Tuning NEUT's physics models using a new electron scattering extension

Jordan McElwee, Lee Thompson

Contact: jmmcelwee1@sheffield.ac.uk

1. Introduction

- Neutrino oscillation experiments rely on:
  - Precise neutrino energy reconstruction
  - Correct neutrino-nucleus interaction modelling
- Nuclear models can be tested with electron scattering; the benefits are detailed in Table 1
- Neutrino event generators should be able to predict this 'simpler' interaction

Electron	Neutrino
Beam energy precisely known	Broad energy spectrum
Easier to identify interaction type	Interaction types can overlap
Lots of electron scattering data available	**ν**-A data very limited
Nuclear properties are studied	Beam properties are studied
Electromagnetic interaction (vector)	Weak interaction (vector + axial)

Table 1: Differences between electron- and neutrino-scattering. These make electrons much better probes of the nuclear response.

2. Turning ν_e into e^-

1. Apply **Coulomb correction:**
   - Empirical if available
   - Effective momentum app.
2. Change **coupling constant:** $\frac{\sigma_{Mott}}{\sigma_0} = N\frac{\alpha^2}{G_F^2 Q^4}$
3. **Nucleon form factor** changes:
   - Set $F_A, F_P \to 0$
   - Alter $G_{E,M}^V$ for EM
4. **Neutral Current** as a framework:
   - Isovector + isoscalar

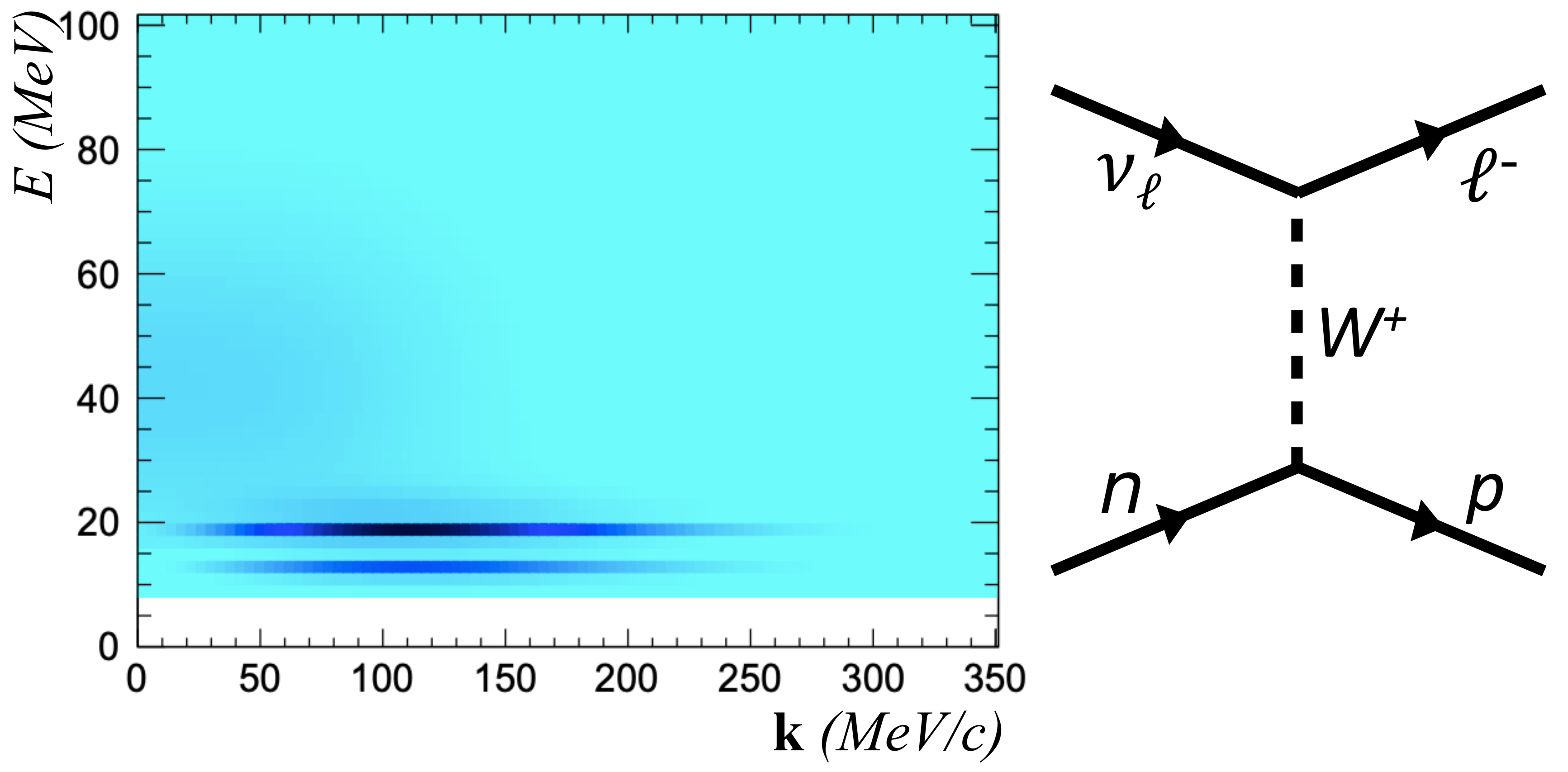

Fig. 1: *Left.* Spectral Function for O-16. Two sharp lines indicate the nuclear p-shells; the diffuse region shows the s-shell. Figure from [1]. *Right.* CCQE Feynman diagram, where the SF is the nuclear ground state model.

3. NEUT's Electron Extension

- NEUT [2] is T2K's neutrino event generator
- Nuclear model is the Spectral Function (SF, Fig. 1), built from:
  - Mean field term from (e,e'p) data
  - Theoretical short-range correlations component
- SF describes nucleon energy/momentum distribution
  - Implemented under the Impulse Approximation (IA)
- Electron extension built from existing SF code
  - Only available for electron elastic scattering
- Provides a baseline test for NEUT's charged-current quasi-elastic scattering (CCQE, Fig. 1) model
- Fig. 2 shows an example validation plot for NEUT's electron scattering

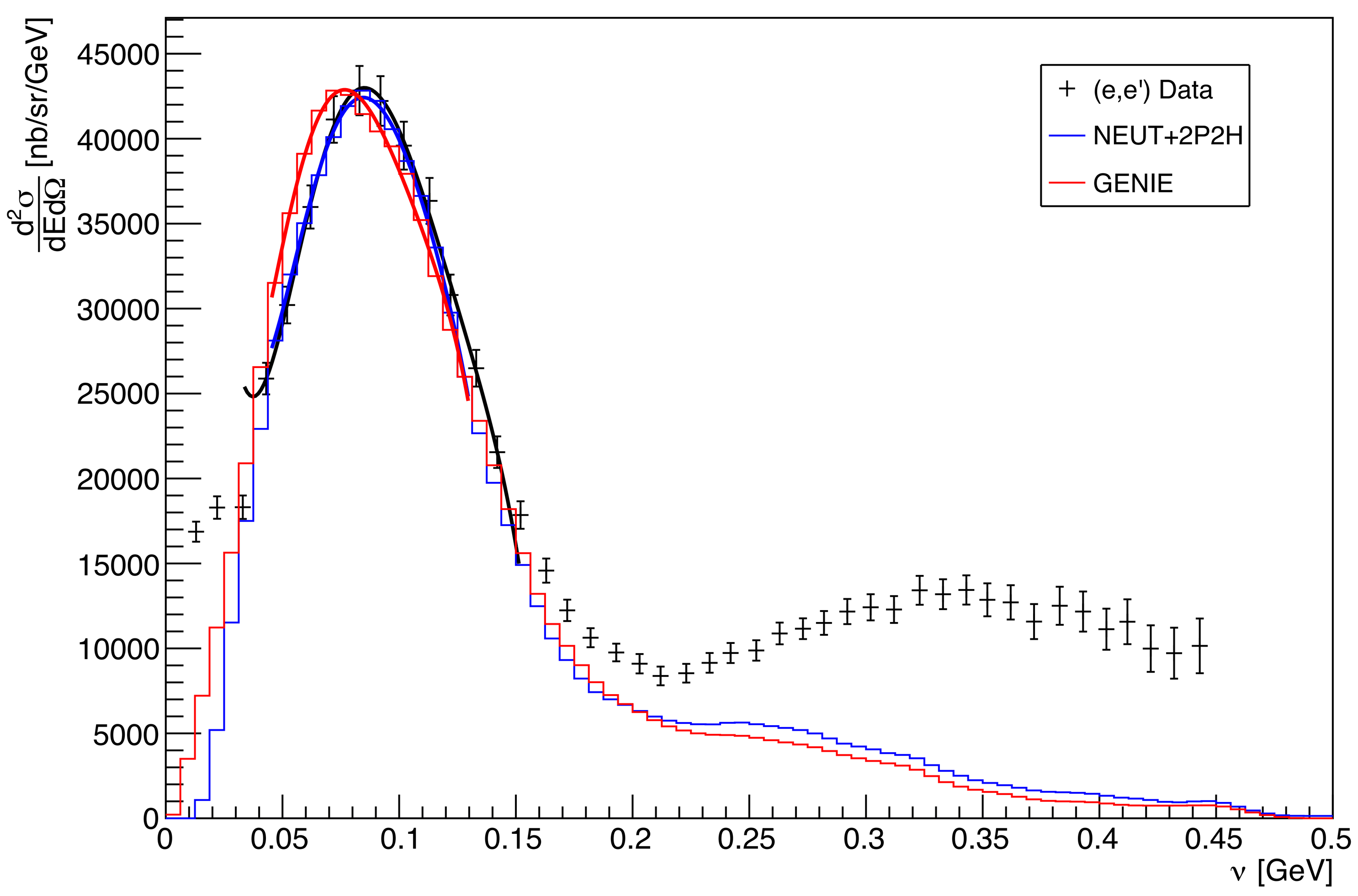

Fig. 2: Comparison of NEUT's electrons, eWro and GENIE's electrons to inclusive electron data. It's clear NEUT's electron extension can predict electron data.

4. Beyond the Impulse Approximation

- Impulse Approximation states:
  - Interaction occurs on a single nucleon
  - Lepton exits with no distortion
- IA simplifies cross-section calculations
  - Breaks down at low energy transfer (q)
- Relativistic Mean Field (RMF) calculations predict a q-dependent scaling function [3]
- Can build this into our model by comparing to (e,e') data
  - Moves beyond the IA
  - Apply to the nucleon removal energy (E_B)
- Fig. 3 compares beyond IA approaches for different generators

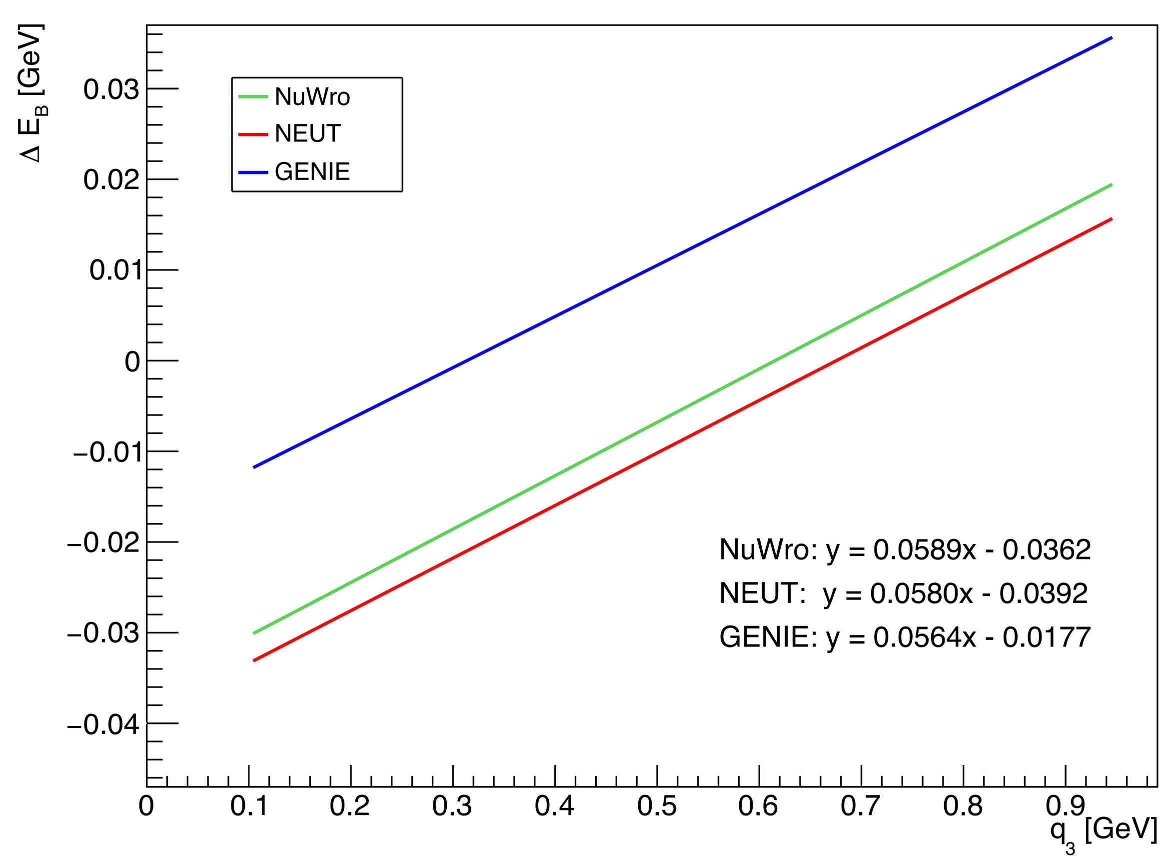

Fig. 3: q-dependence of E_B for 3 different generators. Each is derived in a different way: NuWro with an optical potential, GENIE with RMF calculations and NEUT tuned to (e,e') data.

[1] Atkin, E. *et al.*, "NIWG model and uncertainties for 2019-2020 oscillation analysis", **T2K Technical Note 344** v4, October 2019.

[2] Hayato, Y., "A neutrino interaction simulation program library NEUT", Acta Phys. 1740Polon. B 40, 2477–2489 (2009)

[3] Megías, G. D., "Charged-current neutrino interactions with nucleons and nuclei at intermediate energies", PhD Thesis, Universidad de Sevilla, May 2017.

This work is supported by the Science and Technologies Facilities Council.