2p-2h Cross-Section Systematics in DUNE

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DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

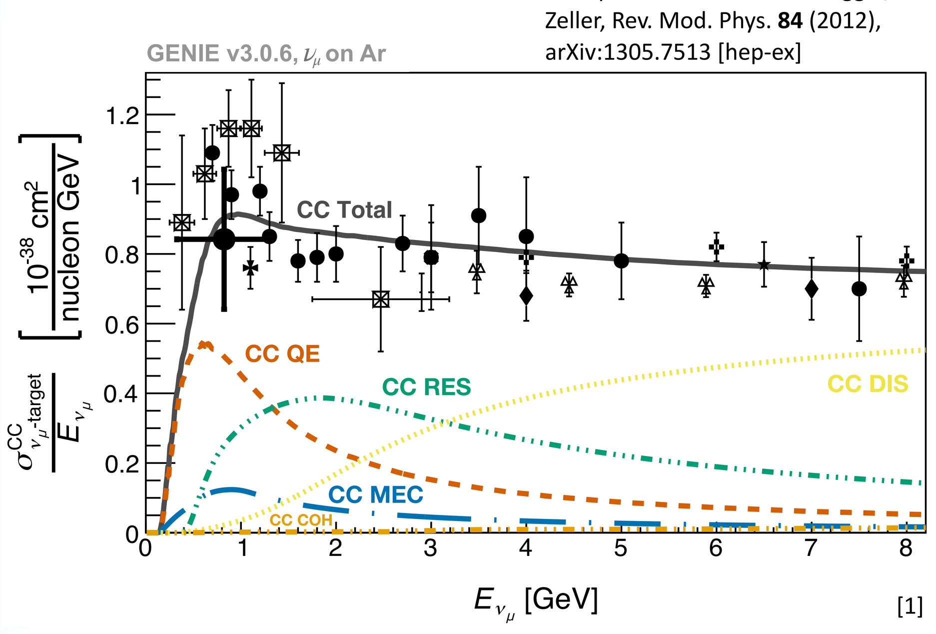
Motivation

- Problem: **Incomplete understanding** of neutrino-nucleus scattering processes and nuclear effects
- Goal: **Obtain interaction model** with associated uncertainties
- How: Design uncertainty parameters to account for model-to-model **discrepancies** in the DUNE oscillation analysis

Processes

- Charged-Current (CC) inclusive muon neutrino interactions

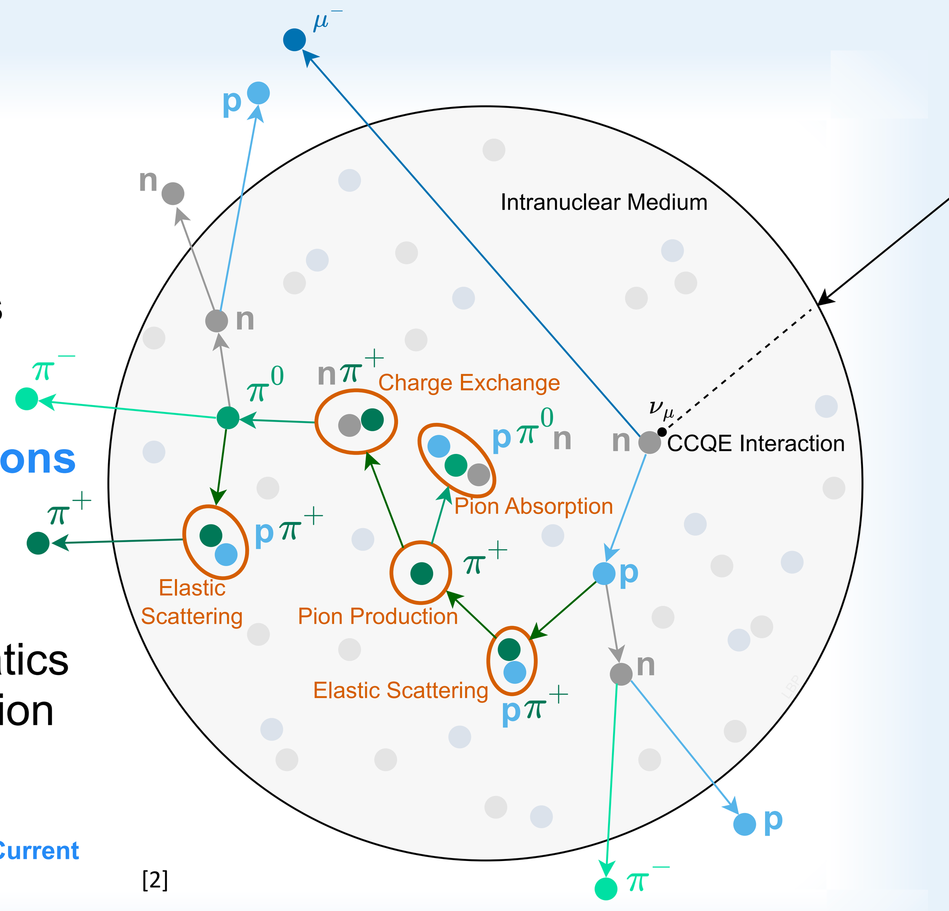
Data points from: J. A. Formaggio, G. Zeller, Rev. Mod. Phys. **84** (2012), arXiv:1305.7513 [hep-ex]



Nuclear Effects

- *Initial State Effects*:
  - Fermi Motion
  - Nuclear Binding Energy
  - Nucleon-Nucleon-Correlations
- *Nucleon Correlation Effects*:
  - 1p1h-, 2p2h-(*MEC-)interactions
- *Final State Interactions*:
  - Intranuclear re-scattering
  - Alteration of final state kinematics
  - Stimulation of nuclear absorption and emission

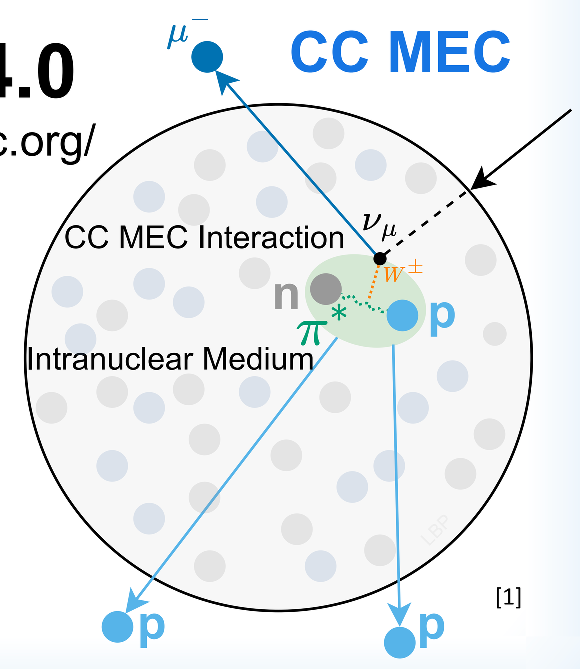
*MEC: Meson Exchange Current



Simulation

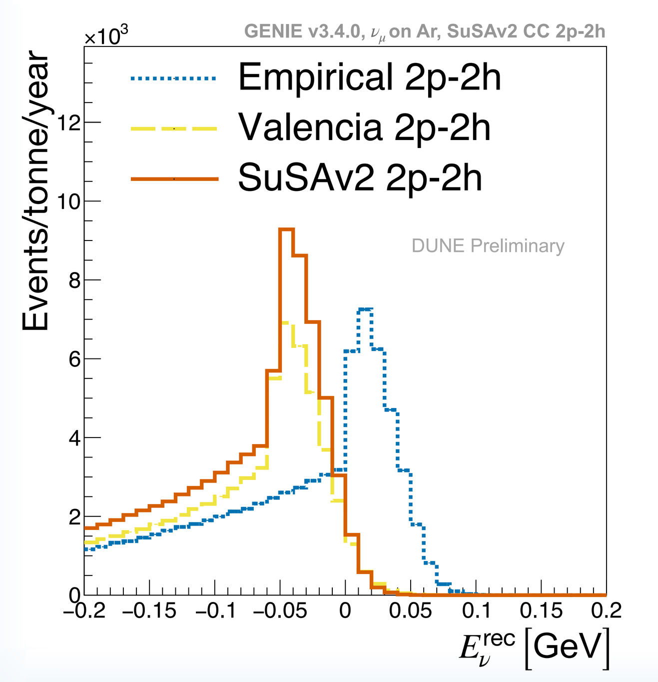
GENIE v3.4.0
http://www.genie-mc.org/

- Simulate CC MEC neutrino interactions with GENIE
- Vary parameters and compare predictions to **determine uncertainties**



Idea

Absolute Reconstructed Neutrino Energy Bias



- **Clear separation** between the distributions of the Empirical and Valencia/ SuSAv2 CC 2p-2h models
- **Choose uncertainties** such that the measurement of the oscillation parameters is not biased in case the wrong model is chosen

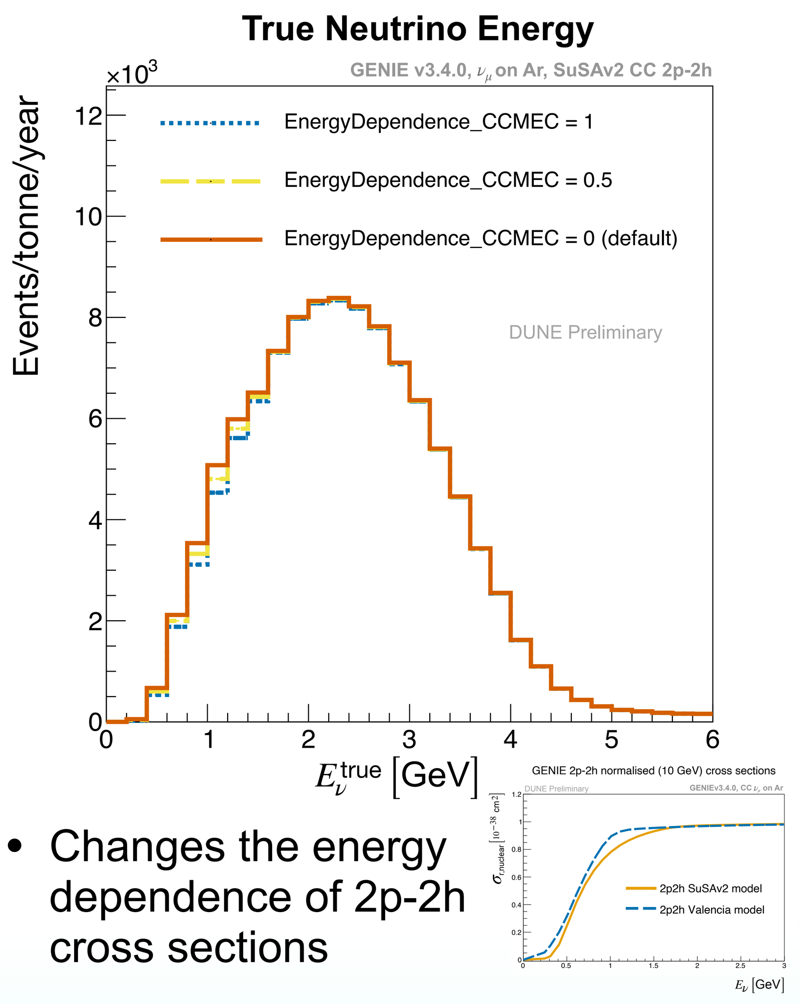
$$E^{rec}_\nu = \sum_p E_{kin} + \sum_{\pi,\gamma} E + E_{lep}$$

Why do we want to vary systematic parameters?

New Meson Exchange Current Model Uncertainties

Energy Dependence

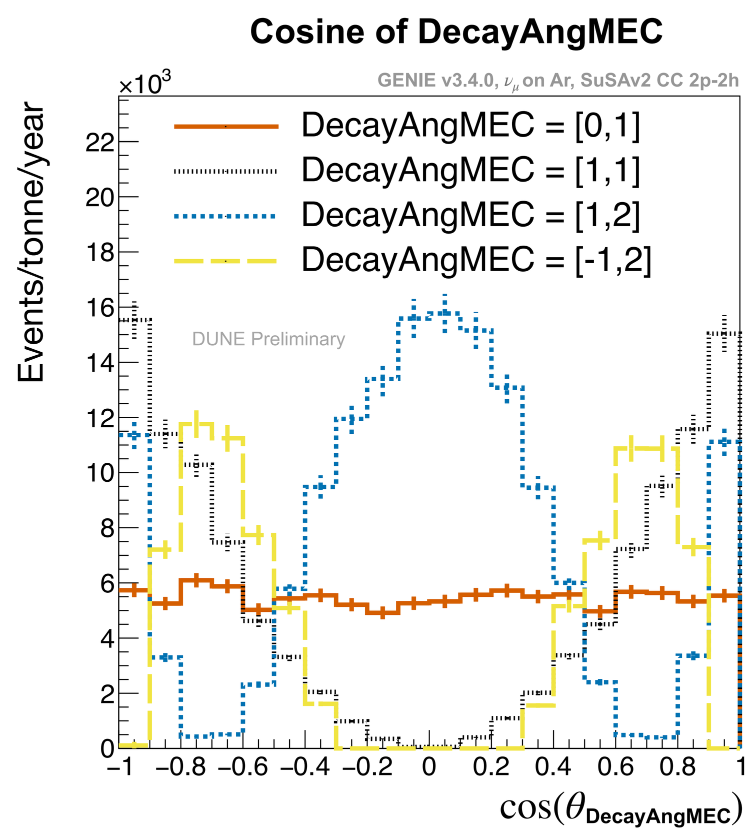
True Neutrino Energy



- Changes the energy dependence of 2p-2h cross sections

Nucleon Decay Angle

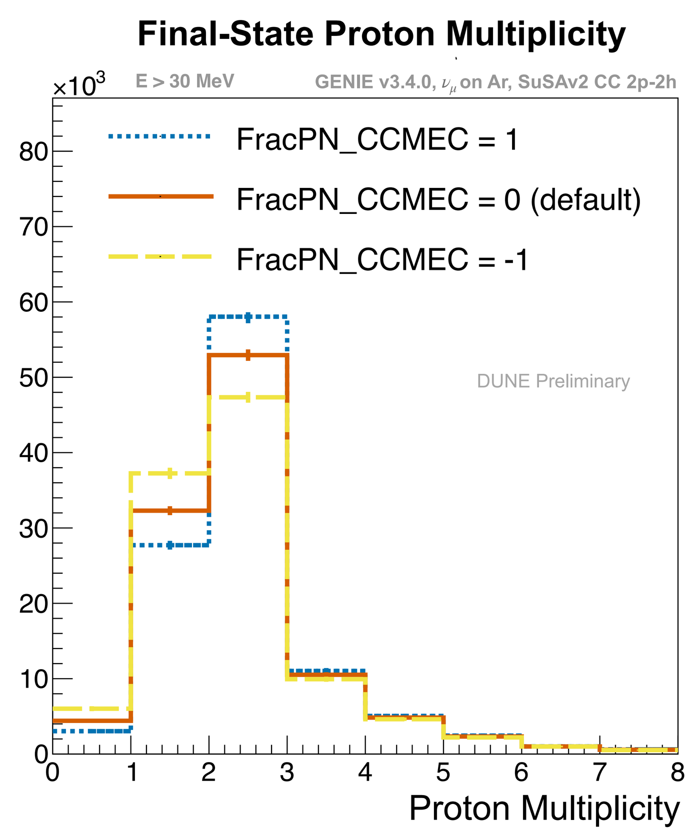
Cosine of DecayAngMEC



- Changes dependence of decay angle of struck nucleon pair (an ad-hoc assumption on angular distribution of outgoing nucleons) away from isotropic distribution

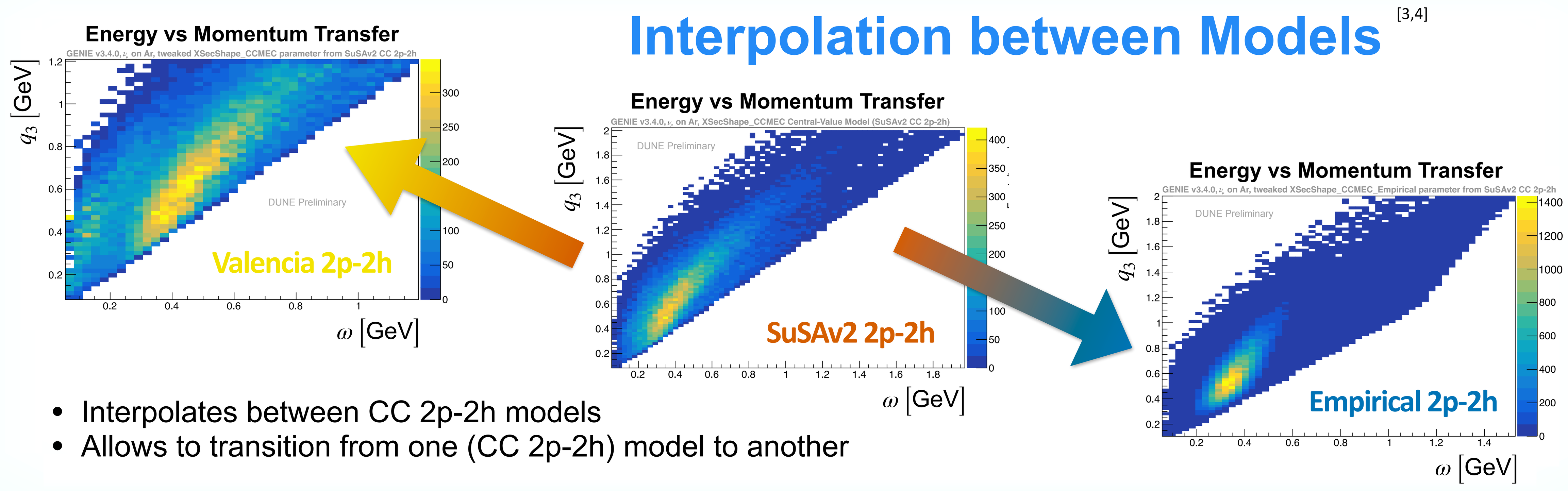
Nucleon Pair Content

Final-State Proton Multiplicity



- Changes the pn-pair content in the initial nuclear state

Interpolation between Models [3,4]



- Interpolates between CC 2p-2h models
- Allows to transition from one (CC 2p-2h) model to another

Conclusion

- Deficiencies in existing neutrino-nucleus interaction modelling represent a **leading source of systematic uncertainties**
- **Reduction of systematic uncertainties** is crucial for precision neutrino oscillation parameter measurements
- Variation of systematic parameters will allow a robust **estimate of systematics** in modern experiments such as DUNE

[1] L. Bathe-Peters, M.S. thesis, Harvard University and Technische Universität Berlin, Apr. 2020.
[2] L. Bathe-Peters, S. Gardiner, R. Guenette., FERMILAB-PUB-22-007-SCD, arXiv: 2201.04664, Jan. 2022.
[3] P. Abratenko, R. An, J. Anthony, et al., Phys. Rev. D, **105**, Apr. 2022.
[4] S. Dolan, G. D.. Megias, S. Bolognesi, Phys. Rev. D, **101** 033003, Feb. 2020.

Poster ID: 35

In collaboration with:
Kirsty Duffy, Stephen Dolan, Laura Munteanu

XXXI International Conference on Neutrino Physics and Astrophysics
June 16-22, 2024 Milan, Italy