New Inclusive Cross Section Measurements from MINERvA

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1. Motivation

- Interaction models are relied on by oscillation experiments for E_ν estimation, background estimation, and signal acceptance
- Uncertainties from models can be a leading systematic
- Inclusive cross section measurements are stringent tests for generators.
- Sample has rich statistics and small backgrounds.

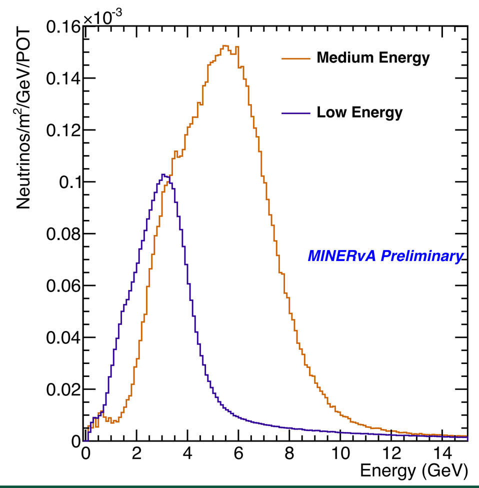
2. MINERvA Detector

MINERvA detector is made up of an active tracking region, a nuclear target regions, and an ECAL and HCAL. For this analysis only the active tracking region is used.

MINERvA took data on-axis in the NuMI beamline at Fermilab[2].

This analysis uses low energy neutrino mode data, where $\langle E_\nu \rangle$ ~3.5 GeV.

The MINOS ND is used as a muon spectrometer. We track muons in the MINERvA detector and then look for matching tracks in the MINOS ND.



3. Signal Definition & Event Selection

Signal definition:

- ν_μ charged current
- $\theta_\mu < 20°$ with respect to beam (restriction due to MINOS acceptance)

Event selection:

- Fiducial cut in active tracker region
- μ^- track in MINOS matched to MINERvA track
- Charge-sign significance

327,987 events selected

0.75% of events from backgrounds, coming from NC and other neutrino flavor CC events (mostly $\overline{\nu}_\mu$ CC)

4. Systematic Uncertainties

Flux[3]

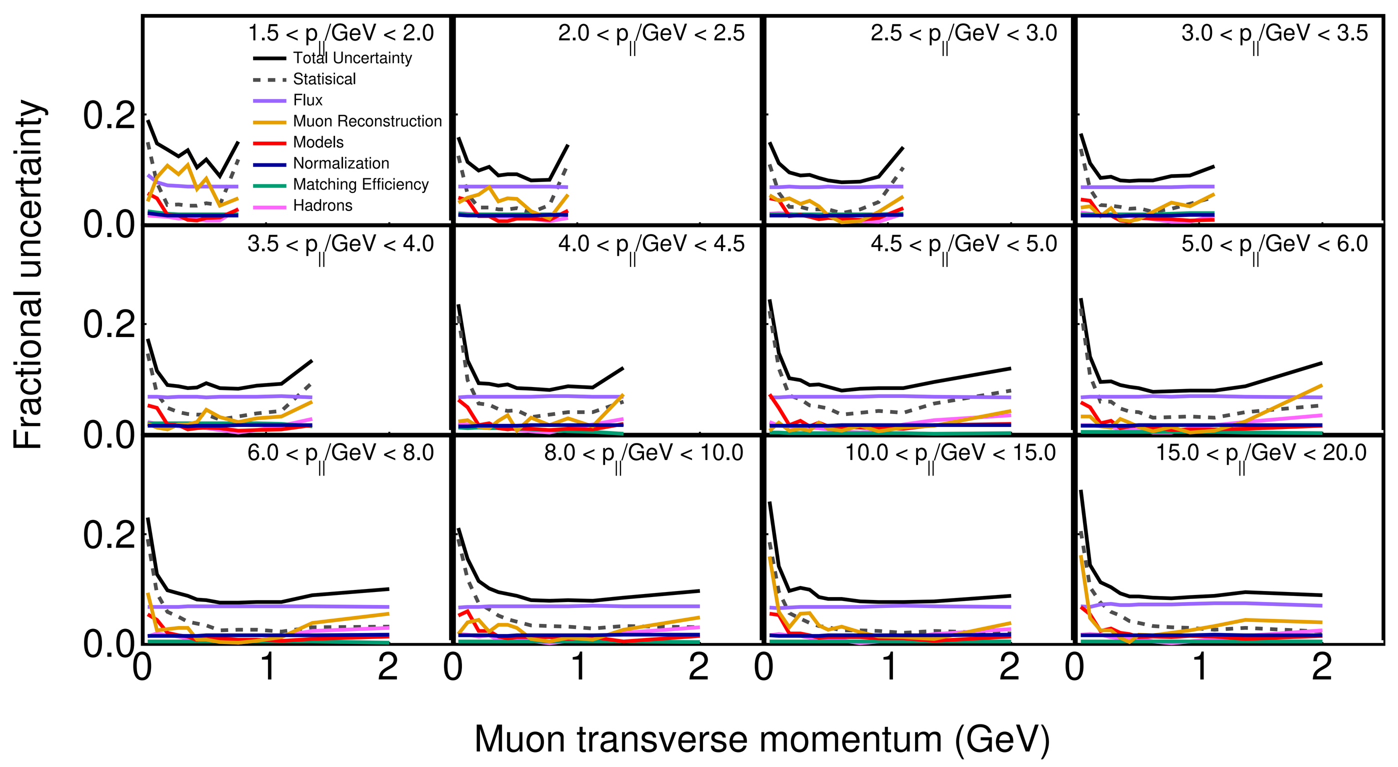
- lLargest uncertainty
- ~ 7%
- Generally flat

Muon reconstruction

- Next largest uncertainty
- Comparable to flux at low $p_{||}$

Statistical uncertainties only significant near edges of phase space

All other systematics smaller than statistical uncertainty



5. Models & GENIE variations

We use GENIE 2.8.4 as our base model, which we then modify to better agree with prior exclusive MINERvA measurements.

MnvGENIE v1

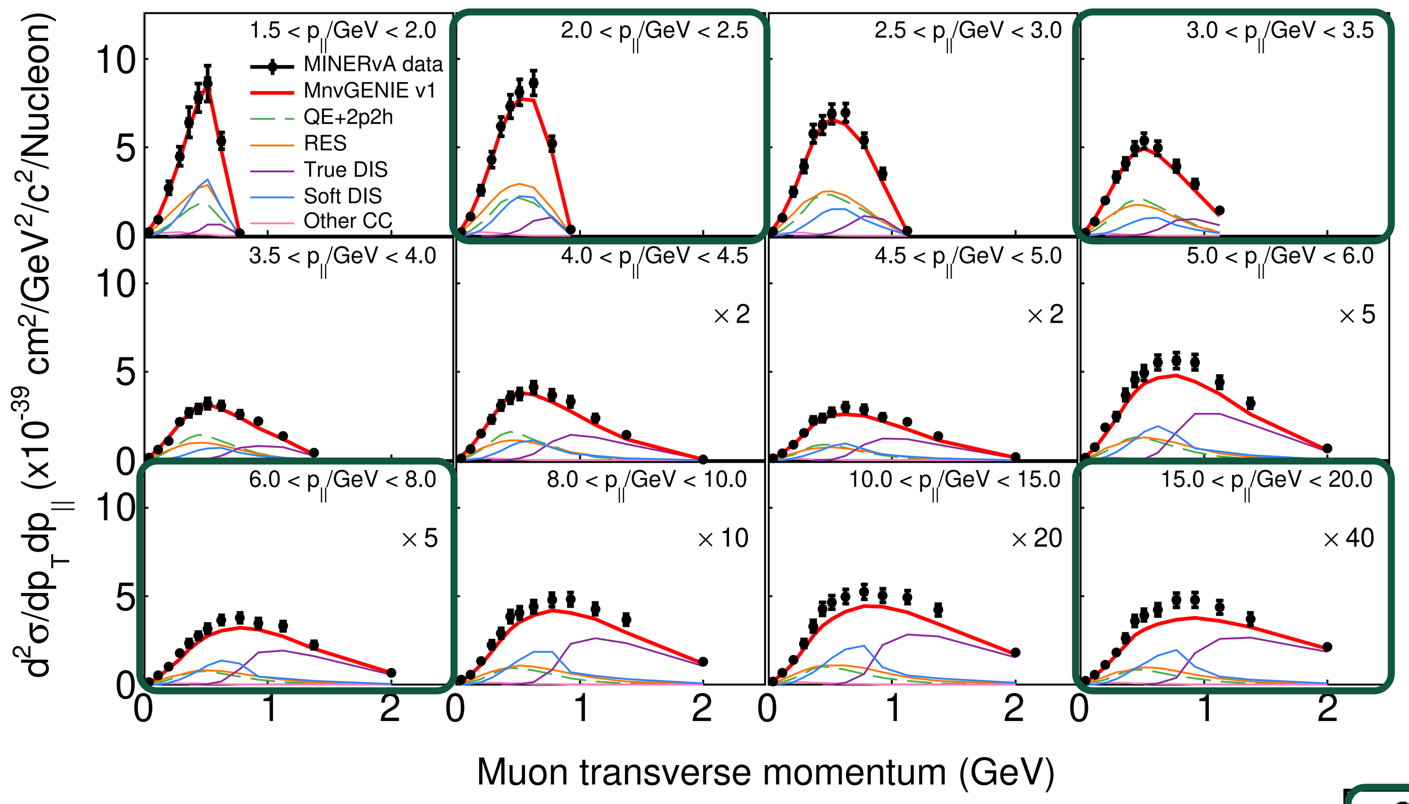
- RPA suppression of QE events at low Q^2
- Valencia 2p2h enhanced based on a fit to our low recoil analysis
- Reduction of non-resonant pion production based on a reanalysis of bubble chamber data

MnvGENIE v2 – MnvGENIE v1 + MINERvA low Q^2 resonant suppression based on our prior pion production measurements[4]

DIS model comparisons[5−7] are applied on top of MnvGENIE v1 by reweighting GENIE DIS events with $W > 2$ GeV & $Q^2 > 1$ GeV^2

Comparisons to event generators: NuWro 19.02[8] and GiBUU 2019[9]

6. Results



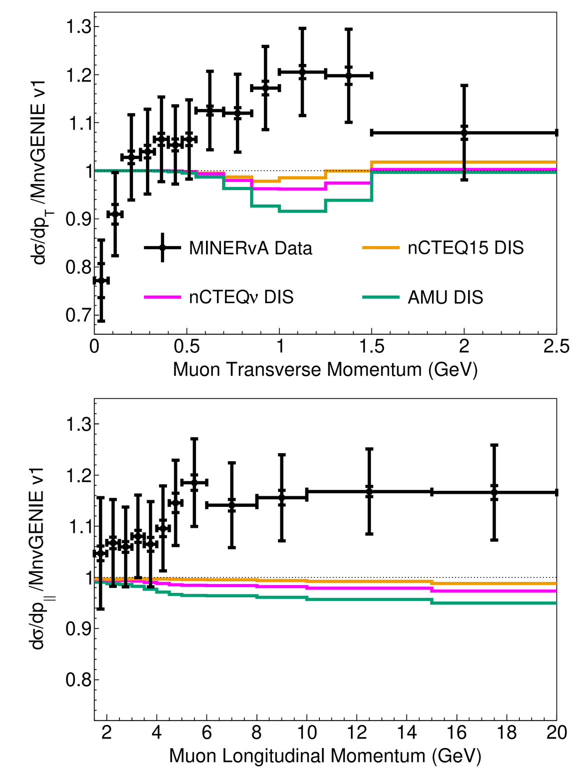
Interaction channels each have regions in which they are the dominant process

Noticeable underpredictions exist with all models in high $p_{||}$ bins — region with many interaction channels

Limitations to how much we can interpret about any one process in inclusive measurement — to be used in conjunction with exclusive results

Mid-range p_T is being underpredicted by all models in the projection

DIS models do not improve data agreement



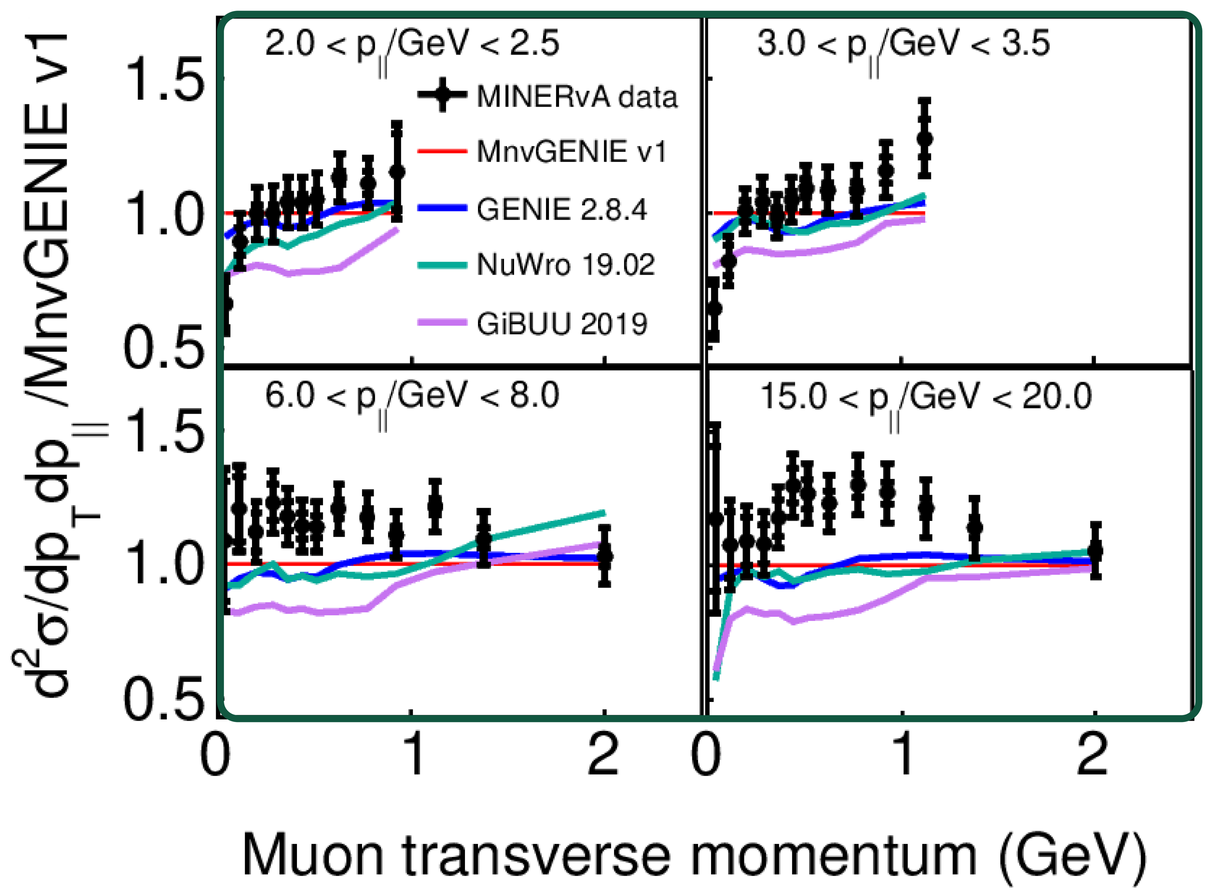
None of the models predict the whole phase space well

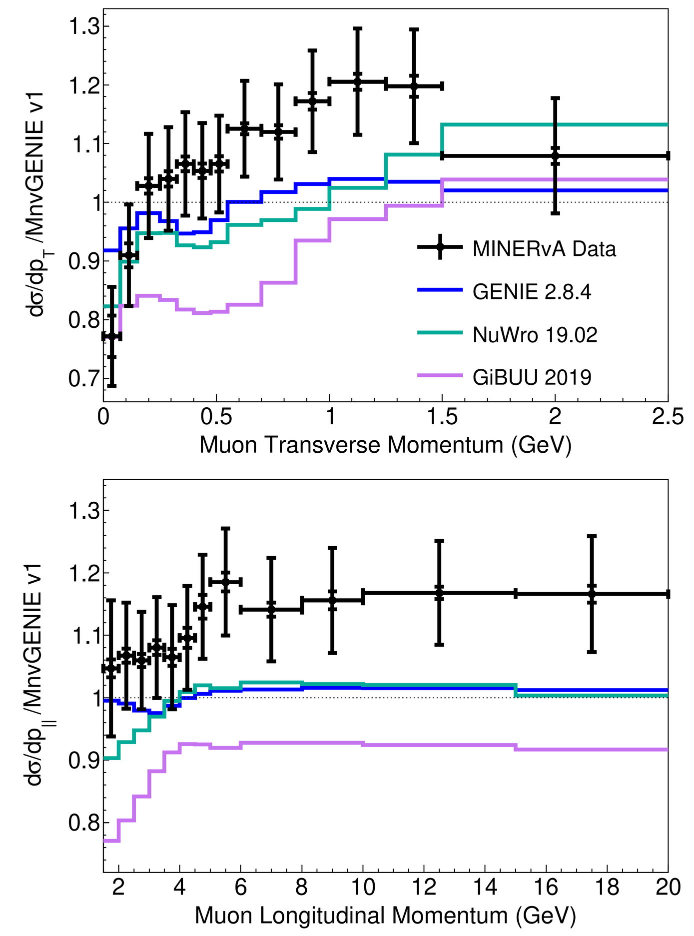
In the upper half of the $p_{||}$ bins, all of the models are consistently underpredicting the measured cross section for middle of the p_T range.

In the lower half of the $p_{||}$ bins, there is good agreement with MnvGENIE and GENIE 2.8.4 for the 3rd-7th p_T bins.

Lowest p_T bins are overpredicted by MnvGENIE v1.

NuWro and GiBUU have better agreement in these bins but don't agree with shape for higher p_T.





7. Comparisons to Models

χ^2 for $d^2\sigma/dp_{||}dp_T$

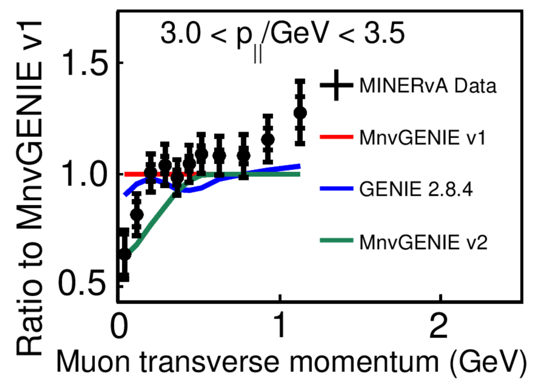
Process Variant	Std.	Log-norm.
MnvGENIE v1	495	547
+ nCTEQ15 DIS	503	551
+ nCTEQν DIS	506	565
+ AMU DIS	549	636
GENIE 2.8.4	422	491
+ RPA	327	459
+ RPA + 2p2h	402	464
MnvGENIE v2	475	665
v1 + MINOS π sup.	381	526
NuWro	820	587
GiBUU	767	815

χ^2s for 144 degrees of freedom

MnvGENIE v2 (v1 + Mnv low Q^2 sup.)

- Improves agreement in the lowest p_T bin
- Too severe in higher p_T bins
- Improves standard χ^2
- MINOS version describes data better

The best χ^2 is achieved by GENIE 2.8.4+RPA, a variation of GENIE which has no 2p2h.



8. Conclusion

- Measured cross sections not reproduced by any single model throughout phase space
- Regions of high $p_{||}$, mid p_T are being underpredicted by all the models and tunes we used
- Indication that some form of a low Q^2 resonant suppression is called for
- MnvGENIE tunes, optimized to better agree with prior exclusive MINERvA measurements, have diminished predictive power when modifications are applied inclusively
- DIS models compared to did not improve agreement with the data
- This measurement should be useful for tuning models

References

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