(A short) theoretical summary

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INT Workshop, Seattle

Goals:

- not a politically correct resumé with one slide from every talk
- focus on topics that were most intensively discussed
- focus on topics important for users: hints for future MC developments
- hopefully, an introduction to even more discussions!

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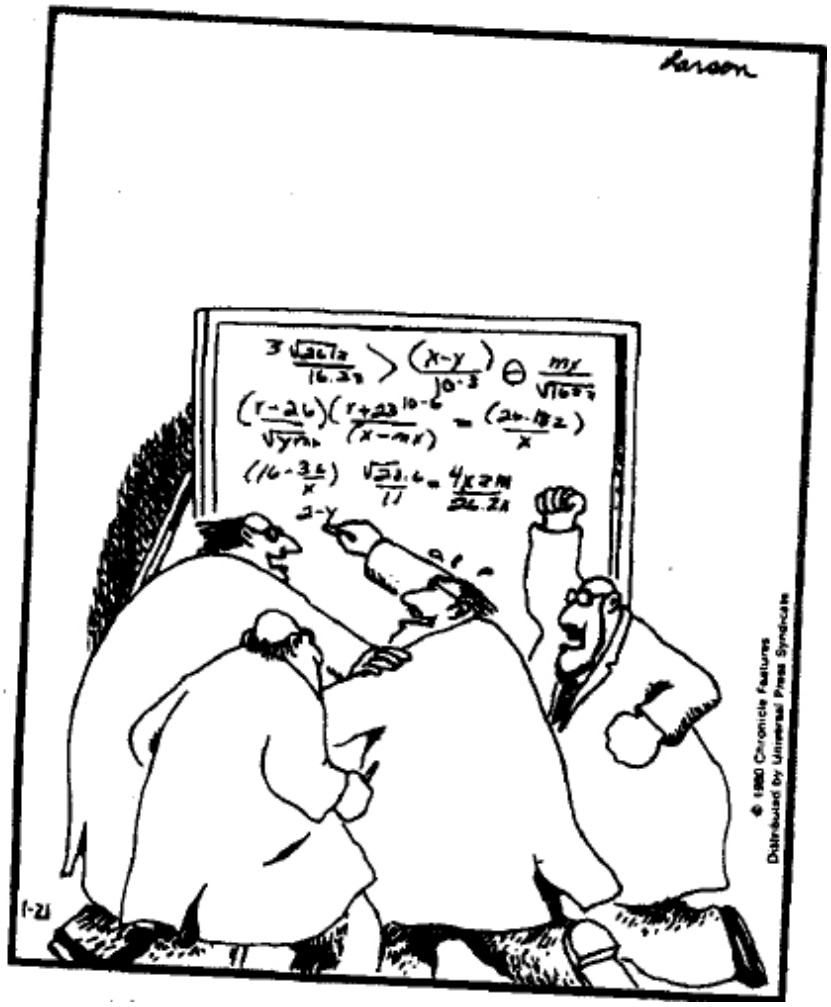


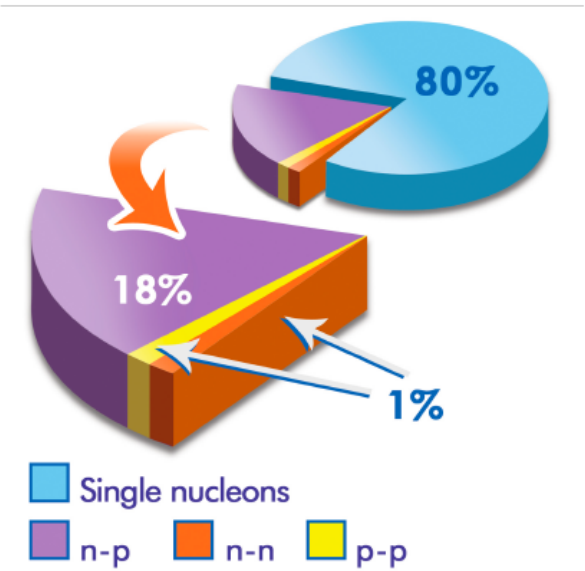
– Spectral function is this!
– No! Spectral function is that!
– No!!!

I. Treatment of nucleon-nucleon correlations

Ia. Several talks gathered experience from electron scattering experiments:

^{12}C From (e,e'), (e,e'p), and (e,e'pN) Results

- 80 +/- 5% single particles moving in an average potential
  - 60 – 70% independent single particle in a shell model potential
  - 10 – 20% shell model long range correlations
- 20 +/- 5% two-nucleon short-range correlations
  - 18% np pairs (quasi-deuteron)
  - 1% pp pairs
  - 1% nn pairs (from isospin symmetry)
- Less than 1% multi-nucleon correlations



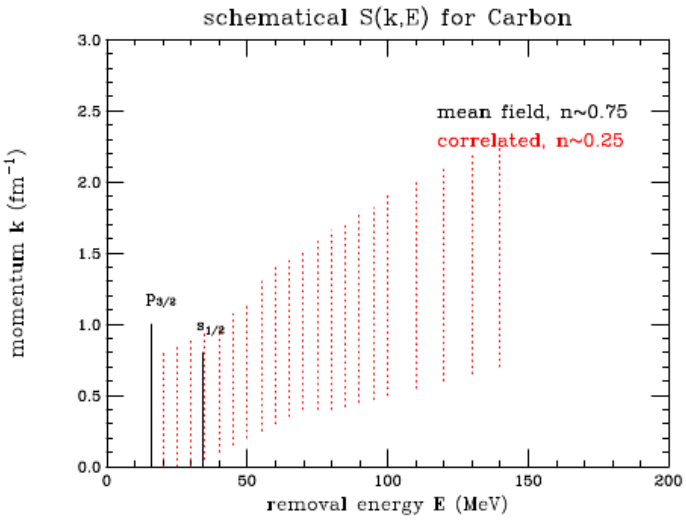
INT Workshop 4 December 2013

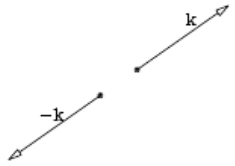
Jefferson Lab

I. Treatment of nucleon-nucleon correlations

Ib. Spectral function approach to describe lepton scattering in impulse approximation was discussed many times:

Qualitative structure of $S(k, E)$





Understanding of structure at high k

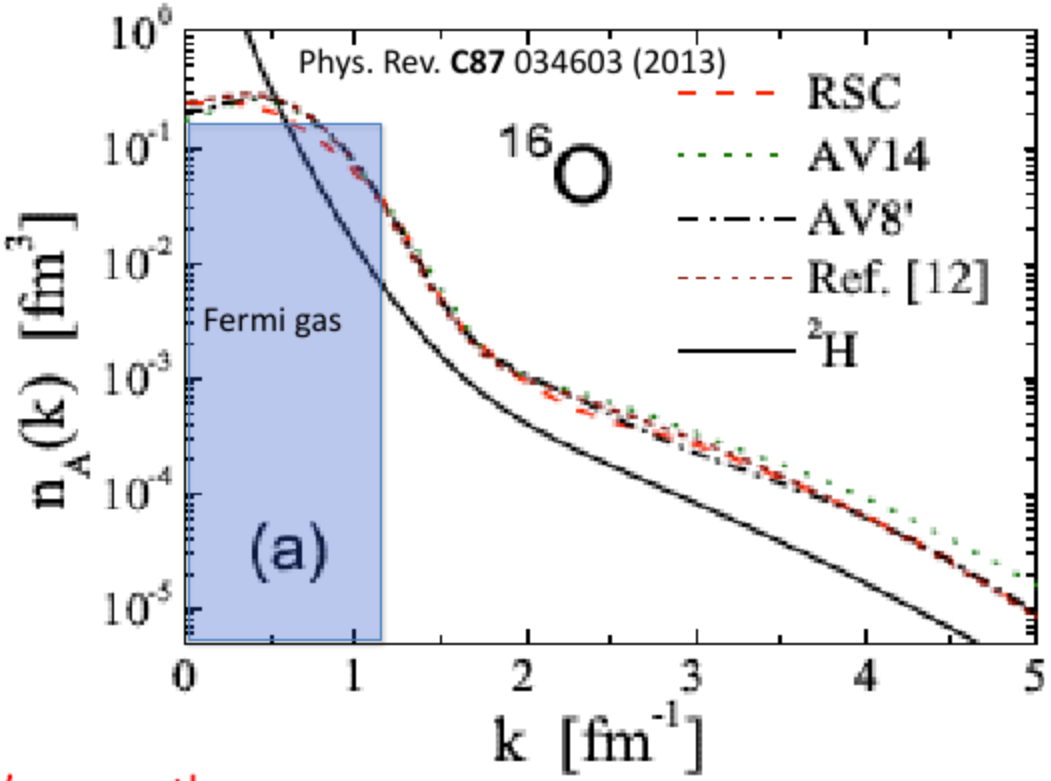
large k cannot occur in nuclear mean-field
large k occur in 2N-collisions, scattering N to k outside Fermi sphere
if remove one N with large k then second N is set free
costs energy $E \sim (-k)^2/2M \rightarrow$ large E
verified by (e,e'pp) Shneor et al.

Large k only appear at large E !!

I. Treatment of nucleon-nucleon correlations

Ic. FG versus SF

For example:The nucleon momentum distribution



It's worse than it looks

$$P_A(k) = 4\pi \int_0^\infty n_A(k) k^2 \, dk$$

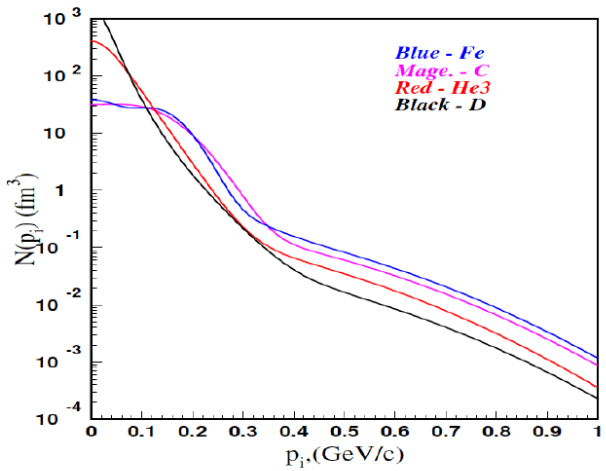
I. Treatment of nucleon-nucleon correlations

Id. If this were the whole story with correlations, life would be easy:

- SF can be (relatively) easily implemented in MC simulations tools (NuWro, recent work in GENIE and NEUT)
- there are clear ideas how to *cook* SF for various nuclei
  - correlated contribution is universal, always deuteron-like

Momentum Distributions

C. Ciofi degli Att and S. Simula, Phys. Rev. C **53** (1996) 1689.



At high *initial* momentums $\mathbf{n_A(p) = N * n_D(p)}$

I. Treatment of nucleon-nucleon correlations

Ie. Correlations seem to play also a crucial role in two-body current contribution to lepton-nucleus cross section:

TABLE II. Transverse sum rule obtained with one body only and with both one- and two-body current operators.

	^{3}He		^{4}He		^{6}Li	
q (MeV/c)	1	1+2	1	1+2	1	1+2
300	0.929	1.31	0.893	1.67	0.912	1.57
400	0.987	1.30	0.970	1.62	0.974	1.52
500	1.01	1.28	1.00	1.55	0.999	1.46
600	1.01	1.25	1.01	1.49	1.01	1.41
700	1.01	1.23	1.01	1.44	1.011	1.37

J. Carlson

TABLE VII. Excess-strength contributions ΔS_L and ΔS_T to the Fermi-gas sum rules from terms involving two-nucleon currents.

q (MeV/c)	ΔS_L	ΔS_T
300	0.004	0.114
400	0.007	0.081
500	0.011	0.066
600	0.017	0.060
700	0.024	0.056

II. Two-body current neutrino computations

II.a A lot of discussion about similaries and differences between existing approaches:

2p-2h contributions in the different approaches

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

M. Martini, M. Ericson, G. Chanfray, J. Marteau — Contribution to all terms in G_M and G_A

J. Nieves, I. Ruiz Simo, M.J. Vicente Vacas et al. — to all the terms

J.E. Amaro, M.B. Barbaro, J.A. Caballero, T.W. Donnelly et al. — only to the G_M^2 term

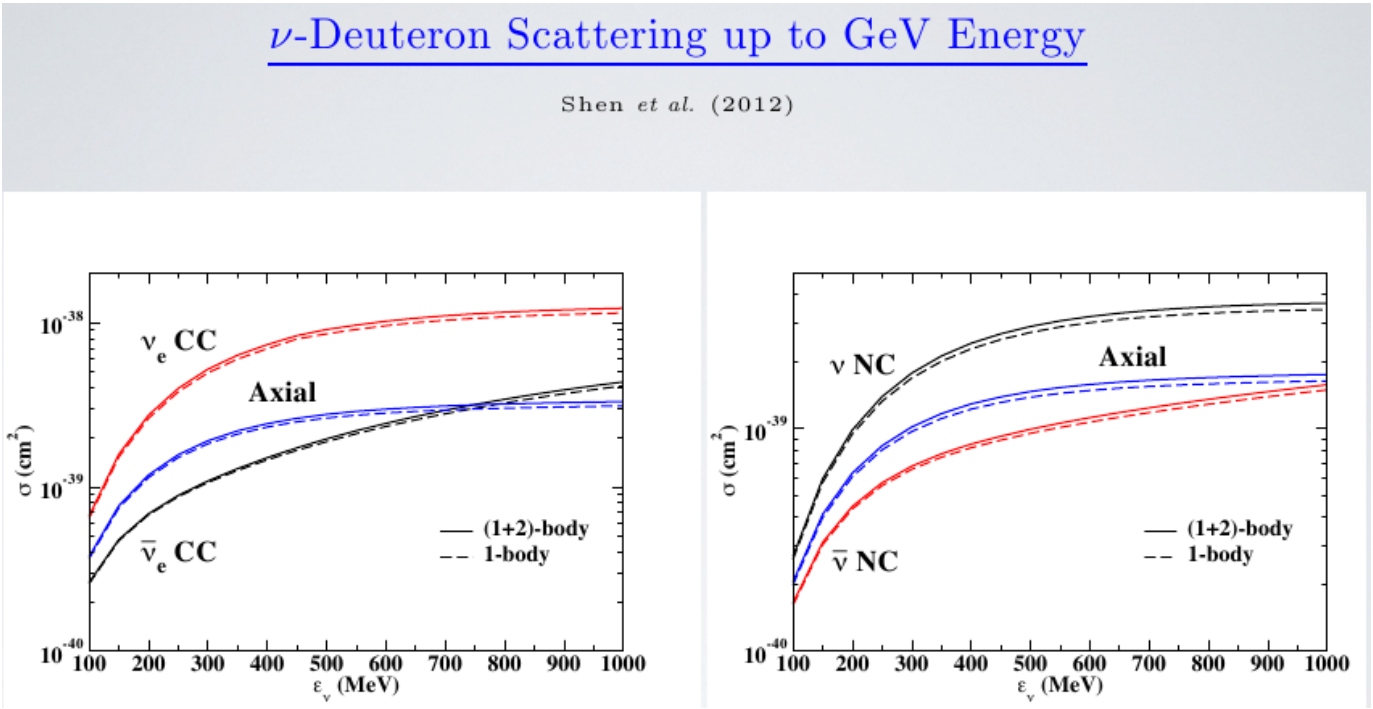
M. Martini

One may add: transverse enhancement – only all G_M containing terms.

J. Carlson: axial part is enhanced as well!

II. Two-body current neutrino computations

II.b A lot of insight is provided by more rigorous computations



J. Carlson

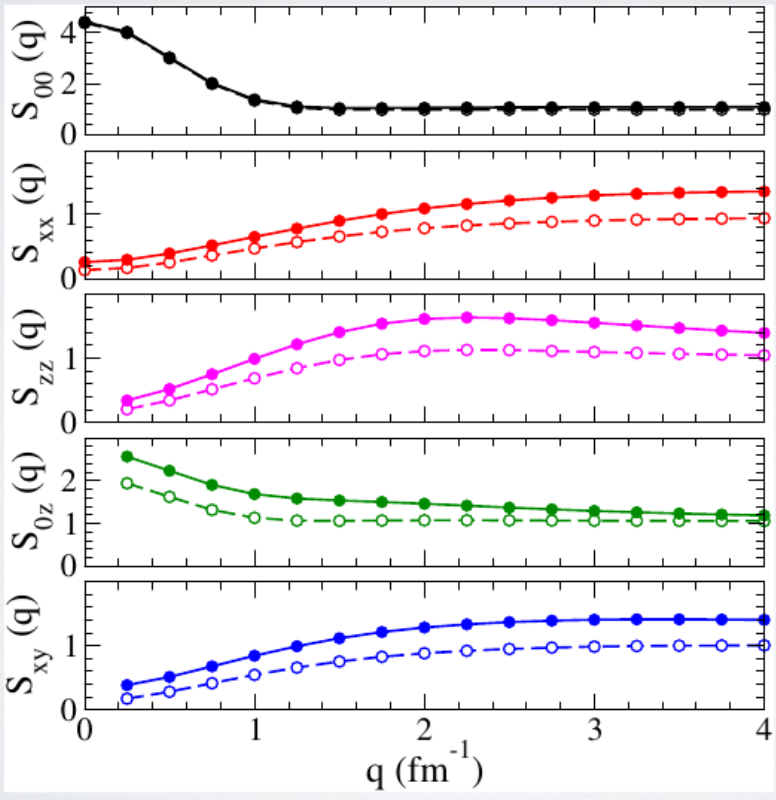
Good news, because much of what is known about M_A comes from old deuteron experiments.

Would be nice to see also an impact on Q^2 distribution.

II. Two-body current neutrino computations

II.c A lot of insight is provided by more rigorous computations

5 response functions
Neutral current sum rules for 12C



J. Carlson

Vocabulary:

$$
\begin{aligned}
R_{CC} &= W^{00} \\
R_{CL} &= -\frac{1}{2}\left(W^{03}+W^{30}\right) \\
R_{LL} &= W^{33} \\
R_{T} &= W^{11}+W^{22} \\
R_{T'} &= -\frac{i}{2}\left(W^{12}-W^{21}\right)
\end{aligned}
$$

J. Amaro

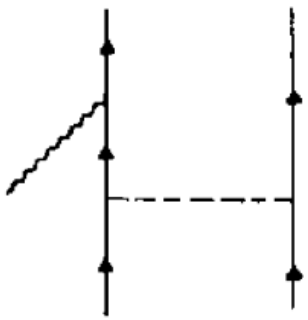
On the left enhancement due to two-body current is shown.

II. Two-body current neutrino computations

II.d There is some worry that existing microscopic computations depart from (local) Fermi gas ground state:

- however, computations include contribution from *correlation diagrams*

Nucleon-Nucleon correlations

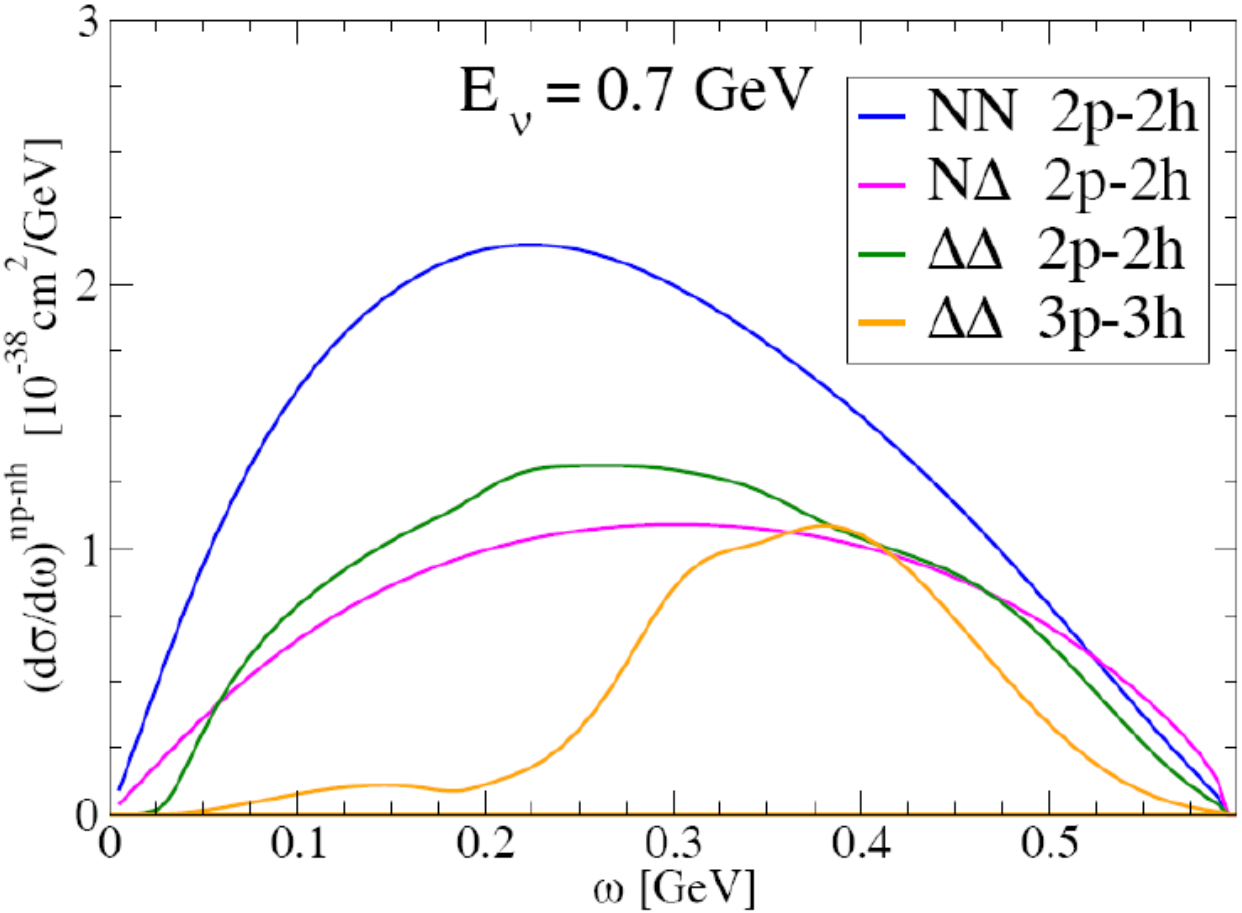


M. Martini

- is *enough* correlation introduced via this diagram? is the whole picture consistent?

II. Two-body current neutrino computations

II.e In the Marco Martini model the correlation (N-N) contribution dominates:



M. Martini

II. Two-body current neutrino computations

II.f Another serious source of worries: consistency of existing approaches

- in MCs (also in GiBUU) two body current contribution is always implemented as another *independent* reaction channel (CCQE, RES, DIS, COH)
- J. Carlson: interference with the one body contribution is large
- MCs need a parametrization of both two body current and interference contribution together
- in impulse approximation in SF approach there is a correlation contribution with two nucleon knock out without FSI effects – how wrong is to use this together with Martini/Nieves model?

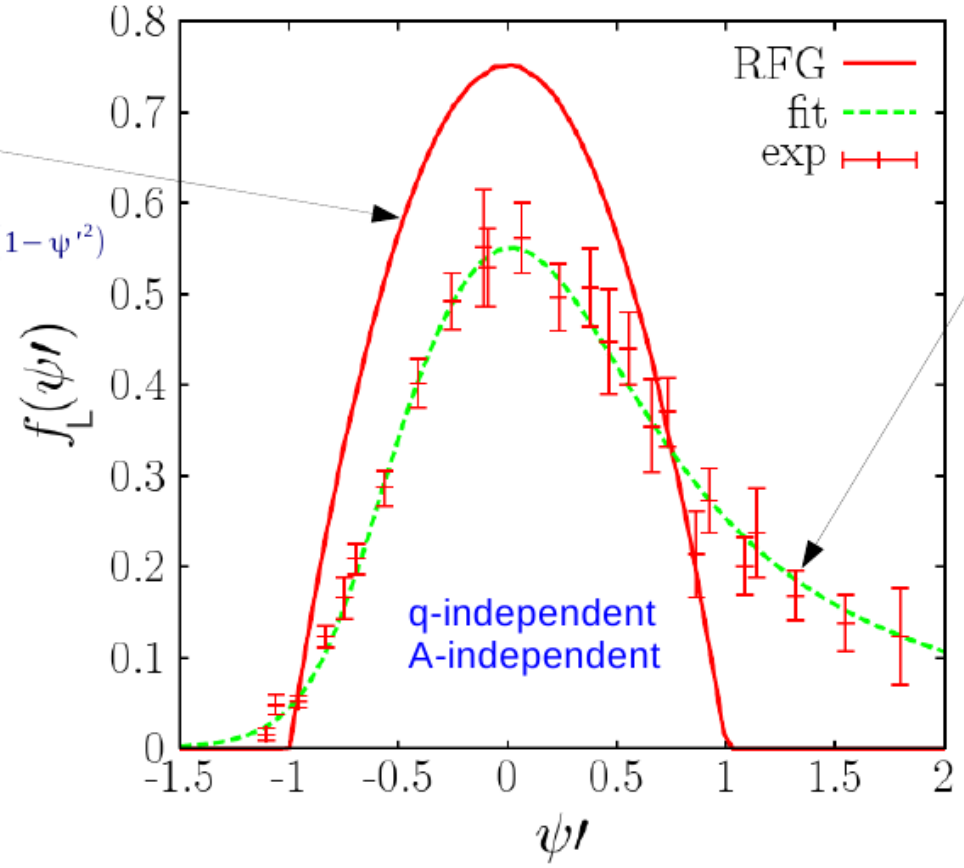
III. Other topics

III.a A series of presentations on (super-)scaling approach:

A **phenomenological super-scaling function** has been extracted from the *longitudinal* (e,e') word data [Jourdan,NPA603, 117 ('96)]

The RFG is very poor

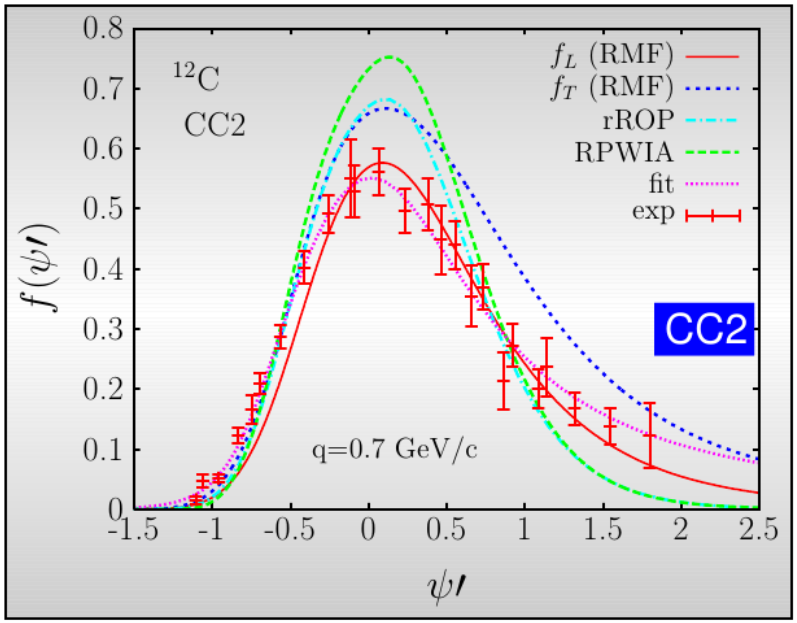
$$f_{RFG}(\psi') = \frac{3}{4}(1-\psi'^2)\theta(1-\psi'^2)$$



Asymmetric shape with long high energy tail

III. Other topics

III.b It was reminded many times (see also Arie Bodek presentation) that models used in MC should agree with superscaling function:



Only the description of FSI provided by RMF leads to an asymmetric function $f(\psi')$ in accordance with the behavior shown by data. Moreover, $f_T > f_L$

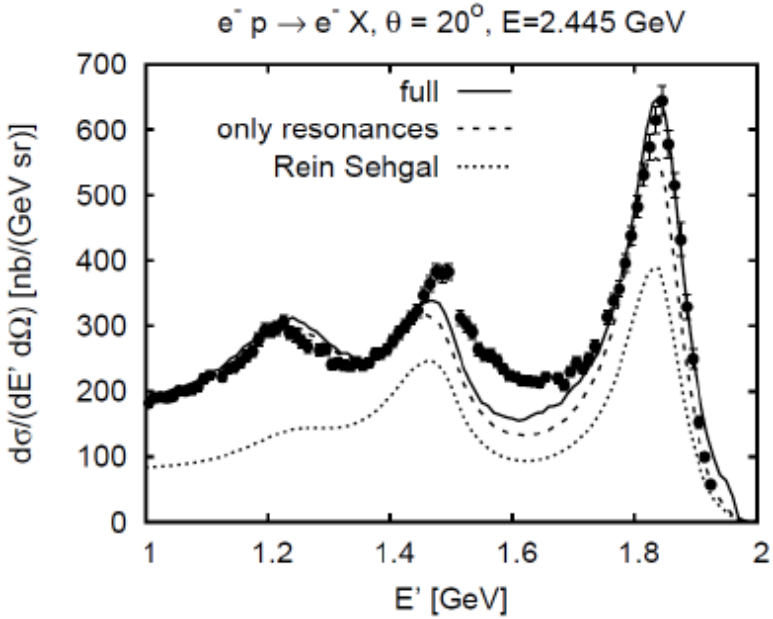
J. Cabbalero

What about LFG+RPA?...

III. Other topics

III.b Pion production (a transition region topic, with presentations in the first and in the second week)

- important to understand CCQE – a background from pion absorption
- precise data is badly needed
- Rein-Sehgal model is not reliable at all
  - nothing new but should be remembered again and again
- important work is being done in GENIE



L. Alvarez-Ruso

IV. A message for MC generators:

- improvements in treatment of nuclear effects (NN correlations) should be done
- spectral function should probably become a default option
- before more rigorous computations are done, existing treatments of two body contribution should be applied
  - comparison to MiniBooNE ν_μ and $\bar{\nu}_\mu$ data is a necessary consistency check
- it will be very difficult to get everything that is required in the completely satisfactory way
  - rigorous computations are non-relativistic
  - experimentalists need to know results for oxygen, argon, ...
  - MCs need predictions for final state nucleons
    - any hints from ^{3}He and ^{4}He computations?...

Summary:

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Correlations have many consequences and must be seriously taken into account!