Understanding ν Interactions with e⁻ Scattering Data

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Introduction

Accelerator-based neutrino oscillation experiments require a precise understanding of neutrino-nucleus interactions to extract fundamental parameters [1].

Neutrinos are similar to electrons in the quasi-elastic (QE) regime. Because electrons are easier to detect, we use mono-energetic electron beams to constrain nuclear models [2].

We use electron scattering data from CLAS [3] and neutrino simulations from the GENIE Monte Carlo (MC) event generator [4] to calculate QE proton transparency.

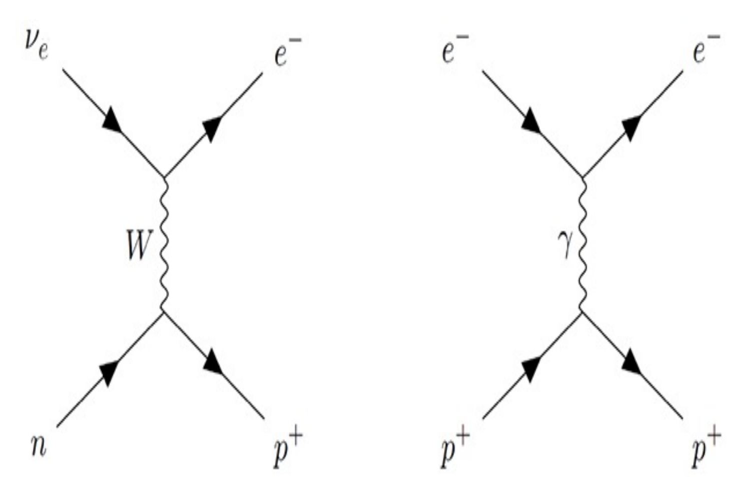


Fig 1: Feynman diagrams for neutrino (left) and electron (right) QE scattering.

CEBAF Large Acceptance Spectrometer

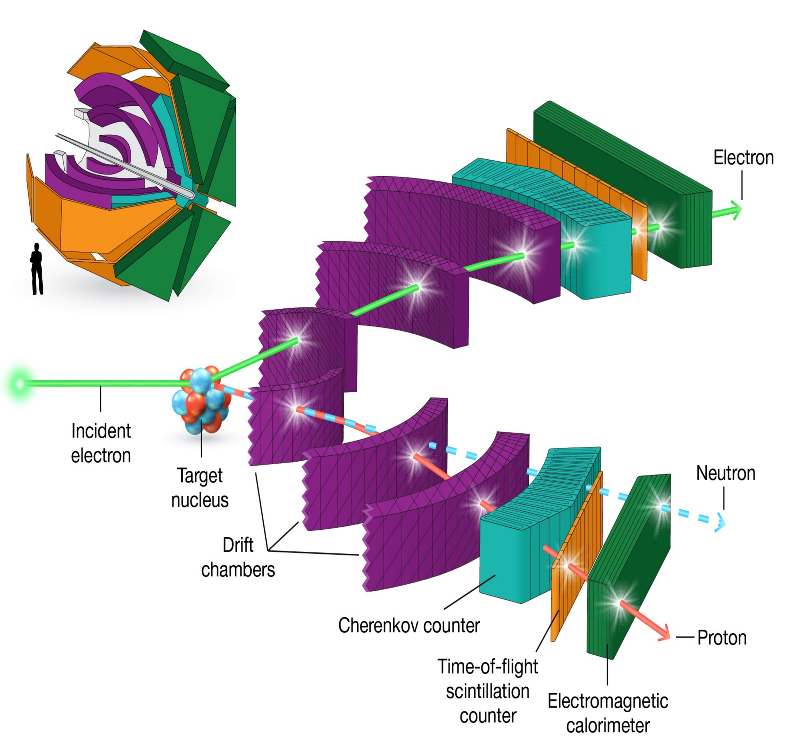


Fig 2: Schematic of the CLAS experiment. [3]

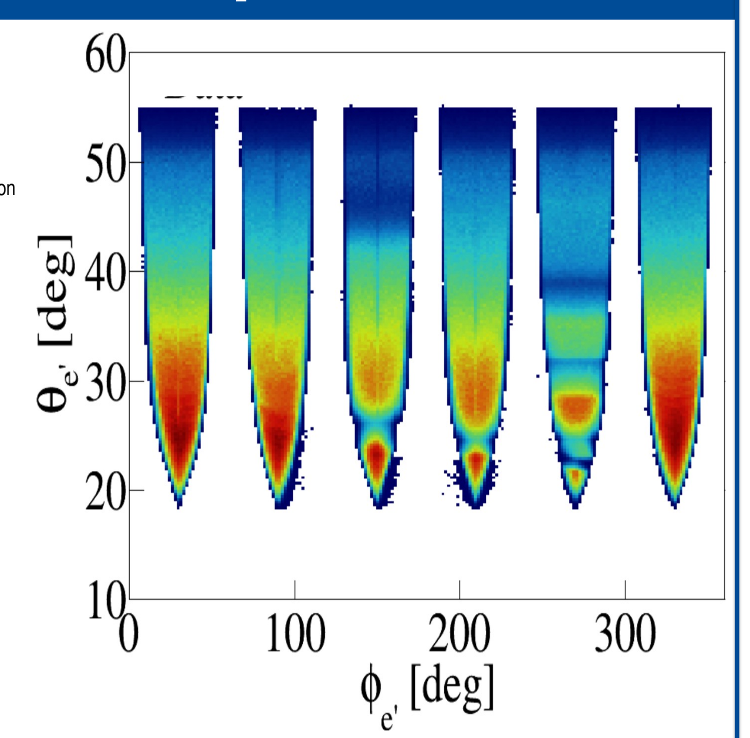


Fig 3: Plot of CLAS angular data for a He-4 target with a 2.261 GeV/c beam.

CLAS detects particles from high-energy electron-nucleus collisions. Large acceptance permits measurements of most particles produced in collisions.

We analyze ^{4}He, ^{12}C, and ^{56}Fe nuclear targets at a beam energy of 2.261 GeV/c. The angular acceptance of the CLAS detector (see Fig. 3) forces us to consider small sections around the center of specific sectors.

Kinematic Cuts on GENIE and CLAS

We place cuts on GENIE MC electron angles and momentum to curate a QE sample of inclusive ^{4}He events:

1. Electron in CLAS sector 1, 2, or 6 (see Fig. 3)
2. $\Delta\phi_{electron} = 12°$
3. $\theta_{electron}$ ranges from 20° – 25°
4. Electron momentum greater than 1.9 GeV/c (see Fig. 4)

Additionally, we place cuts on proton angles and momentum to extract the true QE peak from the inclusive ^{4}He events:

5. Proton in corresponding CLAS sector 4, 5, or 3
6. $\Delta\phi_{proton} = 45°$
7. θ_{proton} : 40° – 80° (see Fig. 5)
8. Proton momentum greater than 0.6 GeV/c (see Fig. 5)

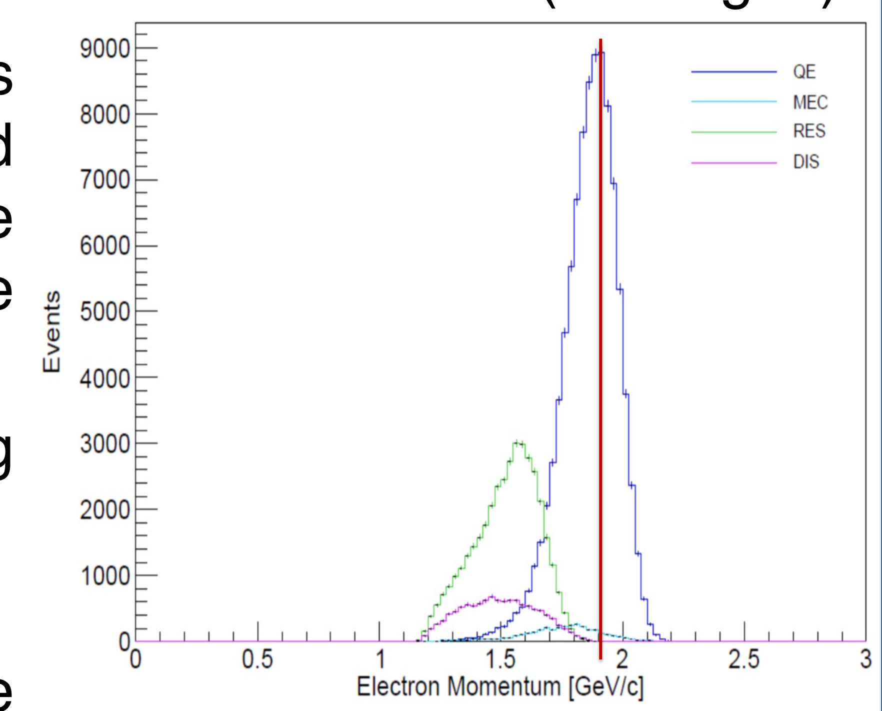


Fig 4: Plot of GENIE MC electron momentum for a He-4 target with cuts 1 through 3 applied.

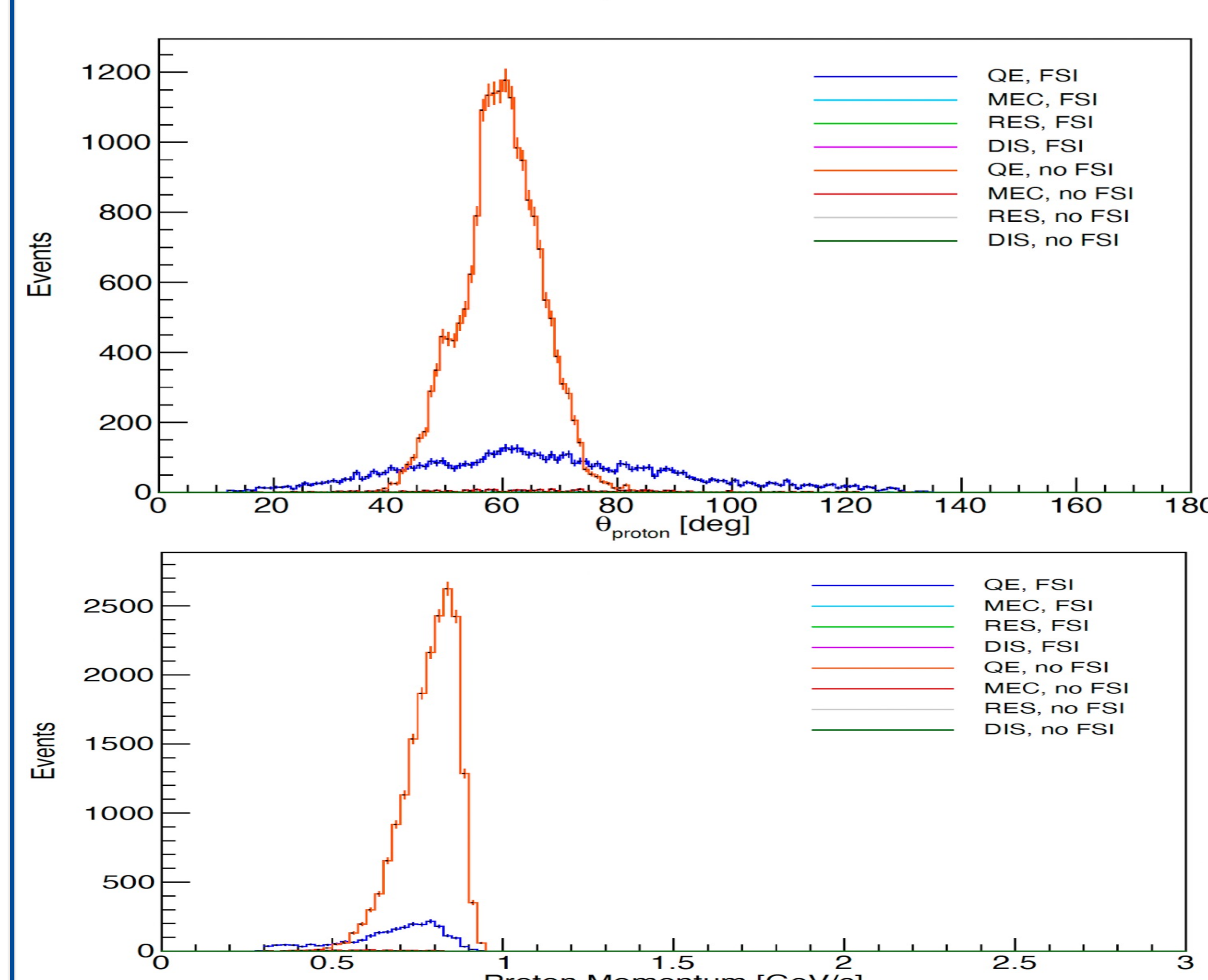


Fig 5: Plot of GENIE MC θ_{proton} (top) and proton momentum (bottom) for a He-4 target with cuts 1 through 4 applied. True QE events' protons do not re-interact with the nucleus and are labeled QE with no final state interactions (QE, no FSI).

Using this procedure, we make the following cuts on ^{4}He:

- **$30° < \theta_e < 35°$:** $p_e > 1.65$ GeV/c, $38° < \theta_p < 62°$, $p_p > 0.9$ GeV/c
- **$40° < \theta_e < 45°$:** $p_e > 1.4$ GeV/c, $30° < \theta_p < 50°$, $p_p > 1.25$ GeV/c

We also make similar cuts on ^{12}C and ^{56}Fe with a 2.261 GeV/c beam and apply the cuts for all three targets to both GENIE MC simulation and CLAS experimental data.

Proton Transparency Calculations

Proton transparency is defined as the number of true QE events over the number of inclusive events and represents the probability that a proton produced in a nucleus escapes.

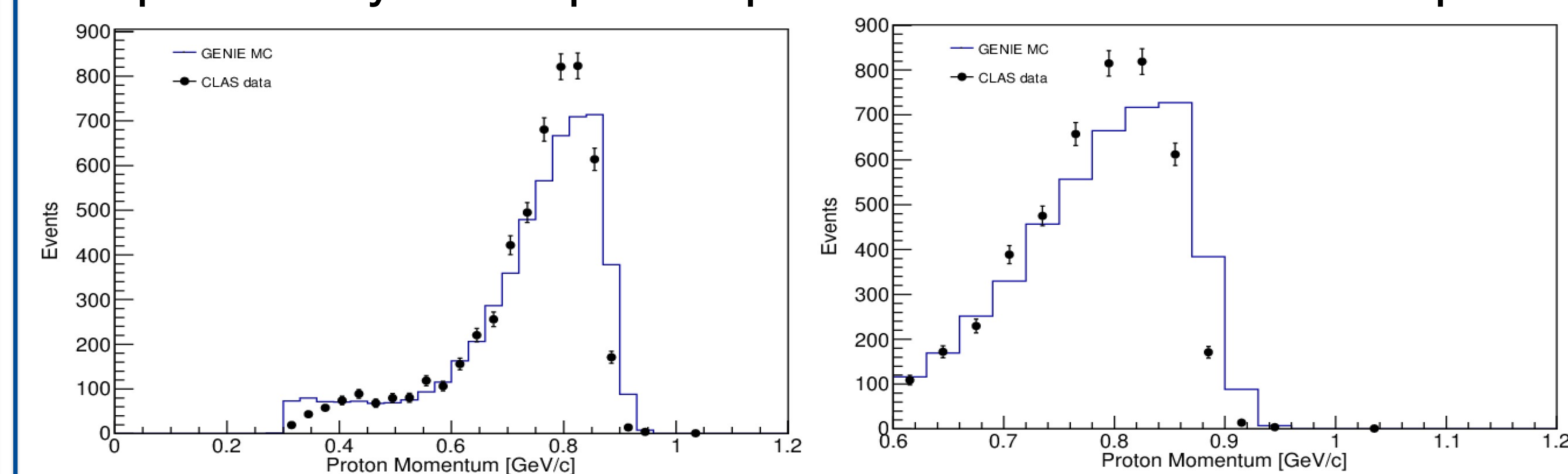
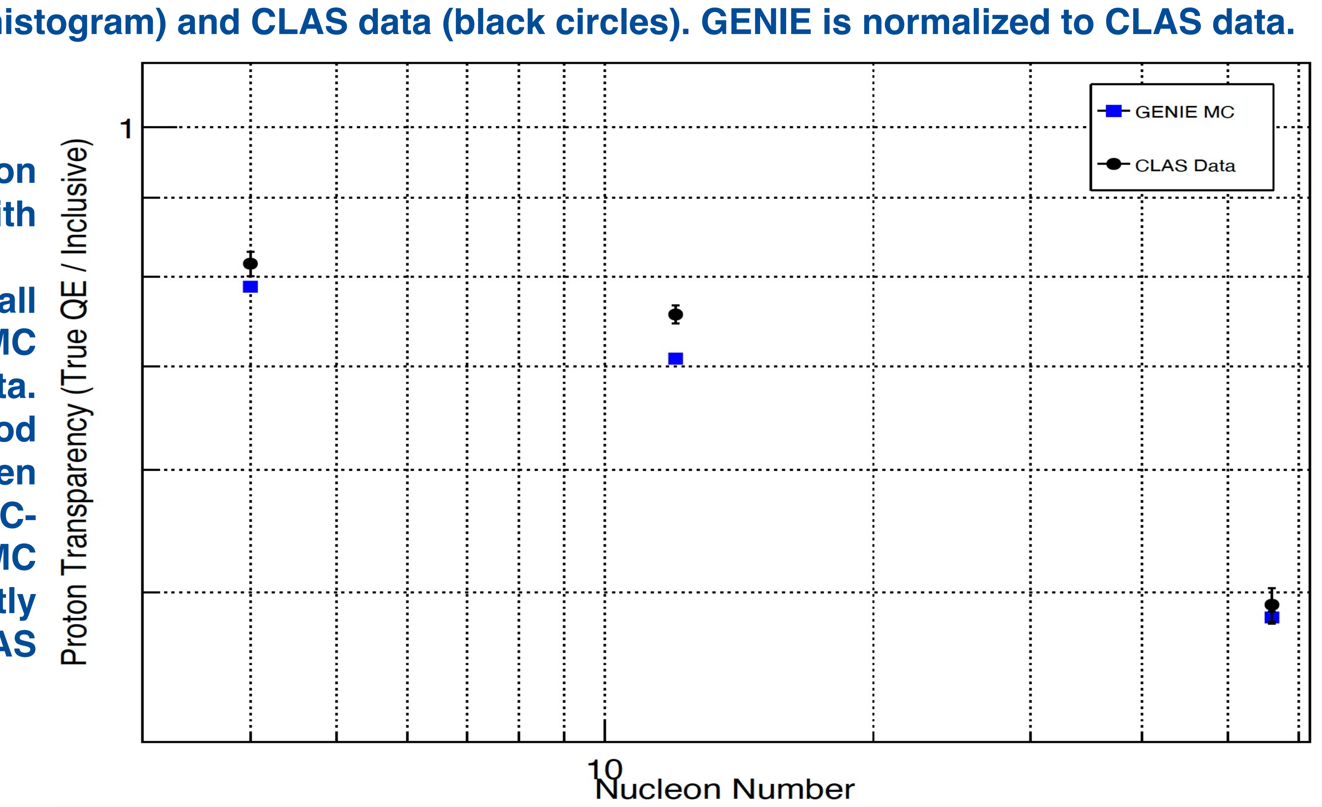


Fig 6: Plot of the inclusive (left) and true QE (right) proton momentum distributions for both GENIE MC (blue histogram) and CLAS data (black circles). GENIE is normalized to CLAS data.

Fig 7: Proton transparencies with statistical uncertainties for all targets' GENIE MC and CLAS data. There is good agreement between He-4 and Fe-56. C-12 GENIE MC deviates slightly from C-12 CLAS data.



Conclusions

We compare the proton transparencies of ^{4}He, ^{12}C, and ^{56}Fe with a 2.261 GeV/c beam between the CLAS experiment and the GENIE event generator. While there is good agreement between GENIE and CLAS for ^{4}He and ^{56}Fe, the disagreement in ^{12}C requires refining our kinematic cuts.

Next steps include adding data for 1.161 GeV/c and 4.461 GeV/c beam energies and using electron-proton correlations to better isolate the true QE component.

References and Acknowledgements

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