Summary SuSAv2, RMF, MEC, implementation in MC gnerators…

RGJ, UCM

Testing and improving Models of Neutrino Nucleus interactions in Generators, 2-7 June 2019

SuSAv2-MEC model: main features, implementation in generators and further works

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DPhP, CEA-Irfu, University of Paris-Saclay

Testing and Improving Models of Neutrino Nucleus Interactions in Generators, Plenary sessions, ECT, 3 June 2019*

Relativistic mean field approach to lepton-nucleon scattering

J.M. Udías
Grupo de Física Nuclear, IPARCOS
Universidad Complutense de Madrid

Implementation of exclusive models in NuWro

Kajetan Niewczas

2p2h for e and ν (inclusive) and Δ propagator

Model implementation with hadron tensors and tests of "factorisable interfaces"

Stephen Dolan
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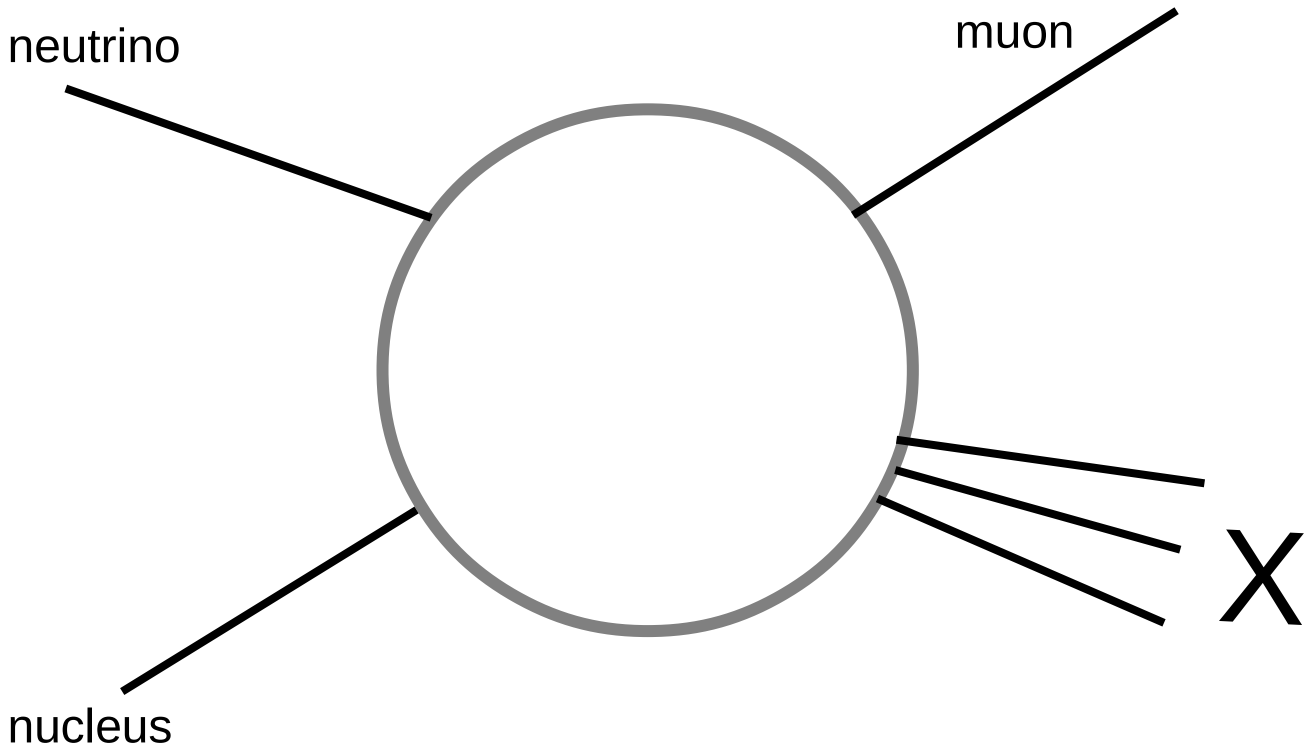
Mean field models

Alexis Nikolakopoulos
Ghent University

Testing and improving models of neutrino nucleus interactions in generators, ECT*, Trento, Italy, 2-7 June, 2019

What do MC neutrino event generators need?

Inclusive cross section?



SuSAv2-MEC model: main features, implementation in generators and further works

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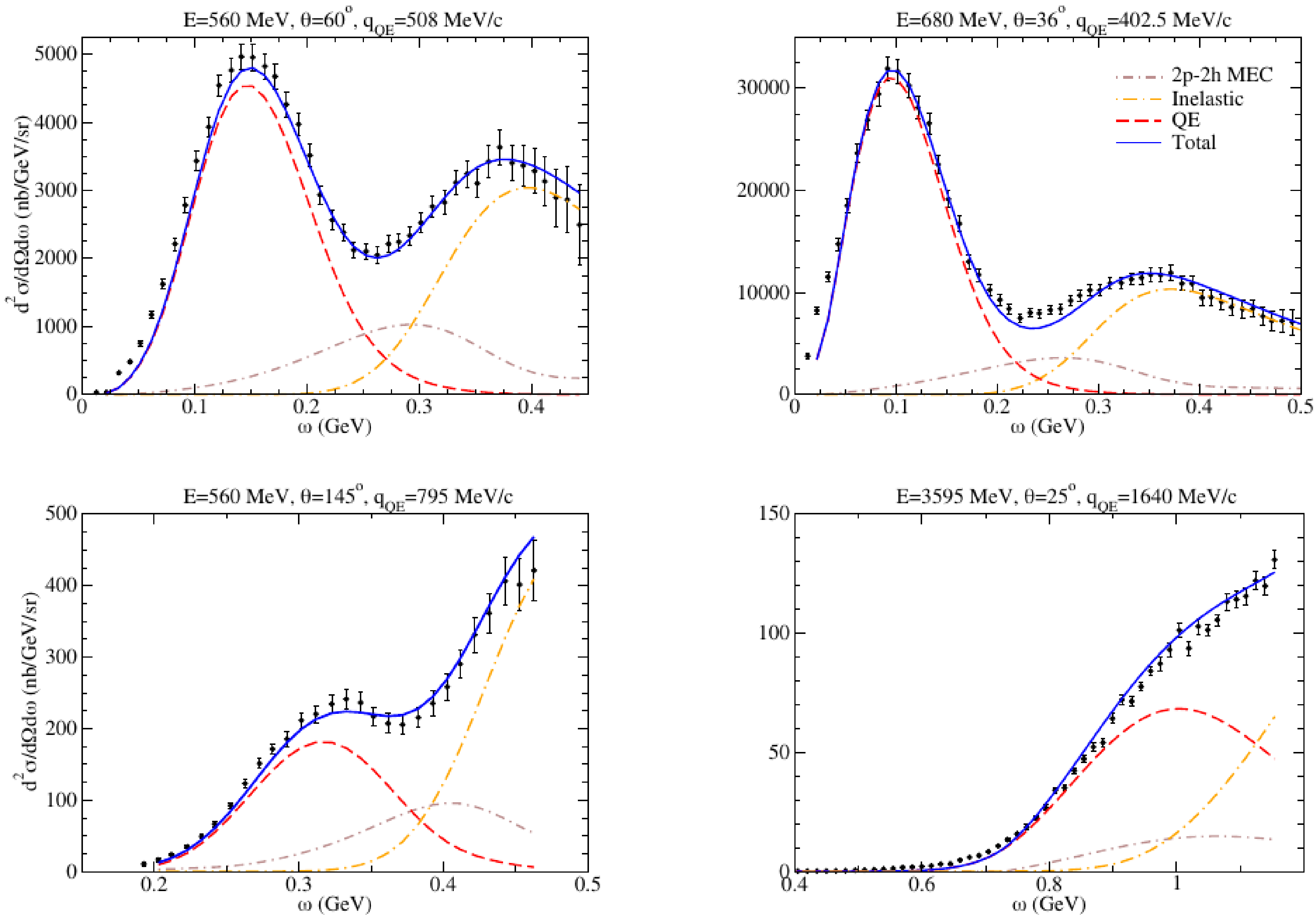
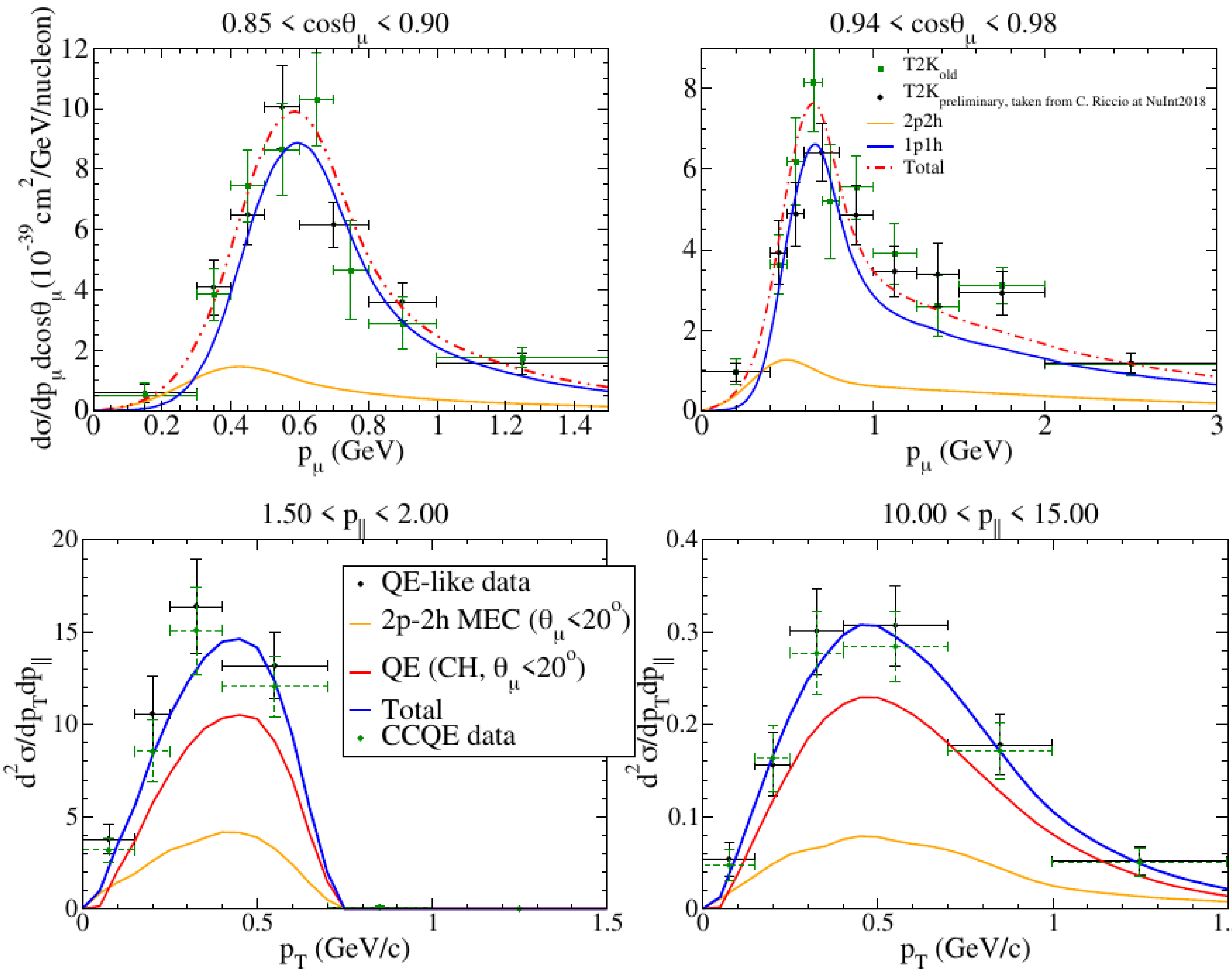
Inclusive $^{12}C(e,e')$ cross sections *PRD 94, 013012 (2016)*



Comparison with CC0π data

T2K CC0π $\nu_\mu - C_8H_8$

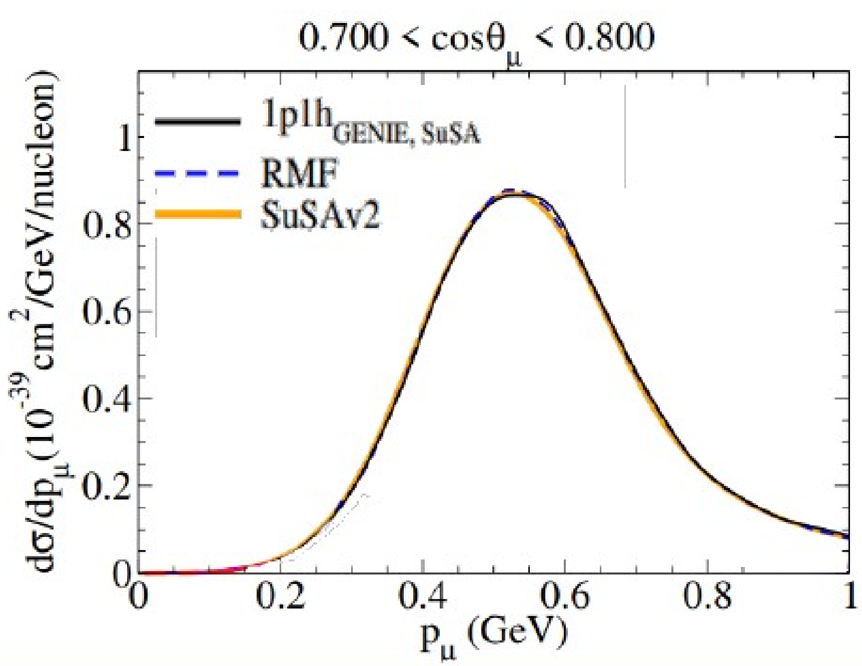
MINERνA $\bar{\nu}_\mu$-CH

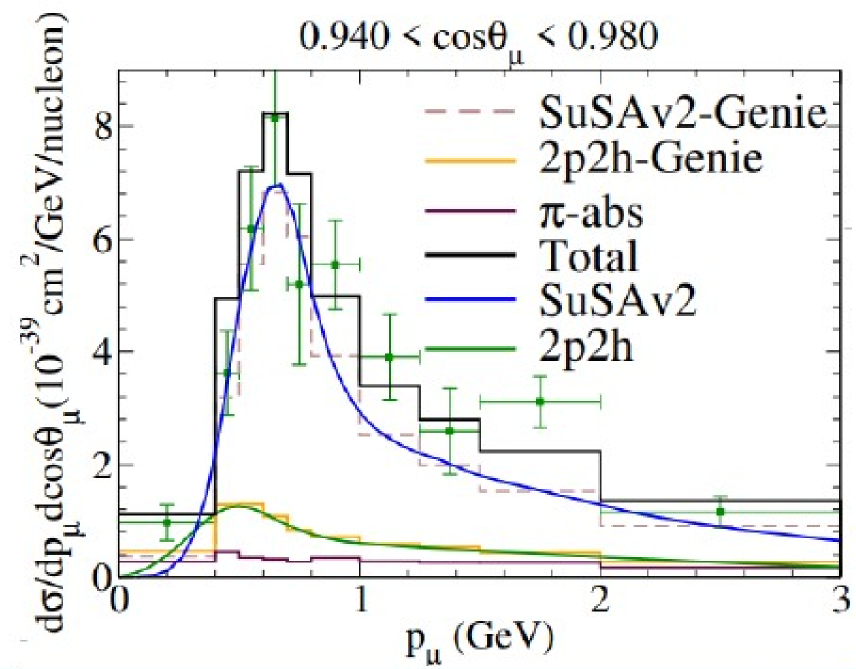


Overview

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

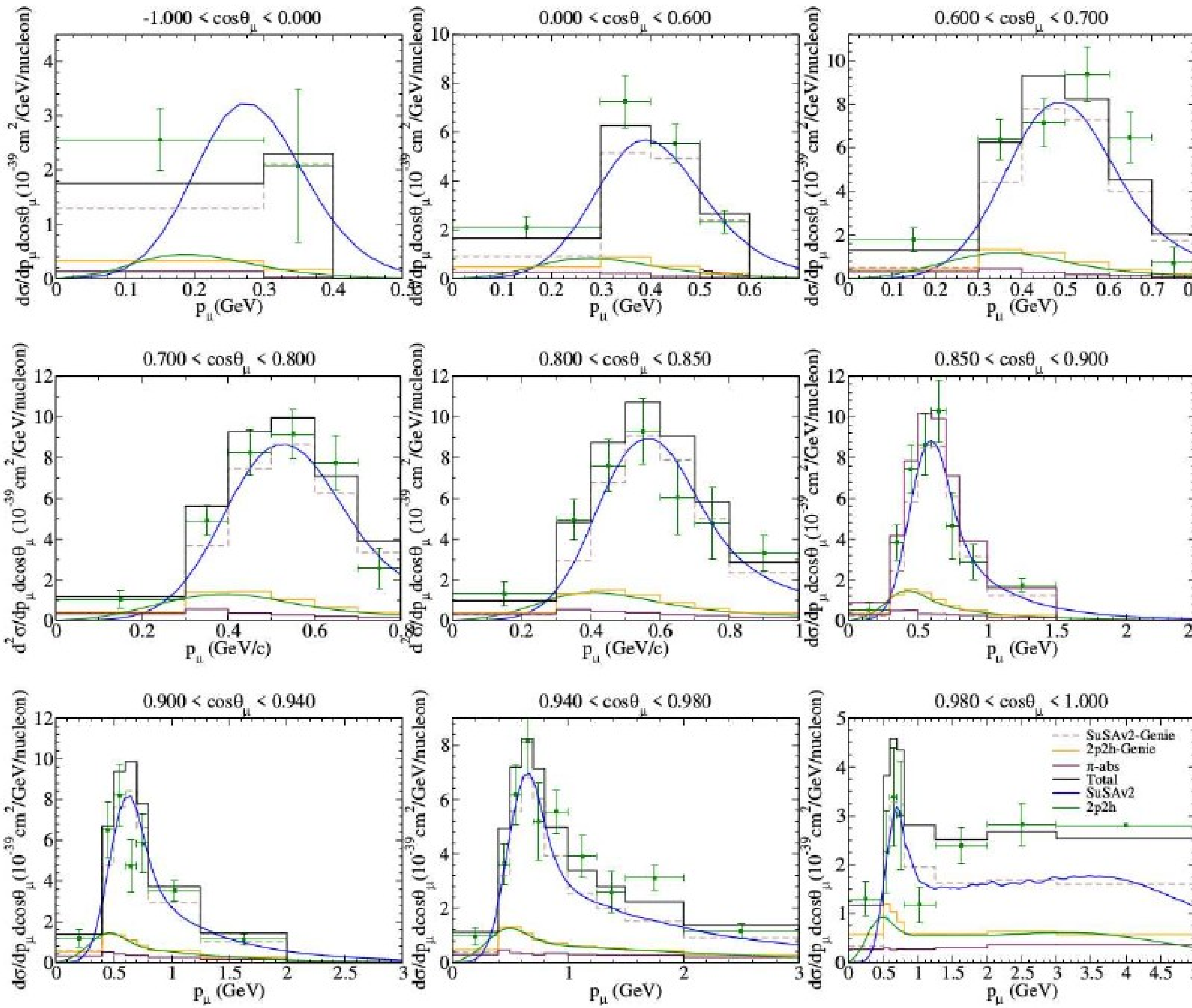




SuSAv2-MEC implementation in GENIE: Validation plots (T2K CC0π)

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

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

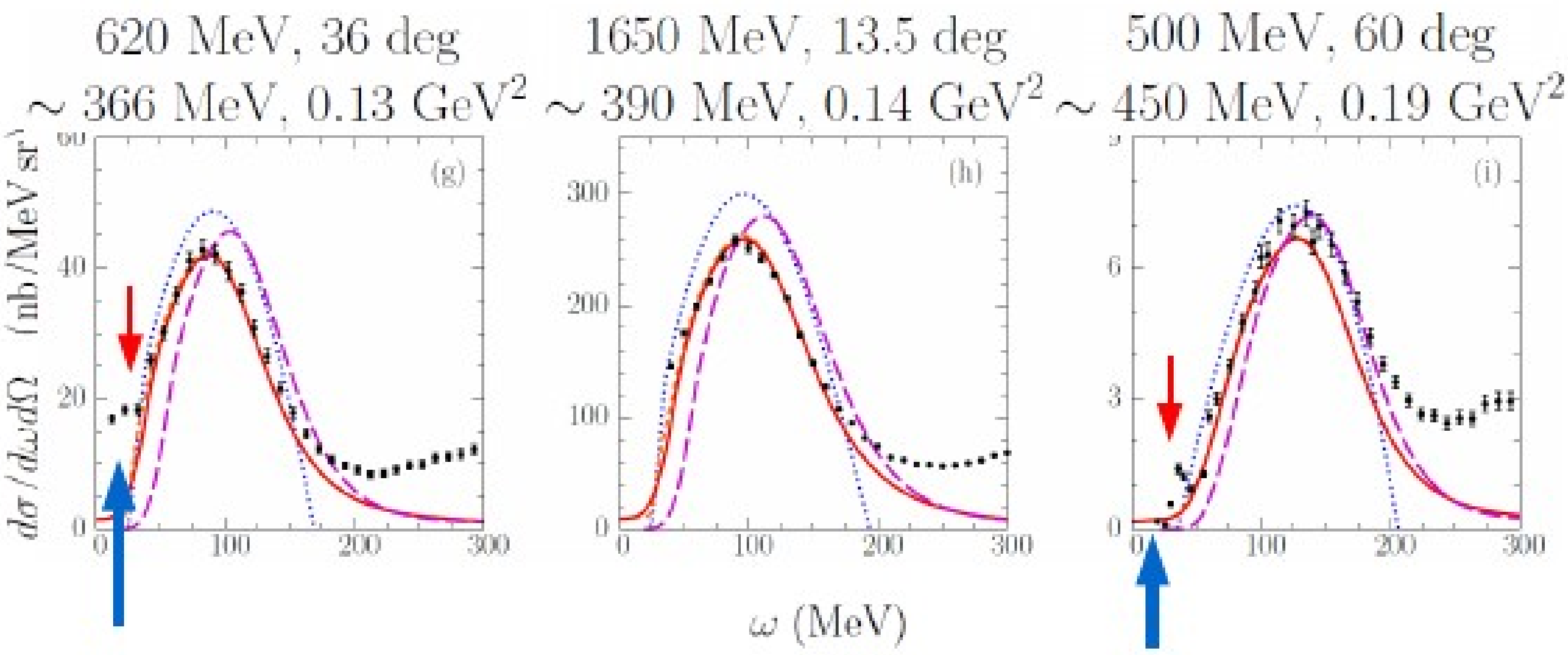


Introduction to the spectral function approach

Artur M. Ankowski
SLAC, Stanford University

Testing and Improving Models
of Neutrino-Nucleus Interactions in Generators
ECT*, Trento, June 3−7, 2019

Comparisons to C(*e*,*e'*) data



Barreau *et al.*,
NPA 402, 515 (1983)

Baran *et al.*,
PRL 61, 400 (1988)

Whitney *et al.*,
PRC 9, 2230 (1974)

Contribution from 2p2h to the inclusive cross section
Meson-Exchanged Currents (MEC)

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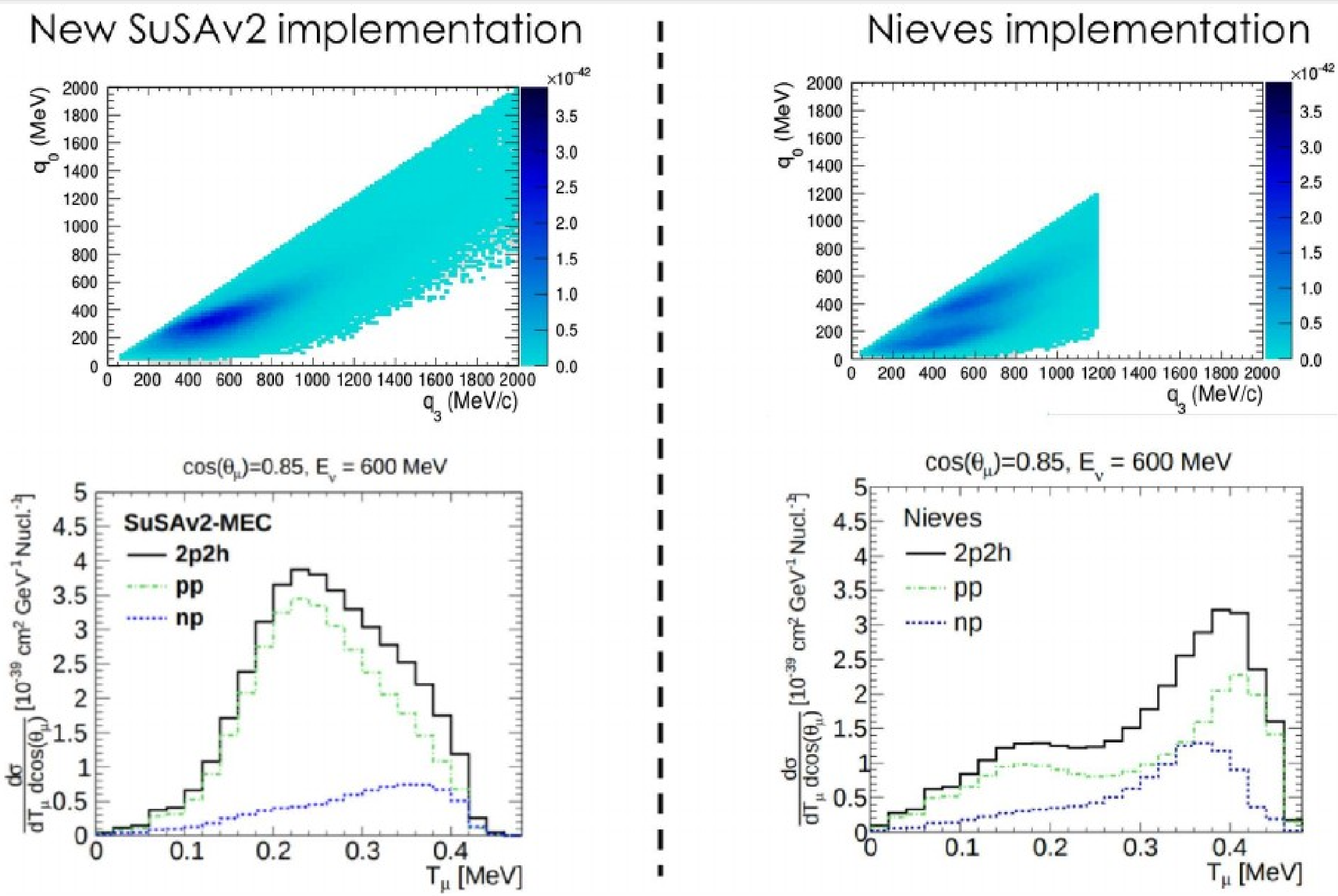
Meson-Exchanged Currents (MEC)

Comparison of SuSAv2-MEC^{Genie} with Nieves^{Genie} 2p2h *arXiv:1905.085*



Differences in np/pp separation are mostly related to the treatment of 2p2h direct/exchange interference terms (absent in Nieves model) $\rightarrow$ strongly affects np/pp ratio by a factor $\sim$ 2 (PRC94:054610,2016) $\Rightarrow$ Implications in nucleon multiplicity and hadron E_{reco}

Real part or full propagator of the delta?

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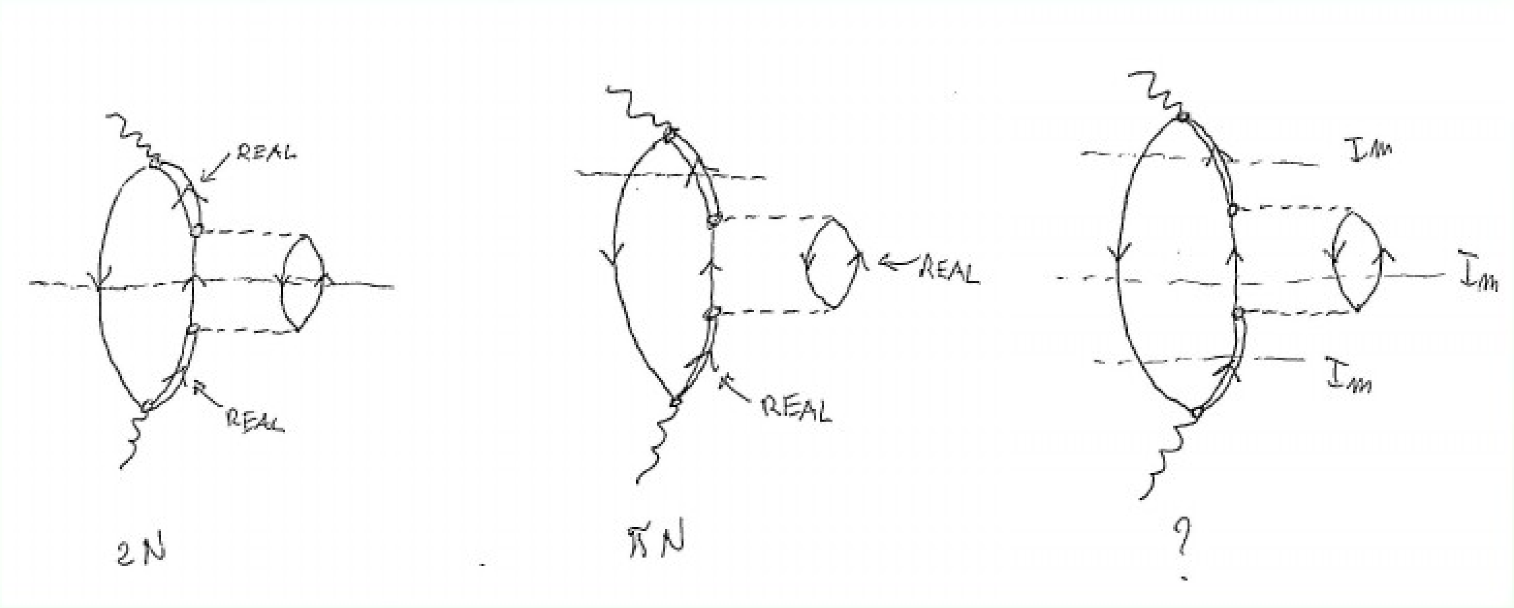
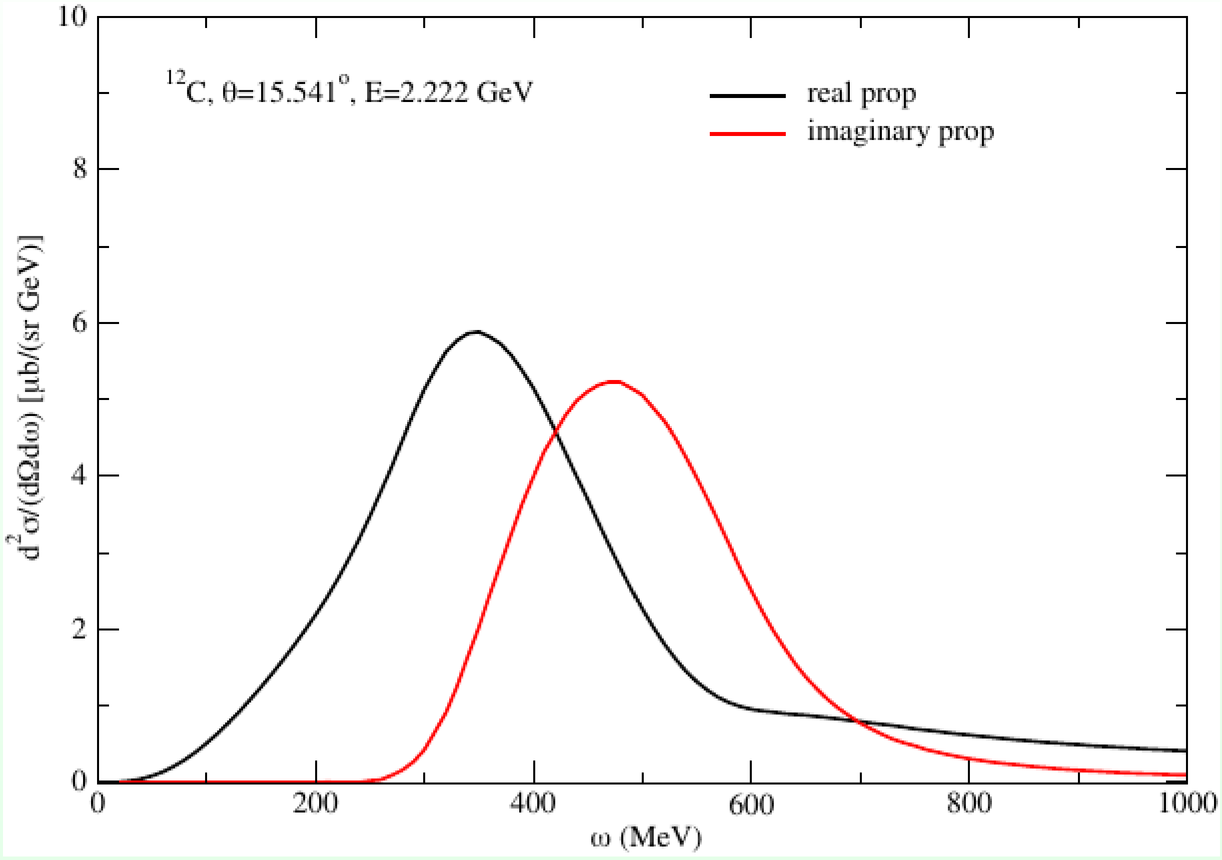


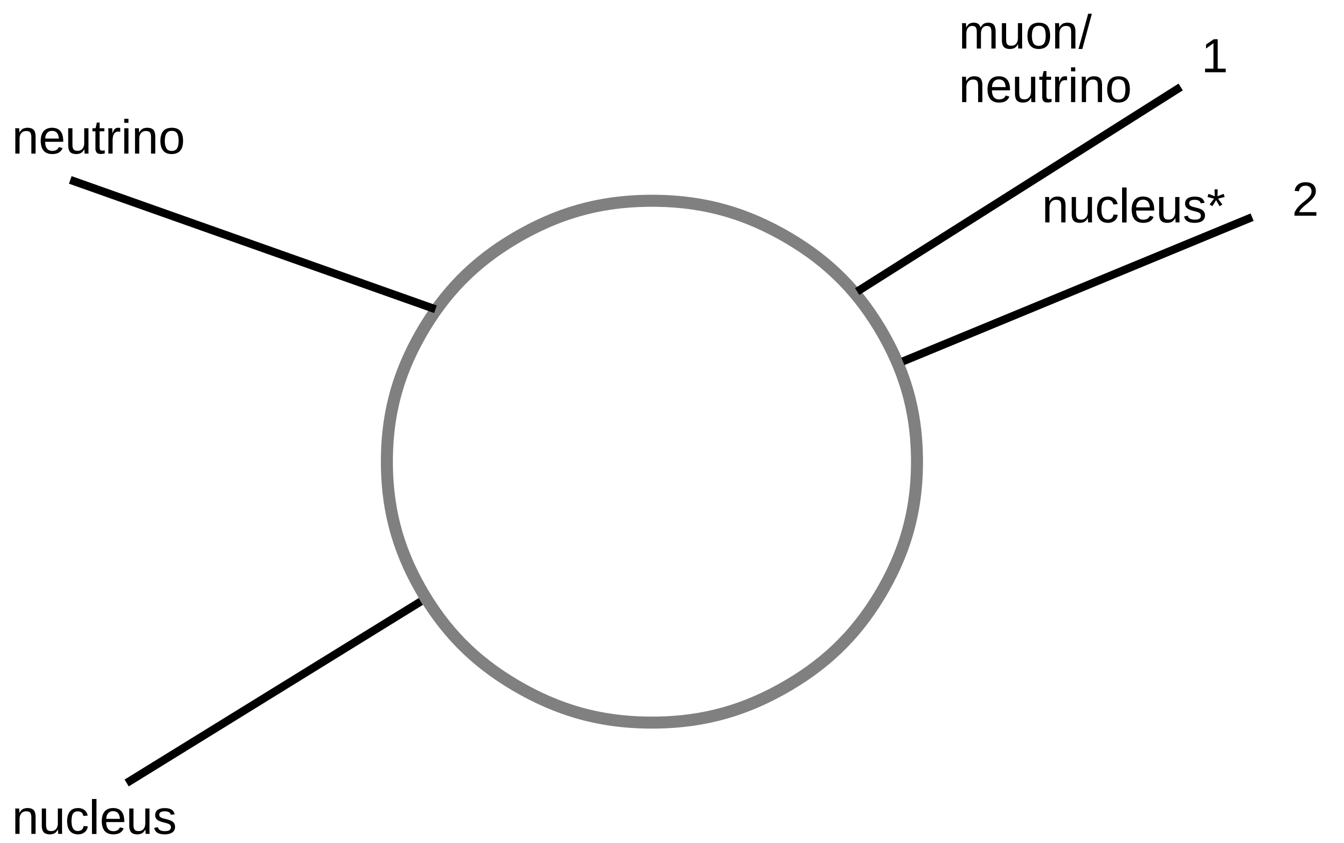
Real part or full propagator of the delta?



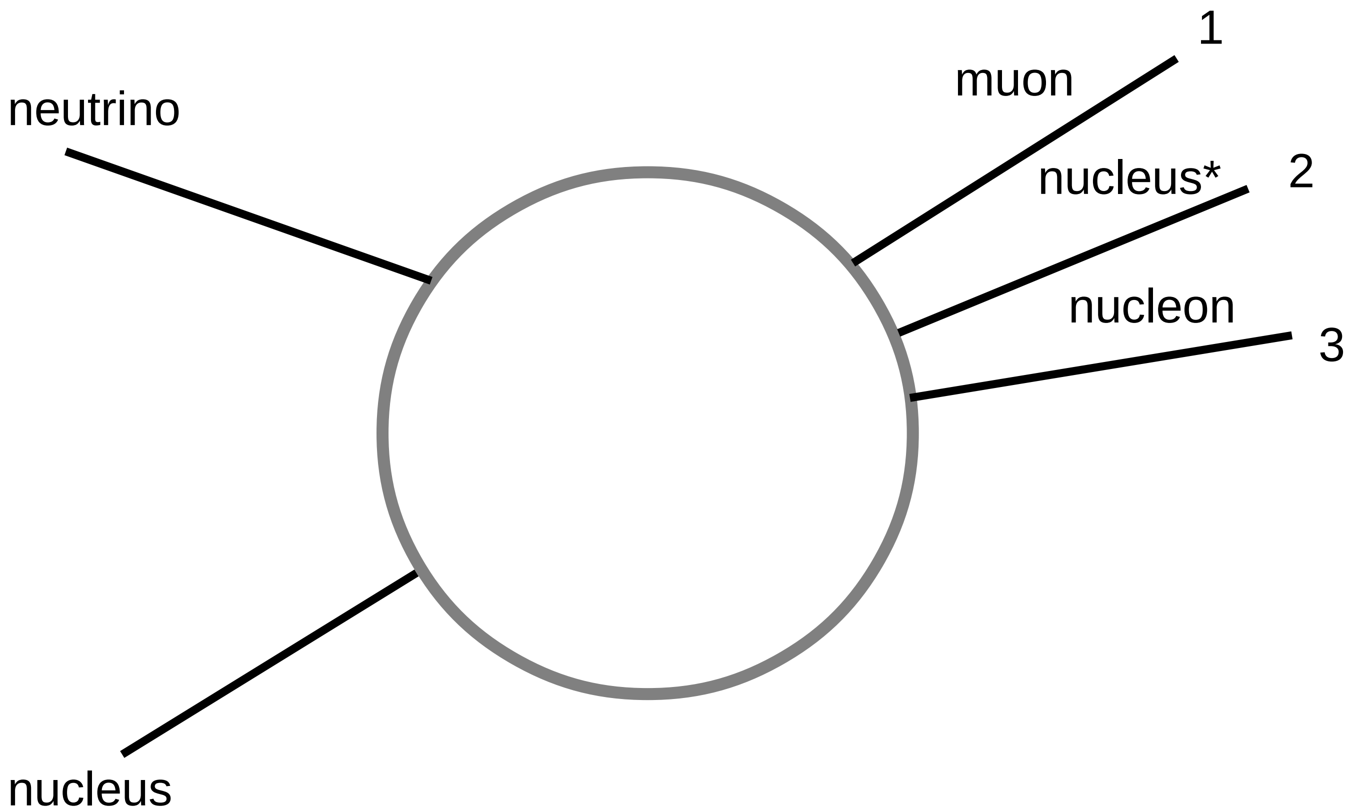
Real part or full propagator of the delta?

What do MC neutrino event generators need?

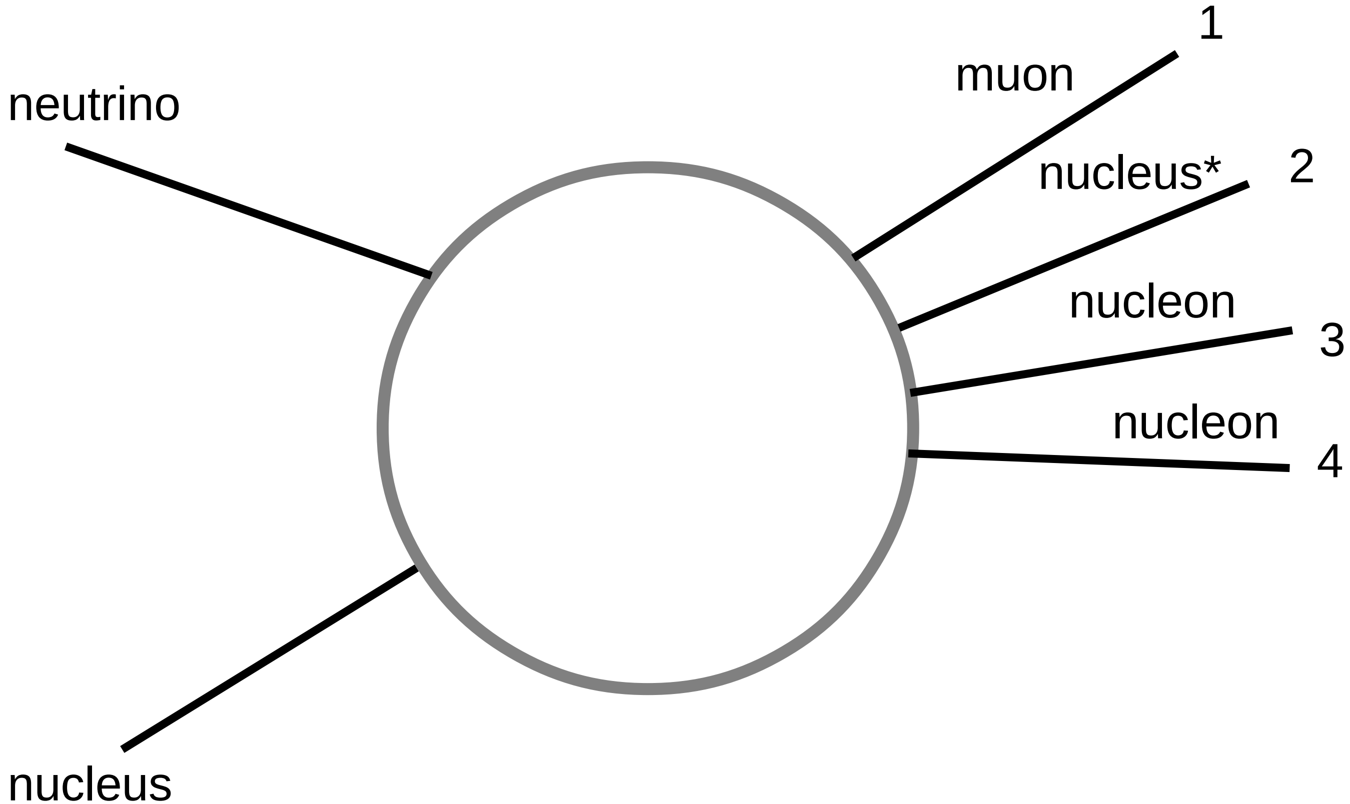
Information about the hadrons?



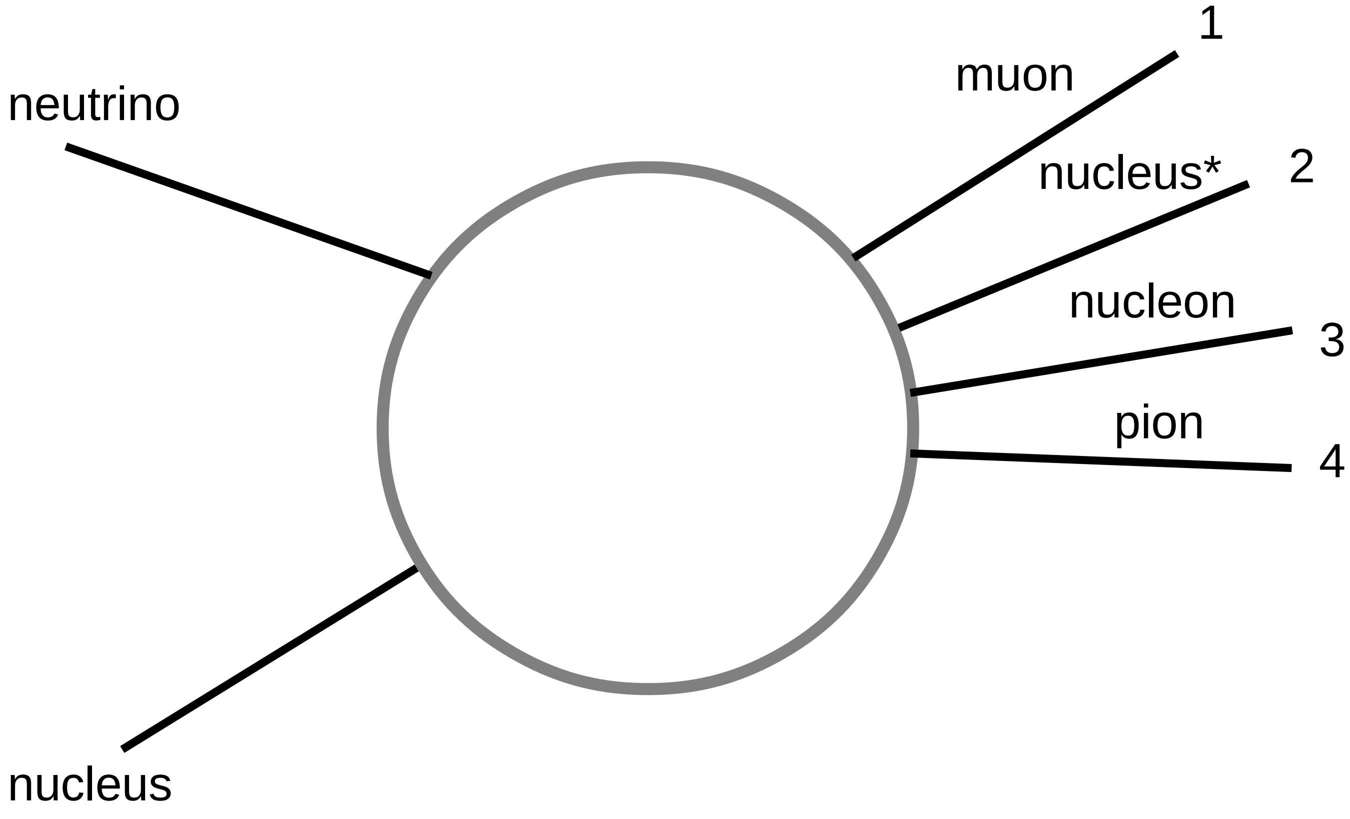
Elastic scattering
(difficult)



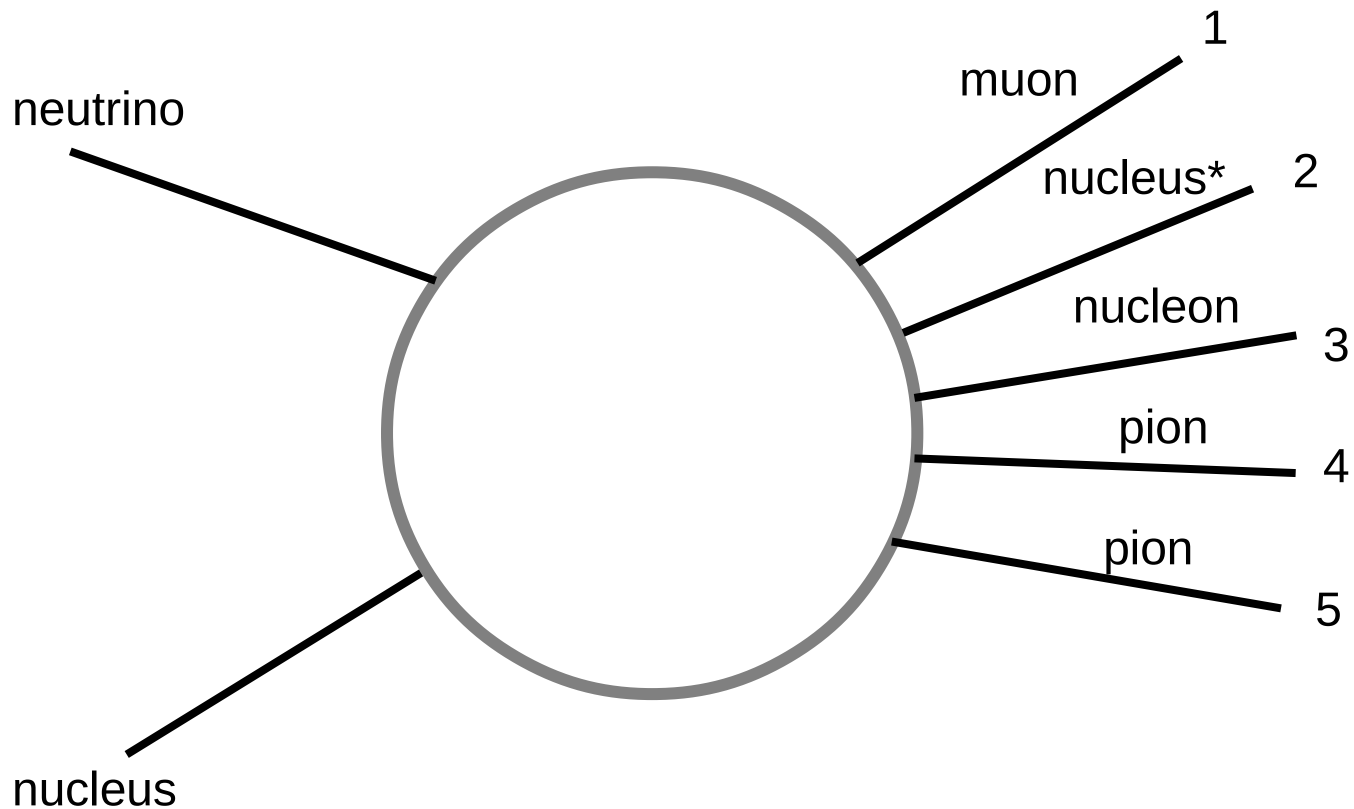
Quasielastic scattering
(difficult)



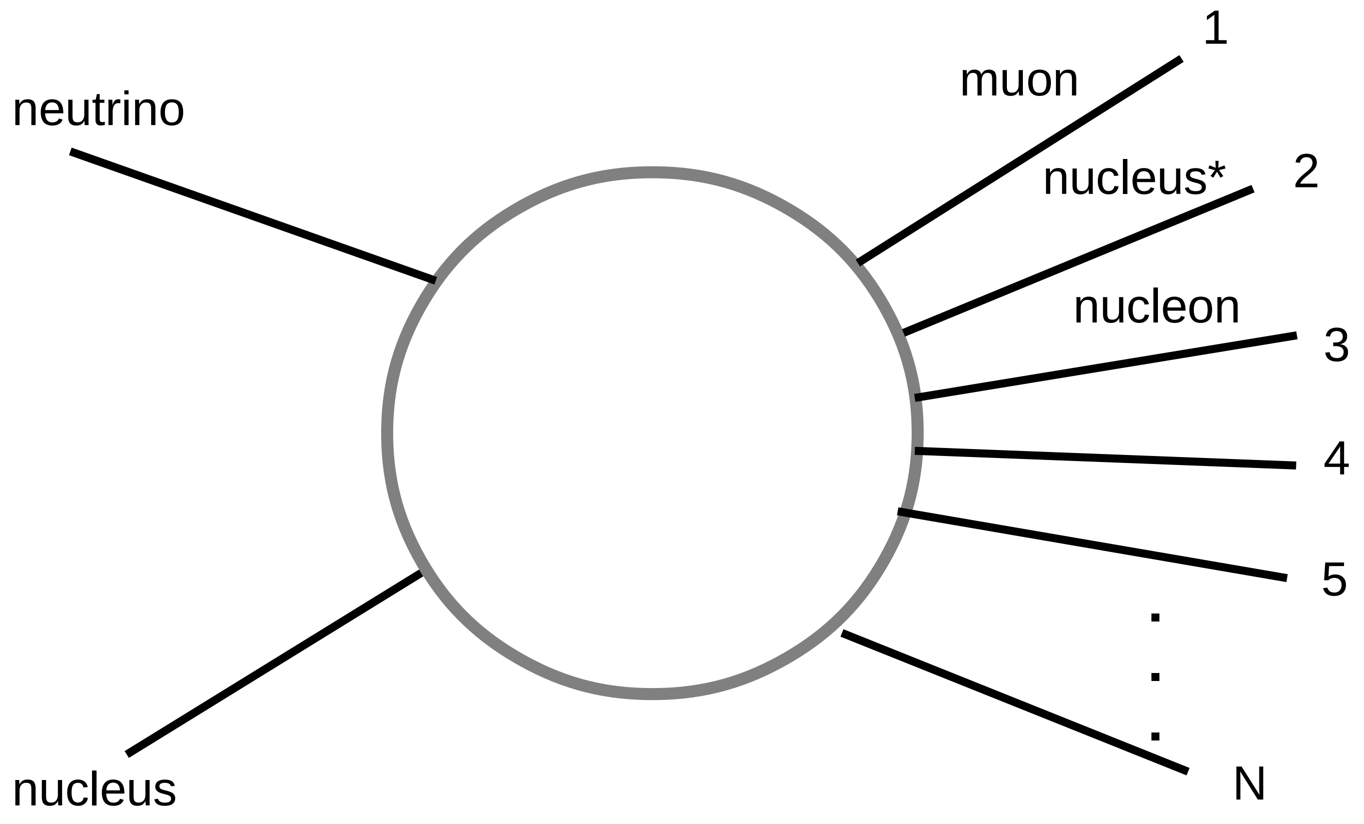
2N knockout
(very difficult)



Single pion production
(very difficult)



Two pion production
(impossible?)



Impossible

How do generators predict hadron kinematics? (Much more detail tomorrow)

- Start with the **inclusive** prediction
- Pick random initial-state nucleon momentum and binding energy based on some spectral function
- Conserve energy / momentum at the vertex to predict hadron kinematics (under impulse approximation)
- Add an FSI cascade to deal with all the stuff that we missed out

This is not the same as **this**

$$\int \frac{d\sigma_{CCQE}}{dp_\mu d\theta_\mu dp_p d\theta_p d\theta_{\mu p}}$$

(They do it differently in NuWro, at least for the Spectral Function approach)

Factorization of the cross section in the **absence of FSI**:

Algorithm $$\frac{\mathrm{d}^6\sigma^{\mathrm{PWIA}}}{\mathrm{d}\omega\mathrm{d}|\mathbf{q}|\mathrm{d}E_m\mathrm{d}\mathbf{p}_m} = \frac{G_F^2\cos^2\theta_C|\mathbf{q}|}{4\pi E_{\mathbf{k}}^2 E_{\mathbf{p}} E_{\mathbf{p}'}} P_{(n)}(E_m,\mathbf{p}_m) L_{\mu\nu}\widetilde{H}^{\mu\nu}\delta(\omega + M - E_m - E_{\mathbf{p}'})$$

Spectral function formalism yields:

$$\sigma^{\mathrm{PWIA}} = \int_V \frac{\mathrm{d}^6\sigma^{\mathrm{PWIA}}}{\mathrm{d}\omega\mathrm{d}|\mathbf{q}|\mathrm{d}E_m\mathrm{d}\mathbf{p}_m}[\mathrm{d}\omega\mathrm{d}|\mathbf{q}|\mathrm{d}E_m\mathrm{d}\mathbf{p}_m]$$

In **NuWro**, the **invariant variables** are: Ω_μ^*, E_m, $\mathbf{p}_m$.

Additionally, E_m, p_m are **sampled** from the **spectral function**.

Therefore, **NuWro calculates**

$$\sigma^{\mathrm{PWIA}} = \int_V \frac{\mathrm{d}^6\sigma^{\mathrm{PWIA}}}{\mathrm{d}\omega\mathrm{d}|\mathbf{q}|\mathrm{d}E_m\mathrm{d}\mathbf{p}_m}\frac{1}{S(E_m,|\mathbf{p}_m|)}[\mathrm{d}\Omega_\mu^* S(E_m,|\mathbf{p}_m|)\mathrm{d}E_m\mathrm{d}\mathbf{p}_m]$$

What is the best **seed** for a Cascade?

Condition:
Good inclusive cross section.

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We are not able to model with accuracy any of the non-inclusive reaction channels.

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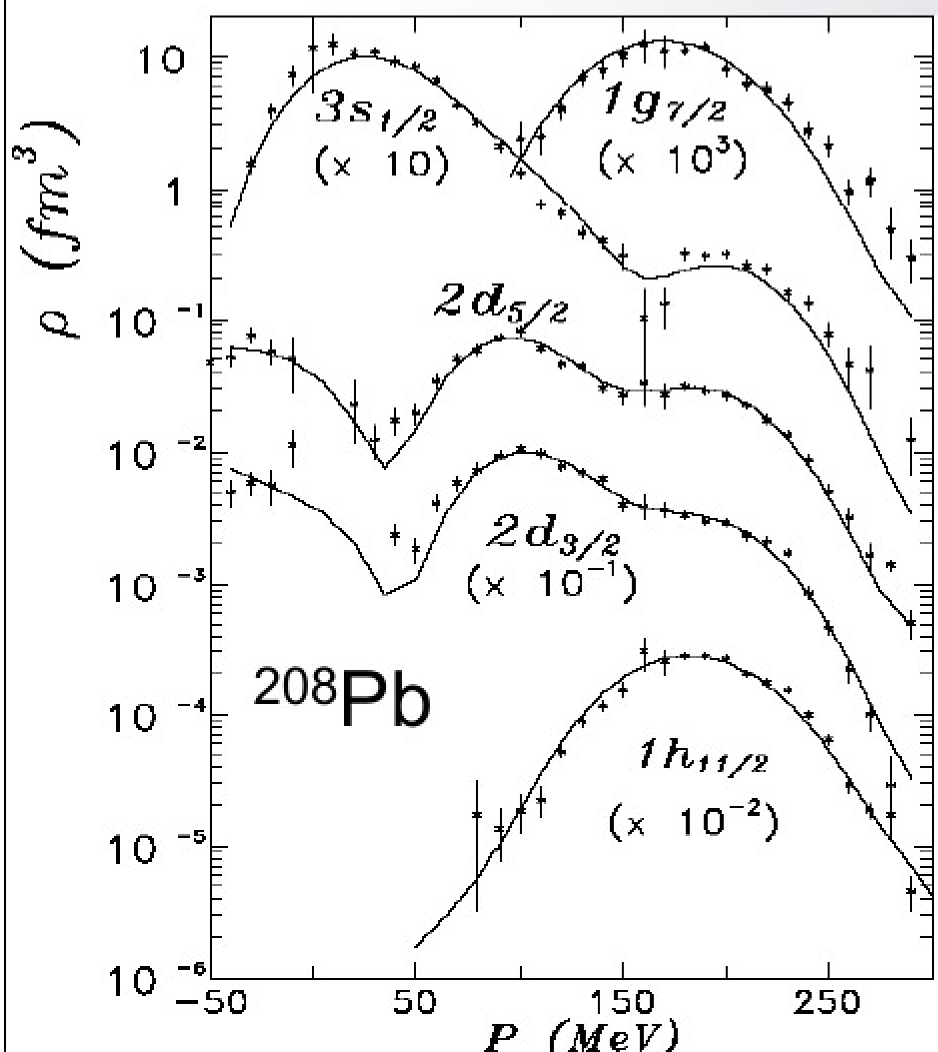
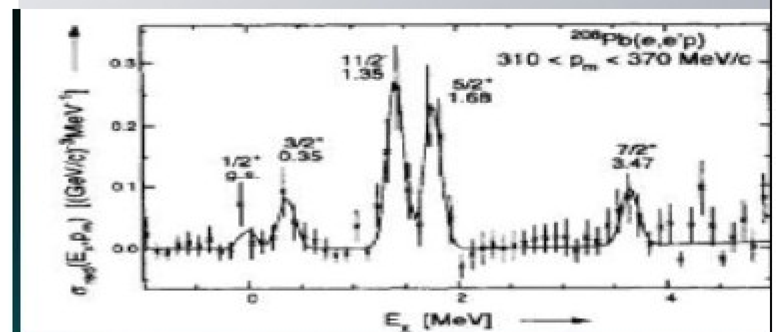
One exception: **Exclusive** A(e,e’p)A-1

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

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



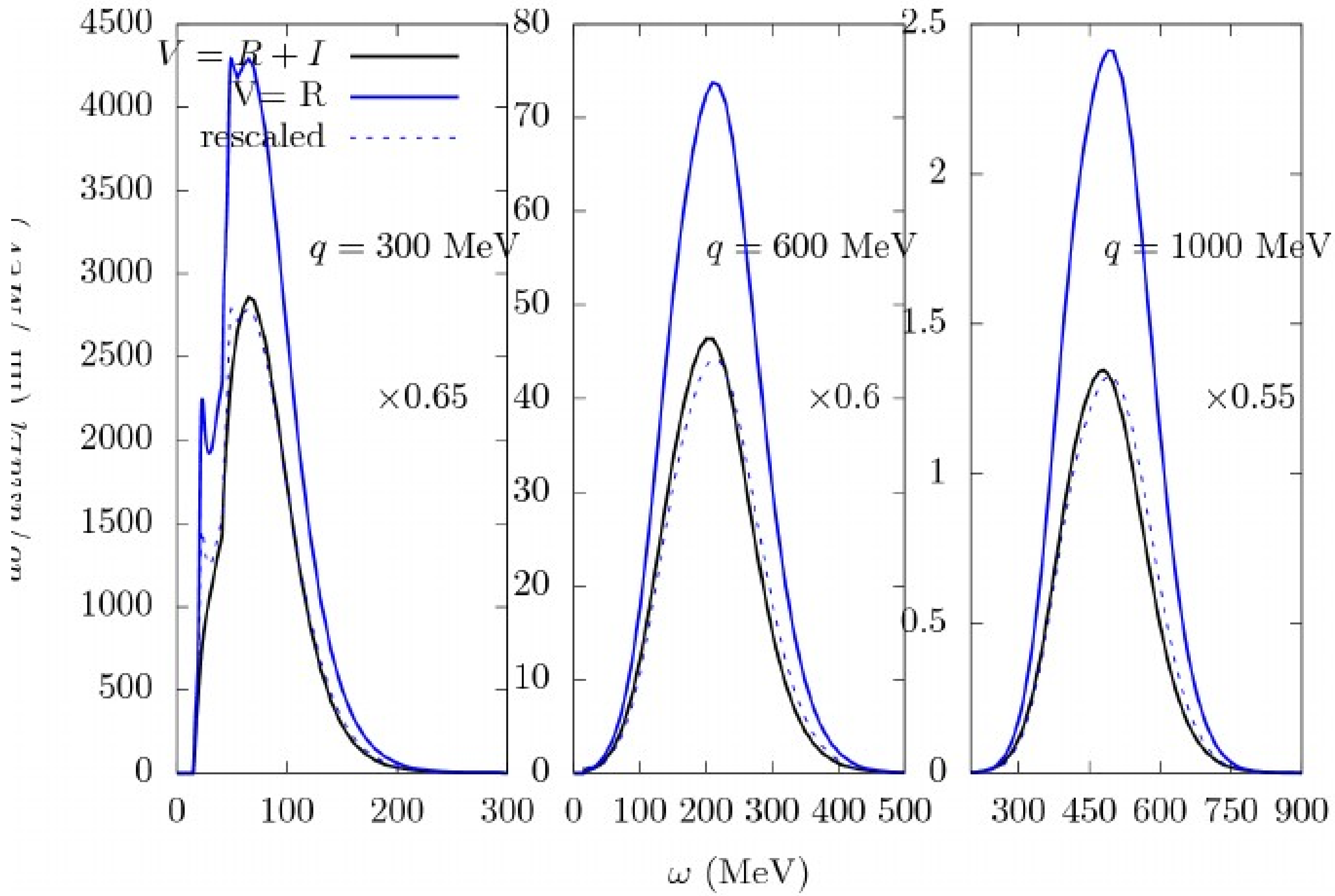


Reasonably good agreement with data under exclusive kinematics

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%

(e,e' p) and Final-State Interactions

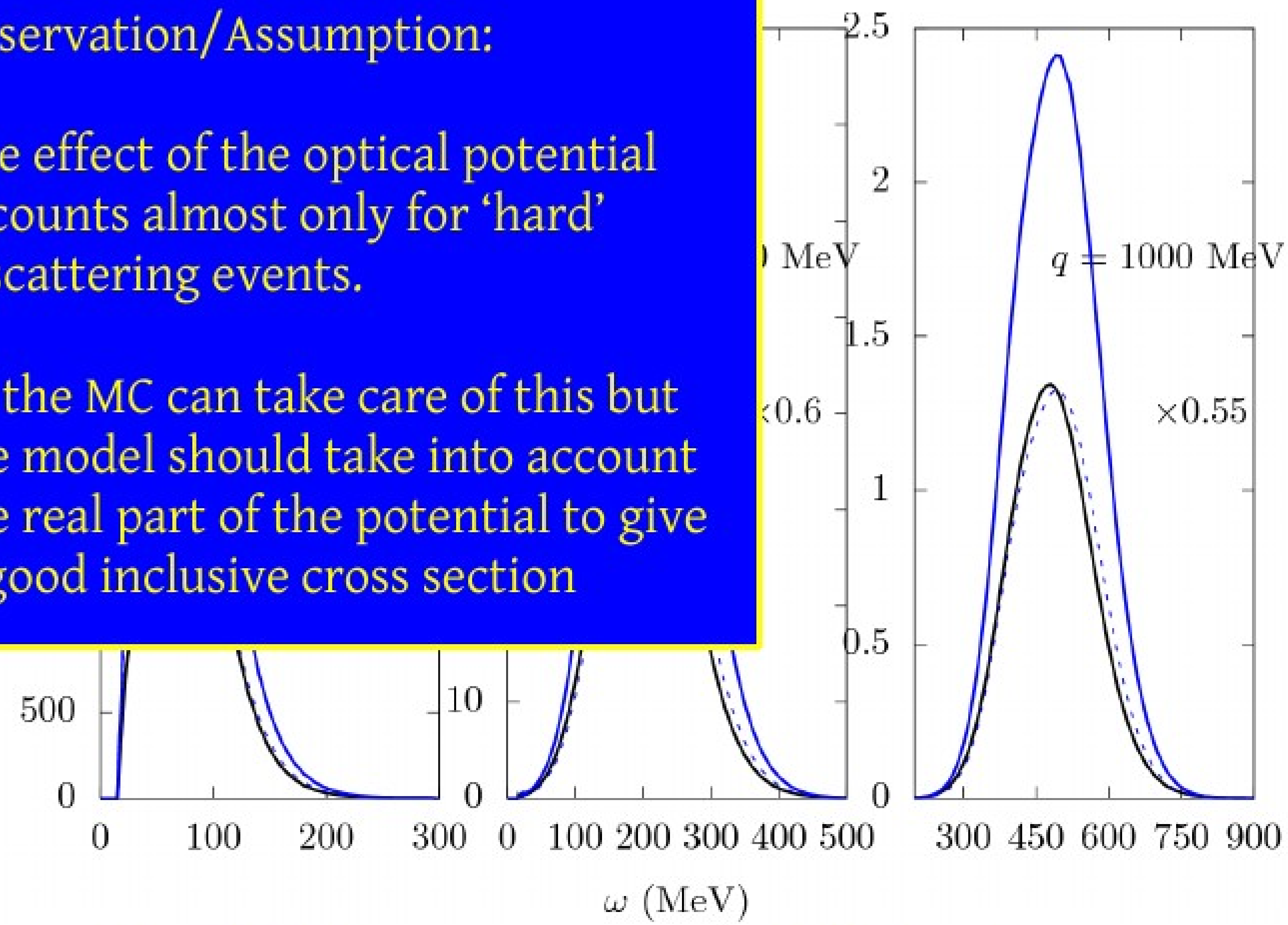


(e,e' p) and Final-State Interactions

Observation/Assumption:

The effect of the optical potential accounts almost only for 'hard' rescattering events.

So the MC can take care of this but the model should take into account the real part of the potential to give A good inclusive cross section



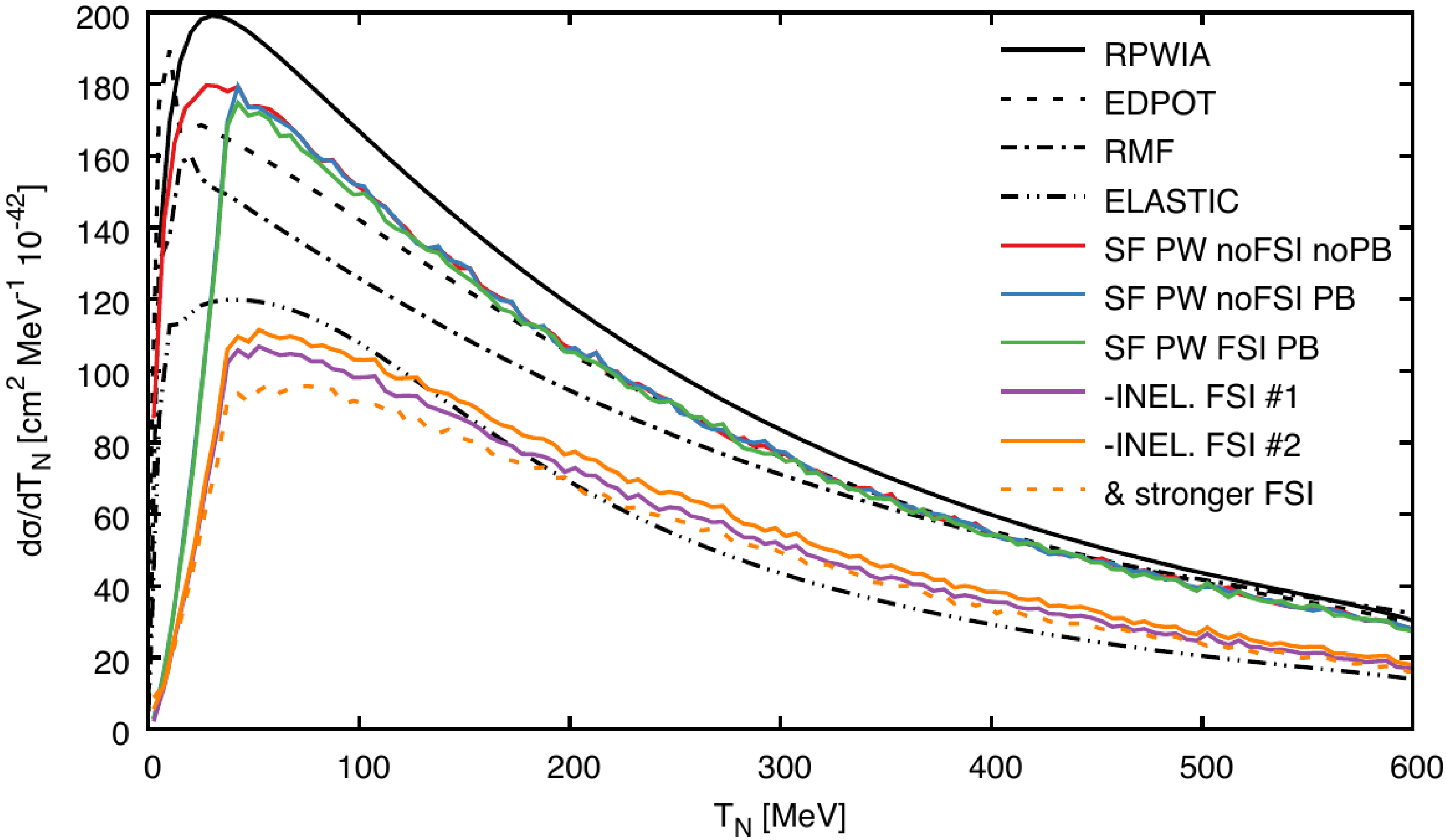
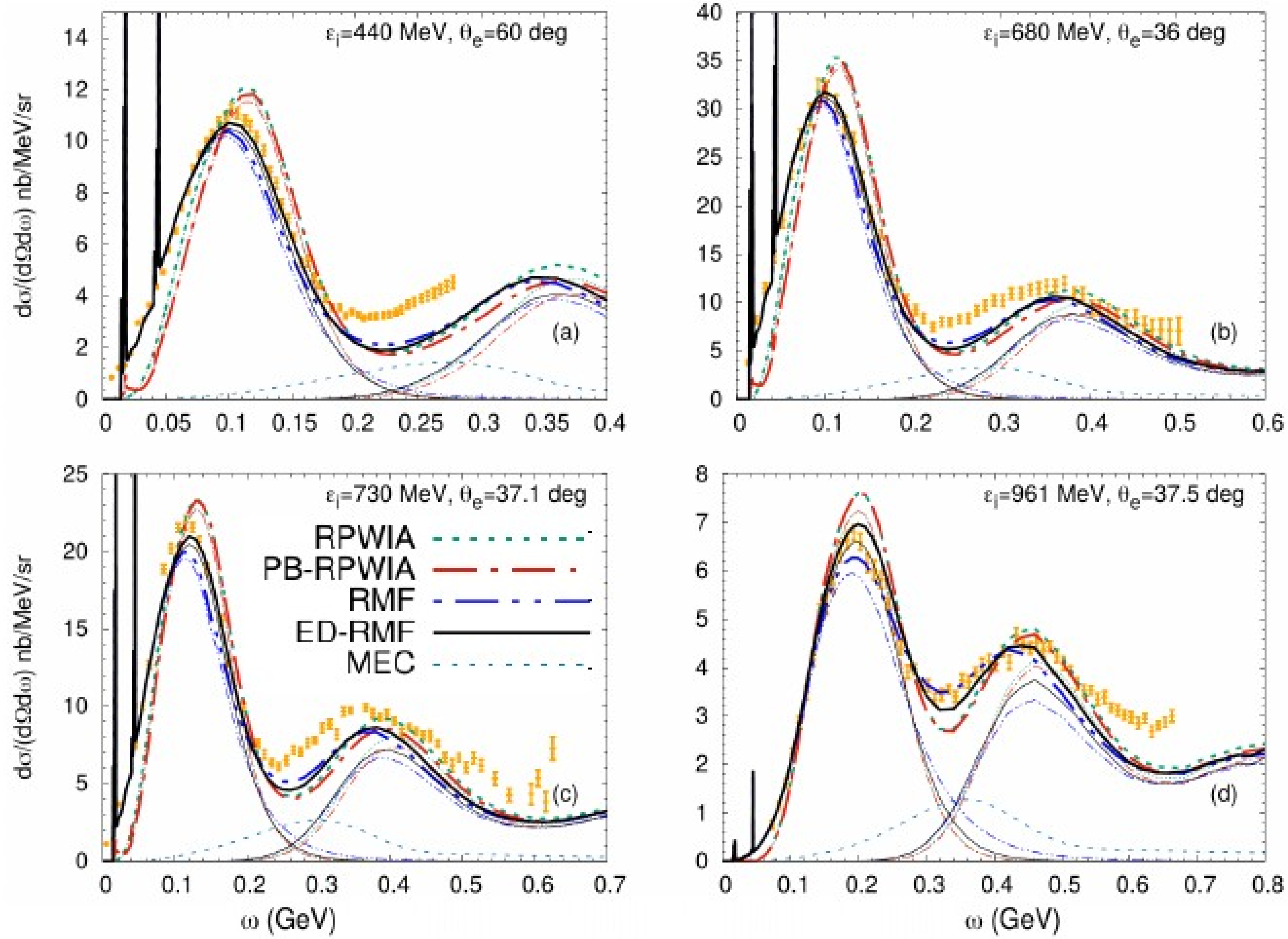
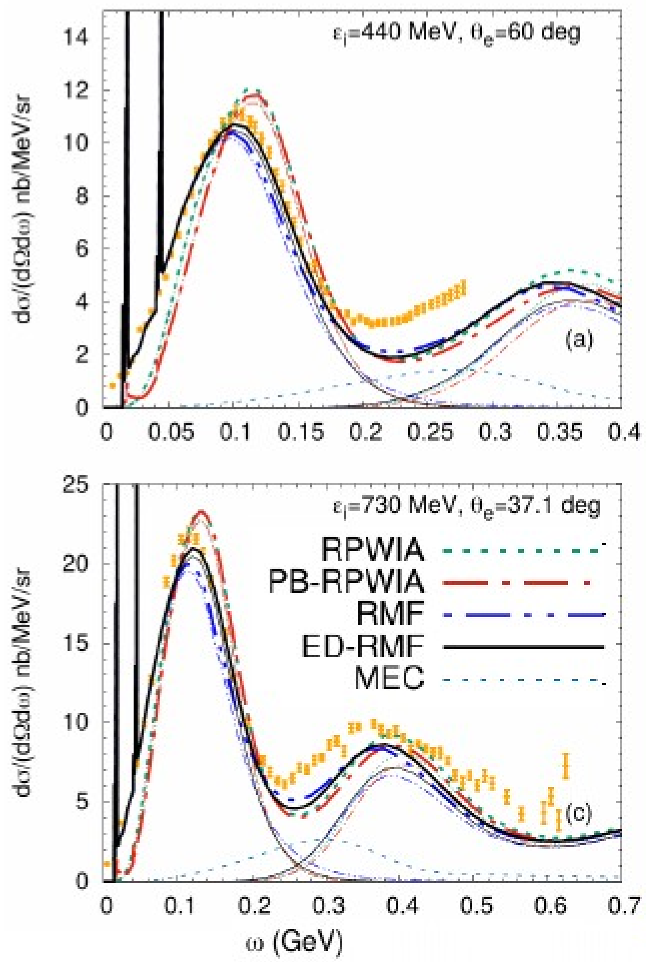


Figure and results by K. Niewczas and JM. Udias

Intermediate momenta and distortion



Intermediate momenta and distortion



Quantum mechanical elastic distortion

1. Shifts the peak to the correct position
2. Distributes peak strength to the tails

This is <u>not</u> a 'hard' scattering

(this is important for later)

The dispersion relation of the outgoing nucleon is determined in the potential this leads to a 'broadening' of the energy-momentum relation.

MF: The energy is the quantum number and k_N is only asymptotically defined.

PW: The outgoing nucleon has fixed k_N

ω (GeV)

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