Resonance Experiments
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Introduction
MiniBooNE, new Minerva data
resonances in GENIE (continued from Luis talk Fri)

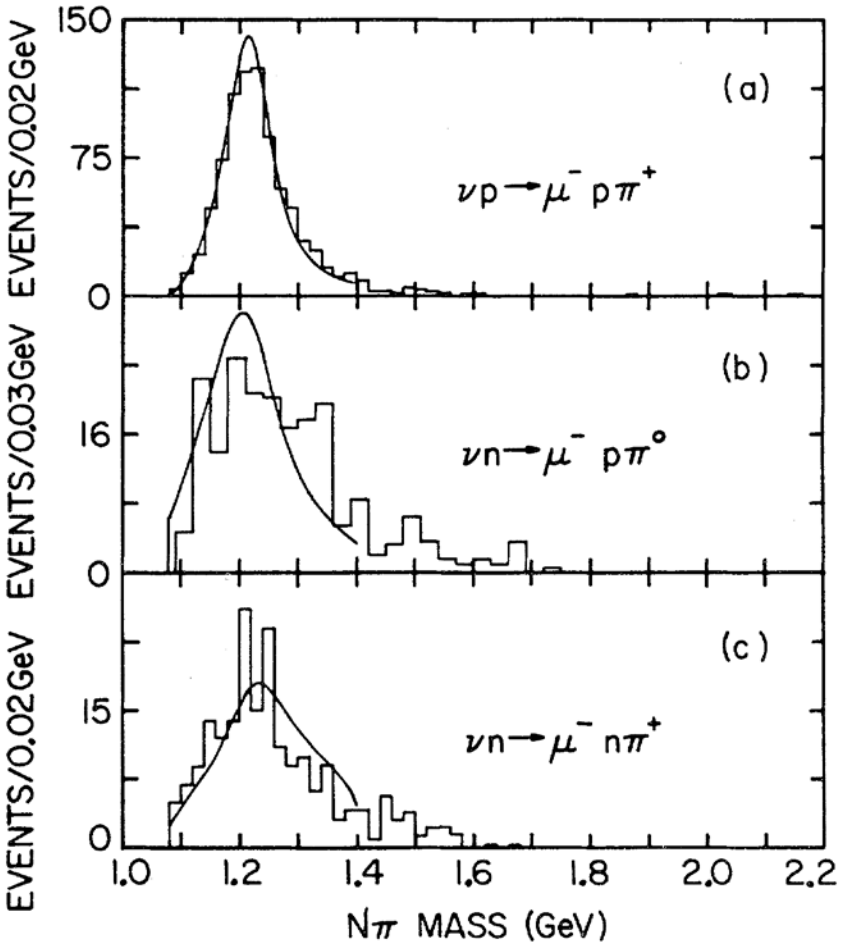
Cascade, GENIE FSI

Role of Resonances

- Background to QE
  - Confuses QE signal as μ kinematics overlap
  - In nuclei, π absorption makes noπ topology problem
- Primary signal in LBNE
  - Need tracking/calorimetry with pions to reconstruct Eν.

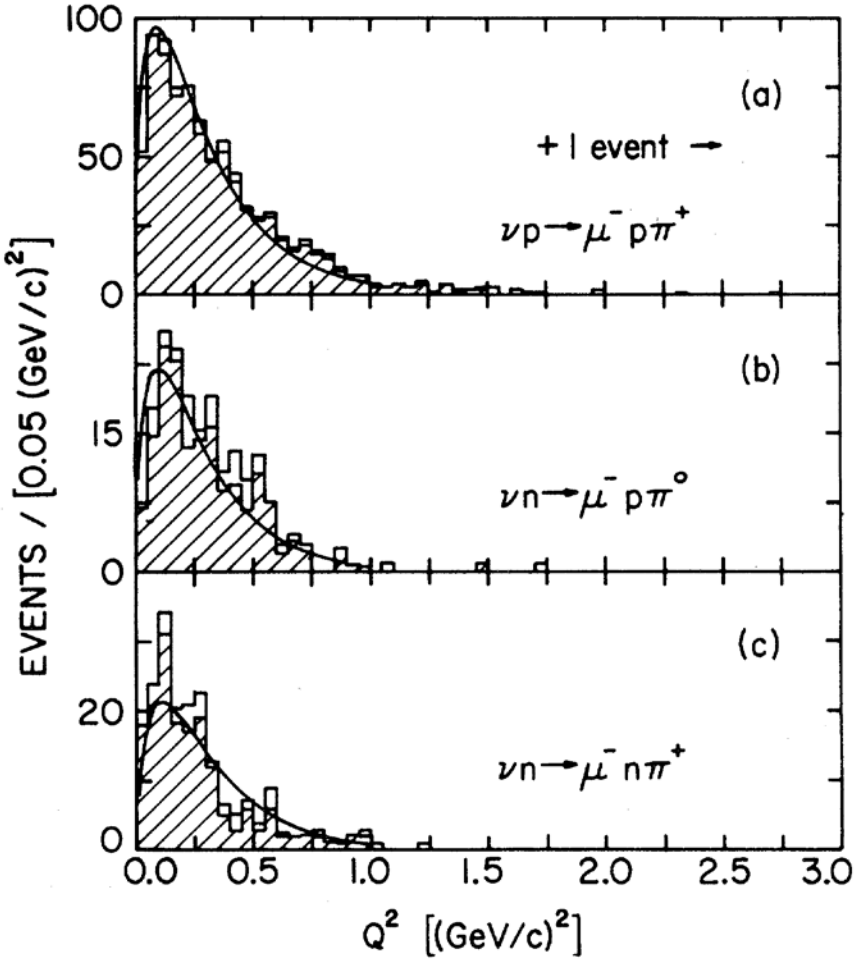
Resonances from Deuterium bubble chbr data from ANL (Eν~few GeV)

- Here are 3 of the major channels. Top figure shows Δ dominance through π^+ (T=3/2).
- Other channels have more T=1/2, couple less to Δ and more to other resonances.
- If you detect π^+ with ν_μ beam, you get mostly Δ (golden chan).



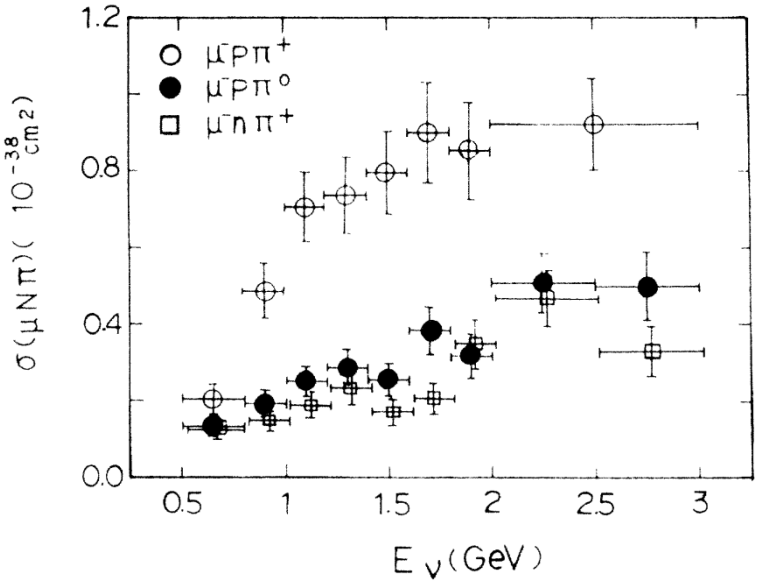
results

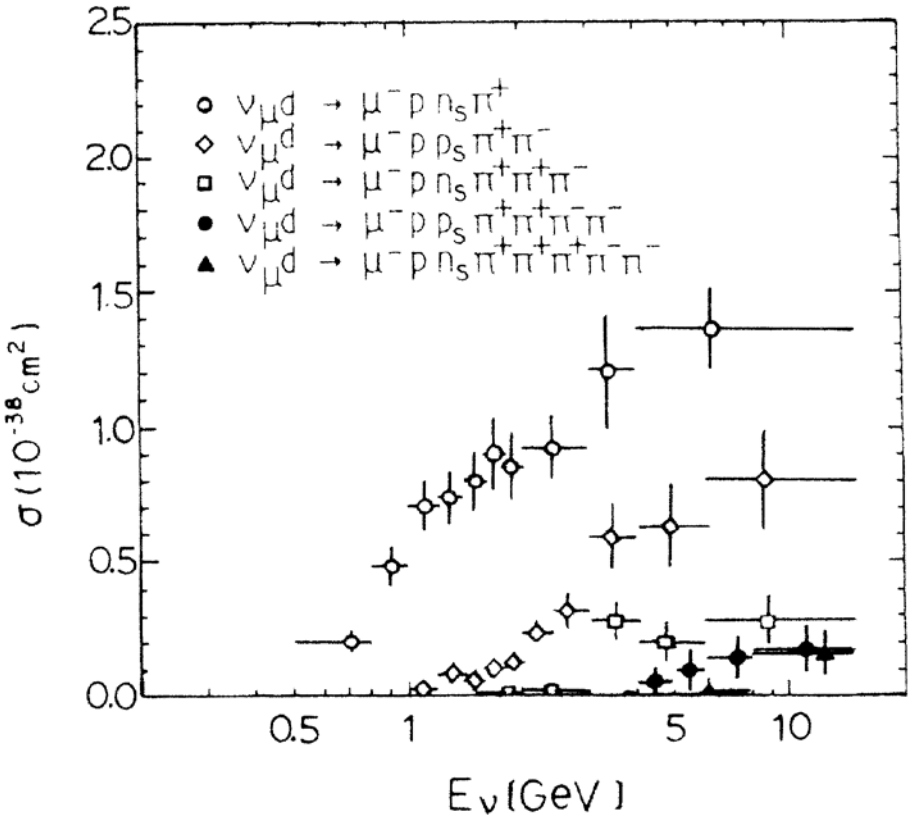
- Form factors (MA)
- Isospin decomposition
- Rough density matrix extraction
- (e,e') data far more copious
- Luis showed extraction of photon couplings to many resonances (requires millions of events).



Total xs – Evidence for 2pi (BNL)

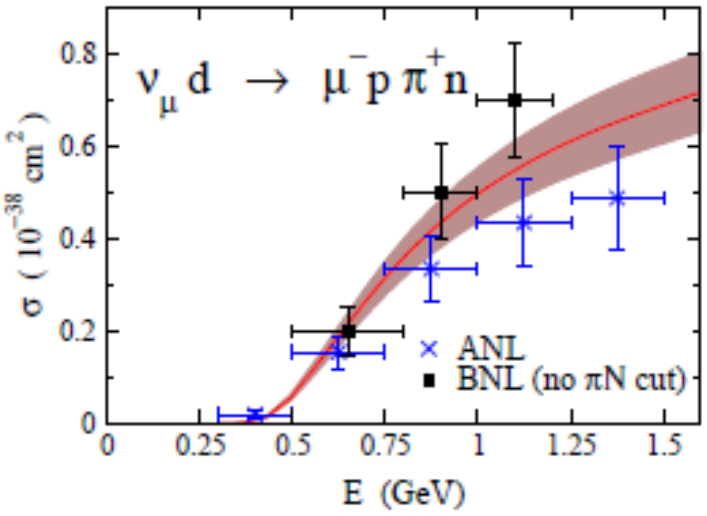
- s

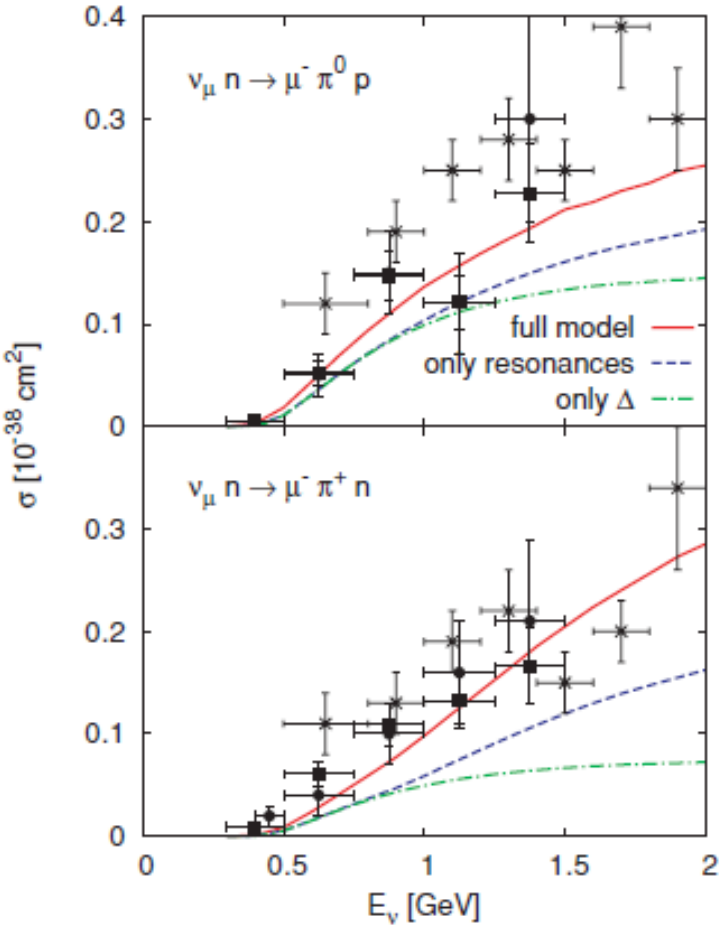




And of course controversy

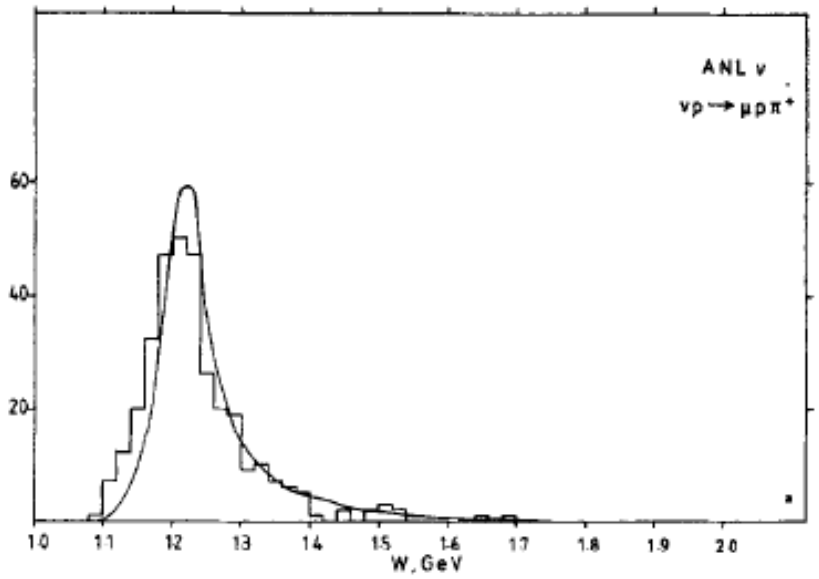
- BNL systematically higher than ANL at low energies.

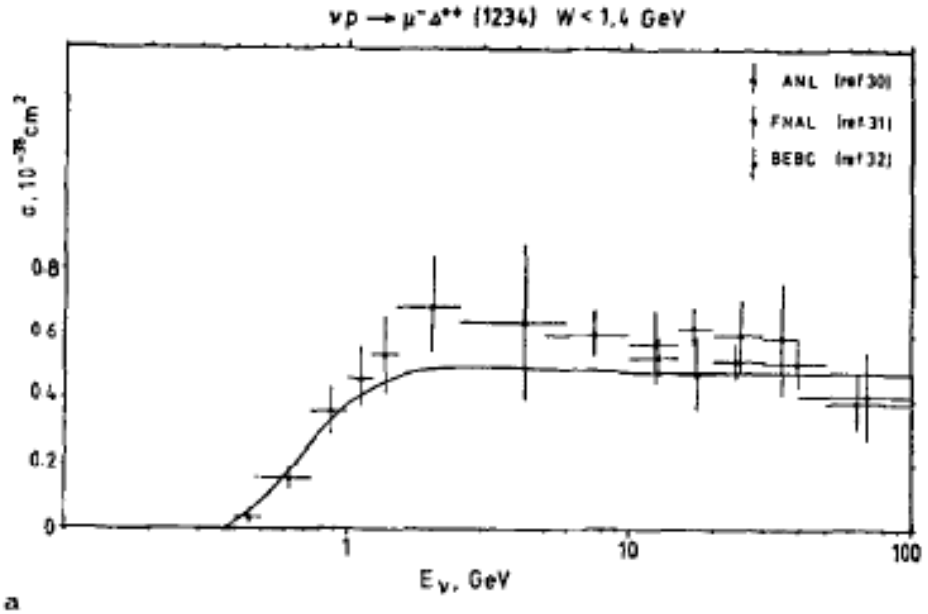




And the famous Rein-Seghal model

- Fit data available in 1981 (including ANL)
- Underlying quark model, very few free parameters.
- 'simple' formulas for ν, νbar, and electron with p and n targets.
- For W spectrum, caption says calc area normalized to data





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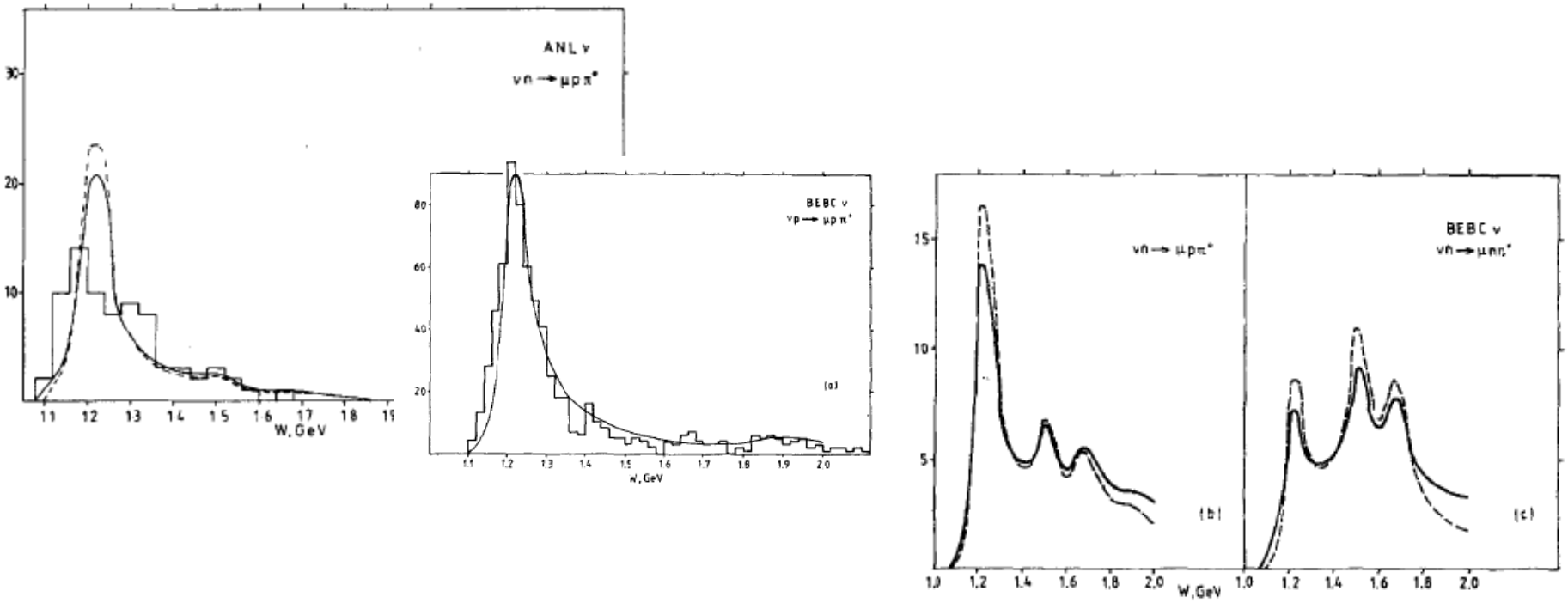
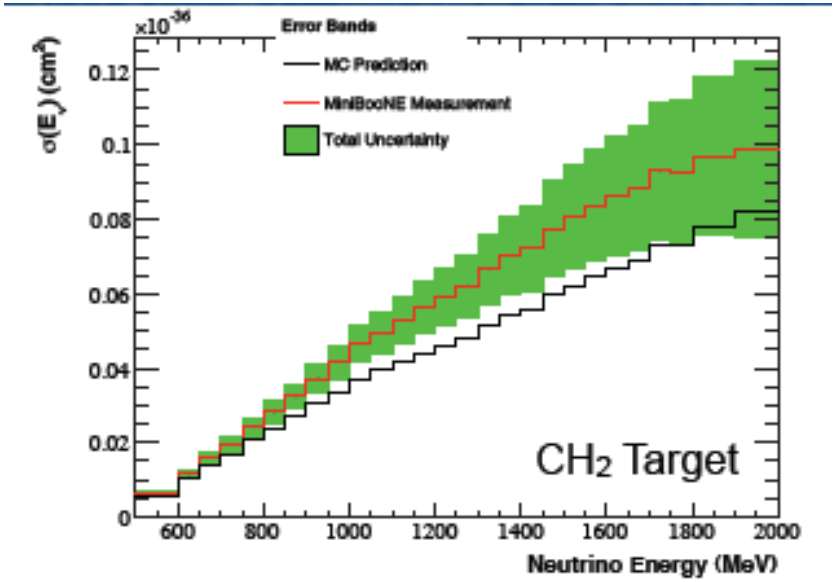
More RS plots

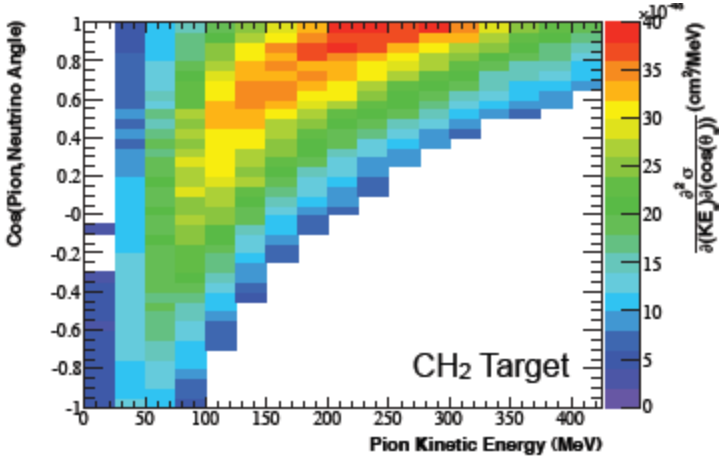
- BEBC at higher energy->more resonances
- Compares dashed (res only) with full (solid line).
- Hmm, are these all area normalized?

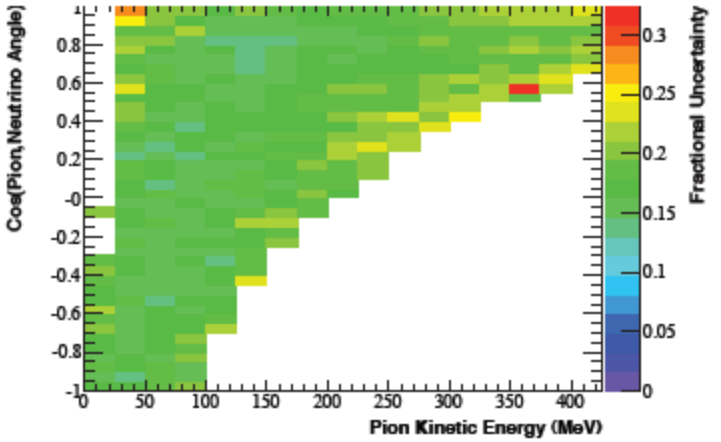


Wilking data from MiniBooNE
first detailed ν data

- En~1 GeV (Δ dominates)
- Total xs
- Double differential xs in pion KE, cos(θ)

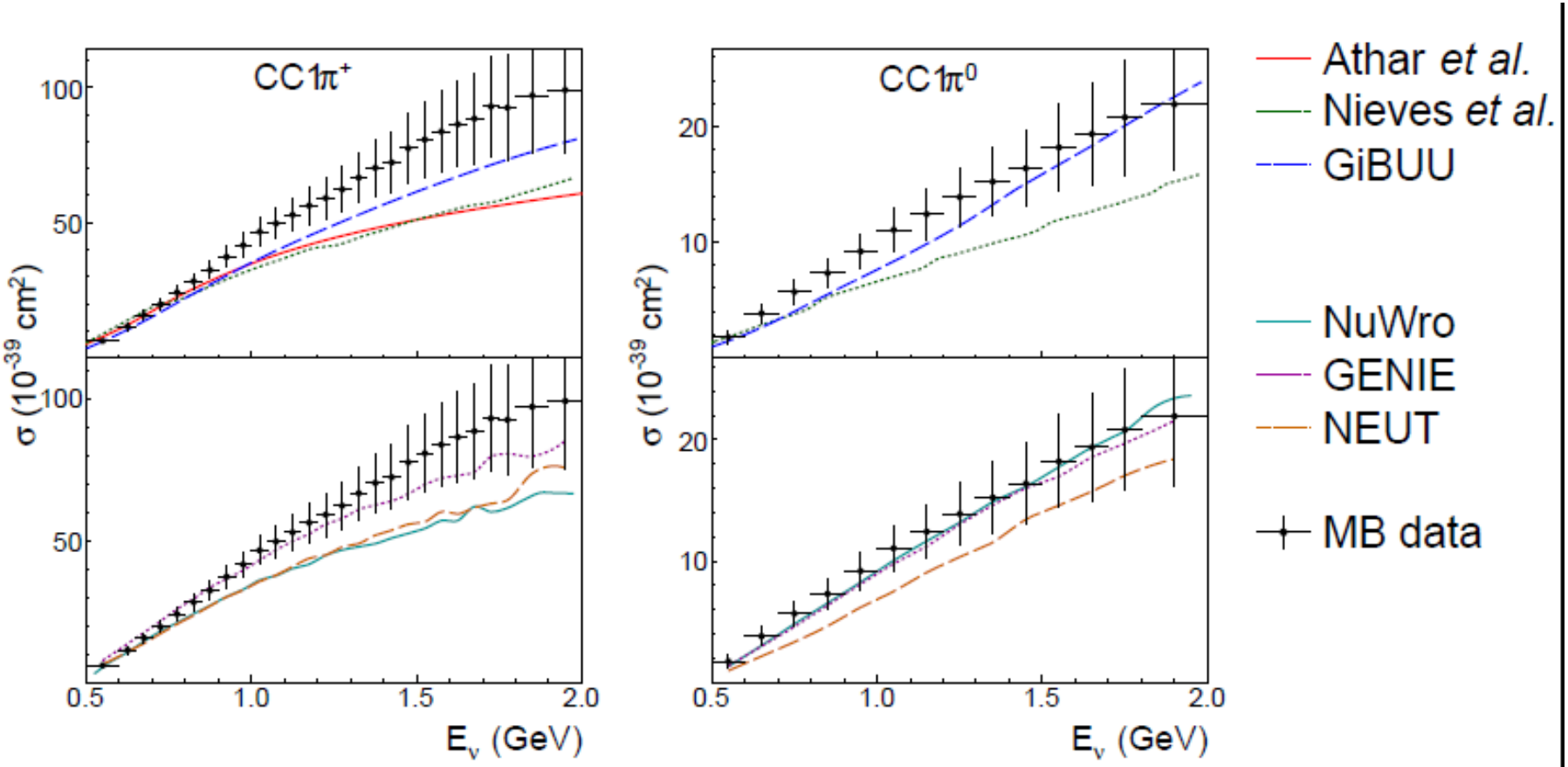






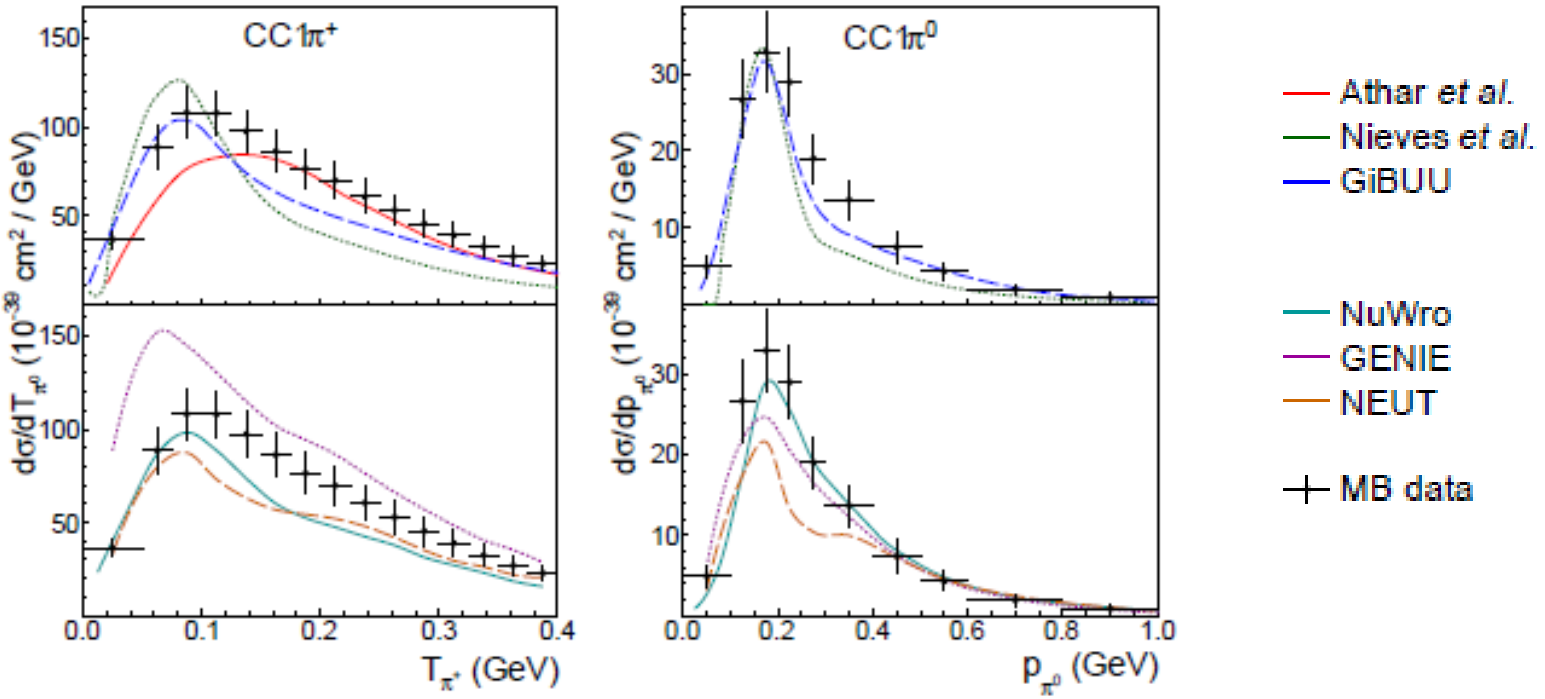
Modern theory against modern data
total xs collected by P. Rodriguez (NUINT12)

- Calculations tend to be low – both theory and generator



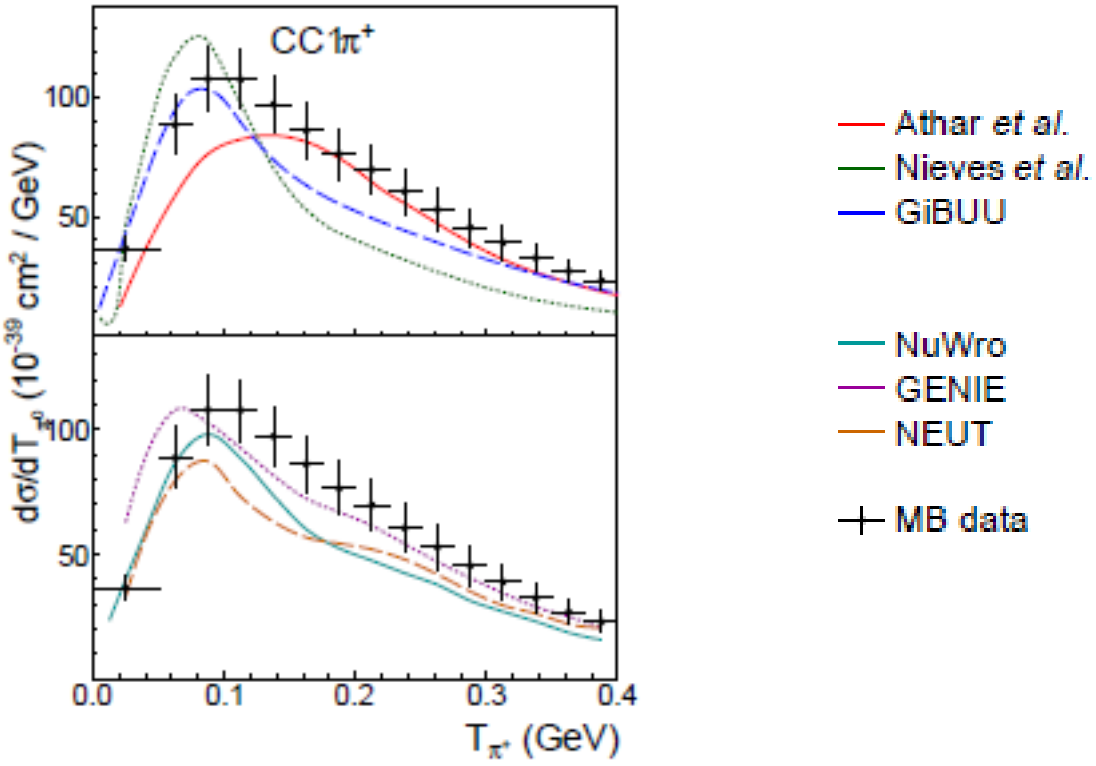
And more controversy

- As discussed by Luis on Friday, best theory doesn't agree with pion KE spectrum.
- Modern theory had Δ medium effects, π^+ rescat from piA



Gee, why is GENIE so large? (I checked)

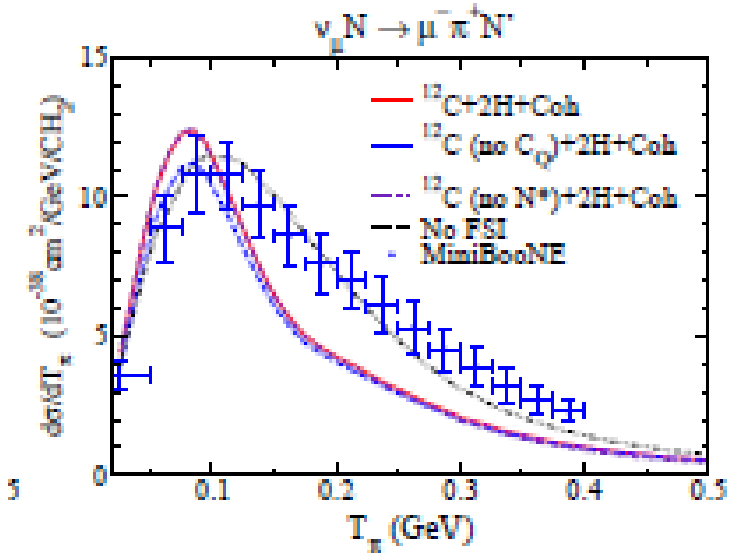
- Error in nucleon counting when Phil ran GENIE.
- GENIE has correct magnitude, here and in total xs!



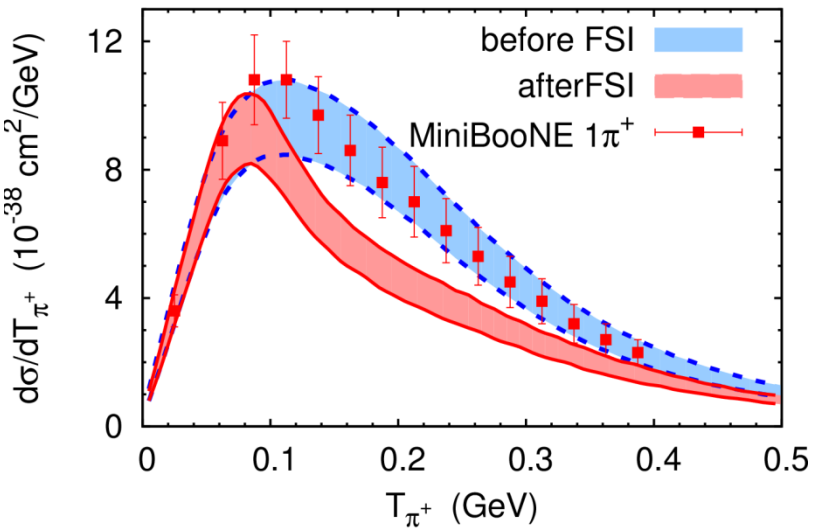
More controversy

- Data prefers calculation with no FSI
- Unrealistic because strong pion absorption expected at $T\pi \sim 150$ MeV (peak of Δ).
- Theorist: we have best ingredients
- Experiment: we checked our methods carefully, trust errors

Valencia

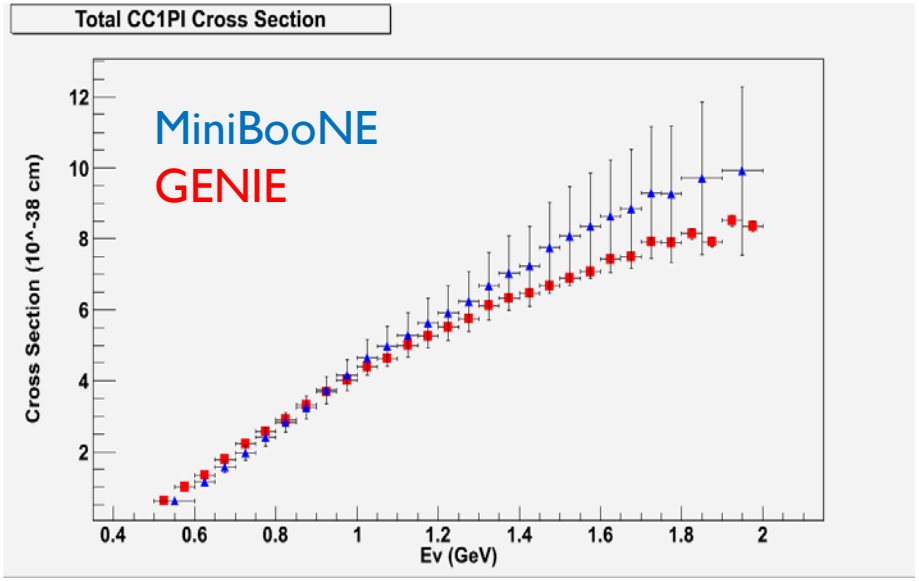


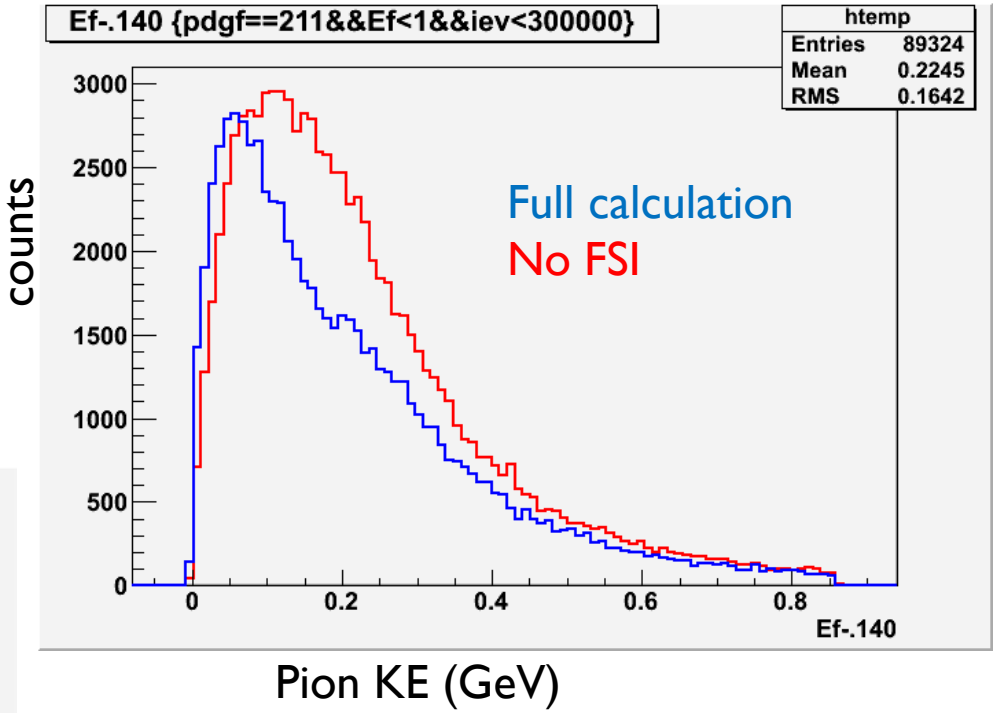
GiBUU



GENIE shows different shape

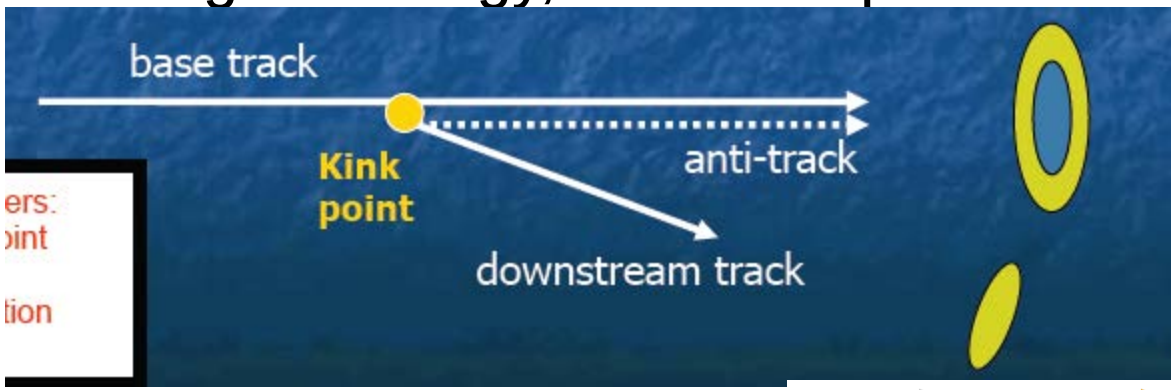
- Dip due to FSI is less sharp.
- Below, show GENIE vs. MiniBooNE total xs data.

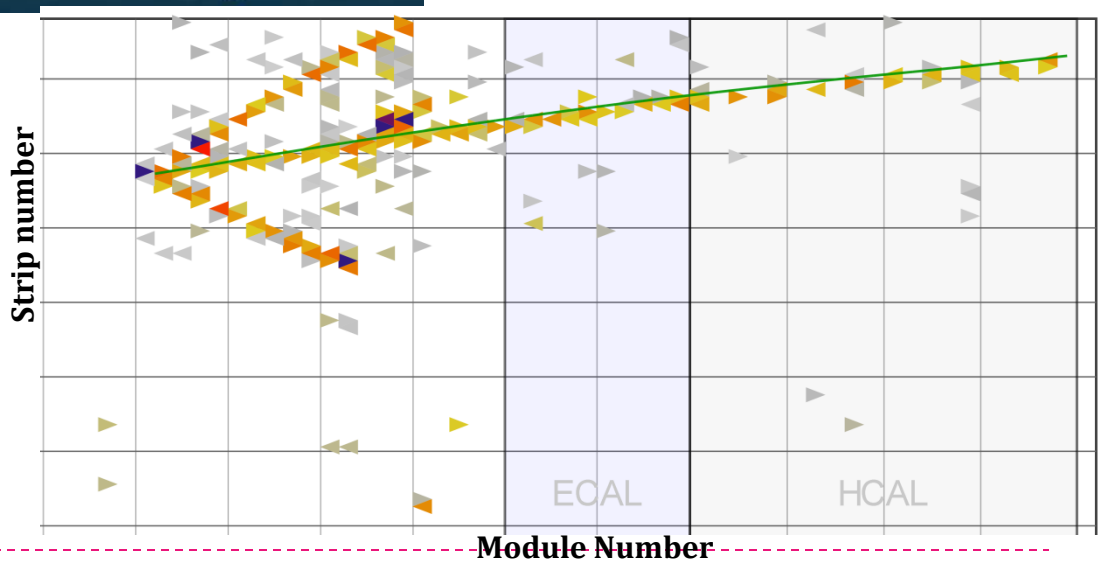




New data from Minerva soon!

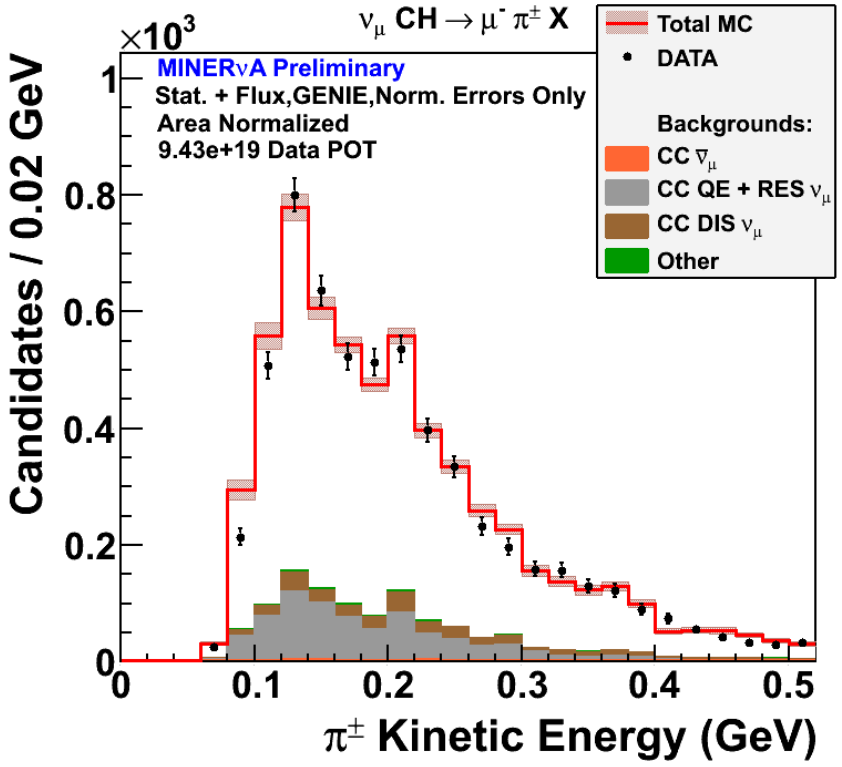
- Different method, better energy resolution
- Higher energy, more complicated cuts

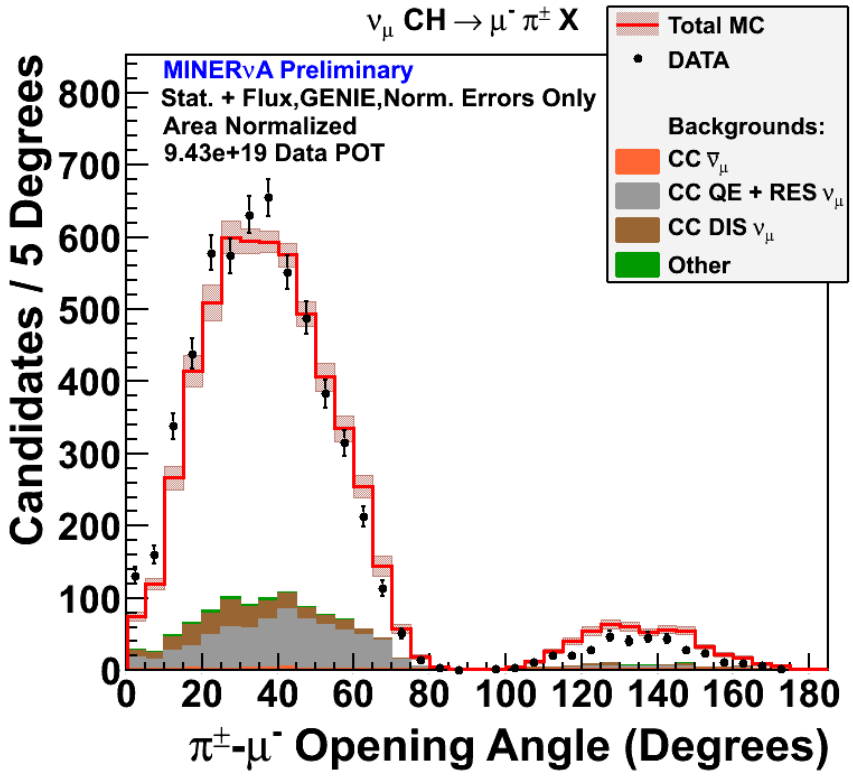




Results at NUINT12

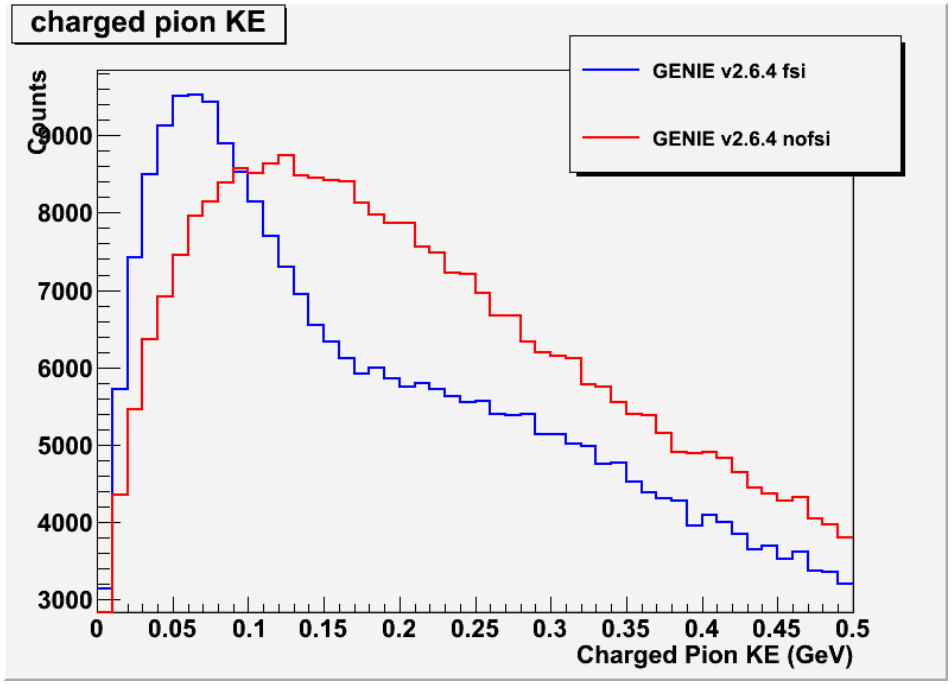
- pion kinetic energy, angle for W<1.8 GeV (~85% π^+ - MC)
- Uncorrected for background, no efficiency correction.

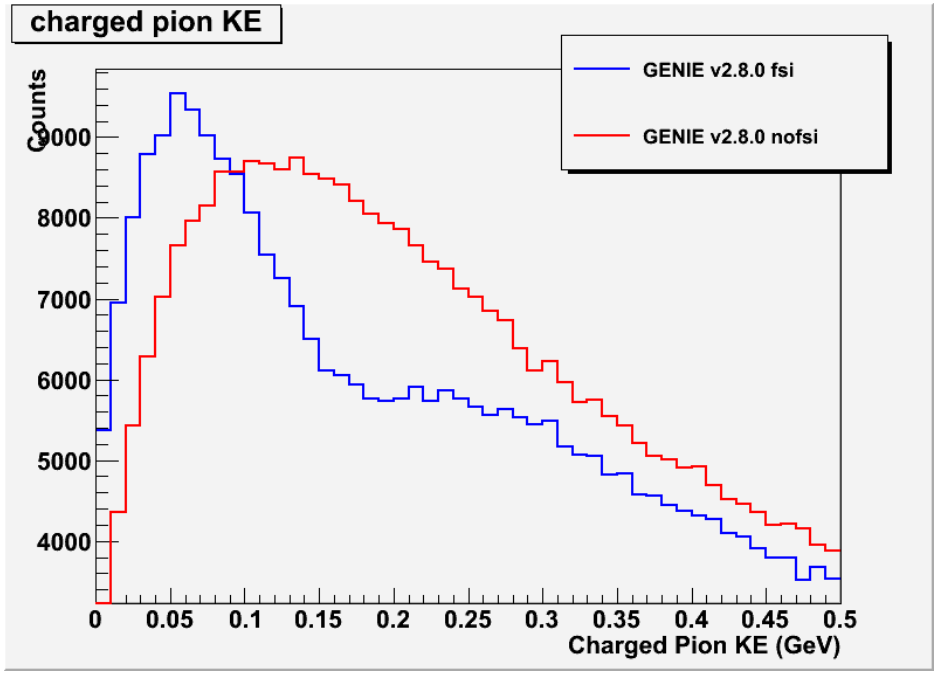




GENIE prediction For NuMI LE beam

- With and without FSI, v2.6.4 and v2.8.0
- Note similarity to same plot for MiniBooNE p. 13



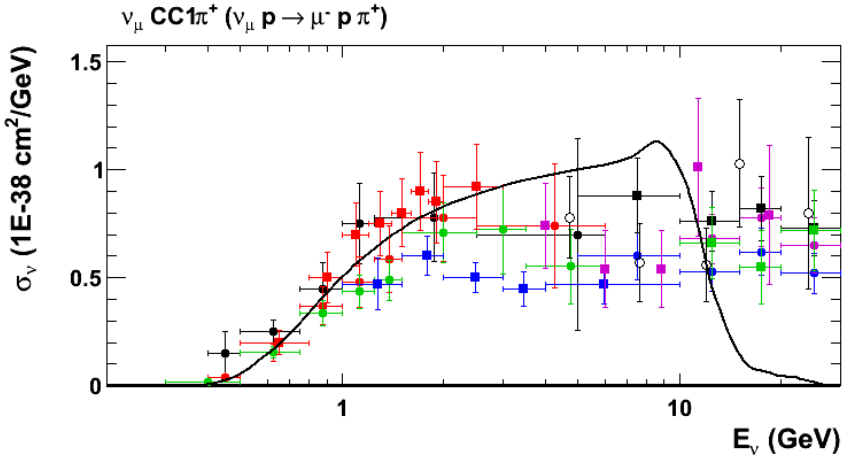


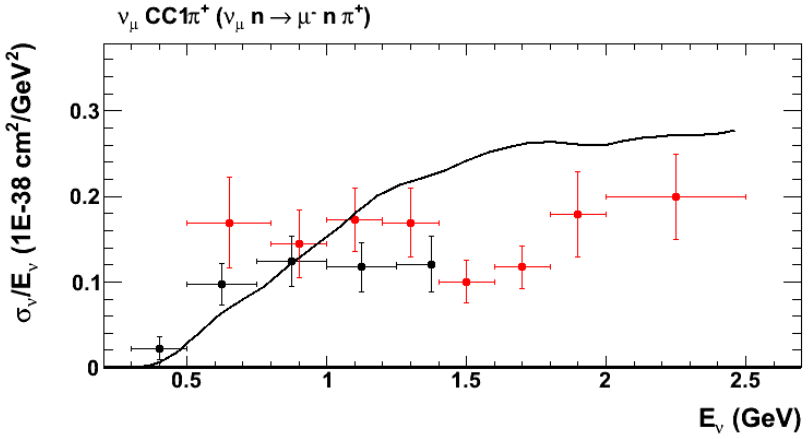
progress

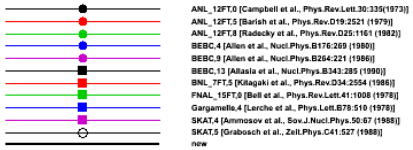
- Improved efficiency, purity, and resolution.
- Factor of 3 in statistics
- Backgrounds subtracted, energy resolution unfolded, and efficiency corrected
- Focus on 1-pion spectra (W<1.4 GeV) for neutrino
  - Will have W<1.4, 1.8 GeV for ν_μ and $\nu_\mu$bar
- Shape only until flux understood better
- Expect to release results Feb. 7.
- Seek theoretical calculations by Jan. 8, requests as soon as we have flux calculation.

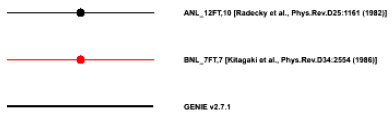
GENIE resonant channel

- Based on Rein-Seghal, updated for masses, widths
  - Not what theorists show for RS
  - Old vector couplings*, no μ mass*, no medium corrections
  - Resonances represented by Breit-Wigner shapes
- Nonresonant background from Bodek-Yang (scaled up)
- Go between ANL and BNL (like theorists)



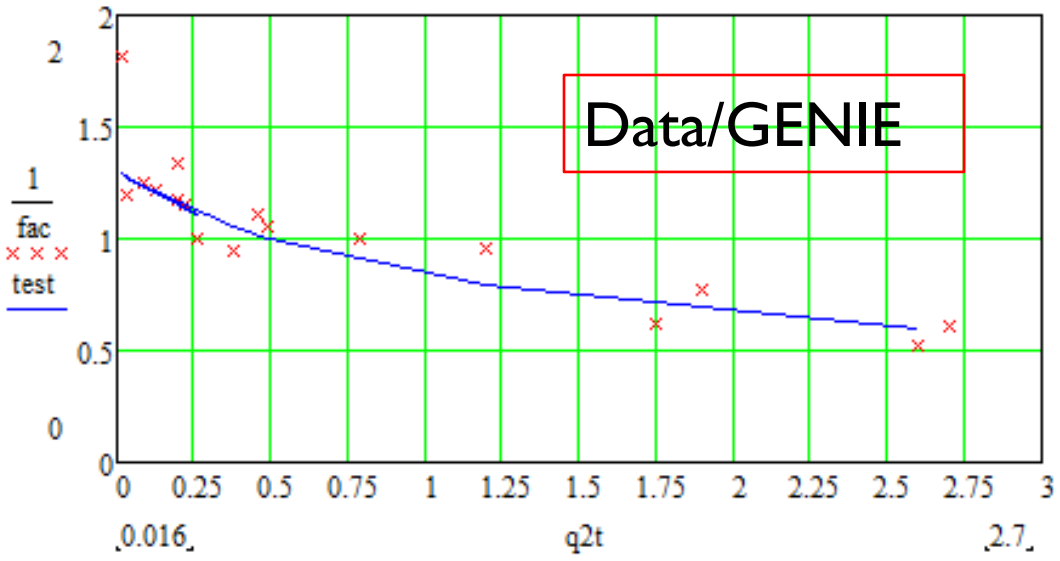


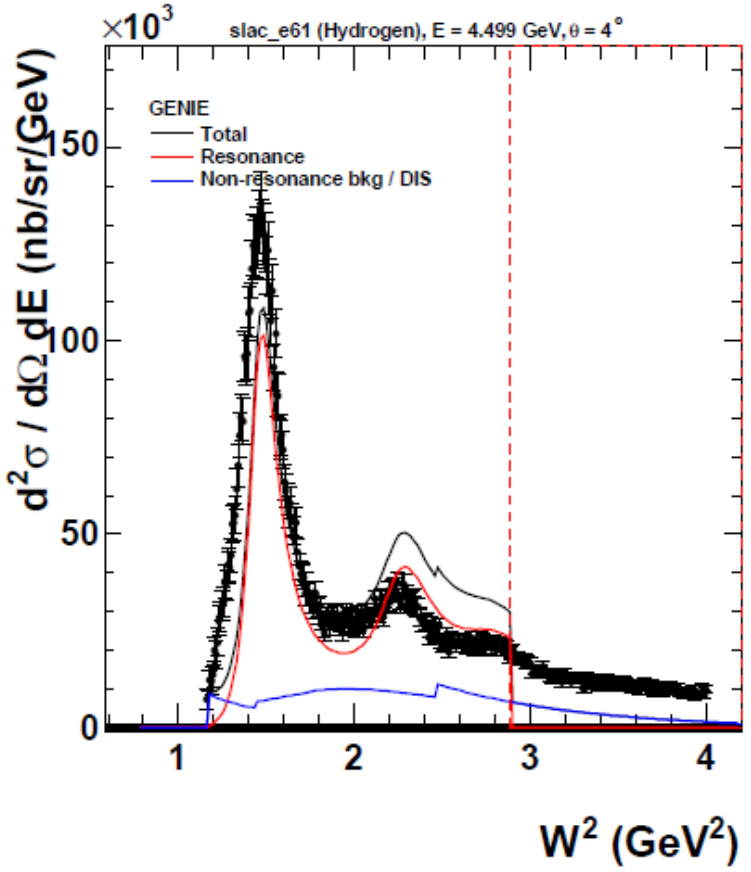




Check form factor with ep→e'p data

- p(e,e')X data from Steve Wood
- GENIE now has extensive validation pkg for (e,e')
- Plot at right is for Q^2=.09 GeV^2.
- Shape is significantly wrong

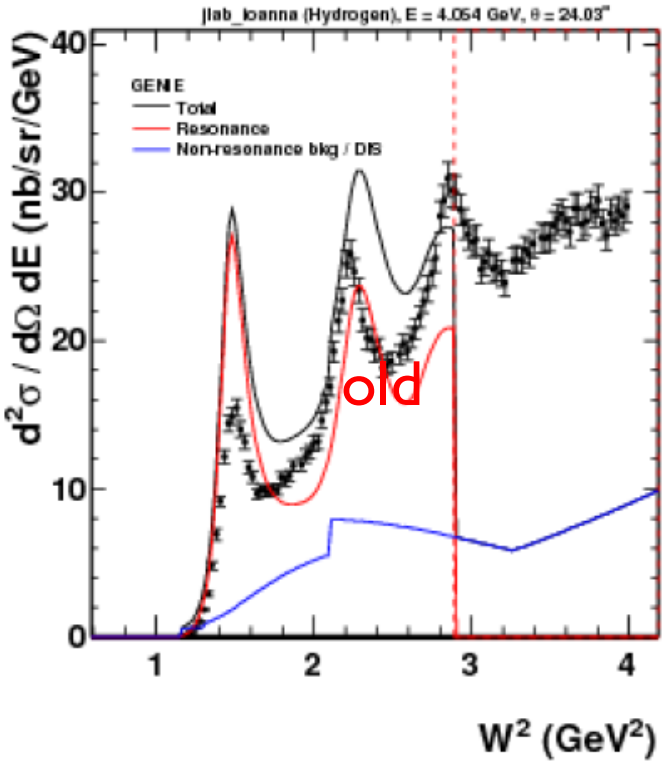


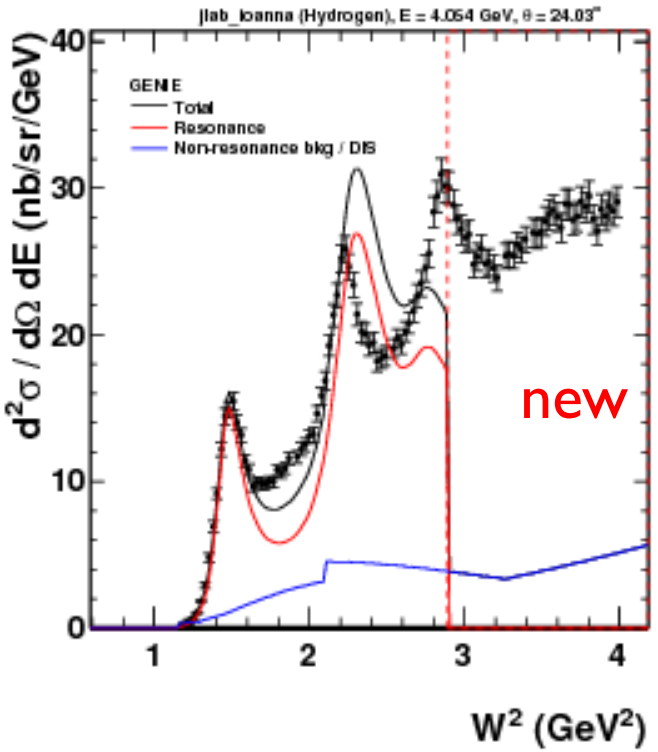


Luis suggests improvement
Experimenter/theorist collaboration good for GENIE

- Abandon ancient vector couplings (γ*N$\rightarrow$N*)
  - Substitute values from new MAID analysis of new (e,e'p) data
  - Luis contributes proper factors to match RS, I provide code

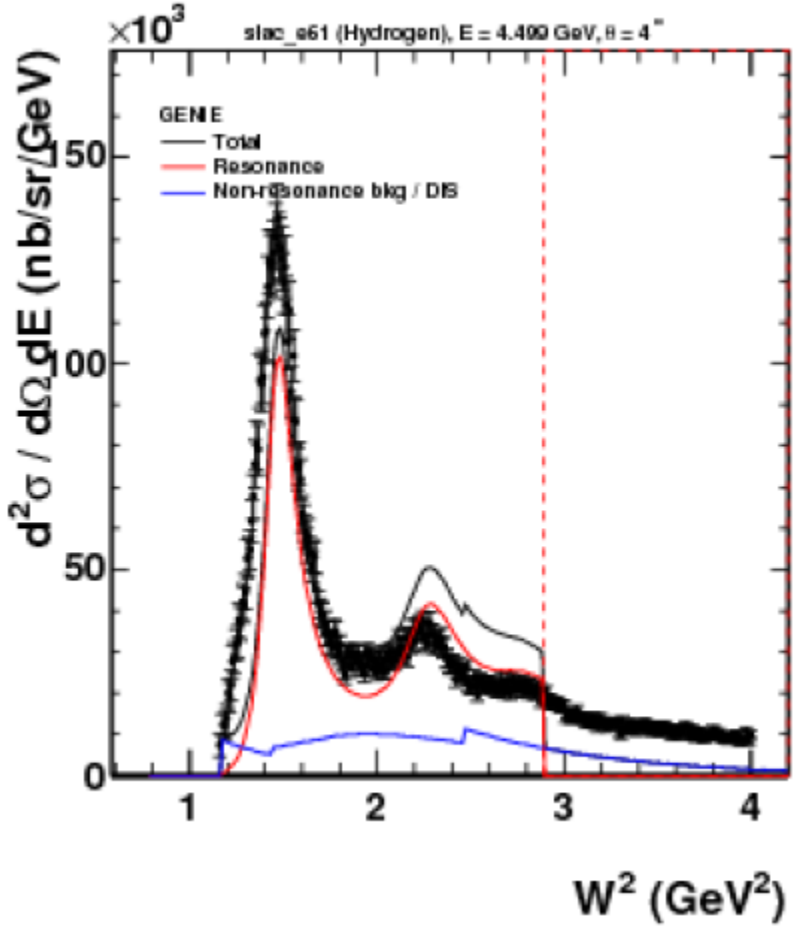
Q^2=2.5 GeV^2

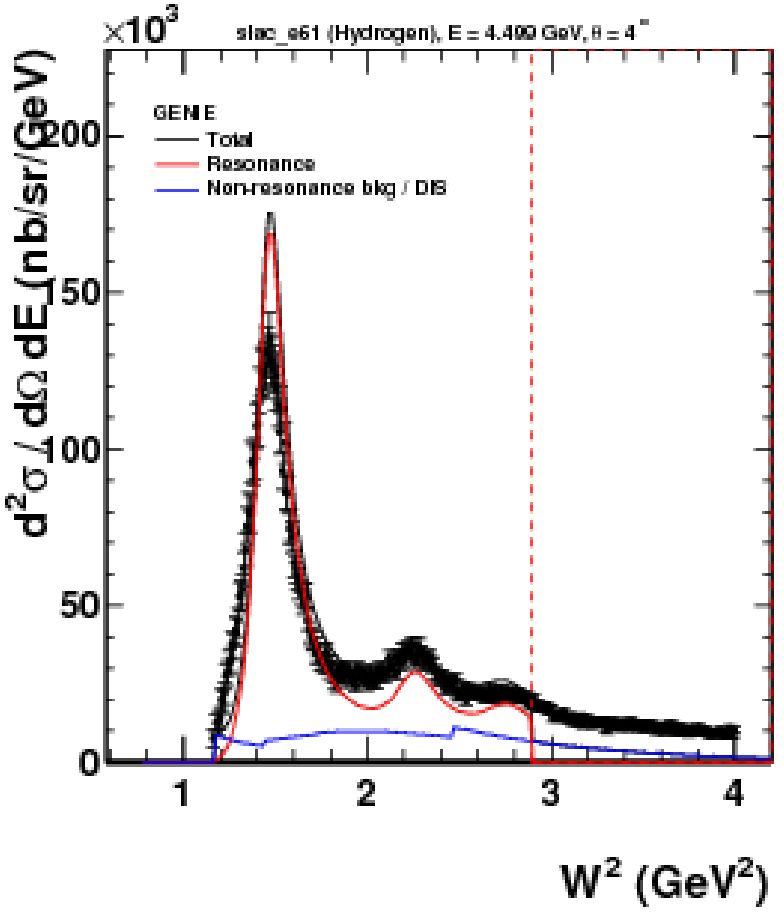




Problem at low Q^2 for Delta

- Was too low, now too high





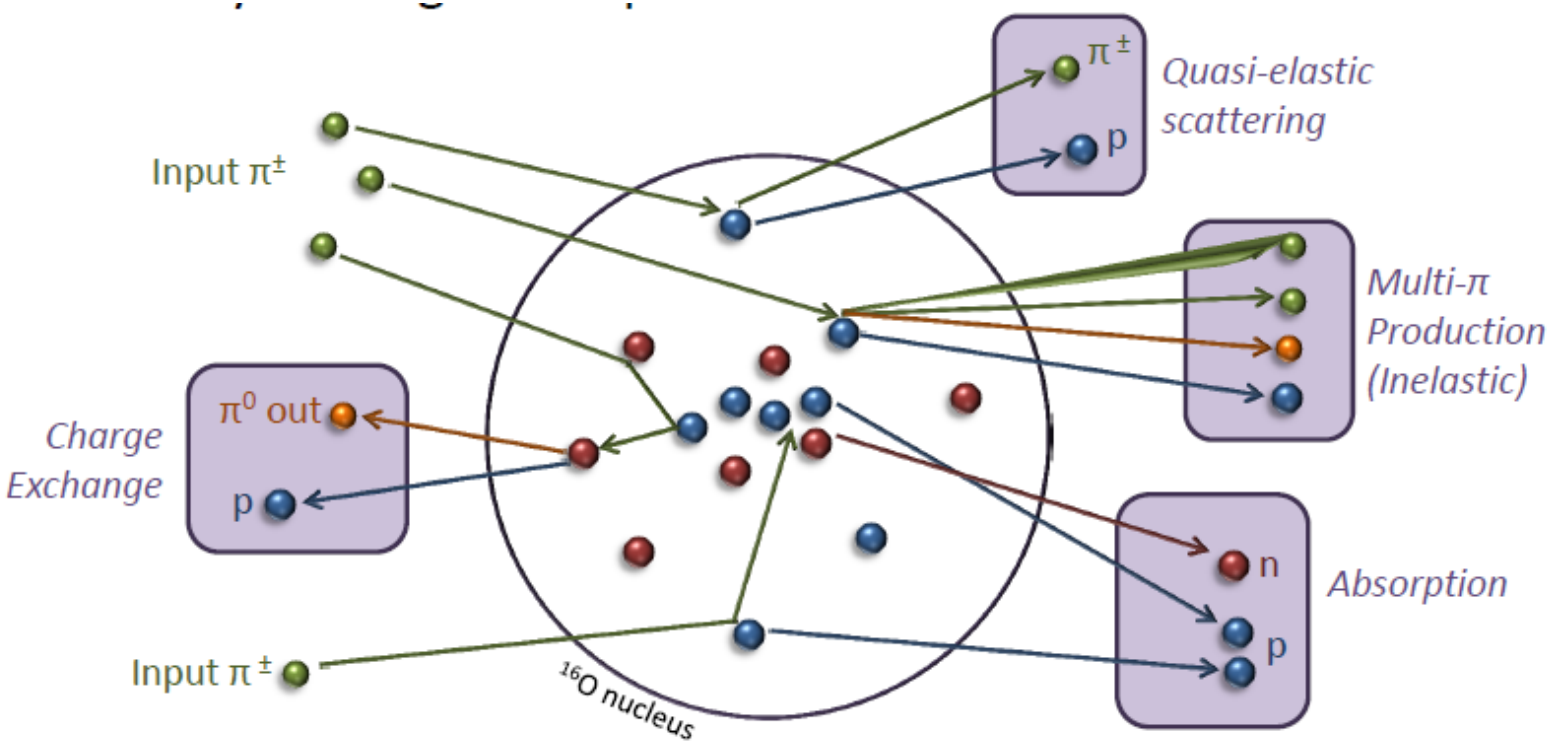
Looking forward

- MAID has 11 resonances
- First implementation is ok, but we see problems
  - They fit to (e,e'π) multipoles, we compare with (e,e') inclusive xs
  - MAID uses different background
- Start communication with Lothar Tiator (Mainz)
  - Make sure we implement resonances correctly
  - Make new nonresonant background to get agreement
- Use Jarek Novak's implementation of Berger-Seghal formalism with muon mass (done).
- Adopt Δ medium correction (take from literature)
- We will then have modern resonance implementation
- As of now, no need to use formalism different than RS

Cascade FSI GENIE model

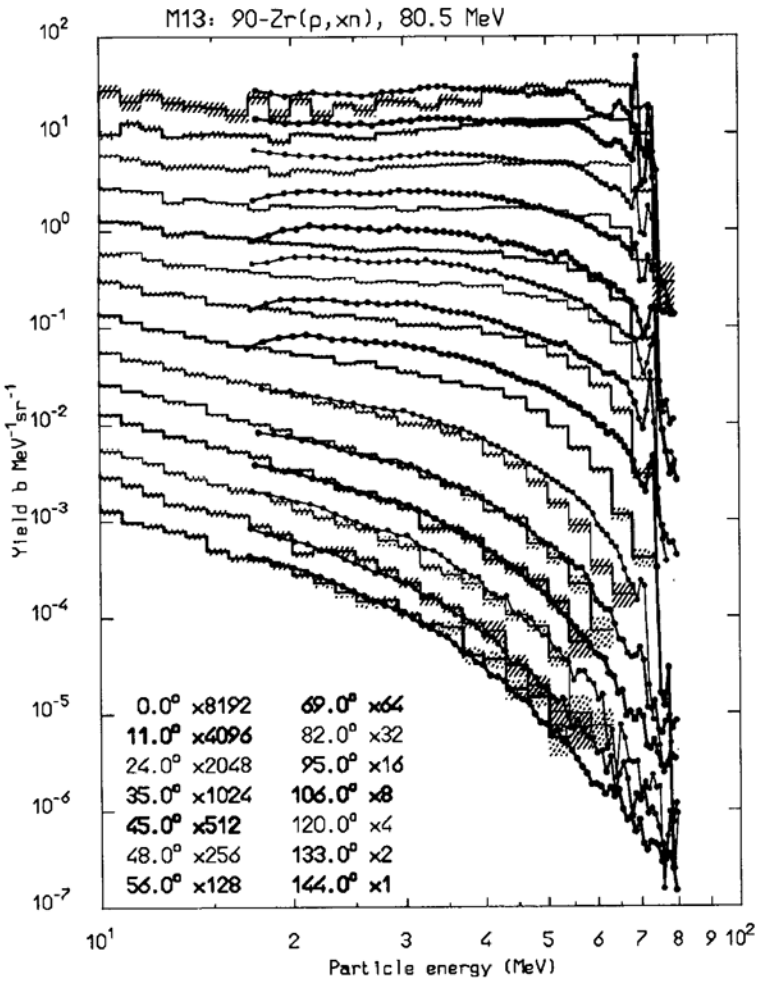
Strategy
P. De Perio (NUINT11)

- step hadron through nucleus
- Use free cross-sections to choose where and how to interact
- Propagate all new particles



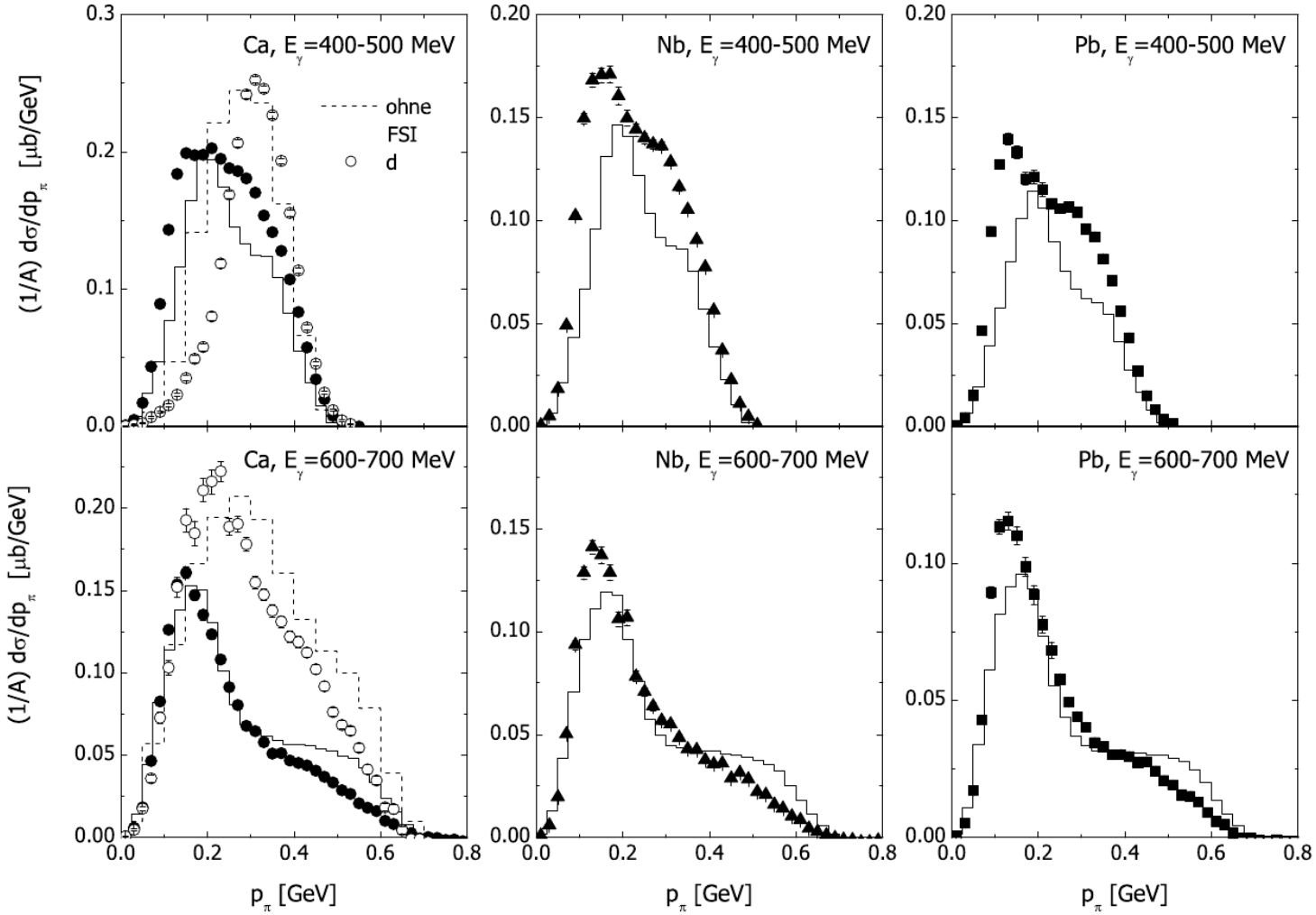
Cascade models used everywhere

- Most recent calculations for pion scattering
- All neutrino generators use them
- FLUKA has best model, fits wide variety of data
  - Implement quantum mechanical corrections – coherence length
  - Statistical methods at low energies
- GiBUU uses semi-classical transport method
  - Nontrivial Medium corrections
  - nonlocalities



GiBUU photoproduction results

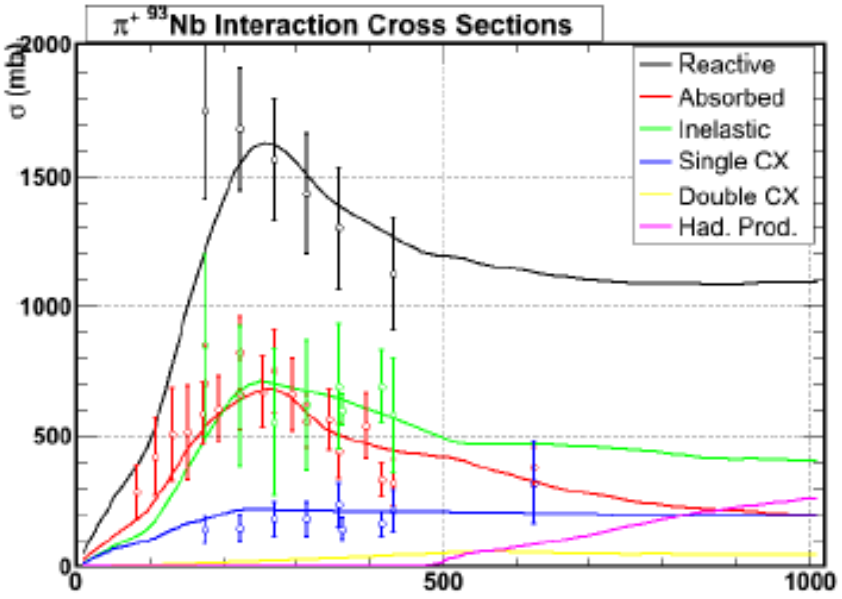
Olga Lalkulich (NUINT11)



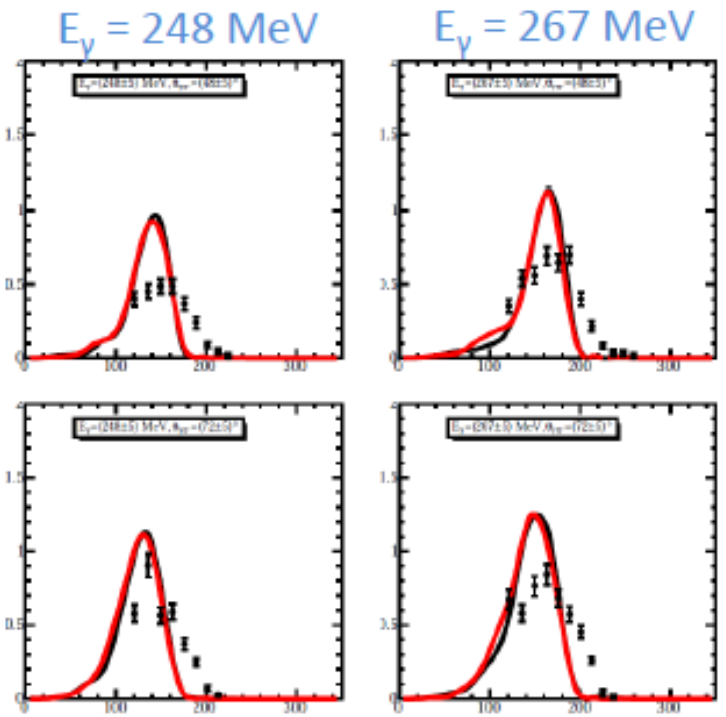
Simpler methods also work

- NEUT, NuWro use Oset development of medium corrected interactions.

Plots from P. de Perio (NUINT11)



$^{12}C(\gamma, \pi^+)X$ data from *Arends*

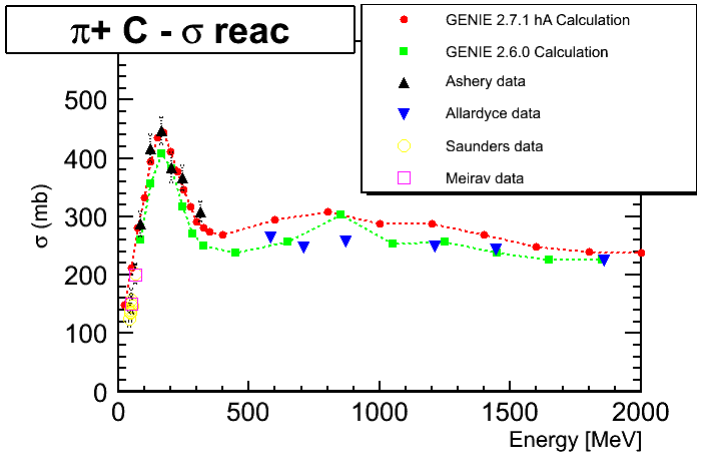


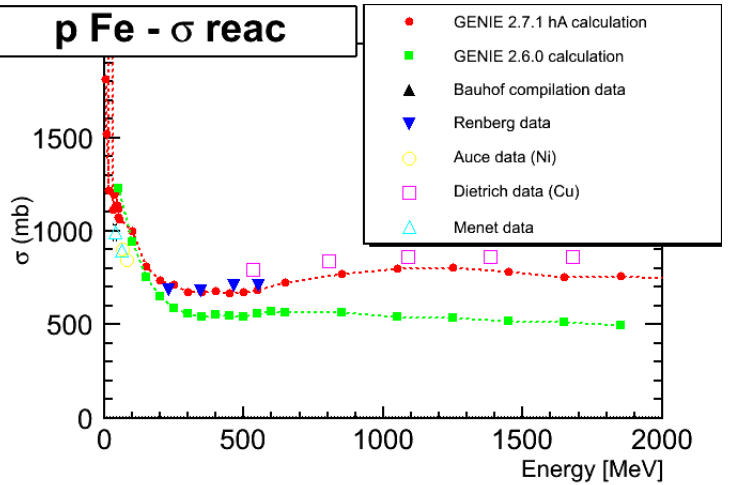
GENIE model is even simpler

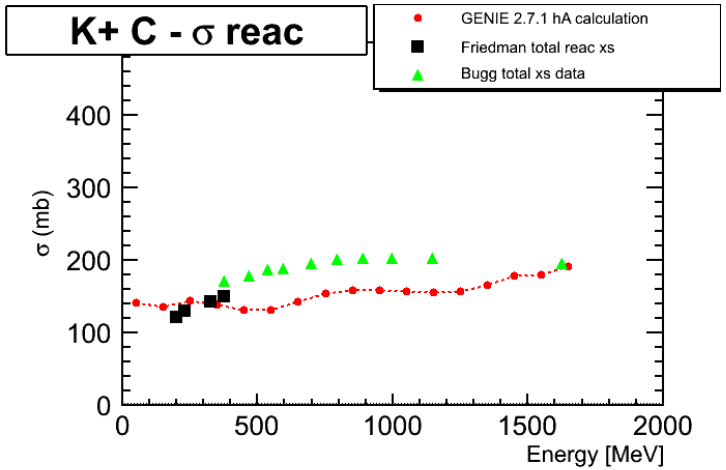
- Data-driven, empirical
- Pions, kaons, nucleons (no photons yet)
- Use free hadron-nucleon cross sections to choose where interaction occurs (same as others)
- Use data for total cross sections to determine which interaction happens (e.g. cex, abs, elas, inel, pi prod)
- Use simple models (phase space, dominant kinematics, empirical factors) to choose final state particles, angles, energies.
- Simple, exactly reweightable, easy to define errors.

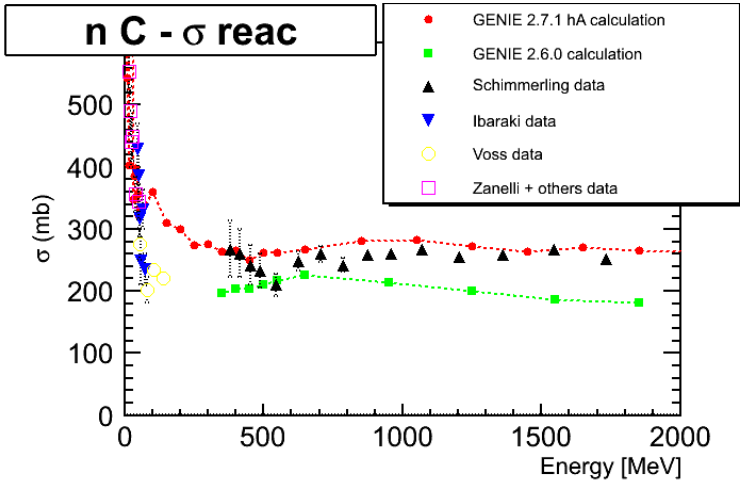
GENIE hA FSI model (v2.6.4 vs. v2.8.0)

- FSI does p, n, π^+, π^-, π^0, K+.

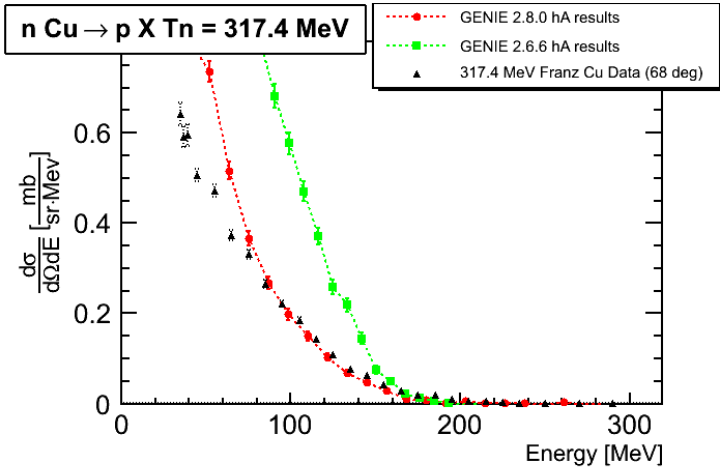


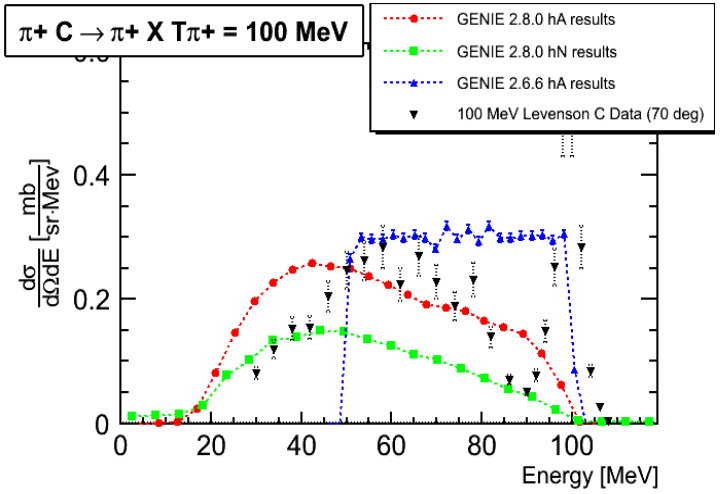


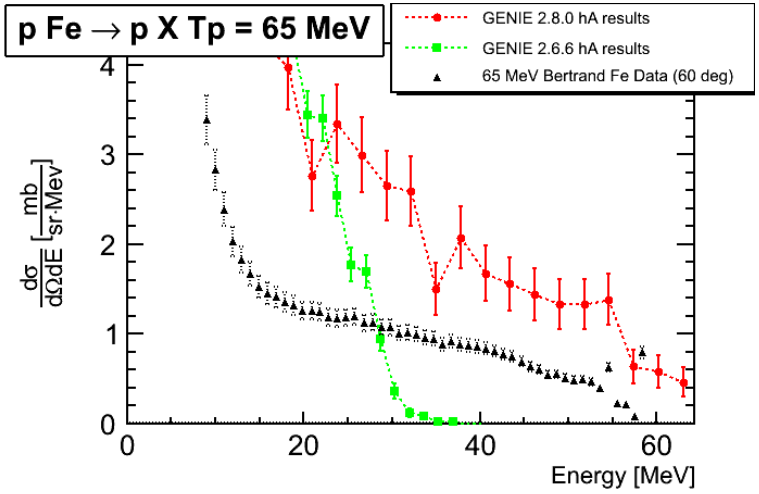


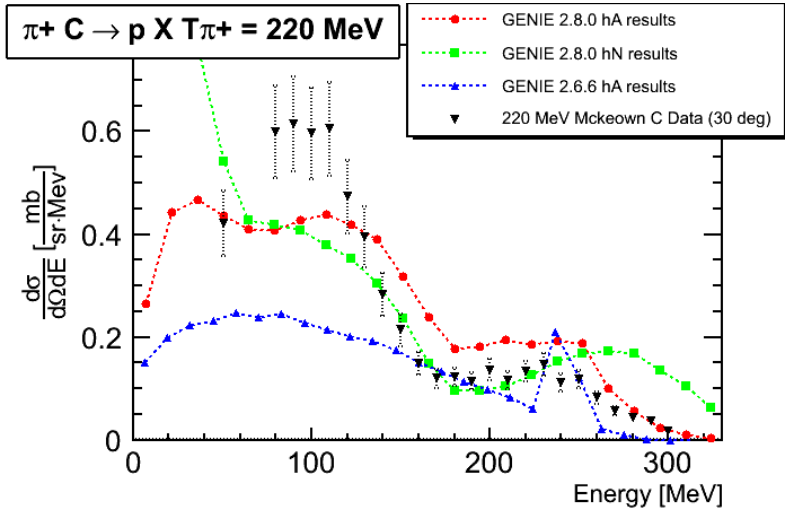


Validation plots
a few among hundreds – scripts do the work







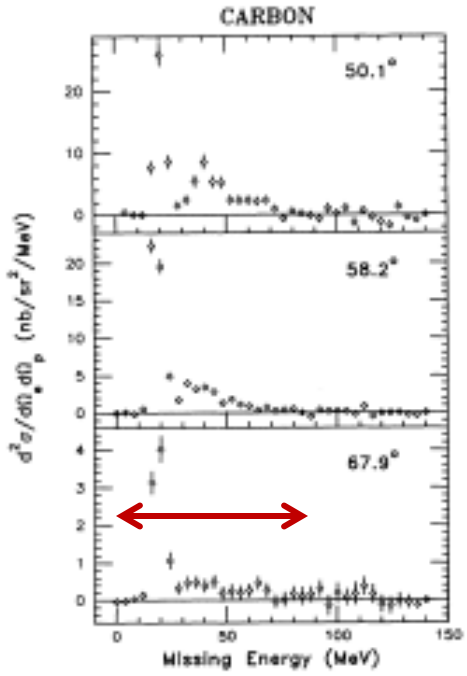


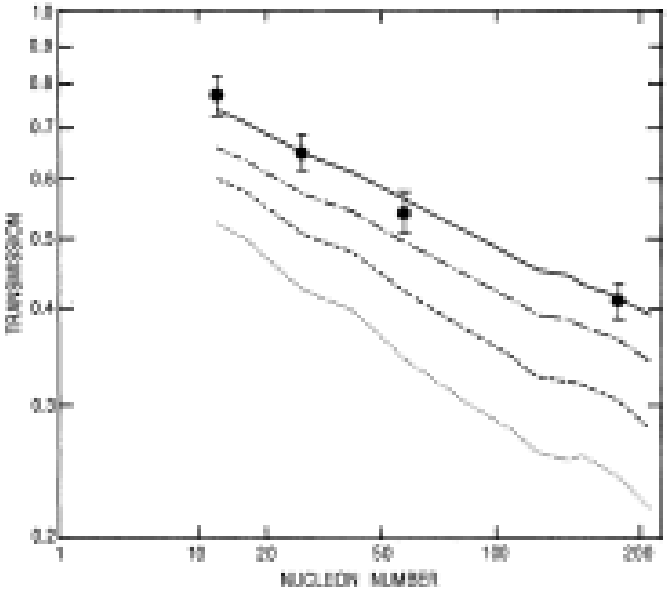
summary

- Neutrino pion production from proton, neutron remains a problem. Normalization of all modern calculations is uncertain by ~20%.
- Modern calculations at low energies solidly based on data from other probes. Yet, unable to reproduce MB pion data.
- New data from Minerva will be available soon.
- GENIE Δ model needs modernization, work in progress.
- Cascade models only way to do general hadron-nucleus simulation. Well adapted to producing multiparticle final states.
  - Generators don't have most sophisticated models, but not clear where they are inadequate.

Attenuation with electron probe

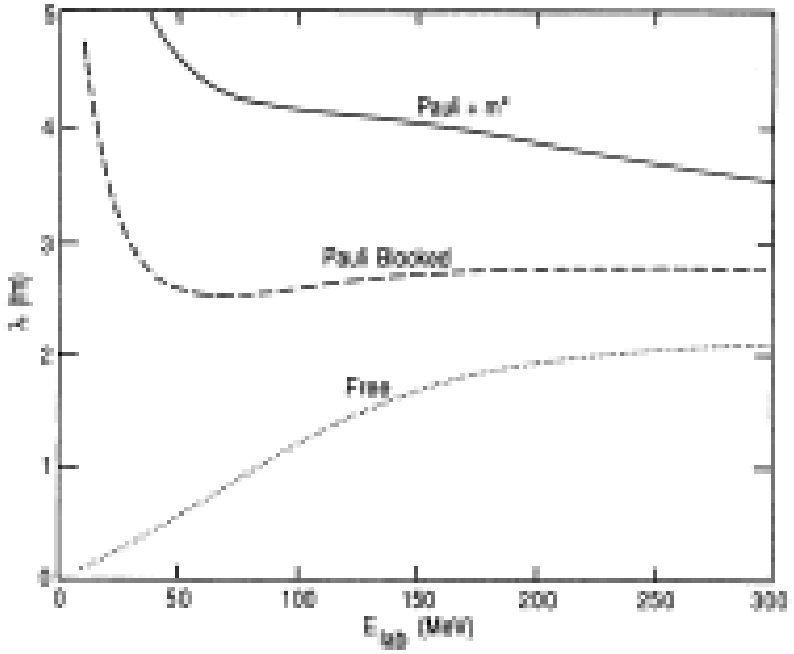
- Earliest work was with protons from (e,e'p)
- Main issue was optical potential vs. pN scattering
  - Mean free path of ~2-3 Fm vs. 5-7 Fm
- Garino expt (JLab) first definitive result, prefers opt pot.
- Ratio of data to PWIA calc for 180 MeV p
- (GENIE doesn't have any strength at low missing mass)

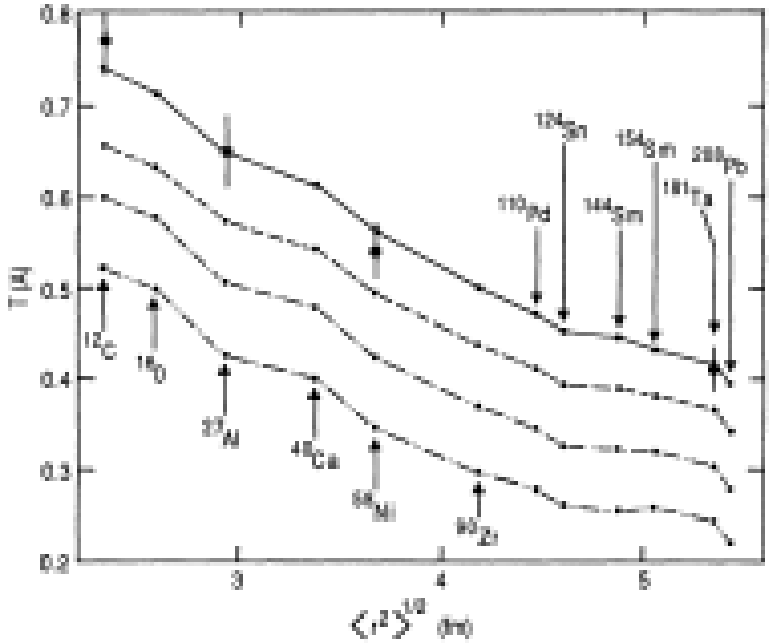




Pandharipande & Pieper explain

- Proton mfp in nuclear matter (L), real nuclei (R)
- Add Pauli blocking, then medium effects & correlations





extensions

- Go to high Q^2, different probes to search for color transparency
  - same goals as we want
  - Single principal vertex, check attenuation.
  - Validity of mechanism is key
- Here, show Qian pion data.
  - W=2.1 GeV, Q^2>1.1 GeV^2
  - Very different than MiniBooNE
  - Shows color transparency?
- Interesting test of >2 GeV pion interactions.