Data Analysis of (e, e'p) Argon Electron Scattering Including Final State Interaction

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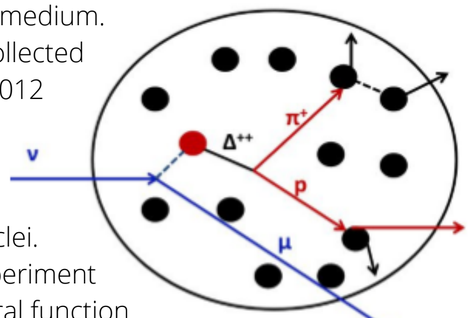
Introduction

The final state interaction (FSI) describes the interactions a particle produced at the primary interaction vertex while traveling in the nuclear medium.

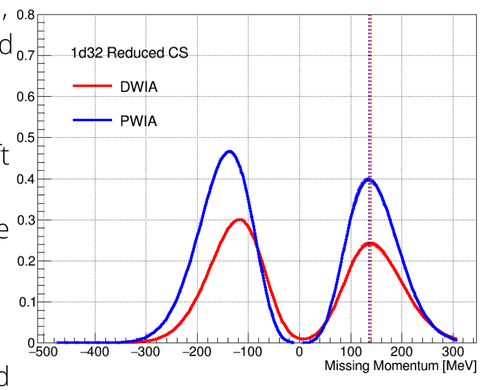


Our study used data collected by experiment E12-14-012 at JLab, which was an electron scattering experiment done on Argon and Titanium nuclei. The purpose of this experiment was to study the spectral function of these nuclei which gives information on the probability of finding nucleons with certain energy and momenta. This is useful for us as it describes the nuclear response in the interaction. In neutrino experiments, since the neutrino cannot be detected directly, we can only reconstruct neutrino energy by using the energy of the final state particles. Through FSI, the nucleus affects the neutrino energy and thus neutrino oscillation. So with this study, we will calculate the cross section of electron-nucleus scattering with relativistic FSI code and compare the Monte-Carlo (MC) with experimental data. The method I used to complete this study was running a Fortran code provided by Prof. C. Giusti to calculate the cross section on both the plane and distorted wave impulse approximation for the different orbitals present in the argon nucleus. Once this was calculated for each orbital, a C program was run to further analyze the data.

	E_e	$E_{e'}$	θ_e	P_p	θ_p	$\lvert\mathbf{q}\rvert$	p_m
	MeV	MeV	deg	MeV/c	deg	MeV/c	MeV/c
kin1	2222	1799	21.5	915	−50.0	857.5	57.7
kin3	2222	1799	17.5	915	−47.0	740.9	174.1
kin4	2222	1799	15.5	915	−44.5	658.5	229.7
kin5	2222	1716	15.5	1030	−39.0	730.3	299.7
kin2	2222	1716	20.0	1030	−44.0	846.1	183.9
c-kin5	2222	-	15.5	-	-		

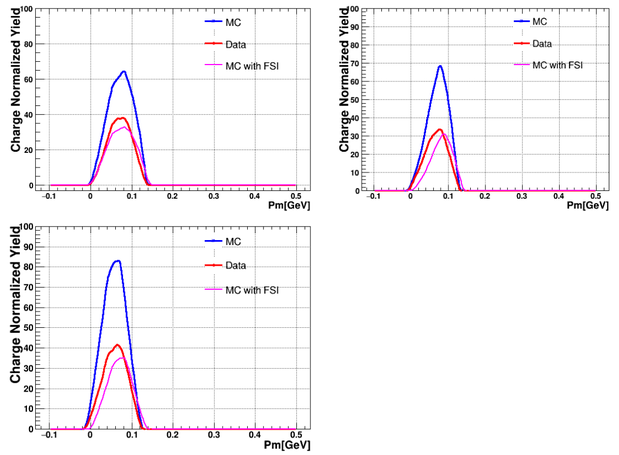
Methods

To calculate the cross section and reduced cross section over various energy ranges and orbitals, a fortran script was run with various inputs. This code came from the Carlotta group [3]. Inputs included which orbital to calculate the cross section for and a choice of cross section type. One important input for the code was between Distorted - Wave Impulse Approximation (DWIA) and Plane Wave Impulse Approximation (PWIA). The difference between these options is that DWIA includes FSI and PWIA does not. There are two effects of FSI to the cross sections. First is that there is a shift given by the optical potential, second is that there is a calculated cross section reduction. This is useful for us as both can be calculated to then find the shift and ratio which can be used to reweigh the MC to account for the FSI. By comparing cross sections calculated by DWIA and PWIA, we can study the effect of FSI. Once the cross sections were calculated using PWIA and DWIA, the relation between them must be calculated to reweigh the MC. To do this, we used a C file compiled with ROOT to read the outfile of the fortran code to perform these calculations. ROOT is an object oriented data analysis framework designed by CERN for particle physics. From the figure, both the PWIA and DWIA plots make a distinct curve for each orbital. From these curves the C code calculated the ratio of the integral between each curve and the shift of the peaks in the positive region between the curves (the dotted line in the figure) This was calculated for each orbital and these values were used for C program to reweigh the MC which is then compared to actual data. This was done with ROOT as well. This method of using shifts and ratios to reweigh the MC is used to include FSI because this way is simpler than than including FSI directly into the MC. Since DWIA and PWIA are related by this constant shift and ratios, it is easier to reweigh afterwards than to implement FSI directly.



Results

The figure provided shows the result of the reweighing of the MC compared to the original MC. To re-weight the MC we compute event by event the missing energy and missing momentum, then using the missing energy we try to determine the orbital from which the electron was emitted. Once we know the orbital we can determine with ratio and shiift to use for that single event. We repeat for all events in the MC. The result of reweighing much more closely resembles the actual data than the original data and thus the FSI was more successfully modeled by our methods.



References

[1] H. Dai, M. Murphy, V. Pandey, D. Abrams, D. Nguyen, B. Aljawrneh, S. Alsalmi, A. M. Ankowski, J. Bane, S. Barcus, and et al., First measurement of the ar(e,e)x cross section at jefferson laboratory, Physical Review C 99, 10.1103/physrevc.99.054608 (2019).
[2] P. Lipari, Introduction to neutrino physics, (2003).
[3] Nuclear response in electromagnetic interactions with complex nuclei.
[4] R. Brun and F. Rademakers, ROOT: An object oriented data analysis framework, Nucl. Instrum. Meth. A 389, 81 (1997).