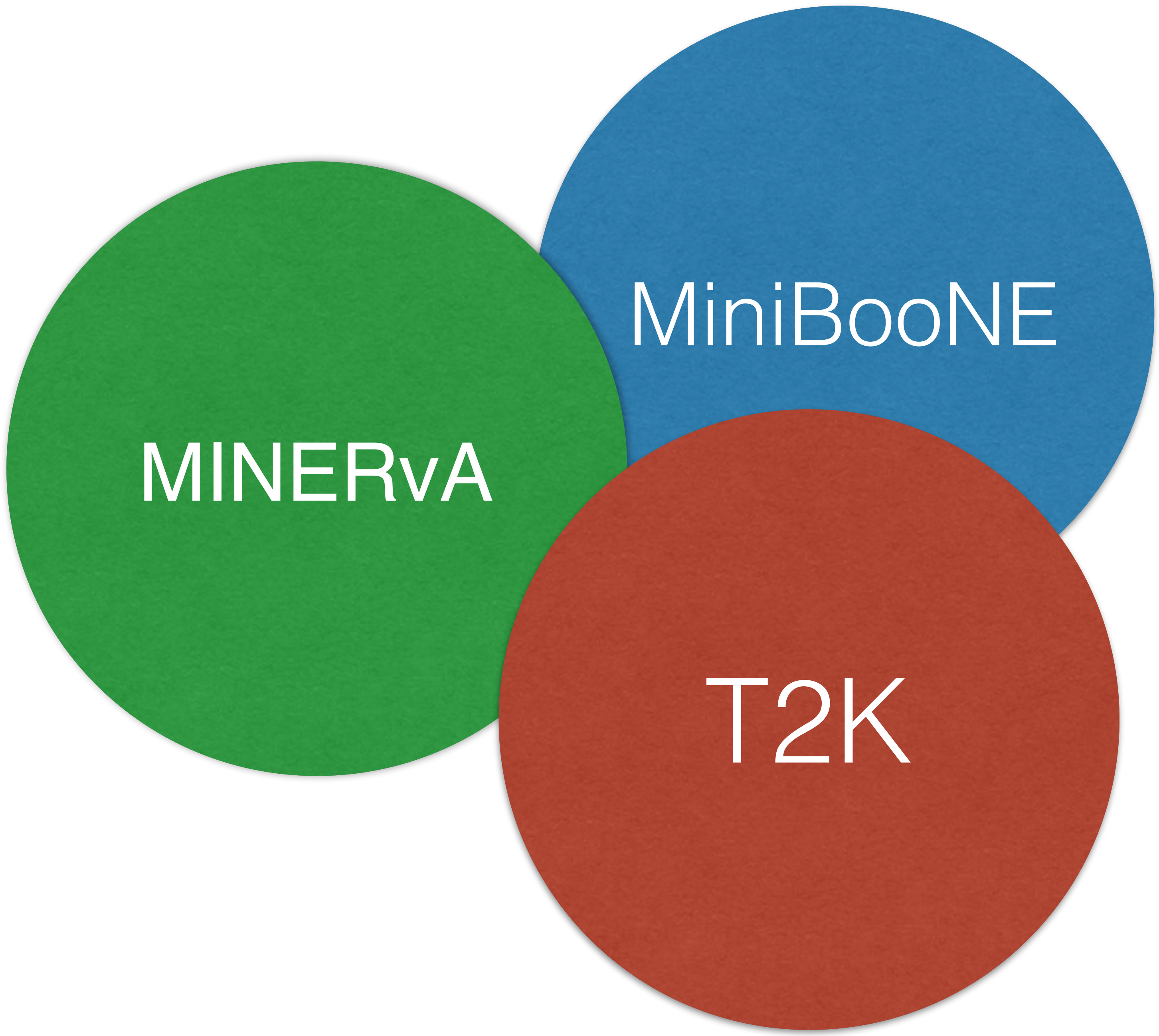
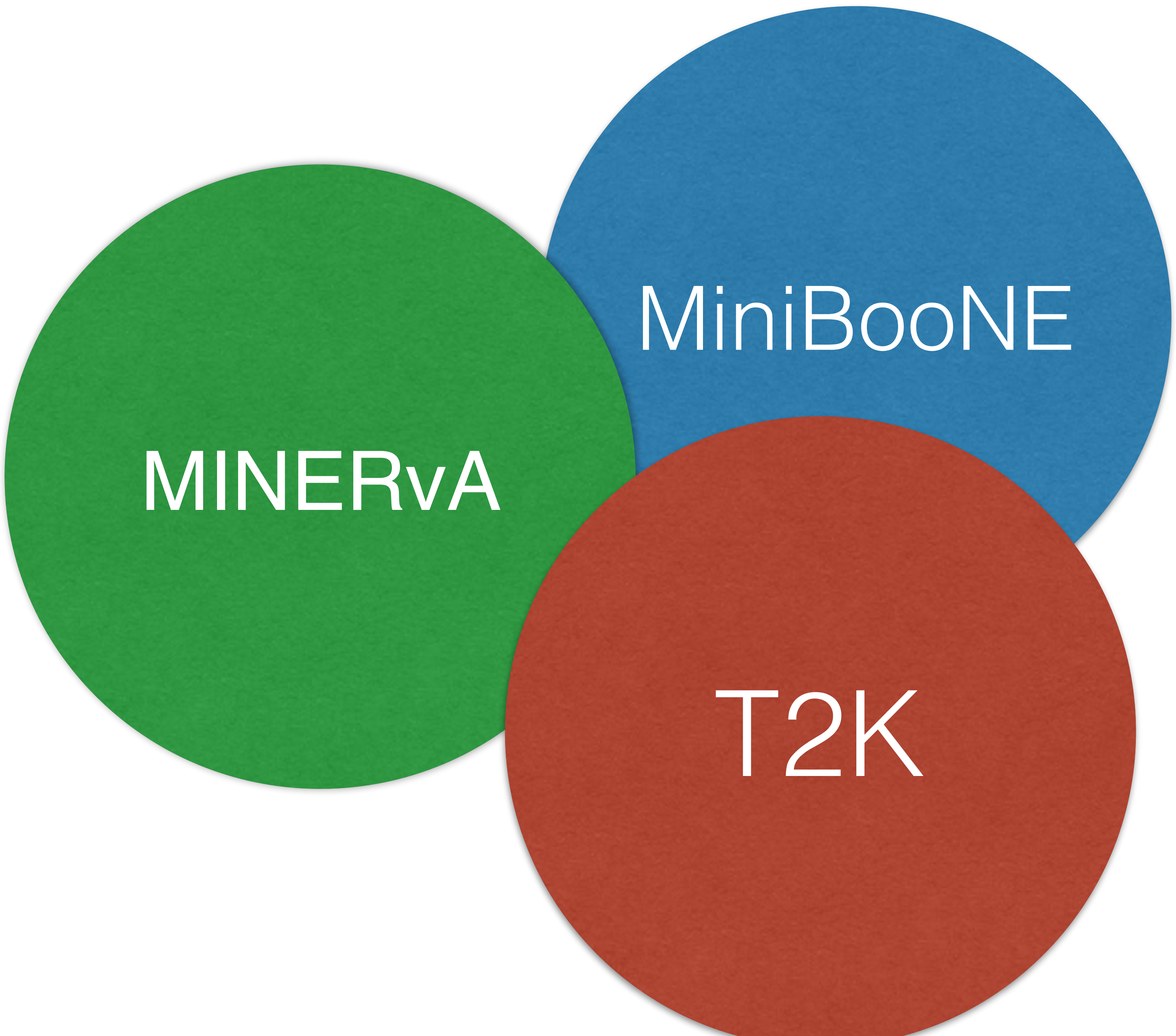
Global Neutrino Cross Section Fits and Challenges: Summery of TENSIONS2016



Kendall Mahn
Michigan State University

Global Neutrino Cross Section Fits and Challenges: Summery of TENSIONS2016



- Axiom: Improved cross section understanding important for oscillation physics
- But, tensions in measurements of ~1 GeV cross sections
- How do we treat efficiency and model-based uncertainties in measurements?
- How do we handle signal, background separations?

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Michigan State University

Processes in Neutrino Scattering

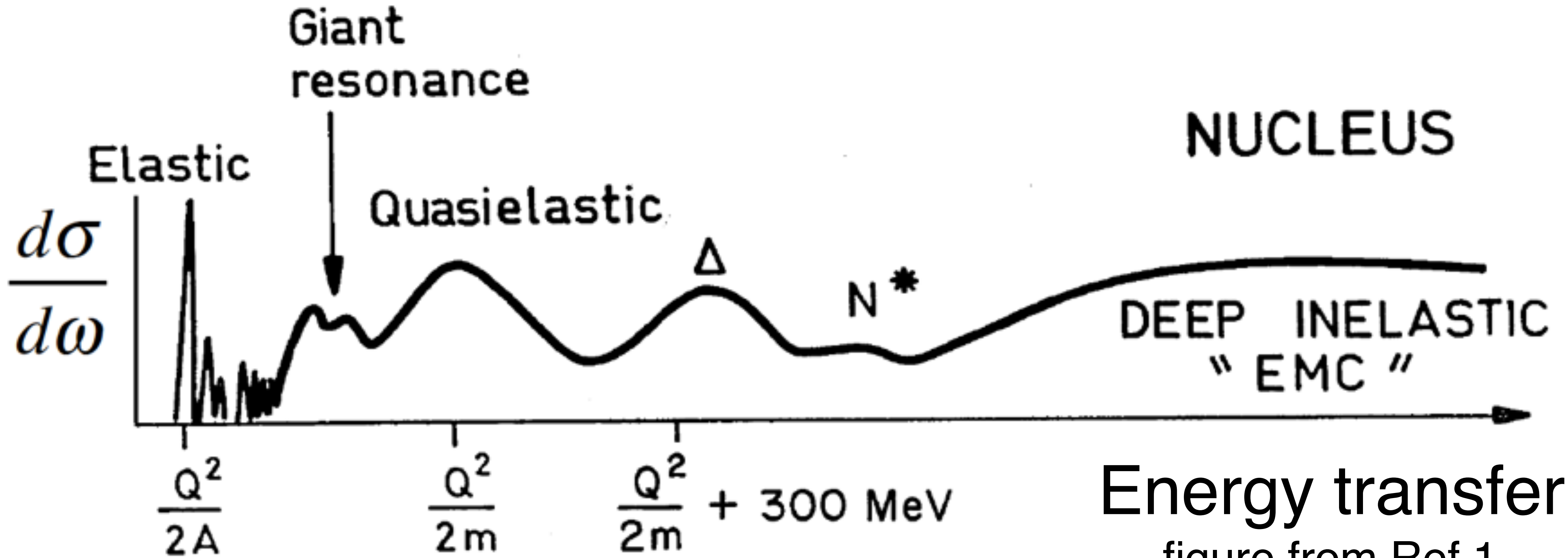
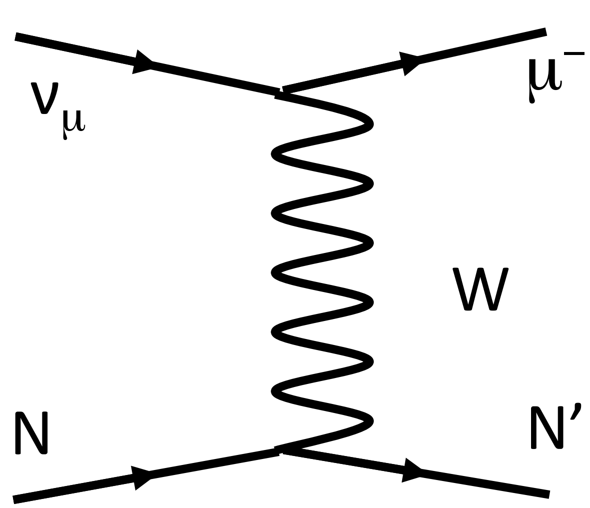


figure from Ref 1

- Charged Current Quasi Elastic (CCQE) and multinucleon processes (2p2h)

CCQE

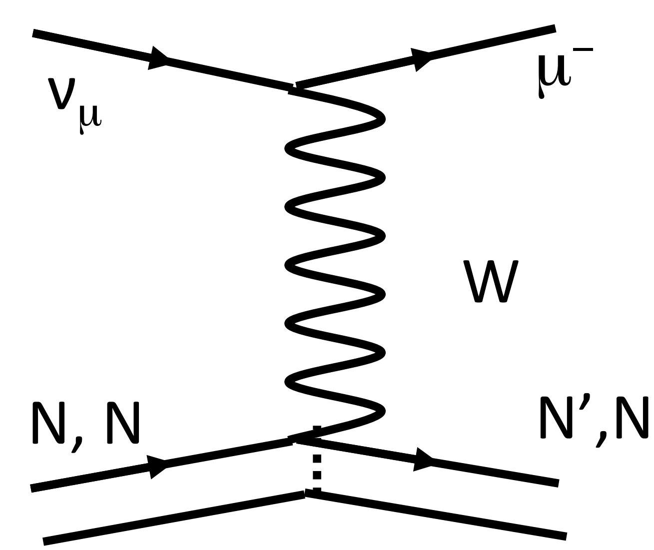


Observable

neutrino (anti)

- muon or electron (+)
- proton (neutron)

2p2h



Processes in Neutrino Scattering

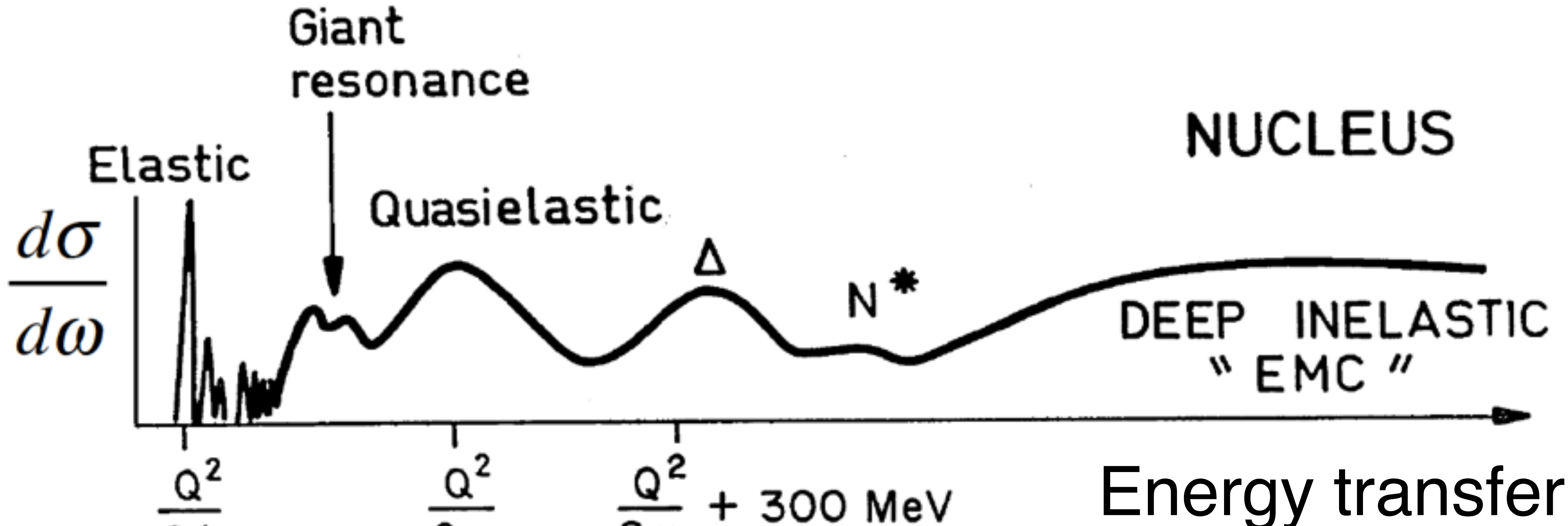
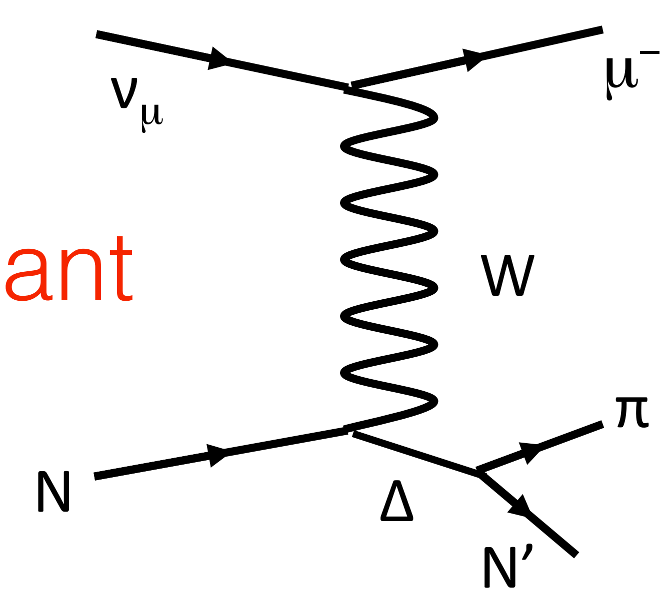


figure from Ref 1

- Production of pions, CC1$\pi^{+/0/-}$ and NC1$\pi^{+/0/-}$

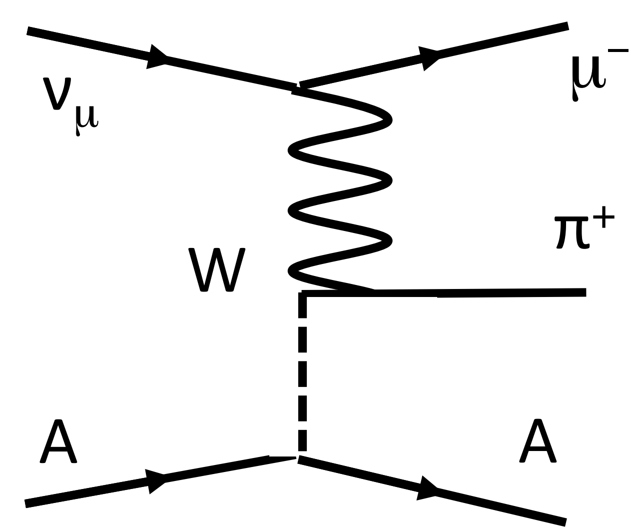
CCπ

resonant

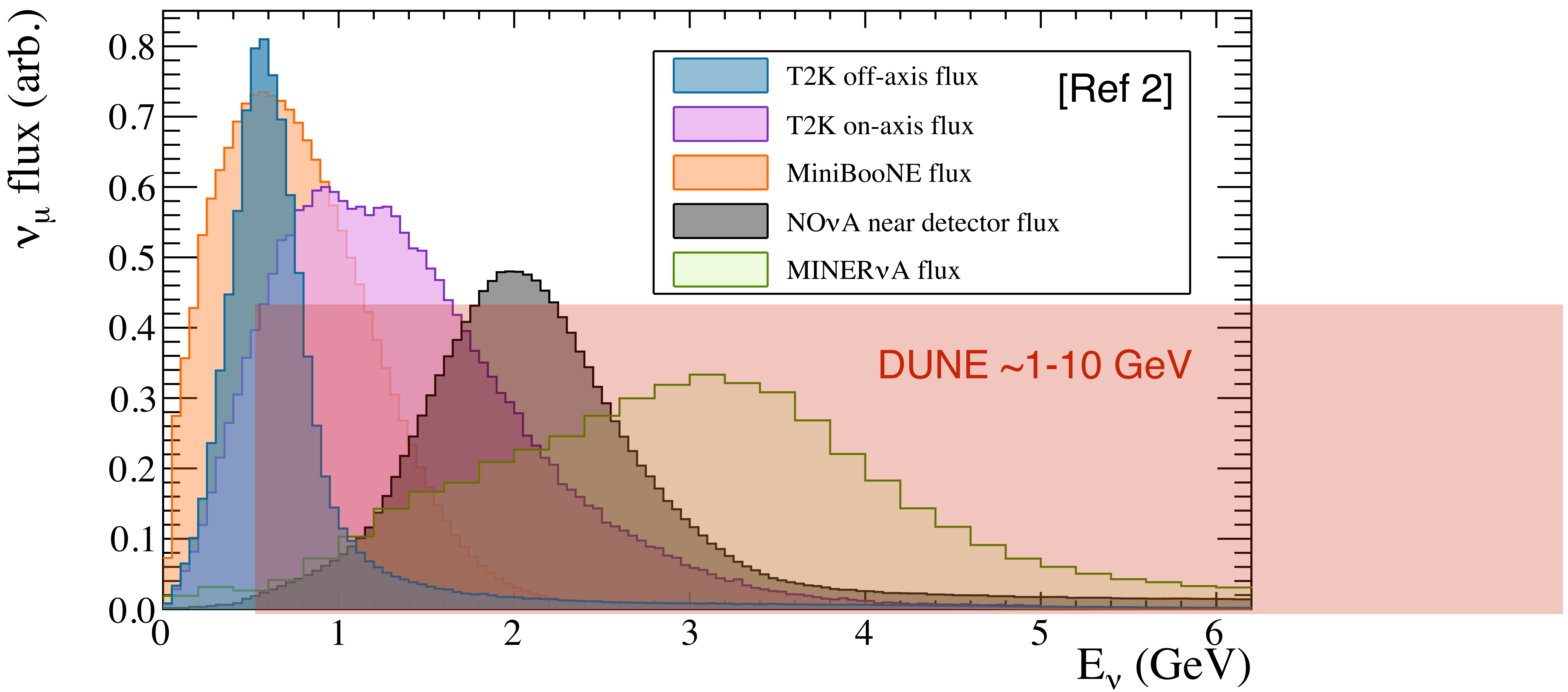


CCπ

coherent



Neutrino Sources and Nuclear Effects

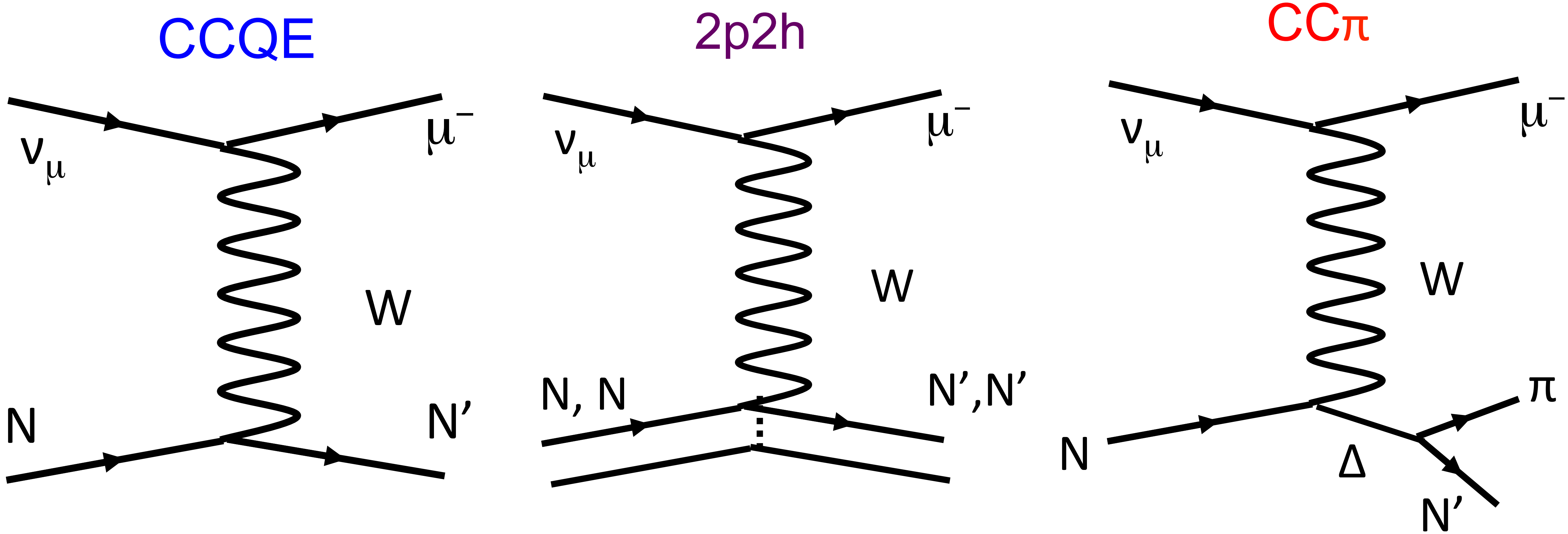


- Neutrino decay-in-flight beams are not mono-energetic
  - Spread of beam is larger than nuclear effects
  - Measurements are ``flux integrated''; difficult to get at true E_ν etc

Nuclear Effects Example

Multiple processes contribute to each observable topology

- CCQE-like observable topology: muon, proton, no pions
- Includes true CCQE, 2p2h, CC1π (pion absorbed in nucleus)



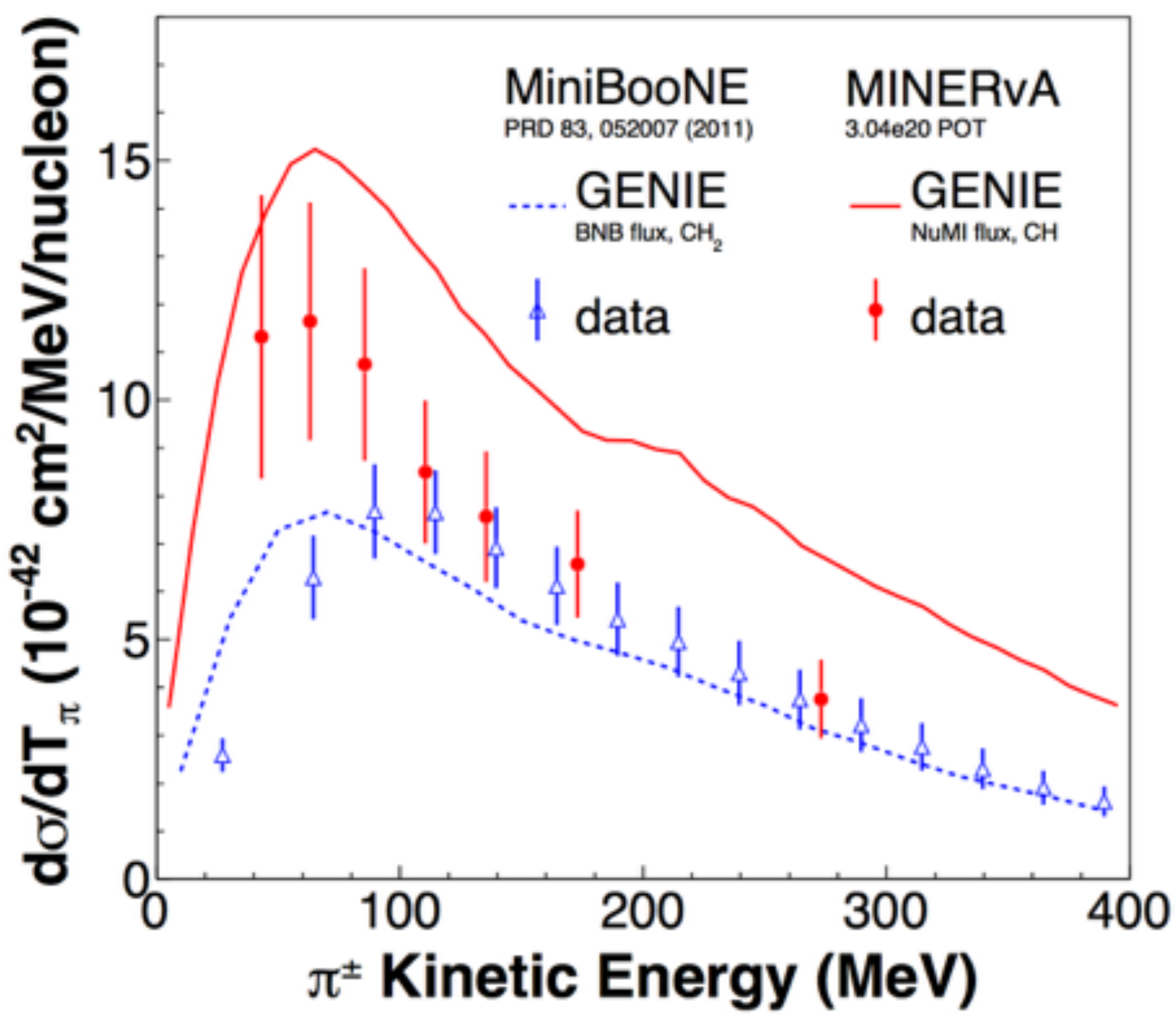
Data "Tensions" Workshop Idea

Inability to reconcile MiniBooNE, MINERvA QE-like, and single pion measurements within a single model

- Last PhyStat-v: [QE: PRD93 no.7, 072010 (2016)] and NuTUNE: https://indico.fnal.gov/conferenceDisplay.py?confId=11610]

Modern experiments, what's going on?

- **Signal definition? Selection? Extraction? Hidden model dependance, where?**
- Background subtraction? Control sample selection? Flux?
- Unfolding pathologies? Better data release materials? - Last PhyStat-v



MINERvA comparisons to MiniBooNE

[PRD92, 092008 (2015)]

TENSIONS 2016 Workshop Goals

What is the best way to understand CCQE+2p2h/MEC?

- Is there a good definition of CCQE-like that is unbiased across experiments? Is selecting CC, 0 pions in the final state best?

- Is it possible for high energy experiments (e.g. MINERvA) to produce data that is directly comparable with lower energy expts (e.g. MiniBooNE, T2K)?

- Is it possible to get agreement on signal definition between scintillator/TPC and Cerenkov experiments?

What is the best way to access the 1π physics? How do experimental specific acceptances and selections affect our interpretation?

Workshop Scope and Participants

Focus on subset of recent neutrino measurements + primary analysers

- MiniBooNE QE-like (2010 PRD), 1π (2011 PRD)
- MINERvA QE (2010 PRD), 1π (2015 PRD)
- T2K QE-like (2016 PRD), 1π (official result)

Pair above with simulation-only (no reconstruction) neutrino interaction simulation information + simulation, experiment experts

- Use fluxes which correspond to measurements made
- Can compare models unavailable to experiments at time of measurement
- Can compare model used by one experiment to one used on another

Incredible effort by participants on three collaborations, and dedicated neutrino interaction software experts

- Yoshinari Hayato, Libo Jiang, Gabe Perdue, R. Tyler Thorton, Jan Sobcyzk, J. Patrick Stowell, Luke Pickering, Callum Wilkinson, Clarence Wret (simulation samples)

- Minerba Betancourt, Sara Bolognesi, Andrew Furmanski, Joe Grange, Teppei Katori, Fnu Nuruzzaman, Nicholas Suarez, Rex Tayloe (QE samples)

- Raquel Castillo, Matt Dunkman, Brandon Eberly, Federico Sanchez, Ben Messerly, Mike Wilking (1pi samples)

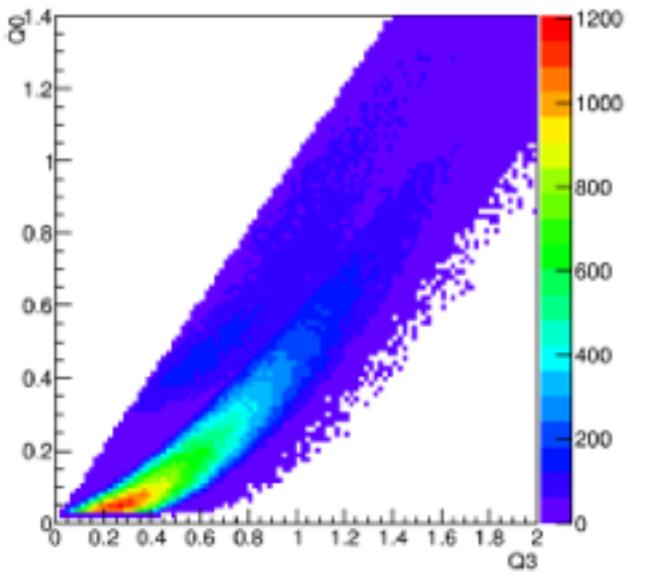
- Mark Hartz, Laura Fields (flux information)

- Steve Dytman, Kendall Mahn, Hiro Tanaka, Sam Zeller (organizers)

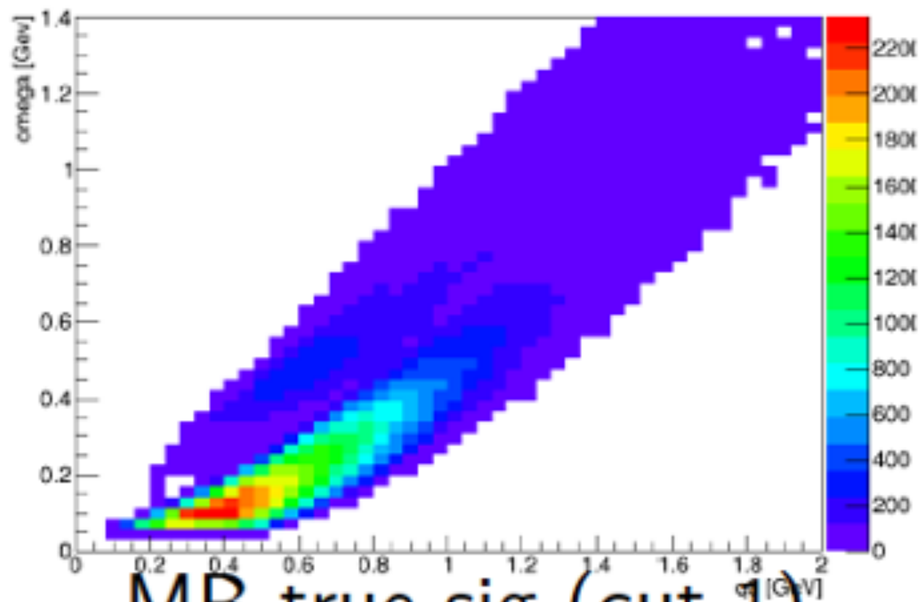
What follows are my (KM) personal conclusions

A summary document is in preparation and will be discussed with all relevant parties/collaborations

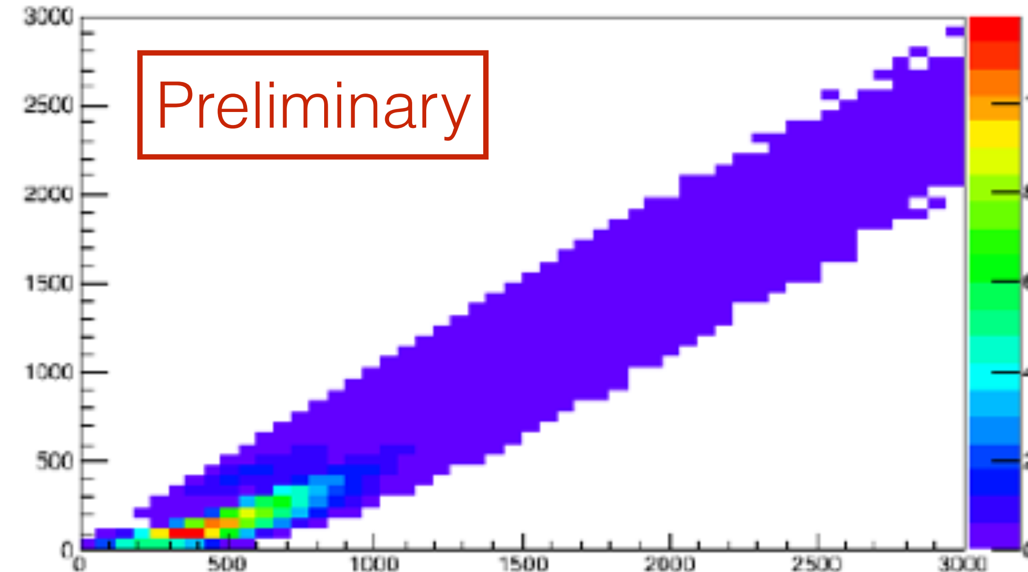
True phase space: CC0π topology



MINERνA true sig.

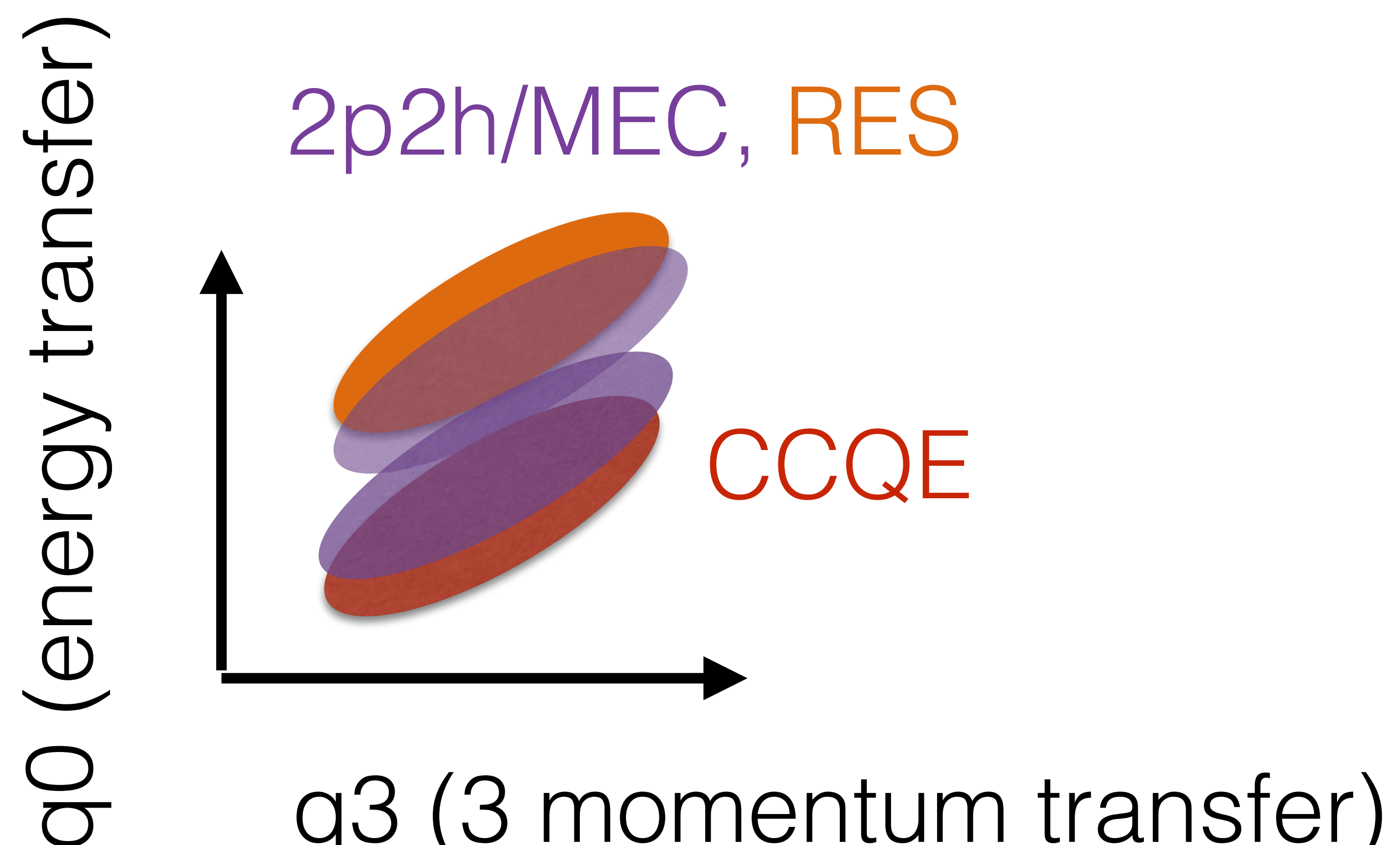


MB true sig (cut 1)



T2K true sig.

- For each simulation of the experiment for CC0π topology
- **All probe similar region prior to selection**



QE-like Signal, Background Definitions

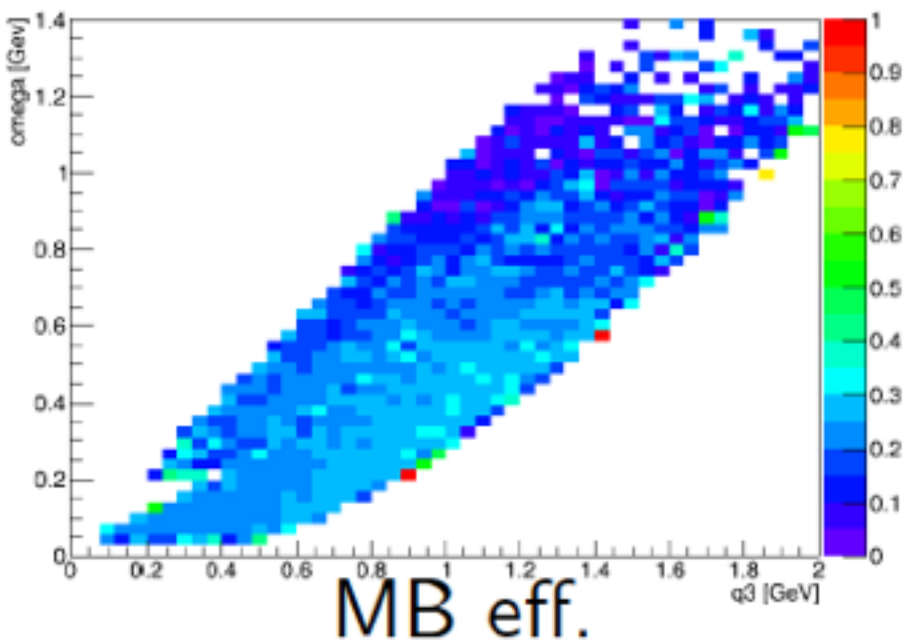
What signal definition is used by each experiment?

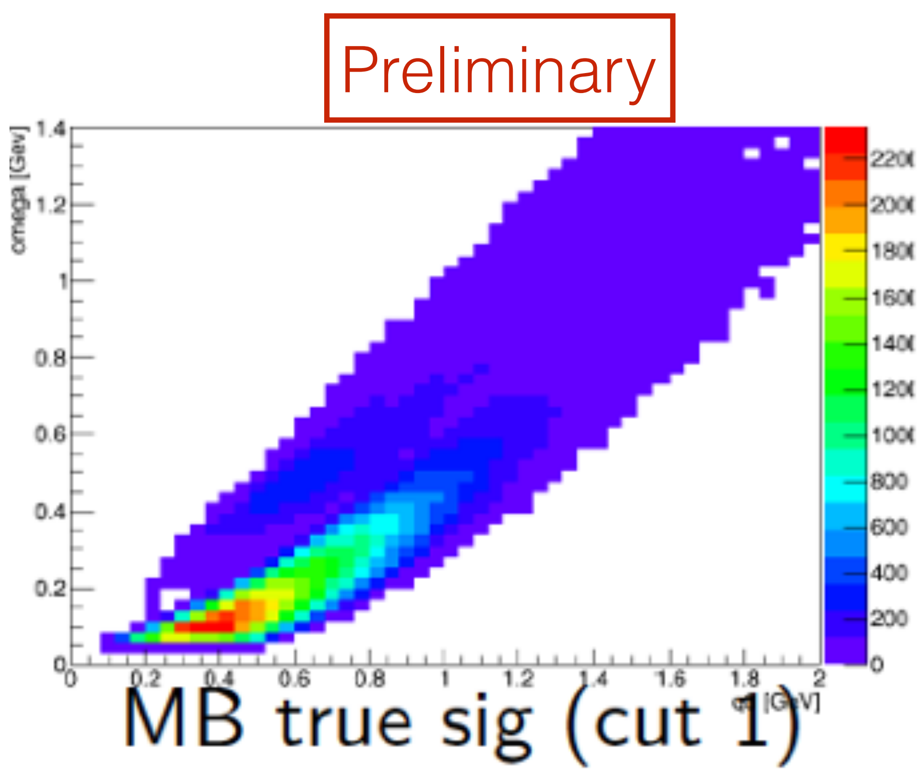
- MiniBooNE: CC0π and CCQE (NUANCE)
- MINERvA: CCQE* (GENIE) before FSI
- T2K: CC0π (NEUT)

Tensions: Different signal/background definitions

- * MINERvA separated RES from QE/2p2h/MEC as these events had a very different efficiency
- No 2p2h model at that time, assumed similar efficiency to QE (MiniBooNE, MINERvA)
- ***Separation does matter on experiment, but hard to interpret later***

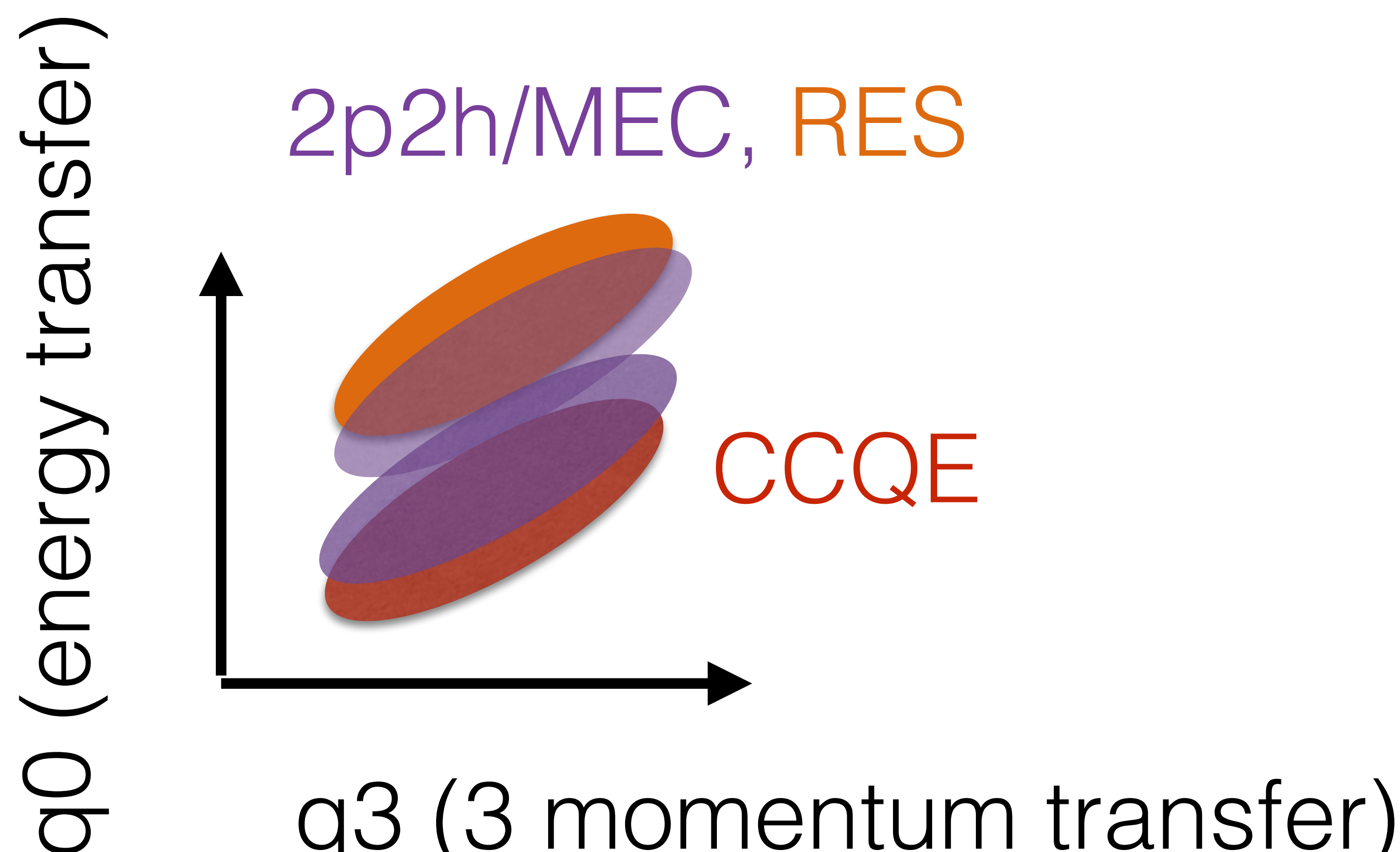
What is the effect of efficiency/acceptance?





What is the effect on signal CC0π?

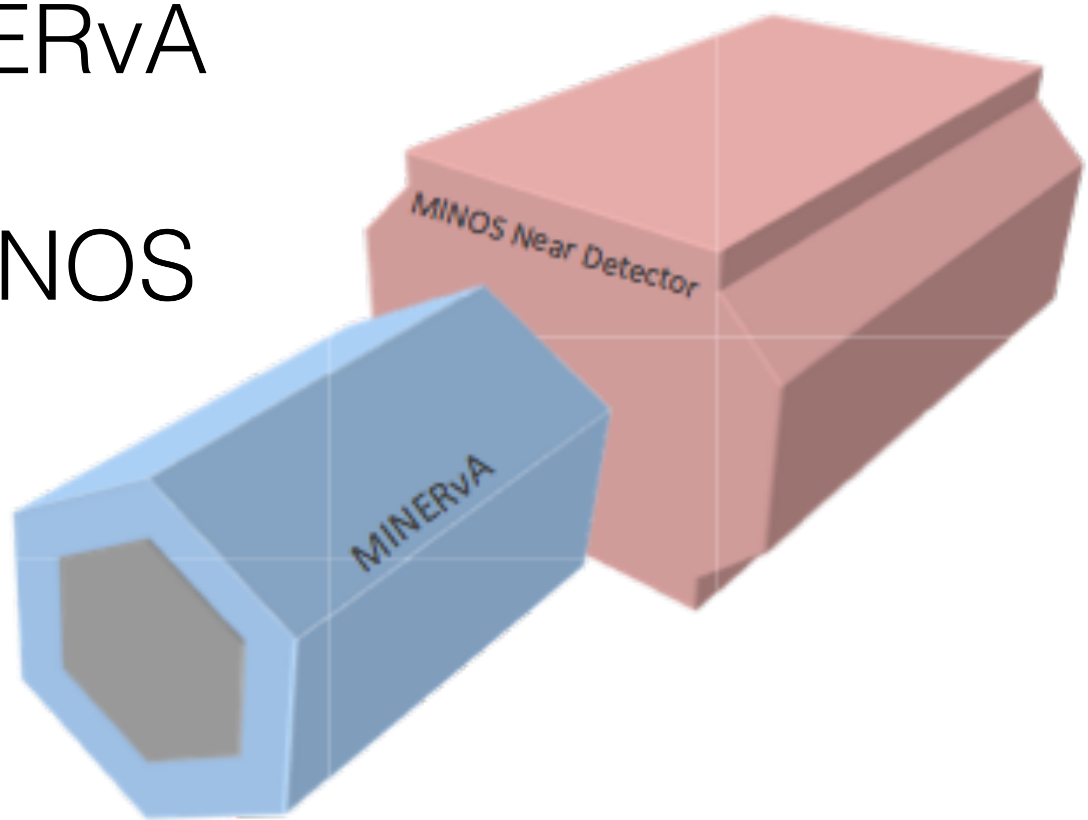
- MiniBooNE efficiency quite flat
- Later: efficiency with alternate models overlaid



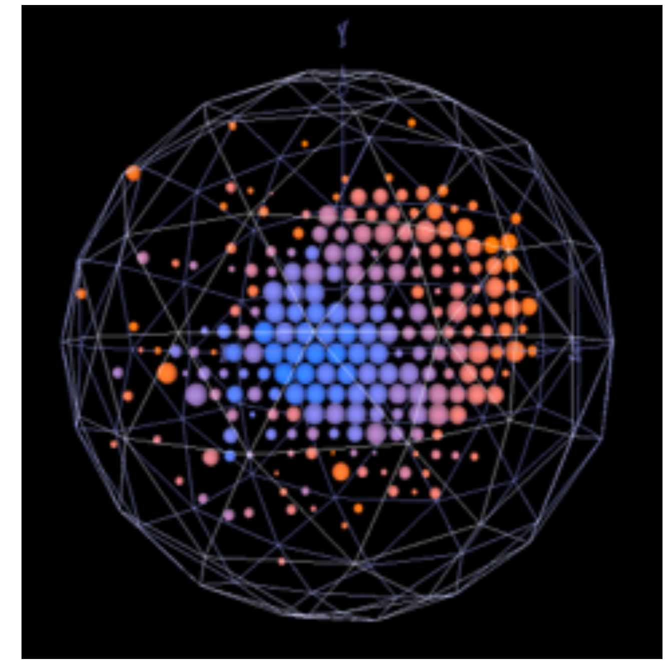
Tensions: Acceptance

MINERvA

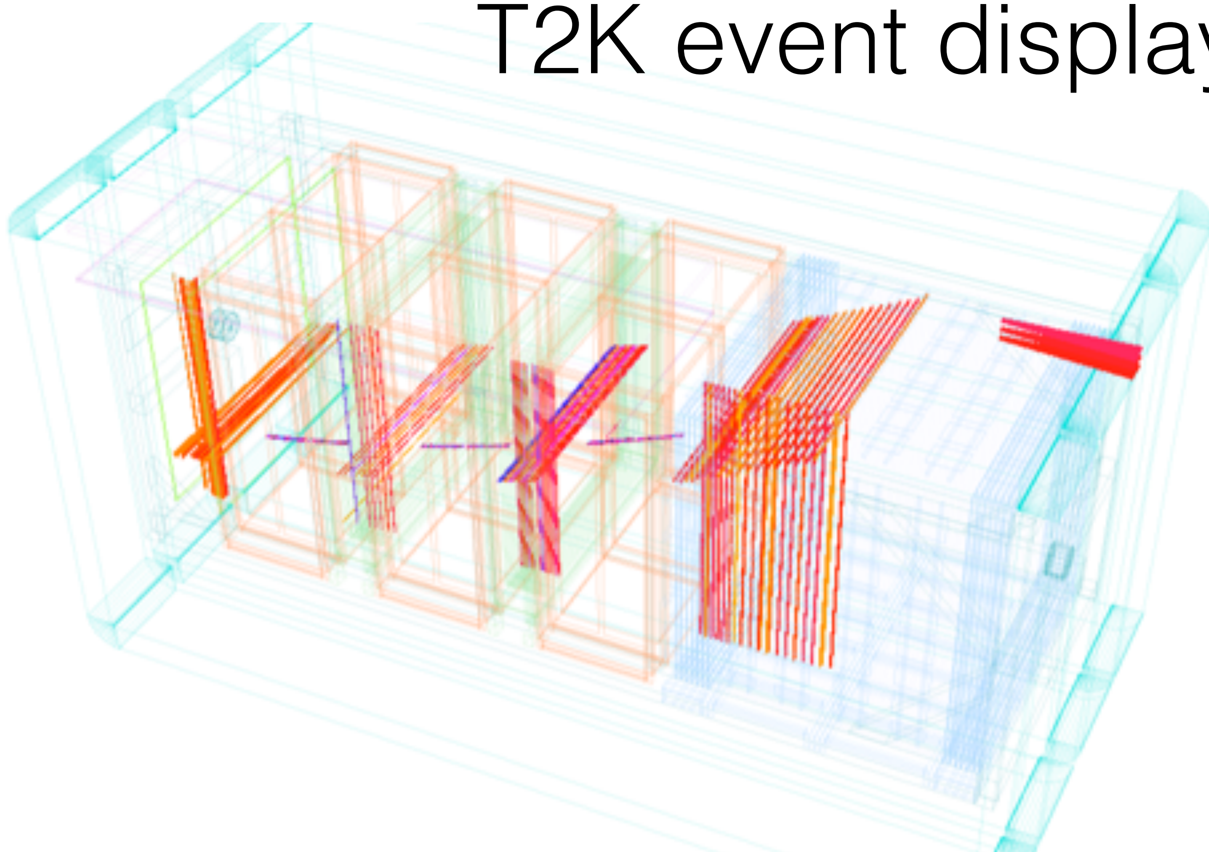
+ MINOS



MiniBooNE muon

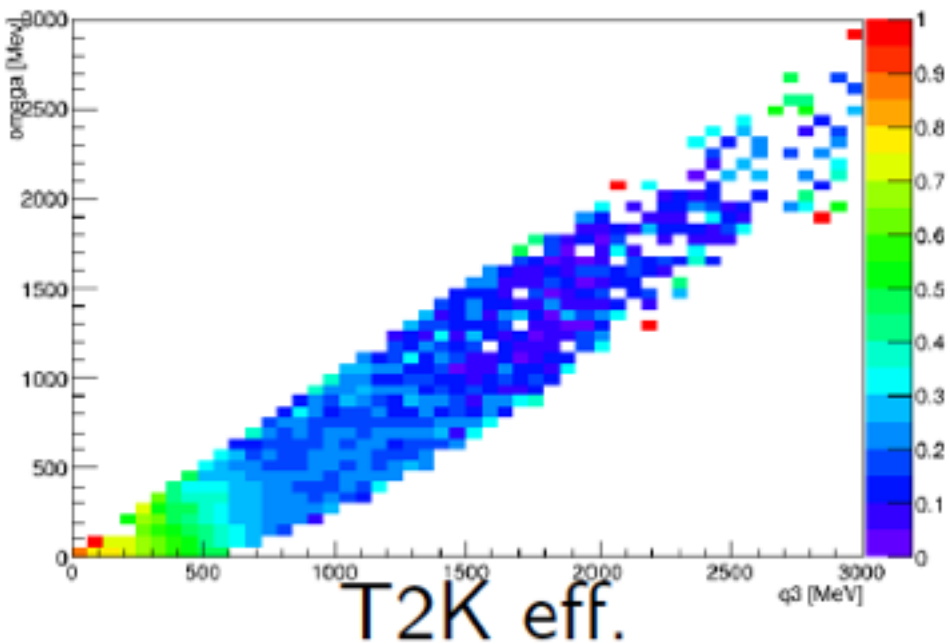


T2K event display

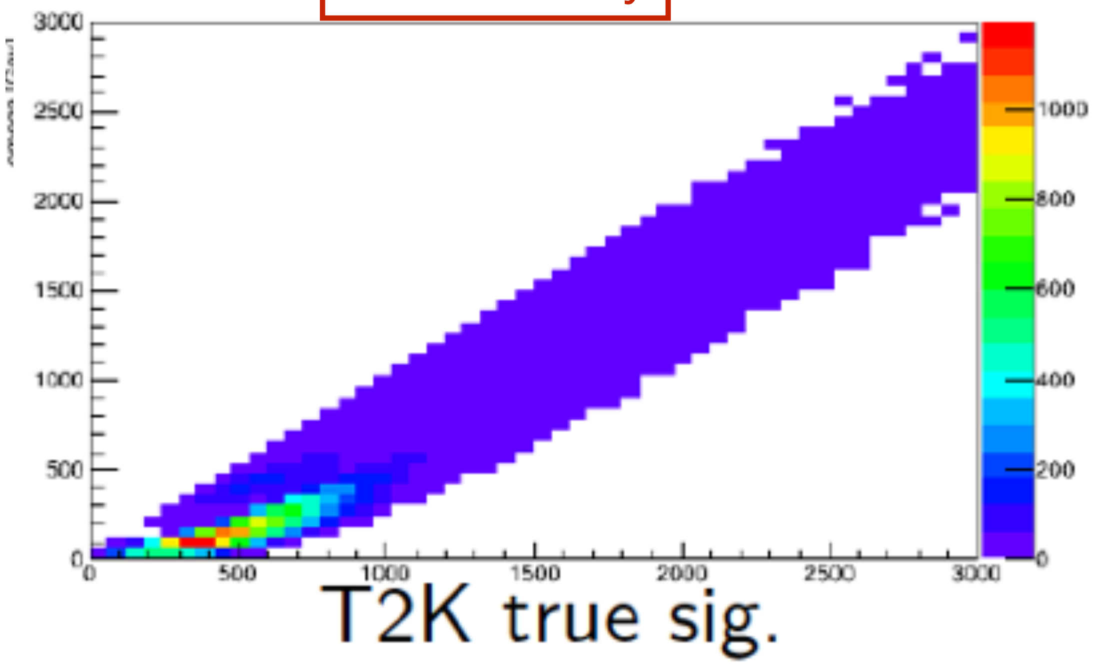


- Acceptance determined mostly by geometry, detector method
- ***Solution? state acceptance in terms of final state particle kinematics***

Tensions: Detector efficiency



Preliminary

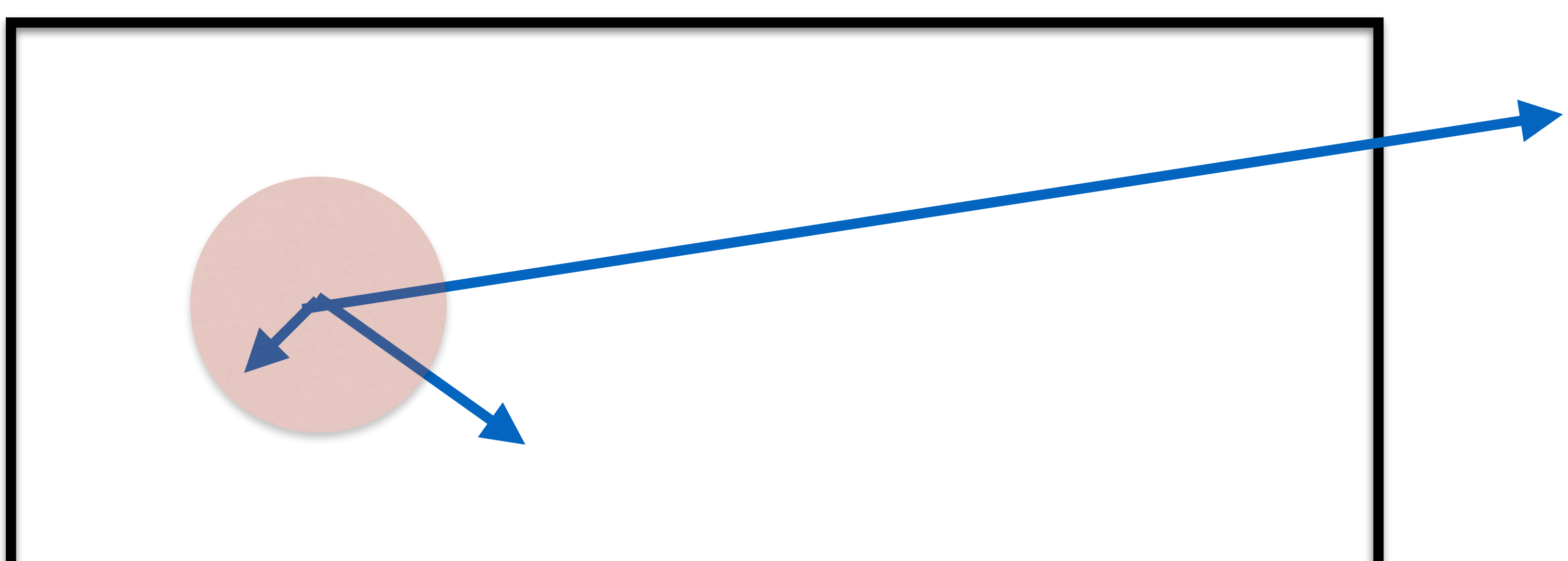


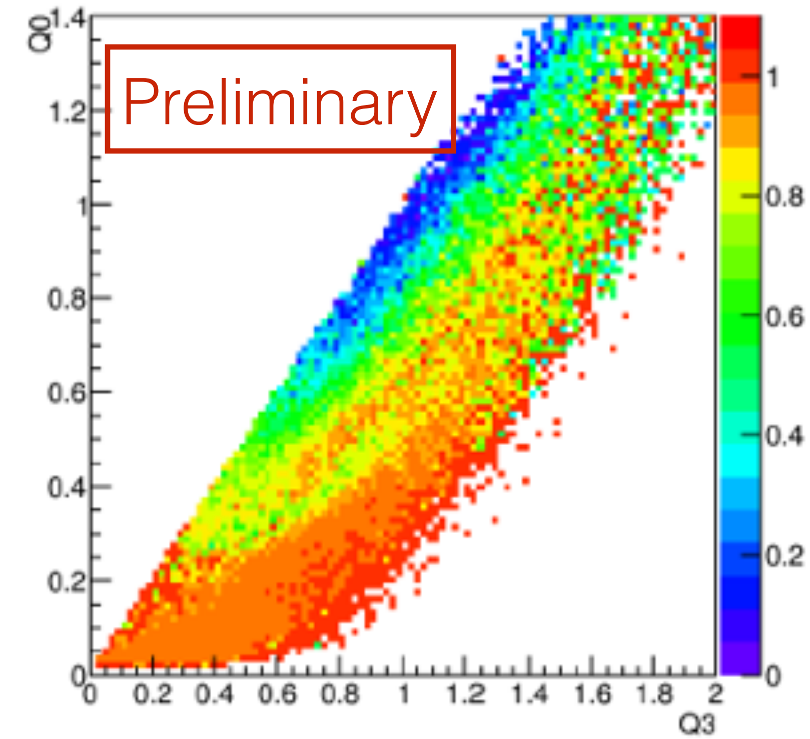
- T2K uses different CCQE-like subsamples, with different efficiencies
  - Easier to select forward tracks than backward or high angle
- Experiments provide efficiency in data release and state regions of high efficiency
- **Caution: Efficiency coupled to signal model. (See next page as well)**

Tensions: Selection Choices

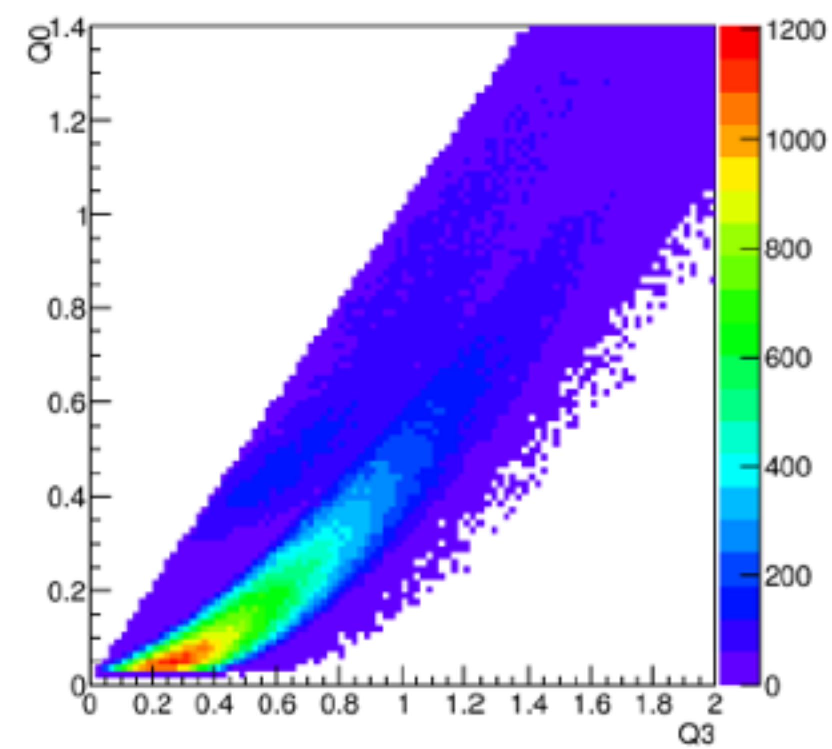
Attempt to reduce sensitivity of analysis to 2p2h models

- Calculate energy deposit outside a region around the vertex
- But, this cut sculpts on q0-q3 for both CCQE, 2p2h signal interactions
- ***Efficiency coupled to signal model. Covered by model systematic uncertainties?***





Eff. w.r.t. previous (CC0π)



Total simulated

Tensions: model and efficiency coupling

- Efficiency is calculated from MC, which is a combination of particles in space (from the interaction simulation) and detector response
- Sensitivity to simulation phase space? **Is this large?**
  - Extreme case: model predicts no forward interactions. Is the efficiency 0 there or not?
- **Solutions?**
  - Model systematic uncertainties— limits to including future nonexistent models?
  - Data driven methods possible (e.g. cosmic rays)
  - Particle gun studies (challenge with phase space for *all* particles?)

1π-like Signal, Background Definitions

What signal definition is used by each experiment?

- MiniBooNE: CC1 muon, 1 π^+ exiting nucleus
- MINERvA: CC1$\pi^{+/-}$. any number of π^0.
- T2K: CC1 muon, 1 π^+ exiting nucleus

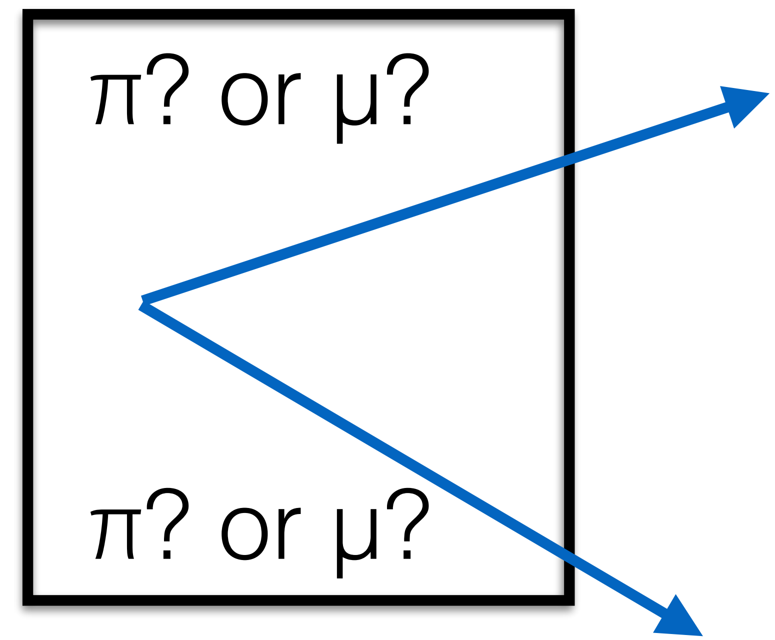
Tensions: Accidental agreement of samples, hidden model dependance?

- On MINERvA, it is similar to an inclusive selection, but then there's a cut in W which removes much of the π^0.
- Also use of true invariant mass (W) vs reconstructed W in selection cuts/ signal definition.
- ***May not want to enforce measuring "same" process?***

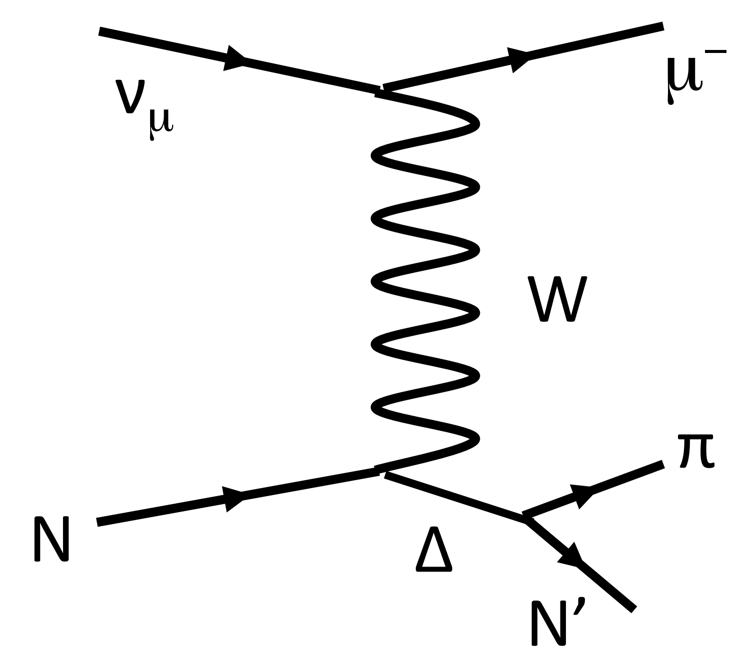
Tensions: Migration of background and signal

- Signal: CC1 muon, 1 π^+ exiting nucleus
- Detector imperfect: muon is correctly identified but the pion is not
- T2K treats these as background to remove them from the matrix which relates true - reconstructed muon variables.
- ***How do we handle (detector) backgrounds which are actually (cross section) signal events?***

Not remotely correct diagram



CCπ



(Personal) Summary

TENSIONS2016 workshop: exciting connection between cross section fits and measurements!

- What do we want to measure? How will it be used by us and others?
- Is there a unified approach to signal or background subdivisions?
  - Different detectors have different efficiencies to different topologies
  - What's background and what's signal (MisID muon/pions)
- How do we treat cross section model uncertainties which enter via rapidly changing efficiencies? By each experiment or?
  - Study with particle guns? Data driven? But always some will remain

Backup slides

Ongoing work

Preparation of a document for collaborations, community to summarize what was learned. In addition, complete following studies:

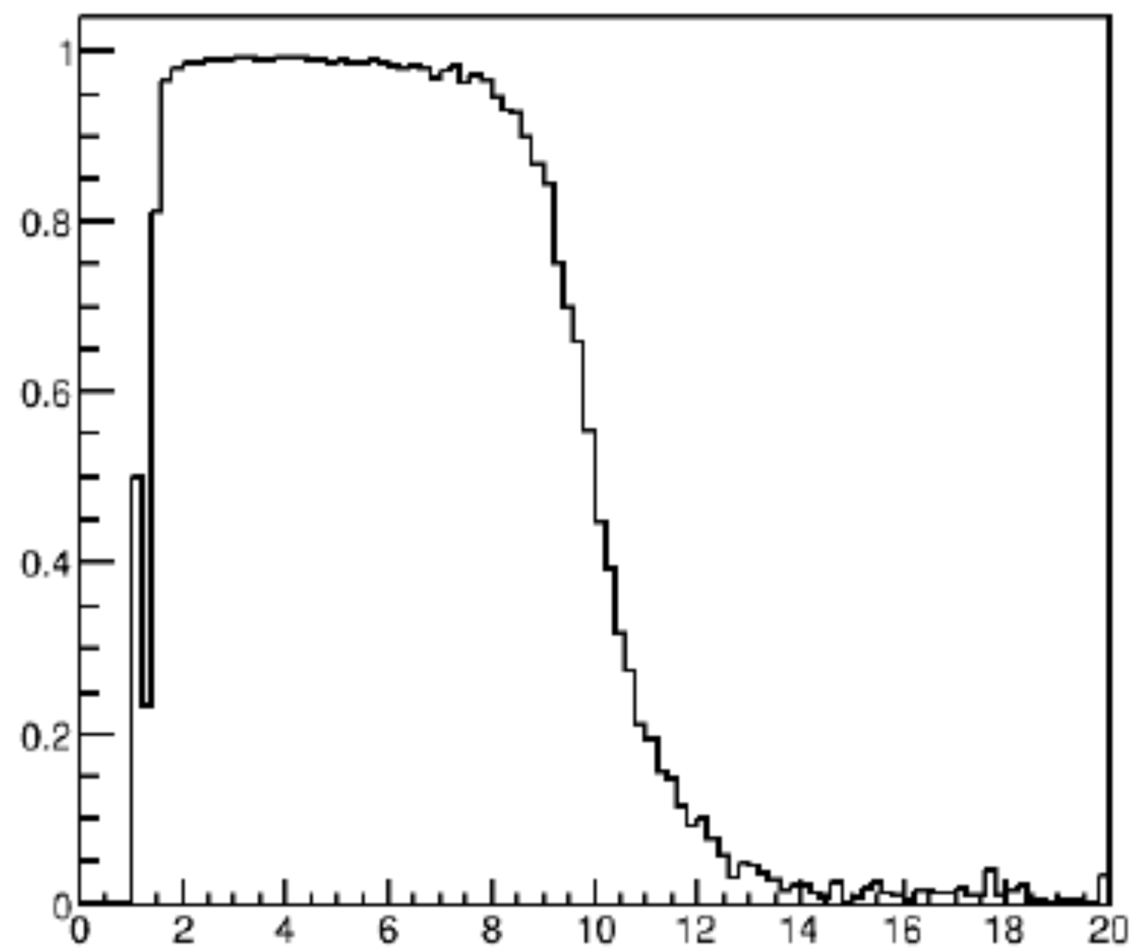
- Compare generators (especially GiBUU and NUANCE). Where are signal and background predictions markedly different for each experiment?
- Combining efficiency and models, do we see regions where experiments are especially susceptible to model differences?
- Are there regions where all models may be relying on assumptions not tested by experiments?
- Comparison of backgrounds, background treatment in control samples

Experiment info: “Tagged samples”

In advance of the workshop, special MC samples were prepared

- Example: T2K CC0π: highland files with flags for each of the cuts for signal, control samples
  - Can reproduce efficiencies, but includes additional generator information (and signal, background information)
  - Details in presentation to XSEC: http://www.t2k.org/nd280/physics/xsec/meetings/2016/may11/cc0piPublicForWS/view
- Limitations/concerns: Size can be an issue, long term hosting challenges need to be revisited.

MINERvA signal definition as a cut



Eff. after all cuts

Signal definition included 1.5 < Ereco < 10 GeV

- But significant smearing between Etrue-Ereco
- **Best to just cut on muon momentum for upper threshold**

Generator files: “Raw samples”

In advance of the workshop, special MC samples were prepared

- Used multiple configurations of NEUT, GENIE, NuWro + NUANCE, GiBUU
- Included what experiments used and modern/updated models
  - Example: T2K, MINERvA fluxes with NUANCE (MiniBooNE) or MiniBooNE with GENIE
- Limitations/Issues: Space to host the files and generate comparisons.
  - Comparisons ongoing, so far consistent with what has been done within the NIWG