

# Status of Resonances in GENIE

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Emphasis on resonances above the  $P_{33}(1232)$

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- Rein-Sehgal is very old, but still used
- Berger-Seghal improved, but same formalism
- To me, RS and BS are shells, much remains
- How do we go forward?

# Resonances in GENIE

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- ▶ Default before v3 has been Rein-Sehgal (RS) (1981)
- ▶ Many complaints about this – “old and out-moded”
- ▶ Knowledge about resonances/non resonant bkgd has greatly improved since 1981!!
- ▶ Electron scattering experiments (my emphasis long ago) have fantastic statistics/interpretation on many targets
  - ▶ Masses, widths, **photocoupling** (Jlab) greatly improved
- ▶ Nonrelativistic quark model is no longer important
- ▶ Dividing line between resonances/DIS remains in dispute

# GENIE progress

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## ▶ GENIE default (2017)

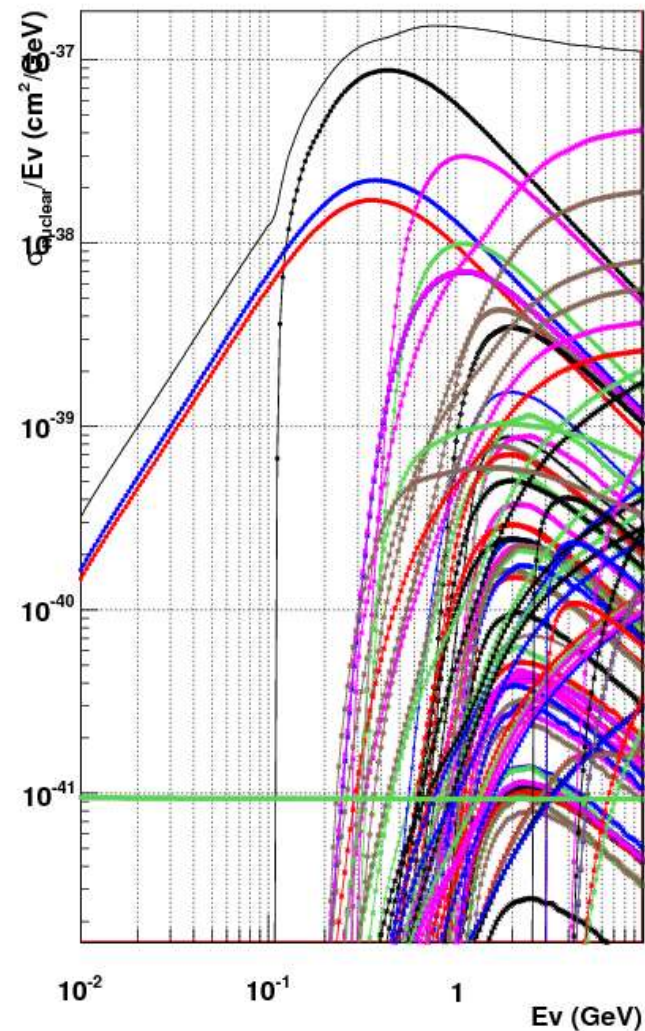
- ▶ Rein-Sehgal formalism
- ▶ Include all 3\*, 4\* PDG states, some 2\* states (18 total – so what?)
- ▶ Keep masses, widths up-to-date using PDG (major overhaul 2016)
- ▶ Resonances  $W < 1.7$  GeV, DIS for  $W > 1.7$  GeV ( $\sim 10$  resonances)
- ▶ Nonresonant background from scaled Bodek-Yang (DIS tail averages over  $W$ )
- ▶ Dipole form factors – axial and vector – same for all resonances
- ▶ Corrected  $\Delta \rightarrow N\gamma$ ,  $\Delta$  nonisotropic decay ( $\theta$ )

## ▶ Alternate models

- ▶ Berger-Sehgal (2007) add lepton mass/vac pol diagrams (also KLN)
- ▶ MiniBooNE axial form factors fit to all nucleon data
- ▶ MAID vector form factors (still private)

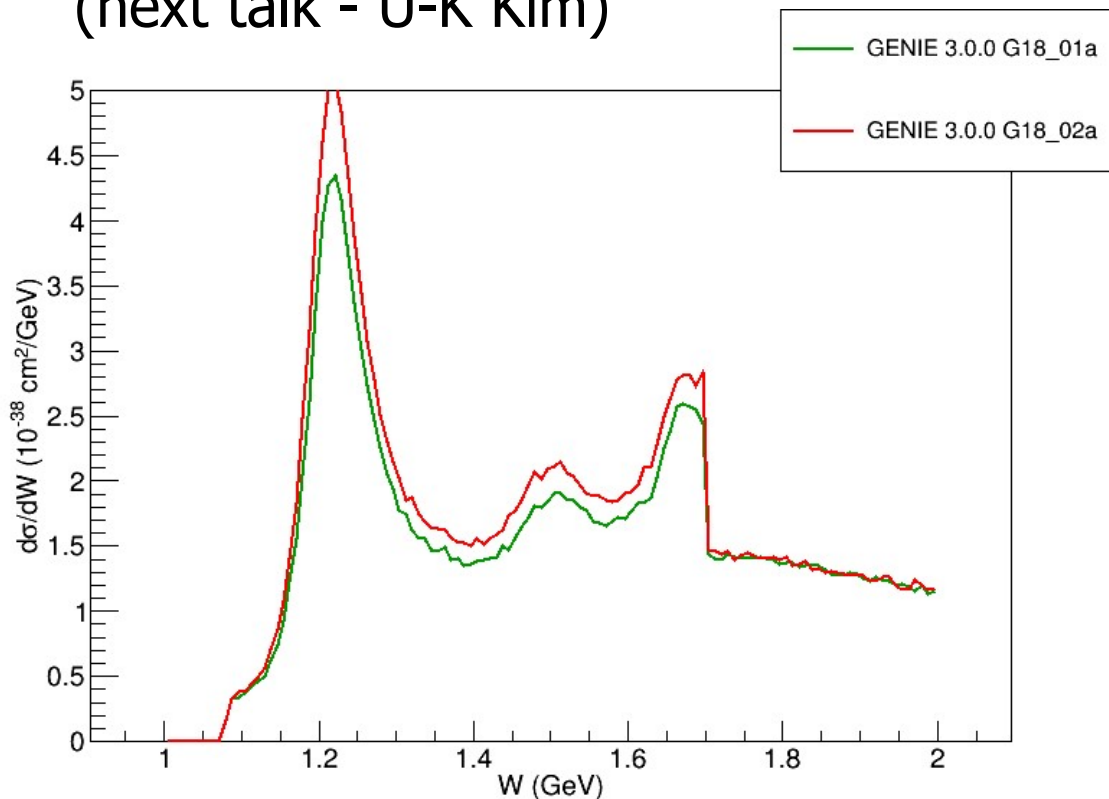
# Many resonances!

- ▶ Plot is of all GENIE processes for  $\nu C$ , but over half are resonances.
- ▶ Strengths vary, lots of overlap as function of  $E_\nu$ .



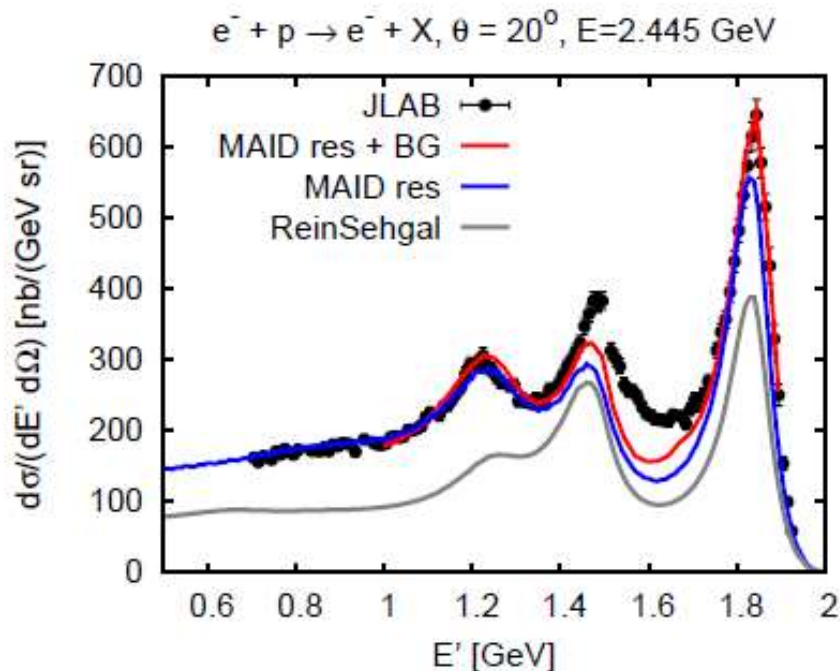
# GENIE resonances

- ▶ RS (01a) vs. BS (02a) (MINERvA LE flux)
- ▶ Increase overall level due to new form factors
- ▶ Resonances end at  $W=1.7$  GeV, only 'DIS' at higher  $W$  (next talk - U-K Kim)

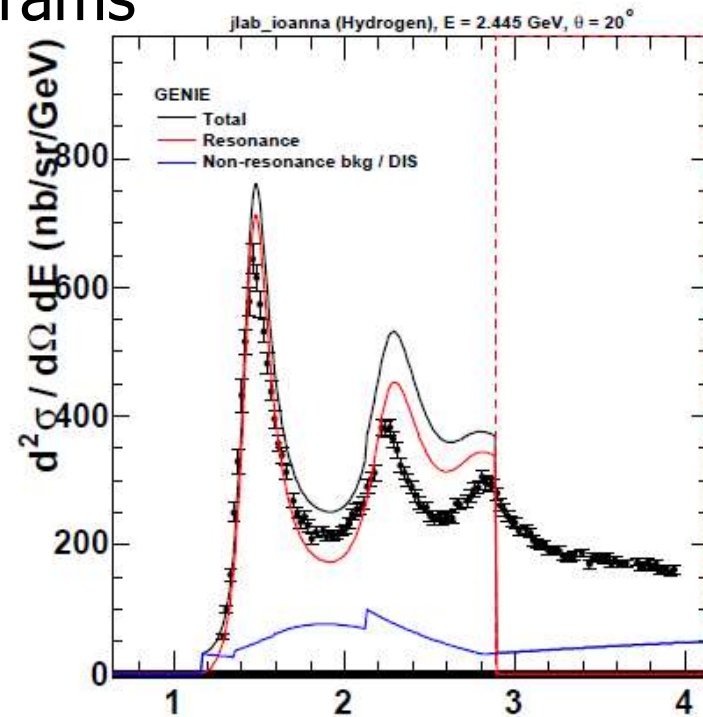


# Repeat comparison from NUINT14

- ▶ 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  $W^2 \text{ (GeV}^2\text{)}$

# V3.0.0

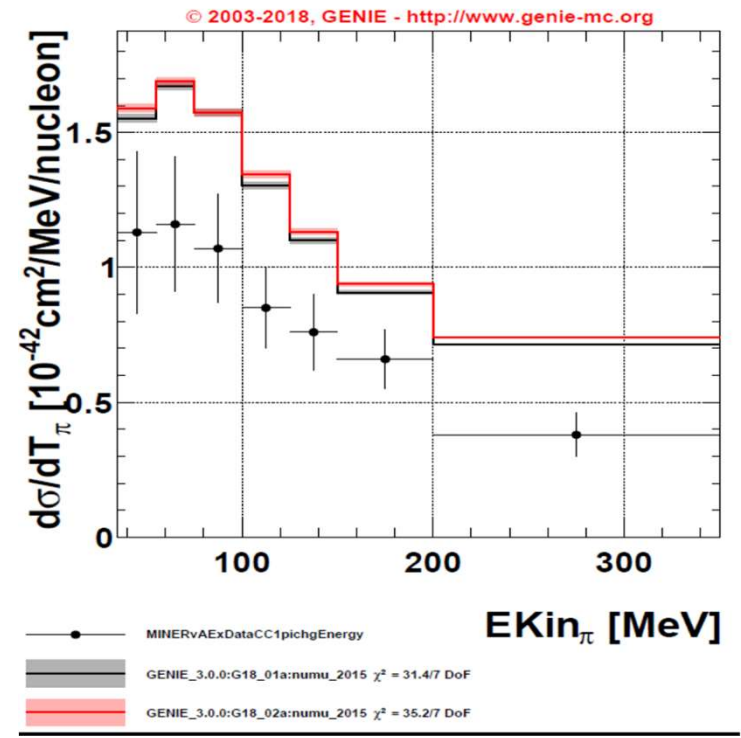
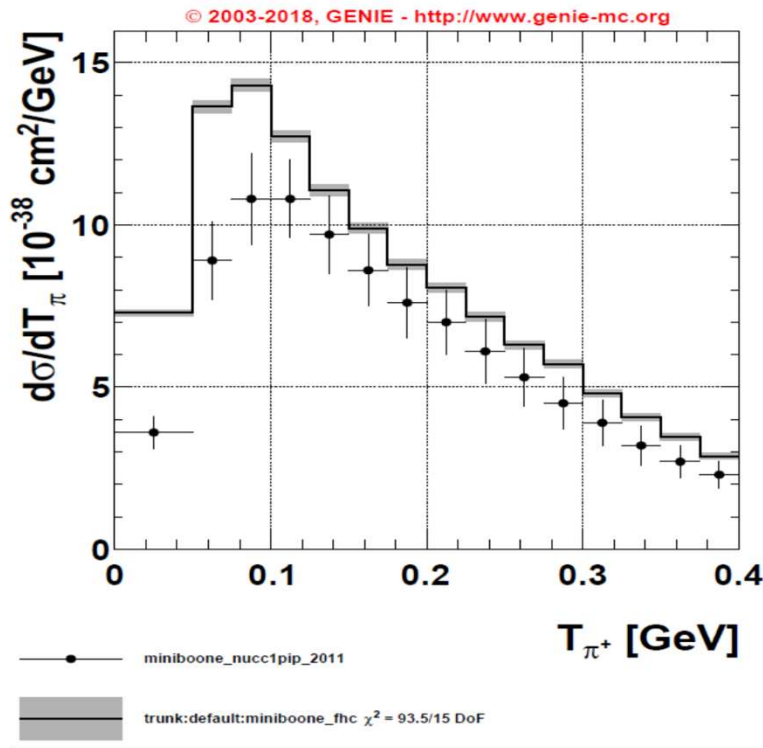
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- ▶ Major release
  - ▶ Make all models equally accessible (no switching of xml files)
  - ▶ Model sets get designations
    - ▶ **G00\_00a** is old default for historical reference
    - ▶ **G18\_01a** is updated old default (still RS)
    - ▶ **G18\_02a** 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  $\pi$ , 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 (very close to final)

# RS+dipole vs. BS+updated GA

[G18\_01a vs. G18\_02a]

- ▶ Change in form factors more important
- ▶ Show MiniBooNE  $1\pi$  and Minerva  $1\pi$  (2015)
  - ▶ What is available in GENIE

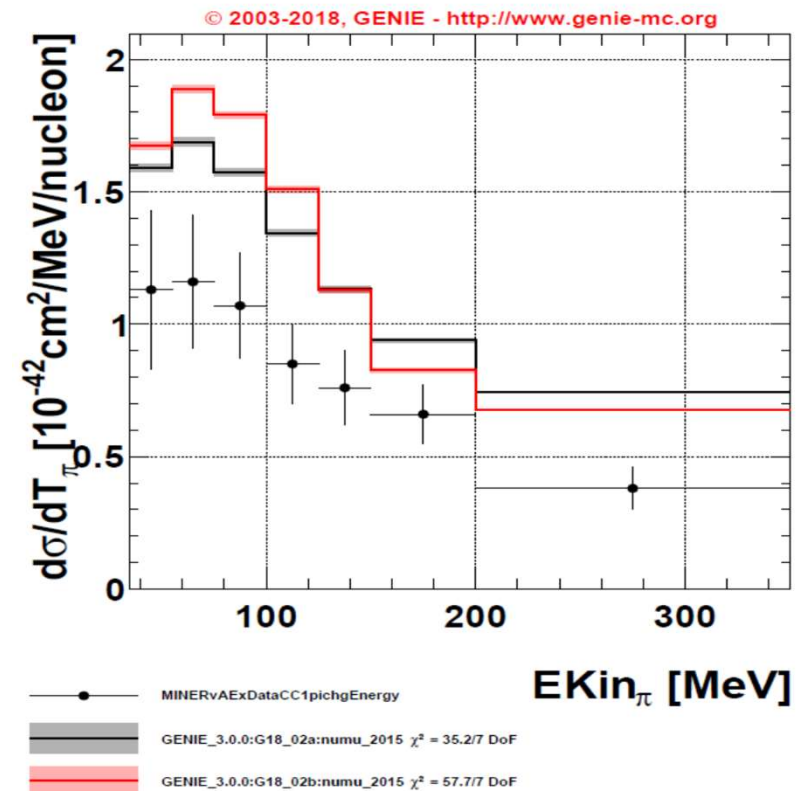
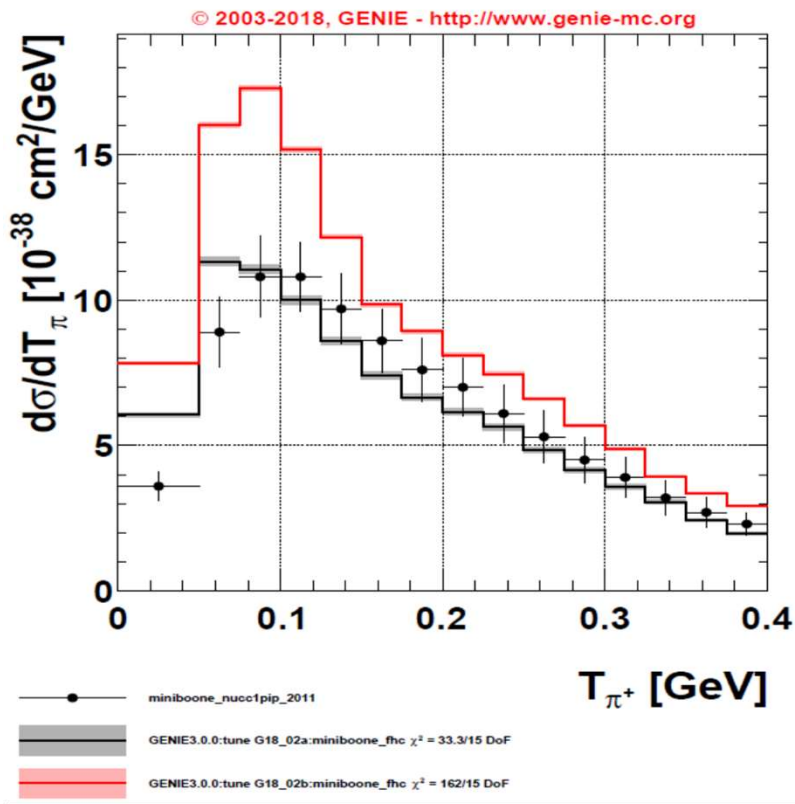




# FSI effects - schematic vs. cascade

[G18\_02a vs. G18\_02b using BS]

- ▶ BS with schematic does best
- ▶ BS with cascade is systematically high (too little abs?)



# Where we are with v3.0.0

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- ▶ All existing GENIE validation is  $\Delta$  dominated
  - ▶ All models tend to be above data (BS with schematic FSI best)
- ▶ That's where the data is, later MINERvA data will come shortly, more about that tomorrow.
- ▶ No medium corrections (not in  $e, e'$  either)
- ▶ All the high  $W$  resonances are there, but untested
  - ▶ All resonances have very similar form factors (not true for vector)
  - ▶ Vector form factors same as RS

# Data available - primary input to models

## *GENIE has extensive database*

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- ▶ Hadron-nucleus – 100's of distributions for  $n, p, \gamma, \pi, K$  beams
- ▶ Electron-nucleus – dozens of distributions for  $(e, e')$ 
  - ▶ Nucleon, many nuclei
  - ▶ Inclusive only, need to get  $(e, e'p)$  data
  - ▶ No data for pion, multihadron production
- ▶ Neutrino-nucleon
  - ▶ All bubble chamber data including recent  $\pi$  reanalysis
  - ▶ Many final states, but limited statistics
- ▶ Neutrino-nucleus
  - ▶ Rapidly growing, but still small range in  $A$ , low statistics, and flux-integrated
  - ▶ Most data for Carbon, new Argon detectors important
- ▶ **For transition region - lot of  $eN$ , some  $\nu N$ , very little  $eA$  or  $\nu A$**

# Upgrades to GENIE in progress/anticipated

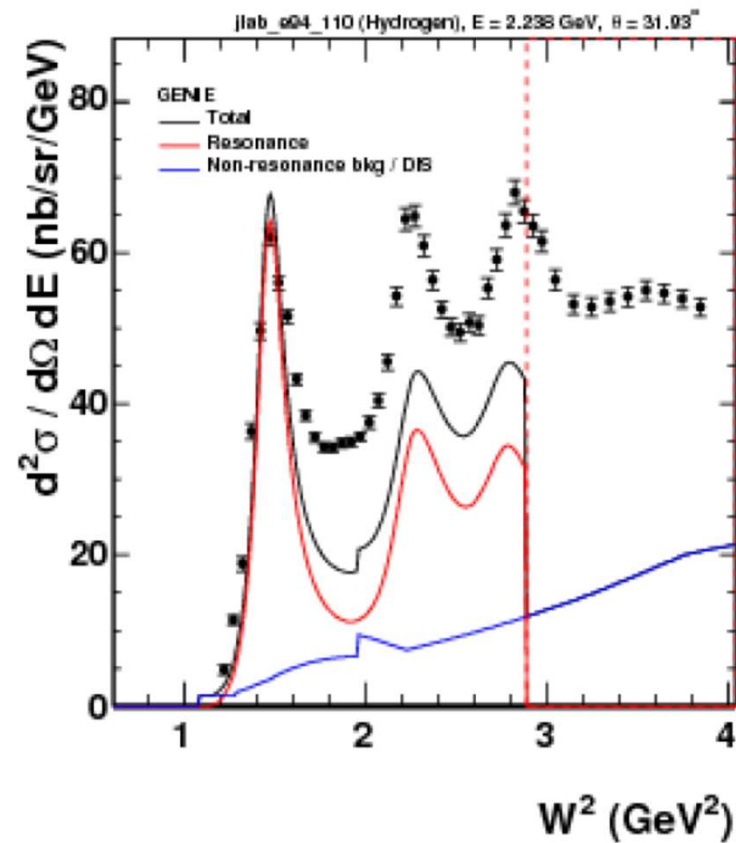
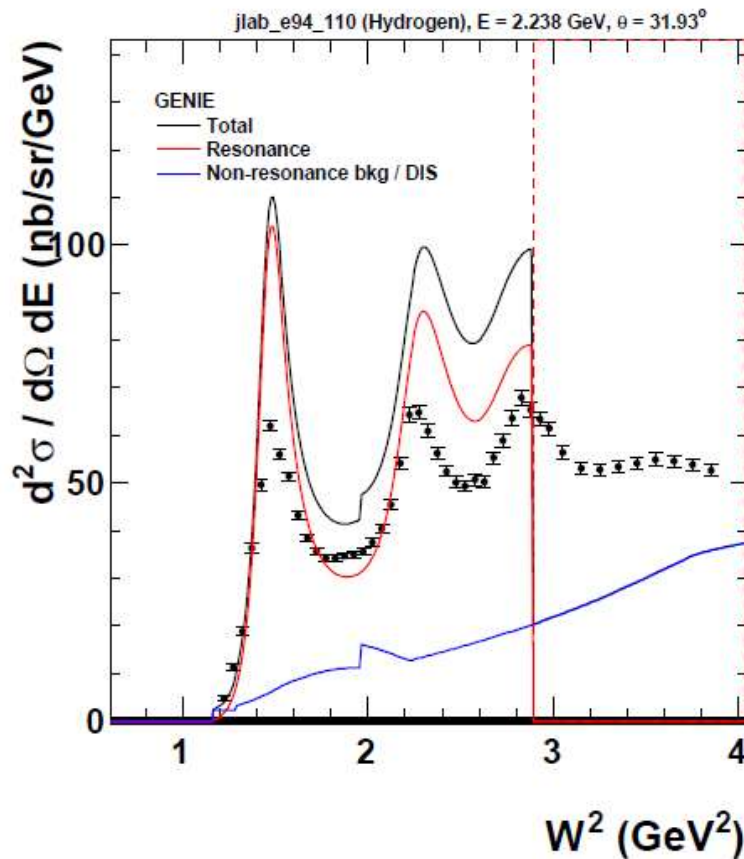
## *Form factors*

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- ▶ MAID resonance vector form factors soon (long delay)
  - ▶ Retune axial form factor?
  - ▶ Axial form factors for each resonance?

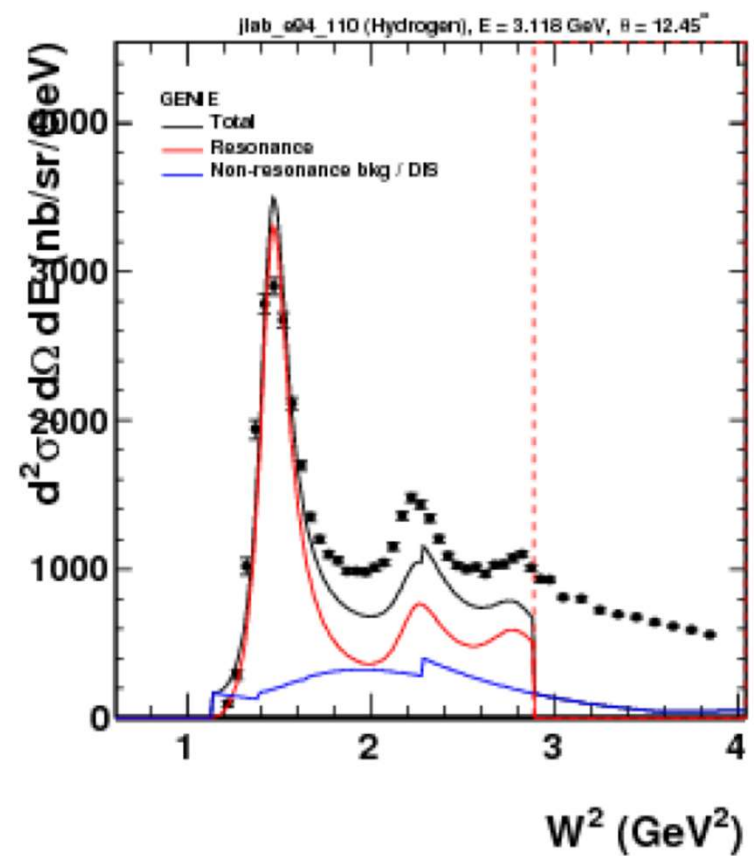
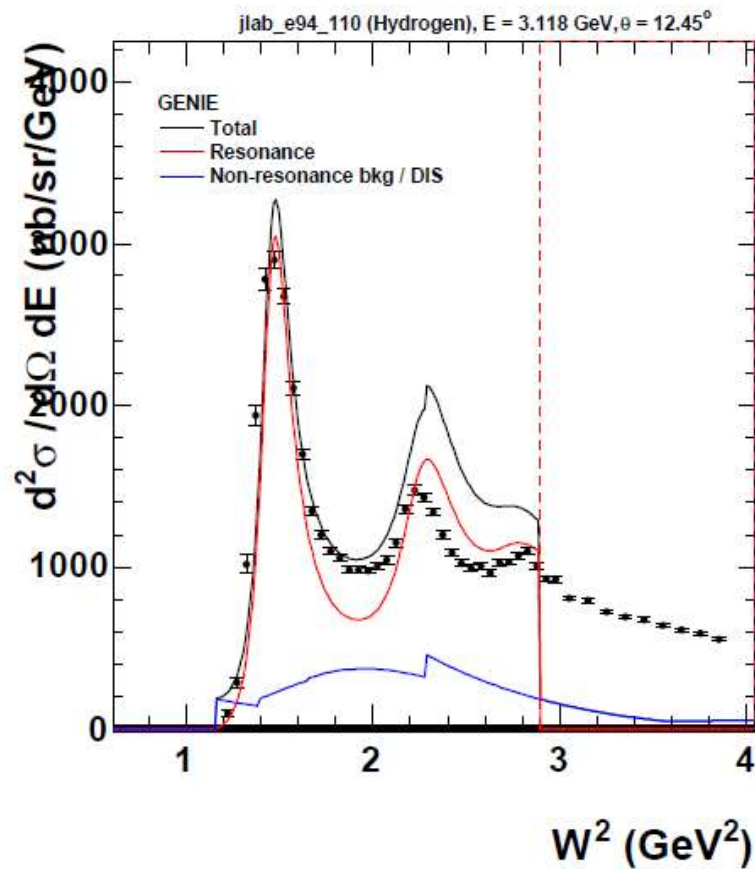
# New comparisons (ep→e'X) p, d targets

- ▶ Original on left, maid FF on right – high  $Q^2$  at  $\Delta$  peak



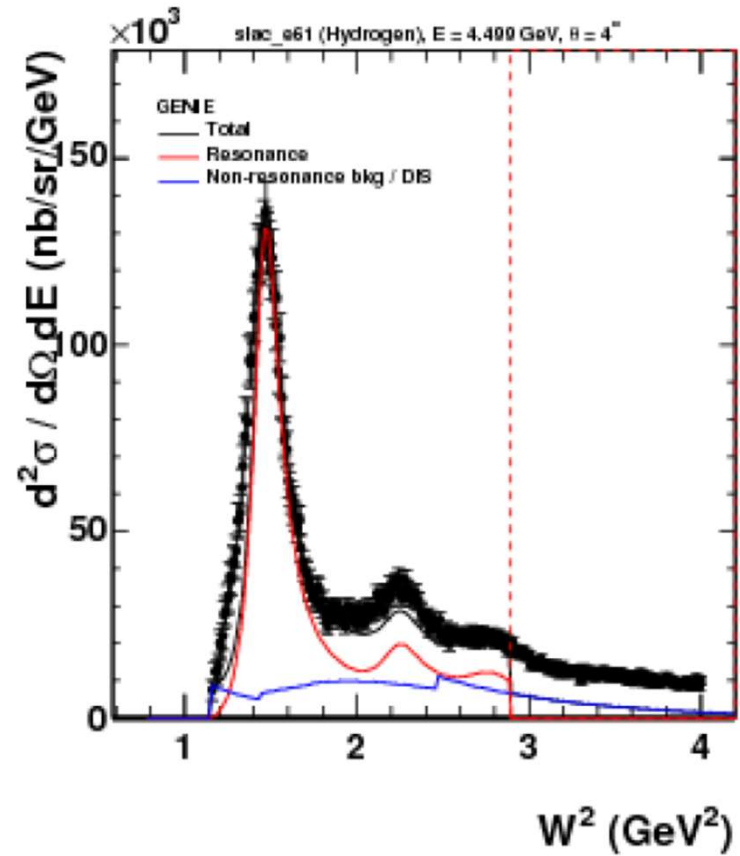
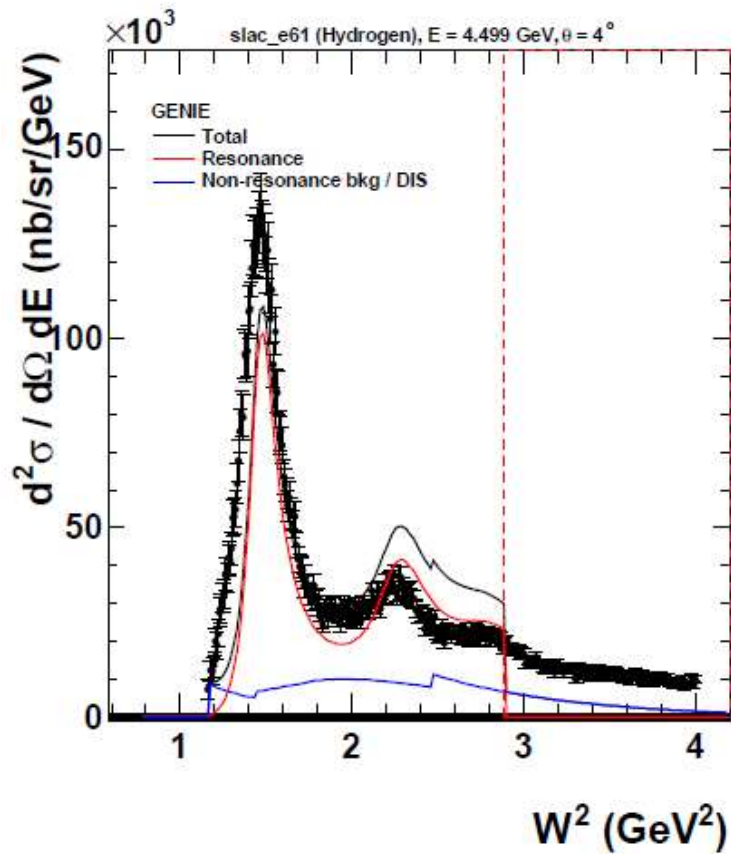
new

- ▶  $Q^2 = .377 \text{ GeV}^2$  – better overall agreement



new

►  $Q^2 \sim 0.09 \text{ GeV}^2$



# Summary of form factors

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- ▶ 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*

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- ▶ New formalism beyond Rein-Sehgal, Berger-Sehgal?
- ▶ New  $\nu N \rightarrow \mu \pi N$ ?
  - ▶ 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

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- ▶ 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  $\nu A$  data emphasizes  $\Delta$  in light targets
- ▶ More eA data – JLab experiment recently approved
  - ▶ New neutrino-electron collaboration (e4 $\nu$ )
- ▶ More  $\nu A$  data – Minerva ME beam with C, Fe, Pb
- ▶ More  $\nu N$  data - ?