Charged Current Single Pion Production at MINERvA

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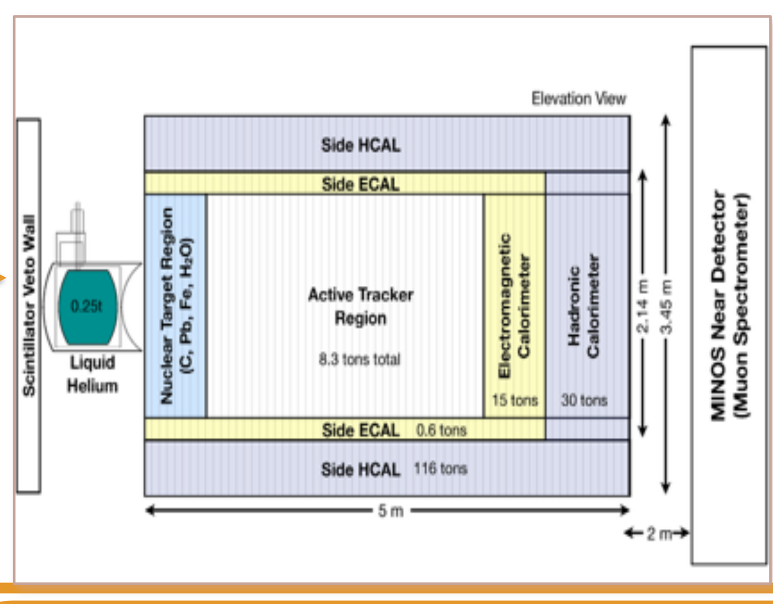
on behalf of MINERvA Collaboration

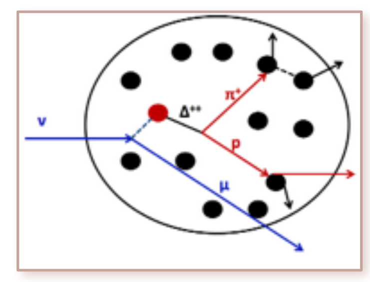
MINERvA Detector

MINERvA is a neutrino scattering experiment at Fermilab designed to make the high precision cross section measurements that are necessary for the next generation of neutrino experiments. MINERvA has a fine-grained scintillator tracker surrounded by calorimeters.



Nuclear Physics – Pion Absorption

- Nuclear processes affect the final state content, and this needs to be modeled to correctly reconstruct the neutrino energy.



- Particles can interact with nucleons before exiting the nucleus: Final State Interactions
- Pions produced in the initial interaction can be absorbed ~25% of the time for π+ from Δ decay!

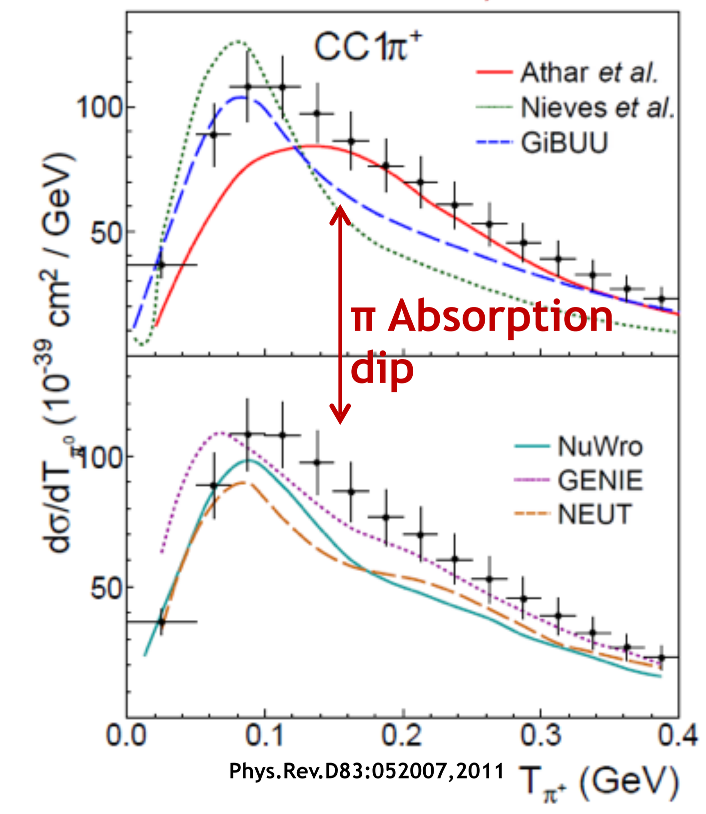
Need to understand the Nuclear Physics

Current knowledge of neutrino-nucleus interactions have to improve, to help future experiments like LBNE in meeting their physics goals!

Neutrino-Nucleus Interaction

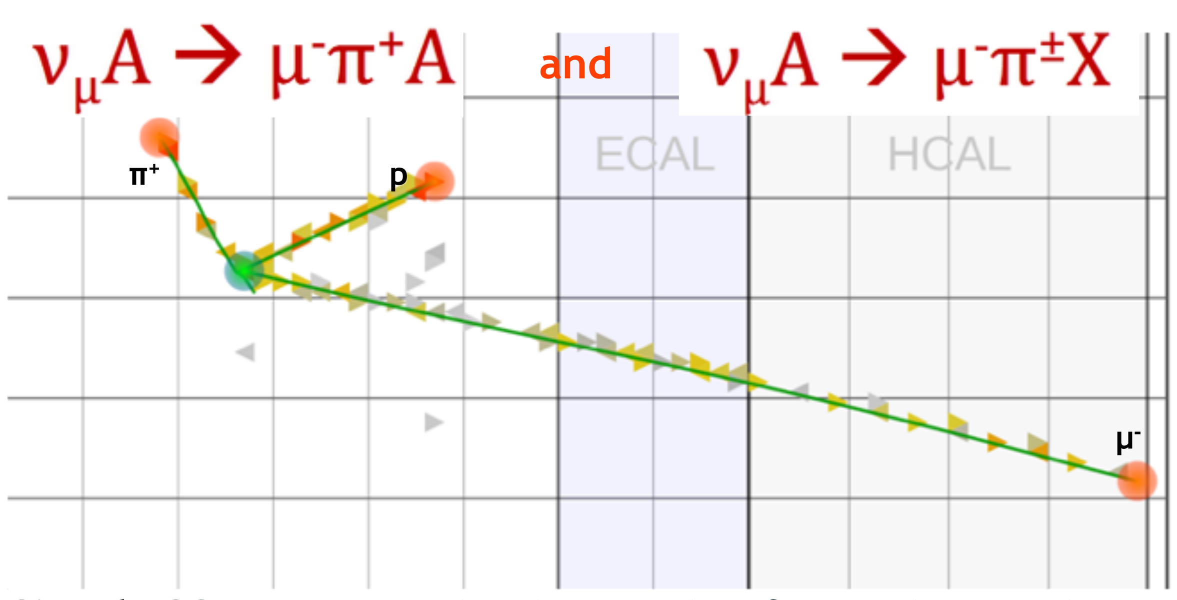
- MINERvA experiment is using the Rein-Sehgal model for νN resonance production. All models generally have poor treatments of nuclear medium effects.
- Fitted models predict a dip in pion energy when the pion interactions peak in Carbon(~160MeV).
- MiniBooNE measured Charged Pion Production on mineral oil and the expected dip is not seen in the data.
- FSI model is responsible for the characteristic dip between 100-200 MeV.
- **MINERvA is providing more data for a better understanding of pion energy and angle distributions to determine strength and nature of FSI interactions.**

$\nu_\mu CH_2 \rightarrow \mu^-\pi^+X$



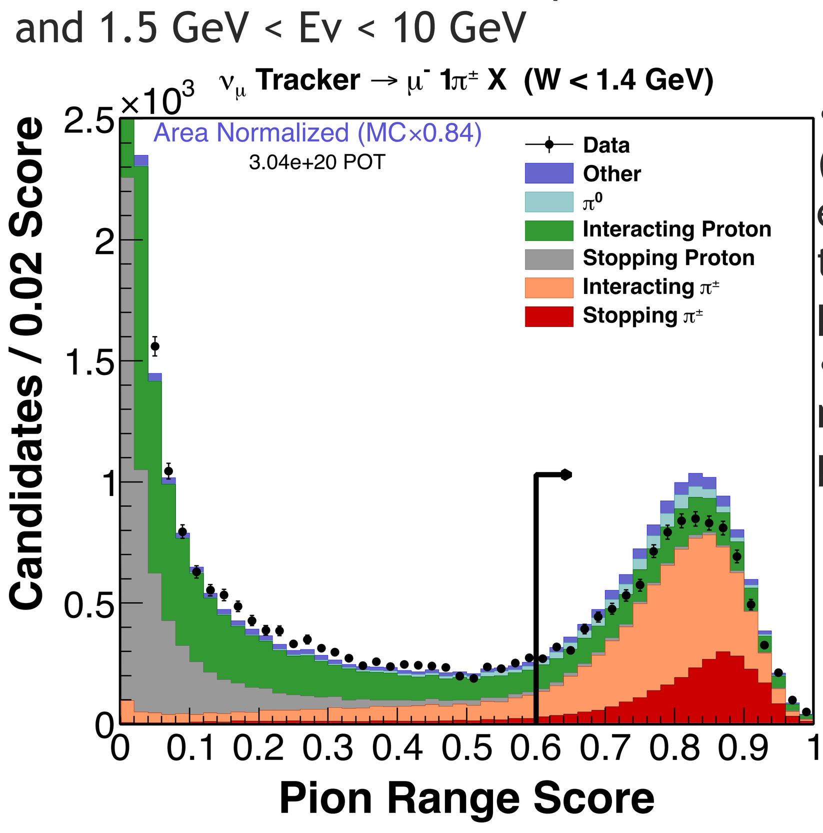
Signal Definition & Event Selection

$\nu_\mu A \rightarrow \mu^-\pi^+ A$ and $\nu_\mu A \rightarrow \mu^-\pi^\pm X$



Signal :CC muon neutrino interaction from a interaction vertex in the active tracker region and selection exactly one charged pion in the final state.

In addition, we cut on the Hadronic invariant mass W < 1.4 GeV to avoid multi-pion events and 1.5 GeV < Ev < 10 GeV



- Use energy loss (dE/dx) profile of each hadron track to separate protons and pions
- Find the best fit momentum for a pion hypothesis.
- Select a pion having good energy reconstruction stop and decay in the detector by looking for a Michel electron at the end of the track

Event Selection – Kinematics

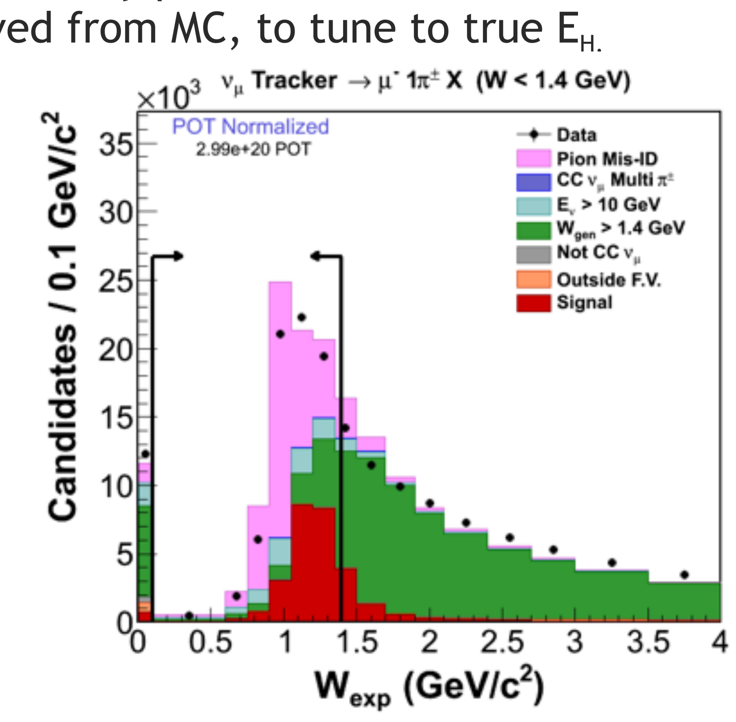
- Select Charge Current events: Muon track In MINERvA matching in MINOS with a reconstructed negative charge.
- Reconstruct hadronic recoil energy (E_H) calorimetrically.
- Sum non-muon energy, weighted by passive material constants
- Apply additional scale, derived from MC, to tune to true E_H.

$$E_\nu = E_\mu + E_{had}$$
$$Q^2 = 2E_\nu(E_\mu - |\vec{p}_\mu| cos(\theta_\mu)) - M_\mu^2$$
$$W^2 = M_p^2 - Q^2 + 2M_p E_{had}$$

Require:

E_ν < 10 GeV

W_{exp} < 1.4 GeV



- Require one or two hadron track candidates.

Background Summaries

-Purity: 77%

-Largest background: W > 1.4 GeV ~17% of sample

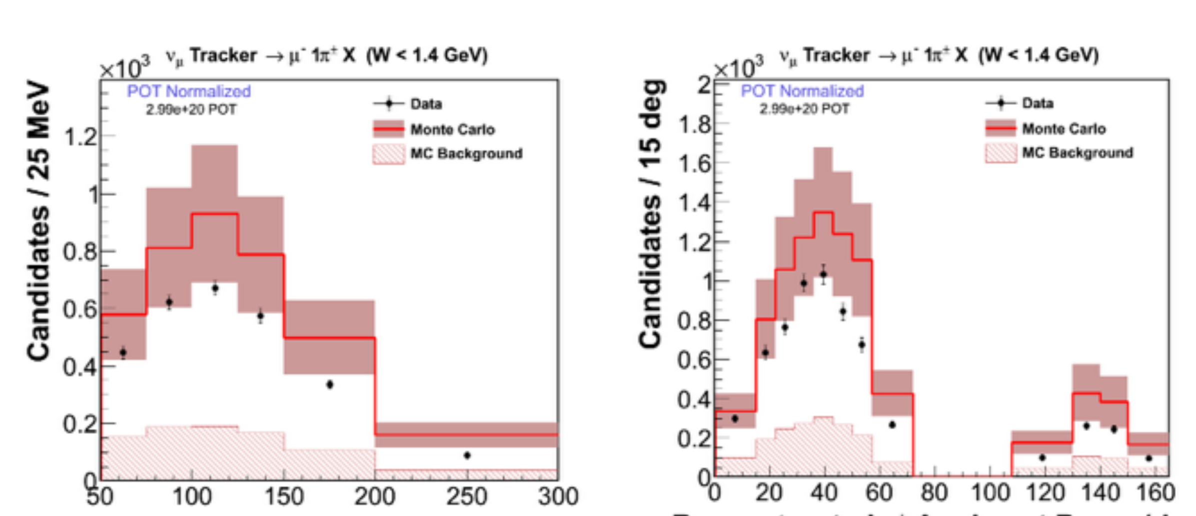
PID backgrounds: Protons and other particles mis-ID as pion ~ **4%** of sample

All other backgrounds combined ~**2%** of sample

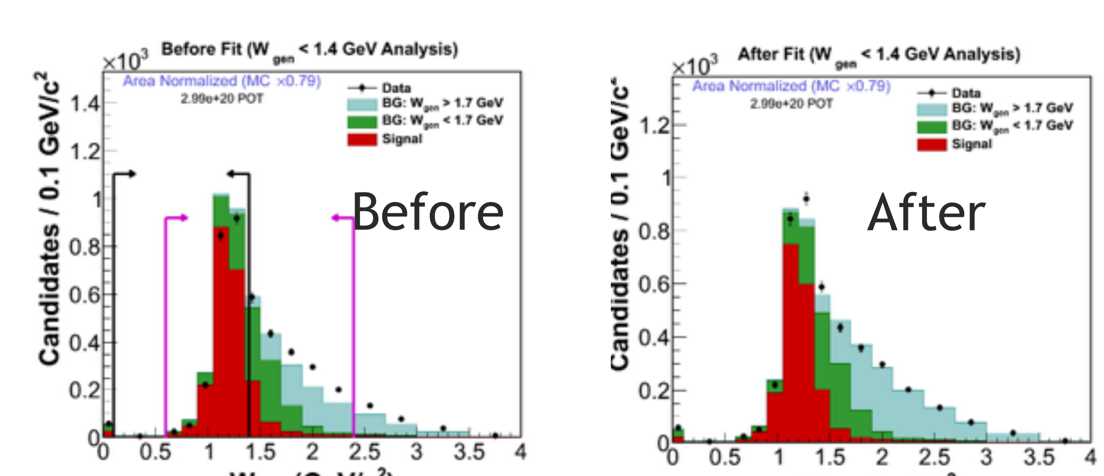
Background	*% of One-*	*% of N-Pion*
Rock Muon	*0.08*	*0.08*
Outside Fiducial Volum	*0.24*	*0.26*
Not CCνμ	*0.05*	*0.01*
W>1.4GeV/c2	*16.6*	*6.02*
Eν >10GeV	*0.45*	*0.84*
Multiple Charged Pions	*1.61*	*N/A*
Proton	*3.31*	*4.47*
Other Particles	*0.8*	*2.2*
Total	*23.1*	*14.0*

Reconstructed Pion Energy and Angle

Event selection yields **3474 pion candidates,** MC error bars include full systematic errors and Data errors are statistical only.

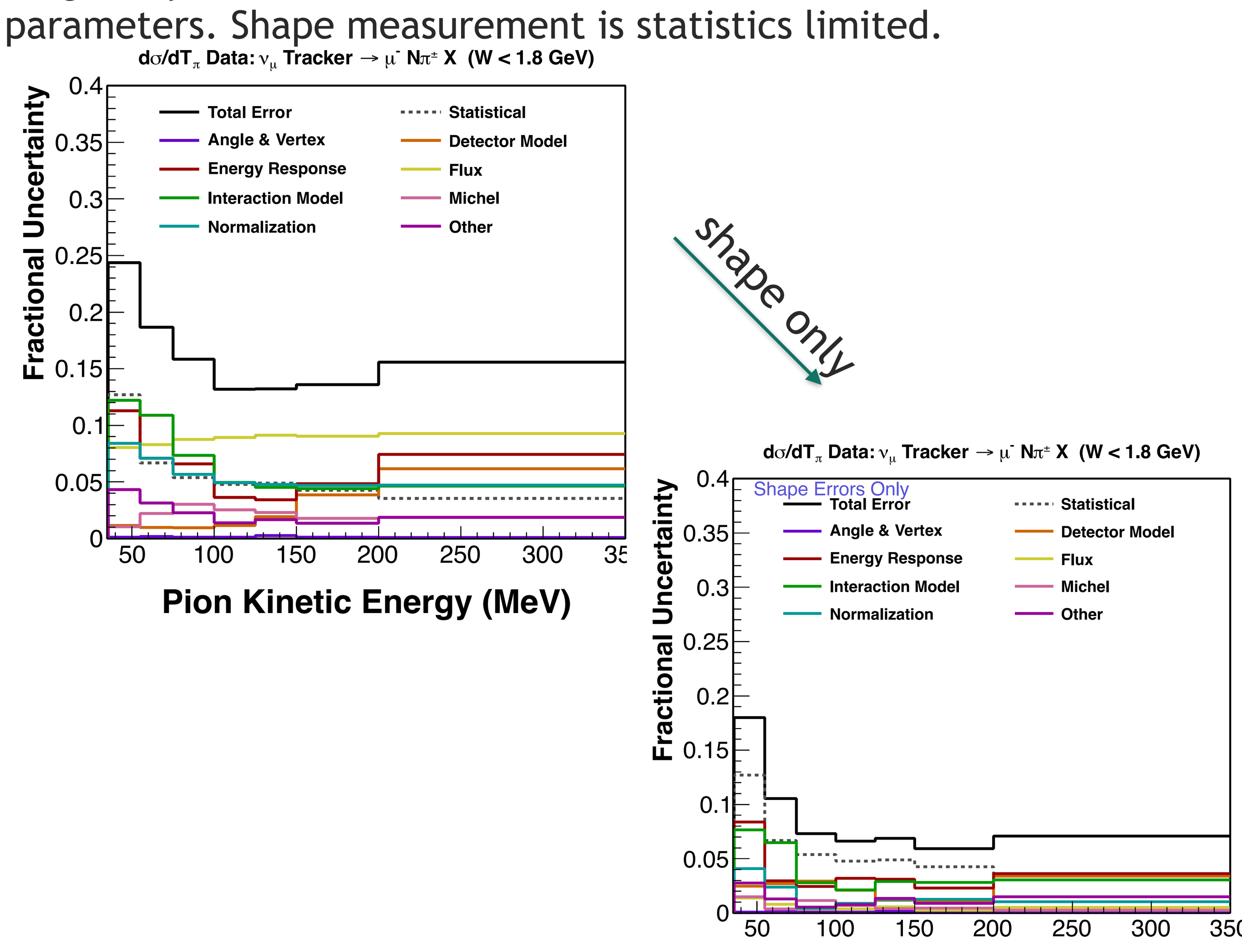


Background Subtraction

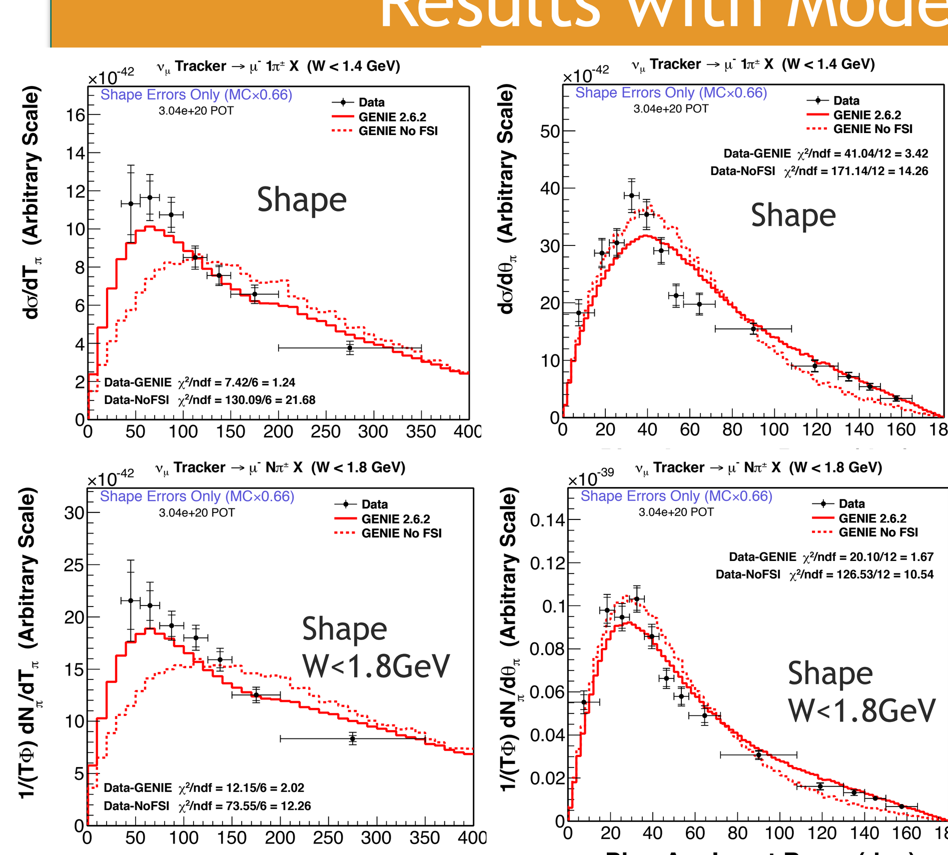


Systematic Errors

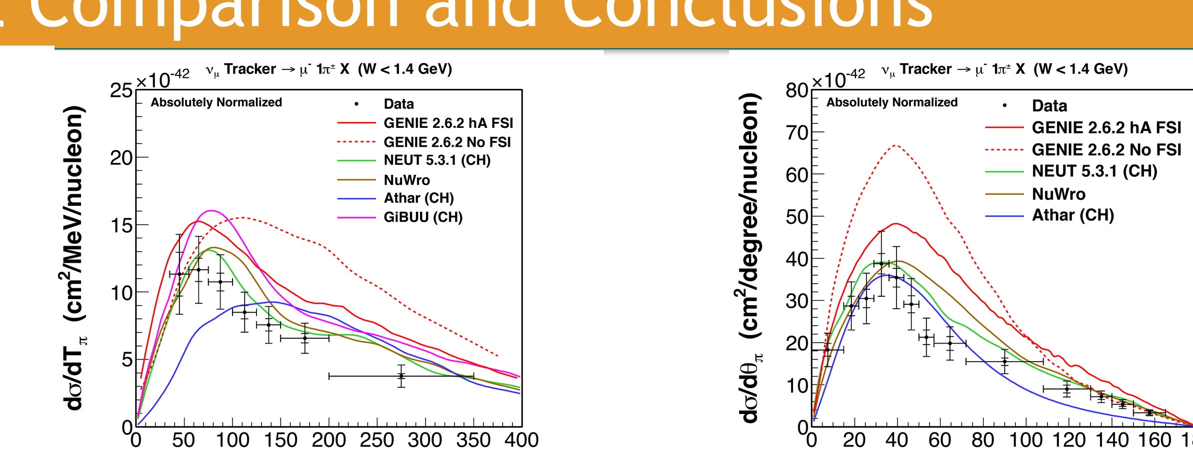
Largest systematic errors are from flux and GENIE cross section model parameters. Shape measurement is statistics limited.



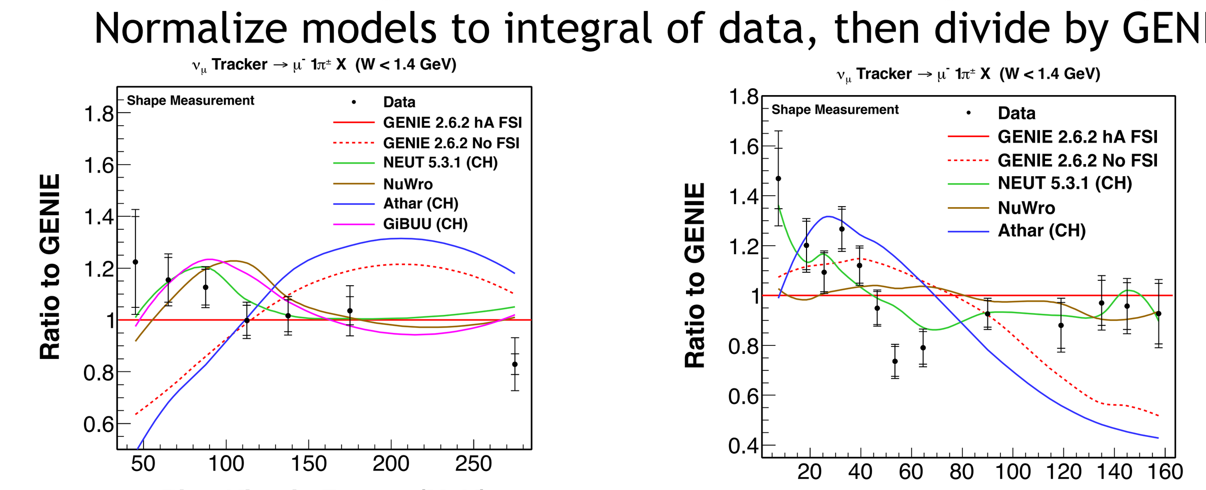
Results with Model Comparison and Conclusions



- Data prefer GENIE with final state interactions- GENIE has difficulty reproducing the shape of the angular distribution
- Allowing for multiple pions in the final state and higher order resonances: W < 1.8 GeV
- Neut and NuWro normalization agree the best with data.



Normalize models to integral of data, then divide by GENIE



NuWro, Neut, GiBUU and GENIE all predict the KE shape well. GENIE seems to do best with the peak. Qualitative feature similar to MinoBooNE Data, strong FSI but shallow dip at the KE of pion interaction should be the strongest.