**Motivation**

Charged-current quasielastic mechanism of interaction is dominant at neutrino energy $E_\nu \sim 600$ MeV (T2K) and important in the few-GeV region (NOvA).

In CCQE events, $E_\nu$ is typically reconstructed from the measured kinematics of the charged lepton only.

The accuracy of this method is limited by the accuracy to which nuclear effects are described by the Monte Carlo simulations involved in data analysis.

**Formalism**

We account for the final-state interactions between the struck particle and the spectator system in the convolution scheme,

$$\frac{d\sigma_{\text{FSI}}}{d\omega d\Omega} = \int d\omega' f_Q(\omega' - \omega - U_V) \frac{d\sigma^{IA}}{d\omega d\Omega},$$

integrating the impulse-approximation prediction $\sigma^{IA}$ with a folding function, which can be decomposed as

$$f_Q(\omega) = \delta(\omega) \sqrt{T_A} + (1 - \sqrt{T_A}) F_Q(\omega),$$

where $T_A$ is the nuclear transparency, and $F_Q(\omega)$ is a finite-width function.

In the energy spectrum of the struck nucleon, we include the real part of the optical potential, $U_V$, obtained from the Dirac phenomenological analysis of Cooper et al. [1].

Our calculations, involving no adjustable parameters, are here compared to the data for electron scattering off carbon reported by Refs. 2, 3. For much more extensive comparison, see the ancillary file of [2014PhRvD..90c3005S].

**References**


**Neutrino energy reconstruction**

The probability distribution that a muon of energy $E_\mu$ observed at angle $\theta$ originates from an interaction of a neutrino of energy $E_\nu$,

$$P(E_\nu | E_\mu, \cos \theta) = \frac{\frac{d\sigma}{dE_\nu d\cos \theta}}{\int dE_\nu \frac{d\sigma}{dE_\nu d\cos \theta}}.$$

Our results (a) are compared to the RFG calculations (b). The maxima (arrows) correspond to $|q|^2 (Q^2) \sim 156, 257, 335$ MeV $^2$.

**Positions of maxima at $E_\mu = 600$ MeV**

<table>
<thead>
<tr>
<th>$\cos \theta$</th>
<th>$E_\mu$ (GeV)</th>
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<tbody>
<tr>
<td>0.97</td>
<td>633</td>
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<tr>
<td>0.92</td>
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<table>
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<th>$E_\mu$ (GeV)</th>
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<tr>
<td>619</td>
</tr>
<tr>
<td>639</td>
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<tr>
<td>661</td>
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</tbody>
</table>

A comparable accuracy can be expected in $\nu$ interactions.

**Conclusions**

- The neutrino energy reconstruction is significantly affected by the description of nuclear effects.
- Its reliable determination can only be obtained from nuclear models validated by a systematic comparison to the electron-scattering data.
- Our approach has reached a remarkable accuracy over a broad kinematical region, uncertainties are under control at quantitative level.
- At energy $\sim 600$ MeV, we observe a sizable $\nu_\mu - \bar{\nu}_\mu$ difference, important for the CP measurements.