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Lepton-Nucleus Quasielastic Scattering

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Neutrino Oscillation and the PMNS Matrix

Neutrino oscillation is a phenomenon where a neutrino oscillates into a different flavor, and it is characterized by four independent constants, which determine the elements of the **PMNS matrix**. Measuring the values of the PMNS matrix is of extreme importance, and many future experiments are being built for this purpose.

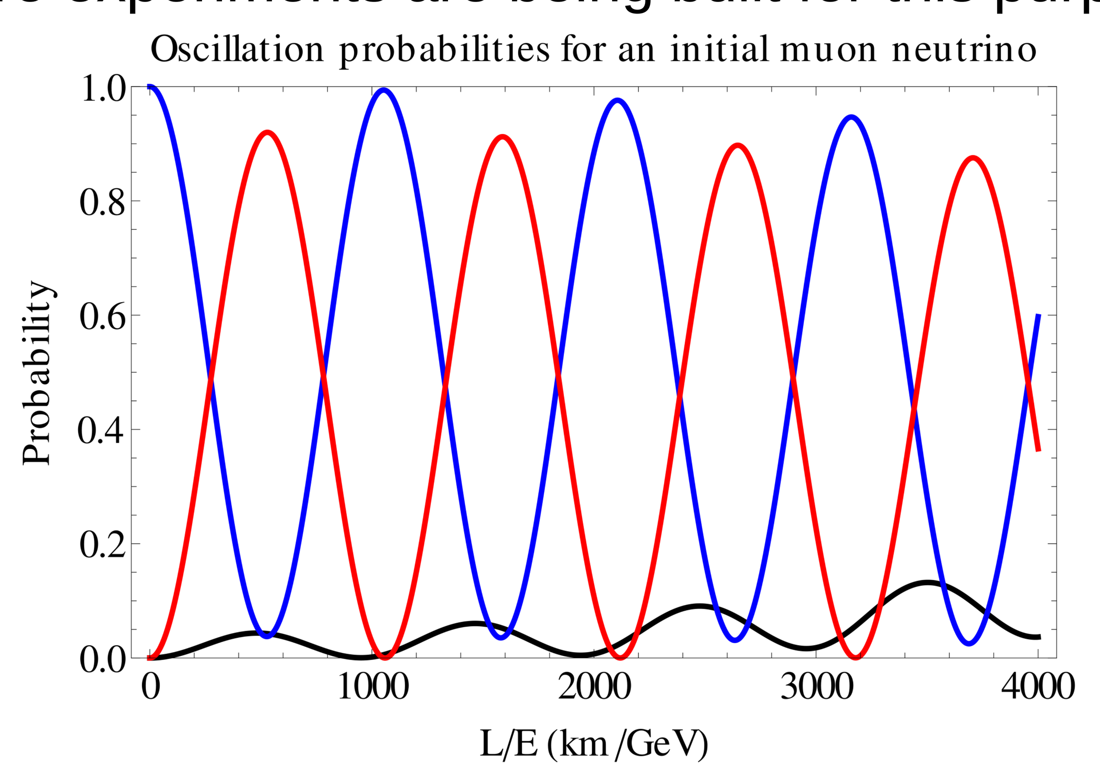

Fig. 1: Probability that a muon neutrino with energy E is measured to be a tau neutrino (red), electron neutrino (black), or a muon neutrino (blue) after traveling a distance L.

Quasi-Elastic Scattering

Measuring the elements of the PMNS matrix requires predicting how many neutrinos will interact in a detector. Current models give poor estimations, so our project entailed improving predictions for **quasielastic scattering**. In quasielastic scattering, a lepton interacts elastically with a single nucleon; because this reaction mechanism is the simplest, it allows us to easily discriminate between different models.

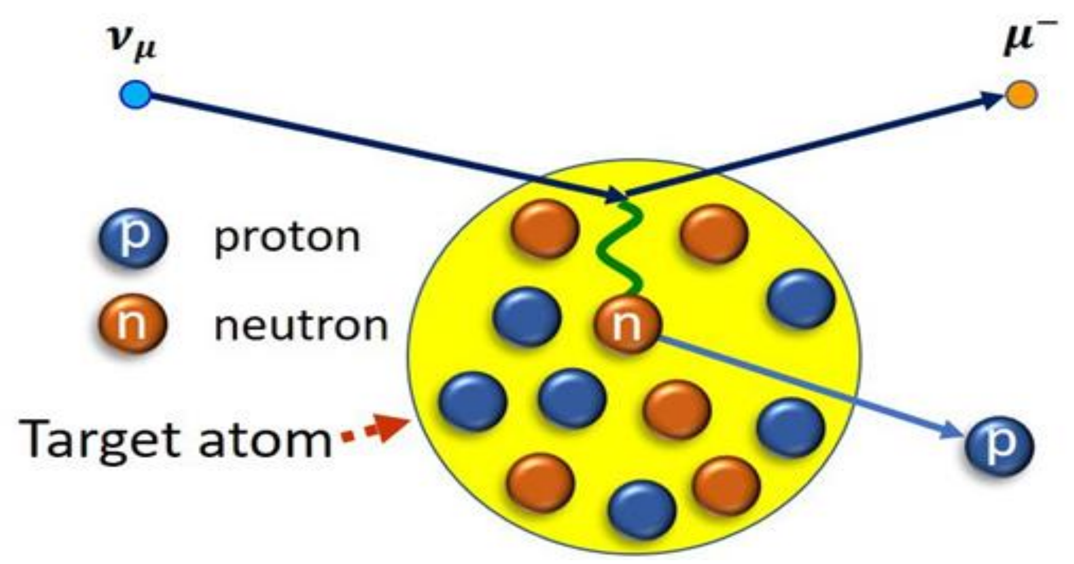

Fig. 2: Image of a muon neutrino scattering off a carbon nucleus. The neutrino collides with a neutron, resulting in a muon and a proton being ejected from the nucleus.

Nuclear Spectral Function

Commonly, simple Fermi gas-like distributions are used to approximate the distribution of nucleon energy and momentum; however, these approximations agree poorly with scattering data. Instead, we use a **Spectral Function**, computed from first principles, that gives a more realistic distribution of nucleon energy and momentum. The Spectral Function also includes the physics of correlated pairs of nucleons.

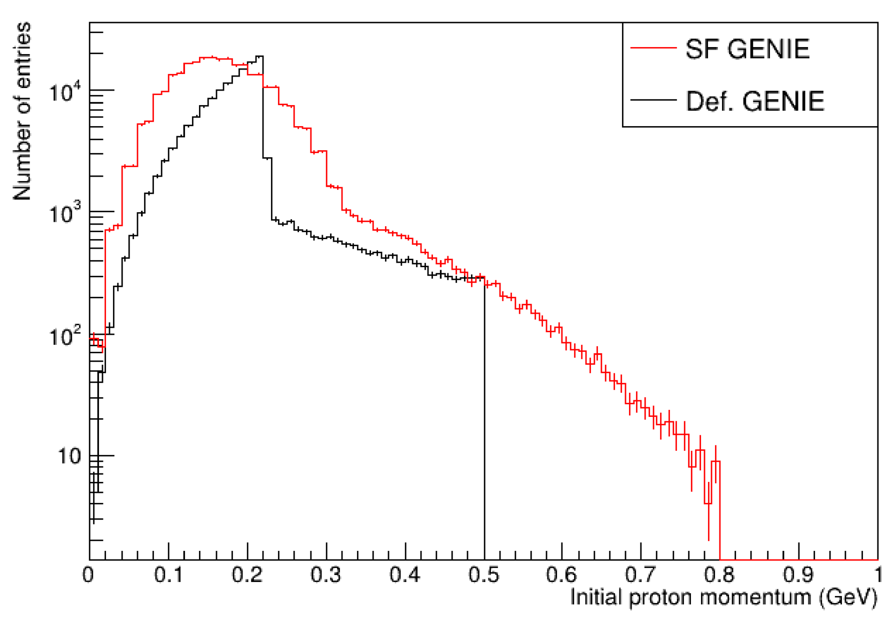

Fig. 3: Distribution of initial proton momenta in GENIE simulation of 1.161 GeV electrons scattering on carbon-12. Distribution is shown for Spectral Function model (SF GENIE) and relativistic Fermi gas model (Def. GENIE).

GENIE Simulations

To compare different models of lepton-nucleus scattering, we used **GENIE**, a lepton-nucleus event generator. After we implemented the Spectral Function model into GENIE, we produced plots to compare this model with the more simplistic default GENIE model.

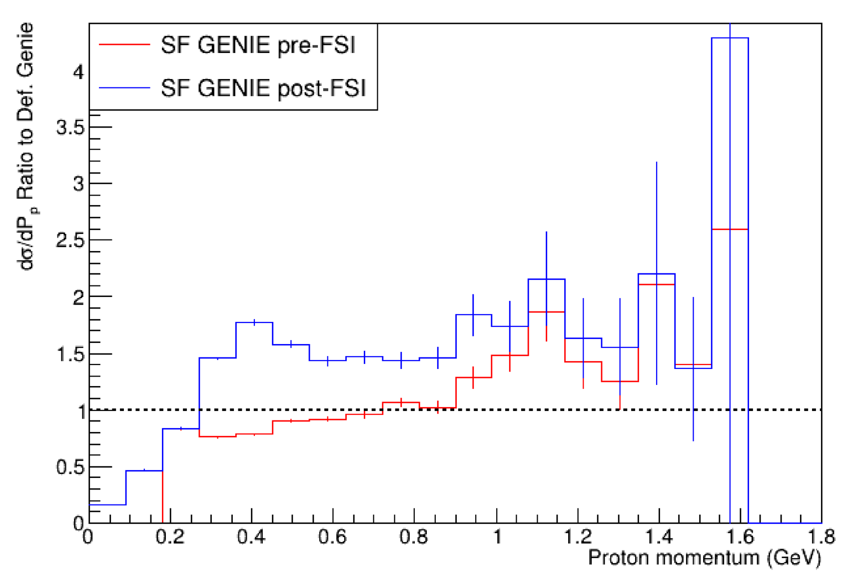

Fig. 4: Plot of ratio of differential cross section for 1.161 GeV electron beam and ^{12}C detector (SF GENIE/Def. GENIE). The ratio is shown as a function of the struck proton's momentum before and after final state interactions (FSI).

Electron Scattering Data

Currently, we are unable to generate a mono-energetic beam of neutrinos, so we need to be able to accurately predict the **initial neutrino energy** from scattering data. To test the accuracy of our model's predictions, we have our model estimate the **initial electron energy** from scattering data produced by a mono-energetic electron beam. By checking how close our model's predictions are to the known beam energy, we can measure its ability to predict initial neutrino energy.

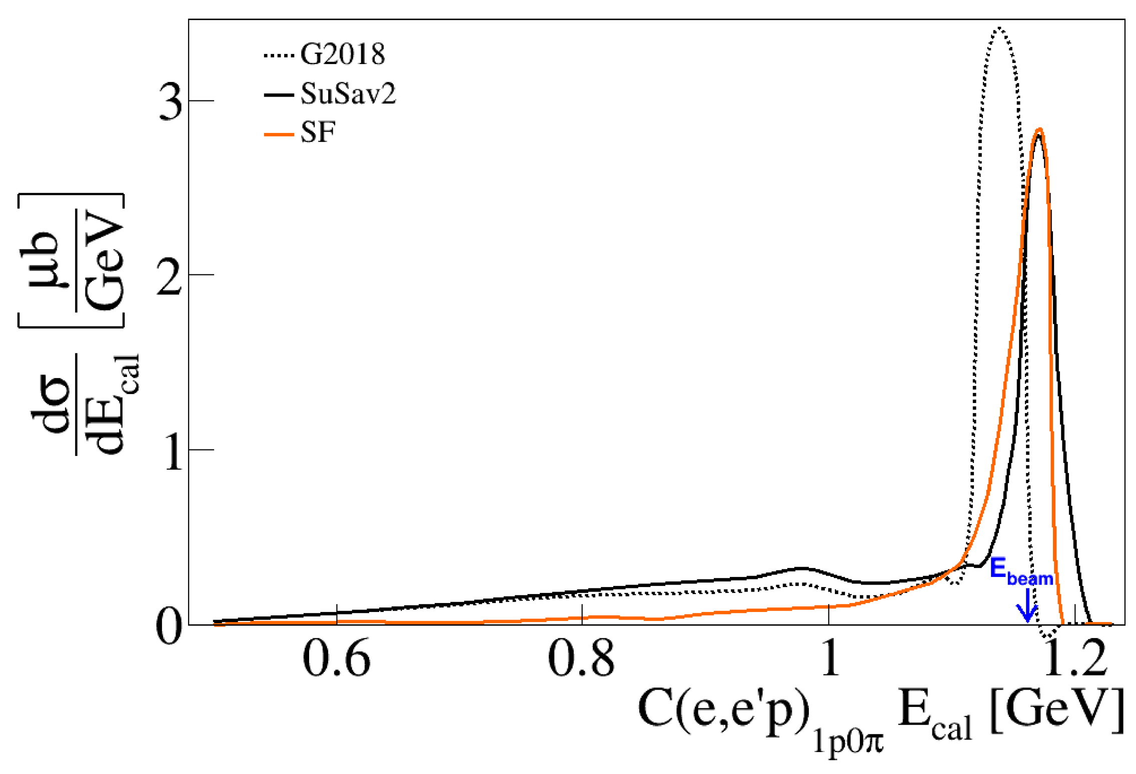

Fig. 5: Plot of differential cross section as function of energy estimator variable E_{cal} in GENIE simulation of 1.161 GeV electrons scattering on ^{12}C. Plot is shown for Spectral Function model (SF), SuSav2 model (SuSav2), and relativistic Fermi gas model (G2018).

Future Work

The Spectral Function model allows for more accurate simulations of electron and neutrino scattering, and testing this model against electron scattering data has returned promising results. In the future, we hope to extend this model with more interaction channels and test against neutrino scattering data.

Acknowledgements

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