CC and NC elastic scattering experimental summary

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TRIUMF

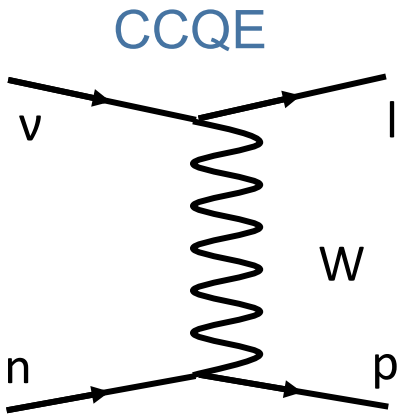
What a week! for both theory and experiment

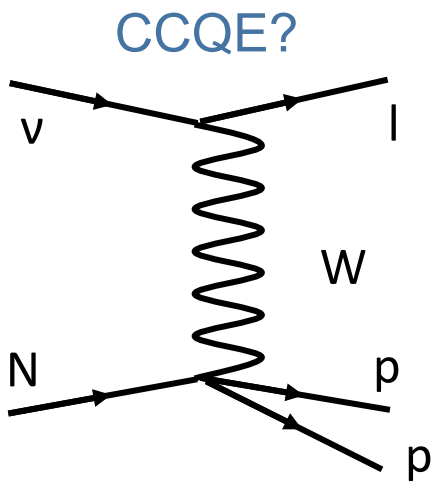
I have to keep to 20 minutes, so this is just highlights and the requests made in the session

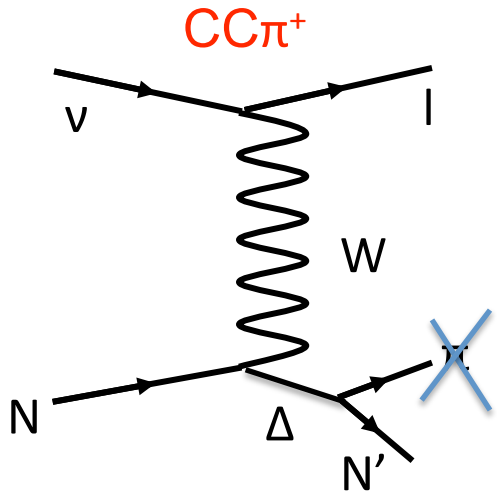
Please add requests or corrections, which will be added to the uploaded slides for record-keeping

In the spirit of the workshop, please also talk to experimenters, theorists directly to follow up on your ideas or concerns, even if it's over email later

What have we called CCQE?







1. "μ+p"
- Simple dipole axial FF as free parameter
- Relativistic Fermi gas representation of nucleon bound in nucleus

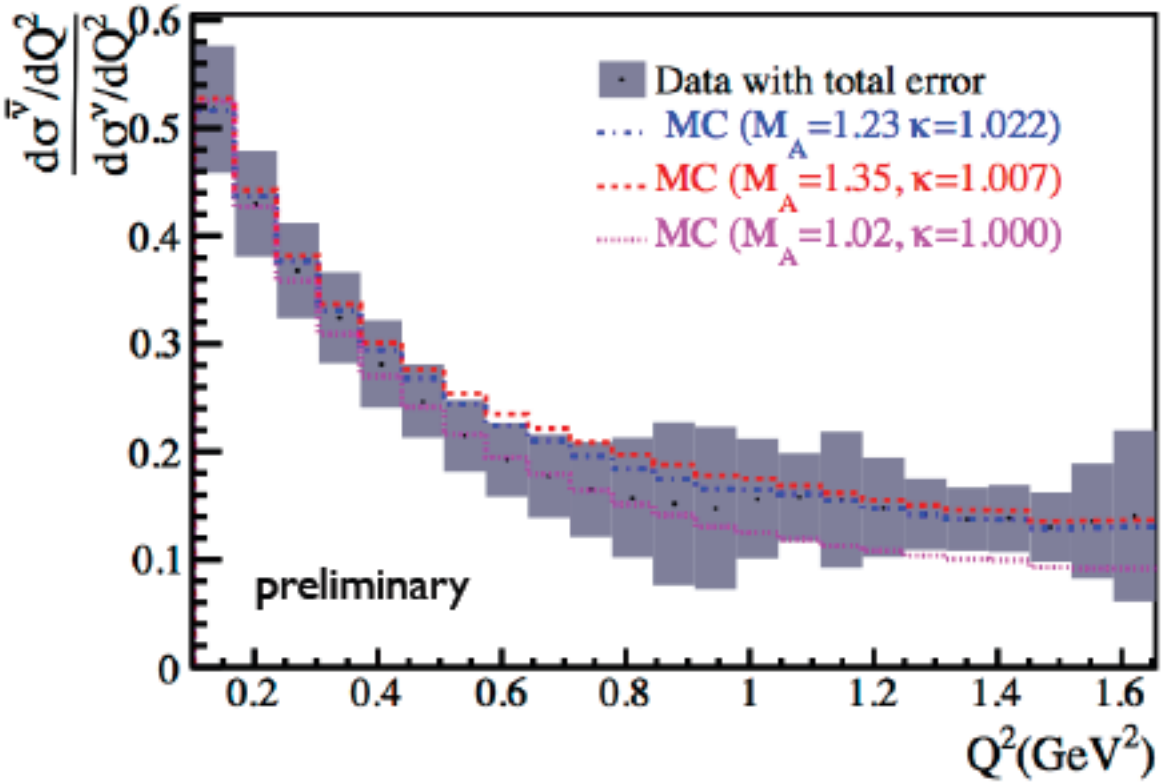
2. "np+nh"or "2p2h"
- "multinucleon" process with correlated pairs of nucleons
- Not included, historically

3. "1π " backgrounds
- CC1π backgrounds
- Complicated by choice of internuclear (FSI) model

Experiments may have different definitions of "CCQE"
- Measure "CCQE-like": 1+2?+3

Experimental results

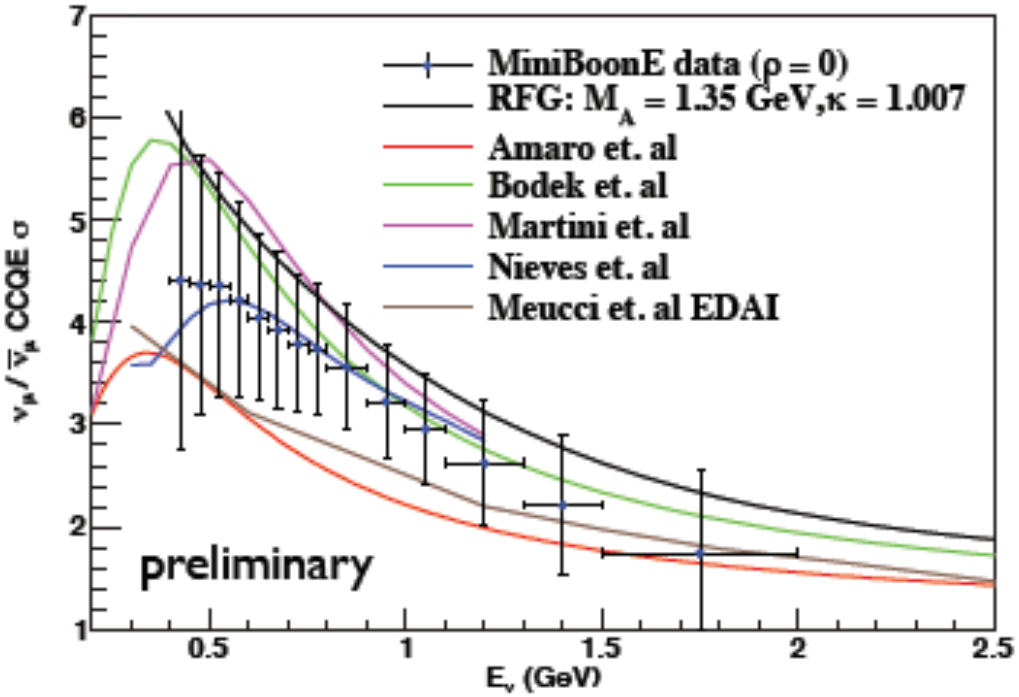
"It was what we could do, so we did it"
-Author of most results per page, Joe Grange



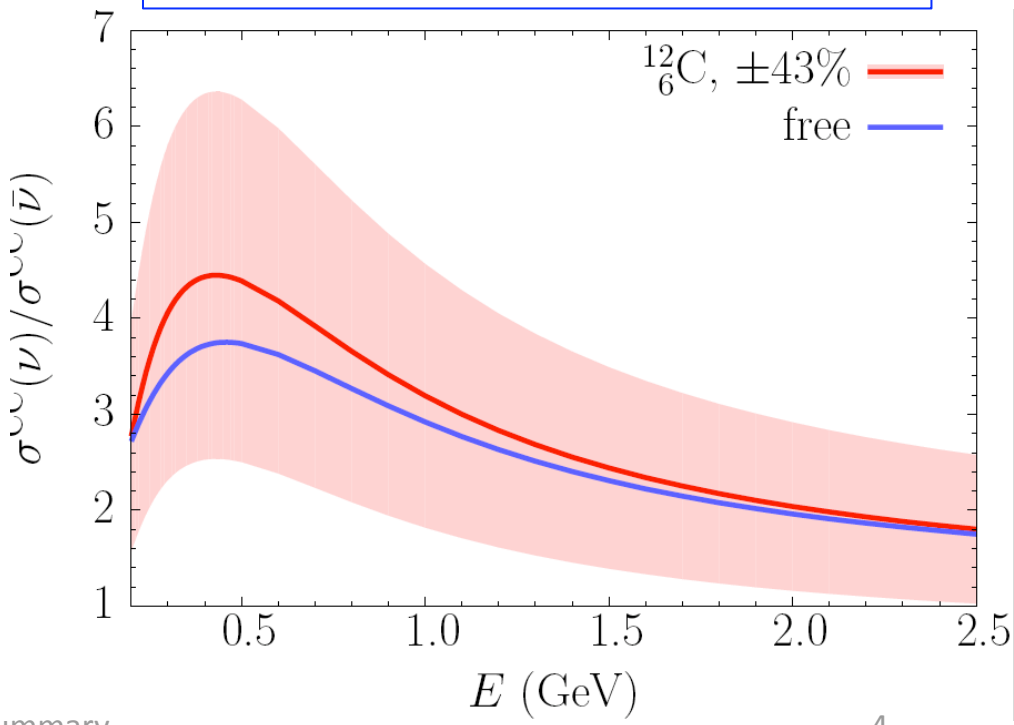
J. Grange, Thursday afternoon
MiniBooNE collaboration

Produced CC and NC differential cross sections!

Extensive ratios, model comparisons in production:
NC EL neutrino/antineutrino ratio has correlations included
CCQE neutrino/antineutrino correlations not yet included fully



A. Ankowski, rapid work



J. Grange, Thursday afternoon

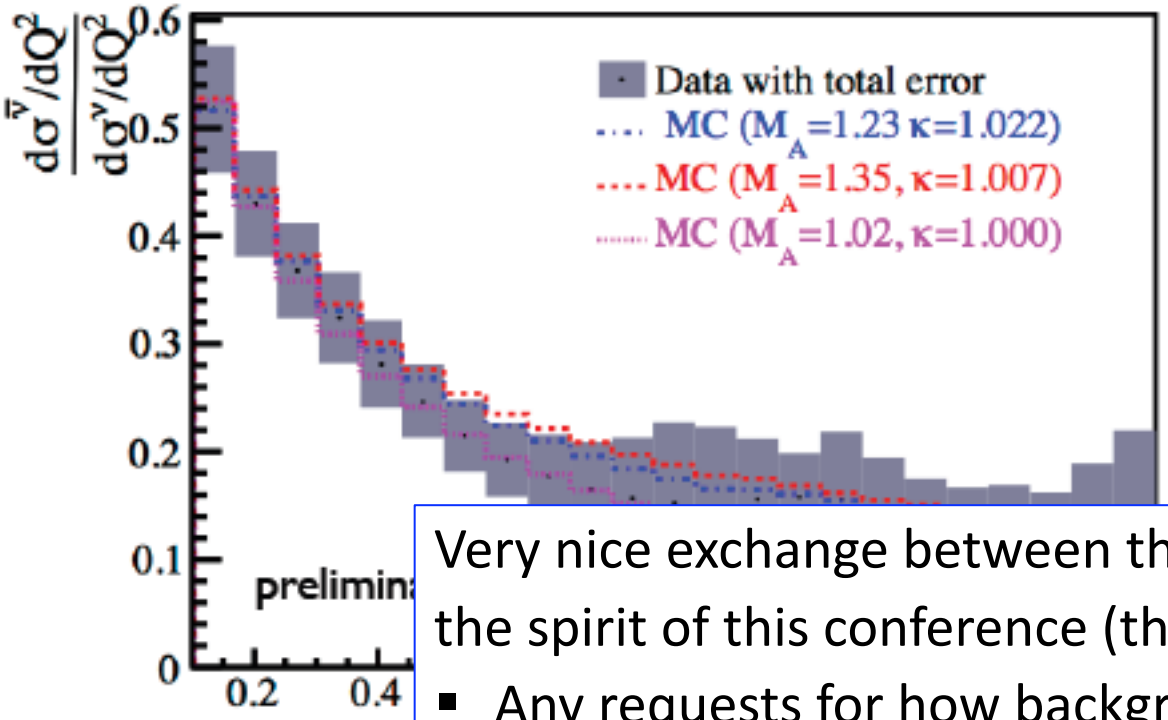
MiniBooNE collaboration

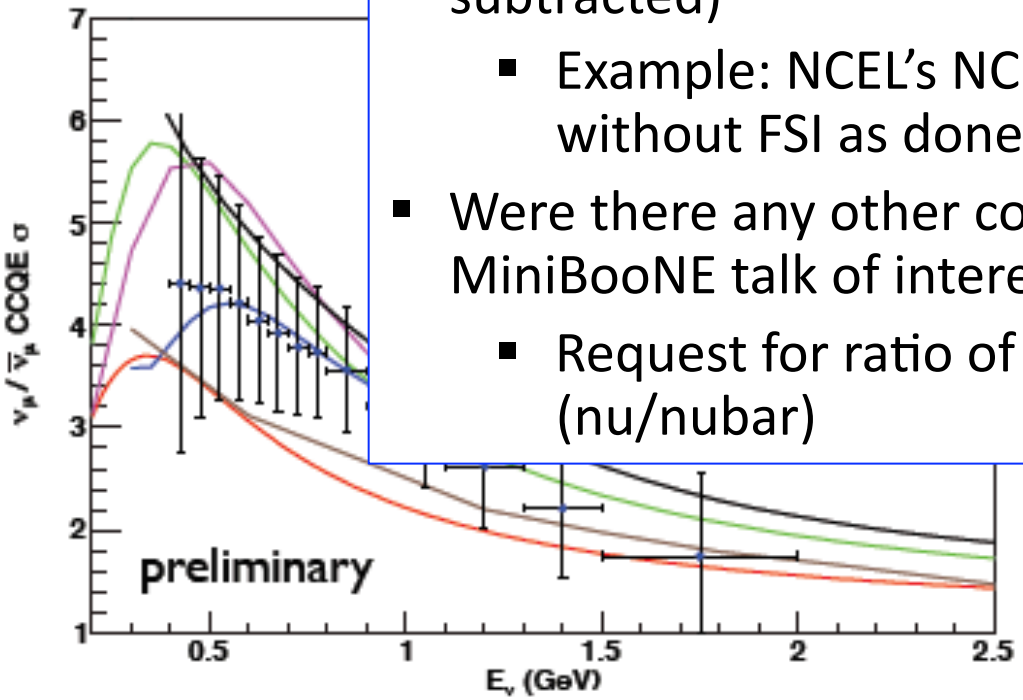
Produced CC and NC differential cross sections!

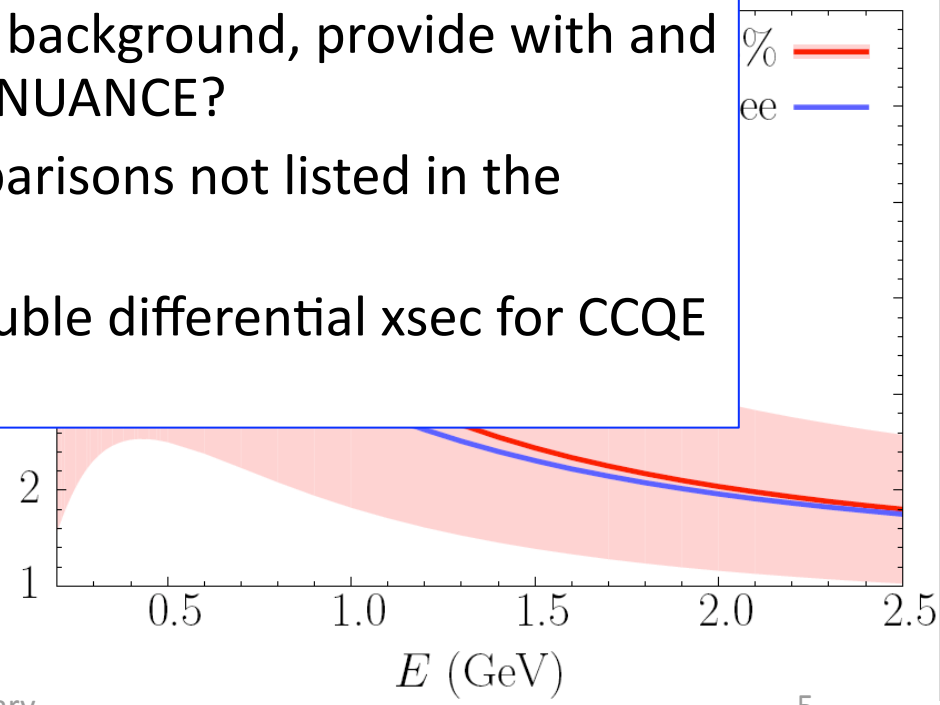
Extensive ratios, model comparisons in production:

Very nice exchange between theory and experiment here, in the spirit of this conference (thank you!)

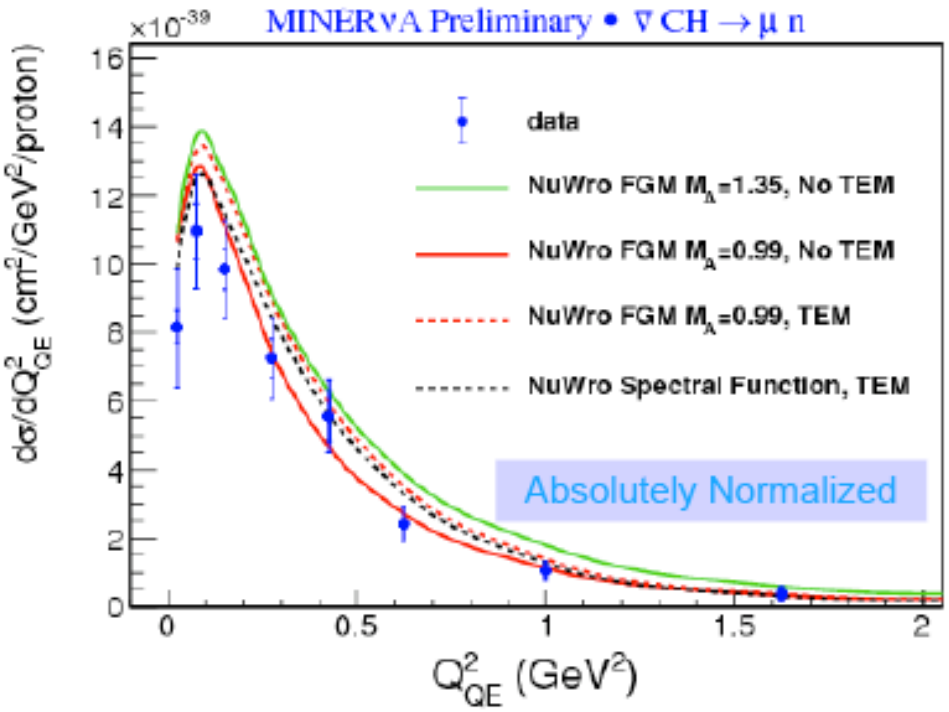
- Any requests for how background subtraction is done or modifications? (MB provides unsubtracted and subtracted)
  - Example: NCEL's NC1pi background, provide with and without FSI as done in NUANCE?
- Were there any other comparisons not listed in the MiniBooNE talk of interest?
  - Request for ratio of double differential xsec for CCQE (nu/nubar)





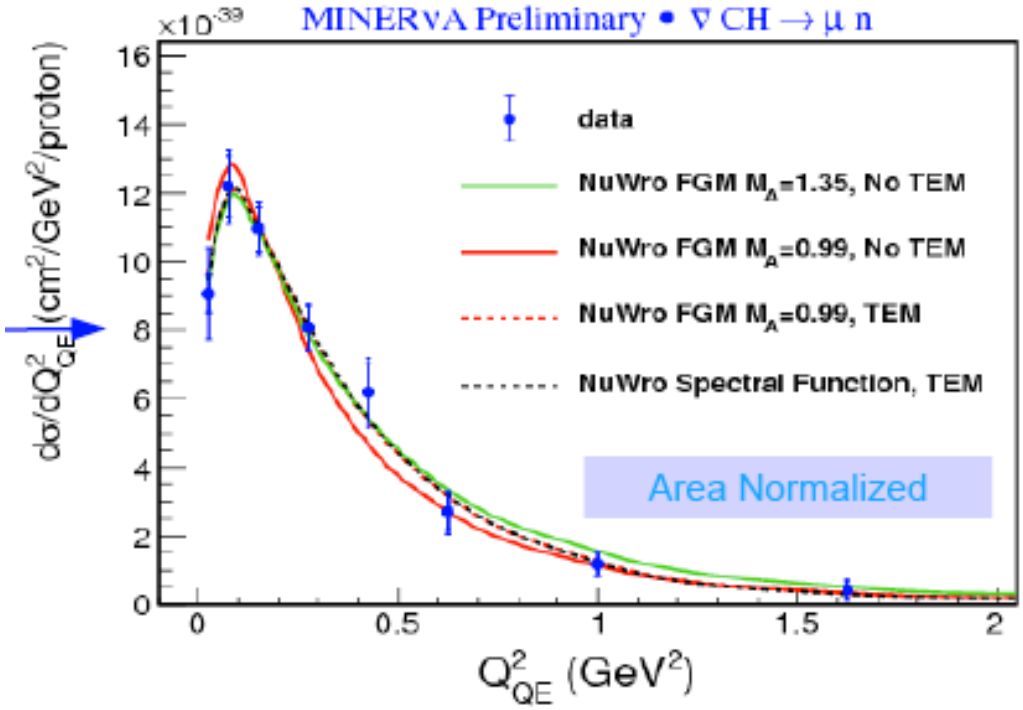


L. Fields, Thursday afternoon
Minerva collaboration



First differential antineutrino cross sections!

- Familiar turn over at low Q^2
- Shape measurement statistically dominated
- Model comparisons soon with more stat and improved flux estimation



Also:

- Consistency between improved neutrino 1 track selection and previous neutrino analysis, extended to include wider angles
- New CCQE selections also on heavier targets
- First look at proton kinematics and vertex activity

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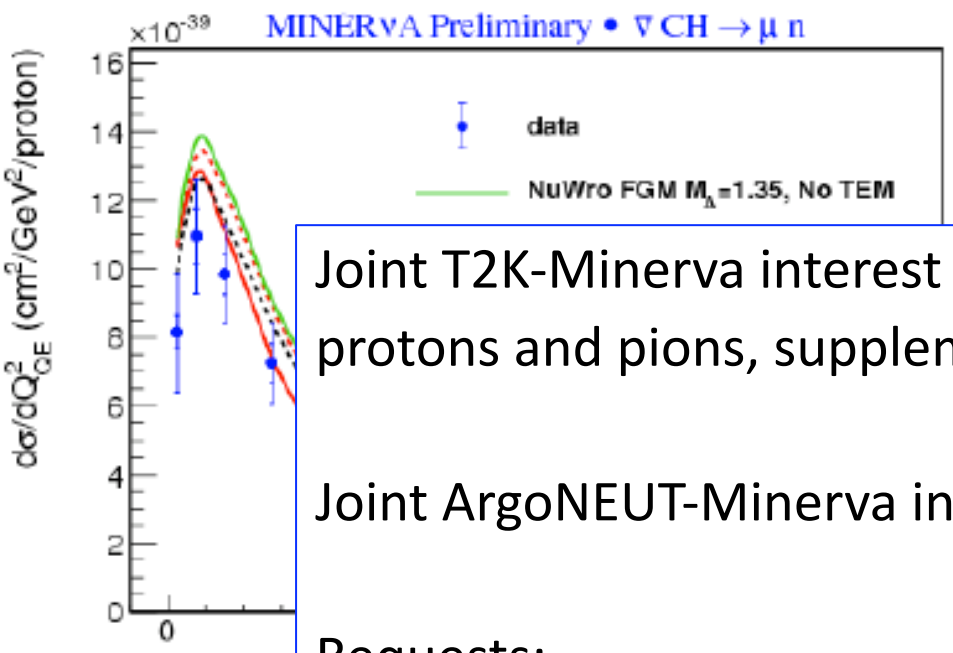
L. Fields, Thursday afternoon
Minerva collaboration



First differential antineutrino cross sections!

- Familiar turn over at low Q^2
- Shape measurement statistically dominated

Joint T2K-Minerva interest in Geant4 modeling for scintillator for protons and pions, supplemented with test beam data

Joint ArgoNEUT-Minerva interest in resolving flux uncertainties

Requests:

- What is KE threshold of proton to produce a reconstructed track vs. vertex activity? Answer: 175MeV for 1 track, with future improvement expected
- How does the proton spectrum change under QE selection cuts which can depend on kinematics of the event?
- Any others?

Also:

- Consistency b
1 track selectio
analysis, extend
- New CCQE sel
- First look at pr
activity

Q^2_{QE} (GeV²)

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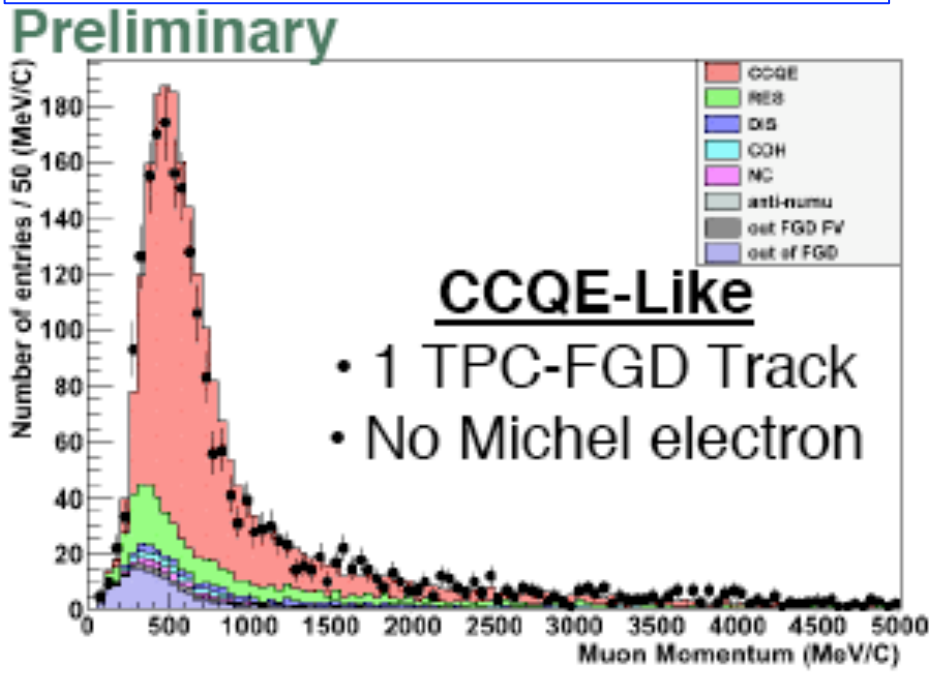
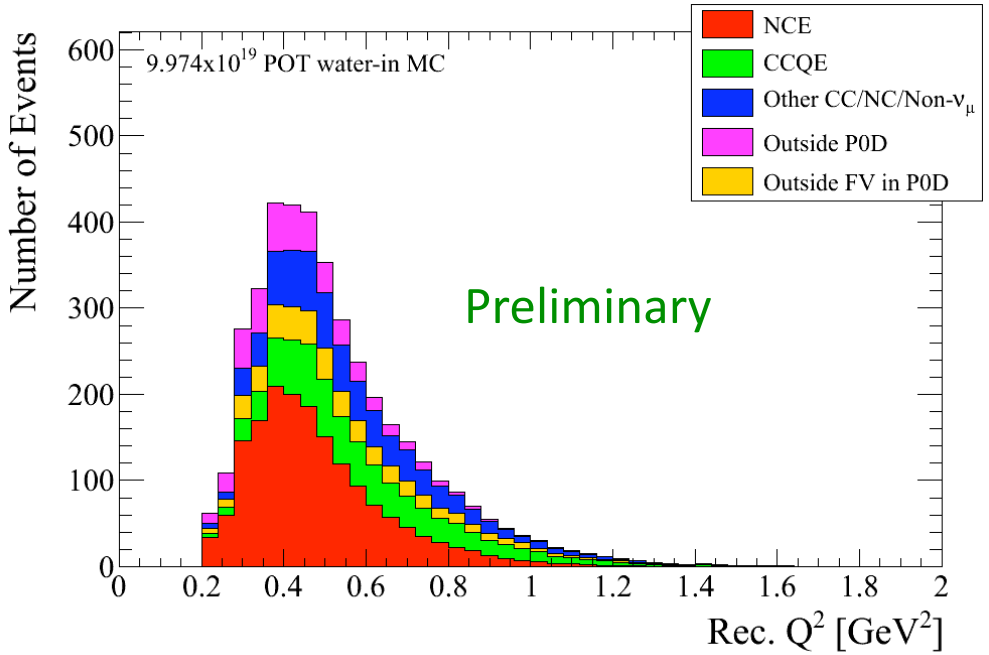
D. Ruterbories, Thursday afternoon
T2K collaboration



Narrow peak of T2K beam for flux averaged measurement as compared to MiniBooNE

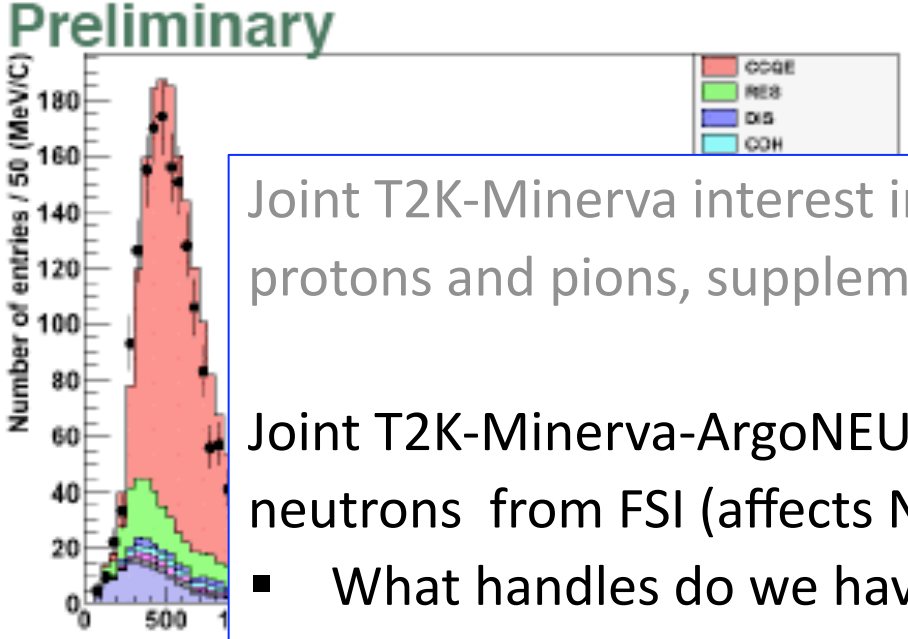
- CCQE enhanced selection is consistent with flux prediction and NEUT generator
- Future selection will include with and without proton information thanks to scintillator, TPC information
- Will provide energy dependant and differential cross section



NC elastic analysis on water target

- Single proton selection, constrain backgrounds with dedicated data samples where possible

D. Ruterbories, Thursday afternoon
T2K collaboration



Narrow peak of T2K beam for flux averaged measurement as compared to MiniBooNE

Joint T2K-Minerva interest in Geant4 modeling for scintillator for protons and pions, supplemented with test beam data

Joint T2K-Minerva-ArgoNEUT interest in understanding protons and neutrons from FSI (affects NCEL measurement and CCQE)

- What handles do we have from data with displaced vertices?
- Do we need a joint FSI program or exchange beyond comparing with GENIE?

Requests:

- Backwards going protons as a probe of FSI with TPC-FGD?
- Capability of eventual CC nue measurement?
- More public data plots and cross sections, please. Answer: soon, my friends
- Any others?

K. Partyka, Friday morning
ArgoNEUT collaboration

Exciting progress on QE analysis based on proton multiplicity in final state (plus muon) on Ar target

- Muon track determined by software. Scanners select tracks (start and end point) around vertex. Software does PID and calculates 3D track to determine containment
- Proton threshold 21 MeV
- Data low compared to GENIE, but difficult to draw firm conclusions until flux uncertainties, and GENIE version details are confirmed
- Valuable tests of Ev(μ) vs. Ev(μ,p) in development

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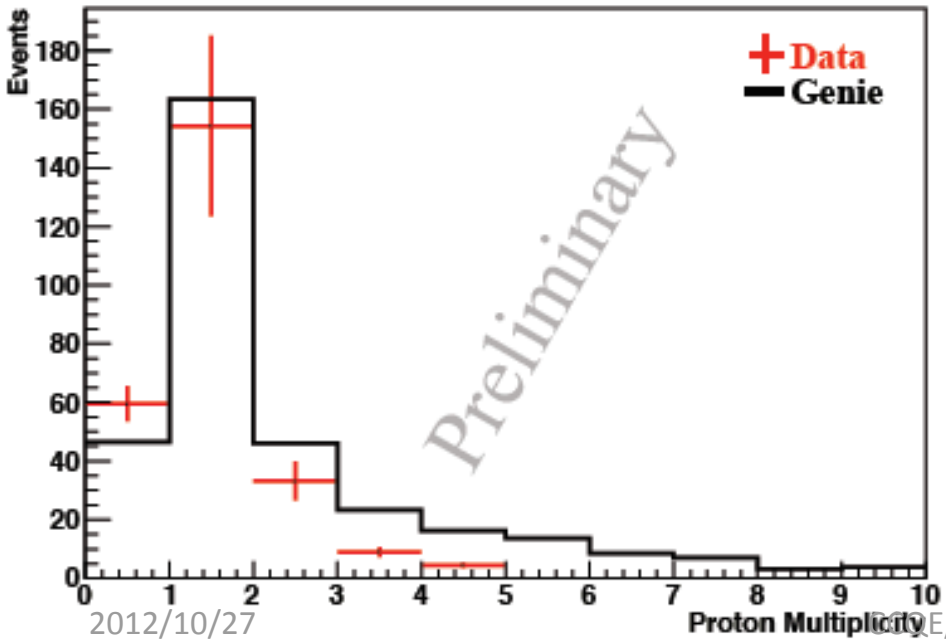

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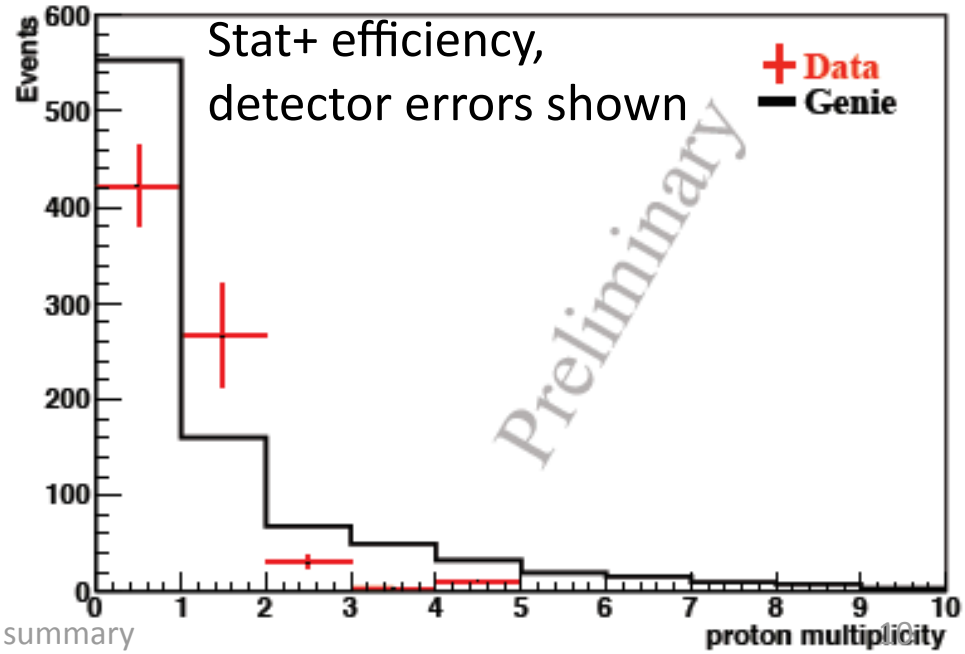

K. Partyka, Friday morning
ArgoNEUT collaboration

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Joint T2K-Minerva-ArgoNEUT interest in understanding protons and neutrons from FSI (affects NCEL measurement and CCQE)

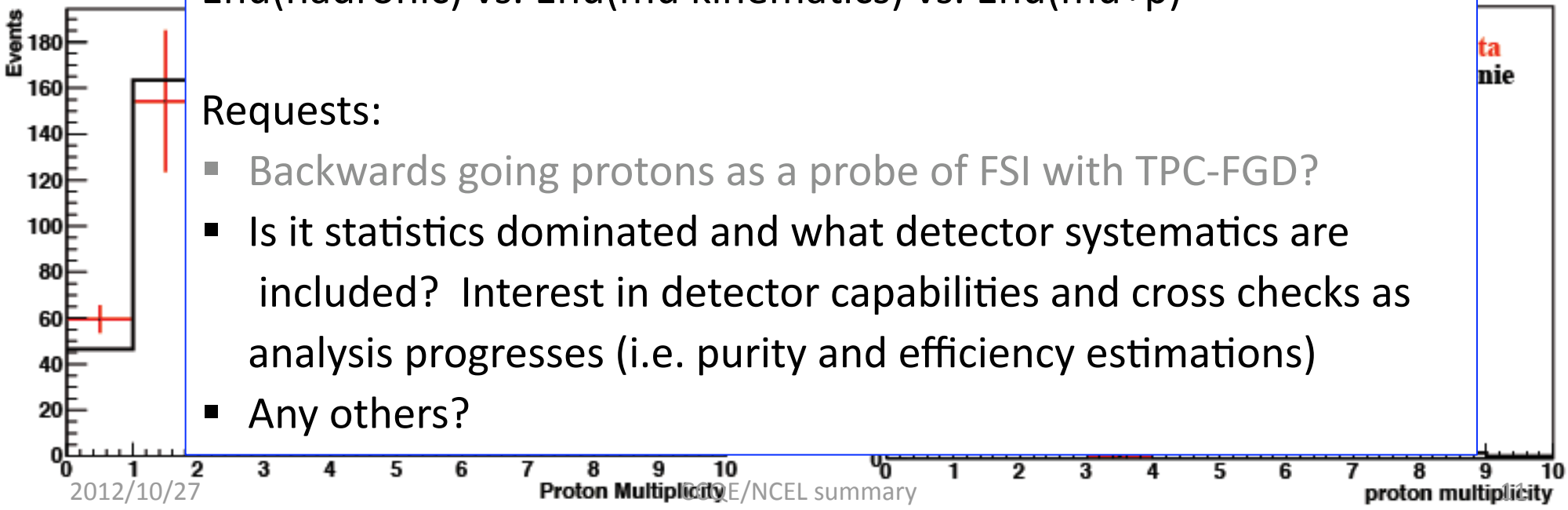
- What handles do we have from data from displaced vertices?
- Do we need a joint FSI program or exchange beyond comparing with GENIE?

Joint ArgoNEUT-Minerva interest in resolving flux uncertainties

Joint ArgoNEUT-Minerva-T2K interest in comparisons of Enu(hadronic) vs. Enu(mu kinematics) vs. Enu(mu+p)

Requests:

- Backwards going protons as a probe of FSI with TPC-FGD?
- Is it statistics dominated and what detector systematics are included? Interest in detector capabilities and cross checks as analysis progresses (i.e. purity and efficiency estimations)
- Any others?



Theoretical results

"I never manage to get to the final part of my talk, but I want to!"
- *Author of 45 wonderful slides, Juan Nieves*

A. Ankowski, Friday morning

Important reminder: MiniBooNE and NOMAD have kinematic overlap for CCQE:

For a neutrino energy of **100 GeV**, **89.8 (97.5)%** of the CCQE cross section comes from the momentum transfer range allowed for neutrino of ***E* = 1 (2) GeV**.

Comparison of MB CC/NC data with NOMAD and spectral function approach

- Multinucleon effect disfavored because it would affect both samples, needs to affect just one selection
- ~20% increase to xsec, independently of nucleon kinetic energy for T > 50 MeV
- Possible reason: MiniBooNE flux normalization issues, supported by excesses in all event samples

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Requests:

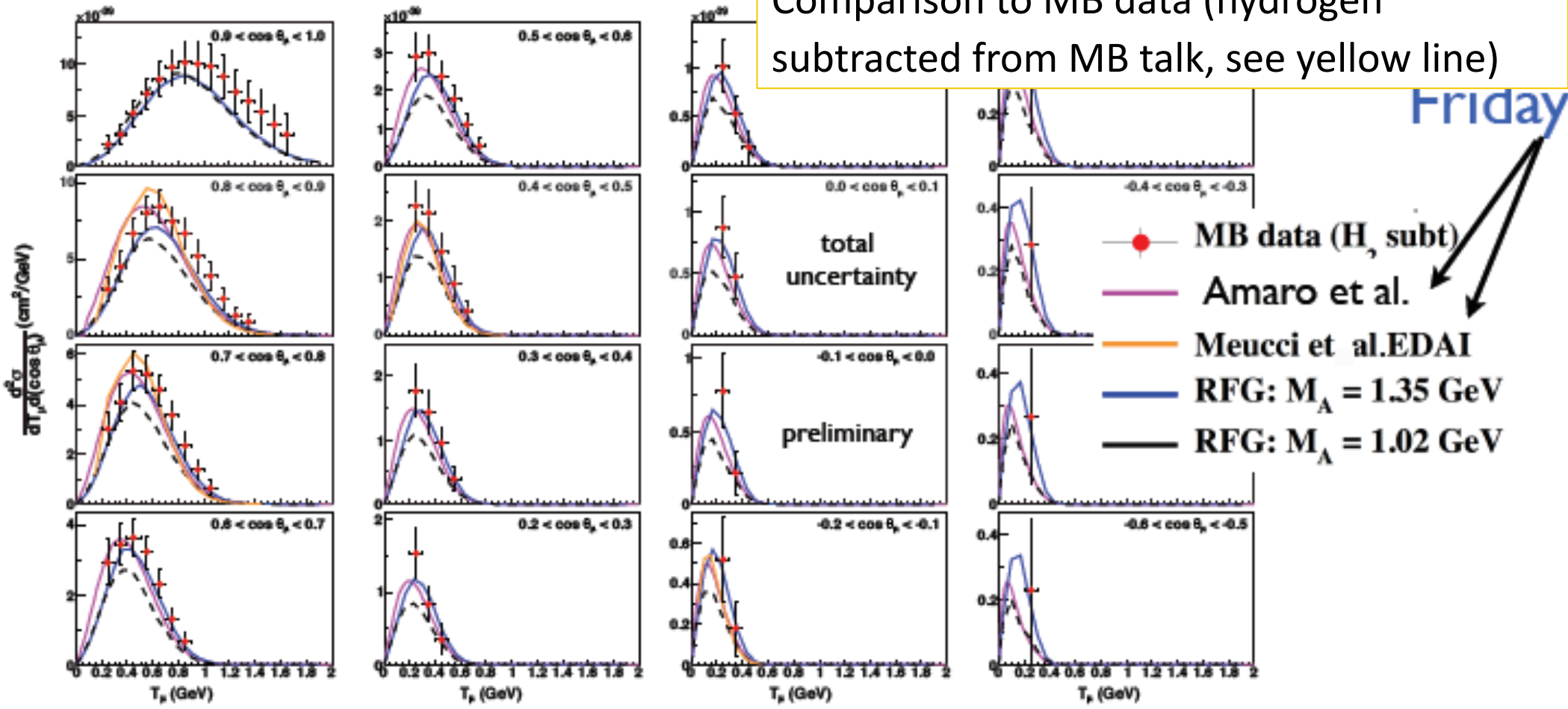
- Unsure of what was fit for the results. Increase of MA(eff) to 1.2 as is assumed may disagree with Q2 distribution from NOMAD. Answer: Did confirm kinematic agreement in Q2 with NOMAD at MA~1.17 GeV
- Please don't scale the data (it may lead to confusion later)
- Any others?

A. Meucci, Friday morning

Relativistic Green's function approach provides a consistent treatment of FSI in inclusive and exclusive scattering

- Good agreement with electron scattering data in QE peak
- Underpredicts ratio of QE nu/nubar vs. Enu (see MB talk)

Comparison to MB data (hydrogen subtracted from MB talk, see yellow line)



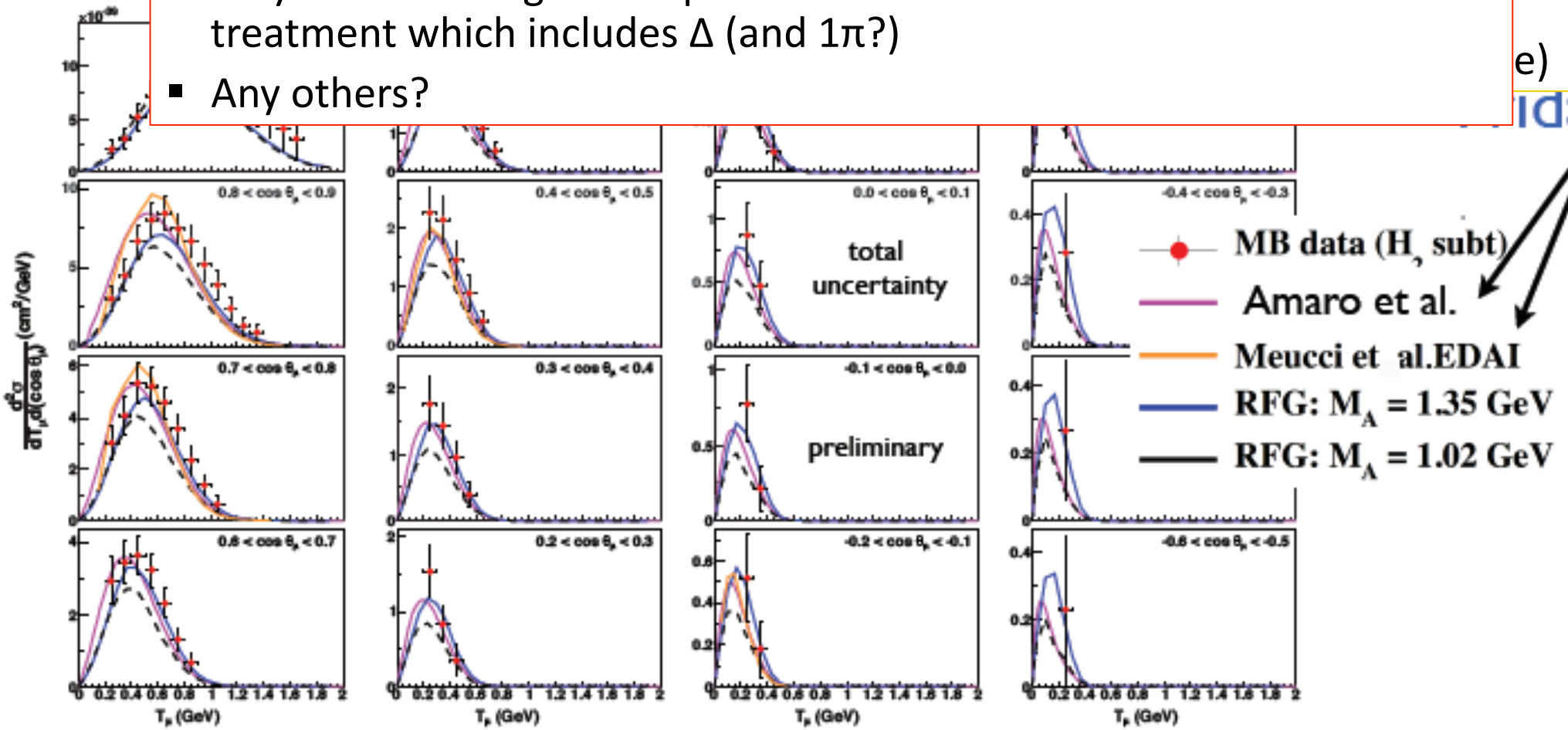
A. Meucci, Friday morning

Relativistic Green's function approach provides a consistent treatment of FSI in inclusive and exclusive scattering

- Good agreement with electron scattering data in QE peak
- Underpredicts ratio of QE nu/nubar vs. Enu (see MB talk)

Requests:

- Maybe interesting to compare to CC inclusive data because of treatment which includes Δ (and 1π?)
- Any others?



J. Nieves Friday morning

State of the art model (Pauli blocking, RPA/SRC, Delta and MEC) agrees with MiniBooNE, electron scattering data better than FG, with M_A=1.08 GeV

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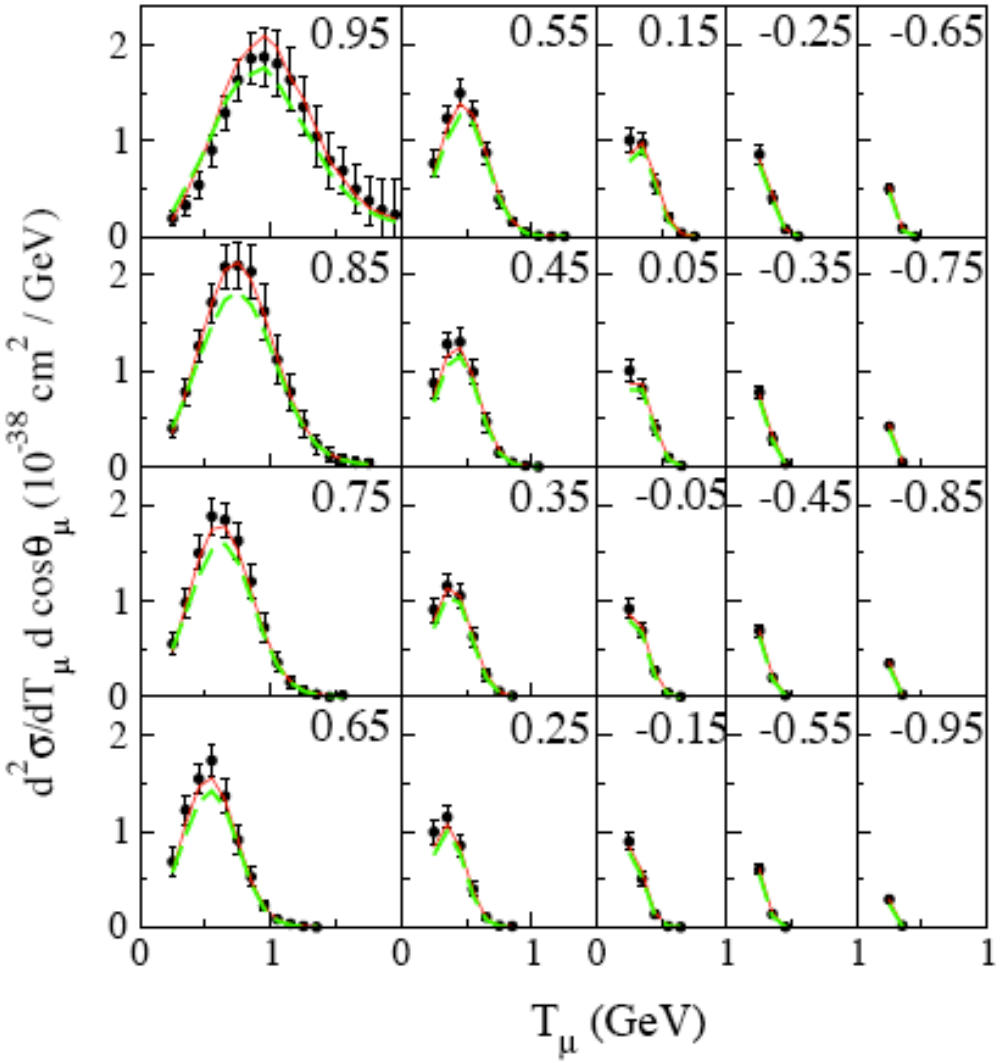
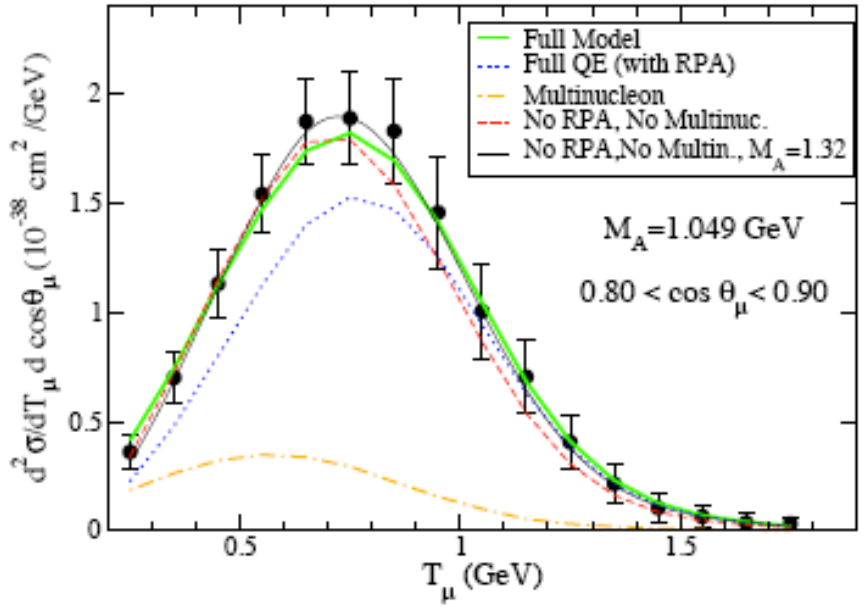
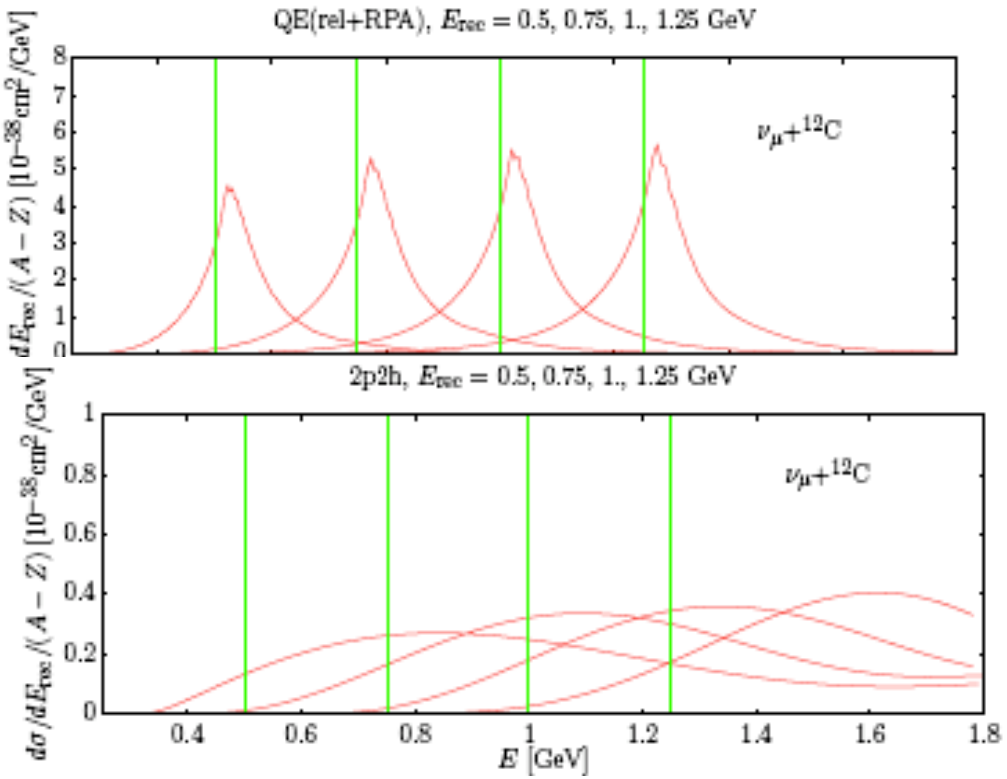




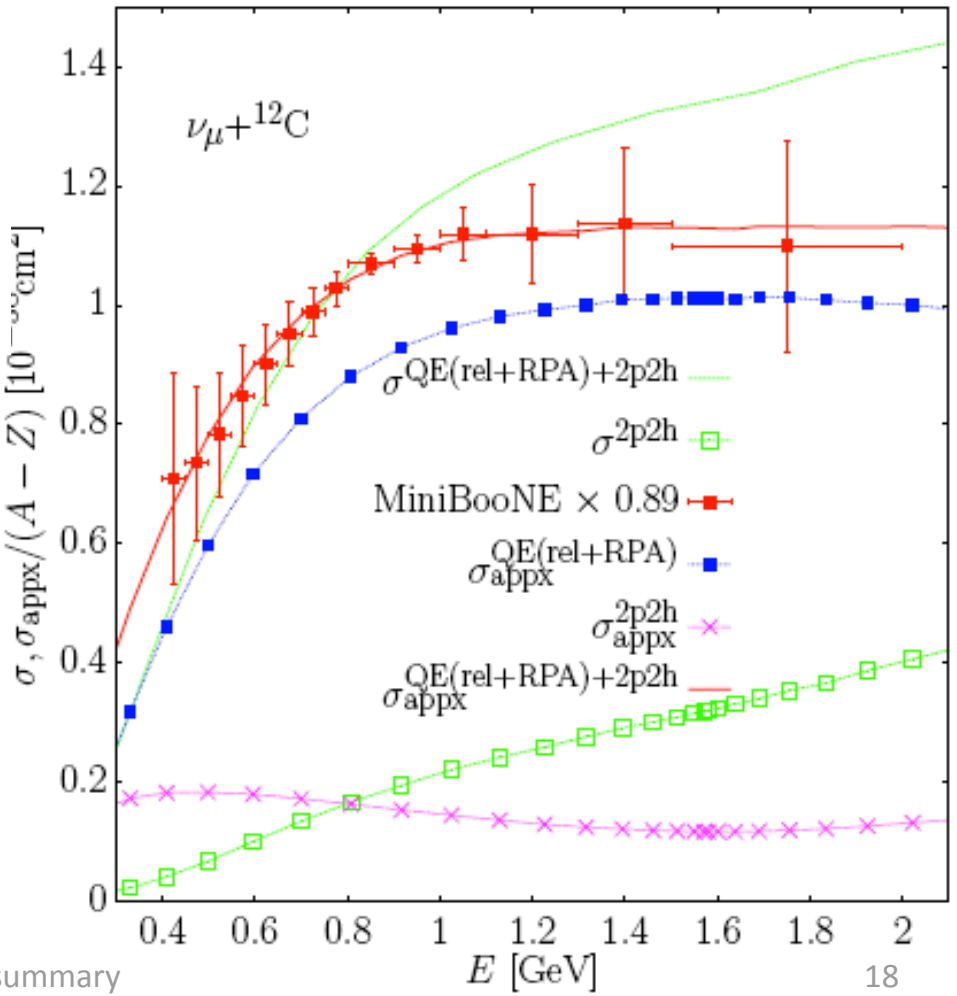
Model	Scale	M_A (GeV)	$\frac{\chi^2}{\#bins}$
LFG	0.96±0.03	1.32±0.03	35/137
Full	**0.92±0.03**	**1.08±0.03**	**50/137**
Full $\|q\| > 0.4^\dagger$ GeV	0.83±0.04	1.01±0.03	30/123

† : As suggested by Sobczyk et al. PRC 82, 045502

J. Nieves Friday morning



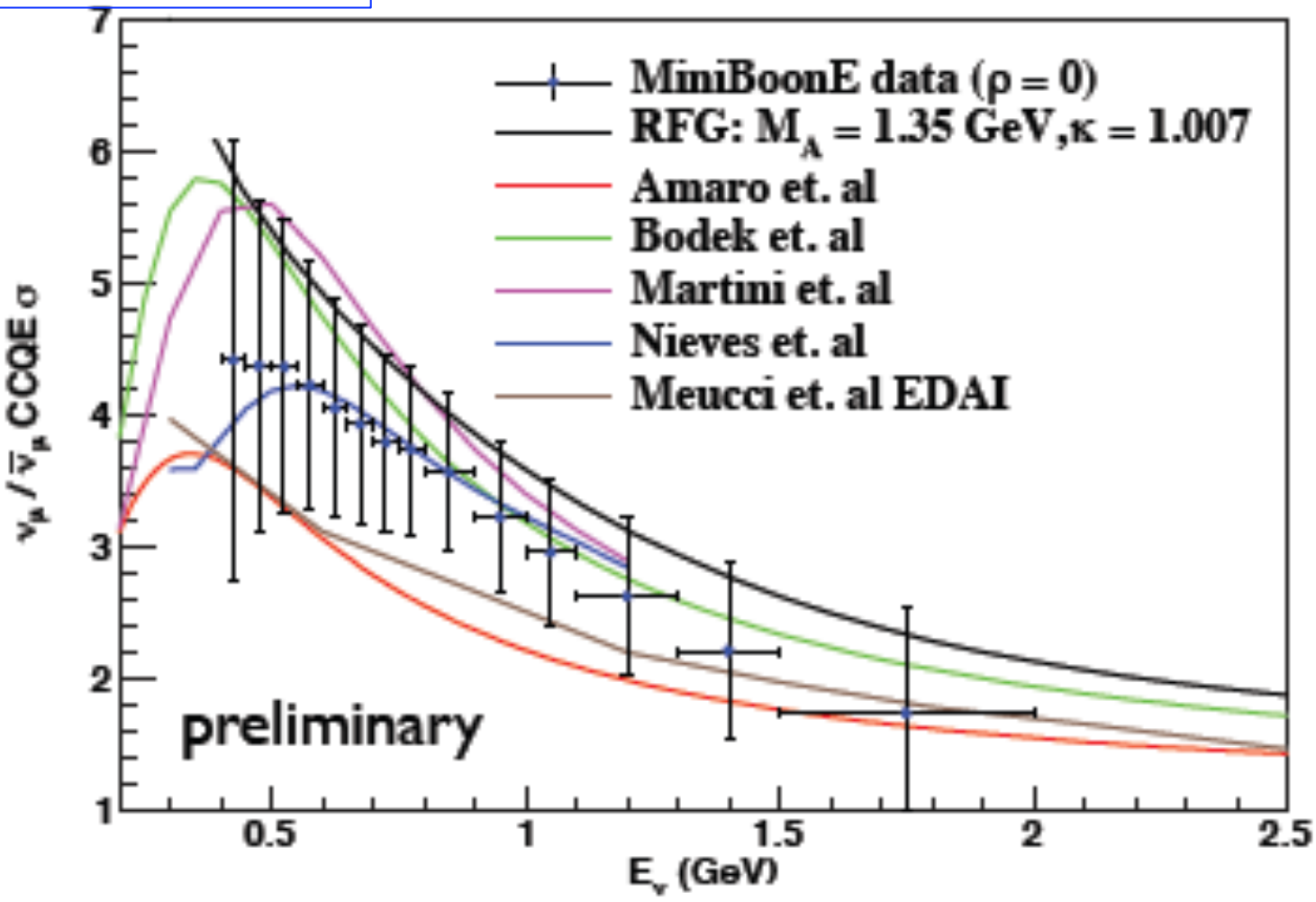
MEC interactions have a broader spread in neutrino energy (true relative to simple reconstructed quantity)



Redo neutrino energy reco-> true unfolding using MiniBooNE differential data with and without MEC components

Agreement within MiniBooNE 10% flux errors, much improved shape dependence

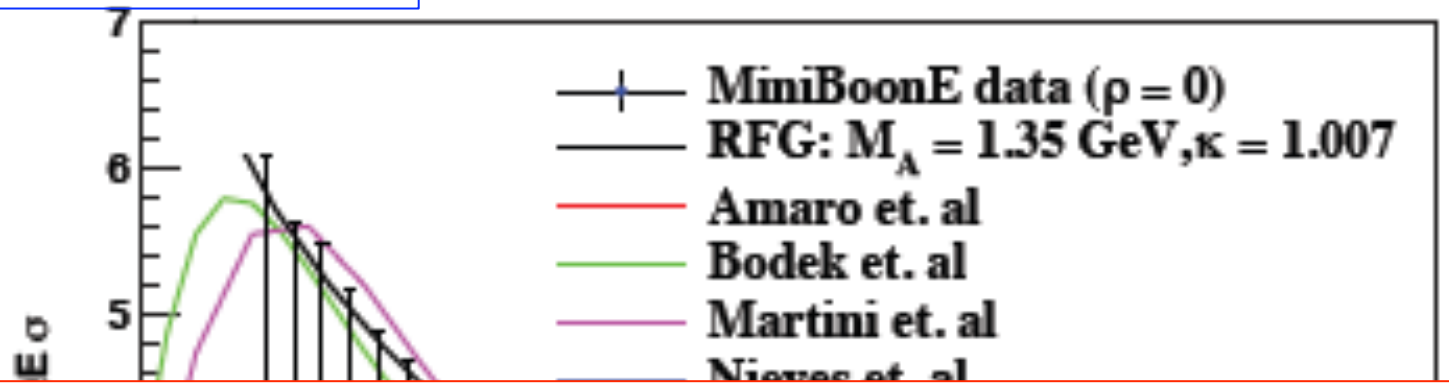
J. Grange, Thursday afternoon



Note that Juan's model (blue) has the same dependence in neutrinos and antineutrinos

- MB MC relationship between true and reconstructed energy is different when you include 2p2h, but this difference is similar for neutrinos and antineutrinos

J. Grange, Thursday afternoon



Requests (experiment for theory)

- Can experimenters provide "Enu-rec" prior to unfolding and is that helpful? Or was using differential p-theta simple or preferred?
- Is it useful for experiments to separate flux uncertainties from detector?
- Please extend this model to higher energies for Minerva
- Please don't scale data points, just the predictions (can lead to confusion later)

Requests (theory to experiment)

- Calorimetric measurements are also helpful antineutrinos
  - MB MC relationship between true and reconstructed energy is different when you include 2p2h, but this difference is similar for neutrinos and antineutrinos

Summary

This workshop has been wonderful, because of the hard work of everyone involved

Are there any other specific QE/EL requests to experiments or theorists about:

- Conventions, terminology?
- Data release and model comparisons?

Is there anything else people are ~~thinking~~ worrying about for QE?

- See considerations for generator development and electron scattering overlap in other sessions

Backup slides