Nuclear models: should the neutrino community care about them?

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Impulse Approximation (IA) and Short Range Correlation

One Particle One (Two) Hole (IA Scheme)

Spectral Function
The initial-state of the target nucleus is described by the spectral function in Eq. 1, \( P(\mu, E) \), yielding the probability of removing a nucleon of momentum \( \mu \) from the target nucleus, leaving the residual system with the excitation energy \( E \).

\[
P(\mu, E) = \frac{1}{\pi \hbar^2} \frac{\delta (\mu - \| \vec{p} \|)}{\sqrt{\vec{p}^2 + m^2 - E_{\perp} - m_0 + E}}
\]

(1)

\( E_{\perp} \) and \( m_0 \) are the Fermi momentum and the average nucleon binding energy, respectively, and the distribution of Fig. 7 collapses to a line: the Fermi momentum and the average nucleon binding energy.

\( Q^2 \) Selection at the Interaction Vertex
In GENIE 2.8.0, \( Q^2 \) is selected randomly within a range defined by a set of minimum and maximal values. Therefore, the value of \( Q^2 \) is not affected by the initial nucleus' kinematics, dictated by the dynamical model employed to describe the target ground state: RFGM or SF. In our implementation, the \( Q^2 \) selection instead takes into account the dependence of the interaction vertex on both separation energy and initial-state momentum of the struck nucleon.

\[
\frac{d\sigma}{dE_\nu} \propto L_{\text{maj}}(\vec{k}, p'N(\vec{p}, \vec{q}))
\]

(3)

Cross-section
The derivation of the double differential nuclear cross section in the impulse approximation regime is described in detail in Refs. [1, 2].

\[
\frac{d\sigma}{dE_\nu} = \int \frac{d\sigma}{dE_\nu} \frac{d\sigma}{dE_\nu} \times \frac{d^2P(\mu, E)}{d\mu dE} \times \delta(\omega - M_\perp - \sqrt{\vec{p}^2 + m^2 - E_{\perp}})
\]

(4)

where \( d^2P(\mu, E) \) reflects the probability of interacting with the structured nucleon at its binding energy and initial-state momentum, and thus manifests the contribution of the lepton-nucleon interaction to the cross-section.

Validation of Electron Cross-section
Comparison of double differential electron-nucleus cross sections between experimental data and simulated predictions in the quasi-elastic channel are shown below:

Figure 5: probability distribution of neutron momentum \( p^2P(\vec{p}, E) \).

Neutrino Oscillation Parameters
To evaluate the impact of three different simulation conditions (RFGM, RF + new Q^2 selection and SF) we took the event rates computed using GLoBES, applied to them the migration matrices computed with one particular setting of the neutrino interaction generator, and try to fit them using the matrices obtained with a different setting. By doing this, the possible biases on the oscillation parameters, induced by the different nuclear models or \( Q^2 \) selection introduced in GENIE 2.8.0 + \( v^\tau \), can be quantified in a robust fashion.

Acknowledgement
Artur Ankowski, Omar Benhar, Andrew Furmanski, Donal Day, Steve Dytman, Douglas Higinbotham, and Camillo Manoni.

References