SuSA and Mean-Field based models: Summary 2019

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Grupo de Física Nuclear,
IPARCOS,
Universidad Complutense de Madrid

NuSTEC meeting, December 12, 2019

In collaboration with...

SuSA and RMF

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Ghent University

Natalie Jachowicz

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Nils Van Dessel

Kajetan Niewczas (Ghent/**Wroclaw**)

CEA Saclay

Stephen Dolan

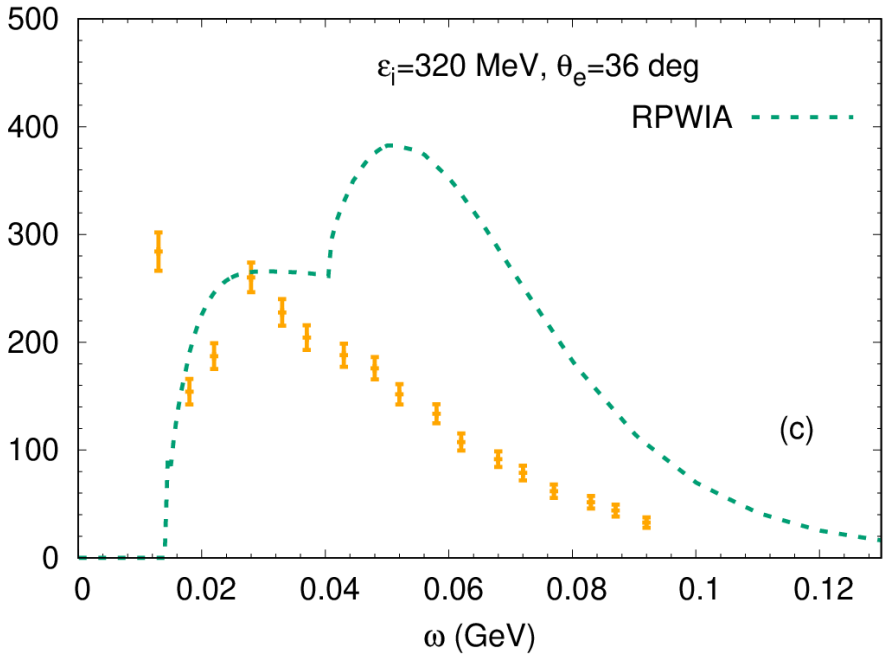
Sara Bolognesi

Vishvas Pandey (**Virginia Tech**)

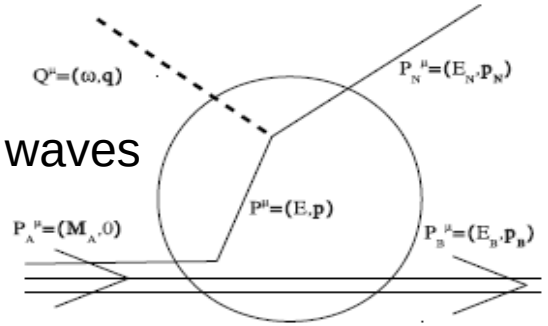
Nuclear effects in electron-nucleus and neutrino-nucleus scattering within a relativistic quantum mechanical framework

R. González-Jiménez,[1,*] A. Nikolakopoulos,[2,†] N. Jachowicz,[2,‡] and J. M. Udías[1,§]

Inclusive electron scattering **at low q:**



Plane waves



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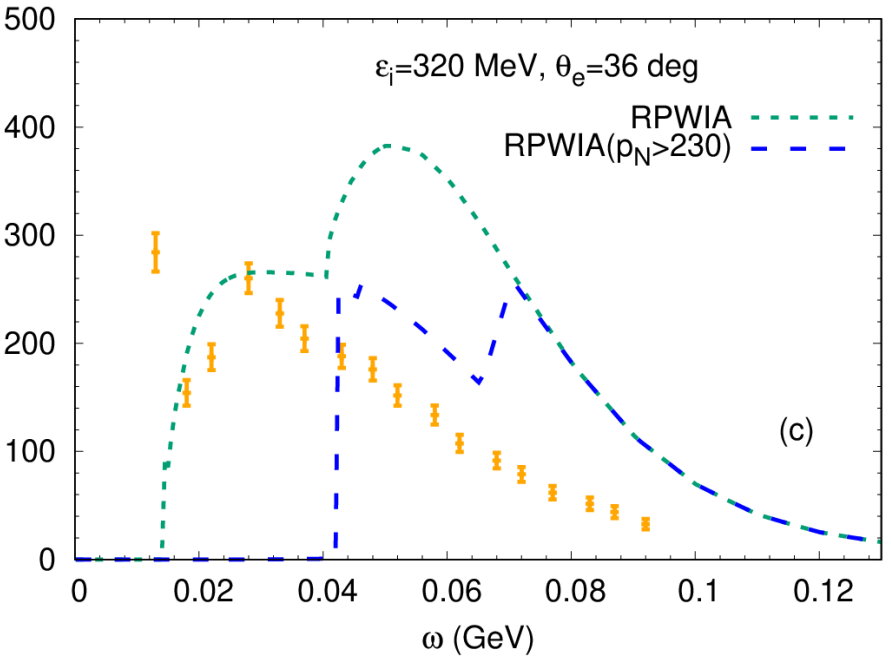

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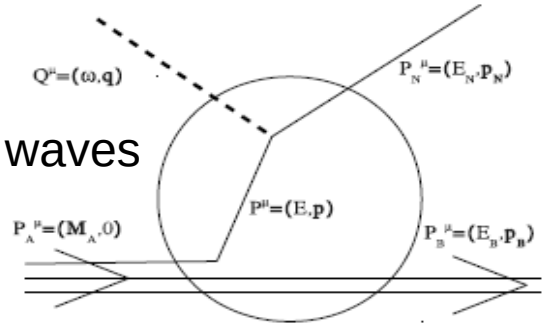

Phys. Rev. C **100** 045501 (2019)

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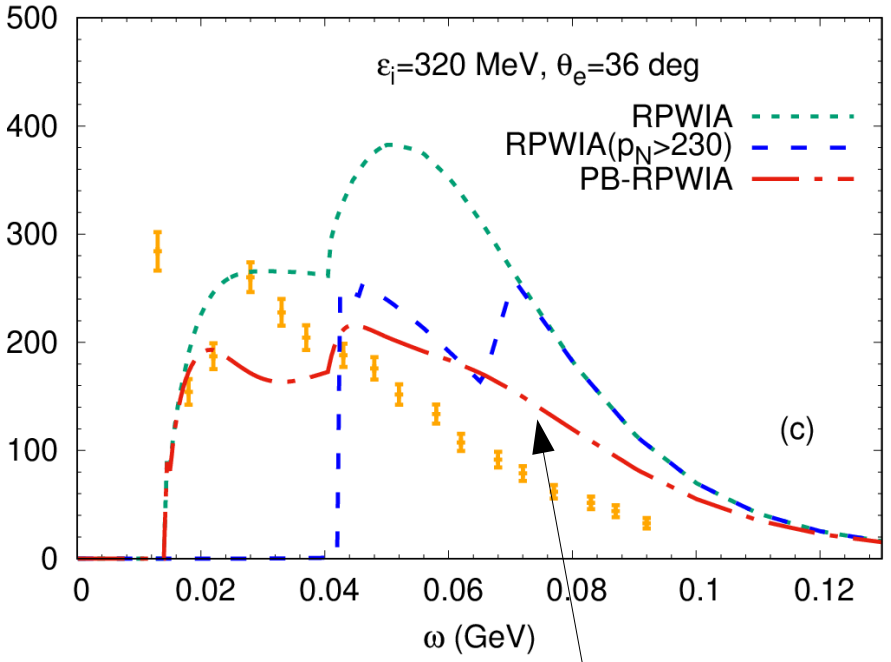
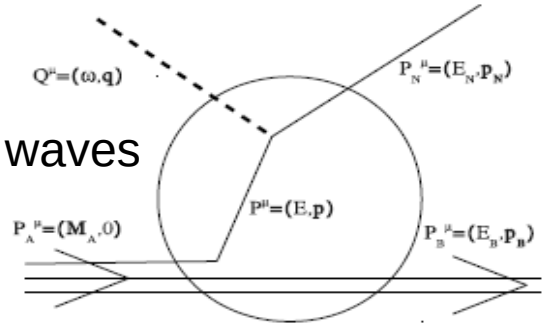


Orthogonalization

Plane waves



$$|\Psi^{s_N}(\mathbf{p}_N)\rangle = \left|\psi_{pw}^{s_N}(\mathbf{p}_N)\right\rangle - \sum_{\kappa,m_j}\left[C_\kappa^{m_j,s_N}(\mathbf{p}_N)\right]^\dagger \left|\psi_\kappa^{m_j}\right\rangle$$

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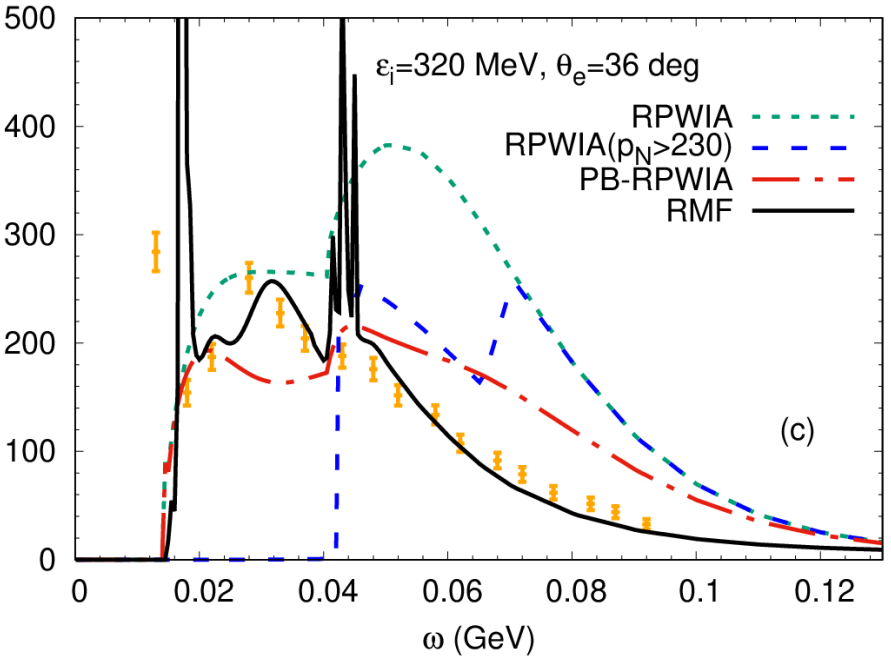
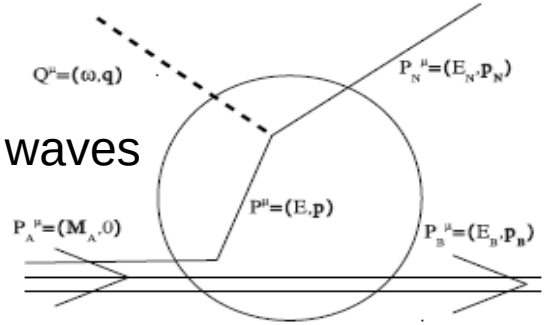
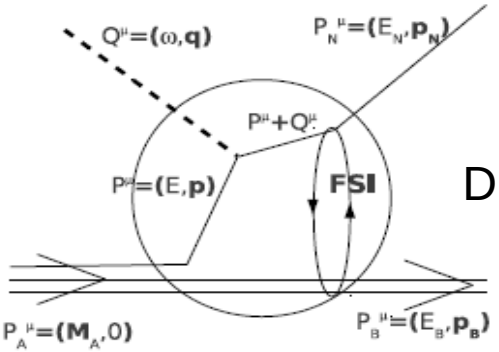


Plane waves





Distorted waves

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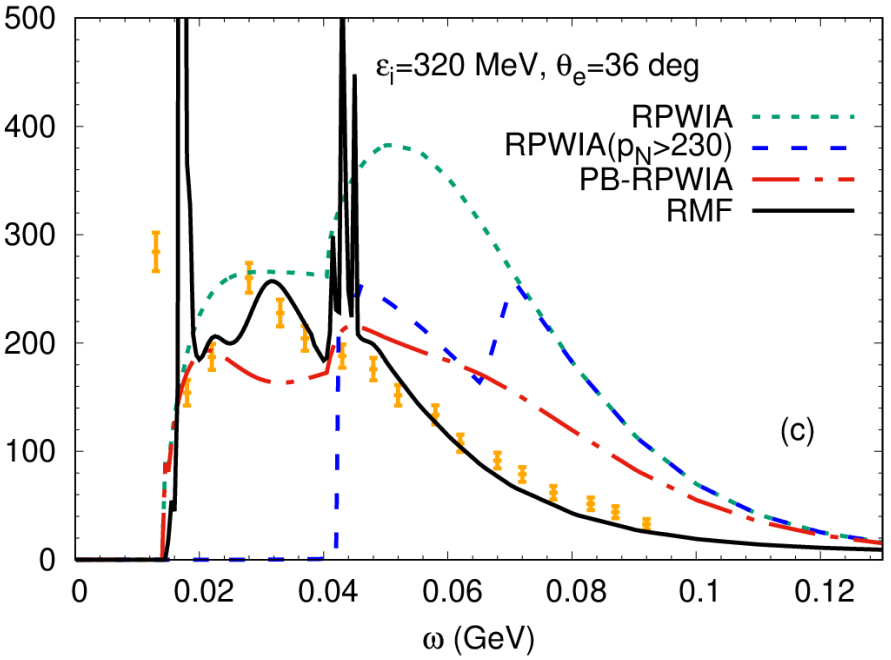

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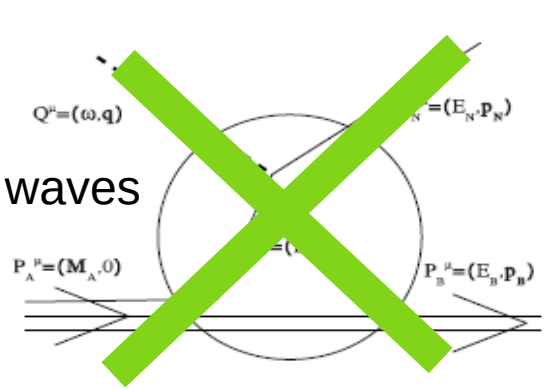

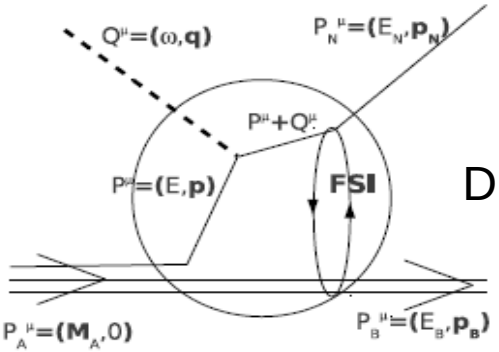

Distorted waves

When the outgoing nucleon has small momentum its wavelength is comparable to the distance between nucleons: **Quantum Mechanics is important !!**

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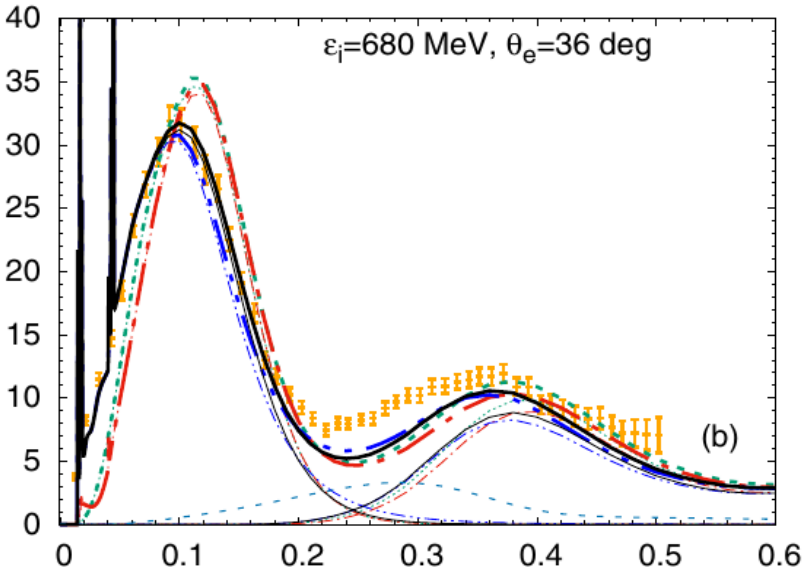

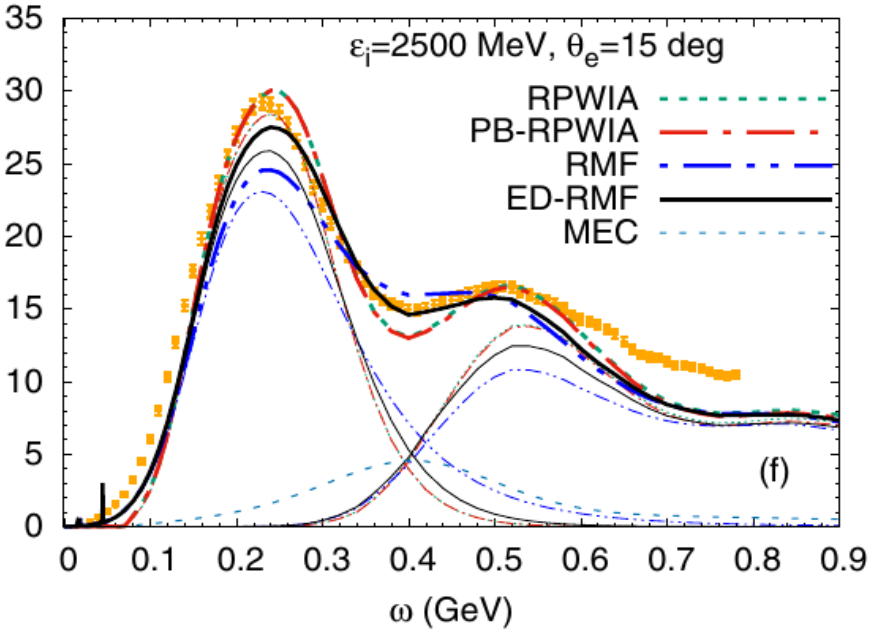

Distortion of the outgoing nucleon (= FSI in a Quantum Mechanical way)
Important at intermediate energies too !!!

Electron versus Muon Neutrino Induced Cross Sections in Charged Current Quasielastic Processes

A. Nikolakopoulos,[1,*] N. Jachowicz,[1,†] N. Van Dessel,[1] K. Niewczas,[1,2] R. González-Jiménez,[3] J. M. Udías,[3] and V. Pandey[4]

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For a given neutrino energy and scattering angle of the final lepton:

$$\frac{\nu_e \text{ QE cross section}}{\nu_\mu \text{ QE cross section}} = 1$$

???

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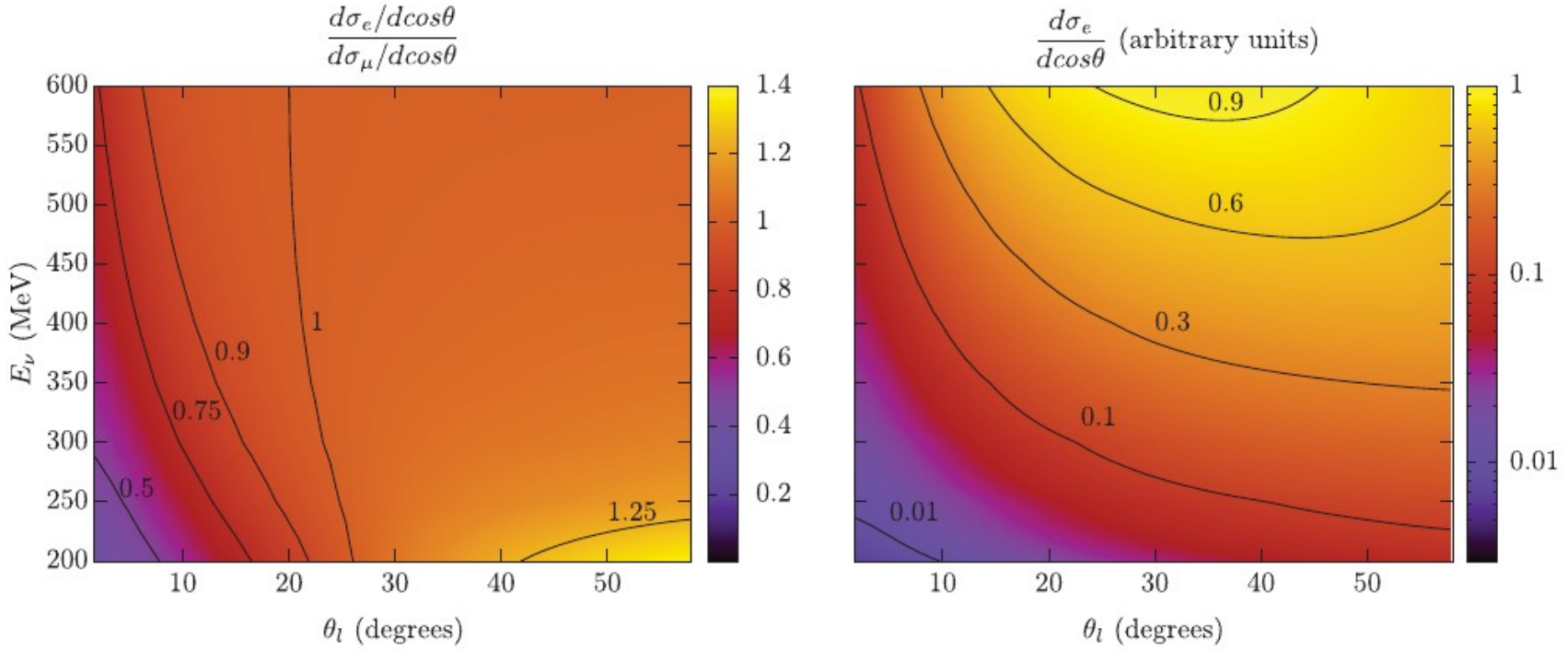

FIG. 4. Ratio of ^{12}C cross sections as a function of incoming energy and lepton scattering angle, combined with relative strength of the cross section at the same kinematics (normalized such that the maximum in this kinematic region is 1). Results shown here were obtained within the CRPA approach, RMF ratios are very similar [30].

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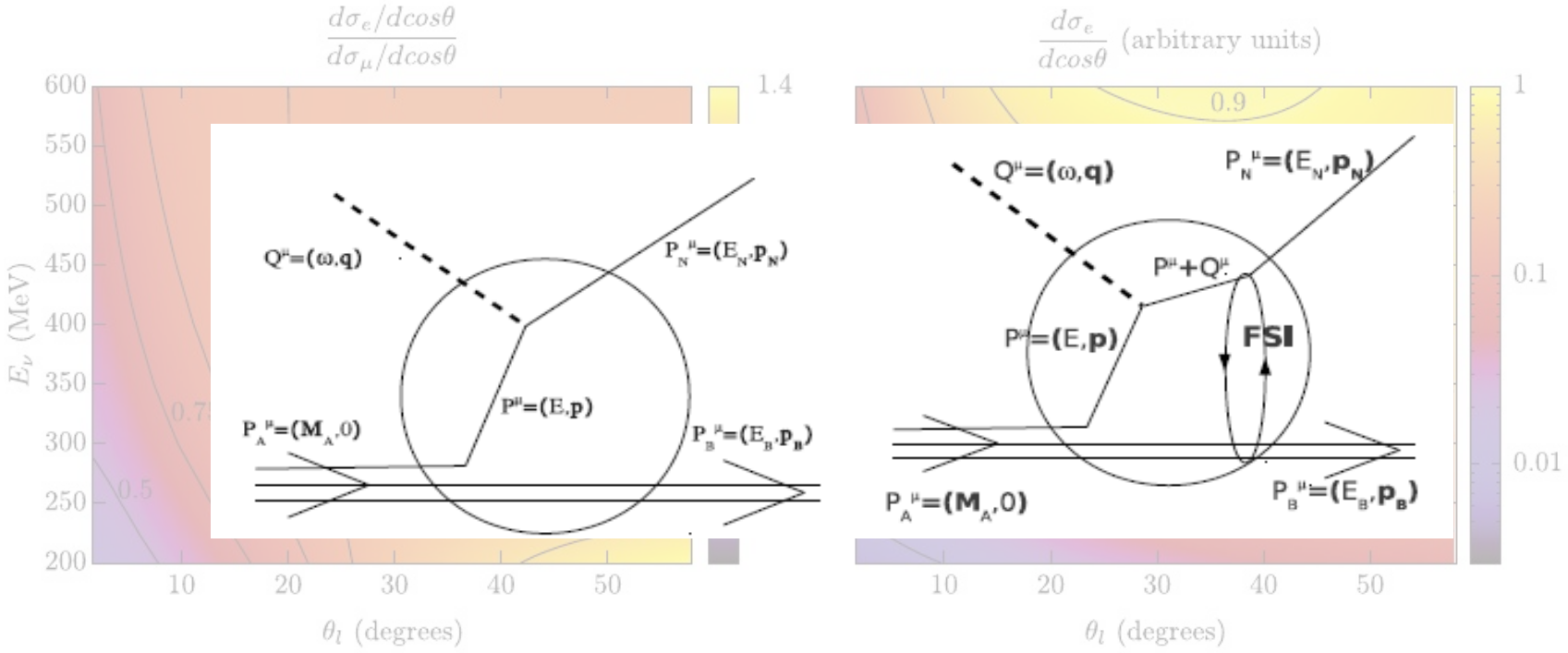

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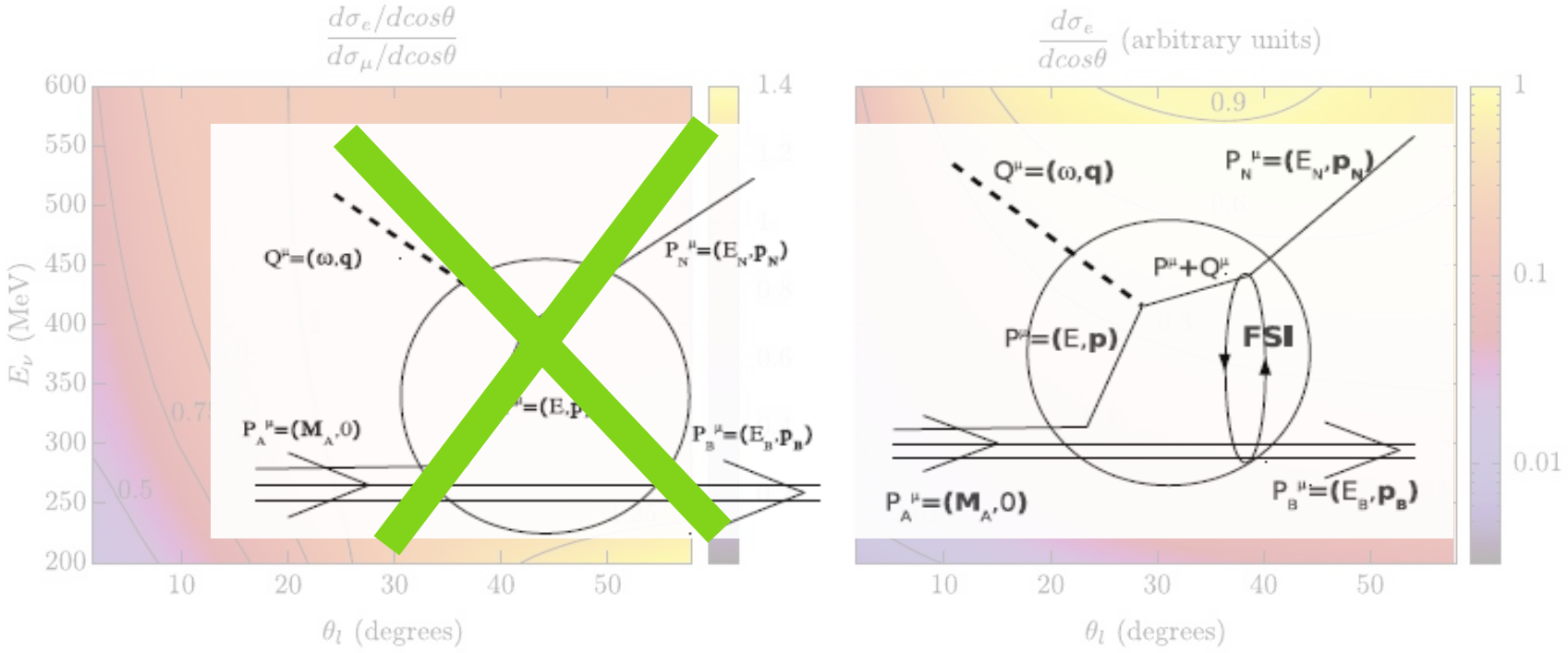

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SuSAv2

SuSAv2-MEC

Analysis of the MINERvA antineutrino double-differential cross sections within the SuSAv2 model including meson-exchange currents

G. D. Megias

Departamento de Física Atómica, Molecular y Nuclear, Universidad de Sevilla, 41080 Sevilla, Spain and IRFU, CEA, Université Paris-Saclay, 91191 Gif-sur-Yvette, France

M. B. Barbaro

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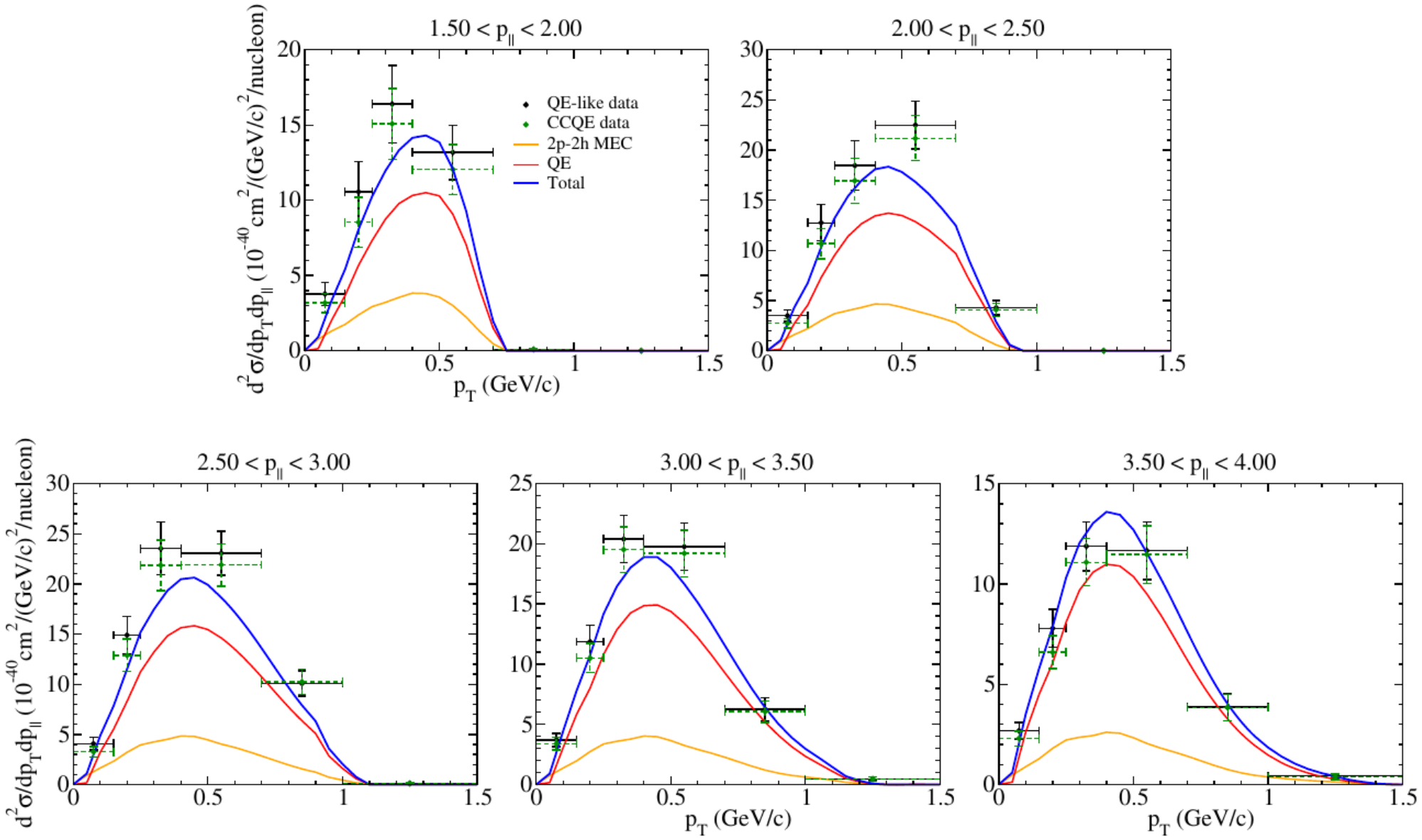
J. A. Caballero

Departamento de Física Atómica, Molecular y Nuclear, Universidad de Sevilla, 41080 Sevilla, Spain

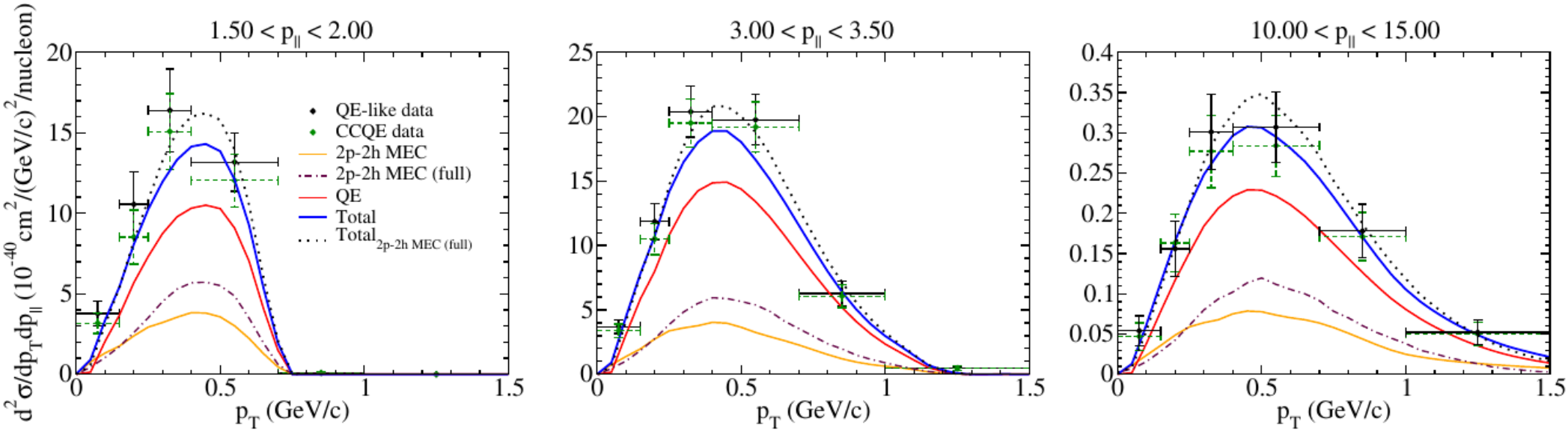
S. Dolan

Ecole Polytechnique, IN2P3-CNRS, Laboratoire Leprince-Ringuet, 91120 Palaiseau, France and IRFU, CEA, Université Paris-Saclay, 91191 Gif-sur-Yvette, France

SuSAv2-MEC versus MINERvA nub 0pions



Full propagator vs real propagator in the delta current.



Rapid Communications

Mean-field and two-body nuclear effects in inclusive electron scattering on argon, carbon, and titanium: The superscaling approach

M. B. Barbaro,[1] J. A. Caballero,[2] A. De Pace,[3] T. W. Donnelly,[4] R. González-Jiménez,[5] and G. D. Megias[2,6]

PHYSICAL REVIEW C **99**, 042501(R) (2019)

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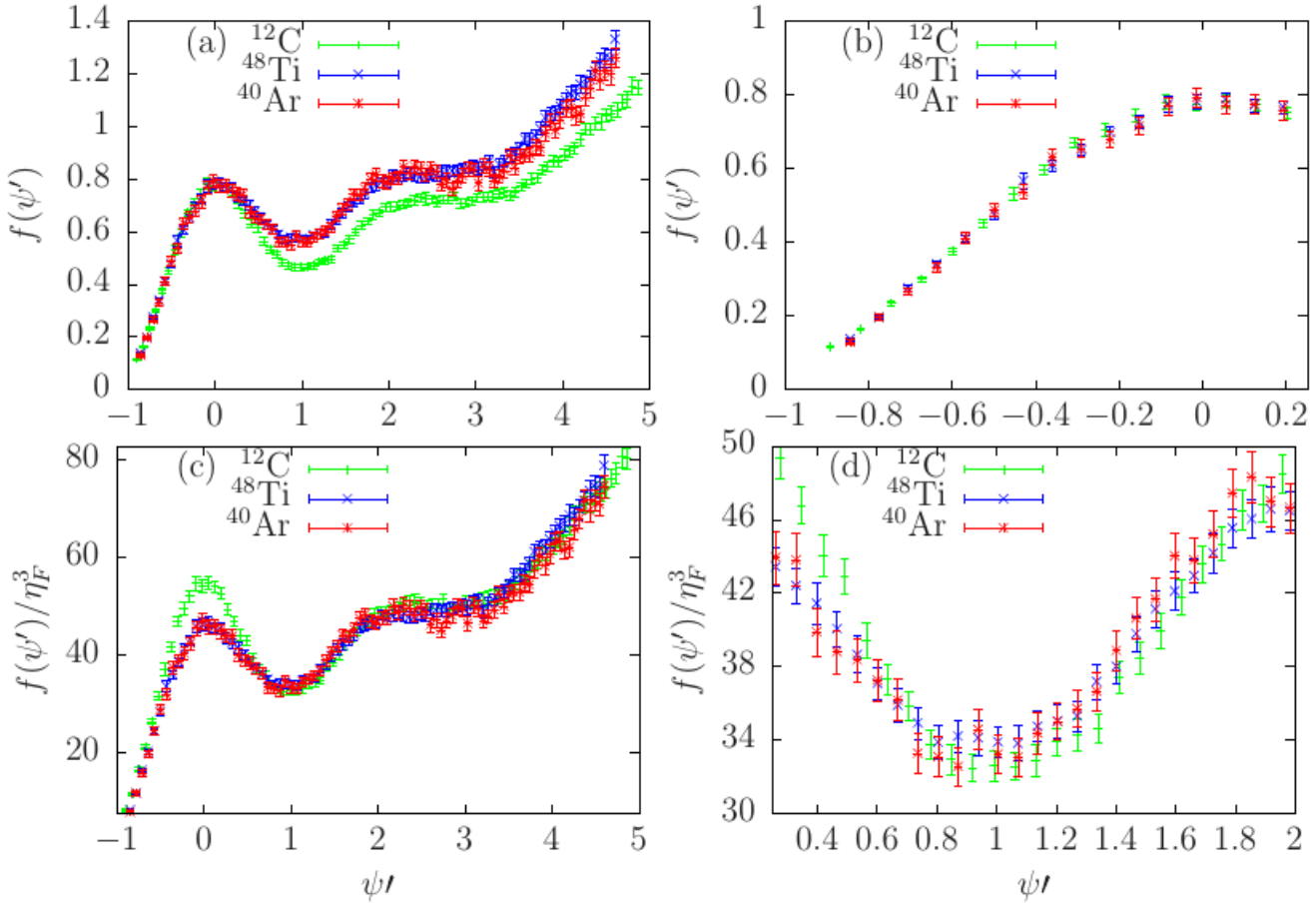

The 2p2h response scales very differently from the quasielastic one, in full accord with what is predicted by the model.

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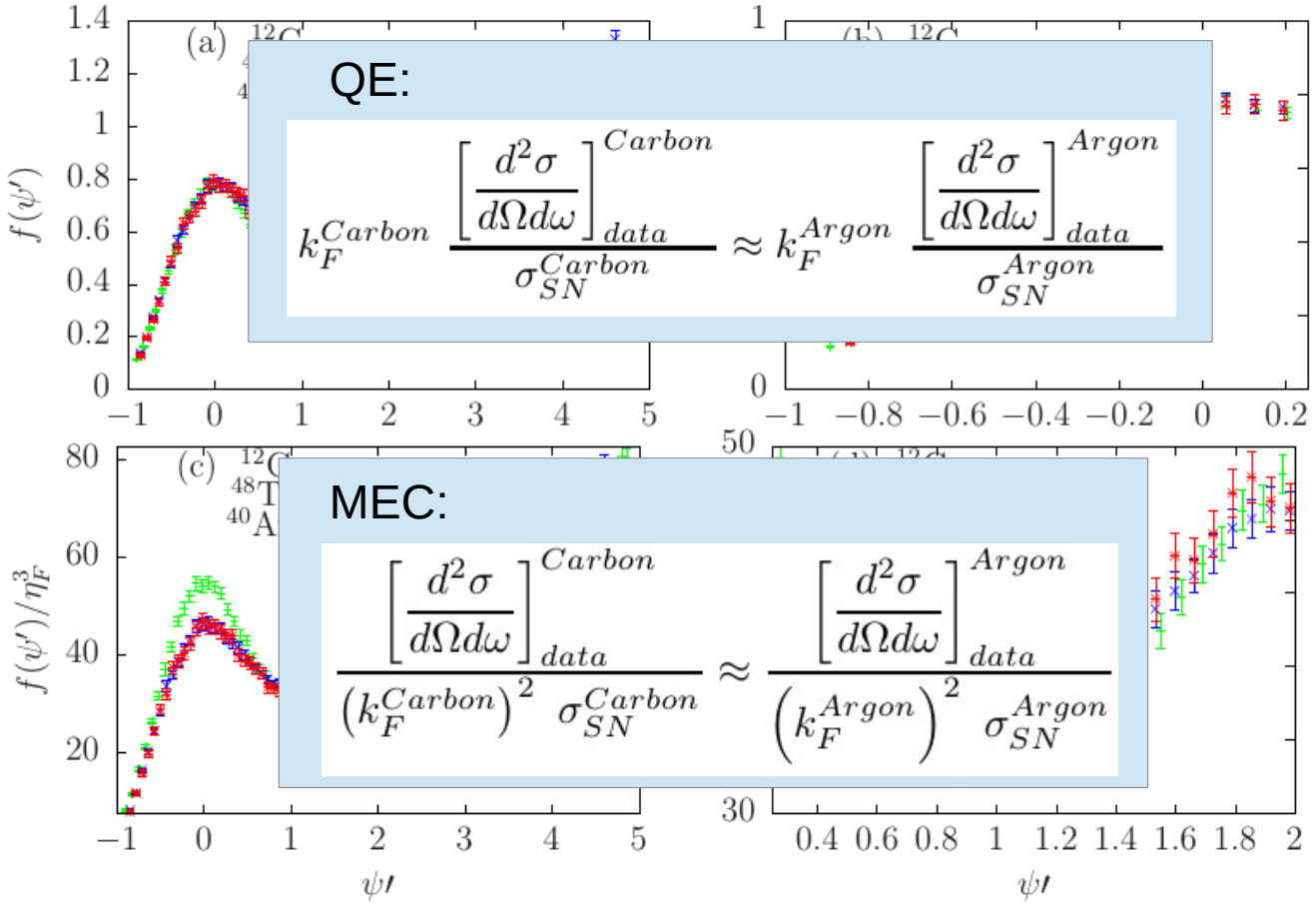

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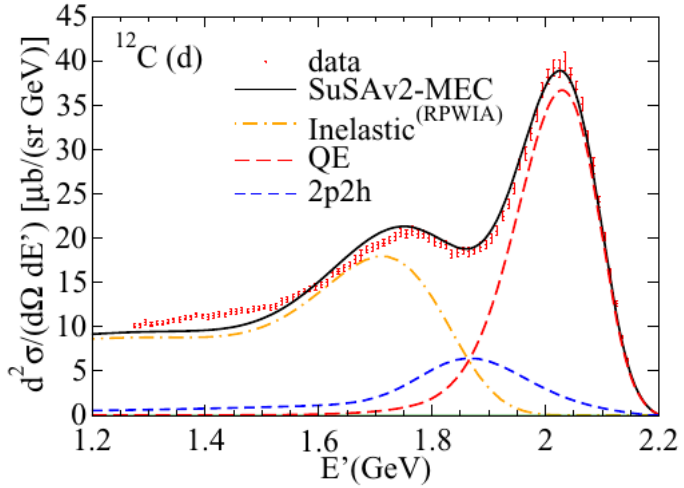
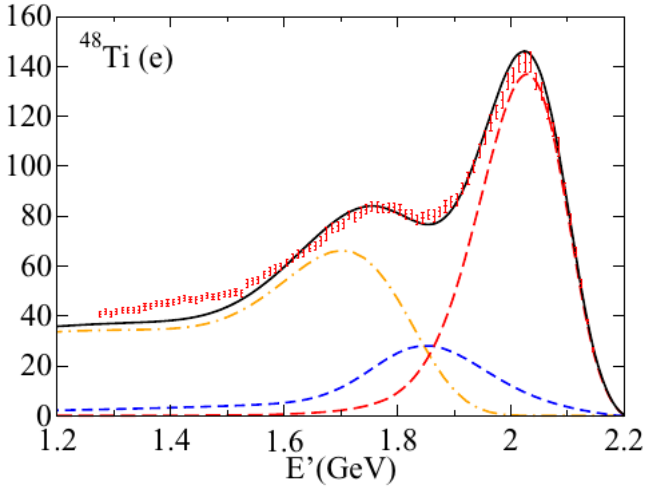
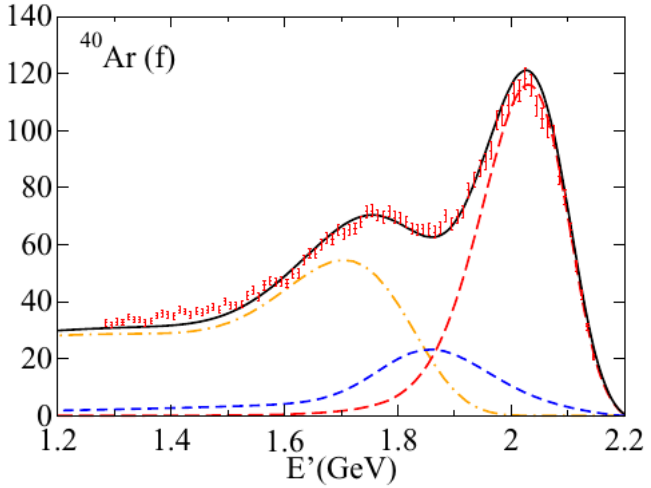
Comparison with recent JLab data.

E_i = 2222 MeV,
θ_e = 15.541 deg







Constraining the quasielastic response in inclusive lepton-nucleus scattering

R. González-Jiménez,[1] M.B. Barbaro,[2] J.A. Caballero,[3] T.W. Donnelly,[4]
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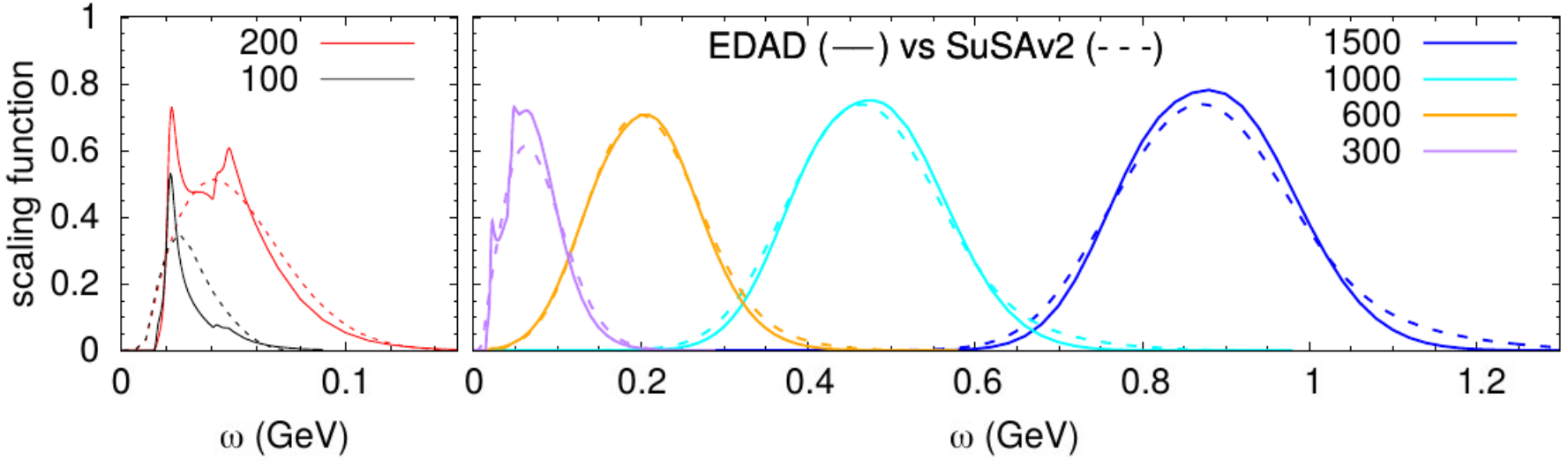
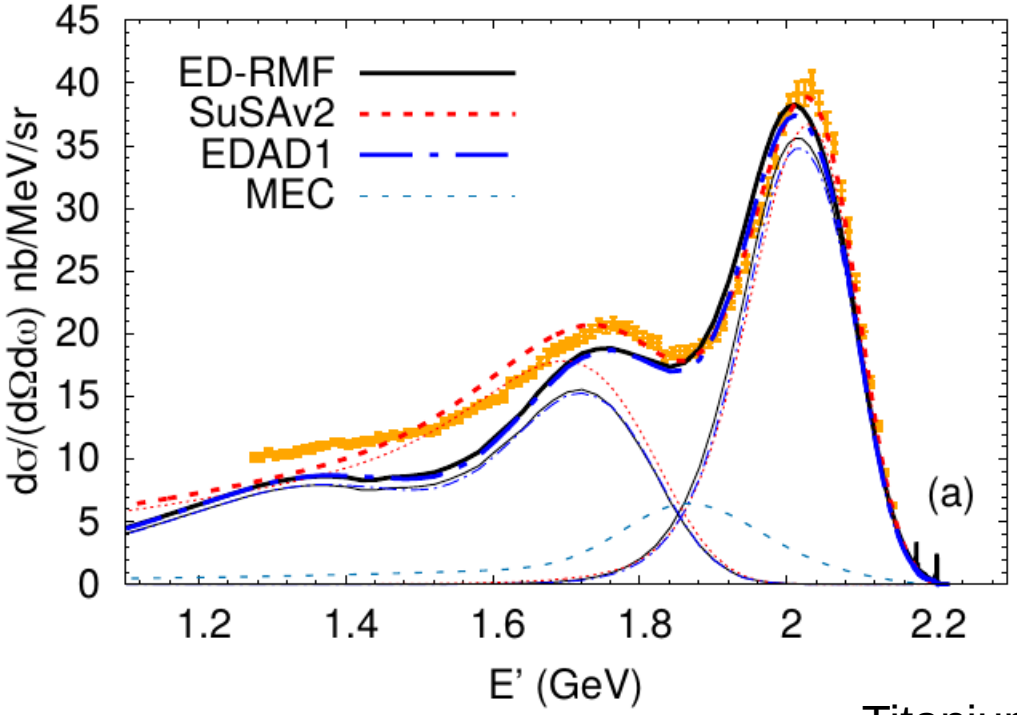


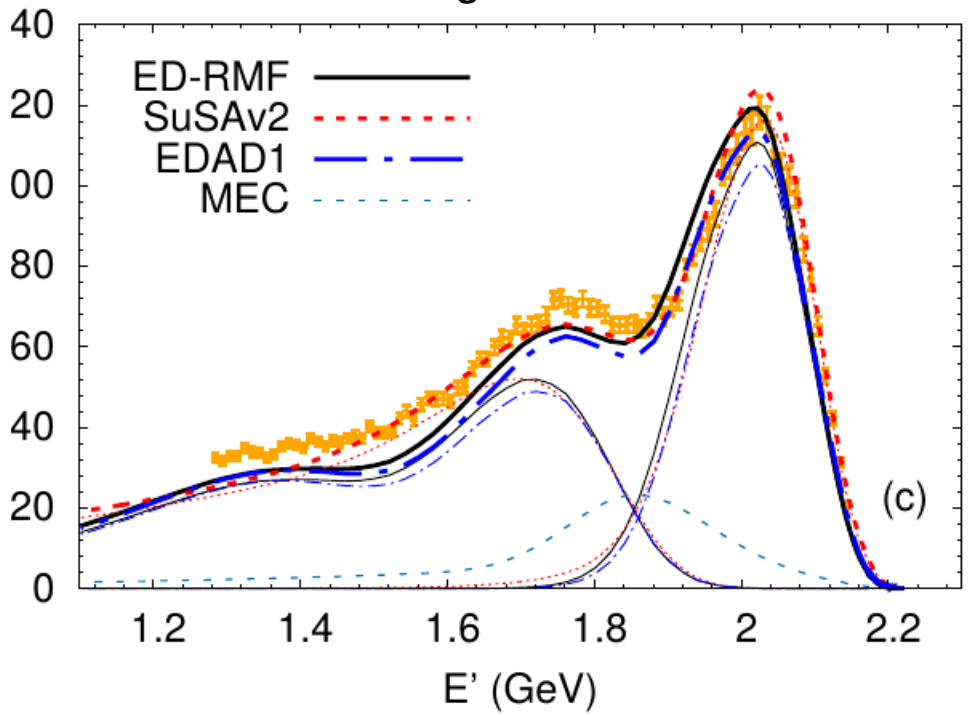
The SuSAv2 QE response is very similar to that from a model that solves the wave equation in presence of a real energy-dependent optical potential.

The coincidence between these two completely independent approaches, which satisfactorily agree with the inclusive data, reinforces the reliability of our predictions and sets constraints for the modeling of the QE response.

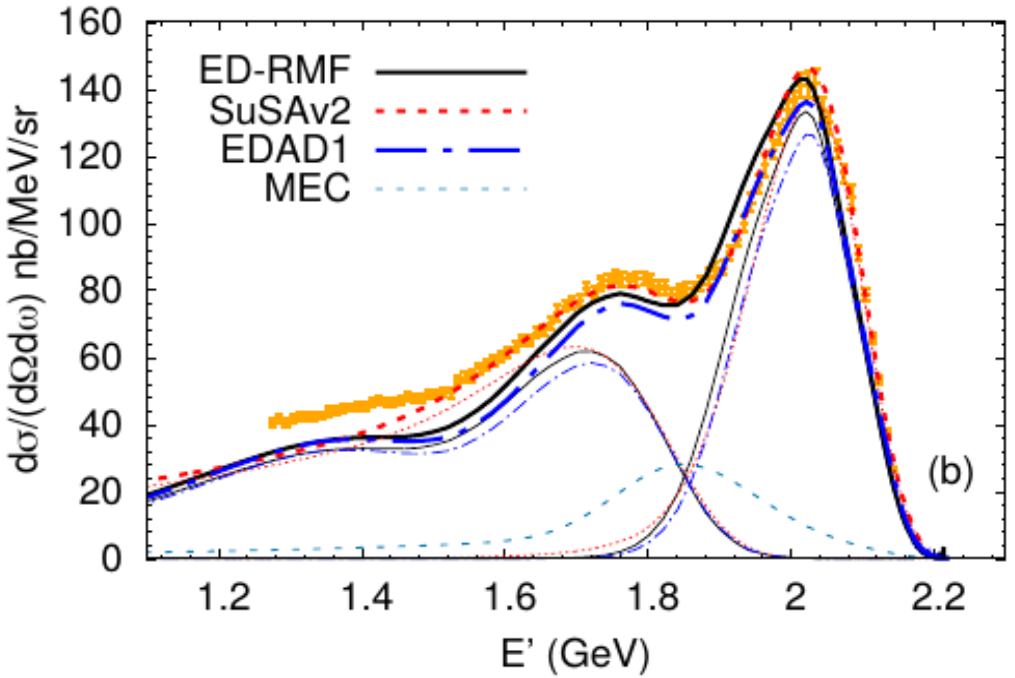
Carbon



Argon



Titanium



Recent JLab data.

E_i = 2222 MeV

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Implementation of the SuSAv2-MEC 1p1h and 2p2h models in GENIE and analysis of nuclear effects in T2K measurements

S. Dolan,[1,2] G.D. Megias,[1,2] and S. Bolognesi[2]

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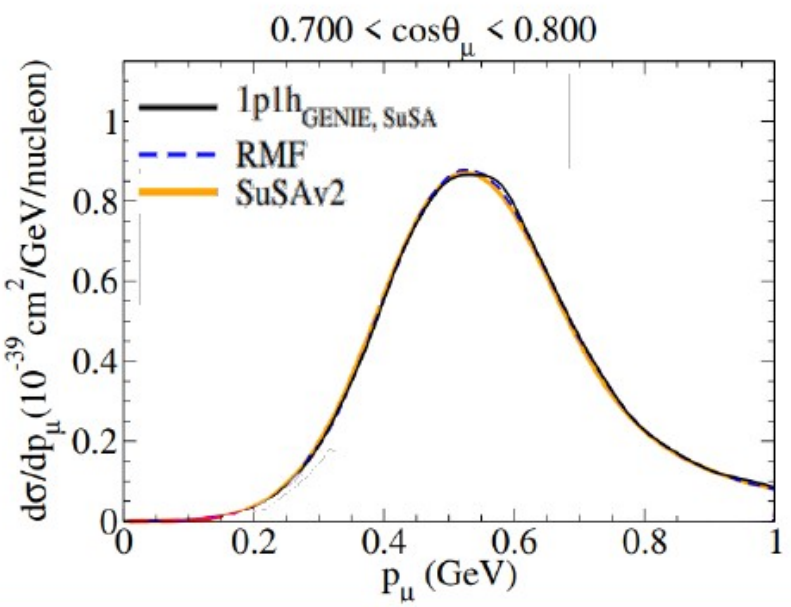
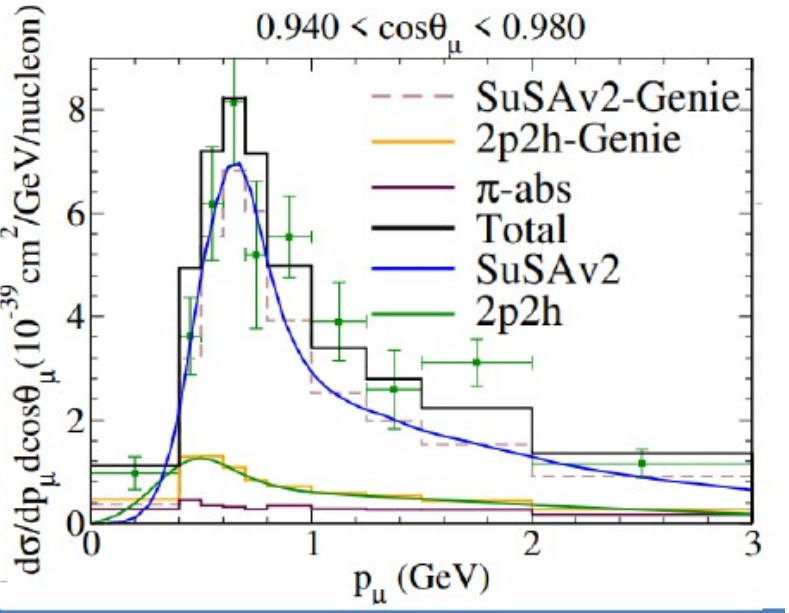
Overview

Based on: arXiv:1905.08556

Also: see Guillermo's talk before this

- Recently implemented the SuSAv2 1p1h and 2p2h models in GENIE using hadron tensors.
- Based on implementations of the Valencia 2p2h (NEUT/GENIE)
- Exactly reproduces the *inclusive* predictions of the models

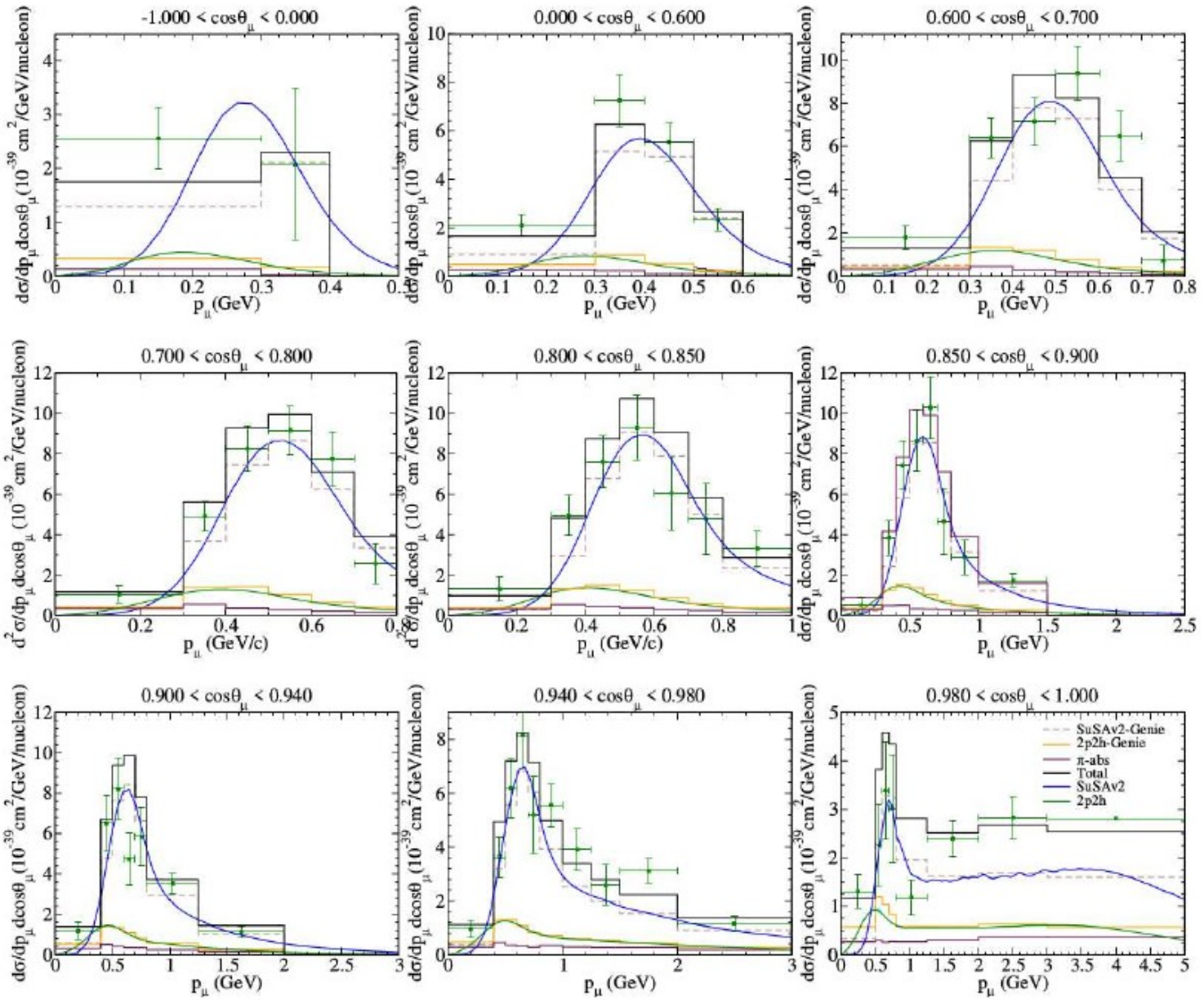




SuSAv2-MEC implementation in GENIE: Validation plots (T2K CC0π)

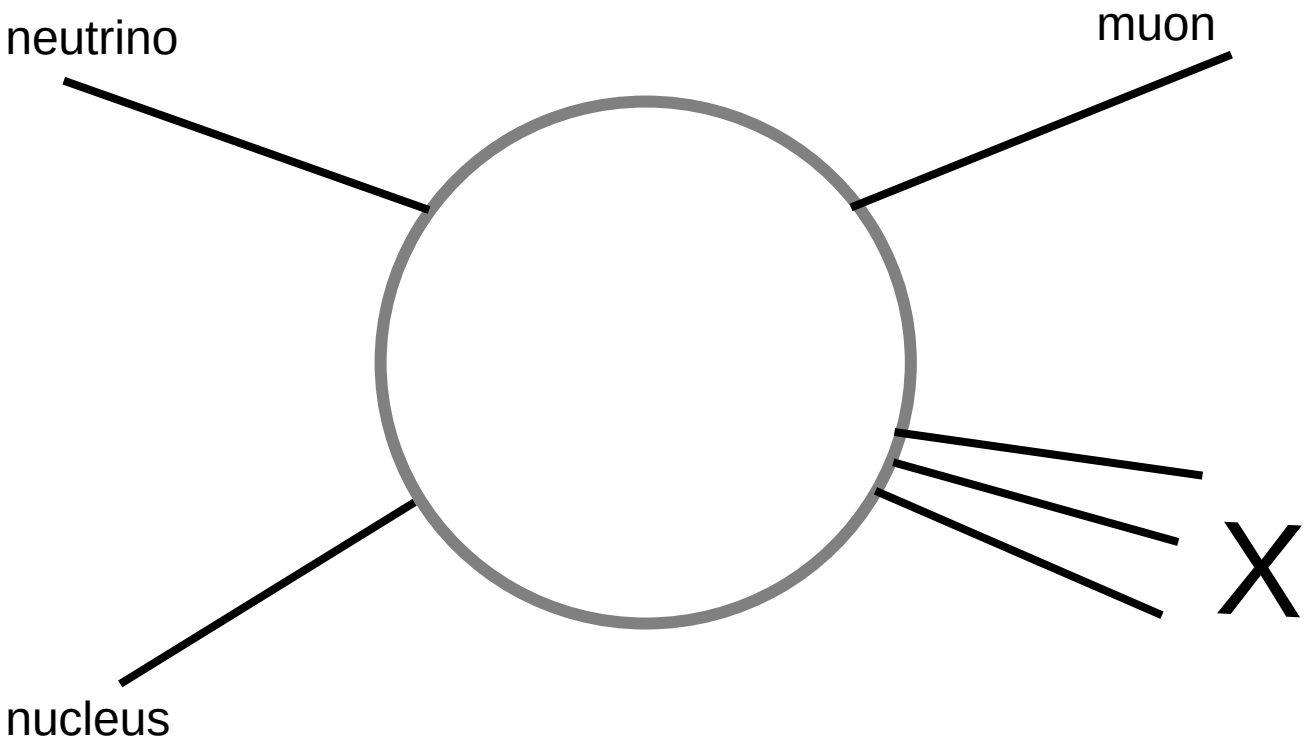
T2K CC0π ν_μ ^{12}C data vs. SuSAv2-MEC$_{GENIE}$

$\chi^2 = 255.8$ (67 bins)



What do we need?

Inclusive cross section?



Inclusive cross section?

Many models are good for the inclusive xs (at typical QE kinematics).

Realistic spectral function model for charged-current quasielastic-like neutrino and antineutrino scattering cross sections on ^{12}C

M. V. Ivanov and A. N. Antonov
Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia 1784, Bulgaria

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Departamento de Física Atómica, Molecular y Nuclear, Universidad de Sevilla, 41080 Sevilla, Spain

M. B. Barbaro
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J. E. Amaro and I. Ruiz Simo
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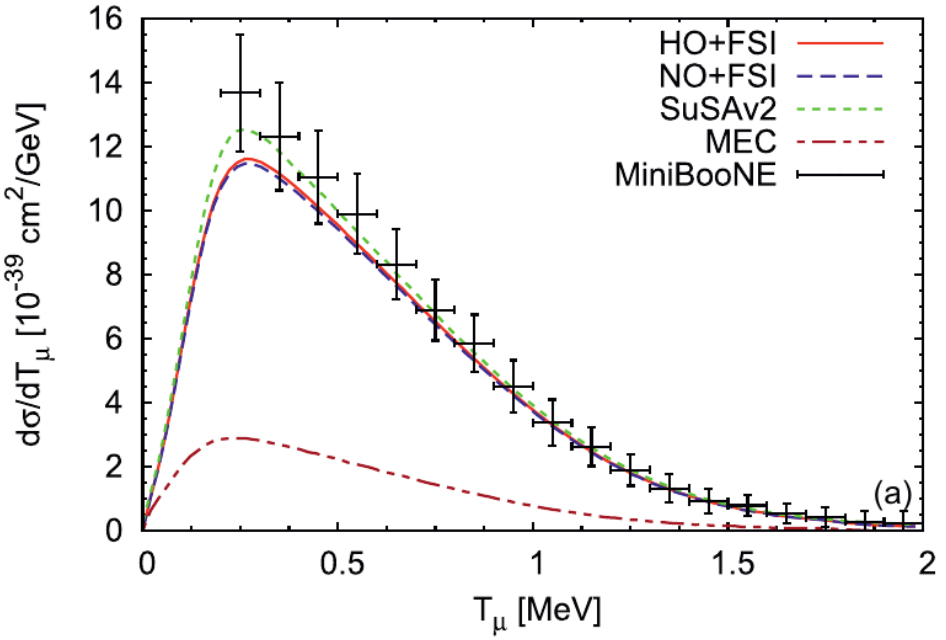
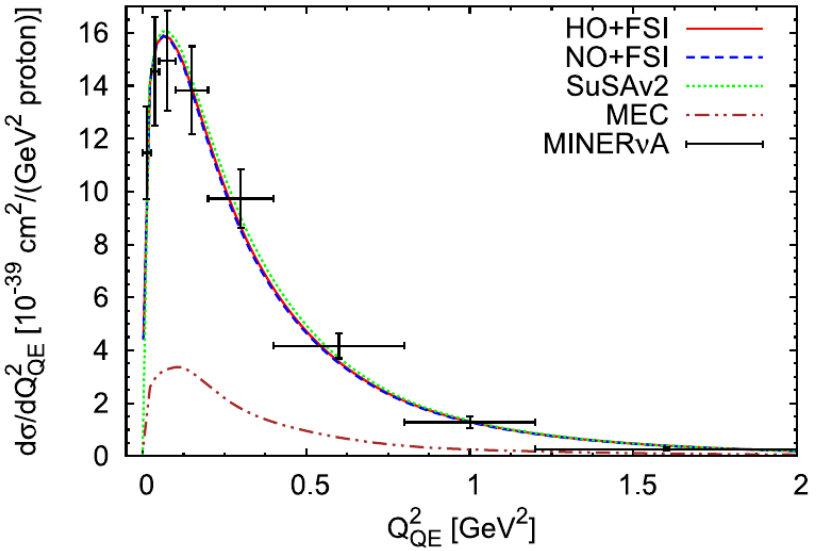
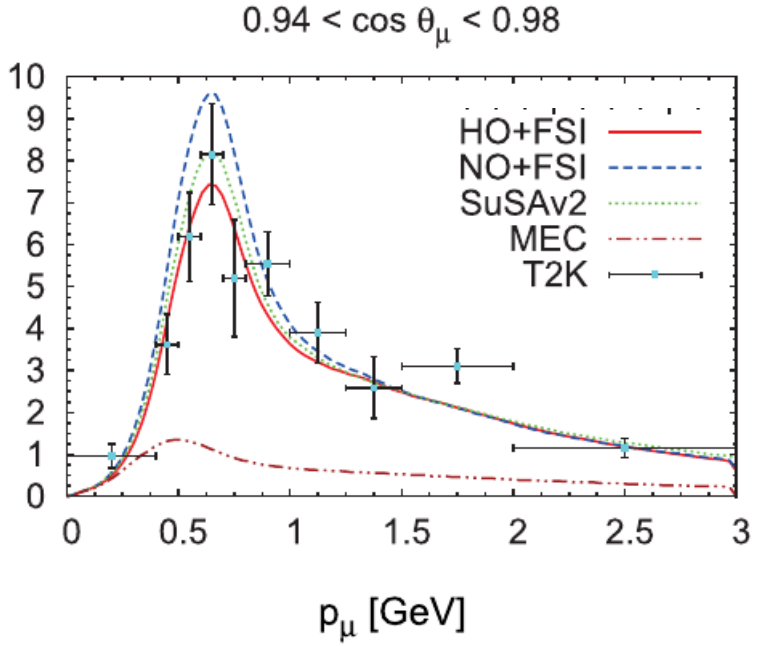
J. M. Udías
Grupo de Física Nuclear, Departamento de Estructura de la Materia, Física Aplicada y Electrónica and UPARCOS, Universidad Complutense de Madrid, CEI Moncloa, 28040 Madrid, Spain


HO+FSI
NO+FSI
SuSAv2
MEC
MiniBooNE
(a)
dσ/dT_μ [10^-39 cm^2/GeV]
T_μ [MeV]


HO+FSI
NO+FSI
SuSAv2
MEC
MINERvA
dσ/dQ²_QE [10^-39 cm^2/(GeV^2 proton)]
Q²_QE [GeV²]


0.94 < cos θ_μ < 0.98
HO+FSI
NO+FSI
SuSAv2
MEC
T2K
p_μ [GeV]

Inclusive cross section?

Many models are good for the inclusive xs (at typical QE kinematics).

SuSAv2+MEC is the state of the art among the inclusive models:

+ Extensively tested against electron and neutrino scattering data: systematically on the data.

+ Fully relativistic.

+ Extremely efficient from computational point of view.

+ For neutrino interactions, it needs to be extended to the DIS region.

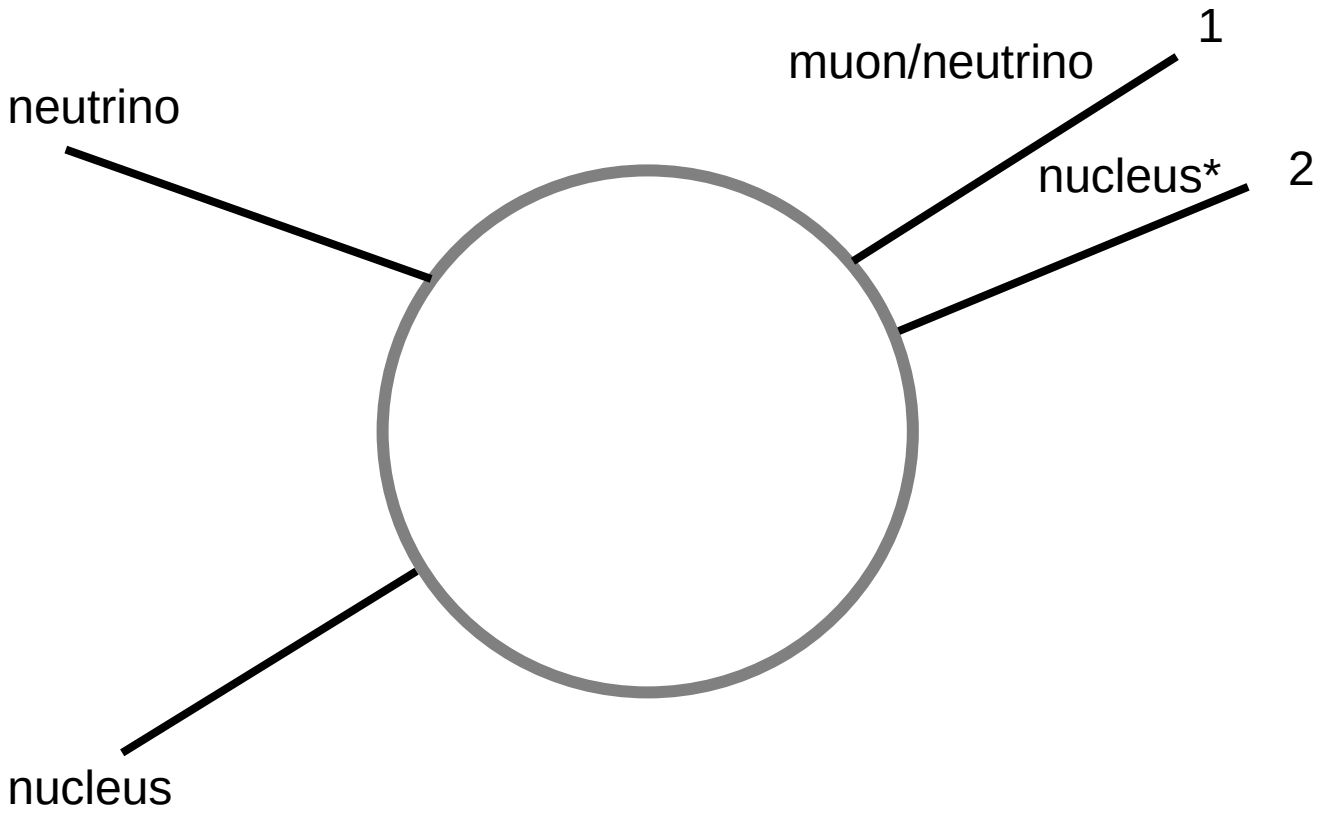
+ Not suppose to work at very low q, but a few things could be done.

What do we need?

Information about the hadrons?

Initial State

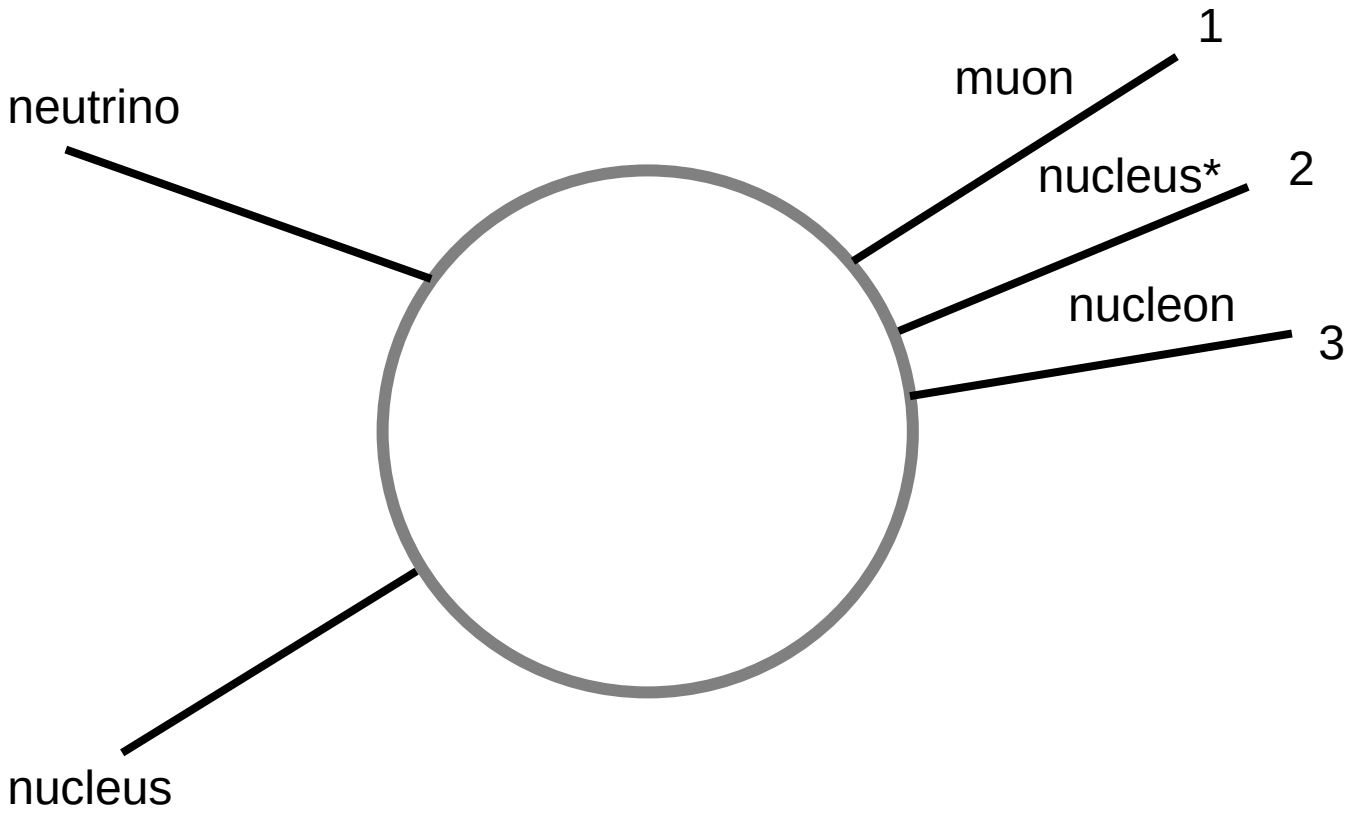
Final State



Elastic scattering
(difficult)

Initial State

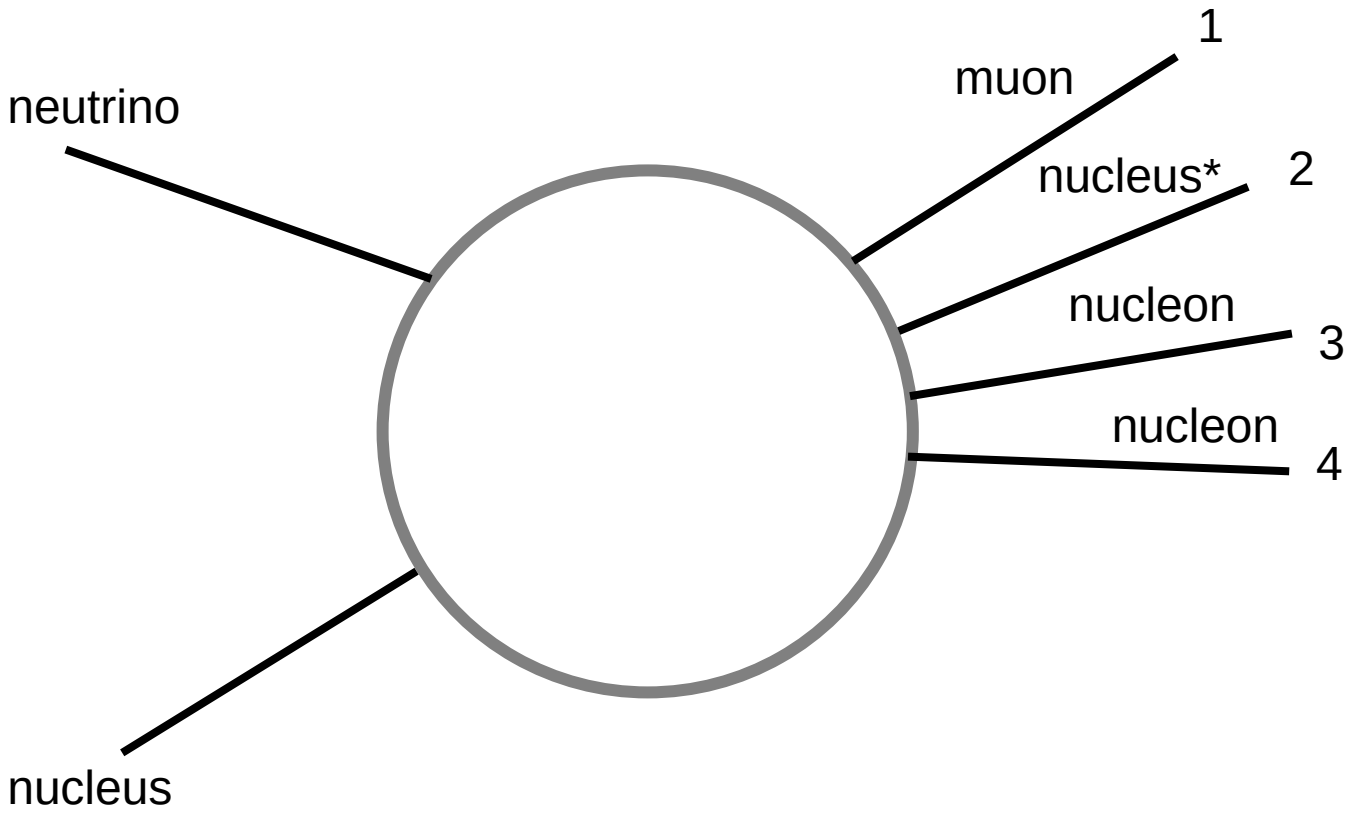
Final State



Quasielastic scattering
(difficult)

Initial State

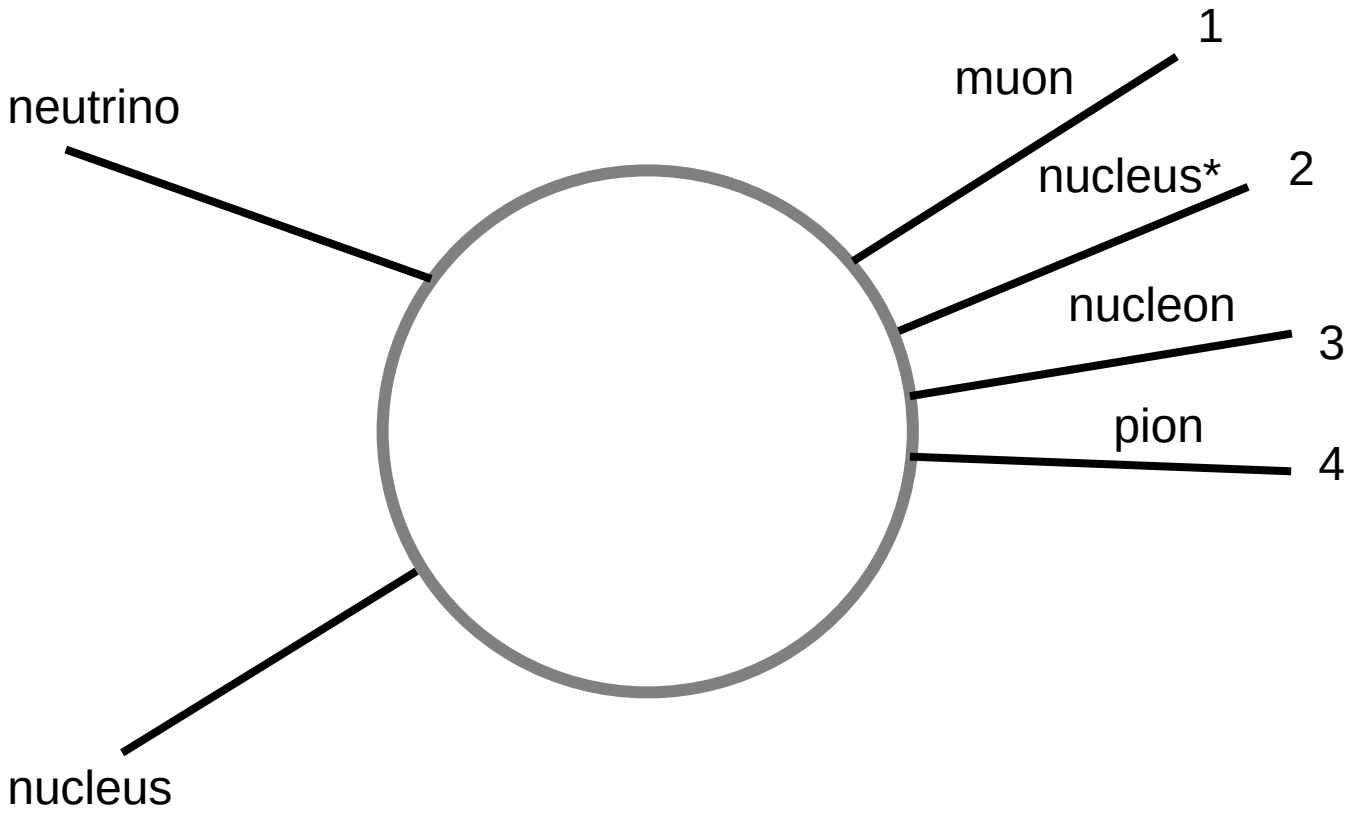
Final State



2N knockout
(extremely difficult)

Initial State

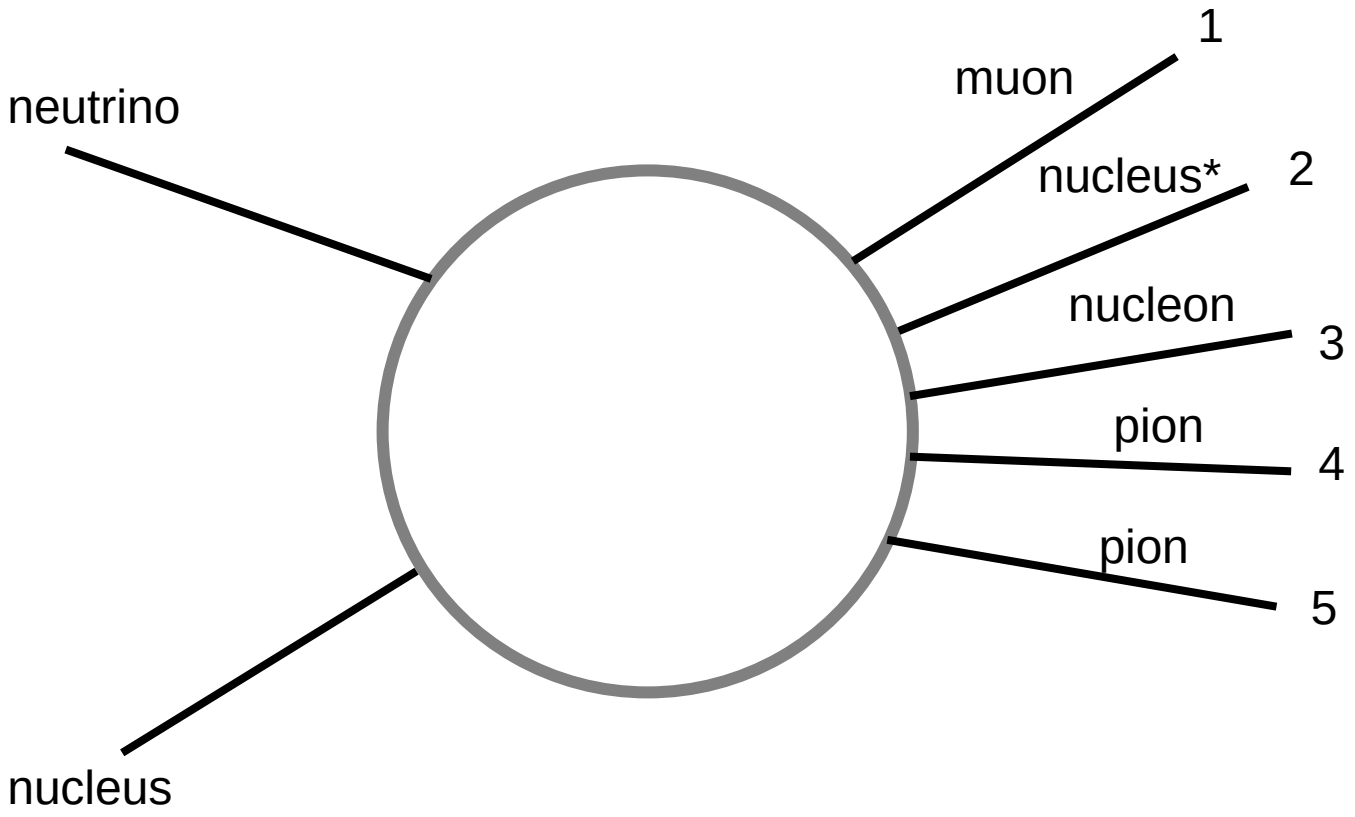
Final State



Single-pion production
(extremely difficult)

Initial State

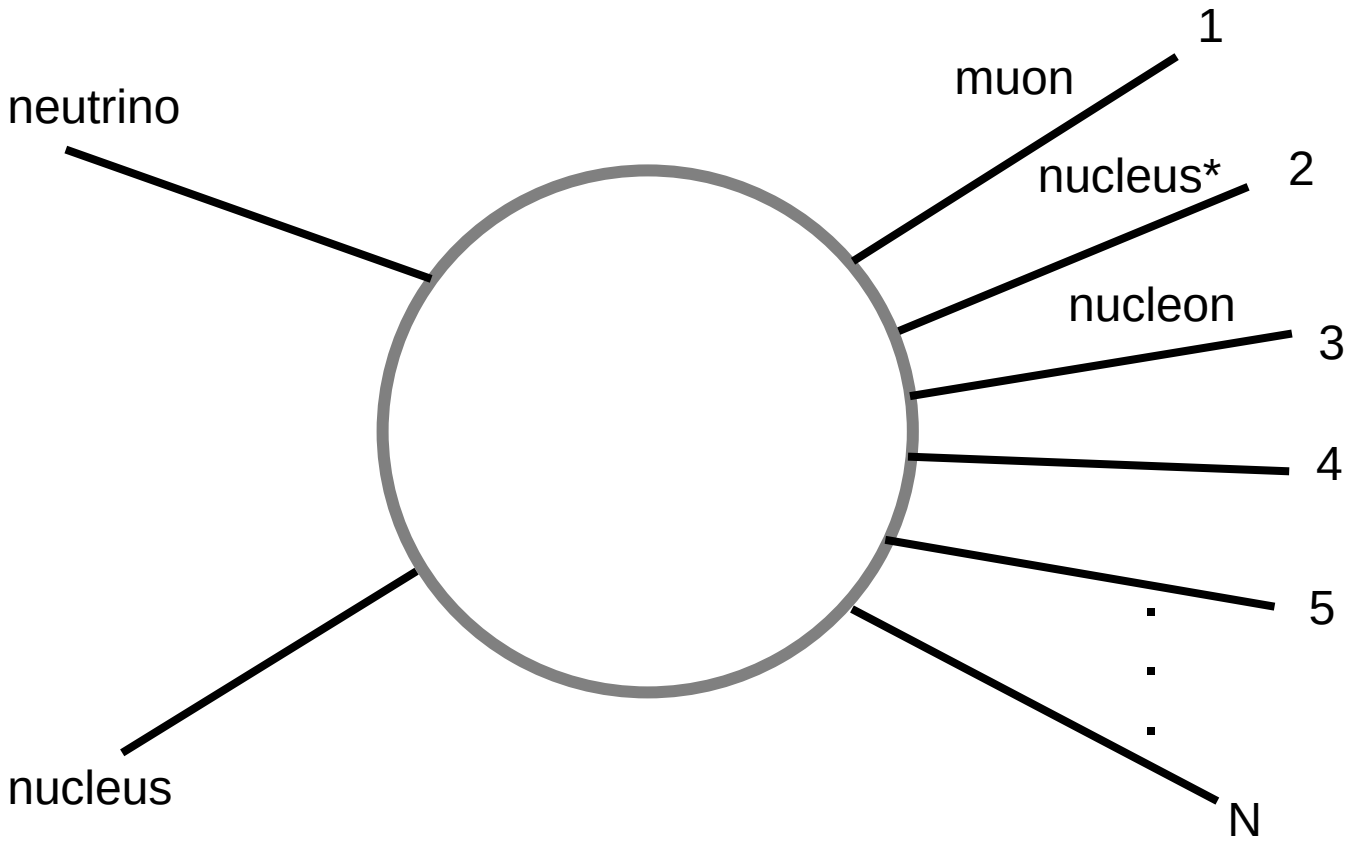
Final State



Two-pion production
(impossible?)

Initial State

Final State



Impossible

Problem:

We are not able to model with accuracy any of the non-inclusive cross sections.

Problem:

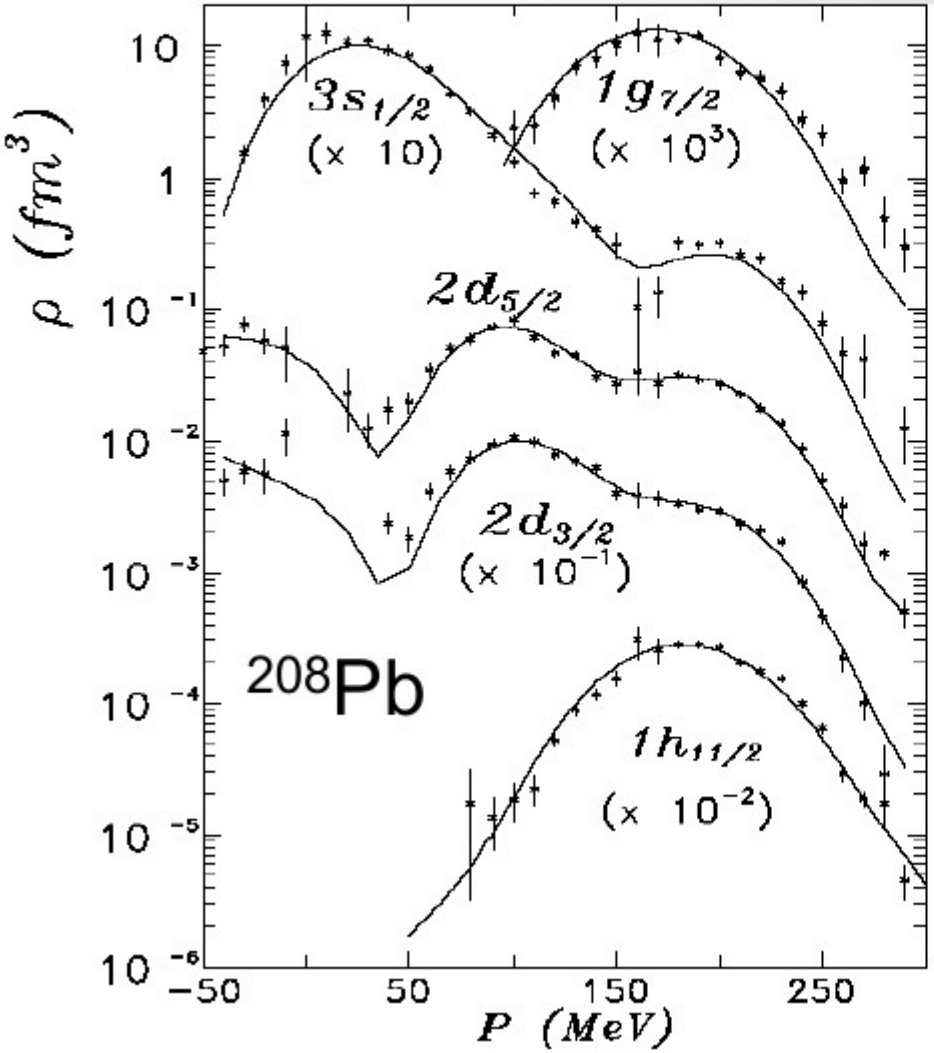
We are not able to model with accuracy any of the non-inclusive cross sections.

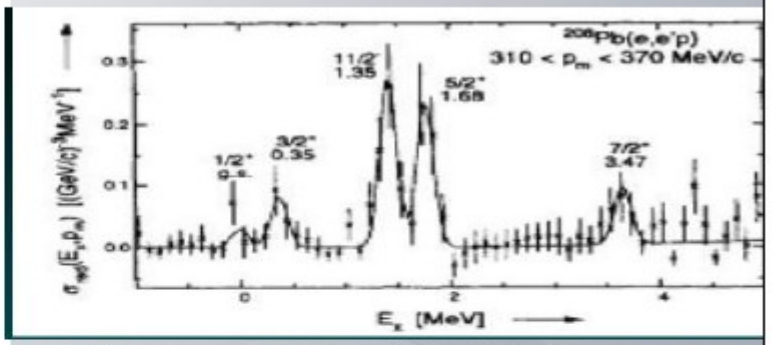
One exception:
Exclusive A(e,e'p)A-1 in a narrow missing energy window (= one nucleon knock out from the outer shells)

Exclusive A(e,e'p)A-1 in a narrow missing energy window (outer shells)

The RMF yields good agreement with exclusive (e,e'p) data

JM Udias et al., PRC48, 2731 (1993), PRC51 3246 (1995)





Reasonably good agreement with data under exclusive kinematics

spectroscopic factors are now a free parameter, fitted to data. RMF tend to imply larger spectroscopic factors.

	$3s_{1/2}$	$2d_{3/2}$	$1h_{11/2}$	$2d_{5/2}$	$1g_{7/2}$
Non rel. (Ref. [41])	50%	53%	42%	44%	19%
Non rel. (Ref. [42])	55%	57%	58%	54%	26%
Rel. (Refs. [40, 6])	70%	72%	64%	60%	30%

Conclusions and Outlook:

+ Modeling all reaction channels with high precision is (and will be) impossible.

+ Actually, we can describe very well only one channel: QE scattering with only one nucleon in the final state and small missing energy left in the residual nucleus, Em<20 MeV.

++ For such events, the **neutrino energy could be reconstructed with few percent accuracy**.
(Van Orden and Donnelly, arXiv:1908.00932)

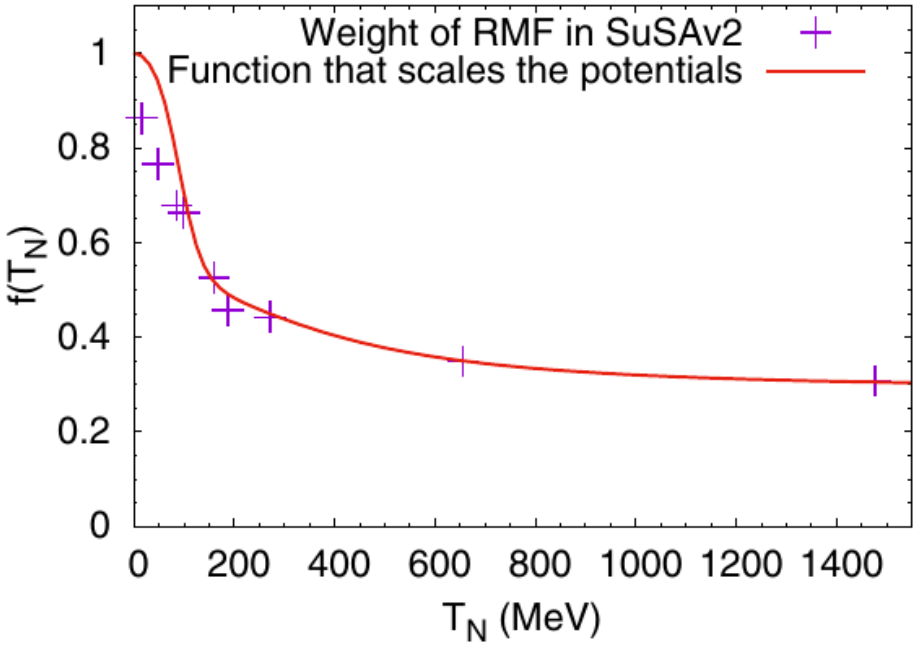
+ We are working on this.

Back up slides

We have presented a **real energy-dependent potential** that can be used in a large energy range:

+ For low energies of the outgoing nucleons it is identical to RMF potential, thus: orthogonality, current conservation and dispersion relations are fulfilled.

+ The phenomenology suggests that for high energies of the outgoing nucleon the potential should become softer.



New energy-dependent potential = RMF potential x f(TN)

Superscaling Approach
Scaling phenomenon - definition

It happens when the inclusive cross section can be written as the product of a *single-nucleon* cross section times a specific function (*scaling function*) that depends on only one variable (*scaling variable*)

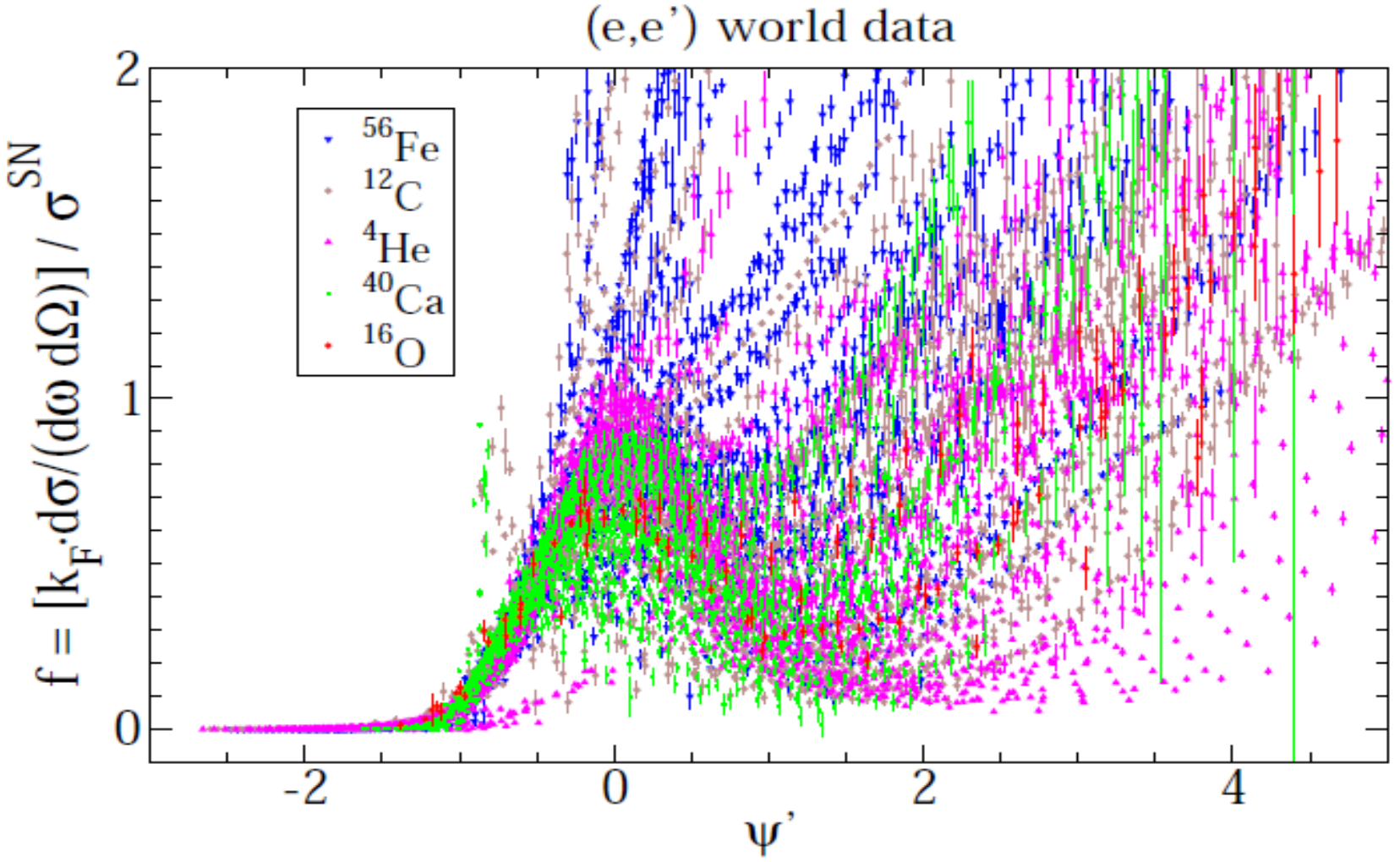
★ $\dfrac{d\sigma^{(ee')}}{d\Omega_e d\omega} = \sigma_{Mott}(v_L R^L + v_T R^T)$, $R^{L,T}$ nuclear responses.

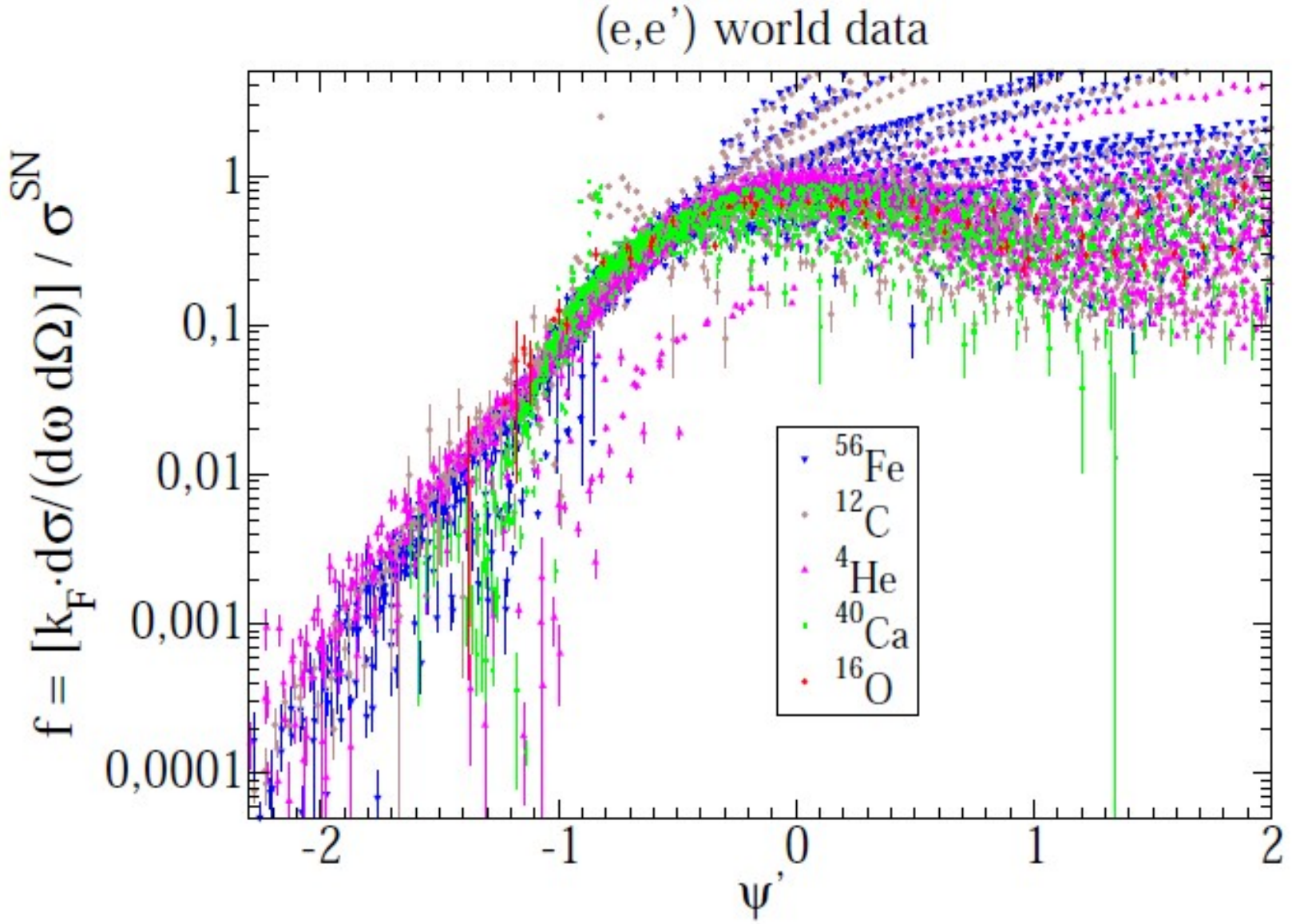
★ $\sigma_{SN} = \sigma_{Mott}(v_L \mathcal{R}^L + v_T \mathcal{R}^T)$, $\mathcal{R}^{L,T}$ single-nucleon responses.

$$\frac{d\sigma^{(ee')}}{d\Omega_e d\omega} / \sigma_{SN} = F(q,\omega) \xrightarrow{q\to\infty} F(\Psi)$$

Most of the models based on IA present scaling at some level.
The scaling function incorporates itself all nuclear information.

Scaling phenomenon




(e,e') world data
f = [k_F·dσ/(dω dΩ)] / σ^SN
1
0,1
0,01
0,001
0,0001
-2
-1
0
1
2
ψ'
56Fe
12C
4He
40Ca
16O

Inclusive $^{12}C(e, e')$ cross sections *PRD 94, 013012 (2016)*