Using Electron Scattering to Constrain Neutrinos

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NF Topical Groups:

☐ (NF1) Neutrino oscillations
☐ (NF2) Sterile neutrinos
☐ (NF3) Beyond the Standard Model
☐ (NF4) Neutrinos from natural sources
☐ (NF5) Neutrino properties
■ (NF6) Neutrino cross sections
☐ (NF7) Applications
☐ (NF8) Theory of neutrino physics
☐ (NF9) Artificial neutrino sources
☐ (NF10) Neutrino detectors
■ (Other) (CompF2) Theoretical Calculations and Simulation

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Abstract: (200 Words)

The ability of current and next generation accelerator based neutrino oscillation measurements to reach their desired sensitivity requires a high-level of understanding of the neutrino-nucleus interactions. These include precise estimation of the relevant cross sections and the reconstruction of the incident neutrino energy from the measured final state particles. In this Letter-of-Interest, we present the ongoing effort and prospects of wide phase-space electron scattering data sets collected at CLAS and new data sets to be collected at CLAS12 to constrain neutrino simulations.

An international effort is underway to perform precision measurements of the physics that govern neutrino interactions and its impact on oscillation measurements [1–4]. A positive observation of CP violation in neutrino oscillations, in conjunction with the resolution of the mass hierarchy and precise determinations of mixing angles, will shed light on the predominance of matter over antimatter in our present-day universe. This effort requires large detectors and intense beams; ultimately, we are looking for what is likely to be a small difference between neutrino and antineutrino oscillation in matter, or an excess in appearance of one type of neutrino over the other. To isolate this small difference, we need an unprecedented understanding of how neutrinos and antineutrinos interact with atomic nuclei.

Current neutrino oscillation experiments rely heavily on interaction models in the estimation of oscillation parameters. Recent experiments, like T2K and NOvA, have significant uncertainties in the selected ν_e signal due to the interaction model, from uncertainties in the ν-nucleus cross-sections and the final-state interactions (FSIs) (7.7% for the NOvA experiment [1] and 6.8% for the T2K experiment[2]). Improving the systematic uncertainty from the current 5–15% to the precision era 1–3% is critical. In addition to the program to probe neutrino oscillation, searches for exotic physics also depend on understanding of neutrino models.

This LOI describes the effort to leverage wide phase-space exclusive electron scattering data for the benefit of neutrino experiments by benchmarking models and improving neutrino event generators. Electron and neutrino interactions with nuclei share the same vector part and many identical nuclear effects, including final state interactions. Electron data provides a pure measurement of the vector component, so that neutrino near detector data can be used to properly constrain the axial piece. Thus, by comparing electron-nucleus scattering simulations to electron data it is possible to test the accuracy of current Monte Carlo nuclear models in order to improve them to the needed accuracy for neutrino experiments. Additionally, the monochromatic electron beams can be used to study incoming lepton energy reconstruction methods and to constrain their systematic uncertainties.

Event generators are critical inputs for analysis of neutrino oscillation and cross section experiments. They are used to estimate signal and backgrounds, efficiency correction, systematic errors, training algorithms, and comparison of the final results. Providing data to test and improve those generators can significantly decrease the systematic uncertainties in neutrino experiments.

The first electrons-for-neutrinos $e4\nu$ analysis used 1999 CLAS-detector[5] data on He, C and Fe targets with monochromatic electron beams of 1.2, 2.3 and 4.5 GeV at the Thomas Jefferson National Accelerator Facility (JLab). CLAS was a large acceptance spectrometer with about a 2π solid angle for charged particles. The analysis focused on Quasi Elastic (QE) like events, by selecting events with one electron and one proton and no charged pions in the final state ($1p0\pi$). It found (a) most of the $1p0\pi$ events do not reconstruct to the correct beam energy, (b) 10–20% discrepancies in the fraction of events that reconstruct to the correct beam energy between the data and the interaction model and (c) that the interaction model does not describe the exact shape of the low-energy tail for quasi-elastic energy reconstruction. These differences could lead to significant misreconstruction of the incident neutrino flux at the far detector. Further analysis is underway to look at the $1p1\pi$ channel.

JLab recently approved a dedicated $e4\nu$ measurement with an A scientific rating, for 90 run days. 60 days are scheduled for summer 2021. Data will be taken using targets from d to Sn, including neutrino-detector materials (C, O, and Ar), at a range of beam energies (1, 2, 4, and 6 GeV), in order to test neutrino energy reconstruction techniques and to benchmark neutrino event generators.

The experiment will use the new high-luminosity CLAS12 spectrometer that can measure very low momentum-transfer reactions (down to 5° from the beamline)[6], and has extensive neutron and photon (π^0) detection capabilities. This experiment will provide a much larger data set, with many more event channels (e.g., $1p0\pi$, $1p1\pi$, etc), greater angular and kinematic coverage, and many more targets than the existing CLAS data.

In summary, the "Electrons for Neutrino" collaboration leverages wide phase space electron scattering data to constrain neutrino event generators, in order to reduce systematic uncertainties associated with the myriad of nuclear effects impacting neutrino scattering. Initial analysis of the $1p0\pi$ channel using 1999 CLAS data showed significant discrepancies between data and event generator. We will take much more data in 2021 with a better selection of targets and an improved large acceptance spectrometer. This will allow us to better constrain neutrino event generators over a wider kinematic range (especially including the resonance region) to help ensure the success of SBN and DUNE.

We are forming a broader $e4\nu$ collaboration to exploit this data, with members from ten institutions so far, and working groups on data analysis, improving event generators, and implications for oscillation analyses. Funding support is needed for this effort. We welcome new collaborators and new ideas.

Join us!

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