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# NUISANCE

Luke Pickering

NNN19: 2019/11/08

MICHIGAN STATE UNIVERSITY

# Team NUISANCE

Comparison tools used in this talk developed as part of NUISANCE with numerous external contributions:

Special thanks to A. Mastbaum and S. Dolan!

**C. Wret**

MICHIGAN STATE UNIVERSITY

UNIVERSITY of ROCHESTER

**C. Wilkinson**

UNIVERSITÄT BERN

# This Talk

- How do we use neutrino interaction models
- What is NUISANCE
- Some recent comparisons
- What do global cross-section fitters really want? #3 will shock you!

# This Talk

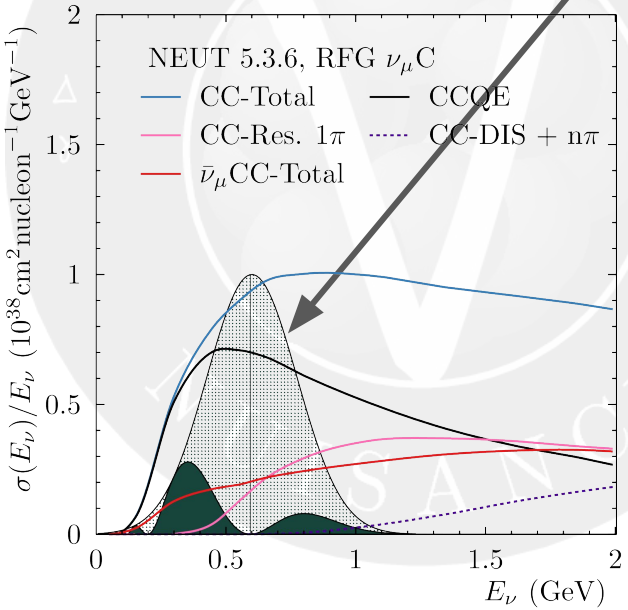
- How do we use neutrino interaction models
- What is NUISANCE
- Some recent comparisons
- What do global cross-section fitters really want? #3 will shock you!

**Disclaimer:** This talk will mostly focus on data/worries of few-GeV, long baseline neutrino experiments.

**I am a T2K and DUNE collaborator**: Feel free to call me out on any biases!


# Why do we need good interaction Models?

- Want to learn about **neutrinos**.




**Flux x Cross section**

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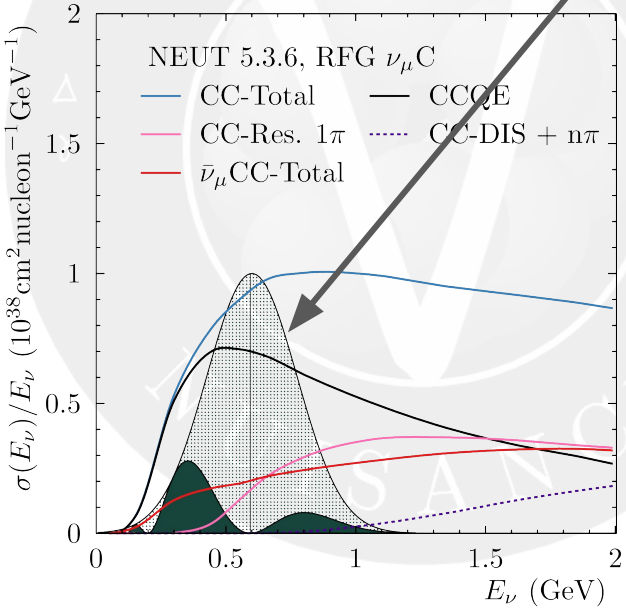
**NEUT:** Acta Phys.Polon. B40 (2009) 2477-2489

# Why do we need good interaction Models?

- Want to learn about **neutrinos**, but see **interactions**

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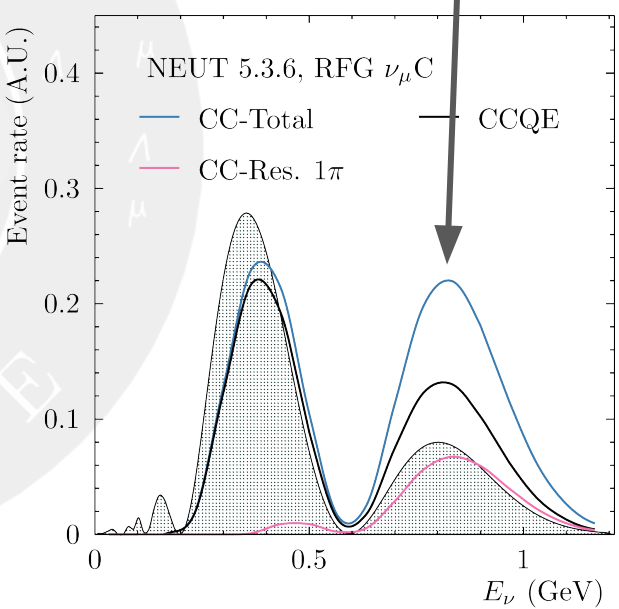


**= Event rate**



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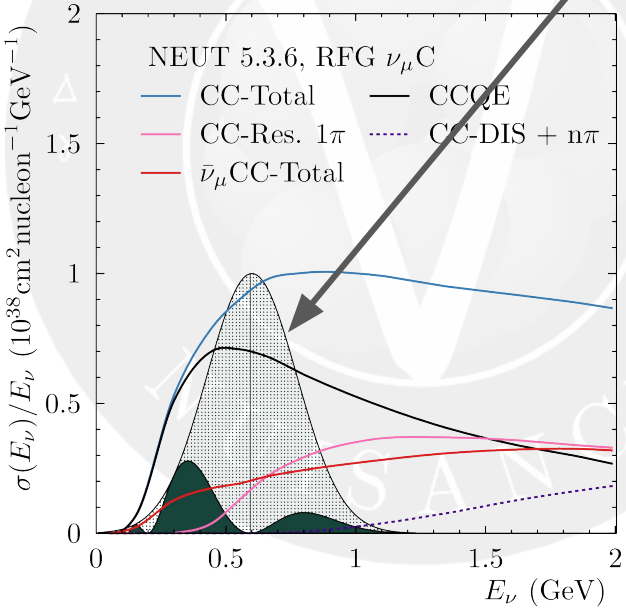
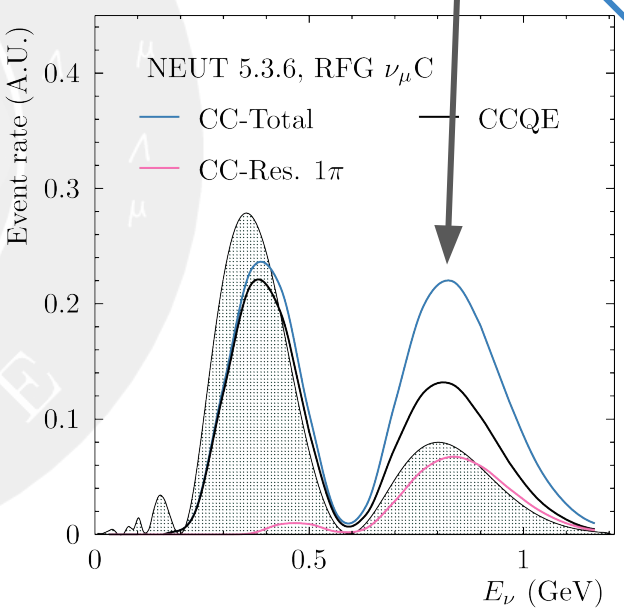
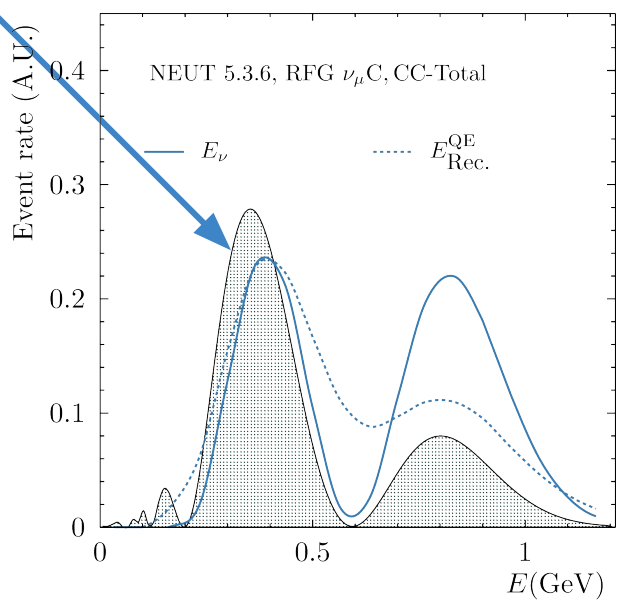


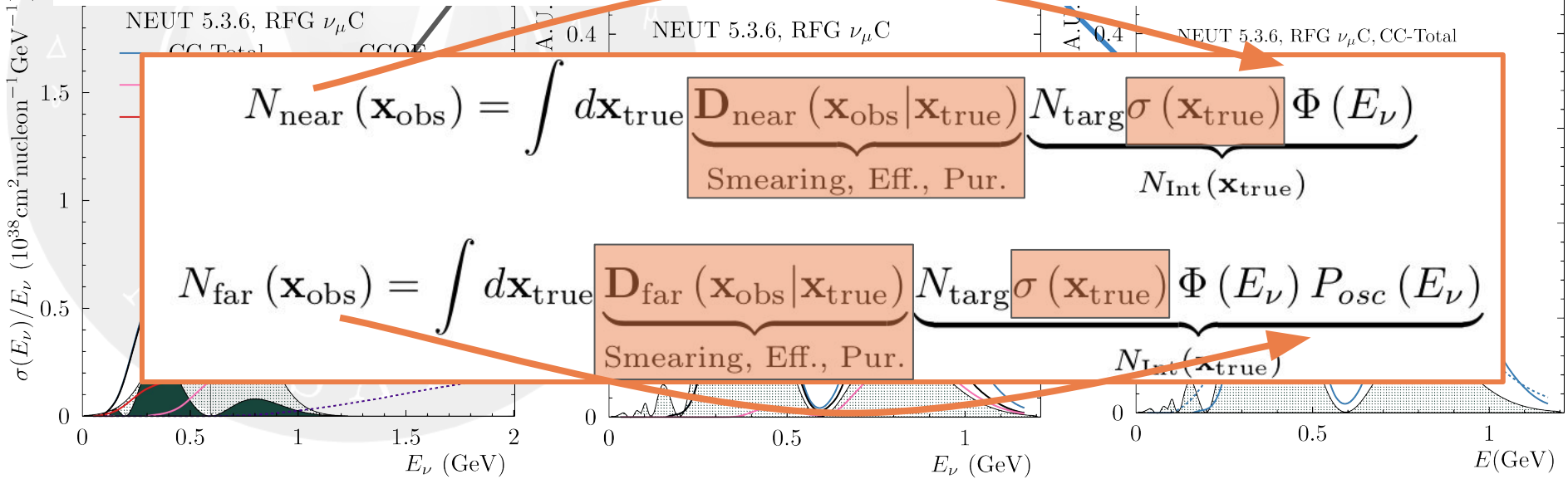




**Flux x Cross section** **= Event rate** **Observed properties**

# Why do we need good interaction Models?

**Need to work back from observables to learn about neutrinos: Done via generators**



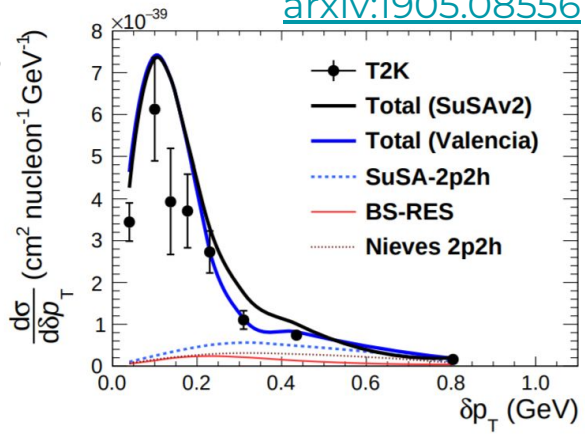

**Flux x Cross section** **= Event rate** **Observed properties**

# How do we try and improve them: Theory

- Improve nuclear response models in generators:
  - *e.g.* SuSAv2 1p1h+2ph2 **PRD 94, 093004 (2016)**
- Improve primary interaction models in generators:
  - *e.g.* MK single pion production **PRD 97, 013002 (2018)**

$\chi^2$ SuSA: 21/8
$\chi^2$ Val.: 27/8

arxiv:1905.08556



# How do we try and improve them: Theory

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- Improve primary interaction models in generators:
  - *e.g.* MK single pion production **PRD 97, 013002 (2018)**
- Improve simplifications in the MC:
  - Un-doing factorisation
  - Better-capture:
    - initial and final state physics
    - lepton-hadron correlations.

arxiv:1905.08556

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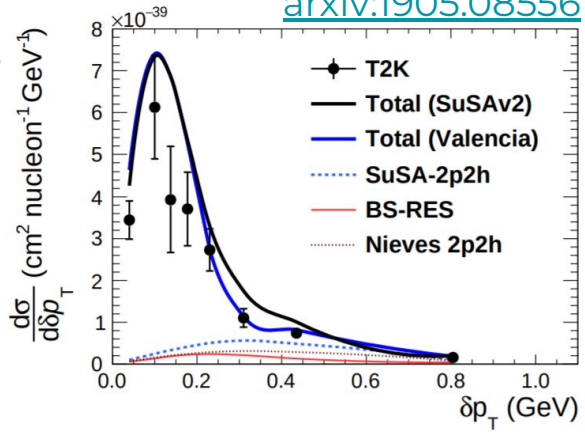
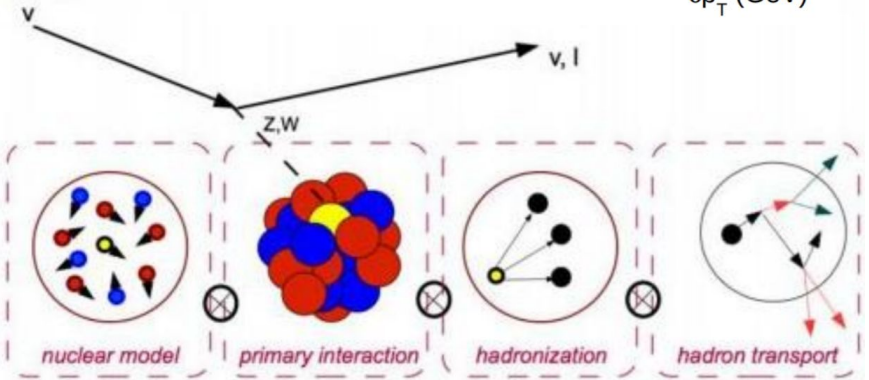
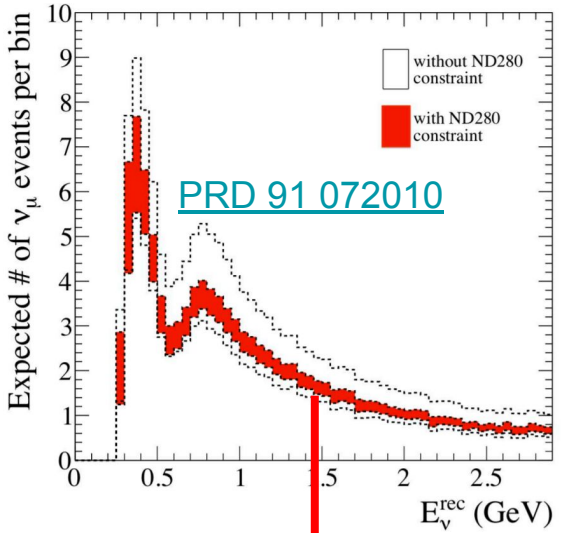


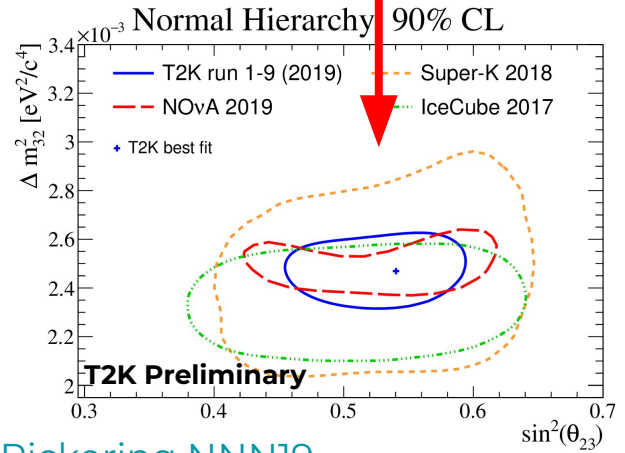



# What about uncertainties?

- Need plausible variations of models that can ‘cover’ the extant data.
- Compare to historic data ⇒ well-motivated prediction and uncertainties:
  - Then assume model is predictive for new data
- If experimentalists don’t have the ability to vary ‘theory’ parameters:
  - Have to make something up…




PRD 91 072010

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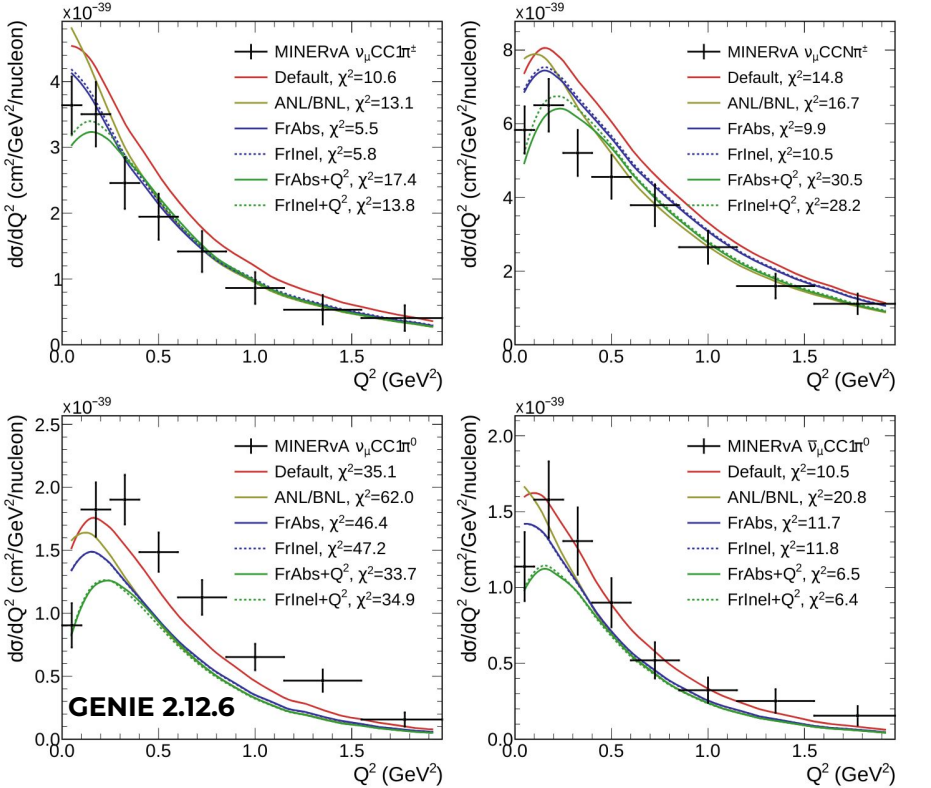
# How do we try and make them right: Tune

- **Ideal world:** model describes nature up to some unknown parameter values.

**MINERvA Single pion production comparisons**




Phys. Rev. D 100, 072005 (2019)

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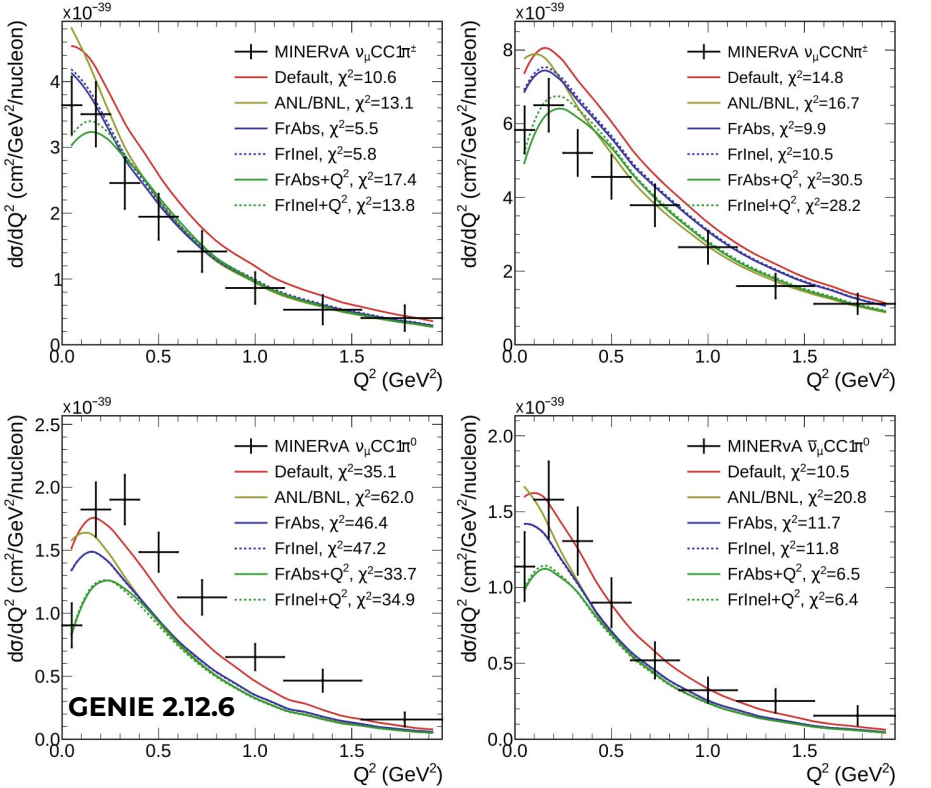


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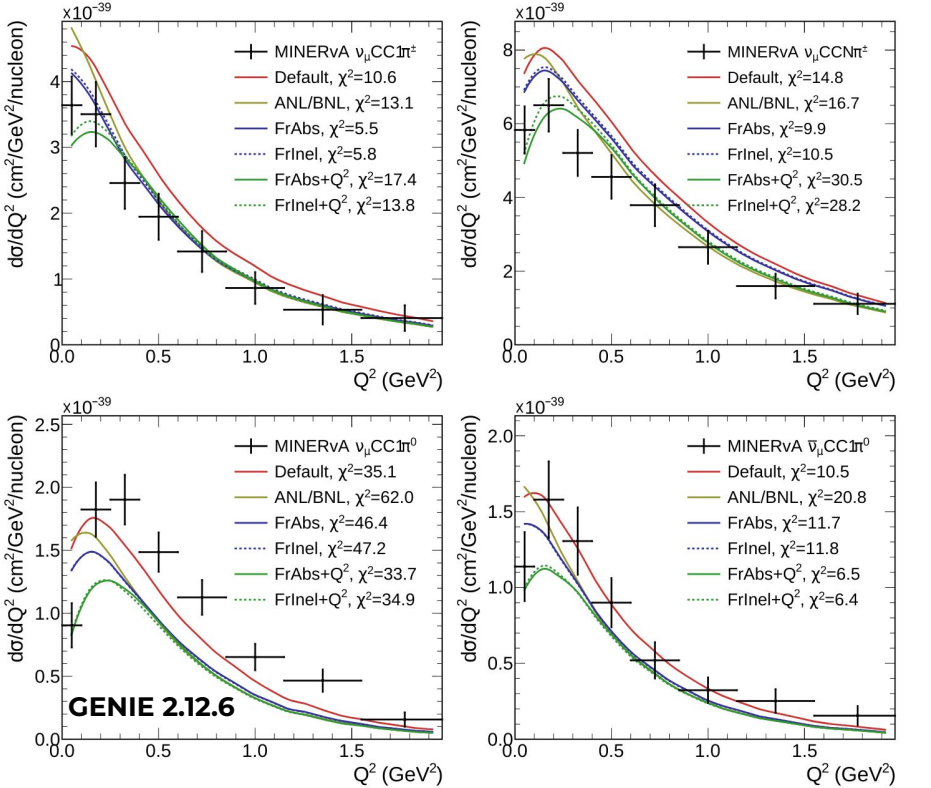
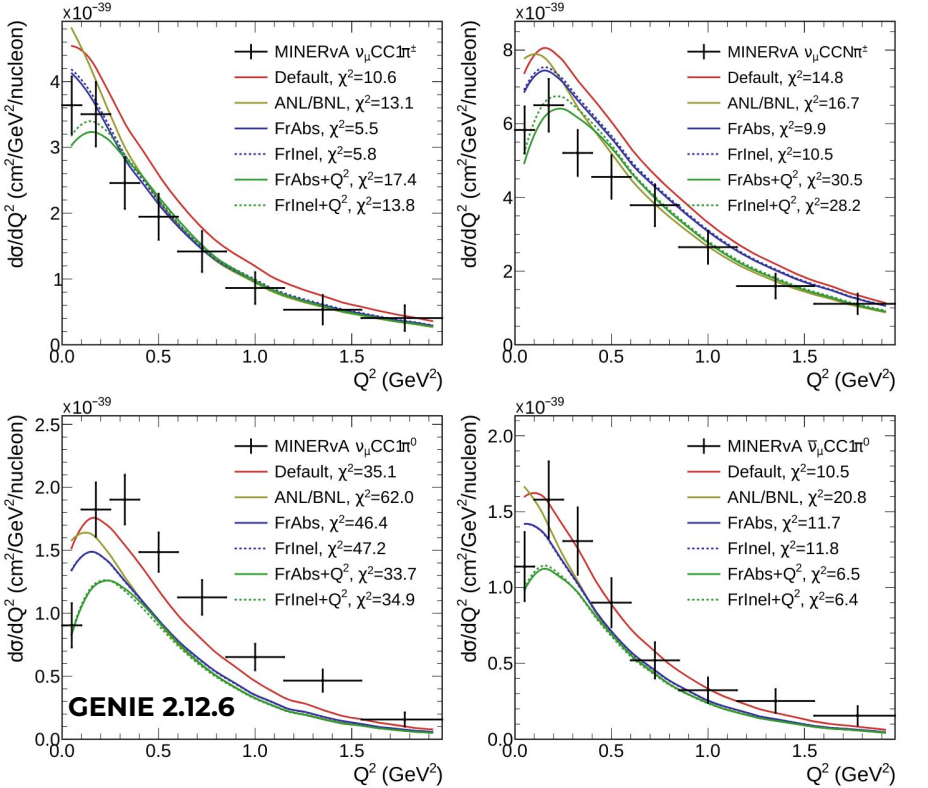



Phys. Rev. D 100, 072005 (2019)

# How do we try and make them right: Tune

- **Ideal world:** model describes nature up to some unknown parameter values:
  - **We don't live in that world.**
- **Dangers of tuning:**
  - Absorb data/MC discrepancy into poor parameterization.
  - Propagate CV+uncerts from well-described projection to poorly described projection.
  - *e.g.* Tune in inclusive lepton variables and predict hadronic shower.

**MINERvA Single pion production comparisons**




Phys. Rev. D 100, 072005 (2019)


# NUISANCE

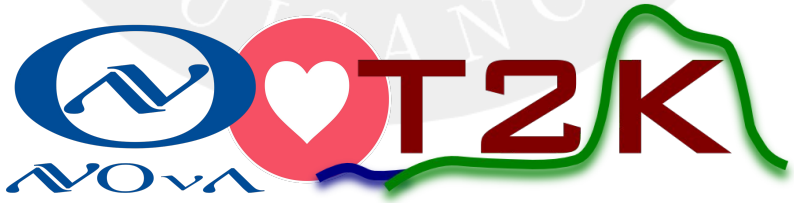
# What a NUISANCE


- Global neutrino scattering data comparator and model fitter:
  - Contains hundreds of published data sets with associated errors and signal definitions.
  - **The most valuable part of NUISANCE is the person-hours that have been spent implementing and validating data!**
- Applies experimental signal definitions to MC events from: GENIE, NEUT, NuWro, GiBUU, HepMC, ...
- Links to MC event generator interaction systematic uncertainty tools for model parameter variation.
- Code is open source so analyses can be reproduced and extended: https://github.com/NUISANCEMC/nuisance

# Who are we working with?

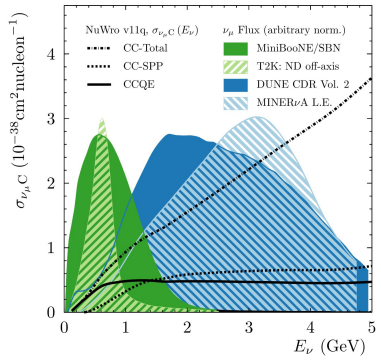







# What we want out of comparisons to data

- Range of:
  - Neutrino energies



# What we want out of comparisons to data

- Range of:
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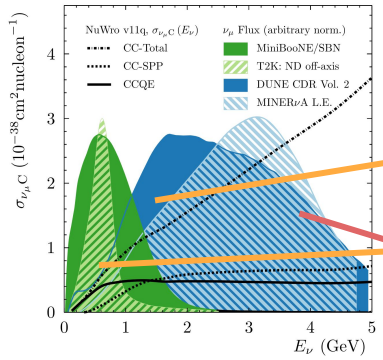
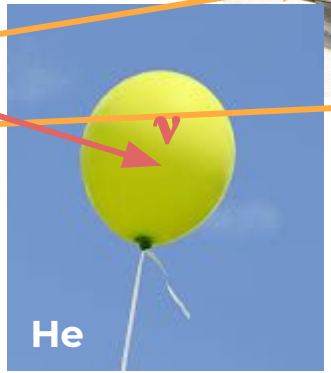
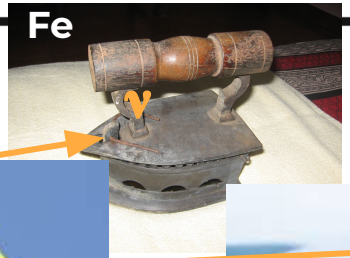
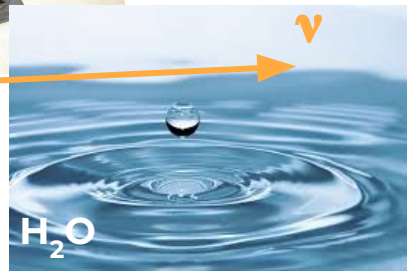
  - Targets



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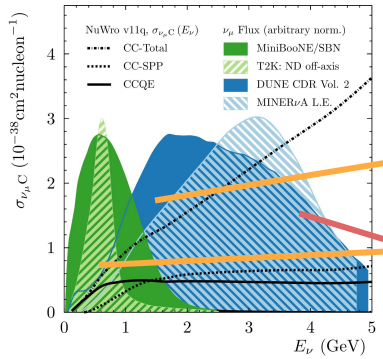
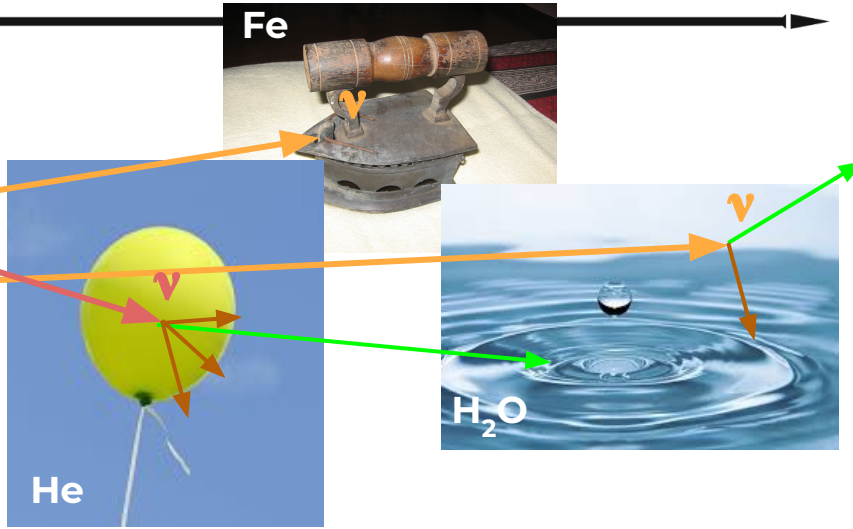
  - Final state topologies
  - Observable projections



# What we want out of comparisons to data

- Range of:
  - Neutrino energies
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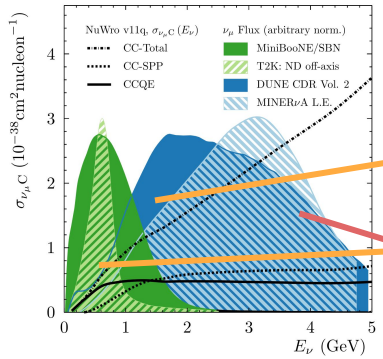
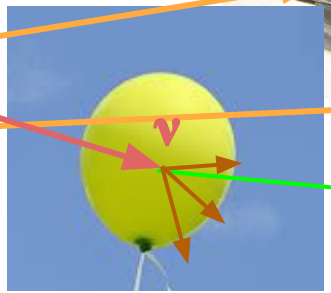
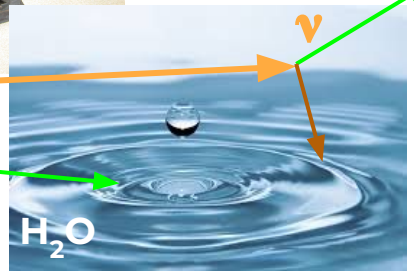
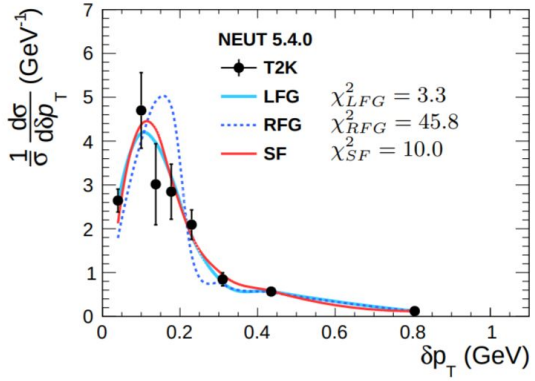
- Sensitivity to:
  - Model choice
  - Free parameter central values
  - Free parameter uncertainties







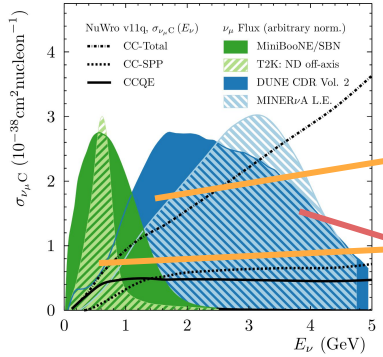



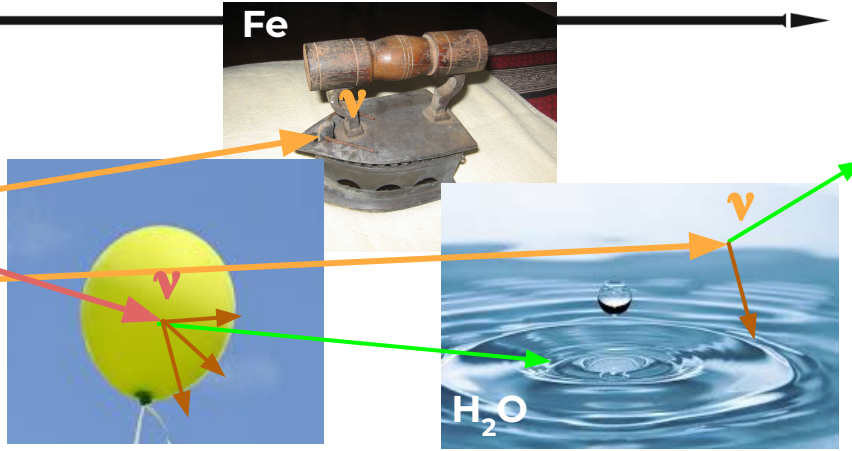



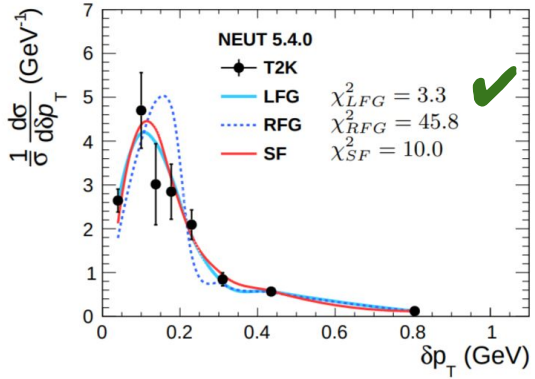

**T2K data**: PRD98, 032003 (2018)
**Plots**: arXiv:1810.06043

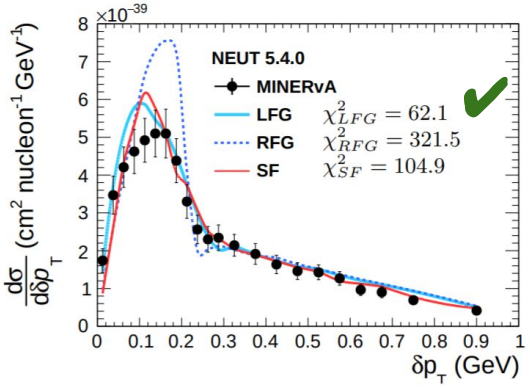
# What we want out of comparisons to data

- Range of:
  - Neutrino energies
  - Targets
  - Final state topologies
  - Observable projections
- Sensitivity to:
  - Model choice
  - Free parameter central values
  - Free parameter uncertainties
- Ability to make quantitative statements about GOF

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**T2K data**: PRD98, 032003 (2018) **MINERvA data**: PRL 121 (2018) no.2, 022504
**Plots**: arXiv:1810.06043

# Anatomy of a Cross-section Fit

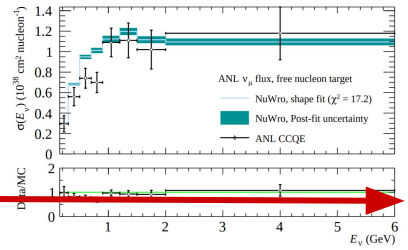
**Choose model parameters**

Interaction model

ANL CCQE

Data + Errors

Th. Prediction




**χ2**

**+**

BNL CC1pi+

Data + Errors

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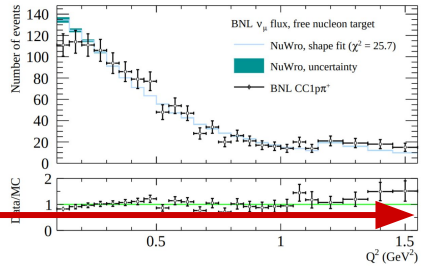


**χ2**

**+ …**

**+ Model parameter prior penalties**

**= Global χ2**

Minimize χ2 by varying model parameters

# Simple, Right?

- Cross-section tune recipe:
  - Add all the data you can find

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- Cross-section tune recipe:
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  - Serve for updated interaction model and correlated uncertainties!

- But… have to take care:
  - Model parameterizations can be hard to uniquely constrain.
  - Hard to consistently evaluate test statistics.
  - Incomplete data coverage:
    - *e.g.* Many measurements focus on just charged lepton kinematics.
    - Need to be predictive in hadron kinematics…
  - Signal definitions not always clear/well defined in the context of an experiment.

- **These are problems that the community is working on together:** we know things now that we didn't before, but it is still worth highlighting specifics in historic data to be aware of.

# Some Example Comparisons

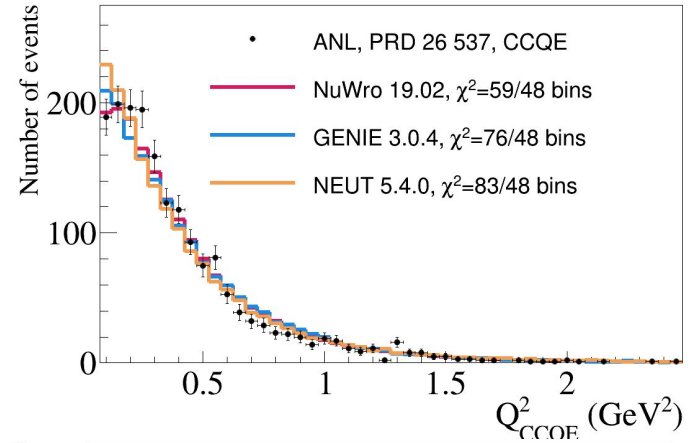
- Bubble Chamber lepton variables
- Nuclear-target CC0$\pi$ lepton variables
- Nuclear-target CC0$\pi$ lepton-hadron correlation variables

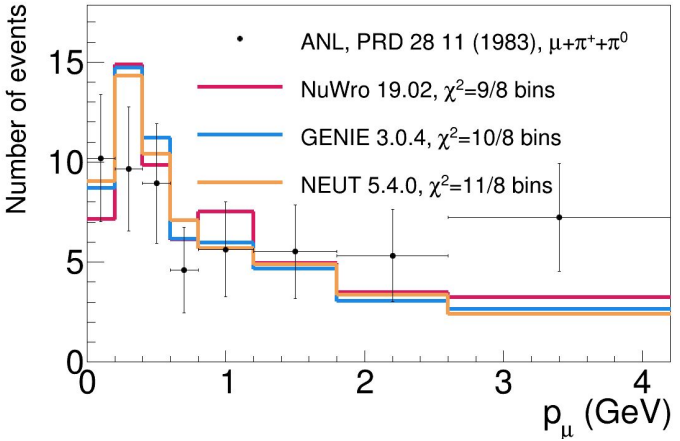
# Meet the Generators

| | Version/ Tune Used | Nuclear-model + QE-like | Single Pion Production | Higher W | Fragmentation | FSI |
|---|---|---|---|---|---|---|
| NEUT | 5.4.0 | Valencia:<br>- 1p1h+RPA<br>- 2p2h | Rein-Sehgal + lepton mass effects | Bodek-Yang low $Q^2$ | Pythia 5 | Tuned Salcedo-Oset cascade |
| GENIE | v3.0.4 G1810a_0211 + bug-fixed splines | Valencia:<br>- 1p1h+RPA<br>- 2p2h | Rein-Sehgal 16 resonances non-interfering (BC Tuned) | Bodek-Yang low $Q^2$ | AGKY+Pythia 6 | Tuned effective single interaction (hA) |
| NuWRO | v19.02 | - Benhar SF w/ opt. pot.<br>- Valencia: RPA & 2p2h | Delta + Pythia Low W | Bodek-Yang low $Q^2$ | Pythia 6 | Tuned Salcedo-Oset cascade |

# Comparisons to Bubble Chamber data

- (quasi-)free of any nuclear effects.
  - Granular reconstruction and unambiguous final state topologies.
  - Allows tuning of ‘primary’ neutrino nucleon/part interaction.

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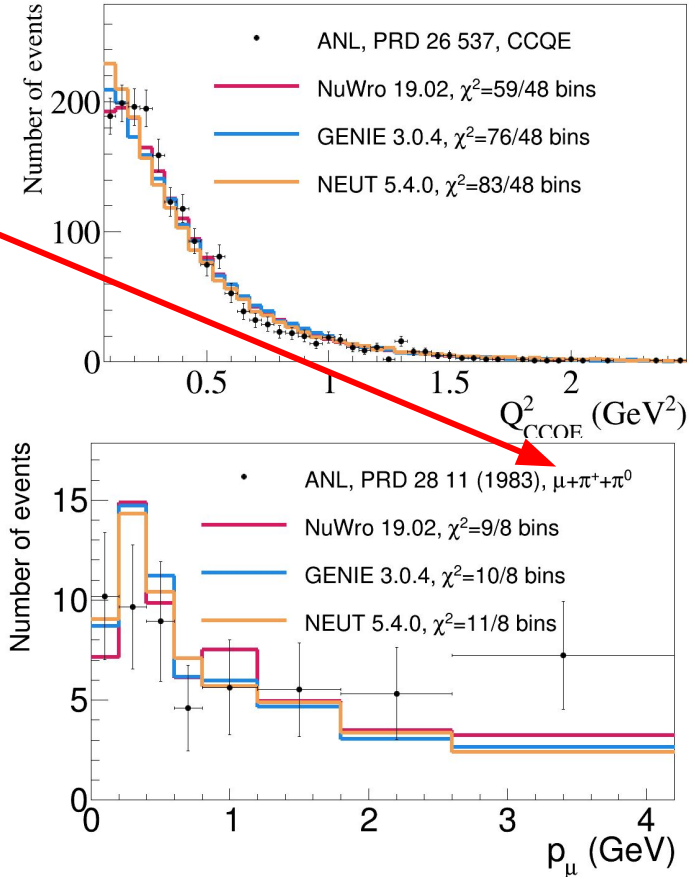
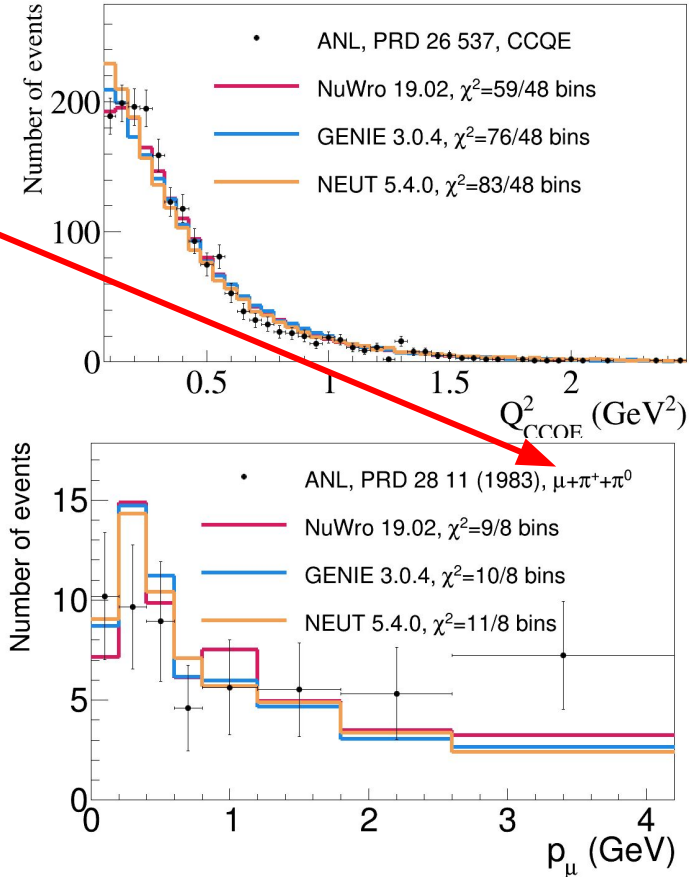


# Comparisons to Bubble Chamber data

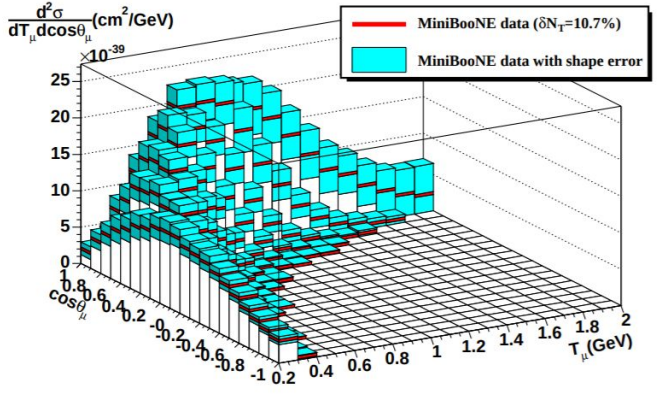
- (quasi-)free of any nuclear effects.
  - Granular reconstruction and unambiguous final state topologies.
  - Allows tuning of ‘primary’ neutrino nucleon/part interaction.
- Data is old with large statistical errors and often unknown systematic errors (largely flux).



# Nuclear data: MiniBooNE CCQE

- Data sets without published, correlated errors are difficult to use in a global fit.
- MiniBooNE CCQE(like):
  - Many bins, no published error matrix.

PRD 81 092005




PRD 93 072010

| | $\chi^2_{\text{min}}/N_{\text{DOF}}$ |
|---|---|
| All | 117.9/228 |
| MINER$\nu$A | 30.3/13 |
| MiniBooNE | 65.7/212 |
| $\nu$ | 69.1/142 |
| $\bar{\nu}$ | 46.1/83 |
| M$\nu$A vs MB | 117.9/228 |
| $\nu$ vs $\bar{\nu}$ | 117.9/228 |

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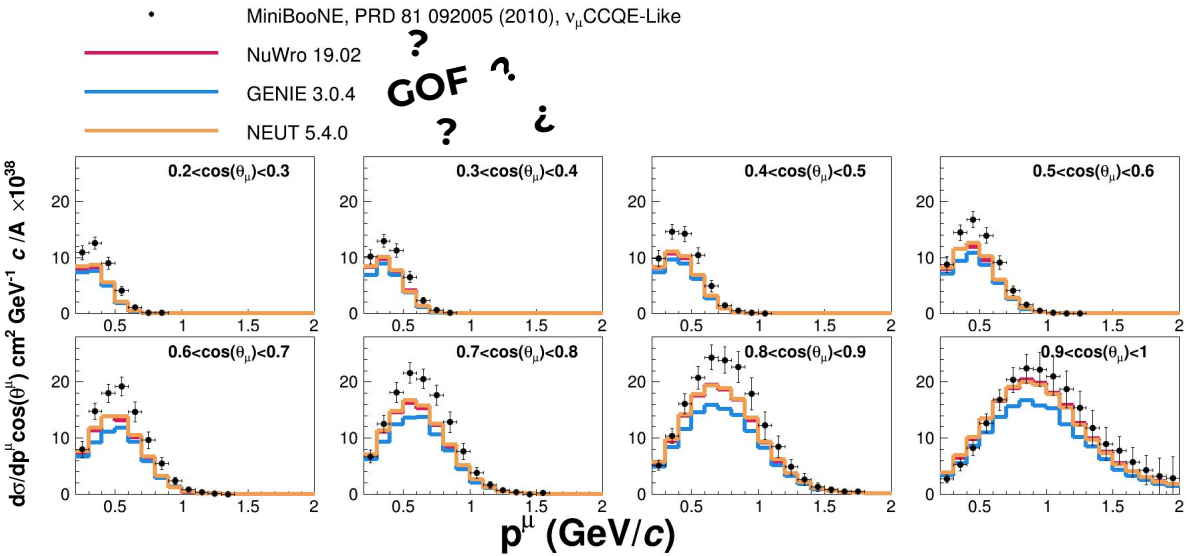
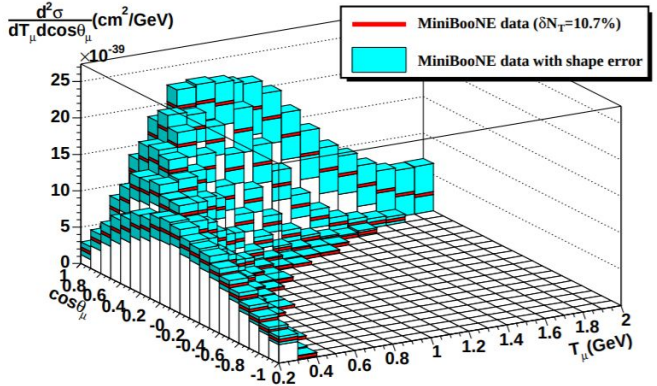



PRD 81 092005




PRD 93 072010

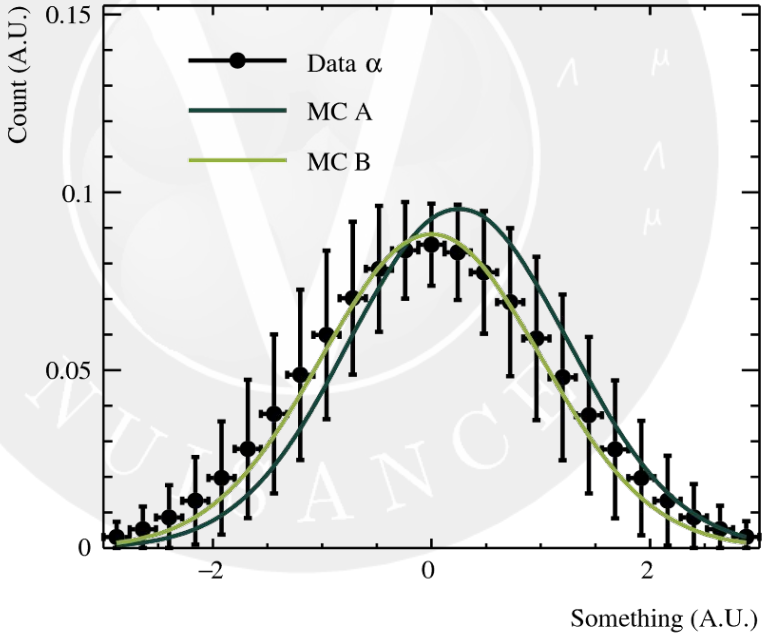
| | $\chi^2_{\text{min}}/N_{\text{DOF}}$ |
|---|---|
| All | 117.9/228 |
| MINER$\nu$A | 30.3/13 |
| MiniBooNE | 65.7/212 |
| $\nu$ | 69.1/142 |
| $\bar{\nu}$ | 46.1/83 |
| M$\nu$A vs MB | 117.9/228 |
| $\nu$ vs $\bar{\nu}$ | 117.9/228 |

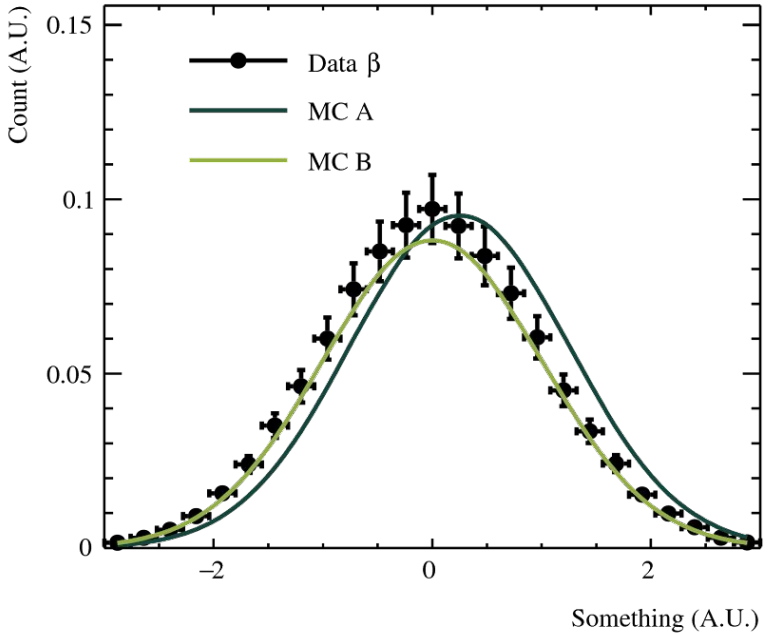
Audience Participation

# Let's Play... χ-by-eye!

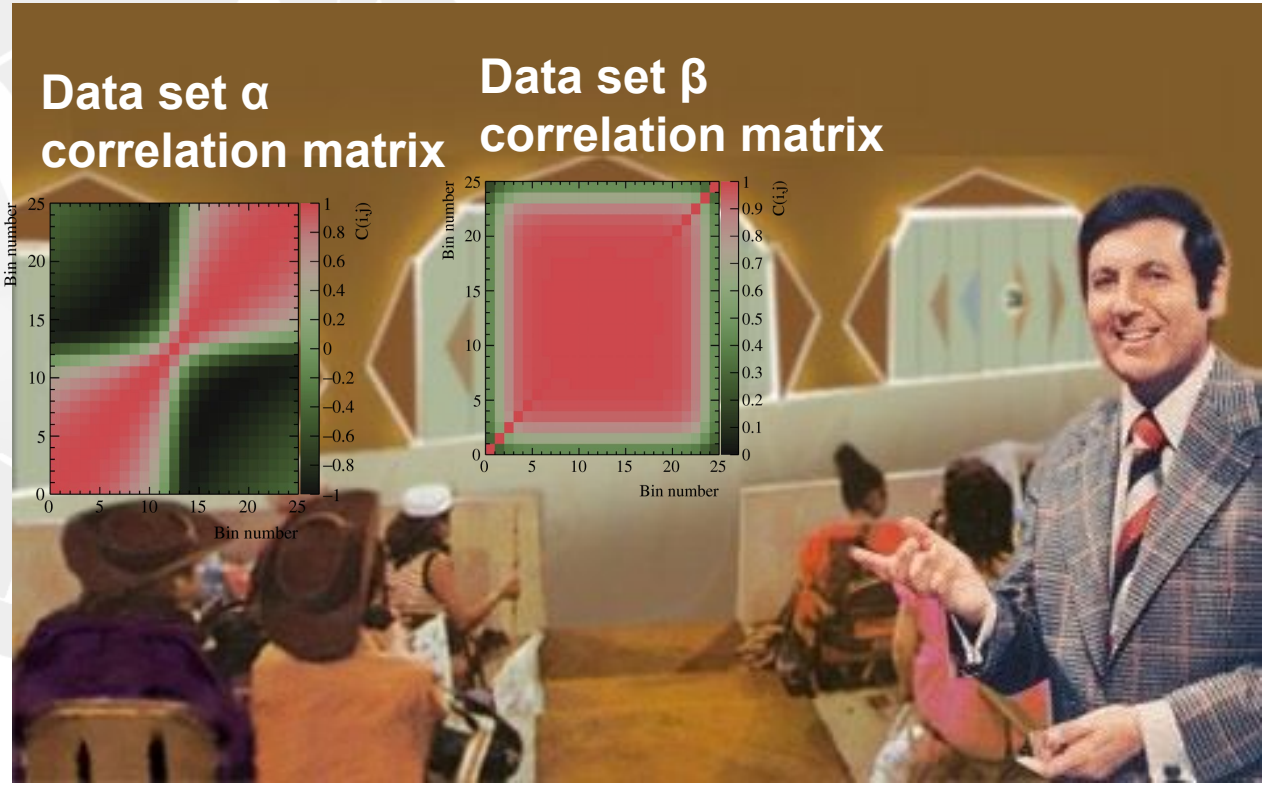
# Let's Play... $\chi$-by-eye!

- For each 'data set', guess which MC prediction fits the data better.

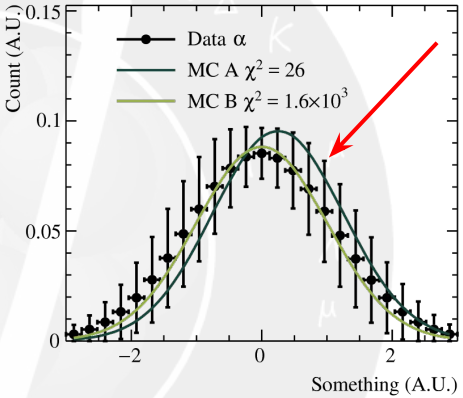


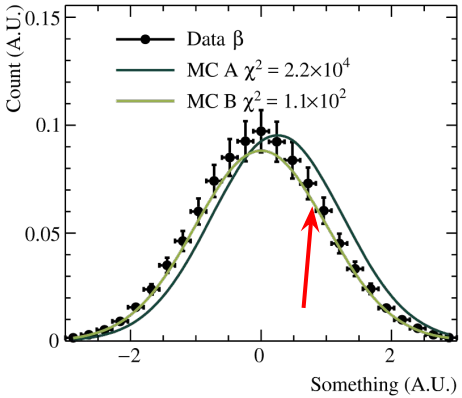



# How About Now?

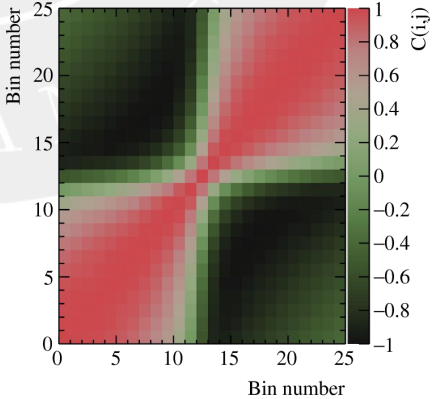


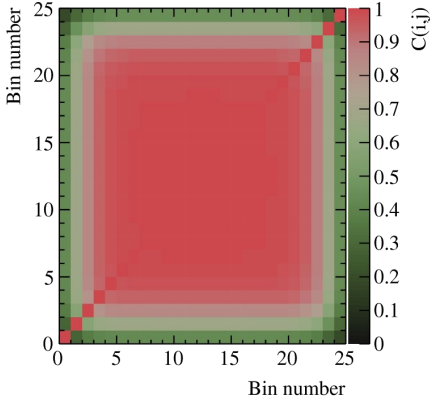
# What you expected?




Systematic parameter allows shift in Something. *e.g.* separation energy



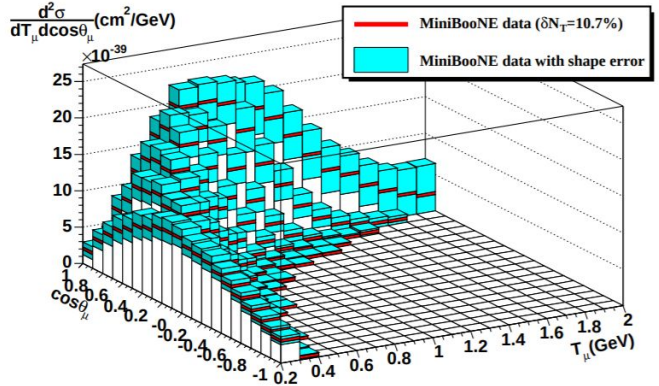




Systematic parameter allows normalization change. *e.g.* flux uncertainty.

# Nuclear data: MiniBooNE CCQE

- Data sets without published correlated errors are difficult to use in a global fit.
- MiniBooNE CCQE(like):
  - Many bins, no published error matrix.
  - What should the contribution to the global GOF be
    - **Fully uncorrelated**: $\sim \sum_{i \in \text{bins}} (\text{Data} - \text{MC})_i^2$
    - **Fully correlated**: $\sim \sum_{i \in \text{bins}} (\text{Data} - \text{MC})_i^2 / \text{NBins}$
  - In reality, probably somewhere in between.
  - If used naively, will incorrectly dominate a tune **and more data won't help**...
- But, we want to use the information that this data holds, unsatisfactory to just ignore it...

PRD 81 092005




PRD 93 072010

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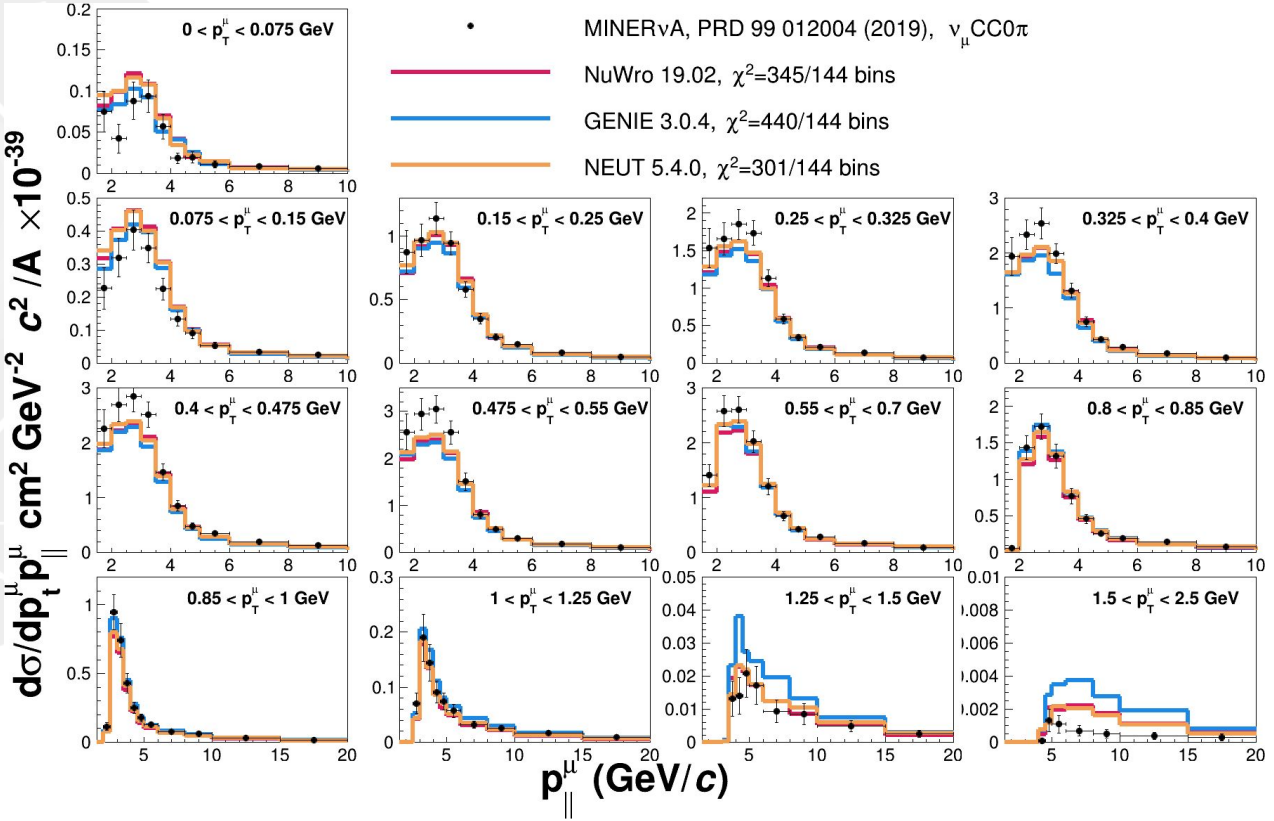
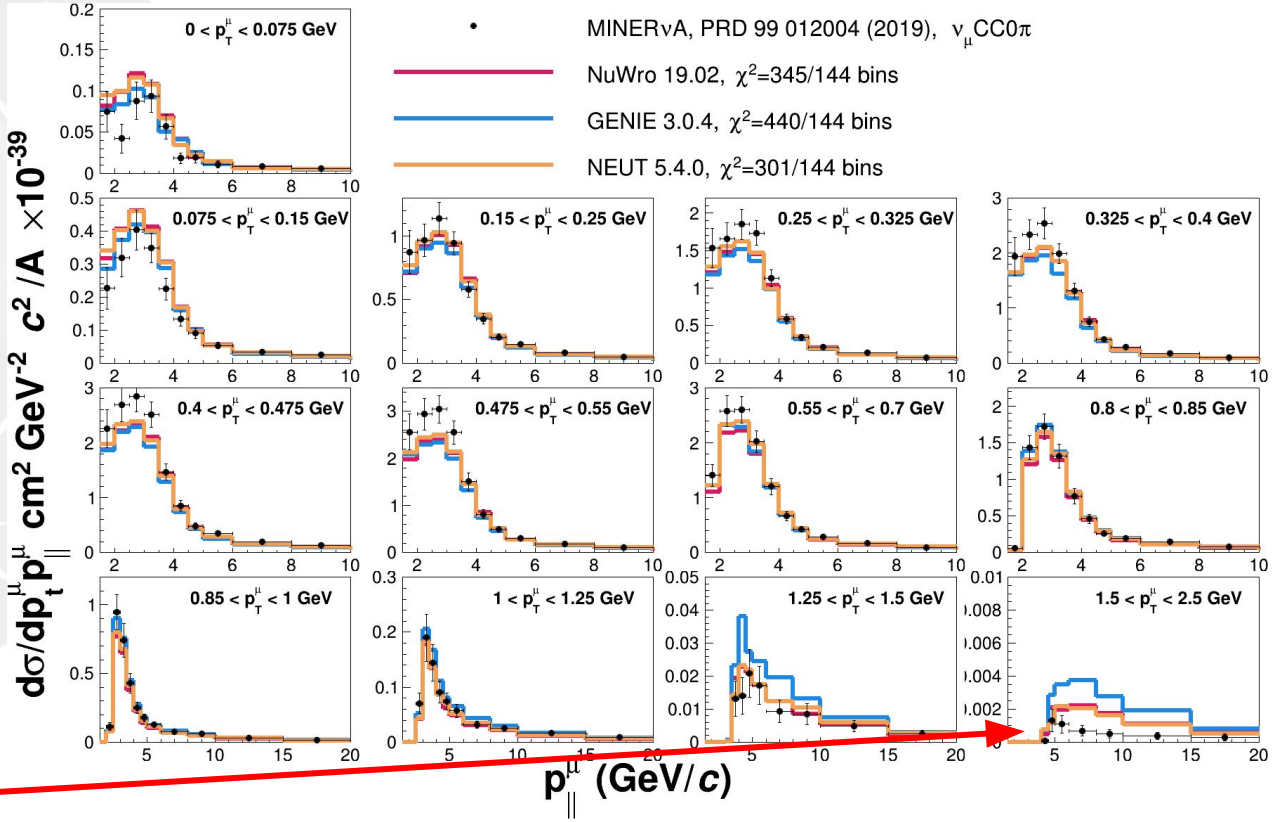
# MINERvA 0pi neutrino-mode

- Sensitive to neutrino energy ($p_{||}$) and momentum transfer ($p_t$) in a known flux



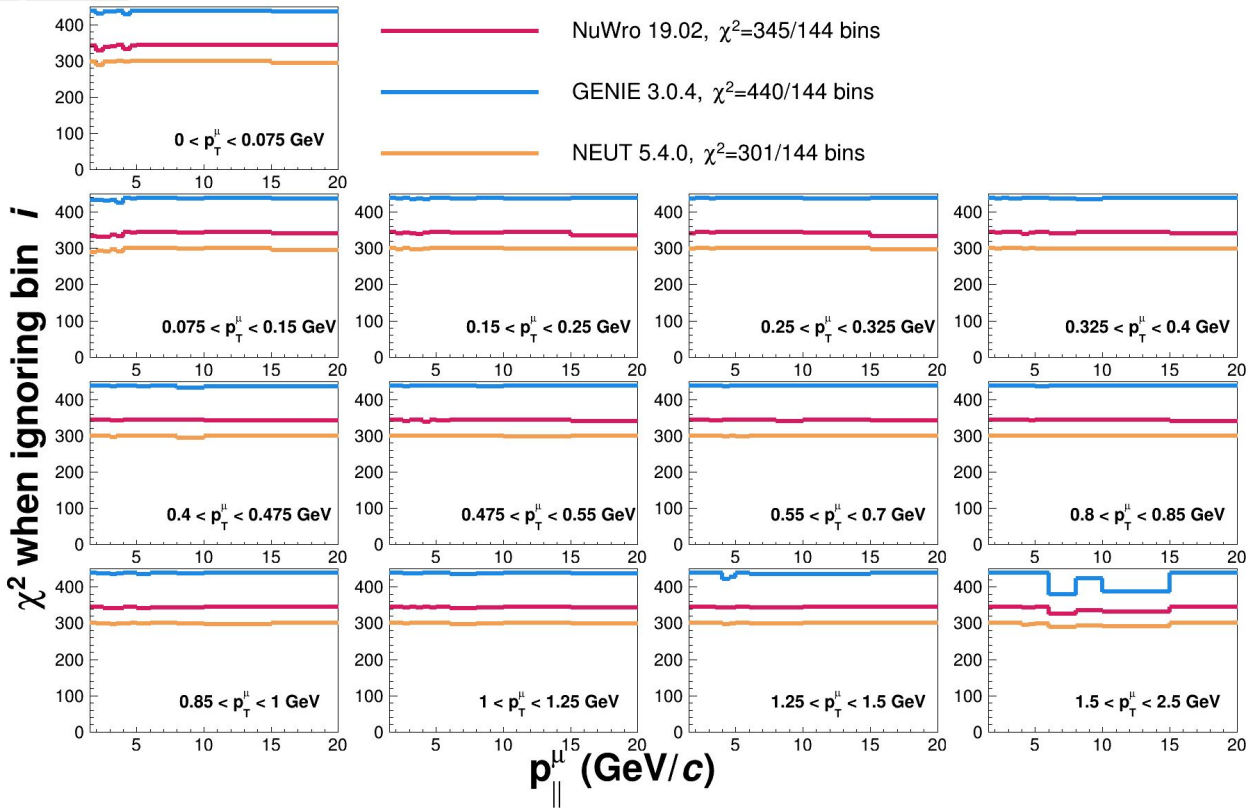
# MINERvA 0pi neutrino-mode

- Sensitive to neutrino energy ($p_{||}$) and momentum transfer ($p_t$) in a known flux
- Predicted ~well for bulk of distribution:
  - Higher angle poorly predicted



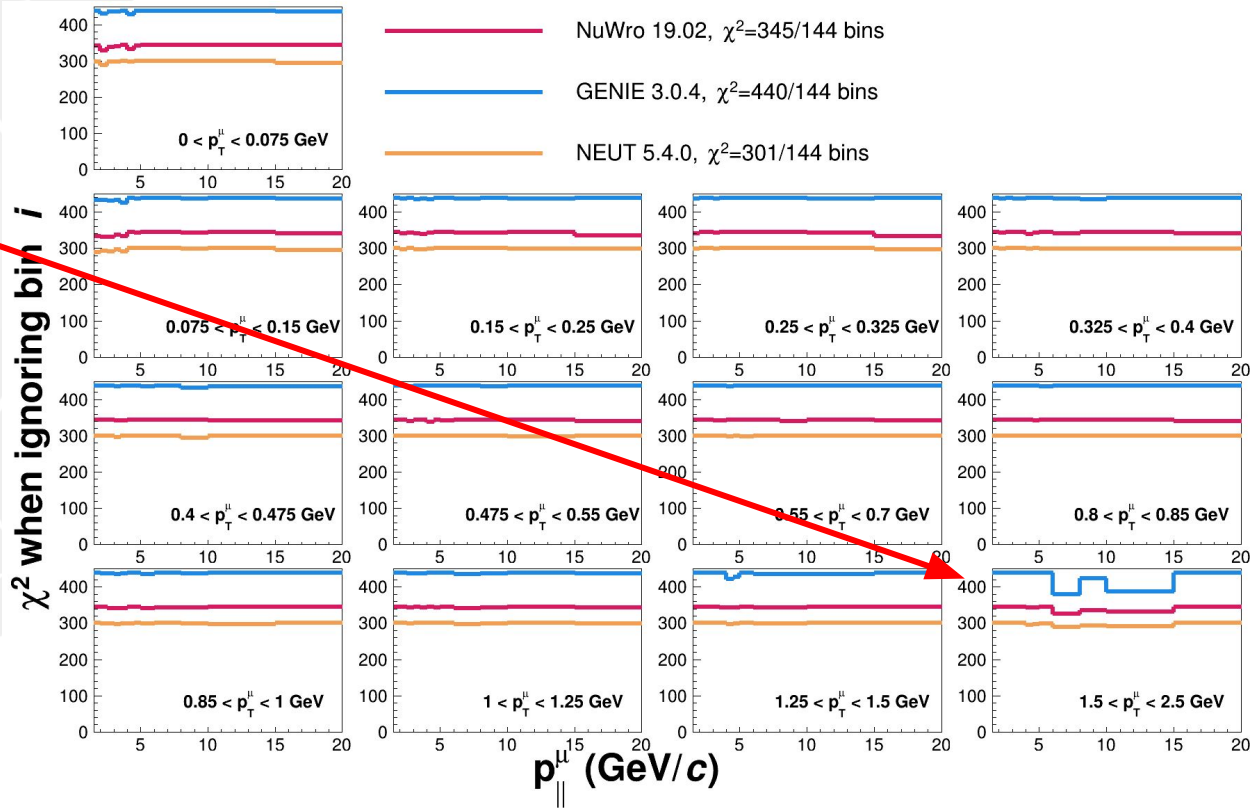
# MINERvA 0pi neutrino-mode

- Majority of difference comes from high angle bins.



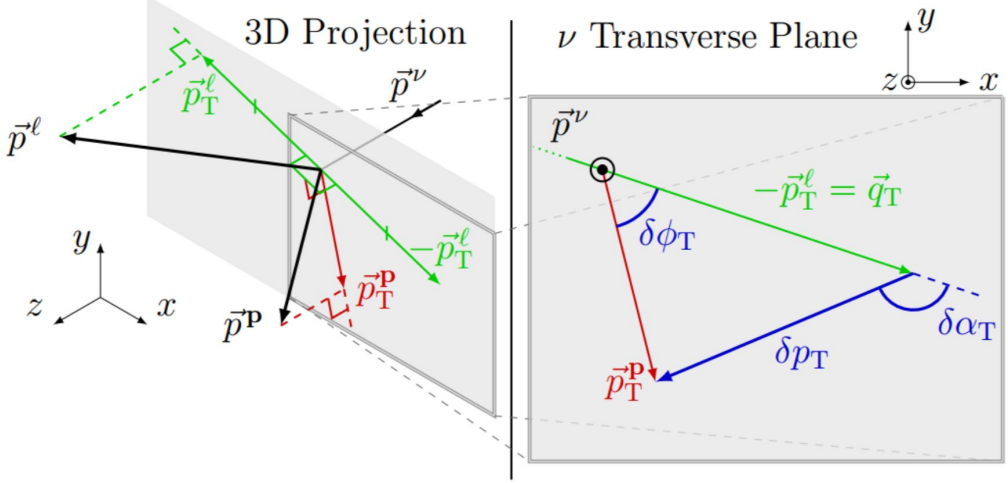
# MINERvA 0pi neutrino-mode

- Majority of difference comes from high angle bins.
- Could mask out bad bins, but when to stop p-hacking...



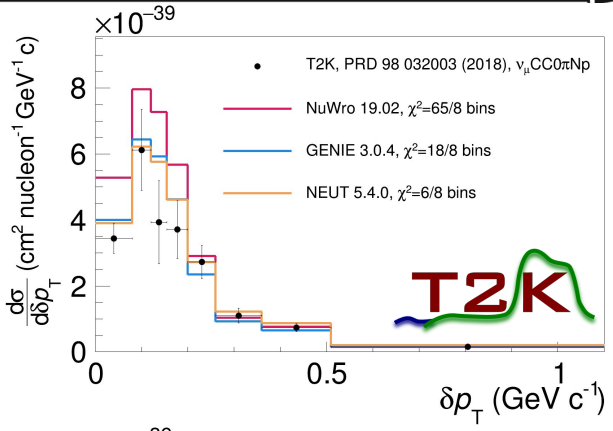
# Single Transverse Variables

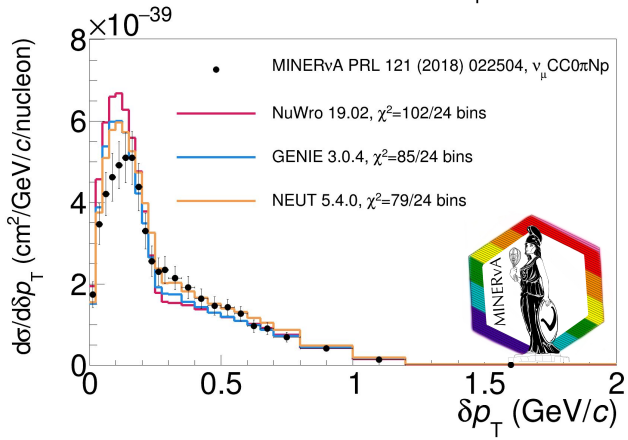
- Recent interest in lepton-hadron correlations:
  - Can be more sensitive to certain effects than lepton-/hadron-only
  - Efficiency/smearing corrections need to be treated with more care.
- Direction/magnitude of momentum imbalance is sensitive to initial and final state effects PRD 98 032003 (2018).



# Transverse missing momentum

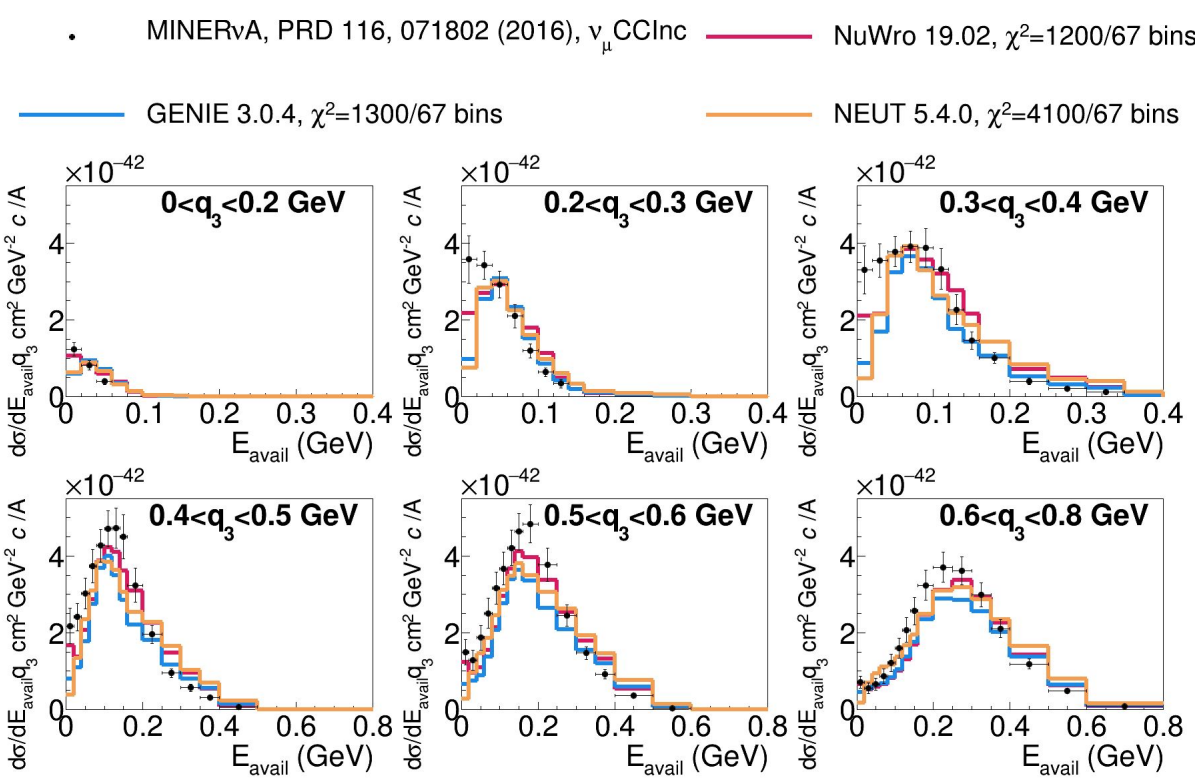
- Signal phase space cuts chosen for detector capabilities:
  - Results in less model-dependent efficiency correction.
  - T2K:
    - 500 MeV < $p_p$
    - 250 MeV < $p_\mu$, 1 < cos($\theta_\mu$) < -0.6
  - MINERvA:
    - 450 < $p_p$ < 1200 MeV, 0 < $\theta_p$ < 70°
    - 1.5 < $p_\mu$ < 10 GeV, 0 < $\theta_\mu$ < 20°



# MINERvA CCInclusive: Low recoil

- Inclusive models described by q0/q3:
  - Requires model-dependent reconstruction of EAvail and true momentum transfer.
- GOF is awful for all available models:
  - Inconclusive when comparing one bad fit to another bad fit.



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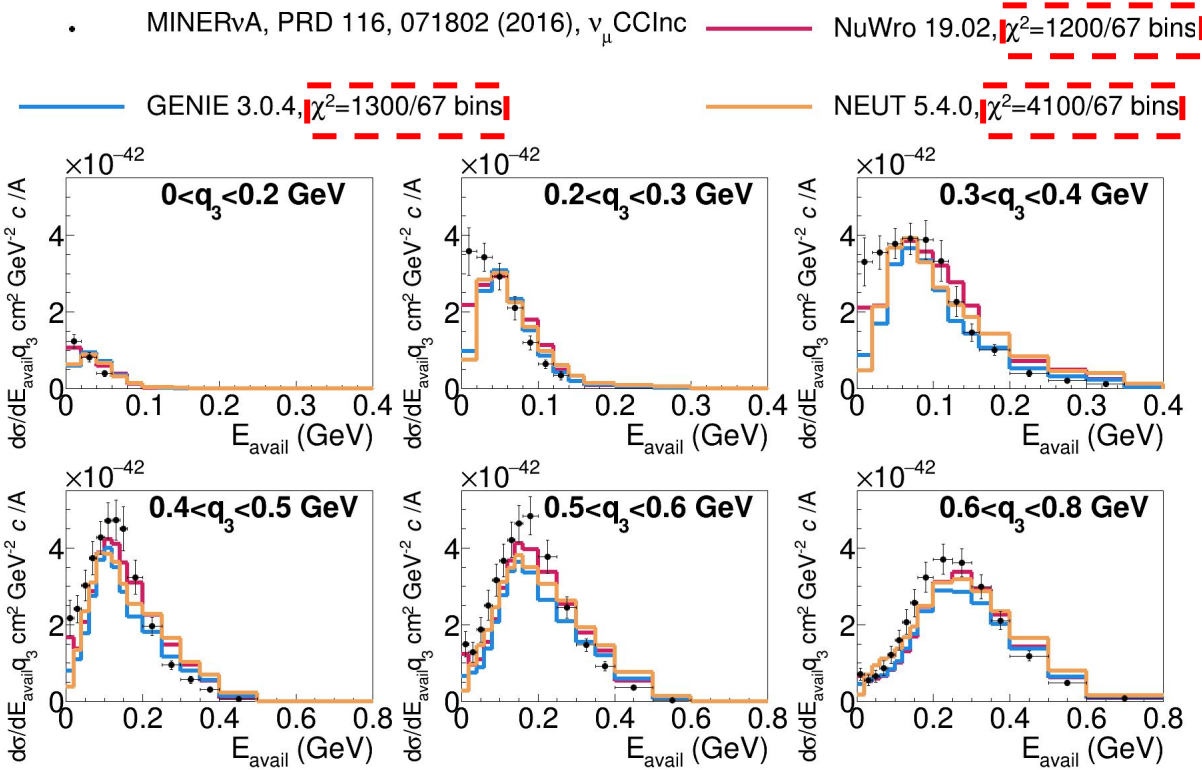

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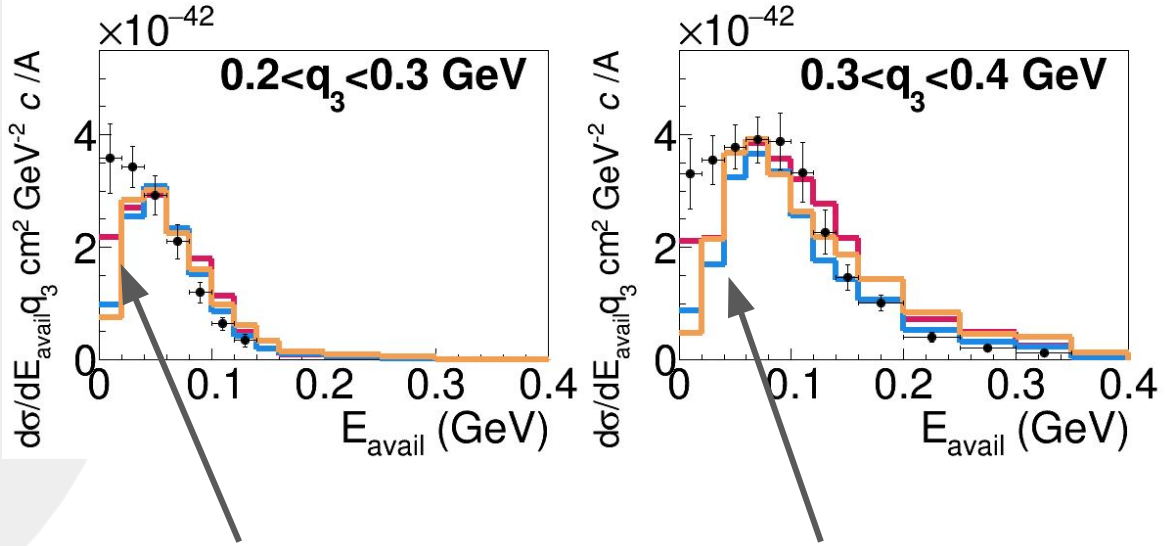
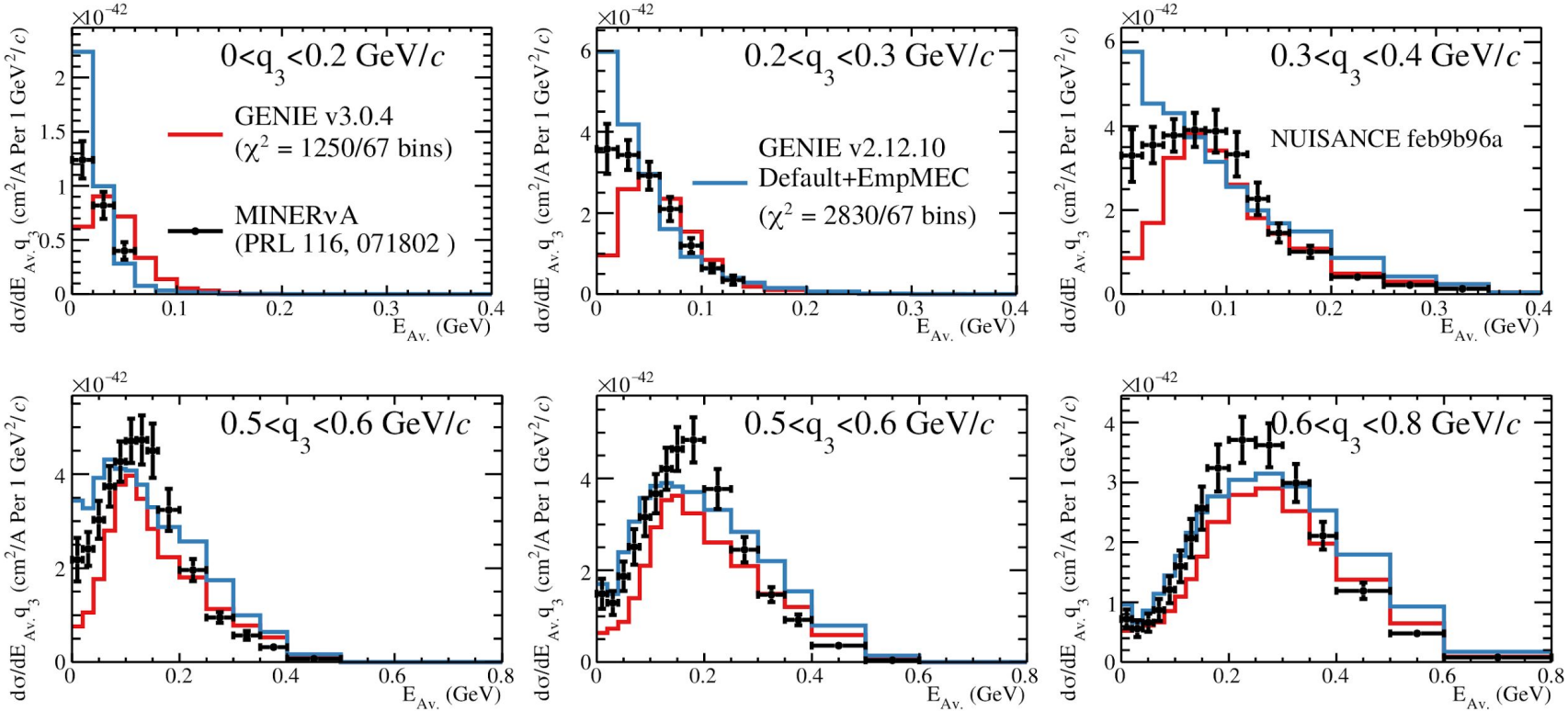


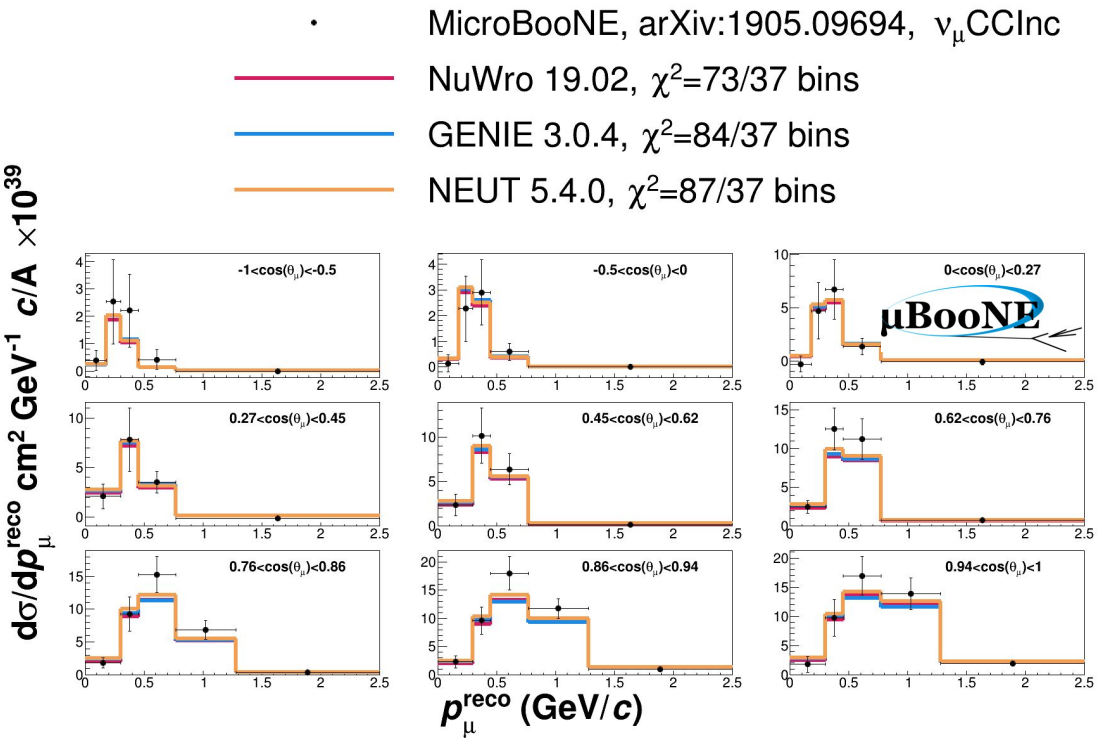

**Low energy transfer region especially poorly predicted.**

# MINERvA CCInclusive: Low recoil



# Comparisons to Nuclear data: MicroBooNE

- Need to understand neutrino interactions on Ar40 target.
- Data release:
  - Reconstructed distributions
  - True→reco folding matrix
- Potentially useful technique to reduce model bias in published data.



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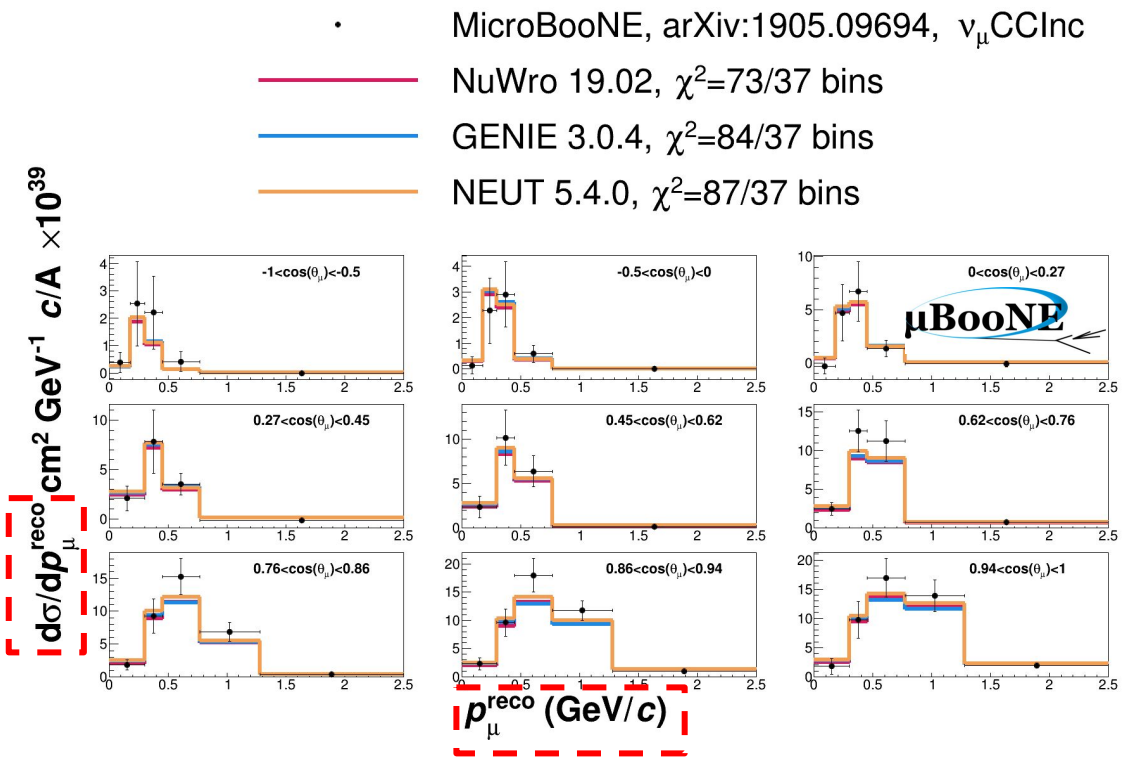
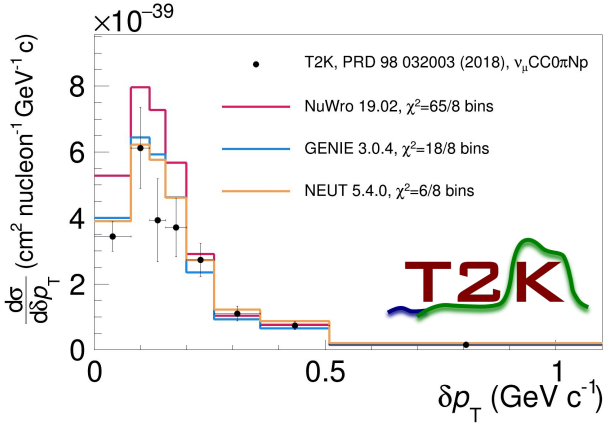


# What Fitters Want

# What is needed from Data Measurements

- Minimize model bias while maximising efficacy of data:
  - Well-understood selection efficiency over signal phase space.
  - Projections the require minimal MC correction.
- Publish errors with bin-to-bin correlations.



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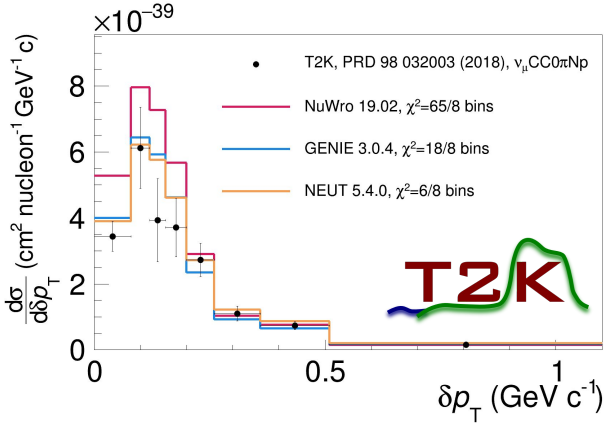


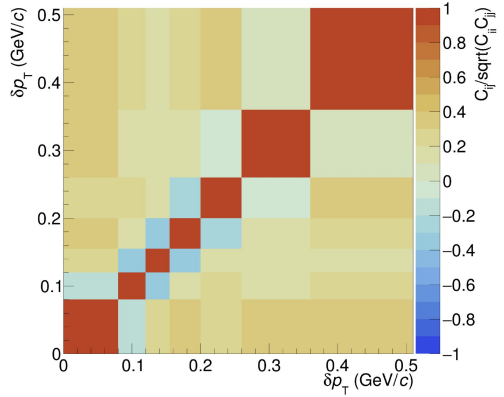

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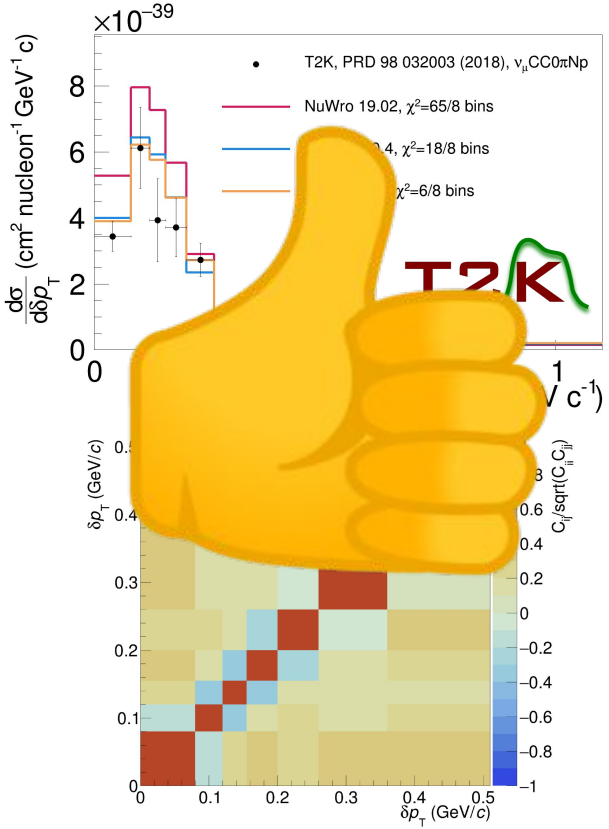
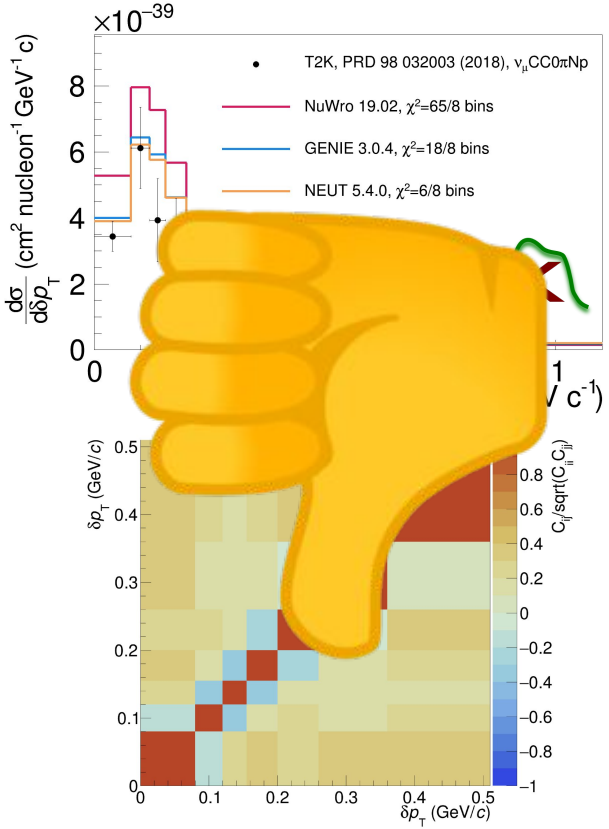


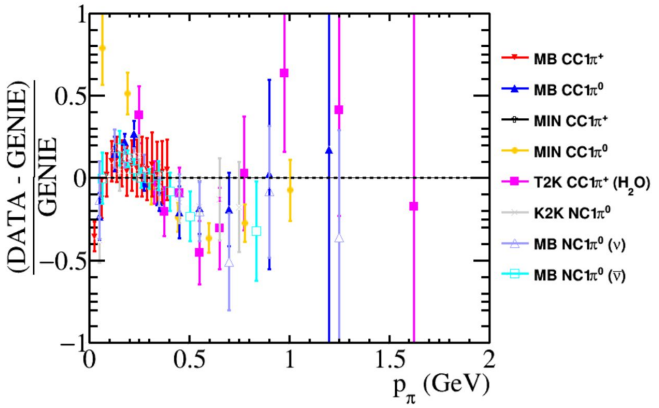
# What is needed from Data Measurements

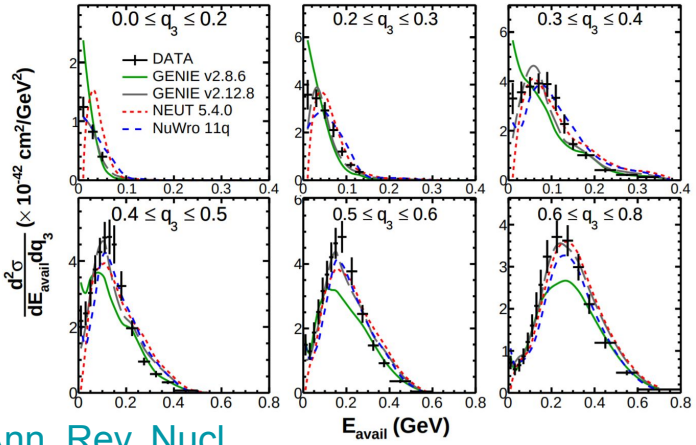
- Minimize model bias while maximising efficacy of data:
  - Well-understood selection efficiency over signal phase space.
  - Projections the require minimal MC correction.
- Publish errors with bin-to-bin correlations.
  - **Wherever possible:**
    - **Between projections**
    - **Between datasets.**



# Why NUISANCE might be right for you

- Consistently comparing your model predictions to many data-sets.
- Producing comparisons to your new data set with a variety of MCs --- without having to be an expert.
- **Ensure that comparisons to your data are done correctly.**
- Tools make cross-section parameter fitting mechanically simple:
  - **But, garbage in → garbage out.**
  - Choice of data, choice of parameters, structure of fit is the tough bit.




Ann. Rev. Nucl. 101917 020930

# Future

- More data: Your data!
  - Want to increase use of electron-scattering data
  - Possibly also include nucleon/pion scattering data for FSI/SI tuning.
- More comparisons:
  - New generators everywhere: GENIE v3, NEUT 5.4.0, NuWro 2019, GiBUU 2019
  - Aim to produce comprehensive, quantitative model comparisons with available data in the next 6--12 months!
- More tunes:
  - Recent collaboration with MINERvA on fitting GENIE to their published pion production data fruitful—looking forward to more collaboration!
- Sharing and comparing:
  - Can apply MINERvA, T2K, and NOvA in-house tunes on top of relevant ‘base’ models.

# Summary

- NUISANCE is a tool for generator--data comparisons
  - Contains a large number of datasets and associated signal definitions for you to use.
  - Has tools for performing ‘global’ cross-section comparisons and tunes.
  - **But: You have to be aware of the details of the data you comparing to!**
- We hope that you develop a NUISANCE sample for your new dataset before/during publication:
  - Ensure that the data is used correctly and effectively while it’s hot stuff!
  - Support is on hand if you need help.
- If any of this sounds interesting, get in touch, plenty of work and development that can be done by people with a range of experiences!

# Thanks for listening

L. Pickering

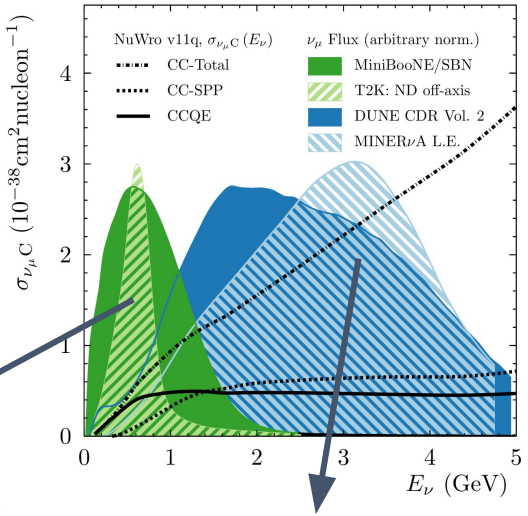

MICHIGAN STATE UNIVERSITY

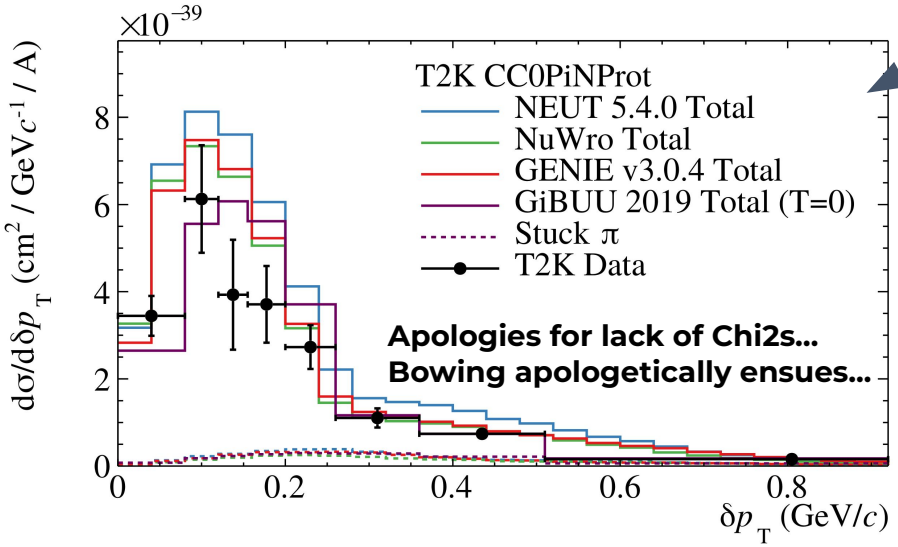
NuFACT2018, VT, Blacksburg

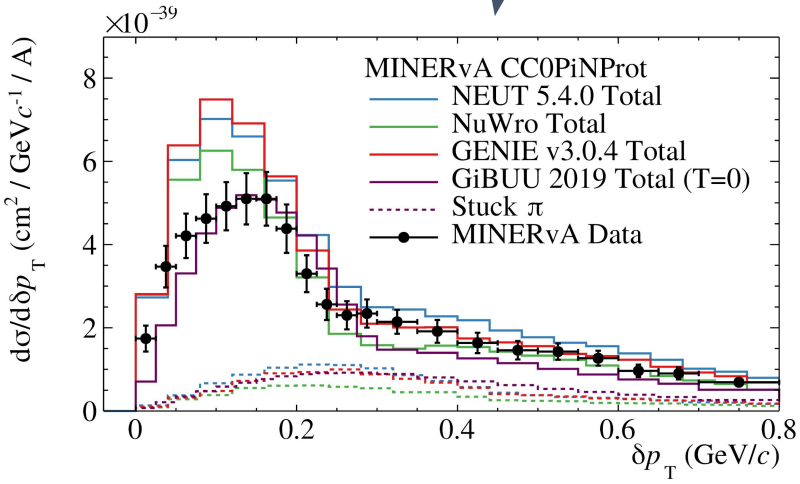
https://doi.org/10.1016/j.physrep.2018.08.003

# Data Comparison: $\delta p_T$

- T2K: 1802.05078
- MINERvA: 1805.05486
- (GENIE norm may not be quite right to a few %, its fine for here, but probably not best to show these plots as is elsewhere)



# Signal definitions

- T2K: 1802.05078
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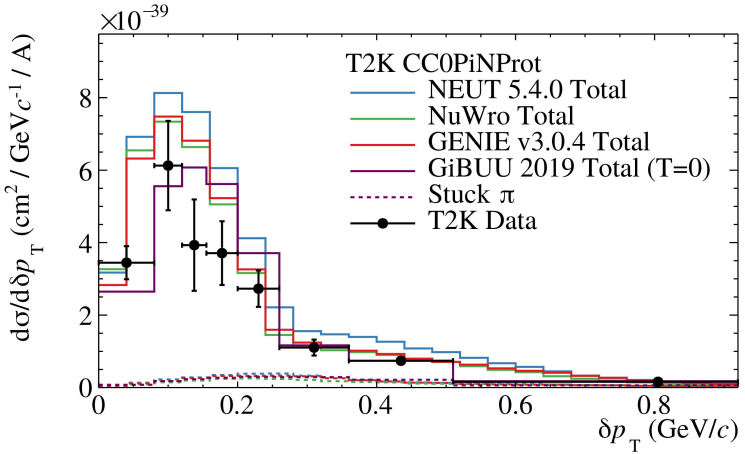
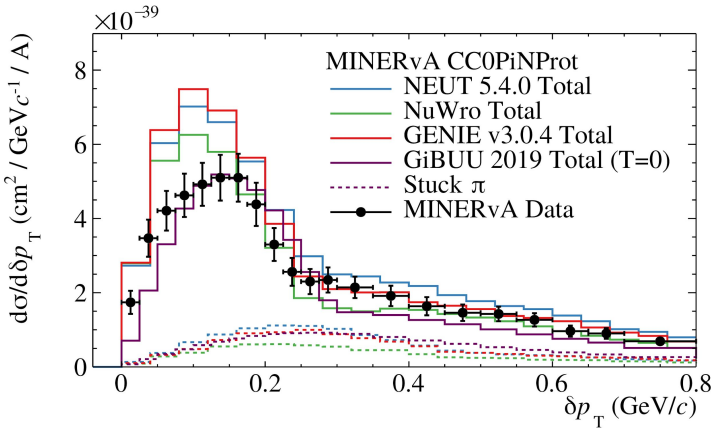
**500 MeV < pp**
**250 MeV < pmu, 1 < cos(theta_mu) < -0.6**

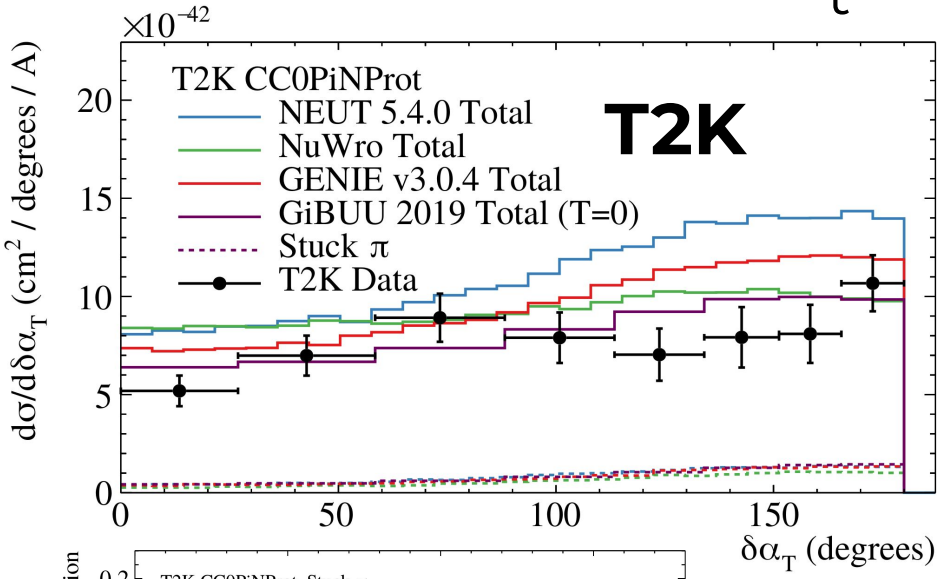


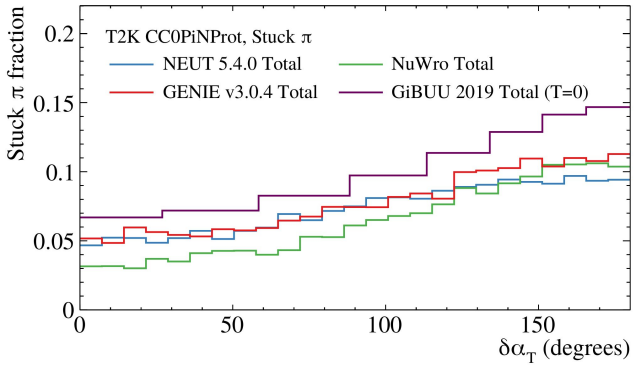

**450 < pp < 1200 MeV, 0 < theta_p < 70°**
**1.5 < pmu < 10 GeV, 0 < theta_mu < 20°**

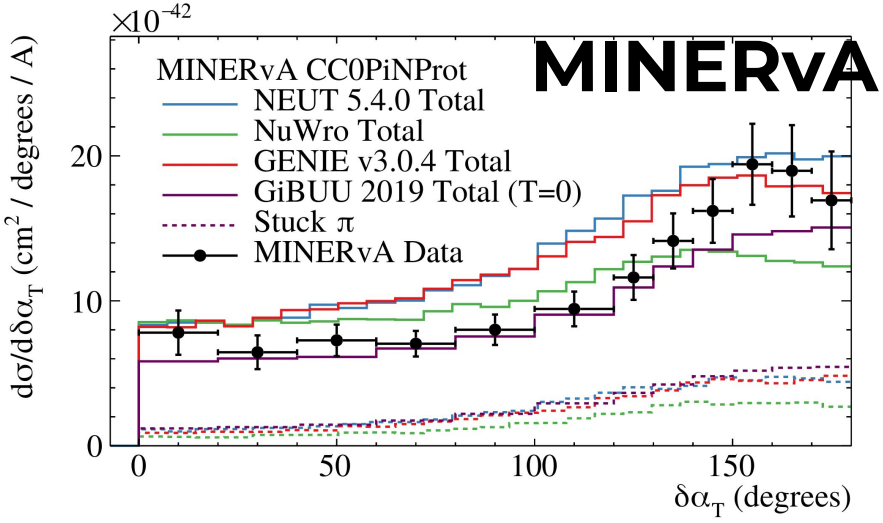


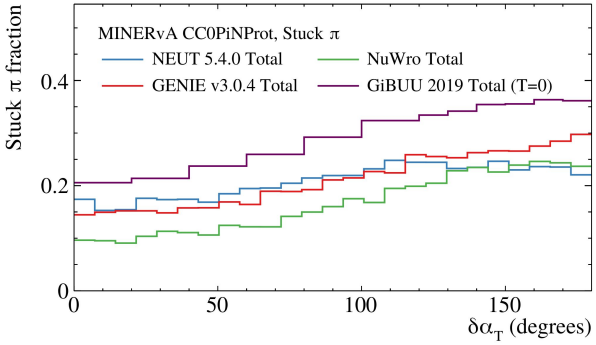
# Stuck pion rate: $\delta\alpha_t$

QEL-pure at low δαt
FSI and stuck pion rich at higher δαt



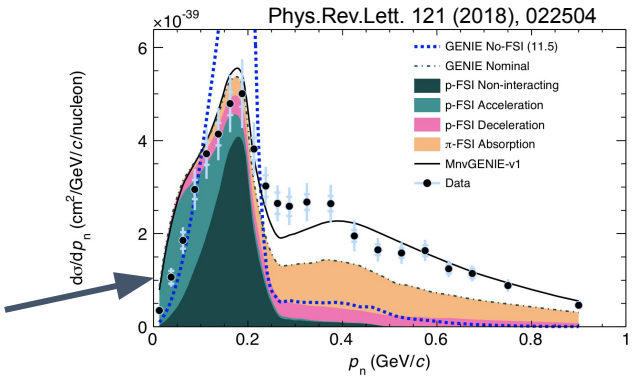



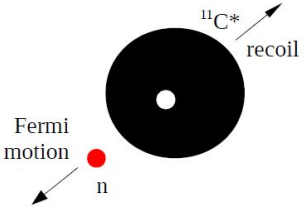



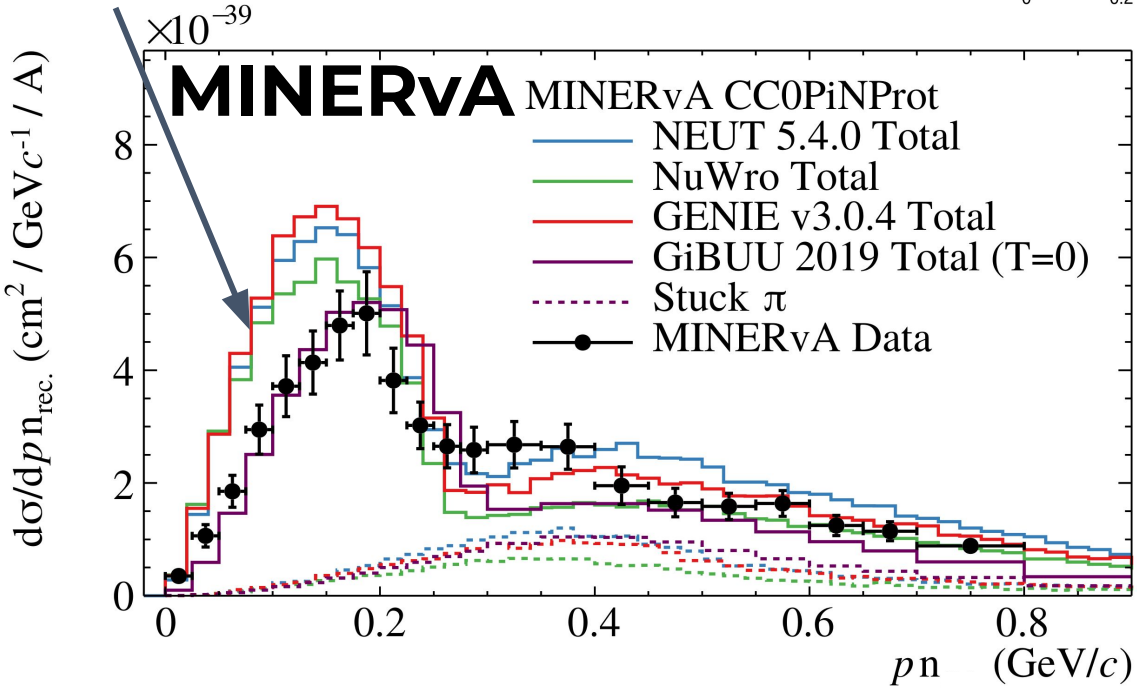
# pn

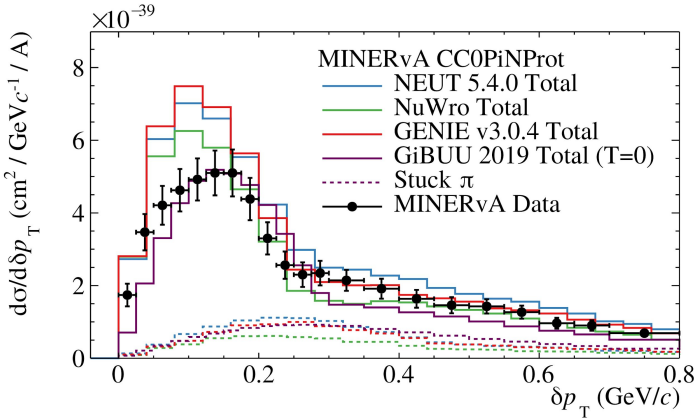
Phys.Rev. C95 (2017) 065501,
see definition in BACKUP

- S. Dolan: Relative to dpt, stuck pions more away from QEL peak **(all non-QE, see later, backup)**
- GENIE V304 below no longer has elastic hA, less lumpy



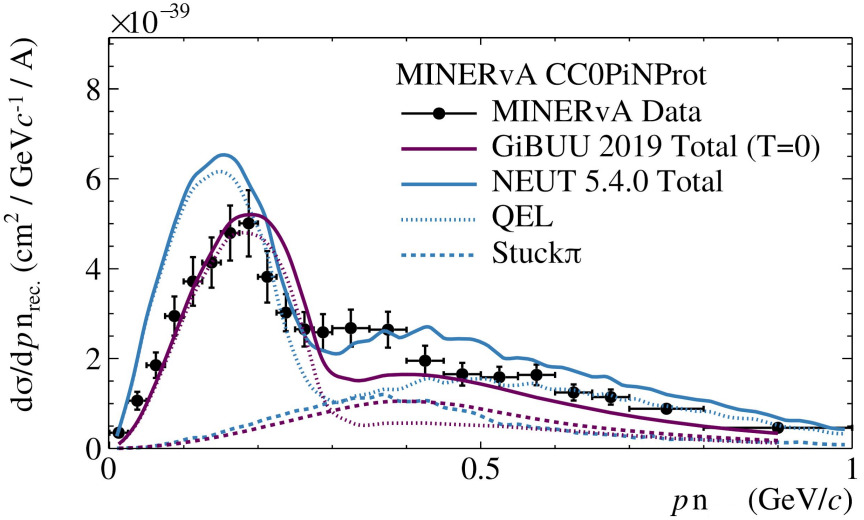



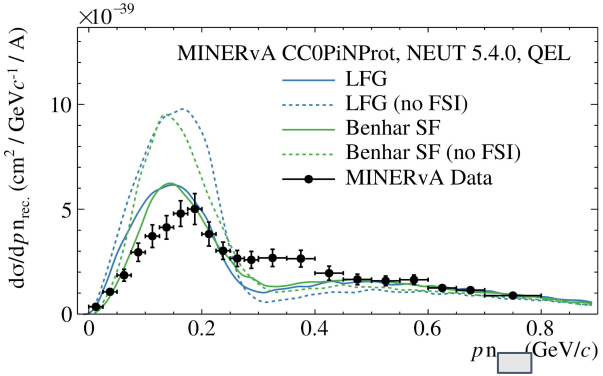



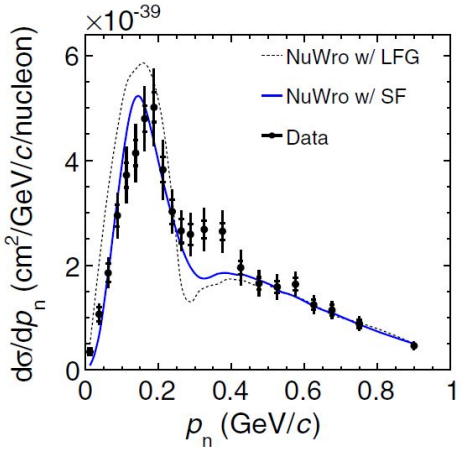



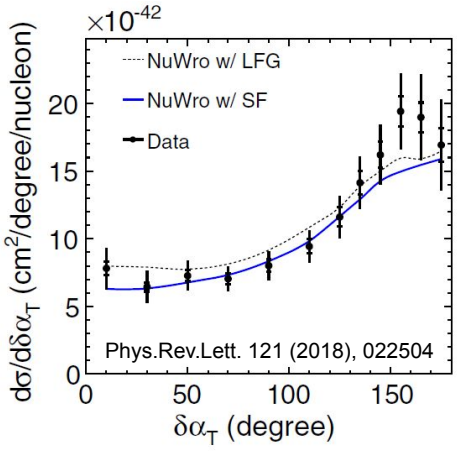
# More pn

- Also wanted to look at stuck pi vs. 2p2h
  - GiBUU predicts no second peak for QEL, but NEUT does.
- And FSI/Nuclear momentum/binding model changes:
  - LFG/SF in NEUT qualitatively similar, **contrary to NuWro**
  - FSI mostly interacts with signal selections
- May be interesting to look at energy evolution as well. (see last BACKUP)



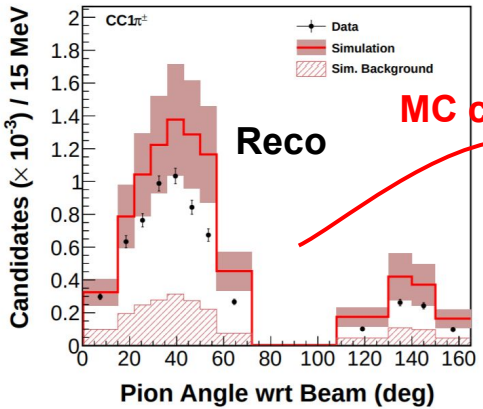



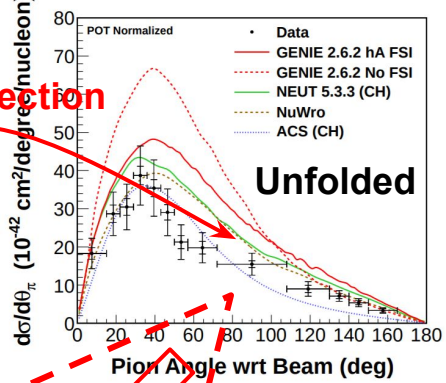
# MINERvA 1pi neutrino-mode

- For the charged pion analyses:
  - ~100% efficiency correction at high angle.
  - Where is this ‘MC fill-in’ in other distributions?
- Upcoming re-analysis still no phase space cuts.
- No covariance between distributions ($p\mu$, $\theta\mu$, $T\pi$, $\theta\pi$, $Q^2$) or samples ($\pi+$, $\pi0$, $\nu$, $\bar{\nu}$):
  - Difficult to consistently use together in a meta-analysis.

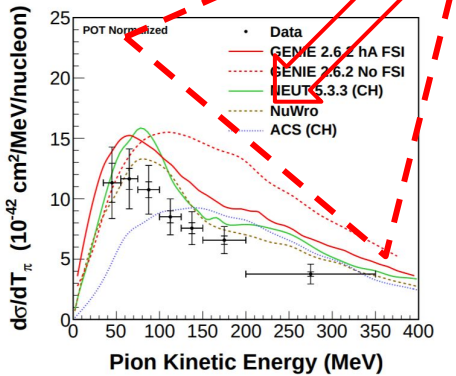
PRD 92 092008




MC correction

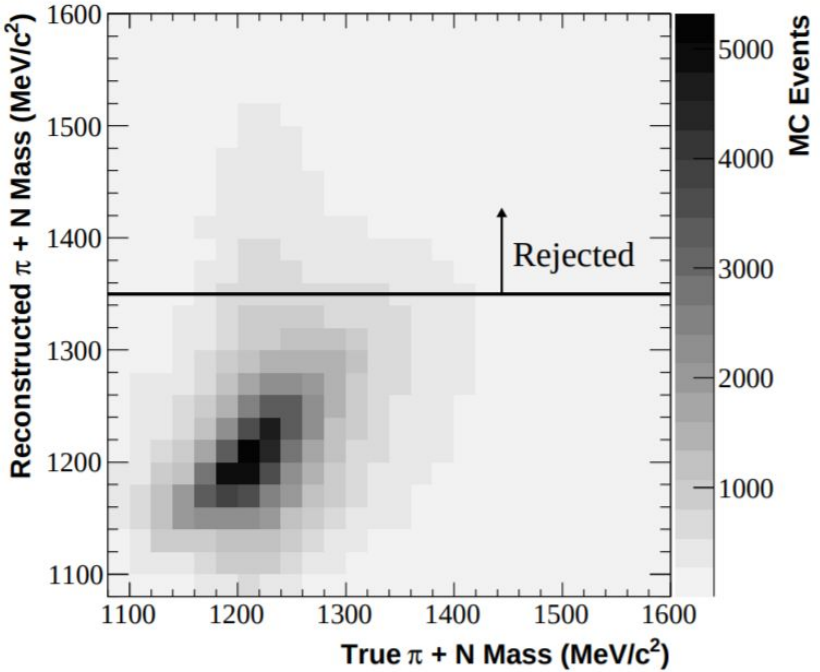



Where is MC in different projection…?



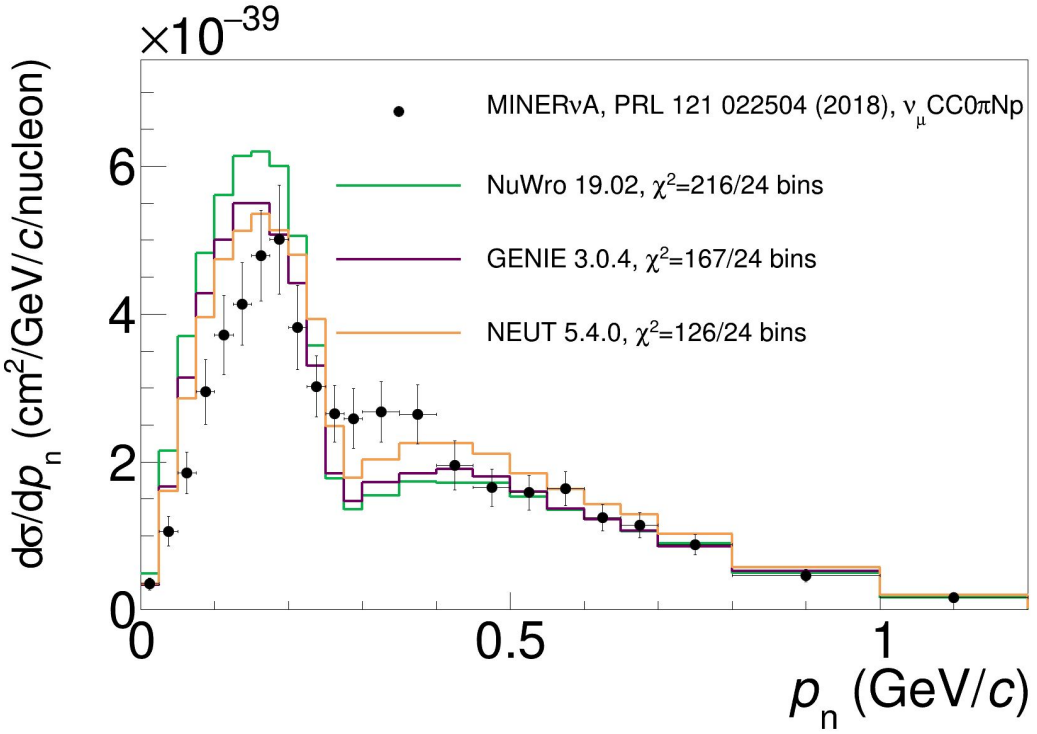
# MiniBooNE 1Pi+

- Rejection only in selection, not signal definition:
  - Will be efficiency corrected back with NUANCE-calculated efficiency.
  - Better to include analysis cuts in both signal and selection where possible, then handle new out-of-phase space backgrounds, but smaller, less model dependent efficiency corrections.



# MINERvA: Initial state neutron momentum

- Momentum imbalance in all three dimensions is sensitive to initial state fermi nucleon momentum distribution.
  - GOF is poor for all models.



# Notable Recent Developments

- NEUT:
  - Nieves 1p1h, LFG nuclear model
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Phys. Rev. C 100, 015505 (2019)

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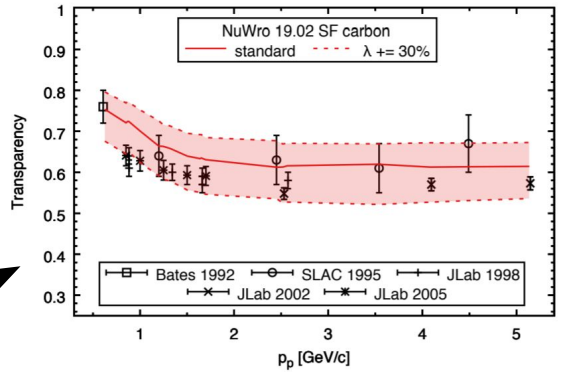
  - Integration of electron scattering simulation.



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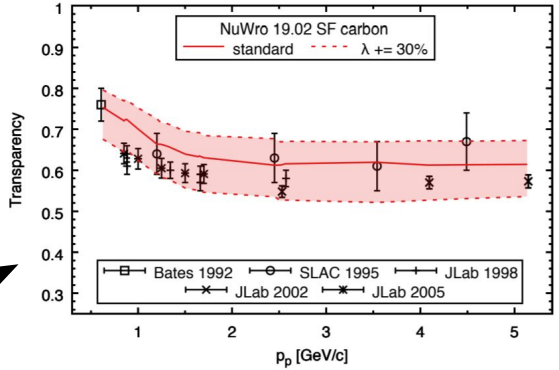
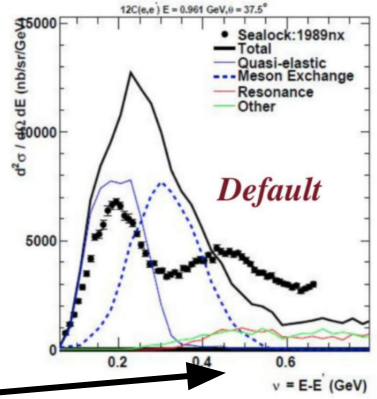
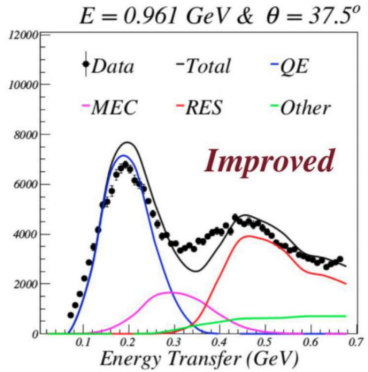
- NuWro:
  - Updates to spectral function
  - Update of FSI cascade by comparison to nuclear transparency data.
  - Integration of electron scattering simulation.
- GENIE:
  - Version 3 released!
  - Extensive $\nu$-N tuning to bubble chamber data
  - **Many improvements to electron scattering simulation (c.f. Or Hen e4nu Plenary)**
  - Some significant bug fixes



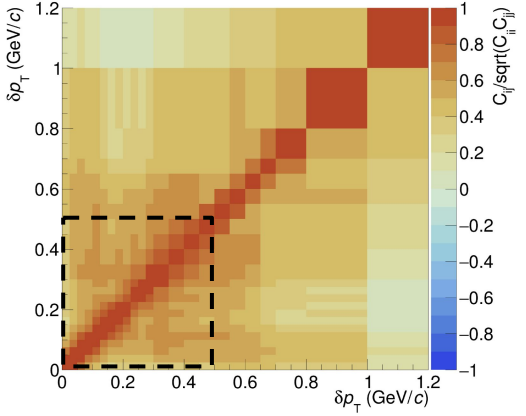



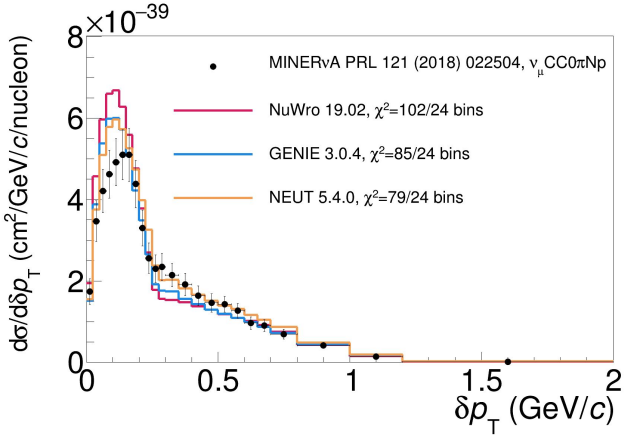

*Genie R-2_12_10

# Transverse missing momentum

- MINERvA error matrix provides a tight shape constraint around the peak which drives the high GOF.

MINERvA: PRL 121 (2018) 2, 022504

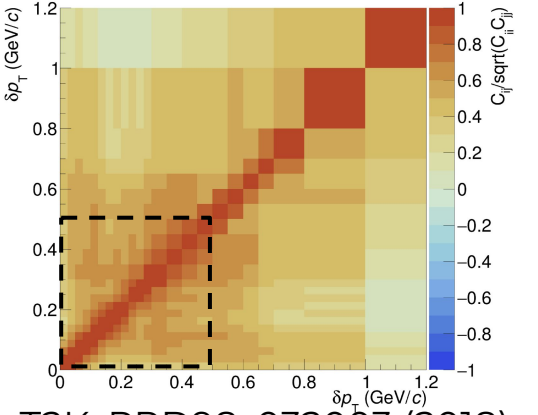


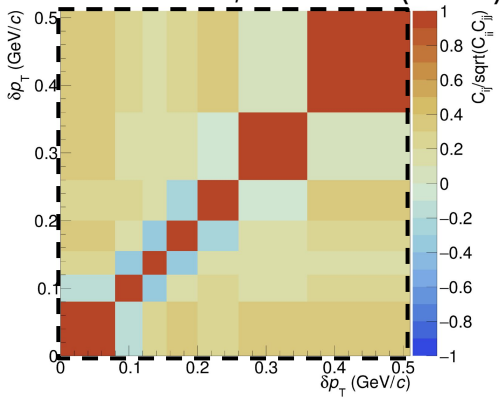
# Transverse missing momentum

- MINERvA error matrix provides a tight shape constraint around the peak which drives the high GOF.
- Equivalent matrix for the T2K result exhibits anti-correlations between neighbouring bins:
  - More expected for uncertainties that cause bin migrations.

MINERvA: PRL 121 (2018) 2, 022504




T2K: PRD98, 032003 (2018)



# Gen Summary

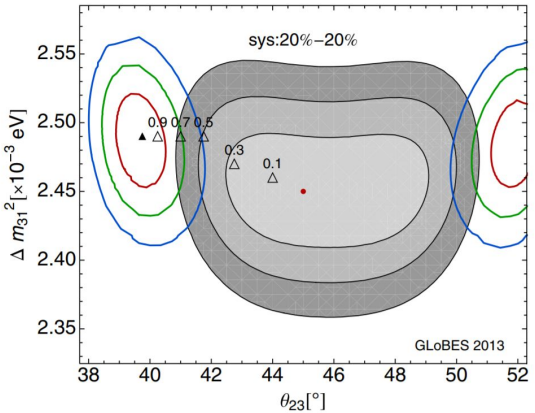
- The loftiest goals of neutrino oscillation physics depend on the accuracy of event generator predictions and associated uncertainties.
- Recent $\nu_\mu \rightarrow 0\pi$ data releases have been more statistically robust, but GOF between available models is generally poor
  - Room for improvement in generator predictions, xsec analyses and data releases and global fitting methodology.
  - Correct, correlated errors are a comparators best friend!
- More recent work on removing assumptions in generator factorization and implementing state-of-the-art predictions is promising!

# Why do we need good interaction Models?

- The aim is to perform measurements of neutrino oscillations.
  - Oscillation occurs as a function of true neutrino energy, which is **not observable**.
- We use models to estimate: $\mathbf{D}\left(\mathbf{x}_{\mathrm{obs}}|\mathbf{x}_{\mathrm{true}}\right)$: *If we see* $\mathbf{x}_{\mathrm{obs}}$, *what was the true neutrino energy?* We need to understand:
  - Selected backgrounds
  - Selection efficiency
  - Exclusive channel interaction rates and kinematics
- Wrong model → wrong inferred $P_{osc}\left(E_{\nu}\right)$.

$$N_{\mathrm{near}}\left(\mathbf{x}_{\mathrm{obs}}\right)=\int d\mathbf{x}_{\mathrm{true}}\underbrace{\mathbf{D}_{\mathrm{near}}\left(\mathbf{x}_{\mathrm{obs}}|\mathbf{x}_{\mathrm{true}}\right)}_{\text{Smearing, Eff., Pur.}}\underbrace{N_{\mathrm{targ}}\sigma\left(\mathbf{x}_{\mathrm{true}}\right)\Phi\left(E_{\nu}\right)}_{N_{\mathrm{Int}}\left(\mathbf{x}_{\mathrm{true}}\right)}$$

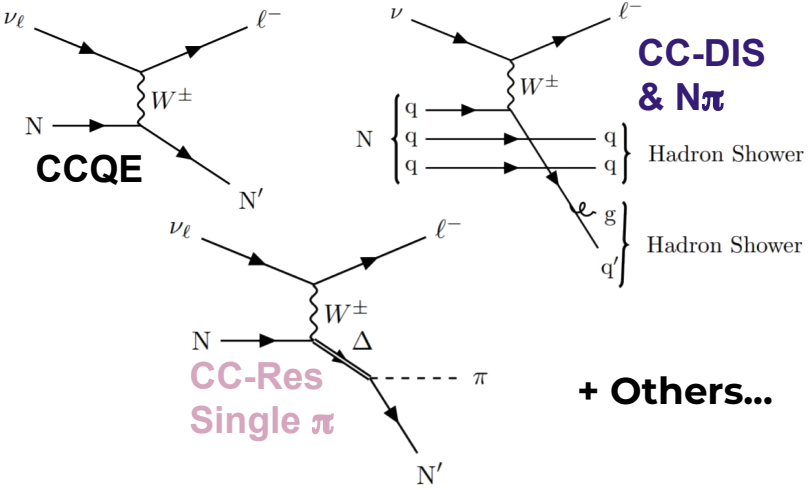
$$N_{\mathrm{far}}\left(\mathbf{x}_{\mathrm{obs}}\right)=\int d\mathbf{x}_{\mathrm{true}}\underbrace{\mathbf{D}_{\mathrm{far}}\left(\mathbf{x}_{\mathrm{obs}}|\mathbf{x}_{\mathrm{true}}\right)}_{\text{Smearing, Eff., Pur.}}\underbrace{N_{\mathrm{targ}}\sigma\left(\mathbf{x}_{\mathrm{true}}\right)\Phi\left(E_{\nu}\right)P_{osc}\left(E_{\nu}\right)}_{N_{\mathrm{Int}}\left(\mathbf{x}_{\mathrm{true}}\right)}$$

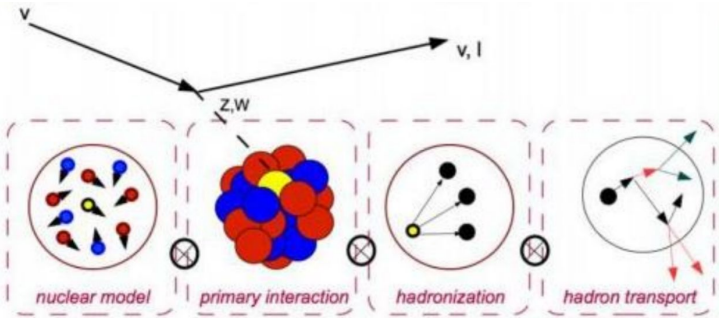



PRL 111.221802

# What is a Neutrino Event Generator

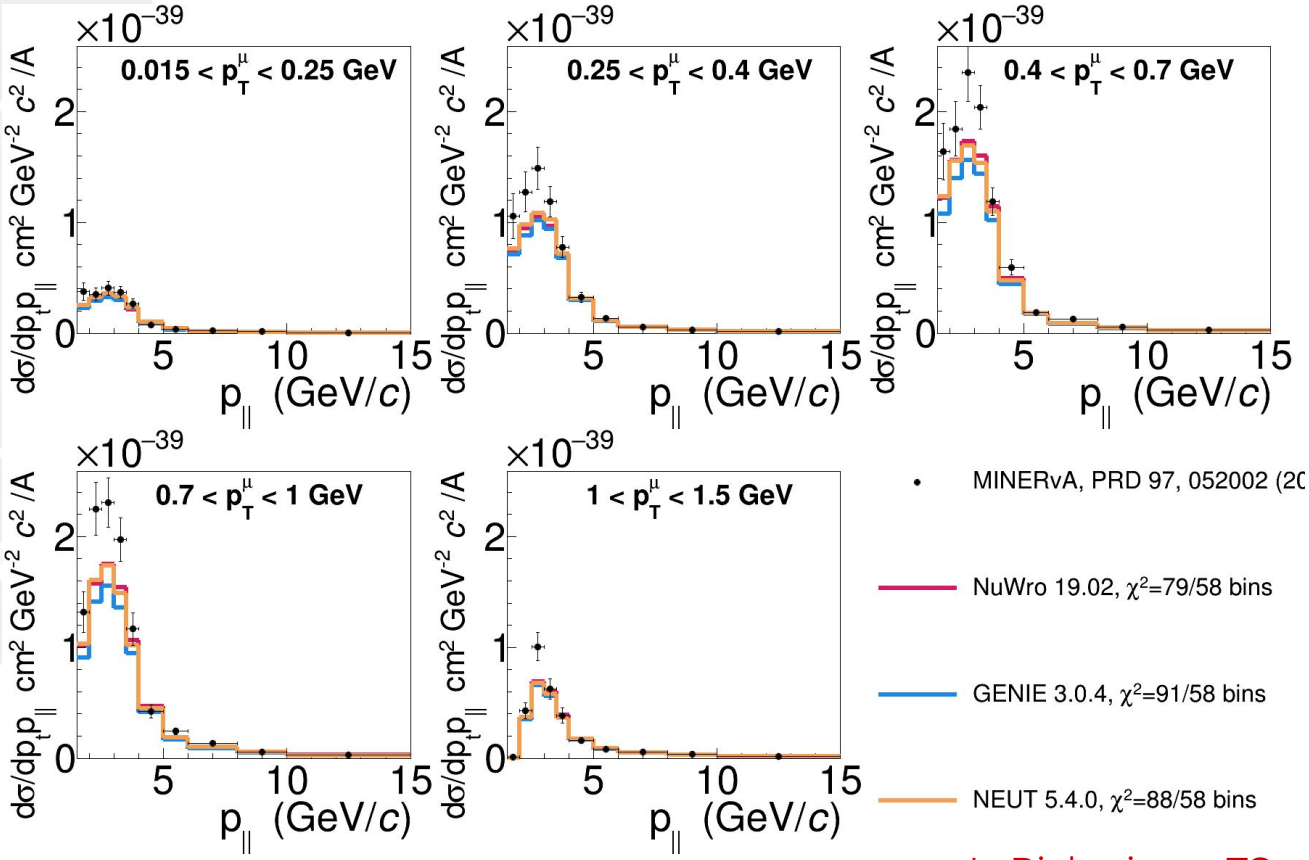
- Selects neutrino ‘events’ from interaction models:
  - **Over a range of neutrino energy and species,**
  - **For a number of ‘primary’ channels**:
    - Neutrino--nucleus (COHPi, CvNS)
    - Neutrino--multi-nucleon (2p2h)
    - Neutrino--nucleon (QE, RESPi)
    - Neutrino--parton (DIS)
  - **In a nuclear environment**:
    - Fermi motion distribution
    - Removal energy
    - Collective effects (RPA)
    - Final state re-interactions of primary particles
- Often factorises the simulation of nuclear model, primary interaction, and FSIs.



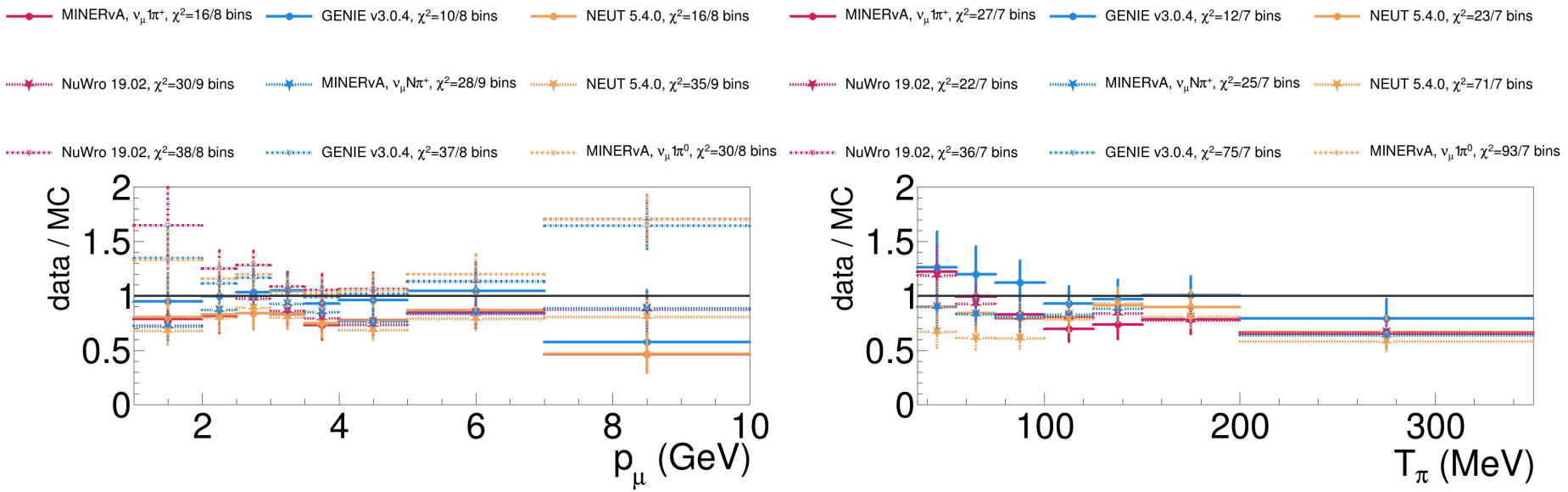
# MINERvA 0pi anti-neutrino-mode

- $\chi$-by-eye GOF seems worse (to me) than calculated GOF.
- Possibly because of PPP:
  - Smaller MC normalization can give 'artificially' low $\chi^2$ if uncertainty is not fully characterized.
- Need to be wary of PPP when fitting.



# MINERvA 1pi neutrino-mode

- MINERvA have released a number of pion datasets, each with multiple projections
  - Lots of information, much more than shown here.
  - Fairly poorly predicted all around.
- arXiv:1903.01558: discusses some of the difficulties seen fitting these data.



# Gen Future: 1

- Last few years seen increase in sophistication of 0pi analyses
  - Lepton/hadron correlations
  - Less Model-dependent selections and projections
  - Would be very useful to see similar renaissance in pion production datasets.
- Future MicroBooNE (and SBND) data sets will be critical for model builders to benchmark and develop before DUNE and Fermilab Short Baseline program.

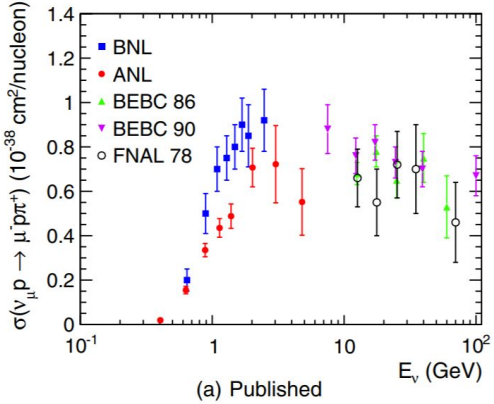
# Gen Future: 2

- These last two years have seen an uptick in model development:
  - GENIE tuning, v3, NEUT and NuWro model developments, ECT* Trento workshops
  - Lots of progress due to closer interaction with theory community, need to continue!
- But given how much LBL programs will rely on the predictions and uncertainties, the community is quite under person-powered…
  - Plenty of room for important work and novel intellectual contribution
- Can learn a lot of the necessary nuclear physics from electron scattering: GENIE + NuWro have e-A modes, ongoing work by **e4nu**.
- See what GiBUU has to say for itself…

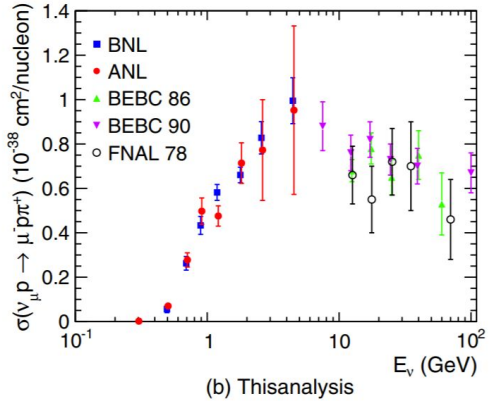
# The data is the data is the data

PRD 90 112017

- Sometimes the data is not the data is not the data.
- ANL/BNL CC1pi+1proton discrepancy:
  - Data biased by problems in the neutrino flux models
  - ~ Reconciled by re-analysis.
  - **But, no correction for Q2 distribution!**
- Need to be familiar with included data sets and tensions between them.
  - May need to assign *confidence* weights to samples in the global GOF.



(a) Published

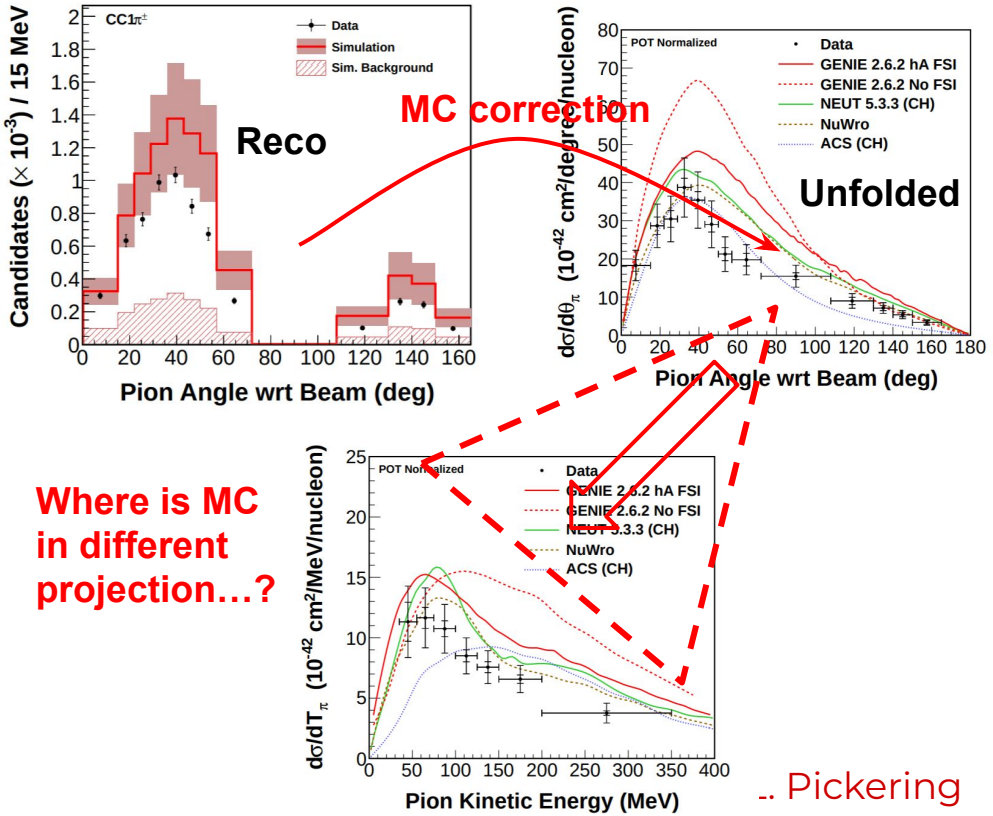


(b) Thisanalysis

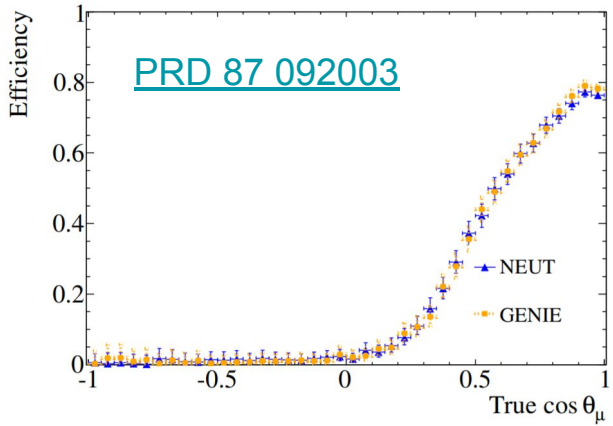
# Hidden Model Biases 1

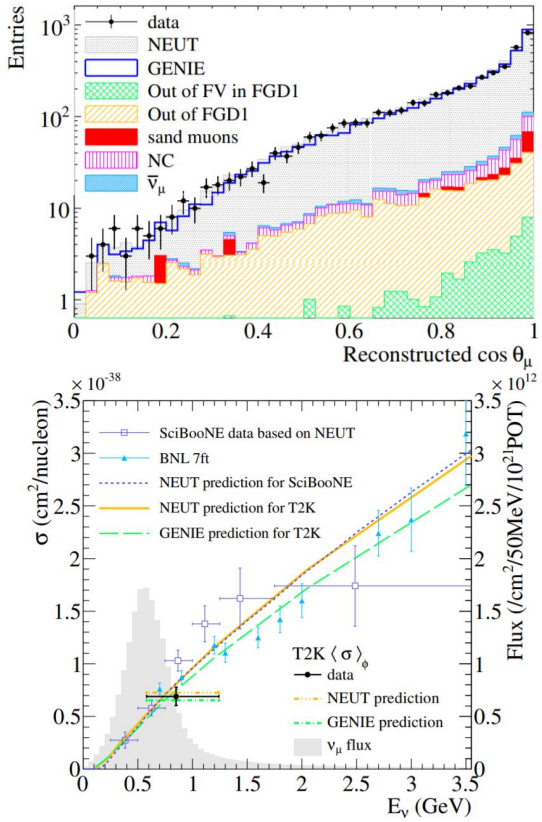
- Un-smearing and efficiency corrections introduce bias.
- From a fitters point of view, it is better to cut out regions of very poor efficiency:
  - Don't want to compare to *model-of-the-day* contaminated 'data'.
- Very helpful that such plots are in the publication!
- *N.B.* These problems are tricky and ubiquitous, not specifically calling out this publication.

PRD 92 092008



# Hidden Model Biases 2: Stealth mode

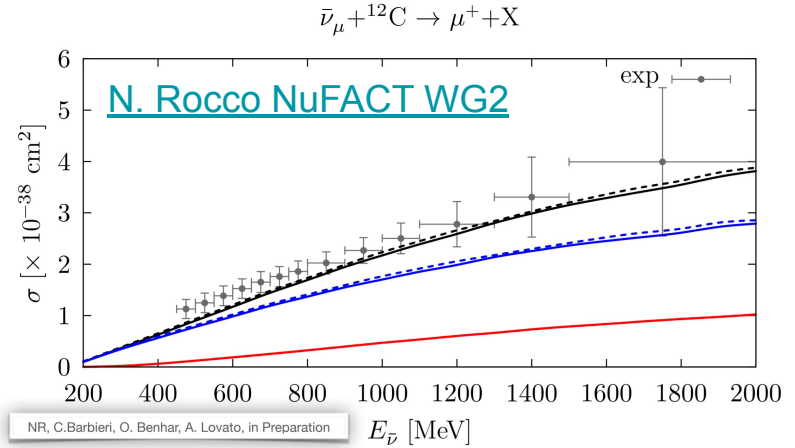


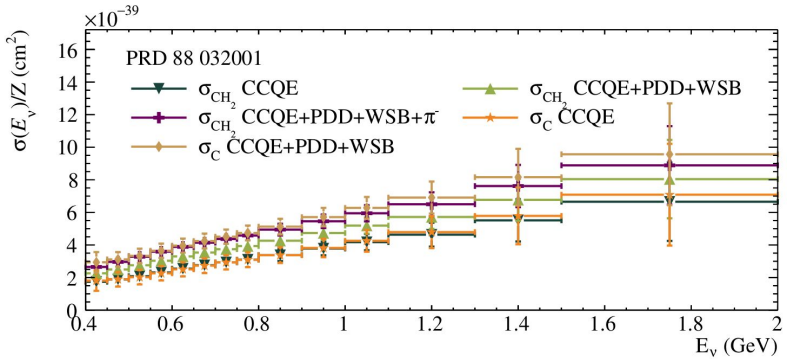




- It isn't always so clear: *e.g.* ND280 CCIncl
  - Practically cannot measure cos(θμ) < 0.
  - But, publish total cross-section.
- Similar out-of-acceptance corrections in many recent measurements: *Fiducial* cross-sections are much preferred!

# Experimental Signal Definitions

- Not always fully clear from the publication:
  - Getting this correct is essential for interpreting the data.
- *e.g.* MiniBooNE CCQE C12 data, subtracts:
  - Wrong-sign background CH2.08 component
  - H2.08 component
  - non-QE component (PDD)
  - Mis-ID'd π-
- All predicted by **NUANCE**…
- But, the background subtractions are provided:
  - Might be better to produce H and ν-C12 predictions and compare to the less-corrected data.

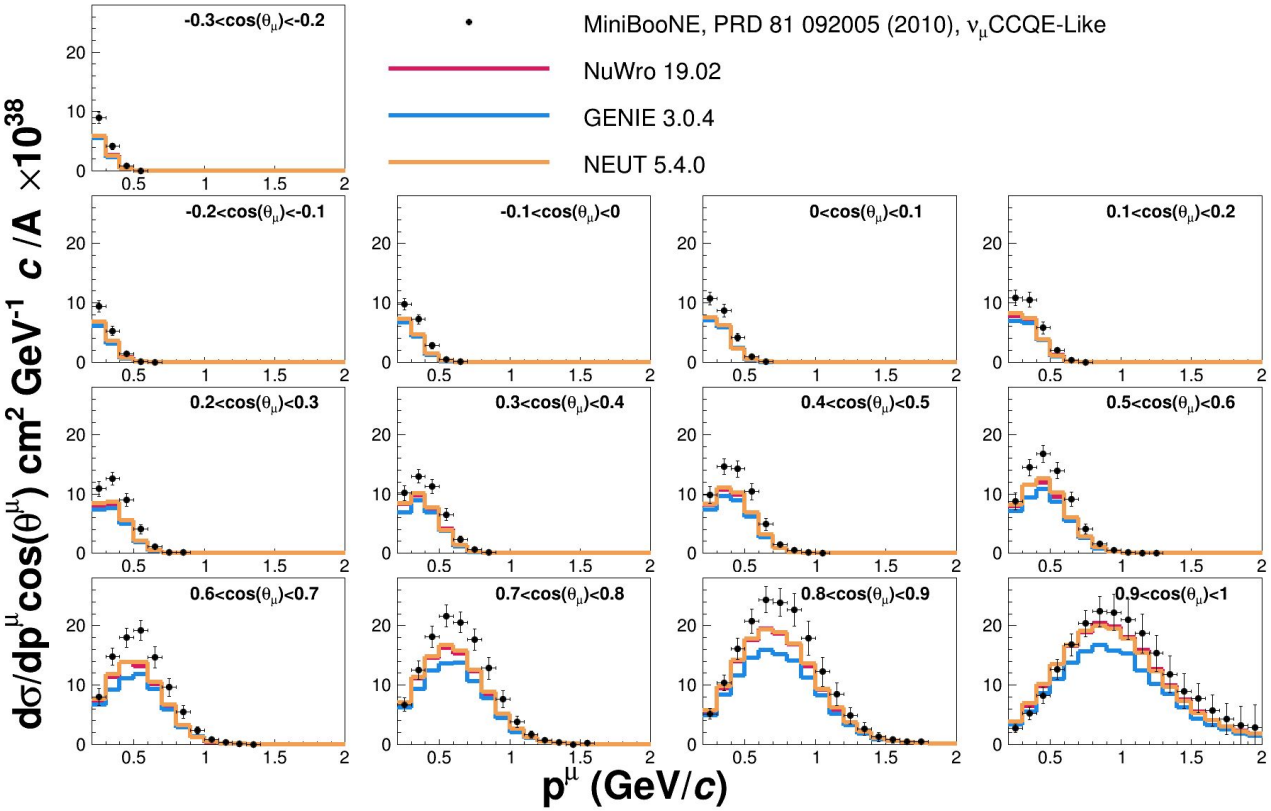



PRD 88 032001

# MiniBooNE CCQE-Like

- Not possible to calculate useful GOF, so I'm not going to attempt to…
- The data here is the 'less corrected' CCQE-like data:
  - No pionless delta decay subtraction (subset of MEC diagrams).



# Data In NUISANCE

**Bubble Chamber:**

- **ANL:** 7 selections, 56 projections
- **BEBC:** 6 sel. nu+nubar, 11 proj.
- **BNL:** 4 sel., 15 proj.
- **FNAL:** 3 sel., nu+nubar, 5 proj.
- **Gargamelle:** 1 sel., 1 proj.

**Nuclear:**

- **C:**
  - **MINERvA:** 3 sel., 6 proj.
- **CH:**
  - **T2K:** 9 sel. 24 proj.
  - **MINERvA:** 10 sel., nu+nubar, 106 proj.
  - **SciBooNE:** 1 sel. 16 proj.
- **$CH_2$:**
  - **MiniBooNE:** 5 sel., 33 proj.

**Nuclear:**

- **$H_2O$:**
  - **K2K:** 1 sel., 1 proj.
  - **T2K:** 1 sel. 7proj.
- **Ar:**
  - **ArgoNeuT:** 3 sel., nu+nubar, 12 proj.
  - **MicroBooNE:** 1 sel. 1 proj.
- **Fe:**
  - **MINERvA:** 3 sel., 6 proj.
- **Pb:**
  - **MINERvA:** 3 sel., 6 proj.

**Electron Scattering:**

- **Virginia QE Archive**