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Implement Spectral Function Model Into GENIE via Wrapper

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Introduction

- Fermilab is a leader in experimental neutrino research.
- This research would benefit from improved simulation models of neutrino interactions, for analysis of data.
- Improved understanding of neutrino properties though this, could lead to discovering fundamentally new physics.

Figure 1: MicroBooNE (left), neutrino related experiment; GENIE (right) a "universal neutrino generator & global fit." (Credit: Fermilab, GENIE)

- Fermilab utilizes GENIE for neutrino based simulations.
- GENIE is a large framework, using Monte Carlo event generators for neutrino interaction simulation & analysis.
- However, it would benefit from better neutrino scattering mechanism models, in particular for **quasielastic (QE)**.

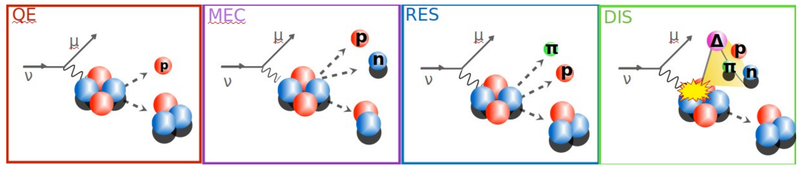
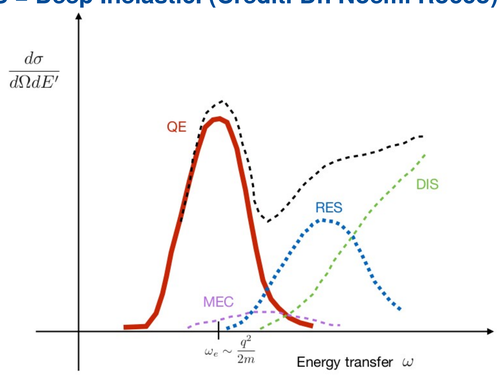


Figure 2: Different neutrino scattering reaction mechanisms: QE = Quasielastic, MEC = Meson Exchange Current, RES = Resonance, DIS = Deep Inelastic. (Credit: Dr. Noemi Rocco)

Figure 3: Example of scattering mechanism models' contributions (colored lines) to final observed experimental data result (black dotted line) for these quantities, which are associated with neutrino interaction events. (Credit: Dr. Noemi Rocco)



Improvements to the Model

- Improvements to the quasielastic scattering models exist via Dr. Noemi Rocco's **Spectral Function (SF)** model.
- Electron and neutrinos interact similarly, many identical nuclear effects. This would allow us to constrain GENIE.

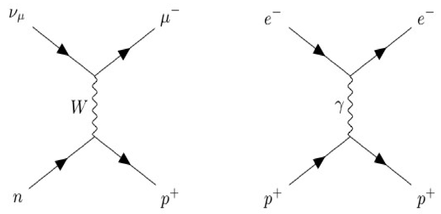


Figure 4: Feynman diagrams show similarity for the charged current quasielastic neutrino (left) and quasielastic electron (right) scattering processes. (Credit: K. Ewart, J. Ellis, M. Allen)

- These calculations are available for neutrino and electron scattering in Fortran 90, but GENIE is written in C++.
- Below: differential cross sections vs. electron energy loss, for experimental/simulation electron scattering data.

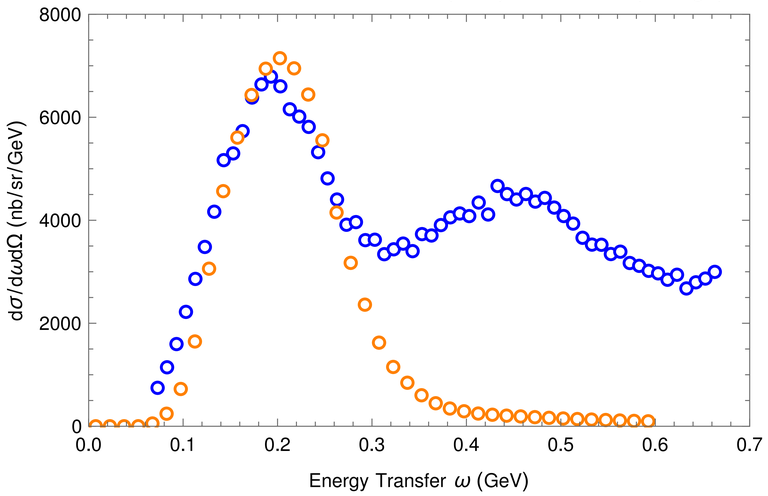


Figure 5: Experimental (blue) and simulation (orange) data of electron scattering off of Carbon-12 nucleus up to 0.961 GeV initial energy and 37.5 degree angle. (Credit: Sealock 1989, Rocco 2021)

- Good agreement within the quasielastic dominated region.
- These results can be extrapolated via electron-neutrino relations into better agreement for neutrino scattering.

Wrapper Implementation

- We utilize the strengths of both GENIE and the Spectral Function model, via wrapping the SF model into GENIE.
- Removing GENIE's current quasielastic model related C++ code lines with C++ code that "calls" Fortran 90 SF code.
- This is our wrapper, which executes only part of Dr. Rocco's (slightly edited) SF code's improved calculations.
- Thus GENIE now generates inputs for part of the SF code, which then returns cross section data for final GENIE/C++ calculations.

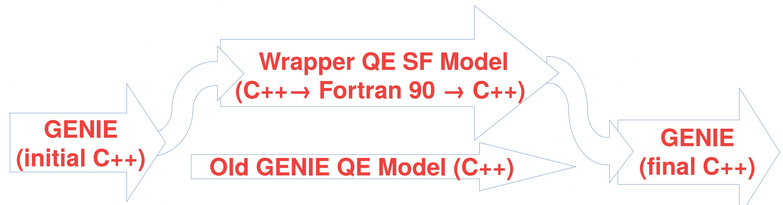


Figure 6: Flowchart depicting new wrapper infrastructure.

Anticipated Results

- We have incorporated the wrapper infrastructure into the GENIE code, with promising preliminary results, but are still in the validation phase, due to slight offset differences, with respect to the wrapper simulation results vs. Dr. Rocco's Fortran 90 only simulation results.
- However, should these results be worked out, we anticipate plots demonstrating the improved quasielastic model agreement between experimental and simulation data for the wrapper-based GENIE infrastructure over the wrapper-less GENIE version (similar to Figure 5).
- Wrapper-based infrastructure addition result success for GENIE would motivate the possibility for further similar additions to improve GENIE's current stock of simulation models, while still utilizing its overall framework.

Citations: [1] The GENIE Neutrino Monte Carlo Generator. http://genie.hepforge.org/manuals/GENIE_PhysicsAndUserManual_20130615.pdf. 2013. [2] Noemi Rocco, Carlo Barbieri, Omar Benhar, Arturo De Pace, and Alessandro Lovato, "Neutrino-nucleus cross section within the extended factorization scheme," Phys. Rev. C 99, 025502 (2019).

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