NUINT17
Generators overview

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- GENIE, NEUT, NuWro, Nuance, GiBUU
  event generators
- features
- comparisons
- looking to future

Event generator tasks

- Help plan future runs/experiments
  - GLOBES used more often – 'whipping post'
- Develop cuts to optimize signal/background
  - Must match data with detailed set of cuts – difficult
- Provide interaction class of systematic error code
  - Need tuning dials and estimated errors - difficult
- Provide a way to compare experiments with different signals
  - Added importance in the nice world of multiple measurements
- Upgrades in physics important – come from new theory, experiments – balance is difficult

Recent progress from new theory

- Many theoretical models available
  - Difficult choices, tend to go with easy applicability and good match with existing data
- Many contributors from experimental collaborations
  - NIWG inside T2K
  - GENIE producers workshop (FNAL, 2015)
  - Result is significant upgrade in models
- Good interplay between NuWro and NEUT/GENIE
- Good results, but could be better
- Need systematic error definitions for new models

Compare to other generators (2.12 default)

Model/generator	GENIE	NuWro	NEUT
QE	Lwlyn-Smith Nieves, Eff MA	Lwlyn-Smith RPA	Lwlyn-Smith Eff RPA
Nuclear model	RFG, LFG, Effective spectral function	RFG, LFG, spectral function	RFG, LFG, spectral function
MEC	Valencia Empirical	Valencia Marteau	Valencia
Delta model	Rein-Sehgal (updated)	Home-grown	Rein-Sehgal (update)
Coherent	Rein-Sehgal(corrected) Berger-Sehgal	Rein-Sehgal Berger-Sehgal	Rein-Sehgal Berger-Sehgal
FSI	Schematic Cascade (med corr)	Cascade(med corr)	Cascade(med corr)

- Differences more in detail than fundamental (physics)
- Main difference is that GENIE has larger goals, therefore more ponderous

Nuisance – Monte Carlo comparator

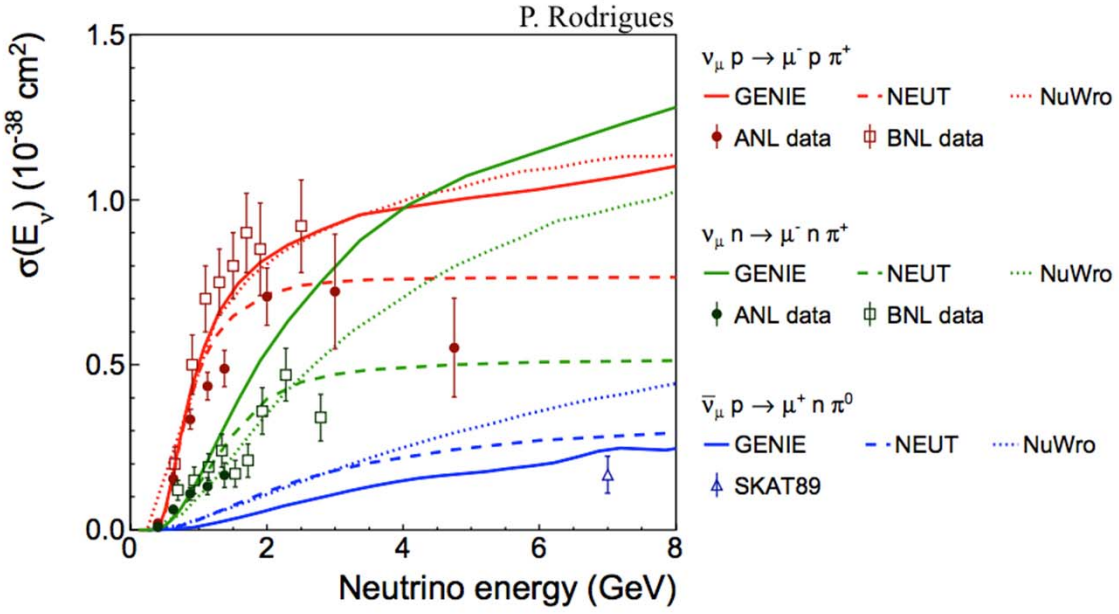
- Grew out of tuning efforts in T2K, publically available
- Authors: P. Stowell, L. Pickering, C. Wilkinson, C. Wret
- Single program makes predictions for various data sets
  - Plots with generator files
  - Reweighting from generator
  - Fitting using Minuit
  - Working copy of each generator required
- They got fit to MiniBooNE data, important for T2K oscillations
- Used (Patrick Stowell and I) for this talk

GENIE

- Tries to be Universal EG
- Almost all experiments use it (excellent tools – flux, geometry)
- Structure allows easy swapping of models
  - Very relevant now when we have multiple models
- Lack of manpower is a constant problem
  - US experiments less willing than Europeans to supply manpower
  - Recent funds for postdocs great
- Presently testing models, goal

ν_μ p,n data/models at core of all codes
The nucleon problem - low statistics BC expts

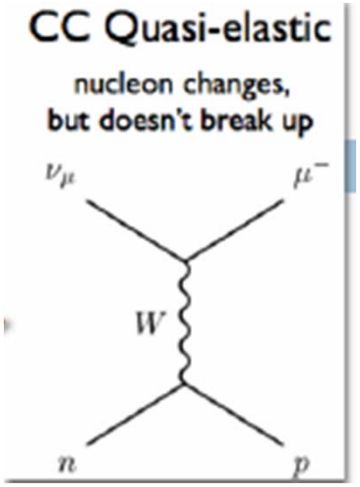
- Plot shows what GENIE, NEUT, and NuWro use (pion prod)
- Historical problem with BNL>ANL at low Eν for all calculation
- Recent reanalysis by Wilkinson et al. favors ANL
- Most models take middle approach

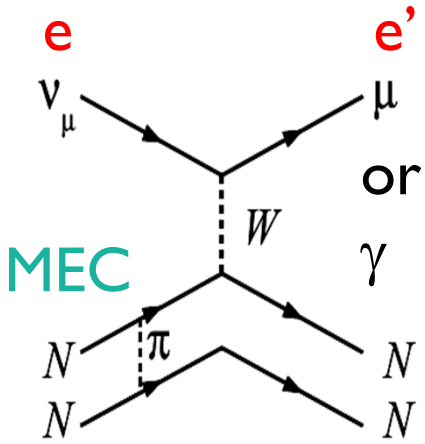


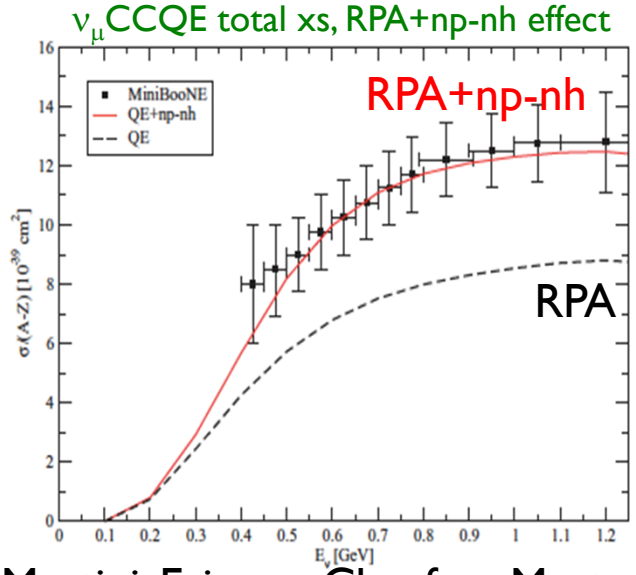
- Wide variation in use of n π^+ data
- Fortunately, p π^+ dominates in results
- NEUT has updated fit to reanalyzed data
- Additional data not shown

CC Quasielastic data

- Shortfall in magnitude clear with MiniBooNE data
  - Agreement of pure QE with higher E_ν NOMAD data still confusing
  - ~50% increase in $M_{A,QE}$
  - (Re)discovery of 2p2h, but only indirect experimental confirmation so far
  - Differing strategies in NEUT/GENIE



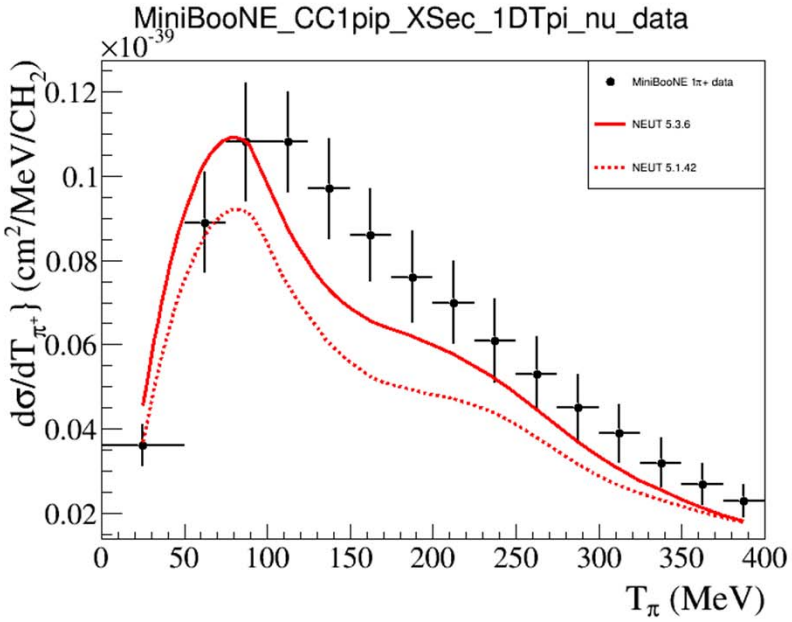


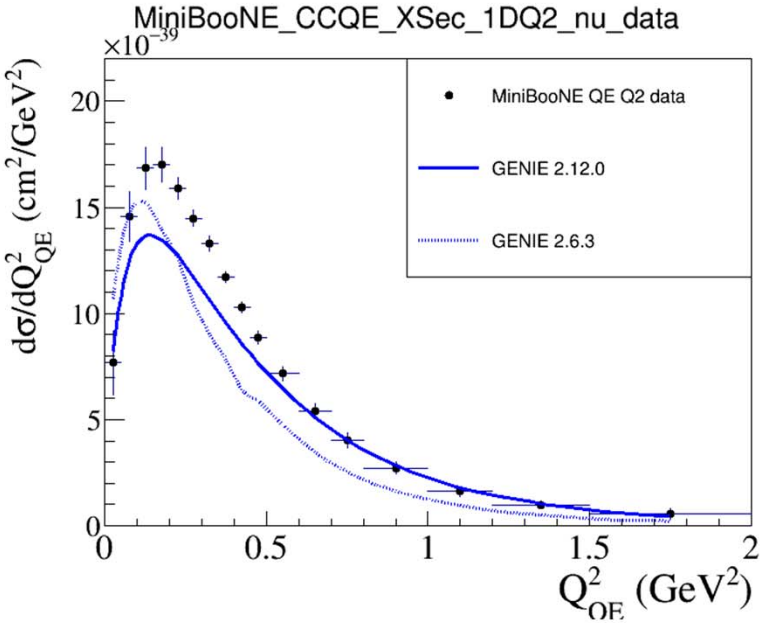


Martini, Ericson, Chanfray, Marteau
Phys Rev C80:065501 (2009)

Generator evolution

- Both NEUT and GENIE have included theory models in last few years.
- Show 2 examples of interest
  - NEUT with retune of nucleon pion production model
  - GENIE after changes in CCQE model (RFG→Valencia LFG+2p2h+RPA)





Model choices

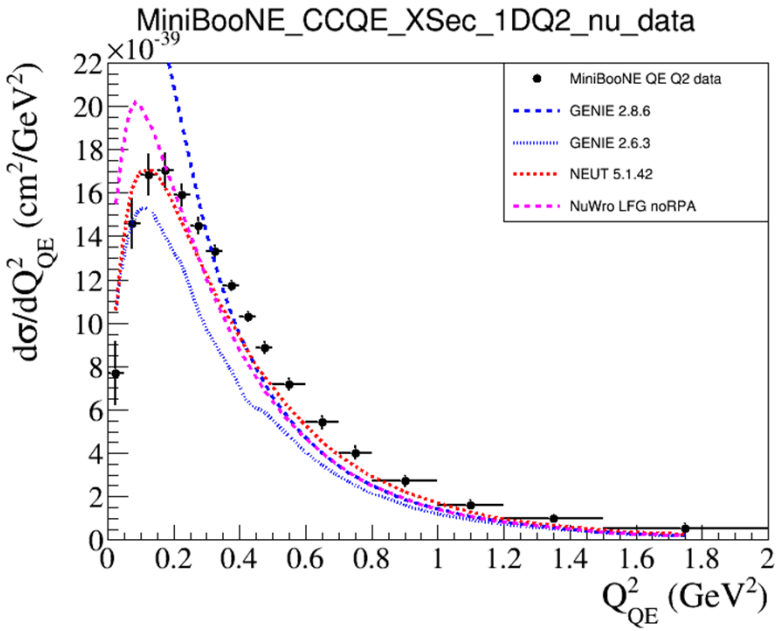
Model	N res	Non resonant	Nucleon Momentum	MEC	RPA
GENIE 2.12.0alt	Berger-Sehgal +	Bodek-Yang (extrap low W	Local Fermi gas	Valencia	Valenica
NEUT 5.3.6	Berger-Sehgal +	Rein-Sehgal	Global (rel) Fermi gas	Valencia	Valencia
NuWro	Adler (Δ only)	Bodek-Yang extrap low W)	Local Fermi gas	Valenica	Valencia
GiBUU	Leitner et al.	Lalakulich et al. - empirical	Local Fermi gas	Home-grown	Home-grown
GENIE 2.6.3/2.8.6	Rein-Sehgal	Bodek-Yang (extrap low W)	Global (rel) Fermi gas	None	none
NEUT 5.1.4.2	Rein-Sehgal	Rein-Sehgal	Global (rel) Fermi gas	None	none

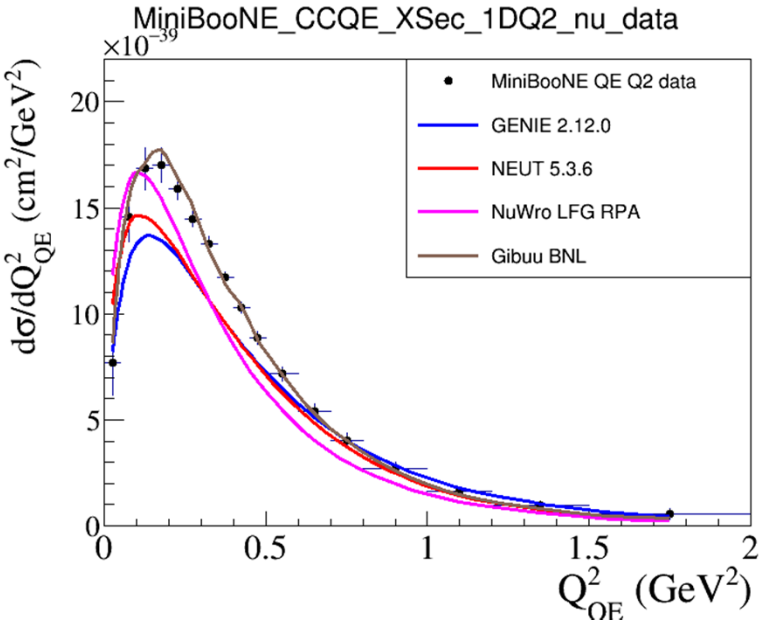
MODERN

OLD

NUISANCE Comparisons – New vs. Old

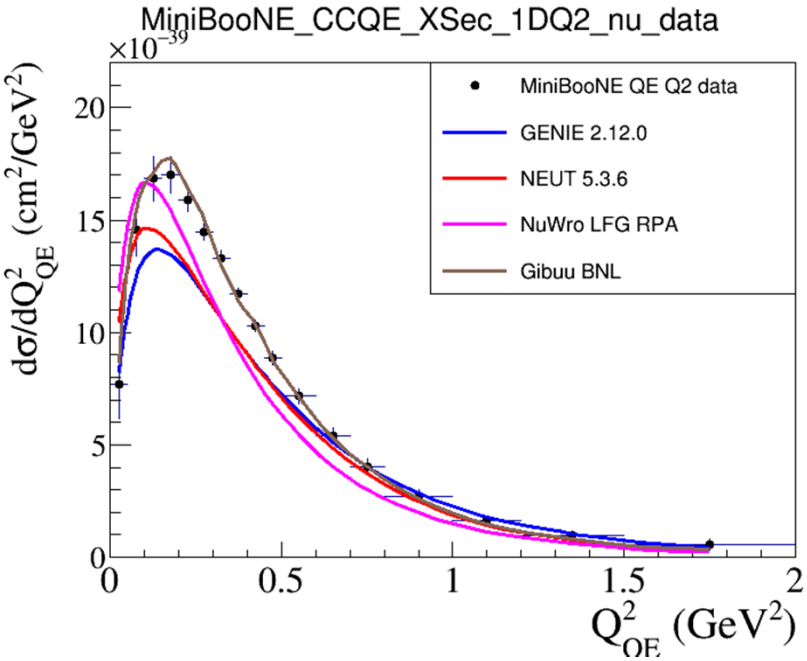
- MiniBooNE Q^2
  - Spread of models smaller for New
  - NEUT partially tuned to this
  - GENIE added improved models, no tuning yet

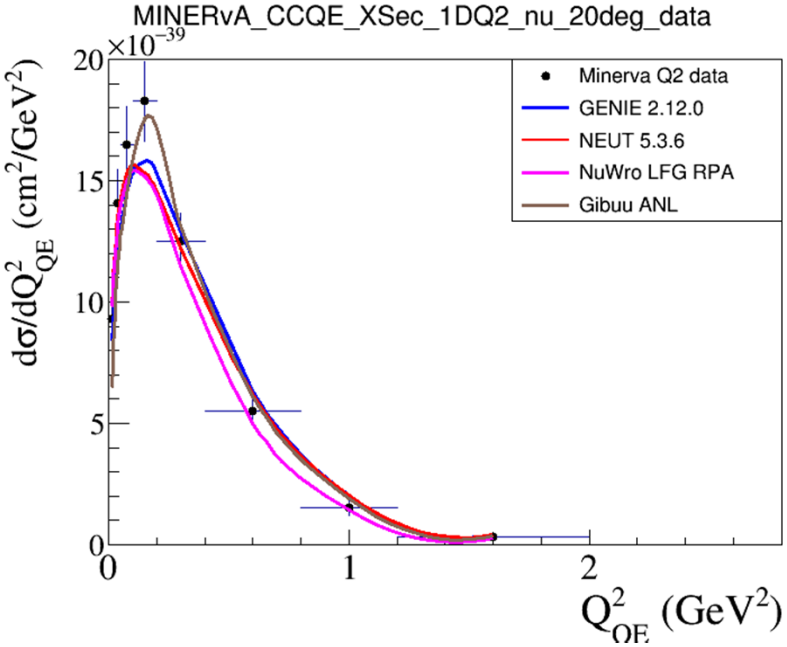




NUISANCE comparison for QE
updated Minerva flux

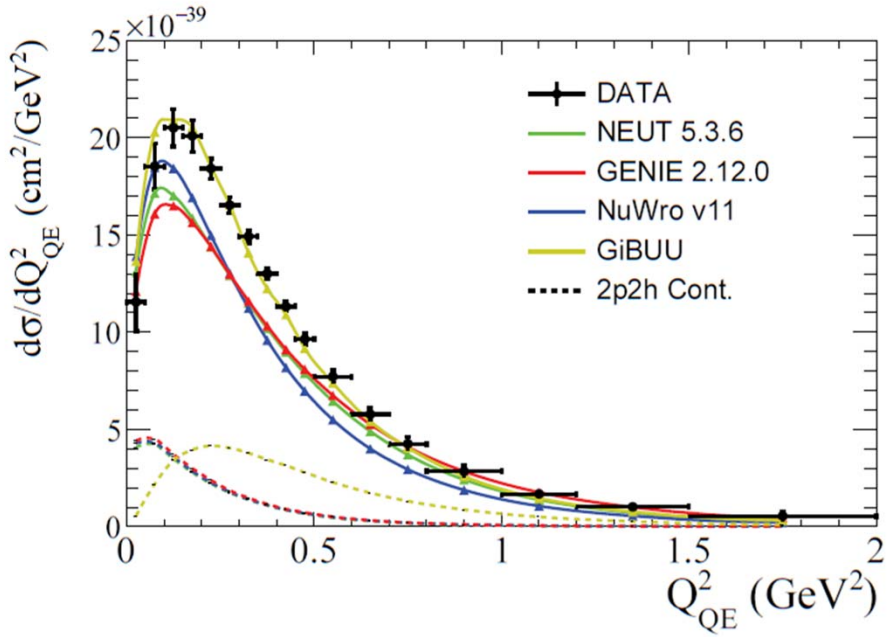
- Calculations using most recent versions of generator (user might have trouble reproducing these plots)
- Note: Minerva data is the alternate version with signal $\theta_\mu < 20$ deg
- Potential problems with normalization mismatch go away
- Shapes very similar, ~right for all

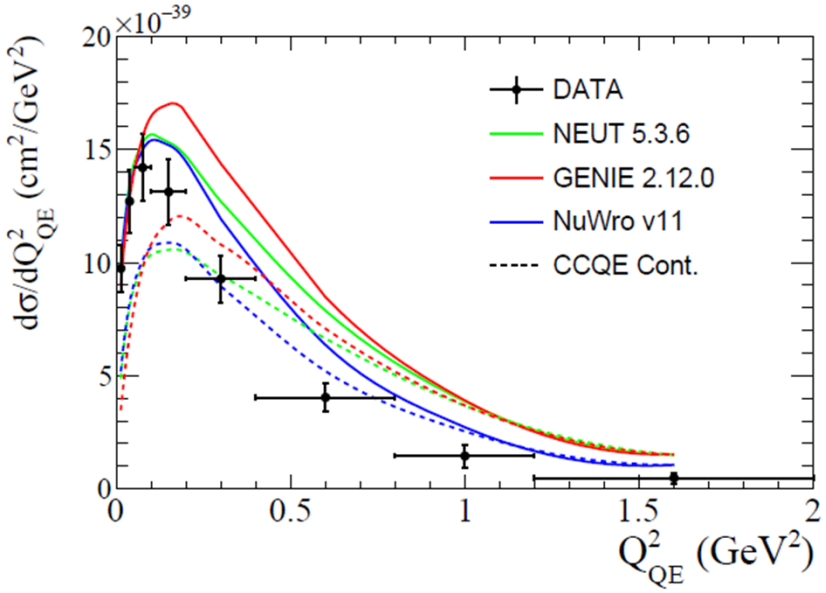




2p2h/QE composition interesting

- Q^2_{QE} assumes pure QE, ignores Fermi motion, constant binding energy
- NuWro, NEUT, and GENIE all use same Valencia 2p2h model and GiBUU is different

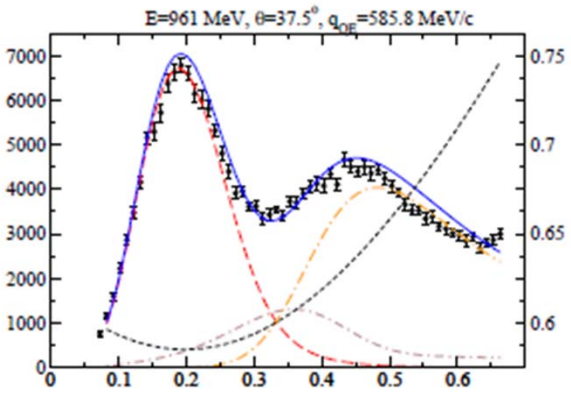




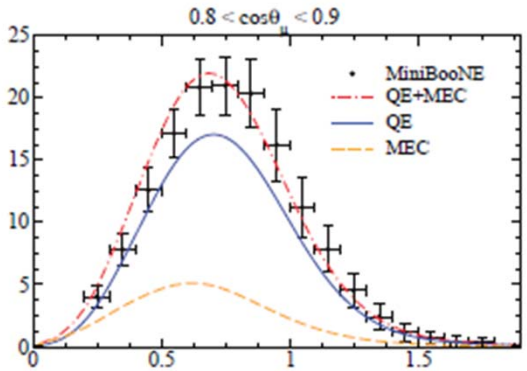
Theory – Super Scaling Approach (SuSA)

- Recent series of papers (Megias, et al.)
  - Inclusive (e,e'), (ν_μ,μ), $(\bar{\nu}_\mu,\mu)$
  - QE, Δ response from scaling fits; calculate MEC in RFG model
  - Excellent agreement with electron, neutrino inclusive data
  - Very hard to go beyond inclusive, not in any generator

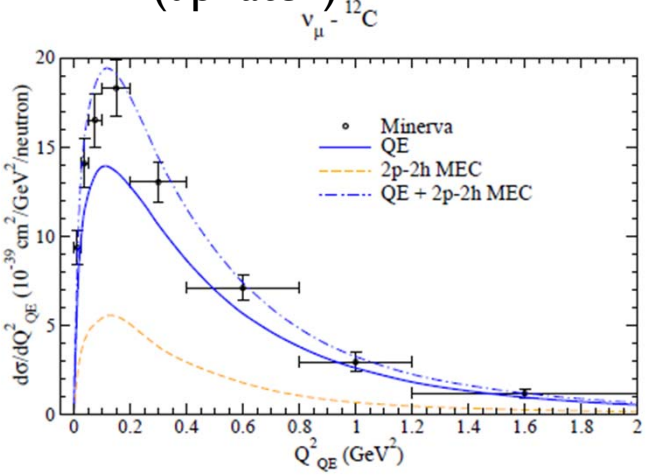
e,e'



MiniBooNE CCQE

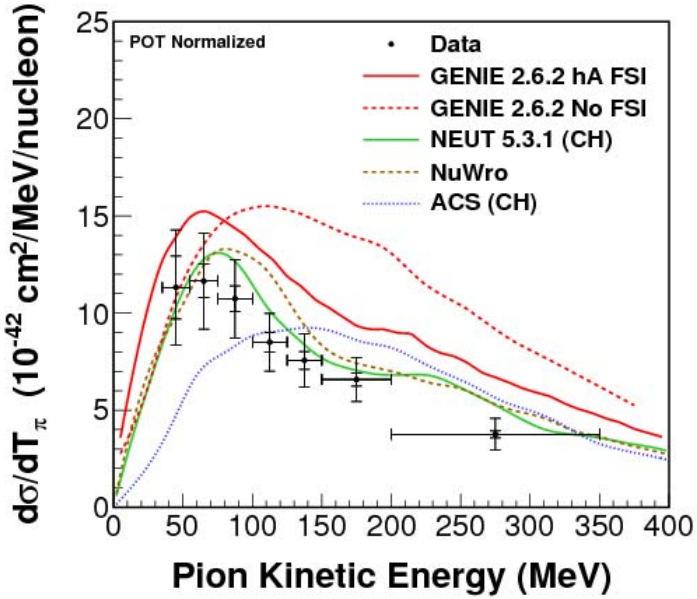


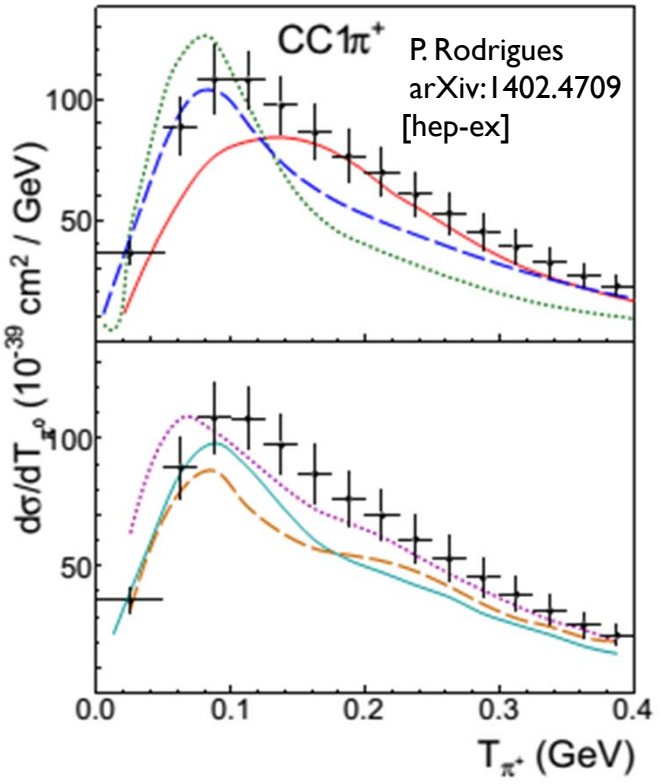
Minerva CCQE (updated)



MiniBooNE CH2 vs. Minerva ν CH π+ data

- Wide variation at first glance, Δ and FSI treatment matter
- FSI strongly affects shape, generators shape close to data
- No model fits both data sets
- Improvement important for oscillation experiments?



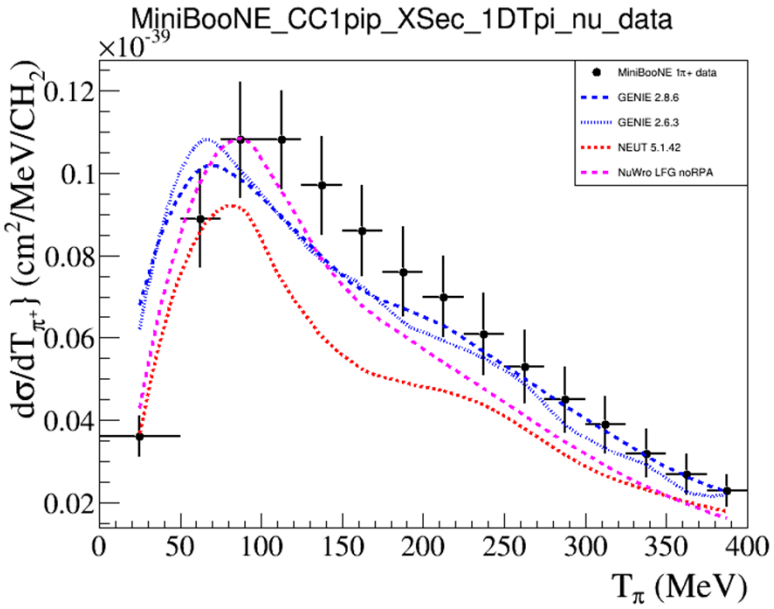


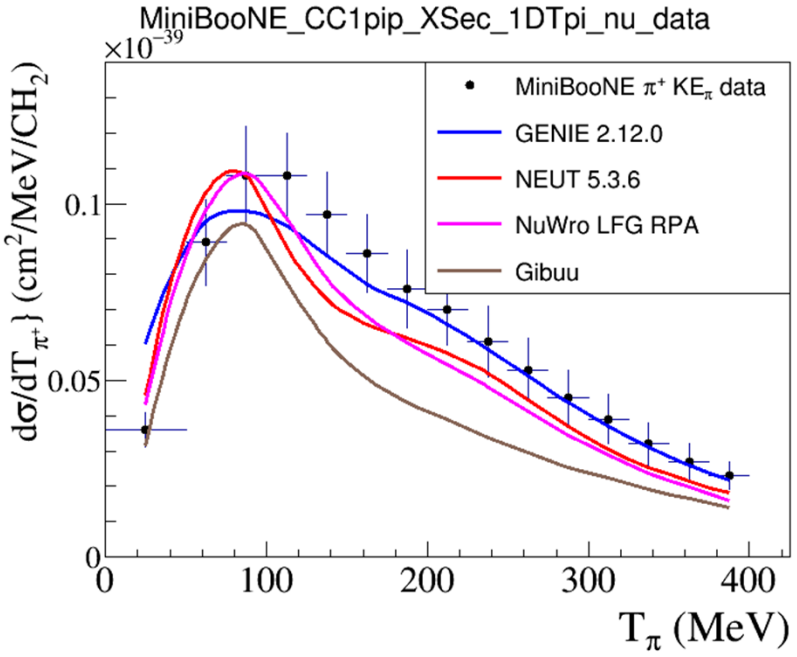
Model choices

Model	N res	Non resonant	Nucleon Momentum	Δ mods	FSI
Athar	Schreiner-Von Hippel	none	Local Fermi gas	Fit to (γ,π)	Attenuation only
GiBUU	Leitner et al.	Lalakulich et al. - empirical	Local Fermi gas	Fit to (γ,π) Oset	Transport
Valencia	Hernandez et al.	Chiral model	Local Fermi gas	Fit to (γ,π)	Salcedo-Oset (full)
GENIE	Rein-Sehgal	Bodek-Yang (extrap low W)	Global (rel) Fermi gas	none	Effective cascade
NEUT	Rein-Sehgal	Rein-Sehgal	Global (rel) Fermi gas	Via FSI model	Salcedo-Oset (full)
NuWro	Adler (Δ only)	Bodek-Yang (extrap low W)	Global (rel) Fermi gas	Via FSI model	Salcedo-Oset (full)

NUISANCE Comparisons – T_π OLD vs. NEW

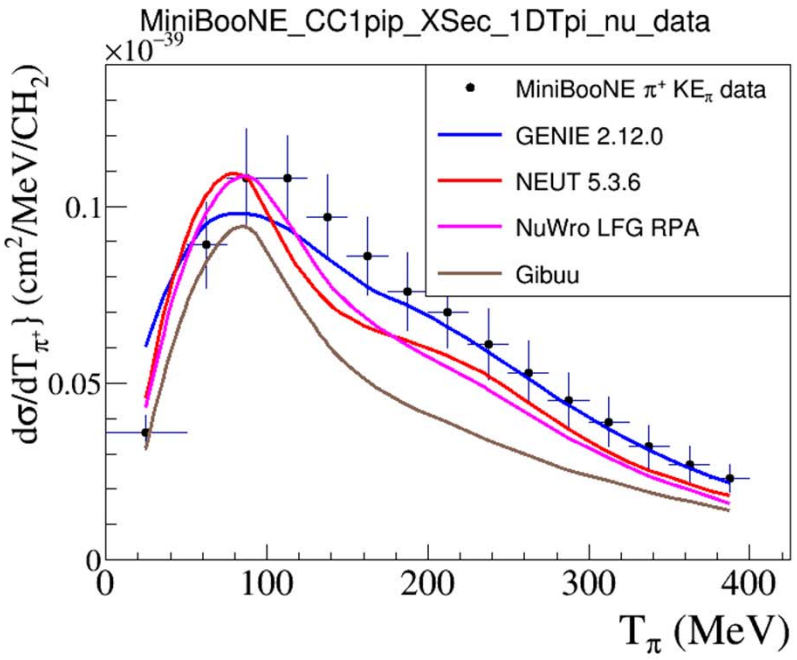
- New has significant improvements
  - NEUT has better tune to N data
  - GENIE has better form factors, FSI
- Better match, but discrepancies remain

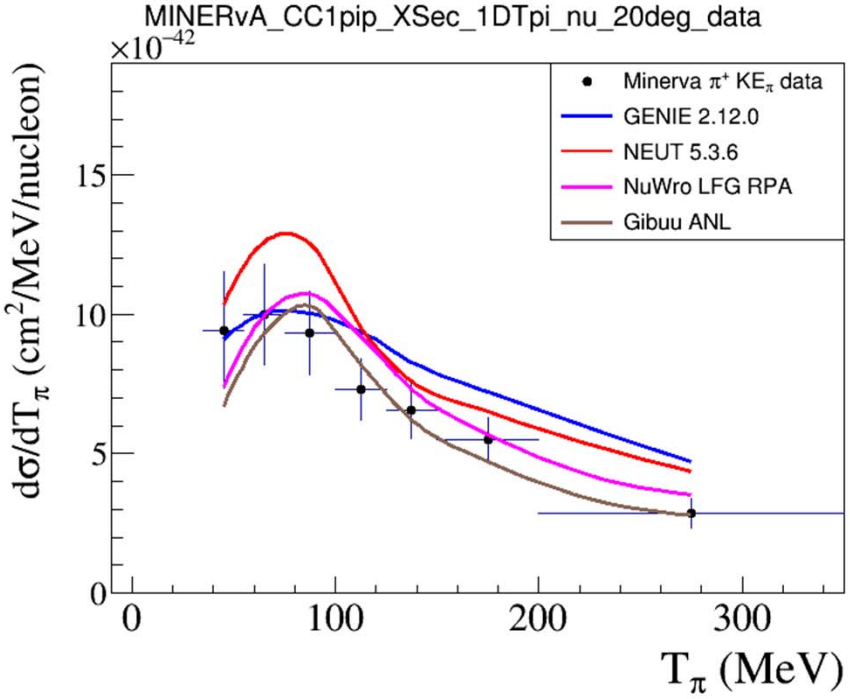




NUISANCE comparisons - T_π

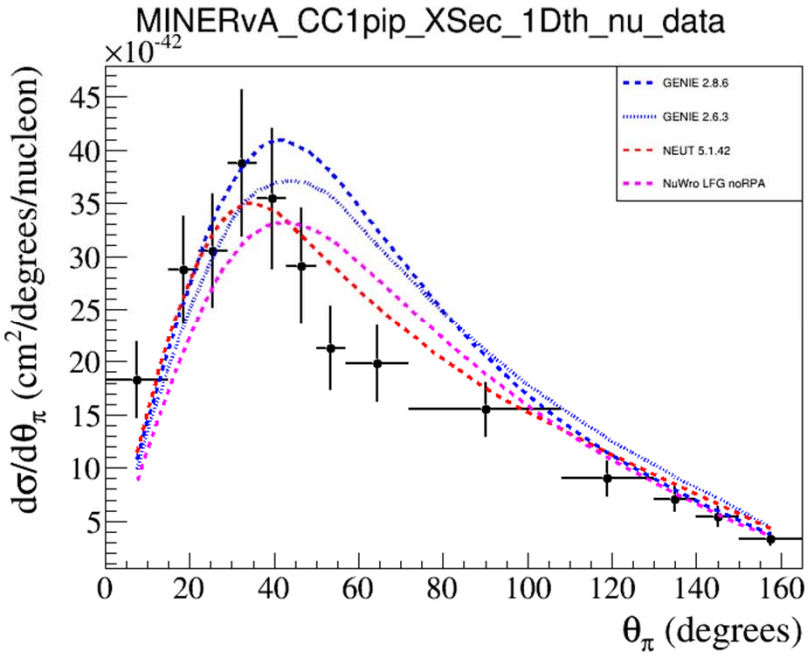
- Both magnitude and shape discrepancies ~10-20%
- FSI bigger issue than nuclear structure

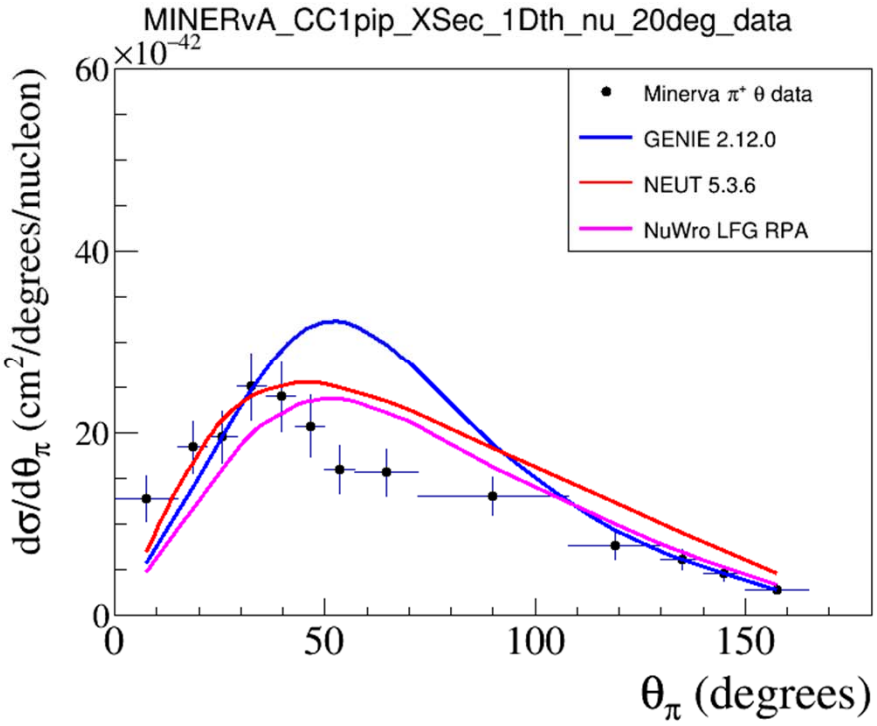




NUISANCE comparisons – θ_π New vs. Old

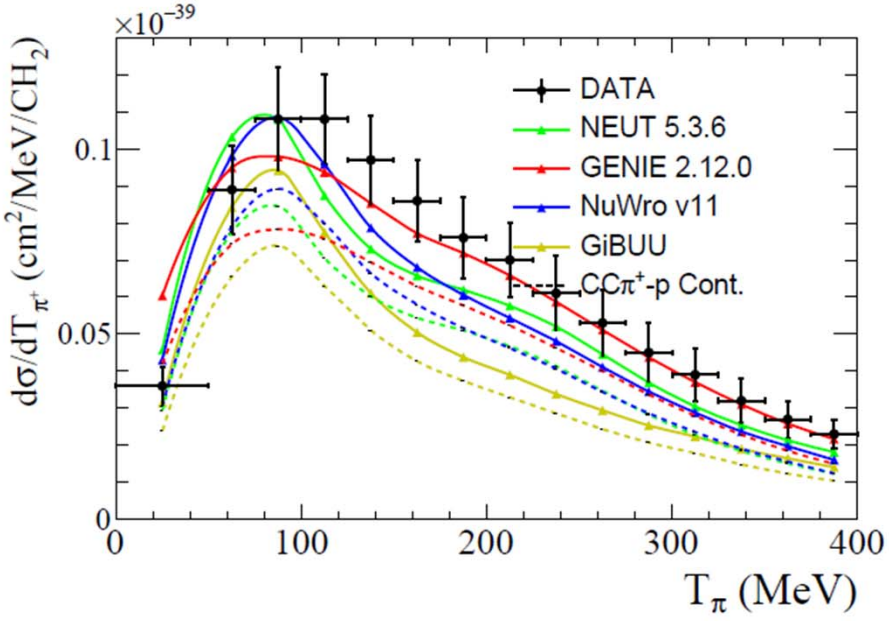
- Hardest to describe for generators
- New GENIE model does worse (T_π also)

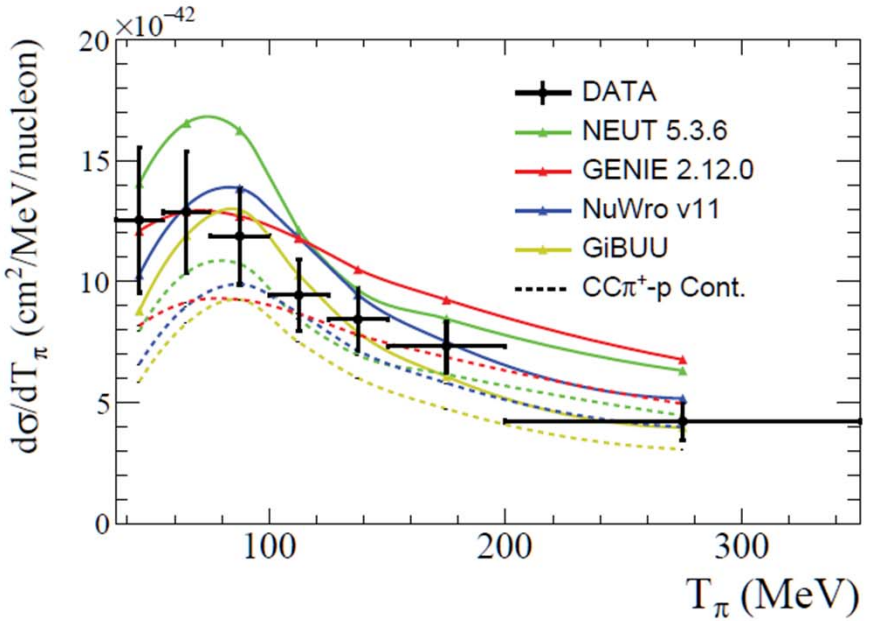




π+ production dominated by Δ^{++}

- Medium effects not in any generator, recently removed from GiBUU
- Wide variation in dominant nucleon diagram
- FSI effects are included





Looking ahead

- NUISANCE should be important tool (growing)
- Better theory?
  - LANL/ANL/Jlab (collaboration proposed - not simple)
  - Lattice form factor calculations to solve the Nucleon Problem?
- Better phenomenology
  - Learn from Pythia (discussions continue, νA harder)
  - Intelligent fitting – avoid parameterizing the unknown
  - Slow progress in electron scattering code (only GENIE, NuWro?)
  - New models tend not to have (e,e') or reweighting
- GENIE model for next steps
  - Find best model combination
  - Tune parameters within models to data (Professor, same as Pythia)

summary

- Large advances in adoption of better theory models
  - Need more?
- In GENIE, we are now tuning parameters in models to data.
  - Is this appropriate?
  - What parameters are important for including, ignoring? (MAQE?)
- Generator development depends on manpower
  - All progress is manpower limited
  - Postdocs funded in US, UK significant advance (but uncertain)
  - Experiments must provide manpower (new experiments)

summary

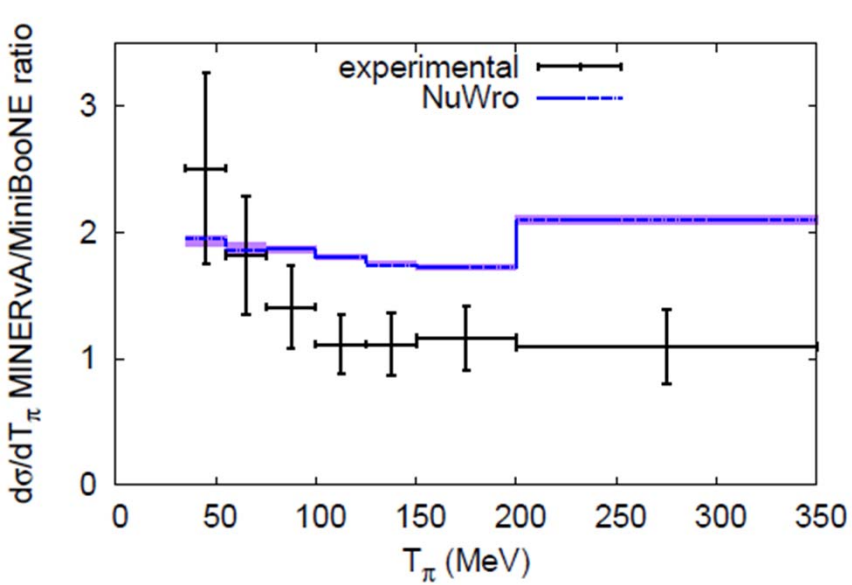
- Improved agreement with MiniBooNE, Minerva QE nuclear models, new Minerva flux
- Some improvement for 1π, ~10-20% discrepancies remain
- When is agreement with experiment good enough?
  - Are we there now?
  - We need to work harder on both event generators and signal definitions in experiment!
- All GENIE activities manpower limited
  - Much better interaction with theory, experimental communities in last few years, could still be better; funding issue complex
  - GENIE is still slow in advances (manpower, complexity)
  - Both NEUT and GENIE have adopted modern theory in last 2 years, improvement positive but limited

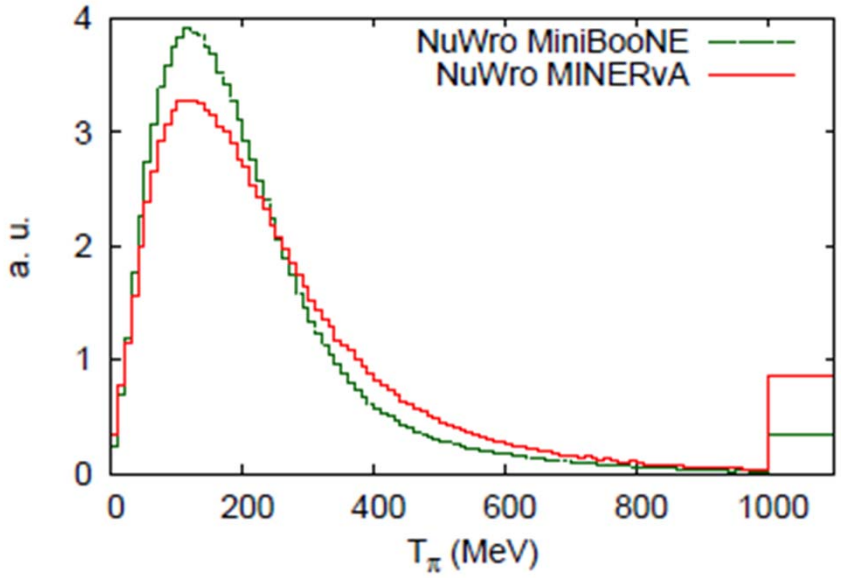
Generator advances (QE like)

- Guided in part by NuWro, GENIE and NEUT have had active programs to use better theory models
- NEUT (5.3.6 default)
  - Local Fermi Gas
  - Llewyllen-Smith
  - Valencia MEC+RPA
  - Improved proton FSI
- GENIE (2.12.0 alternate model)
  - Local Fermi Gas
  - Nieves QE with RPA+Coulomb
  - Valencia MEC
  - Improved proton FSI

Sobczyk & Zmuda (NuWro) PRD 2015

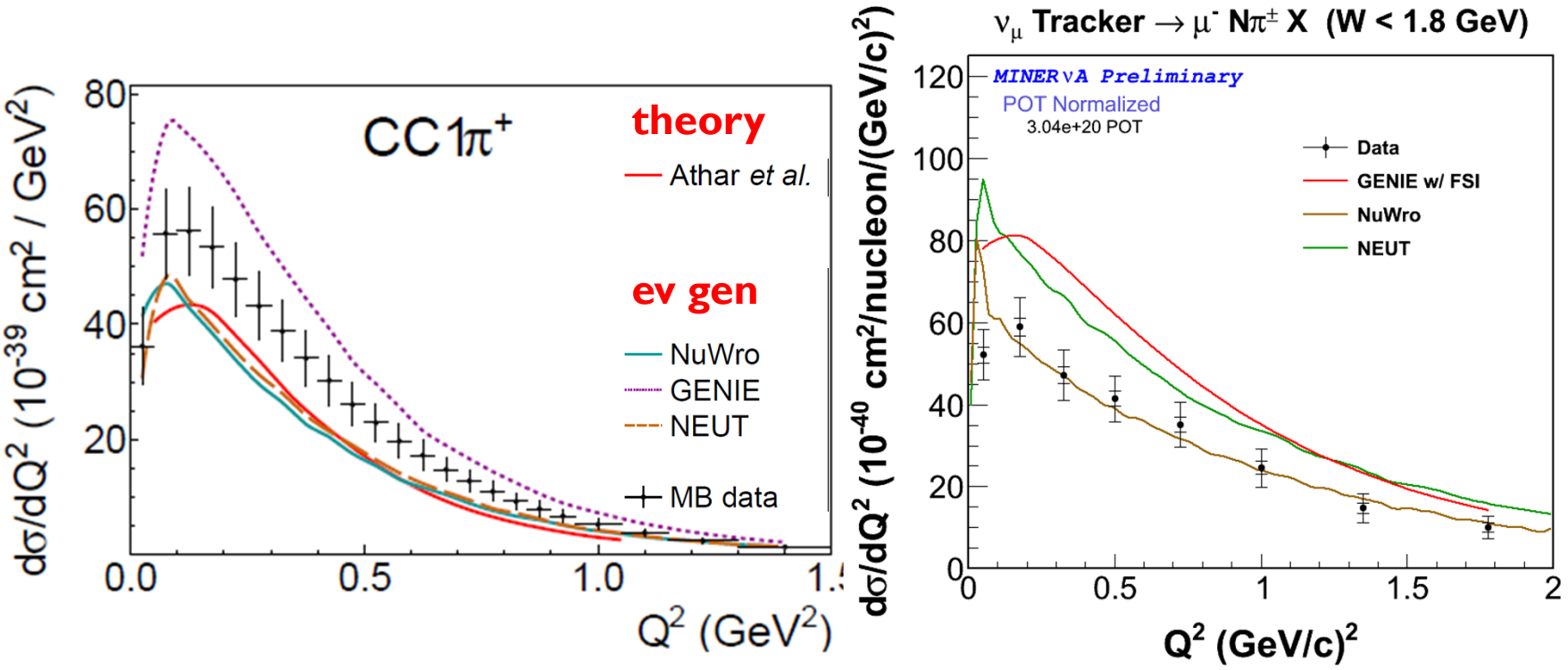
- Made ratio of experiments with proper error propagation.
- They predict factor of ~2, no large shape difference
- Question data normalization
- Predictions for *both* MiniBooNE and Minerva data have same shape for both GENIE and NuWro
- My studies with GENIE agree with these findings





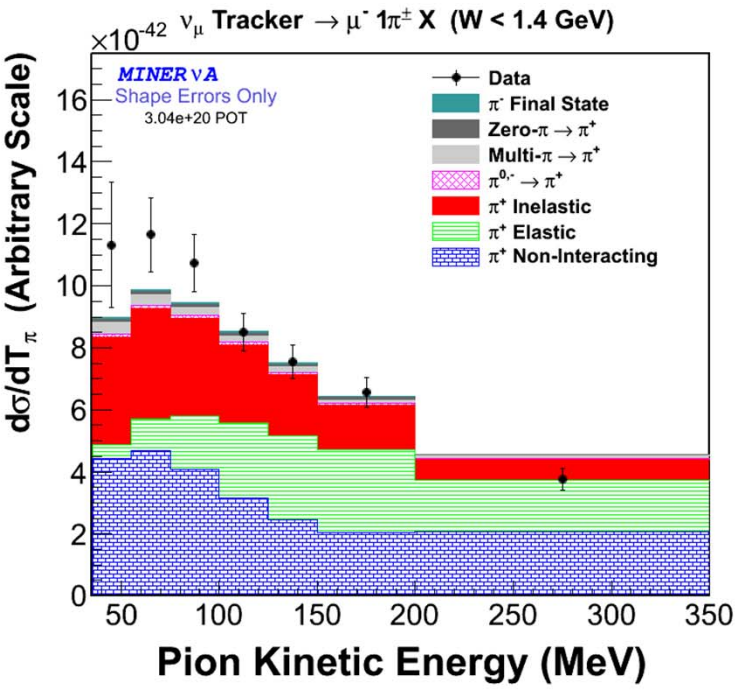
More data for μ, ν variables – Q^2

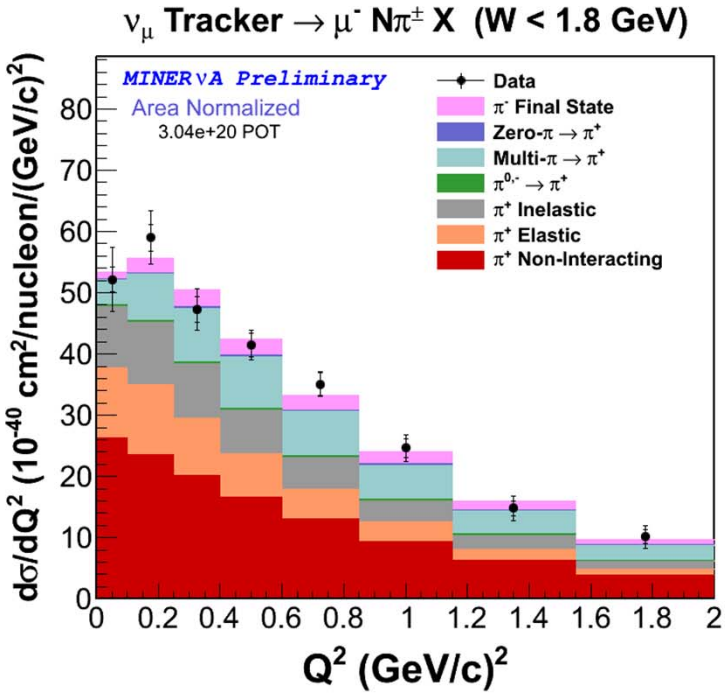
- Minerva (Carrie McGivern, W&C June, 15) for W<1.8 GeV
- Data from 2 expts have similar shapes, calcs ~agree.
- Predictions for Minerva have a spike at low Q^2.



FSI decompositions – focus on shape

- GENIE FSI model has a single interaction
- Pion kinetic energy shows significant changes in shape
- Q^2 shape largely insensitive to FSI interaction (low Q^2)





Theory/generators

- Theory typically from nuclear theorists
  - GiBUU (Mosel and collaborators)
  - Valencia (Nieves, Alvarez-Ruso, Vicente-Vacas, Hernandez+ students)
  - Athar (Athar, Singh and collaborators)
  - Weak ties to experiment, but improving
- Generators typically from high energy experimentalists
  - GENIE (Andreopoulos, SD, Gallagher, Perdue...)
  - NuWro (Sobczyk, Golan ...)
  - NEUT (Hayato and numerous T2K students/postdocs)
  - Fully integrated into experiments
  - Actively including improved nuclear theory, catch up in 2 years?

GiBUU (Mosel) vs. GENIE default

- Local Fermi Gas momentum distribution [global FG]
  - Smearing from local potential well [no]
- Principal vertices
  - Fit to old bubble chamber data with modern models [same]
  - Simple MEC (constant matrix element) [none]
- FSI
  - Transport equations allow some medium corrections [empirical] [no medium corr.]
  - Slow, but very accurate and well-tested [fast, well-tested]
- Best nuclear physics available today
- GENIE is (slowly? surprisingly quickly?) catching up

Tensions in data interpretation

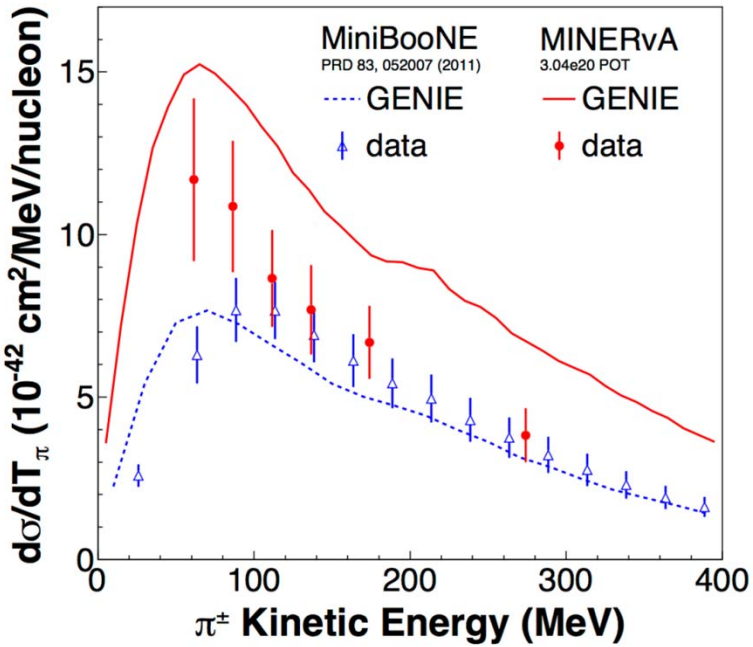
- **Work**shop organized by K. Mahn, SD summer, 2016
- Analyzers from MiniBooNE, Minerva, and T2K
- Core people from GENIE, NuWro, NEUT, Nuance
- Compatibility of measurements
  - Dependence on generators
  - Acceptance, signal issues
- How can results be compared?
  - Single graph
  - Theory intermediary
- Preliminary results here, article in progress

Monte Carlo

- Event generators have significant role in every experiment for background, systematic errors
- Traditionally, EG in neutrino experiments done by experimenters (like me) (unique situation)
- GENIE tries to be Universal EG, some success
- In past few years, nuclear theorists have developed significantly improved models (important advance)
- EG groups have worked hard to include these improved models, show some results today

How well do MiniBooNE and MINERvA agree?

- MiniBooNE - $<E_\nu>$~1 GeV; MINERvA - $<E_\nu>$=4 GeV
- W cuts are different, covered in calculations (GENIE 2.6.2)
- MINERvA (Eberly and I) tried to design experiment for direct comparison.
- MINERvA has much larger contribution from higher W, considers it background. MiniBooNE cuts W<1.35 GeV and adds higher W strength (still Δ) from model (~28% from GENIE)
- Therefore, need to increase MINERvA data by 28% (and corresponding GENIE calc) Direct comparison not advised. MiniBooNE not able to remove model dep.
- Shapes are different

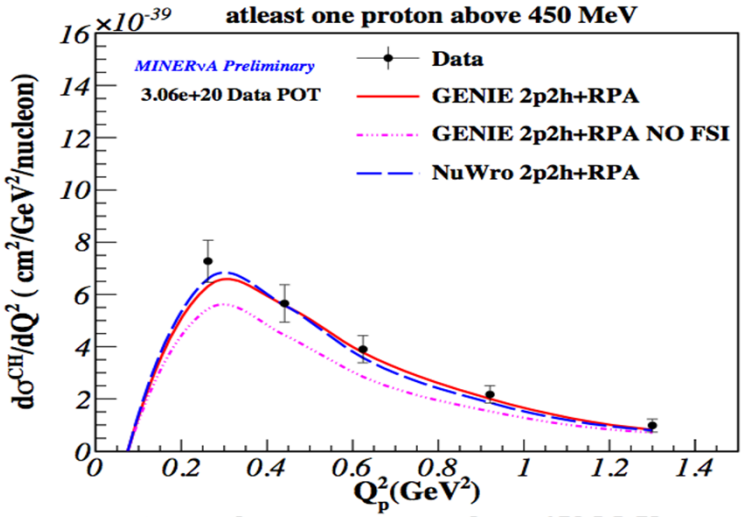


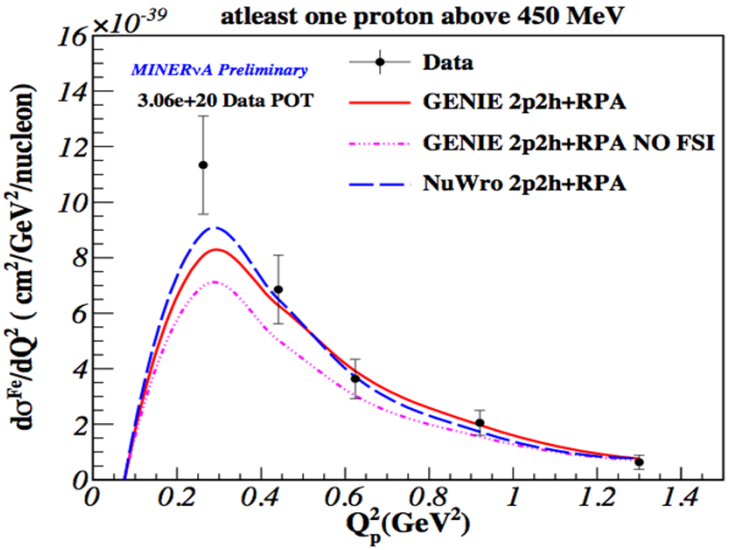
responses

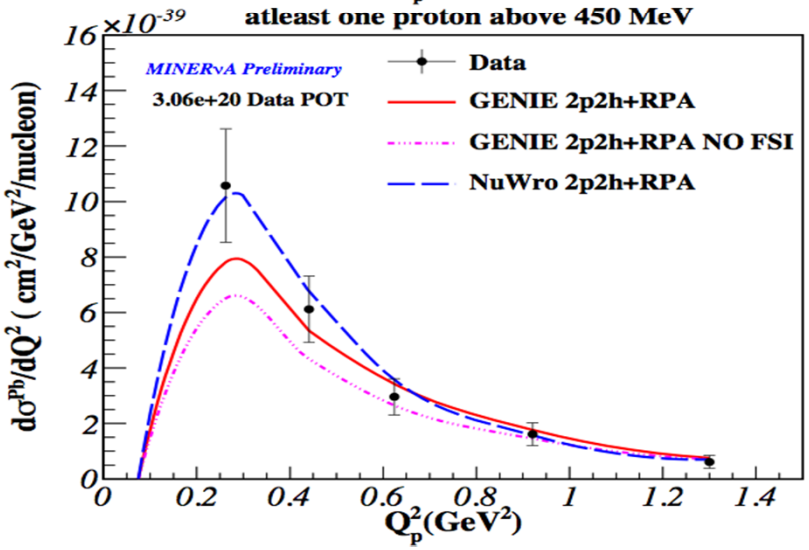
- Theorists have fitted models to existing (e,e'), πA, and older νd data. Clearly better than event gen at the time.
  - What can be changed?
  - GiBUU prefers ANL νd data for fitting
  - Ask why no new νd data?
  - Valencia improves pion production vertex
  - Sobczyk & Zmuda question shape difference, suspect magnitude error
- New and improved data
  - MiniBooNE publishes ν production of π^0
  - Minerva publishes ν production of π^+, νbar prod of π^0.
  - T2K now published
  - More Minerva data coming

Minerva QE-like A dependence

- One of the expt major goals
- p momentum>450 MeV/c
- Q^2 calculated from proton
- No major issues, but NuWro is better (FSI)

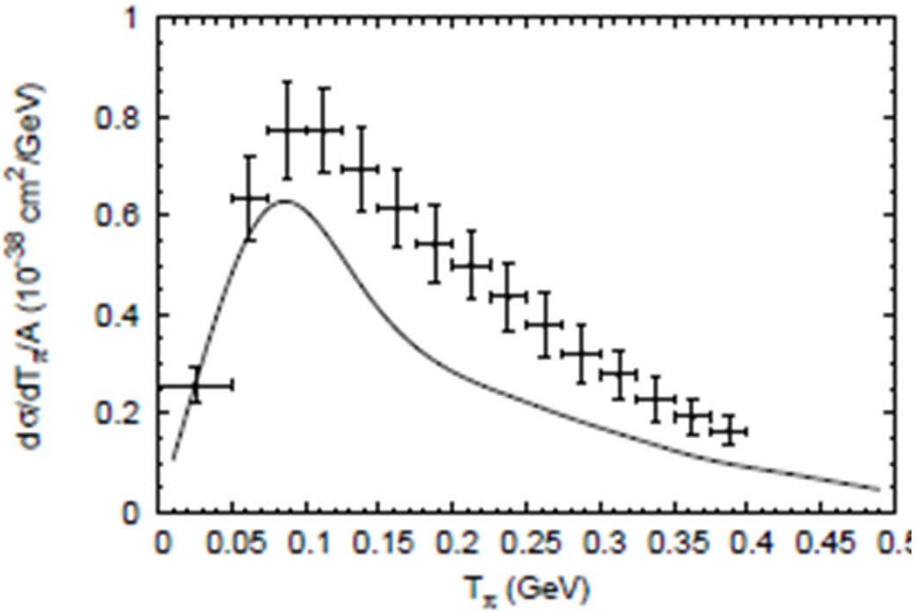


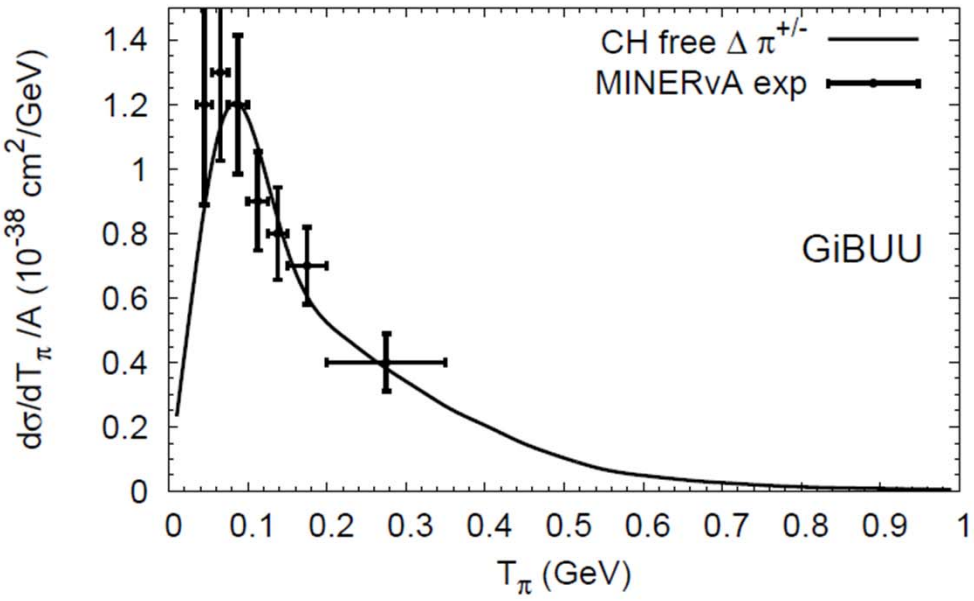




GiBUU comparisons- T_π

- Results from Mosel/Gallmeister arXiv:[nucl-th]1702.04932
- Calculations don't include coherent contribution (~7% for Minerva)
- Seems to be both magnitude and shape problem





Solutions?

- Data
  - Reanalysis of old data
  - New analyses of CH data (T2K, Minerva)
  - New experiment
- Theory
  - Coupled channel work of Nakayama, Sato... very interesting
  - Not in any generator