Measuring the Multi-Neutron Antineutrino Cross Section at Low Charged Hadron Energy in MINERvA

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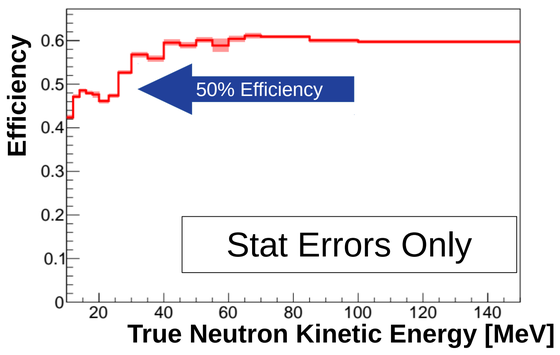
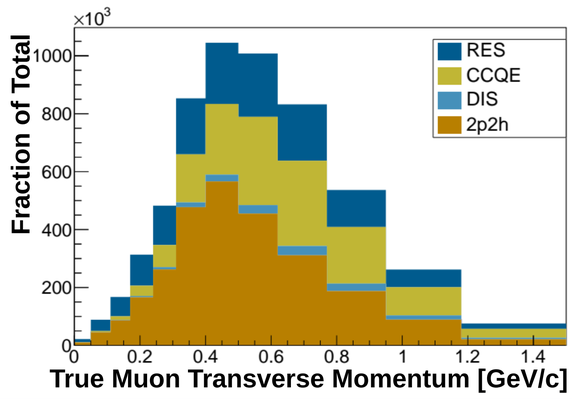
#1 Neutrons from Antineutrinos

- **Neutrons** are an important source of **energy reconstruction** bias for oscillation experiments
- **MINERvA** can detect neutrons efficiently[1]
- Multi-neutron cross section: **2p2h**- and **FSI**-rich[2]

Neutron Detection Efficiency

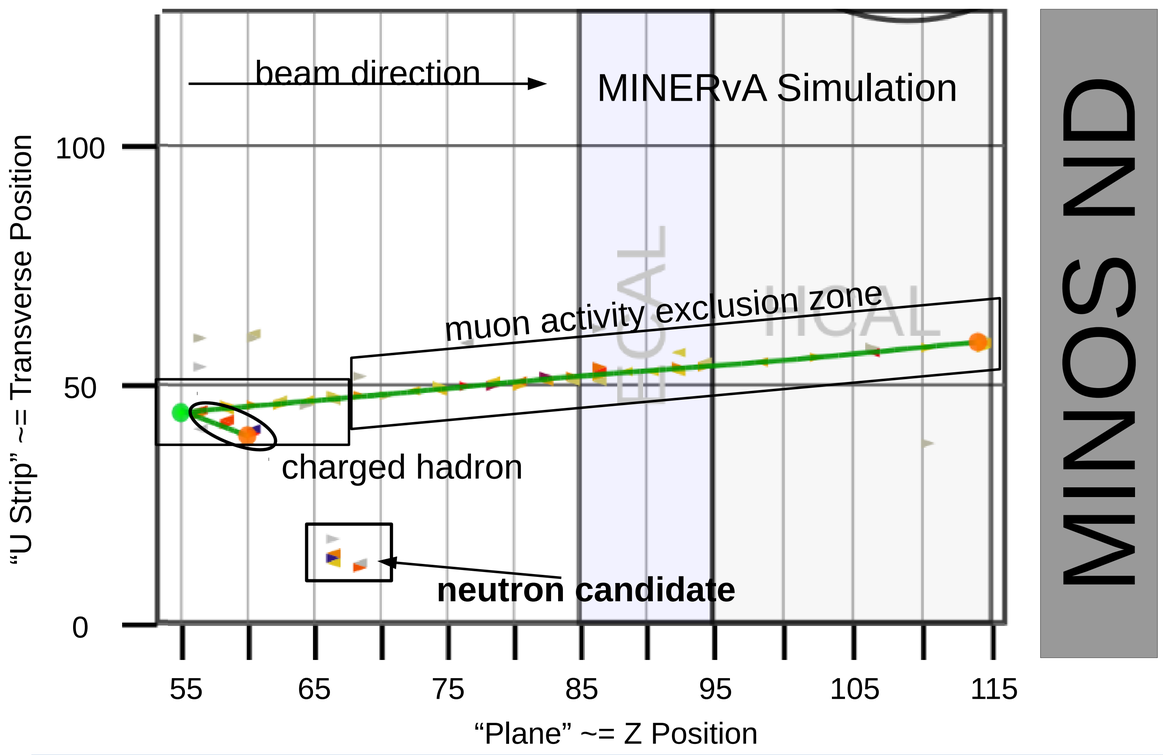


Interaction Channels



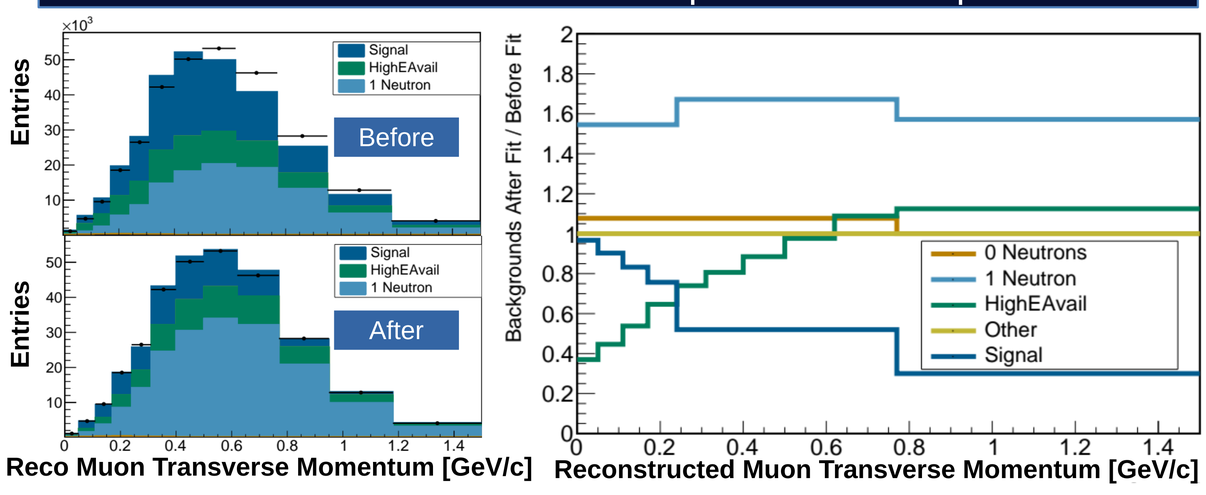
#2 Neutron Counting in MINERvA

- MINERvA sees neutrons primarily by their **inelastic scatters**
  - Primarily **protons**
  - Some photons at low neutron energy
  - Rarely see nuclear fragments
- Neutron candidates must be:
  - Away from **muon**
  - **> 1.5 MeV** energy
  - Not connected to **vertex**



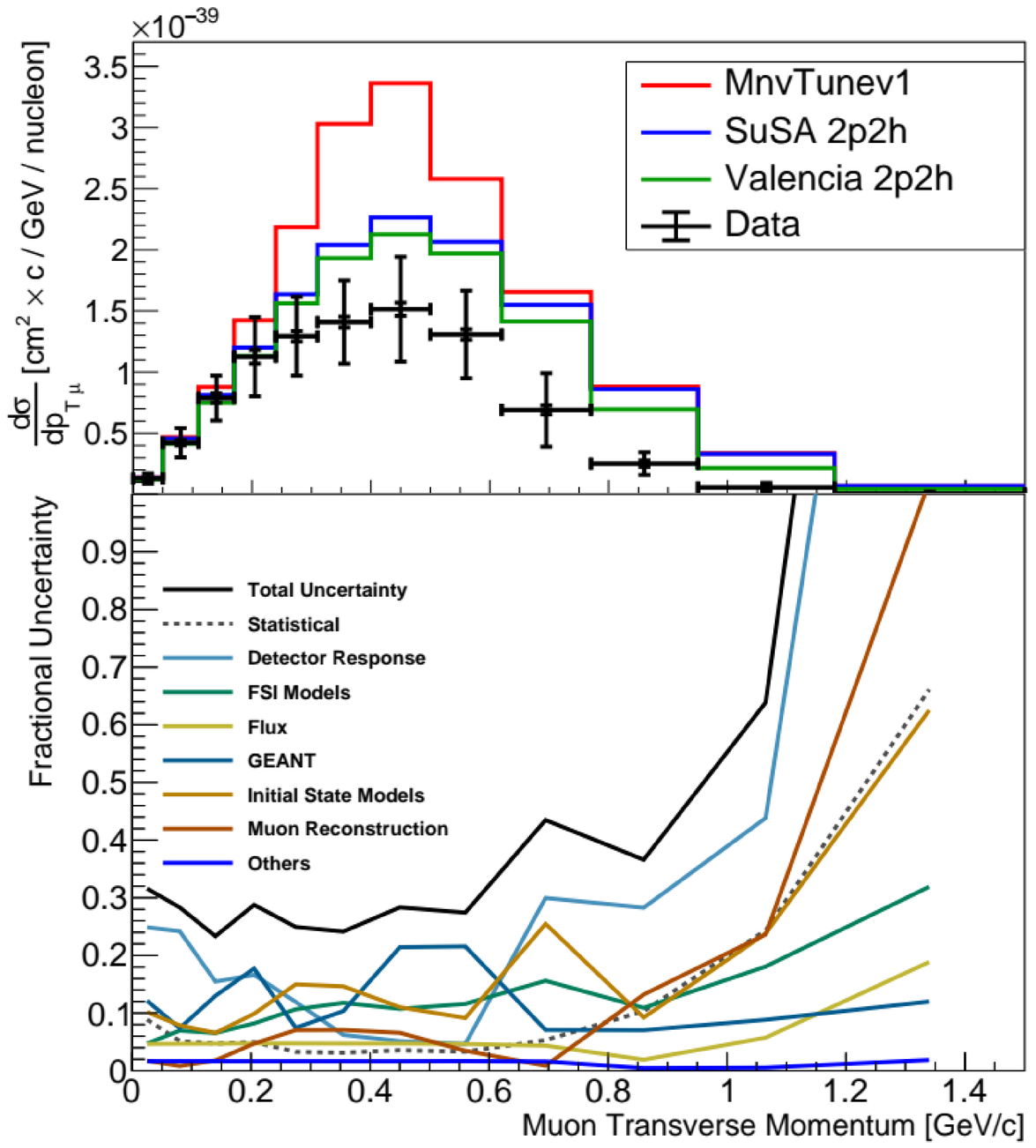
#3 Background Constraint

- Leading backgrounds to multi-neutron interactions:
  - **1 Neutron**: mostly antineutrino QE-like
  - **High $E_{available}$**: energy mis-reconstructed for pions
- Sideband fits resemble trends in past MINERvA publications



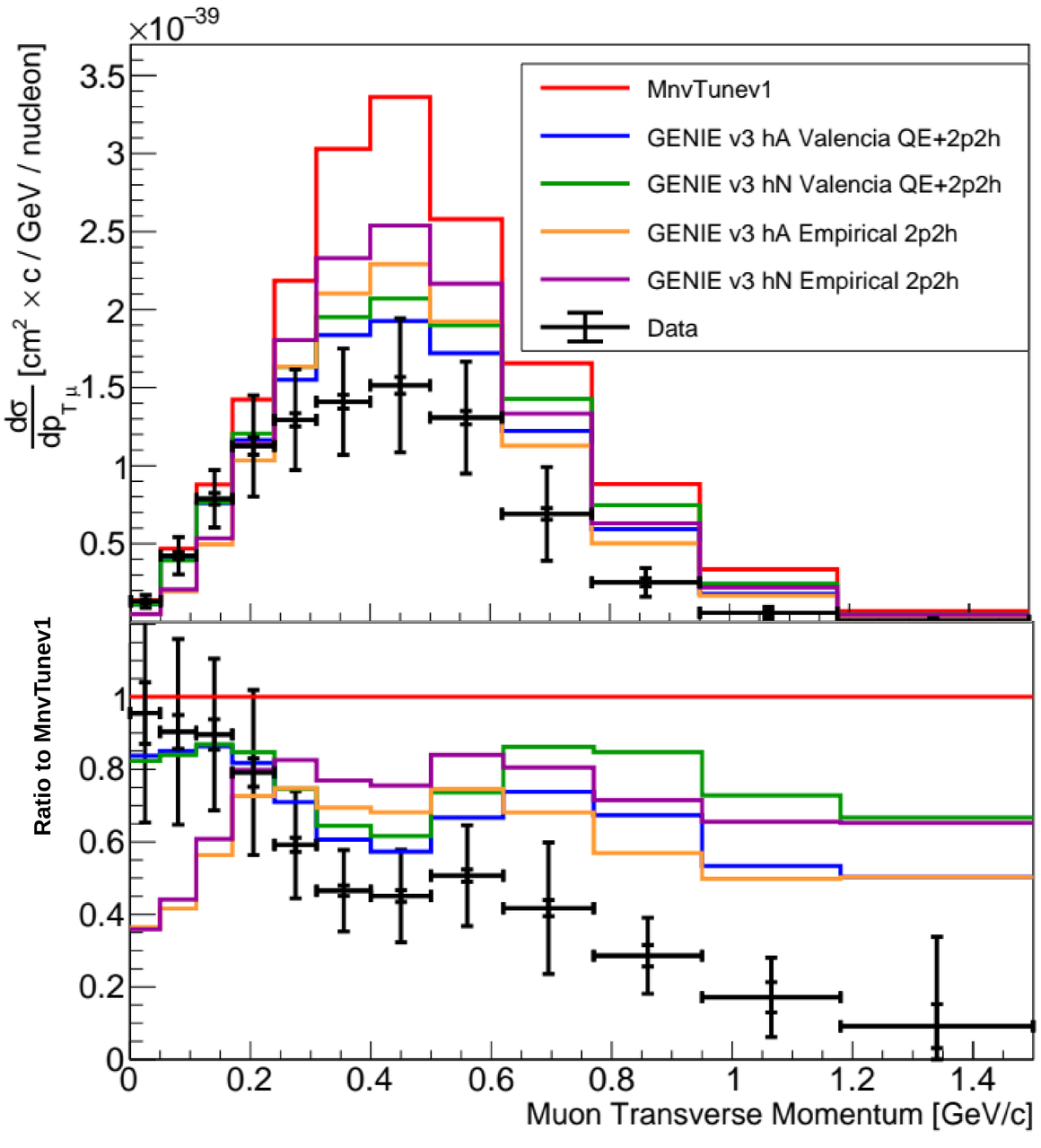
#4 Cross Section

- Cross section for **2+ neutrons** at E_{avail} **< 100 MeV**
- Data prefers models without dedicated **2p2h** tune
- Uncertainties dominated by GEANT **neutron modeling**[3]



#5 GENIE v3 Comparisons

- 2 **2p2h** models[4][5][6]:
  - Empirical: different data from MnvTunev1
  - Nieves = Valencia
- High momentum tail driven by FSI, not 2p2h



#6 Conclusions

- Neutron production sensitive to **2p2h** and **FSI**
- Extracted differential cross section for model comparisons
- Many leading models do not agree

References

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4. C. Andreopoulos et al. The GENIE Neutrino Monte Carlo Generator. *Nucl. Instrum. Meth. A*, 614:87-104, 2010.
5. Júlia Tena-Vidal et. al. Neutrino-nucleon cross-section model tuning in GENIE v3. *Phys. Rev. D,* 104(7):072009, 2021.
6. Júlia Tena-Vidal et. al. Hadronization model tuning in GENIE v3. *Phys. Rev. D,* 105(1):012009, 2022

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