GENIE update – a personal view

Steve Dytman, Univ. of Pittsburgh

NusTec
11 December, 2018

- group changes
- v3 + reweighting
- model advances, plans
- electron scattering
- v4

GENIE group changes

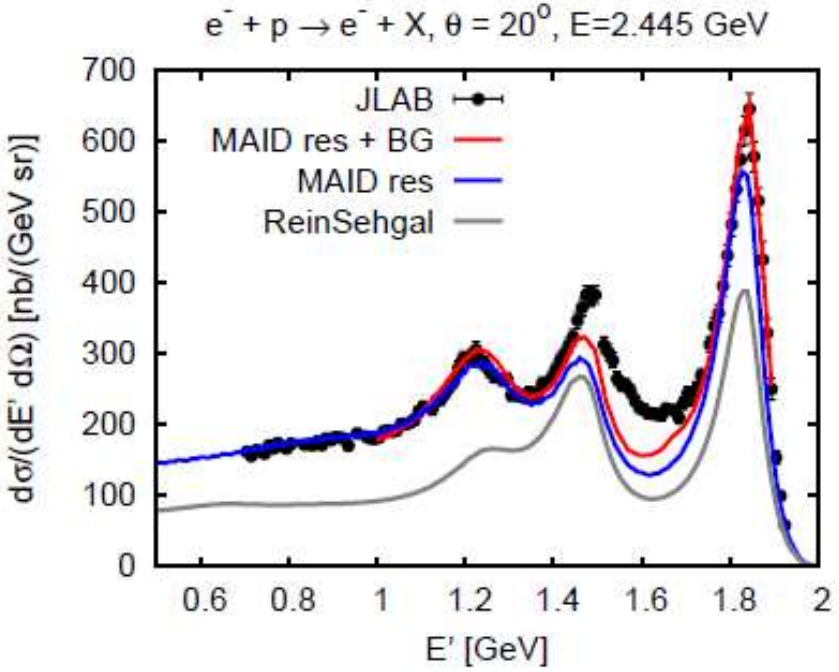
- FNAL
  - After contributing many fantastic advances, Gabe Perdue has left GENIE for Quantum Computing
  - Walter Giele (theory), Steven Gardiner (expt postdoc) joined
  - Group here (including me) key in recent reweighting release
- Liverpool group – Andreopoulos, Roda, Dennis, Tena-Vidal
  - New fitting code
- Dubna group – Kakorin, Naumov, and Kuzmin
  - Important debugging work on Rein-Sehgal…
  - Pauli blocking in Rein-Sehgal resonance model
- MIT group – Hen, Ashkenazi, Padadopoulou
  - Bug fixes, additions to electron scattering section

GENIE v3.0.0

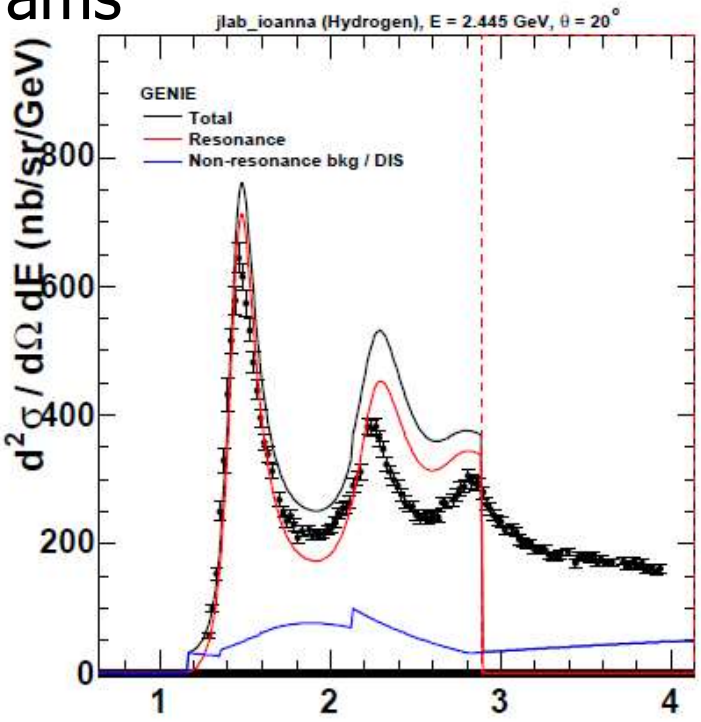
- Collects models into Comprehensive Model Configurations (CMC), I prefer to call them model sets
  - Most compatible physics (too many energy scales to truly compatible)
  - Options to match energy scale of each experiment
  - Models are as good as existing data, theory
  - Not done, new contributions essential (data, *tunes*, theory)
  - New and improved FSI (cascade similar to NuWro)
- Presents new tunes
  - Only deuterium data for now, more later
  - Compatible with each model set (e.g. Rein-Sehgal, Berger-Sehgal)
  - Sometimes expanded resonance region (larger W_{cut})
  - Provide full error analysis for each

Repeat comparison from NUINT14

- Complaints about Rein-Sehgal often assume same masses, width, and form factors as 1981 paper.
- GENIE regularly updates res params



GiBUU from Tina Leitner, NUINT08

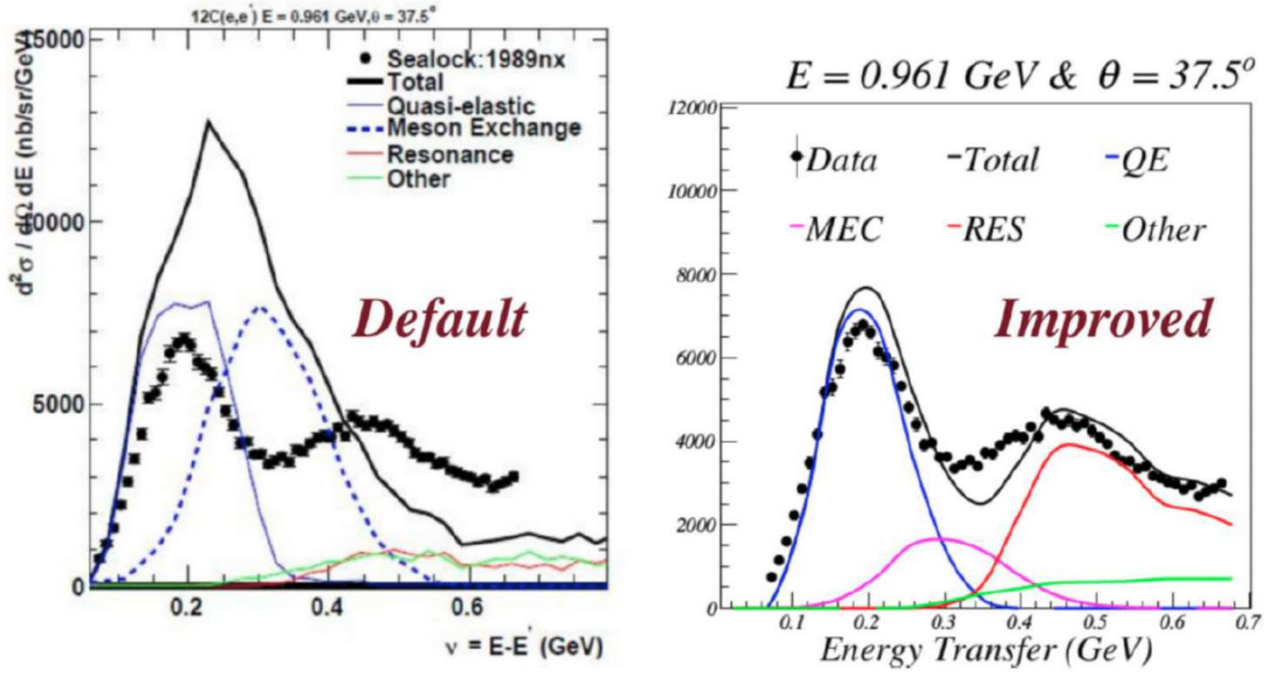


GENIE validation plot 2014

GENIE advances in (e,e')

- From Afroditi Papadopoulou - NUINT18
- Continued progress associated with *e4ν* collaboration

When we got started ... *... Today*



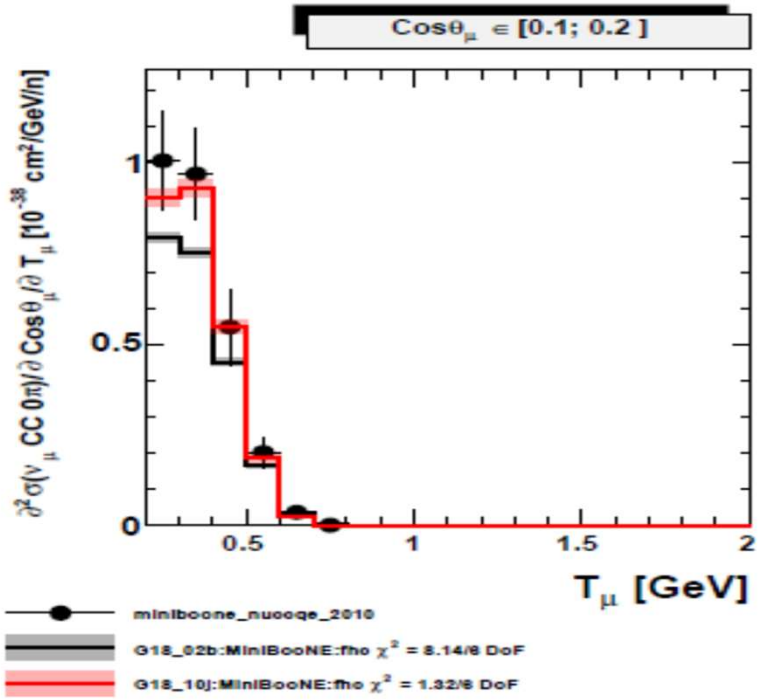
**Genie R-2_12_10*

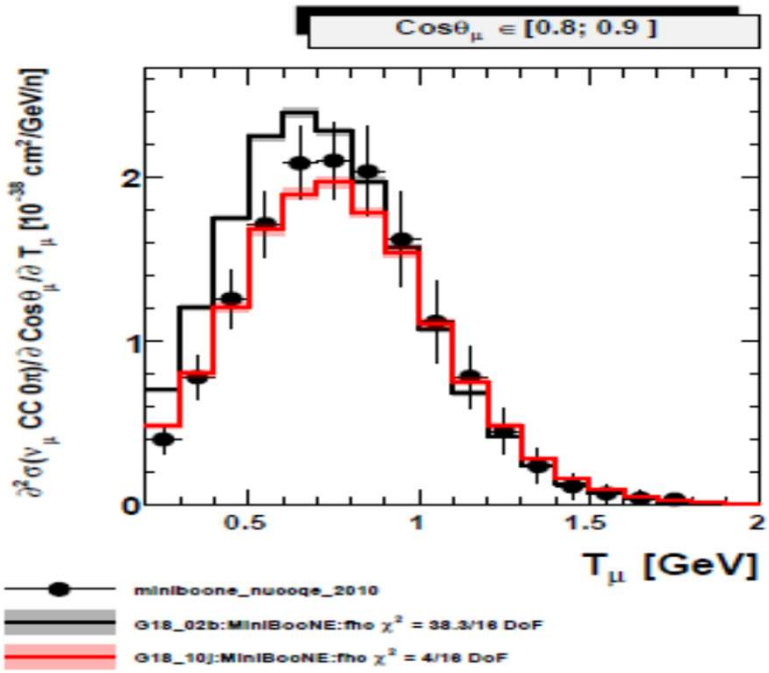
V3.0.0

- Major release
  - Make all models equally accessible (no switching of xml files)
  - Model sets get designations
    - G00_00a is old default for historical reference
    - G18_01a is updated old default (still RS)
    - G18_02a switches BS+MiniBooNE axial form factors for RES/COH
    - G18_10i adds LFG & Valencia quasielastic/2p2h & Z expansion GA
    - G18_01b, G18_02b, and G18_10j switch hN for hA FSI
    - hN is new Cascade model with medium corrections for π, N
    - hA is schematic model which is data-based
  - Include new fits to $\nu N \rightarrow \mu \pi N$ (see Julia Tena Vidal talk)
- All plots in this talk from v3.0.0

Modern calculation has better agreement

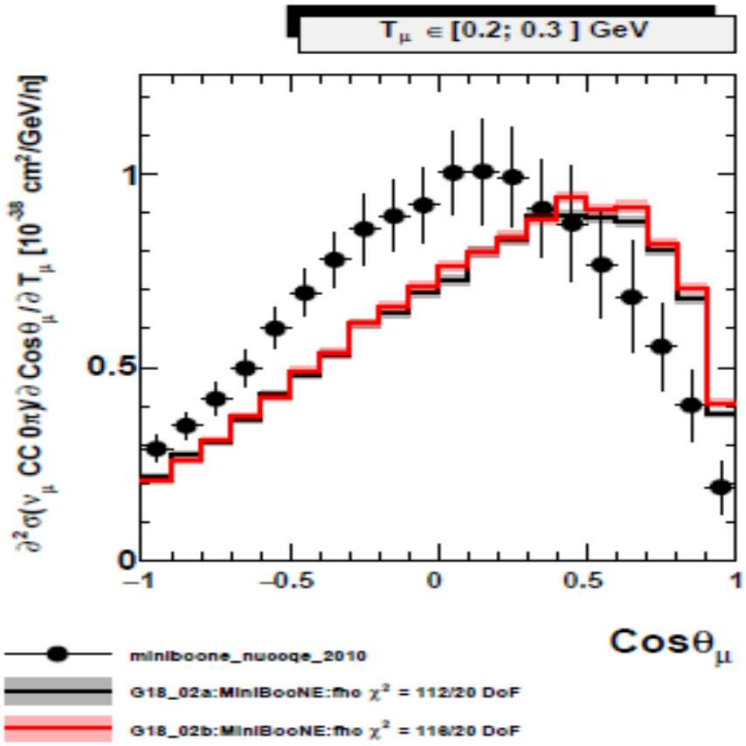
- **G18_10j** has full Valencia CCQE – QE with RPA/Coulomb, 2p2h with local Fermi gas (LFG) nuclear model
- Compared with **G18_02b** – Lwlyn-Smith, Empirical MEC

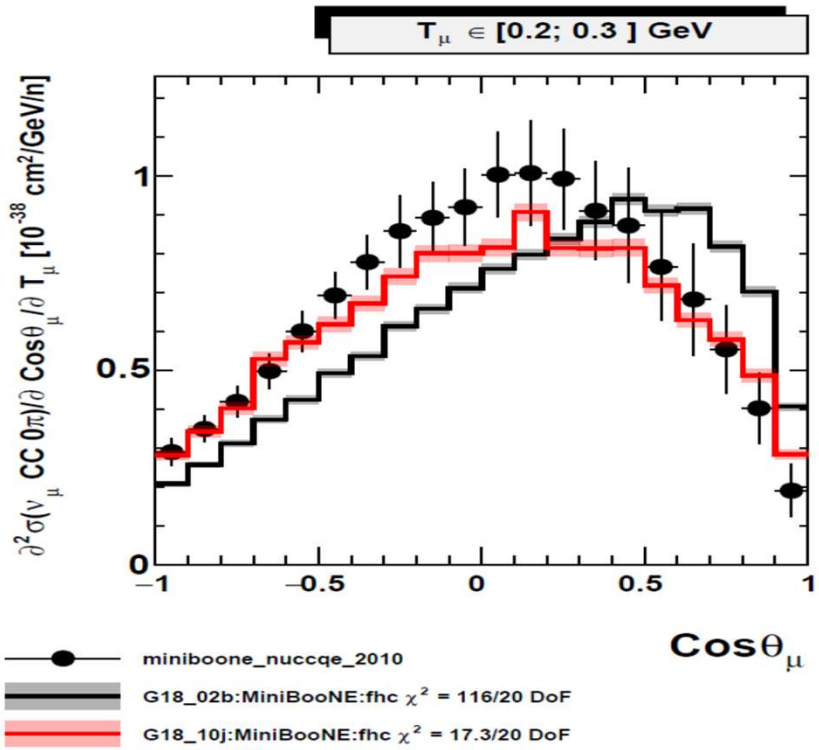




More detail for MiniBooNE CC0π

- Left compare role of FSI (hA2018 vs. hN2018) with LS
  - Angular distribution for low T_μ is not right (data or theory?)
- Right plot shows LS+Empirical MEC vs. Nieves QE+MEC
  - Looks like problem was with theory not designed for low energy





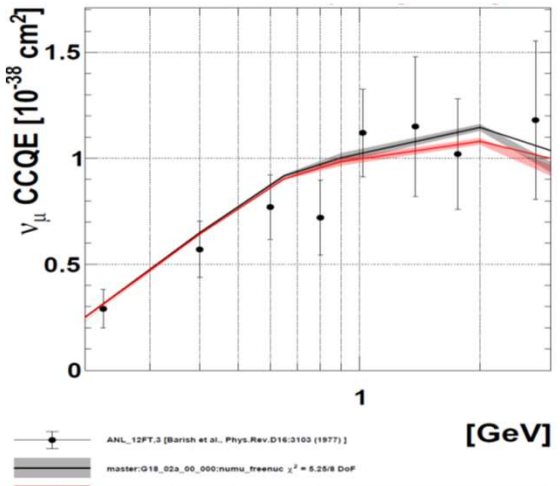
Tuning details - Professor

- Professor is used in many places, e.g. Pythia, for *multi-parameter tuning* (~20 params, improved use of *Minuit*)
- Uses brute force, build solutions for all variations of selected parameter within given bounds on a finite grid
- Find chisquare minima in each parameter
- *Use stored solutions to estimate errors on each parameter*
- Can report full correlation matrix
- *Fit parameters not connected to reweighting in our version*
- Can include priors, nuisance parameters
- Nuisance remains an excellent public option

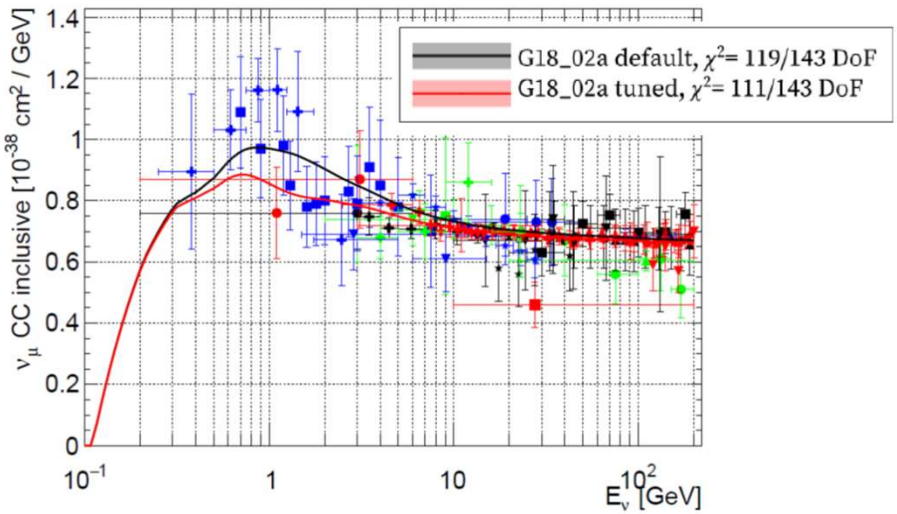
Fitting results

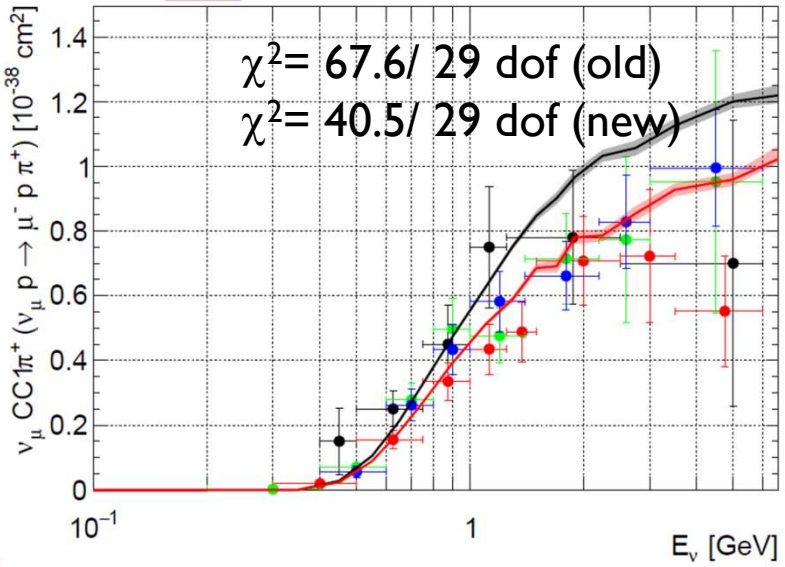
- Adding exclusive channels greatly improves agreement with them; new tension for inclusive data

$\nu_\mu\, n \rightarrow \mu^-\, p$



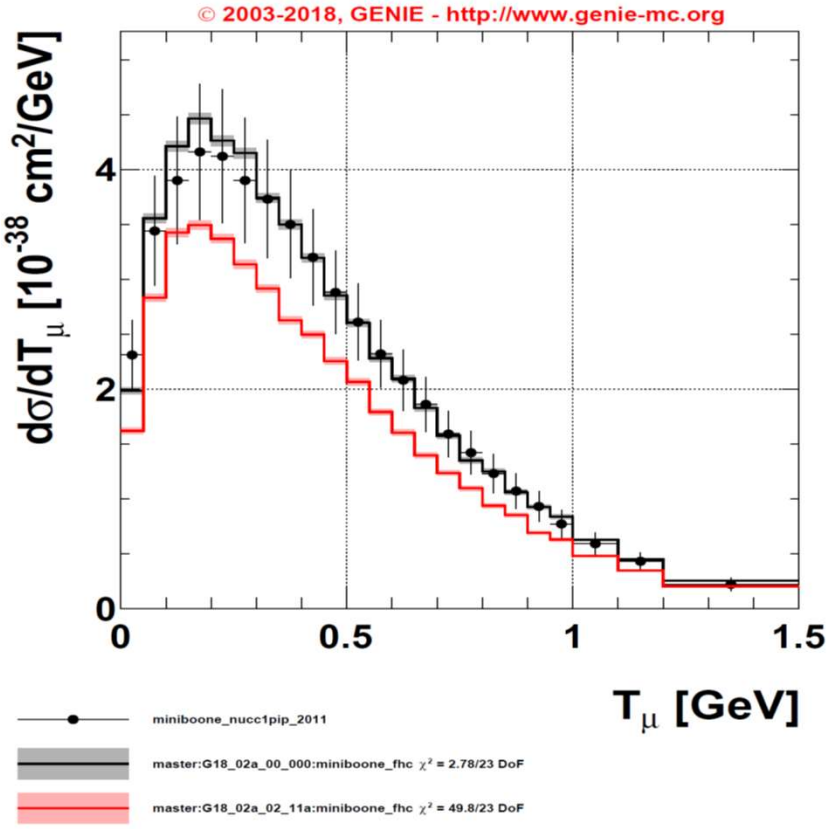
$\nu_\mu\, p \rightarrow \mu^-\, \pi^+\, p$

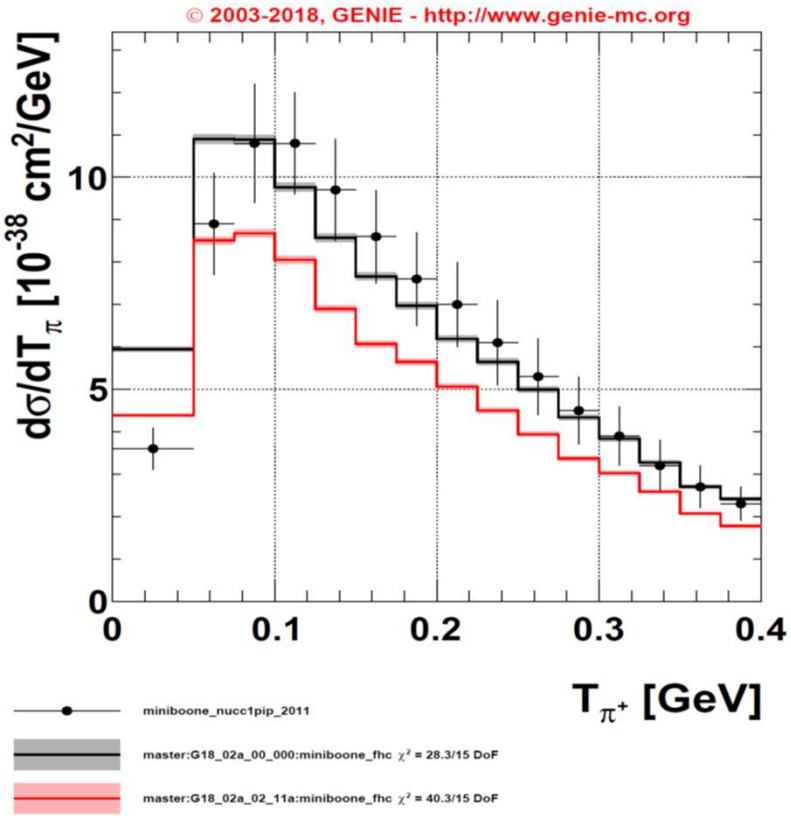




Results - 02a vs. 02a_tune

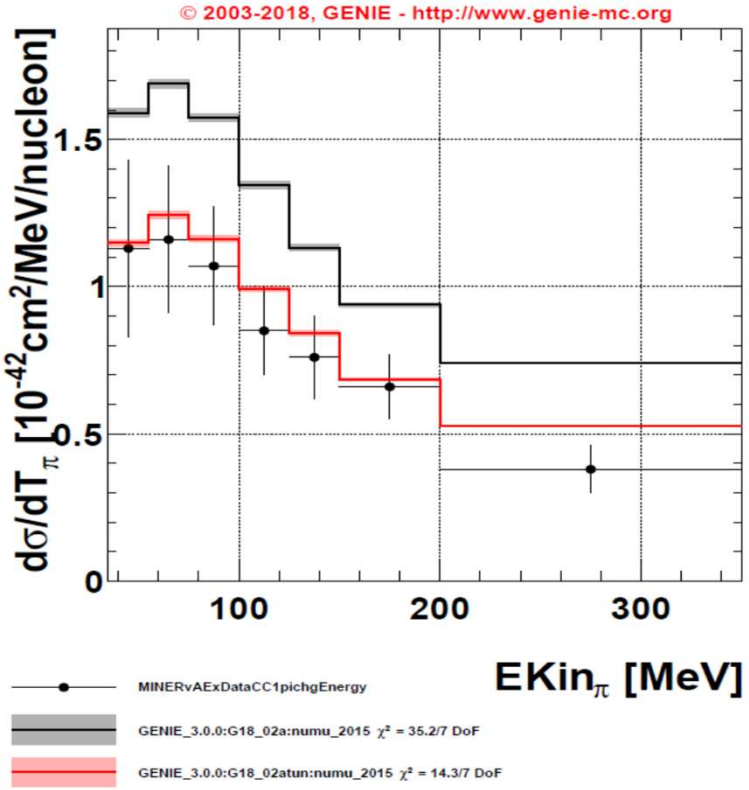
- MiniBooNE ν_μ CC1π^+
- New tune has poorer agreement in magnitude, shape ok

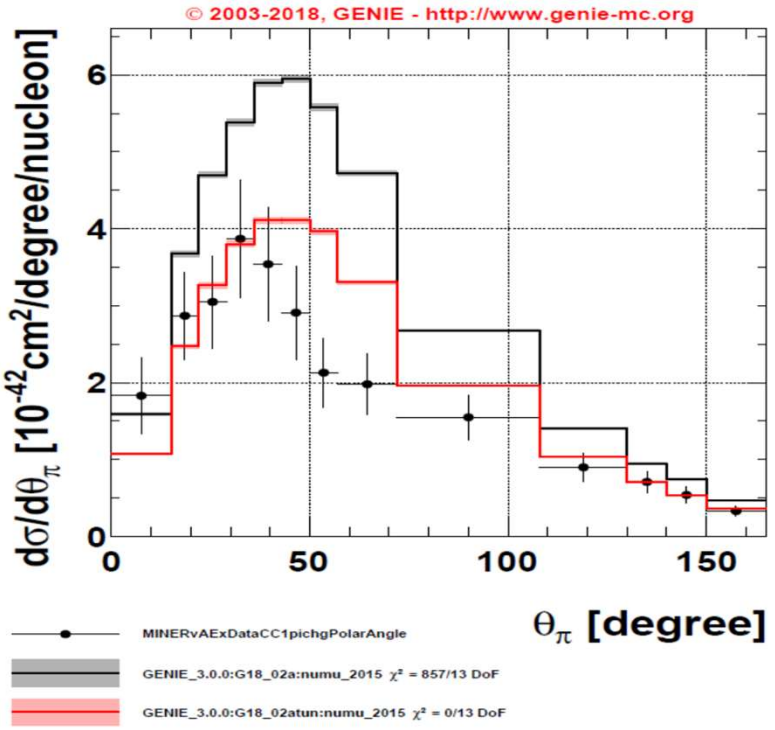




Results - 02a vs. 02a_tune

- MINERvA ν_μ CC1$\pi^\pm$
- New tune produces correct magnitude
- Angle still not easy to match





GENIE status

- ~5 postdocs now in GENIE, 20-50% effort essential
  - With these postdocs and new user groups, improved capabilities
  - Numerous integration tasks, tracking down bugs
  - Comparisons/Fitting software
  - Reweighting
  - Comprehensive FORTRAN interface by Steven Gardiner
  - Common interface for hadronic matrix elements by SG
- FNAL staff provides growing professionalism
  - Sophisticated bug fixing
  - Weekly validation runs posted at public? web site
  - Adding data for comparisons studies
  - Growing number of unit tests

GENIE status - theory

- Growing theory interest much appreciated
  - Expert help from Luis A-R on resonances
  - MAID resonance vector form factors – Libo J, Luis A-R
  - Coherent rho from Nomad via Libo J
  - DIS model from Sajjad A, Huma H with nuclear corrections
  - QE+MEC with spectral function model from Noemi Rocco
  - Ab initiio QE model from Saori P, Allesandro Lovato
  - Radiative corrections from Doreen W, Stefan P
  - DIS model from Walter G
  - SUSA QE+MEC from Sara B, Marco M, Stephen D
  - Sato-Lee-Nakayama principal amplitudes/cross sections (πN, NN)
  - … others I forget

GENIE-NuWro summit mtg in L'Aquila

..and NuWro will become a model within GENIE

GENIE needs

- General
  - Good way to assess systematic errors for more sophisticated models
  - Simple interface for new models
  - Continued support for GENIE postdocs
  - More direct involvement from experiments
  - More and better data from expts – fits as good as inputs
- QE+MEC
  - Good way to integrate *ab initio* models (QE-like from pion abs?)
  - NC 2p2h (MEC) – no theory yet
- RES
  - Better integration of resonant and nonresonant – none now
  - Medium effects on Δ, NN$\rightarrow$NΔ coming from nuclear physics
  - Sato-Lee model – lots of new models, significant integration issue
  - 2p2h (MEC) model

GENIE needs

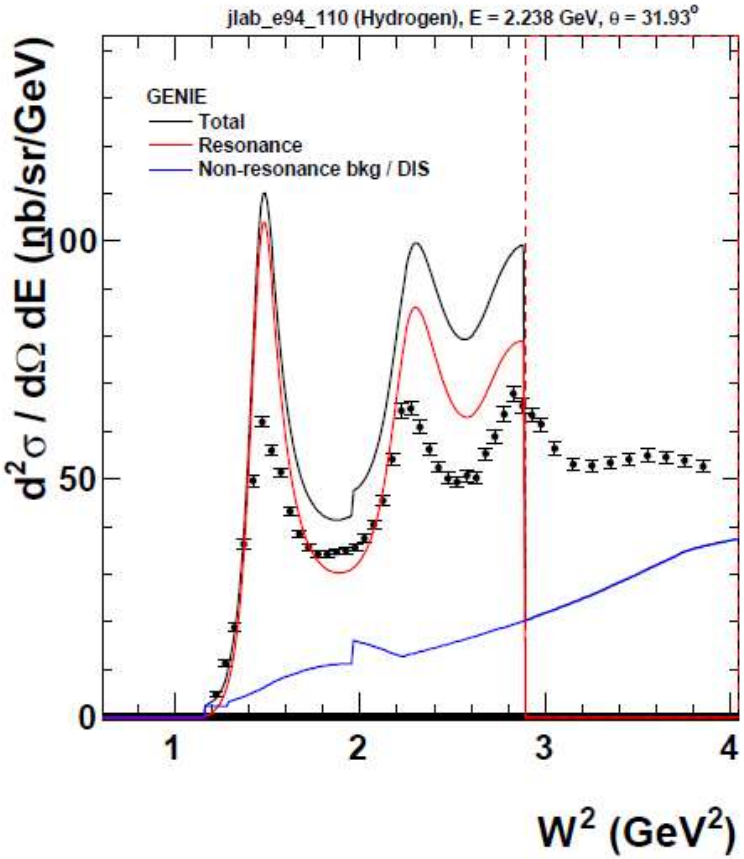
- DIS
  - Nuclear corrections – very little exists now
  - Hadronization - simple now, use Jlab, HERA data
- FSI
  - Effective, cascade model good enough?
  - Low energy interactions, pre-equilibrium/compound (γ,n emission)
  - Integrate GiBUU model
- Electron scattering
  - Continued interaction with e4ν collaboration
  - Rework GENIE to properly use e4ν data
- Newer versions of any of the large number of less visible models – charm production, NC processes…
- Something we haven't thought of

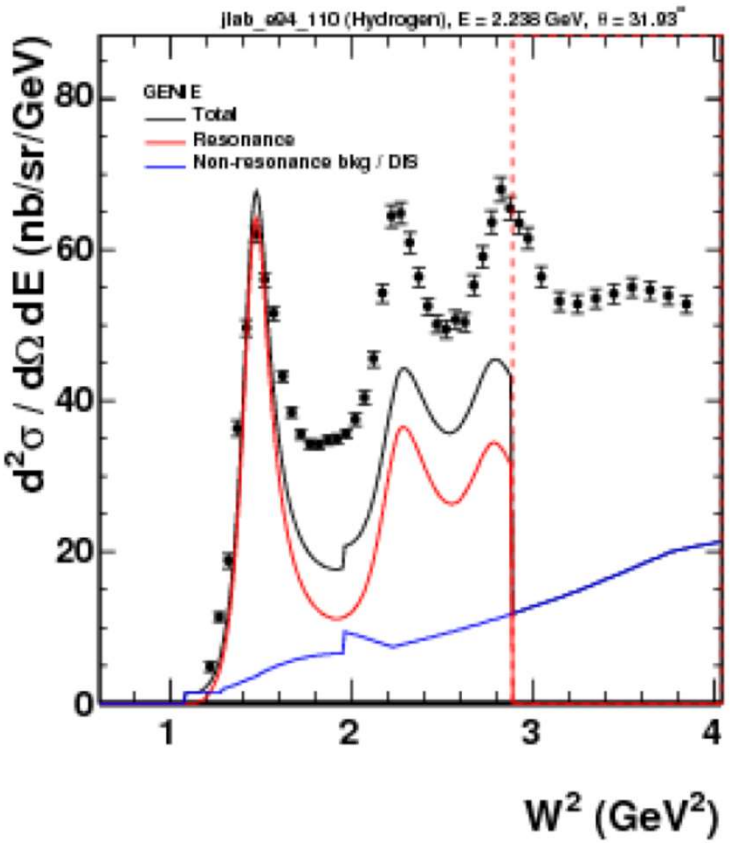
conclusions

- GENIE much better off than a few years ago
  - More postdocs, FNAL group, more theory involvement
  - New models will be introduced
  - Significant tuning underway – v4 will have nuclear tunes
- Level of involvement from experiments still an issue
  - e4ν has committed 2 young people to GENIE
- Addition of NuWro good for everyone
- With argon experiments, needs have grown again
- Community will decide what future is

New comparisons (ep->e'X) p, d targets

- Original on left, maid FF on right – high Q^2 at Δ peak





Model sets

- Historical default (not supported)
  - **G00_00a** with hA, no MEC, **G00_00b** with empirical MEC
  - RFG, Llewyllen-Smith, Rein-Sehgal (not original)
- Improved historical default
  - **G18_01a/b** with hA2018/hN2018. better basic (e.g. coherent)
  - RFG, Llewyllen-Smith, Rein-Sehgal (not original), empirical MEC
- Improved pion production
  - **G18_02a/b** with hA2018/hN2018
  - Includes Berger-Sehgal resonance and coherent, updated axial FF
- Improved quasielastic/ nuclear model/ axial FF
  - All have Local Fermi Gas, Nieves QE, Valencia MEC
  - **G18_10a/b** has dipole FF, **G18_10i/j** has z-expansion FF

Summary of models

- Total of 10 model sets *per deuterium tune*
- Each callable via 1 new switch --tune G18_10a_00_000
- year model set param set tune
- Splines must be compatible with chosen data set
- Low energy experiments (dominated by QE) should choose G18_10x for optimal physics
  - Valencia QE has very good description of MiniBooNE QE
- Higher energy experiments (dominated by pion production) should choose G18_02x or G18_10x
  - Rein-Sehgal/Berger-Sehgal have updated resonance parameters
  - Berger-Sehgal coherent has improved pion scattering model

Summary of form factors

- Vector resonance form factors will be state of the art
  - Delta response at low Q2 was too large
- Need improved nonresonance response (at least vector)
- Need to refit axial form factors

Upgrades to GENIE in progress/anticipated
Other than form factors

- New formalism beyond Rein-Sehgal, Berger-Sehgal?
- New ν N $\rightarrow \mu \pi$ N?
  - Nakamura, Sato, Lee… - work has started
  - Lattice calculation?
- Medium corrections? (GIBUU had them, then taken out)
- MEC/2p2h for resonances
- FSI to properly match nucleon response

significant work remaining, varied needs

- Theory
  - Much remains to be done that we understand
  - Subjects for the future are also evident
- Generators are catching up to theory, still much to do
  - They reflect existing theory/data in simplified form
  - Existing (e,e′) data at high W resonances only for nucleon targets
    - Vector response still not right
  - Existing νA data emphasizes Δ in light targets
- More eA data – JLab experiment recently approved
  - New neutrino-electron collaboration (e4ν)
- More νA data – Minerva ME beam with C, Fe, Pb
- More νN data - ?