Double-Differential ν_μ Charged Current Quasi-Elastic-Like Cross Section on Plastic Scintillator in Muon Momentum from MINERvA

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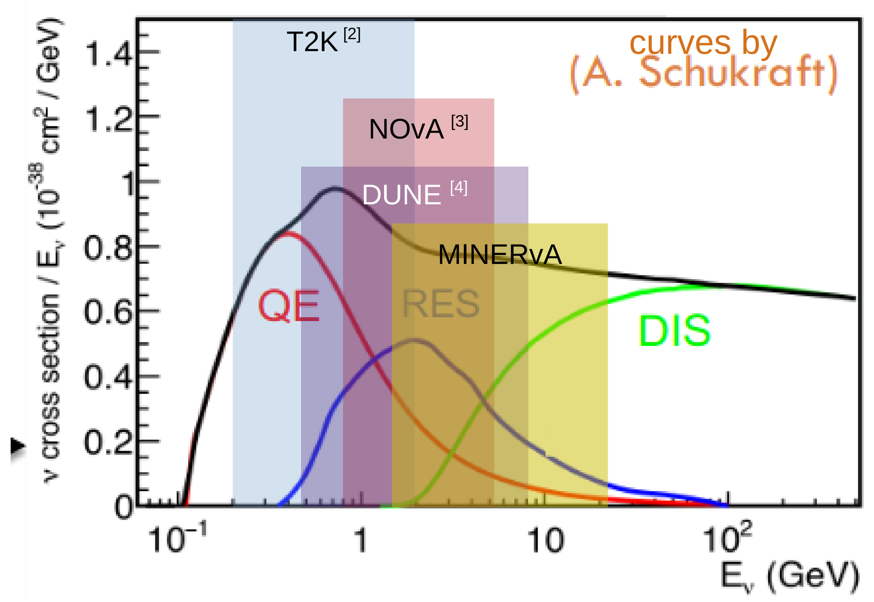
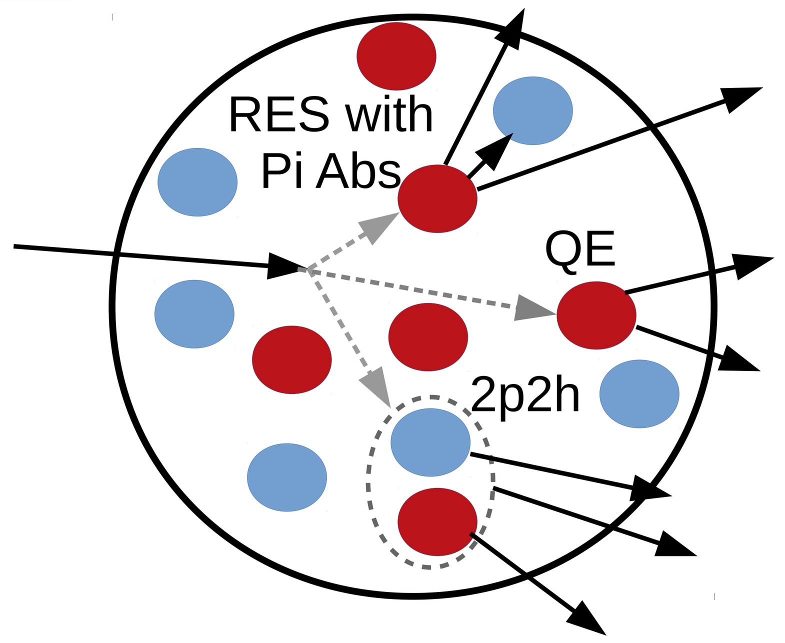
CCQE in Neutrino Oscillation Experiments

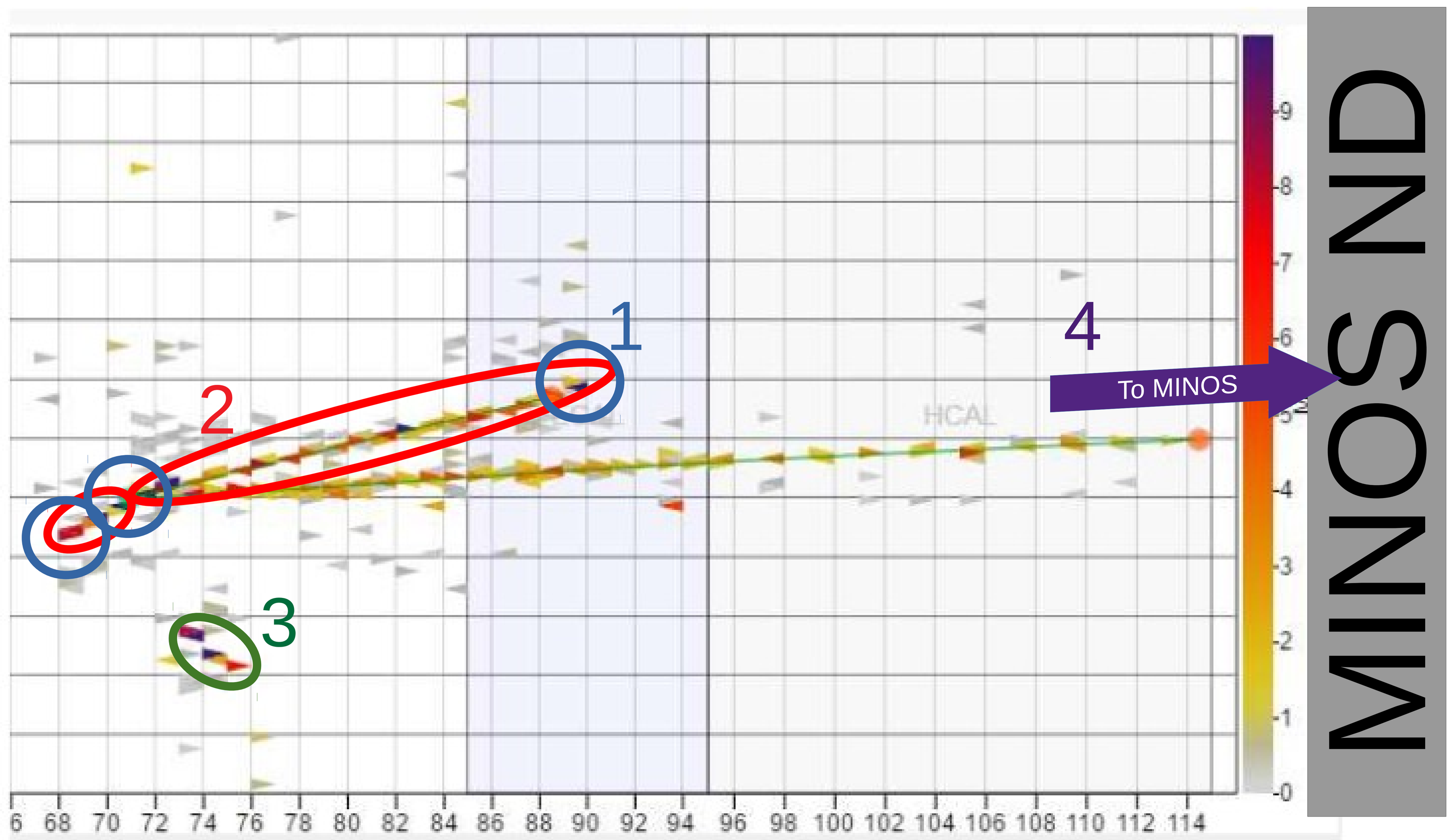
- Oscillation experiments measure
  - **number of neutrinos**
  - **energy**
- Large fraction of events at low E_ν are CCQE
- Can get energy from just lepton kinematics
- How is CCQE defined? $\nu + n \rightarrow \mu + p$
- Experimentally, measure **Quasi-elastic-like**
  - Require only muon and nucleons
  - Can't detect low energy or interacting mesons





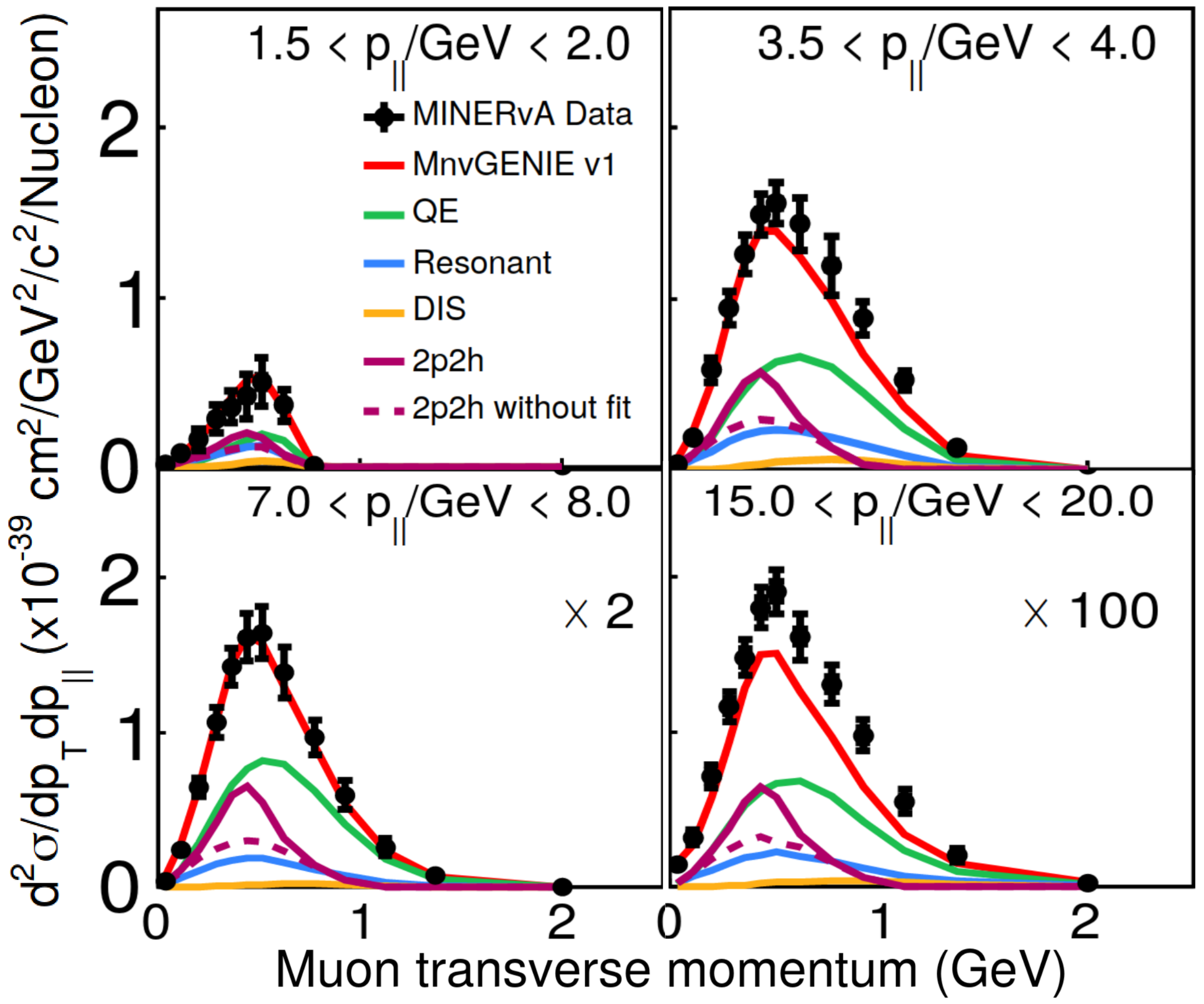
MINERvA CCQE-like Selection

- FNAL NuMI beam at $<E_\nu>$ ~6 GeV
- No charged pions
  1. **Veto Michel electrons**
  2. **Check dE/dx on hadron tracks**
- No neutral pions
  3. **1 disconnected cluster at most**
- Untracked energy < 500 MeV
  - Excludes 150mm around the vertex
- **4. Muon acceptance in MINOS**
  - Muon angle w.r.t. beam < 20 degrees
  - $p_{||}$ > 1.5 GeV/c



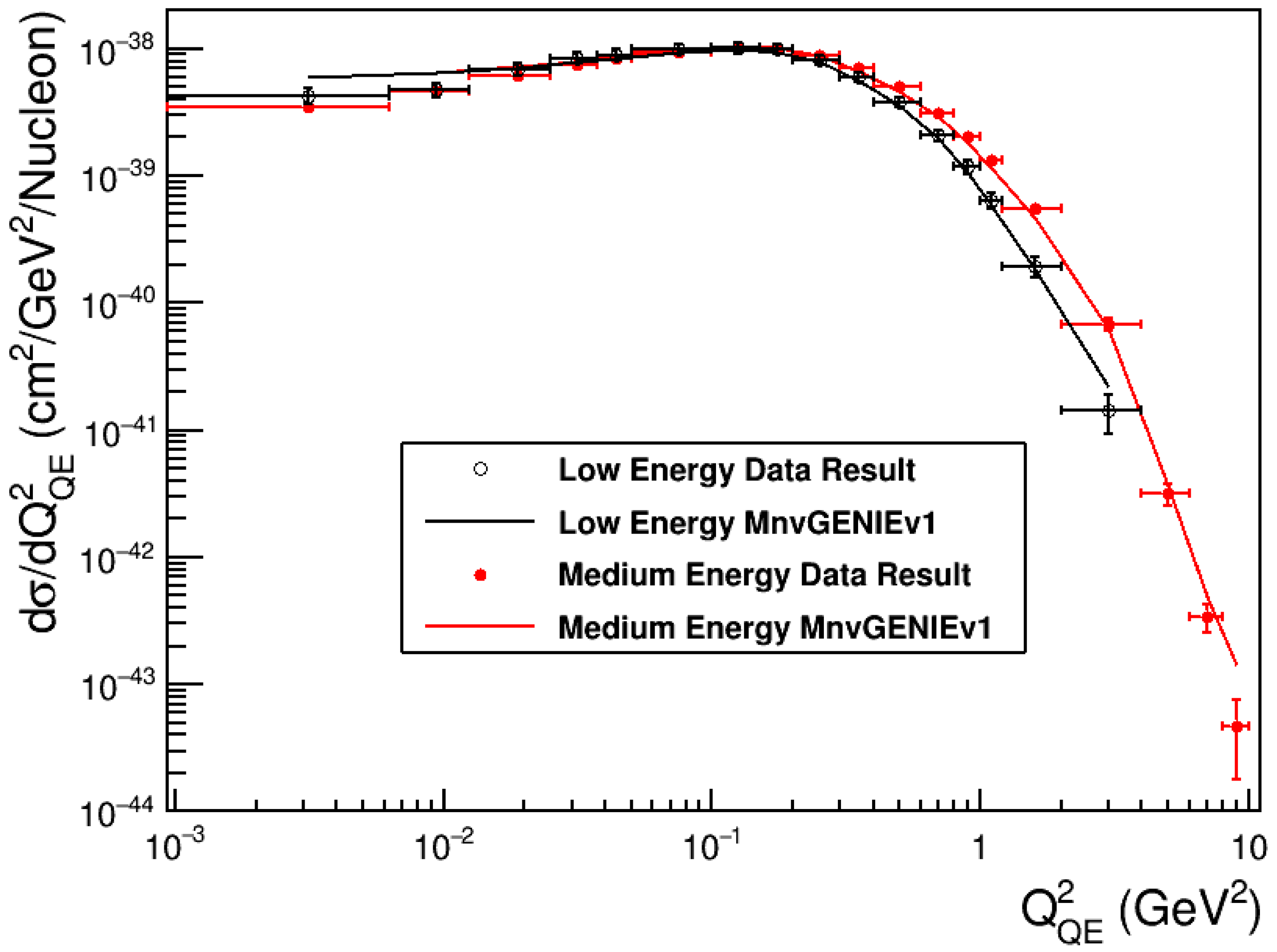
Double-Differential Cross Section

- Large phase space: 4/15 bins on 1.5 GeV < $p_{||}$ < 20 GeV shown
- 2p2h tune improves agreement in some $p_{||}$ bins
- Generally shifted toward higher p_T



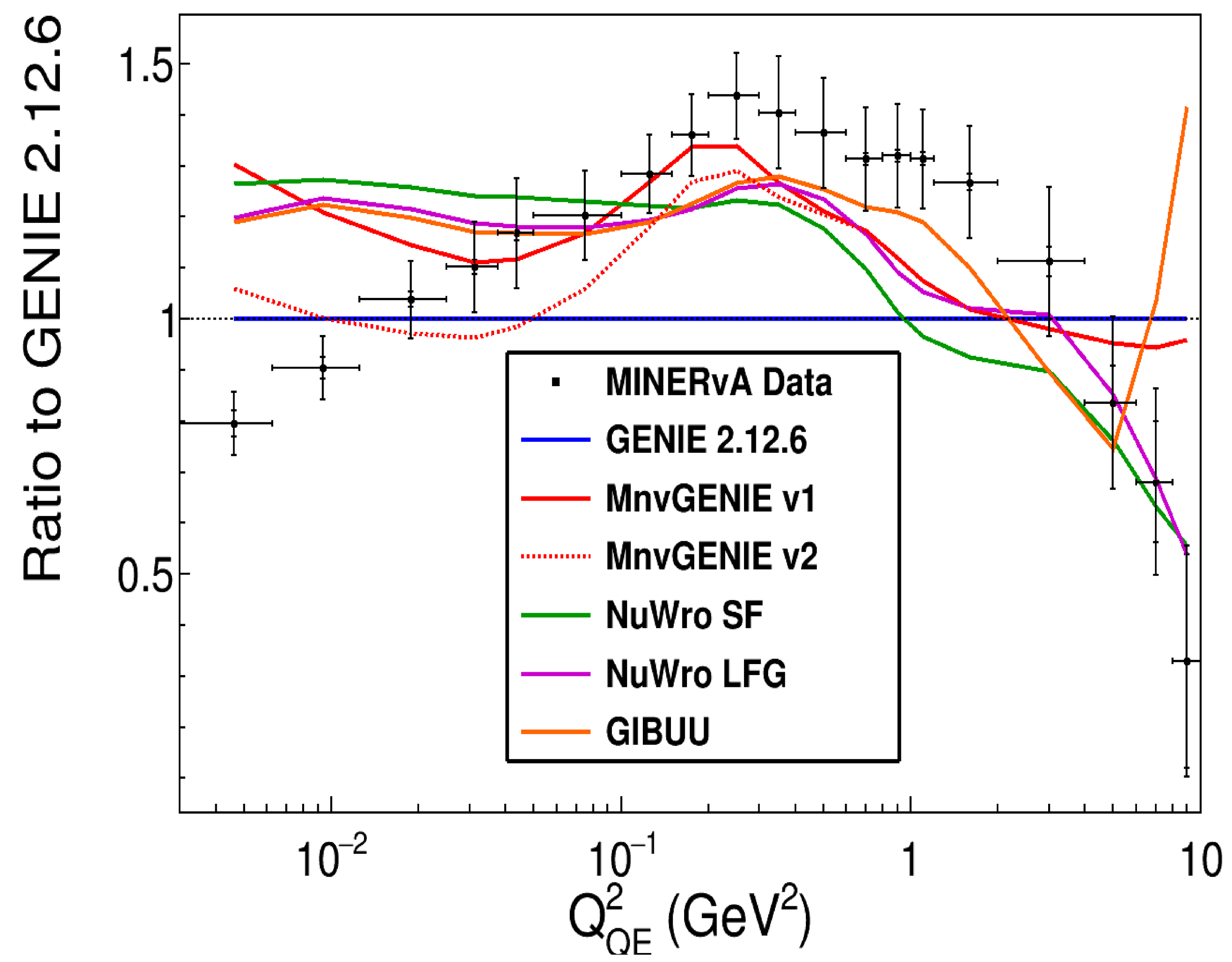
Differential Cross Section in Q^2_{QE}

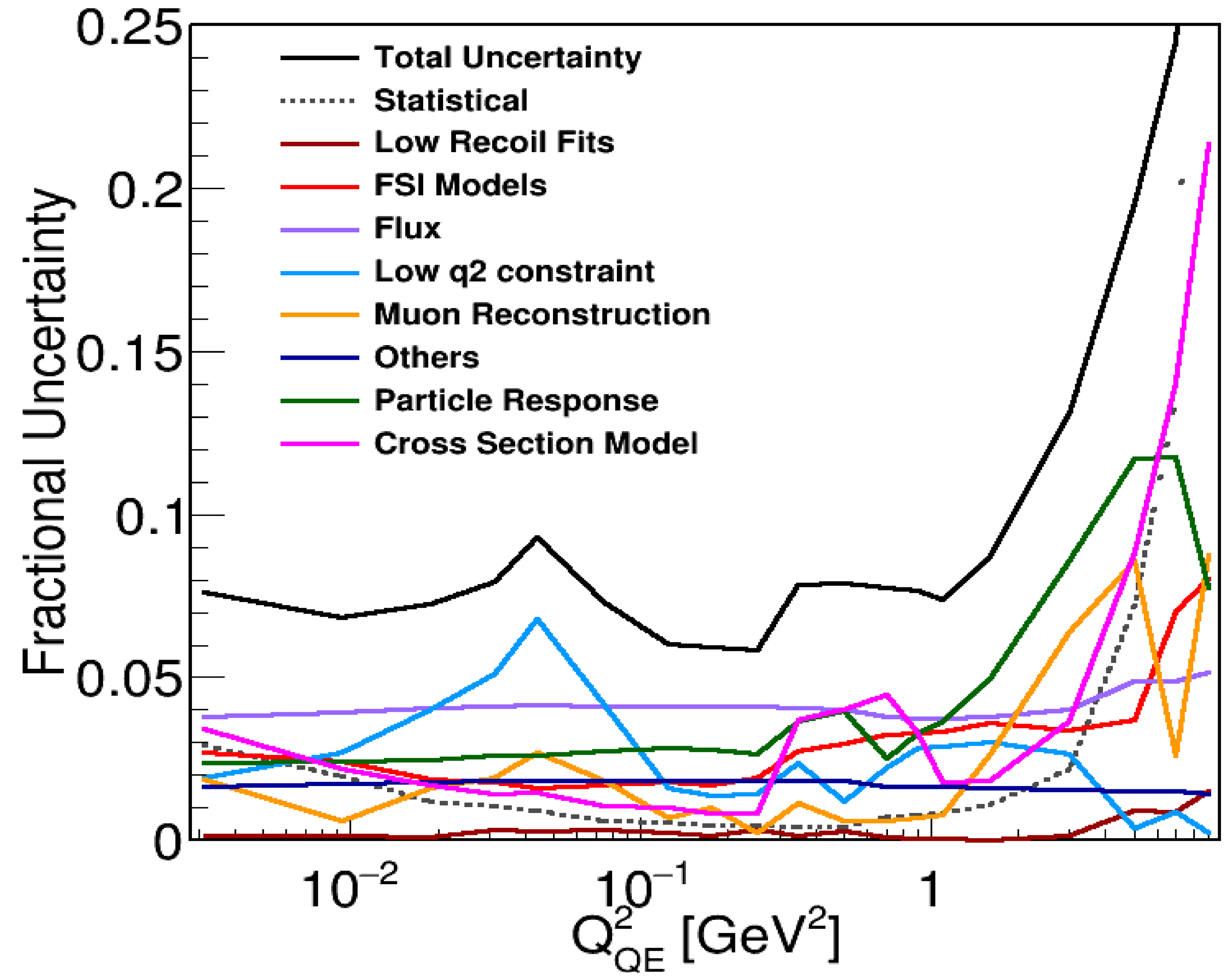
- 4 decades of Q^2
- Cross sections match despite different energy regimes → dipole form factor effective
- Medium Energy more sensitive at high Q^2_{QE}
- ~8% uncertainty averaged in Q^2_{QE}



Model Comparison

- No model has the right shape at both low and high Q^2_{QE}
- MnvGENIEv1[1] = GENIE 2.12.6 + Valencia RPA + Valencia 2p2h[5] + low recoil fit + nonresonant pion tune
- MnvGENIEv2 = MnvGENIEv1 + low Q^2 pion tune [6]





Conclusions

- New phase space in Q^2
- Better phase space breakdown in $p_{||}$ and p_T
- Enabled by high statistics, so stay tuned for 3D results [6]

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Acknowledgments

This material is based upon work supported by the National Science Foundation Graduate Research Fellowship Program under Grant No. DGE-1939268. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.
This document was prepared by members of the MINERvA Collaboration using the resources of the Fermi National Accelerator Laboratory (Fermilab), a U.S. Department of Energy, Office of Science, HEP User Facility. Fermilab is managed by Fermi Research Alliance, LLC (FRA), acting under Contract No. DE-AC02-07CH11359.