Improving Simulation of Tau Neutrinos Using Polarization Information

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Introduction

One of the most challenging aspects of properly modeling tau neutrino charged current interactions is appropriately taking into consideration the produced tau polarization. There is existing code used to simulate tau decay, but instead of calculating the full polarization of the tau, it approximates the polarization as only being longitudinal. ACHILLES is a novel lepton-nucleus event generator that is working towards the needed precision of next generation experiments. Therefore, it is vital to appropriately model the polarization of the produced tau leptons instead of approximating them. My job is to bridge together the tau neutrino's interaction with the detector and the tau's decay by passing polarization information between codes.

Tau neutrinos are extremely difficult to detect. With promising neutrino detection experiments such as DUNE and MicroBooNE on the rise, the purpose of this project is to create proper lepton decay simulations that aid neutrino detection experiments by accurately distinguishing tau neutrino charged current processes from non-tau neutrino neutral current processes.

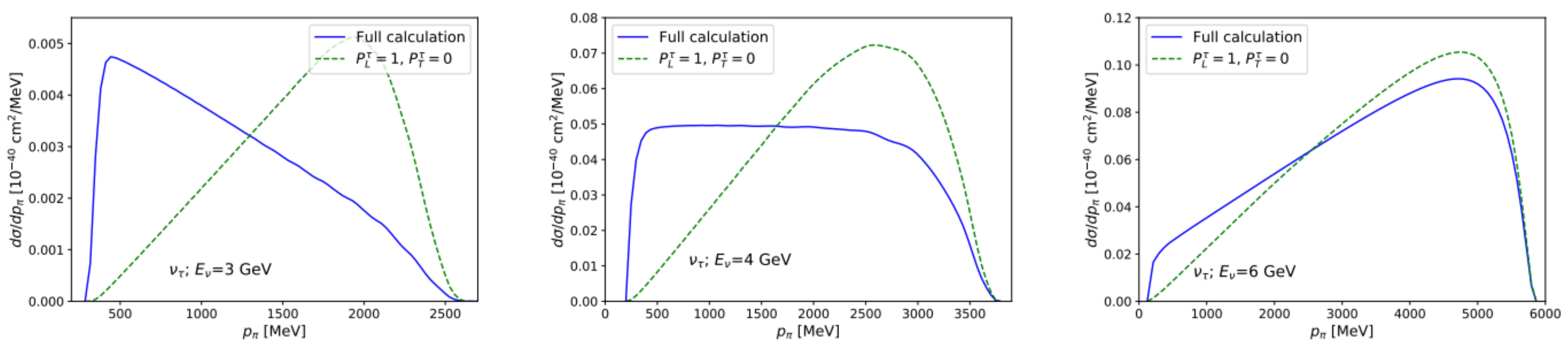


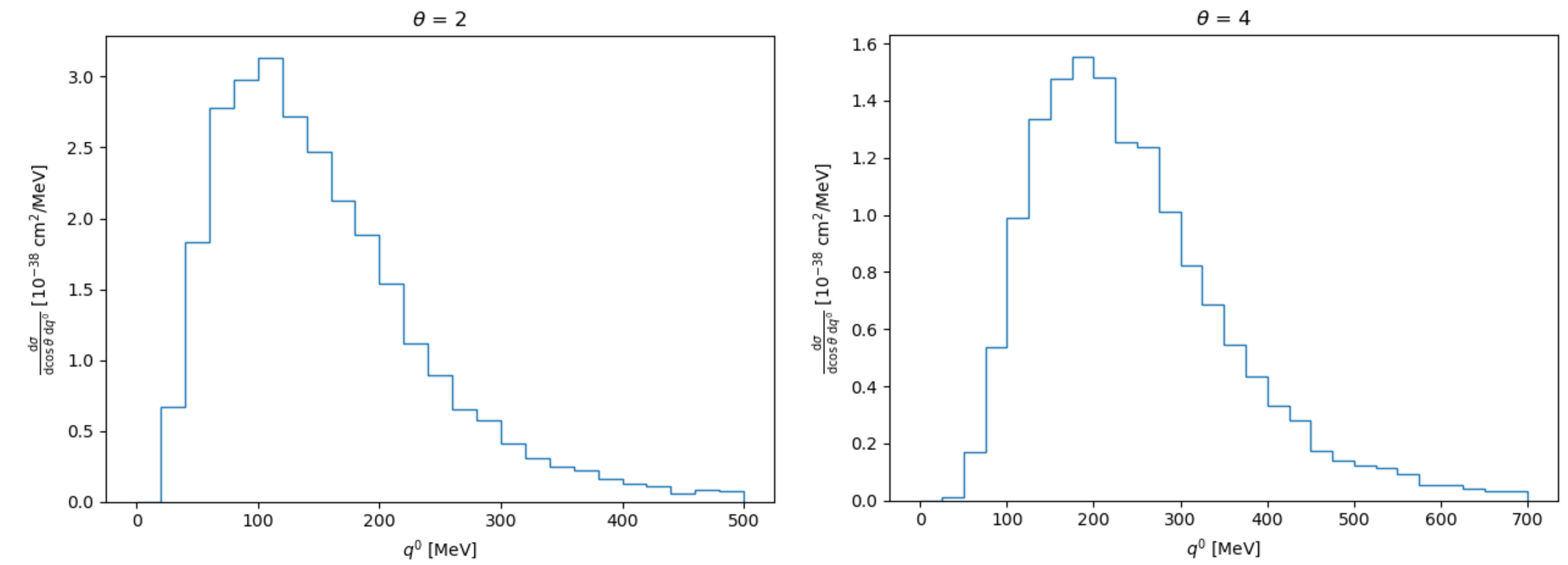
Figure 1: A plot from Hernández (2022) shows the difference in differential cross section calculations when polarization is fully calculated as opposed to being approximated as fully longitudinal.

Methods

Using C++, I implemented a calculation of transverse and longitudinal polarization for both tau neutrino and antineutrino interactions. The calculation takes lepton mass, helicity, beam energy, the leptonic tensor, and the hadronic tensor as inputs. My code also calculates all inputs except for beam energy, which can be configured in a YAML file created by Joshua Isaacson. After producing the polarization calculations, I incorporated relevant values into the existing event generation framework and exported data from each event. Lastly, I am in the process of using Python to create plots of the differential cross section and polarization for a tau neutrino scattering off oxygen at various scattering angles and the mean value of the degree of polarization for taus and anti-taus with respect to beam energy.

Results

The plots that I created (see Figure 2) show the differential cross section of a tau neutrino scattering off oxygen, as depicted in Figure 3 in Sobczyk (2019). Completing the recreation of figures 3 and 7 from Sobczyk (2019) and thus determining the full calculations of the tau's average polarization is a critical step towards our goal of simulating tau decay with maximum accuracy. In the future, we plan on interfacing the polarization information with SHERPA in order to properly decay the taus.



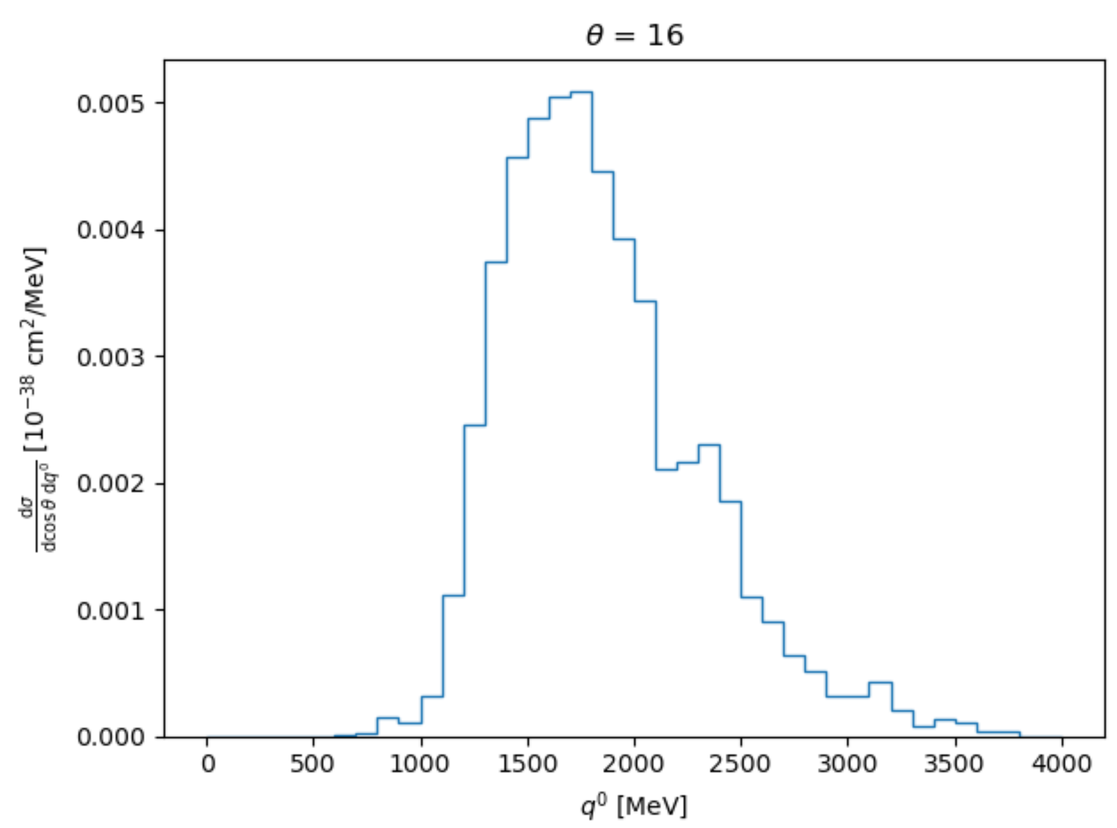


Figure 2: Differential cross sections for tau neutrinos scattering off oxygen for a beam energy of 6 GeV. The top-left panel corresponds to a scattering angle of 2 degrees, the top-right panel corresponds to a scattering angle of 4 degrees, and the bottom-left panel corresponds to a scattering angle of 16 degrees.

References

Hernández, E., et al. "Tau Longitudinal and Transverse Polarizations from Visible Kinematics in (Anti-)Neutrino Nucleus Scattering." *Physics Letters B*, vol. 829, 2022, https://doi.org/10.1016/j.physletb.2022.137046.

Sobczyk, J. E., et al. "Polarization of Tau in Quasielastic (Anti)Neutrino Scattering: the Role of Spectral Functions." *Physical Review C*, vol. 100, 2019, https://doi.org/10.1103/physrevc.100.035501.

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