Comparing ACHILLES to MINERvA

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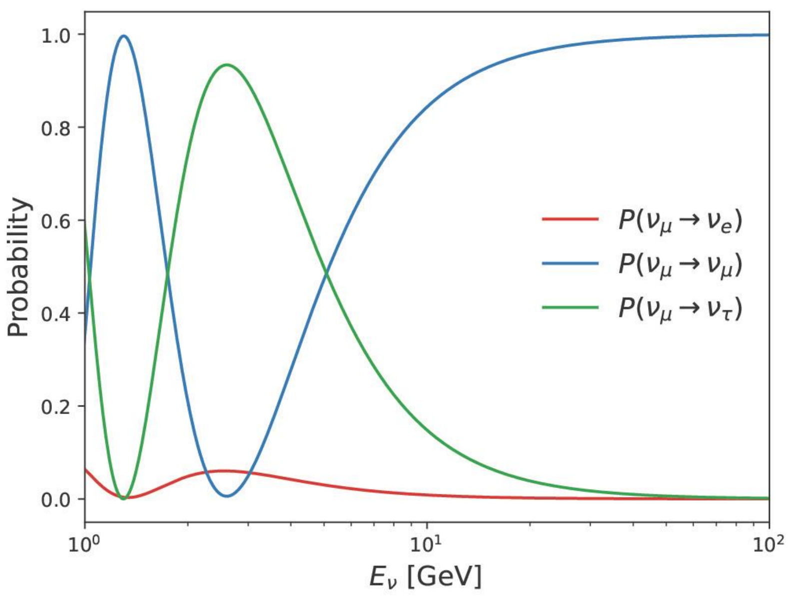
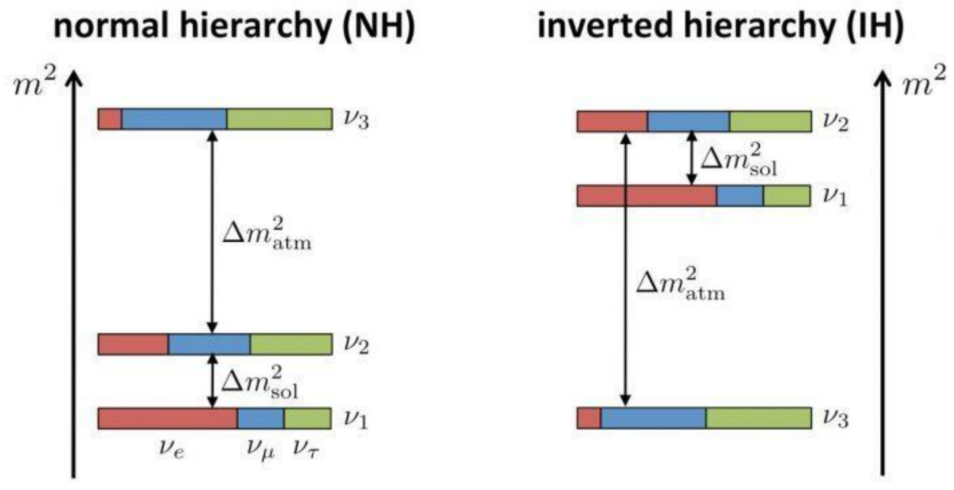
Neutrinos

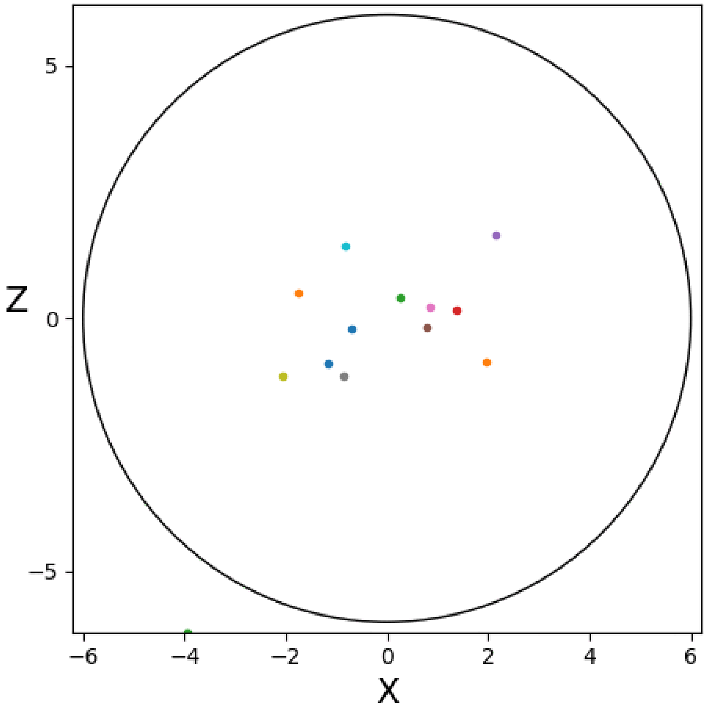
- New generation neutrino experiments are setting out to measure the CP-violation, oscillation parameters, and mass ordering of neutrinos.
- These experiments require percent level precision.
- Because of this precision goal, simulators are needed for comparison of data.





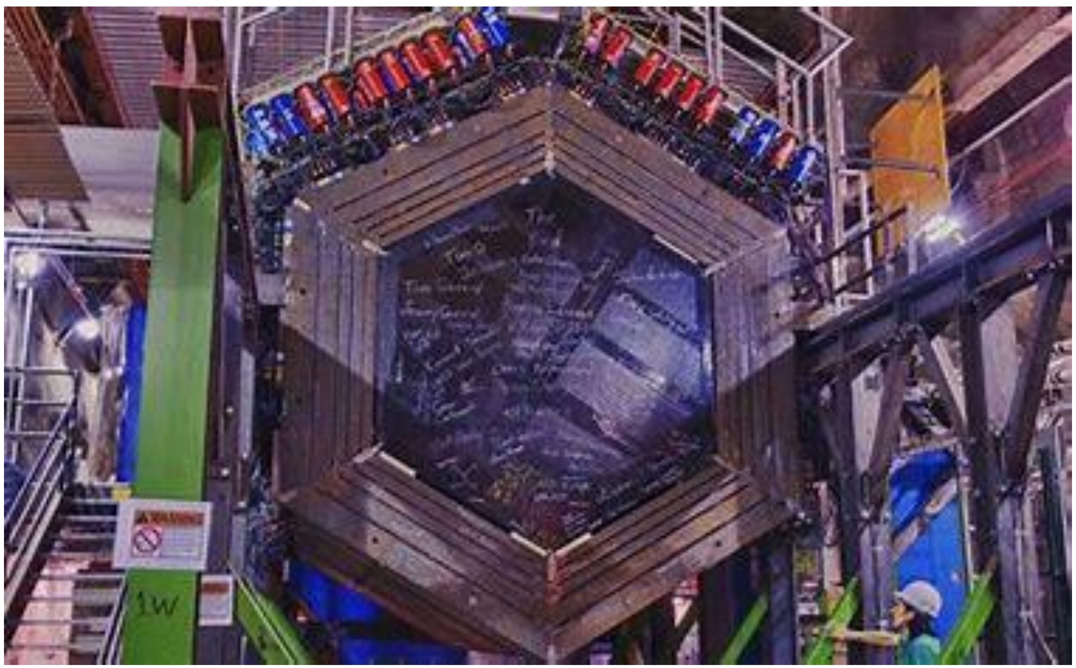
Lepton Event Simulators

- The process of modeling neutrino-nucleus interactions starts with an estimation assuming the nucleons are free.
- However, the nucleons actually act as a many-body quantum system.
  - To account for this, a well-defined factorization scheme can be used (such as the impulse approximation), but these include estimations often times from experimental data.
- The final state interactions (FSI) of the nucleons also have to be accounted for, and there are traditionally two approaches:
  - 1)Solving the Kadanoff-Baym integro-differential equations analytically, but this includes truncations and estimations, making it difficult to account for the theoretical error.
  - 2)The intranuclear cascade approach, which attempts to solve the transport equation numerically. With this the nucleon's propagation are treated as discrete quantum mechanical scatterings and then evaluated using classical scattering.



MINERvA

- The MINERvA experiment took place at Fermilab.
- The experiment set out to make measurements of the neutrino-nucleus cross section, which is important quantity to have in order to make steps towards making measurements of neutrino oscillation parameters.



ACHILLES

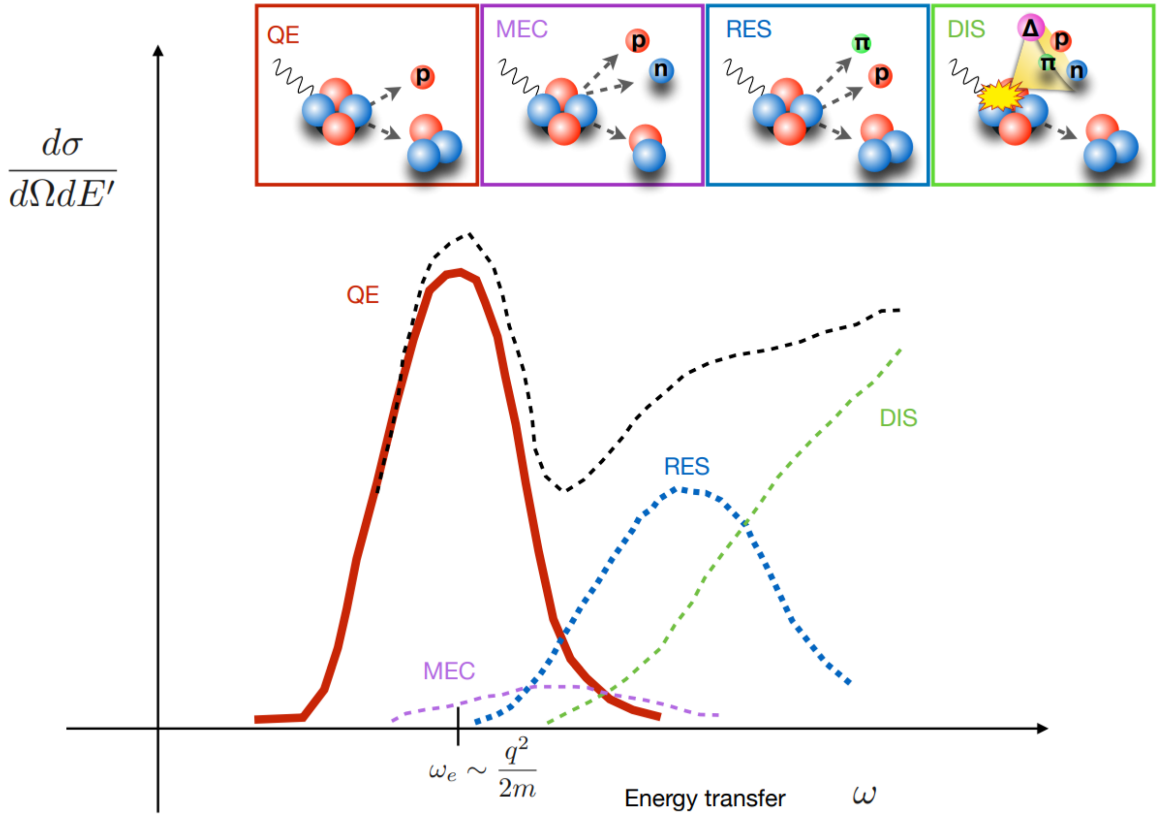
- ACHILLES is a fully theory-driven lepton event generator that is in its early stages of development.
- ACHILLES uses the intranuclear cascade approach to simulate the FSI.
- When running the cascade there are several options:
  - Nucleon-nucleon interaction model: Gaussian or Cylinder.
  - Nuclear potential: WFF, Schrodinger, or none.

Data Generation

- The ACHILLES data was generated by running the code and then reading the output with a HepMC reader.
- The HepMC reader allows each particle's momentum and energy to be obtained for each event.
- For each chosen observable, histograms were filled for the number of events in ranges given by the bin sizes in the experimental papers.
- The code was reran and six different data sets were plotted for the six different run option combinations.

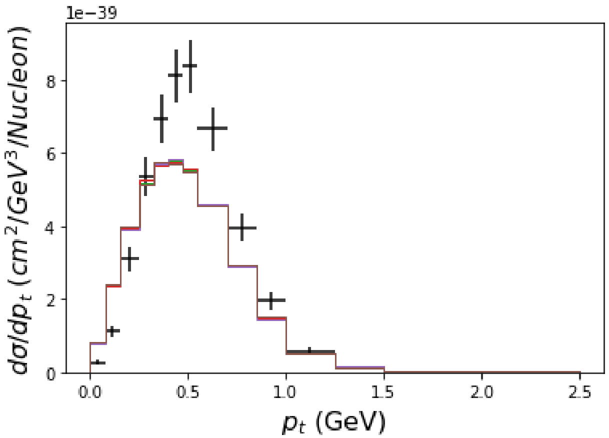
Cross Section Contributions

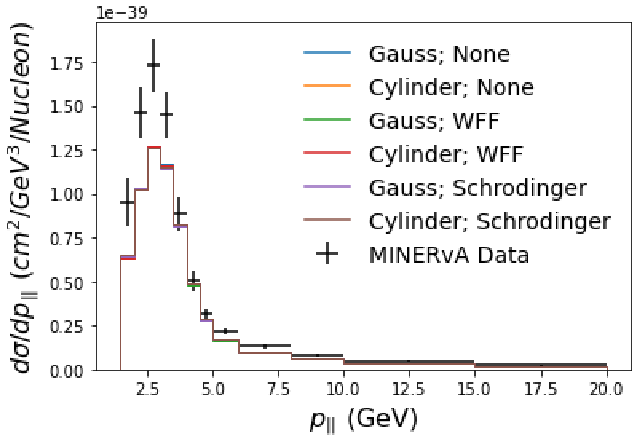
- ACHILLES implements QE contributions and a small amount of 2p2h contributions but not contributions from resonance production or deep-inelastic scattering.

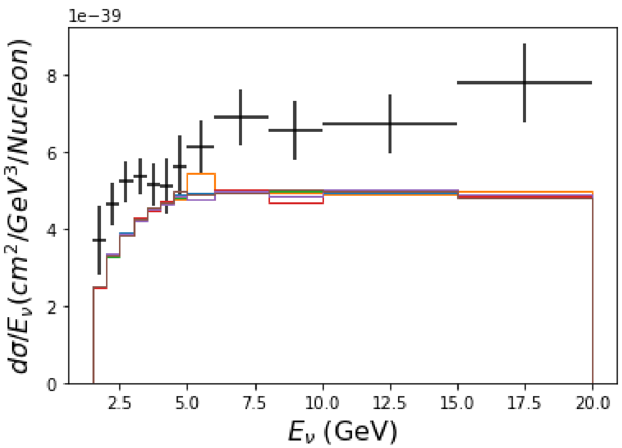


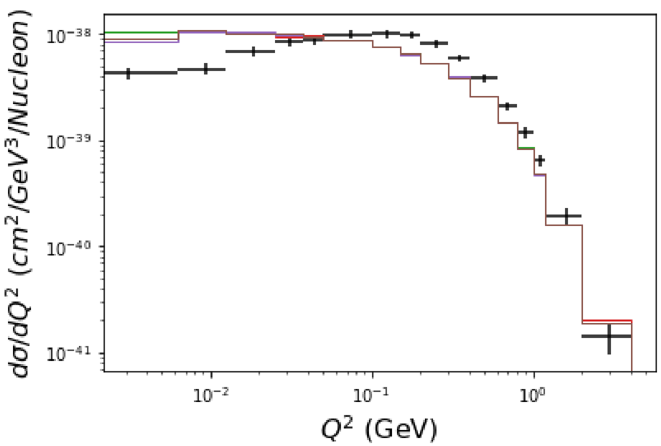
Fermilab

1D Cross Sections









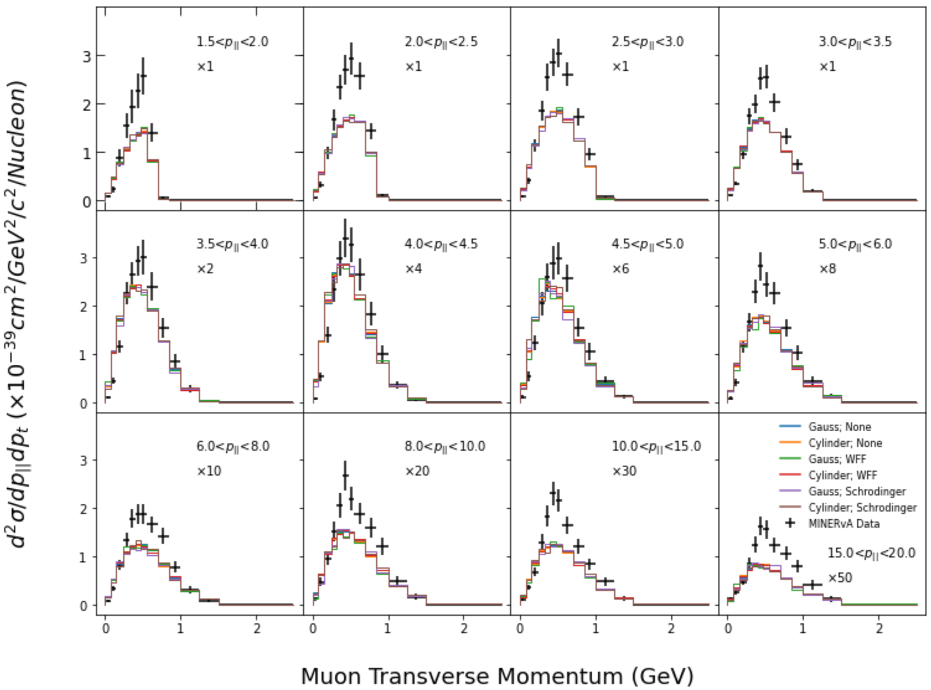
- The observables plotted against are muon transverse momentum, muon longitudinal momentum, reconstructed neutrino energy, and momentum transfer.

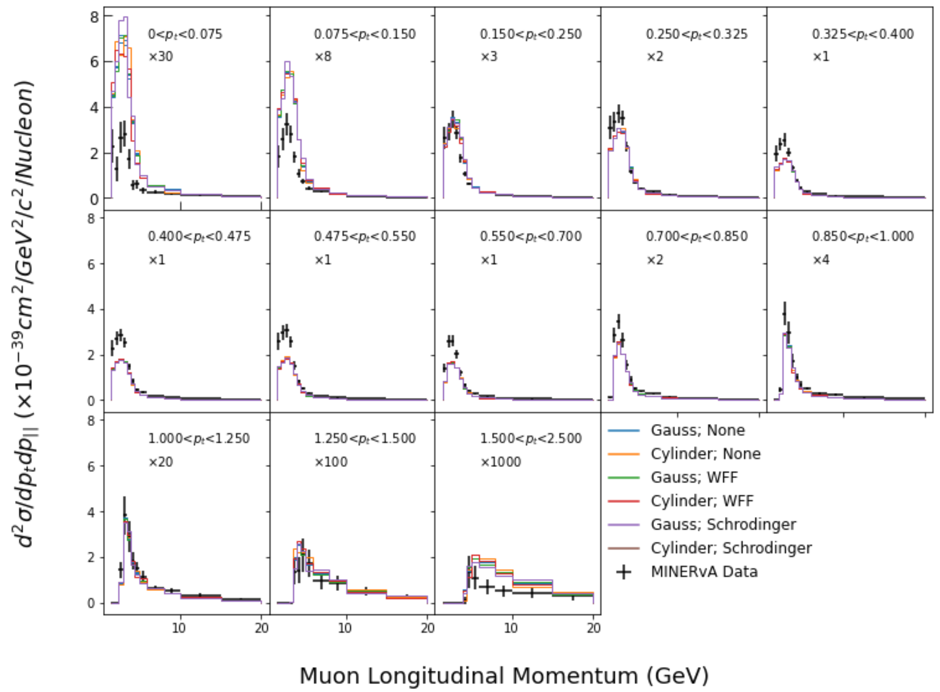
$$E_\nu = \frac{m_n^2 - (m_p - E_b)^2 - m_\mu^2 + 2(m_p - E_b)E_\mu}{2(m_p - E_b - E_\mu + p_\mu \cos\theta_\mu)},$$

$$Q^2 = 2E_\nu(E_\mu - p_\mu \cos\theta_\mu) - m_\mu^2.$$

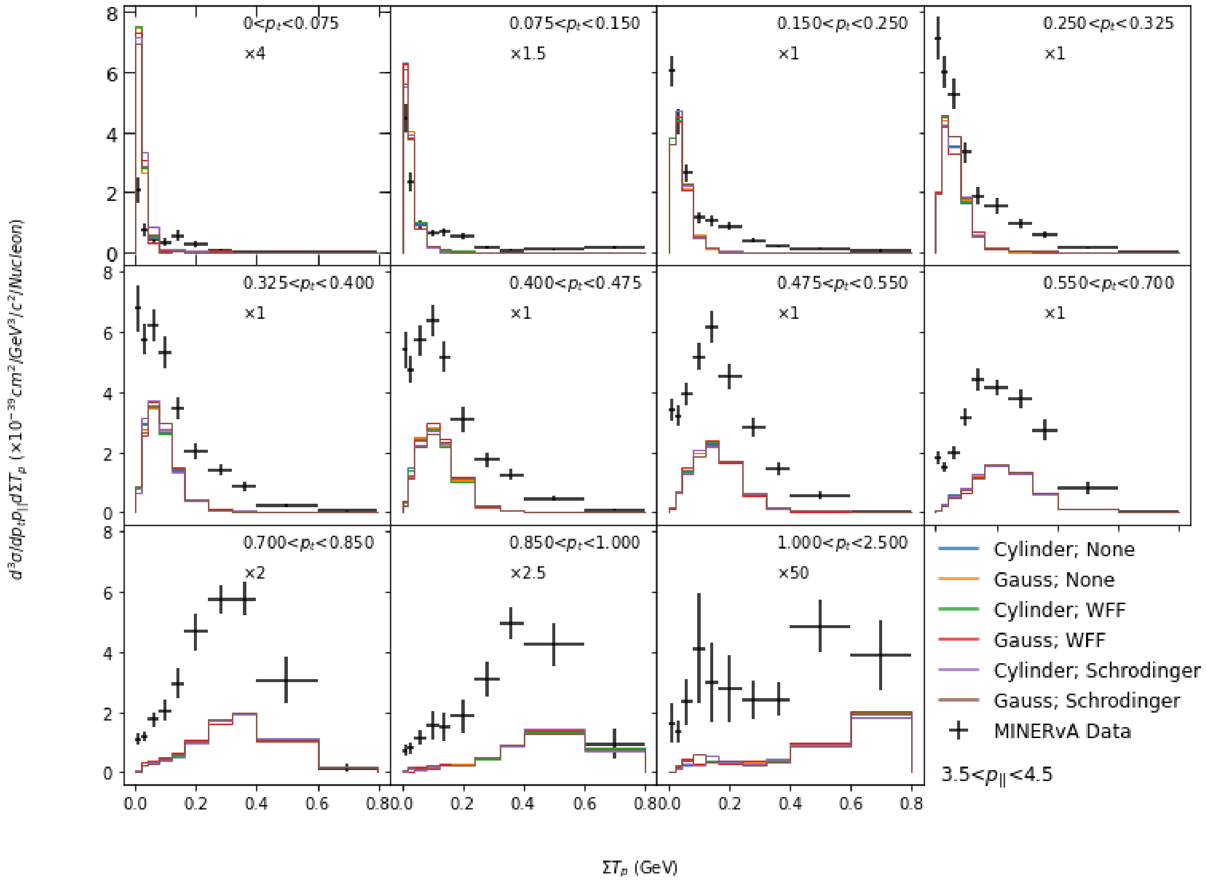
Fermilab

2D Cross Sections





3D Cross Sections



- In all the graphs we see an overestimation in low ranges of muon transverse momentum.

Conclusions

- Considering that ACHILLES is in its early stages, it compared fairly well to the MINERvA data for a QE generator.
- The overestimation can most likely be accounted for by the fact that effects of the FSI are neglected in the intranuclear cascade.
- This analysis can be revisited by the ACHILLES authors in the future when other contributions are implemented in the code.