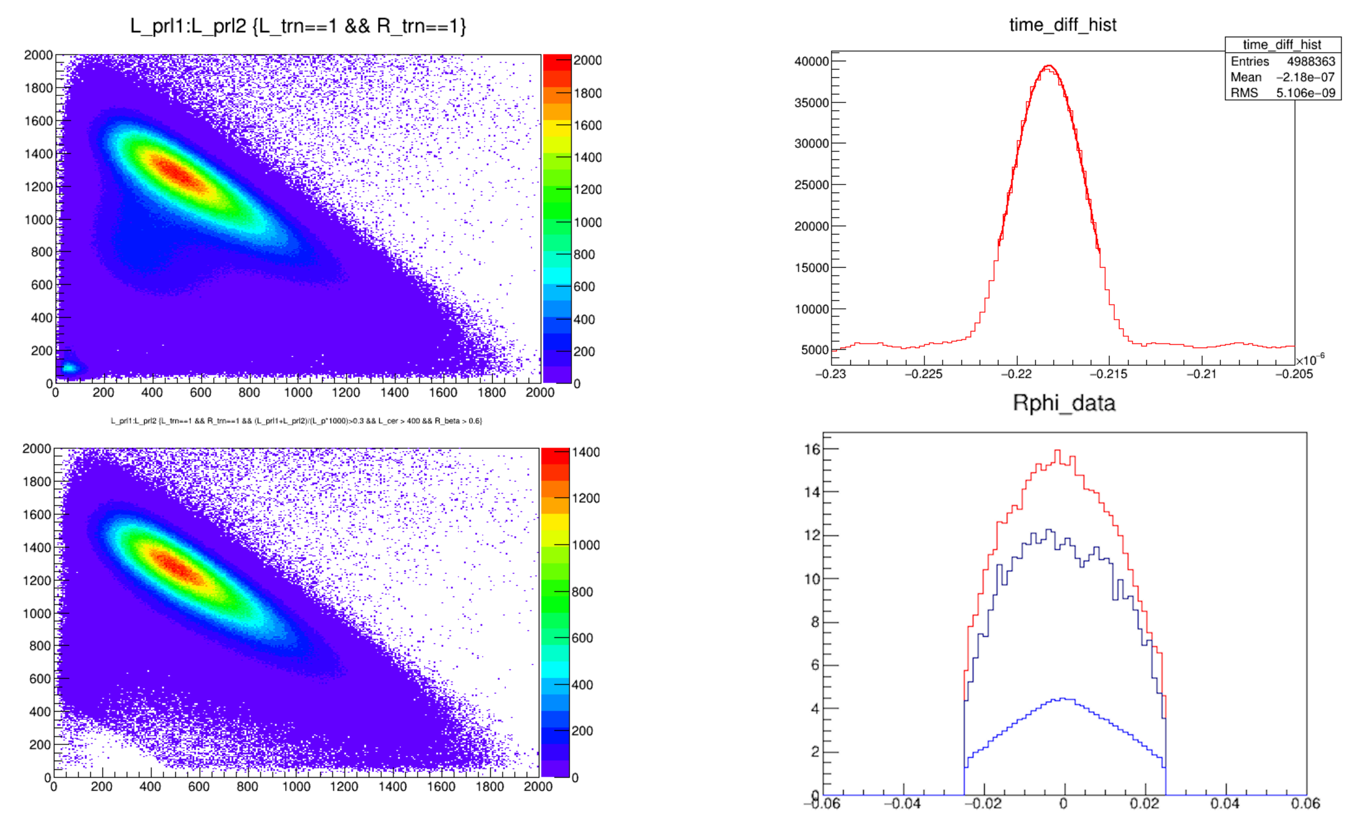




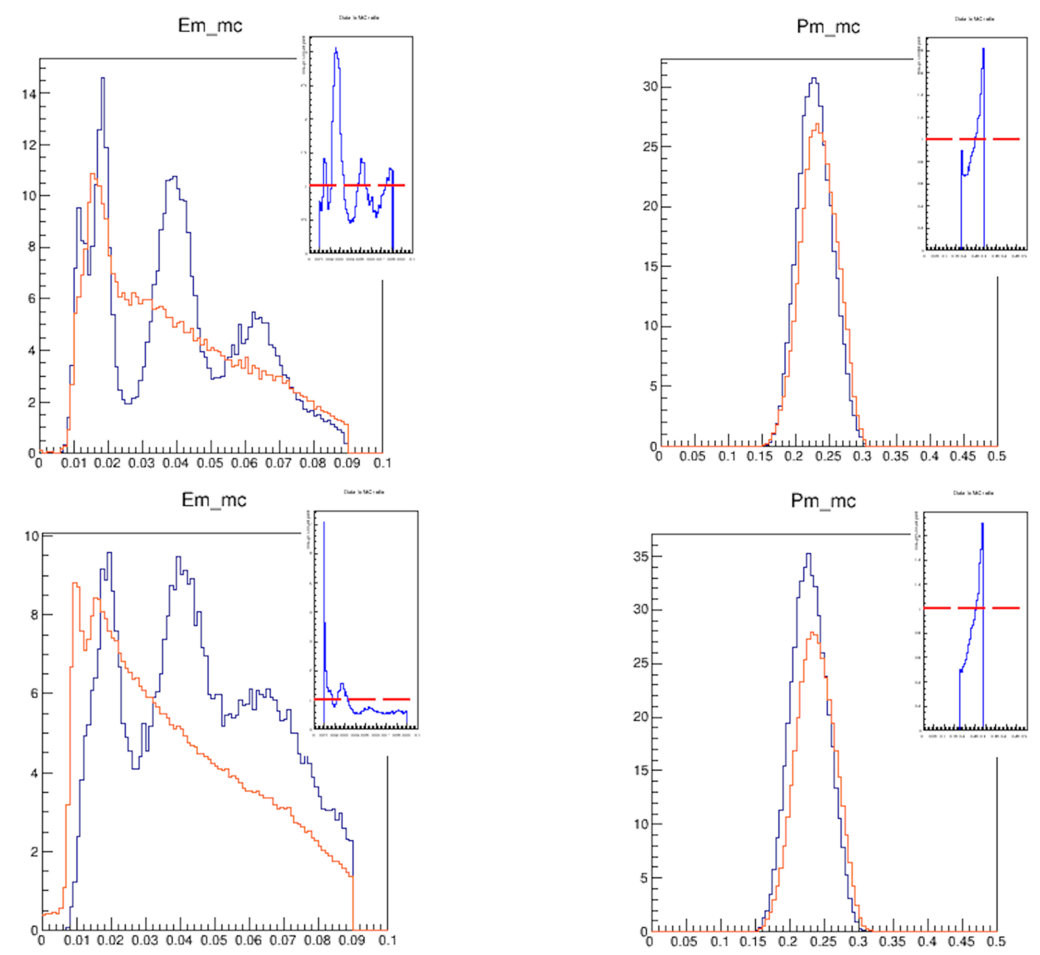
The experiment took place in Hall A of Jefferson Lab. The incident electrons came from JLab's CEBAF beam. The beam struck either a solid titanium foil target or gaseous argon closed cell (shown above). The final state electrons and protons were separated into the left and right high-resolution spectrometers, respectively. These detectors measured several kinematical variables, including the missing energy and momentum of the final state nucleus.

METHODS

We analyzed the data using the ROOT data analysis framework. We applied cuts to the data filter out background events and accurately compare the data to the preliminary Monte Carlo (MC) model. The plots below on the right show energy deposited on the two layers of the calorimeter before and after cuts, and the cuts removed the background peak in the bottom-left corner. However, there were still background events to remove.



The top right plot above shows the distribution of time between the event being detected in the left and right spectrometer. We used the background on either side of the peak to find the distributions of background events. The lower right plot above has distributions of the out-of-plane angle in the proton arm with the data in red, the MC in black, and the background in blue.

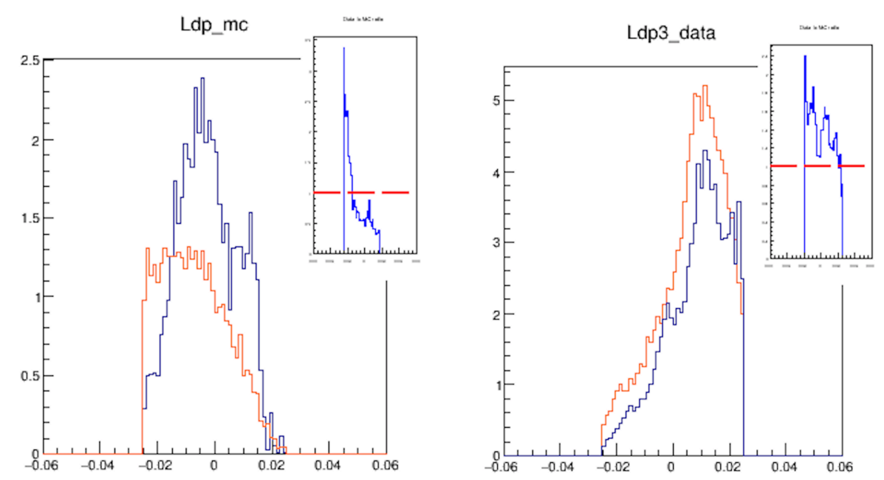


The plots above show the missing energy for argon (top left), missing momentum for argon (top right), missing energy for titanium (bottom left), and missing momentum for titanium (bottom right). The data with background subtracted is orange, the MC is black, and the inset shows the data-to-MC ratio distribution. We also scaled the data using the total charge detected and the efficiency (good events per event that occurred) of the detector.

RESULTS

The background subtraction significantly improved the data-MC agreement. Scaling the data revealed the effects of the final state interaction (FSI), which is where the final state proton interacts with other final state nucleons:

- The data plots are lower than the MC plots.
- The missing energy and missing momentum data peaks are shifted by 3-5 MeV from the MC peaks.
- The effect depends on the nuclear shell of the struck proton.



The above plots represent the detected electron momentum for argon, with events corresponding to low missing momentum on the left and high missing momentum on the right. The relative heights of the data and MC show that FSI has the greatest effect in low missing momentum events, which occur deeper in the nucleus.

CONCLUSION

The disagreement between the data and MC after background subtraction is consistent with the expected effect of FSI. The finding that FSI is related to missing momentum is reasonable since a struck proton deeper in the nucleus is more likely to interact with other final state nucleons. The data-MC comparisons, while imperfect, are enough for the analysis to proceed in refining efficiency calculations and describing systematic uncertainties. Completion of the analysis of the will provide a viable nuclear model of neutrino scattering on argon, which will benefit future long-baseline neutrino experiments such as the Deep Underground Neutrino Experiment (DUNE).

REFERENCES

- H. Dai *et al.*, (Jefferson Lab Hall A) arXiv:1803.01910v2 [nucl-ex] (2018).
- H. Dai *et al.*, (Jefferson Lab Hall A) arXiv:1810.10575v2 [nucl-ex] (2019).
- J. Alcorn *et al.,* Nucl. Instrum. Methods Phys. Res. A **522**, 294 (2004).
- J. Arrington *et al.,* Phys. Rev. Lett. **82**, 2056 (1999).
- J. Mougey *et al.,* Nuclear Phys. A, 262 (1976) p. 482.
- M. Murphy *et al.,* (Jefferson Lab Hall A Collaboration) Al_Working_Draft_v3.pdf. (2019) (in progress).
- R. Acciarri *et al.,* (DUNE Collaboration), 719 arXiv:1512.06148.
- Rene Brun and Fons Rademakers, *ROOT - An Object Oriented Data Analysis Framework*, Proceedings AIHENP'96 Workshop, Lausanne, Sep. 1996, Nucl. Inst. & Meth. in Phys. Res. A 389 (1997) 81-86. See also http://root.cern.ch/
- S. N. Santiesteban *et al.,* arXiv:1811.12167v2 [physics.ins-det] (2019).