Improving the accuracy of neutrino energy reconstruction in charged-current quasielastic scattering off nuclear targets

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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 (NOνA).
In CCQE events, E_ν 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,

$$\frac{d\sigma^{\rm FSI}}{d\omega d\Omega} = \int d\omega' f_{\mathbf{q}}(\omega - \omega' - U_V)\frac{d\sigma^{\rm IA}}{d\omega' d\Omega},$$

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

$$f_{\mathbf{q}}(\omega) = \delta(\omega)\sqrt{T_A} + \left(1 - \sqrt{T_A}\right)F_{\mathbf{q}}(\omega),$$

where T_A is the nuclear transparency, and $F_{\mathbf{q}}(\omega)$ 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 `arXiv:1404.5687`.

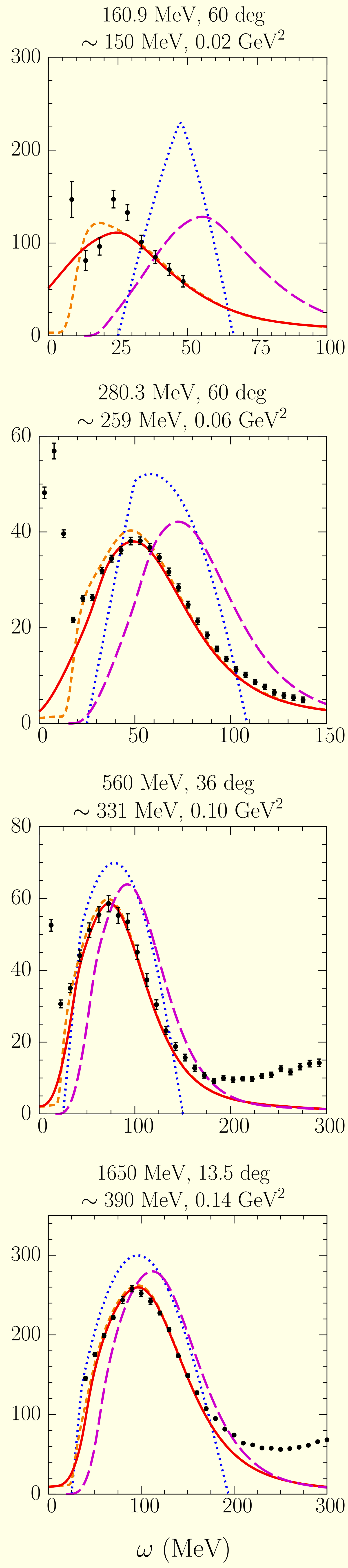
References

[1] E. D. Cooper, S. Hama, B. C. Clark, and R. L. Mercer, Phys. Rev. C **47**, 297 (1993).

[2] P. Barreau *et al.*, Nucl. Phys. A **402**, 515 (1983).

[3] D. T. Baran *et al.*, Phys. Rev. Lett. **61**, 400 (1988).

Electron-carbon cross sections $d\sigma/d\omega d\Omega$ (nb/MeV sr)

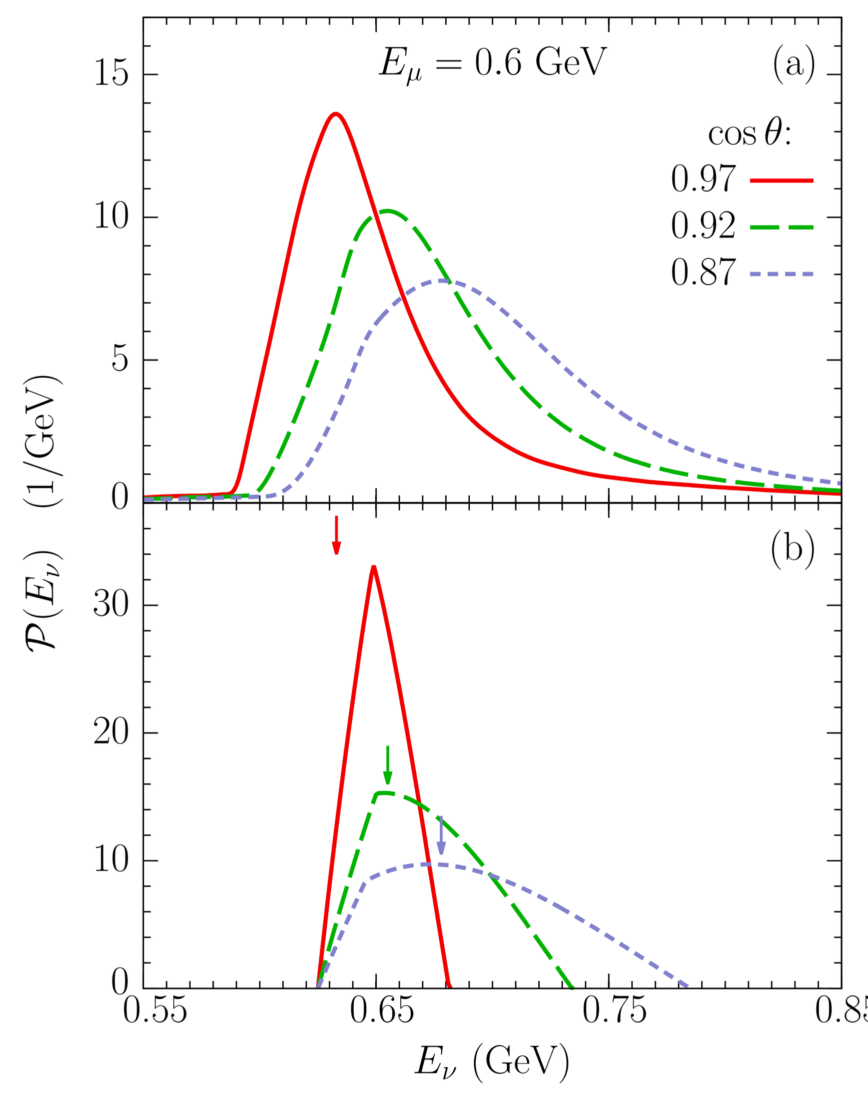


A comparable accuracy can be expected in ν interactions.

Neutrino energy reconstruction

The probability distribution that a muon of energy E_μ observed at angle θ originates from an interaction of a neutrino of energy E_ν,

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



Our results (a) are compared to the RFG calculations (b). The maxima (arrows) correspond to $|\mathbf{q}|$ (Q^2) of ~ 156, 257, and 335 MeV (~ 0.02, 0.06, and 0.11 GeV^2), respectively.

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

$\cos\theta$	0.97	0.92	0.87
ν_μ	633	655	678
$\bar\nu_\mu$	619	639	661

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 ~600 MeV, we observe a **sizable ν_μ-$\bar\nu_\mu$ difference**, important for the $\not{C}\not{P}$ measurements.