The Challenges in Neutrino-nucleus Scattering Physics to be Addressed by nuSTORM

Jorge G. Morfín
Fermilab

!6 February 2017

NuSTEC White Paper : Status and Challenges of Neutrino Nucleus Scattering

- General Challenges plus specific challenges for each production channel of neutrino nucleus scattering.
- General Challenges - selected:
  - Realize that the Neutrino-Nucleus Interaction is the least understood component of a detectors response to neutrinos.
  - Improvements of nuclear and nucleon models by NP and HEP theorists are essential and should include:
    - The development of a unified model of nuclear structure giving the initial kinematics / dynamics of bound-nucleons within the nucleus.
    - Model neutrino bound-nucleon initial interaction cross sections in the full phase space not only at the lepton semi-inclusive cross section level but for all the exclusive channels that are allowed kinematically.
    - Improve our understanding of the role played by nucleon-nucleon correlations in interactions and implementing this understanding in MC generators avoiding double counting of effects.

NuSTEC White Paper : Status and Challenges of Neutrino Nucleus Scattering

- » Improve models of final state interactions. This may call for further experimental input from e-A and h-A communities.

- Identify in an unambiguous quantitative way which ingredients of nuclear models currently implemented in Monte Carlo generators are most critical for the success of future neutrino oscillation experiments leading to establishing priorities for necessary improvements to the implemented models. Rapidly incorporating these improvements in event generators is equally important and requires a collaborative effort of the HEP and NP communities.
- The critical role of neutrino nucleus event generators needs to be emphasized and more community resources devoted to keeping them widely available, accurate, transparent, and current.
- **It is critical to provide highly accurate neutrino nucleus scattering experimental results that can**
  - » **validate and distinguish between improved models**.
  - » **benchmark the generators against**

NuSTEC White Paper : Status and Challenges of Neutrino Nucleus Scattering

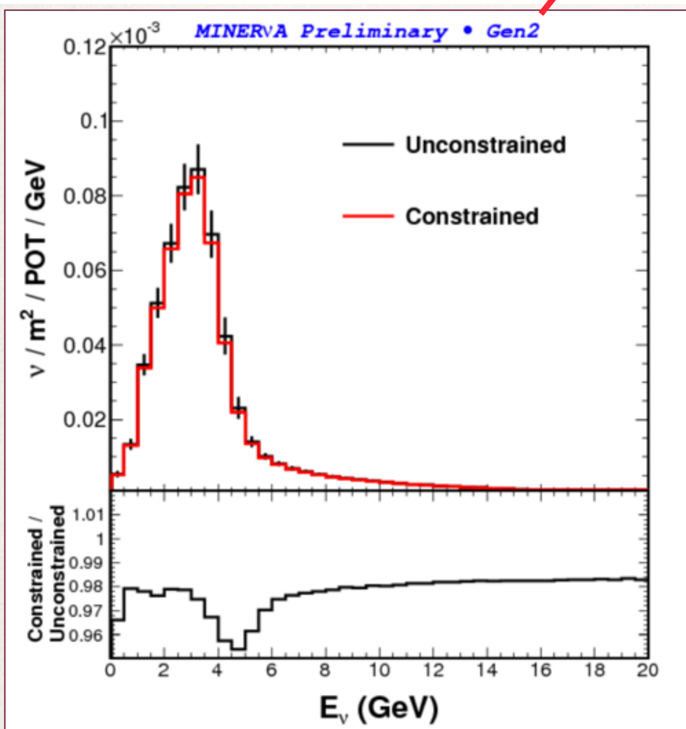
- The current experimental neutrino interaction program (MINERvA, NOvA-ND, Micro-BooNE, T2K Near Detector) continues to provide important data and should be supported to its conclusion. **This includes efforts to improve the precision with which the neutrino flux is known.**
- Future neutrino interaction measurements are needed to extend the current program of GeV- scale neutrino interactions:
  - The feasibility of a high-statistics hydrogen/deuterium experiment should be evaluated.
  - **The possibility of muon-based neutrino beams providing extremely accurate knowledge of the neutrino flux and an intense electron neutrino beam should be considered**.
  - The need for (anti)neutrino Ar scattering data in the energy range relevant for DUNE should be emphasized
  - Current and future long-and-short-baseline neutrino oscillation programs should evaluate and articulate what additional neutrino nucleus interaction data is required to meet their ambitious goals, and support experiments that provide this data.

- **Summary- To perform necessary selective constraints on improved nuclear models and their employment in generators requires increasingly accurate measurements of neutrino nucleus interactions. How do we improve the current situation? Use MINERvA results as an example.**

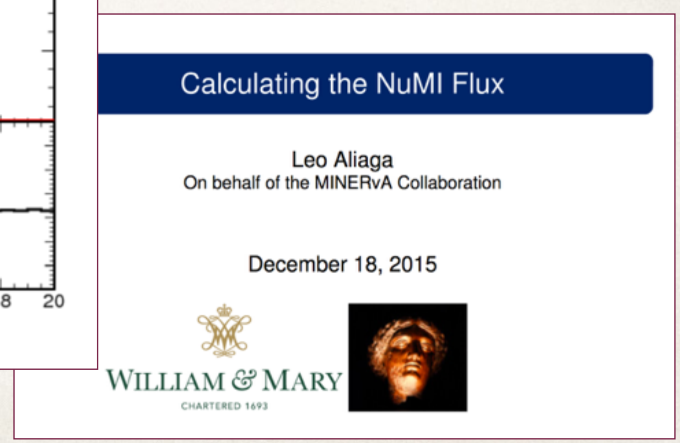
Charged-Current Quasi-elastic Double-Differential Antineutrino Cross Section from MINERvA

- Calculating the cross section: Here comes the neutrino flux!

$$\left(\frac{d^2\sigma}{dx\,dy}\right)_{ij} = \frac{\sum_{\alpha\beta} U_{\alpha\beta ij}\left(N_{\text{data},\alpha\beta} - N^{bkgd}_{\text{data},\alpha\beta}\right)}{\epsilon_{ij}(\Phi T)(\Delta x_i)(\Delta y_j)}$$



We divide by the **integrated** neutrino flux (0-100 GeV). We use the NuMI Gen2 PPFX flux, constrained by ν-e scattering measurements, as explained in the wine and cheese talk on Dec 18, 2015.

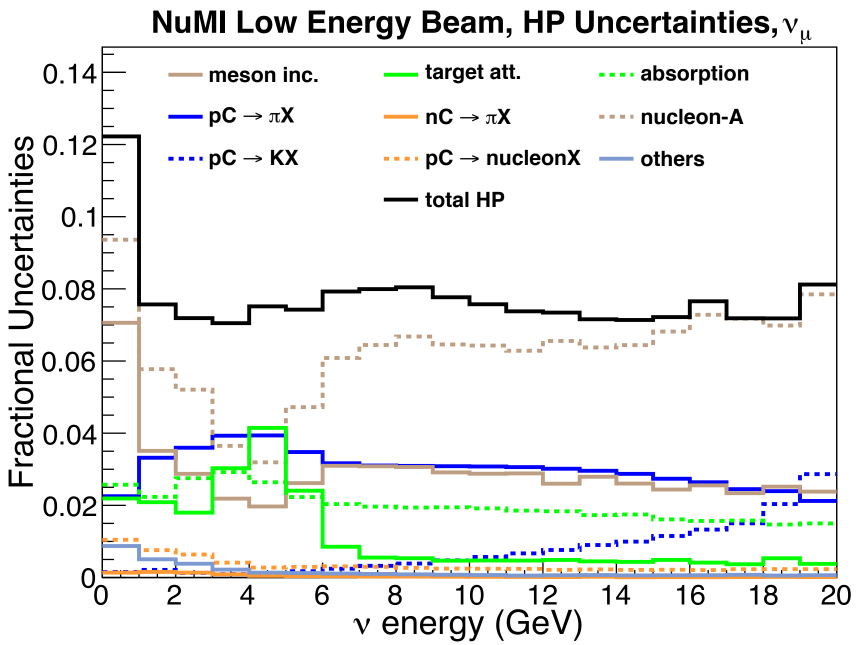


How Well do we Know This Flux?

After considerable effort….

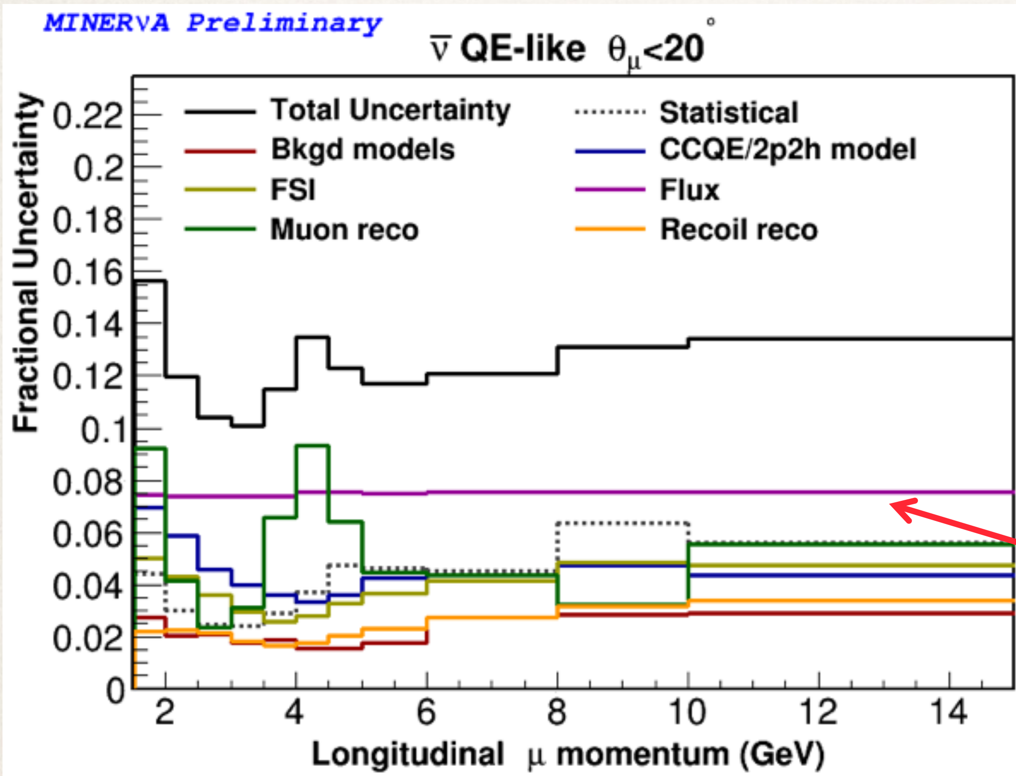
Flux

- Tune to NA49 data
- Remaining O(10%) uncertainties
- Essentially an overall scale
- L. Aliaga W&C, Dec. 18 at 1PM



+beam focusing

Sources of systematic uncertainty in this measurement



Uncertainties projected onto **longitudinal muon momentum**

- - - Statistical uncertainty

Background models

- **resonant** interactions affect background subtraction

CCQE / 2p2h model

- dominated by uncertainty in **correlation effect strength**

Final-state interactions

- **pion absorption** dominates

Flux

- beam focusing
- tertiary hadron production
- reweight to other experiments

Muon reconstruction

- **muon energy scale** dominates
- tracking efficiency
- muon angle and vertex position

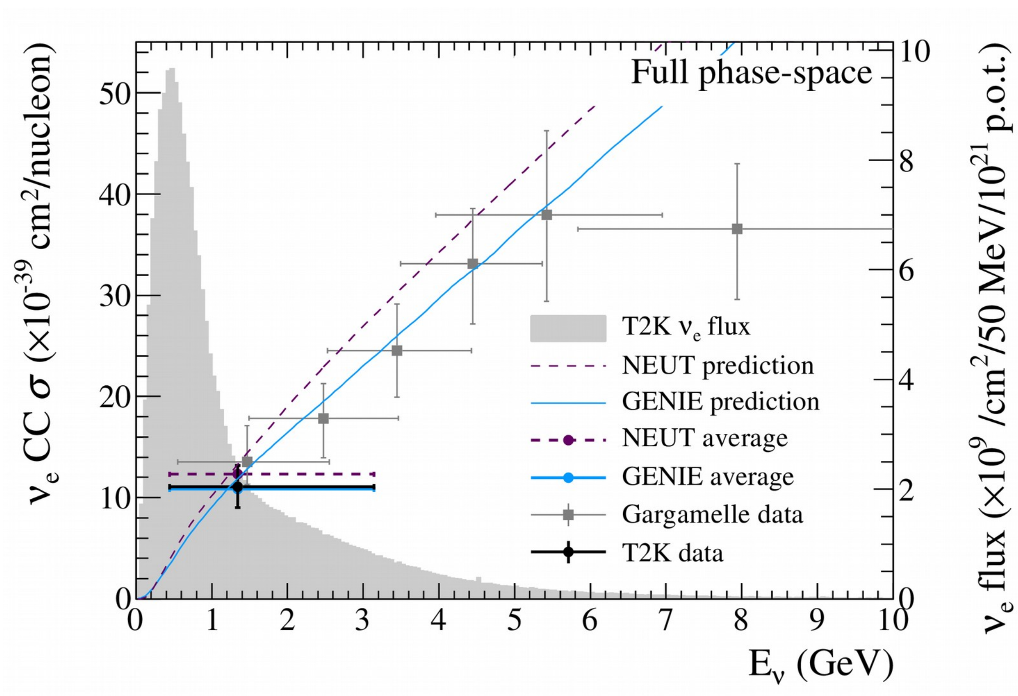
Recoil reconstruction

- detector response to different particles - **neutron** dominates

What about measurements of ν_e cross section

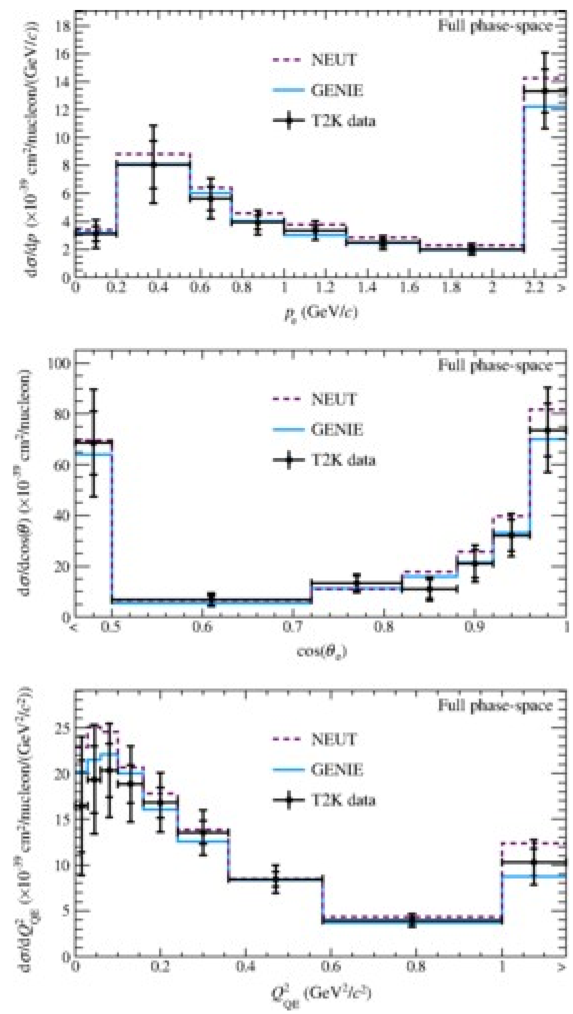
Previous measurements

Gargamelle: 244 events at ~90% purity
T2K: 315 events at ~65% purity



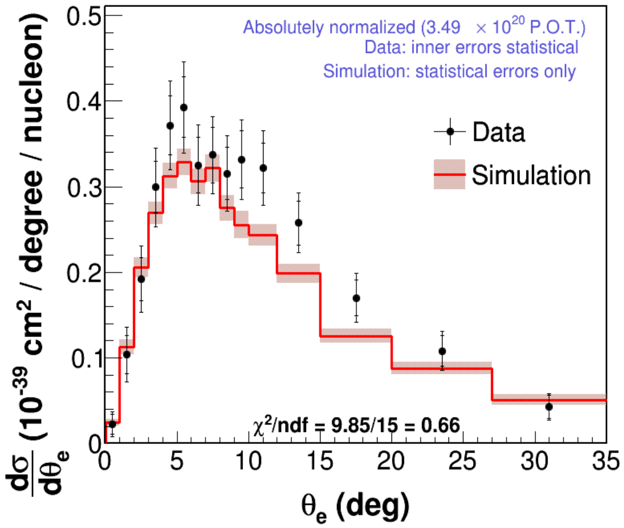
$\sigma_e(E_\nu)$:
Gargamelle (1978) on CF_3Br;
T2K (2014) on CH
Nucl. Phys. B133, 2015
Phys. Rev. Lett. 113, 241803

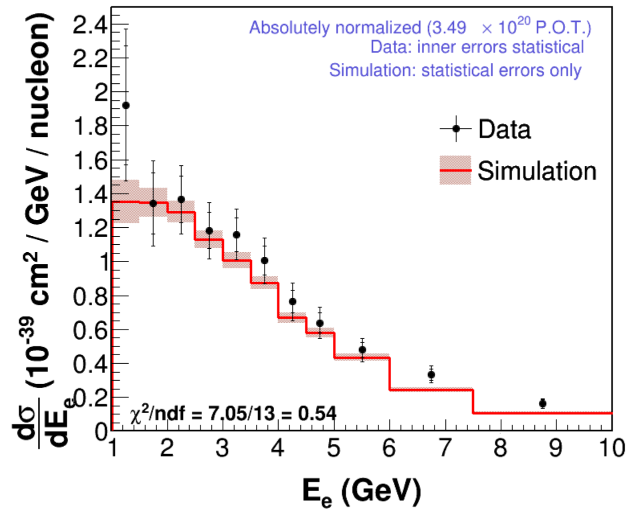
$d\sigma_e/dE_e$, $d\sigma_e/d\theta_e$, $d\sigma_e/dQ^2$:
T2K (2014) on CH
Phys. Rev. Lett. 113, 241803



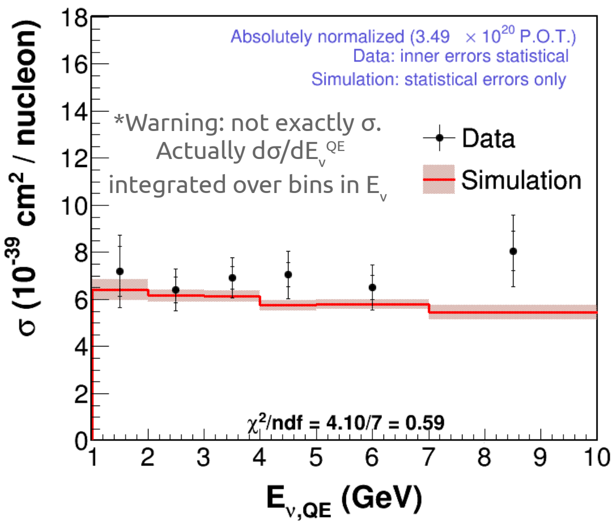
Measuring ν_e QE Cross section with MINERvA

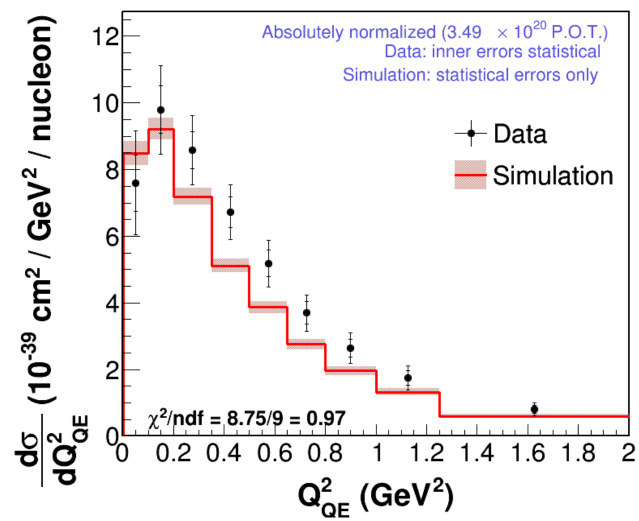
1700 ν_e events of which 1100 CCQE



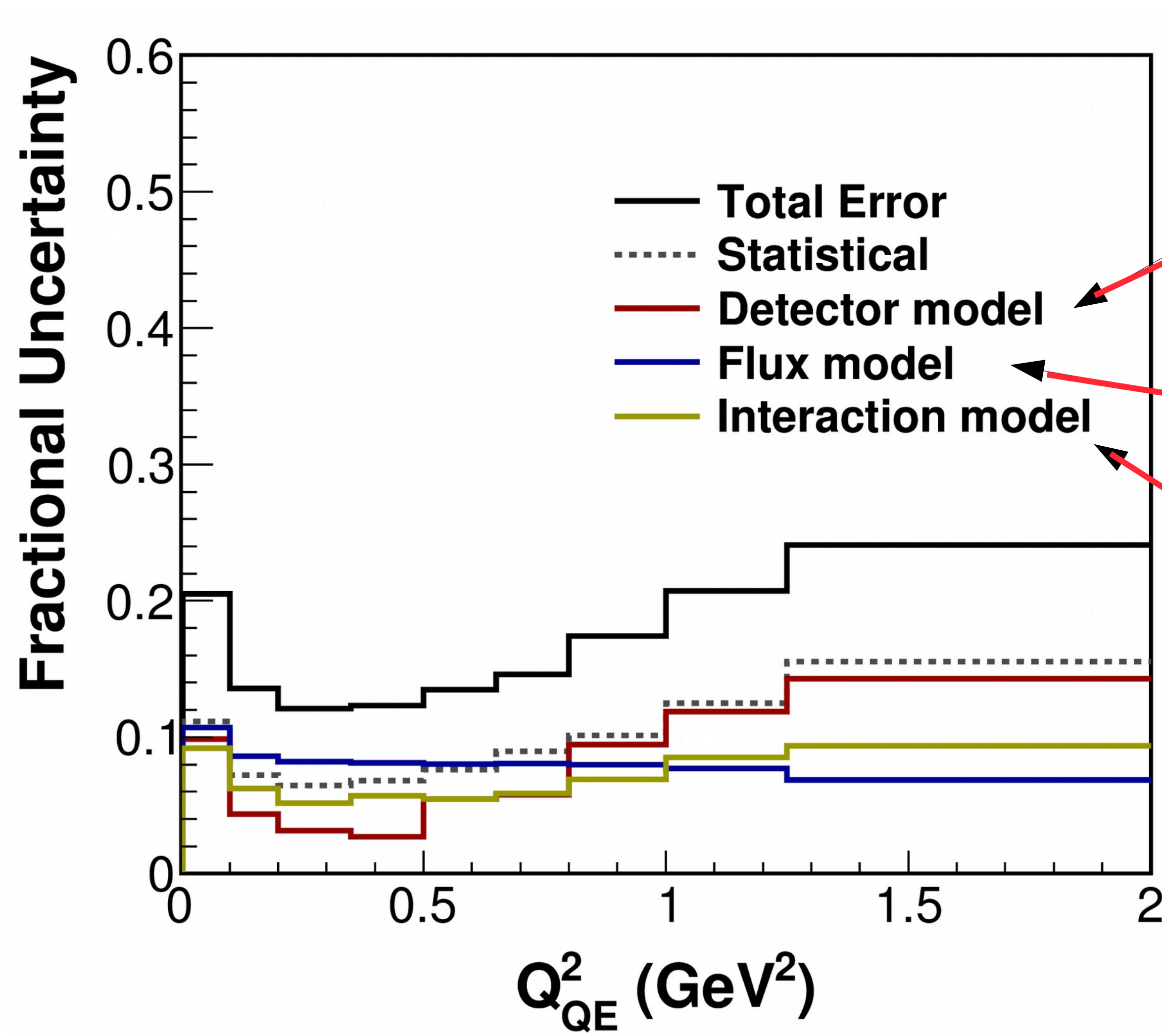


The result and the prediction from GENIE 2.6.2 are statistically consistent.





Uncertainty Summary – statistics dominates

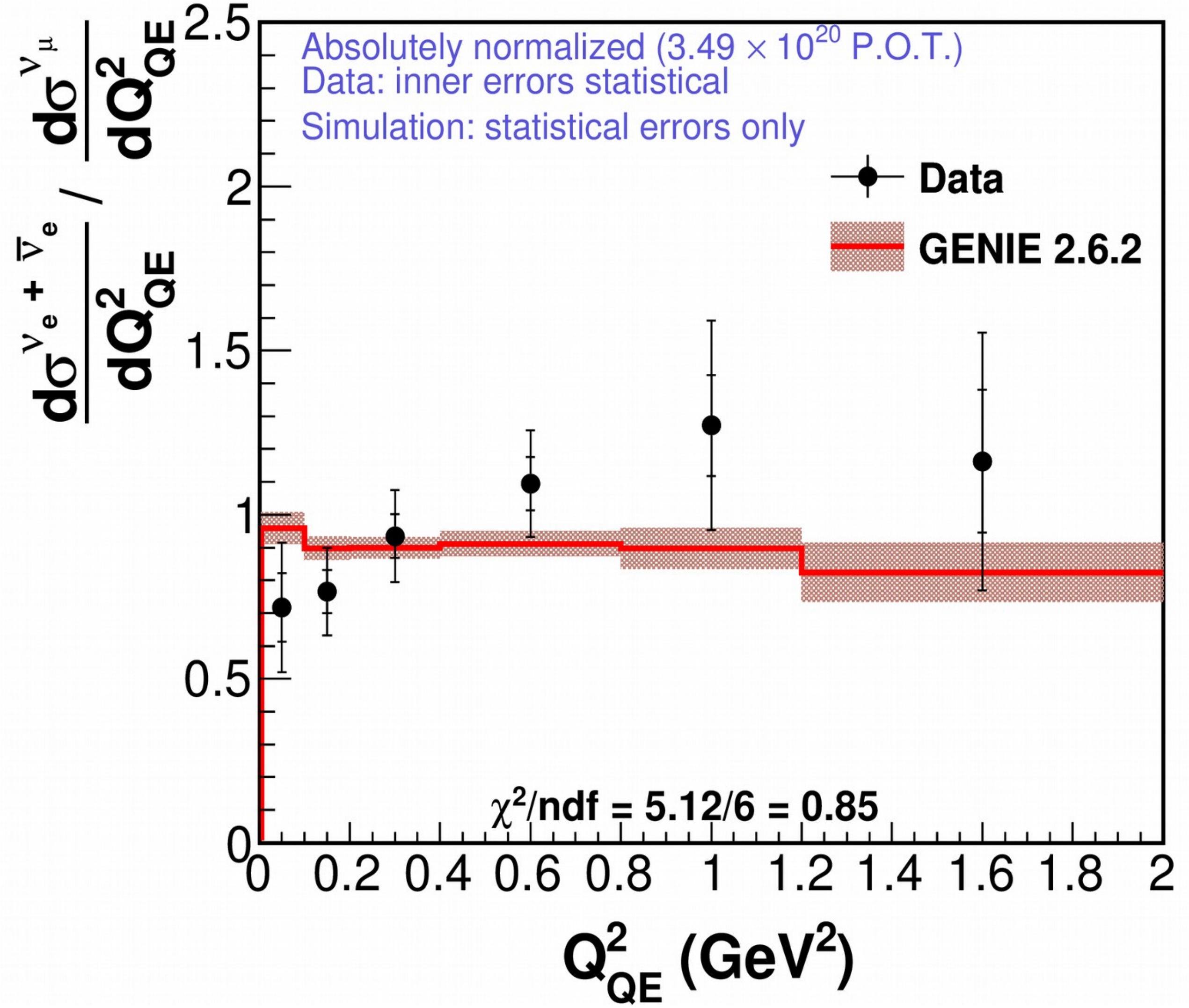


Includes energy scale estimated using the π^0 mass peak in a separate measurement; resolutions; other detector effects

Constrained as noted previously

Mostly enters in background subtraction (from GENIE 2.6.2)

ν_e-ν_μ Comparisons: (20-30)% uncertainty on ratio

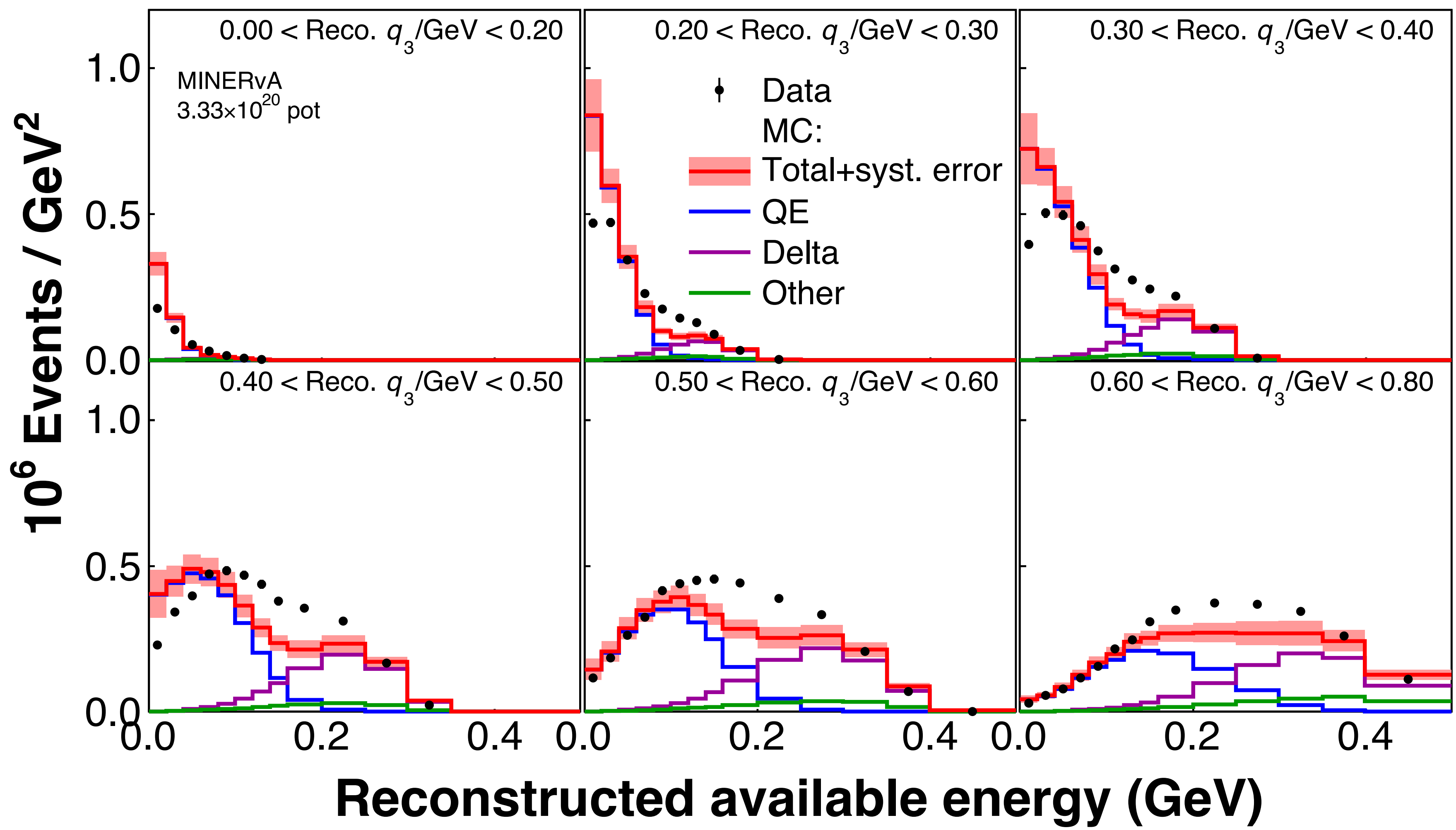


Conclusions

- To help improve the all-important nuclear model in neutrino oscillation experiments nuSTORM is needed to:
  - Significantly reduce the dominant neutrino flux error plaguing every absolute cross section measurement of contemporary neutrino nucleus scattering experiments.
  - Provide a definitive comparison of ν_e to ν_μ cross sections through the reduced flux error and significantly increased ν_e event rate.

Testing Nuclear Models for Multi Nucleon Targets

Data disagrees with model in reconstructed variables



- Evidence for problem with cross section model

10–20% systematic error on MC prediction > statistical error