Delta production, pion absorption in GENIE

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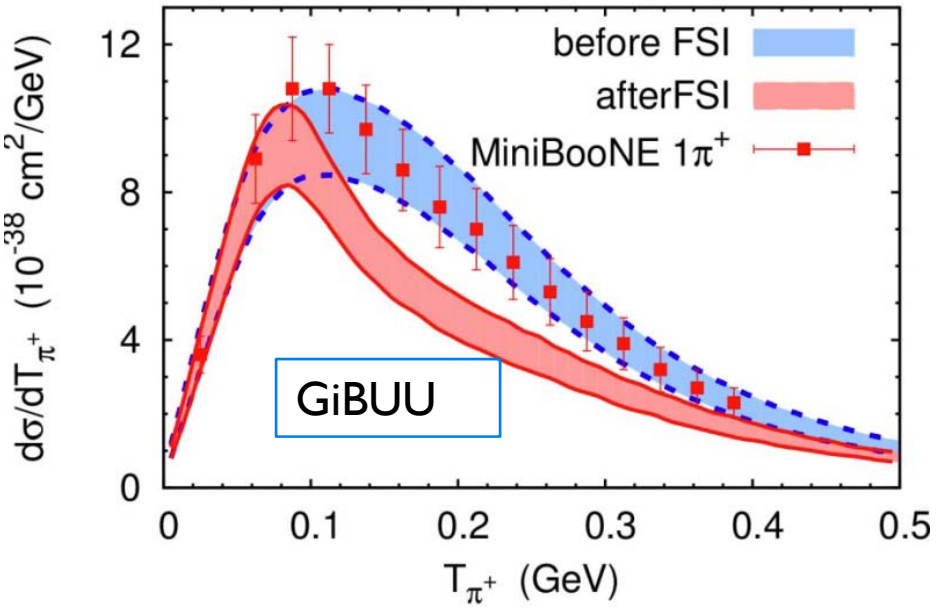
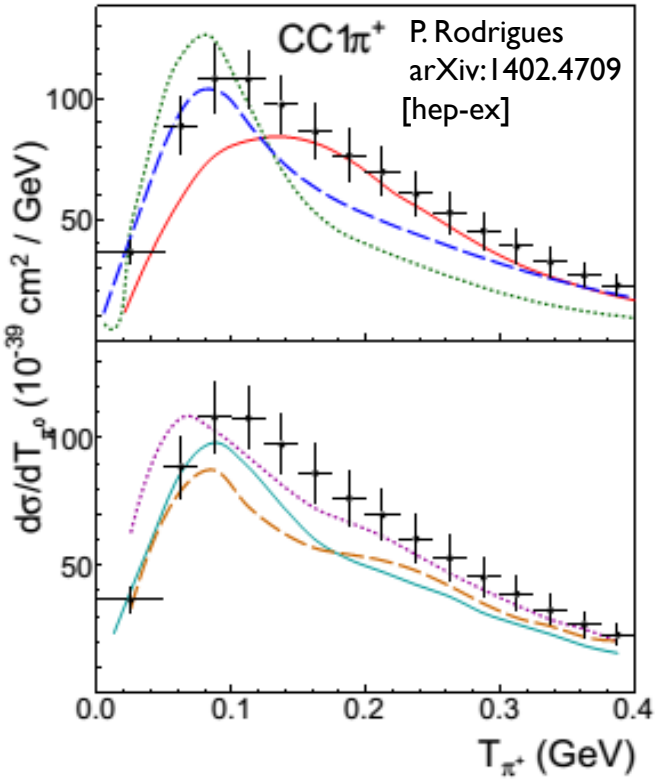
- What Rein-Seghal means to us
- Near term developments
- Some thoughts on MINERvA-MiniBooNE

Data relevant to CCQE-like oscillation signal
(How often does pion disappear in FSI?)

- MiniBooNE data hard to reproduce, questions FSI models?
- Surprising result, needs more data (different detector, E_ν)

Data at E_ν~1 GeV





theory
- Athar *et al.*
- Nieves *et al.*
- GiBUU

ev gen
- NuWro
- GENIE
- NEUT

- MB data

GiBUU: O. Lalakulich and U. Mosel, PRC 87, 014602 (2013)
NuWro: T. Golan, C. Juszczak, J. Sobczyk Phys Rev C80, 15505 (2012)
Nieves: E. Hernanadez, J. Nieves, M. Vicente Vacas, Phys Rev D87, 113009 (2013)

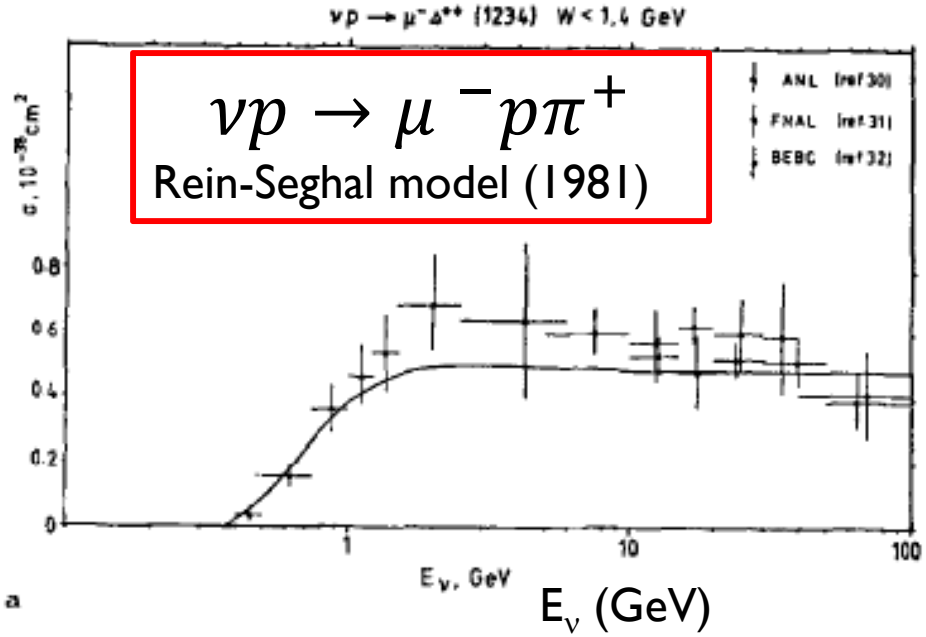
Not all Rein-Seghal models created equal

- Original RS was impressive for its time (1981)
  - Both (e,e') and neutrino production
  - Interfering resonance amplitudes
  - Nonresonant background
  - Helicity formalism
- However, data and theory have advanced since then
  - New s, masses, widths (many authors)
  - Much improved vector couplings (Jlab + MAID)
- What we do in GENIE
  - Use up-to-date ID, masses, widths
  - Throw away interference
  - Use RS vector couplings
  - Use nonresonant background from Bodek-Yang scaled down
  - Lalit would recognize it, but wouldn't call it RS except the formalism

Pion production from proton largest signal

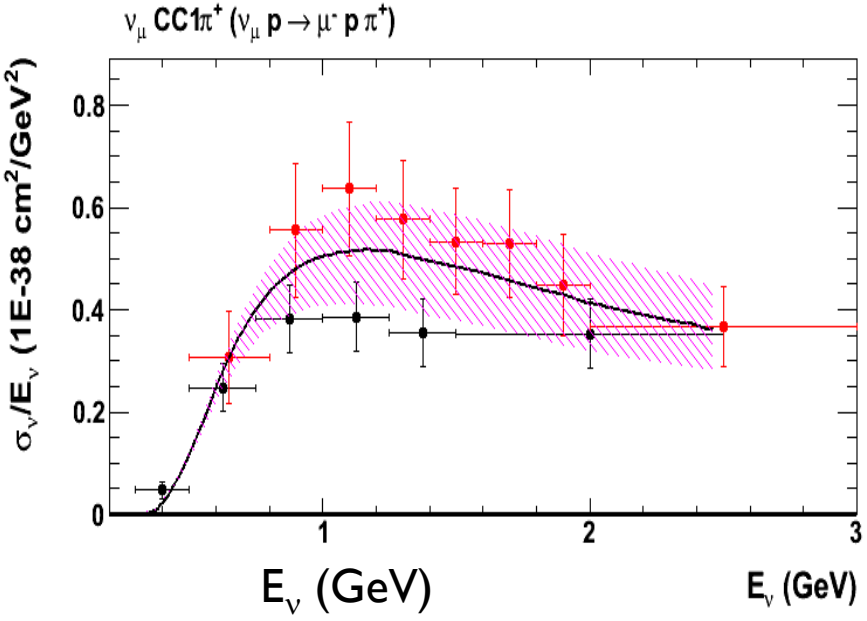
- N.B. Only ANL data available to RS
- Scales are different, GENIE is σ/E linear
- GENIE is about 25% larger at E_ν=1 GeV
- Nonresonant contribution is different

- Fully charged final state
- Couples strongly to Δ^{++}.



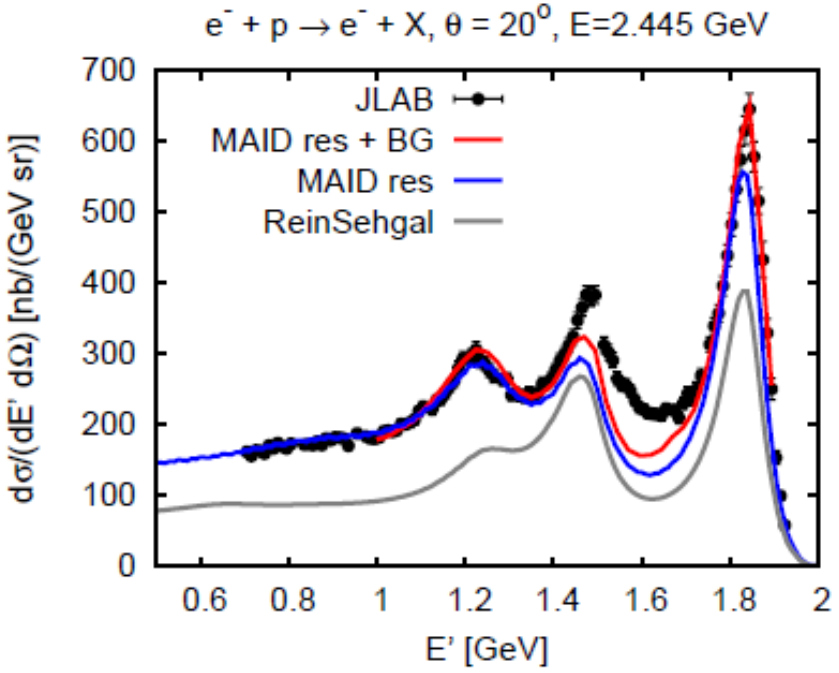
$$\nu p \rightarrow \mu^- p \pi^+$$

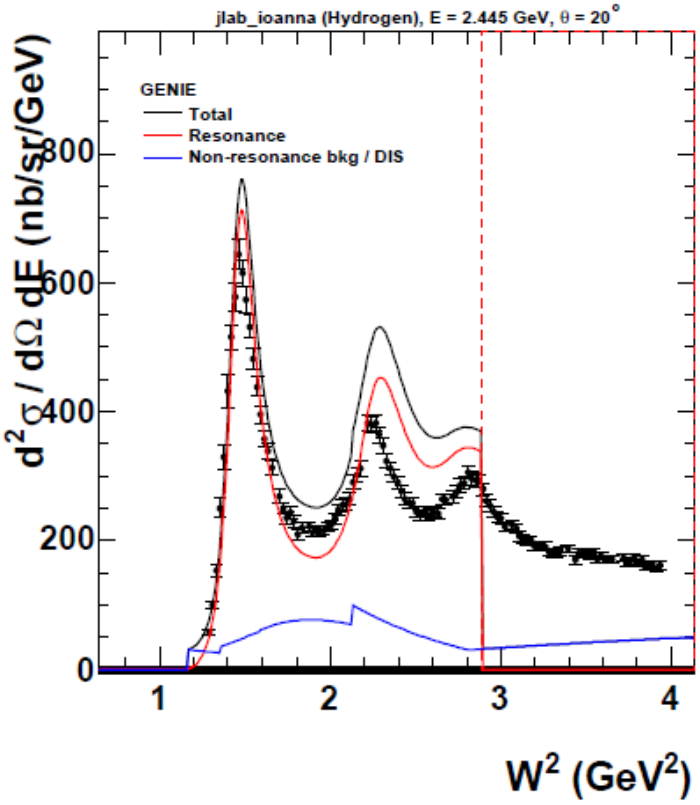
Rein-Seghal model (1981)



GiBUU comparisons vs. GENIE (ep→e'X)

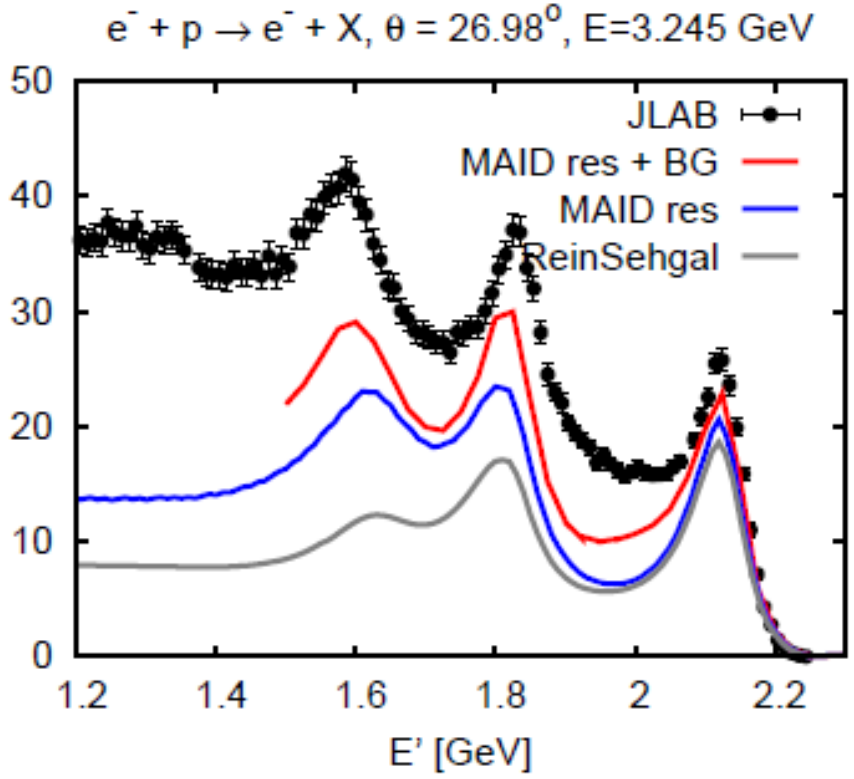
- GiBUU from Tina Leitner, NUINT08
- GENIE calculated with standard validation package
- N.B. horizontal scales reversed, rescaled ($\nu \leftrightarrow s=W^2$)

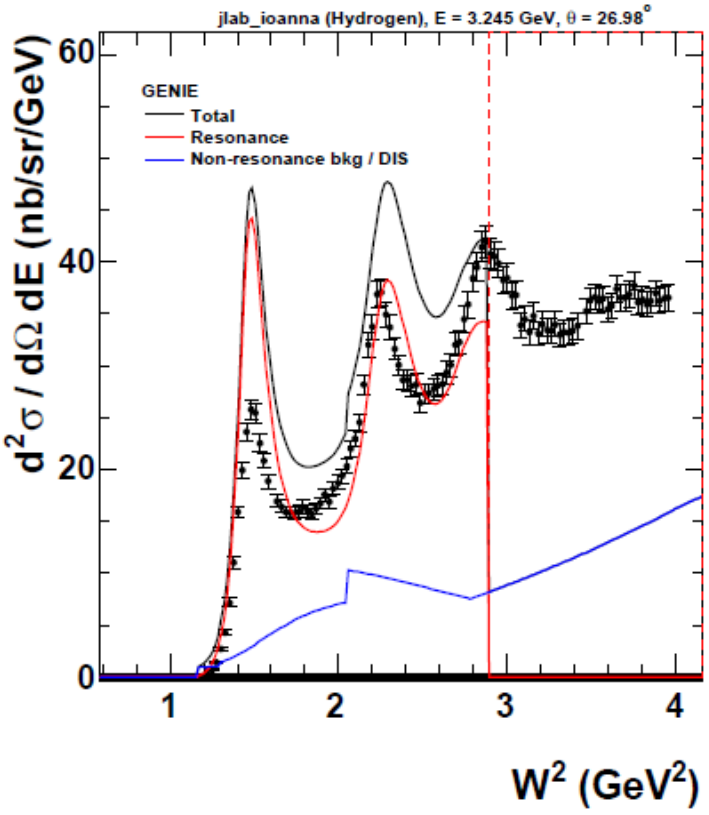




Another comparison

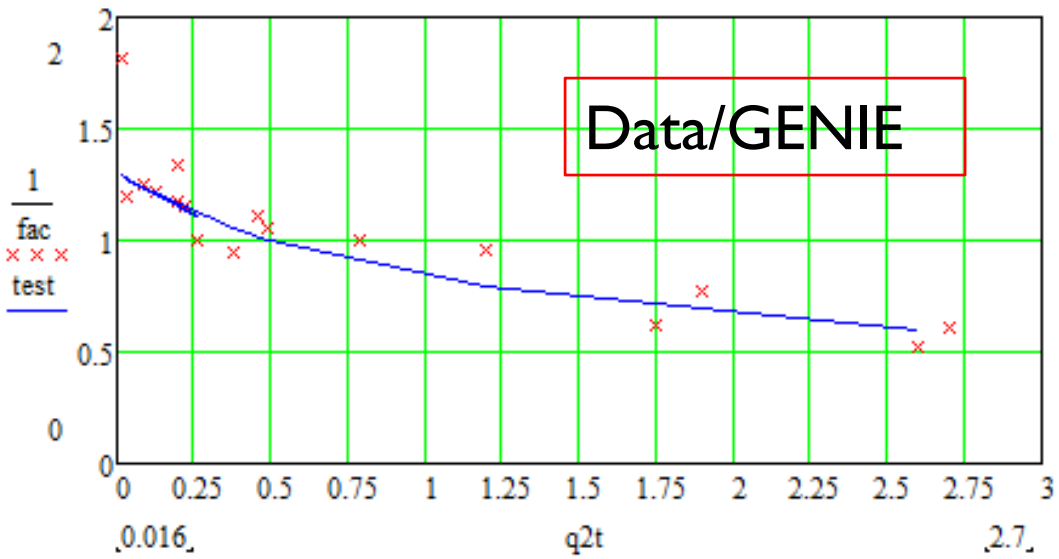
- GENIE not well matched to (e,e') at high Q2.
- Nonresonant bkgd (blue) has some odd discontinuities

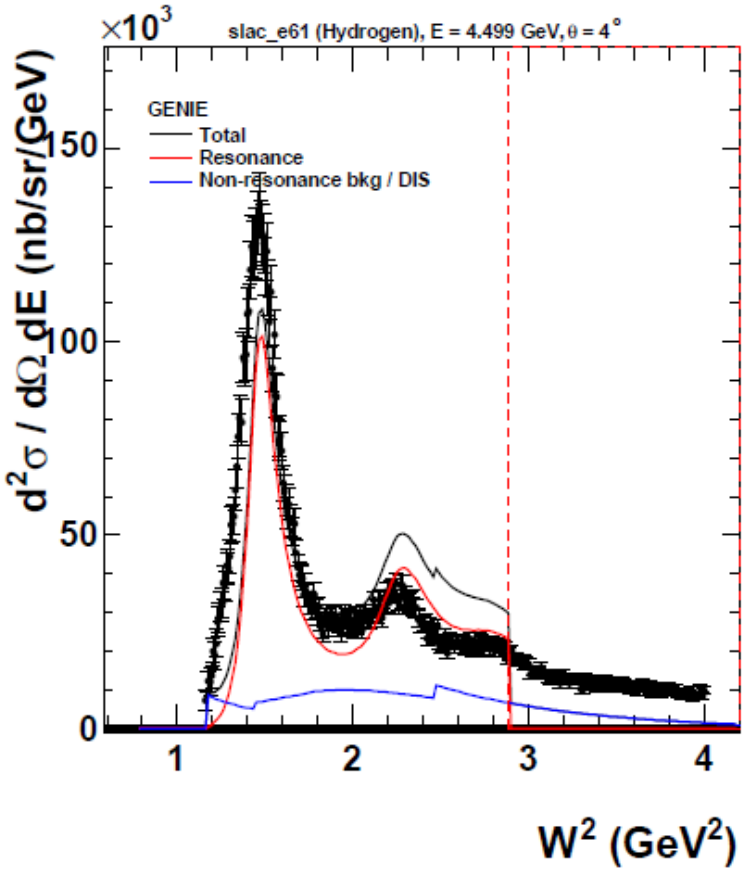




General overview of vector couplings (v2.8.0)

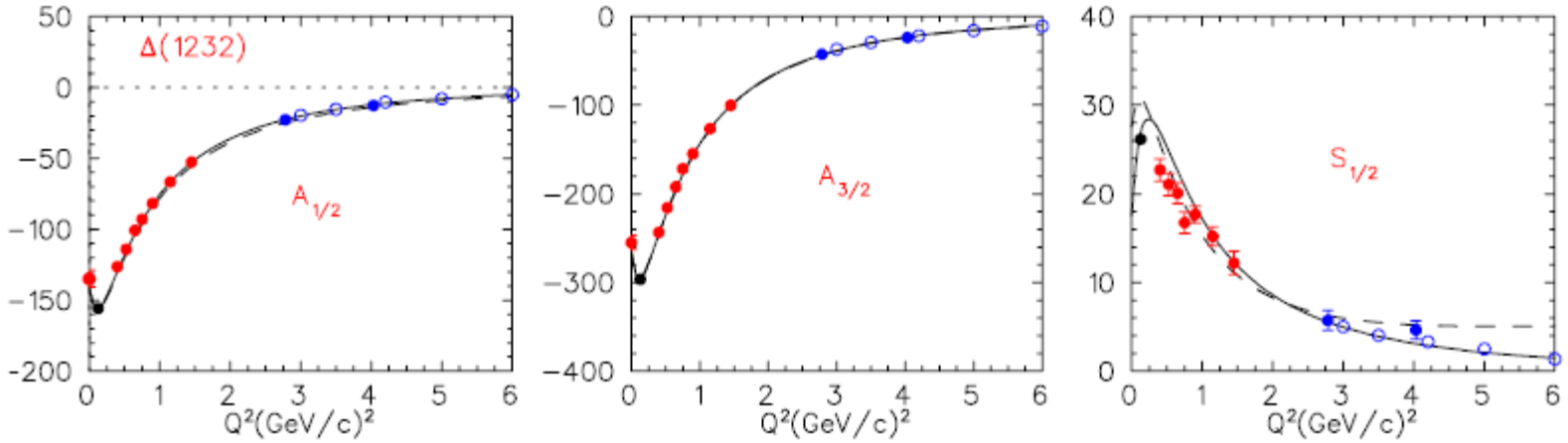
- Plot at right is for Q^2=.09 GeV^2, take ratio Data:GENIE.
- Vector form factor (left) is wrong, very Q^2 dependent.





Switch to MAID – (e,e'π)
Alvarez-Ruso, Dytman

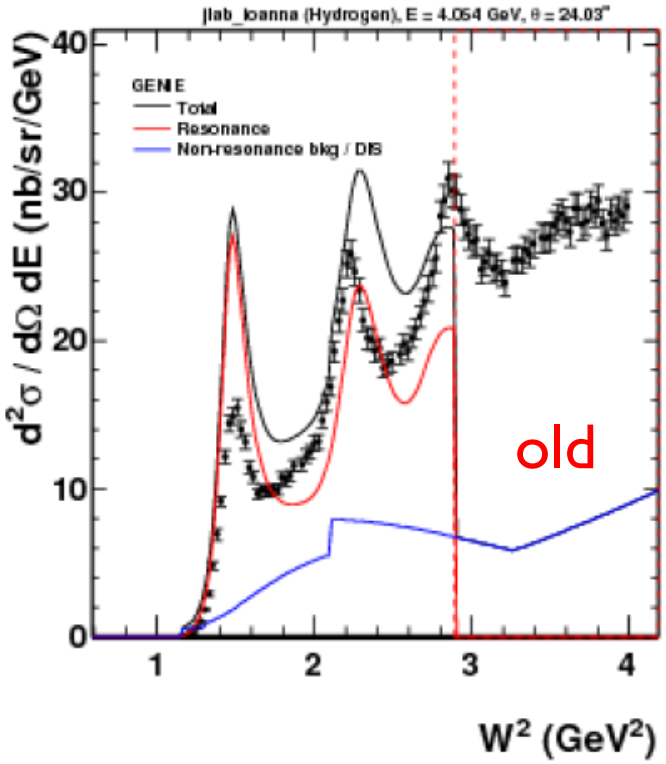
- Fit multipoles (good total spin, parity, helicity) to data
- Fit nonres/resonant model to multipoles to get helicity amplitudes (below).
- There is model dependence, but considered small.
- RS give formulas to relate these values to what is needed for neutrino resonance production.

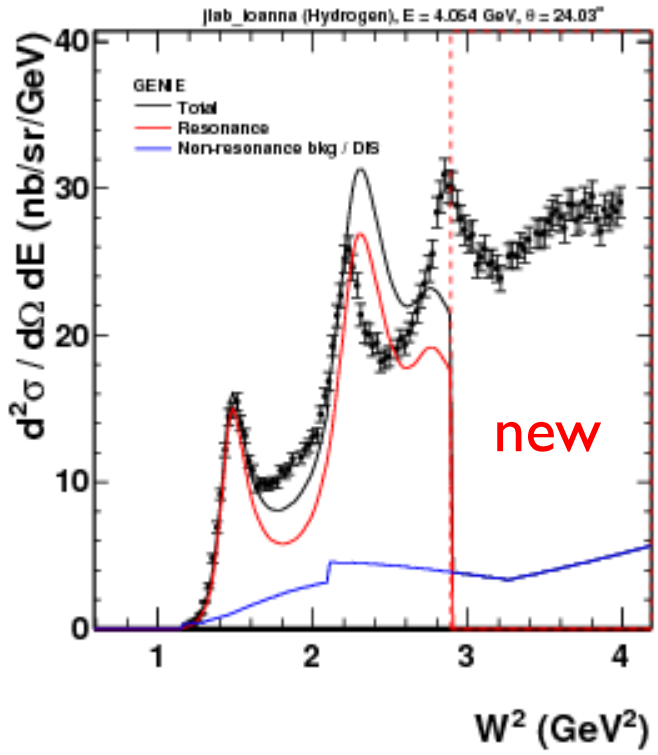


results

- Much better agreement at high Q2.

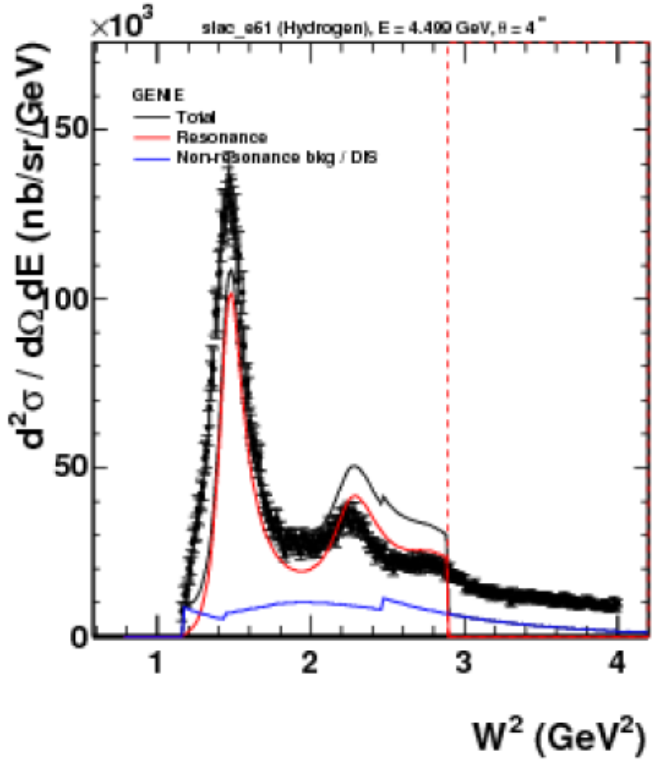
Q^2=2.5 GeV^2

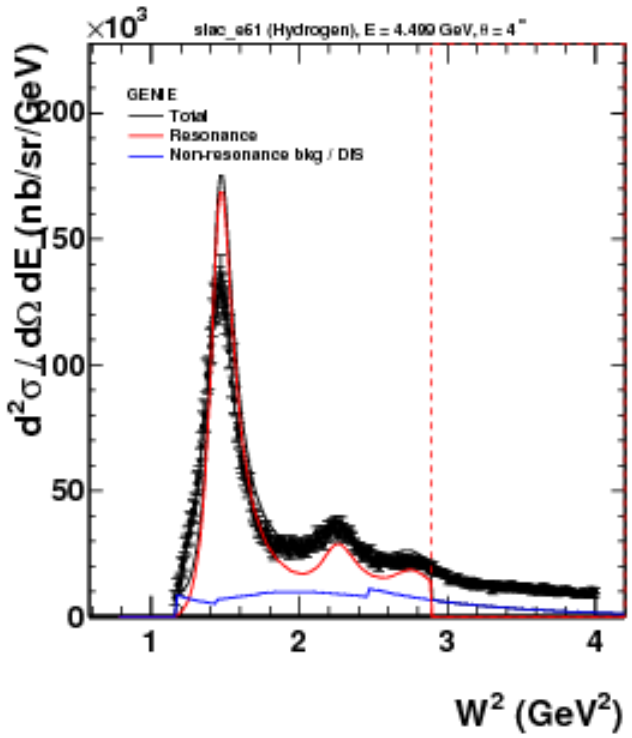




More results

- Problem at low Q^2 for Delta
- Still sorting this out, unable to reproduce results from MAID web site.

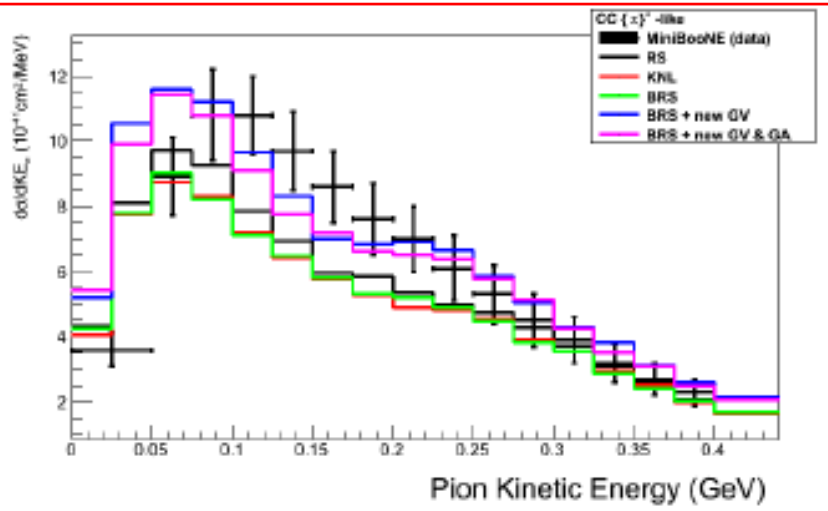




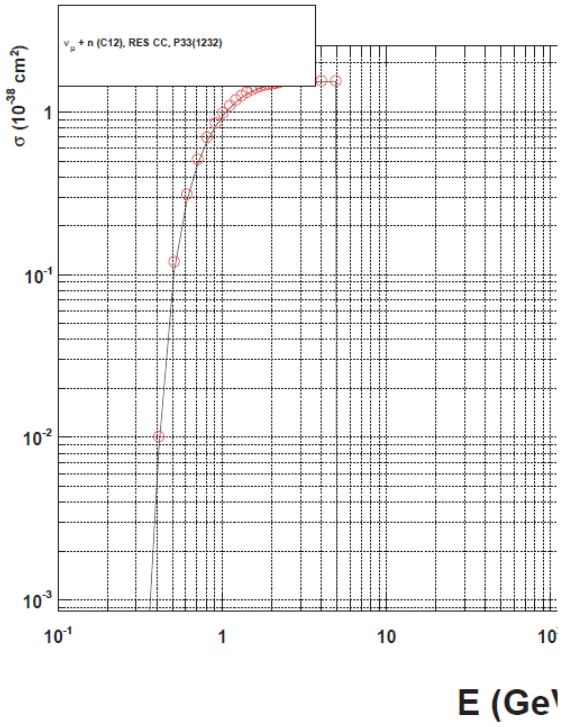
Import muon mass correction
Jarek Novak (Lancaster)

- Use model from Kuzmin... or Berger & Seghal (preferred)
- Jarek provided code a year ago, I use it but not in release
- Important near pion threshold
- Plots from Jarek made with GENIE
- Axial form factors matter!

Various implementations vs. MiniBooNE data

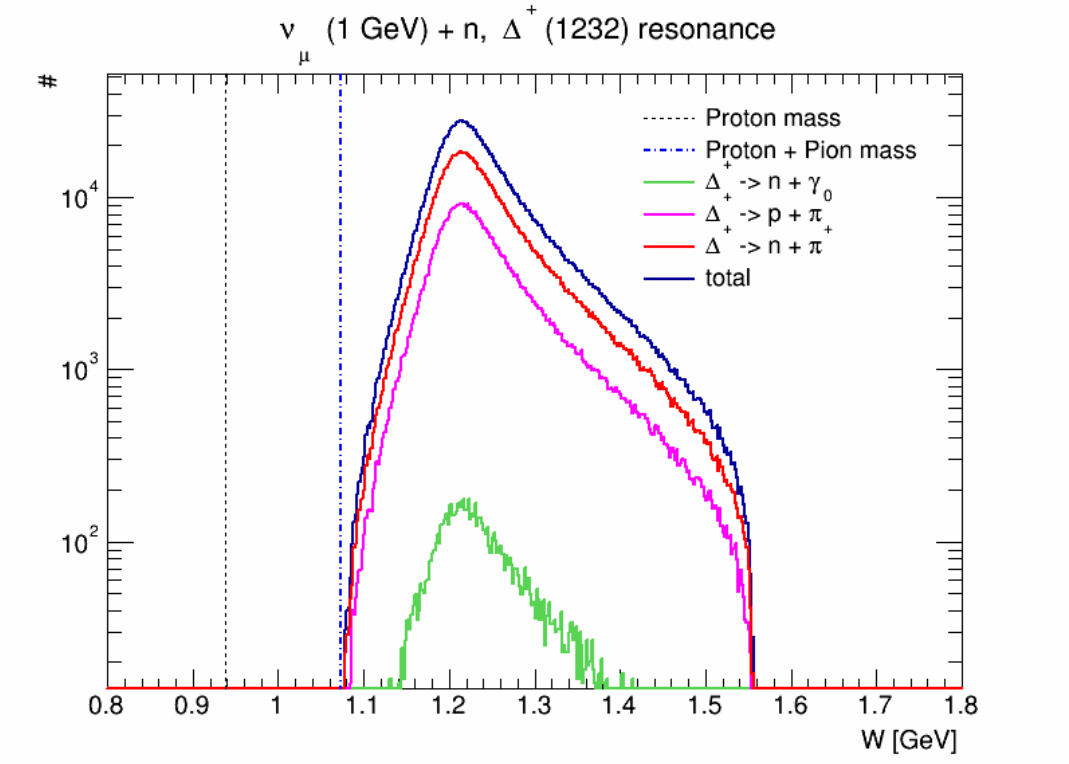


GENIE 2.8.0 vs. GENIE (BS)



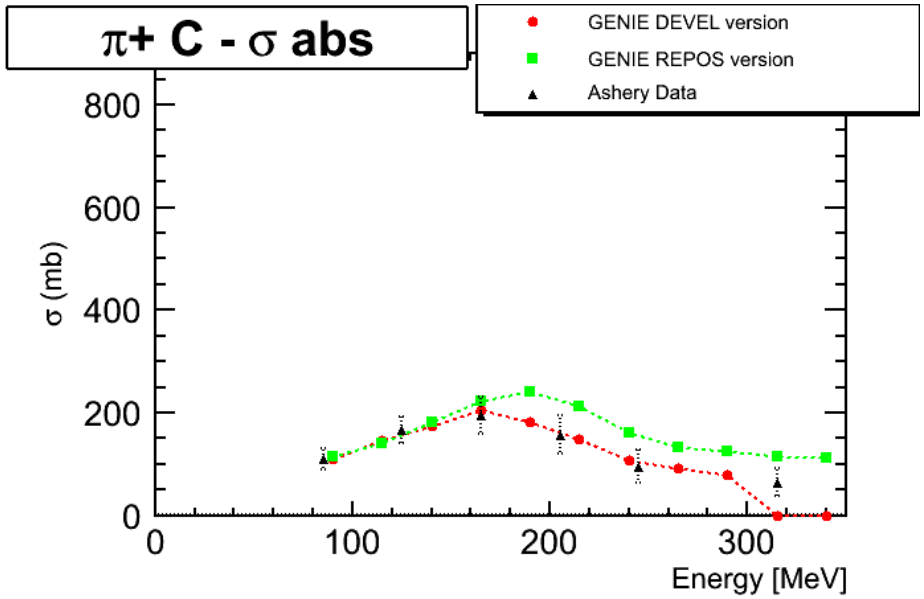
$\Delta \rightarrow N\gamma$
Anne Schukraft (FNAL)

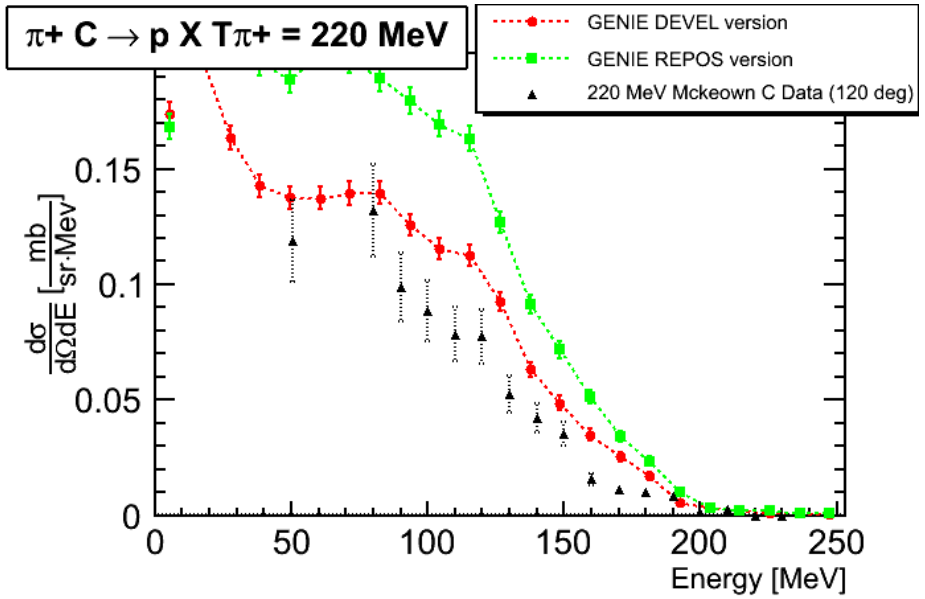
- Only 1.6% of decays, but important for MiniBooNE
- Sam Zeller wants to import their model to GENIE
- So far, investigating what is in GENIE (πN threshold)



Improvements to FSI

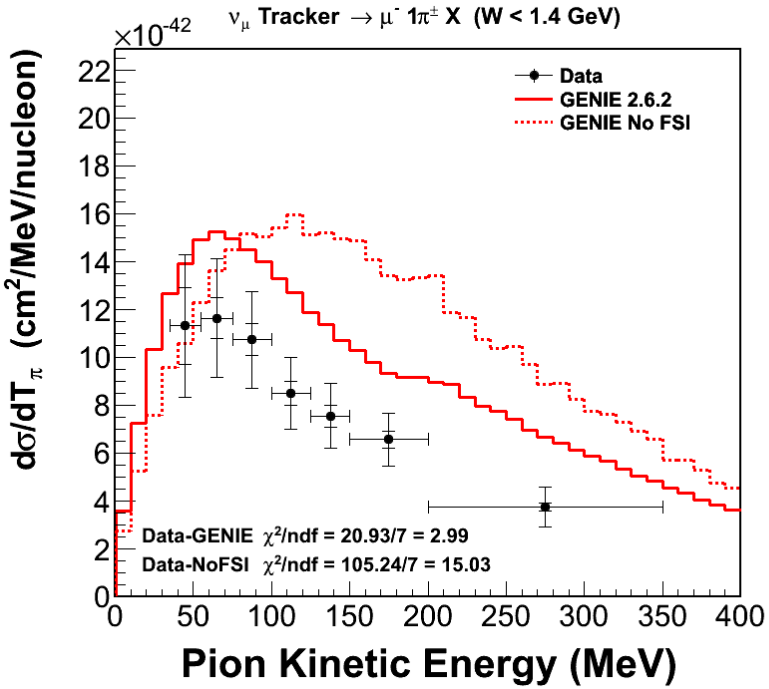
- Pion FSI (v2.8.0) linked to Fe (MINOS-centric), not ideal for CH (MINERvA) or CH_2 (MiniBooNE)
- Update will use data at all A, fill in with calculations (Mashnik) where data doesn't exist.
- In v3.0.0, will have direct impact on MB and MINERvA π^+ data.

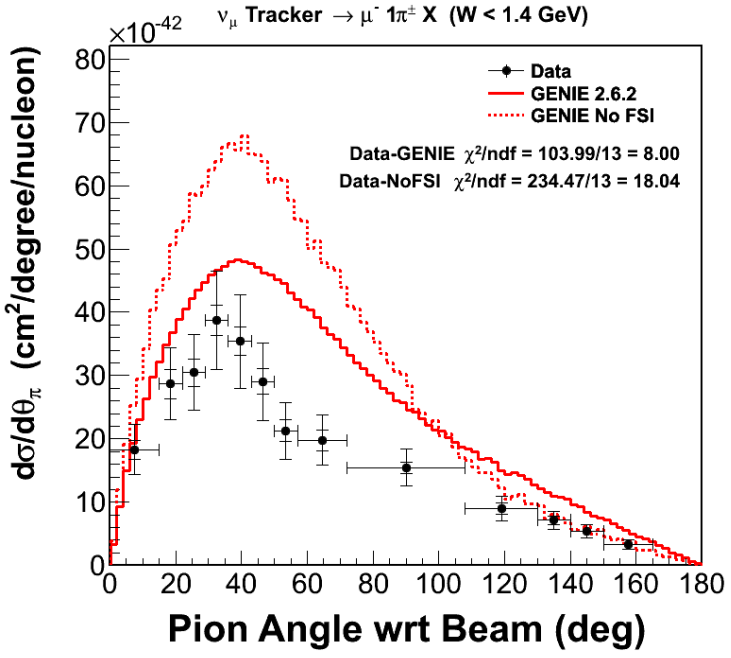




Thoughts on MINERvA vs. MiniBooNE

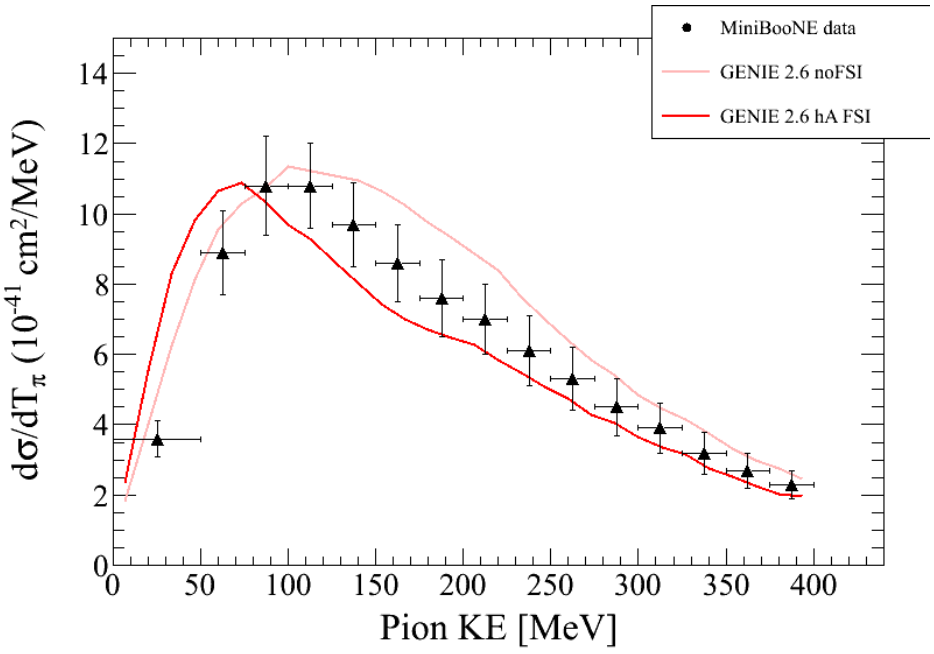
- Effects due to FSI are large improvement in both KE and angle
- FSI Effects more clear in KE
- Angle should be sensitive to e.g. $\Delta \rightarrow \pi$ decay angle, dynamics

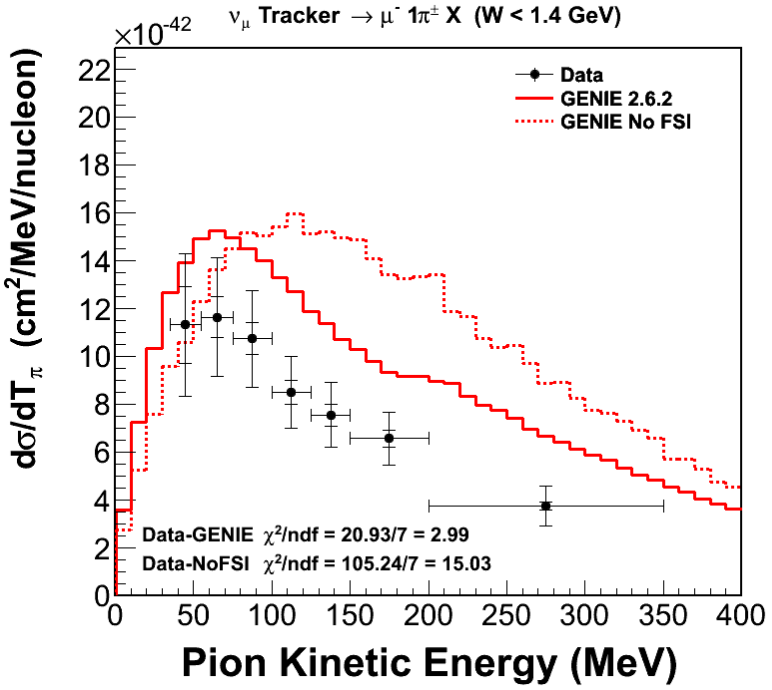




Thoughts on MINERvA vs. MiniBooNE

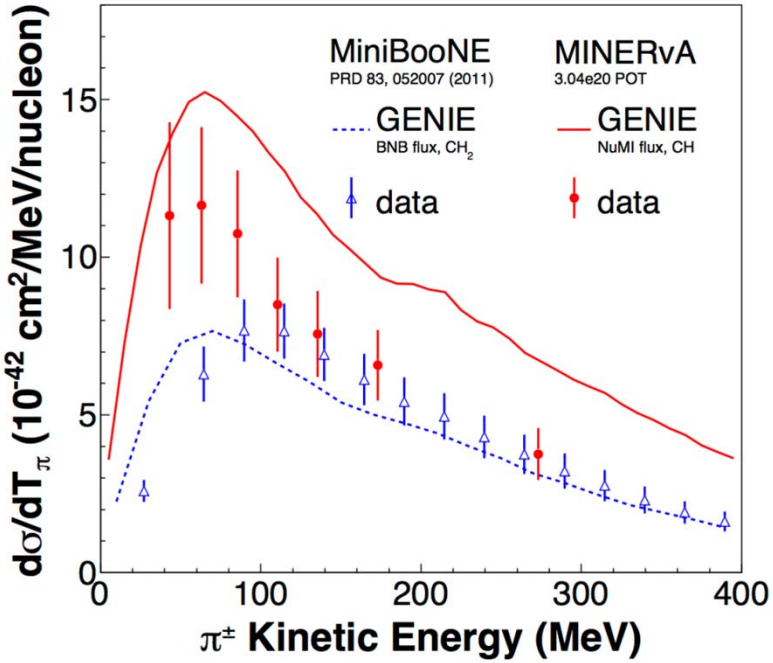
- GENIE FSI-noFSI comparison similar for each, but...
- Shape somewhat wrong for each
- normalization issue different!





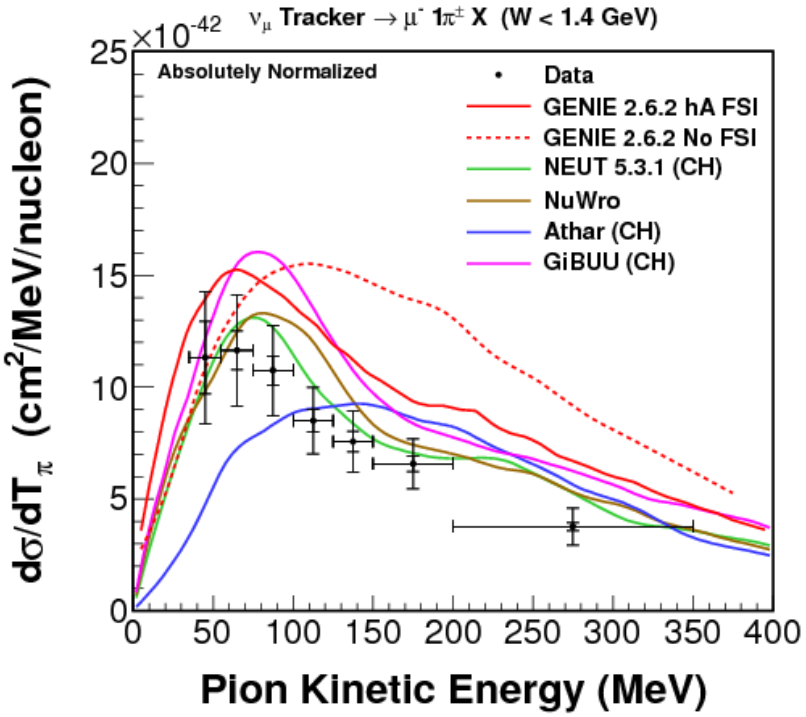
Thoughts on MINERvA vs. MiniBooNE

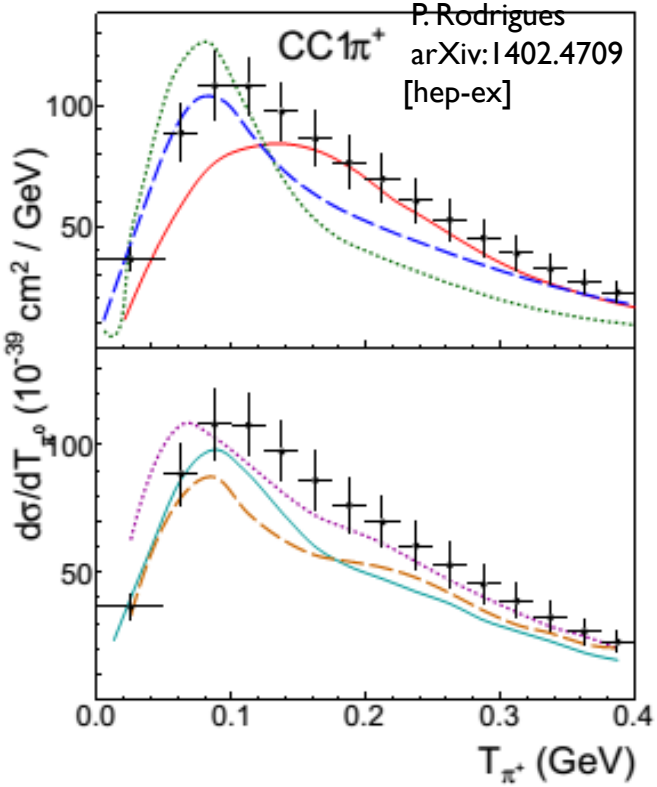
- Shapes very similar, no significant dip in either!
- Small difference in slope (Kinematics, FF, nonres differences).
- Biggest difference is at low energy.



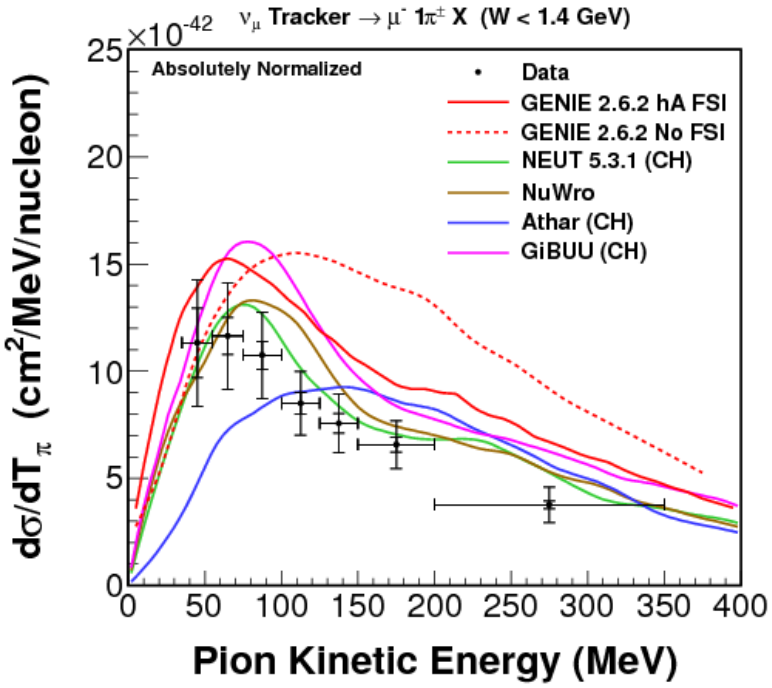
Thoughts on MINERvA vs. MiniBooNE

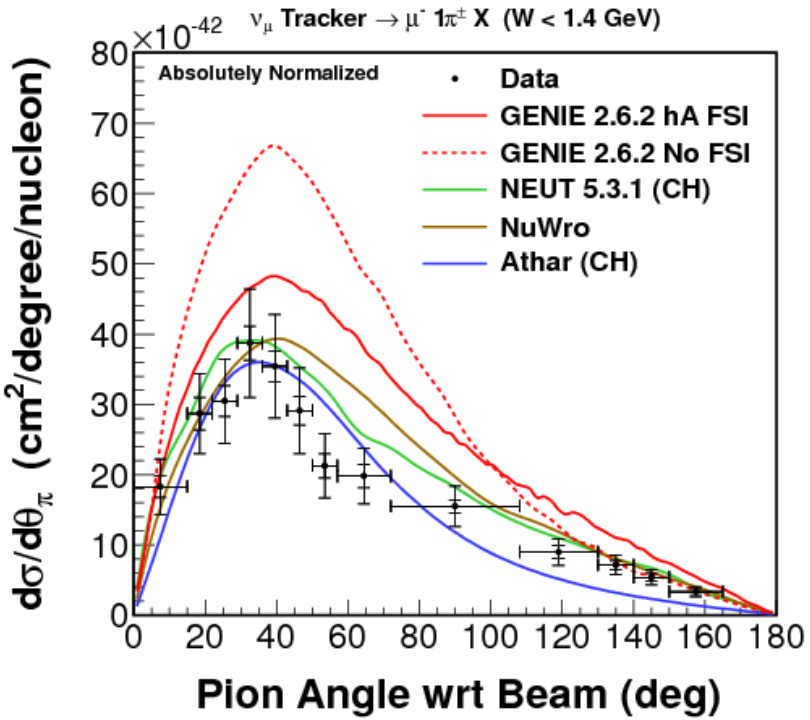
- Note disagreement in colors
- Checked with authors, models are same for both
- No big winners, energy dependence not simple.





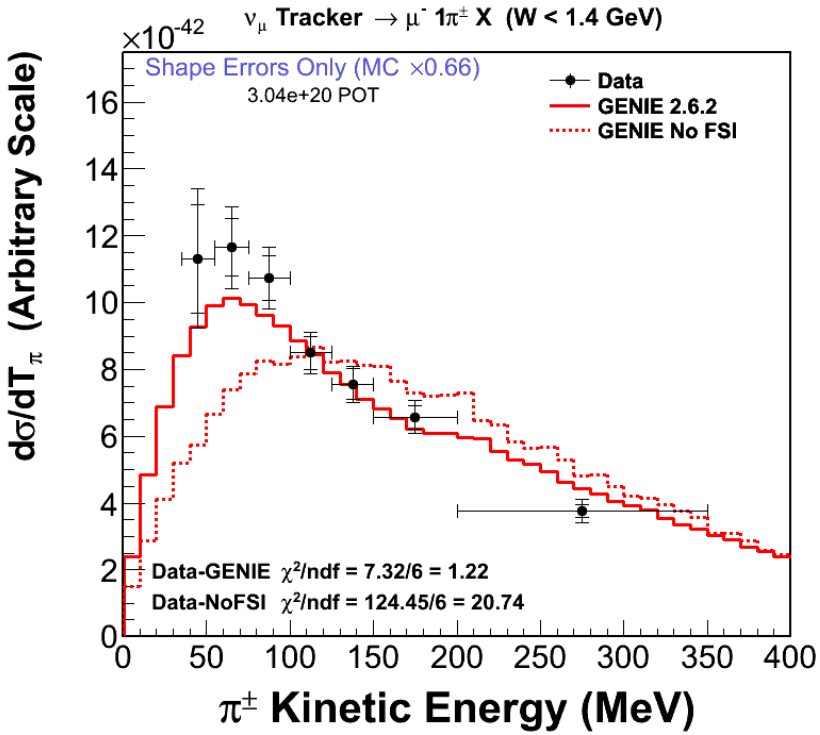
Absolute cross section- model comparisons

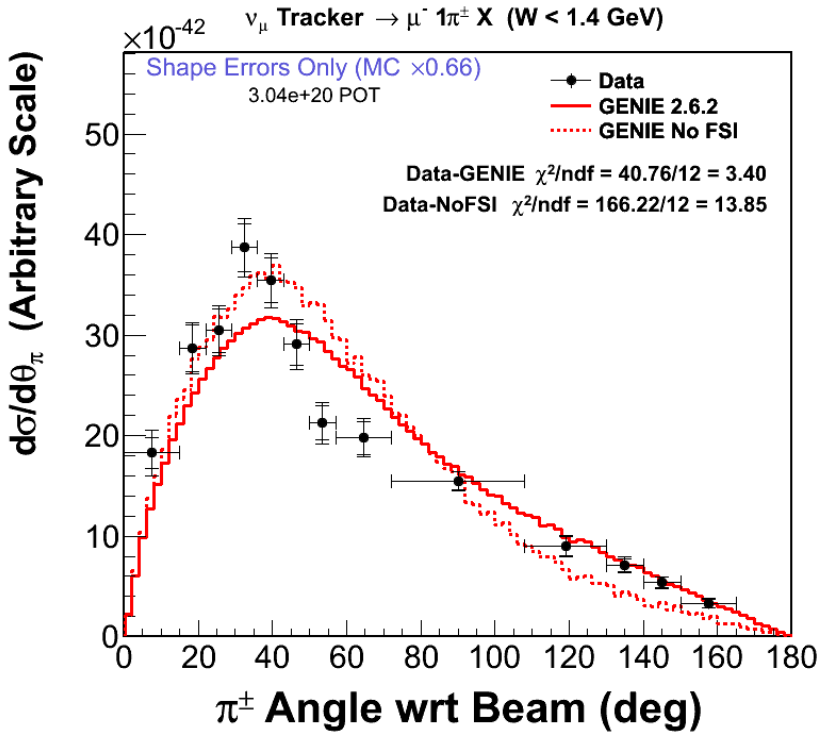




- NEUT and NuWro normalization agree the best with data.
- GiBUU, GENIE normalizations disfavored by a couple σ

Shape results (W<1.4 GeV)

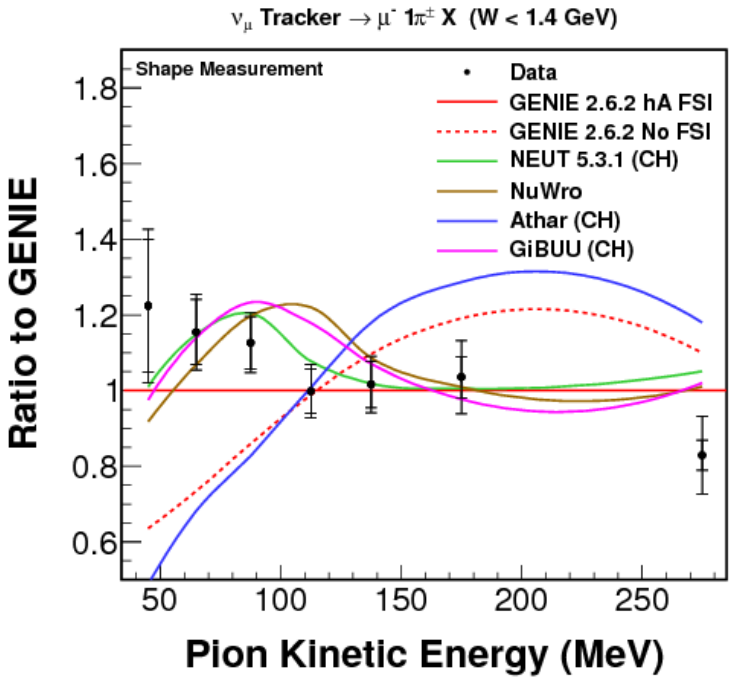


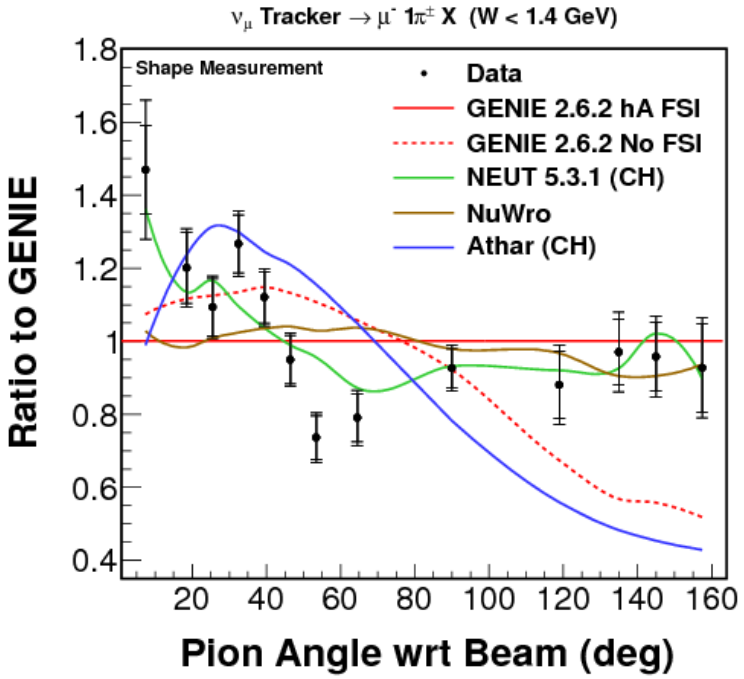


- MC is normalized to match the integral of the data
- GENIE with FSI strongly favored, shows importance of FSI

Shape results – model comparisons

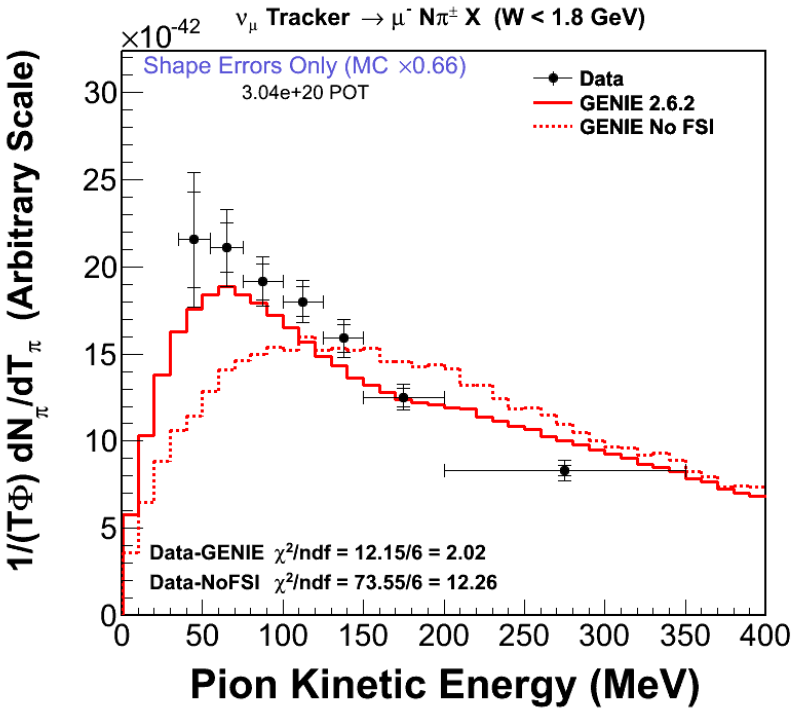
- Each calc normalized to data, show ratio to GENIE w/FSI

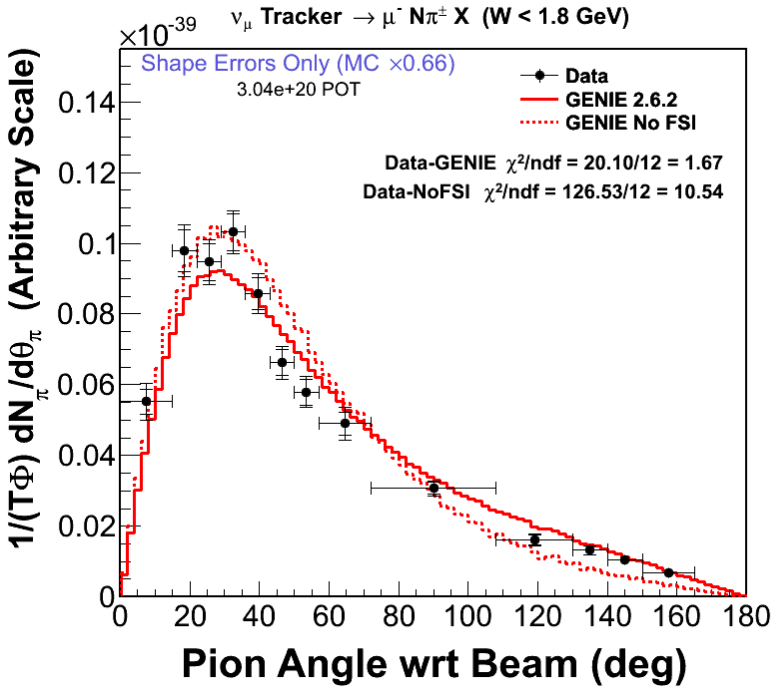




- GiBUU, NuWro, NEUT and GENIE all predict the data shape well
- Data insensitive to the differences in pion interaction model
- Athar does not agree with data. Likely due to an insufficient FSI model

Shape results (W<1.8 GeV)

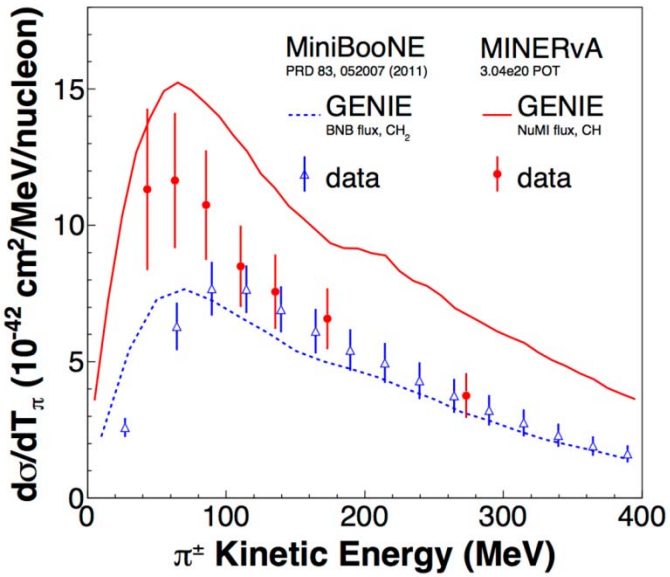




- Another version of the analysis, allowing for multiple pions in the final state and higher order resonances
- Consistency with W < 1.4 provides some reassurance that the analysis is robust against choice of W cut (feed-down), details of Δ.

discussion

- Tension with models is shifted
- MiniBooNE - E_ν~1 GeV
  - Best models (GiBUU, Valencia) strongly disagree in shape
  - Event generators have shape right, but problems in detail
- MINERvA - $<E_\nu>$=4 GeV
  - Dominantly Δ resonance formation, decay in nucleus, very similar to MiniBooNE)
  - Event generators have shape, magnitude
  - GiBUU has shape right, but wrong magnitude
- Physics differences between data sets
  - Different kinematics (shift to higher T_π for Minerva)
  - Different Q2 selection – different dependence on form factors.
  - Different contribution of nonres diagrams



Conclusions

- Rein-Seghal resonant model can be interpreted in many ways
  - GENIE uses updated mass, width, decay branches; ignores interference; substitutes nonres from Bodek-Yang.
  - Good agreement with ν_μ 1π and 2π production data.
- Various improvements underway.
  - Use vector N$\rightarrow$N* couplings from MAID (L A-R)
  - Add nonres to get agreement with (e,e') data
  - Then, adjust M_{Ares} and axial nonres to get agreement with ν_μ data.
  - Add medium corrections to width according to Zhang and Serot
- New MINERvA data very interesting
  - Similar shape to MiniBooNE data, but there are differences.
  - No model agrees with both data sets.
  - No strong Ev affects expected, but Q2 and nonres different.