Double-Differential $\nu_\mu$ 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 $E_\nu$ 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
   - $p_\mu$ > 1.5 GeV/c

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

Model Comparison
- No model has the right shape at both low and high $Q^2_{QE}$
- $MnvGENIE v1$ = GENIE 2.12.6 + Valencia RPA + Valencia 2p2h$^{(1)}$ + low recoil fit + nonresonant pion tune
- $MnvGENIE v2$ = $MnvGENIE v1$ + low Q$^2$ pion tune$^{(6)}$

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

References

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