Impact of new neutrino scattering data on GENIE

S. Boyd and S. Dytman
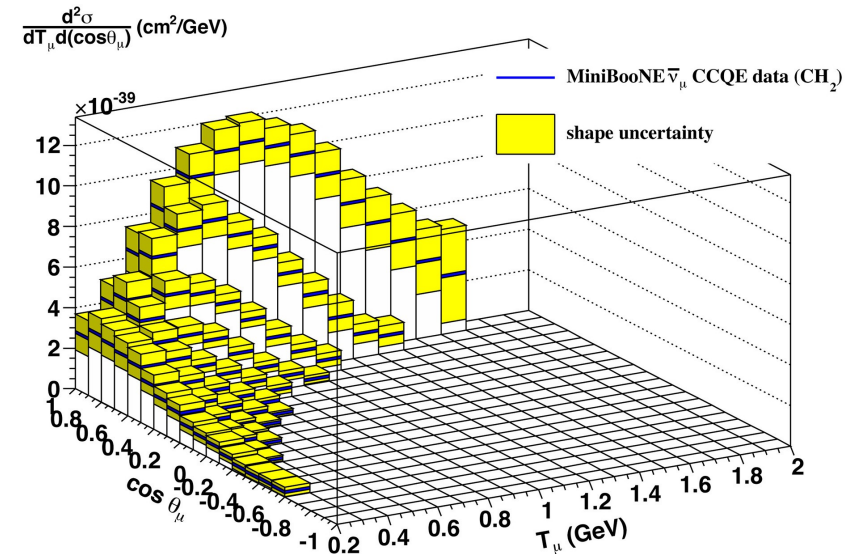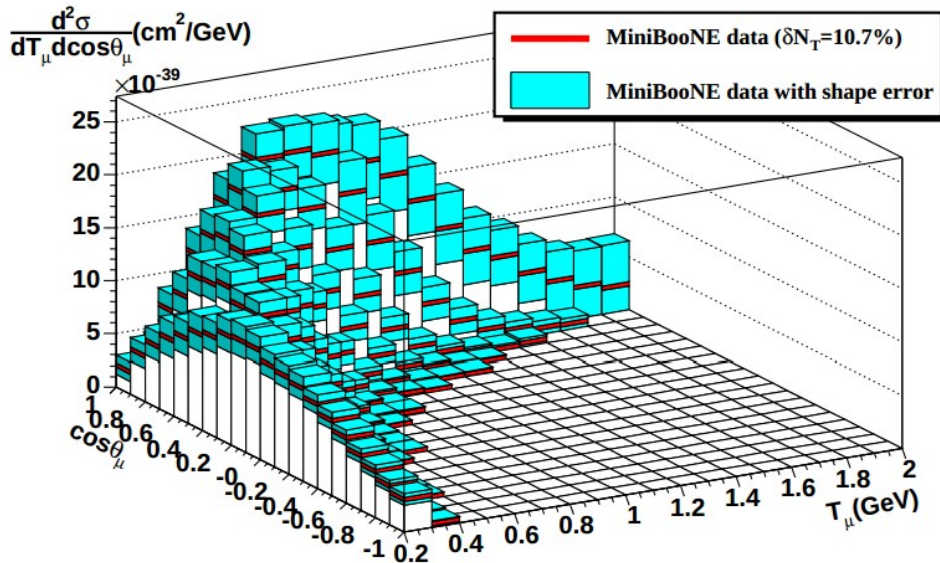
NuFact 14, 28/8/2014

THE UNIVERSITY OF
WARWICK

Introduction

► All modern target/detectors are 'heavy' nuclei- C, O, Ar

► Current generators use a combination of old light target data from the 70's, ad hoc and/or easy-to-implement models

► More precise data now being delivered offers a challenge to model makers and to implementation in generators
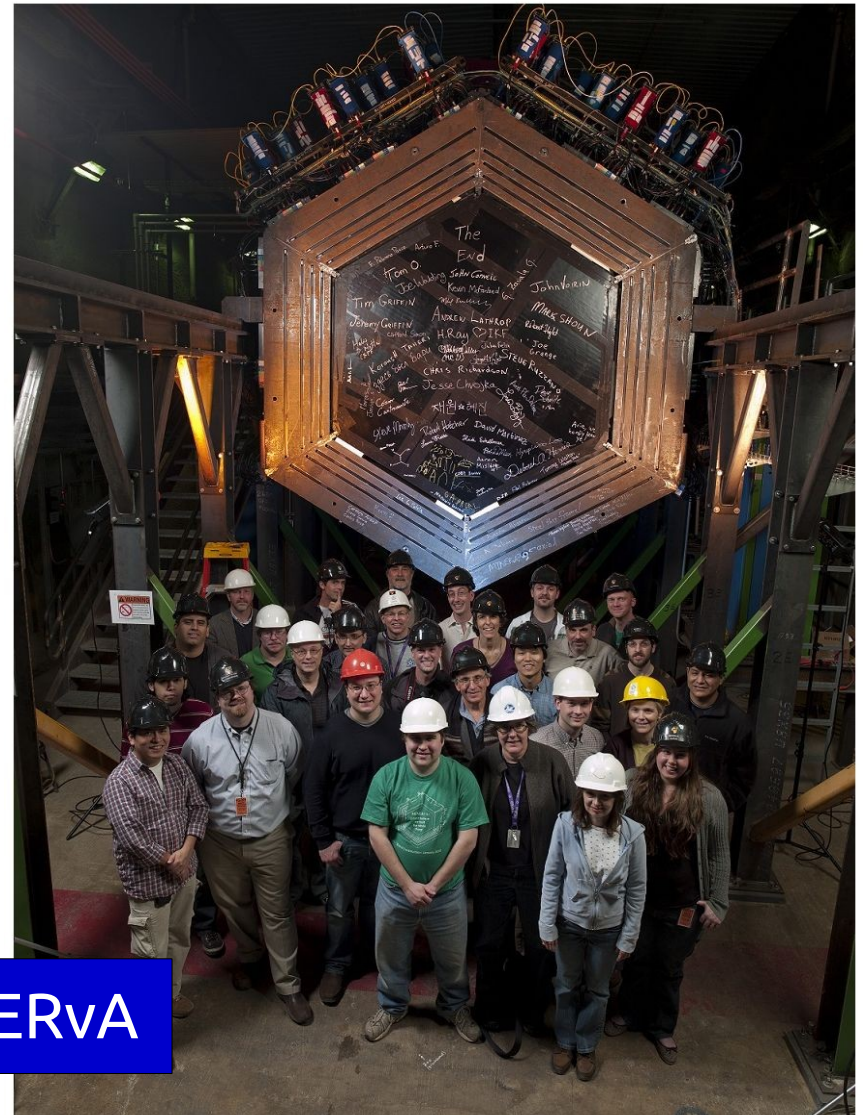
MiniBooNE

MiniBooNE published the first , high statistics, doubly differential cross-section data @ 1-2 GeV

This data has been hugely valuable in trying to understand neutrino interaction models.

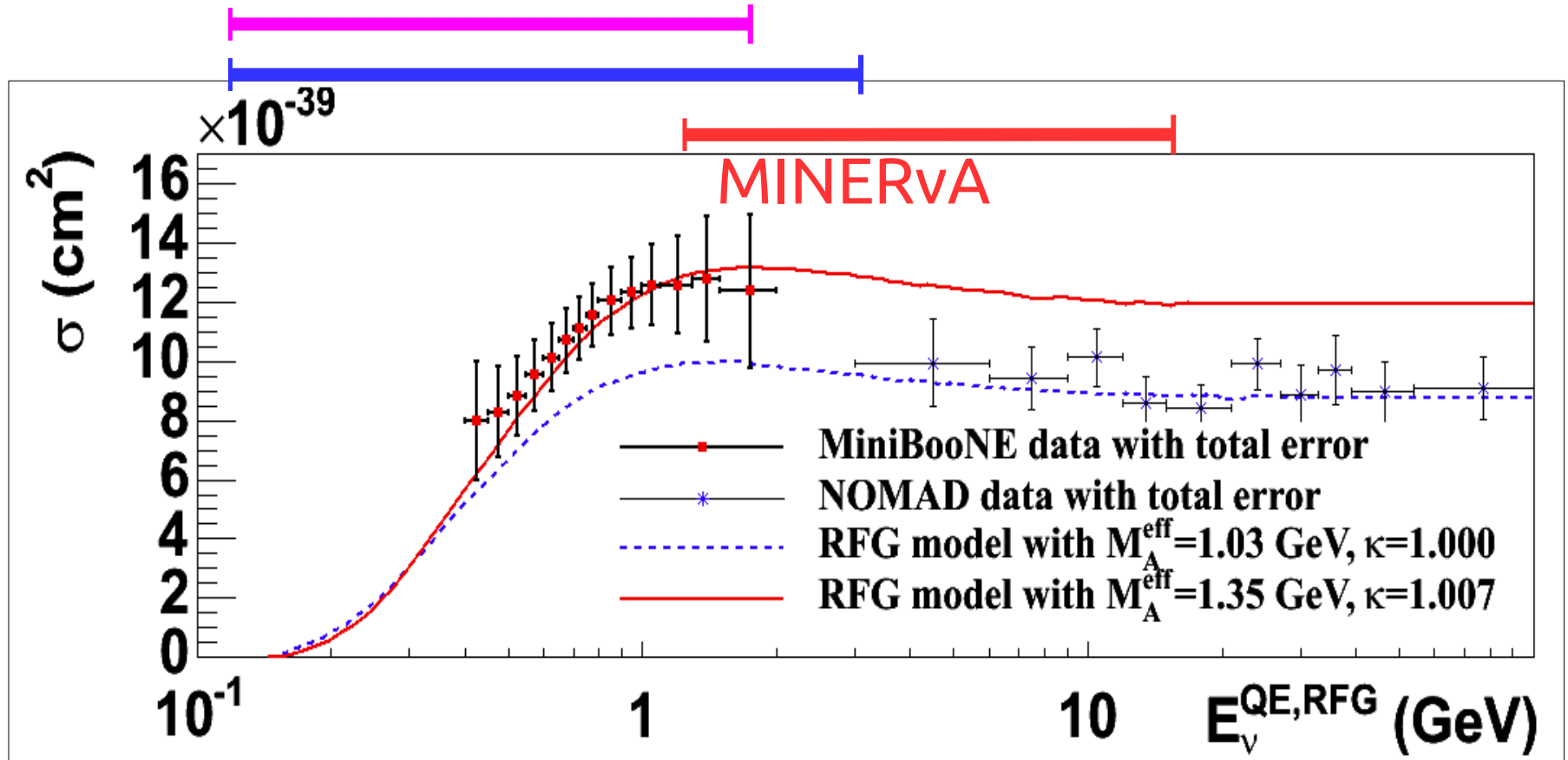# Experimental programme

Argoneut

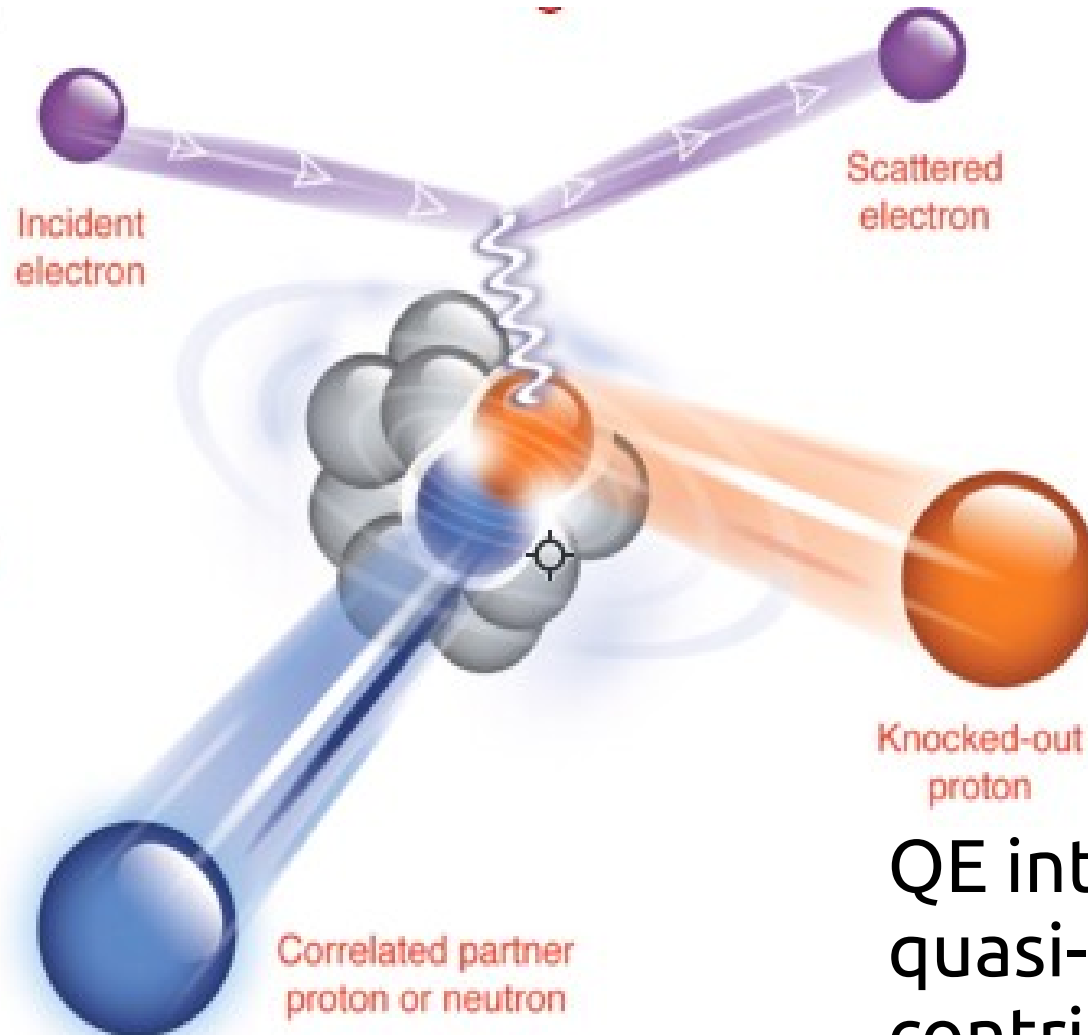MINERvA

Quasielastic questions

Motivation

T2K on (off) -axis

MINERvA

- ▶ Definition of "signal"?
- ▶ Inclusion of extra nuclear processes
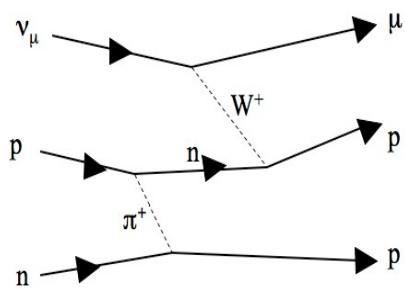
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Experimental Focus : NN-correlations

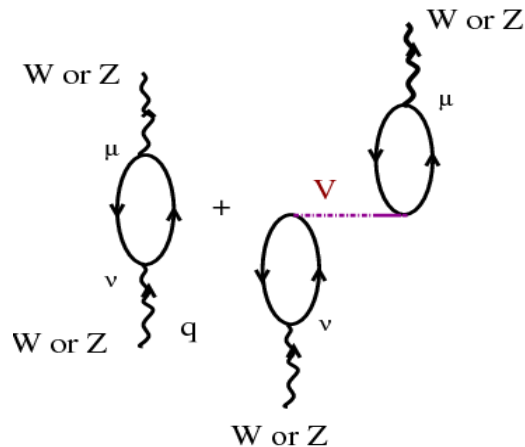QE interactions off quasi-deuterons can contribute to the observed QE signal
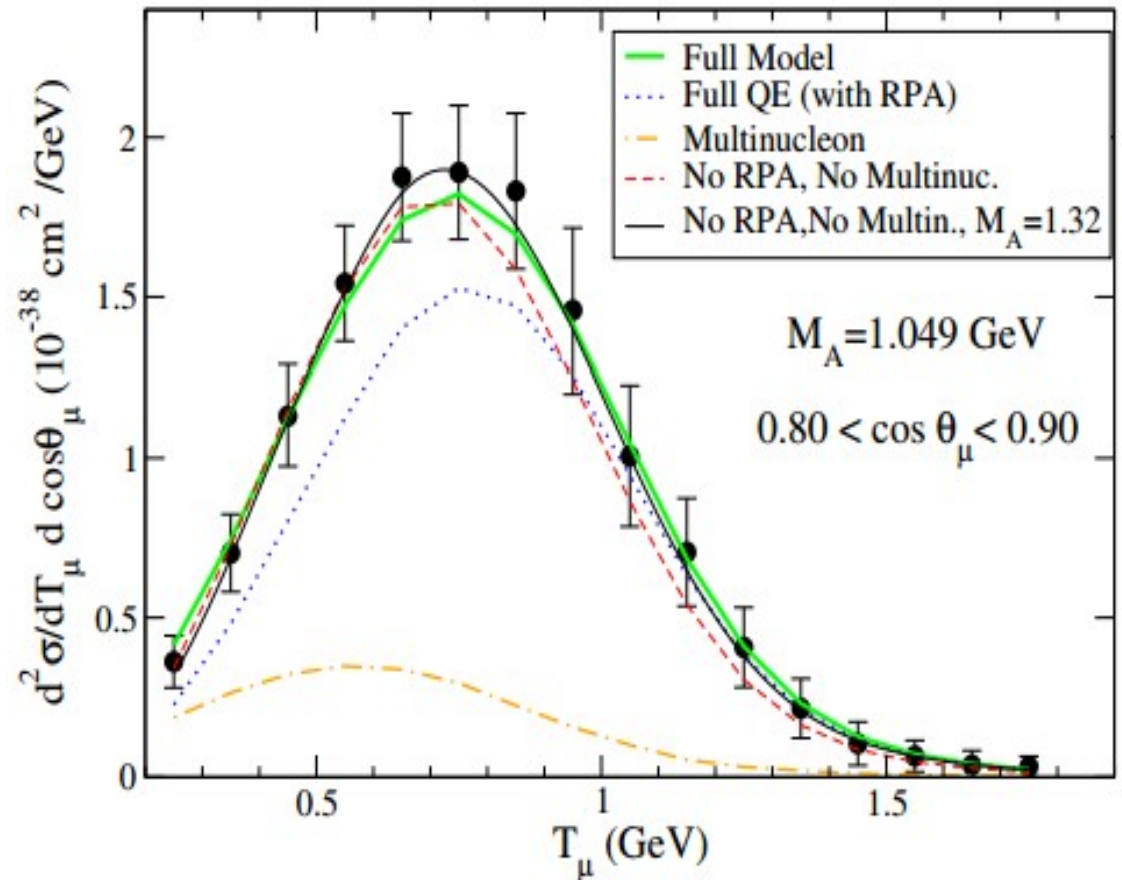
GENIE model : In development (2.10)

▶ Valencia model : Local Fermi gas + RPA + MEC + Delta
▶ Nuclear model with full correlations validated against electron and neutrino data

MEC

RPA

Full Model
Full QE (with RPA)
Multinucleon
No RPA, No Multinuc.
No RPA, No Multin., M_A=1.32

M_A=1.049 GeV

$0.80 < \cos\theta_\mu < 0.90$

$d^2\sigma/dT_\mu\, d\cos\theta_\mu$ (10^{-38} cm^2 /GeV)

T_μ (GeV)

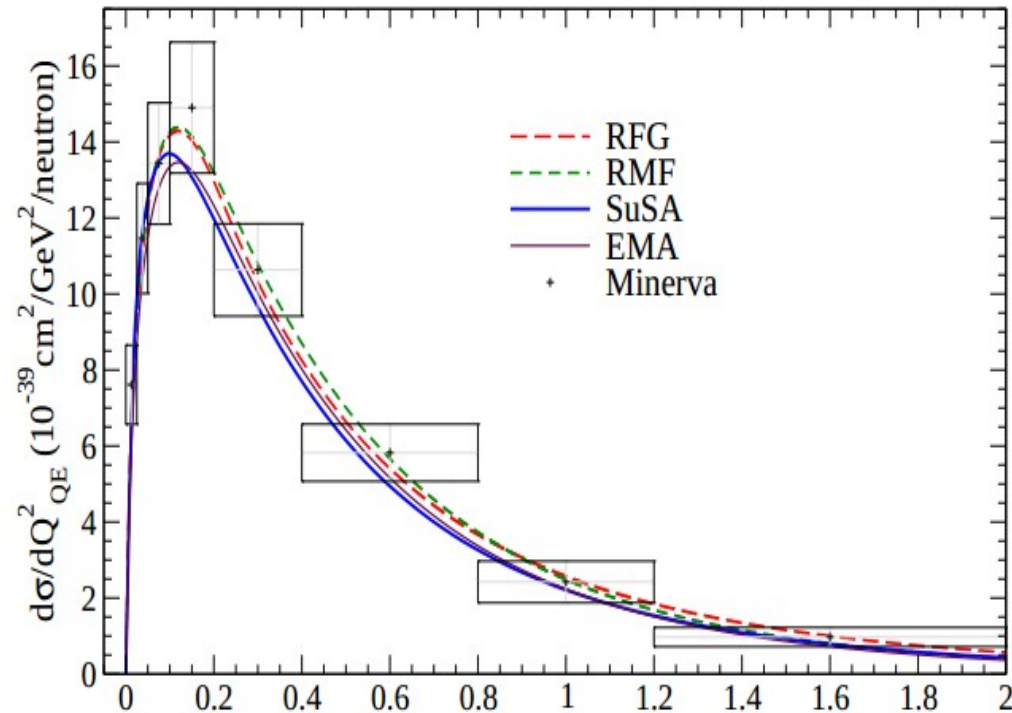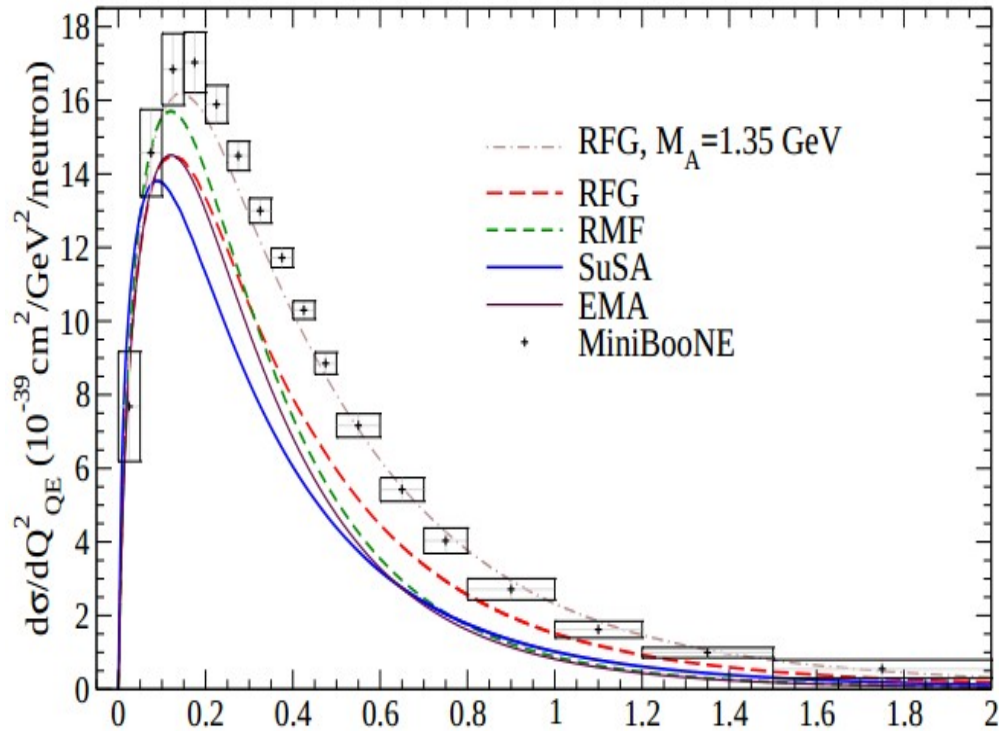*Gran et al, Phys Rev D 88, 113007*   8

Other options are available

miniBooNE

MINERvA

Superscaling model + 10-15% MEC : matches wide range of (e,e') data
Relativistic Mean Field calculation : microscopic model with no MEC

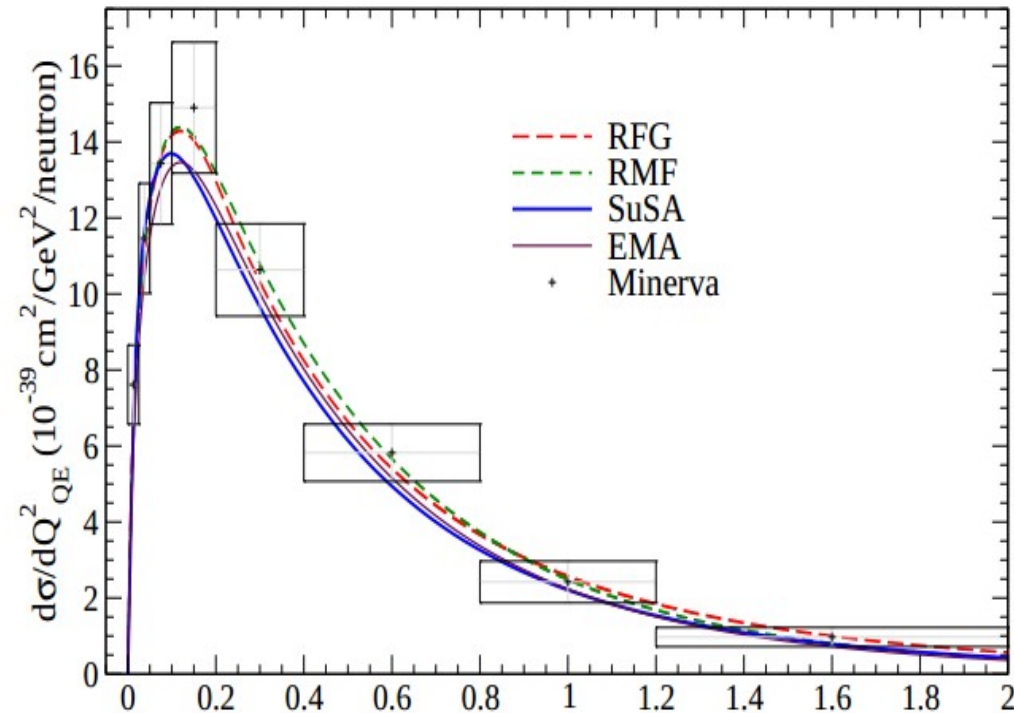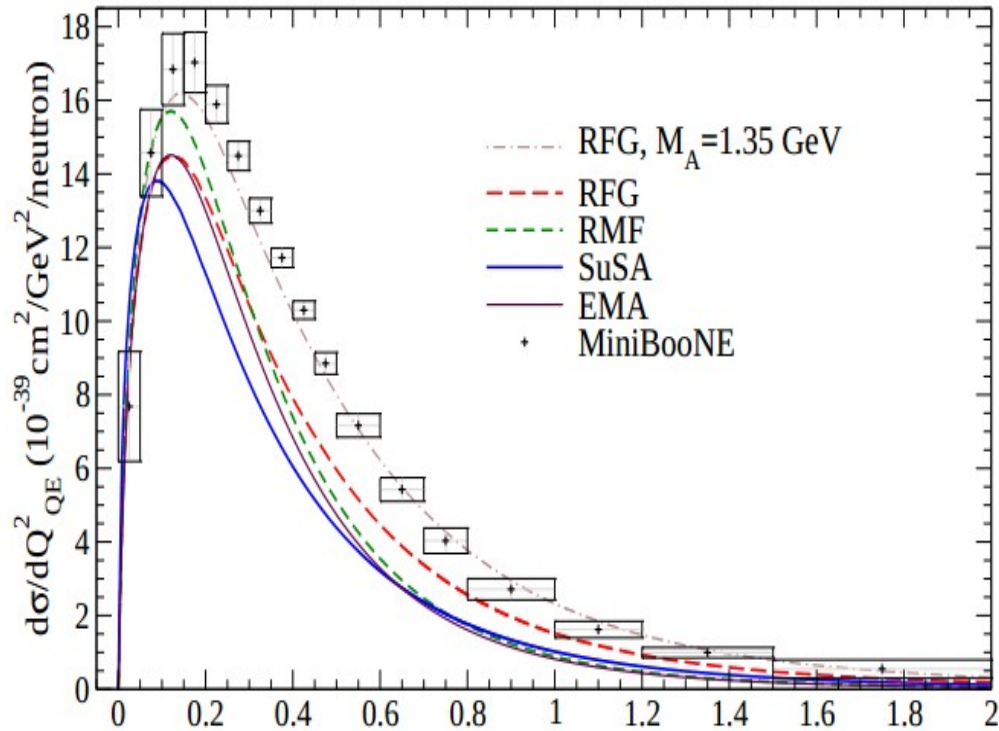Amaro et al, Phys. Rev. C 71 015501
Megias et al., nucl-th 1402.161

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Other options are available

miniBooNE

MINERvA

miniBooNE data needs 20-30% additional MEC to agree
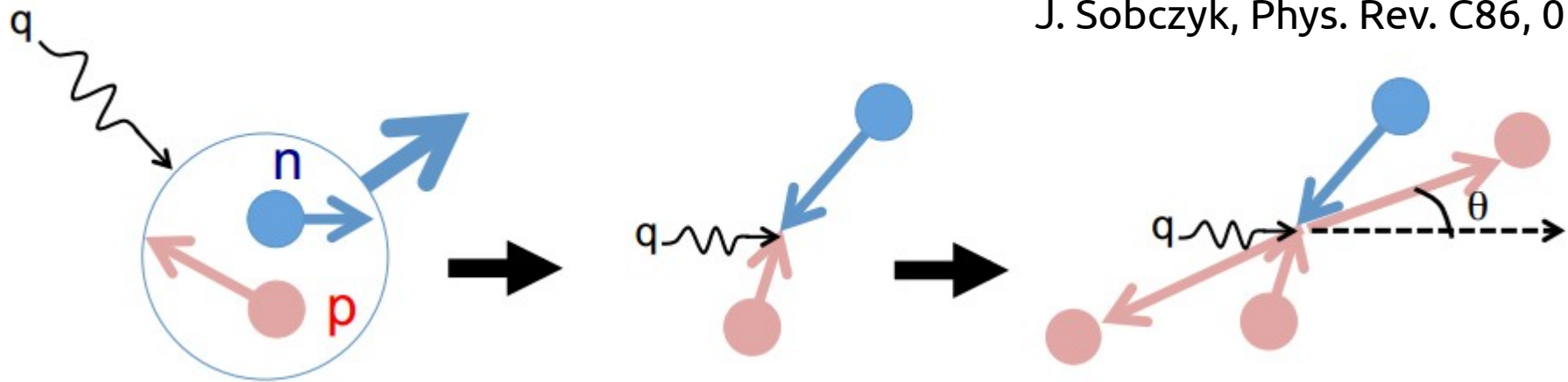
MINERvA is consistent with SUSA & RMF

Hadron kinematics

▶ Event generators also need to have a model of the hadronic side of the interaction.

▶ For MEC GENIE (and others) implement a nucleon cluster model

(T. Katori, Nuint 12
J. Sobczyk, Phys. Rev. C86, 015504)

▶ Prediction about kinematics of secondary nucleon
▶ Is this right? Need some data on the hadronic final state.

Observation of extra nucleons

▶2p2h processes can eject an extra nucleon

▶Observation of extra nucleon multiplicity in CCQE-like events could discriminate Impulse approximation (IA) based models (SUSA,RMF) from 2p2h

▶and would aid generation of the event 4-vectors in generators

▶Sensitivity to the local environment around the primary vertex would be useful

   ▶ ArgoNeut (& microBooNE) can image the vertex

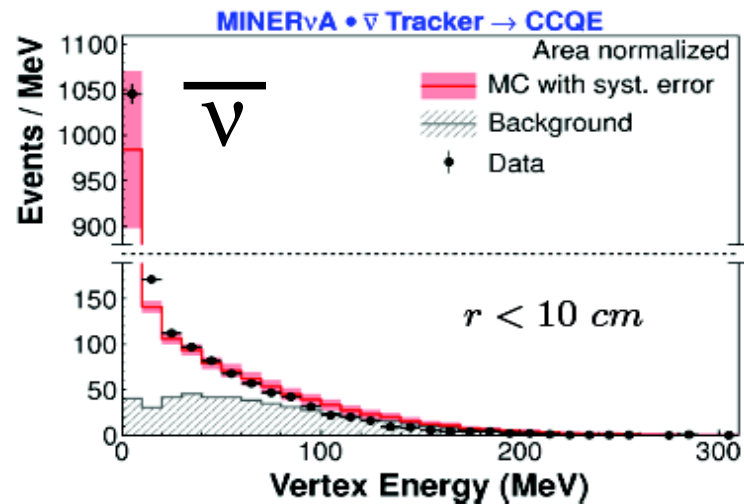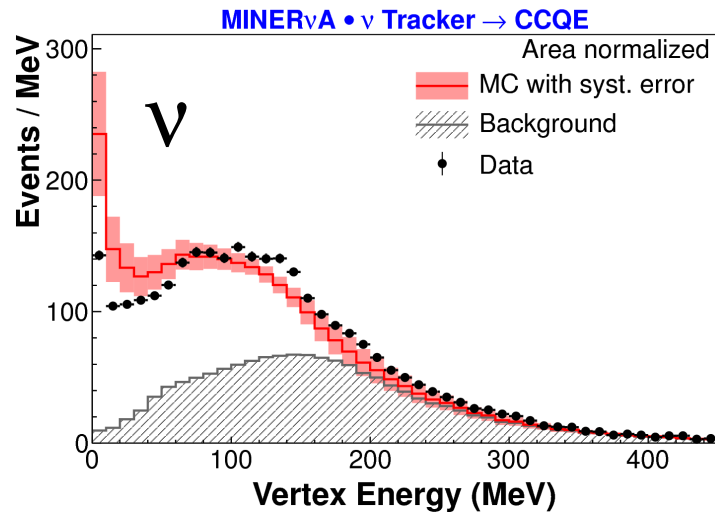   ▶MINERvA (& T2K) can measure vertex activity

Argoneut

▶ one of 4 "hammer" events in μ + 2p topology
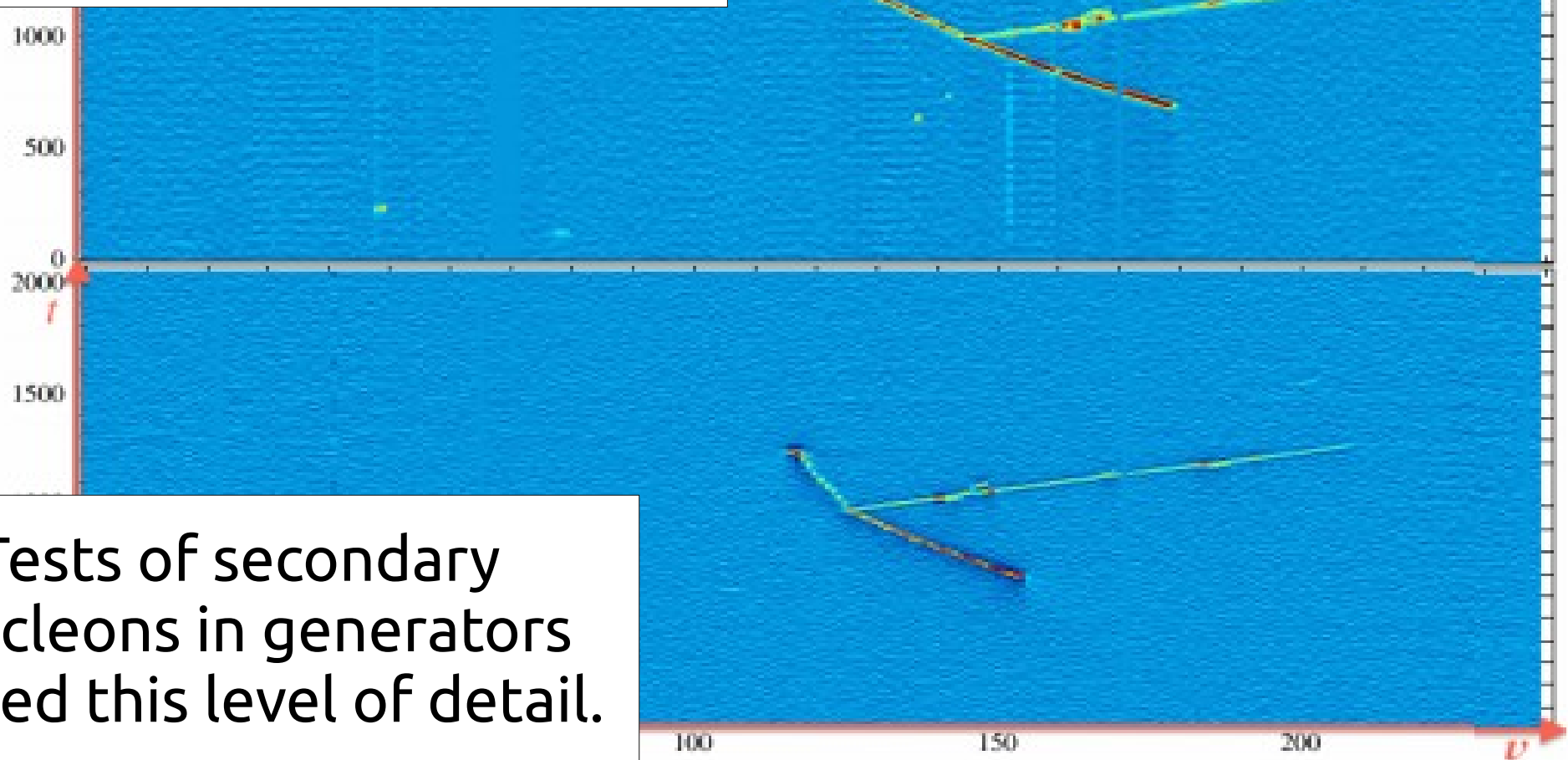
▶ Tests of secondary nucleons in generators need this level of detail.

Minerva

2p2h interpretation

Sum of bins: 0.25 ± 0.01 ± 0.09

Figure: Fraction of CCQE events vs. Proton Kinetic Energy (MeV), ν_μ
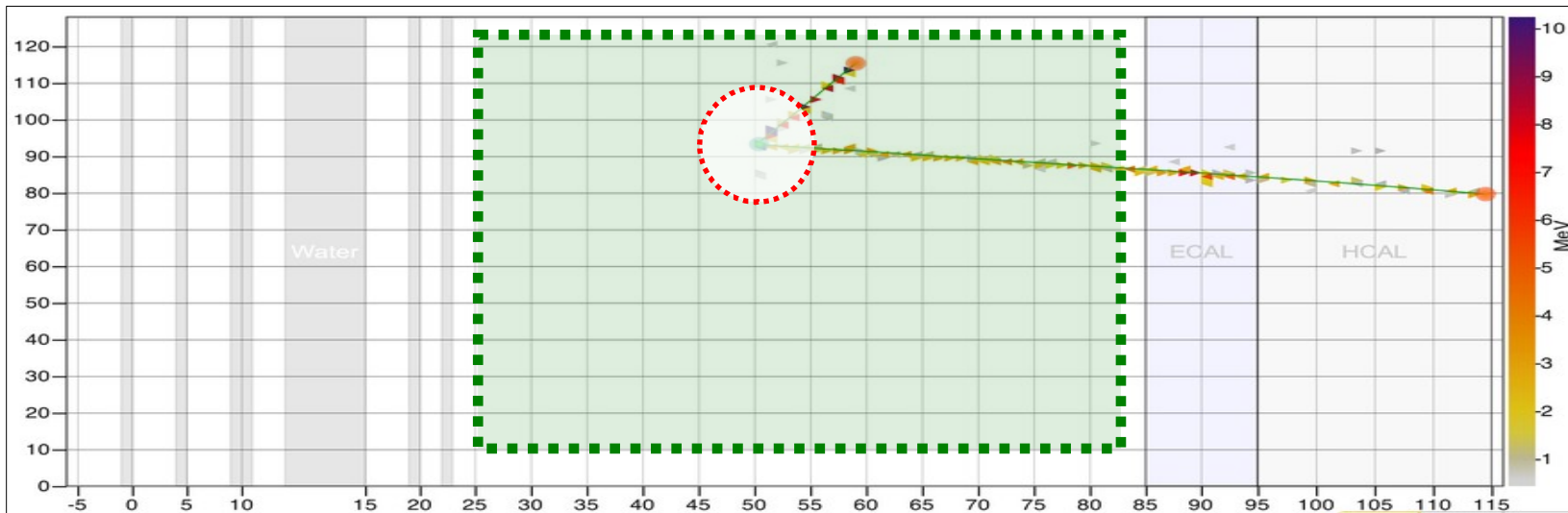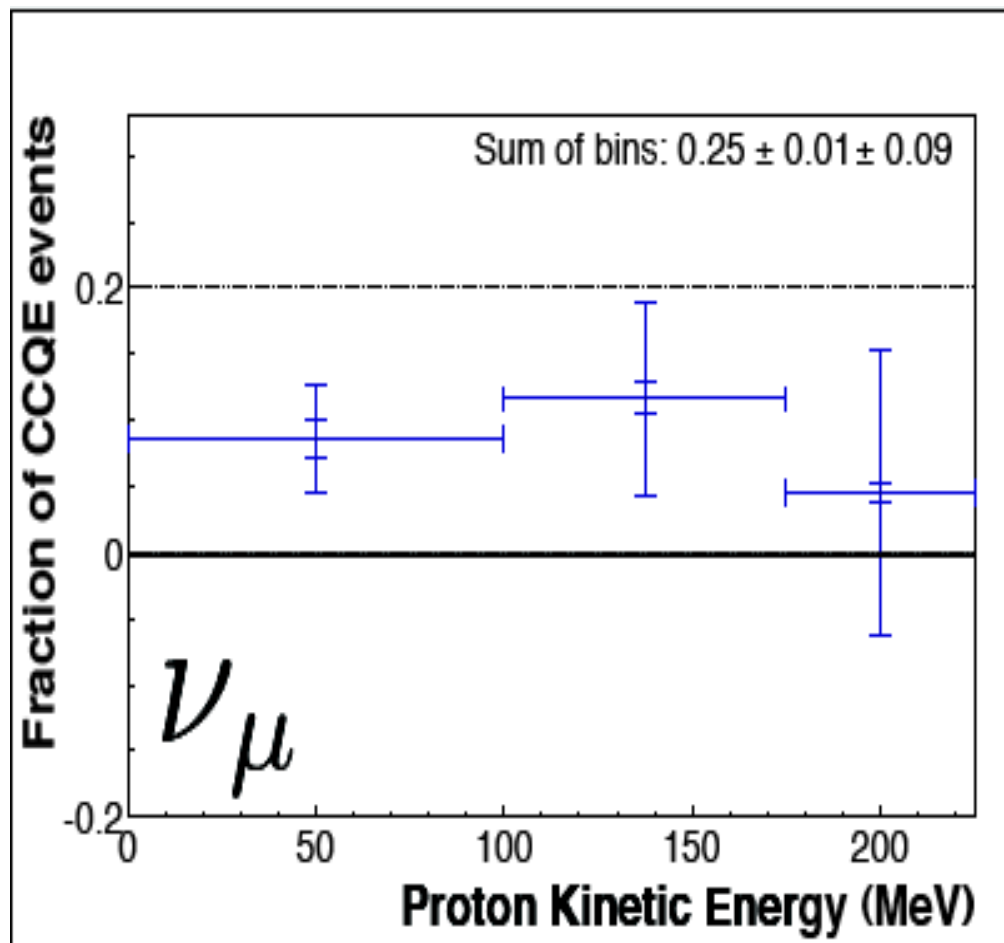
- ▶ Extra vertex activity only seen for ν

- ▶ Consistent with a proton knockout from *np* correlated pair

- ▶ Adding an additional proton with kinetic energy < 225 MeV to (25 ± 9) % of QE events improves data/MC agreement

Summary I

▶ Discrepancy between miniBooNE (@ 1 GeV) and NOMAD (@ 10 GeV) has led to an exploration of additional processes taking part in the CCQE-like cross section measurements

▶ NN processes are the experimental focus

▶ Other processes / models could also contribute

▶ New experiments can image the vertex with unprecedented precision (Argoneut, MINERVA) and can help disentangle the jungle of possible models

▶ gas TPC data would be very valuable
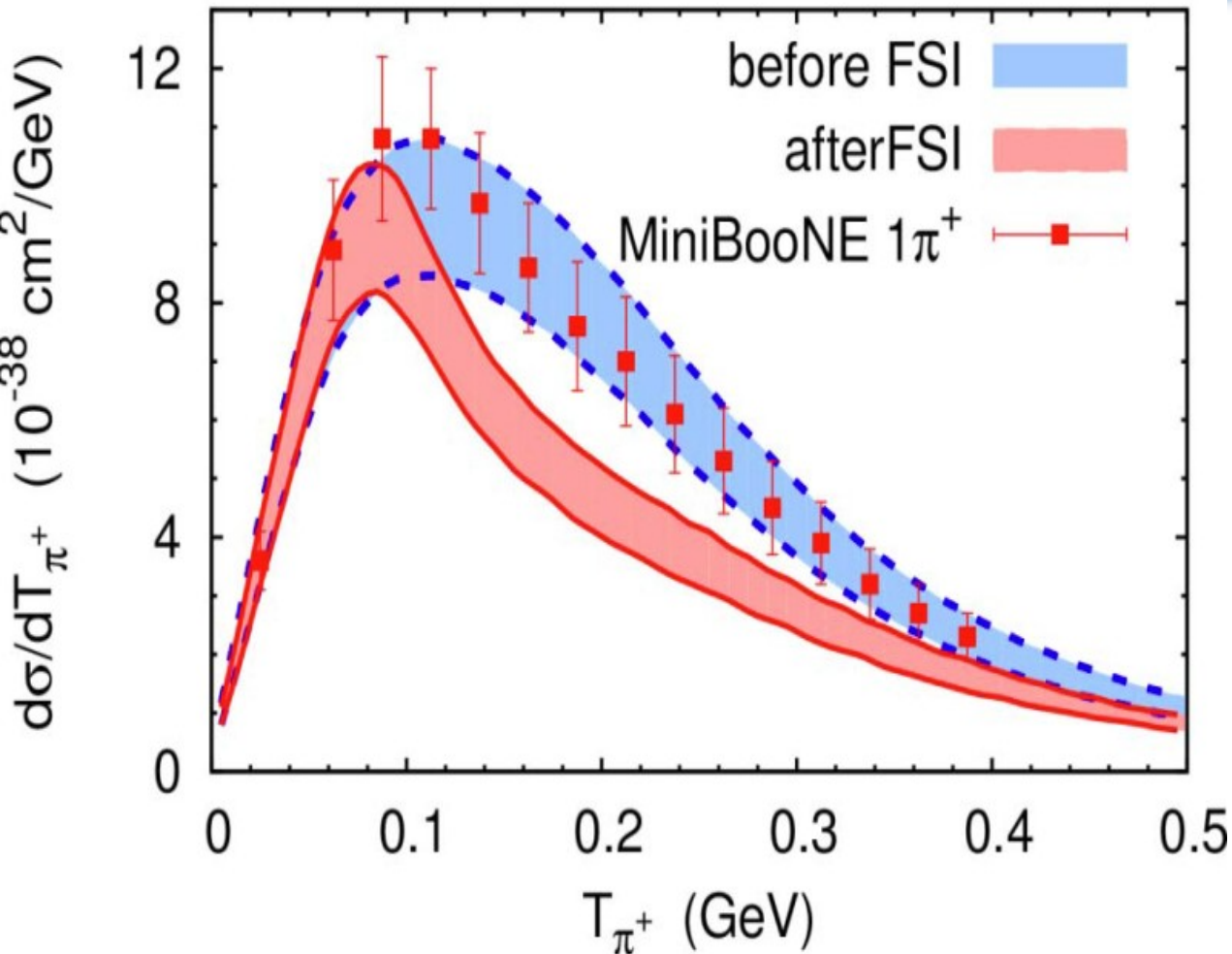
Pion Puzzles

miniBooNE
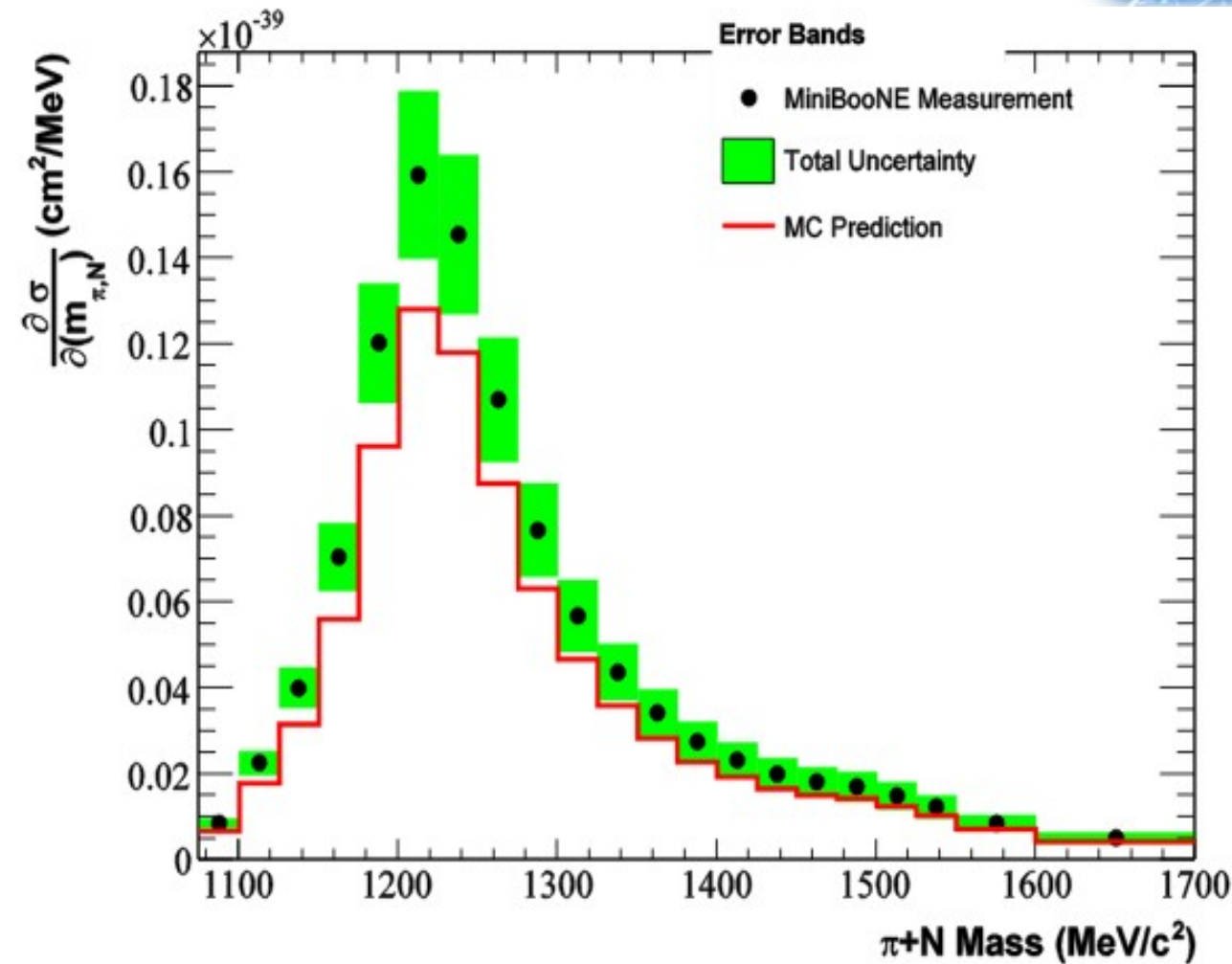
- ▶ First detailed differential cross-section for resonant pion production

- ▶ 1 π , 1 μ and no other visible mesons

- ▶ Background prediction from NUANCE generator

A. A. Aguilar-Arevalo et al, Phys Rev D 83, 052007 (2011)

FSI puzzle

- Comparison with GIBUU generator with and without FSI

- Model with FSI disfavoured!

GiBUU: O. Lalakulich and U. Mosel, PRC 87, 014602 (2013)
NuWro: T. Golan, C. Juszczak, J. Sobczyk Phys Rev C80, 15505 (2012)
Nieves: E. Hernanadez, J. Nieves, M.Vicente Vacas, Phys Rev D87, 113009 (2013)

Model Comparisons

P. Rodrigues [hep-ex] arXiv:1402.4709

π absorption in medium
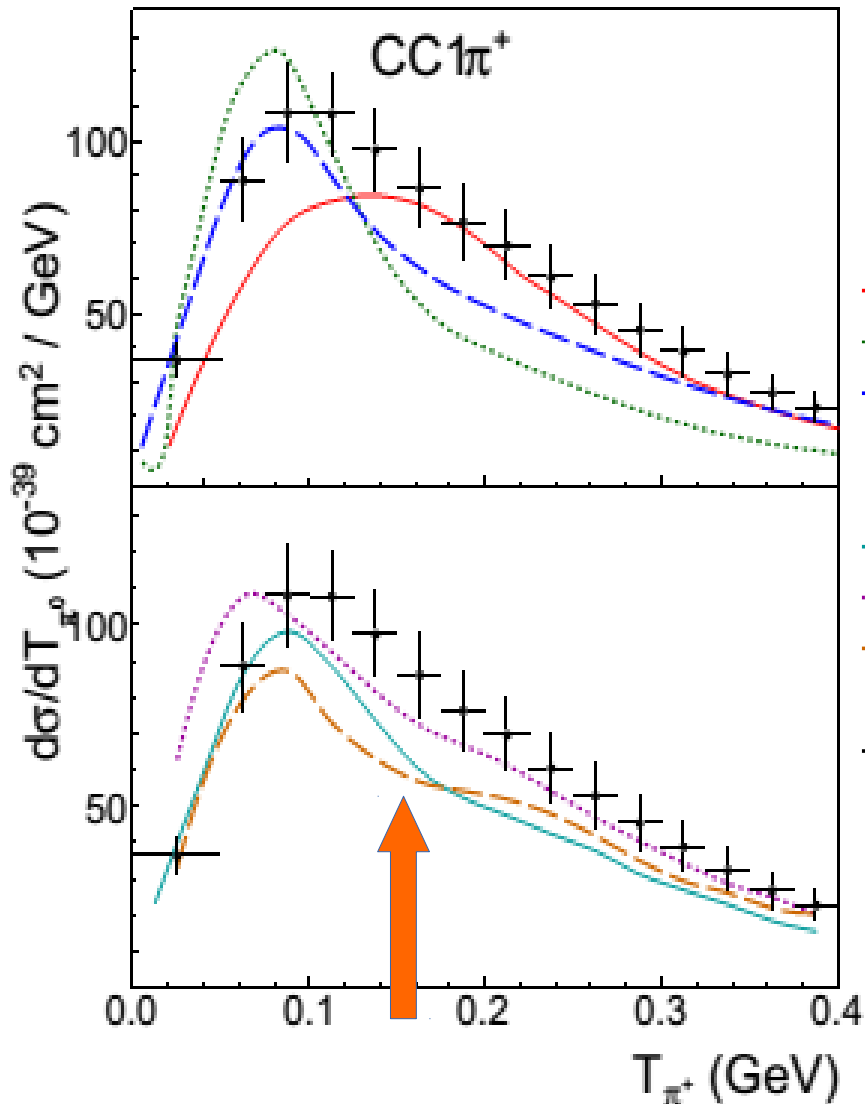
- ▶ Models disagree in
  - ▶ Shape
  - ▶ Normalisation for $T_\pi > 0.1$ GeV

- ▶ Slightly better agreement in shape for generators

- ▶ Most models/gens exhibit a dip around 0.2 GeV indicative of π absorption

- ▶ MB data does not seem to exhibit this

MINERνA

DATA Event

Strip number

μ candidate

ECAL   HCAL

p candidate

π candidate
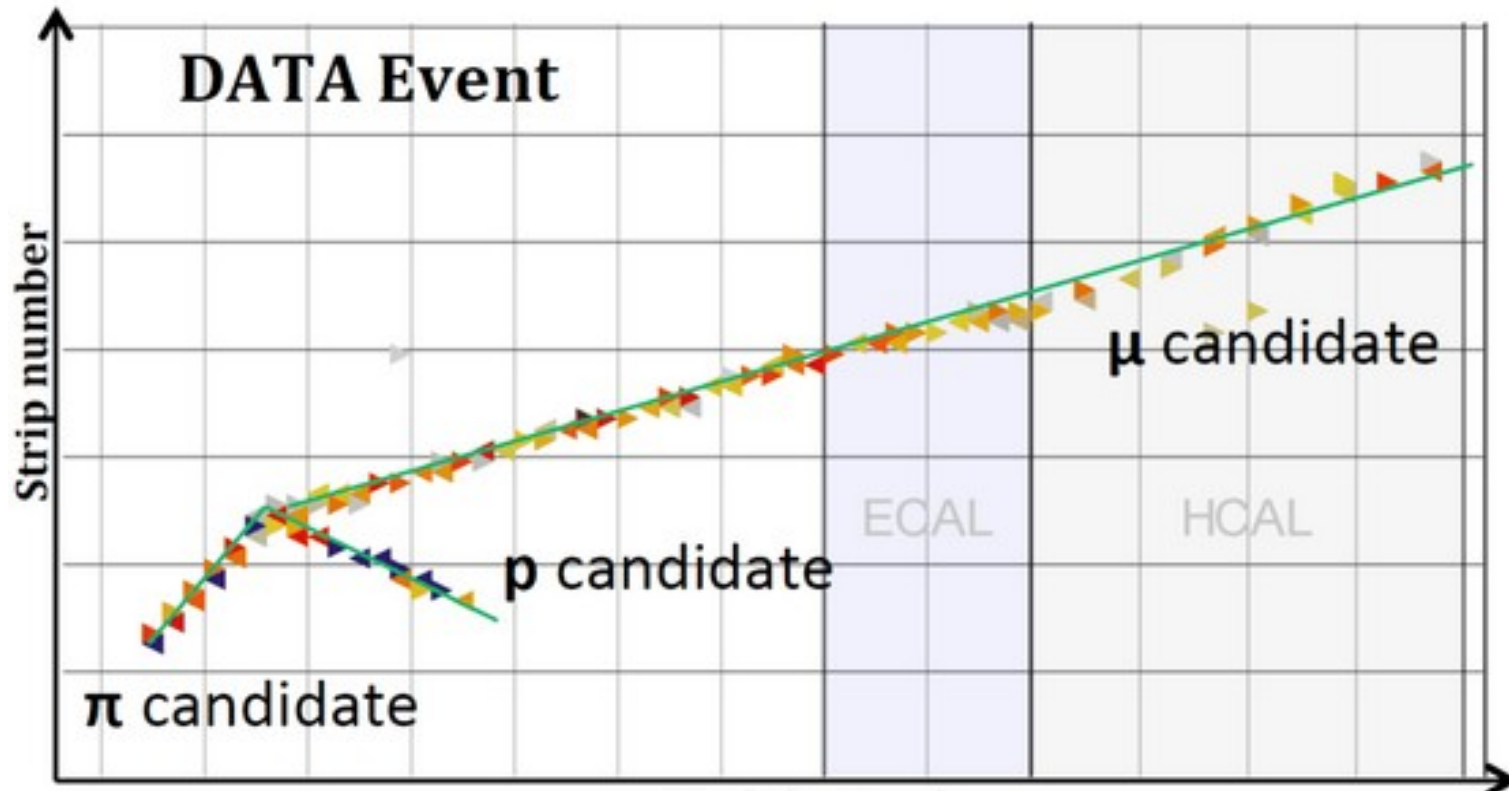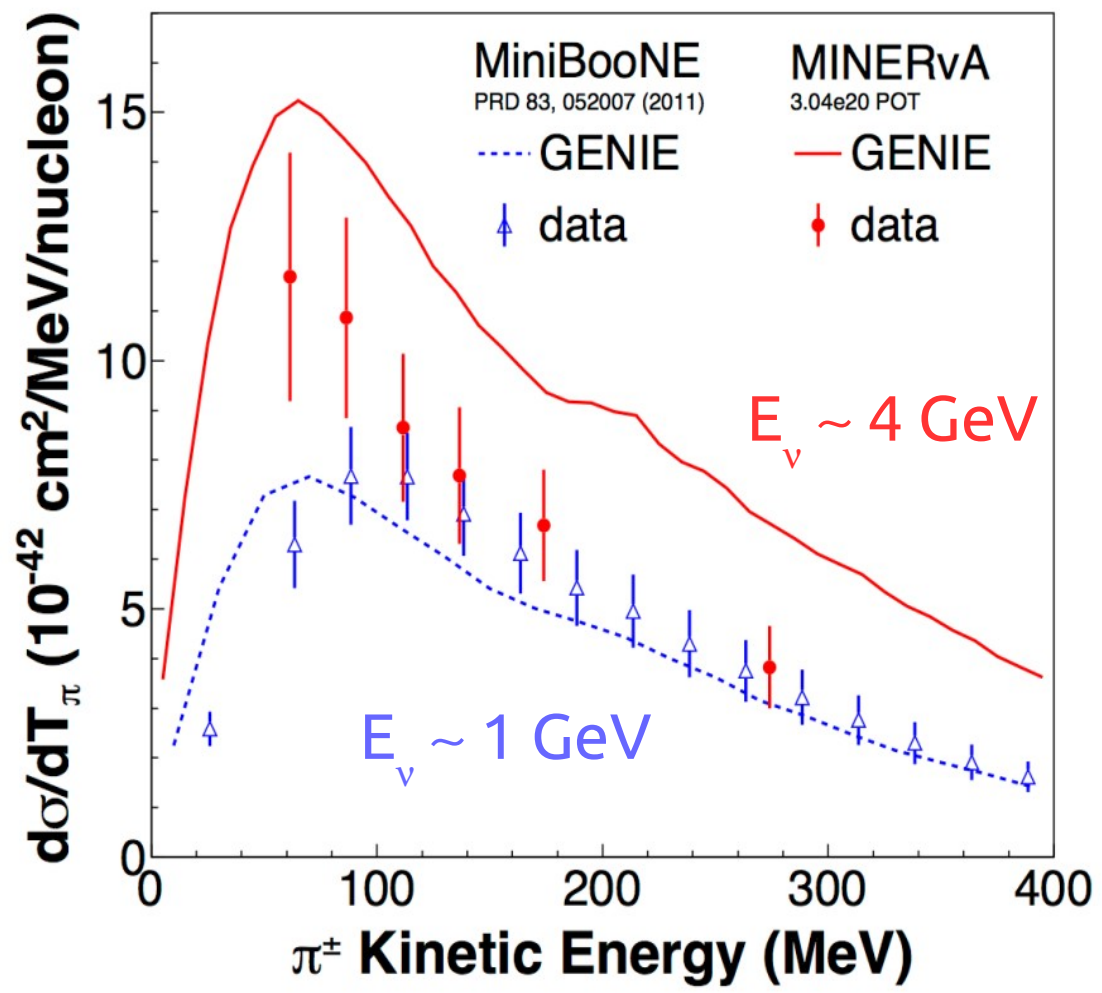
▶ Average neutrino energy of 4 GeV, but Q^2 range comparable to miniBooNE (< 2 $(GeV/c)^2$)

▶ 1 μ , 1 π and other hadrons

▶ Background estimate from data-driven template fit

MINERνA
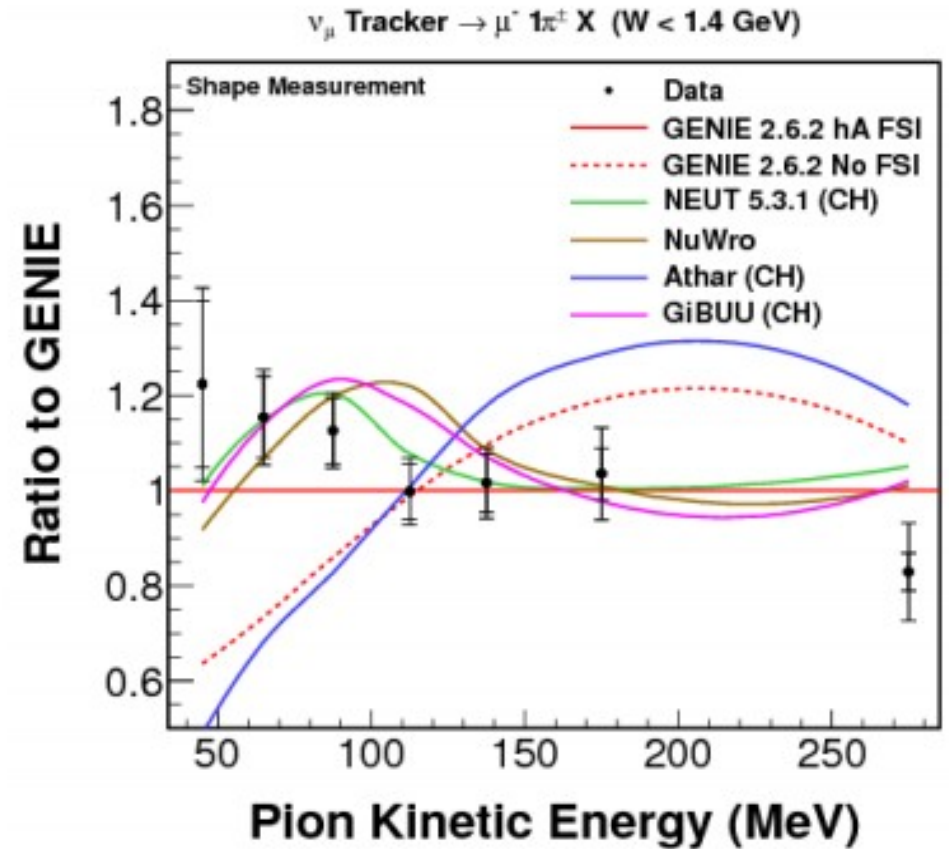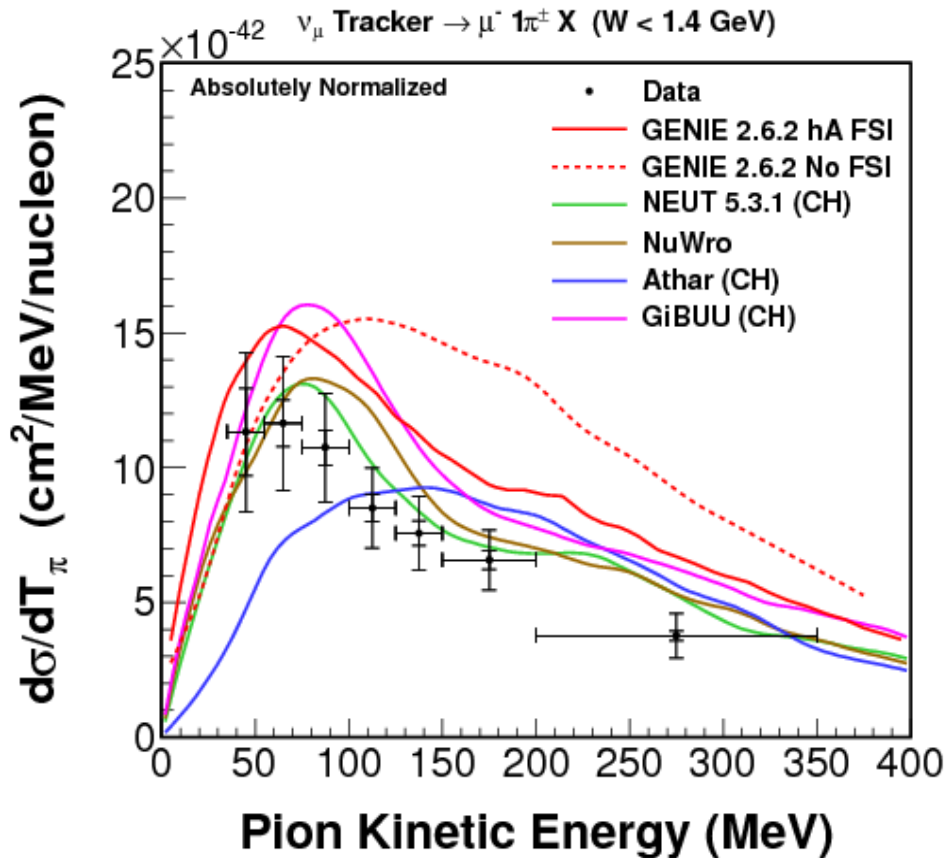
▶ Data disfavours no-FSI GENIE model
▶ Agrees in shape with most models/generators (except no-FSI)
▶ NEUT & NuWro agree best in normalisation

MINERνA vs miniBooNE

- GENIE 2.6.2 predicts
  - the shape but not normalisation of MINERvA data
  - the rate but not the shape of the MB data
- No significant dip in either dataset
- No calculation describes all the data well. Is it possible to get agreement?

GENIE >= 2.8 Improvements

▶ Use MAID model to give better constrained resonance model.
▶ Correctly account for lepton mass thresholds
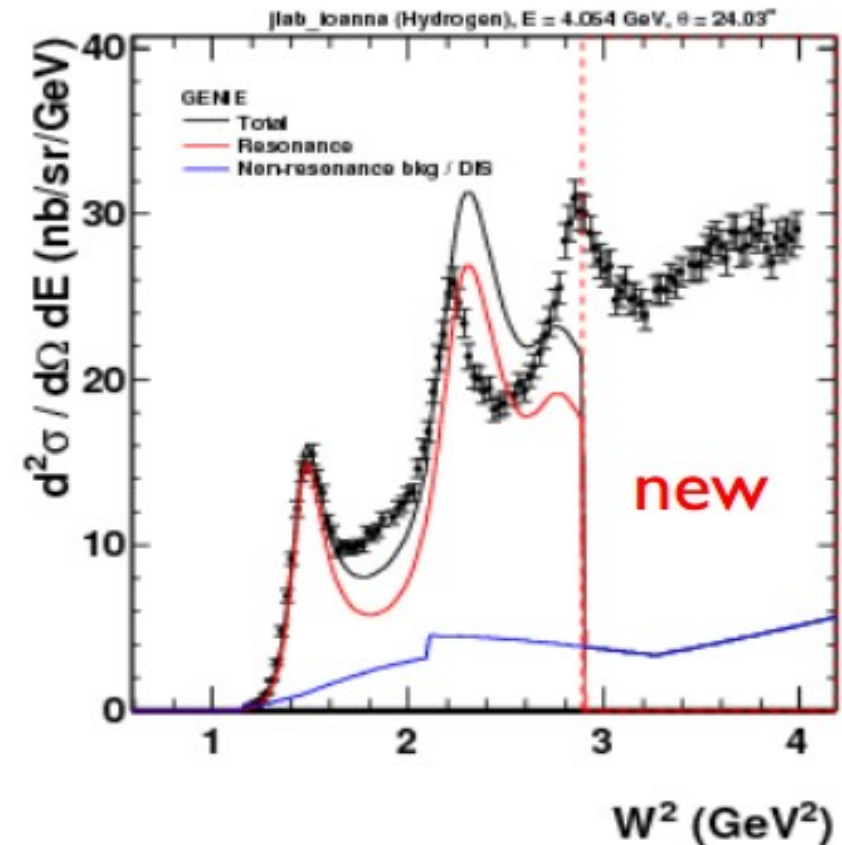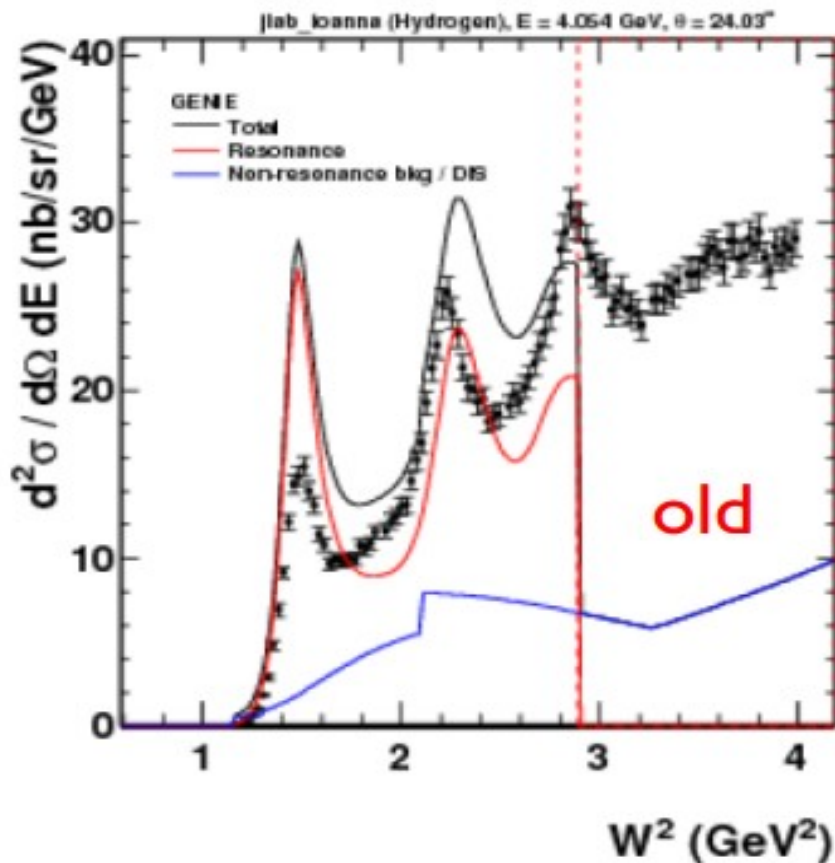
FSI

▶ Pion FSI in GENIE v 2.8 tuned for Fe not CH

▶ GENIE 2.10 will use FSI model tuned for all A
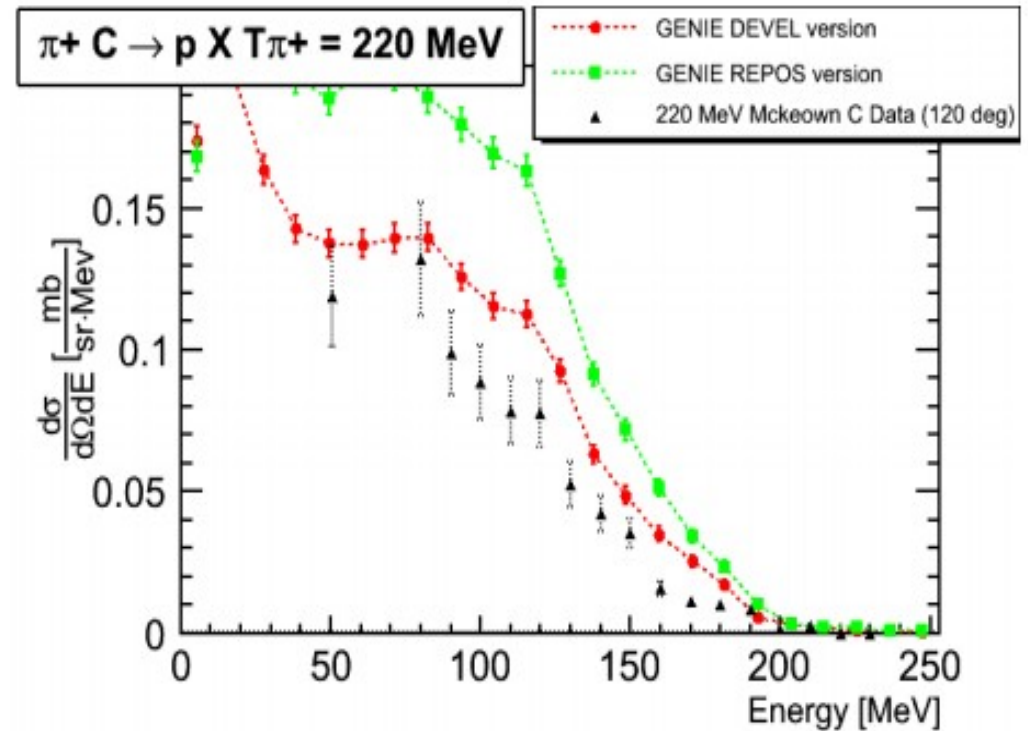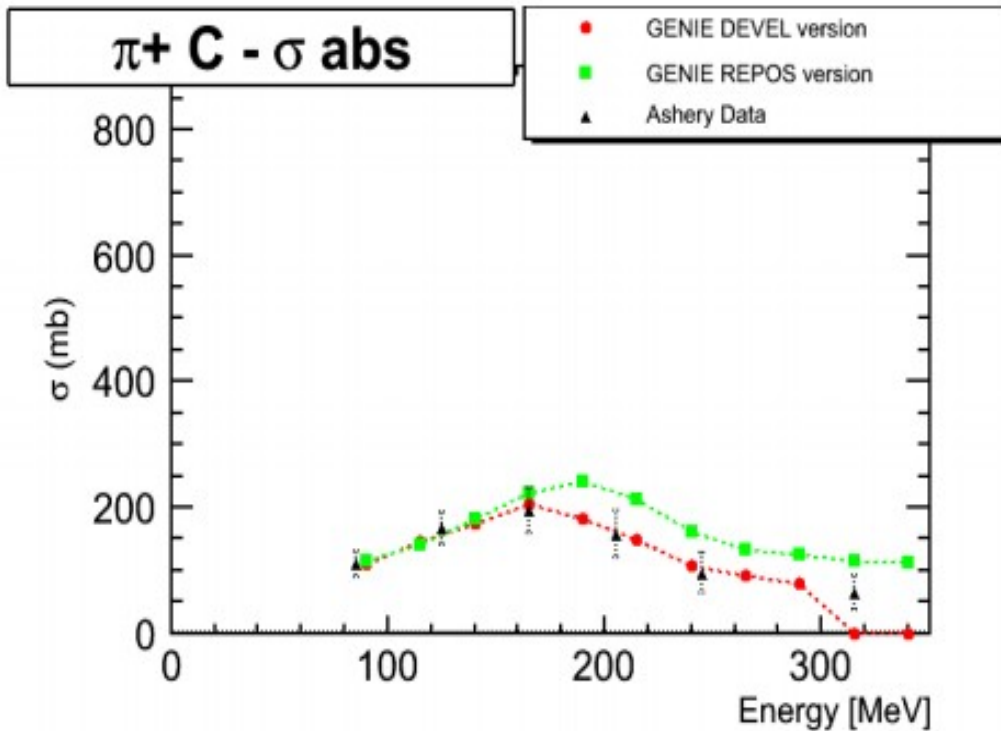
Summary II

► Situation is complicated (!)

► MiniBooNE : Models and generators disagree in shape and normalisation

► MINERvA : Event generators agree (mostly) in shape but normalisation is incorrect.

► More data to cross-check current datasets is needed. T2K is in the same energy range as miniBooNE.

► (Not mentioned but :) light target ANL and BNL data shows normalisation difference which may or may not be significant. Need more light target data.

CC Coherent Conundrum

CC Coherent Production

Experiment	$< E_\nu >$ (GeV)	$< \sigma > (\nu) \times 10^{-39}$ cm^2/nucleus	$< \sigma > (\nu\text{-bar}) \times 10^{-39}$ cm^2/nucleus
T2K Off-axis (C)	0.6	In progress	
T2K On-axis (C)	1.5	1.0 ± 0.74	
MINERvA (C)	5.0	Differential	Differential
Argoneut (Ar)	9.6	27.0 ± 13.0	6.8 ± 2.7

▶ Measurements on this channel are starting to appear
▶ Energy range the experiments cover also covers PCAC/microscopic model validity ranges

MINERvA
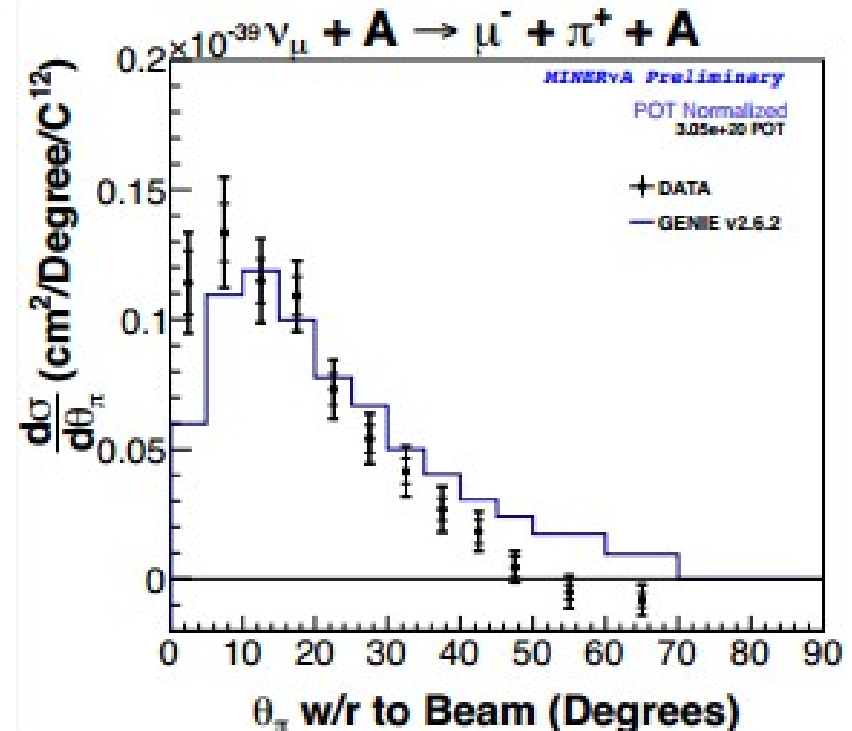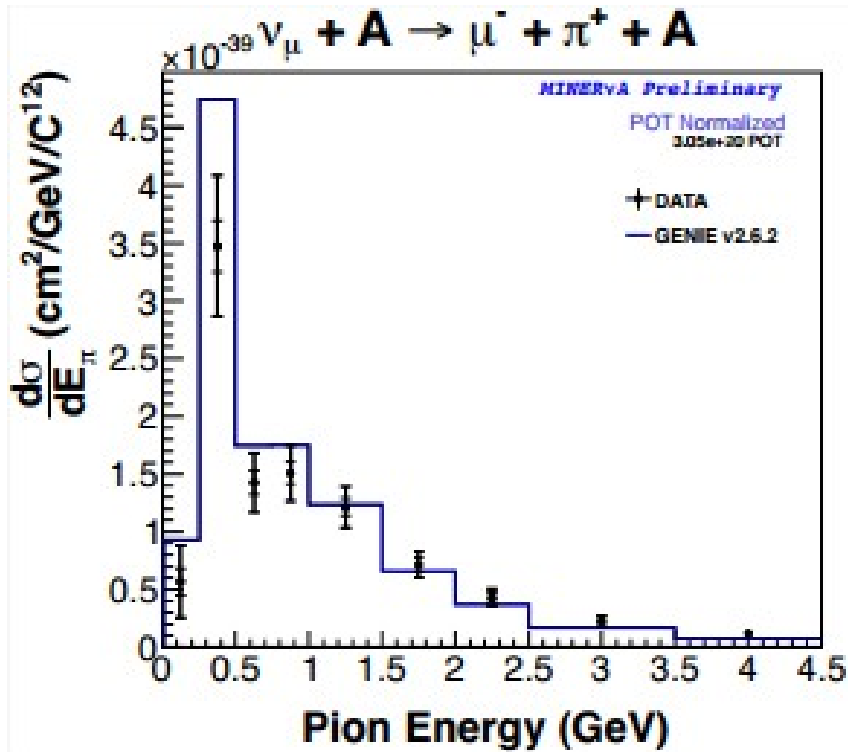
- Pion kinematic distributions from MINERvA ν_μ CC Coh
- Data indicates harder, more forward pion spectra than predicted in GENIE 2.6.2
- See other MINERvA talks by J. Wolcott, J. Morfin and J. Nelson

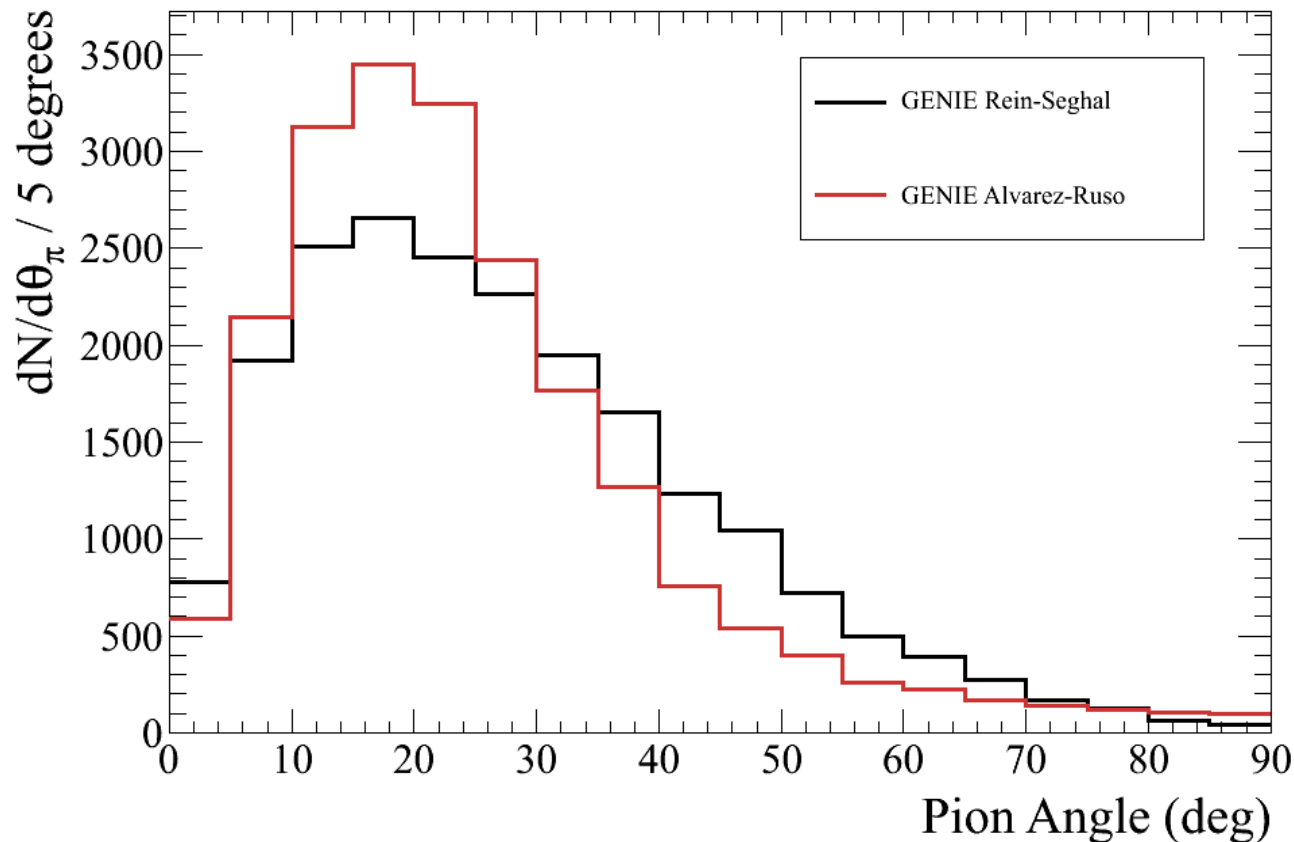# GENIE >= 2.8 Improvements

▶ Implementation of the Berger-Seghal model

▶ Implementation of Alvarez-Ruso microscopic model

Comparison of GENIE Rein-Seghal with Alvarez-Ruso using T2K flux

Summary III

▶ CC coherent measurements are now being made at low energy.

▶ MINERvA, in particular, has the power to make statements about models based on kinematics.

▶ A number of sophisticated microscopic models exist (Alvarez-Ruso, Sato, Nakamura, Hernandez)

▶ Neutrino measurements are still using Rein-Seghal ; mostly through lack of any other implemented option

▶ More work on implementing coherent models is needed.

GENIE Development

▶ To keep up with all this new data, and prepare for upcoming experiments GENIE organisation is evolving

  ▶ Core development team

  ▶ Working group structure

  ▶ Significant resourcing in Europe and US

▶ Forums and workshops (GENIE developers workshop, NUSTEC GENIE workshop for users)

▶ Planned release schedule with medium-term development plan

Release Plans

- GENIE 2.8.0 is production version

- GENIE 2.8.2 soon
  - Bug fixes
  - Validation system

- GENIE 2.9.0 in Autumn, 2014
  - Some new packages
  - Updated Rein-Seghal, Berger-Seghal
  - Spectral functions and improved FSI

- 2.10.0 in Summer 2015
  - Valencia QE (QE+RPA+MEC)

Conclusion

▶ New, detailed data from experiments such as MiniBooNE , MINERvA and T2K are posing a challenge to the model and generator builders.

▶ This is a good thing!

▶ There is a lot of effort going into implementation of new ideas in GENIE. This has benefited from close co-operation between the experiments and theorists.

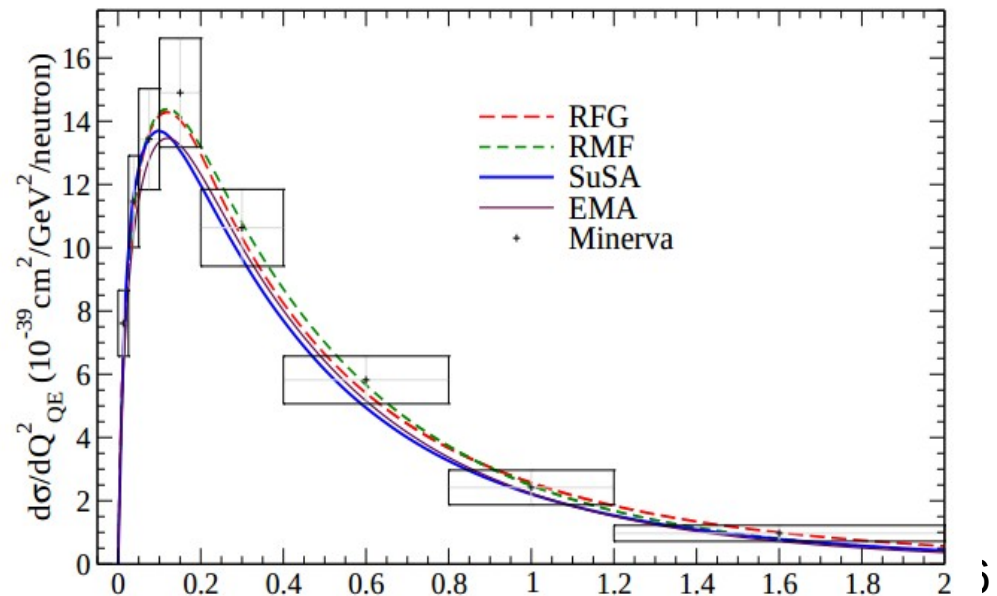▶ Lot's more to do, not many to do it

▶ Please join!

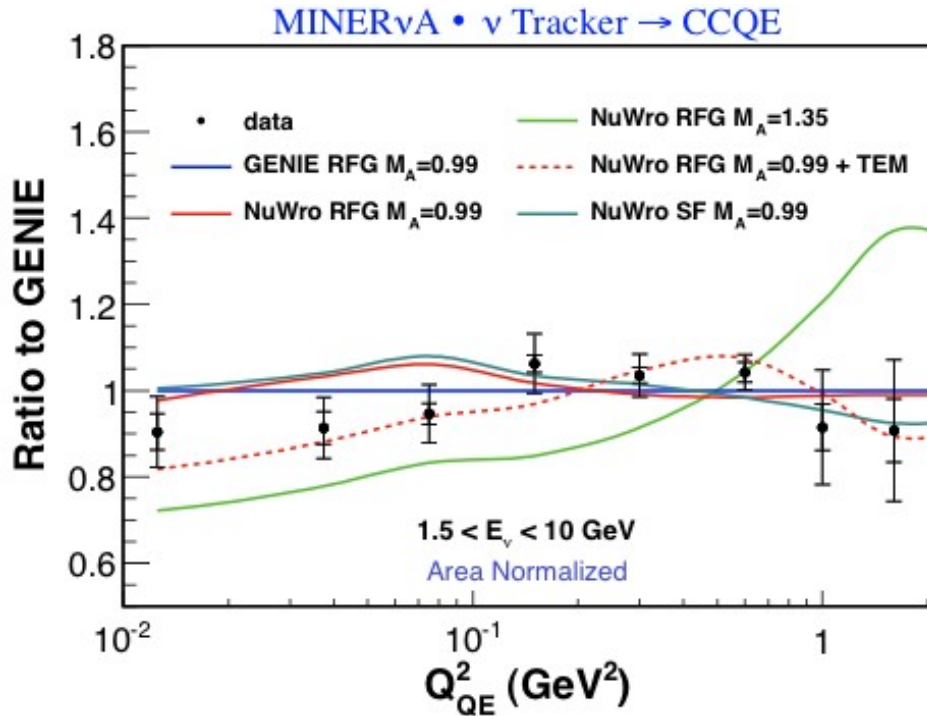# Backups / Excess

Can data help distinguish?

MINERvA • ν Tracker → CCQE
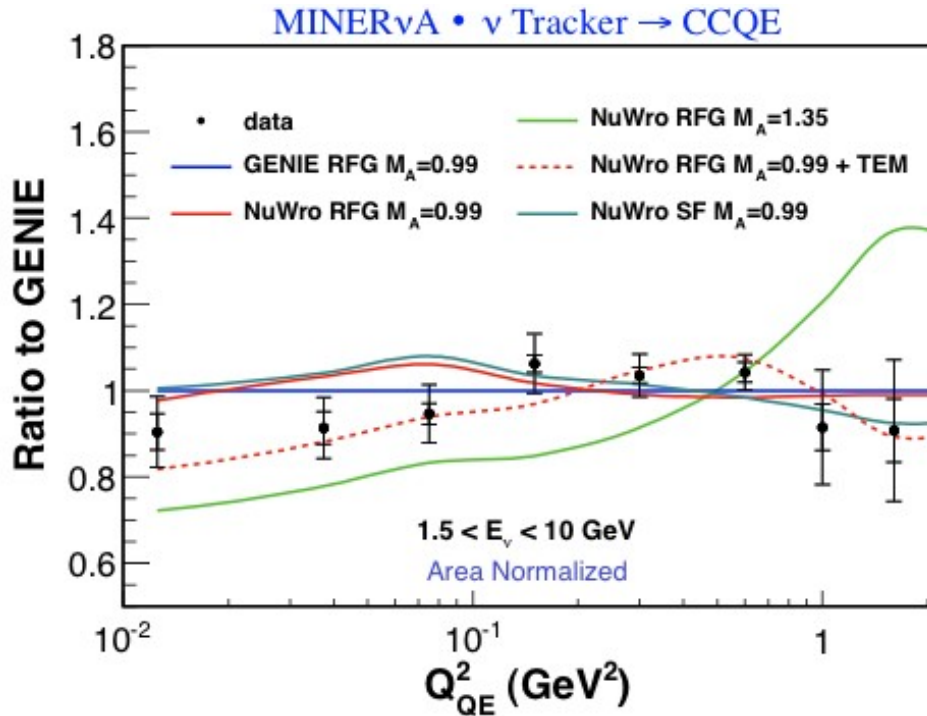
RFG with m_A = 1.35 GeV/c^2 disfavoured

Multi-nucleon model (TEM) is best fit

although SUSA (without MEC) and RMF also agree with MINERvA
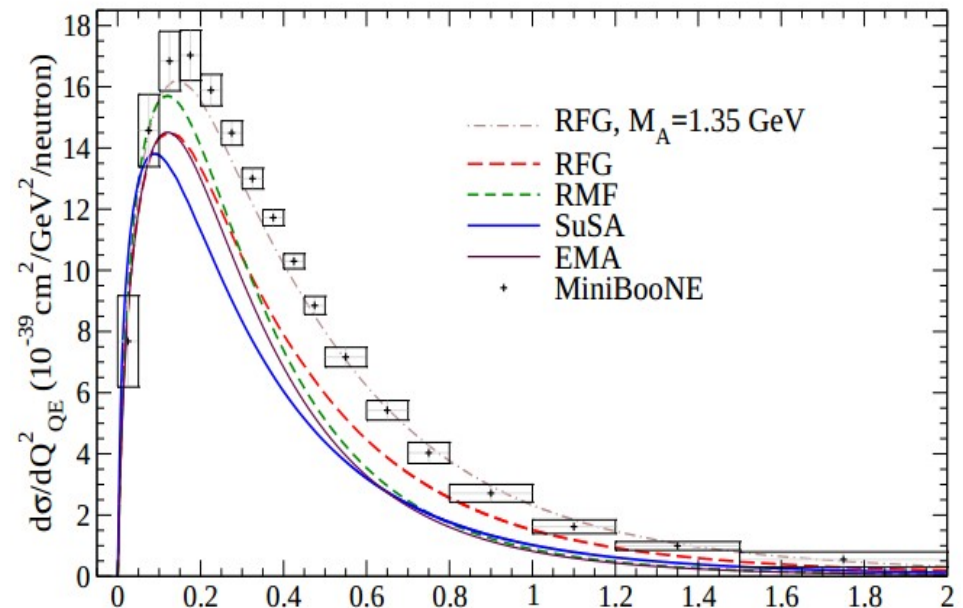
Can data help distinguish?

Bodek, Budd, Christy, Eur. Phys. J. C71, 1726 (2011)

RFG with m_A = 1.35 GeV/c^2 disfavoured

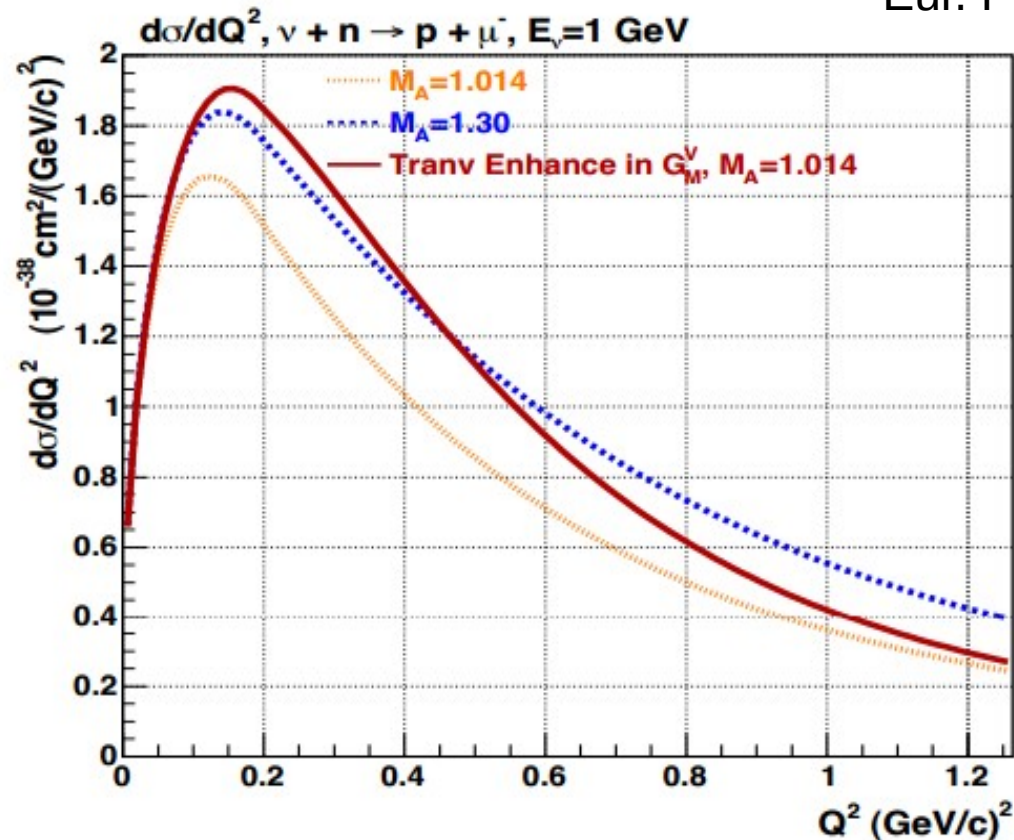Multi-nucleon model (TEM) is best fit

but not with MiniBooNE

Model : Transverse Enhancement

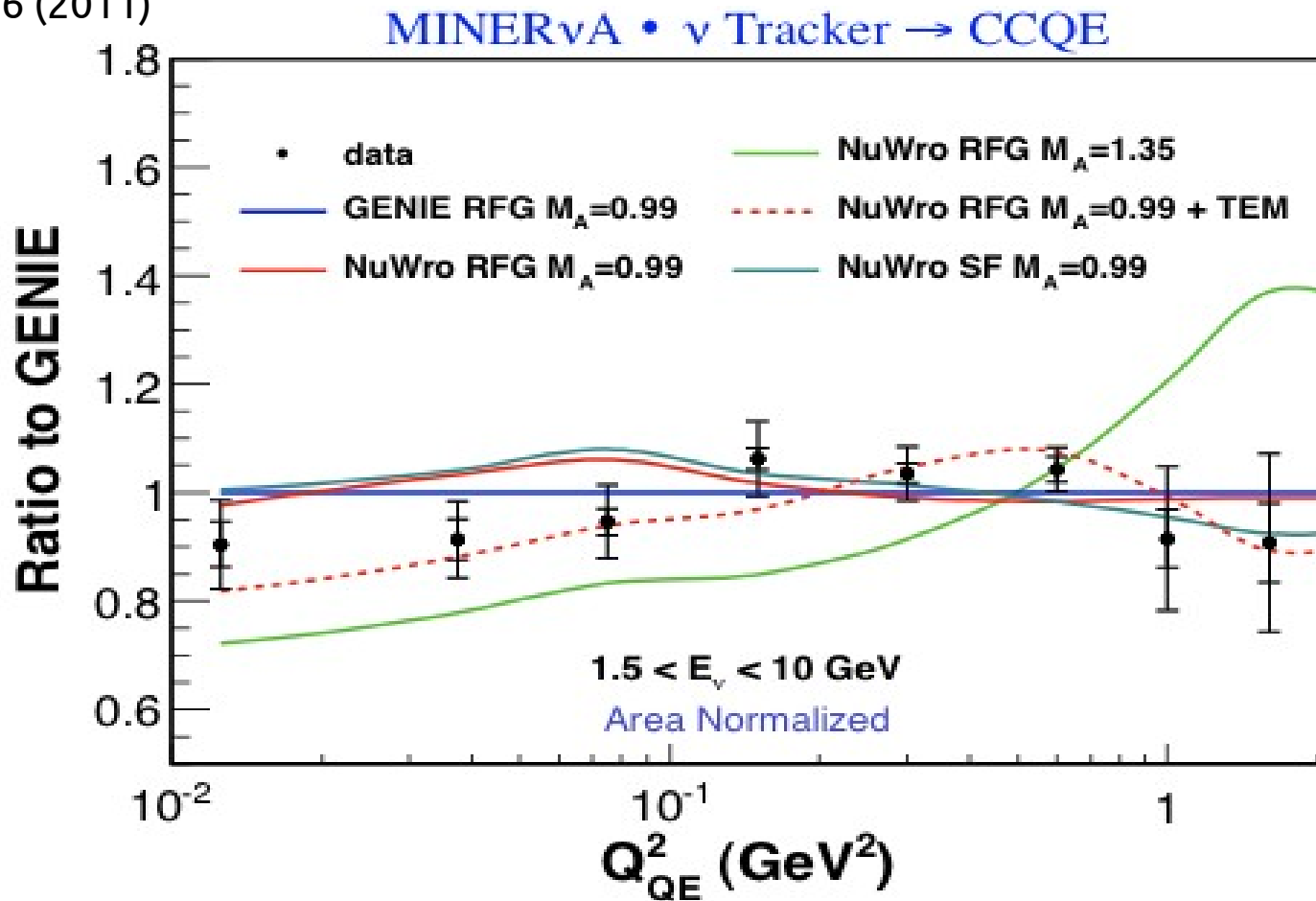Bodek, Budd, Christy
Eur. Phys. J. C 71 (2011) 1726

$$G_{Mp}(Q^2)(nuclear) = G_{Mp}(Q^2)\sqrt{1 + A Q^2 e^{-Q^2/B}}$$

$$G_{Mn}(Q^2)(nuclear) = G_{Mn}(Q^2)\sqrt{1 + A Q^2 e^{-Q^2/B}}$$

Test of MEC in MINERvA

Bodek, Budd, Christy,
Eur. Phys. J. C71, 1726 (2011)

MINERvA • ν Tracker → CCQE

- data
- GENIE RFG M_A=0.99
- NuWro RFG M_A=0.99
- NuWro RFG M_A=1.35
- NuWro RFG M_A=0.99 + TEM
- NuWro SF M_A=0.99

Ratio to GENIE

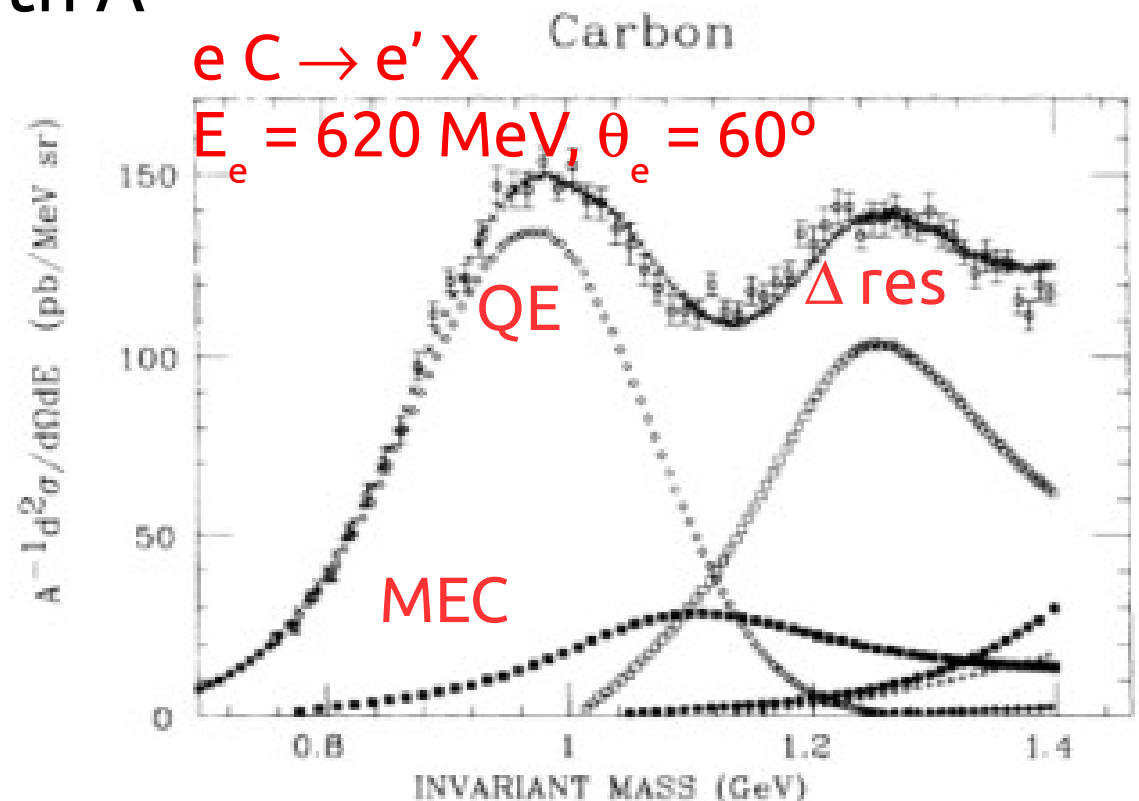$1.5 < E_\nu < 10$ GeV
Area Normalized

Q^2_{QE} (GeV^2)

RFG with m_A = 1.35 GeV/c^2 disfavoured

GENIE Model : Dip region

▶ Based on O'Connell and Lightbody (1988)
▶ MEC contribution added to cross section as a Gaussian in the hadronic invariant mass (M = 1.9 GeV, Γ = 300 MeV)
▶ Tune normalisation with MiniBooNE data
▶ Cross section scales with A

$e\,C \rightarrow e'\,X$
E_e = 620 MeV, θ_e = 60°

QE

Δ res

MEC

GENIE model : Spectral Functions

- ▶ O. Benhar's spectral function model

- ▶ O. Benhar, Nucl. Phys. A, 505 (1989) 267–299

- ▶ Provides 1p1h response for C, O, Ca and Fe

- ▶ Includes NN correlations but only one emitted nucleon