QE-like (aka 0 pion)

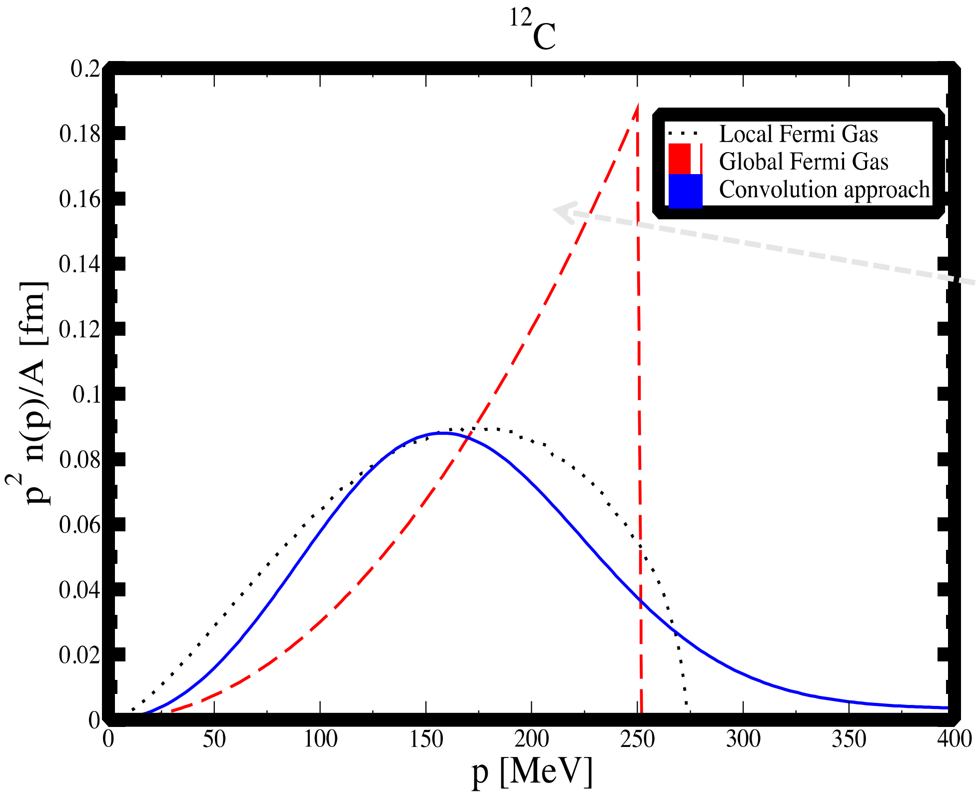
In GiBUU

With Kai Gallmeister

QE like events

- QE-like events consist of
  - True (1-body) QE scattering
  - 2p2h excitations
  - Pion production and subsequent absorption

LTF Momentum Distribution in GiBUU



From: Alvarez-Ruso, Hayato, Nieves, arXiv:1403.2673

GiBUU uses
Local Fermi Gas
energy-distribution smooth
because of r-dependent
potential

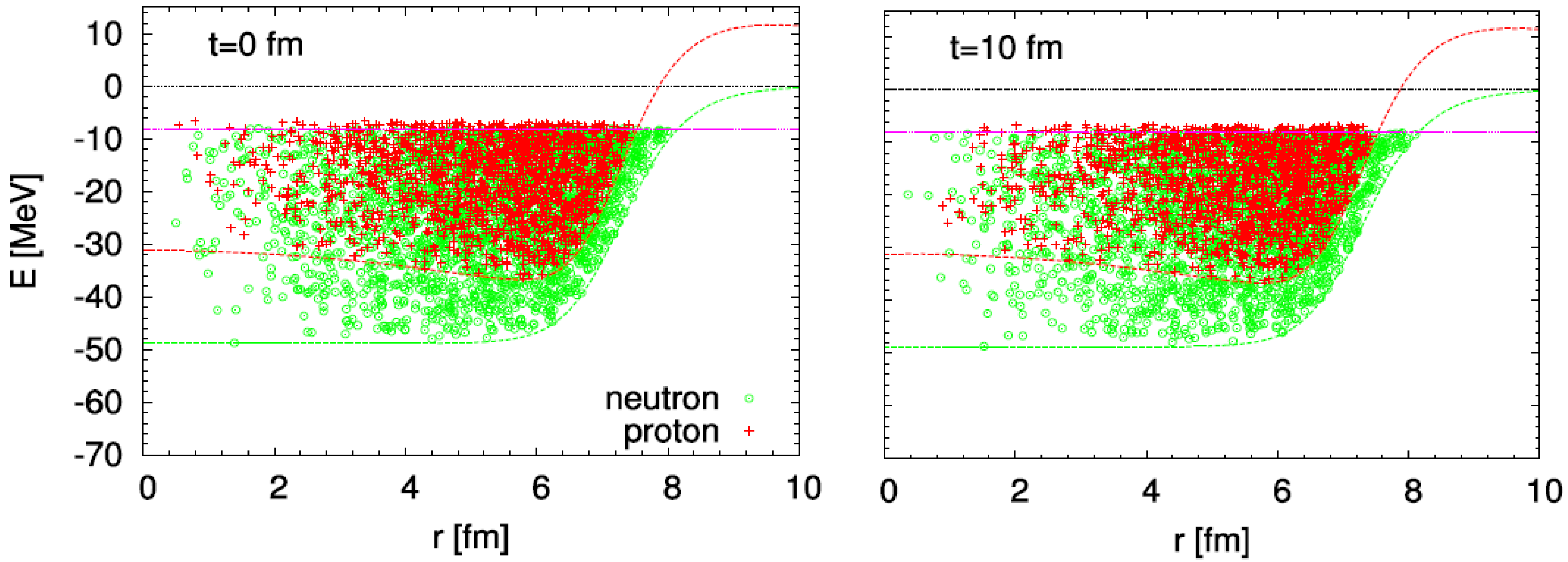
$$P_h(\vec{p}, E) \propto \int d^3r \, [\Theta(p_F(\vec{r}) - p) \, \delta(E + T_p + V(\vec{r}, \vec{p})]$$

Potential obtained from a realistic energy-density functional

Nuclear ground state

- improvement: ensure constant Fermi-Energy

non-mom.dep potential, asymmetry-term, Coulomb



- needs iteration for mom.dep potential
- important for QE-peak (Gallmeister, Mosel, Weil, PRC94 (2016) 035502)

Groundstate Wigner functions

Nucleon phase-space distribution is Wigner transform of one-body density matrix

$$f(\mathbf{x},0,\mathbf{p}) = \frac{1}{(2\pi)^3} \int \mathrm{d}\mathbf{s}\, e^{-i\mathbf{p}\cdot\mathbf{s}} \rho\left(\mathbf{x}-\frac{\mathbf{s}}{2},\mathbf{x}+\frac{\mathbf{s}}{2}\right)$$

In local TF approximation

$$f(\mathbf{x},0,\mathbf{p}) = \Theta\left(p_{\mathrm{F}}(\mathbf{x}) - |\mathbf{p}|\right)$$

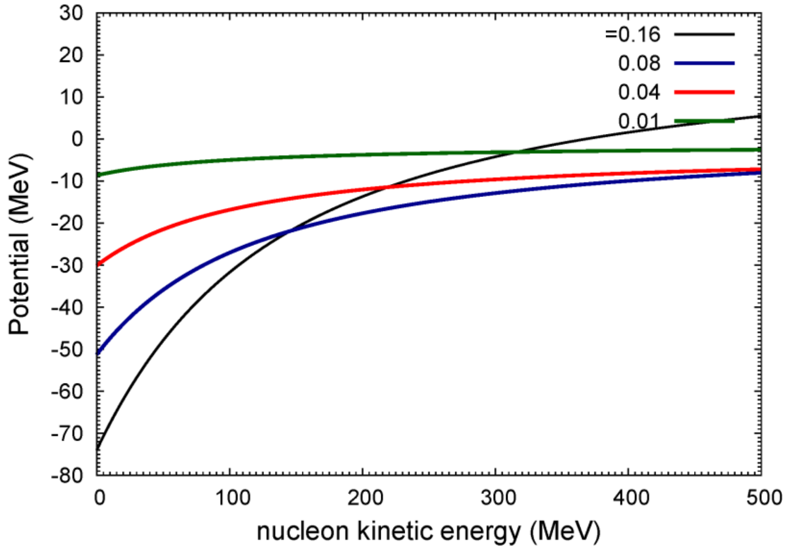
Determines the hole spectral function:

$$\mathcal{P}_h(\mathbf{p},E) = g \int_{\text{nucleus}} \mathrm{d}^3x\, f(\mathbf{x},0,\mathbf{p})\Theta(E)\,\delta\left(E - m^*(\mathbf{x},\mathbf{p}) + \sqrt{\mathbf{p}^2 + m^{*2}(\mathbf{x},\mathbf{p})}\right)$$

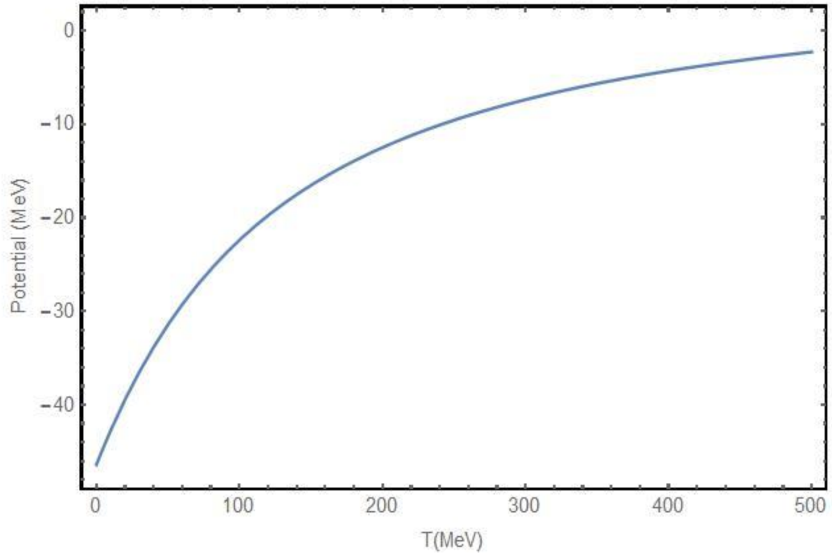
Potential in m* leads to smooth distribution, no longer ‚spiky‘

FSI Potential

density and momentum dependent



density-averaged potential for ^{12}C



Momentum-Dependence from p-A data

Essential for example for QE scattering where initial nucleon sees a lower potential than the final outgoing one

This same potential is used for preparation of groundstate and for all fsi of outgoing nucleons

Nuclear ground state

- This momentum-dependent potential complicates the calculation of all collision amplitudes since

  1. The calculation of the final state phase space is complicated because E-p conservation at each vertex has to be iterated.
  2. The matrixelement itself is changed

- We use these momentum dependent potentials consistently for all reaction channels

QE

Consistent framework for QE with line of improvements

1. Relativistic global Fermi Gas
2. Relativistic local Fermi Gas
3. Semiclassical nuclear binding
4. Spectral Functions
5. Ab initio weak response of nuclei

QE data can never be better than understanding of pion production, QE is always mixed with other processes, even at the QE peak

Nuclei are bound!

Trivial, but often forgotten in generators

Even if you some final state interactions for the initial state,

e.g. spectral function, …,

you better have the same potential also for the outgoing particles!

Mechanics 101: steps in a potential lead to infinite forces.

The momentum dependence of the potential complicates
every single calculation of cross sections in this potential
and of final state phase spaces

Stuck Pions

Events with ‚stuck pions' are experimentally indistinguishable from true QE + 2p2h

Pions can be absorbed in two ways

1. In intermediate steps (offshell pions)

2. In the final step (onshell pions)

Both are included in GiBUU

RPA: essential or not so essential?

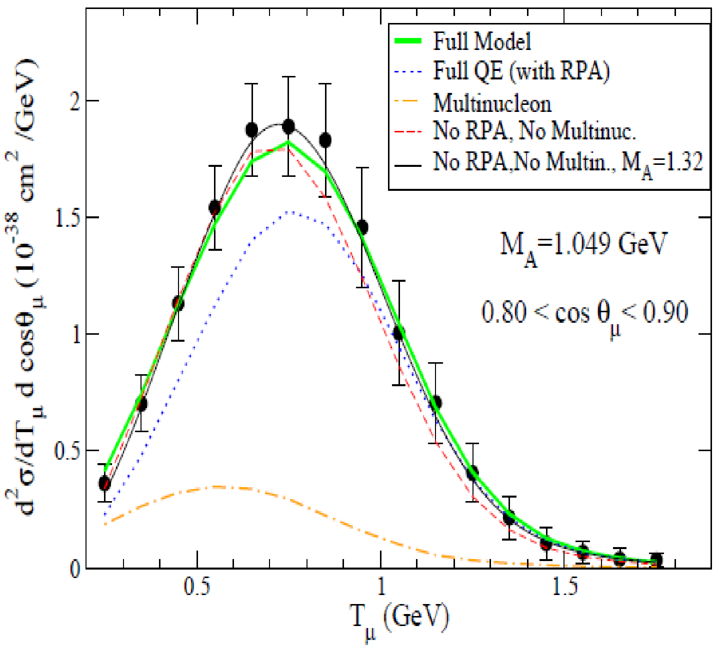
A first (trivial) property of nuclei:
They are bound

But:

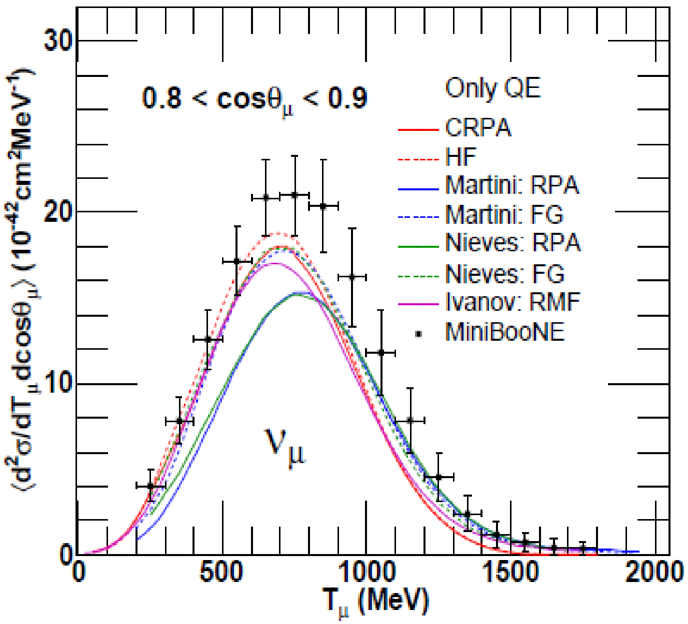
- none of the generator nuclei are bound
- the Martini/Nieves nuclei are not bound

If nucleons are bound in a potential well, then RPA correlations are much less essential
(but play a role at small Q^2)

RPA: essential or not so essential?

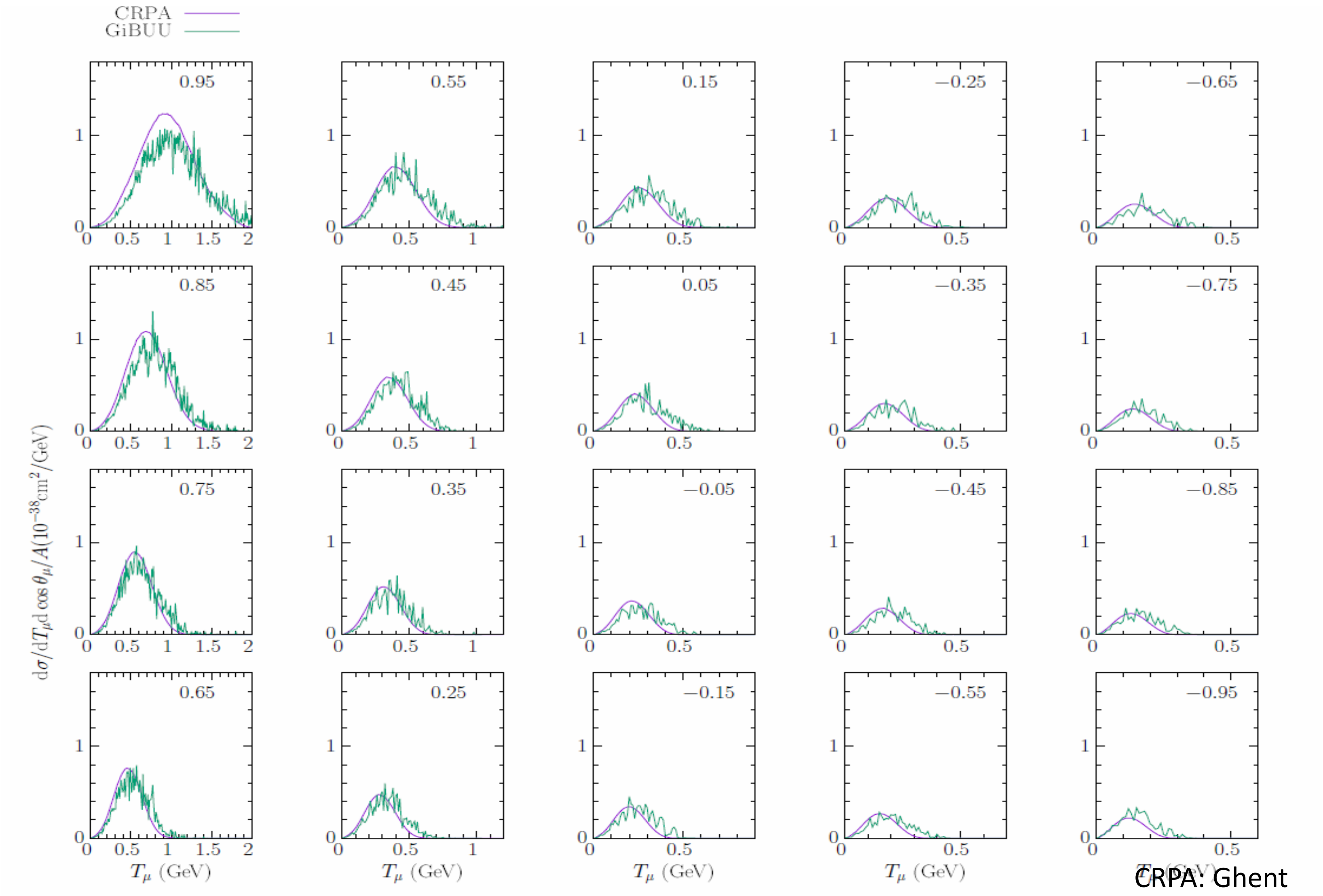


Nieves



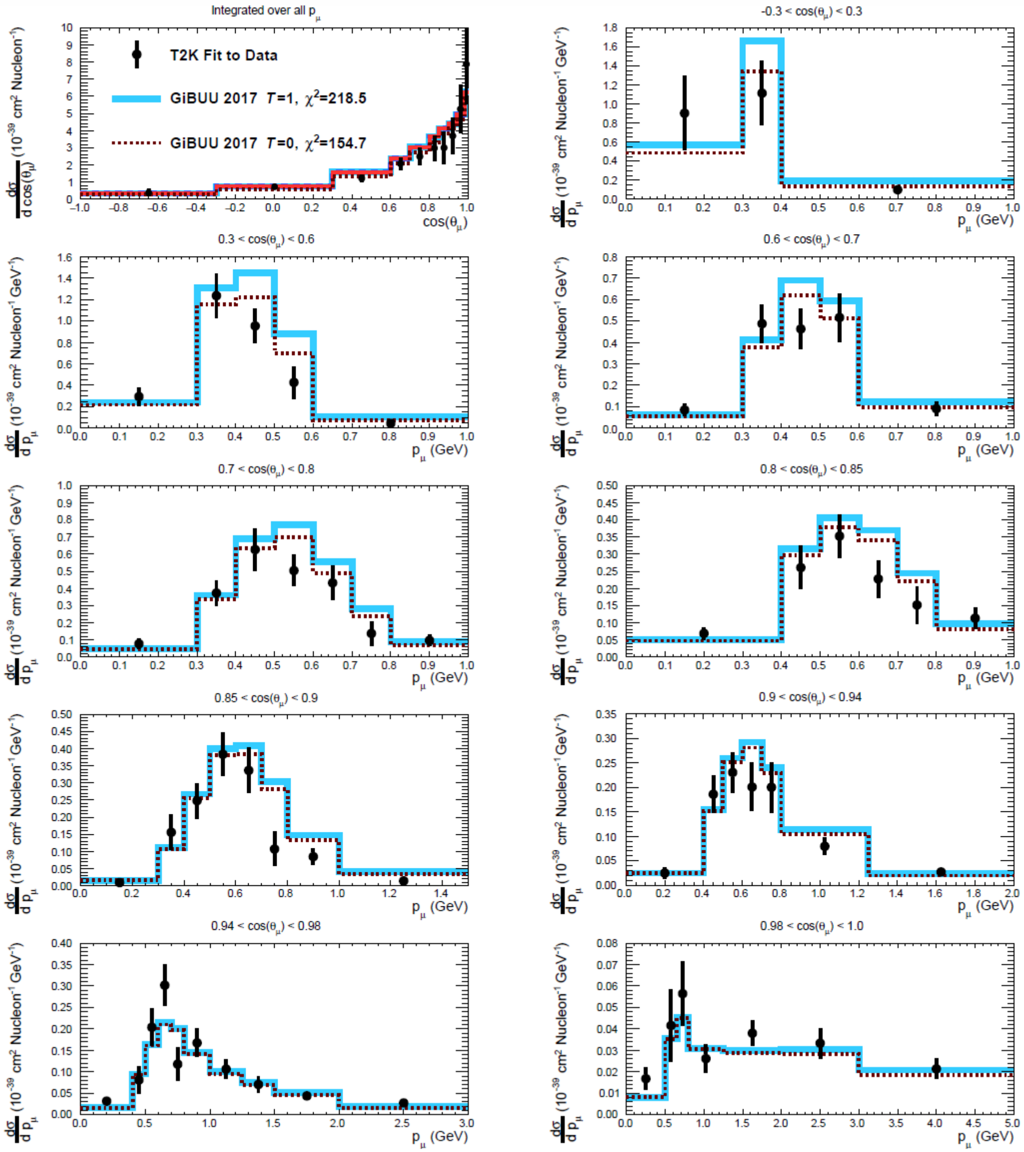
Pandey, Jachowicz

Pure QE in CRPA and GiBUU



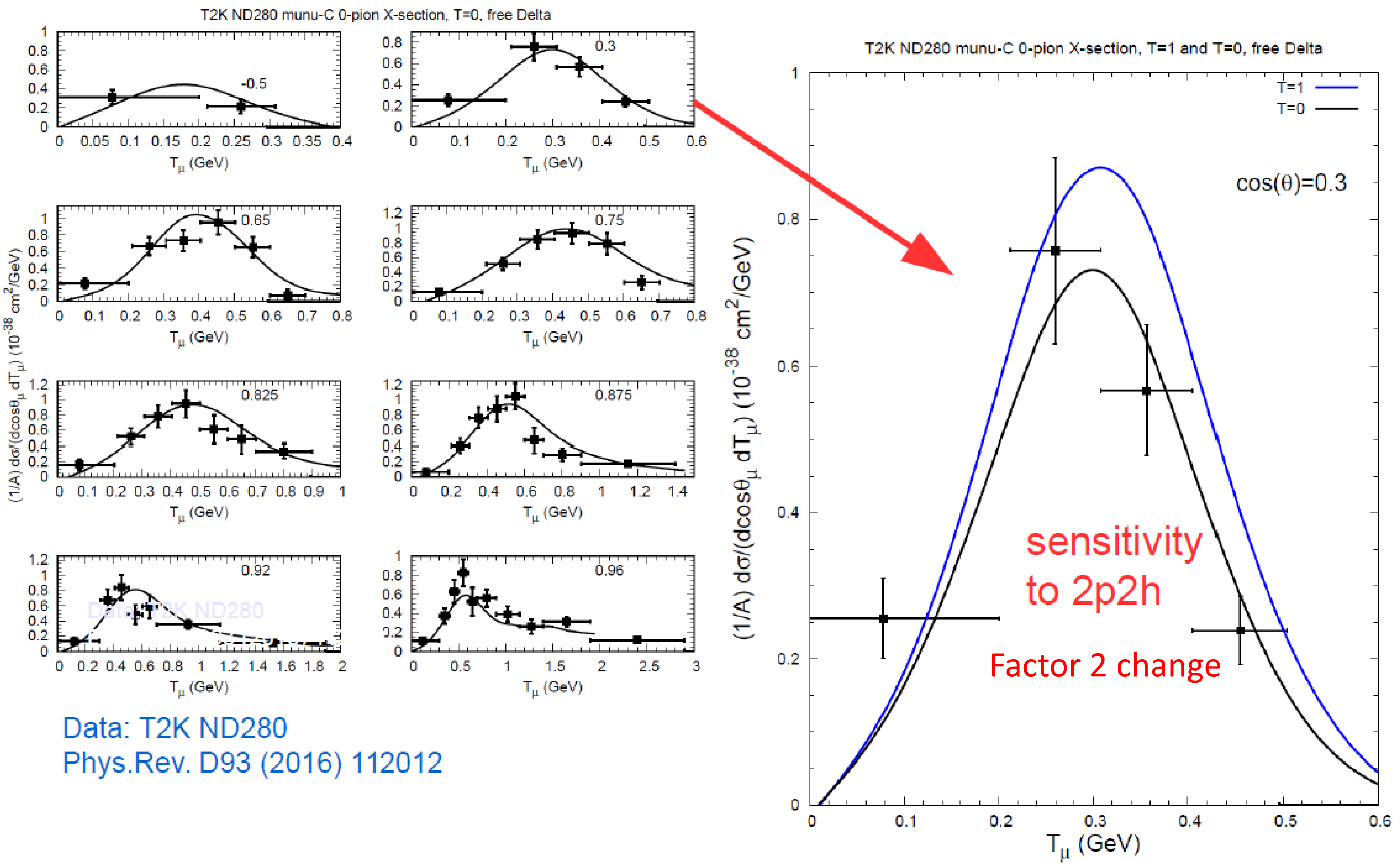
CRPA: Ghent group, van Dessel et al

T2K 0pion = QE + 2p2h + π reabsorb



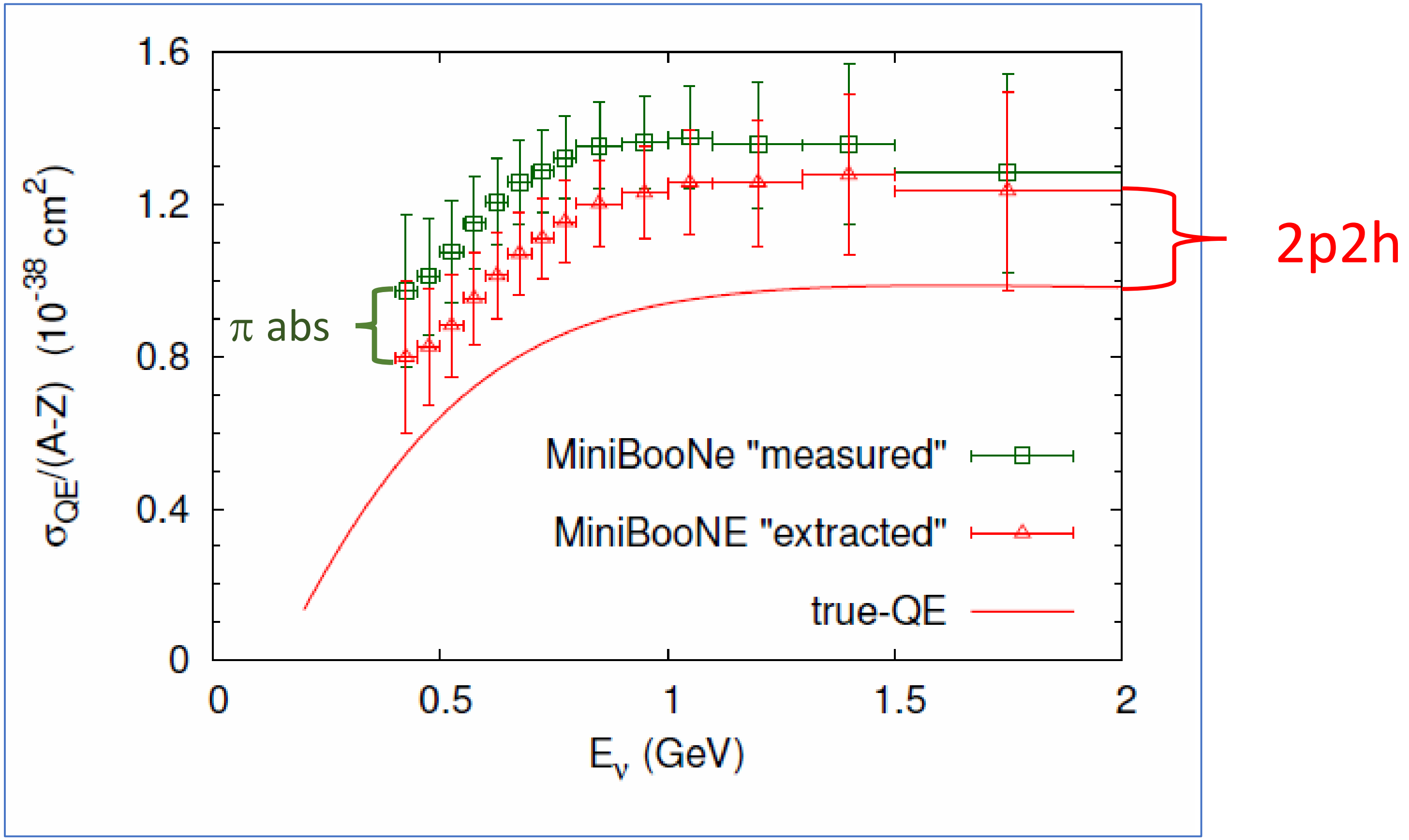
Dolan et al,
arXiv 1804.09488

T2K 0pion = QE + 2p2h + stuck pions



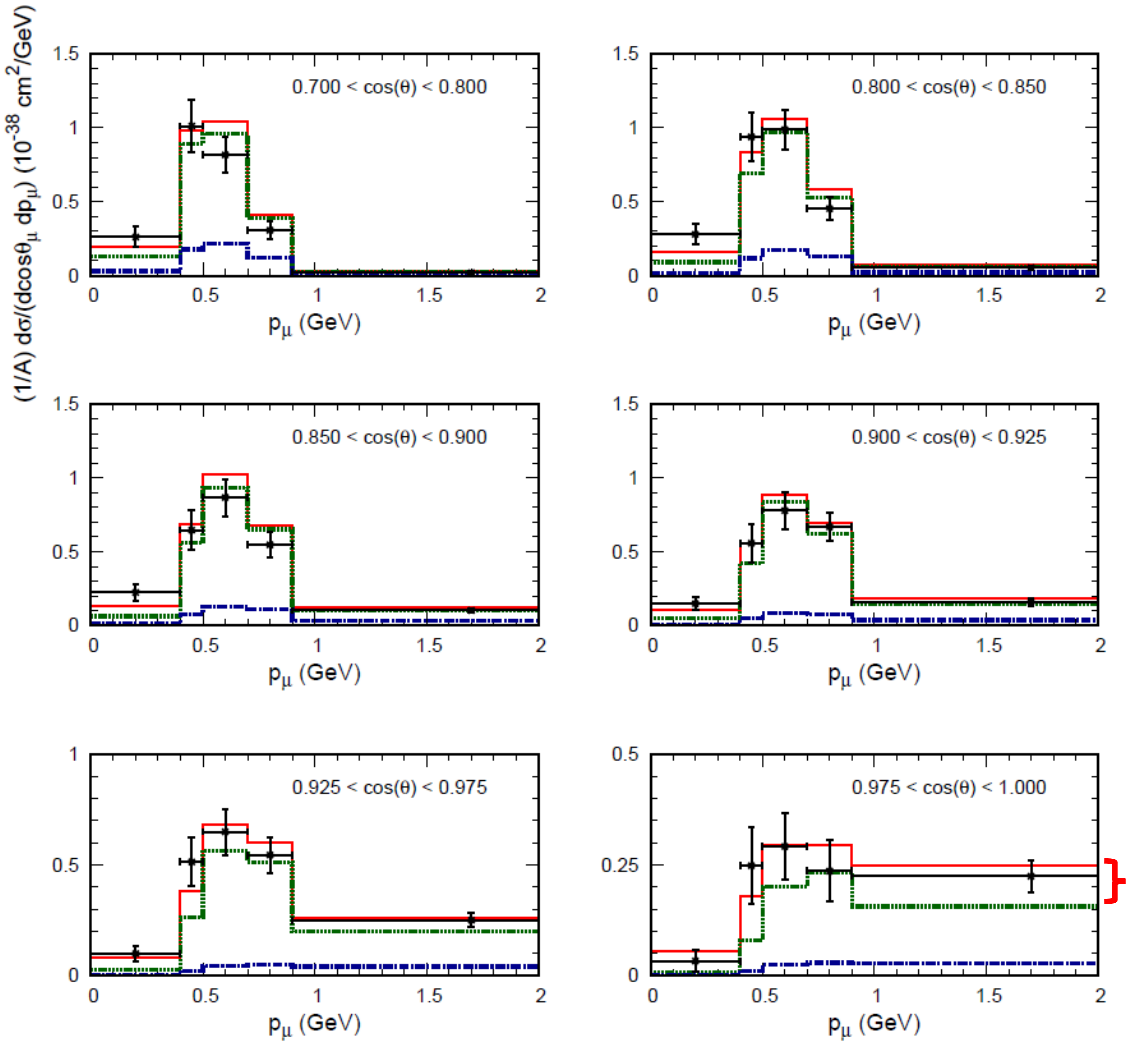
Data: T2K ND280
Phys.Rev. D93 (2016) 112012

MiniBooNE 0pion = QE + 2p2h + π reabsorb



π Reabsorbtion ~ 10 – 20%

T2K 0pion on H2O = QE + 2p2h + π reabsorb

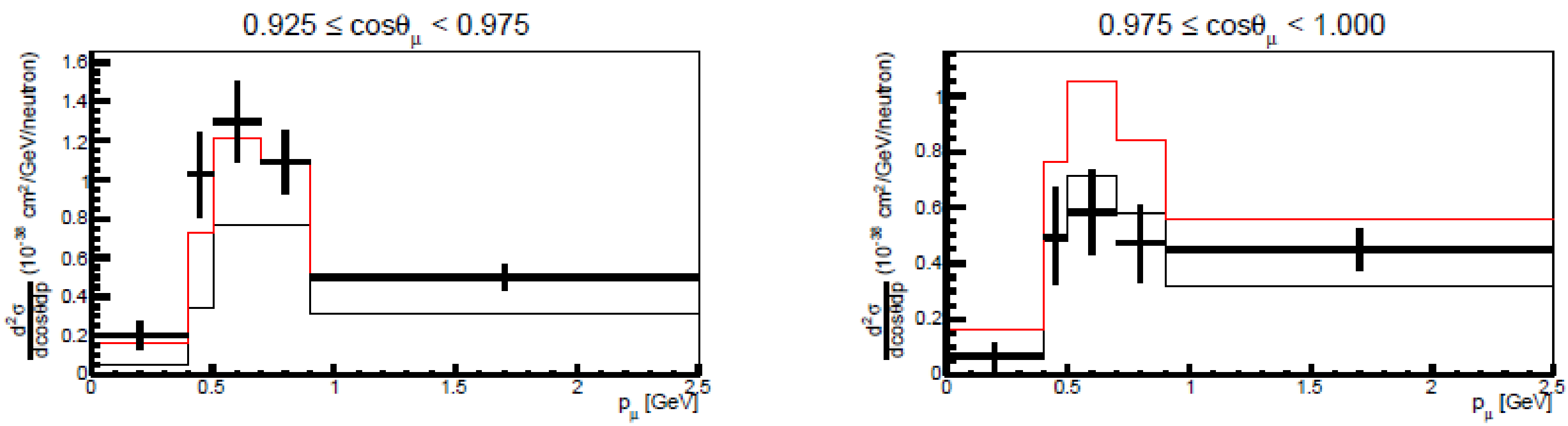


Pion reabsorption is essential,
in particular at forward angles

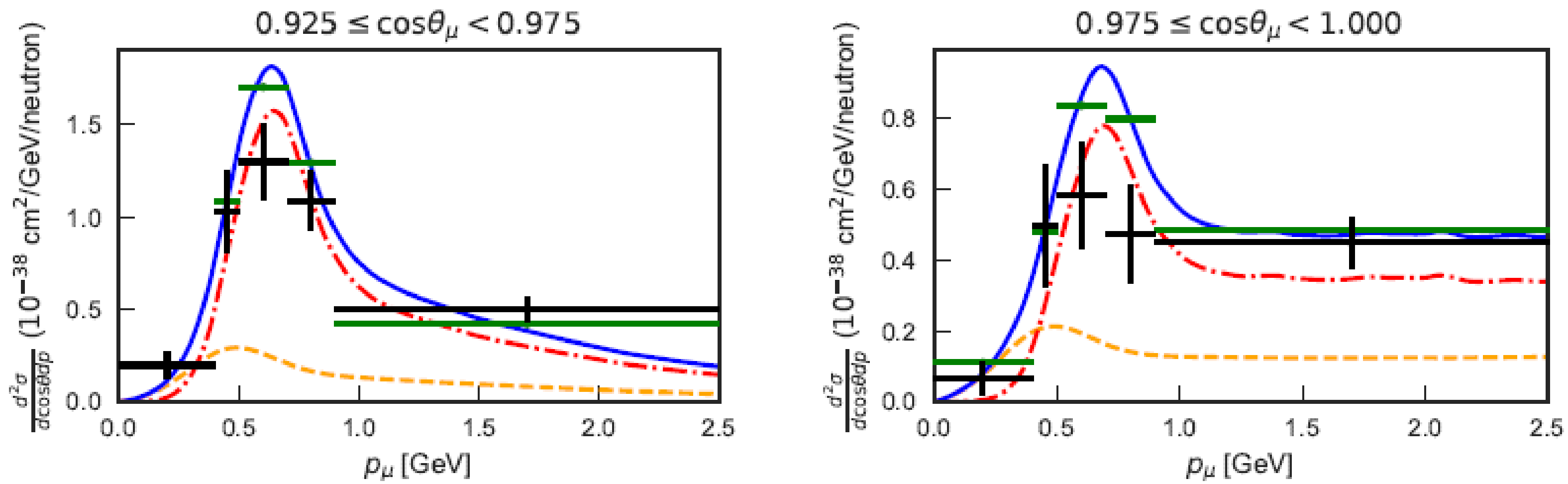
Pion reabs

T2K 0pion on H2O = QE + 2p2h

Martini



SUSA (Megias et al)



Both have no pion reabsorption, both are too high at forward angles

Conclusions

- 0-pion events are not just QE (+2p2h)
- They do contain pion reabsorption
- 2p2h models by Martini and by SUSA grossly overestimate the forward cross sections, even without the pion reabsorption