Fun Timely Intellectual Adorable!

nuclear many-body problem

Spin physics

Lattice QCD

Neutrino oscillation

Weak interaction

NuSTEC News

Nucleon correlation

EMC effect

electron scattering

Dark matter

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Highlights from NuSTEC-News 2015-2017

1. Introduction
2. CCQE, CCQE-like, and CC0π data
3. CC data with nucleon final state
4. Electron neutrino CC data
5. A-dependence of neutrino cross section
6. Pion puzzle
7. Conclusion

Teppei Katori
Queen Mary University of London
NuInt 17, The Fields Institute, Toronto, Canada, June 25, 2017

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1. Introduction

The "NuSTEC News" (2012 -) is the community newsletter about neutrino interaction physics. It discusses the latest interesting neutrino cross result, either experimental or theoretical, roughly every other week. This is the place for all of us to learn neutrino interaction physics together.
http://nustec.fnal.gov/nustec-news/
Please subscribe today!

We also have a Facebook page ("NuSTEC News" or @nuxsec, please "like" now!)

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3. CC data with nucleon final state

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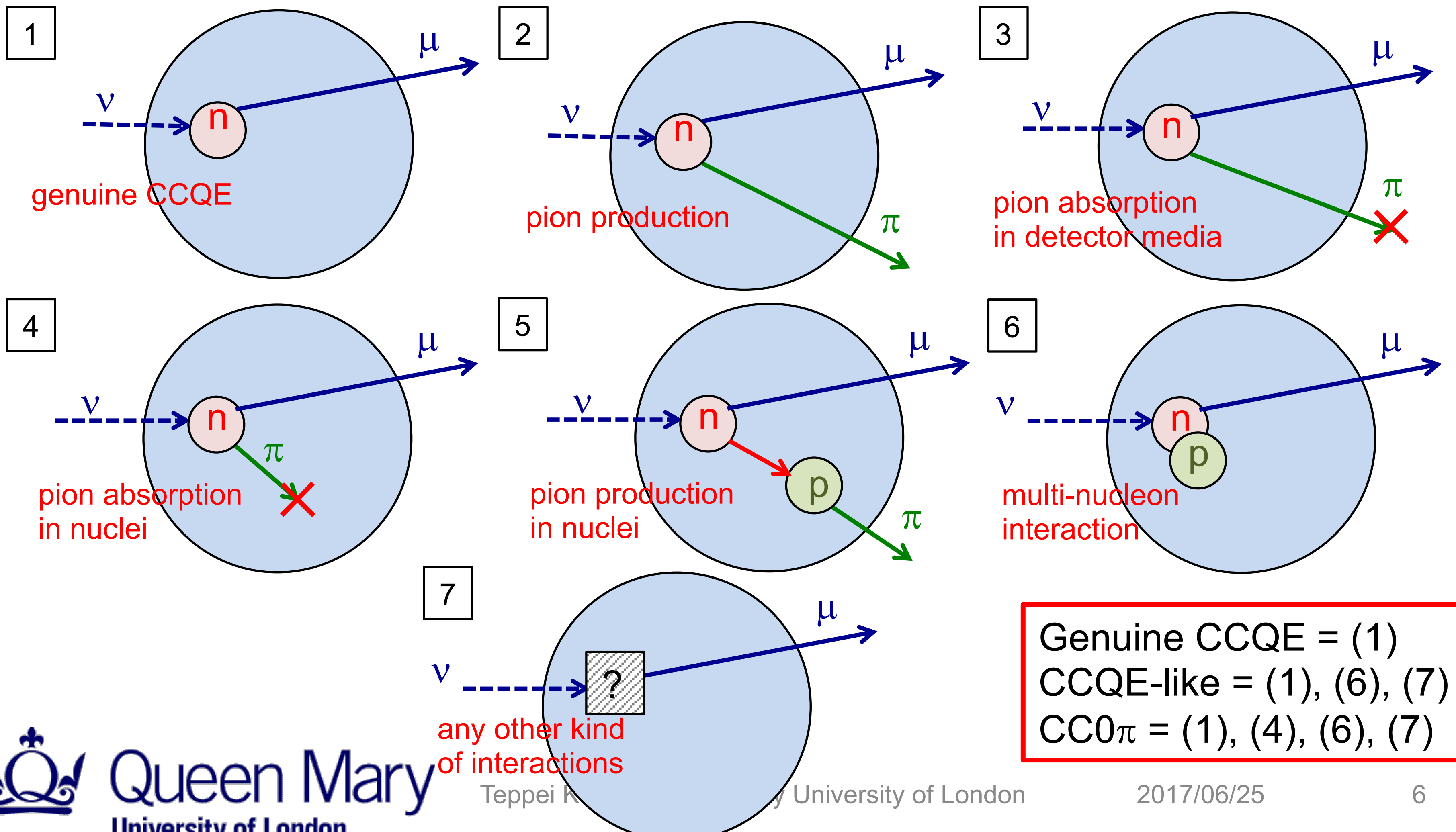
7. Conclusion

2. CC0π data

Final state particle topology dependent definition is widely used.

CC0π data → 1 muon + 0 pion + N nucleon



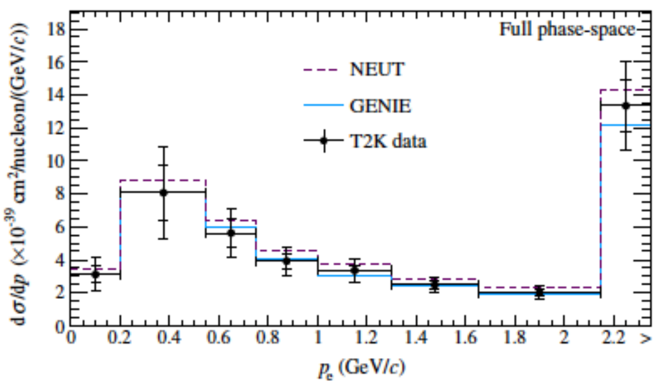
Genuine CCQE = (1)
CCQE-like = (1), (6), (7)
CC0π = (1), (4), (6), (7)

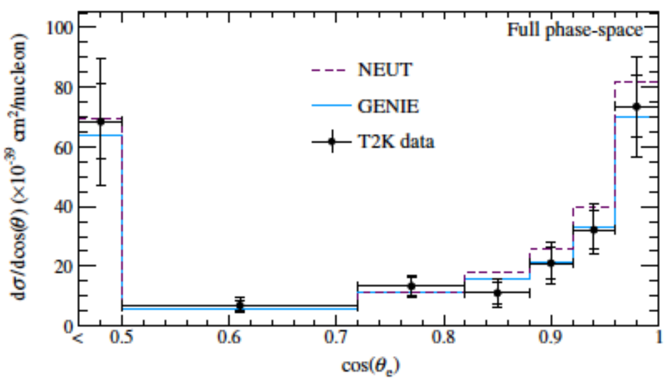
2. Flux-integrated differential cross-section

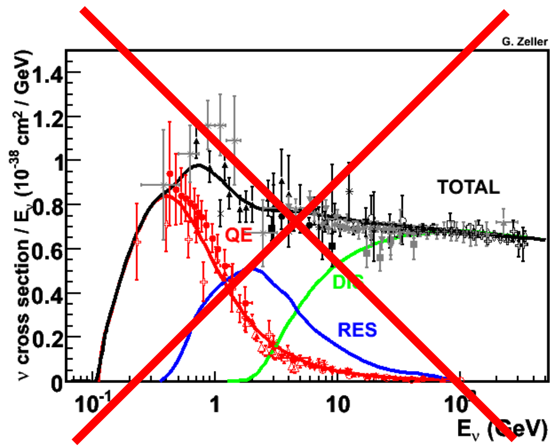
Various type of flux-integrated differential cross-section data are available from all modern neutrino experiments.

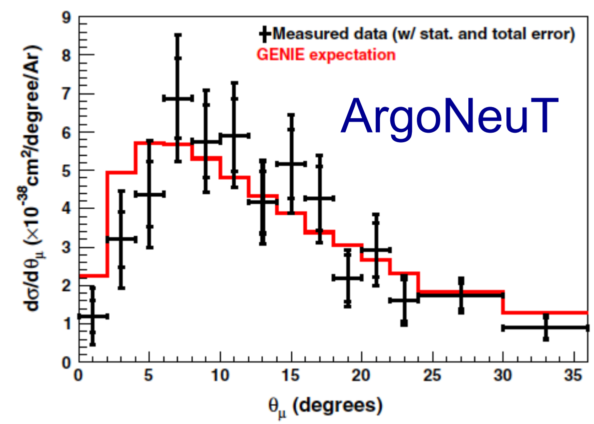
→ Now PDG has a summary of neutrino cross-section data! (since 2012)

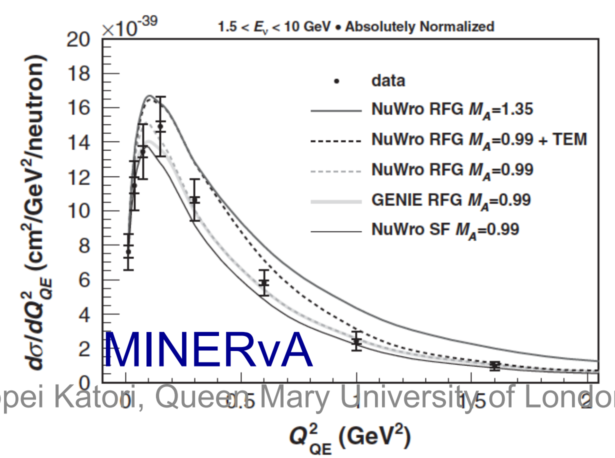
T2K



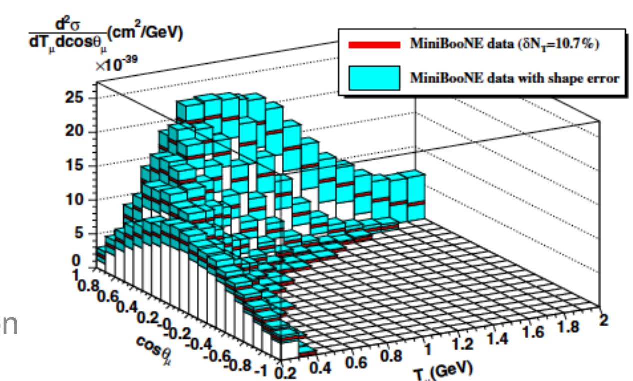








MiniBooNE



PDG2014 Section 49 “Neutrino Cross-Section Measurements”

2. Flux-integrated differential cross-section

Various type of flux-integrated differential cross-section data are available from all modern neutrino experiments.

→ Now PDG has a summary of neutrino cross-section data! (since 2012)

$$\frac{d^2\sigma}{dT_l\, d\cos\theta} = \frac{1}{\int \Phi(E_\nu)\, dE_\nu} \int dE_\nu \left[\frac{d^2\sigma}{d\omega\, d\cos\theta}\right]_{\omega=E_\nu-E_l} \Phi(E_\nu)$$

Theorists

Experimentalists

$$\frac{d^2\sigma}{dT_l \cos\theta} = \frac{\sum_j U_{ij}(d_j - b_j)}{\Phi \cdot T \cdot \varepsilon_i \cdot (\Delta T_l, \Delta\cos\theta)_i}$$

Flux-integrated differential cross-section data allow theorists and experimentalists to talk

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Various type of flux-integrated differential cross-section data are available from all modern neutrino experiments.
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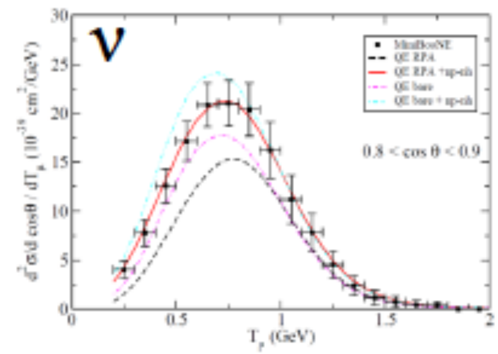
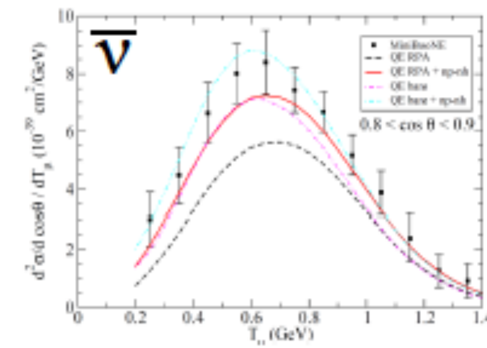
Flux-integrated differential cross-section data allow theorists and experimentalists to talk

2. CCQE-like data, MiniBooNE (2014)

SuSAv2 shows lower normalization due to lack of axial current enhancement.





Where 2p-2h contributions enter in the different approaches

Martini et al. *Nieves et al.* *Amaro et al.* *Lovato et al.* *Bodek et al.*

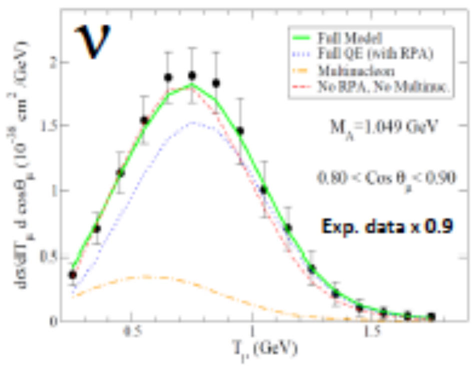
[Follow the color and the style of the lines:]

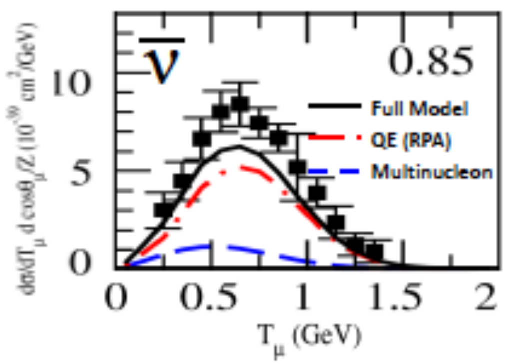
$$\frac{\partial^2\sigma}{\partial\Omega\,\partial\epsilon'} = \sigma_0\left[L_{CC}(R^V_{CC}+R^A_{CC}) + L_{CL}(R^V_{CL}+R^A_{CL}) + L_{LL}(R^V_{LL}+R^A_{LL}) + L_T(R^V_T+R^A_T) \pm L_{T'VA}R^{VA}_{T'}\right]$$

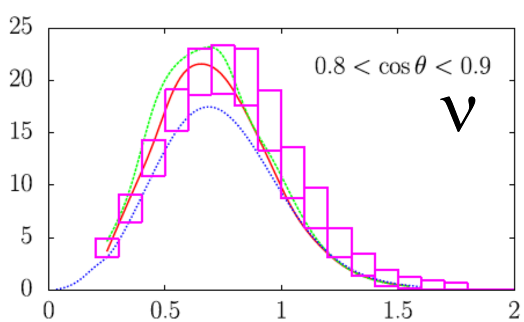
$$\frac{\partial^2\sigma}{\partial\Omega\,\partial\epsilon'} = \sigma_0\left[L_{00}R_{00} + L_{0z}R_{0z} + L_{zz}R_{zz} + L_{xx}R_{xx} \pm L_{xy}R_{xy}\right]$$

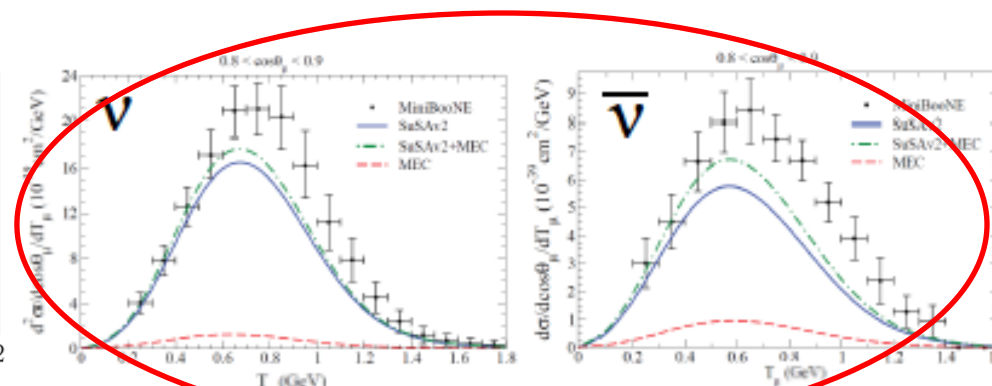
$$\frac{\partial^2\sigma}{\partial\Omega\,\partial\epsilon'} = \frac{G_F^2\cos^2\theta_c}{2\,\pi^2}k'\epsilon'\cos^2\frac{\theta}{2}\left[\frac{(q^2-\omega^2)^2}{q^4}G_E^2\,R_\tau + \frac{\omega^2}{q^2}G_A^2\,R_{\sigma\tau(L)} + \right.$$
$$\left. + \; 2\left(\tan^2\frac{\theta}{2} + \frac{q^2-\omega^2}{2q^2}\right)\left(G_M^2\frac{\omega^2}{q^2} + G_A^2\right)R_{\sigma\tau(T)} \pm 2\frac{\epsilon+\epsilon'}{M_N}\tan^2\frac{\theta}{2}G_A G_M\,R_{\sigma\tau(T)}\right]$$

Relative role of 2p-2h for neutrinos and antineutrinos is different due to the **interference term**









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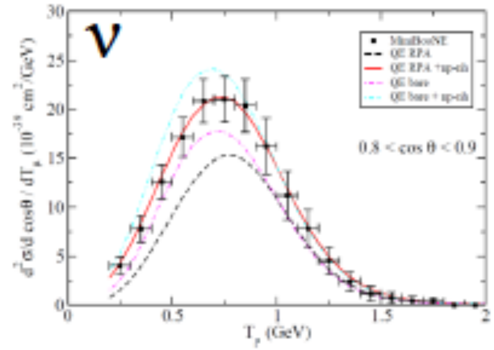
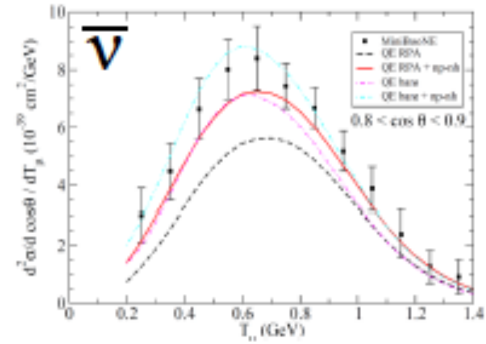
2. CCQE-like data, MiniBooNE (now)

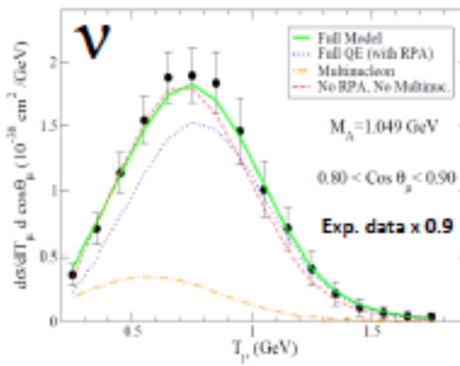
SuSAv2 shows lower normalization due to lack of axial current enhancement.

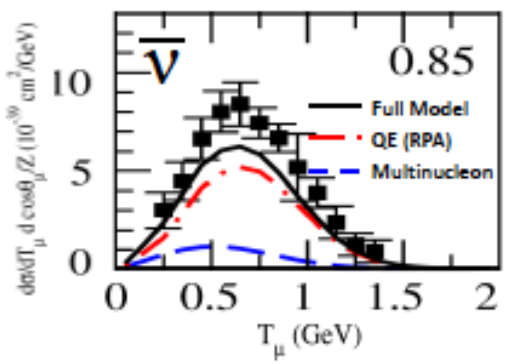
After adding axial MEC contribution, SuSA collaboration (Megias et al.) shows similar enhancement with other groups (Martini et.al., Nieves et al., Meucci et al., Mosel et al., Bodek et al.).

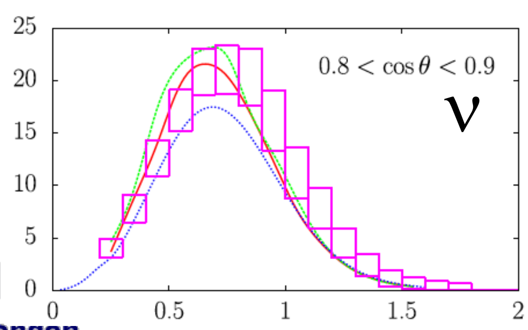
All groups agree qualitatively with MiniBooNE CCQE-like double differential data.

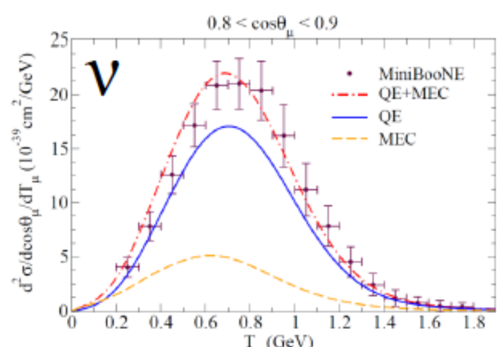


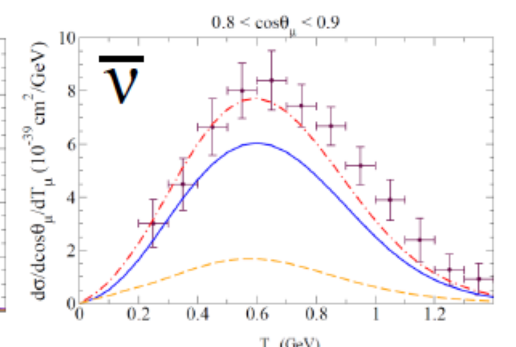












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2. CC inclusive data, T2K (now)

SuSAv2 shows lower normalization due to lack of axial current enhancement.

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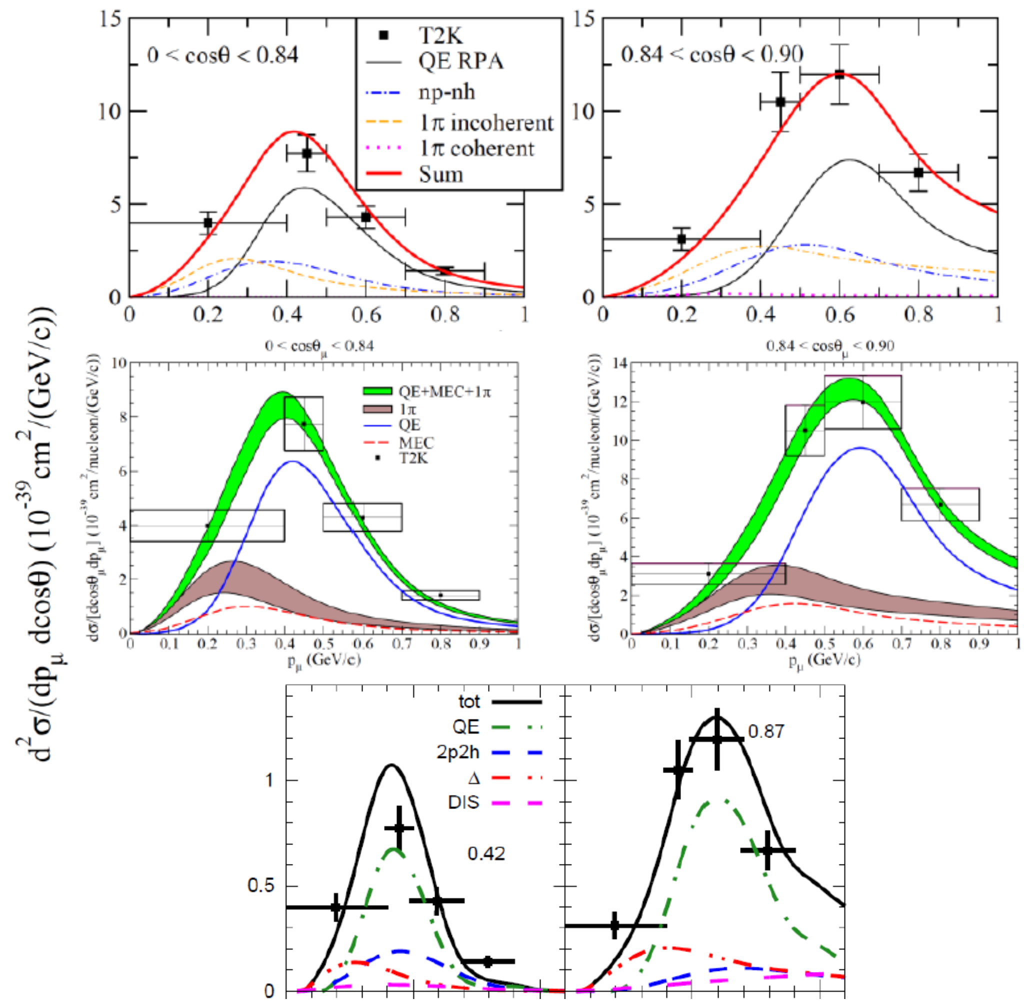
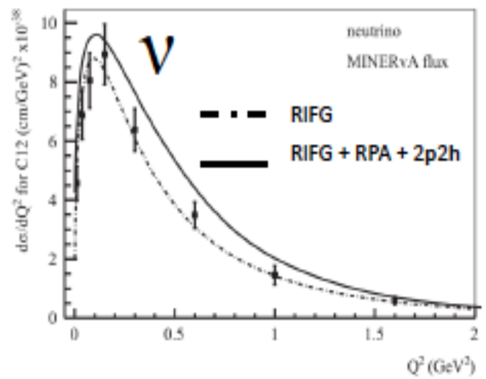
All groups agree qualitatively with MiniBooNE CCQE-like double differential data.

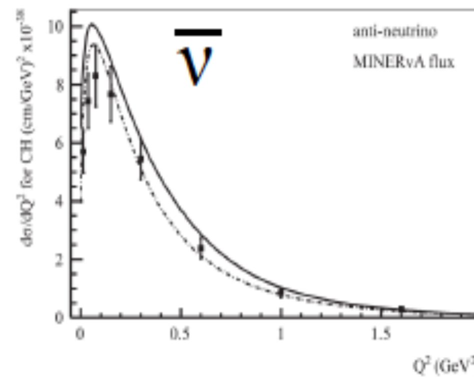
These models are also successful to reproduce T2K CC inclusive data (BNB flux cannot explain MiniBooNE data normalization)

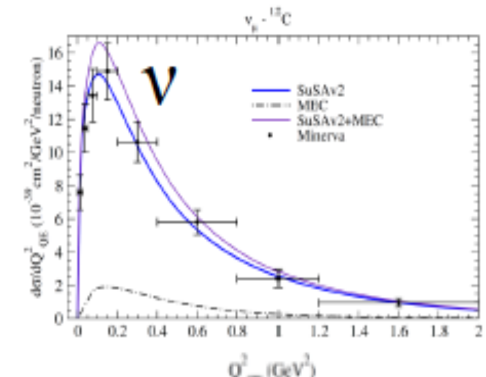


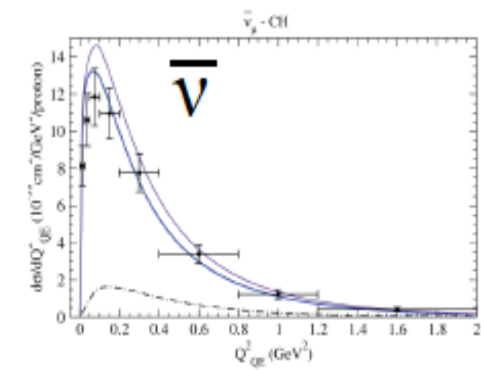
2. CCQE-like data, MINERvA (2014)

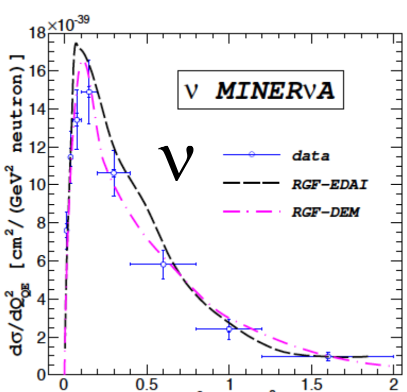
On the other hand, models work for MiniBooNE overestimate MINERvA cross sections.

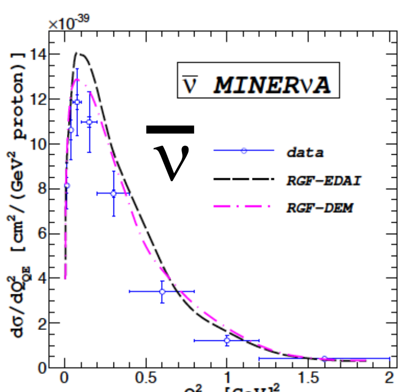




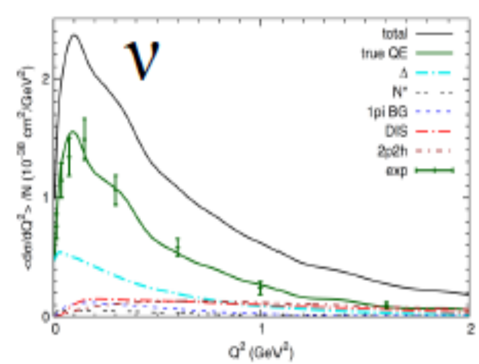


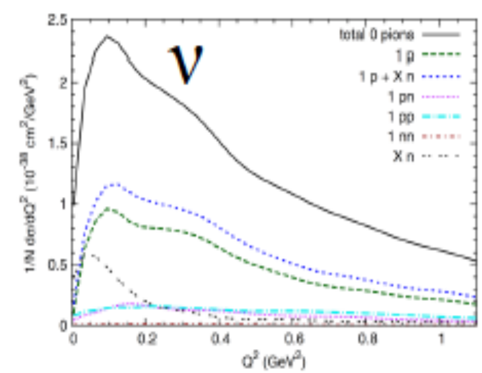






Que

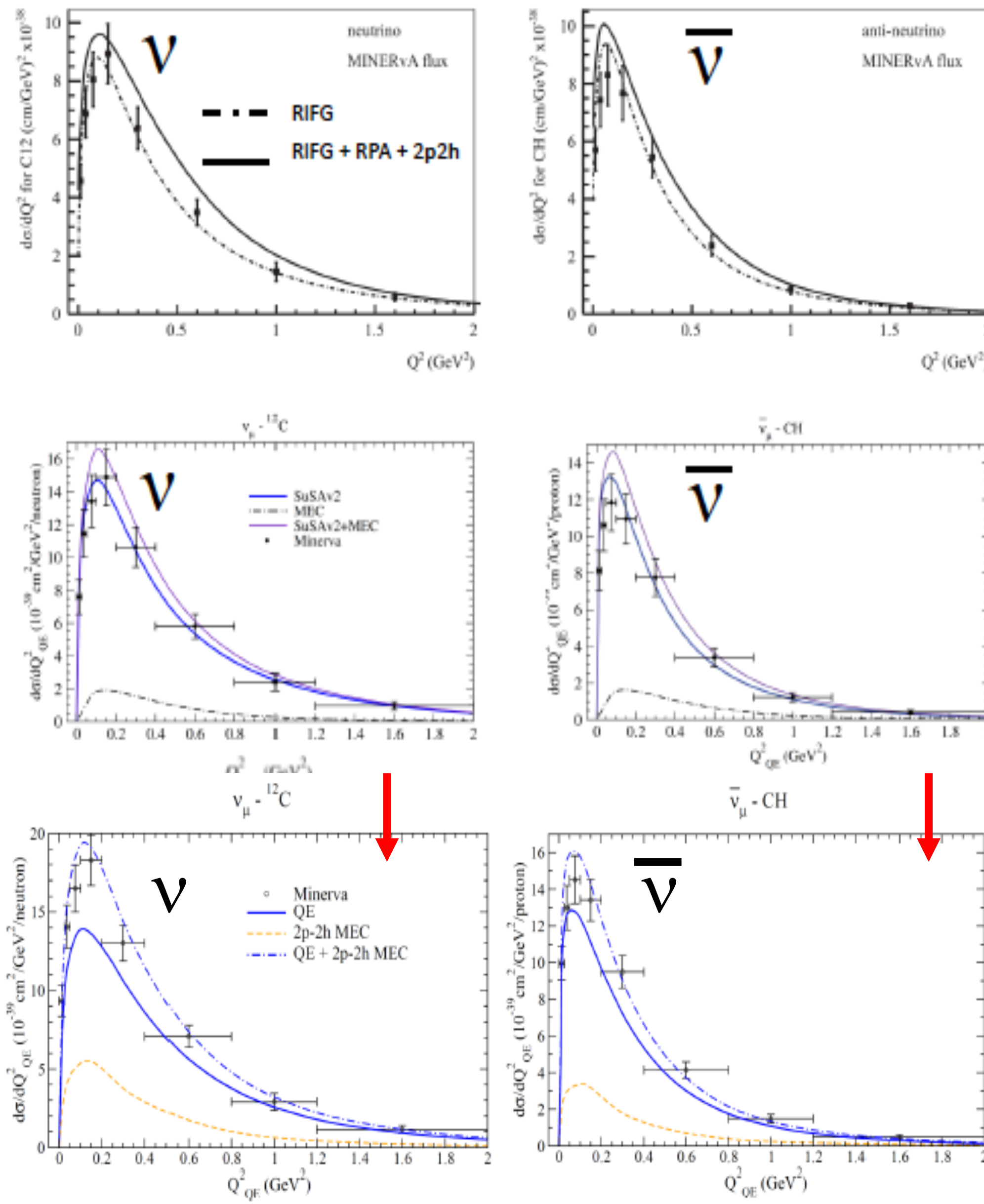




2. CCQE-like data, MINERvA (now)

On the other hand, models work for MiniBooNE overestimate MINERvA cross sections.

MINERvA found NuMI flux was overestimated. With new flux calculation, normalization tension between MiniBooNE and MINERvA is reduced



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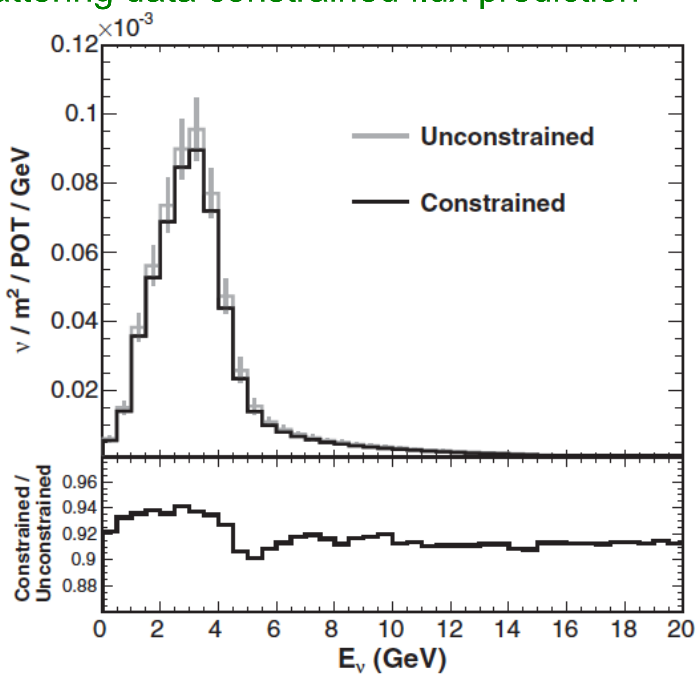
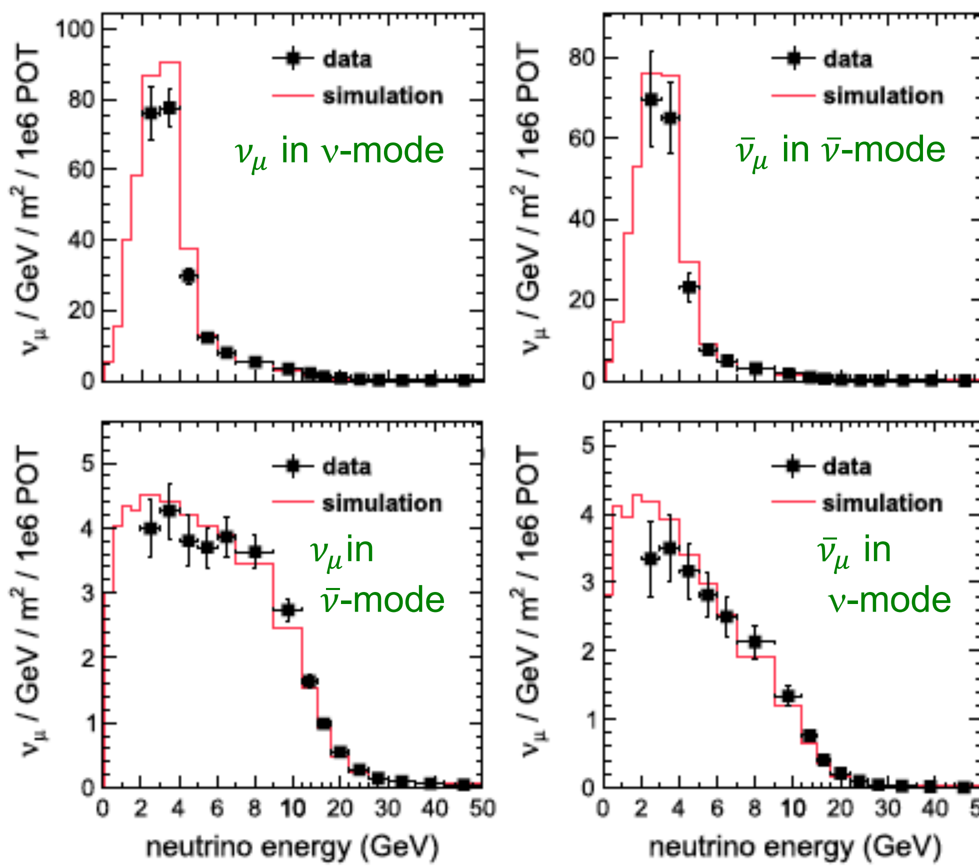
ν-e scattering data constrained flux prediction



New flux results are independently tested by ν-e scattering data and low-ν method.

low-ν method data vs old flux prediction



2. CCQE-like data, global fit tension (now)

MiniBooNE and MINERvA data show strong tensions. The origin of tension includes;

1. Lack of full covariance matrix from MiniBooNE data
2. Lack of systematic errors from theoretical models
3. Validity of models at MiniBooNE, T2K, and MINERvA kinematics

New models are qualitatively right idea, but they don't pass a quantitative test

MiniBooNE-MINERvA CCQE-like data simultaneous fit

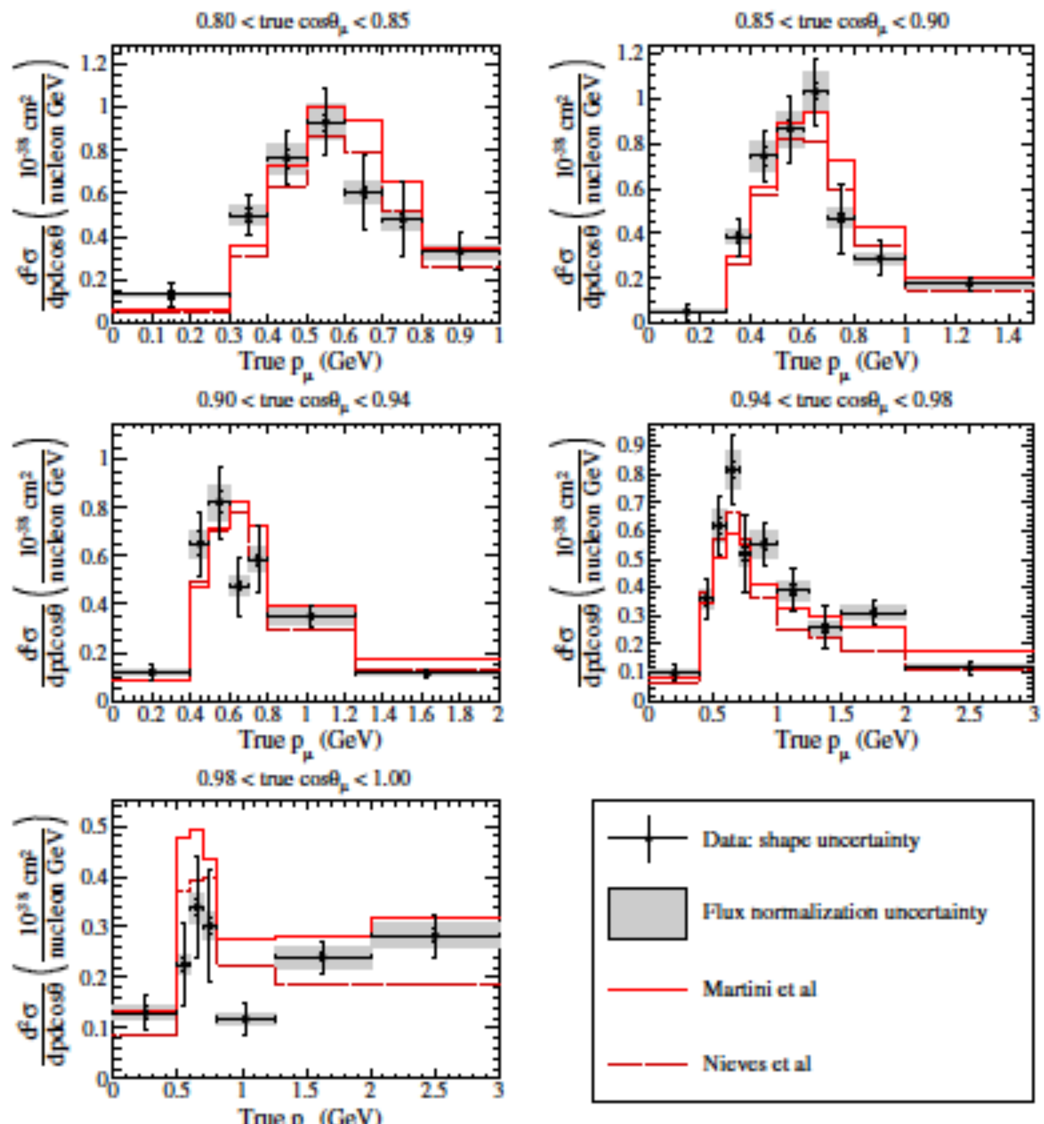
Fit type	χ^2/N_{DOF}	M_A (GeV/c^2)	2p2h norm (%)	p_F (MeV/c)	$\lambda_{\nu}^{\mathrm{MB}}$	$\lambda_{\bar{\nu}}^{\mathrm{MB}}$
RFG + rel RPA + 2p2h	97.8/228	1.15 ± 0.03	27 ± 12	223 ± 5	0.79 ± 0.03	0.78 ± 0.03
RFG + nonrel RPA + 2p2h	117.9/228	1.07 ± 0.03	34 ± 12	225 ± 5	0.80 ± 0.04	0.75 ± 0.03
SF + 2p2h	97.5/228	1.33 ± 0.02	0 (at limit)	234 ± 4	0.81 ± 0.02	0.86 ± 0.02

T2K,PRD93(2016)112012

2. CC0π double differential data, T2K (now)

T2K publish CC0π double differential cross section. This took into account many issues on MiniBooNE data set

1. clearly state what was measured
2. full covariance matrix for precise fit



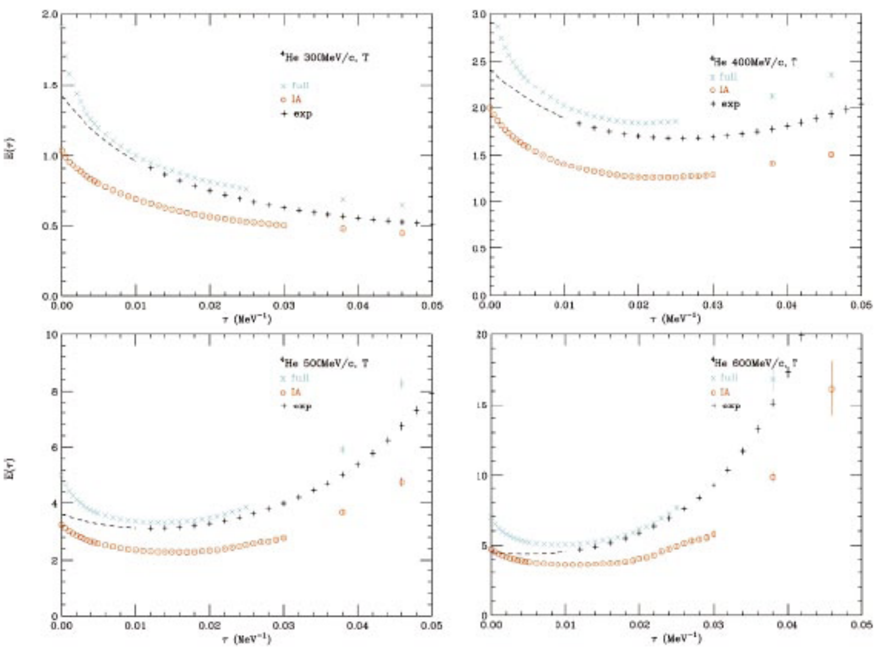
Study of lepton kinematics is not completed, yet.

Carlson et al., PRC65(2002)024002
Lovato et al.,PRL112(2014)182502

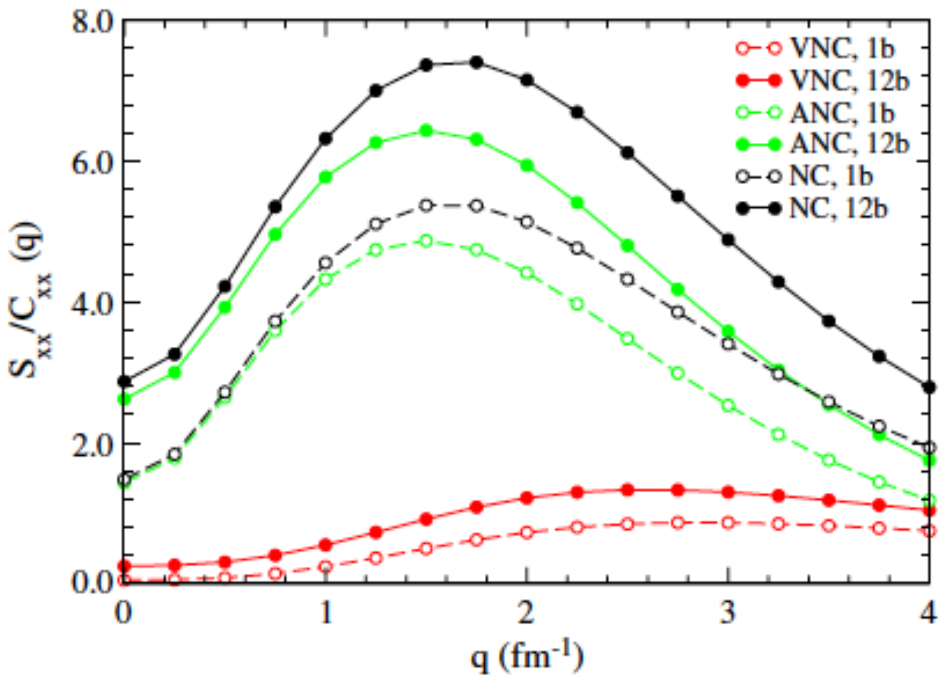
2. Ab initio calculation (2014)

Ab initio calculation support the general idea of transverse response enhancement for neutrino scatterings.

^{4}He Euclidian transverse response



Transverse sum rule for NC interaction



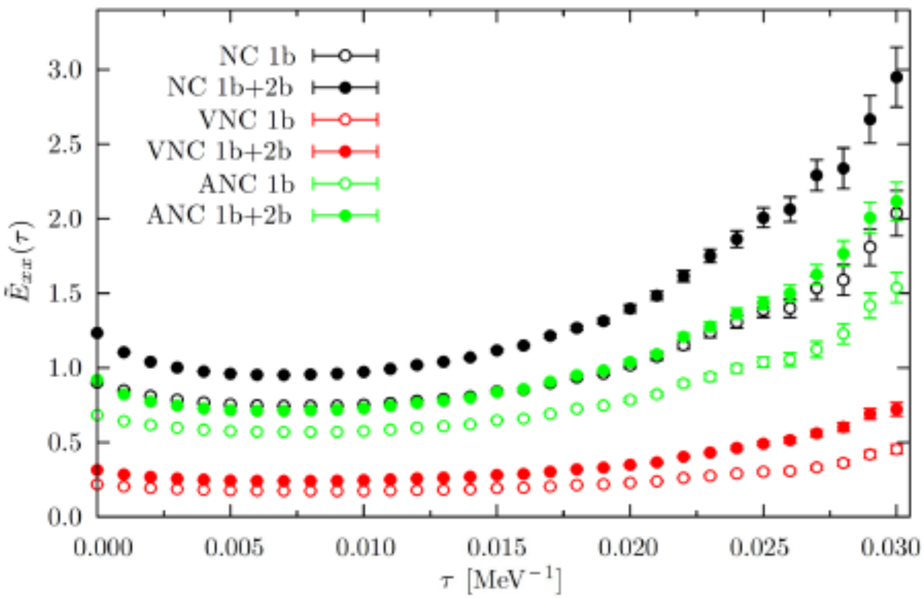
2. Ab initio calculation (now)

Ab initio calculation support the general idea of transverse response enhancement for neutrino scatterings.

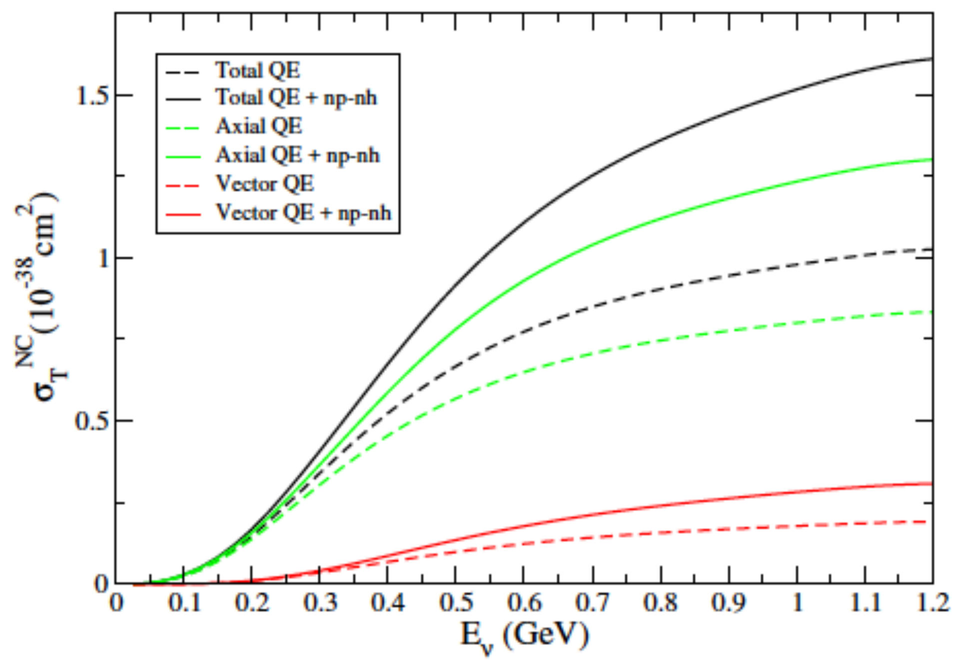
Ab initio calculation for weak interaction response function shows same features with phenomenological models.

Next step: ab initio calculation for oxygen and argon

NC Euclidean transverse response function by ab initio calculation (q=570 MeV)



NCQE-like cross section transverse response contribution by Martini et al.



Bhattacharya et al.,PRD92(2015)113011, Mayer et al.,PRD93(2016)113015
Alexandrou et al, arXiv:1705.03399, Amaro and Arriola,PRD93(2016)113015

2. More thoughts on nucleon parameters (now)

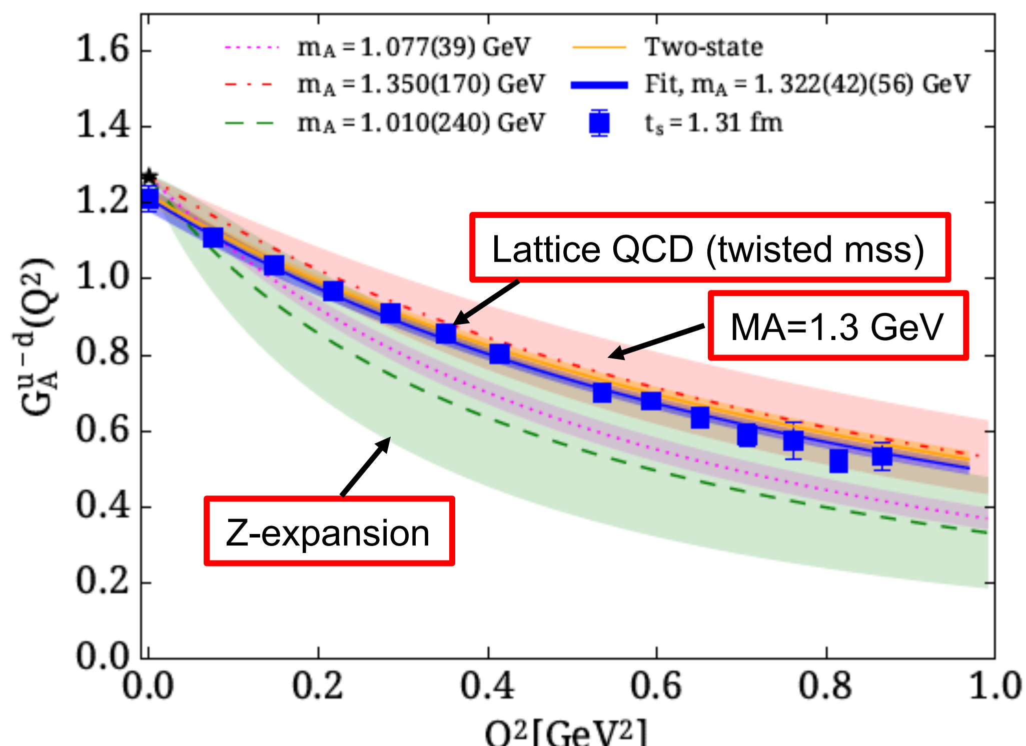
There are number of new thoughts on nucleon parameters

Z-expansion: Form factor errors are underestimated
Lattice QCD: axial mass could be larger
Large MA: could be motivated from theories

We often say "ν-A" scattering is complicated, but the reality is we are also confused about "ν-N" scattering…

Jury is still out?!

Axial vector form factor comparison

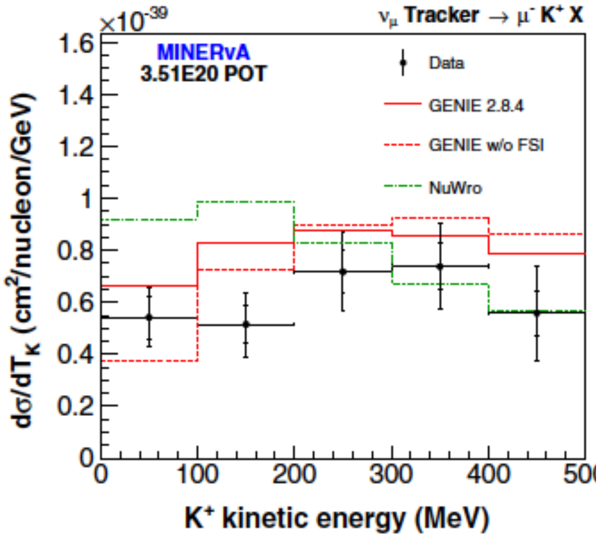


Coffee Break

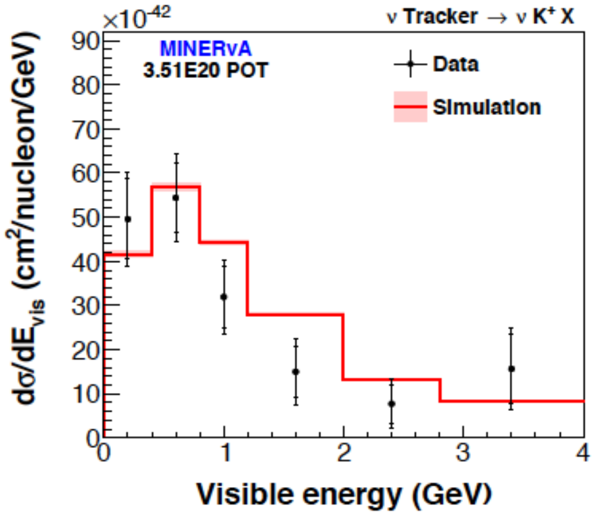
Honorable mention: Other MINERvA results (now)

Kaon bombs

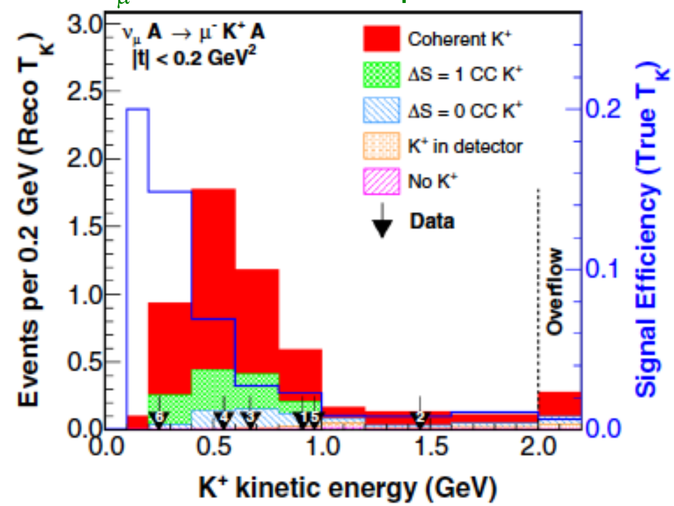
ν_μCC K^+ production



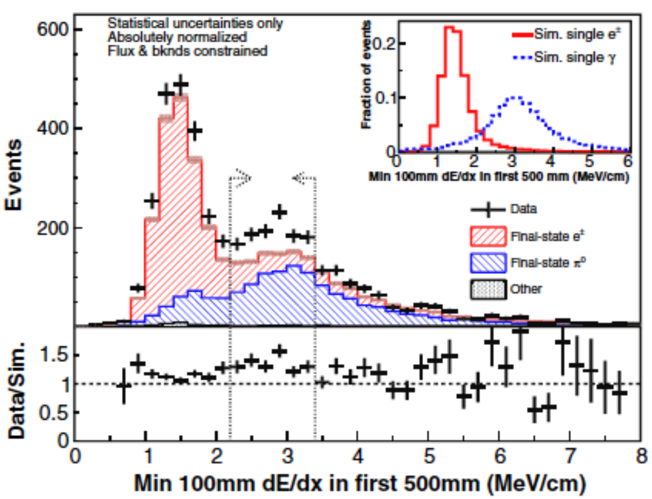
$\nu(\bar{\nu})$NC K^+ production



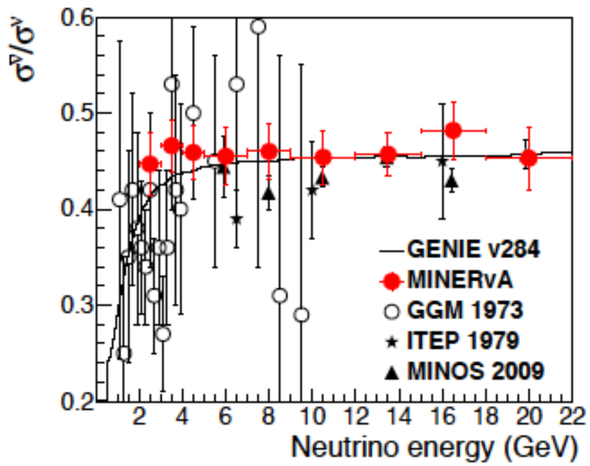
ν_μCC coherent K^+ production



Diffractive pion production



DIS $\bar{\nu}/\nu$ ratio

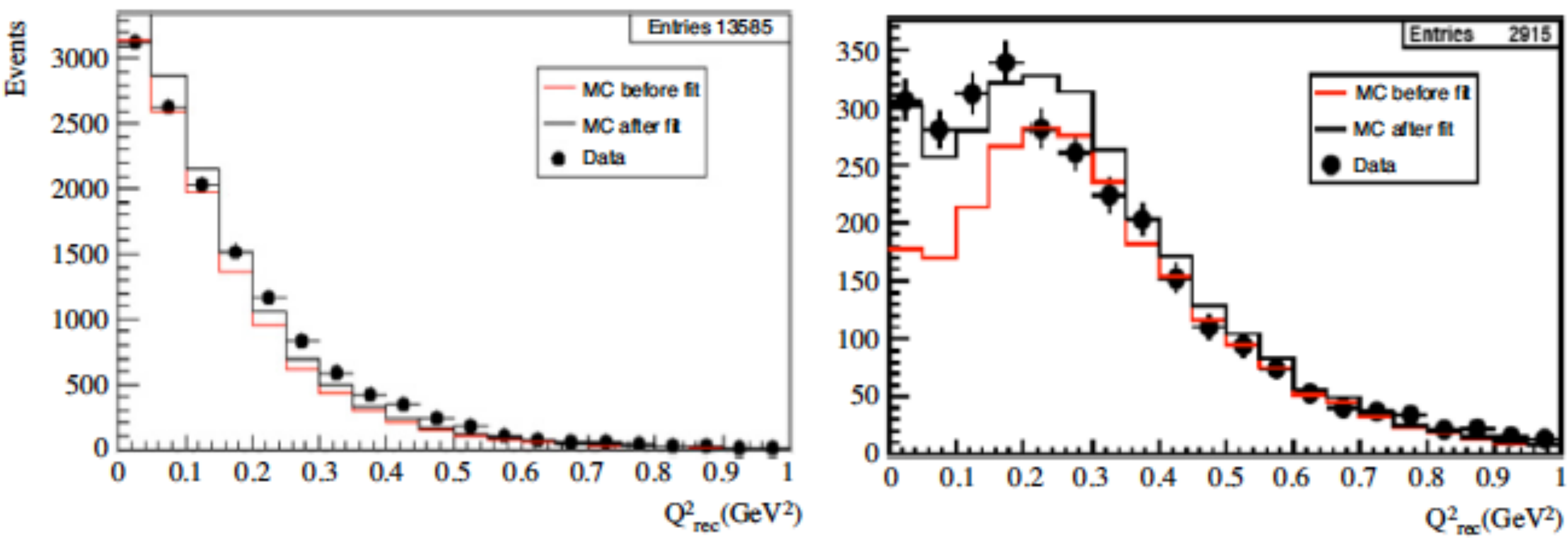


K2K,PRD74(2006)052002 (2006), NOMAD,EPJC63(2009)355
SciBooNE,arXiv:0909.5647

3. CC data with nucleon final state (2006)

Tensions between 1 track (μ) and 2 track (μ+p) are known, but experimentalists tried to understand that within their simulations.

SciBooNE 1 and 2 track Q^2 distribution



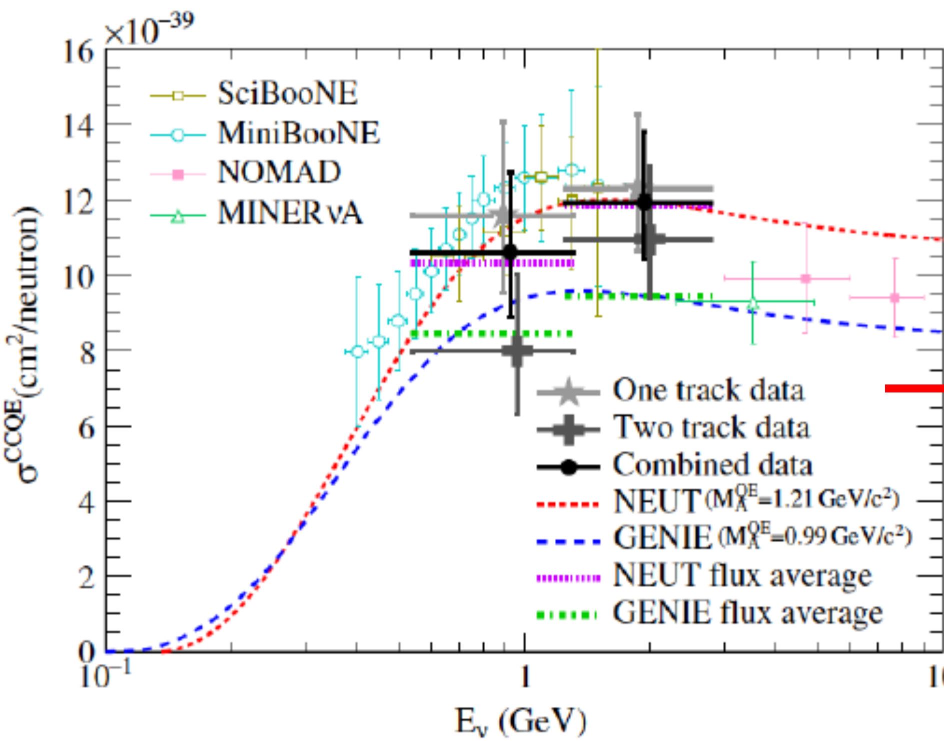
T2K,PRD91(2015)112002

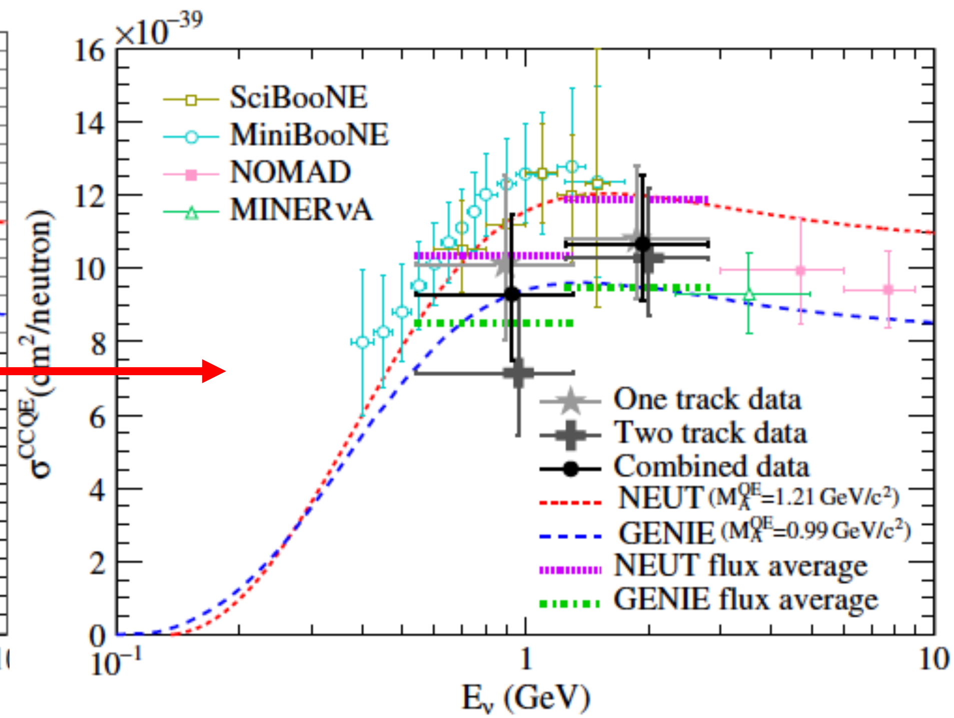
3. 1&2 track genuine CCQE total cross section, T2K (now)

T2K measured CCQE total cross section from 1 track (μ) and 2 track (μ+p) sample separately (model-dependent). 1 track cross sections are consistently higher than 2 track cross section.

→ 2p2h contribution is contaminated in 1 track.

Unfortunately, after including 2p2h in analysis (=2p2h contribution becomes background and removed) 1 trach cross section is still higher than 2 track cross section.

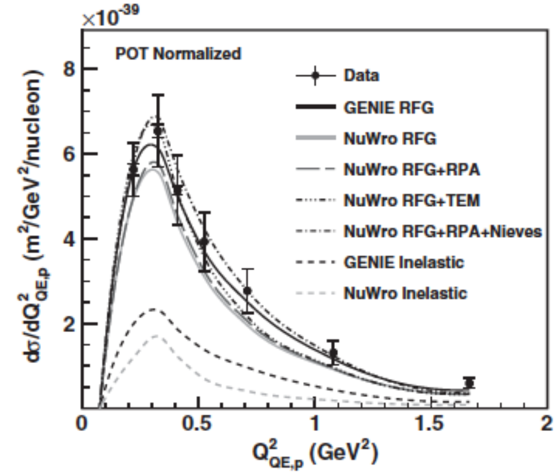




3. CC0πNp data, MINERvA (now)

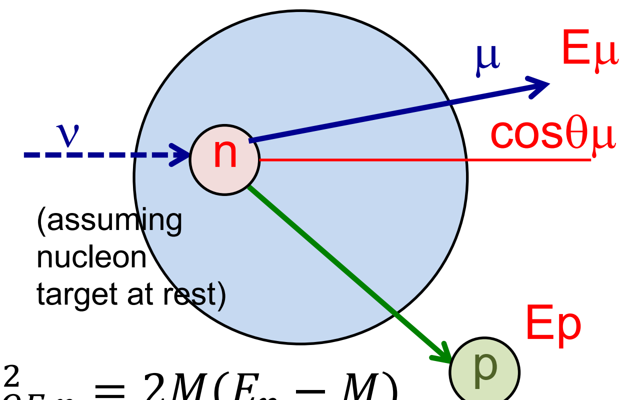
MINERvA measured μ+p sample differential cross section, more precisely "final state include a muon, at least one proton, and no pions". Q^2 is reconstructed from muon kinematics and proton kinematics, and they agree.

1. normalization agrees with old flux.
2. background subtraction is complicated.

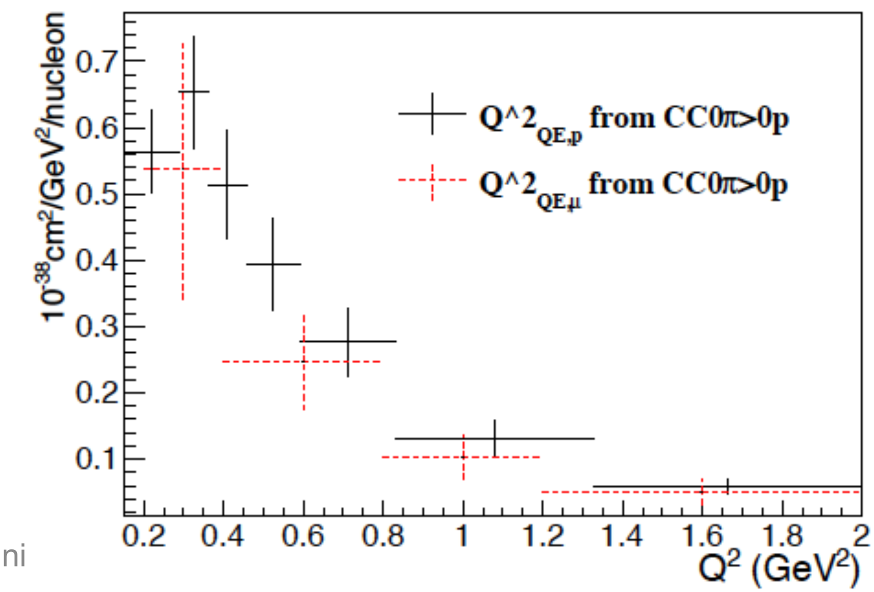


$$E_{QE,\mu}^{\nu} = \frac{ME_\mu - 0.5m_\mu^2}{M - E_\mu + p_\mu cos\theta}$$

$$Q_{QE,\mu}^2 = -m_\mu^2 + 2E_{QE,\mu}^{\nu}(E_\mu - \sqrt{E_\mu^2 - m_\mu^2}cos\theta_\mu)$$



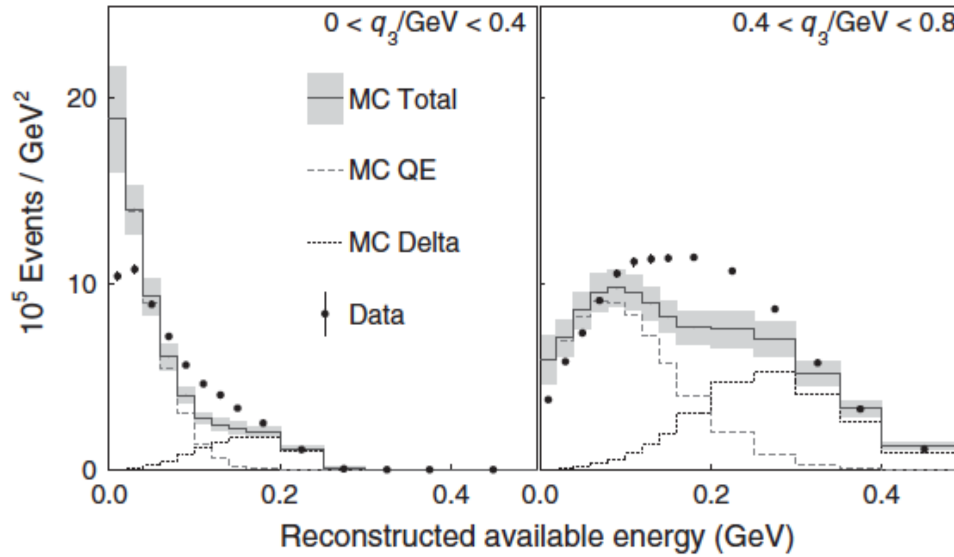
$$Q_{QE,p}^2 = 2M(E_p - M)$$



3. $d\sigma/dE_{avail}$ data, MINERvA (now)

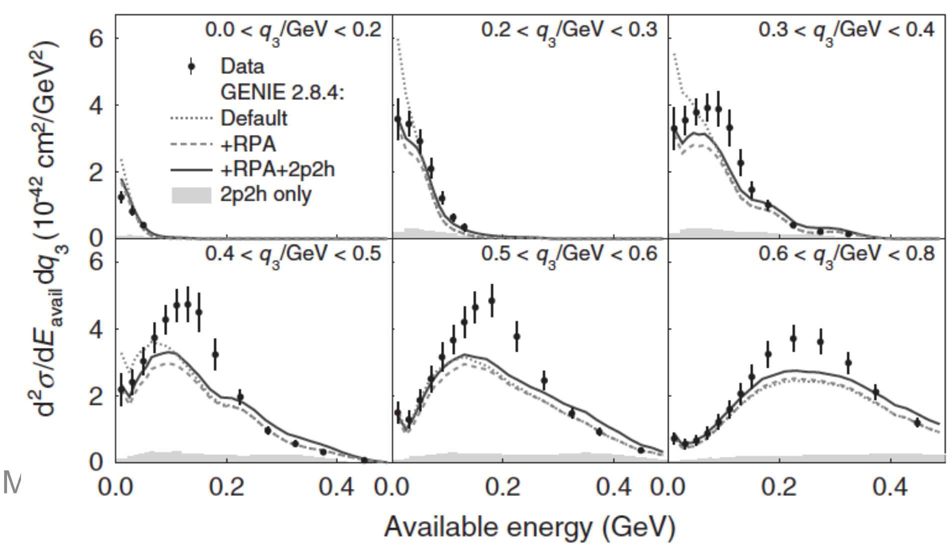
MINERvA reconstruct full inclusive kinematics (once we thought impossible!)

available energy
(visible hadron energy deposit)
↓
energy transfer
↓
3-momentum transfer



Double differential distribution shows "dip" structure in MC, but not in data

Excess of data around the dip region is very large.



Queen Mary
University of London

3. Backward going proton (1978)

Special topology of nucleons from neutrino interactions are studied at Fermilab 15ft bubble chamber, but the subject was forgotten in neutrino physics…

Probing nuclei with antineutrinos

J. P. Berge, D. Bogert, R. Endorf,* R. Hanft, J. A. Malko, G. Moffatt,* F. A. Nezrick, W. G. Scott,† W. Smart, and J. Wolfson
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

V. V. Ammosov, A. G. Denisov, P. F. Ermolov, V. A. Gapienko, V. I. Klyukhin, V. I. Koreshev, A. I. Mukhin, P. V. Pitukhin, Y. G. Rjabov, E. A. Slobodyuk, and V. I. Sirotenko
Institute of High Energy Physics, Serpukhov, USSR

V. I. Efremenko, P. A. Gorichev, V. S. Kaftanov, V. D. Khovansky, G. K. Kliger, V. Z. Kolganov, S. P. Krutchinin, M. A. Kubantsev, A. N. Rosanov, M. M. Savitsky, and V. G. Shevchenko
Institute of Theoretical and Experimental Physics, Moscow, USSR

J. Bell, C. T. Coffin, H. T. French,‡ W. C. Louis, B. P. Roe, R. T. Ross, A. A. Seidl, and D. Sinclair
University of Michigan, Ann Arbor, Michigan 48109
(Received 24 April 1978)

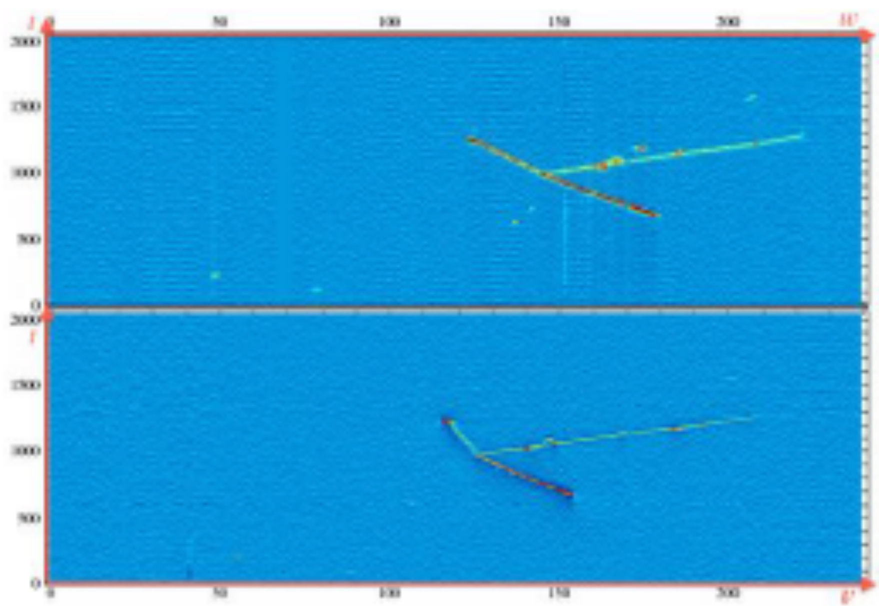
Variable[a]	Backward-proton events	Charged-current events
Number of events	36	837
$\langle E_{\bar\nu}\rangle$ (GeV)	25.48 ± 2.82	28.78 ± 0.71
$\langle P_\mu\rangle$ (GeV/c)	18.10 ± 2.36	19.02 ± 0.53
$(1-\cos\theta_\mu)$	$(2.87 \pm 0.60) \times 10^{-3}$	$(5.96 \pm 0.31) \times 10^{-3}$
$\langle \nu\rangle$ (GeV)	7.38 ± 1.47	9.71 ± 0.44
$\langle Q^2\rangle$ [(GeV/c)^2]	1.43 ± 0.25	3.58 ± 0.15
$\langle x\rangle$	0.17 ± 0.02	0.23 ± 0.01
$\langle y\rangle$	0.26 ± 0.03	0.33 ± 0.01
$\langle n\rangle$	7.42 ± 0.64	6.20 ± 0.11
$\langle C\rangle$	2.14 ± 0.17	1.25 ± 0.04
$\langle C_1\rangle$	0.81 ± 0.28	0.98 ± 0.04

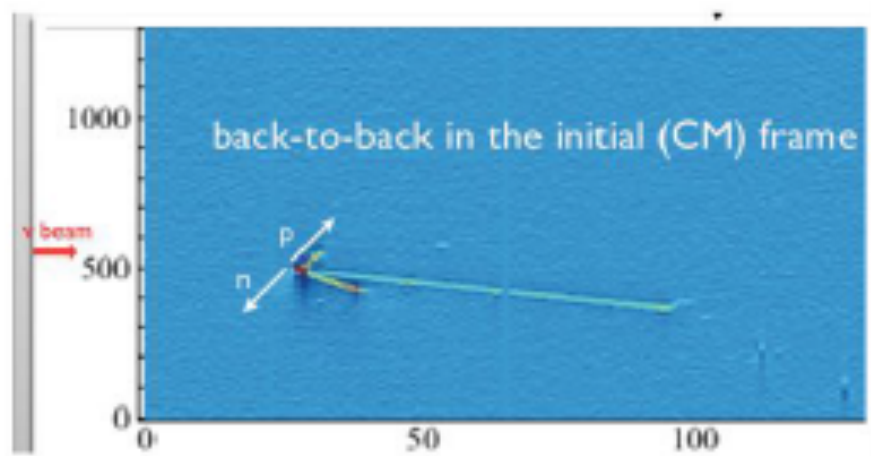
Queen Mary University of London

ArgoNeuT,PRD90(2014)012008

3. Hammer events, ArgoNeuT (2014)

ArgoNeuT published so called “hammer” events.
→ candidate topology of NNSRC from ν_μ+(np)→μ+p+p

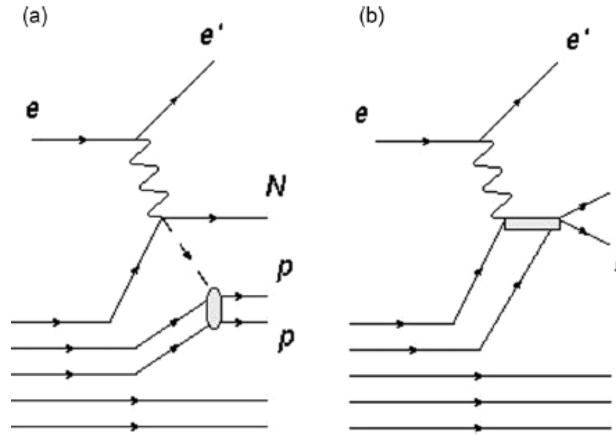




ArgoNeuT,PRD90(2014)012008
Niewczas and Sobczyk,PRC93(2016)035503,Weinstein et al.,PRC94(2016)045501

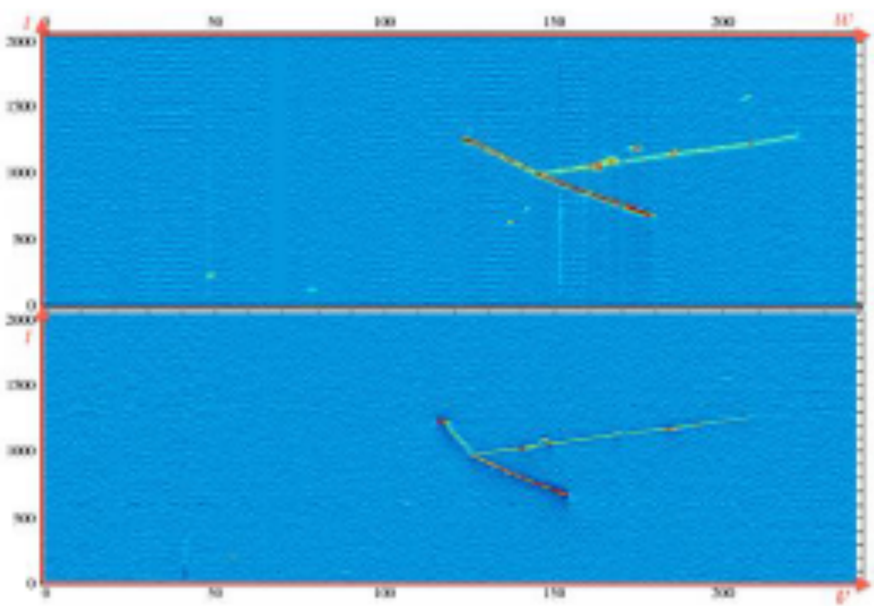
3. Interpretation of Hammer events (now)

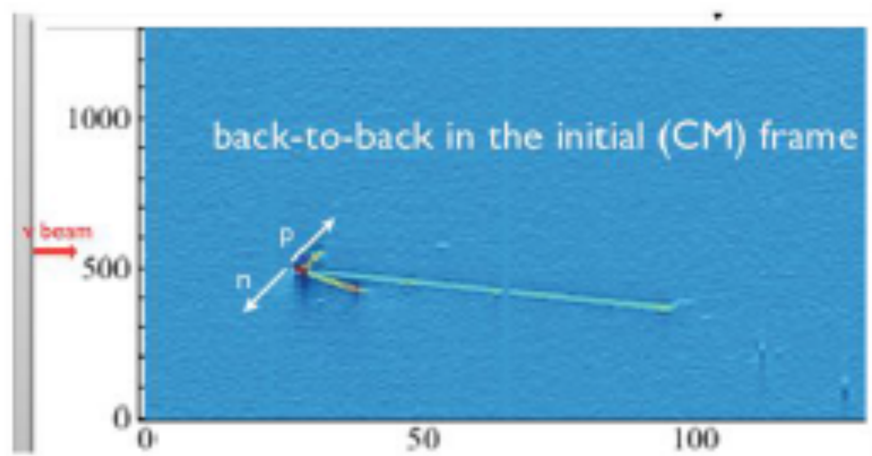
ArgoNeuT published so called "hammer" events.
→ candidate topology of NNSRC from ν_μ+(np)→μ+p+p



Other reactions contribute comparable amount on this topology…

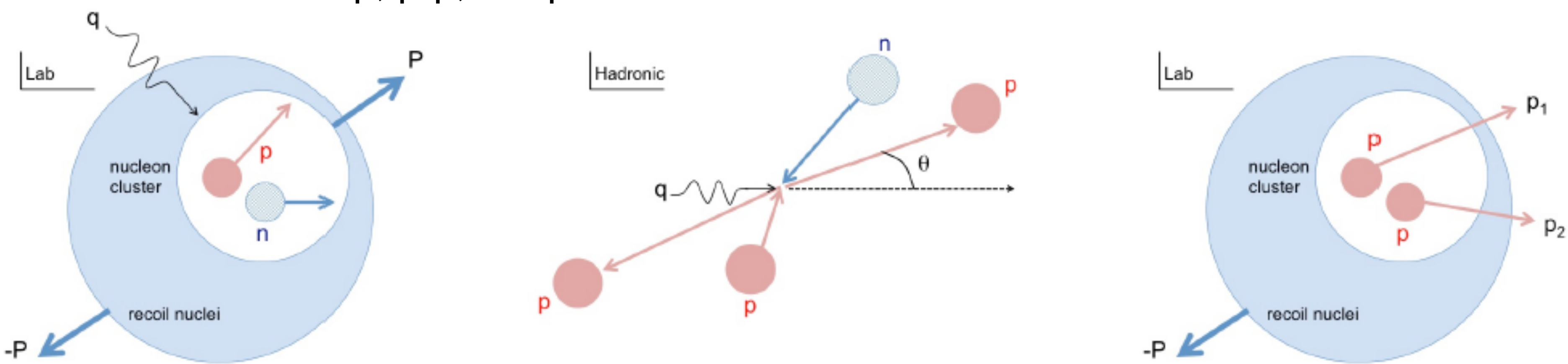
To study more detail, detection efficiency need to be understood.





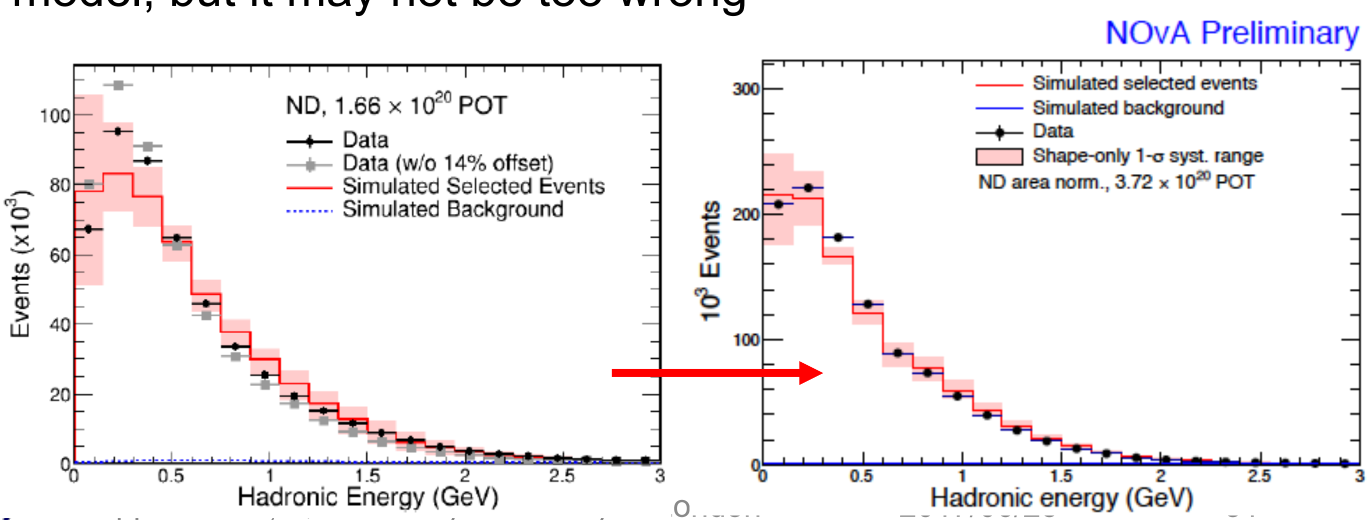
3. Nucleon kinematics predictions (2015)

So far, all generators are based on "nucleon cluster model"
- isotropic decay in hadronic frame
- fixed ratio for n-p, p-p, n-n pairs



Although it is too naïve model, but it may not be too wrong

NOvA reduce energy scale mismatch from 5 to 2% by 2p2h+MEC (Nieves et al.)+nucleon cluster model



Van Chuyk et al.,PRC94(2016)024611
Ruiz Simo et al.,PLB762(2016)124

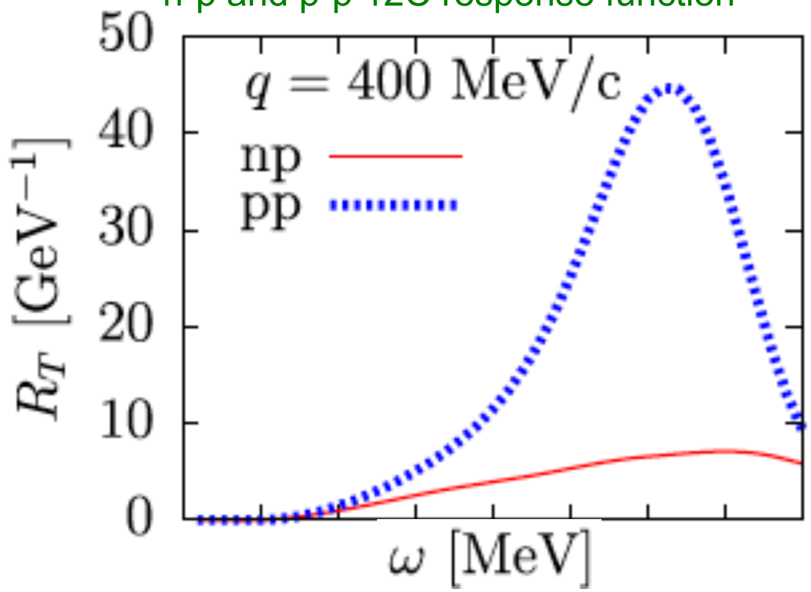
3. Nucleon kinematics predictions (now)

So far, all generators are based on "nucleon cluster model"
- isotropic decay in hadronic frame
- fixed ratio for n-p, p-p, n-n pairs

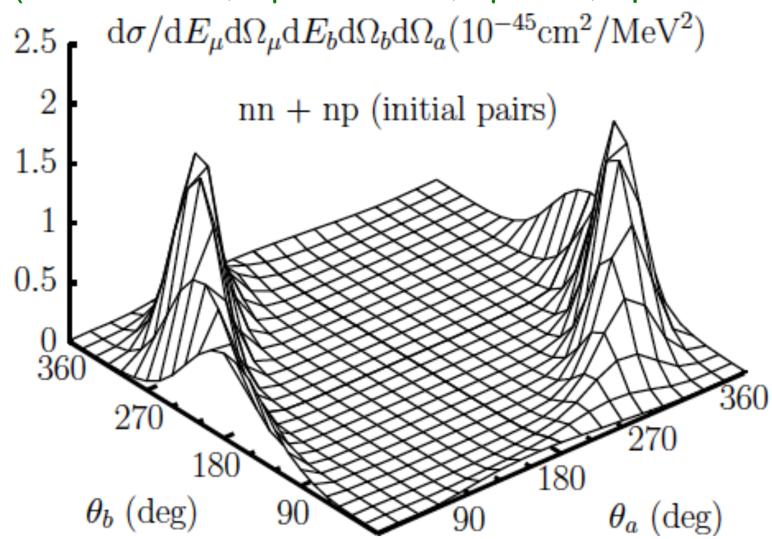
Number of groups made detailed predictions of hadron final states

→ Question, how to use them in experiments?

n-p and p-p 12C response function



proton in-plane kinematics from 2p2h
(Eν=750MeV, Eμ=550MeV, θμ=15°, Tp=50MeV)



Gargamelle,NPB133(1978)205

4. ν_eCC data (1978)

No ν_eCC data in low energy region. This was a main argument for neutrino factory (including nuSTORM).

ν_e to ν_μ cross section ratio is an important systematics, but it is often optimistic.

TOTAL CROSS SECTIONS FOR ν_e AND $\bar{\nu}_e$ INTERACTIONS AND SEARCH FOR NEUTRINO OSCILLATIONS AND DECAY

Gargamelle Collaboration

J. BLIETSCHAU, H. DEDEN, F.J. HASERT, W. KRENZ, D. LANSKE, J. MORFIN, M. POHL, K. SCHULTZE, H. SCHUMACHER, H. WEERTS and L.C. WELCH
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E. BELLOTTI, S. BONETTI, D. CAVALLI, E. FIORINI, A. PULLIA and M. ROLLIER
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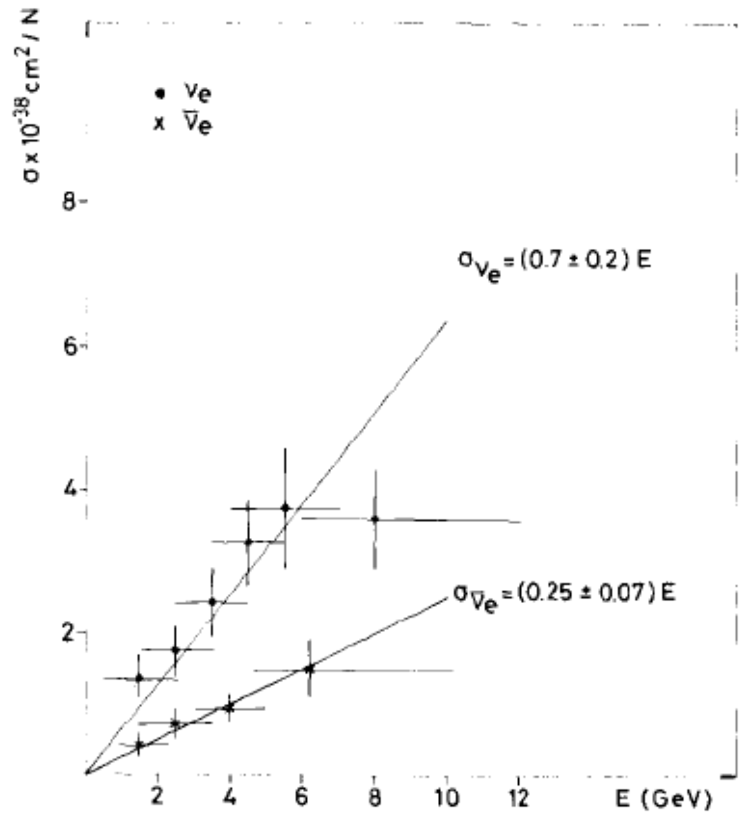
B. AUBERT, D. BLUM, A.M. LUTZ and C. PASCAUD
Laboratoire de l'Accélérateur Linéaire, Orsay, France

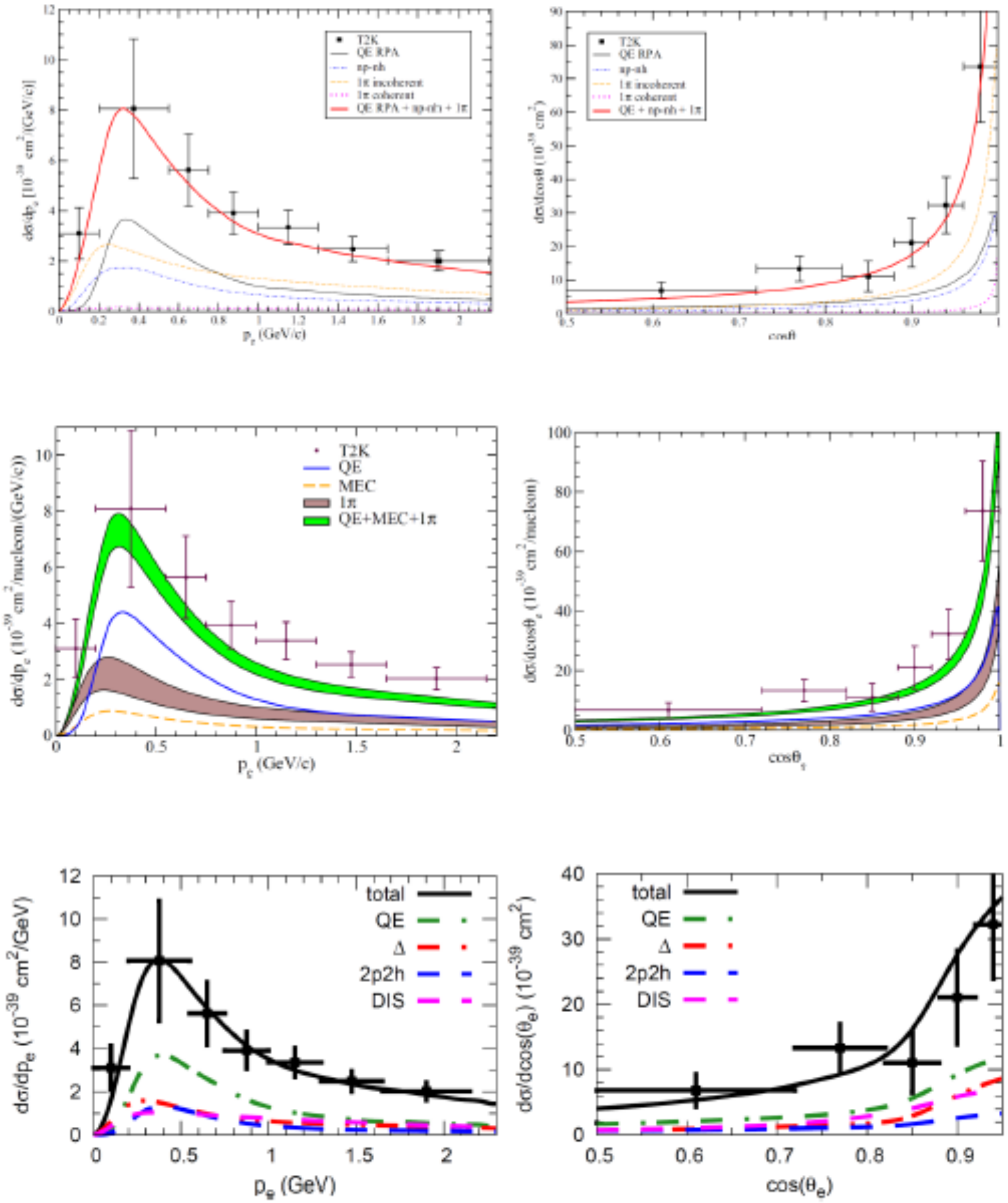
F.W. BULLOCK and A.G. MICHETTE +++
University College London, London, UK



T2K,PRL113(2014)241803;PRD91(2015)112010
Martini et al.,PRC94(2016)015501,Gallmeister et al.,PRC94(2016)035502,Megias et al.,PRD94(2016)093004

4. ν_eCC inclusive data, T2K (now)

T2K measured ν_eCC inclusive cross section, and models already reproduced them!

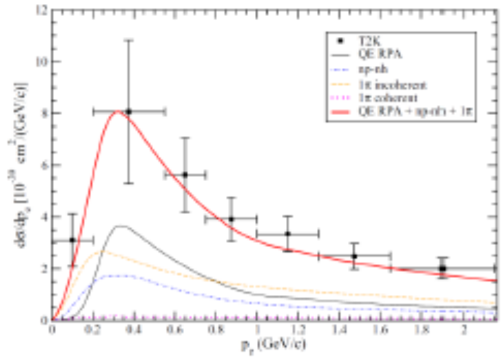


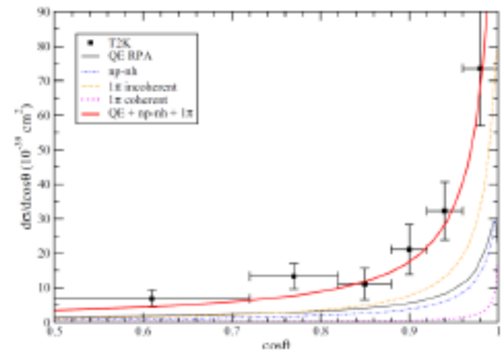
MINERvA,PRL116(2016)081802

4. ν_eCCQE-like data, MINERvA (now)

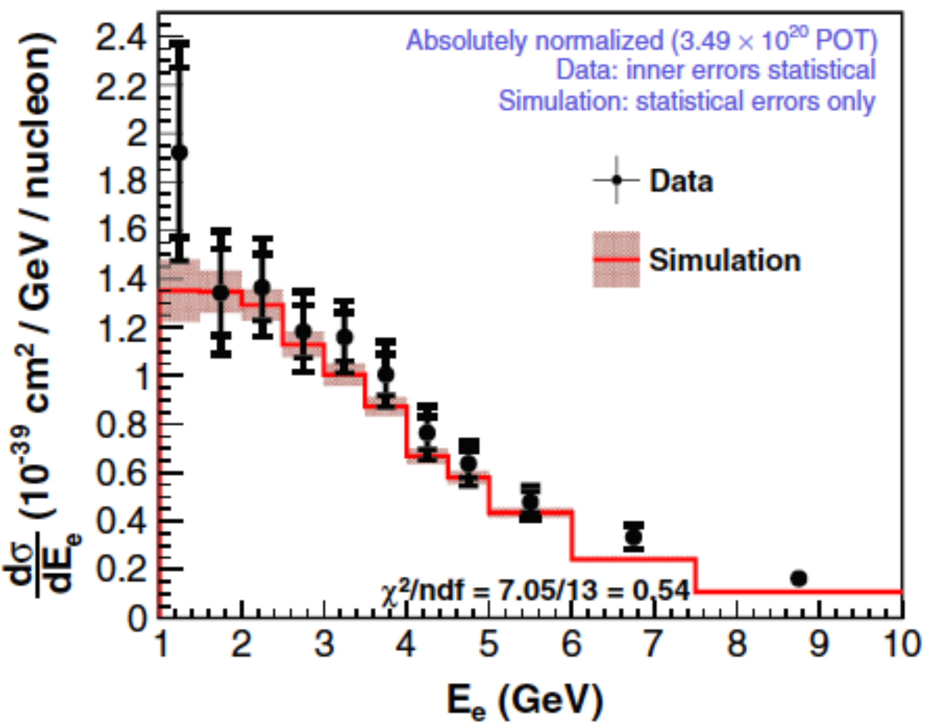
T2K measured ν_eCC inclusive cross section, and models already reproduced them!

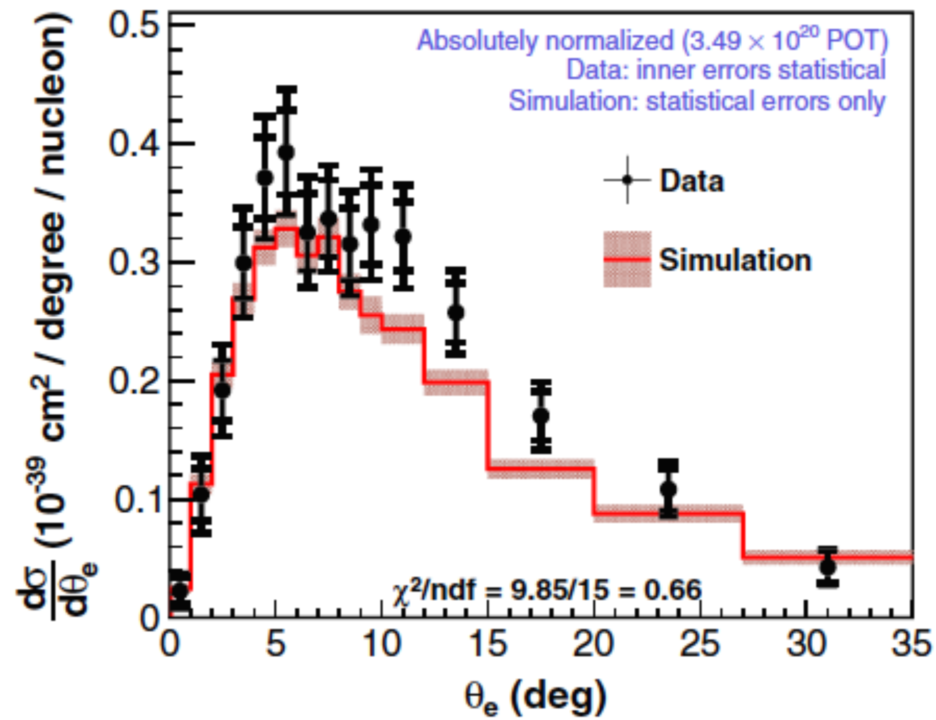
MINERvA measured ν_eCCQE-like





Summary: we have many ν_eCC data from zero, but precision (=statistics) is much worse than ν_μCC data.





5. Target dependent results (2015)

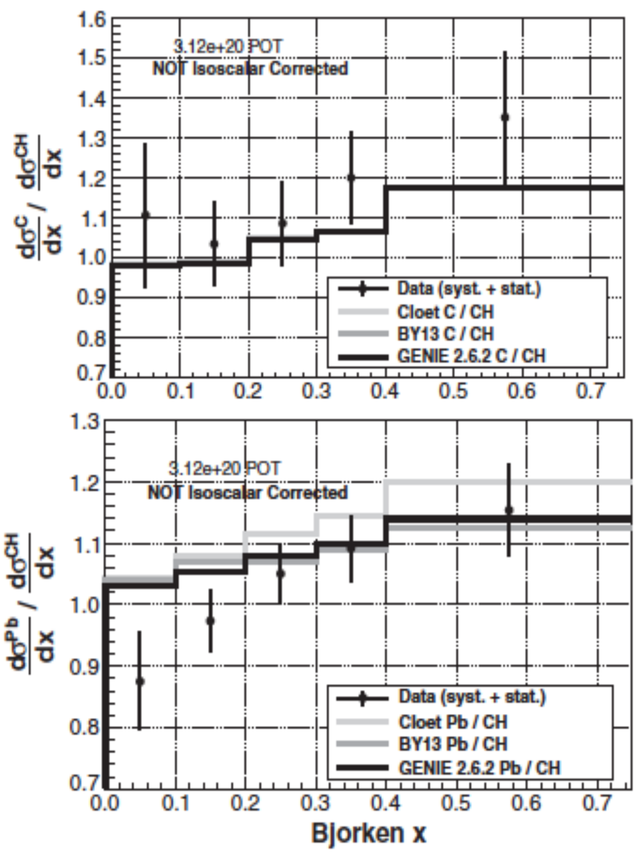
Nuclear PDFs for neutrinos

CCQE from iron

5. Target dependent results (now)

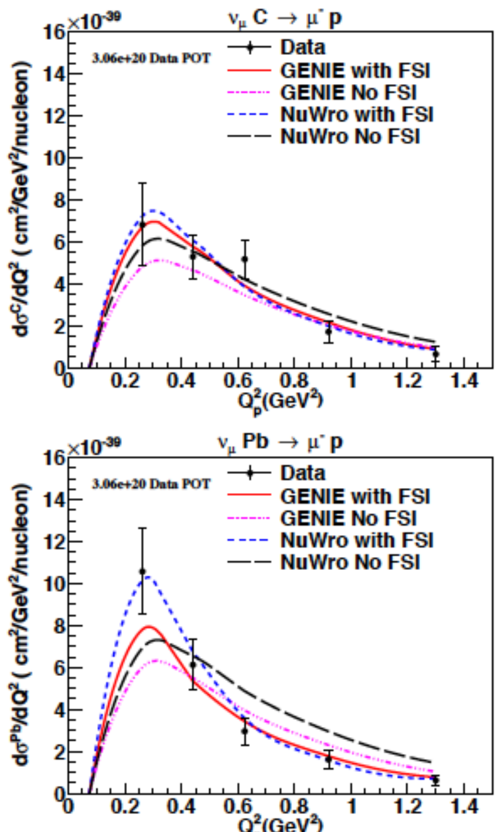
DIS target ratio cross section

- nuclear shadowing may be stronger than simulation

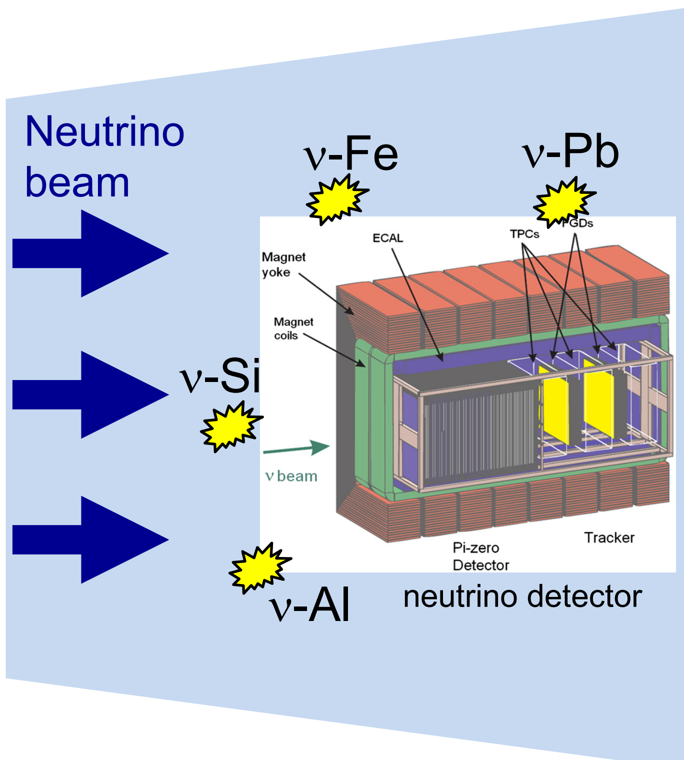


CC0πNp A-dependent cross section

- proton feels more FSI in larger A



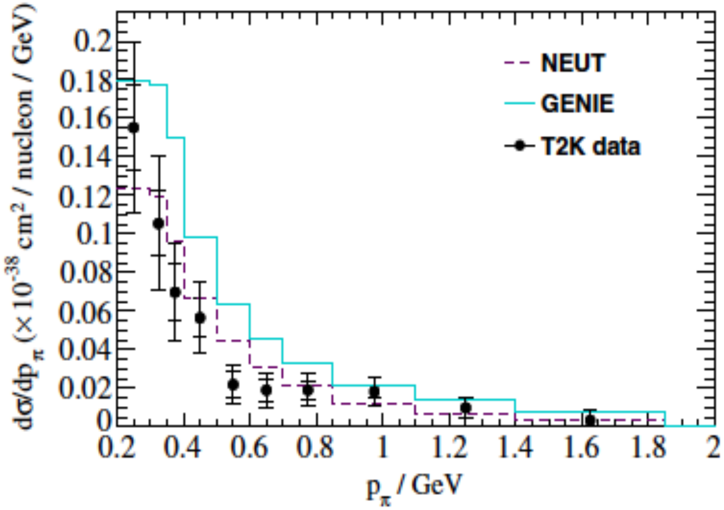
Modern neutrino experiments need characterizations of all elements with all energy



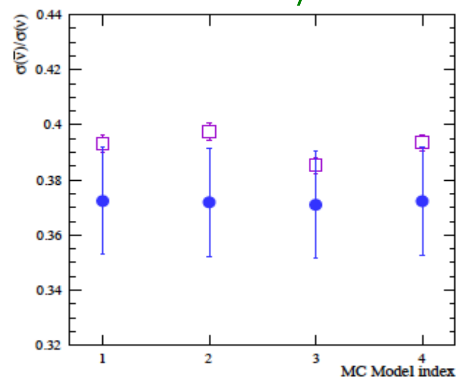
Coffee Break

Honorable mention: T2K water target results (now)

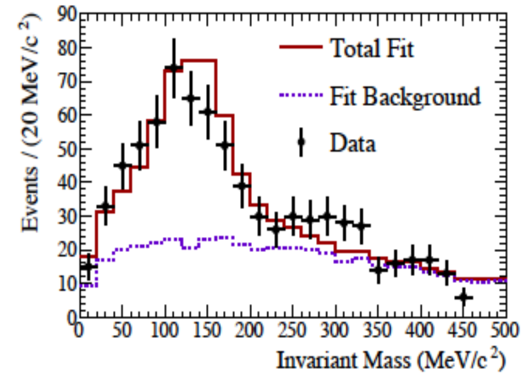
CC1π⁺ production differential cross section



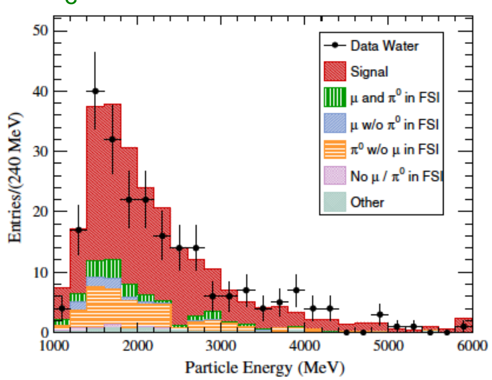
CC inclusive $\bar{\nu}/\nu$ ratio



NCπ⁰ production rate

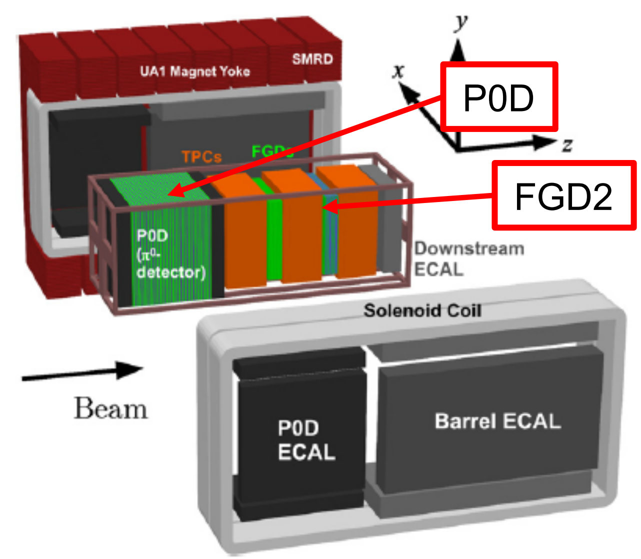


ν_eCC rate measurement



Problem: If the target material is inactive (=water layer), systematic errors are inflated during active material subtraction process

$$N_{\text{On-Water}} = N_{\text{WI}} - \frac{\epsilon_{\text{NW}}\text{POT}_{\text{WI}}}{\epsilon_{\text{WO}}\text{POT}_{\text{WO}}} N_{\text{WO}}$$



6. Open question of neutrino interaction physics (2012)

CCQE puzzle
- Low Q2 suppression, high Q2 enhancement, high normalization

NCgamma
- Can NCgamma explain MiniBooNE ν_e-candidate excess?

Coherent pion
- Is there charged current coherent pion production?

ANL-BNL puzzle
- Normalization difference between ANL and BNL bubble chamber pion data

Pion puzzle
- MiniBooNE and MINERvA pion kinematic data are incompatible under any models

Baryon resonance, pion production by neutrinos

6. Open question of neutrino interaction physics (now)

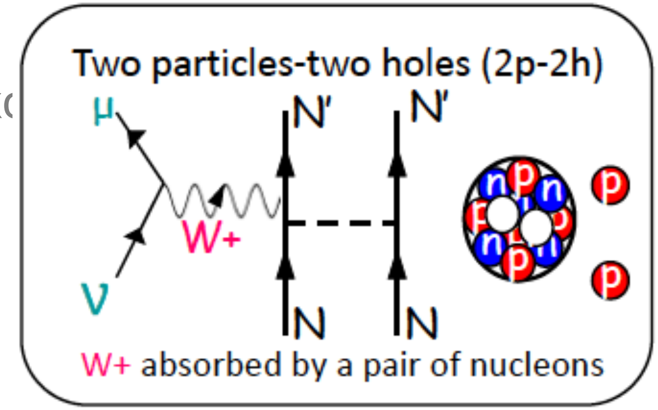
CCQE puzzle

- Low Q2 suppression, high Q2 enhancement, high normalization

→ presence of short and long range nucleon correlations

NCgamma

- Can NCgamma explain MiniBooNE ν_e-candidate exc



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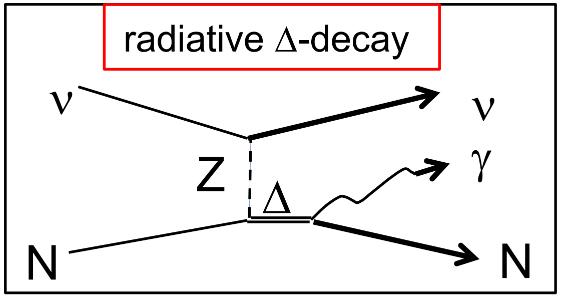

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K2K,PRL95(2005)252301, SciBooNE, PRD78(2008)112004

6. Open question of neutrino interaction physics (2008)

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→ presence of short and long range nucleon correlations

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- Can NCgamma explain MiniBooNE ν_e-candidate excess?

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Coherent pion

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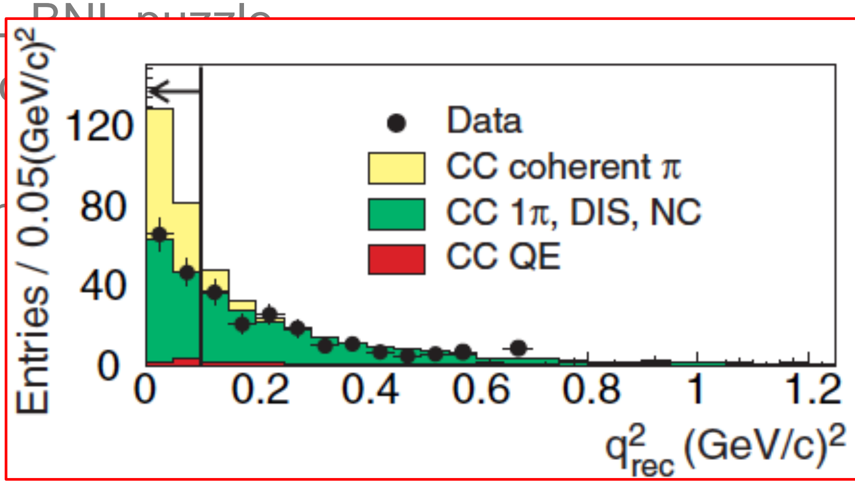
ANL

- N BNL bubble chamber pion data

Pion

- M data are incompatible under any models



6. Open question of neutrino interaction physics (now)

CCQE puzzle
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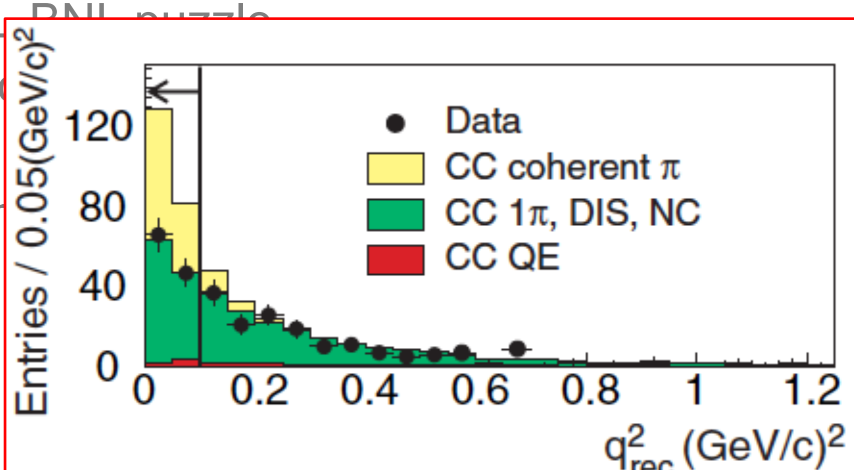
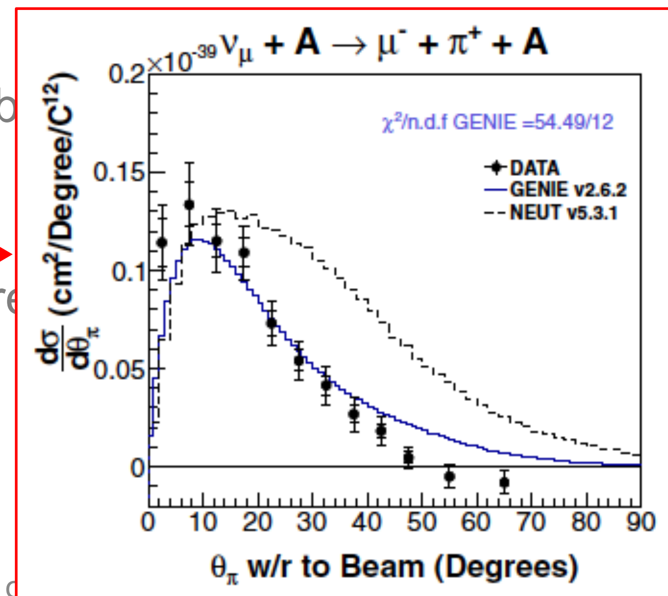
→ probably not, but no measurement, yet

Coherent pion
- Is there charged current coherent pion production?
→ yes, data from T2K, MINERvA, ArgoNeuT, MINOS

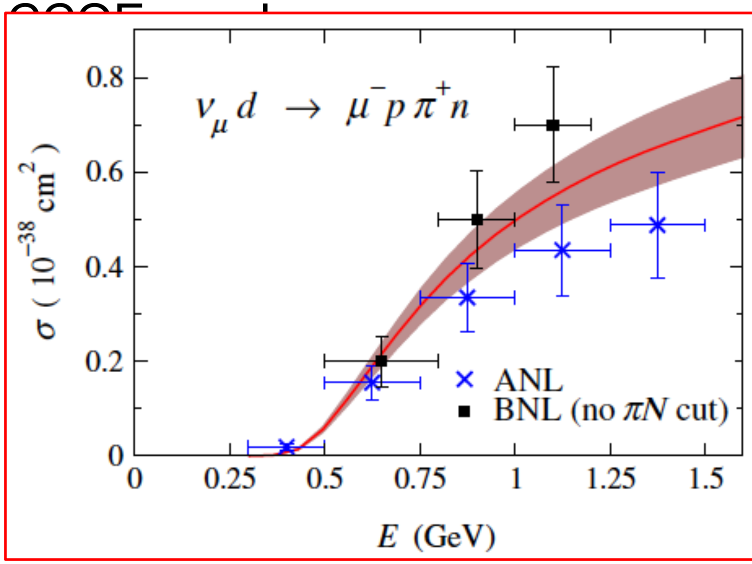
ANL BNL puzzle
- N... BNL b...

Pion...
- M... data are ... s





6. Open question of neutrino interaction physics (1980s)



hancement, high normalization

e nucleon correlations

NE ν_e-candidate excess?

ent, yet

pion production?

ArgoNeuT, MINOS

ANL-BNL puzzle

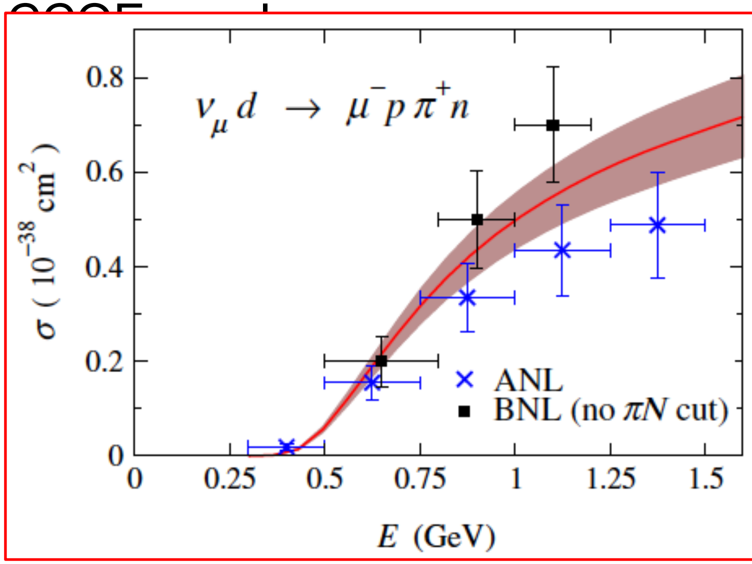
- Normalization difference between ANL and BNL bubble chamber pion data

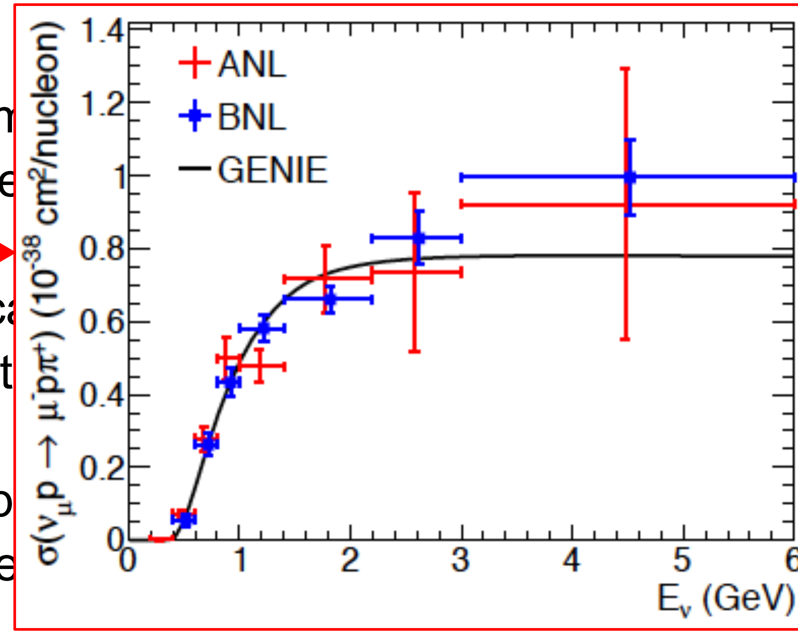
Pion puzzle

- MiniBooNE and MINERvA pion kinematic data are incompatible under any models

Alvarez-Ruso et al,NewJ.Phys.16(2014)075015, Morfin et al,AHEP(2012)934597, Garvey et al.,Phys.Rept.580 (2015)1
Wilkinson et al,PRD90(2014)112017,Graczyk et al,PRD80(2009)093001,Wu et al,PRC91(2015)035203

6. Open question of neutrino interaction physics (now)





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pion p
ArgoNe

ANL-BNL puzzle

- Normalization difference between ANL and BNL bubble chamber pion data

→ BNL data was wrong, but both might have wrong deuteron correction

Pion puzzle

- MiniBooNE and MINERvA pion kinematic data are incompatible under any models

Alvarez-Ruso et al,NewJ.Phys.16(2014)075015, Morfin et al,AHEP(2012)934597, Garvey et al.,Phys.Rept.580 (2015)1
Wilkinson et al,PRD90(2014)112017,Graczyk et al,PRD80(2009)093001,Wu et al,PRC91(2015)035203

6. Open question of neutrino interaction physics (2014)

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→ probably not, but no measurement, yet

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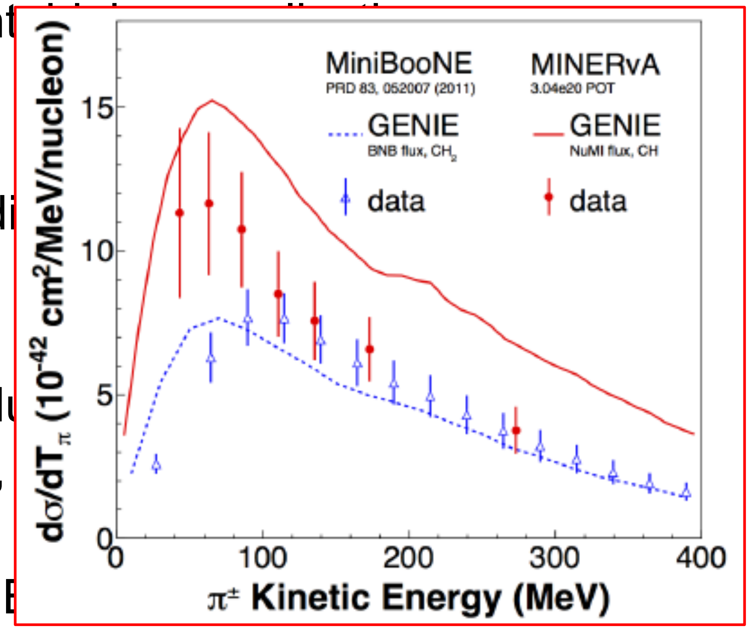
ANL-BNL puzzle
- Normalization difference between ANL and B
→ BNL data was wrong, but both might have wrong deuteron correction

Pion puzzle
- MiniBooNE and MINERvA pion kinematic data are incompatible under any models



6. Open question of neutrino interaction physics (now)

CCQE puzzle
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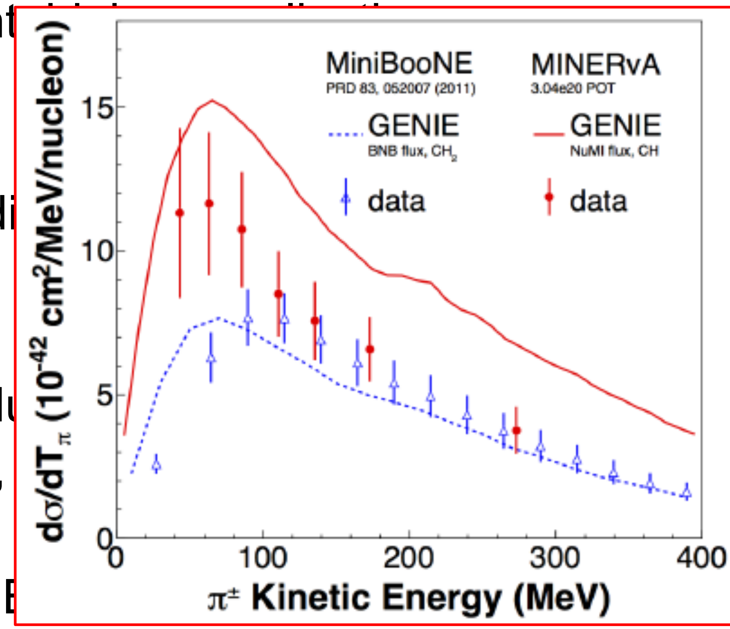
ANL-BNL puzzle
 - Normalization difference between ANL and B
 → BNL data was wrong, but both might have wrong deuteron correction
Pion puzzle
 - MiniBooNE and MINERvA pion kinematic data are incompatible under any models
 → ???



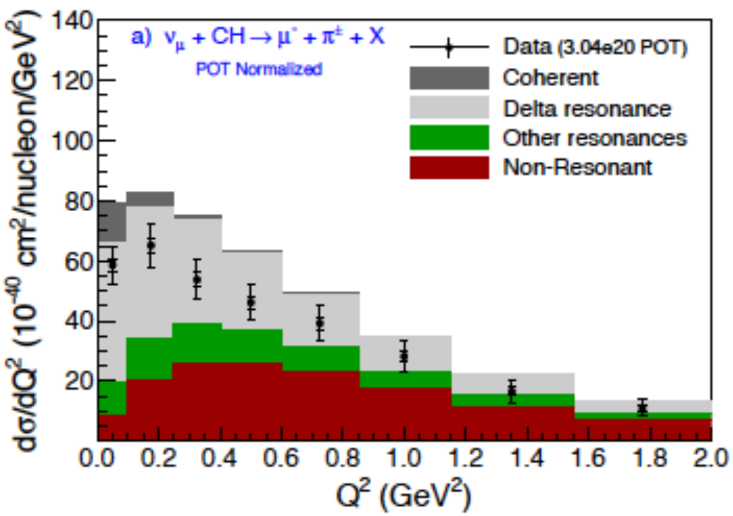
MINERvA,PRD94(2016)052005
Rodrigues et al.,EPJC76(2016)474

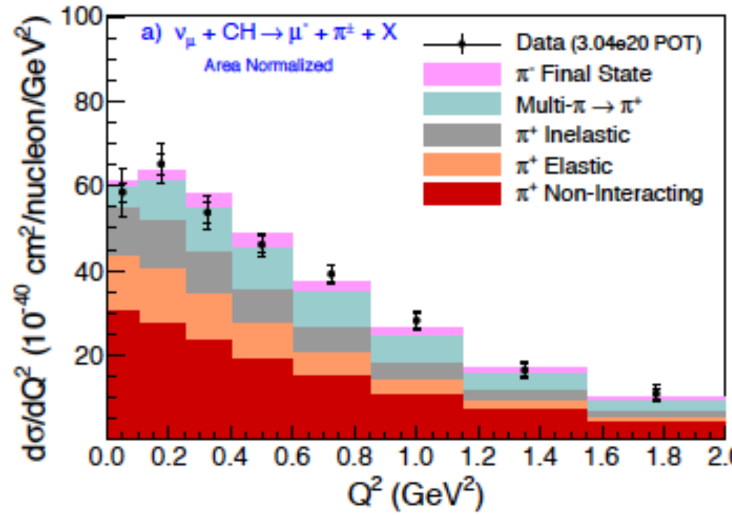
6. Pion puzzle (now)

MINERvA $\nu_\mu CC1\pi^+$ vs. $\overline{\nu_\mu} CC1\pi^o$

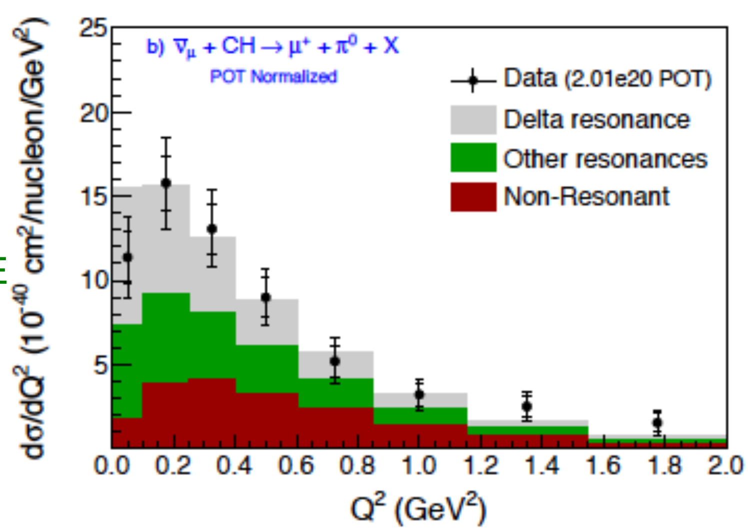
- this moment, there is no clear way to tune MC…

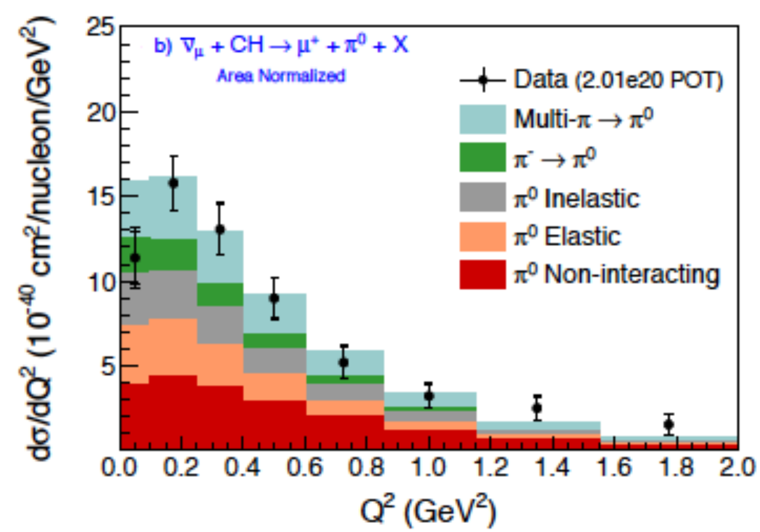
$\nu_\mu CC1\pi^+$ data has better shape agreement with GENIE





anti-$\nu_\mu CC1\pi^o$ data has better normalization agreement with GENIE





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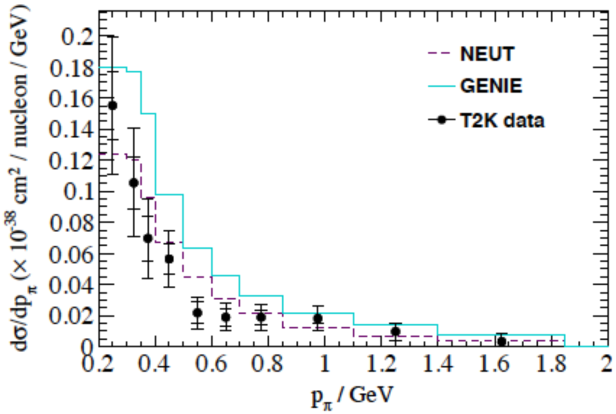
University of Lo

T2K, PRD95(2017)012010,arXiv:1704.07467,ArgoNeuT,arXiv:1511.00941,MINOS,PRD94(2016)072006
DUET,PRC92(2015)035205;95(2017)045203

6. Pion puzzle (now)

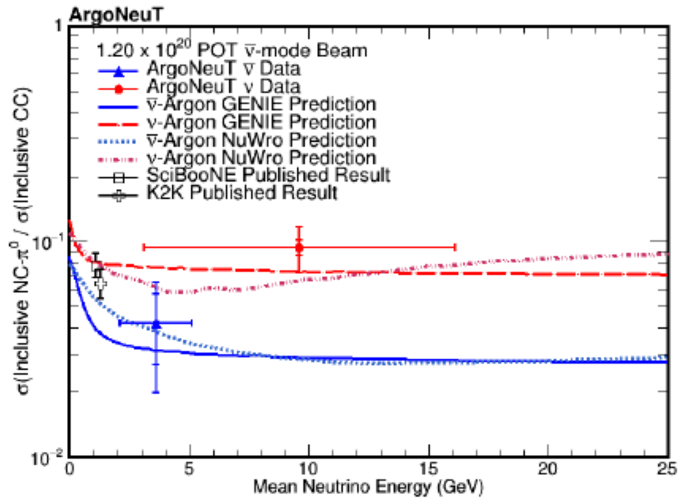
T2K pion data from water target

- Large error for inactive target



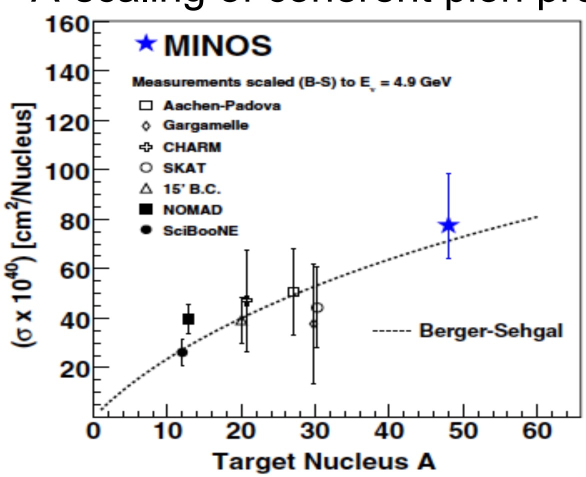
ArgoNeuT $\nu_\mu(\overline{\nu_\mu})NC\pi^o$ on argon

- π^o reconstruction from γ opening angle



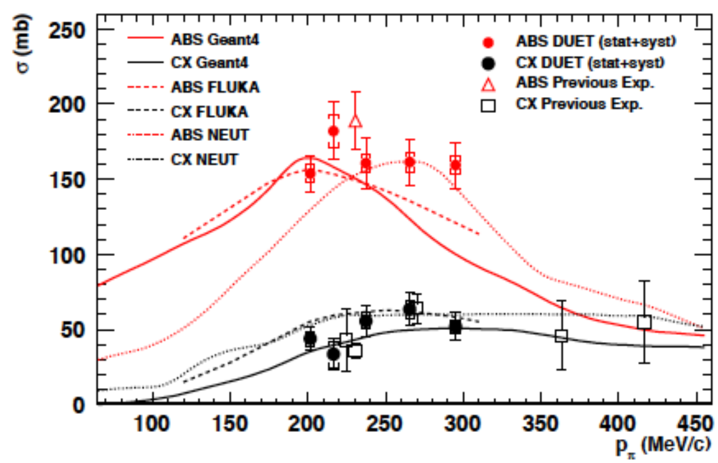
MINOS ν_μNCπ^o on iron

- A-scaling of coherent pion production



DUET FSI study for π^+ in carbon

- σ_{ABS} and σ_{CEX} are measured



Any data from LArIAT?

MINERvA,PRD93(2016)071101,Nakamura et al,PRD92(2015)074024
AGKY, EPJC63(2009)1,TK and Mandalia, arXiv:1602.00083

6. Multi-pion production and beyond (now)

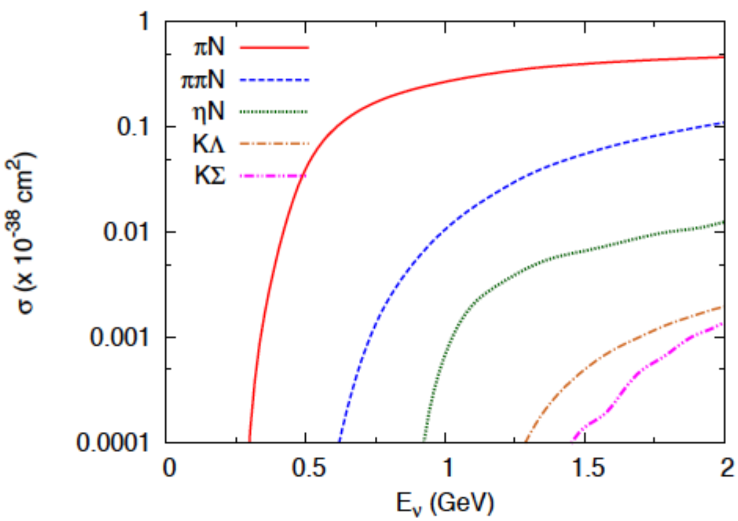
Shallow Inelastic Scattering

- Very small activities to improve DIS and hadronization models in generators

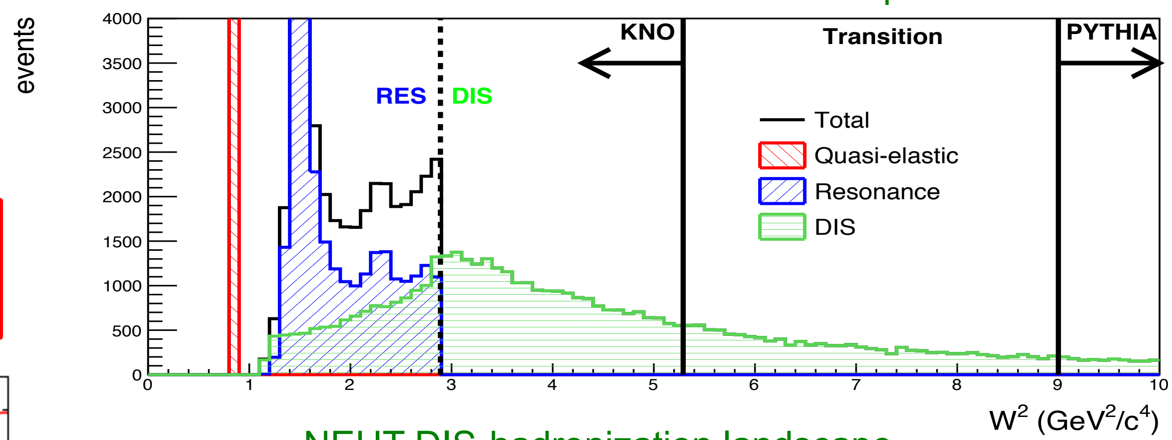
DCC model

- all channels are coupled
- 2 pion production

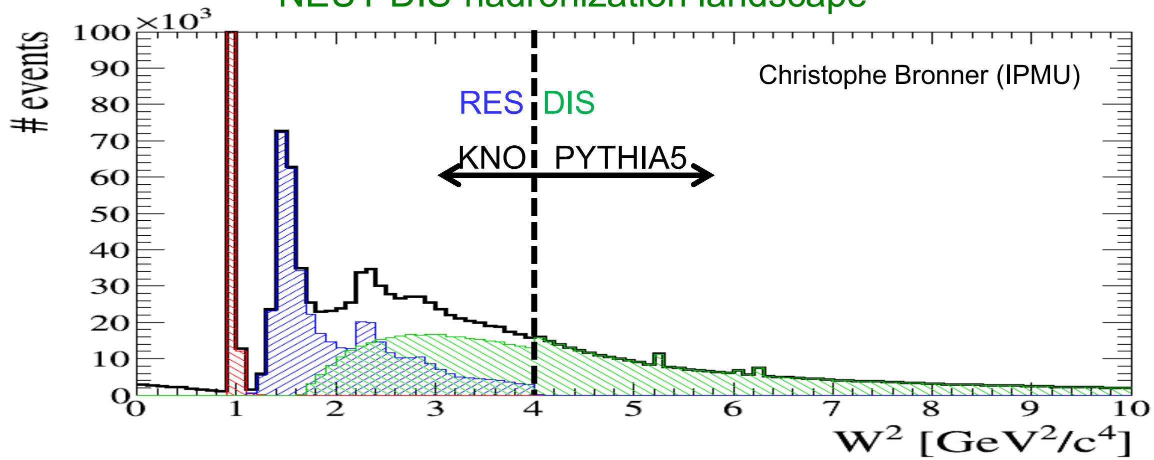
→ Question, how to use this model in experiments?



GENIE DIS-hadronization landscape



NEUT DIS-hadronization landscape



6. Multi-pion production and beyond (now)

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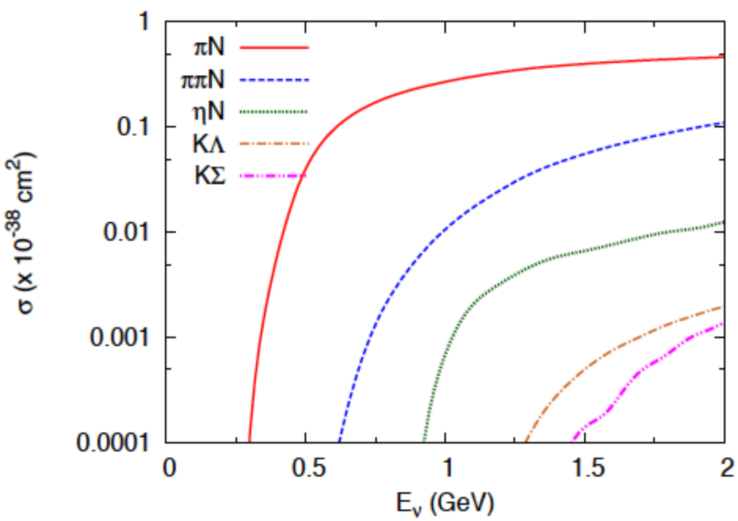
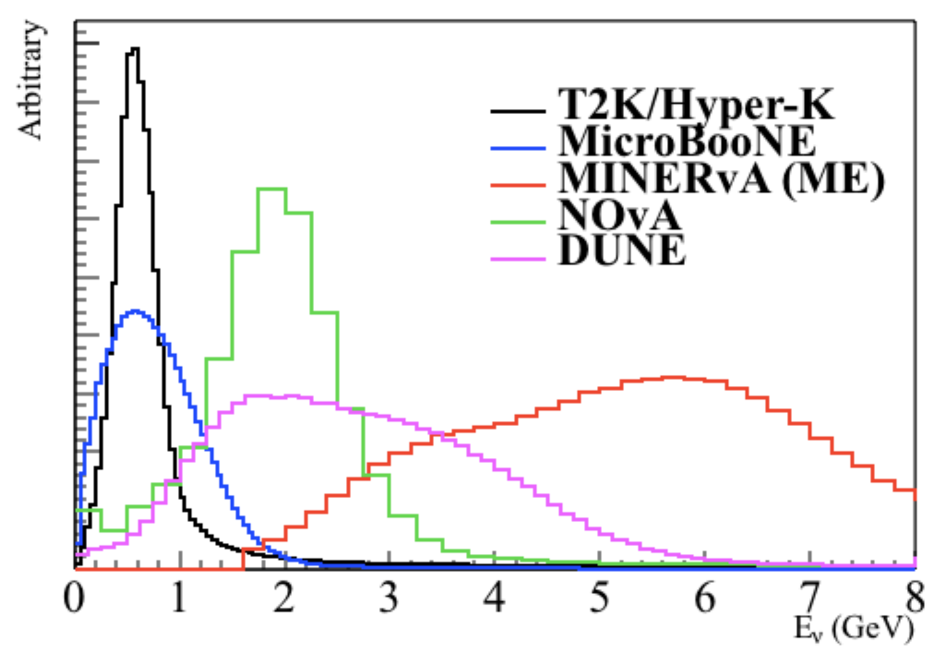


Current and future beams

- DUNE, QE:RES:DIS=1:1:1
- MINERvA may be only place to study SIS/DIS?



1. Introduction

2. CCQE, CCQE-like, and CC0π data

3. CC data with nucleon final state

4. Electron neutrino CC data

5. A-dependence of neutrino cross section

6. Pion puzzle

7. Conclusion

7. Conclusion

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There are many major developments

Lepton kinematics study is not completed. We need a precise quantitative data-theory comparison. For this we need; covariance matrix for all data set, validity of covariance matrices, theoretical systematic errors, better global fit machinery, etc.

Many new data are targeting to identify 2p2h signature from nucleon kinematics. For this, we need; understand nucleon detection efficiencies, simulation of nucleon propagation within detector (GEANT), predictions of initial nucleon distribution and nucleon propagation within nuclear media, and how to use these theories in event generators.

It looks “pion puzzle” is still an outstanding open question. On top of the better understanding of detector efficiency, we need to improve resonance, DIS, SIS, hadronization, FSI, and hadron propagation models.

Fun Timely Intellectual Adorable!

Lattice QCD

nuclear many-body problem

Spin physics

Leptonic CP violation

Neutrino oscillation

Weak interaction

NuSTEC-News

Nucleon correlation

EMC effect

electron scattering

Dark matter

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Backup

2. Remark from Gerry Garvey (circa 2010)

Contrast of e-N with ν-N Experiments

Electron

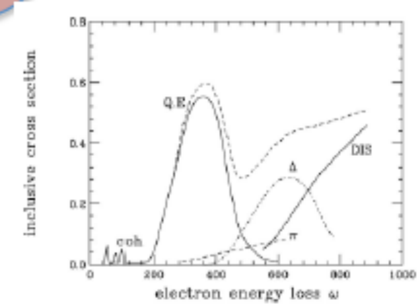
Electron Beam $\Delta E/E \sim 10^{-3}$

Flux known to 1%

Scattered electron

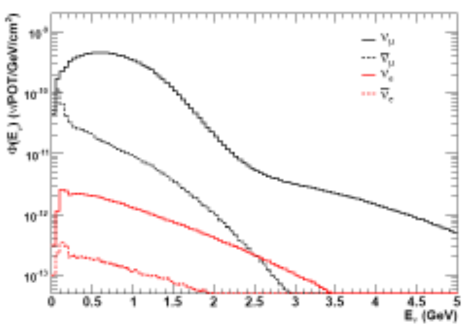
θ

Magnetic Spectograph



Neutrino

Neutrino-Mode Flux



E_ν

Neutrino Beam $\Delta E/\langle E\rangle \sim 1$

Flux known to 20%

θ

l^-

Don't know E_ν !!!

What's ω ???

What's $\vec{q}$????

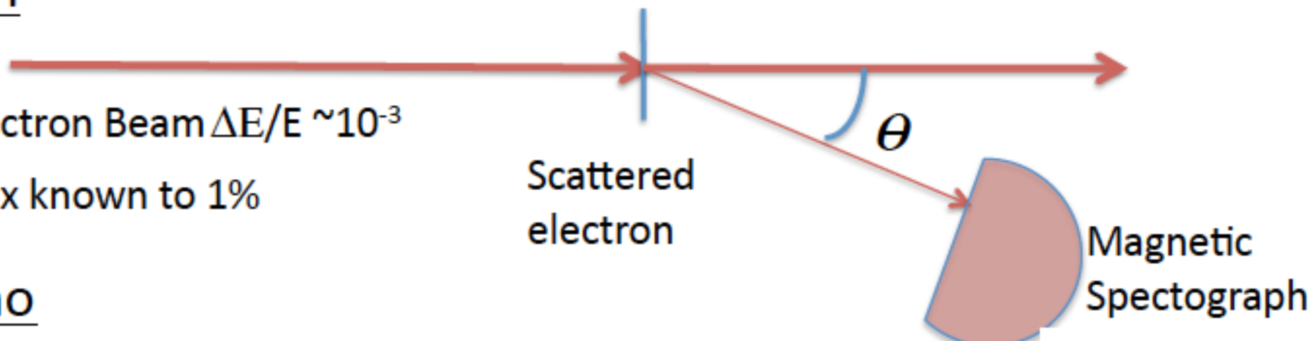
QE peak???

Very Different Situation from inclusive electron scattering!!

2. Remark from Gerry Garvey (circa 2010)

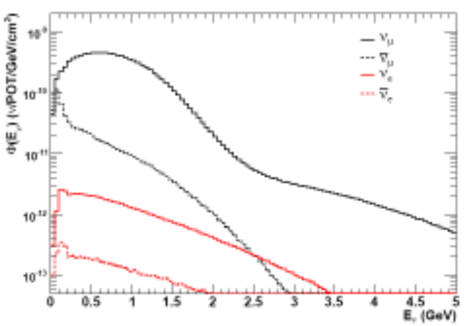
Contrast of e-N with ν-N Experiments

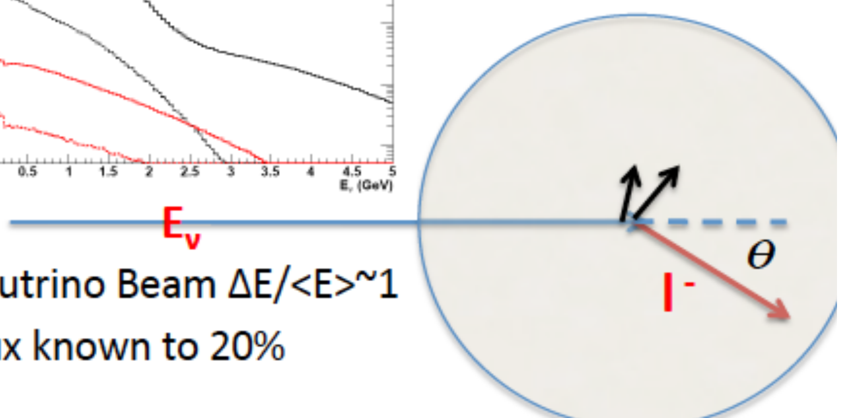
Electron



Neutrino

Neutrino-Mode Flux

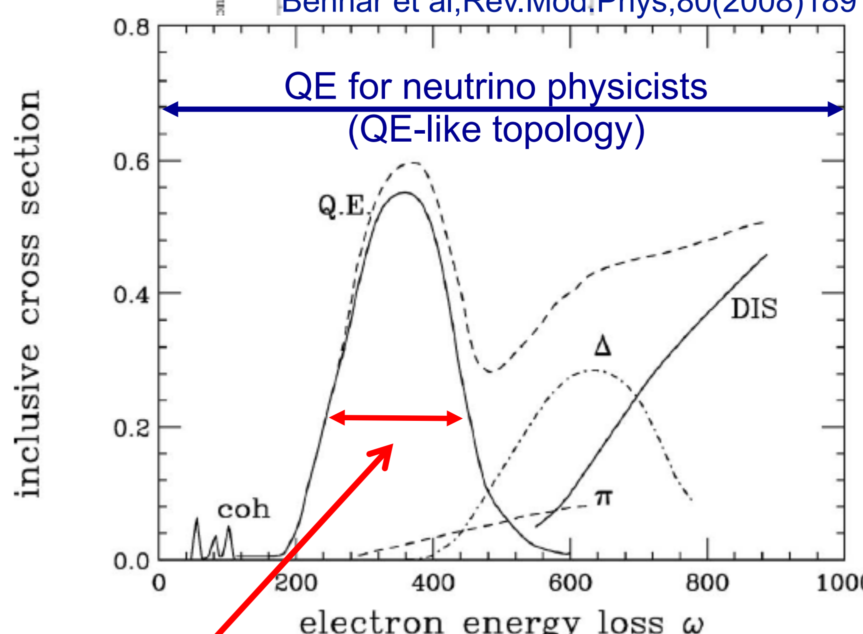




Neutrino Beam ΔE/<E>~1

Flux known to 20%

Benhar et al,Rev.Mod.Phys,80(2008)189



Very Different Situation from inclus

QE for nuclear physicists (genuine QE)

6. Shallow Inelastic Scattering (SIS)

Cross section

$W^2 < 2.9\ GeV^2$: RES

$W^2 > 2.9\ GeV^2$: DIS

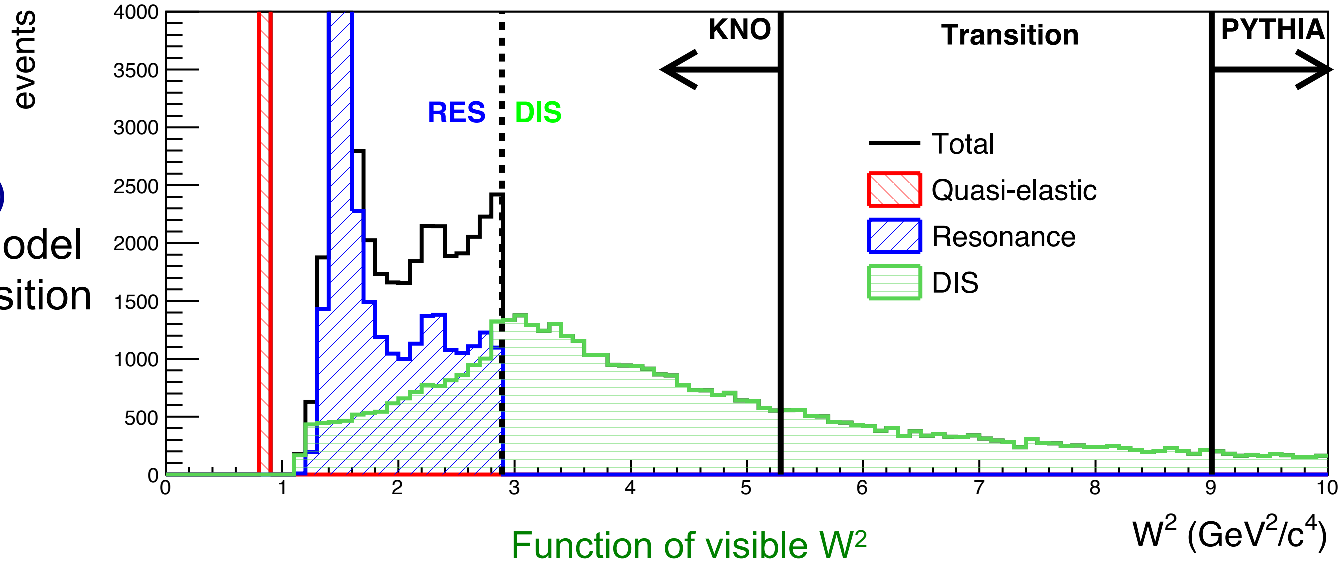
Hadronization (AGKY model)

$W^2 < 5.3 GeV^2$: KNO based model

$2.3 GeV^2 < W^2 < 9.0 GeV^2$: transition

$9.0 GeV^2 < W^2$: PYTHIA6

Function of true W^2



Function of visible W^2