MINERvA data in the community (non-exhaustive!)

How the neutrino scattering community uses MINERvA data to do A, B and C!

A T2K-centric view

Clarence Wret

MINERvA 101
27 June 2019

Introduction

- MINERvA has been pushing cross-sections since 2012

- "Constraint of the MINERvA Medium Energy Neutrino Flux using Neutrino-Electron Elastic Scattering" arXiV:1906.00111, submitted for publication
- "Tuning the GENIE Pion Production Model with MINERvA Data" arXiV:1903.01558, submitted for publication
- "Neutron measurements from anti-neutrino hydrocarbon reactions" arXiV:1901.04892, submitted for publication
- "Measurement of Quasielastic-Like Neutrino Scattering at ⟨Eν⟩~3.5 GeV on a Hydrocarbon Target" Phys. Rev. D 99, 012004 (2019)
- "Reducing model bias in a deep learning classifier using domain adversarial neural networks in the MINERvA experiment" Journal of Instrumentation, Vol. 13 (2018)
- "Measurement of final-state correlations in neutrino muon-proton mesonless production on hydrocarbon at ⟨Eν⟩ = 3 GeV" Phys. Rev. Lett. 121, 022504 (2018)
- "Antineutrino charged Current charged-current reactions on scintillator with low momentum transfer" Phys. Rev. Lett. 120, 221805 (2018)
- "Measurement of the muon anti-neutrino double-differential cross section for quasi-elastic scattering on hydrocarbon at~Eν~3.5GeV" Phys. Rev. D 97, 052002 (2018)
- "Measurement of Total and Differential Cross Sections of Neutrino and Antineutrino Coherent π± Production on Carbon" Phys. Rev. D 97, 032014, (2018)
- "Measurement of νμ charged-current single π0 production on hydrocarbon in the few-GeV region using MINERvA" Phys. Rev. D 96, 072003 (2017)
- "Direct Measurement of Nuclear Dependence of Charged Current Quasielastic-like Neutrino Interactions using MINERvA" Phys. Rev. Lett. 119, 082001 (2017)
- "Measurement of the antineutrino to neutrino charged-current interaction cross section ratio on carbon" Phys. Rev. D 95, 072009 (2017)
- "Measurement of neutral-current K+ production by neutrinos using MINERvA" Phys. Rev. Lett. 199, 011802 (2017)
- "Measurements of the Inclusive Neutrino and Antineutrino Charged Current Cross Sections in MINERvA Using the Low-ν Flux Method" Phys. Rev. D 94, 112007 (2016)
- "Neutrino Flux Predictions for the NuMI Beam" Phys. Rev. D 94, 092005 (2016)
- "First evidence of coherent K+ meson production in neutrino-nucleus scattering" Phys. Rev. Lett. 117, 061802 (2016)
- "Measurement of K+ production in charged-current νμ interactions" Phys. Rev. D 94, 012002 (2016)
- "Cross sections for neutrino and antineutrino induced pion production on hydrocarbon in the few-GeV region using MINERvA"Phys Rev. D 94, 052005 (2016).
- "Evidence for neutral-current diffractive neutral pion production from hydrogen in neutrino interactions on hydrocarbon" Phys. Rev. Lett. 117, 111801 (2016)
- "Measurement of Neutrino Flux using Neutrino-Electron Elastic Scattering", Phys. Rev. D 93, 112007 (2016)
- "Measurement of Partonic Nuclear Effects in Deep-Inelastic Neutrino Scattering using MINERvA", Phys. Rev. D 93, 071101 (2016).
- "Identification of nuclear effects in neutrino-carbon interactions at low three-momentum transfer", Phys. Rev. Lett. 116, 071802 (2016).
- "Measurement of electron neutrino quasielastic and quasielastic-like scattering on hydrocarbon at average E_ν of 3.6 GeV", Phys. Rev. Lett 116, 081802 (2016).
- "Single neutral pion production by charged-current anti-ν_μ interactions on hydrocarbon at average E_ν of 3.6 GeV", Phys. Lett. B749 130-136 (2015).
- "Measurement of muon plus proton final states in ν_μ Interactions on Hydrocarbon at average E_ν of 4.2 GeV" Phys. Rev. D91, 071301 (2015).
- "MINERvA neutrino detector response measured with test beam data", Nucl. Inst. Meth. A789, pp 28-42 (2015).
- "Measurement of Coherent Production of $\pi^\pm$ in Neutrino and Anti-Neutrino Beams on Carbon from E_ν of 1.5 to 20 GeV", Phys. Rev. Lett. 113, 261802 (2014).
- "Charged Pion Production in ν_μ Interactions on Hydrocarbon at average E_ν of 4.0 GeV" , Phys. Rev. D92, 092008 (2015).
- "Measurement of ratios of ν_μ charged-current cross sections on C, Fe, and Pb to CH at neutrino energies 2–20 GeV", Phys. Rev. Lett. 112, 231801 (2014).
- "Measurement of Muon Neutrino Quasi-Elastic Scattering on a Hydrocarbon Target at E_ν~3.5 GeV", Phys. Rev. Lett. 111, 022502 (2013).
- "Measurement of Muon Antineutrino Quasi-Elastic Scattering on a Hydrocarbon Target at E_ν~3.5 GeV", Phys. Rev. Lett. 111, 022501 (2013).

- You might be working towards a thesis adding to this large ensemble
- What happens to an analysis after publication?
- Why are your measurements important?
- Who uses your data and how?

Me

- I did my PhD on T2K, spent parts on writing NUISANCE
  - Compared NEUT generator to data sets

- External data is fairly large effort on T2K
  - Informs experiment of external cross-section constraints and model choices; impacts oscillation analyses
  - Callum used MINERvA+MiniBooNE CCQE/CC0π data to choose Spectral Function or RFG for oscillation analysis
  - Patrick extended this work, put in z-expansion and much more
  - I worked in parallel on single pion production models

- NUISANCE has **117 MINERvA data sets**
  - 7 CC-inclusive, 12 CCQE, 27 CC0π, 38 CC1$\pi^{+,-,0}$, 15 CCN$\pi^{+,-}$, 6 CC DIS, 12 CC coherent
  - Your measurements gives us plenty of work!

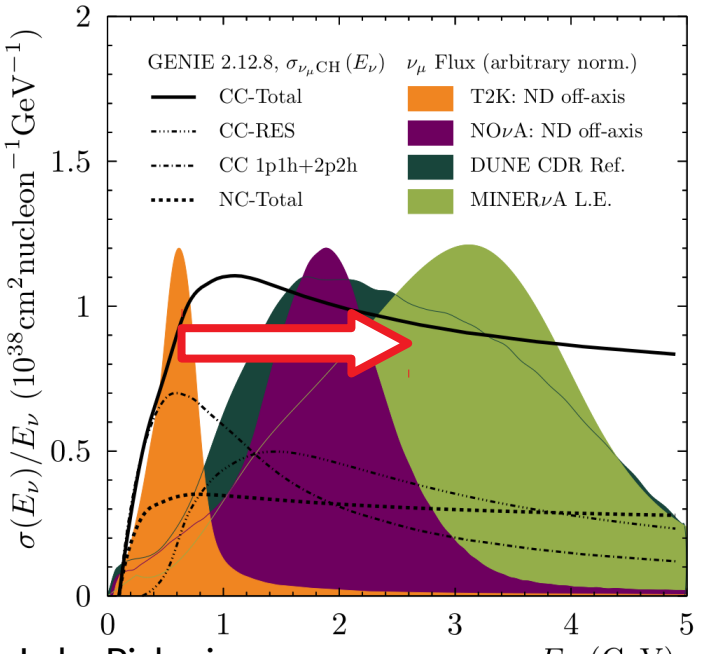
T2K and MINERvA

- Cross-sections impact oscillation analyses

$$R(\vec{\mathbf{x}}) = \overbrace{\Phi(E_\nu) \times \sigma(E_\nu, \vec{\mathbf{x}}) \times \epsilon(\vec{\mathbf{x}})}^{\text{Near}} \times P(\nu_A \to \nu_B)$$

- Constrained by near detector, but doesn't match SK perfectly
- Can inform model choices for $\sigma(E_\nu, \mathbf{x})$ from external experiments

- T2K signal definition is 1μ 0π
  - CCQE, 2p2h and CC1π with low p_π
  - Prioritises the model development
  - And the data we use to inform



T2K and MINERvA

- Can inform model choices for $\sigma(E_\nu, \mathbf{x})$ from external experiments

Phys. Rev. D 96, 092006 (2017)

> Two candidate models were considered for the default model: SF and RFG+RPA+2p2h. RFG+RPA+2p2h was selected as the default because it was most consistently able to describe the available MiniBooNE [42, 43] and MINERvA [44, 45] CCQE-like data (see Ref. [35] for details).

- T2K also imposes penalties for parameters moving far away from their expectation
  - These expectations are sometimes informed by MINERvA

$$-\log \mathcal{L}_{\text{Total}} = \sum_{\text{Bins}} \left[\lambda(\vec{\theta}) - n + n \log \frac{n}{\lambda(\vec{\theta})} \right] + \sum_{\text{Systematics}} \frac{1}{2} \left[(X_i - \mu_i) \left(\boldsymbol{V}\right)^{-1}_{ij} (X_j - \mu_j) \right]$$

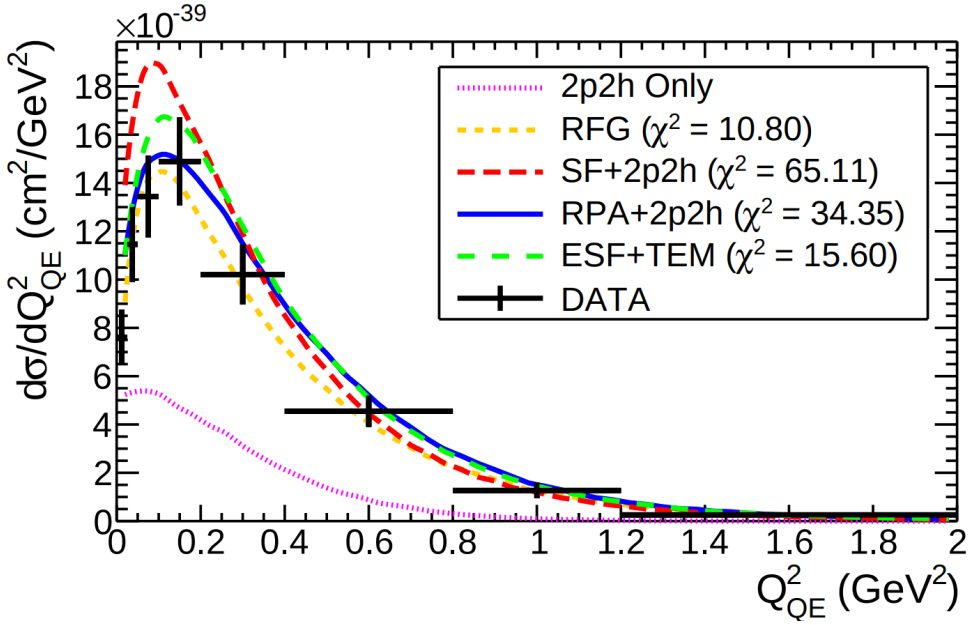
i,j = M_A^{QE}, 2p2h normalisation, etc...

T2K and MINERvA, CC0π

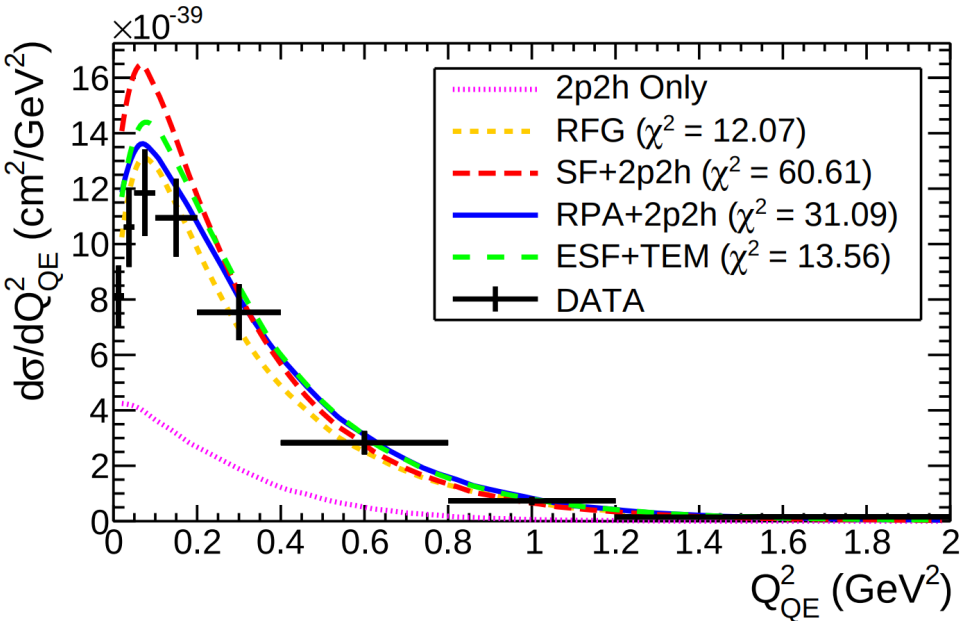
Phys. Rev. D 93, 072010 (2016)

- In 2014/2015 analyses T2K had to choose between Spectral Function and Relativistic Fermi Gas
- Fit MINERvA and MiniBooNE CC0π data with different models and parameters

MINERvA CCQE neutrino



MINERvA CCQE anti-neutrino

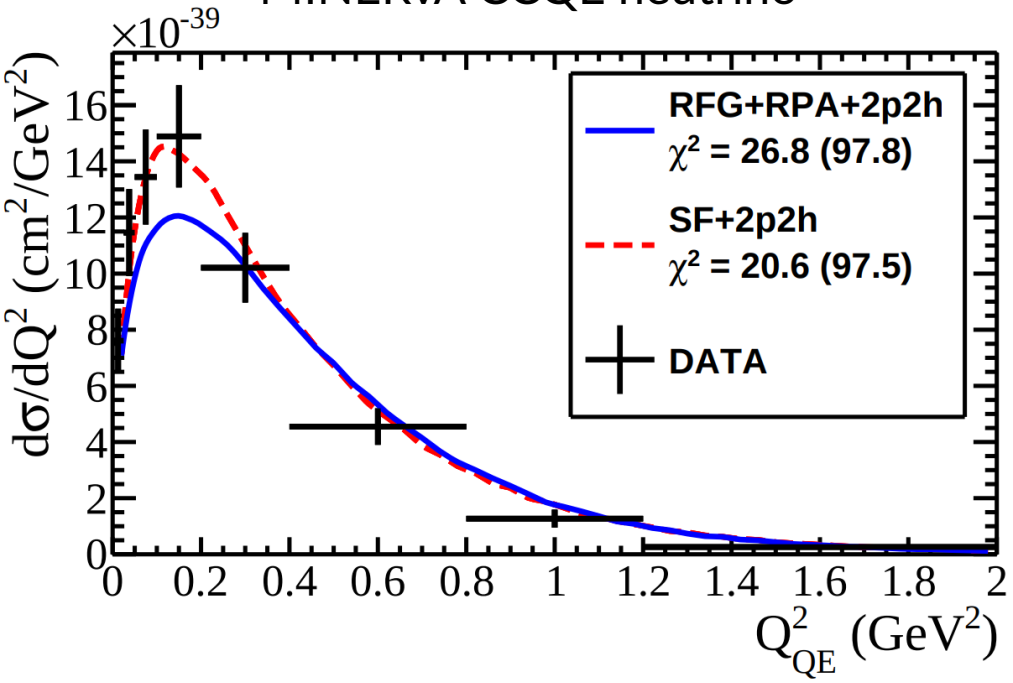


T2K and MINERvA, CC0π

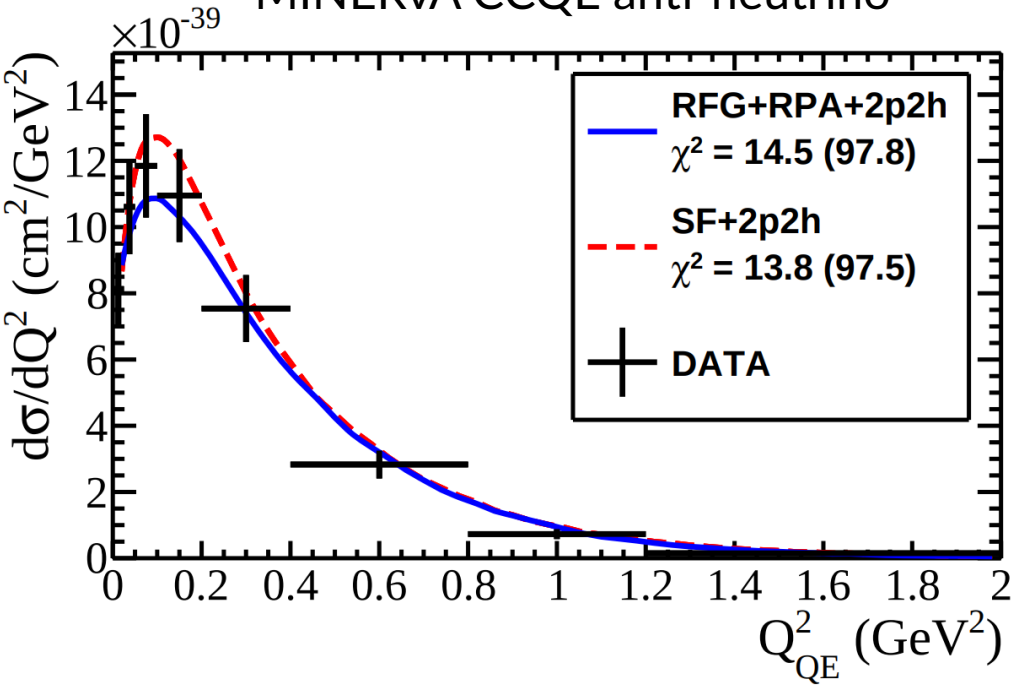
Phys. Rev. D 93, 072010 (2016)

- Post-fit found very similar χ^2
  - RFG+RPA+2p2h: 97.8
  - SF+2p2h: 97.5

MINERvA CCQE neutrino



MINERvA CCQE anti-neutrino



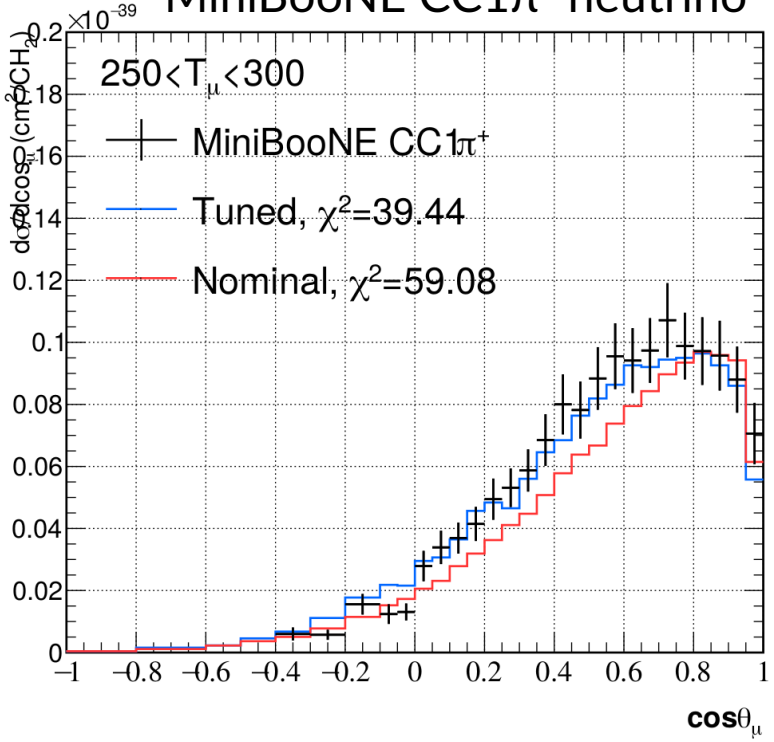
- Neither model adequately describes data
- Assigned to tension between MiniBooNE and MINERvA data
- RFG+RPA+2p2h best described data independently

T2K and MINERvA, CC1π

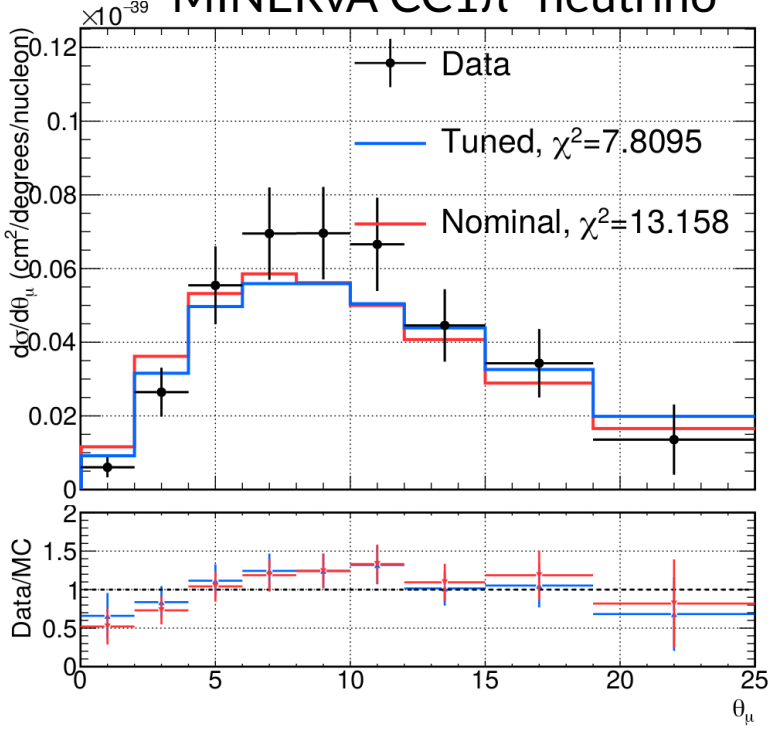
Link to workshop

- T2K tried similar process for single pion production
- Fitting MiniBooNE and MINERvA CC1π⁺ and CC1π⁰ data simultaneously

MiniBooNE CC1π⁺ neutrino



MINERvA CC1π⁰ neutrino

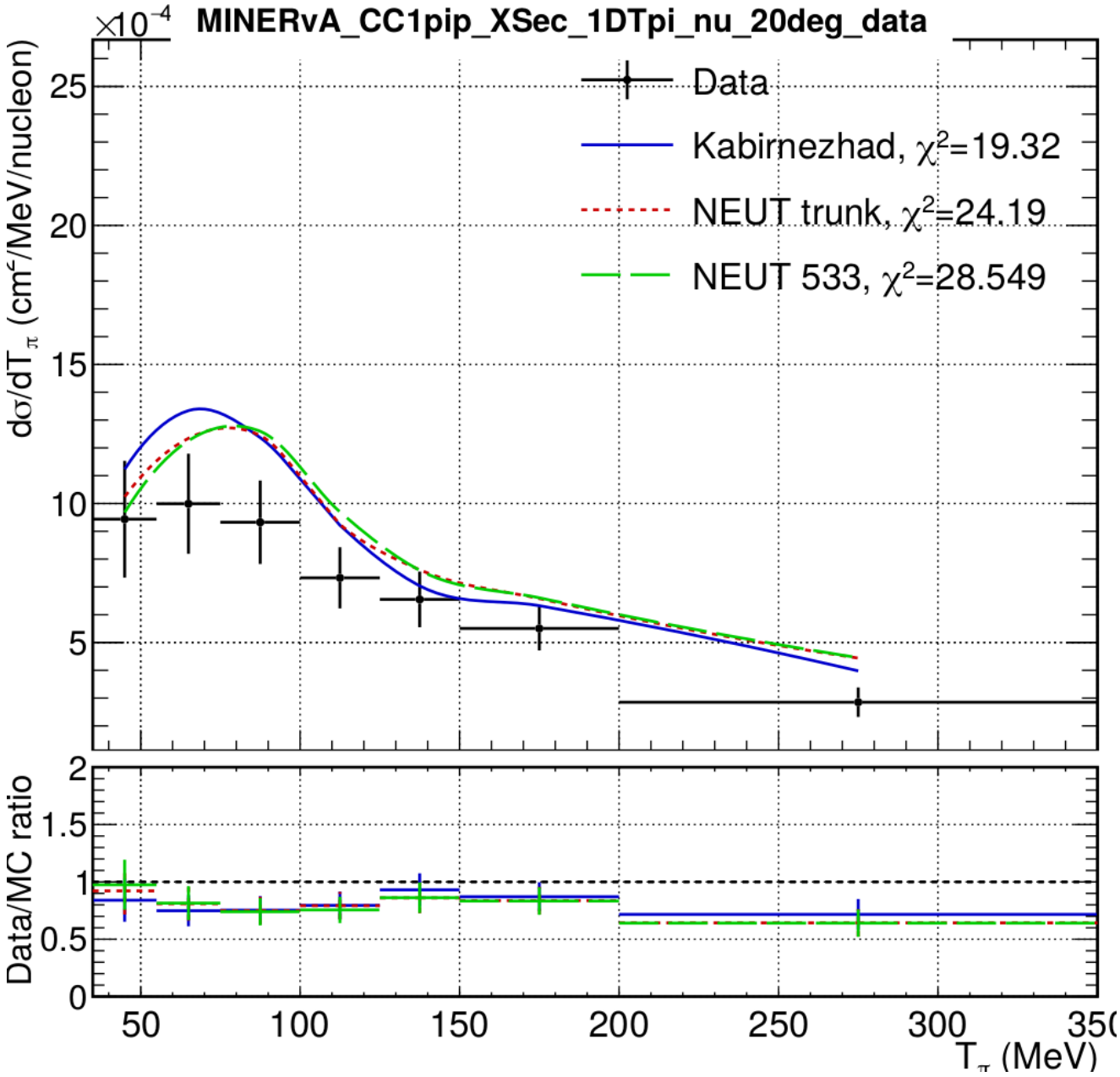


- Used mostly as a cross-check of a nucleon tuning
- Found nucleon/nuclear tension (similar to recent MINERvA paper)
- Found MiniBooNE controlled fit; lacking covariance matrix

T2K and MINERvA, CC1π

Link to workshop

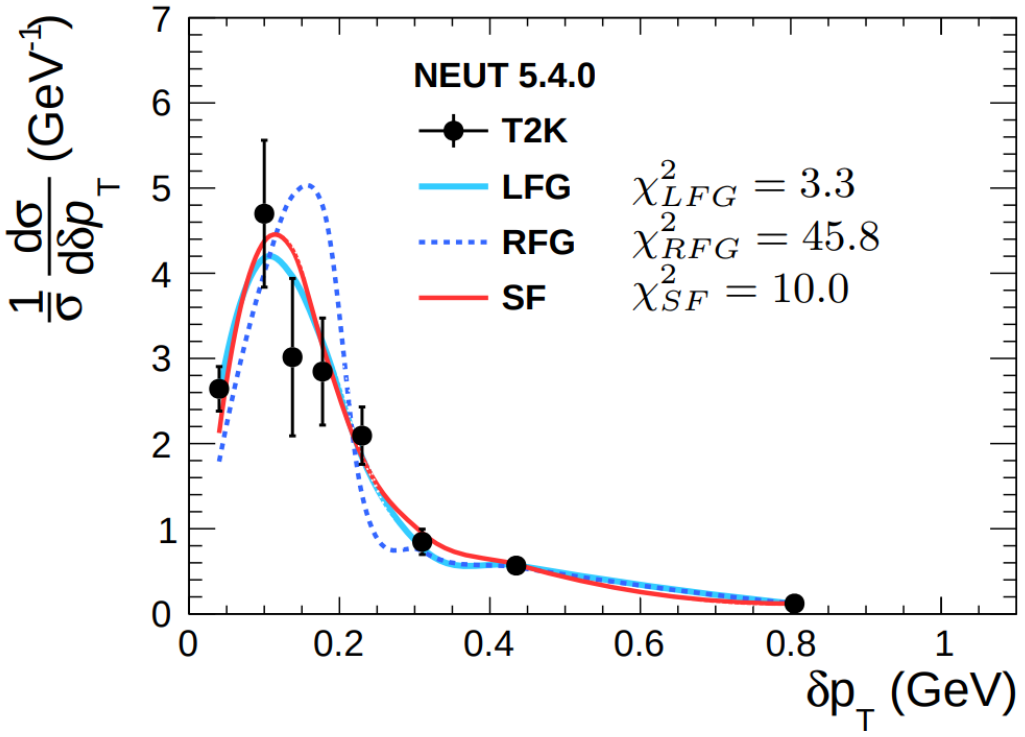
- Also used MINERvA 1π data for comparison of new developed single pion models

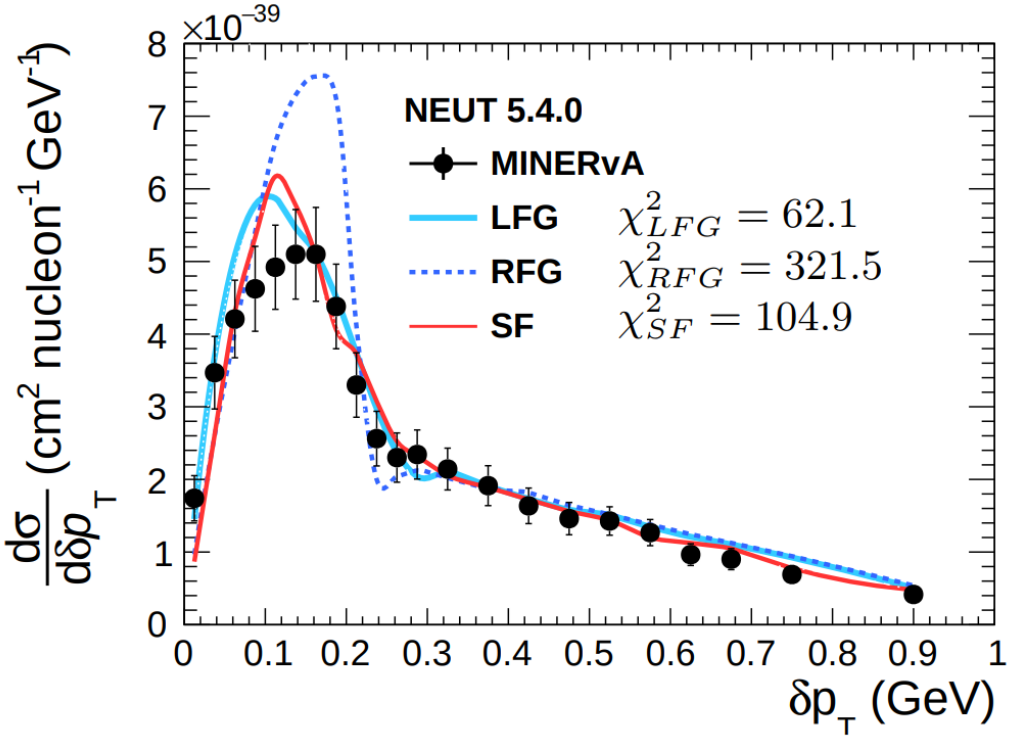


T2K and MINERvA, collaboration

arxiv link

- Have started working closely on e.g. transverse variables
- Benefiting from cross-experiment members
  - Stephen Dolan and Xianguo Lu, single transverse variables



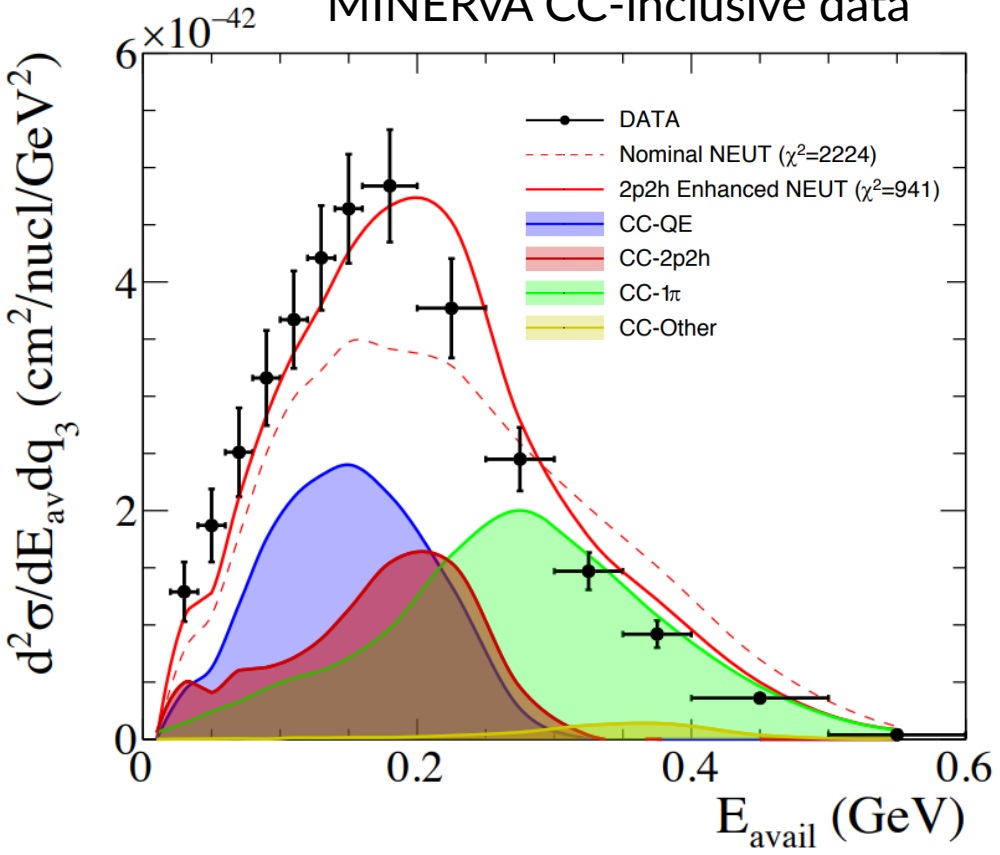


  - David Coplowe, double transverse variables
  - Kevin McFarland, NIWG convener
  - ...me?

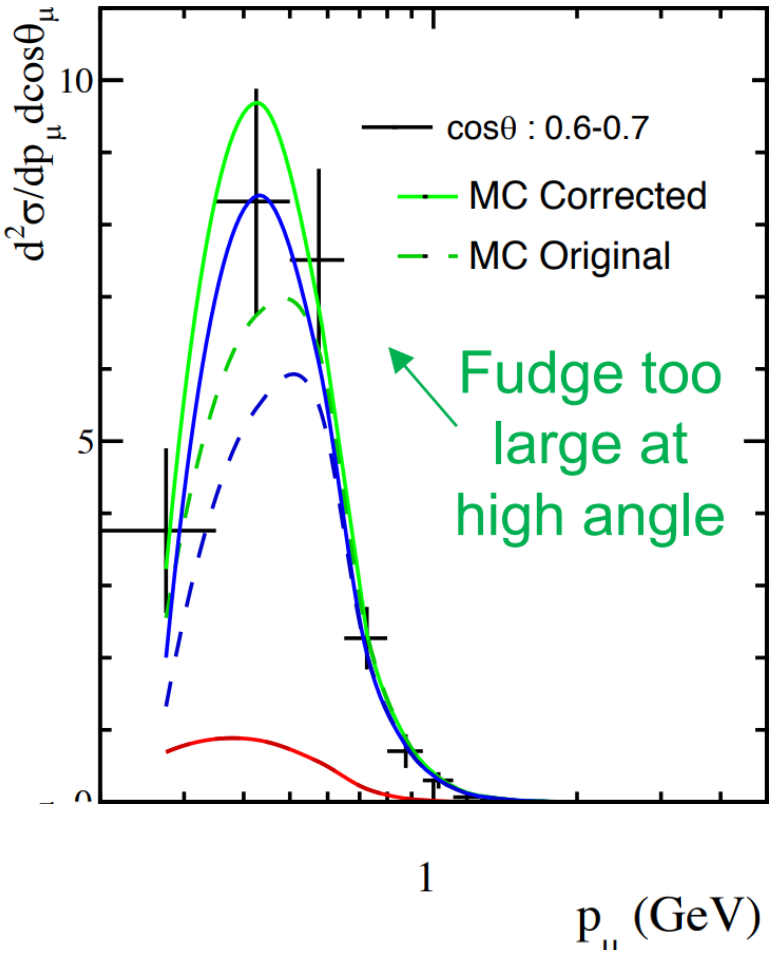
T2K and MINERvA, collaboration

- MINERvA has been forthcoming with providing “MnvGENIE”
- Patrick tested the 2p2h tune against T2K data and was found worse that T2K’s 2p2h tune

MINERvA CC-inclusive data

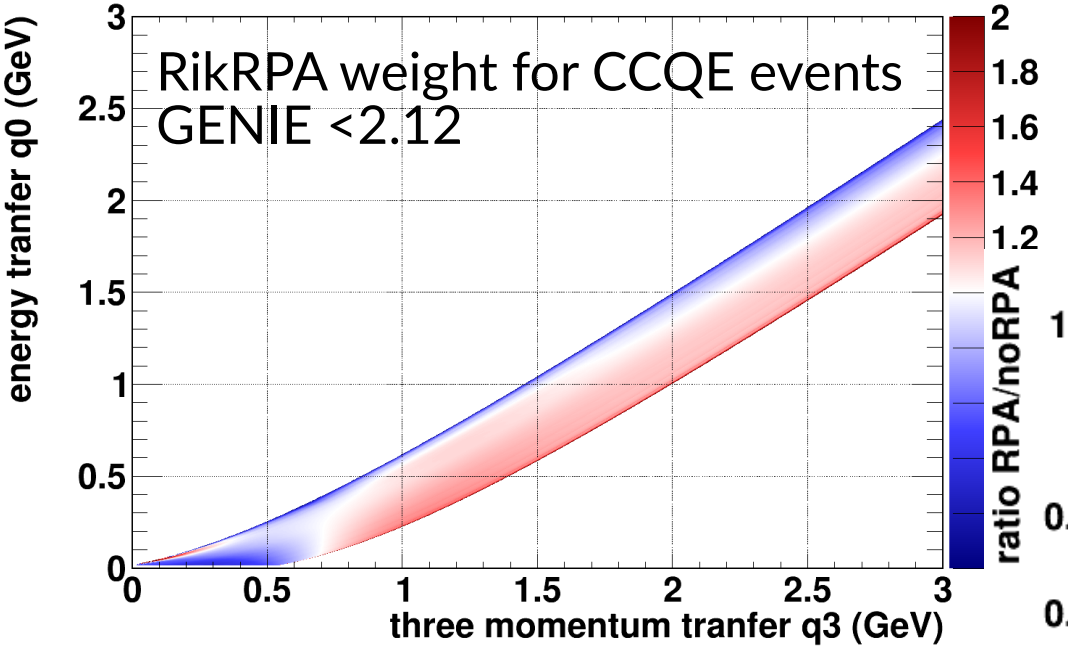


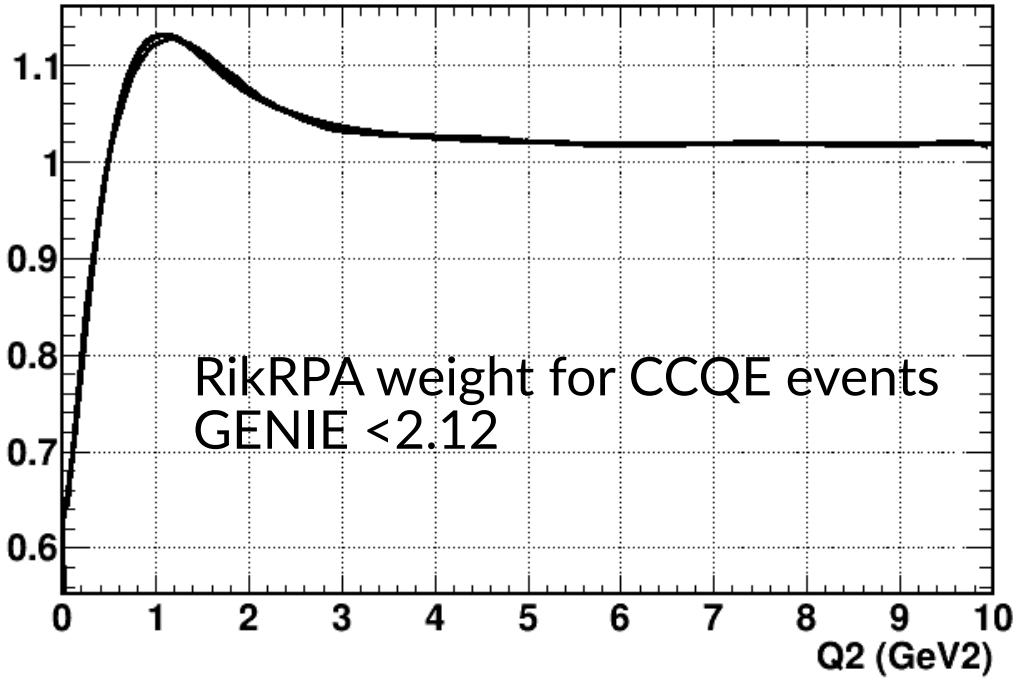
T2K CC0π data



NOvA and MINERvA

- Many NOvA collaborators are ex-MINERvA
  - Jeremy Wolcott, Anne Norrick, Aaron Mislivec etc (sorry if I missed your favourite!)
- RikRPA, developed by MINERvA collaborators and used by NOvA



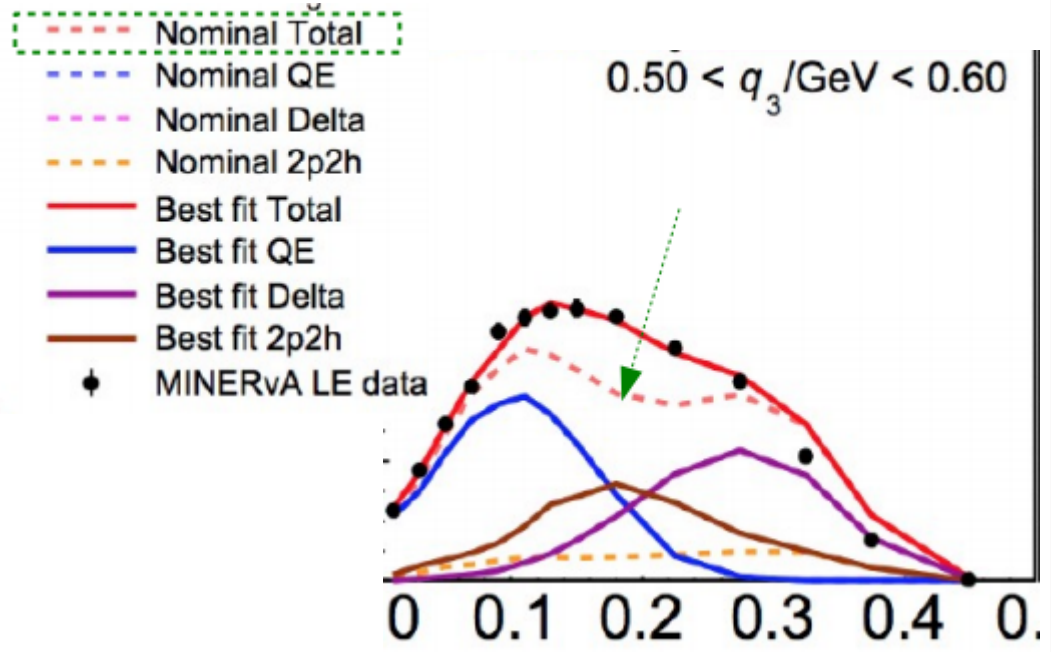


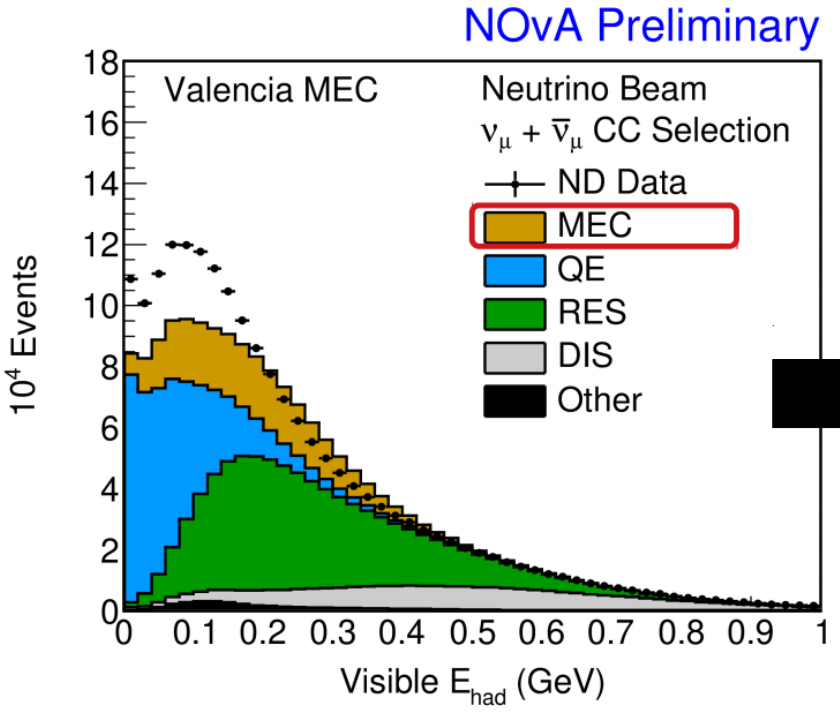
- Also gets applied to RES events

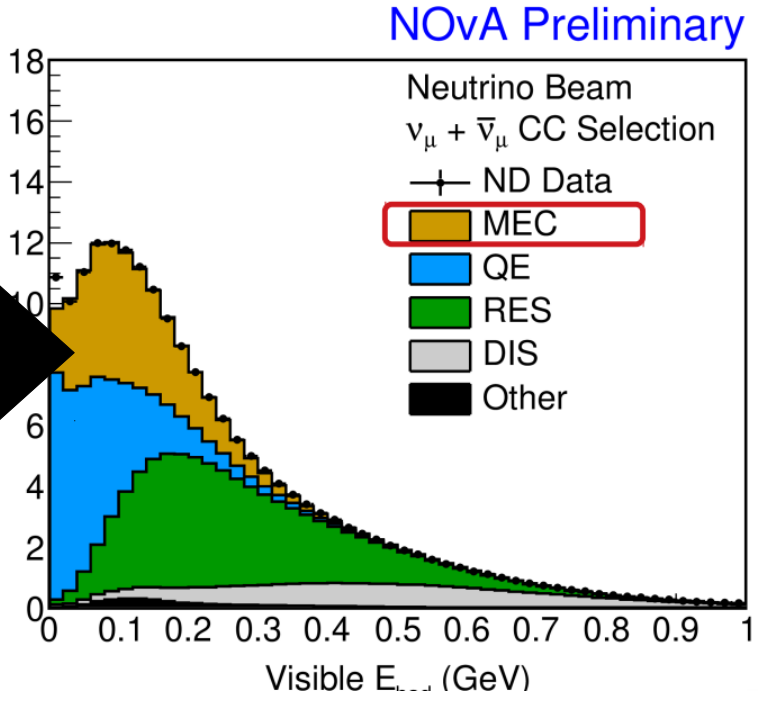
NOvA and MINERvA

Jeremy Xianguo

- CC-inclusive E_{av} q_3 inspiration
- NOvA tune 2p2h in to make up for missing cross-section in E_{av} q_3

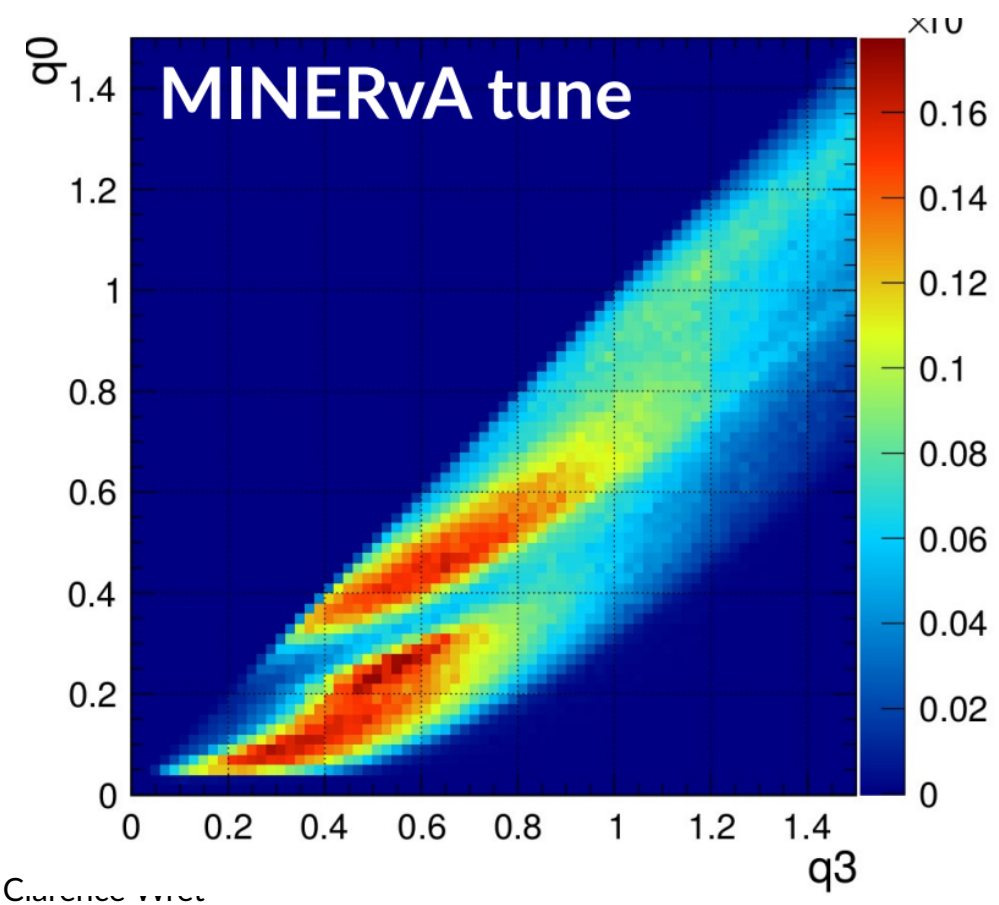


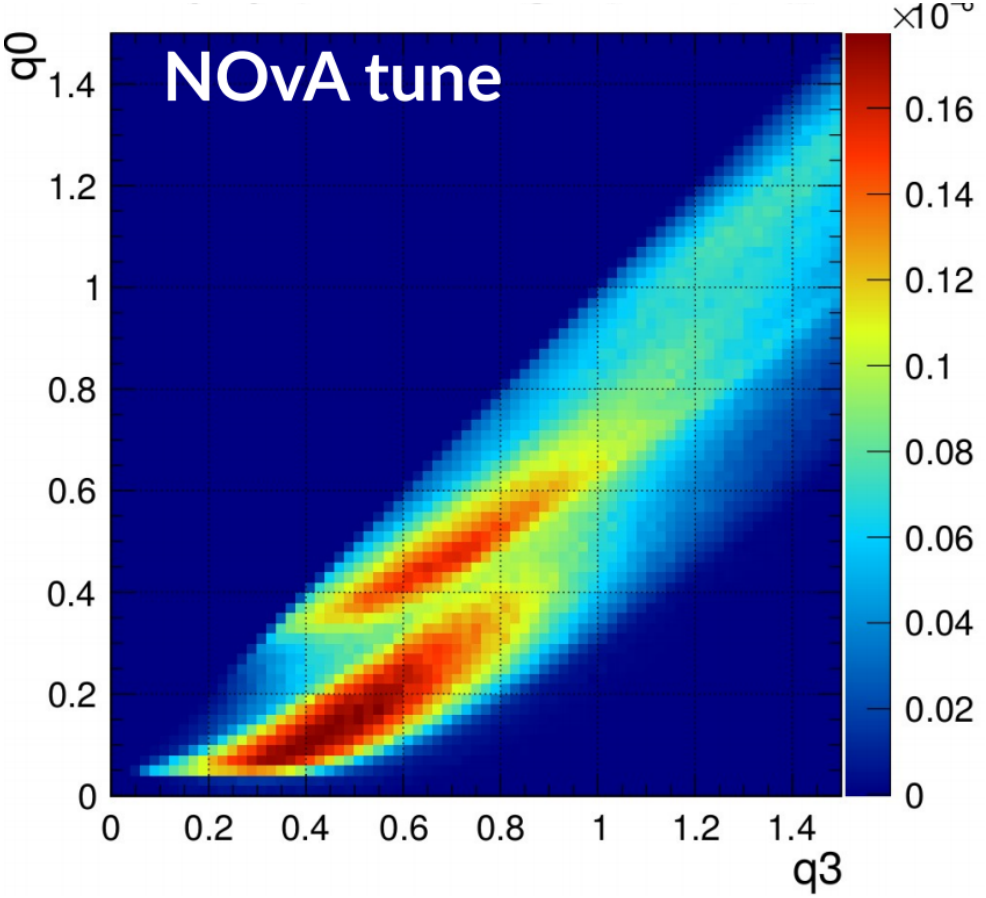




NOvA and MINERvA

- Dedicated NOvA-MINERvA workshop in Sep 2018
  - Link here
- Discussed the NOvA and MINERvA tunes, discrepancies and how MINERvA can keep helping NOvA



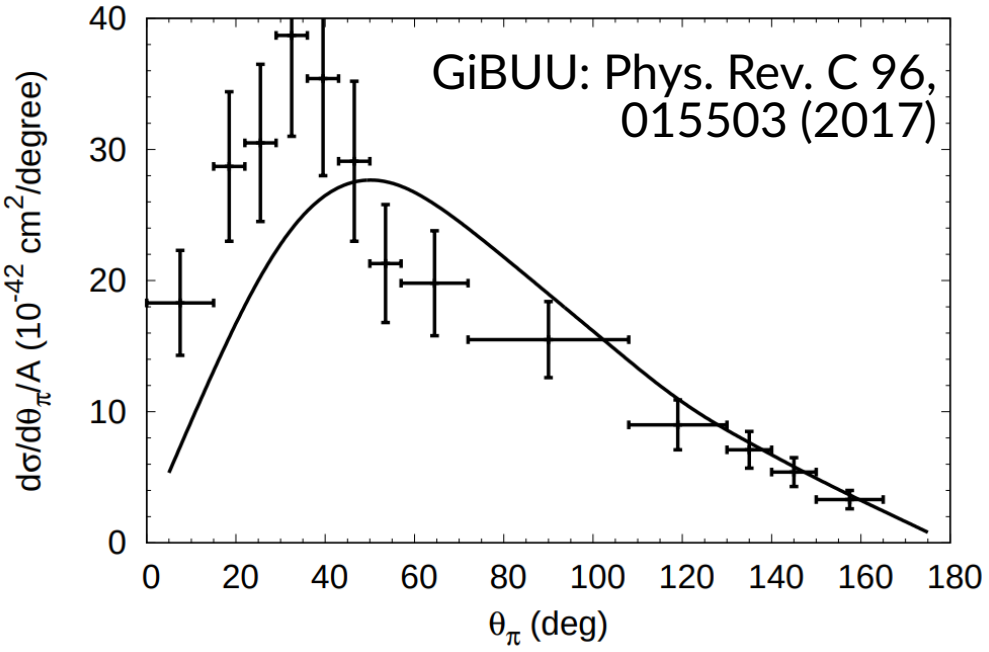


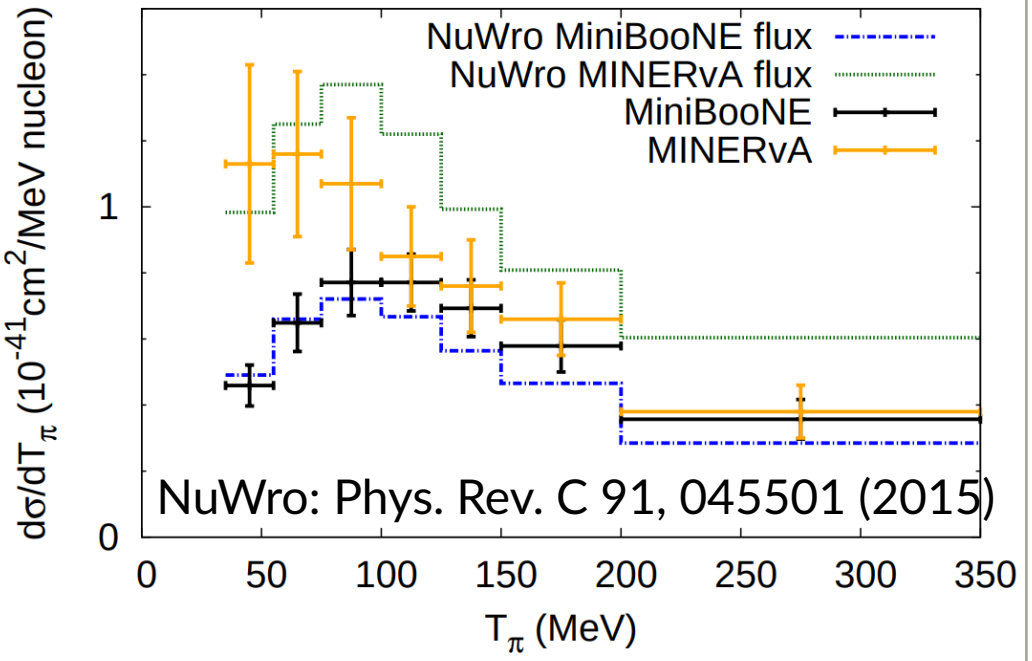
DUNE and MINERvA

- The DUNE Technical Design Report is in its final stages
- Many neutrino cross-section systematics are inspired from MINERvA experience
  - e.g. MINERvA tunes, single pion production tunes
- Neutron measurements at MINERvA are paving the way
  - CH cuboid detectors using MINERvA as reference
  - 3DST detector in DUNE
  - SuperFGD in T2K-II/Hyper-K

Generators and MINERvA

- Hopefully convinced you T2K and NEUT have used MINERvA
- Ulrich uses it to claim GiBUU is nature (although MiniBooNE is not part of nature)

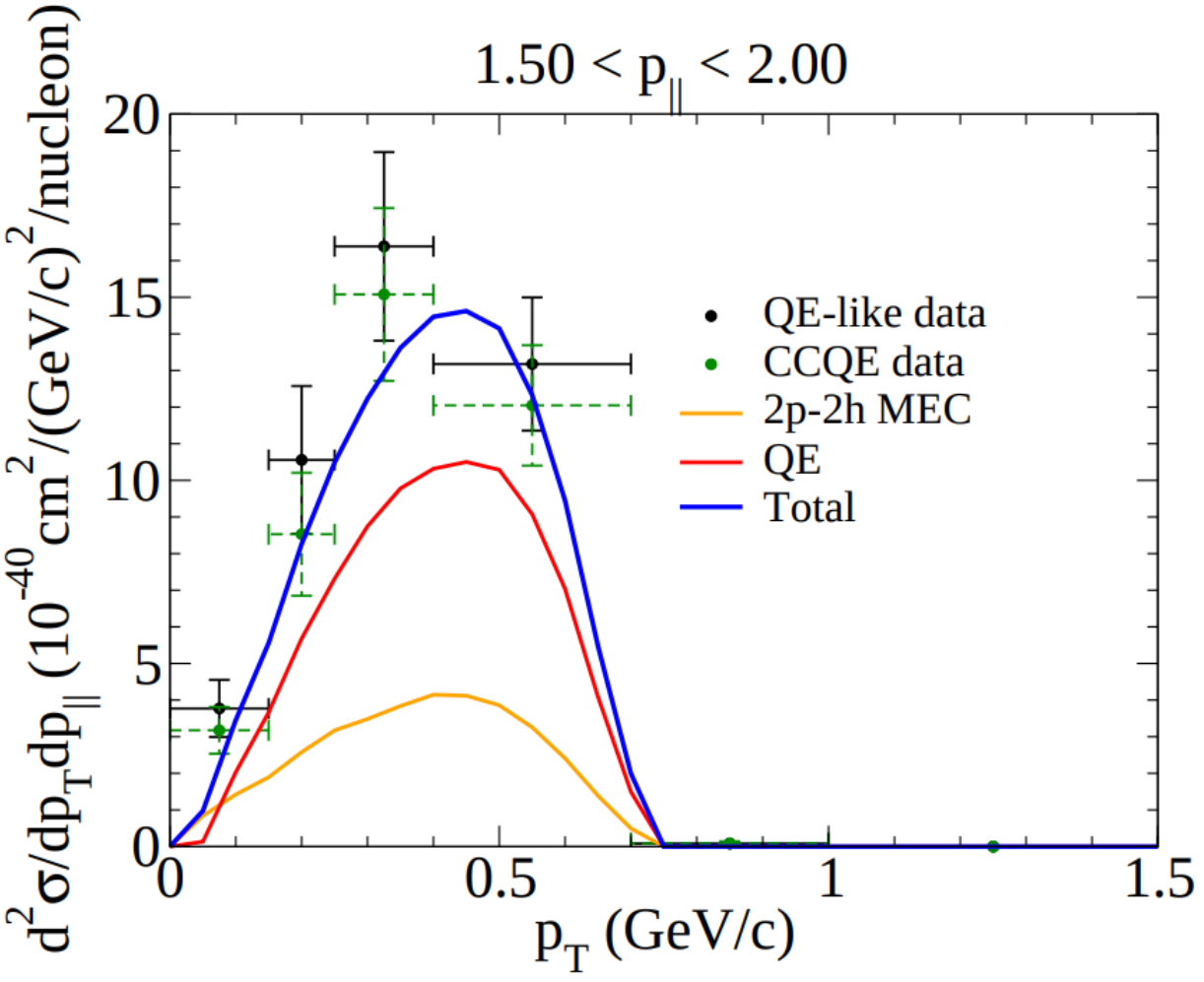




- Jan uses it with NuWro to investigate incompatibilities with MINERvA and MiniBooNE descriptions
- GENIE will likely use MINERvA data for their future tunes

Theorists and MINERvA

- SuSAv2 are testing their models against MINERvA data

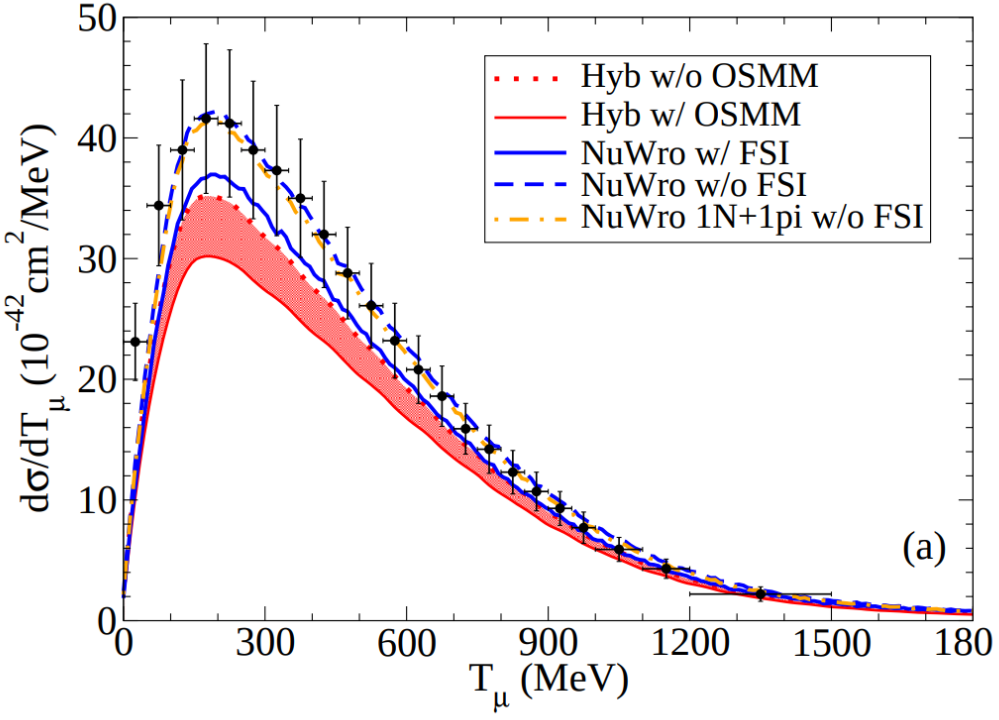


Theorists and MINERvA

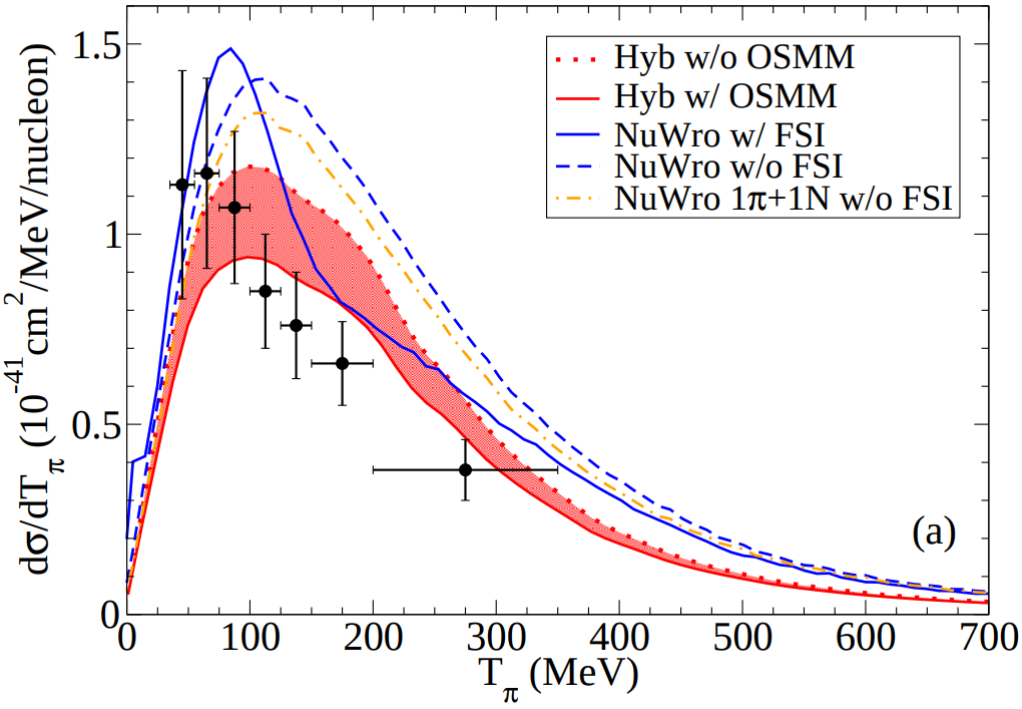
link

- Relativist Plane-Wave Impluse Approximation (RPWIA) tests against MINERvA and MiniBooNE data

MiniBooNE CC1π^+



MINERvA CC1π^+



Hyb = Their model
OSMM = Oset in Medium Modifications

Theorists and MINERvA

- Artur Ankowski is testing their SF against MINERvA data

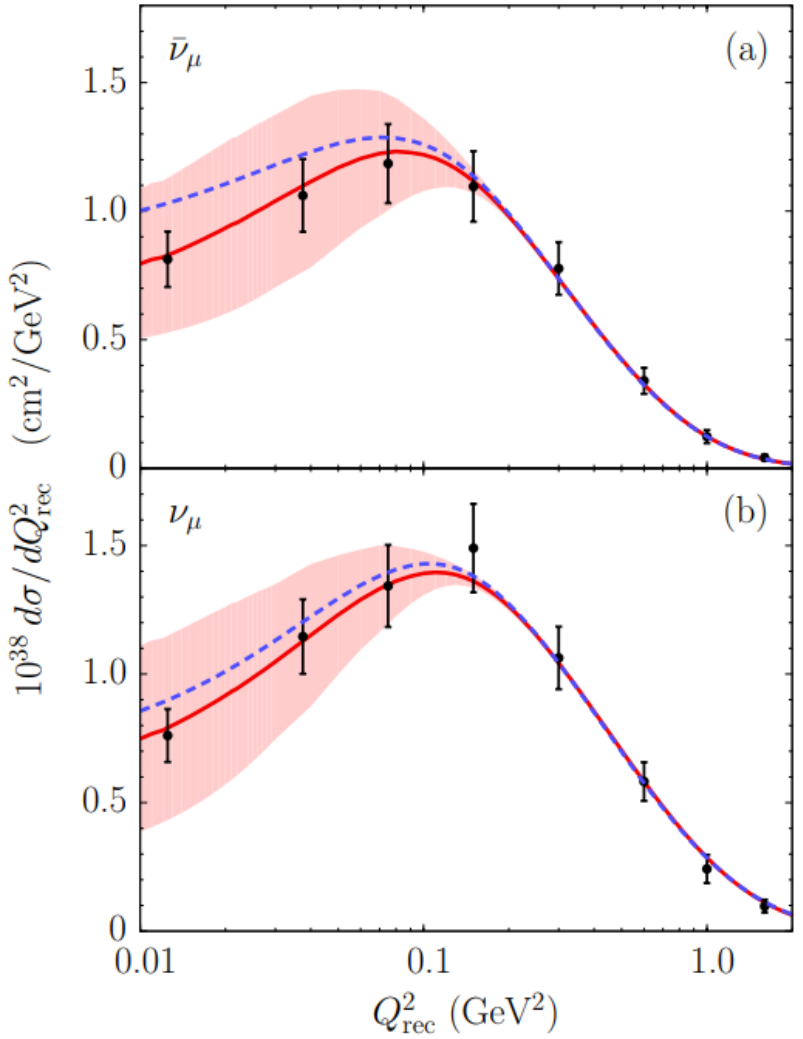


FIG. 2. (color online). Differential cross sections $d\sigma/dQ^2_{\rm rec}$ for CC QE (a) $\bar{\nu}_\mu$ and (b) ν_μ scattering in MINERvA. The SF calculations without (dashed line) and with (solid lines) FSI effects [9] are compared to the data [1, 2]. The bands represent theoretical uncertainties.

How things can improve

DISCLAIMER

The following opinions are from someone tuning generators and providing constraints for oscillation experiments

My primary interest is **model dependence**

I don't want to be fitting my generator to features of your generator

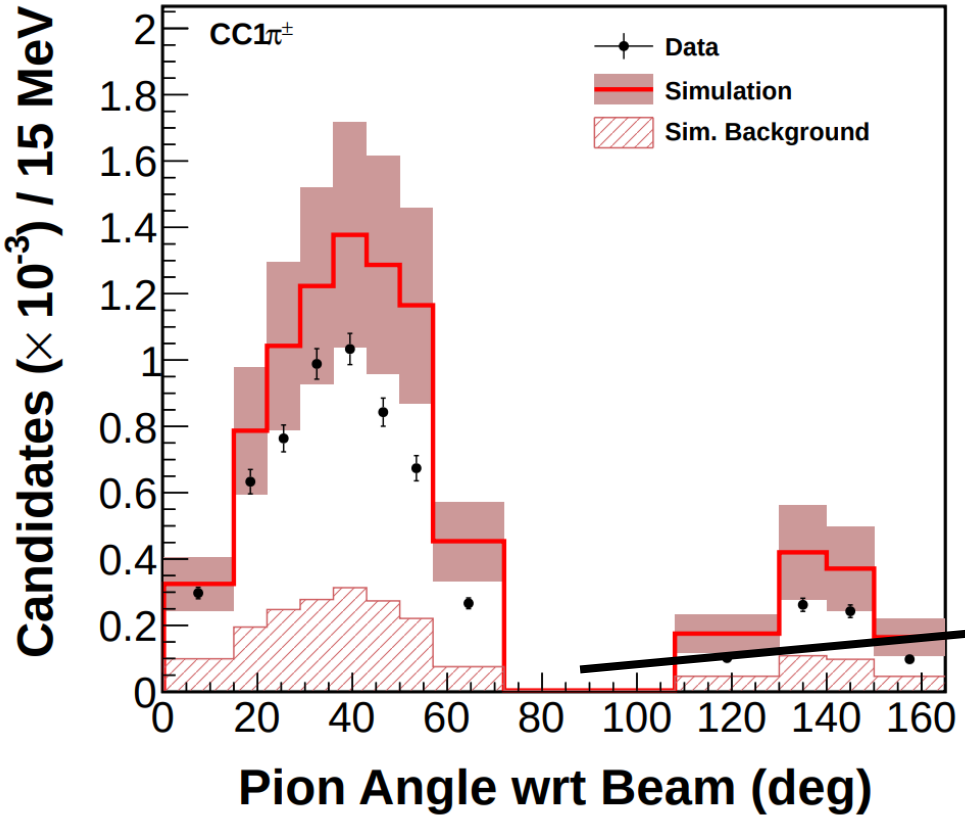
How things can improve

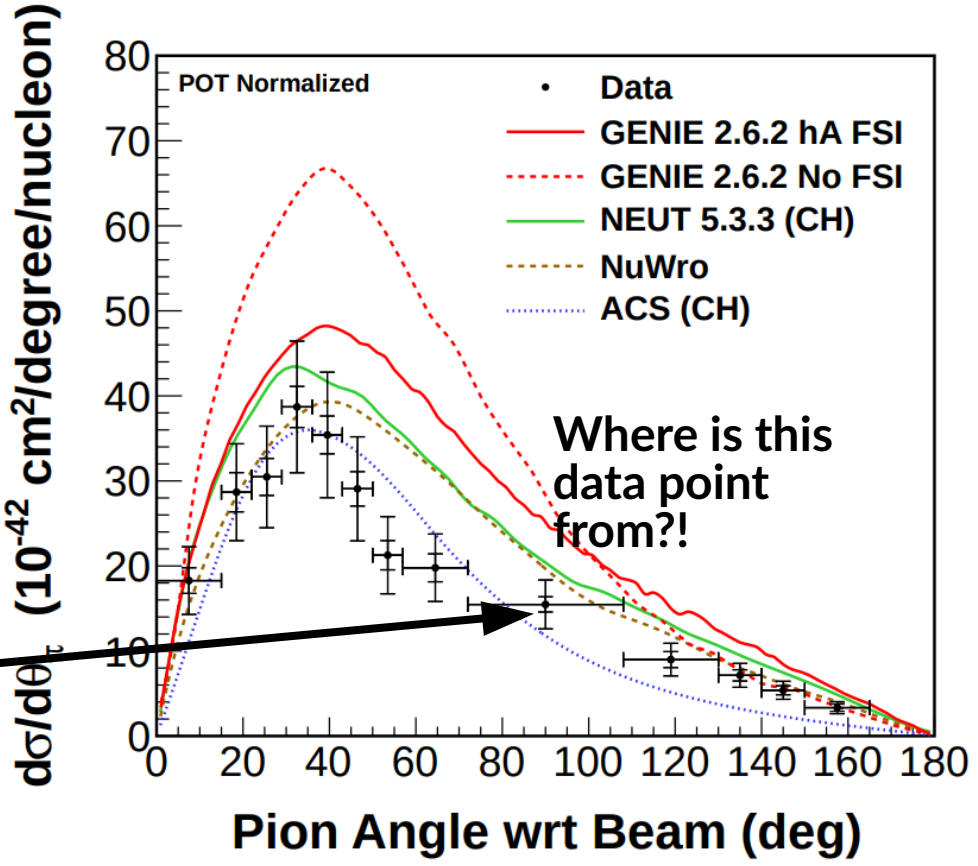
- Have hopefully convinced you that your cross-section is important
- But be responsible in your analysis!
- Study your **model dependence very carefully**, and when you think you're done, study it even more

- Please don't use theory quantities like E_ν^{True}, W^{true}, Q^2_{True}: it confuses everyone and has unnecessary model dependence
  - E.g. first pion analysis placed W cuts, Ulrich was very upset
  - Some analyses still insist on cutting on true neutrino energy
  - Or publishing $d\sigma/dQ^2$
- Are you **really claiming** to understand the complex nuclear dynamics involved in reconstructing these quantities?
  - If there's a model in 5 years that explains all neutrino data, how wrong is your data? **Will your result be used to refute the perfect model because of your data's model dependence?**

How things can improve

- Efficiency correcting in a region of rapidly changing efficiency?
  - Please don't sprinkle your data with GENIE!
  - Please don't fill in efficiency holes with GENIE! Sadly case in CC1$\pi^{\pm}$

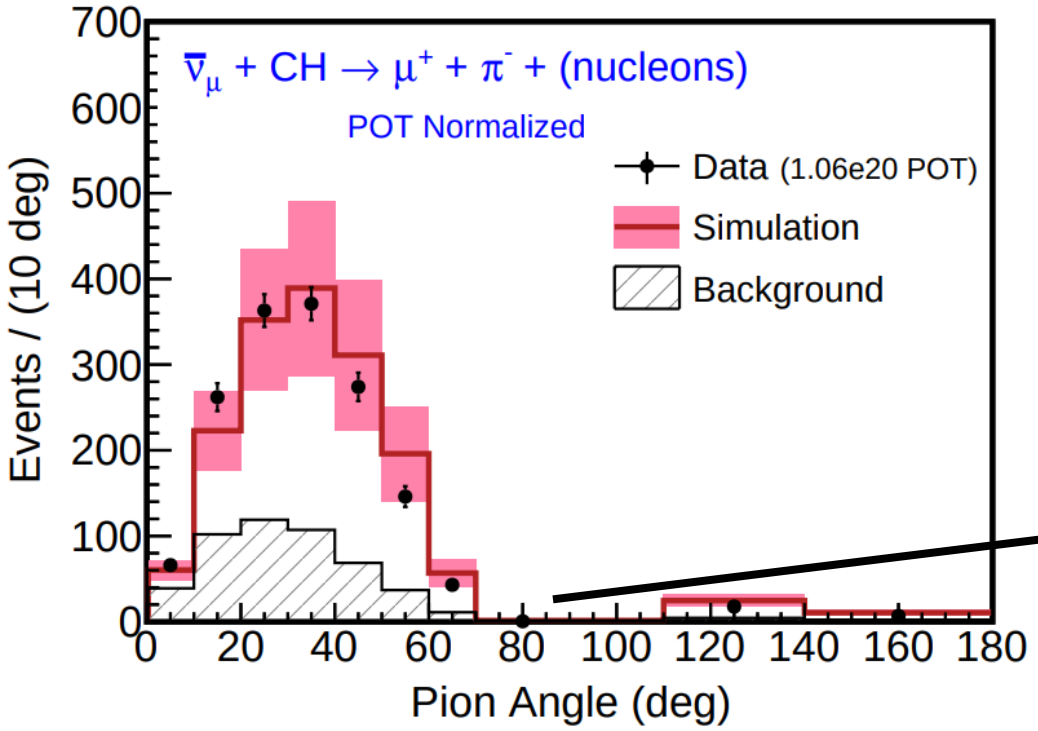


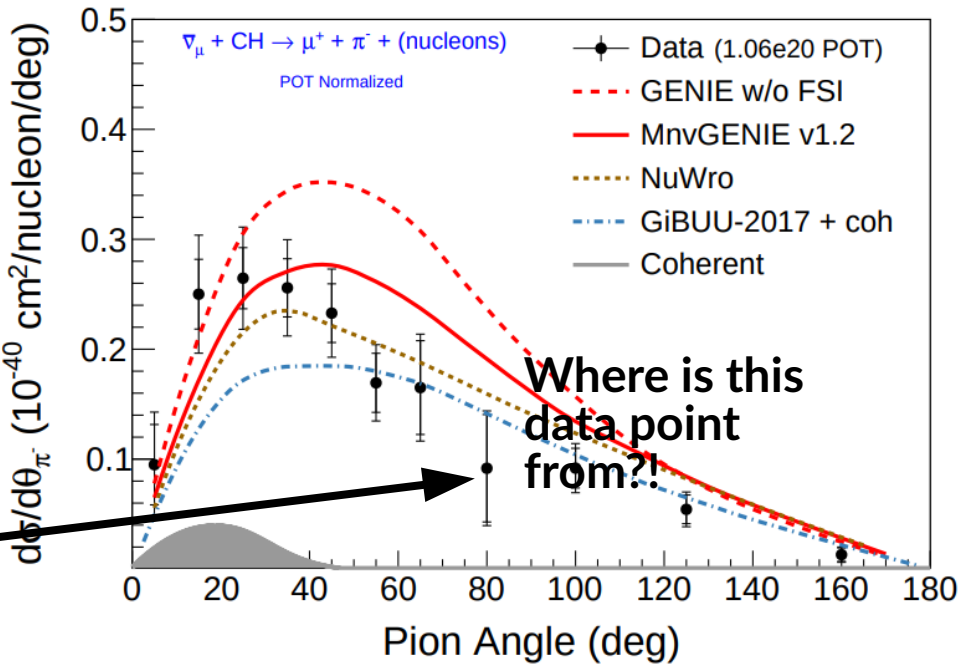


- Place strict signal definition cuts rather than selection cuts
  - If you can't see pions above T_{π}=350 MeV or θ_{π}>60°, make it a signal definition requirement

How things can improve

- Consider the disclaimer
- I personally don't understand why this needs to be done





- From this week's MINERvA CC1π^- cross-section on the arxiv

How things can improve

- Careful release of data: have your friends in NUISANCE test it
  - Have found incomplete data releases, e.g. missing covariances
  - Ozgur's CC1π^0 covariance matrix was wrong, publishing erratum
  - Some covariance matrices don't decompose; difficult for outside world to interpret
  - Unclear signal definitions
- Mistakes will always happen, but it's good to put your release through a sanity test before letting it out in the wild

Conclusions

- MINERvA have been central in the neutrino cross-section community for the last few years
  - Has helped oscillation experiments with priors
  - Interfaced with generator model development and choices
  - Providing theorists with benchmarks for models
  - Cross-experiment collaboration for maximum juice!
- Hopefully keep it going for years with robust data preservation effort

- Want your data to be used by someone like me?
  - Be ultra paranoid about model dependence
  - Show me how paranoid you've been!

Thanks!