

# 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.

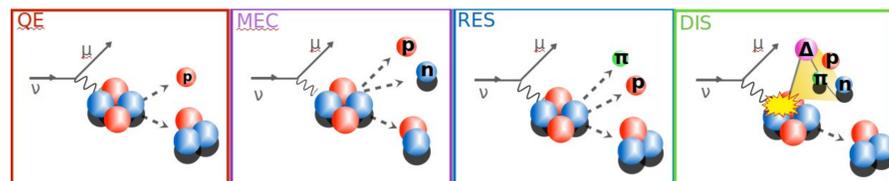
**Figure 1: MicroBooNE** (left), neutrino related experiment; **GENIE** (right) a “universal neutrino generator & global fit.” (Credit: Fermilab, GENIE)



- Fermilab utilizes GENIE for neutrino based simulations. [1]

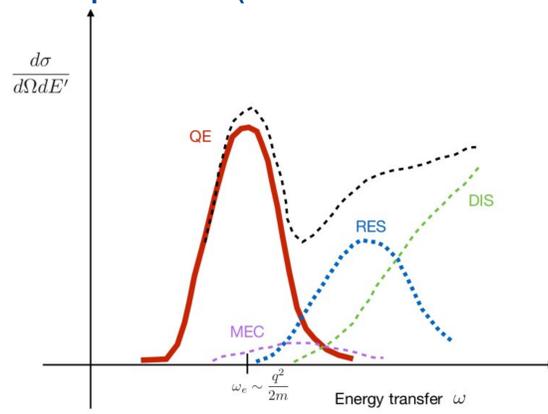
- GENIE is a large framework, using Monte Carlo event generators for neutrino interaction simulation & analysis.

- 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)

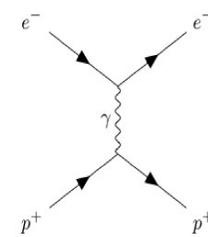
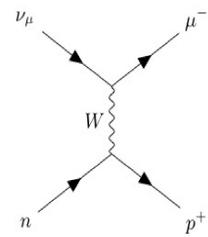
**Figure 3: Example of scattering mechanism models' contributions** (colored lines) to final observed experimental data result (black dotted line) for these quantities, which are associated with neutrino interaction events. (Credit: Dr. Noemi Rocco)



## Improvements to the Model

- Improvements to the quasielastic scattering models exist via Dr. Noemi Rocco's **Spectral Function (SF)** model. [2]

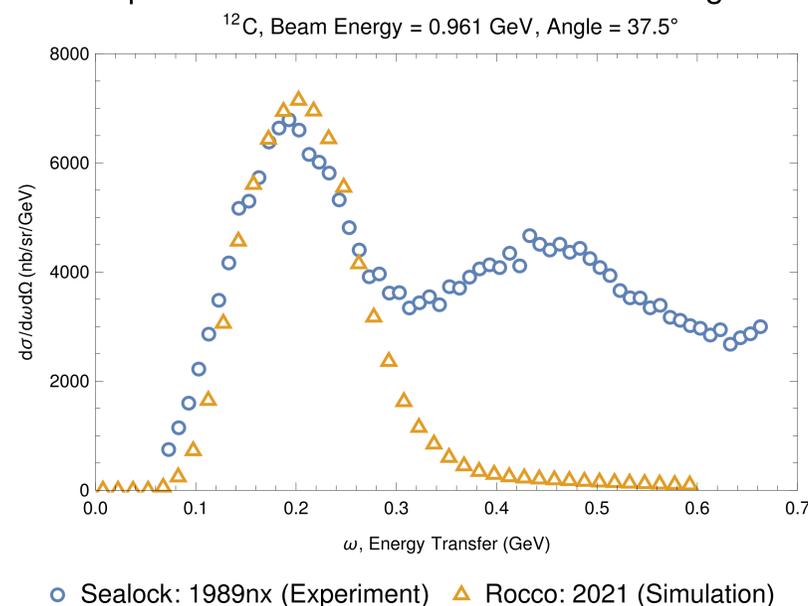
- Electron and neutrinos interact similarly, many identical nuclear effects. This would allow us to constrain GENIE.



**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 with 0.961 GeV beam 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.

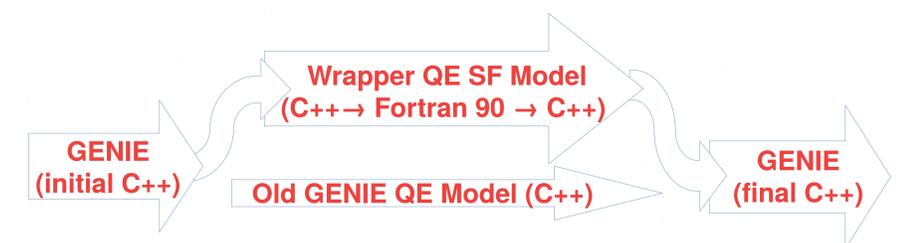
## Wrapper Implementation

- 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.

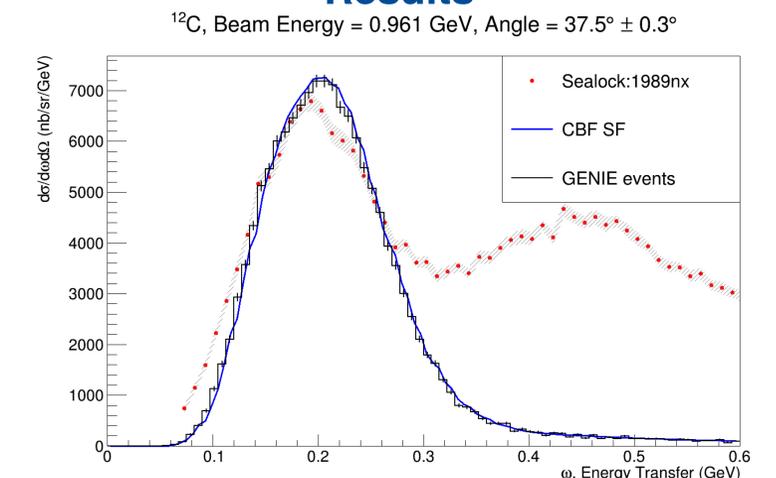
- This is our wrapper, which executes only part of Dr. Rocco's (slightly edited) SF code's improved calculations.

- 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.**

## Results



**Figure 7: Experimental (red), Fortran 90 only (blue), GENIE + wrapper (black) data of electron scattering off of Carbon-12 nucleus with 0.961 GeV beam energy and 37.5 degree angle.** (Credit: Gardiner/Truong 2021)

- Wrapper-based infrastructure addition result success for GENIE motivates the possibility for further similar wrapper additions to improve GENIE's other models (such as MEC, RES, DIS), while still utilizing its overall framework.