QUASIELASTIC NEUTRINO–ARGON CROSS SECTIONS IN A CRPA APPROACH

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Motivation

- There has recently been a surge of interest in Liquid Argon Time Projection Chamber detectors (e.g. ArgoNeuT, MicroBooNE, DUNE, ...). We aim to contribute to these developments.
- Quasielastic scattering is the dominant reaction mechanism in the energy range of interest:

$$\nu_\mu + A(Z,N) \rightarrow \mu + A'(Z,N-1) + p$$

In light of the need for theoretical studies of the neutrino-argon cross section we present results on inclusive quasielastic neutrino-argon differential cross section calculations.

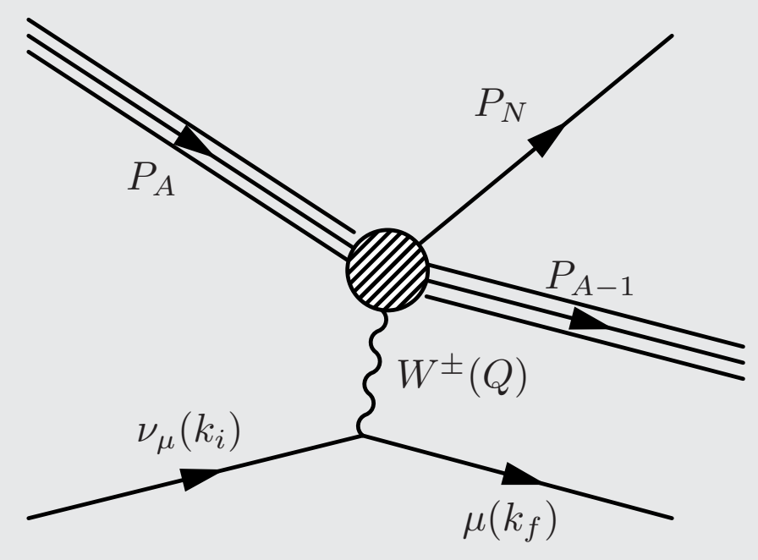


Figure 1: CCQE neutrino–nucleus scattering.

Theoretical model in brief

The inclusive charged current quasielastic (CCQE) neutrino–nucleus scattering cross section can be expressed as follows.

$$\frac{\mathrm{d}^3\sigma^{CC}}{\mathrm{d}\Omega_f \mathrm{d}\omega_f} = 4\pi\sigma^W \zeta[v_{CC}W_{CC} + v_{CL}W_{CL} + v_{LL}W_{LL} + v_T W_T - h v_{T'} W_{T'}],$$

with $h = +/-$ for neutrino/antineutrino scattering respectively and

$$\sigma^W = \left(\frac{G_F \cos\theta_c E_f}{2\pi}\right)^2.$$

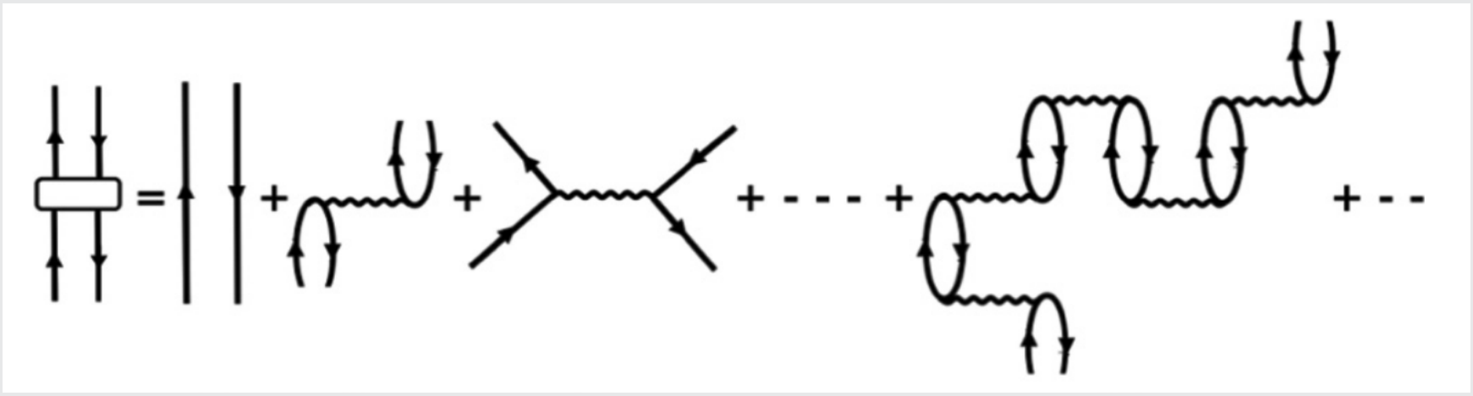
The v factors depend on the leptonic kinematic variables. The W factors are the **nuclear response functions**. These depend on the nuclear current matrix elements.

$$\mathcal{J}_\lambda^{nucl}(\boldsymbol{q}) = \langle \Phi_\mathrm{f} | \hat{J}_\lambda(\boldsymbol{q}) | \Phi_0 \rangle.$$

Nuclear wave functions are Slater determinants calculated in an effective mean–field **Skyrme (SkE2) potential**.

Long–range correlations are introduced through a **Continuum Random Phase Approximation (CRPA)** approach. In this Green's function formalism one considers scattering states as solutions to the RPA–equation in coordinate space:

$$\Pi^{(RPA)}(x_1,x_2,\omega) = \Pi^{(0)}(x_1,x_2,\omega) + \frac{1}{\hbar}\int \mathrm{d}x \int \mathrm{d}x' \Pi^{(0)}(x_1,x,\omega)\tilde{V}(x,x')\Pi^{(RPA)}(x',x_2,\omega).$$



The residual interaction is the same Skyrme interaction used to generate the single–particle wave functions, making this approach **self–consistent**: the ground state and excitations are described by the same interaction.

Relativistic effects are taken into account in an **effective** way.

Application to e^- scattering

The model has been used before for **electron-nucleus scattering**. The differential cross section has the following expression:

$$\frac{\mathrm{d}^3\sigma^{elec}}{\mathrm{d}\Omega_f \mathrm{d}\omega_f} = 2(4\pi)\sigma^{Mott}\zeta[v_L W_L + v_T W_T],$$

with σ^{Mott} the Mott cross section:

$$\sigma^{Mott} = \left(\frac{\alpha\cos(\theta_l/2)}{2E_i \sin^2(\theta_l/2)}\right)^2.$$

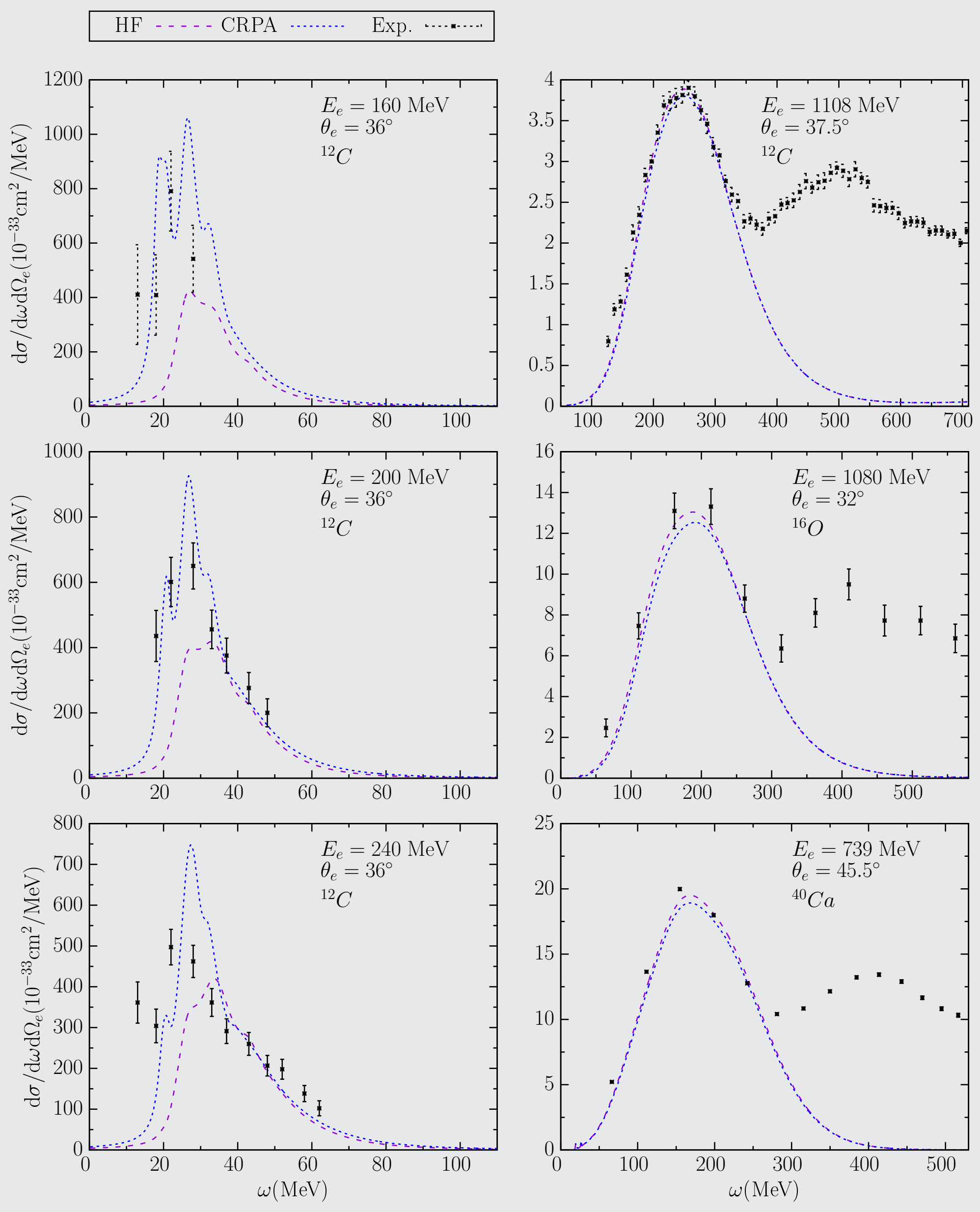


Figure 2: Quasielastic electron–nucleus scattering results.

- The CRPA succesfully reproduces the quasielastic peak over a broad range of electron energies.
- The CRPA is considerably better than a Hartree–Fock approach at modeling the low energy regime. This is important, since neutrino experiments contain **low energy contributions in the incoming flux**.
- The data includes contributions from channels beyond QE, like Δ-excitations, not included in the model.

CCQE (ν, Ar) scattering results

In baseline experiments, one has the added complication that incoming neutrinos are **not monochromatic**: flux–folding is needed.

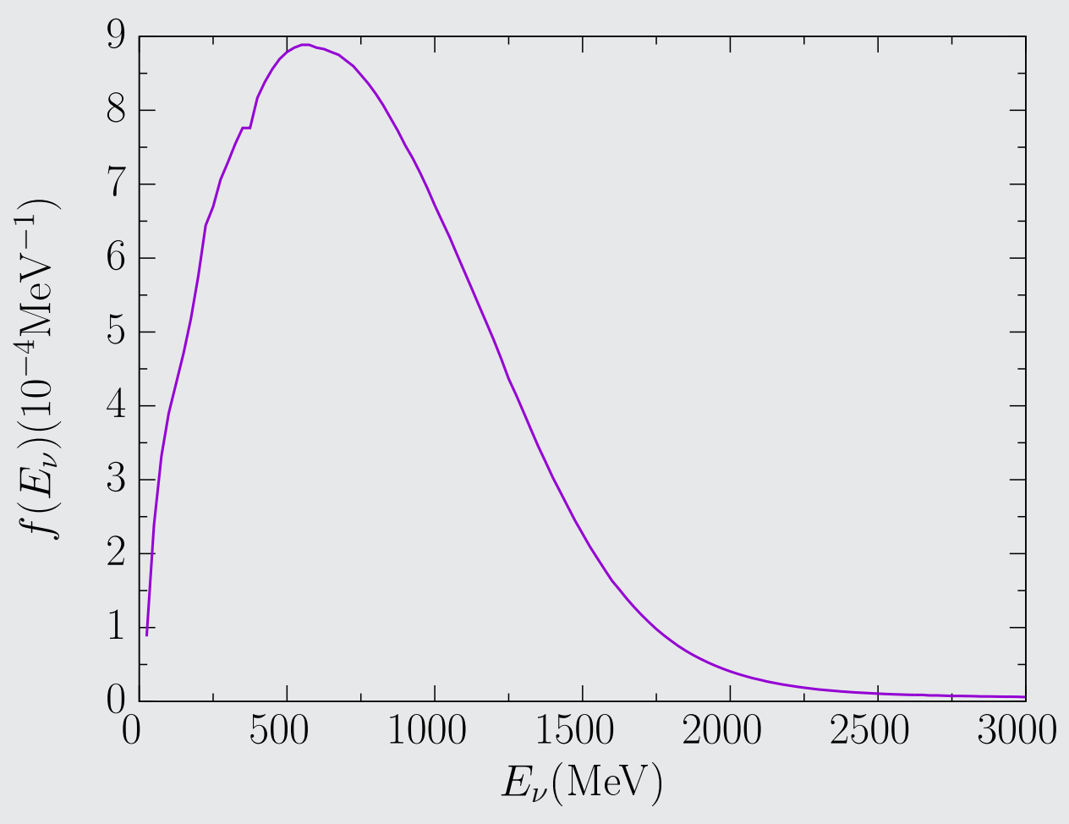


Figure 3: MicroBooNE BNB flux used in flux–folding.

In performing this folding, one gets the double differential cross section for CCQE (ν, Ar) scattering. One can make quantitative comparisons with **other nuclei**, e.g. ^{12}C.

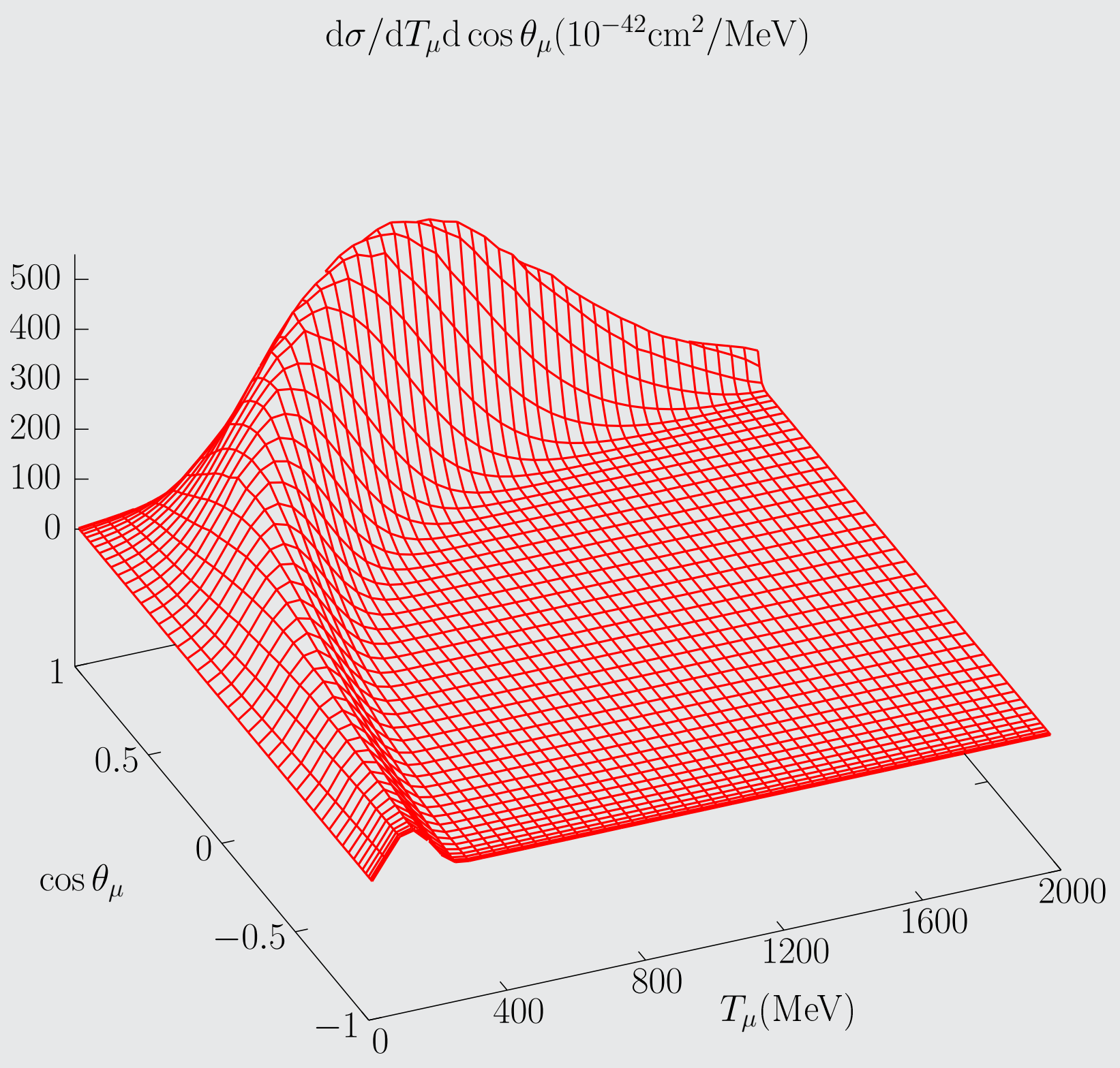


Figure 4: The double differential CCQE cross section for ^{40}Ar target.

One observes that for **forward scattering**, argon has an **enhanced reaction strength**. Furthermore, a similar observation is made for low T_μ events.

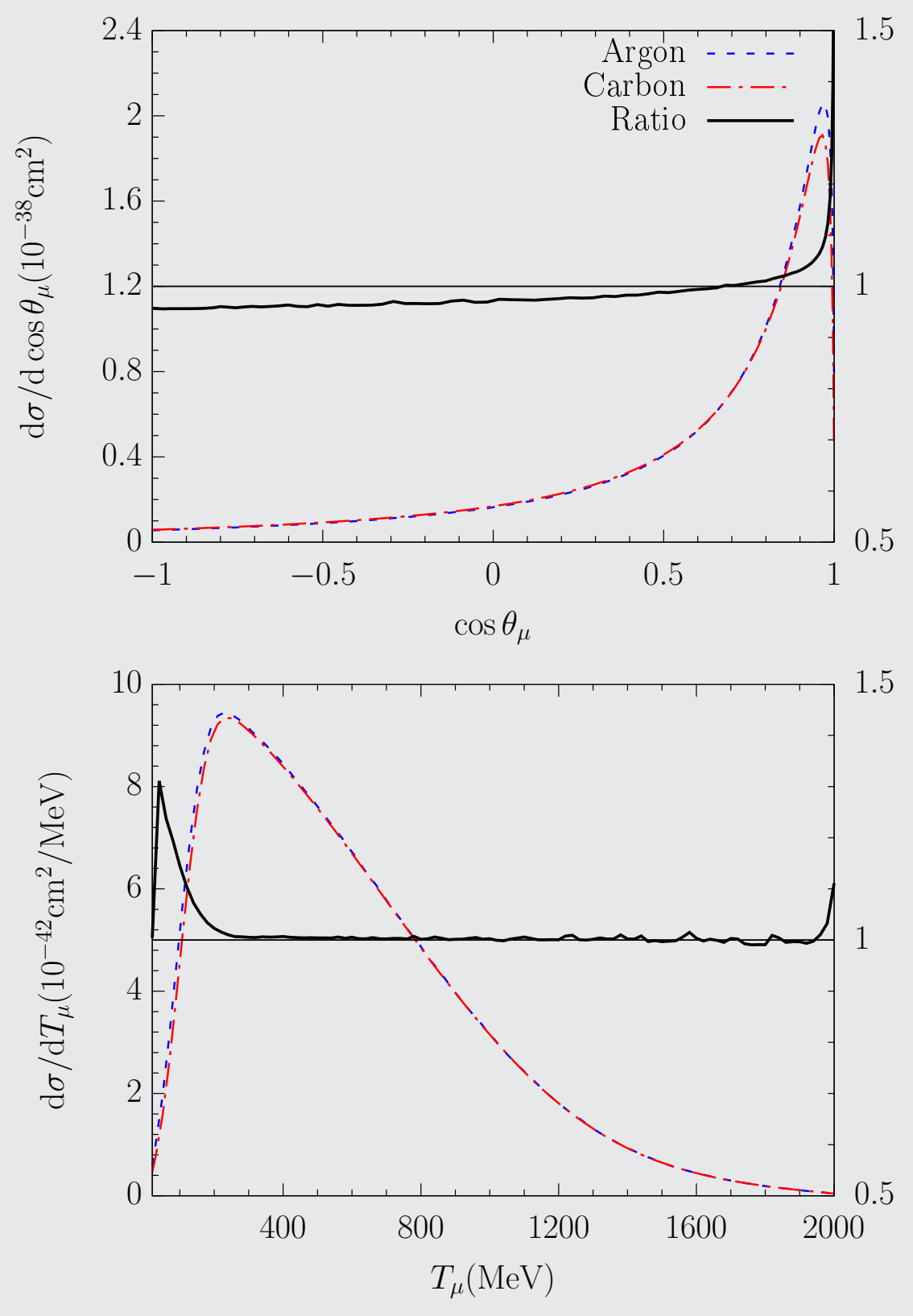


Figure 5: Single differential CCQE cross sections per neutron, comparing ^{12}C and ^{40}Ar predictions, along with the ratio of argon over carbon

Accurate modeling of low q events (low energy and/or forward scattering) is **very important**. Excitations below ≈ 50 MeV contribute a lot of strength to forward scattering bins!

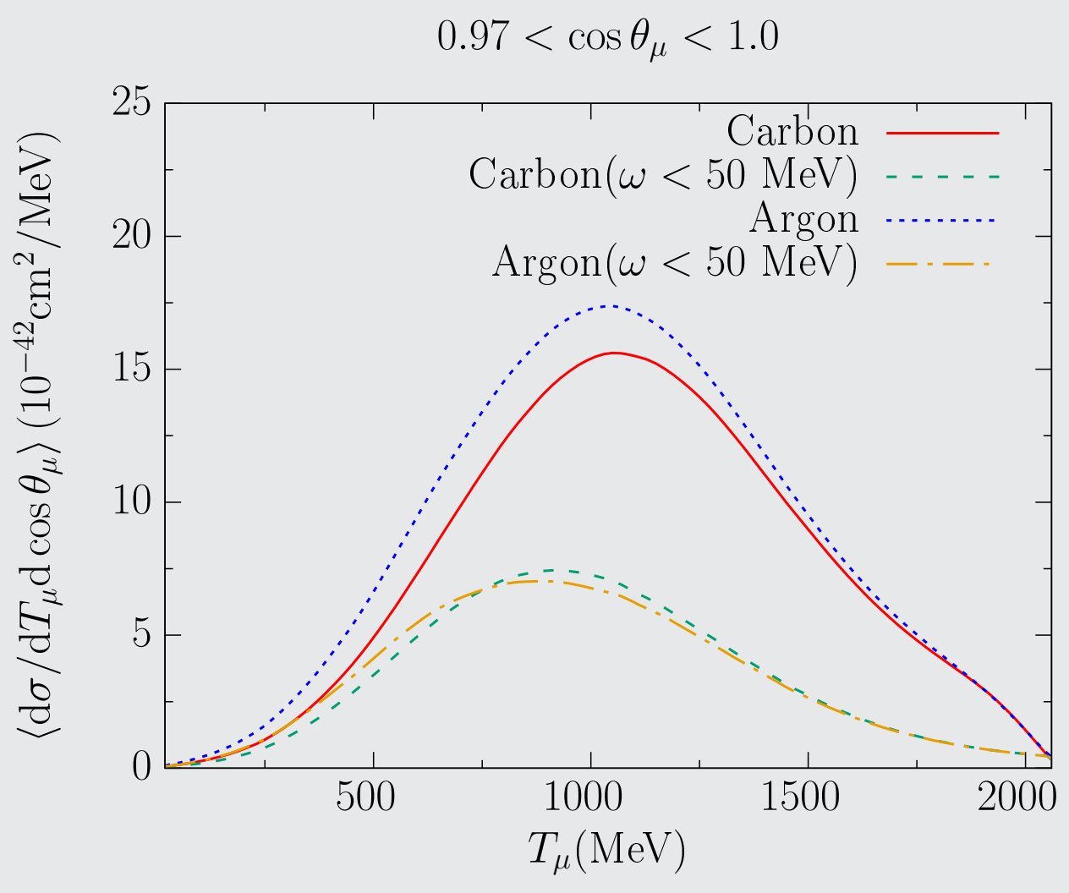


Figure 6: Double differential folded cross section, per neutron, in addition to the $\omega < 50$ MeV contribution.

These results represent the **first step** in modeling neutrino–argon interactions.

- So far, calculations have been **inclusive**, i.e. only containing data on the outgoing muon.
- Future research will focus on **exclusive** calculations, modeling the hadronic variables of the outgoing nucleon(s), including the effects of the aforementioned SRC, MEC and Delta currents.

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References

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[2] N. Van Dessel, N. Jachowicz, R. González-Jiménez, V. Pandey, and T. Van Cuyck, **In review**, nucl-th/1704.07817.

[3] MiniBooNE, `http://www-boone.fnal.gov`.

[4] MicroBooNE, `http://www-microboone.fnal.gov`.