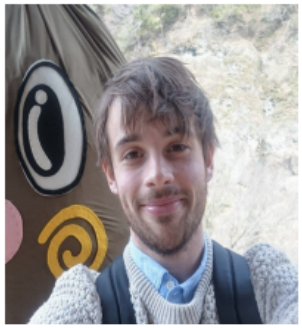
The University Of Sheffield.

NUISANCE

Patrick Stowell, Luke Pickering, Callum Wilkinson, Clarence Wret



NuSTEC/IPPP Meeting

18/04/2017

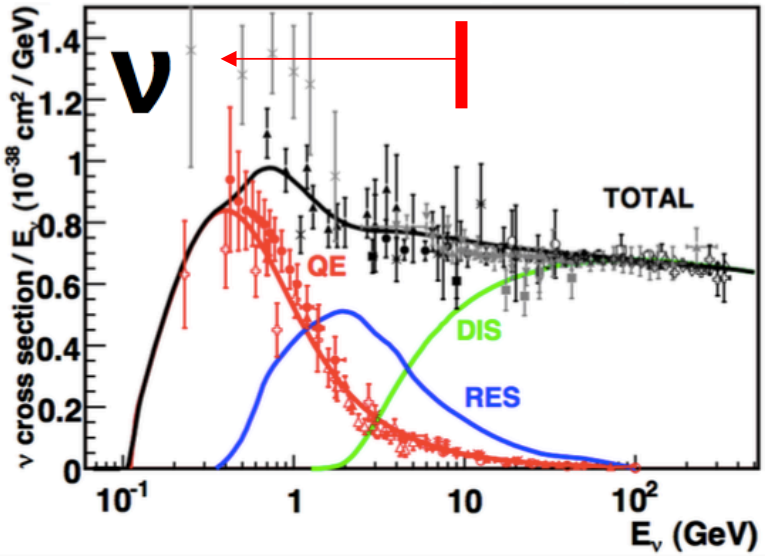
T2K

Disclaimer

Comparisons are a snapshot of what is currently in the main neutrino event generators

Introduction

- T2K has spent a number of years tuning NEUT to external neutrino scattering data to provide priors for oscillation analyses.
- NUISANCE tuning efforts grew out of this T2K work.
- Current efforts aimed at the 0.1-10.0 GeV range of interest for accelerator Oscillation Analysis (OA) experiments.

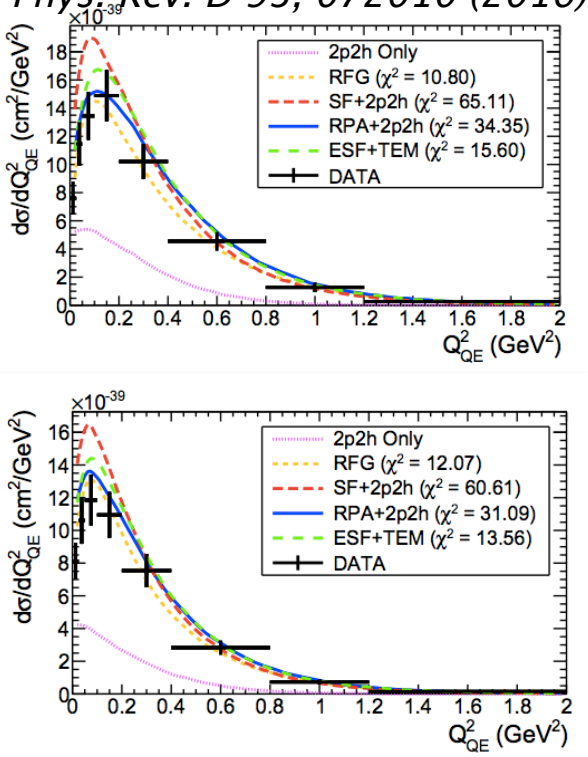


MINERvA – MiniBooNE CCQE

- NEUT 5.3.3 had Nieves RPA and 2p2h models added to to relieve ‘large axial mass’ problem in MiniBooNE data.

- NEUT tuned to CCQE data to provide CC0π constraint for T2K OA:
  - *MINERvA 1D-Q^2 $\nu_\mu + \overline{\nu_\mu}$ (correlations)*
  - *MiniBooNE 2D-T_μ-$cos\theta_\mu$ ν_μ*
  - *MiniBooNE 2D-T_μ-$cos\theta_\mu$ $\overline{\nu_\mu}$*

Phys. Rev. D 93, 072010 (2016)



- The quasi-elastic (1p1h) axial mass, and 2p2h total normalisation were tuned as free parameters.

Model	M_A (GeV/c2)	2p2h Norm (%)	χ^2/NDOF
NEUT Relativistic Fermi Gas + Nieves-2p2h	1.14 ± 0.03	25.5 ± 12.4	106.25 / 229

Joint Tuning Issues

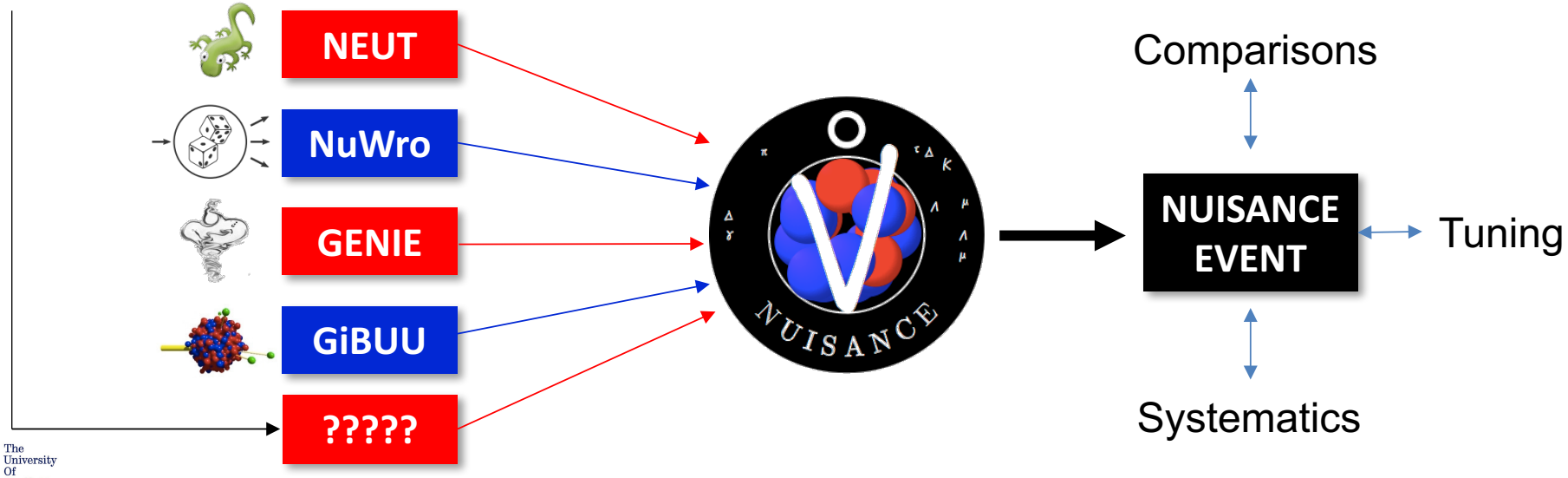
- Joint tunings also saw disagreement between datasets:
  - MINERvA preferred a large suppression of 2p2h (-90%)
  - MiniBooNE anti-neutrino preferred a suppression (-100%)
  - MiniBooNE neutrino preferred an enhancement (+50%)

- Several possible issues need to be considered in these tunings:

1. **RFG+Nieves incorrect, should use LFG+Nieves**
2. True CCQE measurements very model dependent
3. No shape freedom in RPA or 2p2h model
4. No correlations between experiments
5. No proper correlations for MiniBooNE CCQE data

NUISANCE

Insert your generator here



NUISANCE v1r0 Release

- Open source neutrino Monte-Carlo event generator tuning framework

- Easily extendable framework, with a large range of dataset comparisons already included

nuisance.hepforge.org

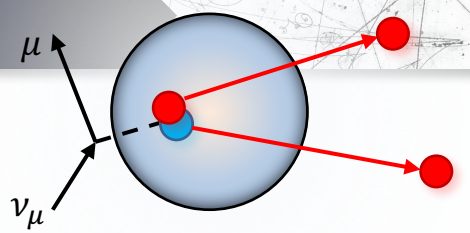
- Plan to create a set of model tunings for the main ‘reweightable’ generators:

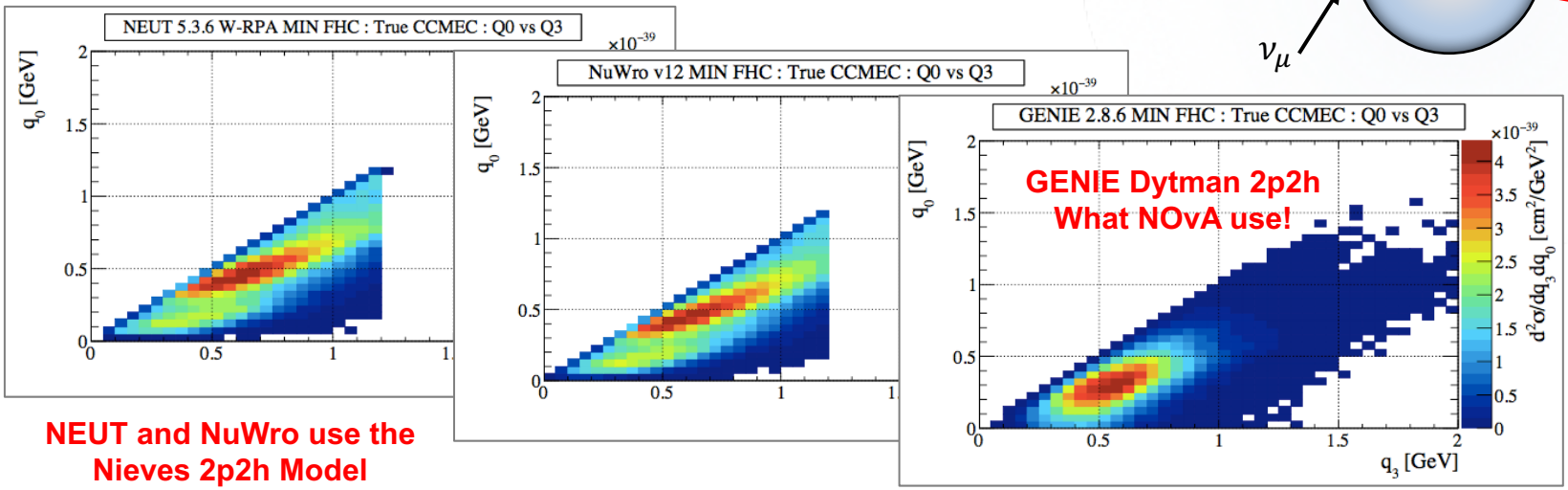
NEUT

NuWro

GENIE

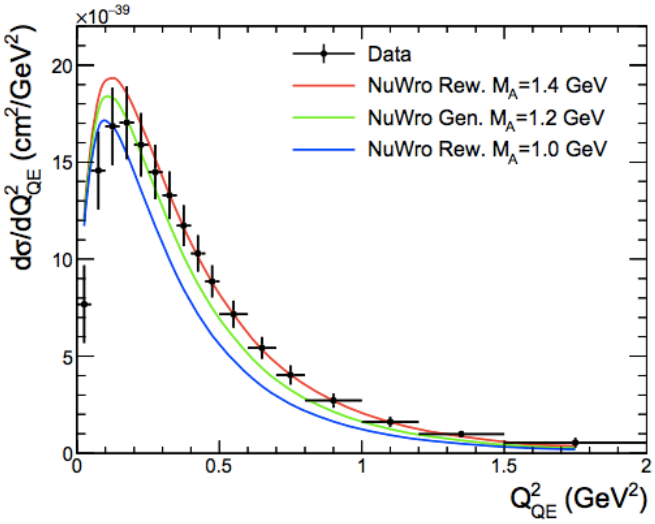
Generator Comparisons





NEUT and NuWro use the Nieves 2p2h Model

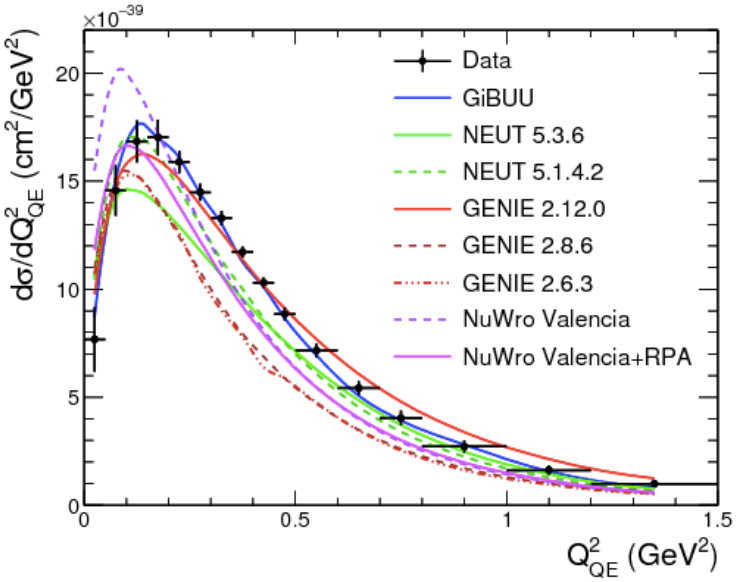
- NUISANCE converts generator events into common format for use by analysis routines
- Can make consistent model comparisons across generators
- Reweight engines allow model predictions to be easily changed




```
neut_parameter MaCCQE  +0.1
```

Data Comparisons

- To add a comparison you need:
  1. Data distribution
  2. Event signal definition
  3. Binning definition (e.g. Q2QE)



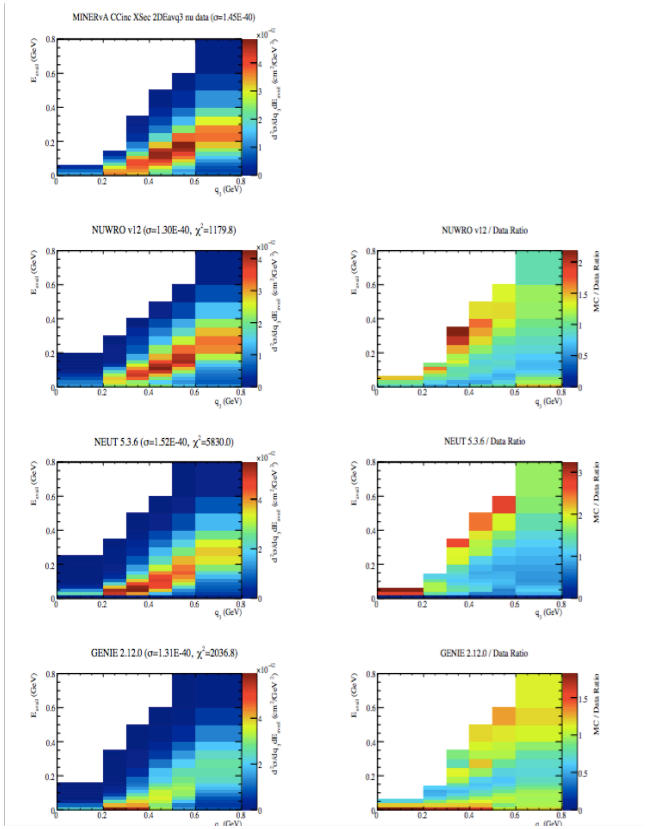
- Support for more complex dataset routines also included:
  - MC True -> Reco Smearing
  - Covariance likelihoods
  - Ratio distributions
  - Arbitrary category MC plots

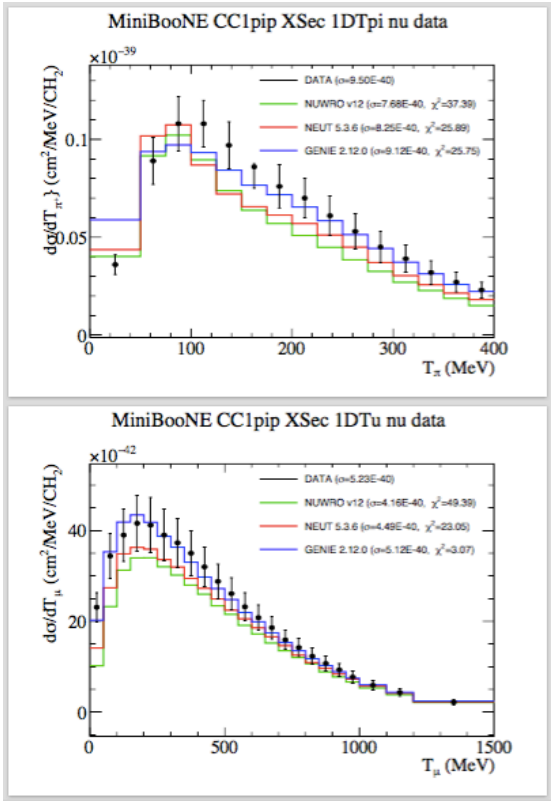
```
//*************************************************************
void MINERvA_CCQE_XSec_1DQ2_nu::FillEventVariables(FitEvent *event) {
//*************************************************************

  if (event->NumFSParticle(13) == 0)
    return;

  TLorentzVector Pnu  = event->GetNeutrinoIn()->fP;
  TLorentzVector Pmu  = event->GetHMFSParticle(13)->fP;

  double ThetaMu  = Pnu.Vect().Angle(Pmu.Vect());
  double q2qe     = FitUtils::Q2QErec(Pmu, cos(ThetaMu), 34., true);

  // Set binning variable
  fXVar = q2qe;
  return;
}
```

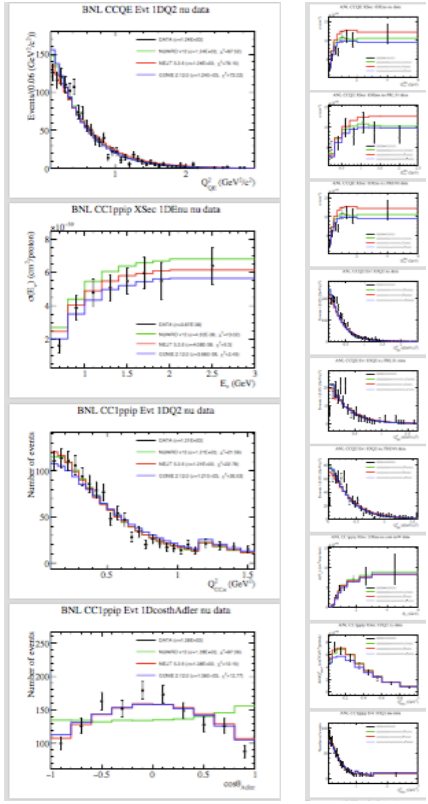
v1r0 Validation

- Perform NEUT, NuWro, and GENIE comparisons during validation of each version freeze to ensure sample predictions behave as expected.

NUISANCE Validation Link : Comparison of generators to ~150 different datasets





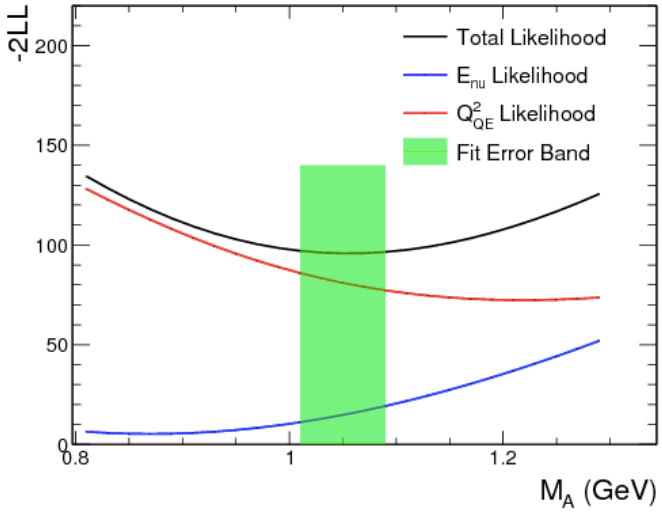


http://nuisance.hepforge.org/files/validation/nuisancevalidation_v1r0_280217/nuisance_v1r0_validation_280217.pdf

host all the MC files used to make these comparisons on our site!

Tuning a model : ‘nuismin’

- Likelihoods calculated for each dataset comparison can be used with Minuit to tune model parameters.



nuisance_tuning.card

```
neut_parameter MaCCQE   0.0 -3.0 3.0 1.0 FREE
neut_parameter MaNFFRES 0.0 -3.0 3.0 1.0 FREE
```

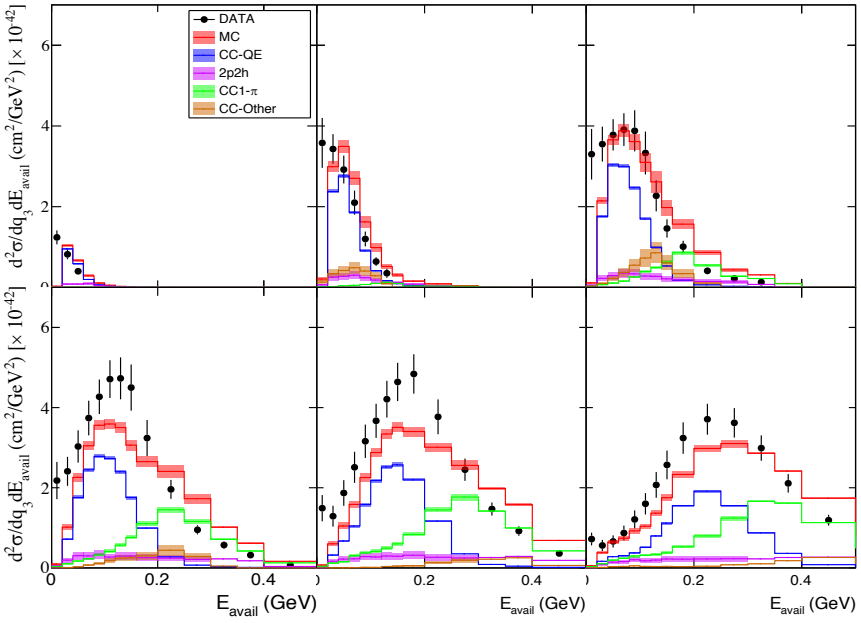
```
$ nuismin -c nuisance_tuning.card
          -o nuisance_tuning.root
```

- Any reweight dial can be specified as a free parameter and tuned to improve the joint likelihood between many datasets.

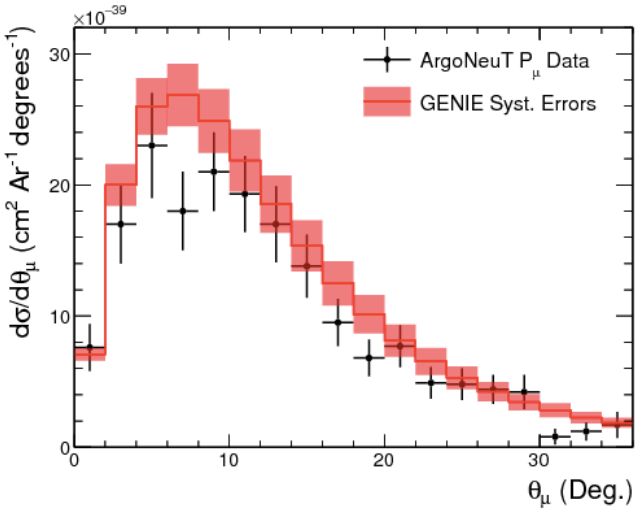
Error Bands

- Included support for systematic error band generation.
- Plan to release an error bands document similar to the NUISANCE v1r0 validation included with every set of model tunings.
- Tuning error bands for every dataset implemented in NUISANCE.

T2K NEUT Uncertainties vs MINERvA Data



GENIE 1-sigma reweight dial throws vs ArgoNeut Data



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Downloading NUISANCE

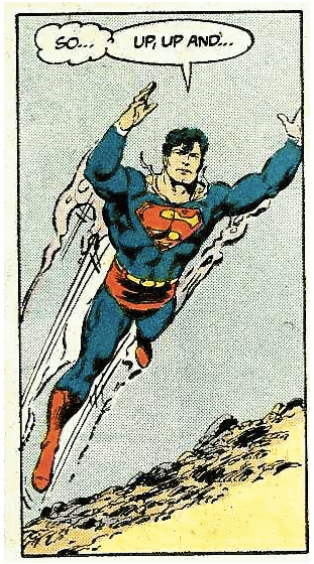
- Code can be checked out from our site, where you can also find build notes, MC files, validation, etc:

nuisance.hepforge.org

Can NuWro LFG save the day?

- Very easy in NuWro to generate events with different nuclear spectral functions.

- Using NUISANCE, we can perform **identical model tuning** of NuWro+LFG+Nieves to data.



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T2K CCQE Tuning Results to MiniBooNE/MINERvA Data

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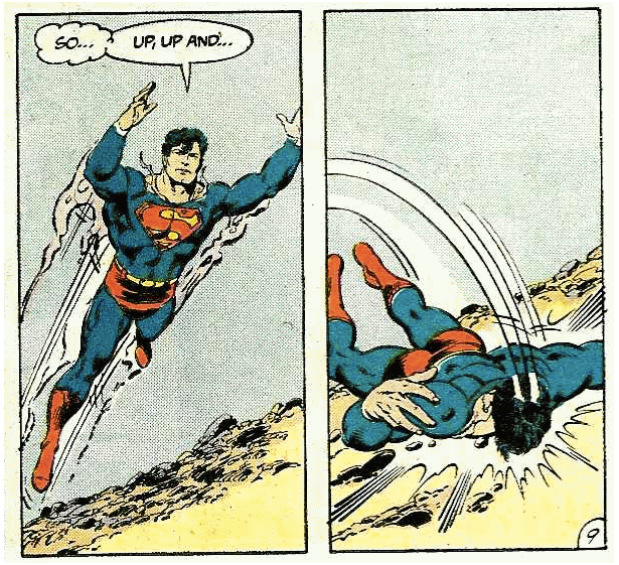

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2. True CCQE measurements very model dependent

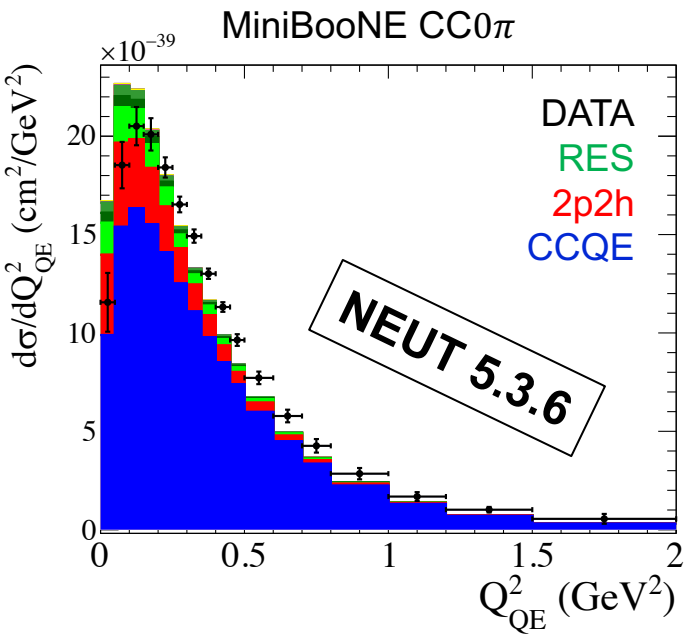
Model	M_A (GeV/c2)	2p2h Norm (%)	χ^2/NDOF
NEUT Relativistic Fermi Gas + Nieves-RPA + Nieves-2p2h	1.14 ± 0.03	25.5 ± 12.4	106.25 / 229
NuWro Local Fermi Gas + Nieves-RPA + Nieves-2p2h	1.16 ± 0.03	8.3 ± 11.9	100.74 /229

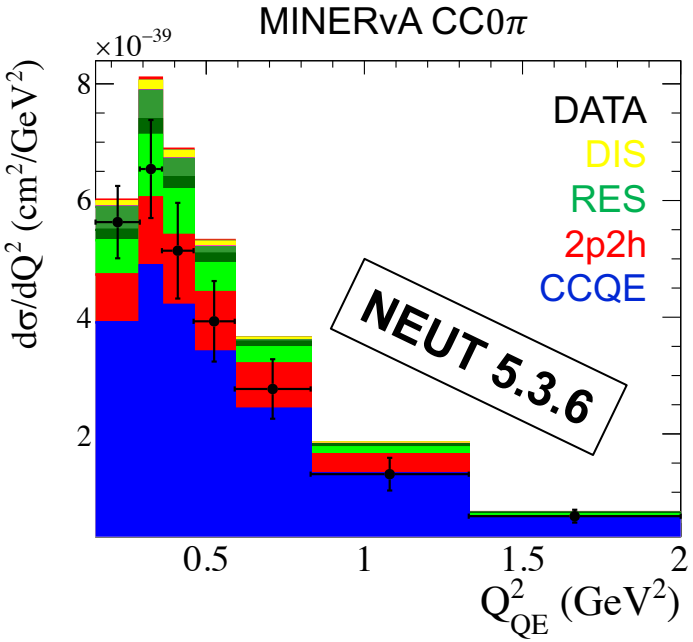
T2K CCQE Tuning Results to MiniBooNE/MINERvA Data

Changing Topology

- MiniBooNE released equivalent CC0π data before background selection.
- MINERvA expect to release similar CC0π data in muon kinematics soon.

- **Measured final state topologies have reduced model dependence.**





- Have to include consider contributions from CC1π where the pion is absorbed before it left the nucleus.
- **Adds lots more free parameters to account for!**

NEUT Model Parameters

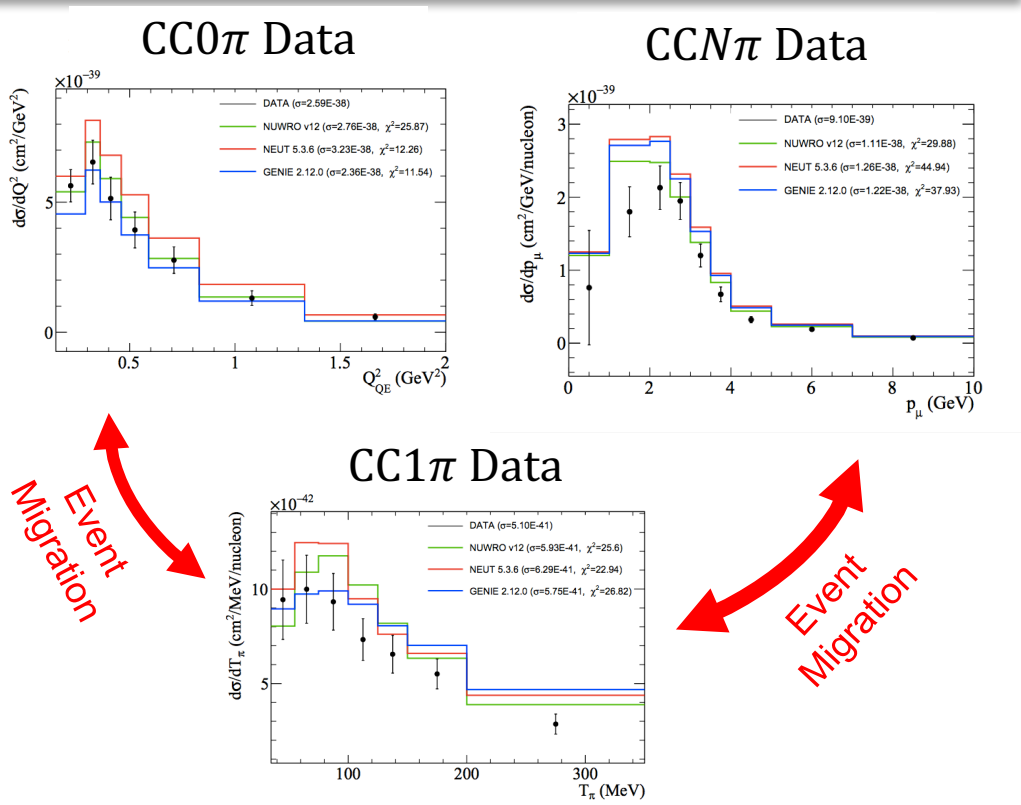
- What model are we using in NEUT 5.3.6?
- What can we actually vary to improve agreement?

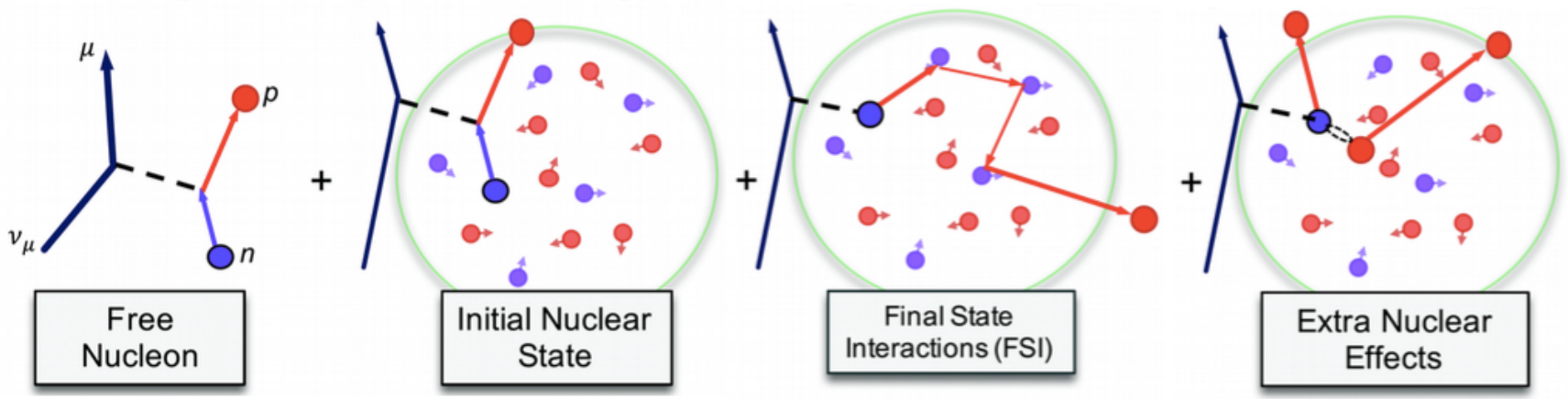
Category	Description	Parameters
CCQE	Llewelyn-Smith	M_A, p_F, E_b, RPA-Shape
2p2h-lepton	Nieves	$\Delta - \mathrm{Non}\Delta$ shape, pn/nn ratios
2p2h-hadron	Sobczyk ejection model	
RES	Rein-Sehgal	M_A^{RES}, C_A^5, $I_{1/2}$
COH	Berger-Sehgal	Rein-Sehgal alternative option
FSI	Oset Model	Pion/Nucleon FSI Fractions
DIS	PYTHIA 5.7	
Nuclear	RFG	SF alternative option
Other		Channel Norms, $\nu_\mu - \nu_e$ ratio

Unless stated otherwise, comparisons from this point on are from NEUT.
See Marco's Talk for GENIE comparisons

Nuclear Model Building

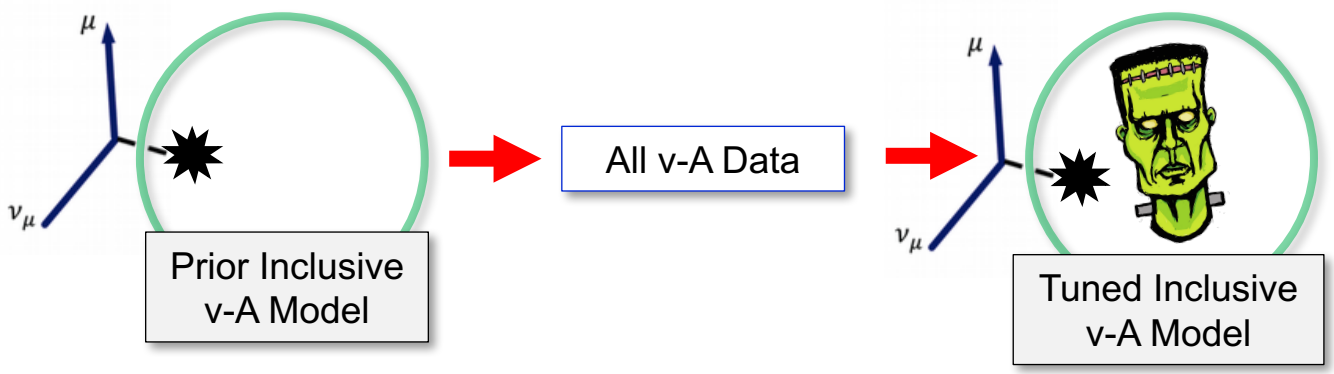
- Difficult to disentangle where model deficiencies are using nuclear scattering data alone.
- Large degeneracies between free model parameters.



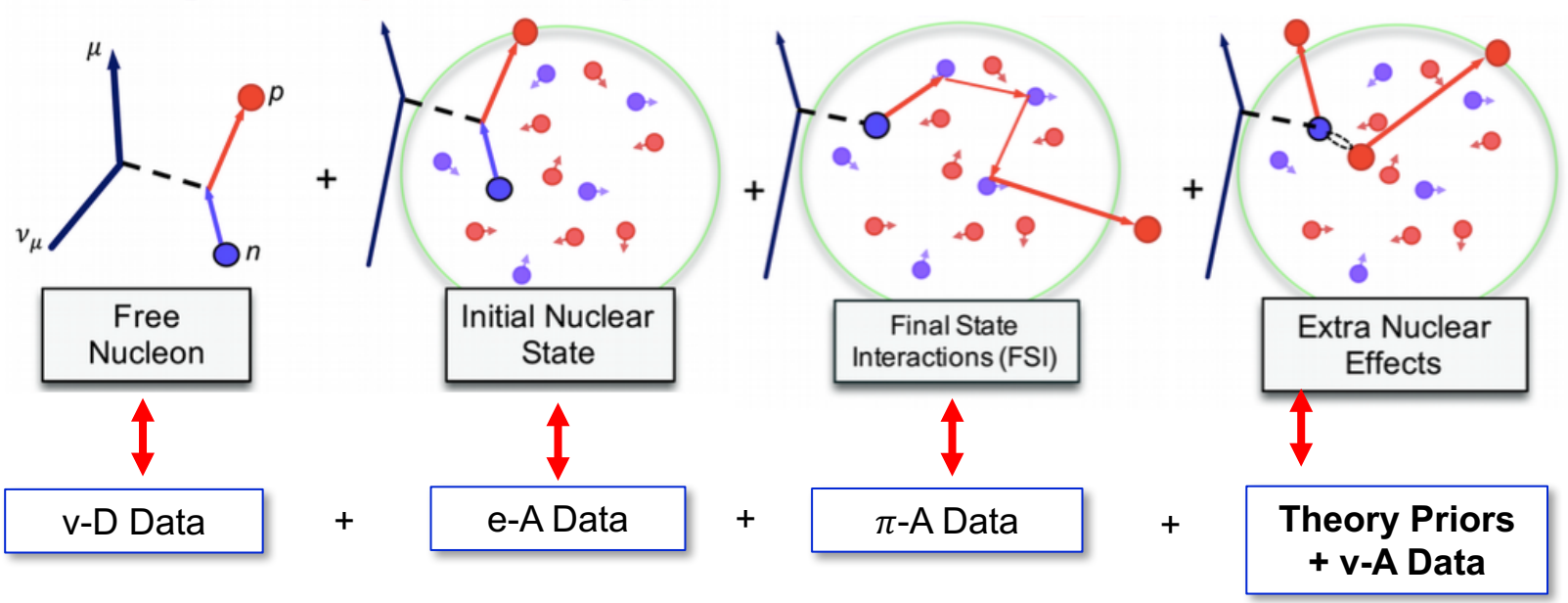


Nuclear Model Building

- **Brute Force Approach:**



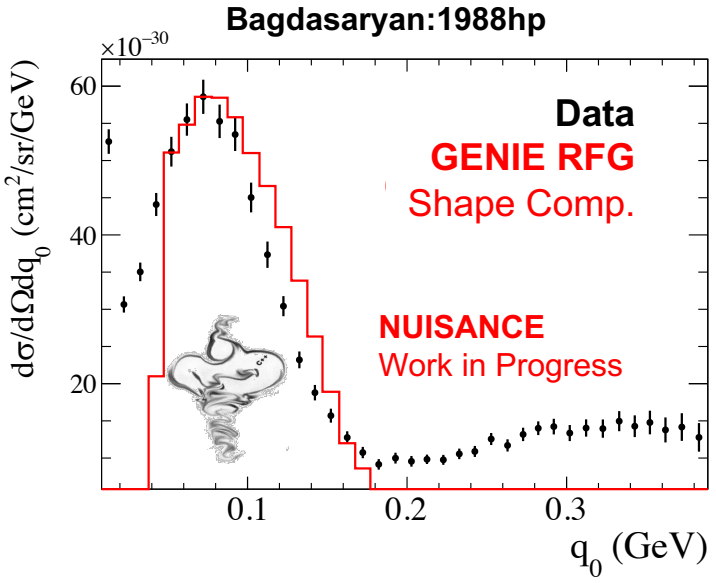
- **Modular Approach:**

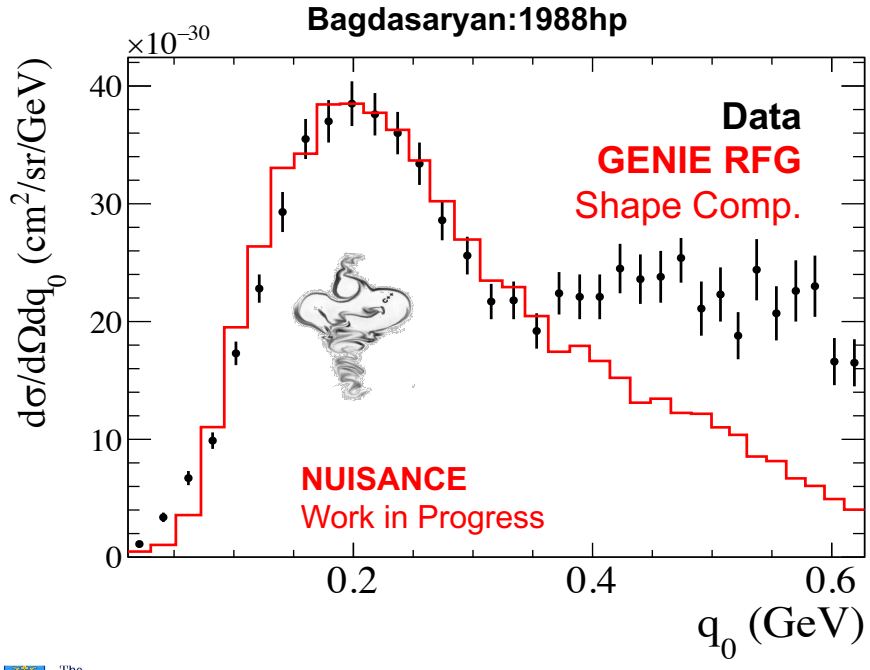


e-A Data

Electron Scattering

- GENIE, and GiBUU both have support for electron scattering (eWro coming soon).
- Want to setup some easy to use standard validation tests using electron scattering.





- Early NUISANCE interface with the QE electron scattering archives.

  (nucl-ex/0603032) http://faculty.virginia.edu/qes-archive/

- Comparisons shown today are just using NEUT's RFG model.
- If interested please come speak to me afterwards!

v-D Data

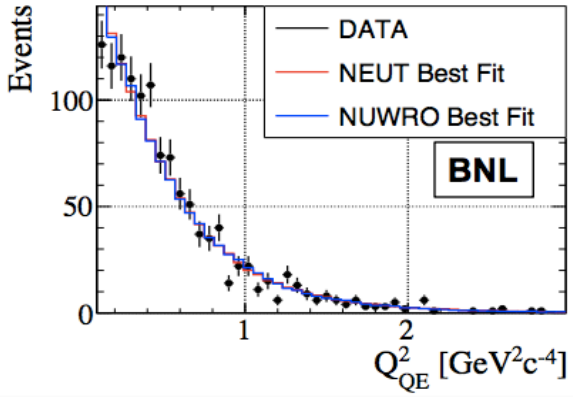
Bubble Chamber Tuning Results

	QE		RES		
Fit Results	M_A [GeV/c^2]	χ^2/NDOF	M_A^{RES} [GeV/c^2]	C_A^5	χ^2/NDOF
NEUT (v5.3.6)	1.04 ± 0.03	159.8 / 146	0.89 ± 0.04	1.02 ± 0.05	102.8 / 102
NuWro (v12)	1.03 ± 0.03	154.4 / 146	0.92 ± 0.03	1.04 ± 0.05	111.9 / 102

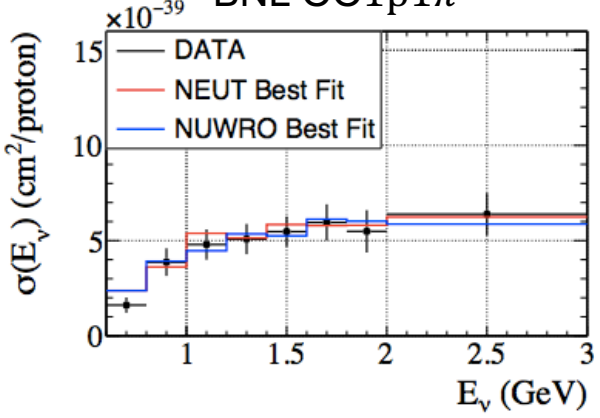
- Find good agreement in tunings to limited datasets from ANL+BNL CCQE+CC1p1π (W<1.4 GeV).

- Already begin to see disagreements appearing due to difference in how NEUT and NuWro handle resonances…

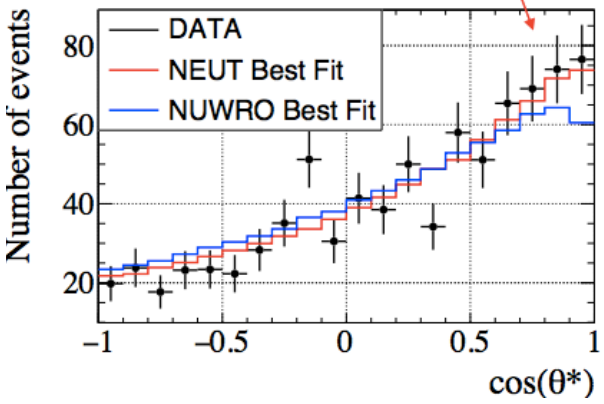
BNL CCQE



BNL CC1p1π



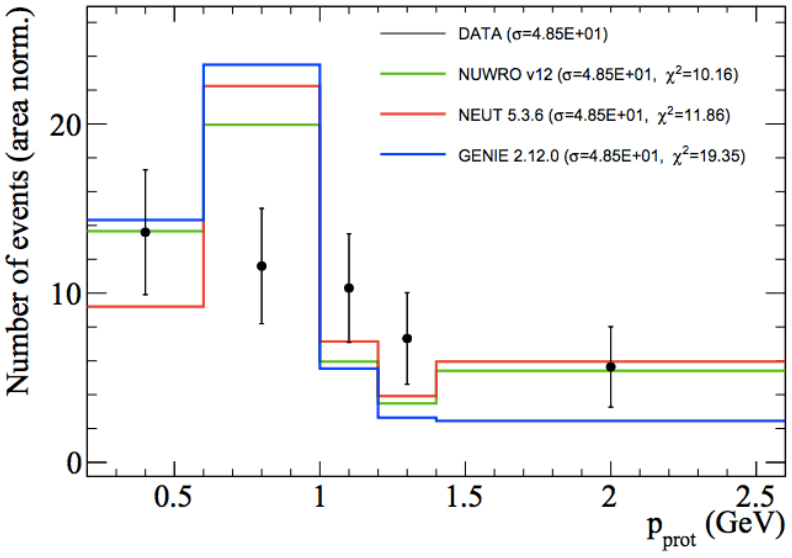
ANL CC1p1π



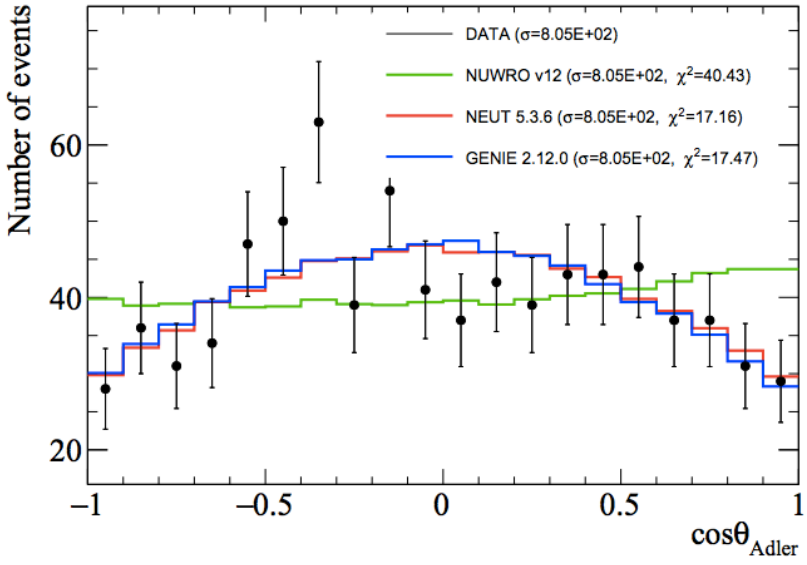
NuWro/NEUT Bubble Chamber

- Expect generator differences to be larger for W > 1.4 GeV pion data.
- Larger range of interesting pion bubble chamber measurements already included in NUISANCE.
- Plan to extend these tunings in official NUISANCE tuning results release for NEUT/NuWro/GENIE later this year.

BNL CC1p1π^+1π^0

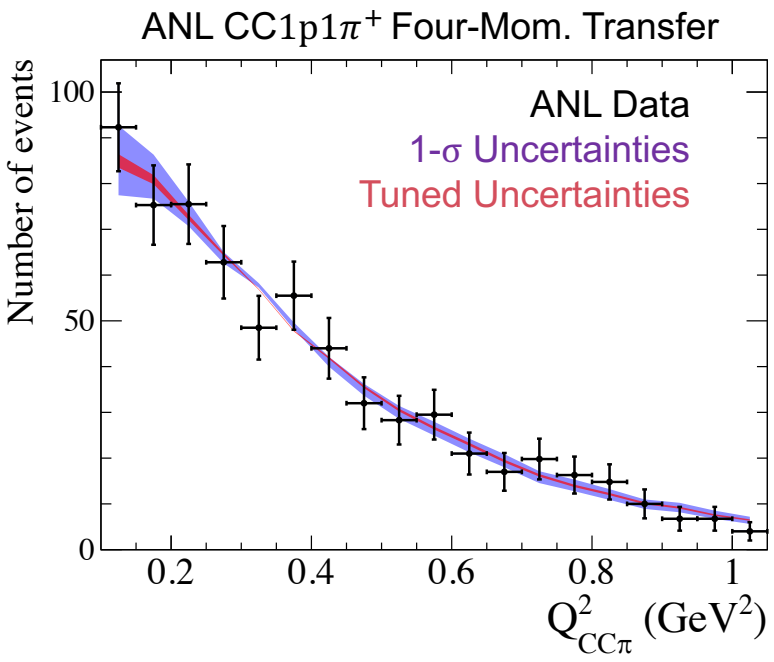


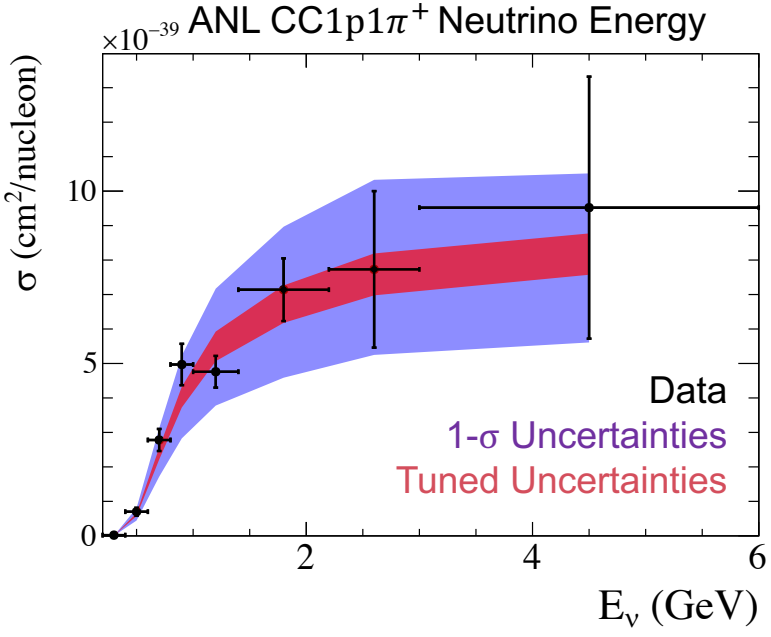
ANL CC1p1π^+ Adler Angle

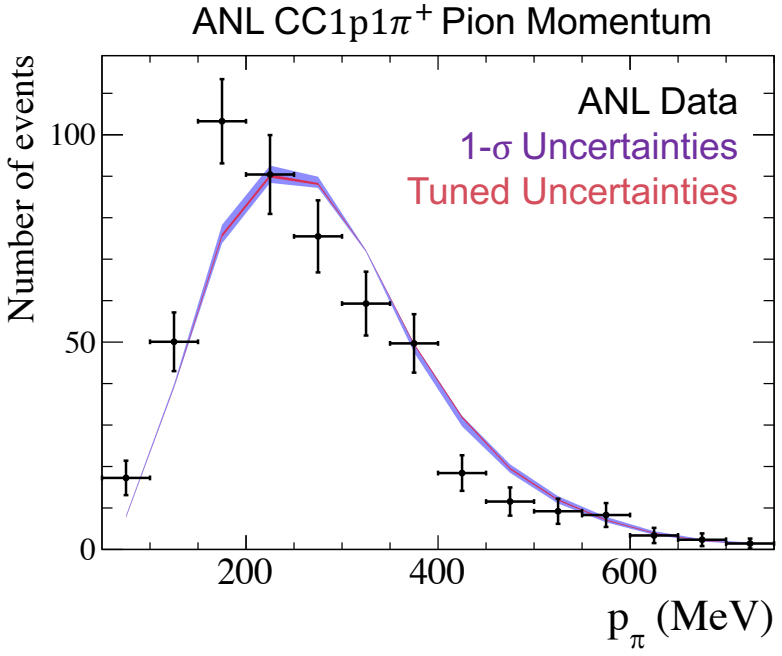


Pion Kinematics

- ANL/BNL Enu Distributions have largest sensitivity to free model parameters.
- Models don't have much freedom to change shape of pion kinematics.





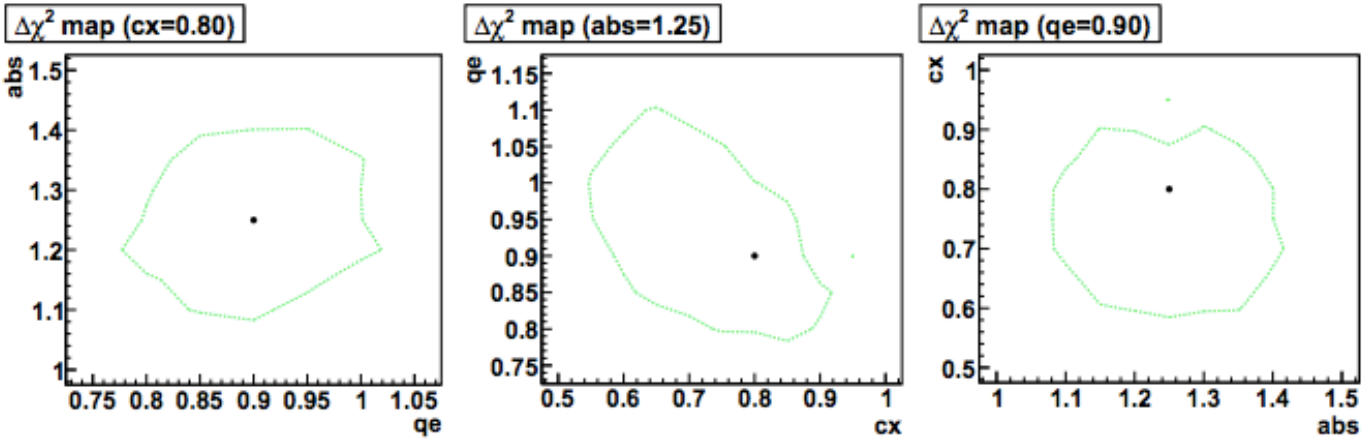


π-A Data (FSI)

FSI Errors on CC0PI

- NEUT's FSI model tuned to π-A scattering data.
- Expect updated tuning on this from T2K FSI group this year.

K. Ieki. Observation of νμ → νe oscillation in the T2K experiment. 2014



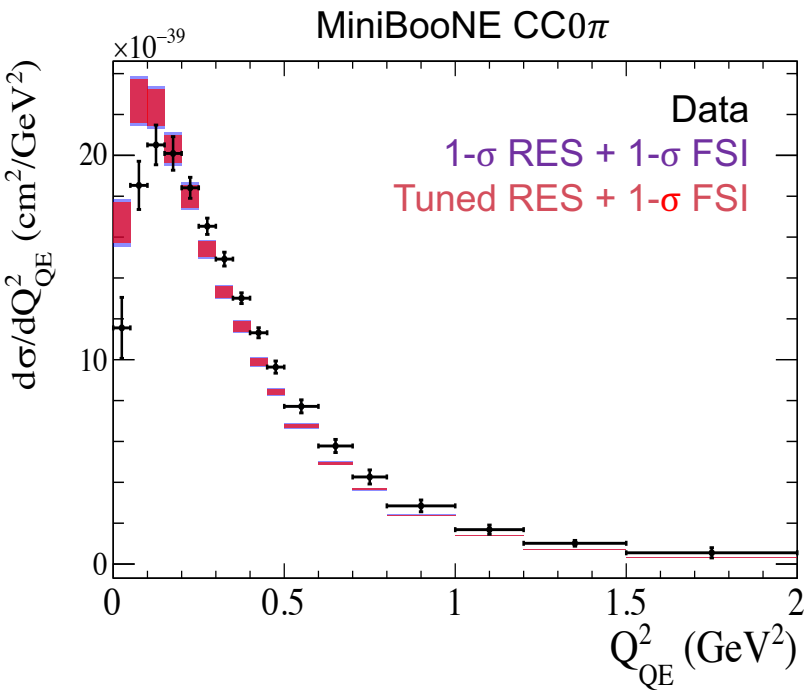
Would also like to include these pion scattering comparisons into NUISANCE to aid future FSI studies in other generators.

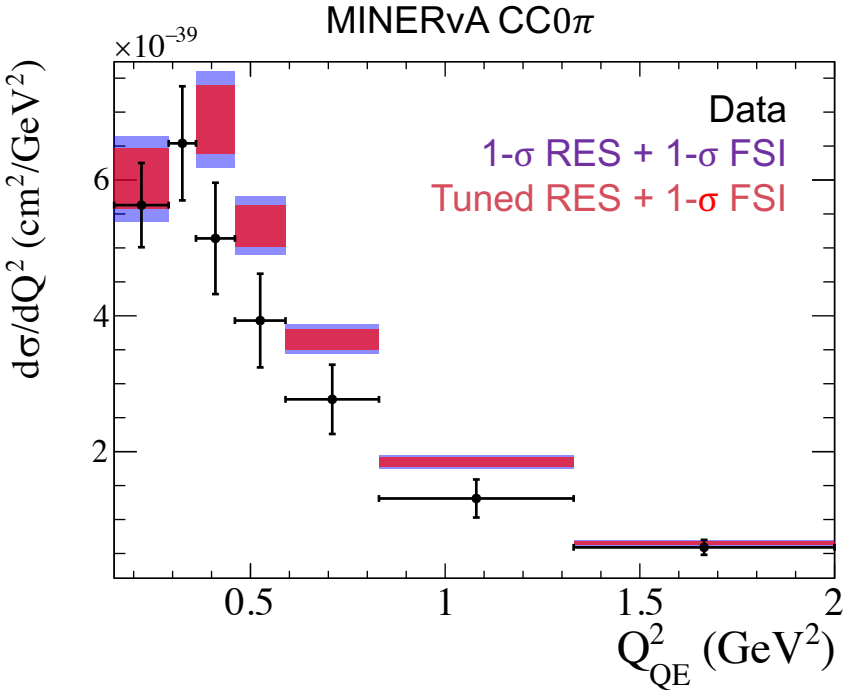
Any takers?

v-A Data

FSI+RES Uncertainties

- FSI contributes a lot to uncertainties at low Q^2 on the resonant background in the $CC0\pi$ samples.

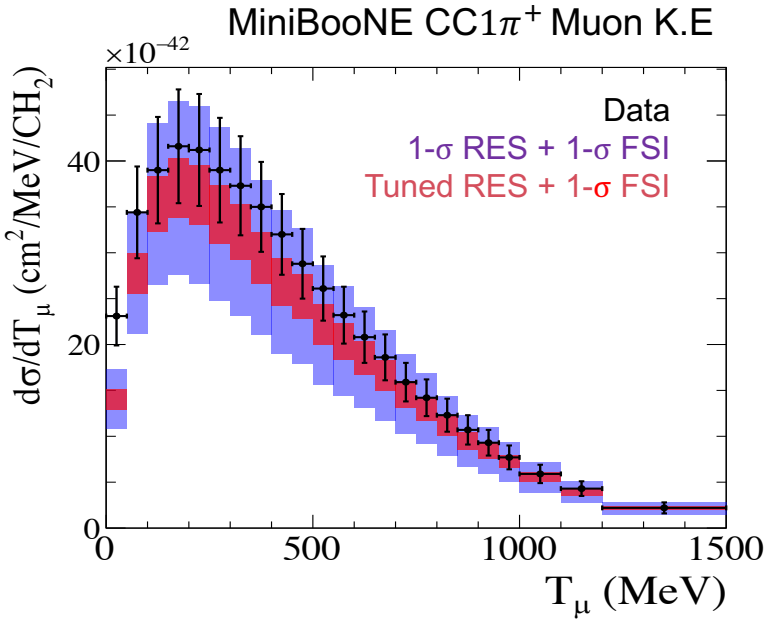


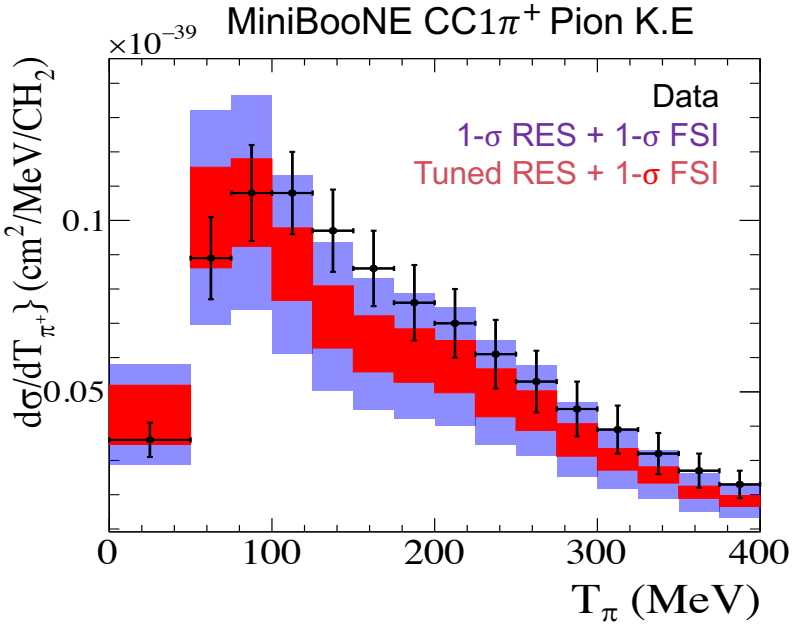


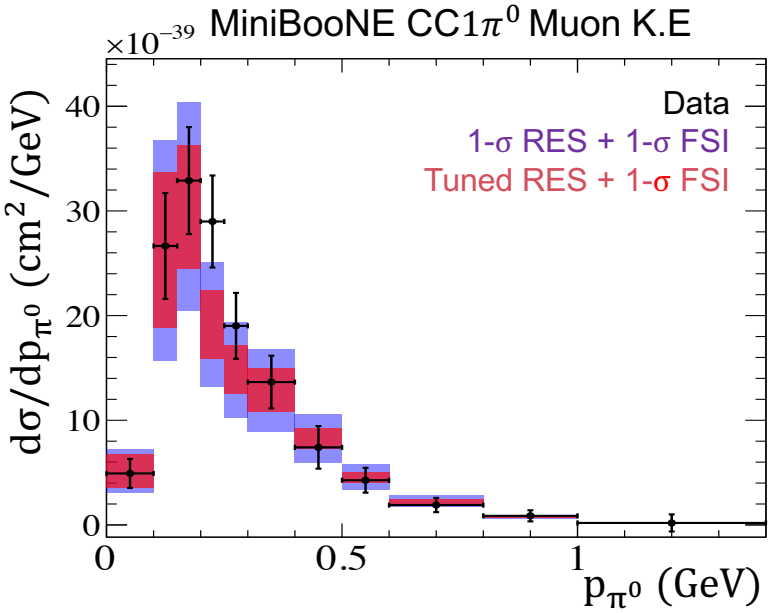
- Expect an updated set of tighter FSI constraints in NEUT later this year.
- Work ongoing to properly marginalize over these sorts of background uncertainties in NUISANCE tunings.

CC1π Data

- Disagreements between nuclear data and MC uncertainties highlight tensions between bubble chamber and nuclear data in pion kinematics.
- Often attributed to FSI model, but remember our pion kinematic model is also fixed…..

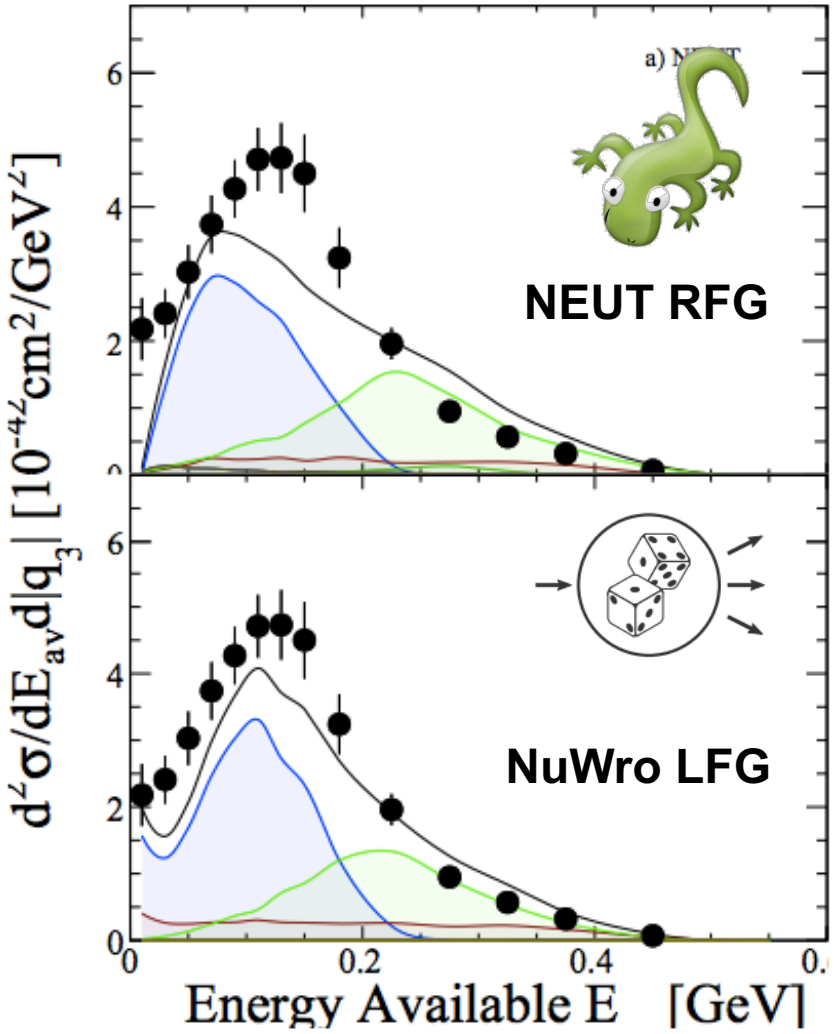




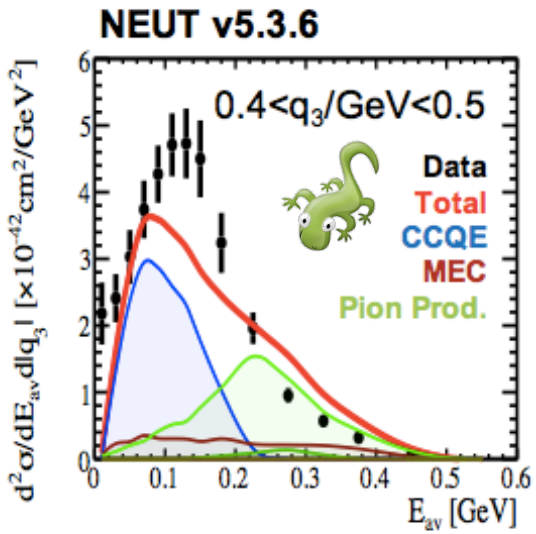


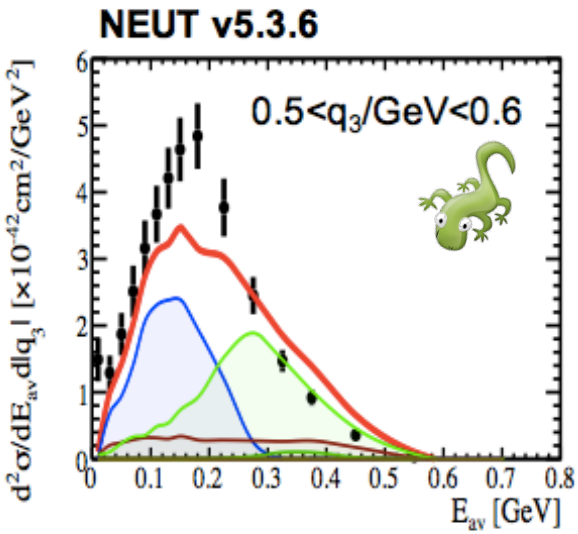
CCInclusive

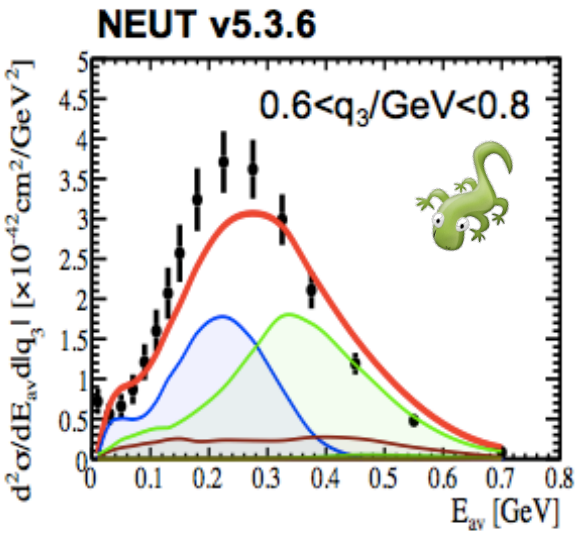
- End goal is to produce an inclusive cross-section model that can also describe exclusive channels well.
- Recent MINERvA data a good example of how difficult this is going to be due to model degeneracies.
- They measure hadronic energy (E_{av}) and three momentum transfer (q_3) for a CC-inclusive signal.
- Evidence of data-MC disagreements in dip region where CCQE, CCRES, CC2p2h all contribute.

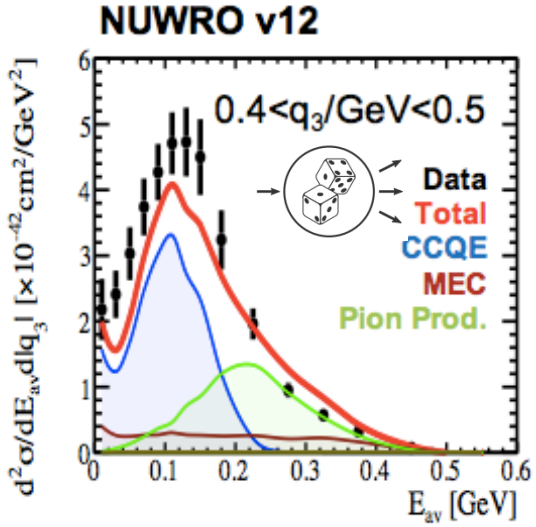


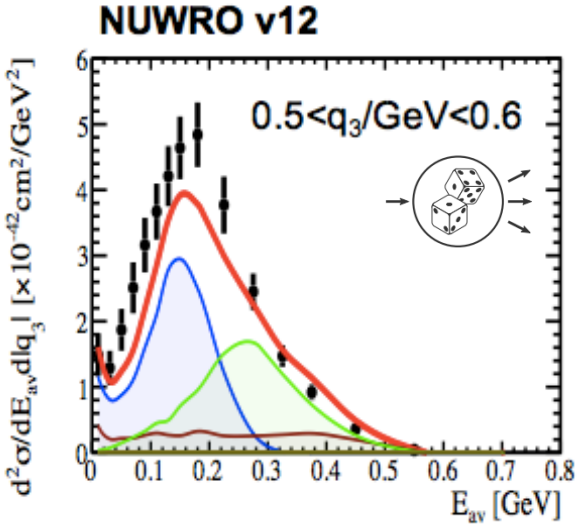
CCInclusive

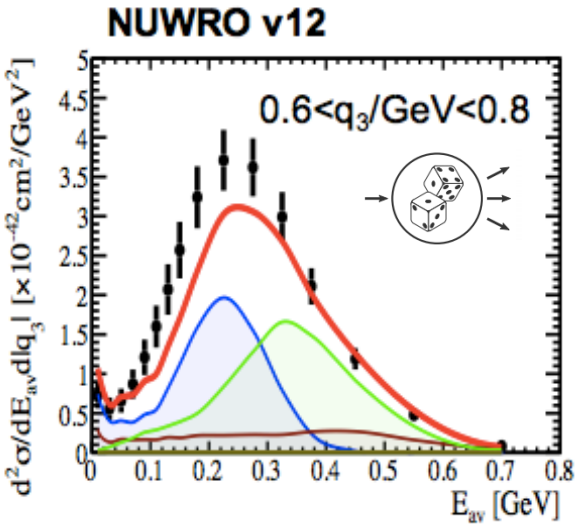












Summary

- Comparisons between generators and data vital tool for model testing.
- Will become even more important as more sophisticated measurements are made (e.g. Transverse Kinematic Measurements)
- Long way to go to have a consistent inclusive model in NEUT.
- Lots of moving parts to think about when running joint fits to v-A data.
- Need much closer collaboration with theorists and generator developers, especially when it comes to data comparisons understanding.

Thanks for listening!

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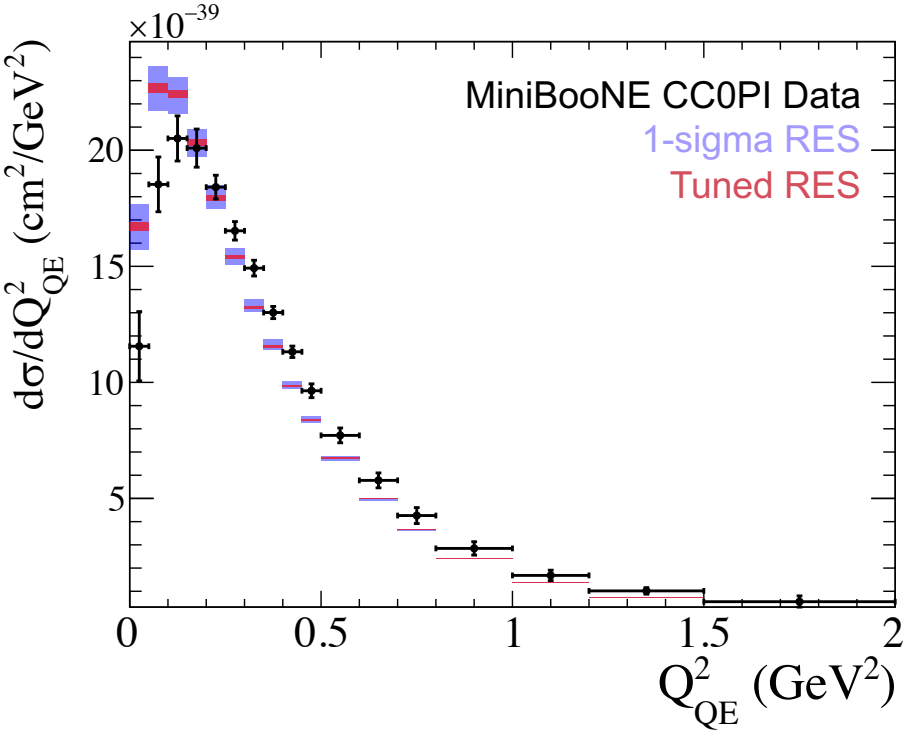
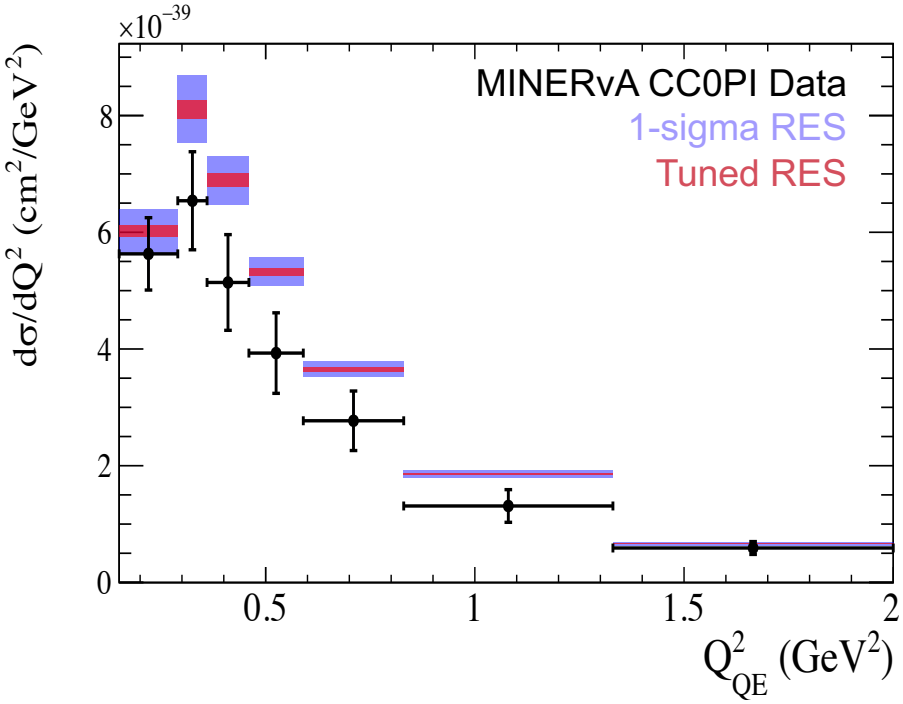
BACKUPS

BC Priors on CC0π RES

- Initial bubble chamber tunings set a tighter constraint than starting 1-sigma uncertainties as expected.

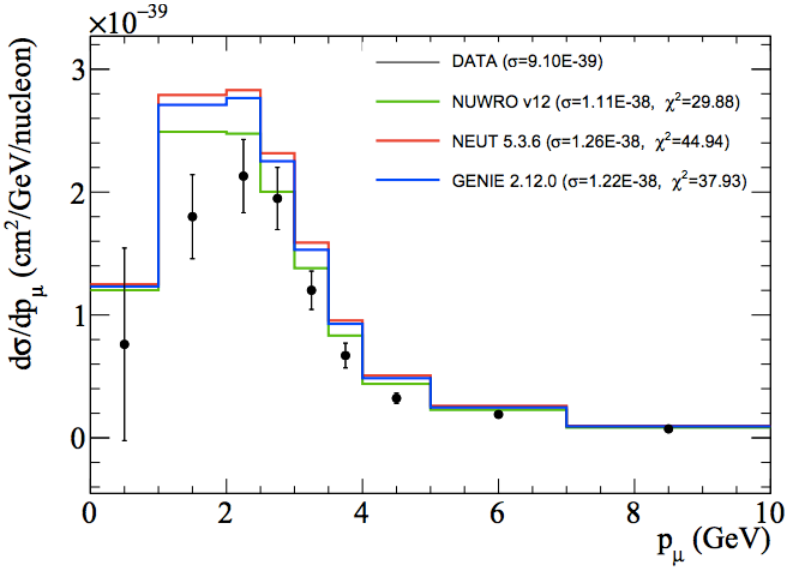




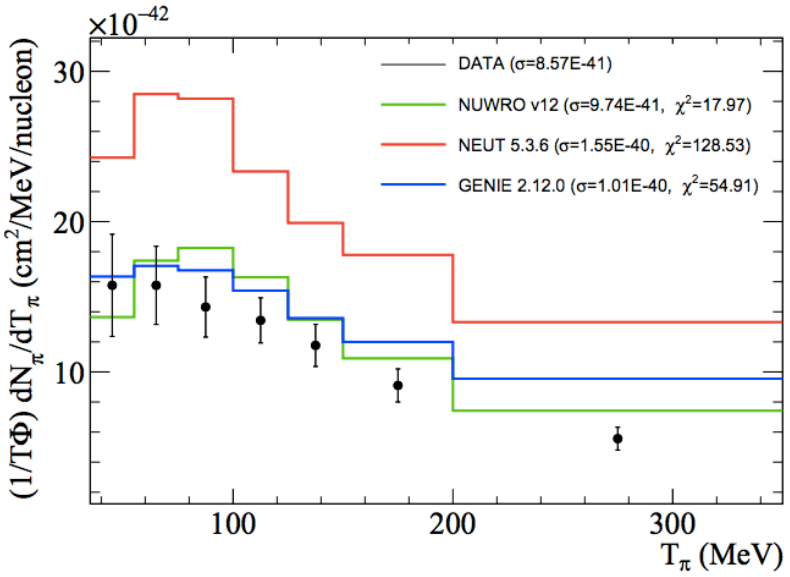
CCNπ

- Comparisons with MINERvA CCNπ data has also show that NEUT pion multiplicity is very different to other generators.

MINERvA CCNπ^+ Muon Momentum

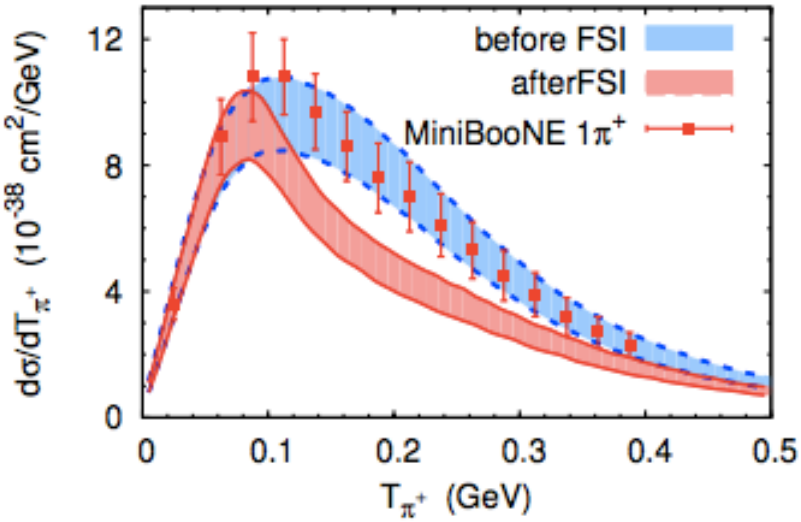


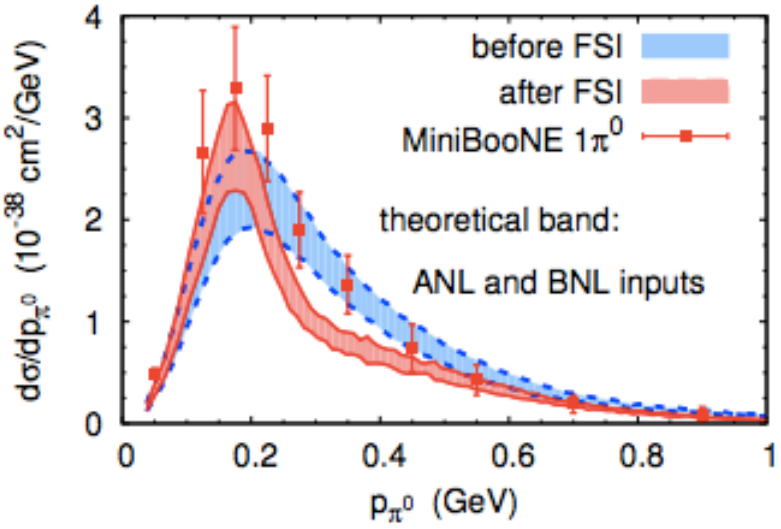
MINERvA CCNπ^+ Pion K.E

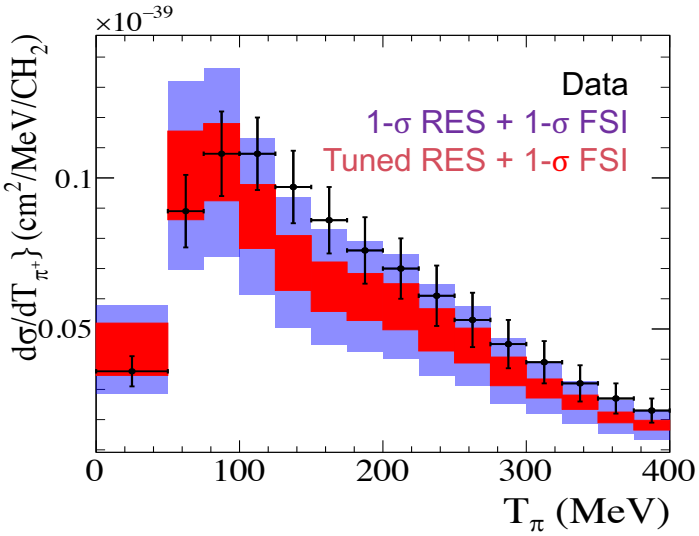


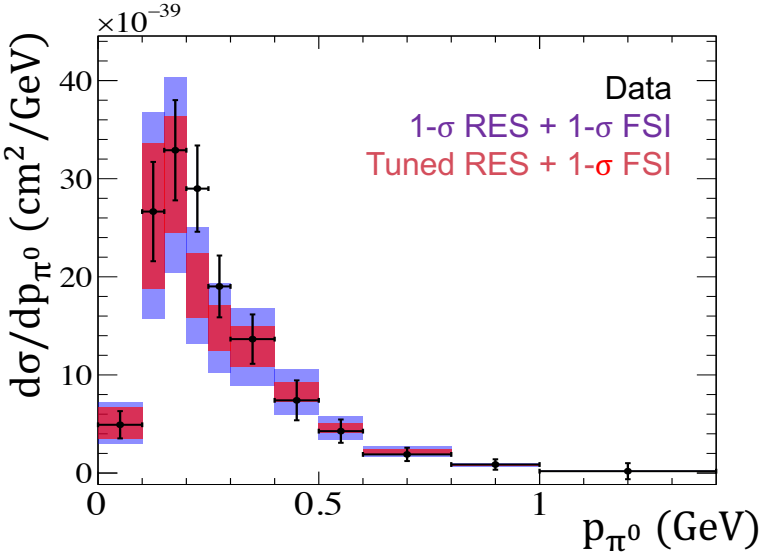
- Pion kinematic plots are **filled per pion not per event**, so very sensitive to total pion multiplicity.

NEUT vs GiBUU









GiBUU vs Generators

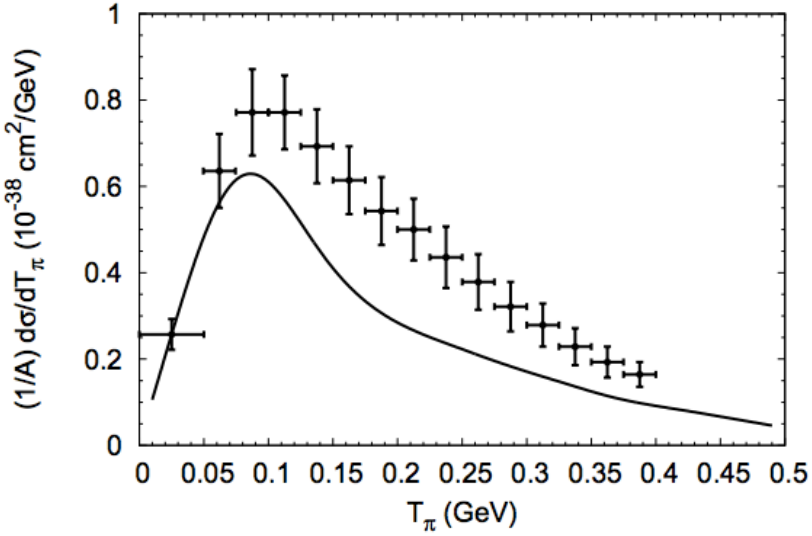
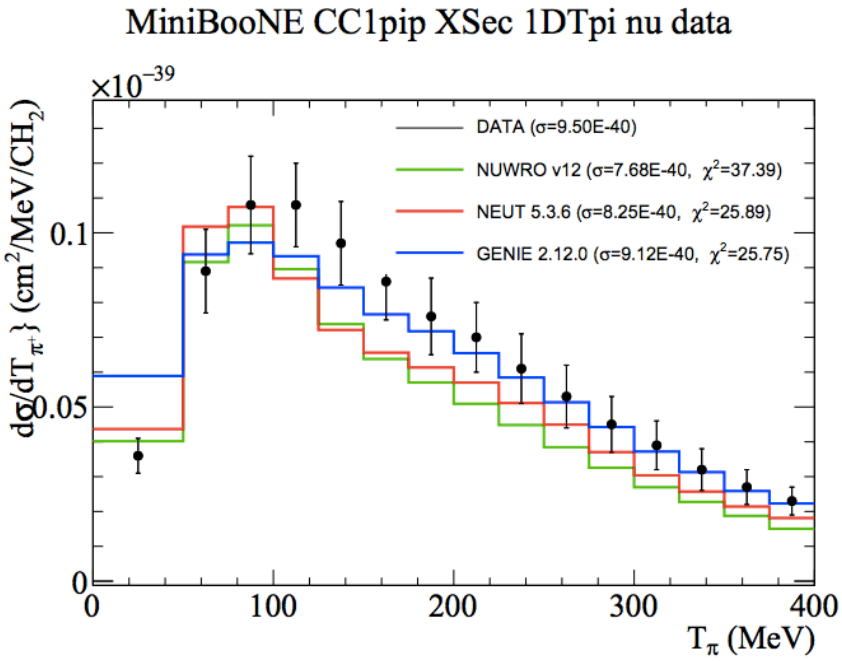


FIG. 1. Kinetic energy spectrum per nucleon of positively charged pions in the MiniBooNE flux for a CH_2 target. Data are from [2].



GiBUU vs Generators

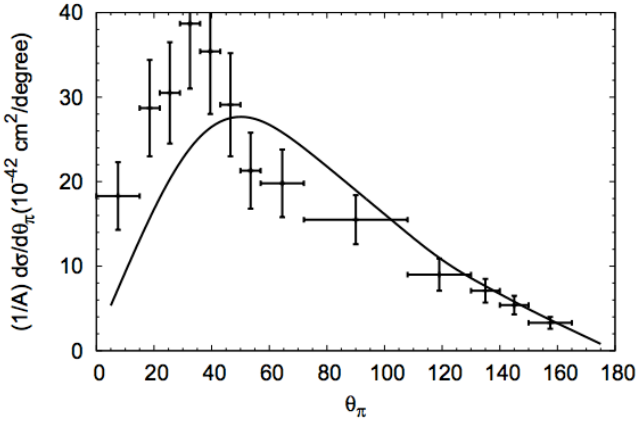
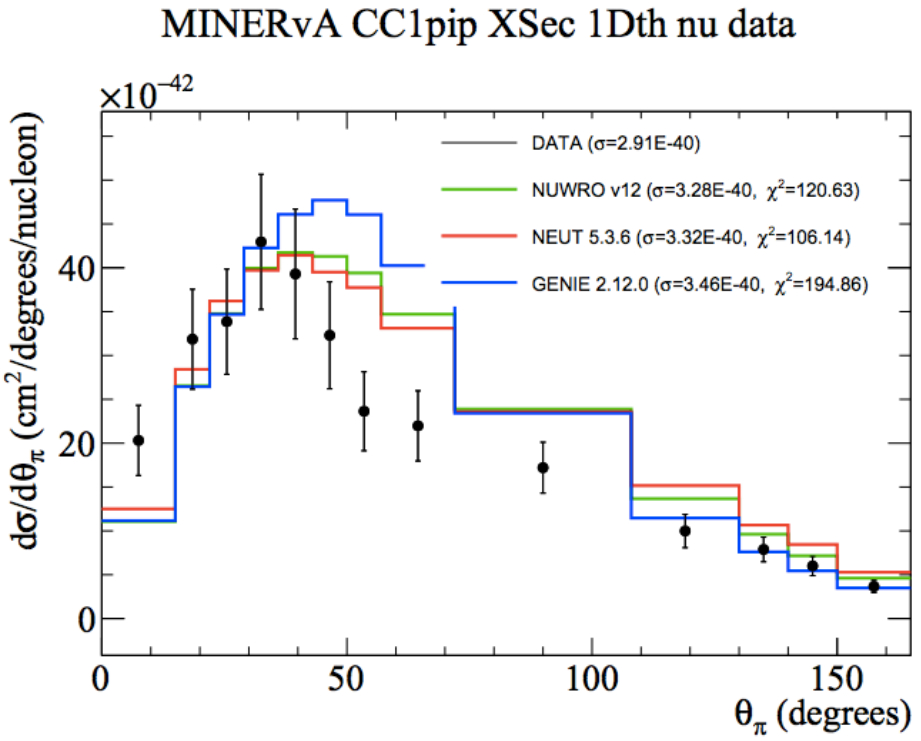


FIG. 7. Angular distribution of single charged pions in the MINERvA flux for a CH target with $W < 1.4$ GeV. Data are from [9].



GiBUU vs Generators

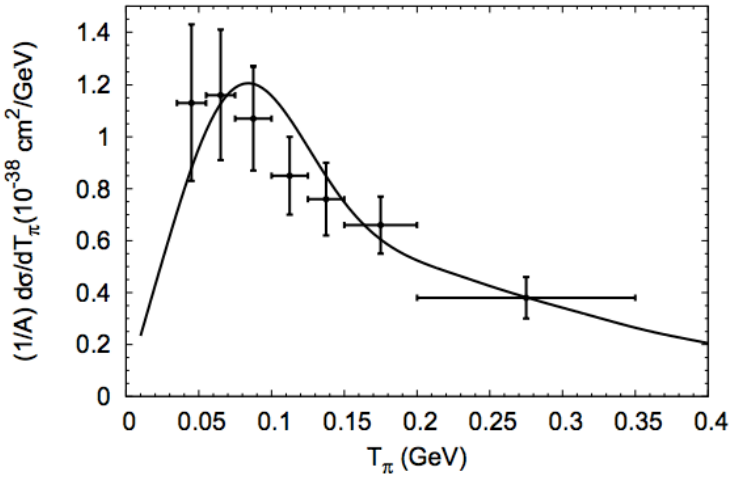
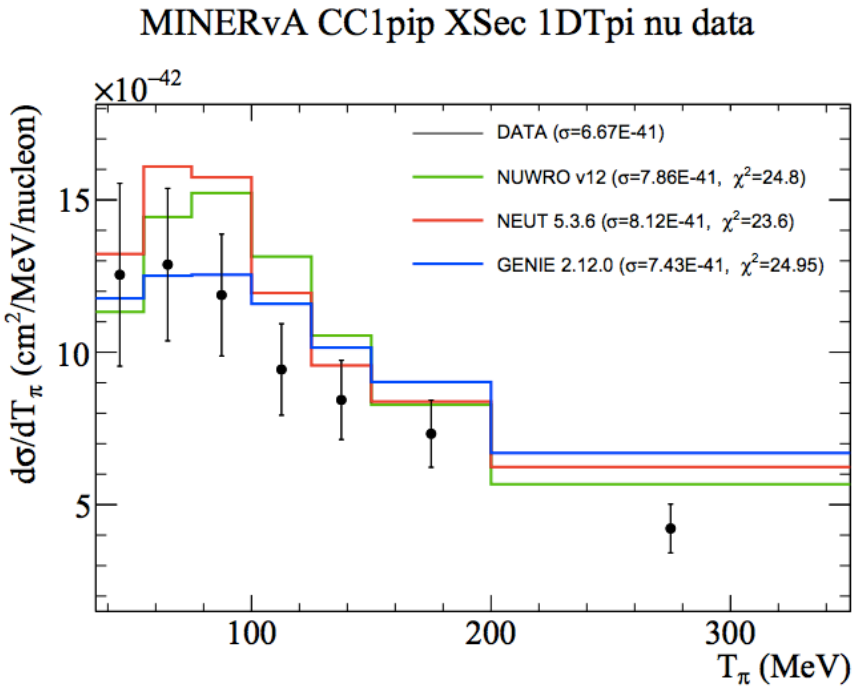


FIG. 6. Kinetic energy spectrum of single charged pions in the MINERvA flux for a CH target with $W < 1.4$ GeV. Data are from [9].



GiBUU vs Generators

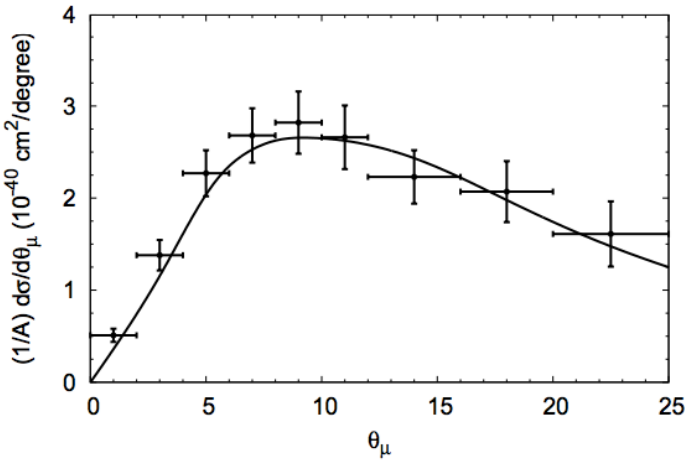
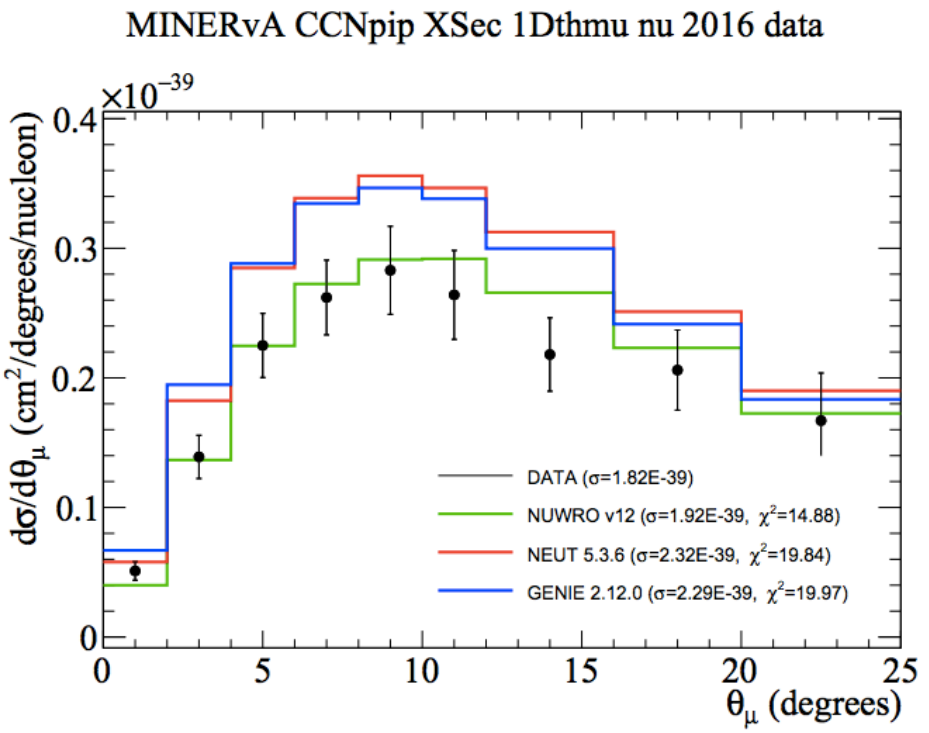


FIG. 11. Angular distribution of outgoing muons for multiple charged pion production in the MINERvA flux for a CH target with $W_{\text{rec}} < 1.8$ GeV. Data are from [10].



GiBUU vs Generators

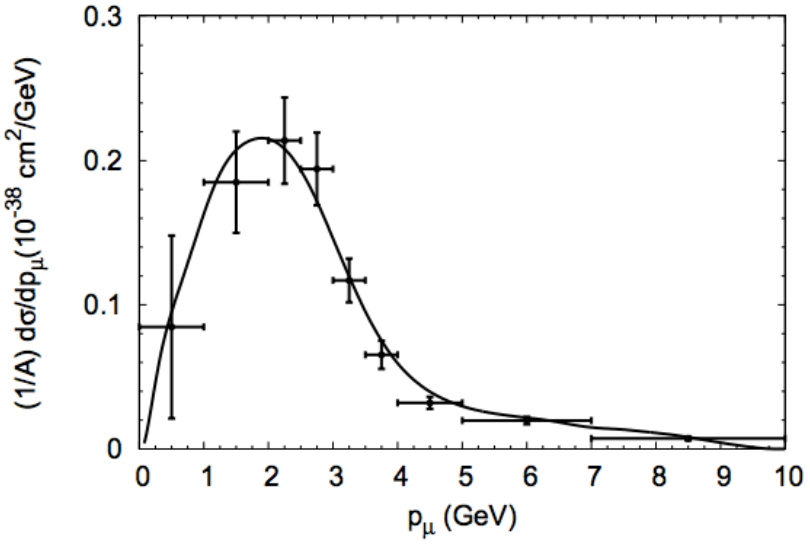
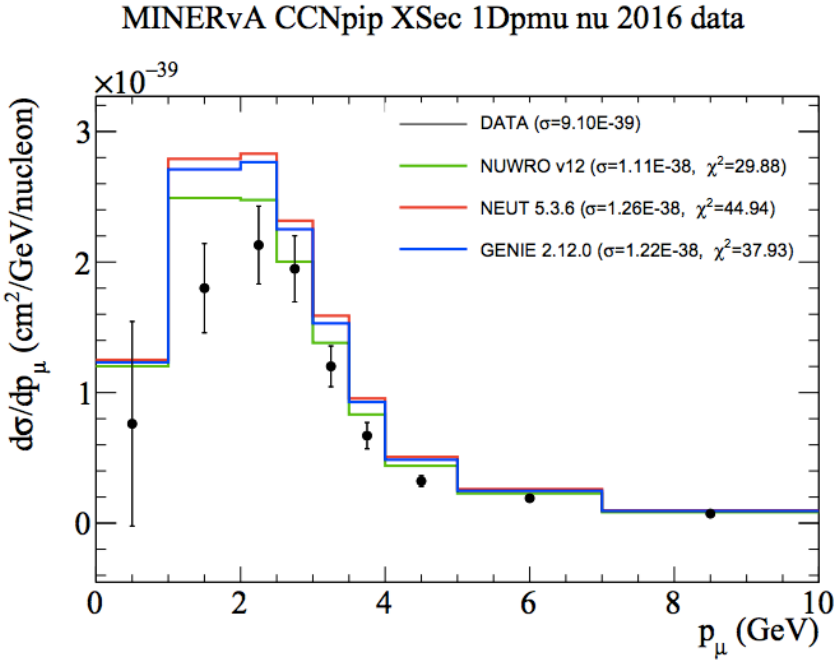


FIG. 10. Momentum distribution of outgoing muons for multiple charged pion production in the MINERvA flux for a CH target with $W_{\text{rec}} < 1.8$ GeV. Data are from [10].



GiBUU vs Generators

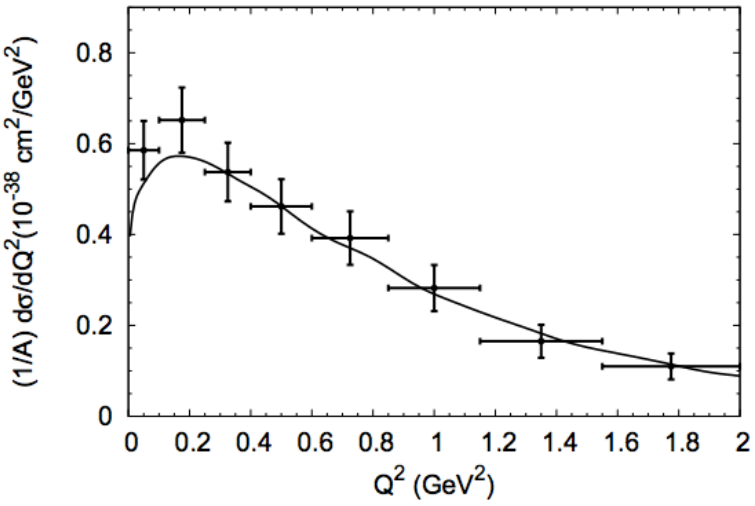


FIG. 12. Q^2 distribution of multiple charged pions in the MINERvA flux for a CH target with $W_{\text{rec}} < 1.8$ GeV. Data are from [10]