Comparison of Electron and Neutrino Modeling

Yuqian "Lily" Li, Bryn Mawr College—SIST internship ▣ Minerba Betancourt, Fermilab

Introduction

Accurate neutrino cross-section measurements and modeling of nuclear effects are required for precise measurements of neutrino oscillation physics. Due to the difficulties to construct and measure neutrino beams, a proposal to use electrons to verify these models is brought out. Neutrino and electrons interact similarly and many nuclear effects are the same. The electron beam energy is also known. Thus, by comparing electron-nucleus scattering data to simulated electrons, it is possible to constrain the current neutrino event generator nuclear models.

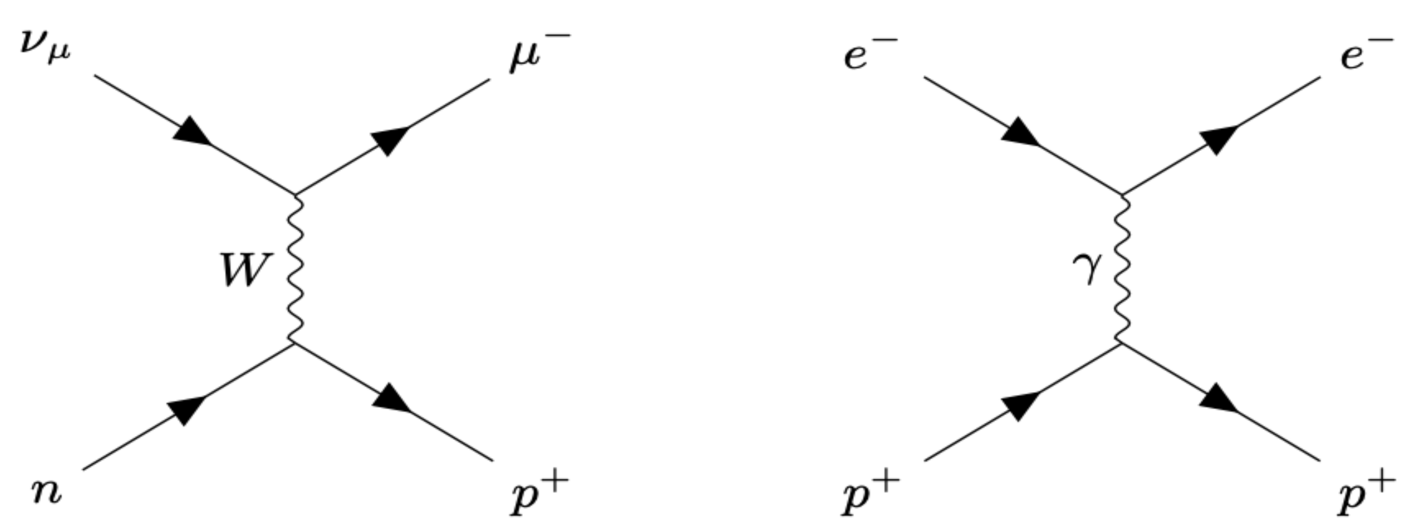

FIG. 1. The Feynman diagram for an idealized CCQE(Quasi-elastic scattering on nucleons) scattering event for a muon neutrino (left) and electron (right).

Moreover, in order to study the broad neutrino spectrum from various neutrino experiments, we compared the observables using Booster, T2K, NuMI and DUNE energy fluxes.

Methods

The experiment generated distributions using The GENIE Neutrino Monte Carlo Generator. GENIE simulates quasi-elastic scattering (QE) with only leptons and nucleons in the final state, resonance production (RES) which results in not only leptons and nucleons but also pions. A graphic explanation of different interactions is shown in Figure 2. ROOT, as a very flexible programming and graphical interface is used to generate histograms of different properties.

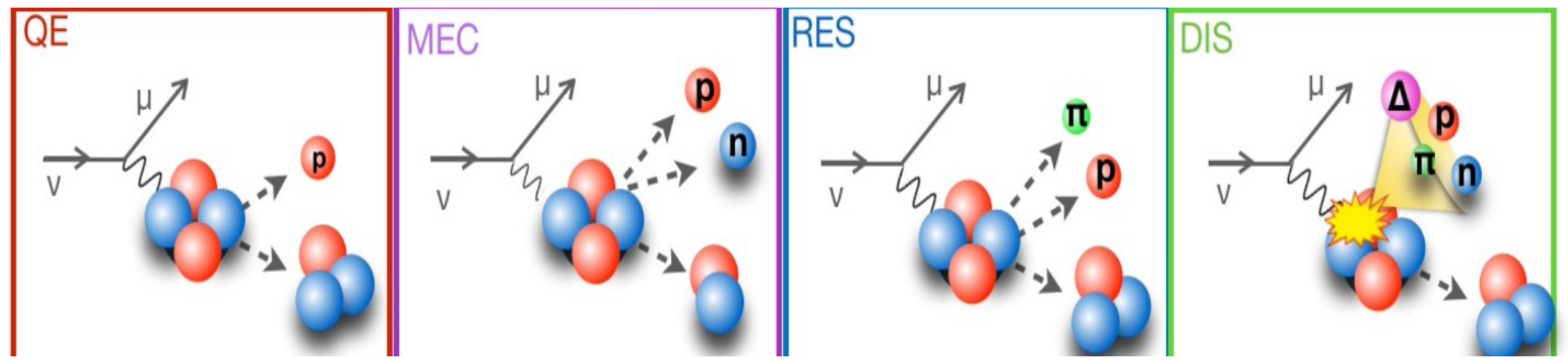

FIG. 2. Four possible interaction for incoming particle interaction. From left to right are Quasielastic, Meson exchange current, Resonance, and Deep Inelastic scattering.

Results and Discussions

- **Electron and Neutrino Comparison**

Neutrino and electron scattering simulations at 2.2 GeV targeting Carbon 12 and Iron 56 are shown in Figure 3. This comparison only takes into account events with one proton and zero pion from the E4Nu[1]analysis and uses quasielastic-like selection cuts. Also, the distributions of the electron have been plotted area normalized to study the shapes. A very similar shape phase and magnitude[2] of the variable, delta momentum magnitude, can be seen in the figure which indicates electron data could provide reasonable constraints to neutrino experiments.

- **Observable with Similar sensitivity**

Figure 4 shows the Proton Angle comparison of electron and neutrino using the same model. The similarity of this observable indicates that when real neutrino fluxes are applied, a similar spectrum will be seen and electron scattering can be used to constrain the different values of proton angle with the electron scattering.

Some real neutrino experiments spectrum are shown in Figure 5. The semblable shape phase of electron and neutrino modeling can be used to estimate different neutrino beams like Booster, T2K, NuMI, and DUNE.

Conclusion and Acknowledgements

The study shows the similarities and differences between electron and neutrino scattering modeling. This indicates the constraints from electron interaction can be used to constrain neutrino measurement and simulations.

I would like to express my gratitude to my mentor, Minerba Betancourt, for her great patience and guidance throughout the project.

Delta Momentum Magnitude for Electron and Neutrinos (Left: Carbon12, Right: Iron56)

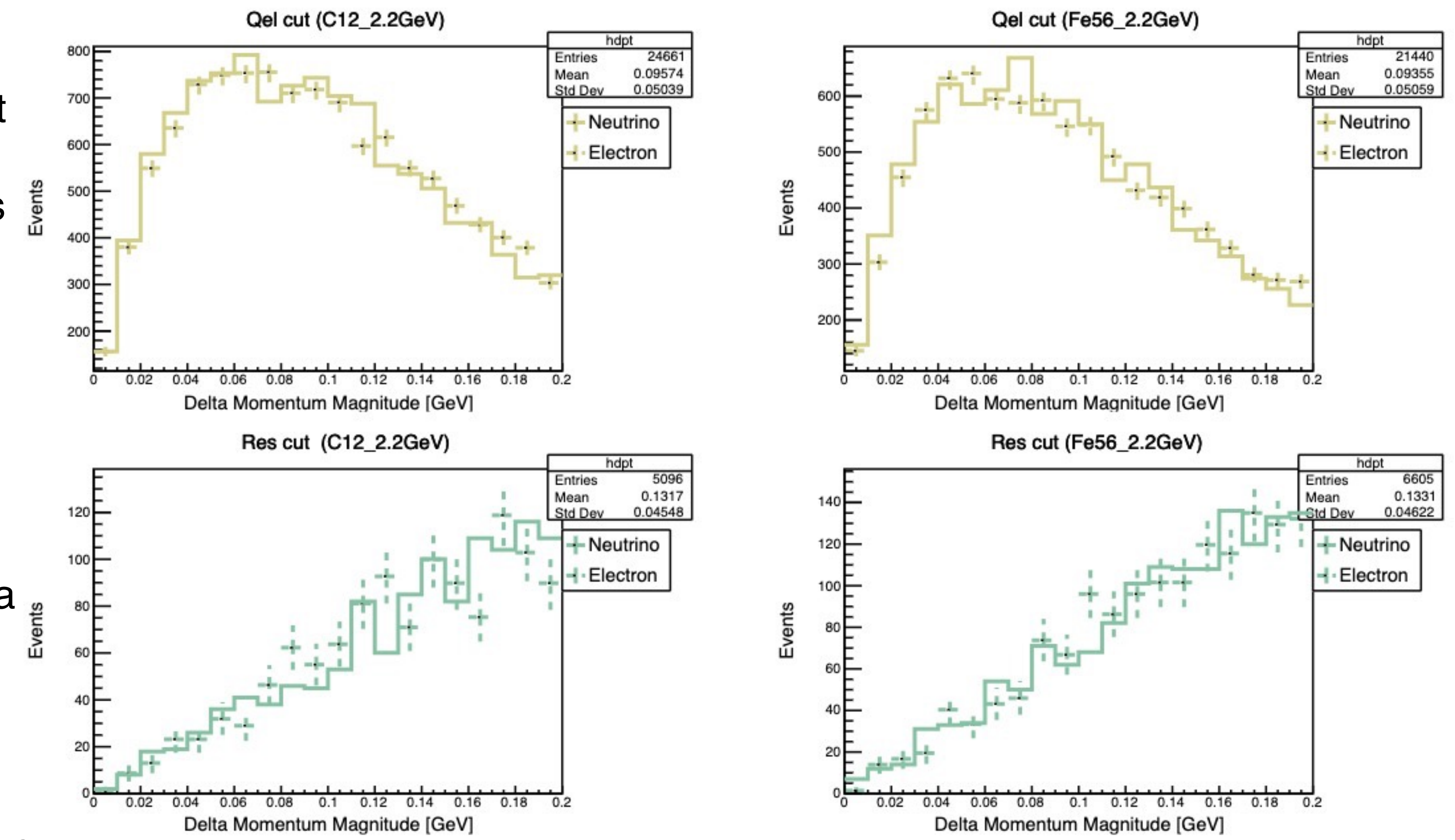

FIG. 3. Delta Momentum Magnitude of Electron and Neutrino modeling comparison under Quasielastic cut generated by GENIE Monte Carlo Generator. (Left: Targeting C12, Right: Targeting Fe56).

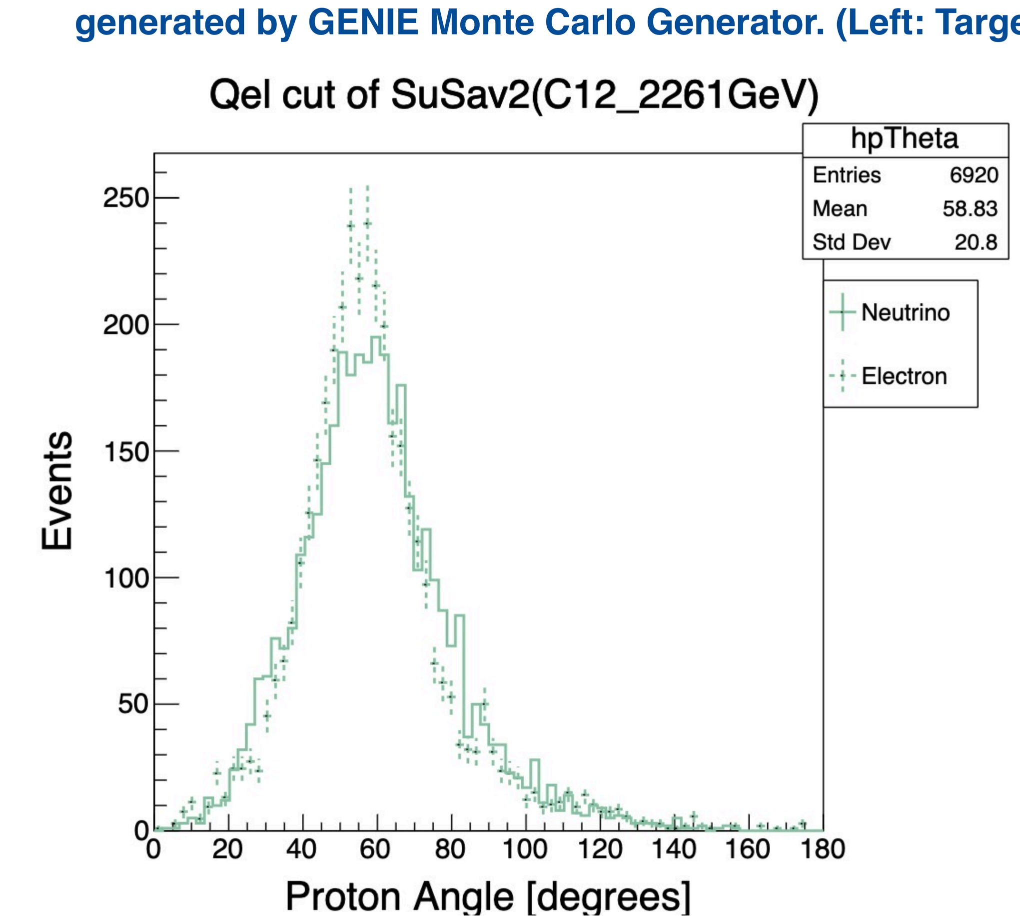

FIG. 4. Proton Angle electron and neutrino modeling under quasielastic cut. SuSA: QE and 2p2h (SuSA) and Berger-Sehgal RES, Bodek-Yang DIS

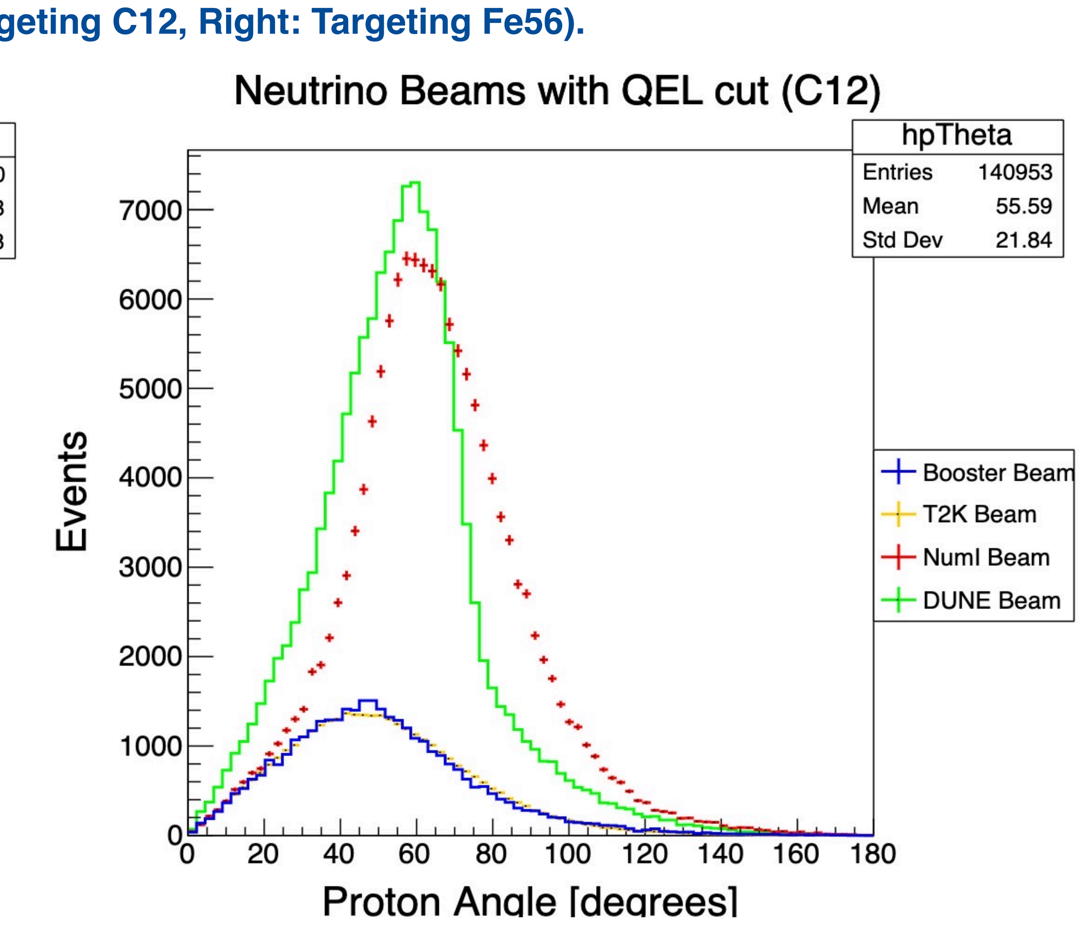

FIG. 5. Proton Angle of Booster, T2K, NuMI, and DUNE beam under Quasi-elastic cut. Distributions have been plotted area normalized to study the shapes.

References

[1] Khachatryan, M., Papadopoulou, A., Ashkenazi, A. et al. Electron-beam energy reconstruction for neutrino oscillation measurements. Nature 599, 565–570 (2021). https://doi.org/10.1038/s41586-021-04046-5

[2] (MINERvA Collaboration) (2018). Measurement of Final-State Correlations in Neutrino Muon-Proton Mesonless Production on Hydrocarbon at Ev ©=3 GeV. Physical review letters, 121(2), [022504]. https://doi.org/10.1103/PhysRevLett.121.022504

This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.