GiBUU Status

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GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

- GiBUU is not a generator, it is a theory framework and code to describe very general nuclear reactions.

- GiBUU was constructed with the aim to encode the „best possible“ theory for a wide variety of nuclear reactions, from AA, pA, πA, γA, eA to νA

Best Possible Theory

- „BEST" requires
  - All energies and all reactions (~ 20 GeV for hadronic reactions, ~ 100 GeV for leptonic reactions) -> relativistic from outset, includes resonances and DIS
  - All targets
  - Not just inclusive X-sections, but full events
  - Reasonable bound nuclear ground states
  - Consistent theory for all reaction types

Practical Infos

- Code is written in modern Fortran 1995-2003
- Code is modular and well documented
- Code is freely available from *gibuu.hepforge.org (since about ~10 years!)*
- Runs on any modern PC under LINUX
- Running time for good statistics:

1. Flux-averaged inclusive on 12C: ~ 1 hour
2. Flux-averated full events on 12C ~ 1 day

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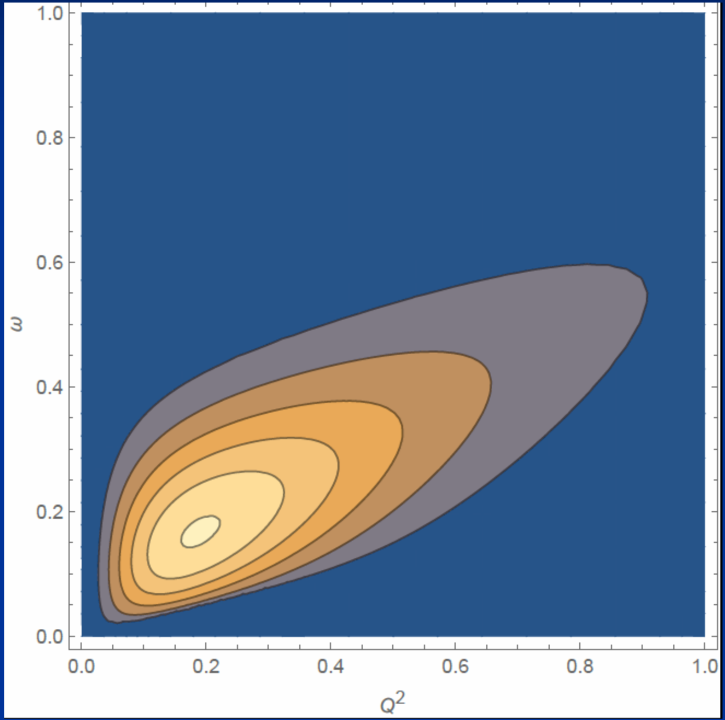
GiBUU: new in 2016 release

- Improved stability of groundstate implemented-> improved hole spectral functions, affects QE

- 2p2h structure function for ***all*** kinematics, not just Delta region, fitted to e-scattering, is used for neutrinos as well

- Gallmeister et al., Phys.Rev. C94 (2016), 035502
  contains the latest changes in GiBUU2016

2p2h Q^2-ω Distribution for 2p2h



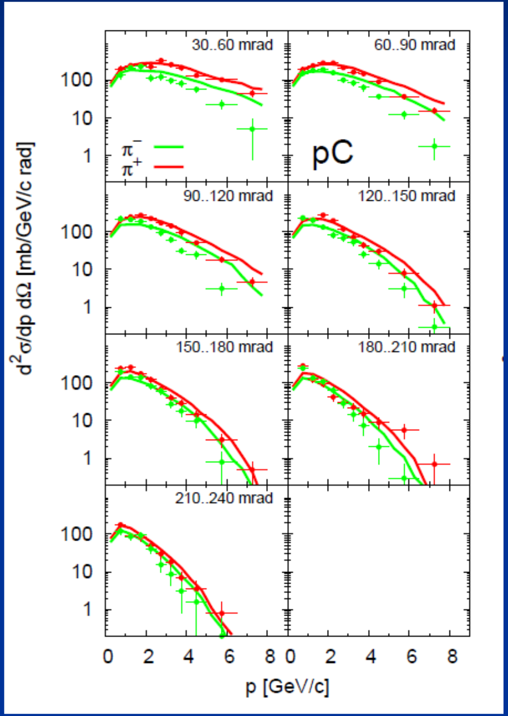
W_1

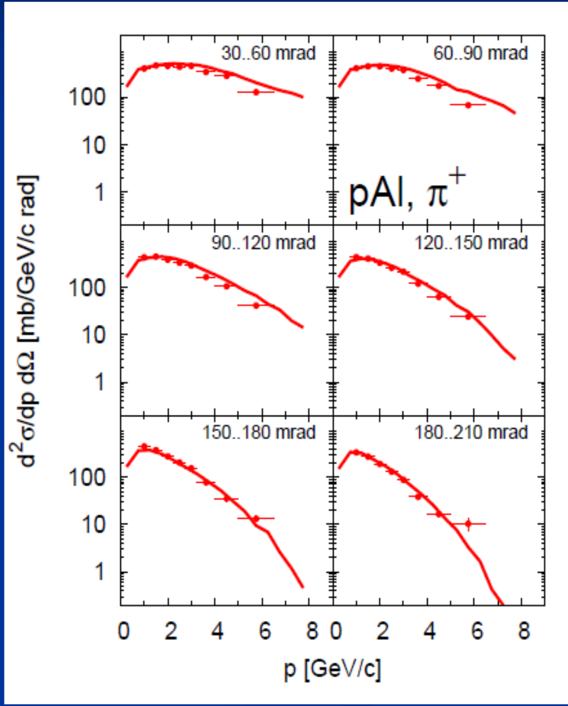
From:
R from data analysis of Bosted and Christy for

$0 < W < 3.2$ GeV
and $0.2 < Q^2 < 5$ GeV^2

$$W_1^\nu = \left(G_M^2 \frac{\omega^2}{\mathbf{q}^2} + G_A^2\right) R^\nu_{\sigma\tau}(T)$$
$$= \left(G_M^2 \frac{\omega^2}{\mathbf{q}^2} + G_A^2\right) \frac{1}{2 G_A G_M} W_3^\nu .$$

GiBUU at the start of a neutrino beam





Gallmeister et al,
Nucl.Phys. A826 (2009) 151

12 GeV/c beam momentum

HARP data

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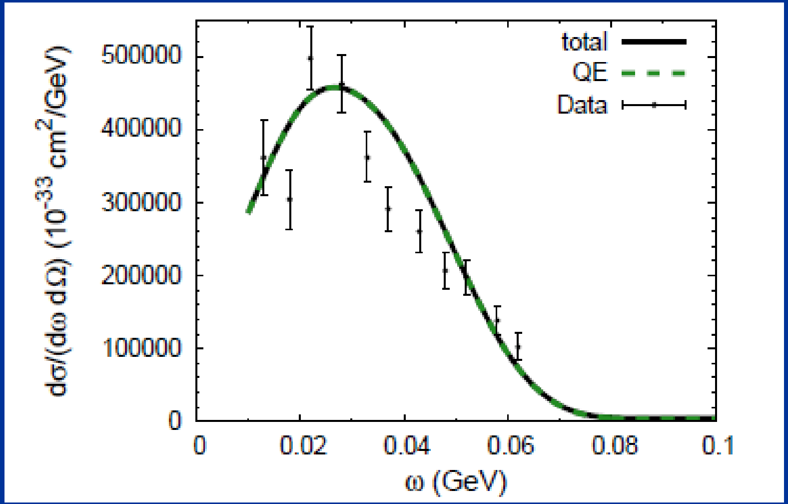
Test with e-Scattering Data

- Necessary Test!
  (often said, but seldom done in generators)

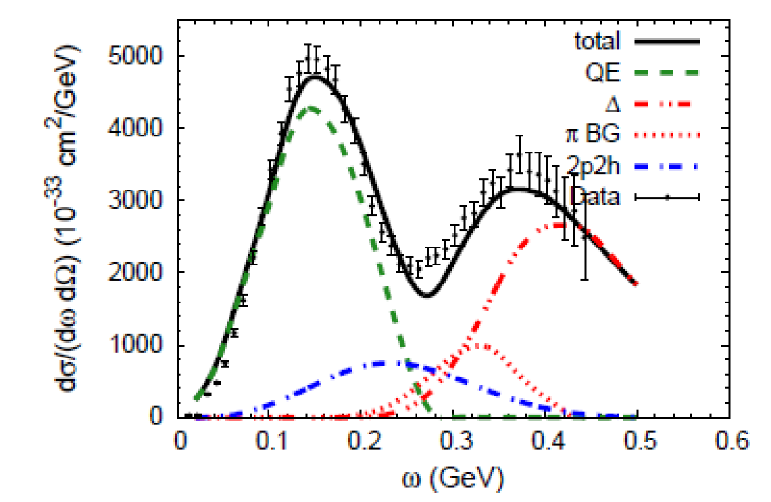
- Test not in some special modules, but same code modules as for neutrinos

Test with Electron Data: QE + Res

- a necessary check for any generator development

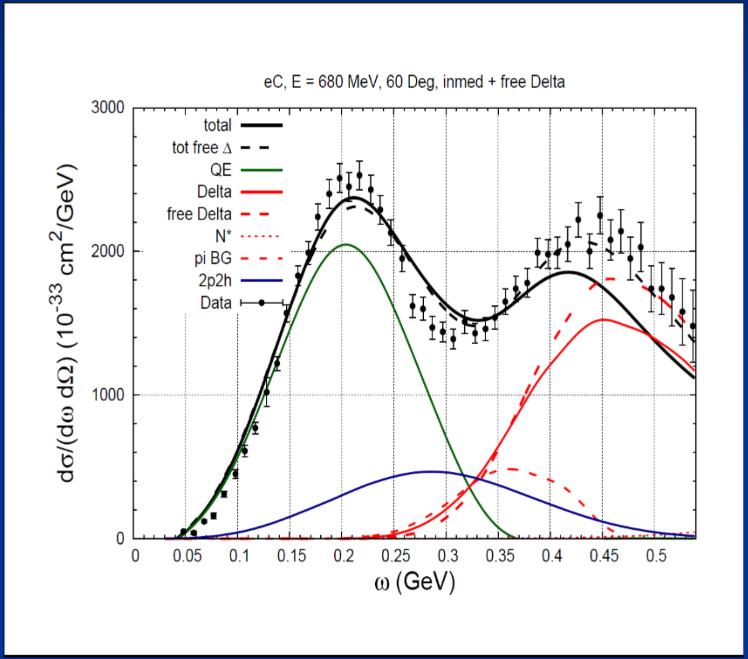


0.24 GeV, 36 deg, $Q^2 = 0.02\ GeV^2$

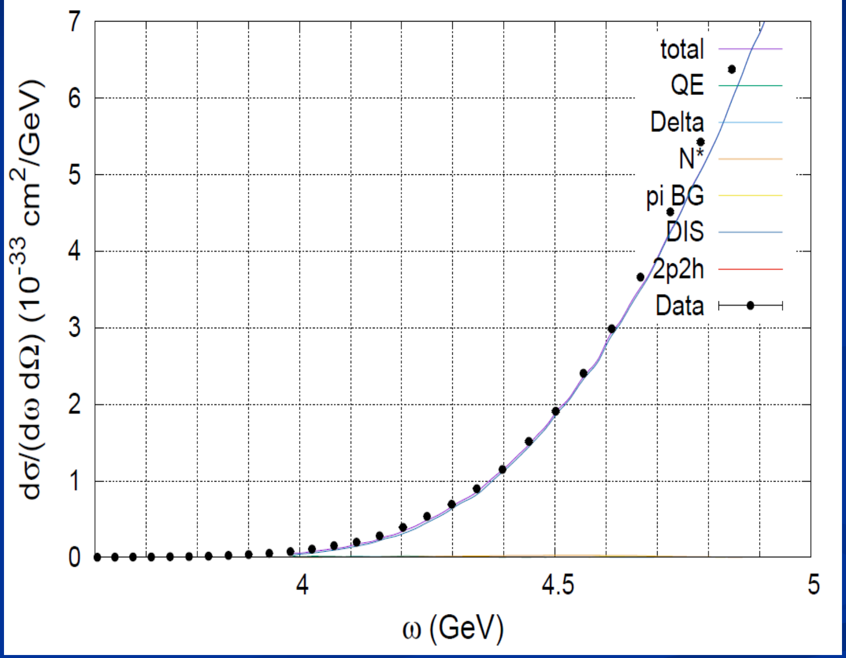


0.56 GeV, 60 deg, $Q^2 = 0.24\ GeV^2$

Test with Electron Data: : QE + Res

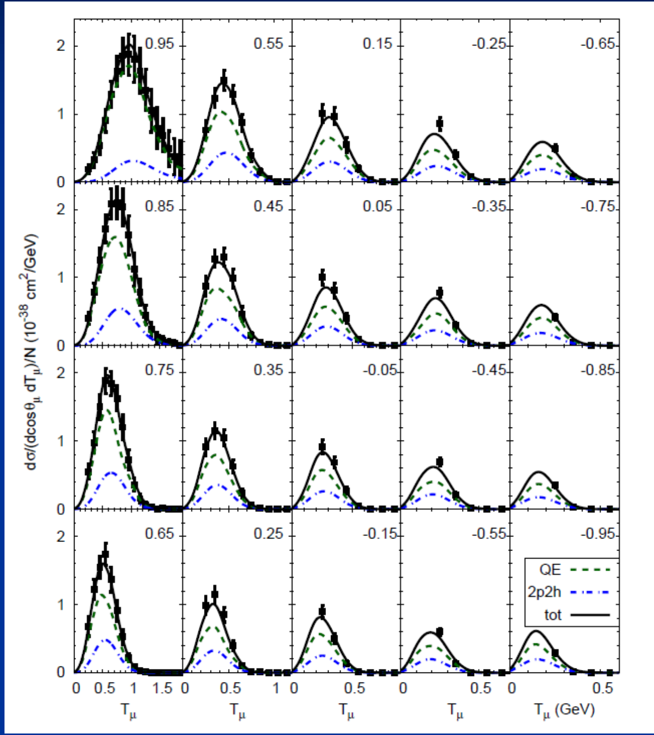


$Q^2 = 0.32\ GeV^2$

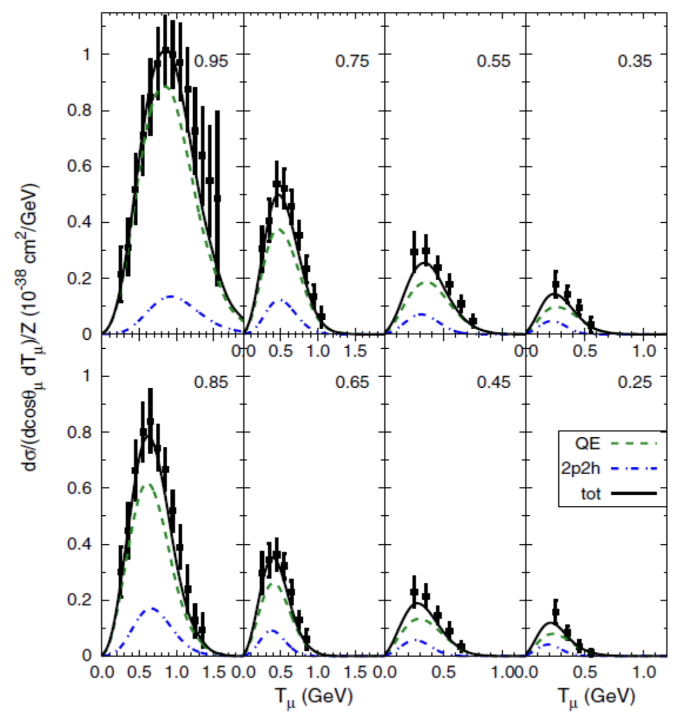


E = 5.766 GeV, 50 deg, $Q^2 = 7.3\ GeV^2$

MiniBooNE 0pion = QE + 2p2h



Neutrinos

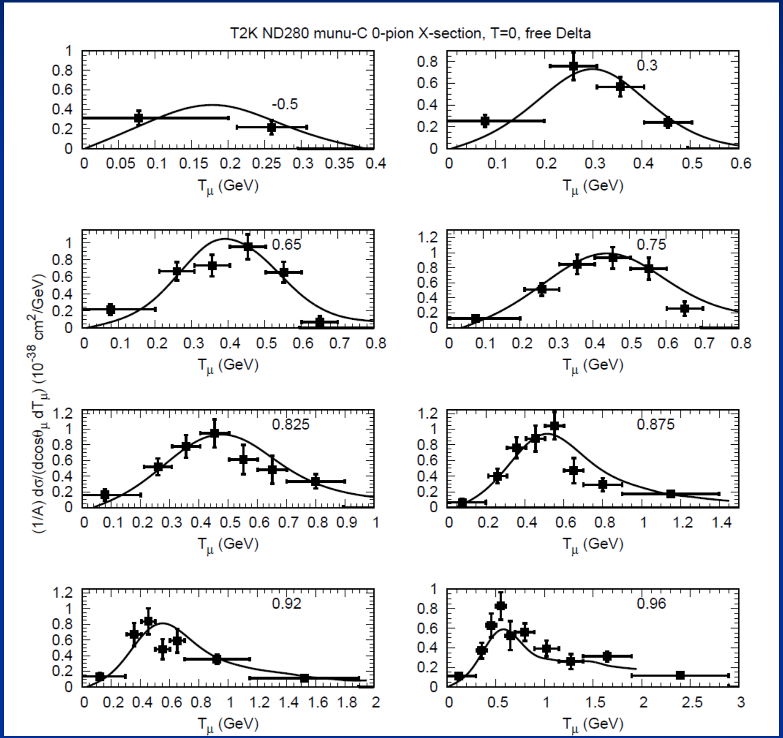


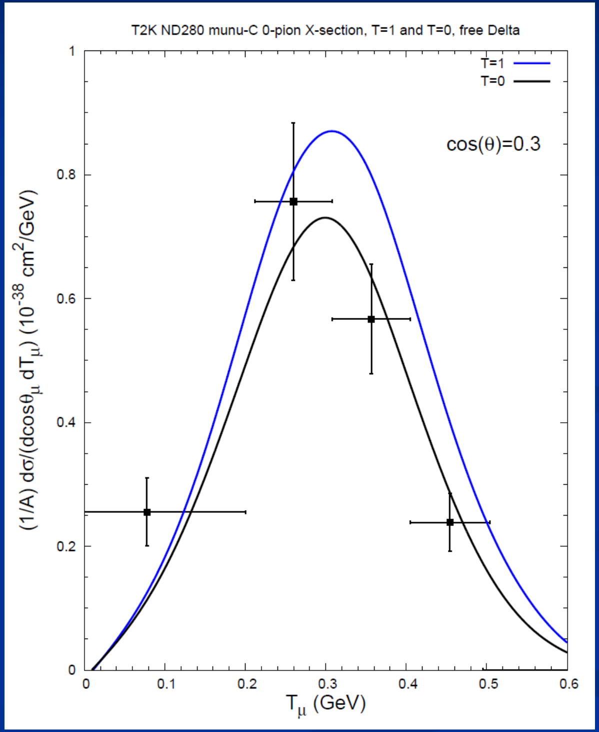
Antineutrinos

No
flux change!

Ambiguity:
flux vs 2p2h

T2K 0pion = QE + 2p2h + stuck pions



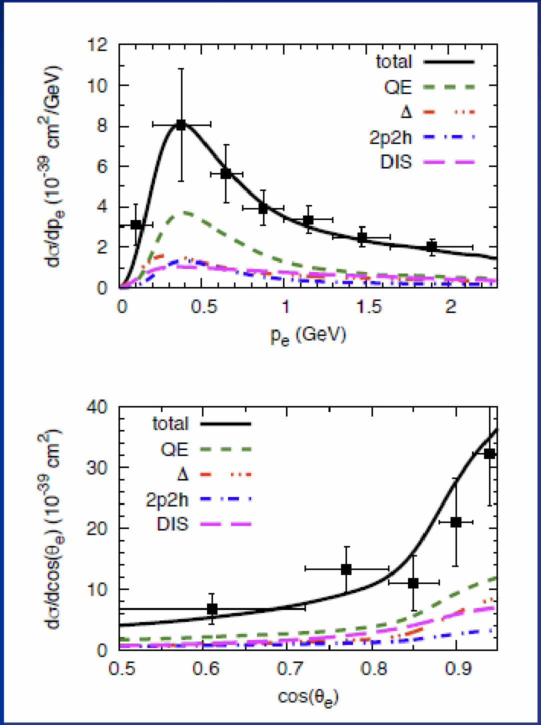


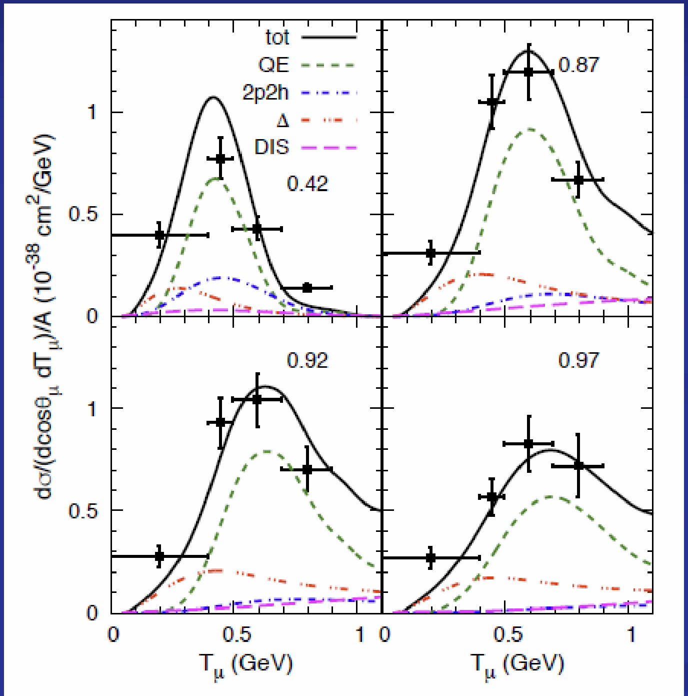
Sensitivity to 2p2h

Data: T2K ND280
Phys.Rev. D93 (2016) 112012

Comparison with T2K incl. Data

T2K, ν_e





T2K, ν_μ

Isospin Sensitivity at cos(theta) =0.42

Agreement for different neutrino flavors

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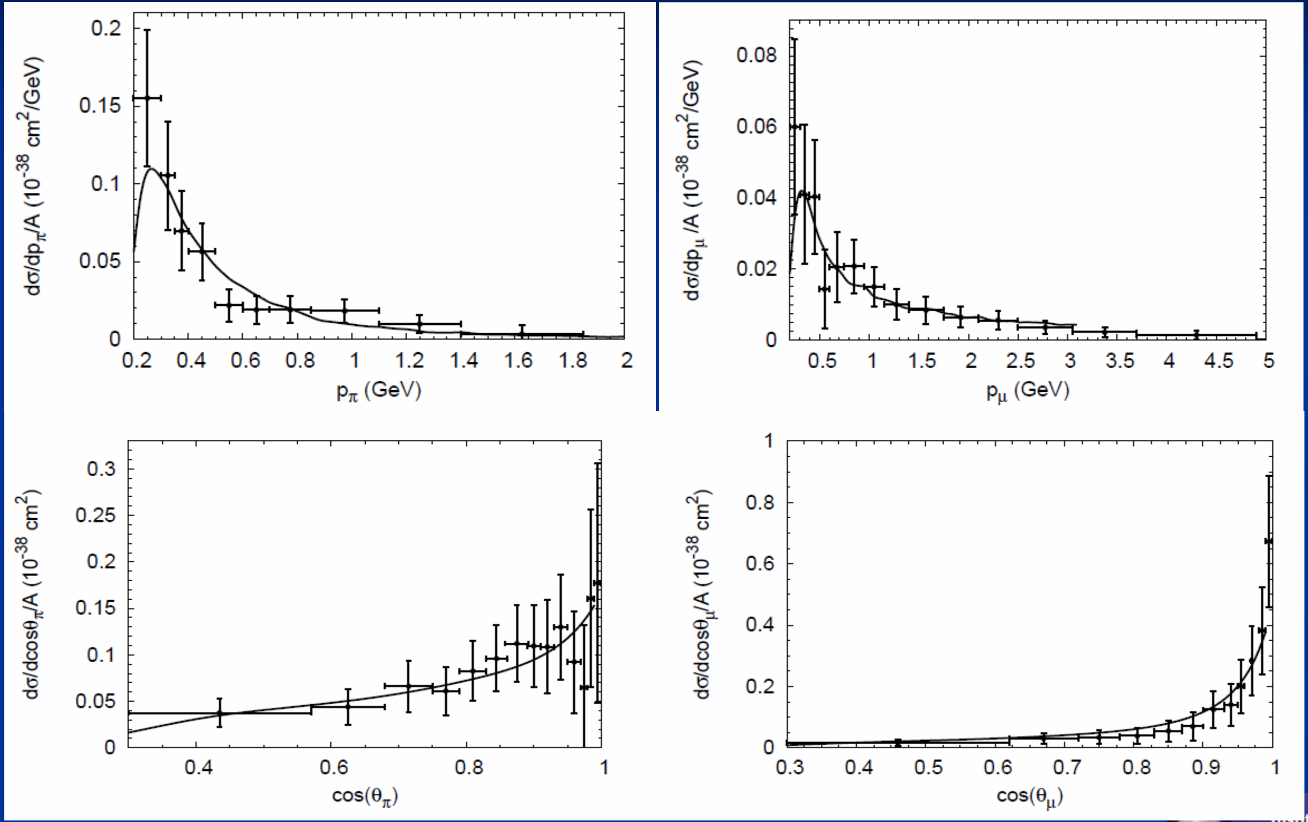
T2K ND280 Pions on Water

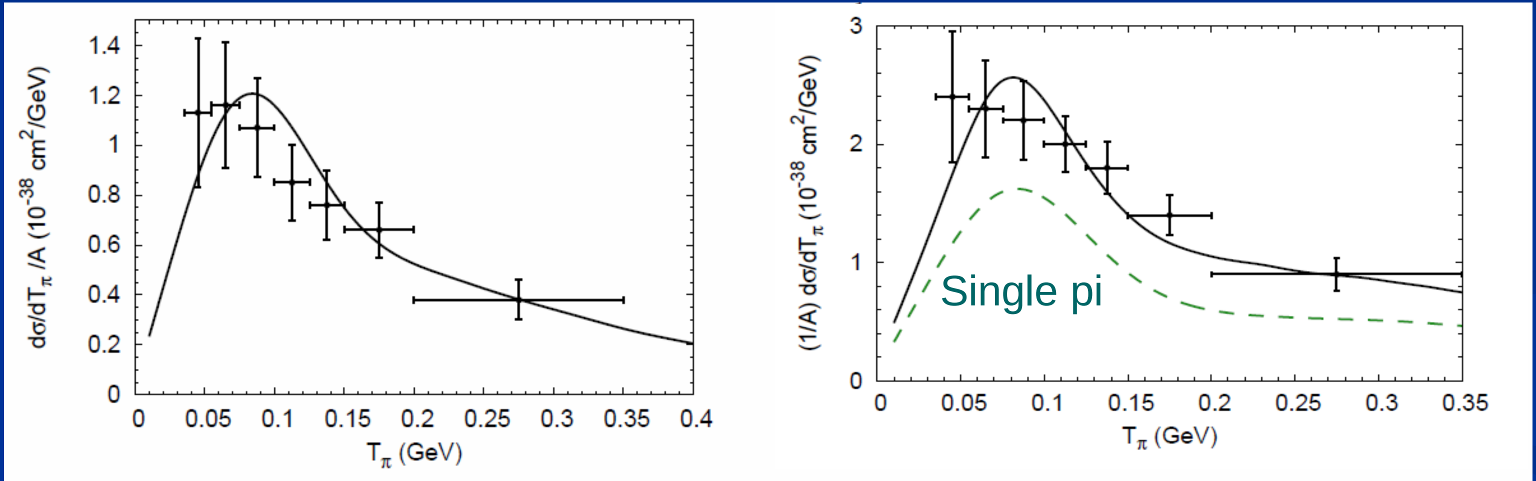


Data: T2K ND

Phys.Rev. D95 (2017) no.1, 012010

MINERvA Pions

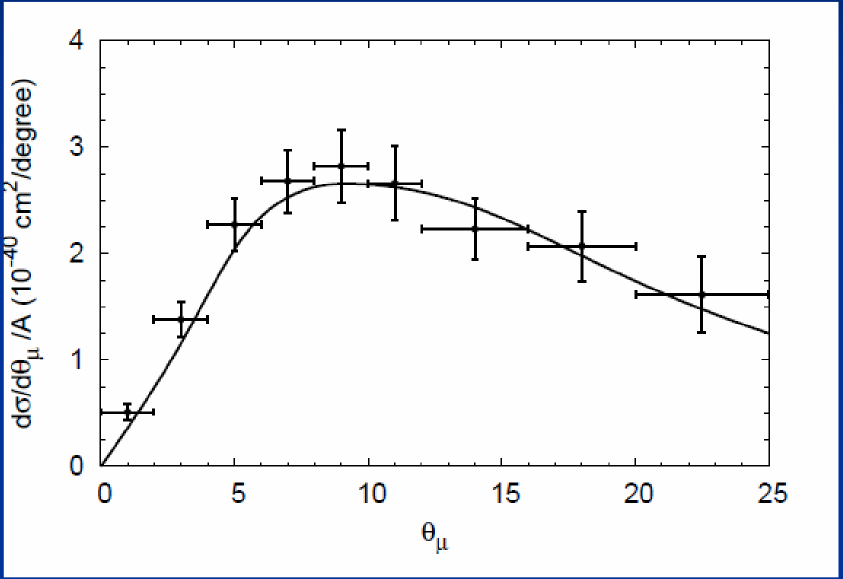
CC charged pions

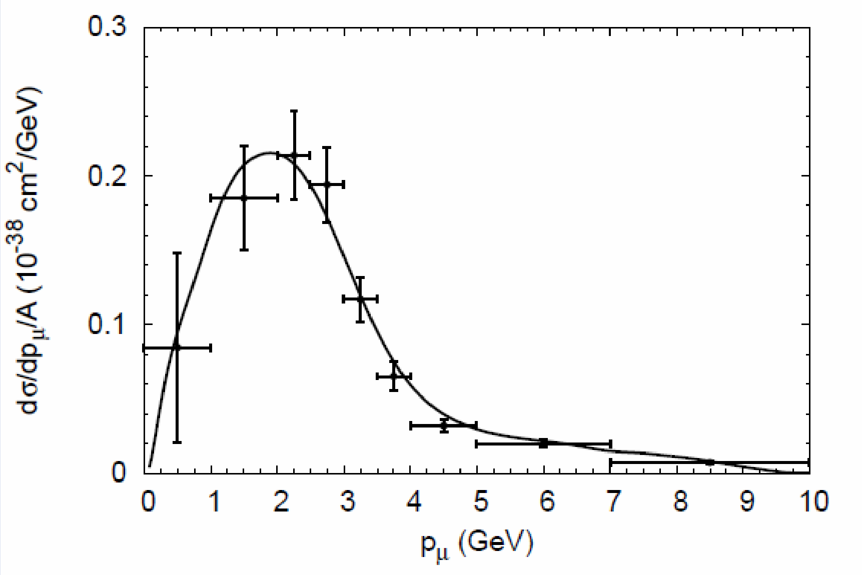


W < 1.4 GeV

W < 1.8 GeV, multiple pions

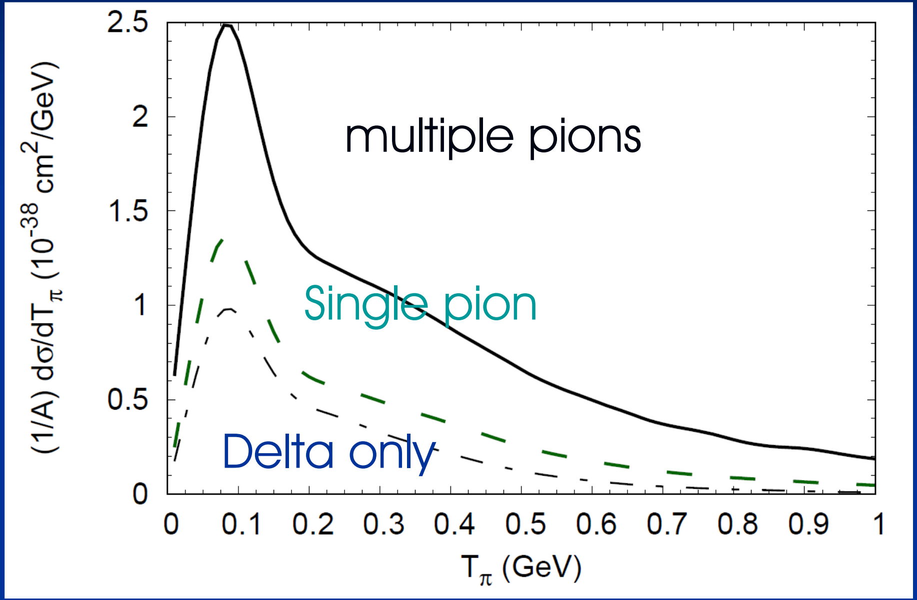
MINERvA Pions

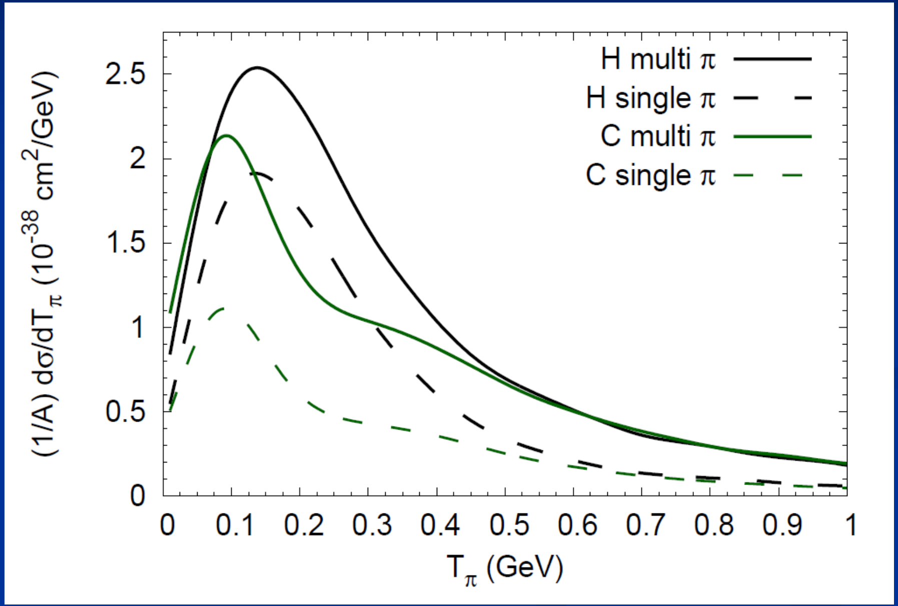




W < 1.8 GeV

Pions at NOvA





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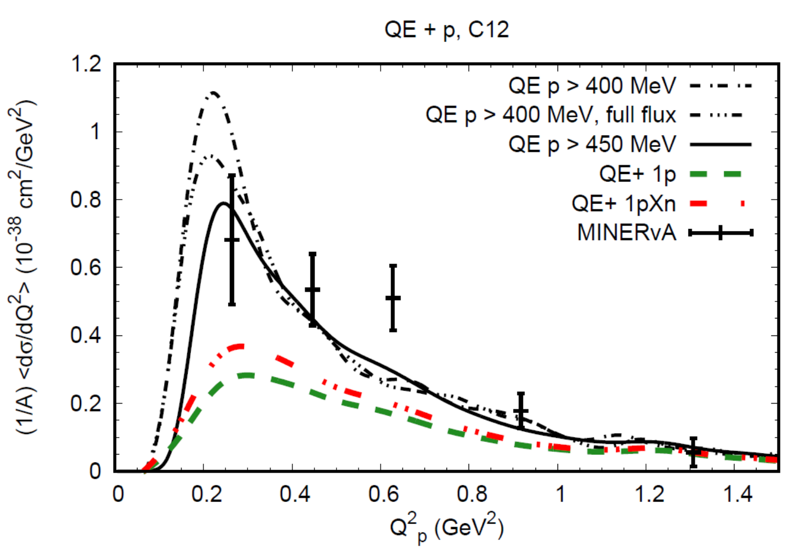
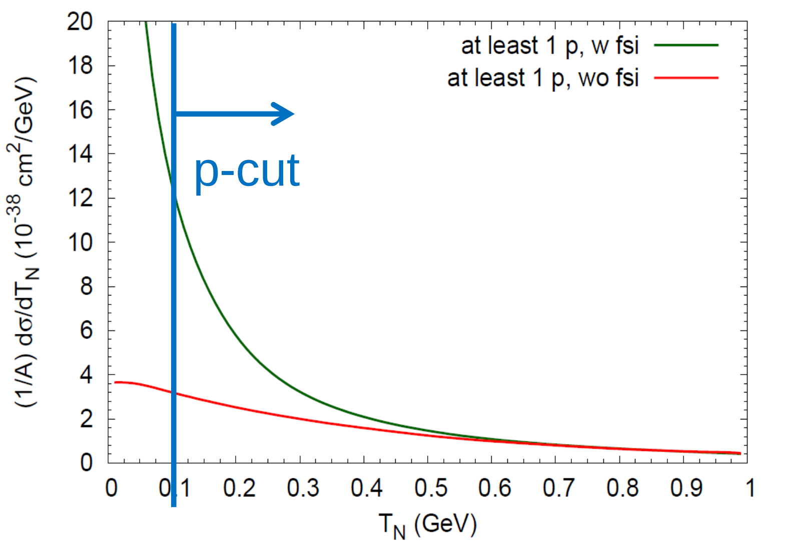
Conclusion

- One and the same consistent model describes all the CC charged pion data from T2K and MINERvA without any special tune
- The MiniBooNE data do not agree with the model predictions
- Solution of the ‚pion puzzle'??

MINERvA QE + 2p2h: 1 mu + p





One and only one p is a clean indicator of QE

Data are fsi-dominated

Need proton spectra from experiment

NuSTEC White Paper: Things to Do

1. Develop a unified nuclear model with nucleons bound in the nucleus
2. Model neutrino-nucleus interactions not only for lepton semi-inclusive processes, but for full phasespace
3. Improve understanding of nuclear correlations and implement them into generators
4. Improve models of final state interactions with input from pi-A (p-A!!!)
5. Express all these improvements in such a form that they can be implemented into neutrino-event generators

- Such a model exists: it is called GiBUU

Open Physics Problems

1. In-medium width of Δ : affects pion spectra

2. Isospin content of 2p2h excitations
   - T=1 vs. T=0 (for pn pairs) gives factor 2 for 2p2h contribution relative to electrons
   - Isospin sensitivity about 10% of total ddsigma
   - Can be determined IF flux better than 10%

Summary

- GiBUU is a consistent theory framework for all events
- GiBUU gives *both inclusive X-sections and full events.*
- GiBUU is *publicly available*: gibuu.hepforge.org
- GiBUU describes inclusive electron and neutrino data, *without any tuning, both QE and pion production.*
- GiBUU works in *all energy regimes*, both BNB and MINERvA/LBNF energies
- GiBUU works for *all nuclei*

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GiBUU: References

- Essential References:
  1. Buss et al, Phys. Rept. 512 (2012) 1
     contains both theory and practical implementation of transport theory
  2. Gallmeister et al., Phys.Rev. C94 (2016), 035502
     contains the latest changes in GiBUU2016
  3. Mosel, Ann. Rev. Nucl. Part. Sci. 66 (2016) 171
     review, contains some discussion of generators
  4. Mosel et al, arXiv:1702.04932
     pion production comparison of MiniBooNE, T2K and MINERvA