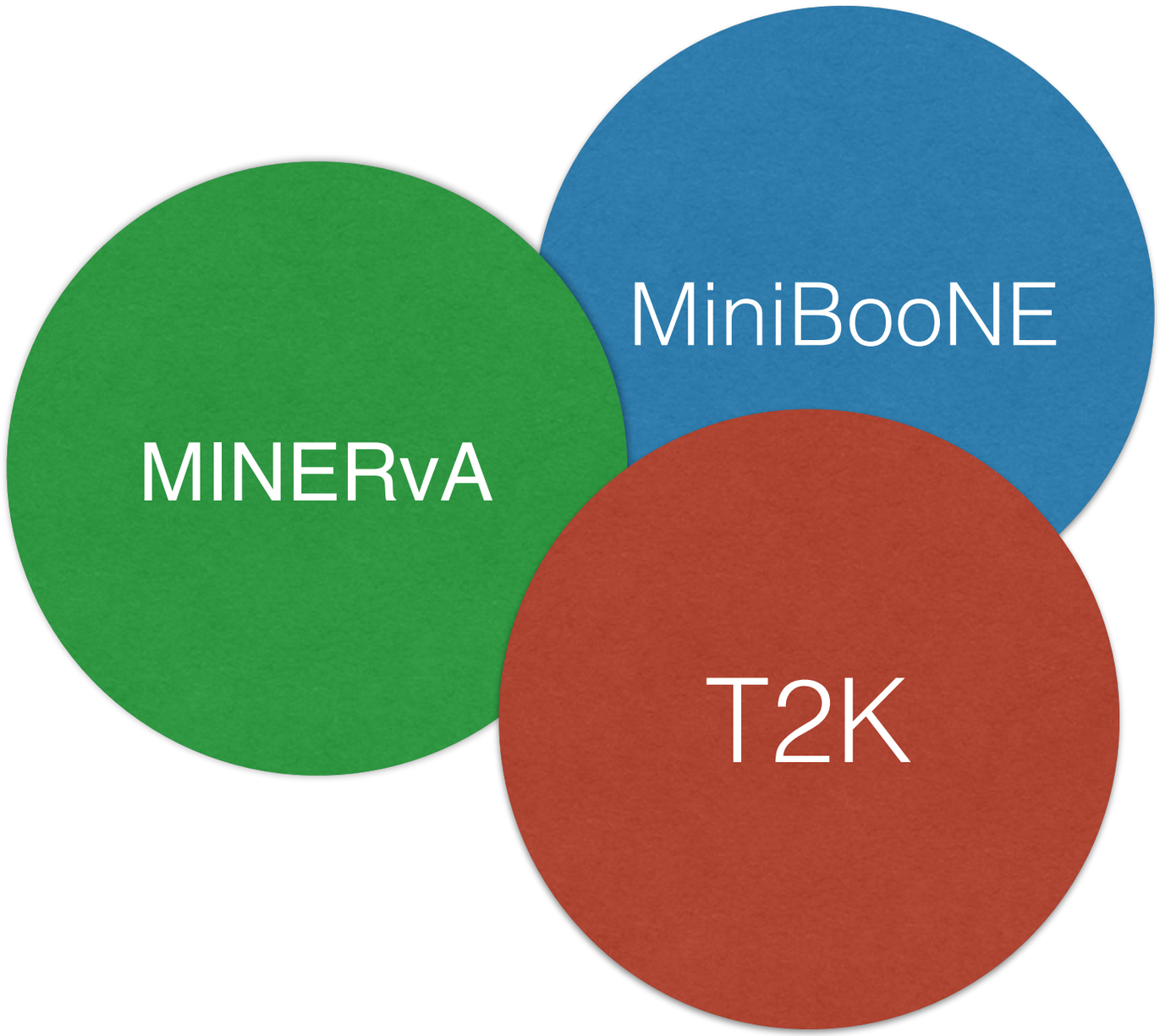
“TENSIONS2016”: QE results



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Michigan State University

“TENSIONS2016” Workshop Idea

Difficulty in reconciling MiniBooNE, MINERvA QE-like, and single pion measurements within a single model (“data tensions”)

- All same “target” (CH or CH2) and same processes (CCQE-like, CC single pion)

- T2K Neutrino Interactions Working Group [QE: PRD93 no.7, 072010 (2016)] Difficulty fitting a QE model to available data, MiniBooNE and MINERvA preferred different model combinations.

What’s going on?

- **Same underlying process?**

- **Signal definition?**

- **Hidden model dependance?**

- Poor choice of models? Incomplete information for fit?

- Background subtraction? Control sample selection? Flux?

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 Cudd, 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

Experimental Information: “Tagged samples”

Focused on a subset of recent results:

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

In advance of the workshop, special supplemental information was prepared

Includes additional generator-level or reconstruction-level information:

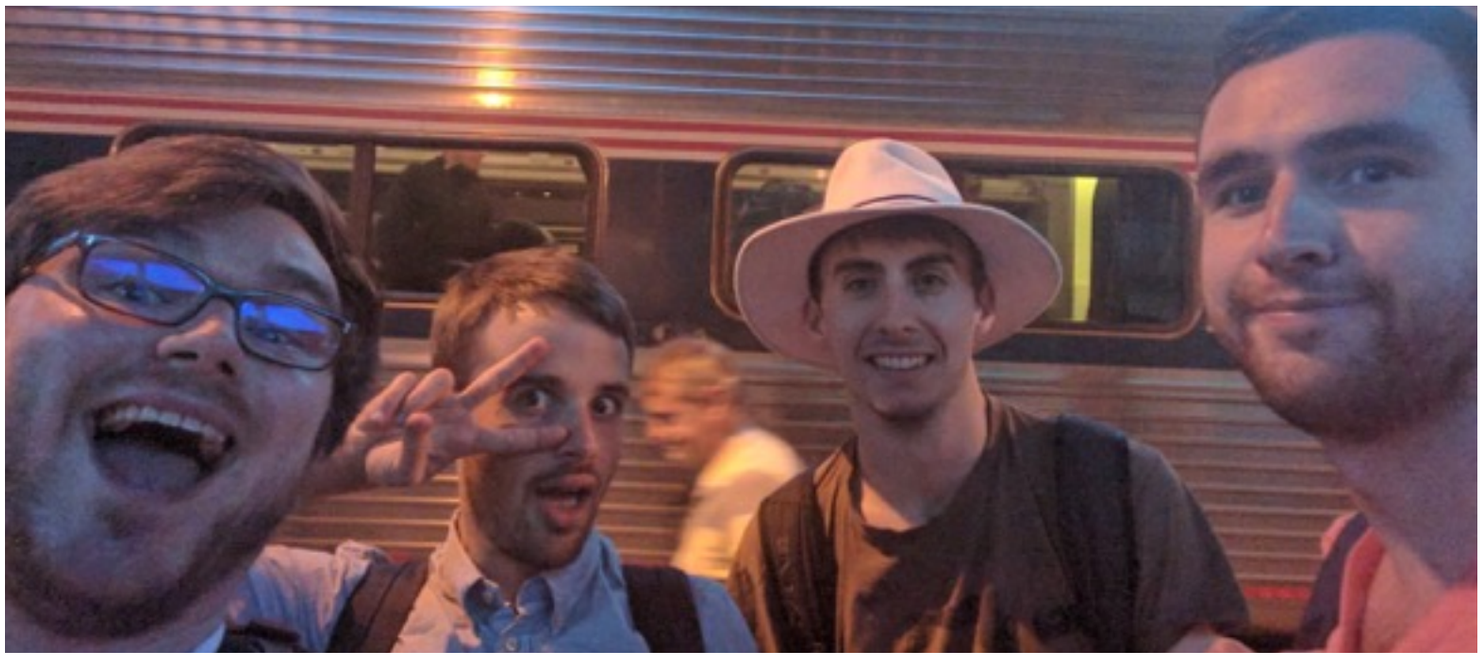
  - Reproduce efficiency of selection for signal, background in any (true or select detector-level) variables
  - Information from alternate generators if exist (T2K)

- Common list of material requested, prepared and approved by collaborations

Generator-Model information: “Raw samples”

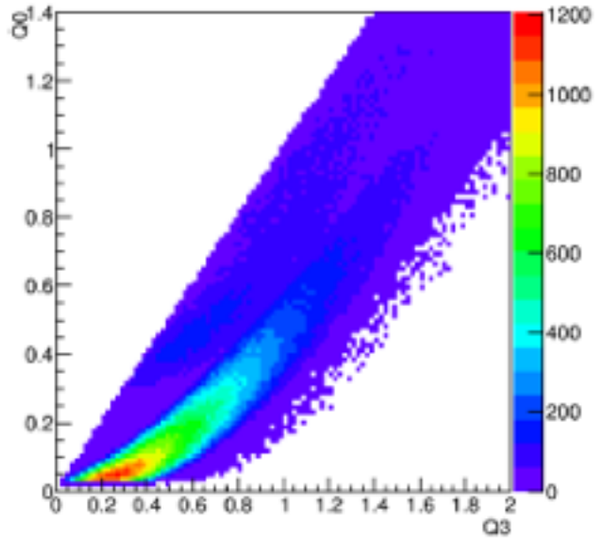
In advance of the workshop, special MC samples were prepared

- Used multiple configurations of NEUT, GENIE, NuWro + NUANCE, GiBUU — coordinated through **NUISANCE** framework

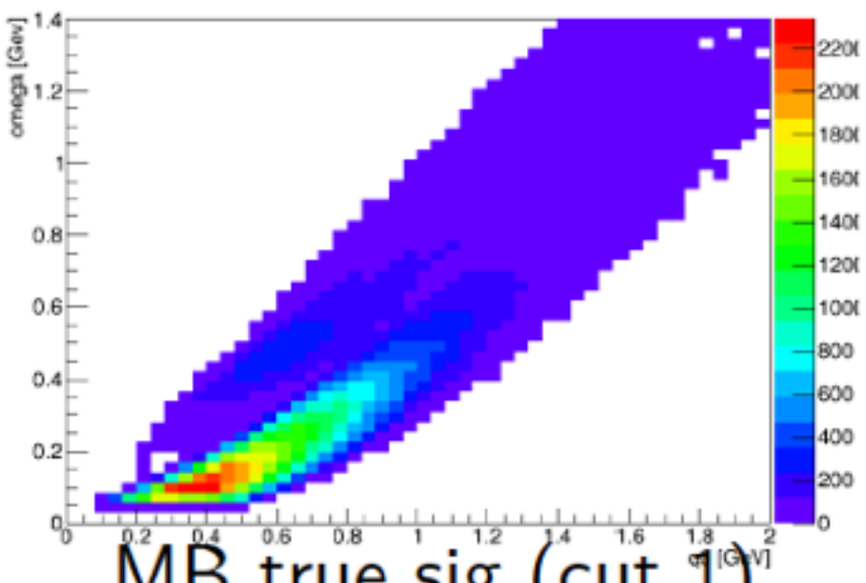


- Included models used for experimental results and updated models:
  - Example: Generate T2K flux with MINERvA’s GENIE version
  - Example: Generate MiniBooNE flux with GiBUU

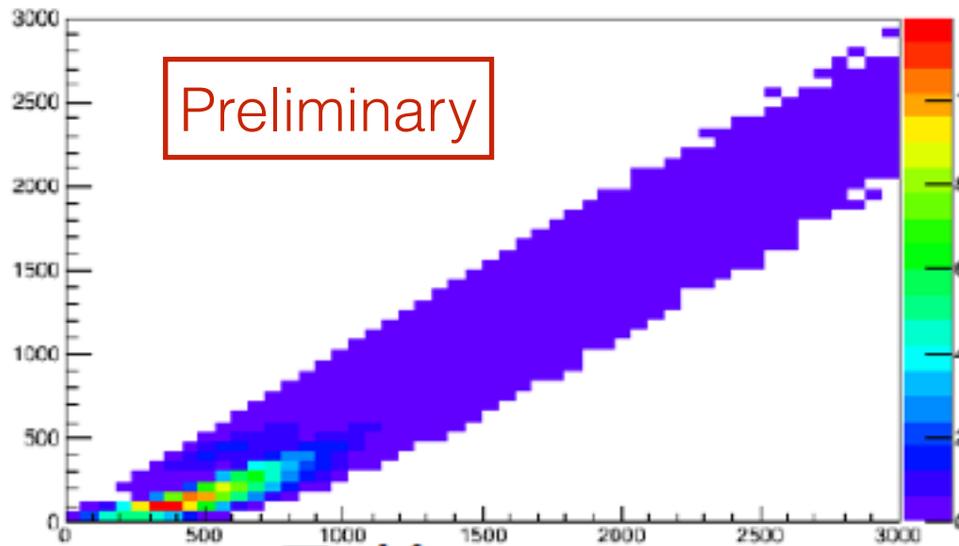
Are we measuring the same underlying process?



MINERνA true sig.

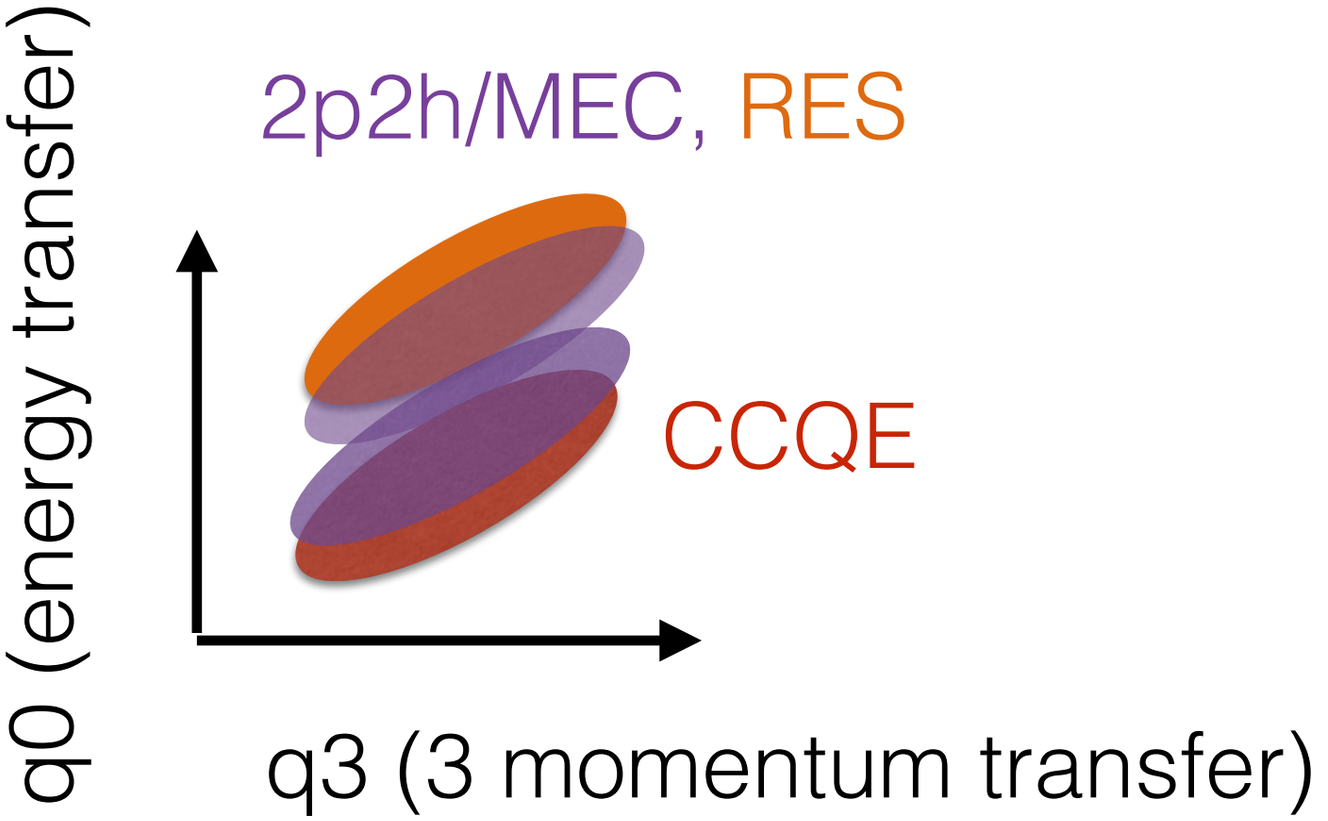


MB true sig (cut 1)



T2K true sig.

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



What is the signal definition?

What signal definition is used by each experiment?

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

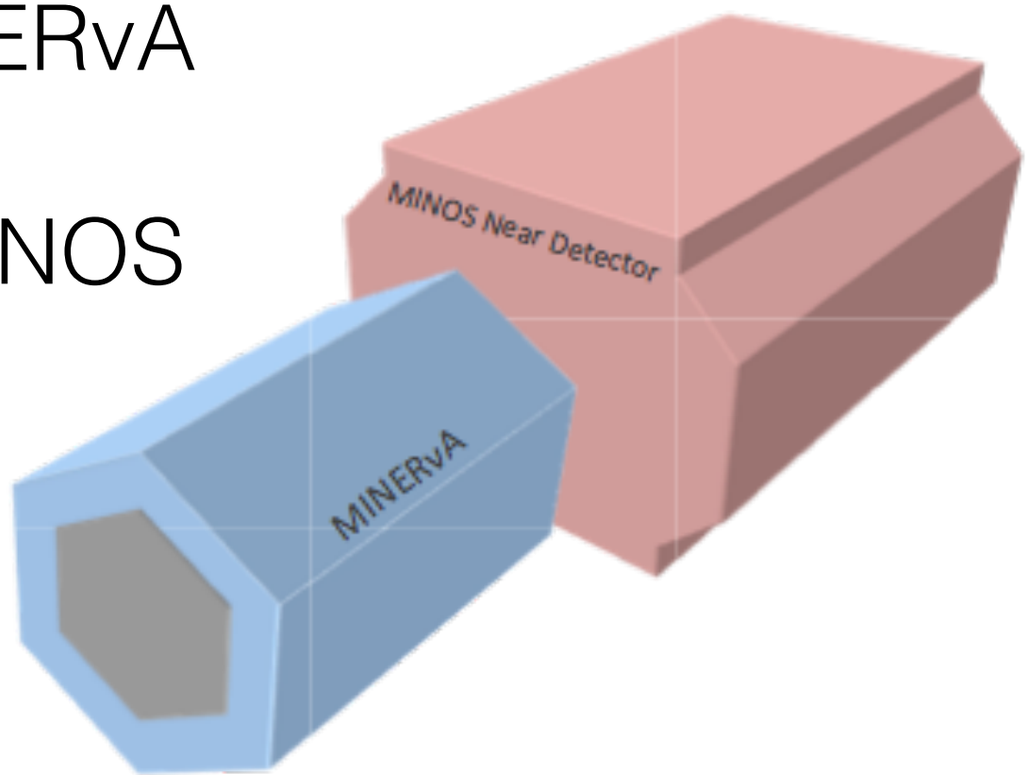
Tensions: Different signal/background definitions

- MINERvA separated RES from QE/2p2h/MEC as these events had a very different efficiency
- **Separation chosen based on experiment's capabilities and not necessarily easy to unify. But, this complicates comparisons.**

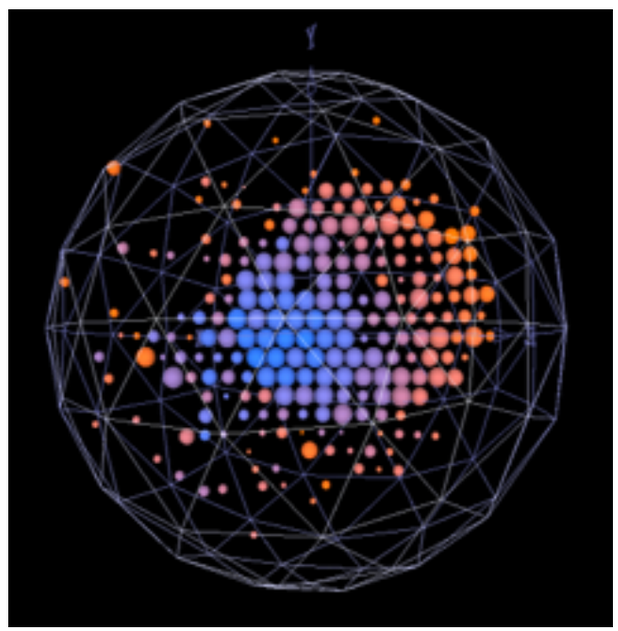
**Before FSI. No 2p2h model at that time, assumed similar efficiency to QE (MiniBooNE, MINERvA)*

MINERvA

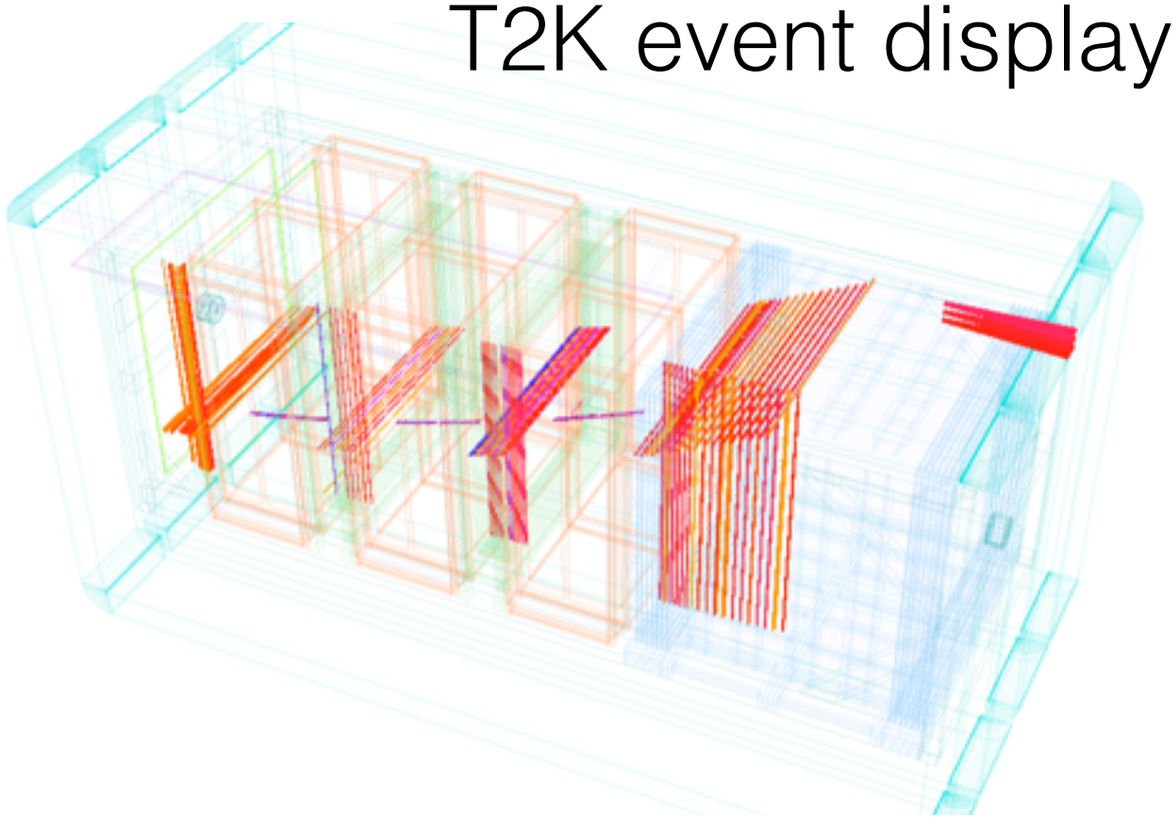
+ MINOS



MiniBooNE muon

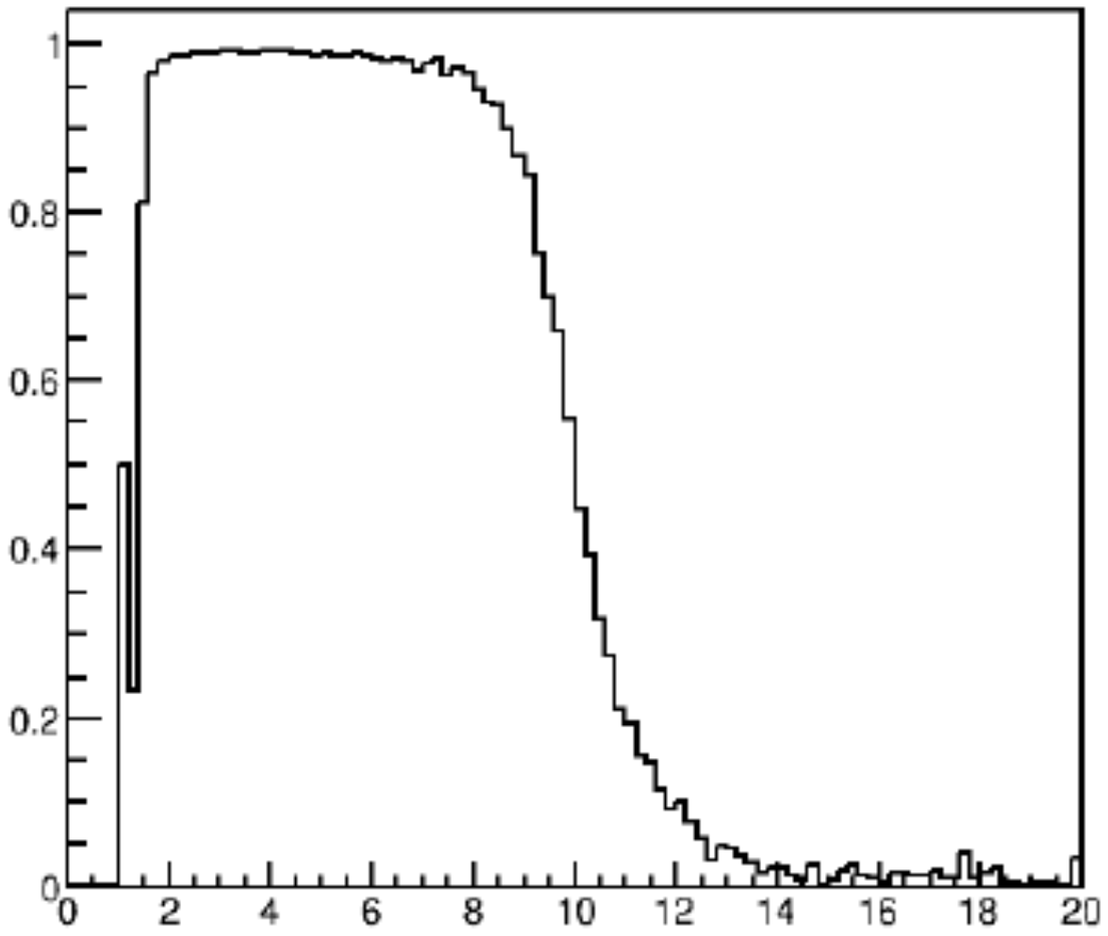


T2K event display



- **Acceptance** determined mostly by geometry, detector method
- Example: muon momentum greater than 350 MeV
- Example: Track angle (relative to the beam) is less than 20 degrees

Model dependence? Acceptance



Eff. after all cuts

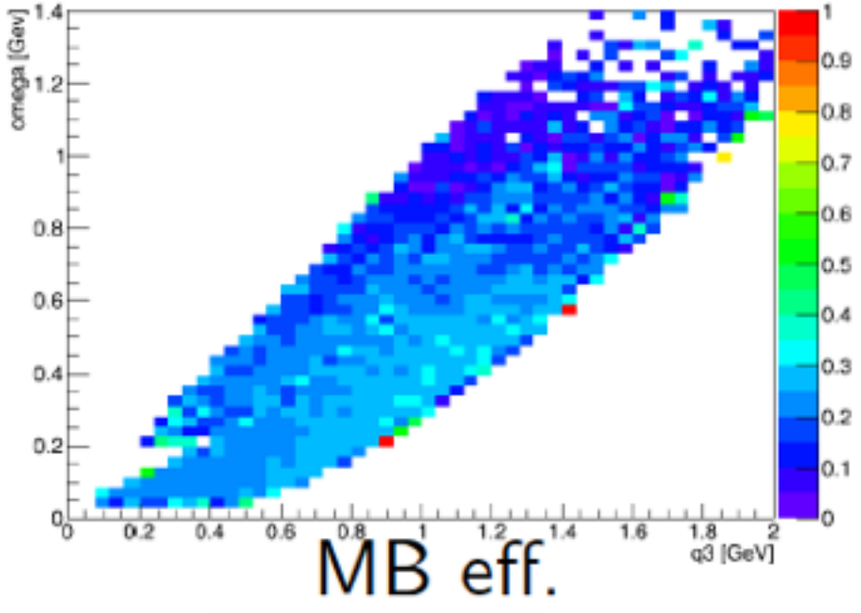
Example: MINERvA Signal definition included
1.5 < Ereco < 10 GeV

- But significant smearing between Etrue-Ereco

Solution?

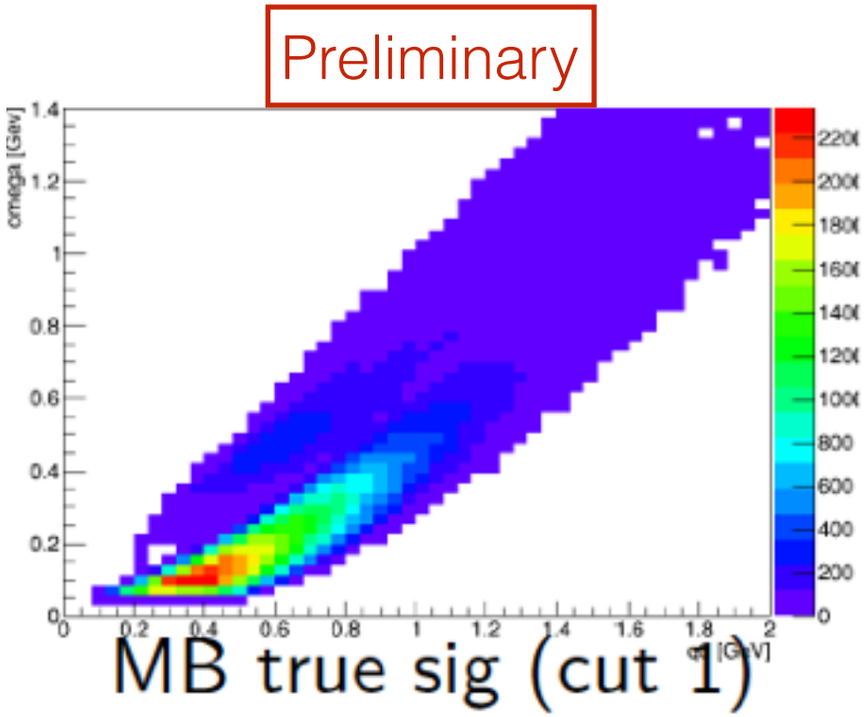
- State acceptance in terms of particle kinematics
- Note: Most experiments are moving this way

Model dependence? Efficiency, MiniBooNE



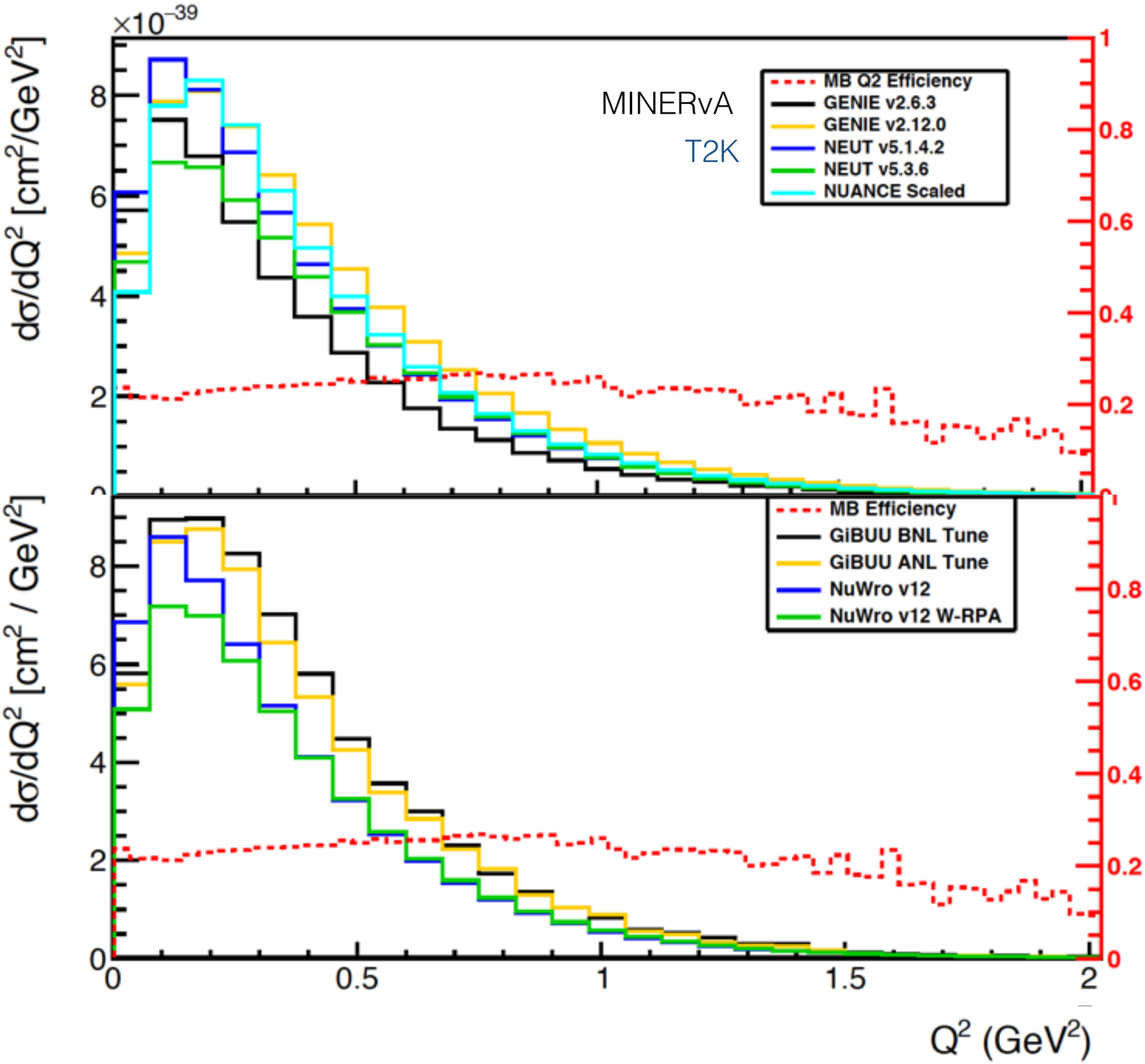
MiniBooNE: signal CC0π

- **Note: efficiency calculated relative to whatever low-level selection was easy for experiment**

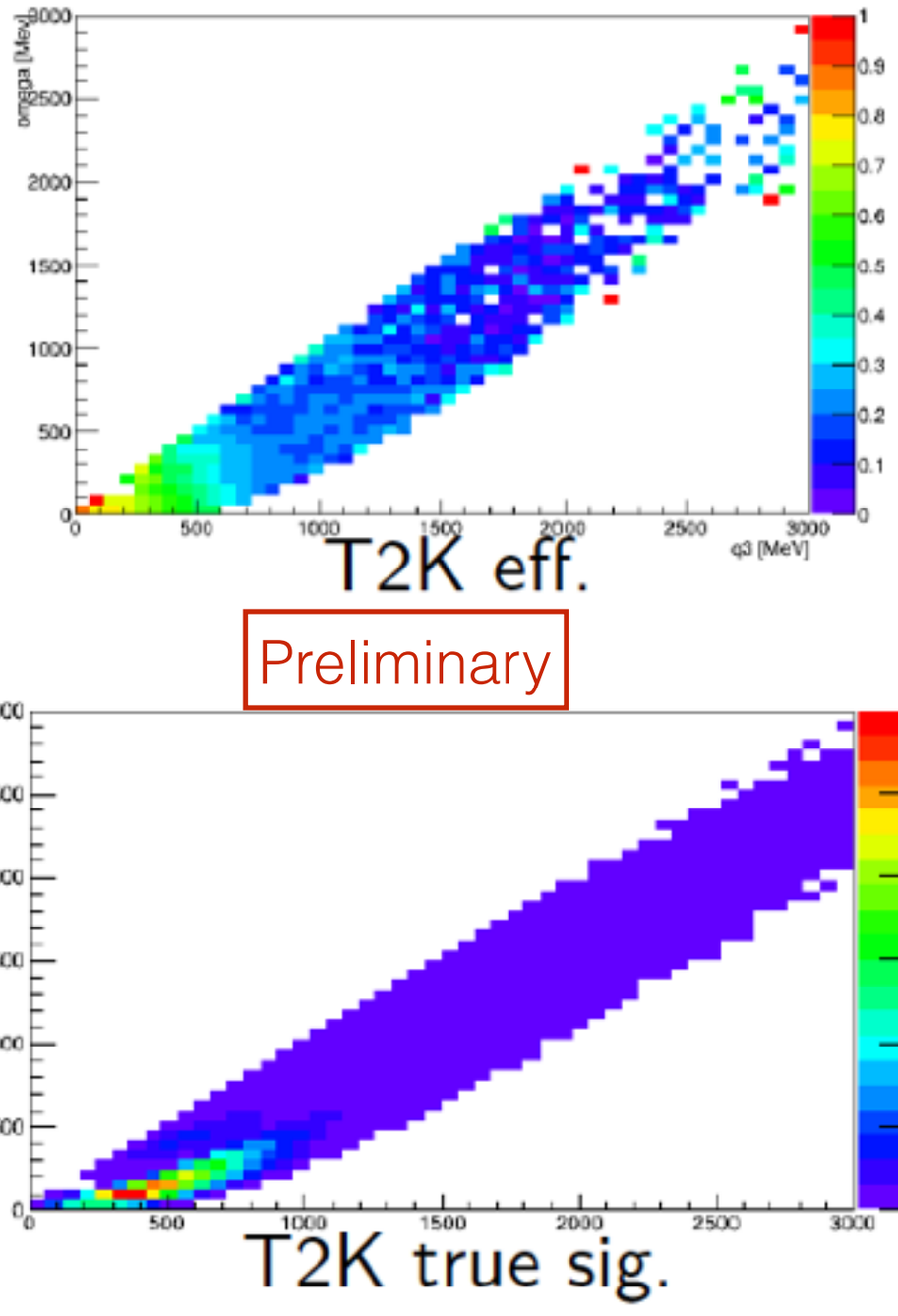


- Efficiency quite flat in q0-q3, Q^2
- Accepts all momentum and angle (except lowest muon KE, see later data plots)
- Limited predominantly from geometry (range)

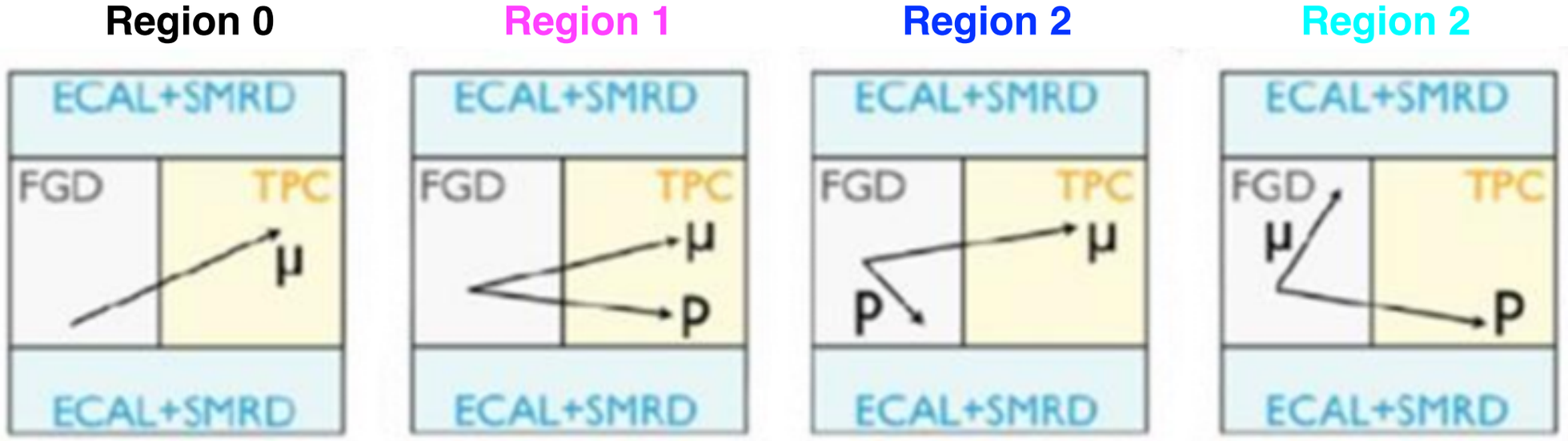
CC0π Model & MiniBoone Efficiency in Q^2

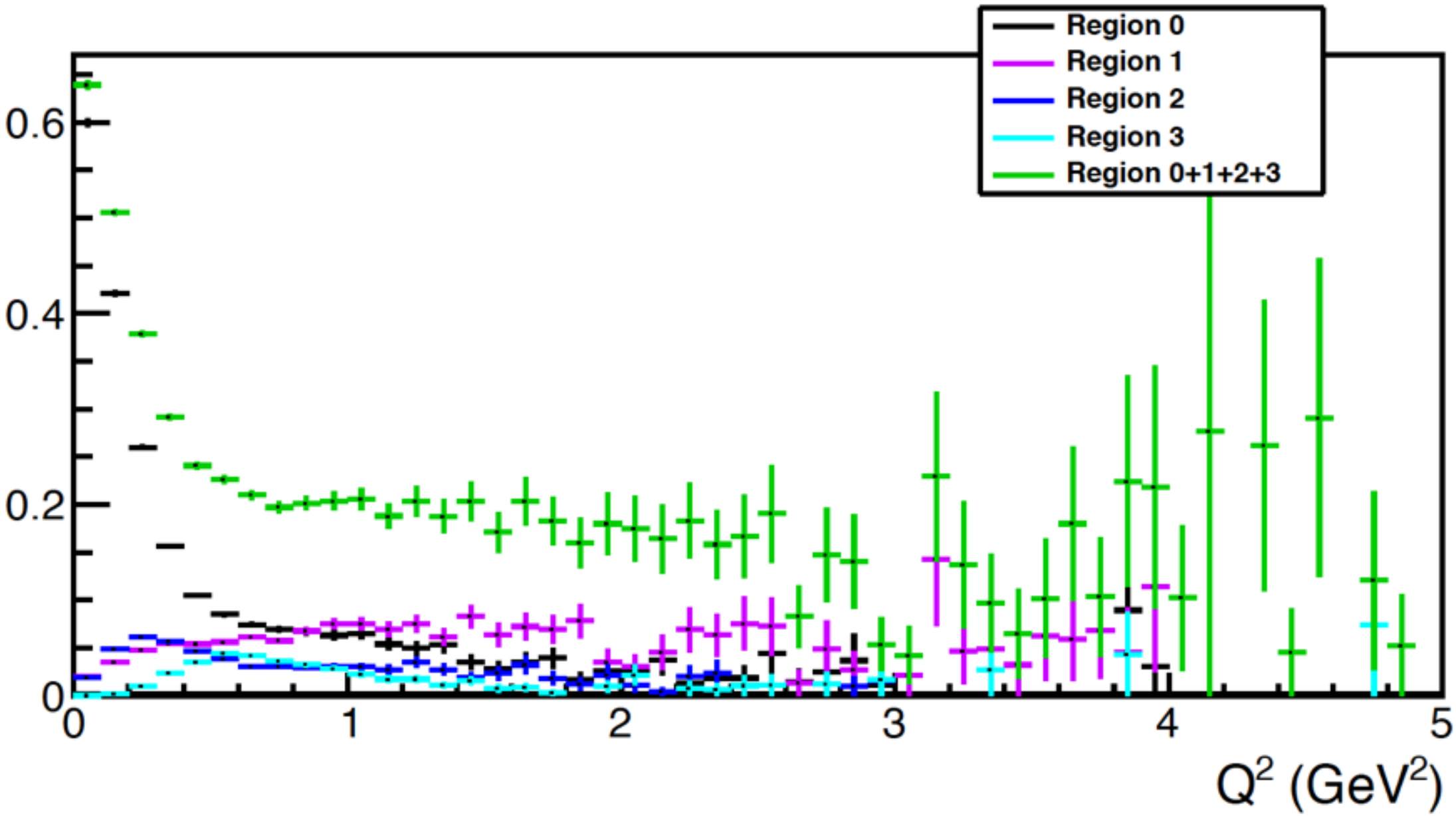


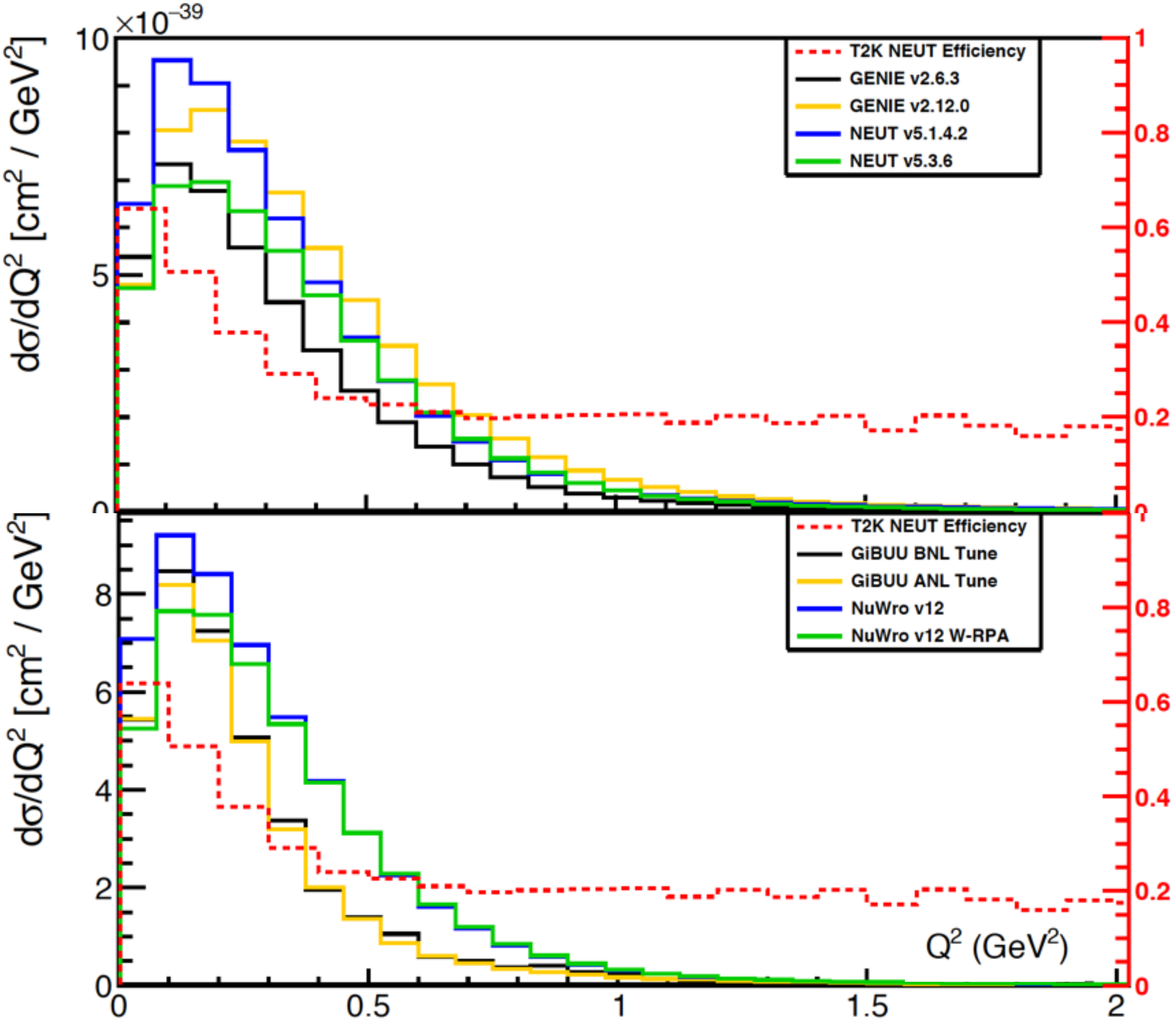
Model dependence? Efficiency, T2K



- T2K uses different CCQE-like subsamples, with different efficiencies
  - Easier to select forward tracks than backward or high angle
- T2K's changing efficiency driven by sub-samples, angular acceptance


Region 0
Region 1
Region 2
Region 2
ECAL+SMRD
FGD
TPC
μ
p


Region 0
Region 1
Region 2
Region 3
Region 0+1+2+3
0.6
0.4
0.2
0
0
1
2
3
4
5
Q² (GeV²)


×10⁻³⁹
dσ/dQ² [cm² / GeV²]
T2K NEUT Efficiency
GENIE v2.6.3
GENIE v2.12.0
NEUT v5.1.4.2
NEUT v5.3.6
T2K NEUT Efficiency
GiBUU BNL Tune
GiBUU ANL Tune
NuWro v12
NuWro v12 W-RPA
Q² (GeV²)

Model dependence? Efficiency Calculation

- 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 for each analysis?**

  - Extreme case: model predicts no forward interactions. Is the efficiency 0 there or not?

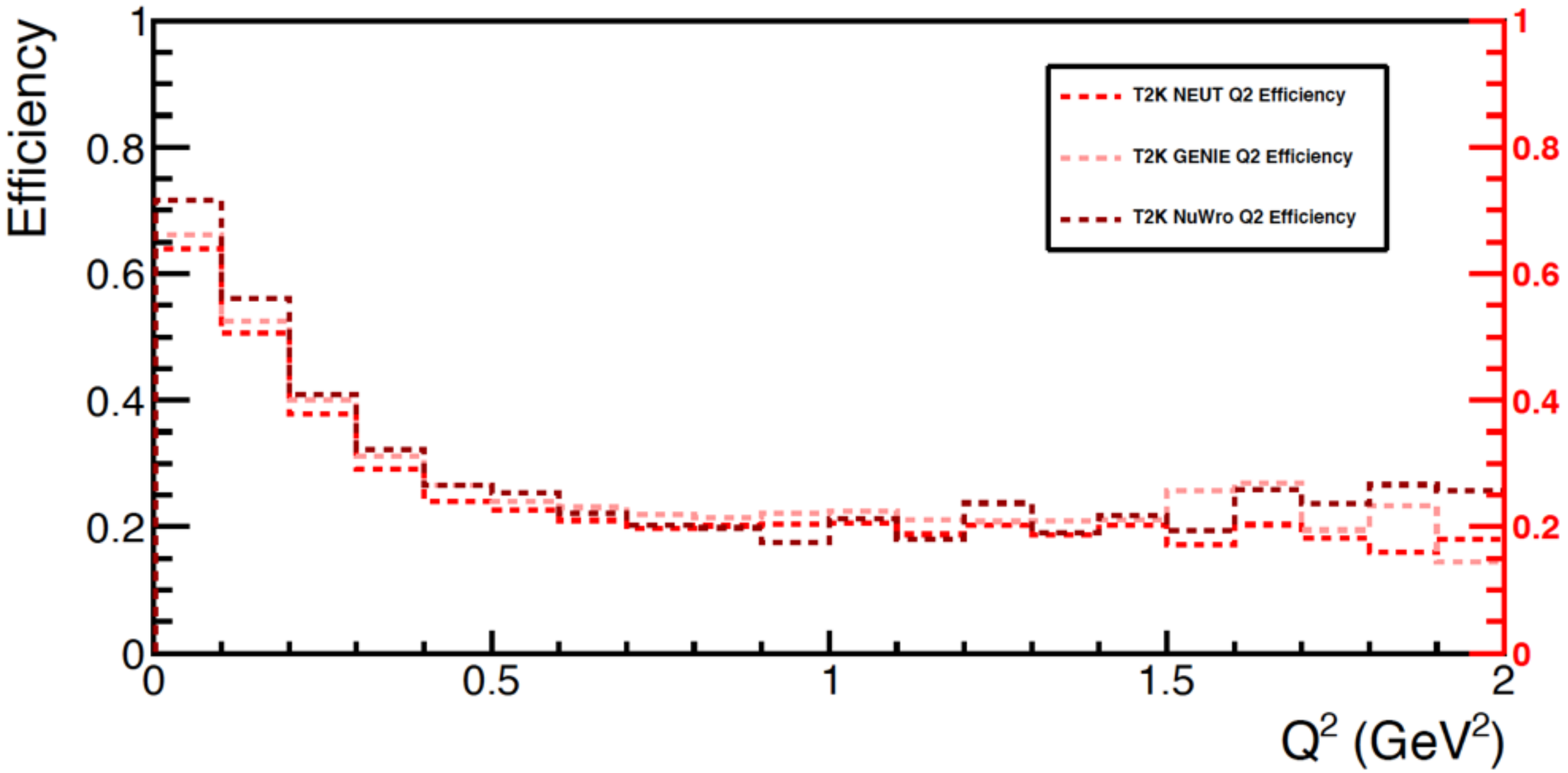
- **Solutions?**

  - 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?)

Efficiency on T2K with three models

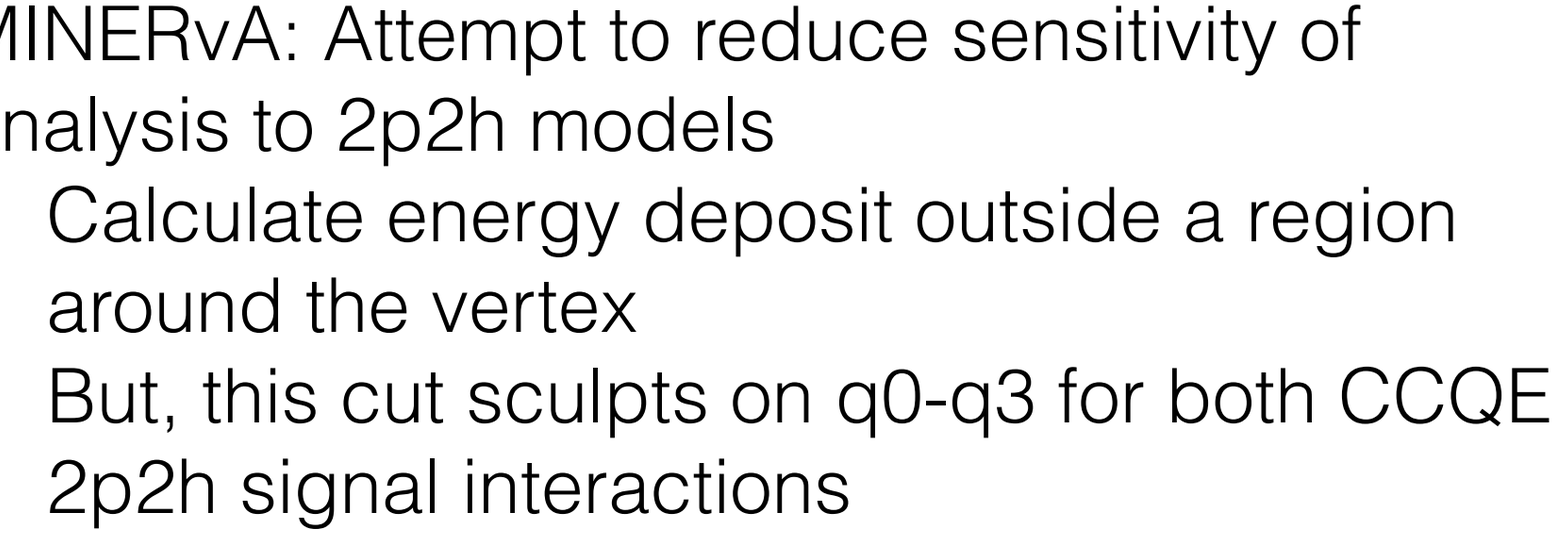


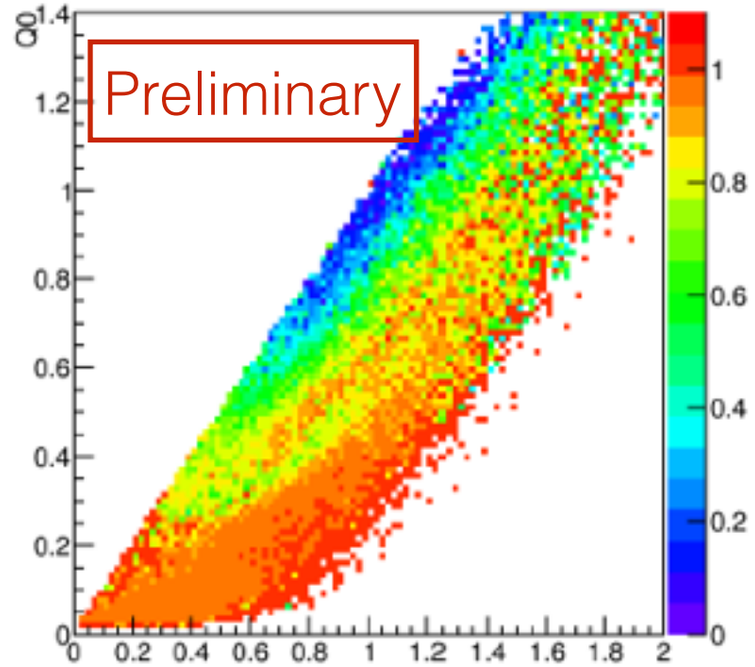
Selection designed to have minimal effect on hadronic final state

Model dependence? Selection

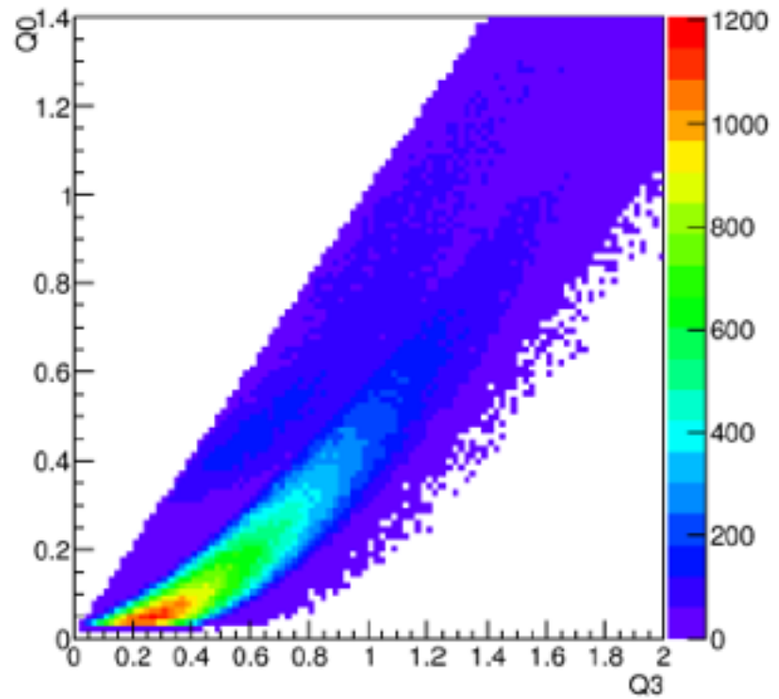
MINERvA: Attempt to reduce sensitivity of analysis to 2p2h models

- 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 leptonic and hadronic state. Covered by model systematic uncertainties?



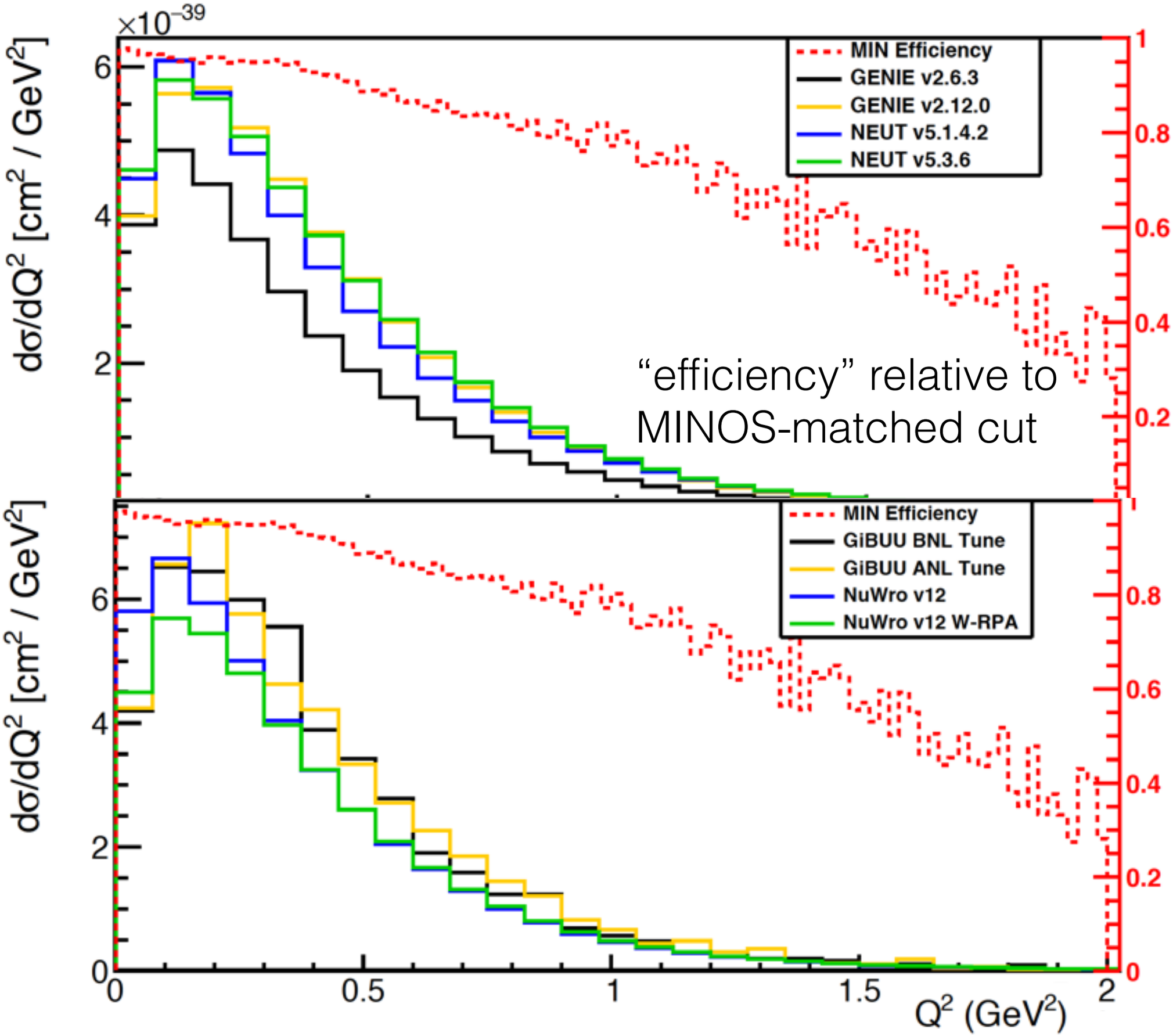


Eff. w.r.t. previous (CC0π)

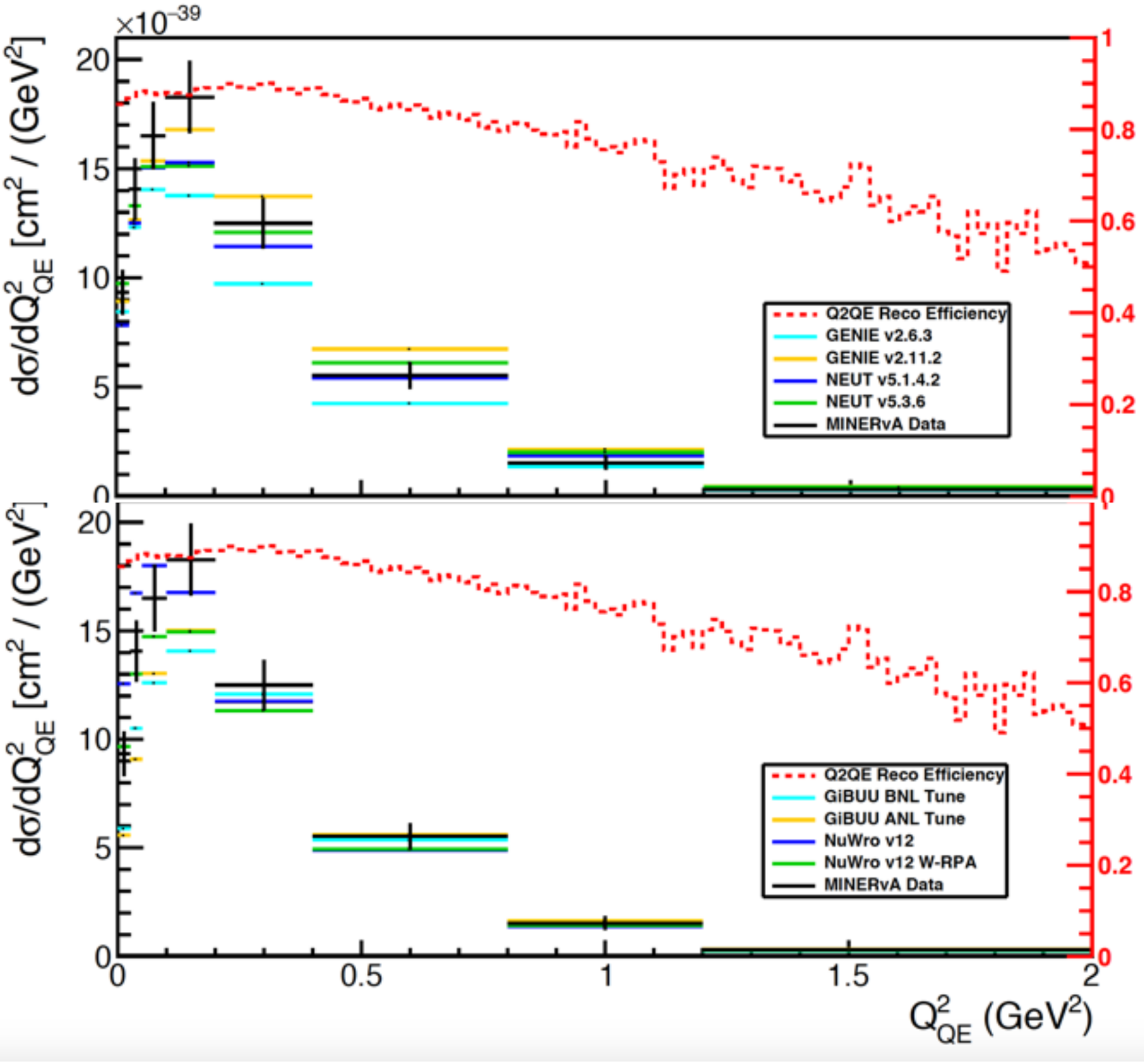


Total simulated

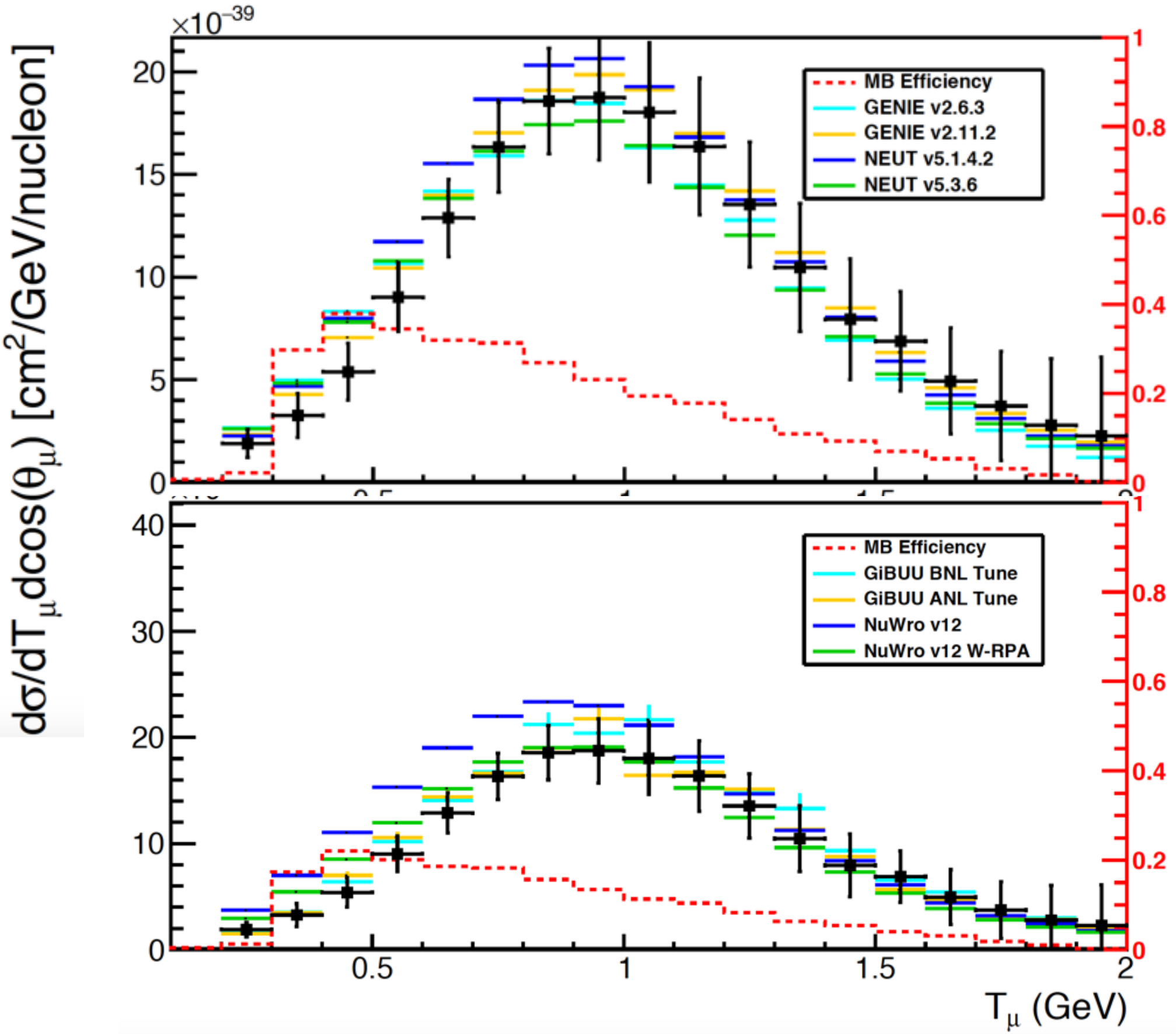
CCQE Model for MINERvA Q2 & Efficiency



MINERvA Data + CCQE+2p2h Model



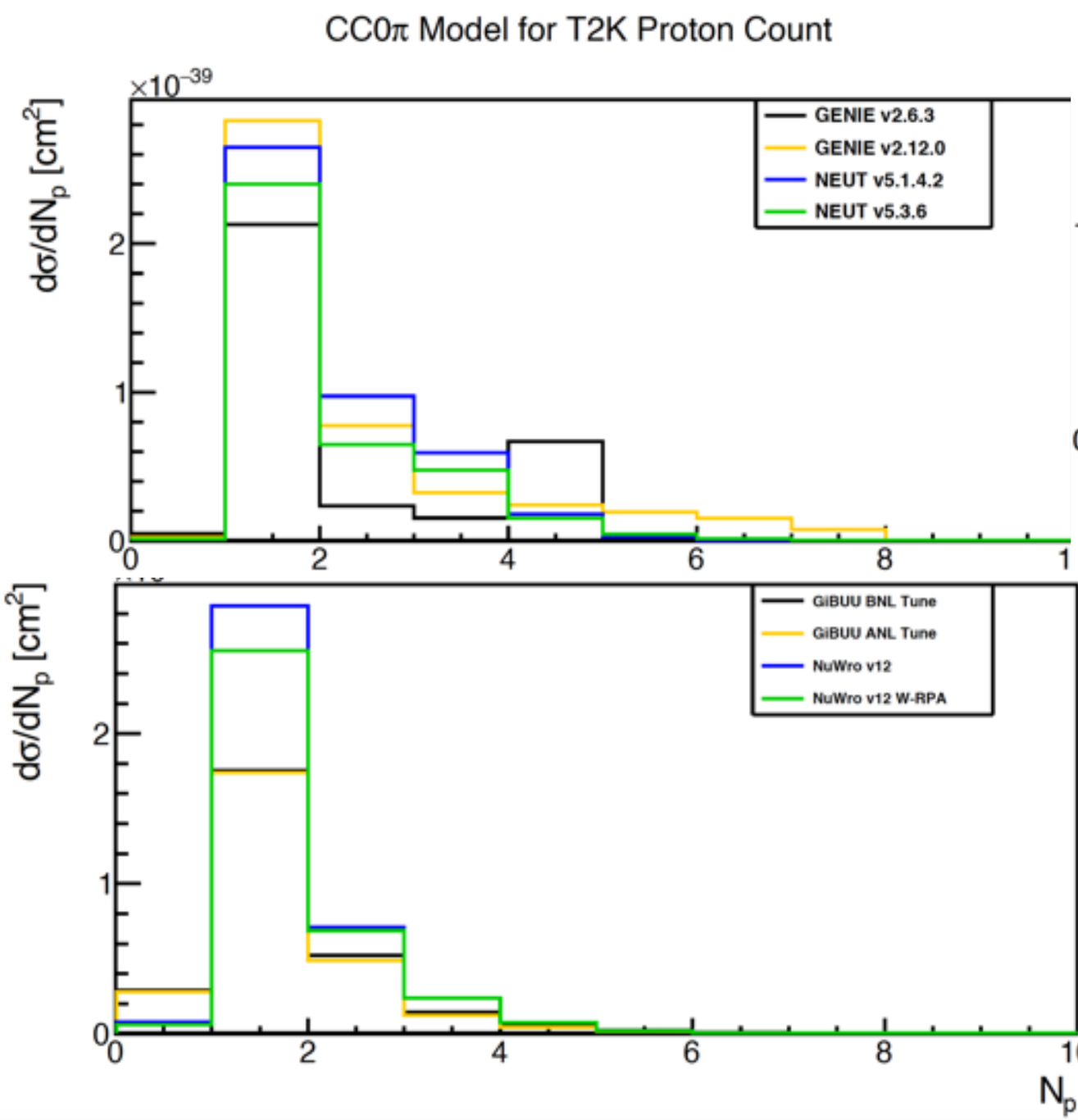
"efficiency" relative to MINOS-matched cut

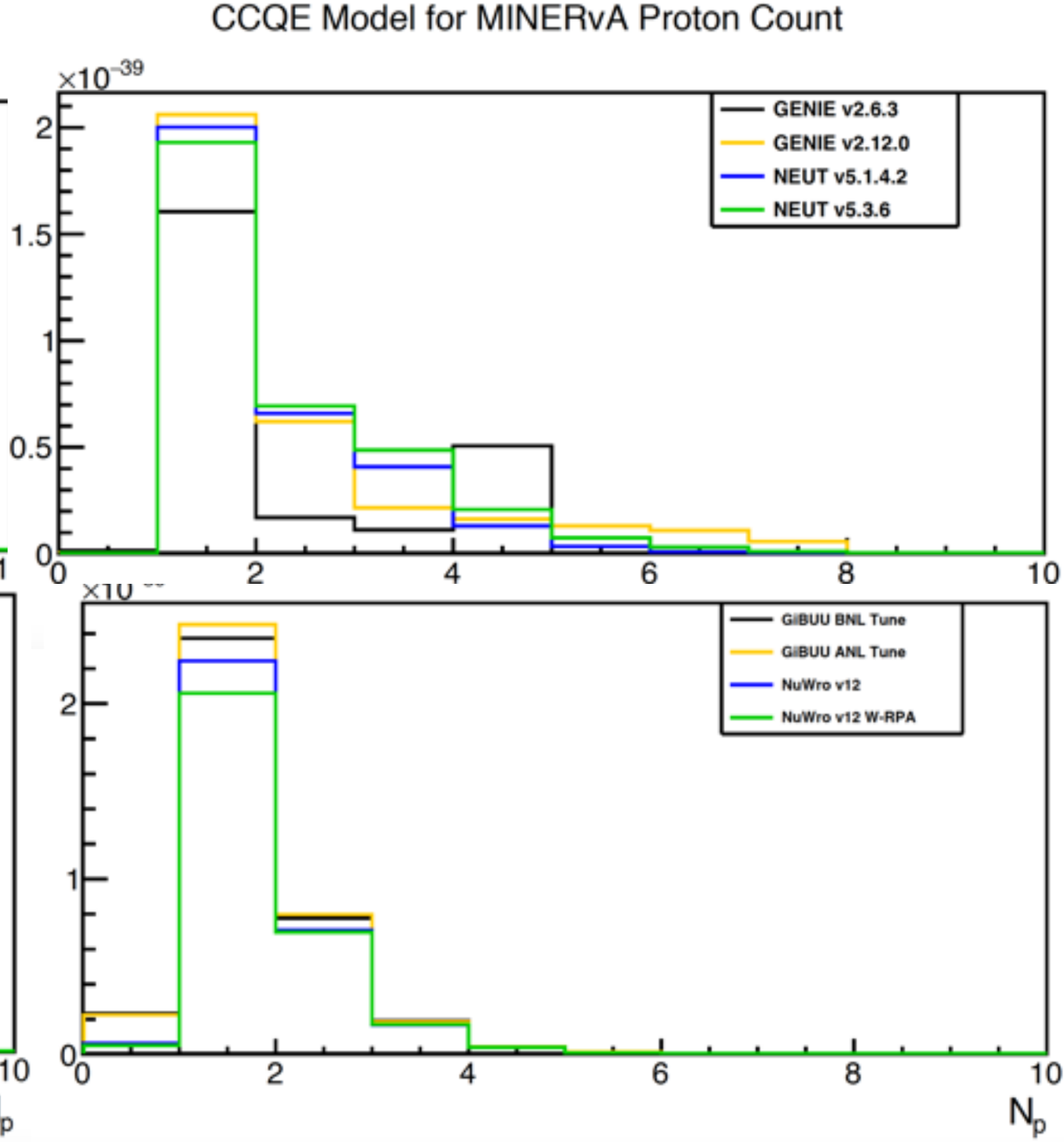


CC0pi models

efficiency in muon variables

Model only comparisons





Different experiments can see similar behavior:

- NUISANCE capable of wealth of interesting comparisons (highest momentum (HM) neutron, proton KE, neutron count, etc)

Logistical Challenges

“Tagged samples”: Required extensive coordination with collaborations, which want to balance effort of old work against ongoing analyses. Concern about content and use of information. Size (transfer, long term hosting) significant challenge. Digging up old information is hard, people move on.

“Raw samples”: Also has archival (transfer, hosting) issues. NUANCE failed to generate properly for T2K/MINERvA.

Usage: First contact between (experimental) users of data sets and producers of data sets. Surprising level of confusion (missing details not in papers, not clear signal definitions) which affected how users would fit data sets. All of the (experimental) users used generators. Extra barrier for theory?

- Experiment-experiment: How do we communicate between ourselves about details of the experiment?

- Experiment-theory: What is needed from experiments to make robust, complete comparisons to theory?

Summary

- **Apparent disagreement "tension" between MiniBooNE/T2K/MINERvA measurements led to a workshop in Pittsburgh (TENSIONS2016)**
  - (New information from each experiment) x (new generator comparisons)
  - Used new tool (NUISANCE) to aid comparisons in a consistent way
  - Summary document underway, for discussion by collaborations
- **Expected and unexpected model dependance possible through: acceptance, <u>efficiency calculation</u>, selection cuts**
  - Model dependance may be mitigated by systematic uncertainties, but how much?
  - (Already) moving towards reporting what we measure— avoid filling in with models
  - Discuss how calculate efficiency, show efficiency.
- **Need collaboration and cross-collaboration awareness and discussion to move forward with experimental understanding of QE**
  - How do we communicate details to users (theory or experiment)? What needs to be done to ensure longevity of results?
  - Solvable problems, but need more conversation, conventions.