Effect of outgoing nucleon wave function on reconstructed neutrino energy

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Abstract The main goal of accelerator-based neutrino experiments is the determination of the neutrino oscillation parameters, The oscillation probability depends on the ratio of the distance traveled by the neutrino to its energy, therefore the determination of the distribution of neutrino energies in a detector is crucial. The reconstructed neutrino energy is a kinematic variable which is determined by the energy and scattering angle of the final state lepton in charged current (CC) scattering off an atomic nucleus. The distribution of reconstructed energies around the true incoming energy depends on the nuclear model used to describe the ν-nucleus cross section. We show the effect of distortion of the outgoing nucleon wave function on these distributions.

In a detector one observes the CC scattering of a neutrino off a nucleus where a single final-state lepton, with energy E_l and scattering angle $\cos\theta_l$, is detected. In the experimental analysis the reconstructed energy $\overline{E}_\nu\,(E_l,\cos\theta_l)$ is the energy of the neutrino scattering of a neutron at rest, corrected for binding [1, 2]. After binning the data in terms of $\overline{E}_\nu$, the true energy distribution has to be recovered. This requires a nuclear model for the interaction. In the experimental analysis a relativistic Fermi gas (RFG) model is commonly used for this task.

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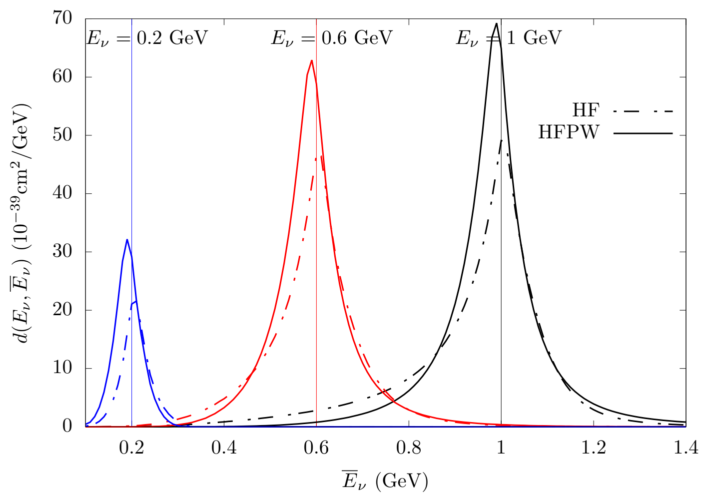

Fig. 1 $d(\overline{E}_\nu, E_\nu)$, defined and described in Refs. [6, 1], is proportional to the probability of a neutrino with real energy E_ν giving rise to a reconstructed energy $\overline{E}_\nu$. Calculated for CCQE scattering of electron neutrinos off ^{12}C. $\overline{E}_\nu$ is defined as in Eq. (1) of Ref. [1] with $E_B = 25$ MeV.

In the HF model for quasielastic (QE) scattering [3, 4, 5], the final-state wave function is constructed from continuum states in the same HF potential used for the bound states. In Fig. 1, we compare the distribution of $\overline{E}_\nu$ for a fixed real E_ν obtained with the full HF model, with the results of the HFPW model in which the final state nucleon wave function is a plane wave. In this way we directly asses the effect of the outgoing wave function.

The outgoing nucleon wave function affects the magnitude of the cross section, owing to the elimination of non-orthogonal contributions which are present in the plane wave. More important is that a reshaping occurs in the HF model, the peak of the distribution shifts to slightly larger values of $\overline{E}_\nu$, while the low $\overline{E}_\nu$ tail is strongly enhanced. This asymmetry is not reproduced with PW models or with the commonly used RFG. Not taking these more asymmetric distributions into account could introduce a significant bias in the analysis of oscillation experiments [1].

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