Binding Energy Validations in NEUT

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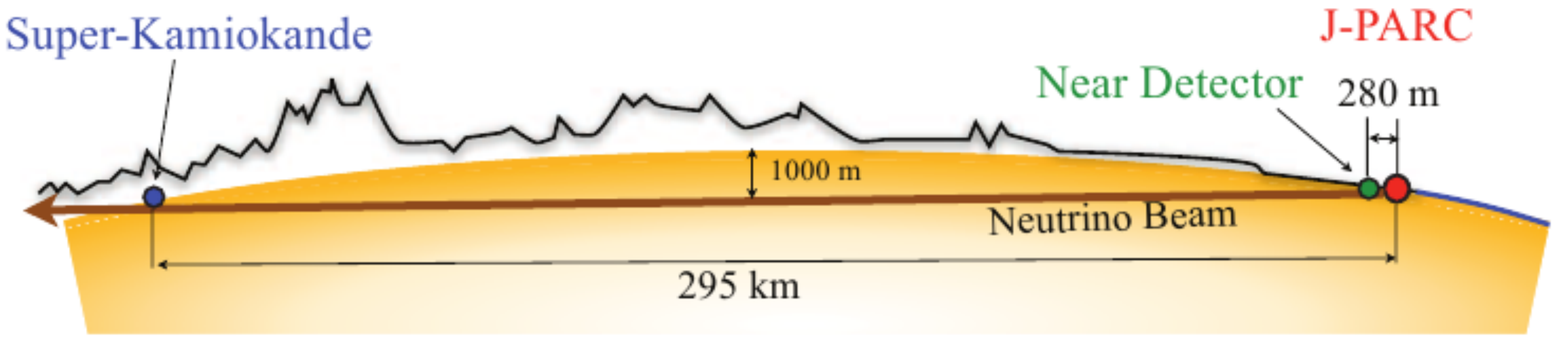
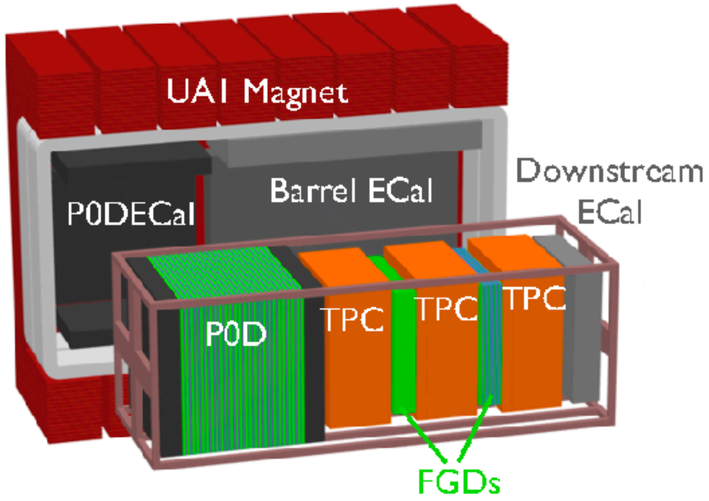
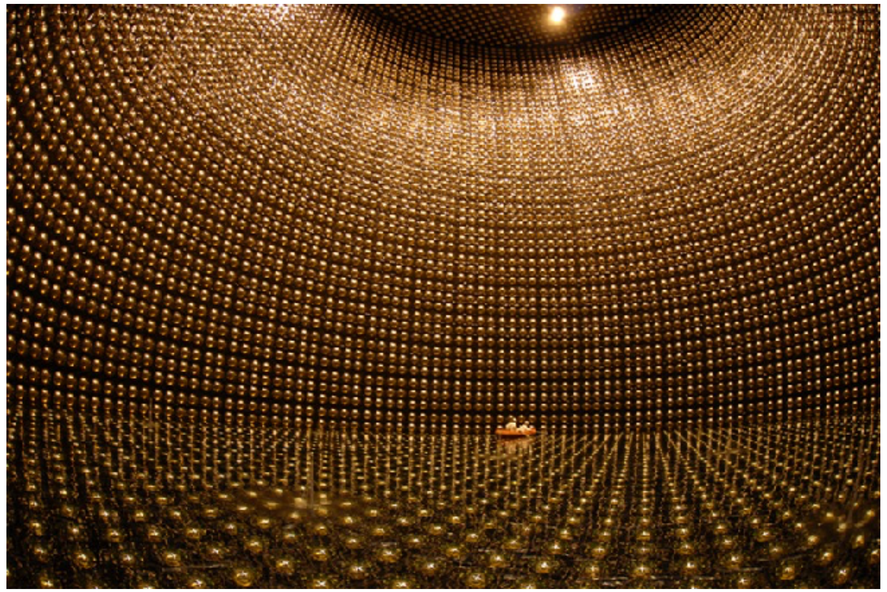
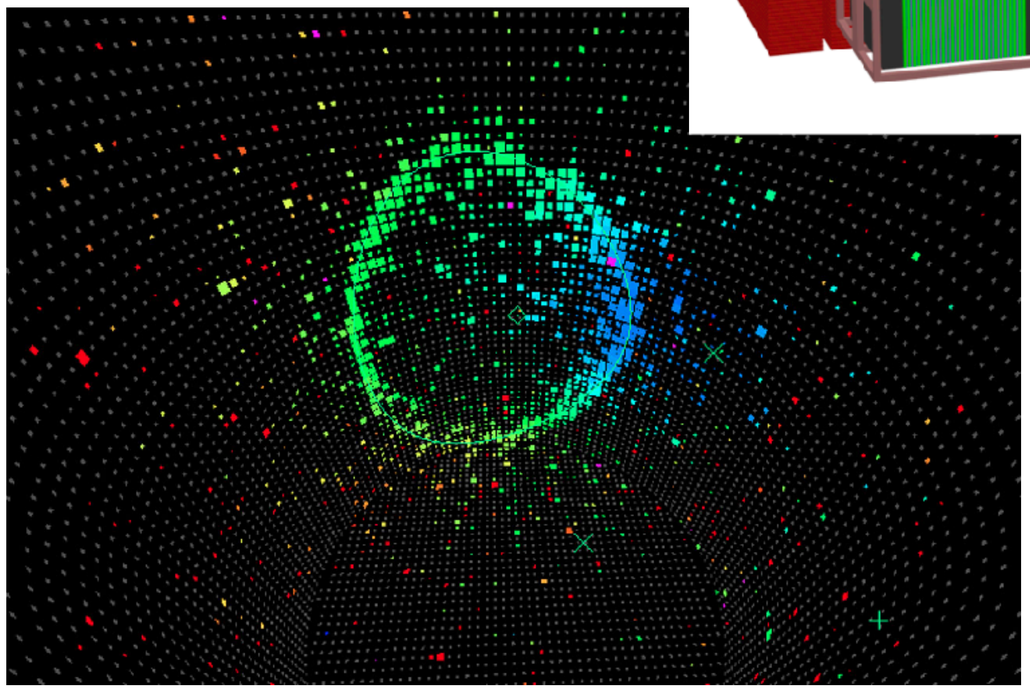
T2K Experiment

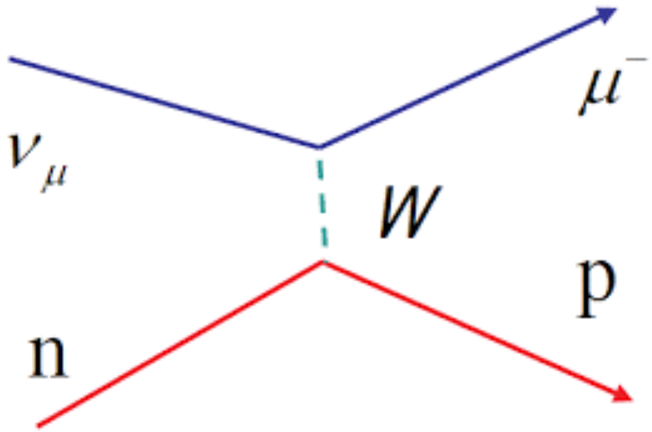


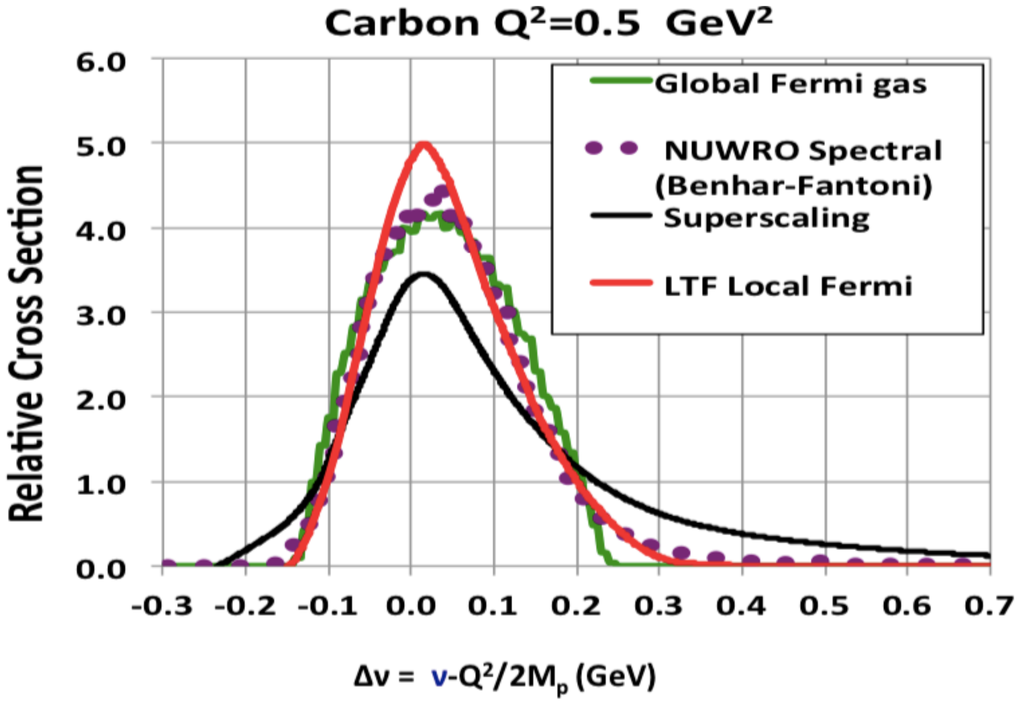


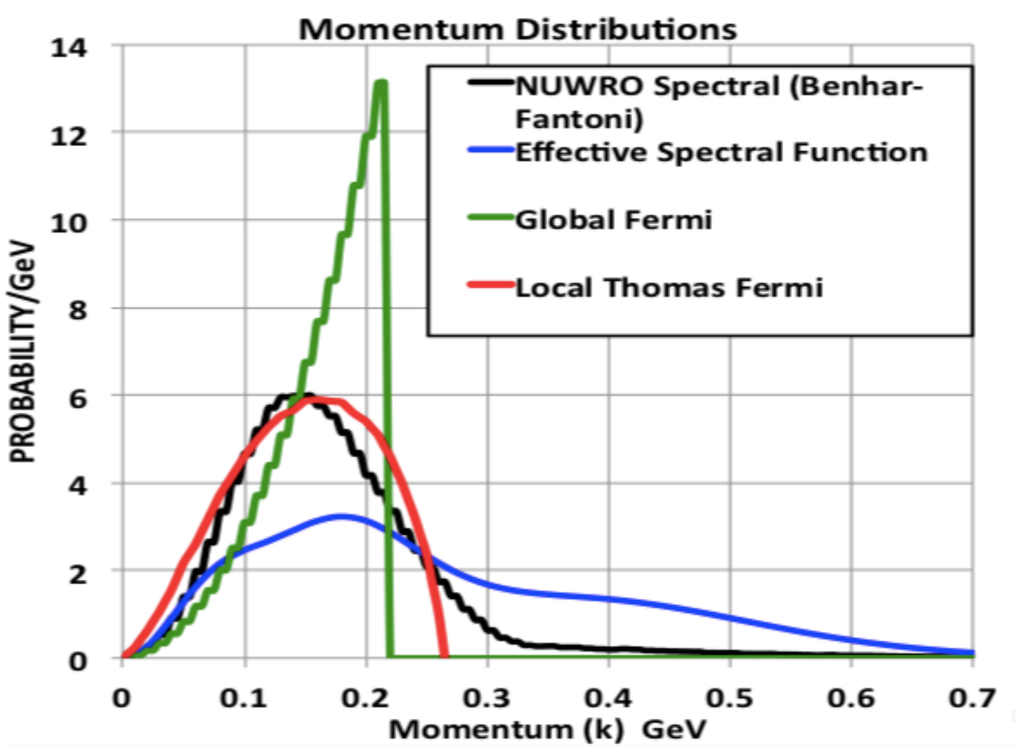




Neutrino-Nucleus Interactions

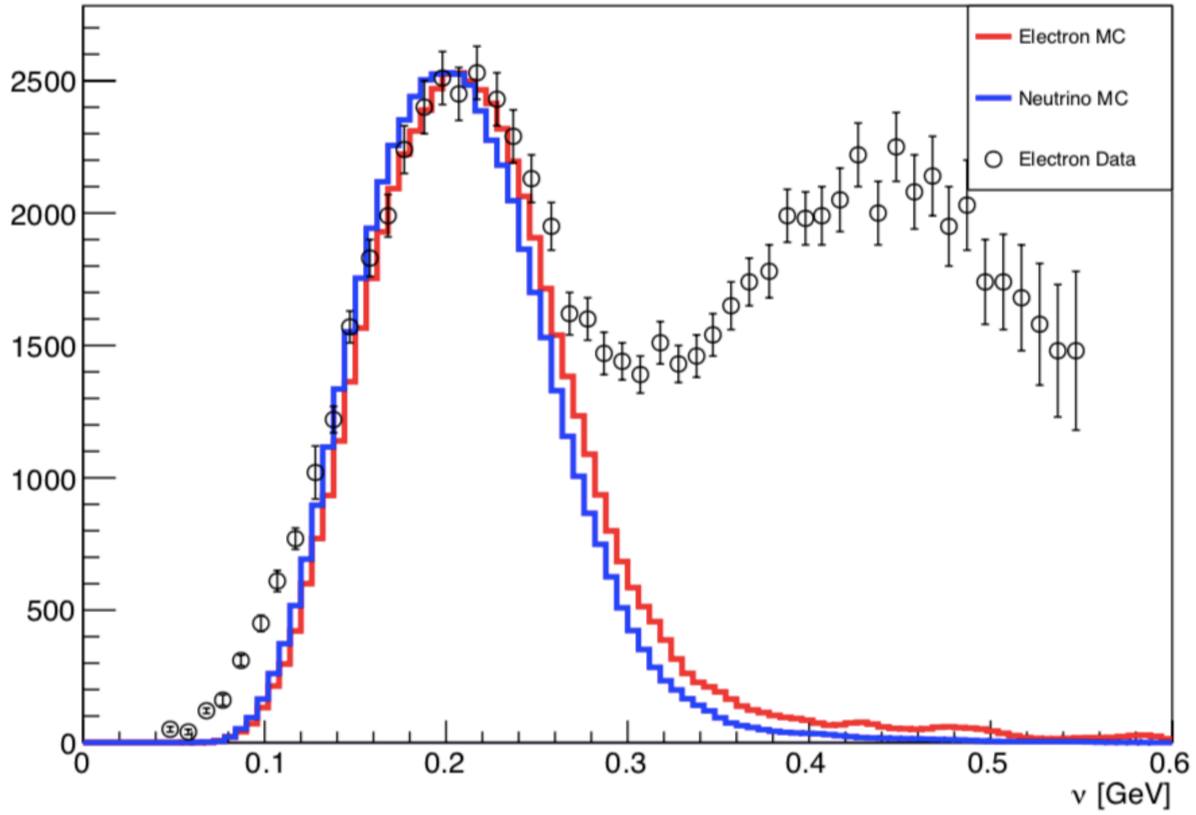


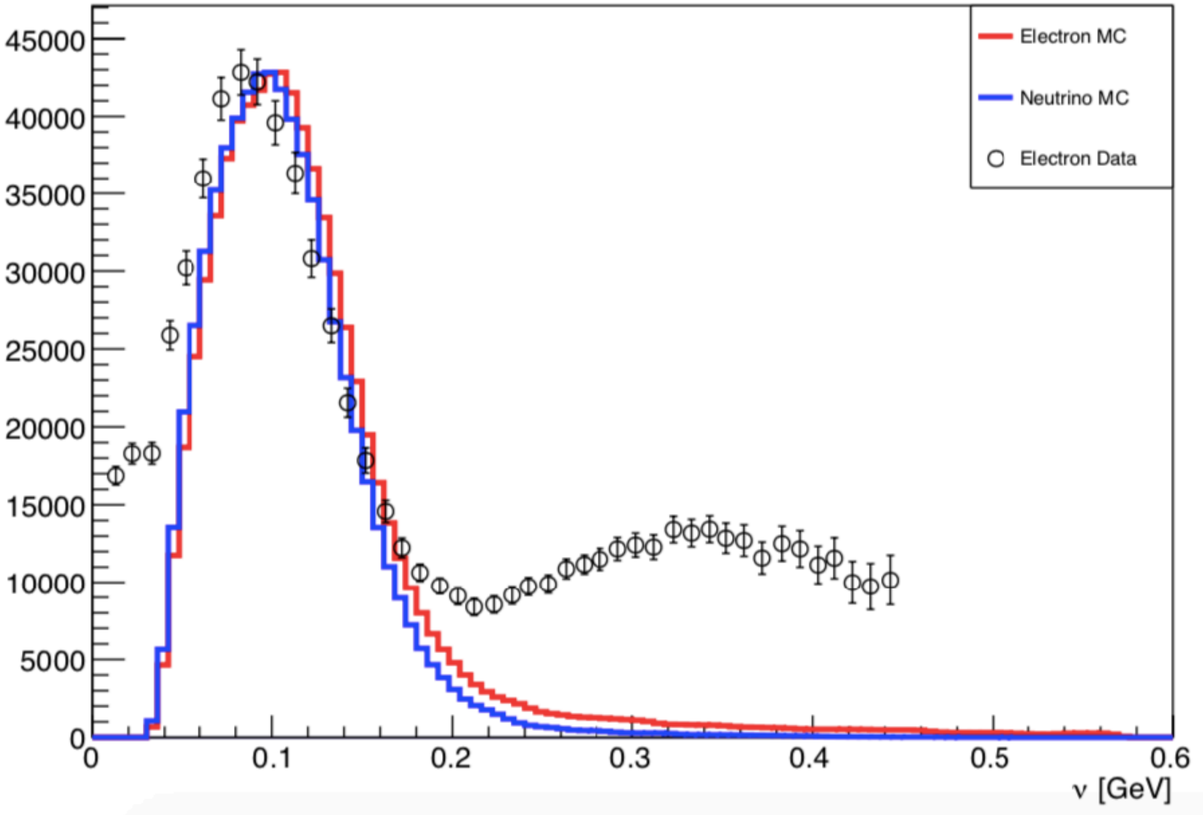




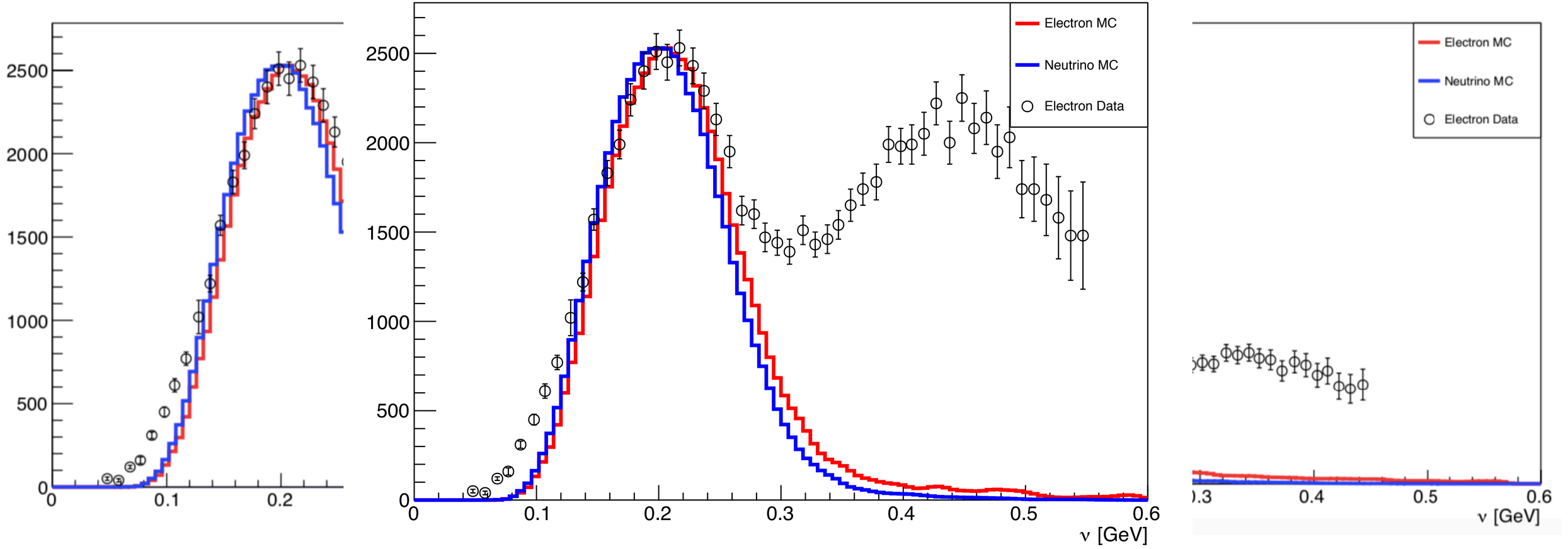
A. Bodek, M. E. Christy and B. Coopersmith, AIP Conf. Proc. **1680**, 20003 (2015), arXiv:1409.8545 [nucl-th].

Electron Scattering





Electron Scattering



Any questions or comments, come see me:

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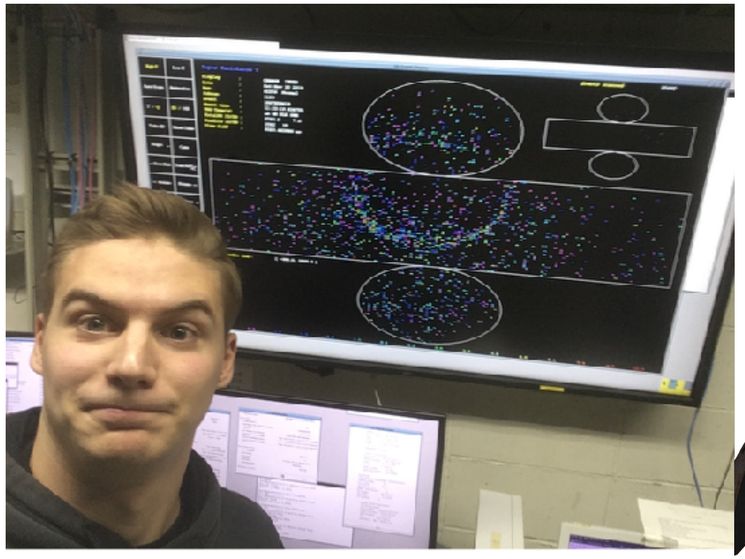

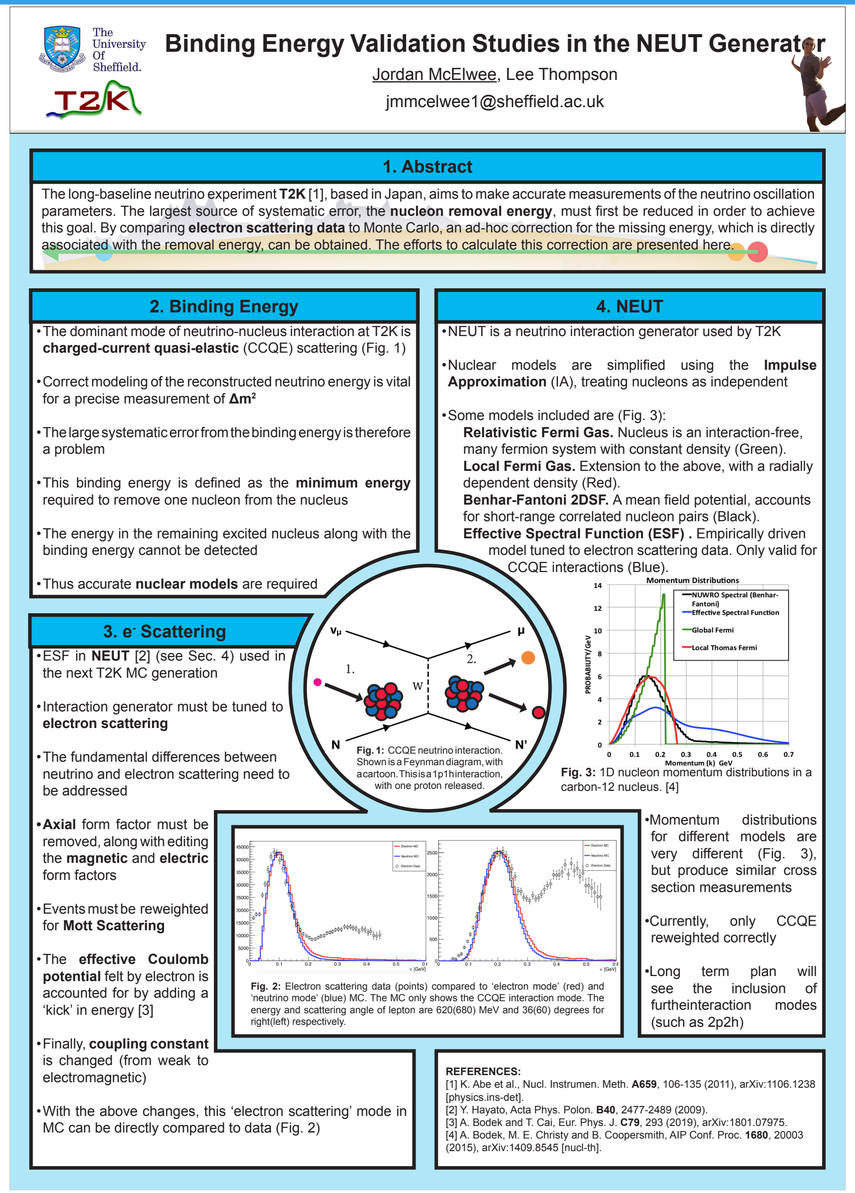

The University Of Sheffield.

T2K

Binding Energy Validation Studies in the NEUT Generator

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1. Abstract

The long-baseline neutrino experiment **T2K** [1], based in Japan, aims to make accurate measurements of the neutrino oscillation parameters. The largest source of systematic error, the **nucleon removal energy**, must first be reduced in order to achieve this goal. By comparing **electron scattering data** to Monte Carlo, an ad-hoc correction for the missing energy, which is directly associated with the removal energy, can be obtained. The efforts to calculate this correction are presented here.

2. Binding Energy

- The dominant mode of neutrino-nucleus interaction at T2K is **charged-current quasi-elastic** (CCQE) scattering (Fig. 1)
- Correct modeling of the reconstructed neutrino energy is vital for a precise measurement of Δm^2
- The large systematic error from the binding energy is therefore a problem
- This binding energy is defined as the **minimum energy** required to remove one nucleon from the nucleus
- The energy in the remaining excited nucleus along with the binding energy cannot be detected
- Thus accurate **nuclear models** are required

3. e^- Scattering

- ESF in **NEUT** [2] (see Sec. 4) used in the next T2K MC generation
- Interaction generator must be tuned to **electron scattering**
- The fundamental differences between neutrino and electron scattering need to be addressed
- **Axial** form factor must be removed, along with editing the **magnetic** and **electric** form factors
- Events must be reweighted for **Mott Scattering**
- The **effective Coulomb potential** felt by electron is accounted for by adding a 'kick' in energy [3]
- Finally, **coupling constant** is changed (from weak to electromagnetic)
- With the above changes, this 'electron scattering' mode in MC can be directly compared to data (Fig. 2)

4. NEUT

- NEUT is a neutrino interaction generator used by T2K
- Nuclear models are simplified using the **Impulse Approximation** (IA), treating nucleons as independent
- Some models included are (Fig. 3):
  - **Relativistic Fermi Gas.** Nucleus is an interaction-free, many fermion system with constant density (Green).
  - **Local Fermi Gas.** Extension to the above, with a radially dependent density (Red).
  - **Benhar-Fantoni 2DSF.** A mean field potential, accounts for short-range correlated nucleon pairs (Black).
  - **Effective Spectral Function (ESF) .** Empirically driven model tuned to electron scattering data. Only valid for CCQE interactions (Blue).

Fig. 1: CCQE neutrino interaction. Shown is a Feynman diagram, with a cartoon. This is a 1p1h interaction, with one proton released.

Fig. 3: 1D nucleon momentum distributions in a carbon-12 nucleus. [4]

Fig. 2: Electron scattering data (points) compared to 'electron mode' (red) and 'neutrino mode' (blue) MC. The MC only shows the CCQE interaction mode. The energy and scattering angle of lepton are 620(680) MeV and 36(60) degrees for right(left) respectively.

- Momentum distributions for different models are very different (Fig. 3), but produce similar cross section measurements
- Currently, only CCQE reweighted correctly
- Long term plan will see the inclusion of furtheinteraction modes (such as 2p2h)

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[1] K. Abe et al., Nucl. Instrumen. Meth. **A659**, 106-135 (2011), arXiv:1106.1238 [physics.ins-det].
[2] Y. Hayato, Acta Phys. Polon. **B40**, 2477-2489 (2009).
[3] A. Bodek and T. Cai, Eur. Phys. J. **C79**, 293 (2019), arXiv:1801.07975.
[4] A. Bodek, M. E. Christy and B. Coopersmith, AIP Conf. Proc. **1680**, 20003 (2015), arXiv:1409.8545 [nucl-th].