FACULTY OF SCIENCES

- DEPARTMENT OF PHYSICS AND ASTRONOMY

CRPA predictions of neutrino-nucleus interactions

Alexis Nikolakopoulos & Natalie Jachowicz

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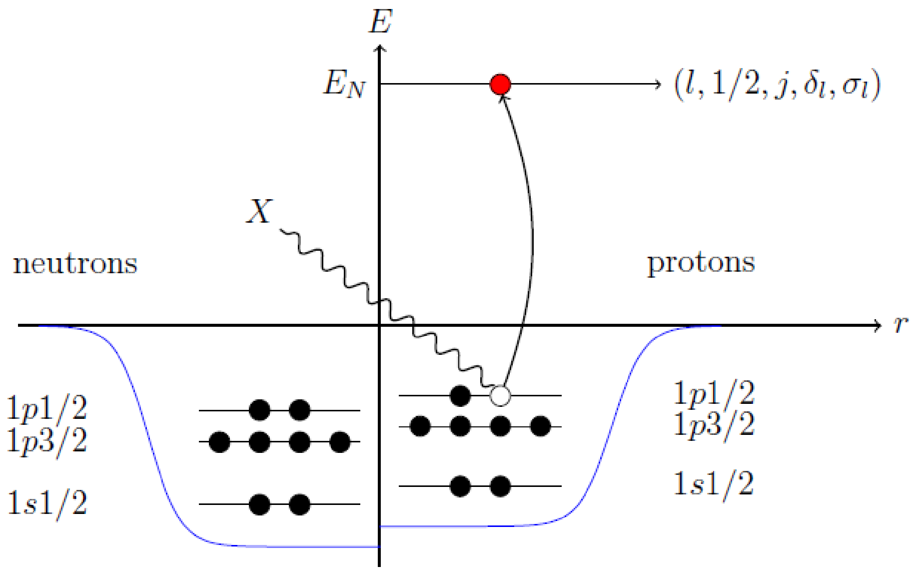
Modeling the nucleus

Independent-particle shell-model from **self-consistent mean field** with **effective Skyrme interaction**.



Mean field nucleus

- Mean field potential
- Single-particle wavefunctions with (l,j,E,s)
- Binding energies
- Orthogonal states (→ Pauli-blocking)

Modeling the nucleus

Independent-particle shell-model from **self-consistent mean field** with effective Skyrme interaction.

$$-\nabla\left[\frac{\hbar^2}{2m_q^*(\boldsymbol{r})}\nabla\phi_{\alpha_q}(\boldsymbol{r})\right]+[U_q(\boldsymbol{r})-i\boldsymbol{W}_q(\boldsymbol{r})\cdot(\nabla\times\sigma)]\phi_{\alpha_q}(\boldsymbol{r})=\varepsilon^{\mathrm{HF}}_{\alpha_q}\phi_{\alpha_q}(\boldsymbol{r})\,. \quad (2.9)$$

Density dependent effective mass:

$$\frac{\hbar^2}{2m_q^*}(\boldsymbol{r})=\frac{\hbar^2}{2m_q}+\tfrac{1}{4}(t_1+t_2)\rho_{\mathrm{tot}}(\boldsymbol{r})+\tfrac{1}{8}(t_2-t_1)\rho_q(\boldsymbol{r})+\tfrac{1}{24}t_4(\rho^2_{\mathrm{tot}}(\boldsymbol{r})-\rho^2_q(\boldsymbol{r}))\,.$$

Density dependent potential:

$$\begin{aligned}U_q(\boldsymbol{r})=\;&t_0[(1+\tfrac{1}{2}x_0)\rho_{\mathrm{tot}}-(\tfrac{1}{2}+x_0)\rho_q]+\tfrac{1}{4}(t_1+t_2)\tau_{\mathrm{tot}}+\tfrac{1}{8}(t_2-t_1)\tau_q\\&+\tfrac{1}{8}(t_2-3t_1)\nabla^2\rho_{\mathrm{tot}}+\tfrac{1}{16}(3t_1+t_2)\nabla^2\rho_q+\tfrac{1}{4}t_3(\rho^2_{\mathrm{tot}}-\rho^2_q)\\&-\tfrac{1}{2}W_0'(\nabla\cdot\boldsymbol{J}_{\mathrm{tot}}+\nabla\cdot\boldsymbol{J}_q)+\delta_{qp}V^C(\boldsymbol{r})+\tfrac{1}{24}t_4[2\rho_{\mathrm{tot}}\tau_{\mathrm{tot}}-2\rho_q\tau_q\\&+\tfrac{5}{2}\rho_q\nabla^2\rho_q-\tfrac{5}{2}\rho_{\mathrm{tot}}\nabla^2\rho_{\mathrm{tot}}+\tfrac{5}{4}(\nabla\rho_q)^2-\tfrac{5}{4}(\nabla\rho_{\mathrm{tot}})^2+\tfrac{1}{2}J^2_{q'}]\,,\end{aligned}$$

Self-referential equation:

$$\rho_q(\boldsymbol{r})=\sum_{\alpha_q\gamma_q}\rho^{(q)}_{\alpha\gamma}\phi^*_{\alpha_q}(\boldsymbol{r})\phi_{\gamma_q}(\boldsymbol{r})\,,$$

→ Solve the system iteratively

Modeling the nucleus

Independent-particle shell-model from **self-consistent mean field** with **effective Skyrme interaction**.
Parameters in nucleon-nucleon interaction fit to nuclear matter and ground-state properties of nuclei

M. Waroquier et al. / Effective Skyrme-type interaction (I) Nuclear Physics **A404** (1983) 269–297

	t_4 (MeV · fm^8)	K (MeV)	$(E/A)_{\text{n.m.}}$ (MeV)	k_F (fm^{-1})	m^*/m	a_τ (MeV)
SkE2	−15808.79	200	−16.0	1.33	0.72	29.7
SkE4	−12258.97	250	−16.0	1.31	0.75	30.0
SkIII	0.0	356	−15.87	1.29	0.76	28.2

	E/A	r_p	r_n	r_c	E/A	r_p	r_n	r_c
		^{16}O				^{40}Ca		
SkE2	−7.92	2.63	2.60	2.68	−8.56	3.37	3.31	3.42
SkE4	−7.96	2.65	2.62	2.70	−8.59	3.40	3.35	3.46
SkIII	−8.03	2.64	2.61	2.70	−8.57	3.41	3.36	3.46
exp	−7.98			2.71 [a])	−8.55		3.36 [c])	3.48 [b])
		^{90}Zr				^{132}Sn		
SkE2	−8.67	4.17	4.24	4.21	−8.36	4.62	4.84	4.66
SkE4	−8.71	4.22	4.29	4.26	−8.36	4.68	4.89	4.71
SkIII	−8.69	4.26	4.31	4.30	−8.36	4.73	4.90	4.78
exp	−8.71			4.27 [c])	−8.36			

Modeling the nucleus

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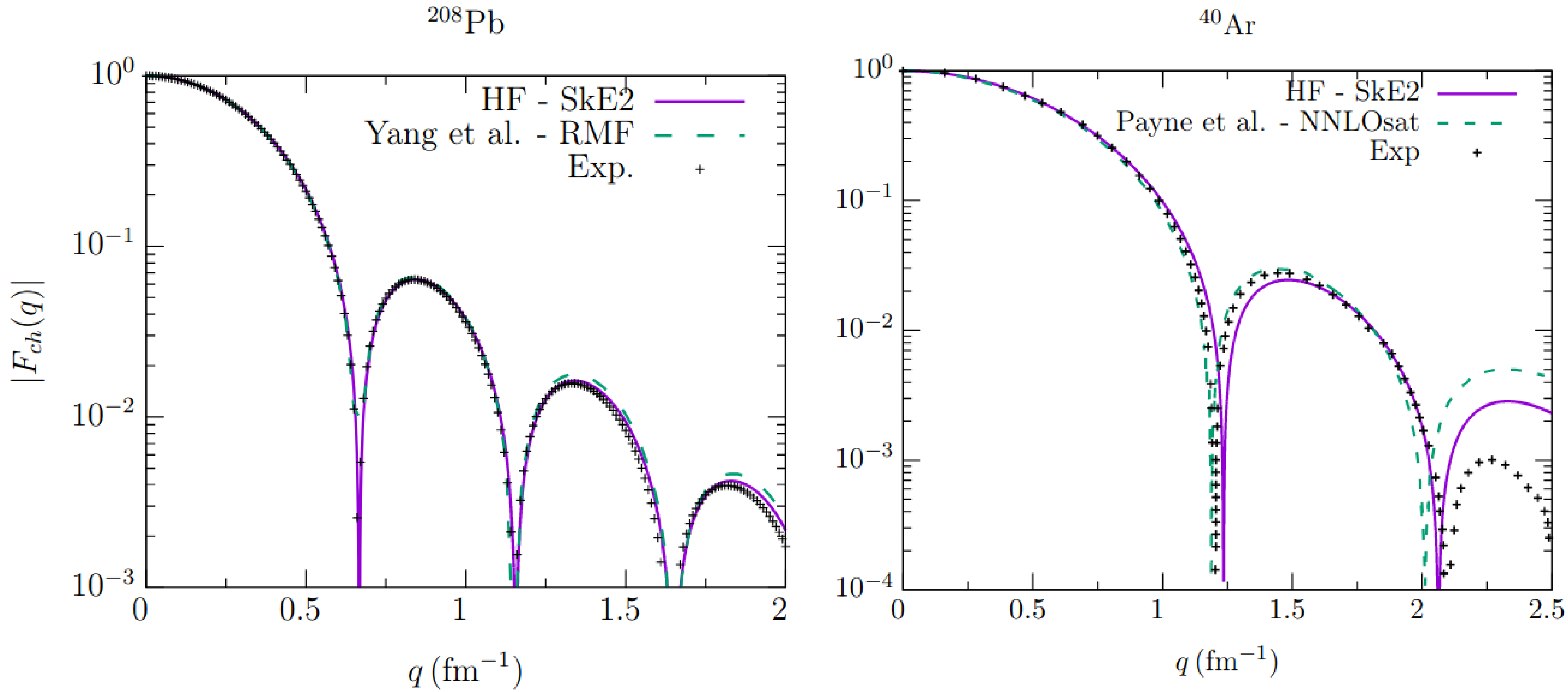

Charge form factors (FT of charge-density) [N. Van Dessel et al. Arxiv:2007.03658] (→ also weak FF)

Modeling the nucleus

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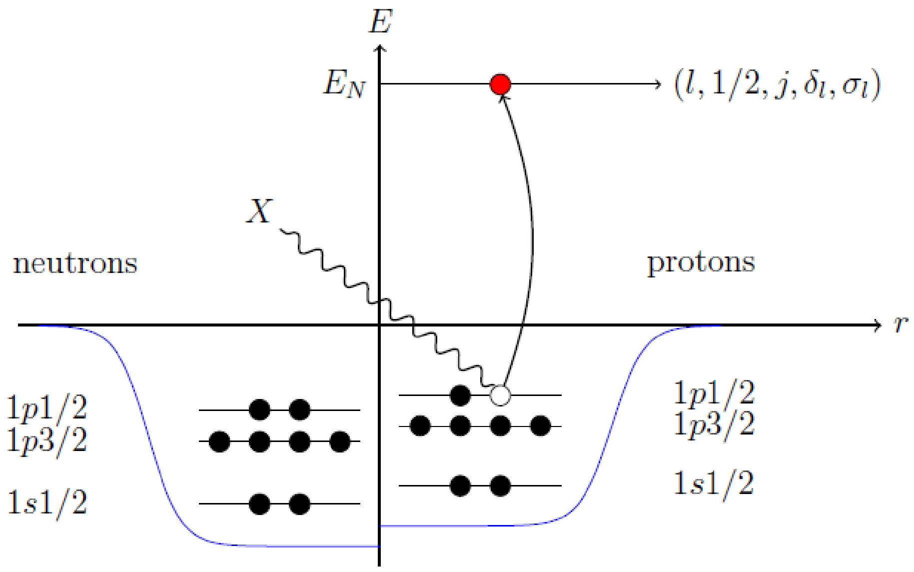
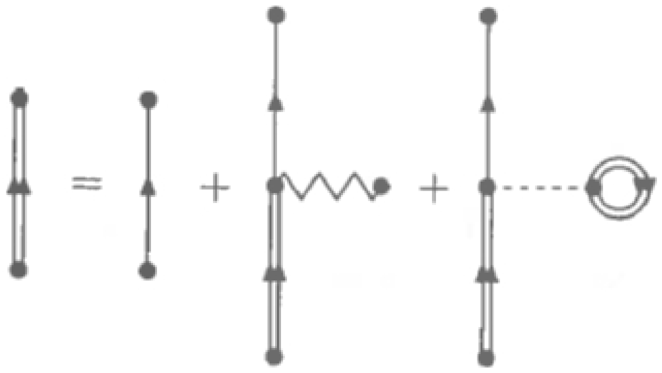


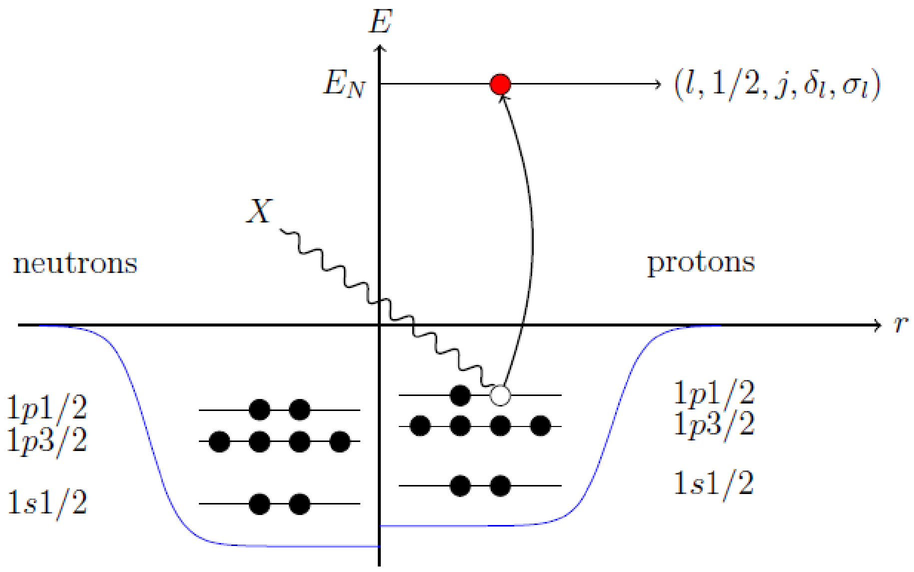
Mean field nucleus

- Mean field potential
- Single-particle wavefunctions with (l,j,E,s)
- Binding energies
- Orthogonal states (→ Pauli-blocking)
- Effective interaction projects complexity on Mean field



Single-nucleon excitation of the nucleus

Independent-particle shell-model from **self-consistent mean field** with **effective Skyrme interaction**.



Non-relativistic reduction of the current

$$\vec{J}_V^{\alpha}(\vec{x}) = \vec{J}^{\alpha}_{convection}(\vec{x}) + \vec{J}^{\alpha}_{magnetization}(\vec{x})$$

with $$\vec{J}_c^{\alpha}(\vec{x}) = \frac{1}{2Mi}\sum_{i=1}^{A} G_E^{i,\alpha}\left[\delta(\vec{x}-\vec{x}_i)\overrightarrow{\nabla}_i - \overleftarrow{\nabla}_i\,\delta(\vec{x}-\vec{x}_i)\right],$$

$$\vec{J}_m^{\alpha}(\vec{x}) = \frac{1}{2M}\sum_{i=1}^{A} G_M^{i,\alpha}\,\overrightarrow{\nabla} \times \vec{\sigma}_i\,\delta(\vec{x}-\vec{x}_i),$$

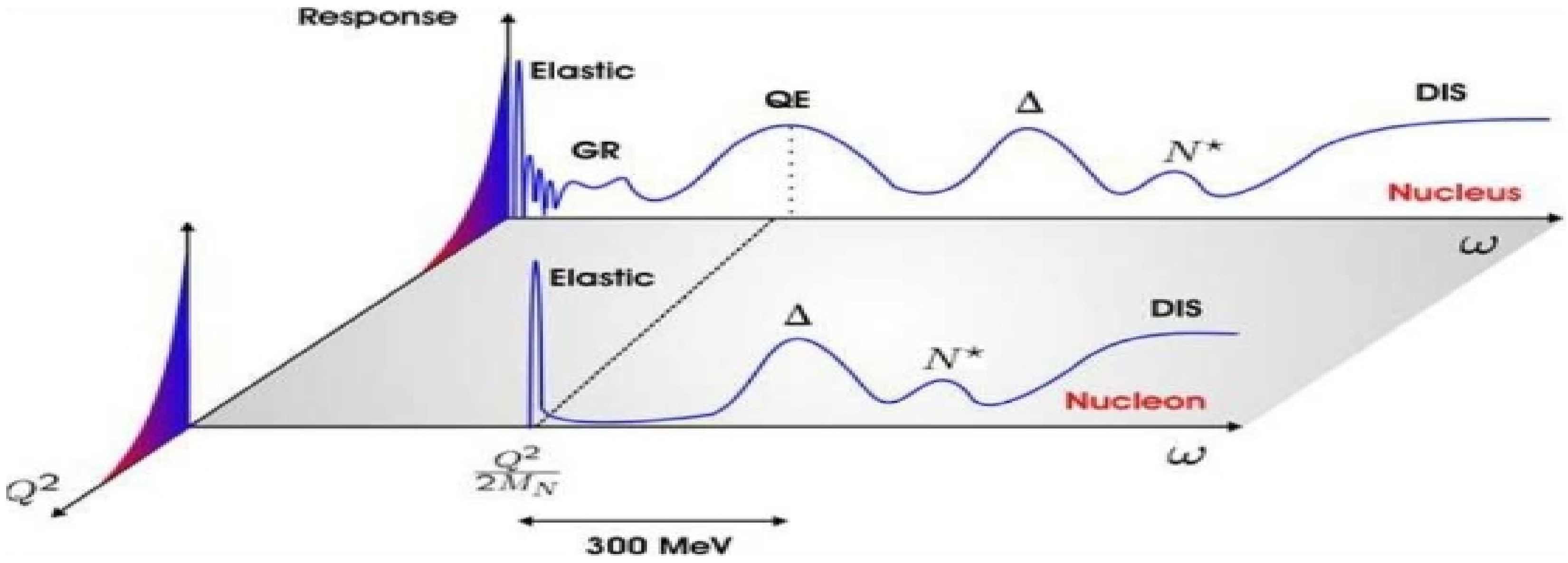
$$\vec{J}_A^{\alpha}(\vec{x}) = \sum_{i=1}^{A} G_A^{i,\alpha}\,\vec{\sigma}_i\,\delta(\vec{x}-\vec{x}_i),$$

$$J_V^{0,\alpha}(\vec{x}) = \rho_V^{\alpha}(\vec{x}) = \sum_{i=1}^{A} G_E^{i,\alpha}\,\delta(\vec{x}-\vec{x}_i),$$

$$J_A^{0,\alpha}(\vec{x}) = \rho_A^{\alpha}(\vec{x}) = \frac{1}{2Mi}\sum_{i=1}^{A} G_A^{i,\alpha}\,\vec{\sigma}_i\cdot\left[\delta(\vec{x}-\vec{x}_i)\overrightarrow{\nabla}_i - \overleftarrow{\nabla}_i\,\delta(\vec{x}-\vec{x}_i)\right]$$

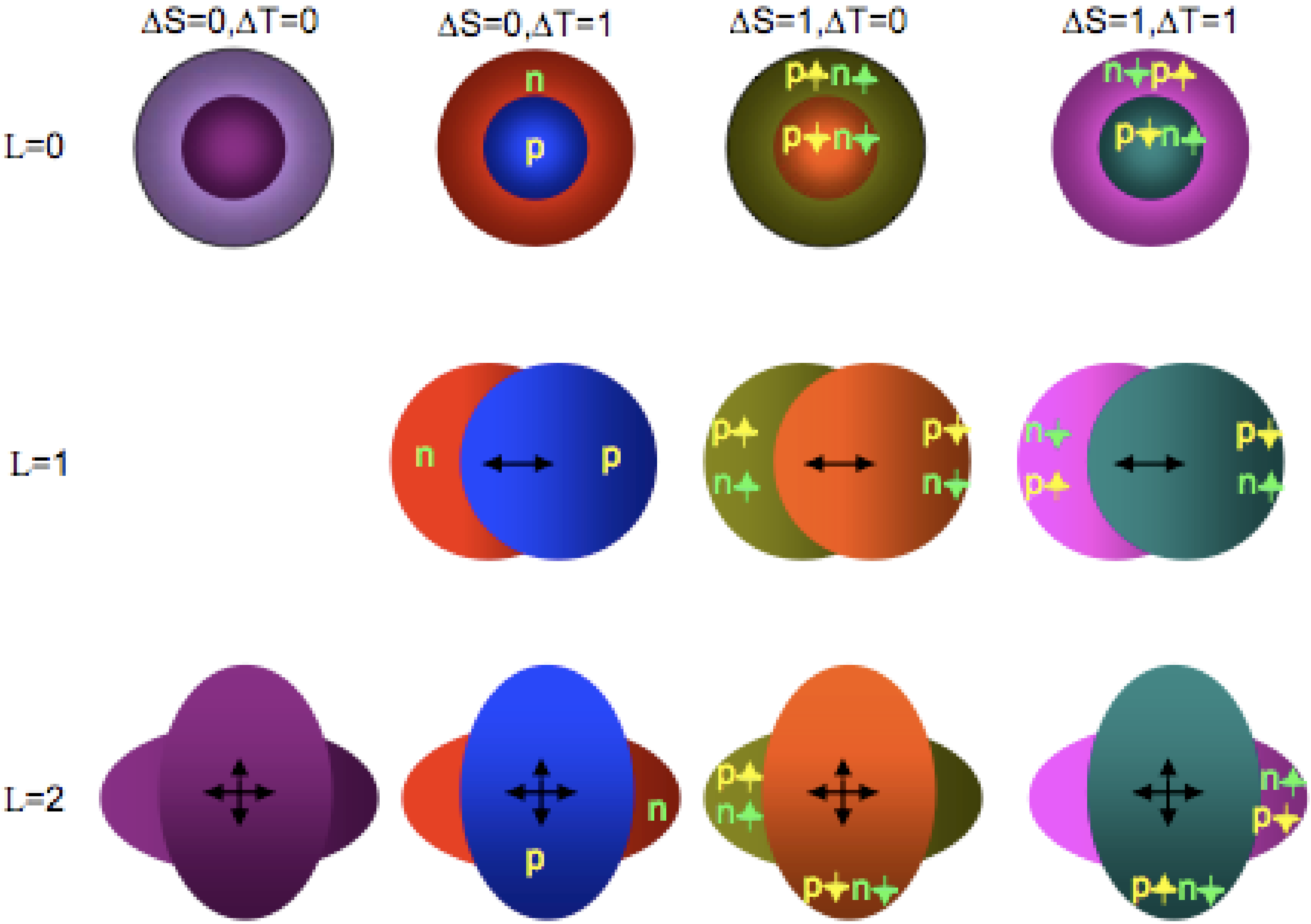
$$J_P^{0,\alpha}(\vec{x}) = \rho_P^{\alpha}(\vec{x}) = \frac{m_\mu}{2M}\sum_{i=1}^{A} G_P^{i,\alpha}\,\overrightarrow{\nabla}\cdot\vec{\sigma}_i\,\delta(\vec{x}-\vec{x}_i)$$

The Random Phase approximation



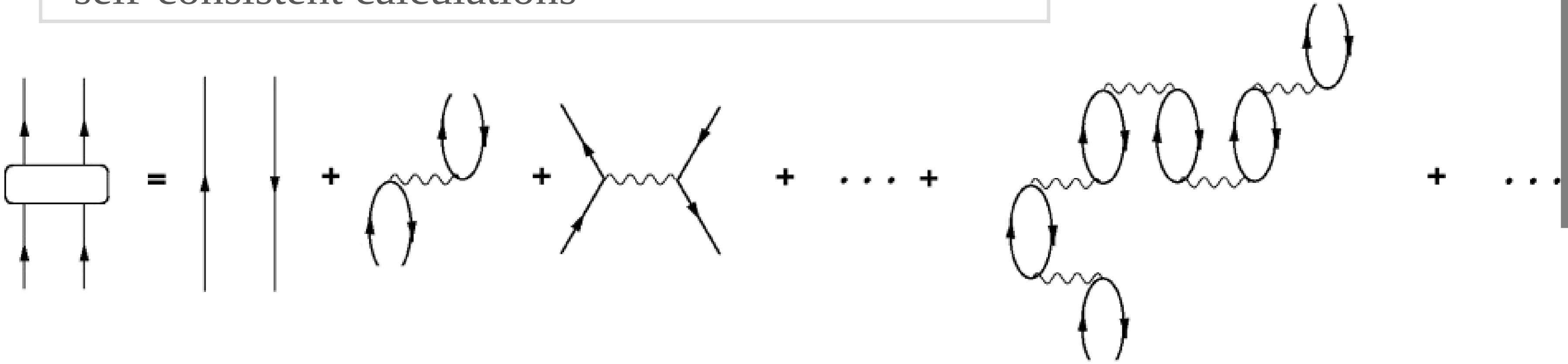
- Long-range correlations are correlations over the whole size of the nucleus
- They can redistribute the incoming energy transfer to the nucleus over all the nuclear constituents.
- They manifest themselves in collective excitations such as giant resonances

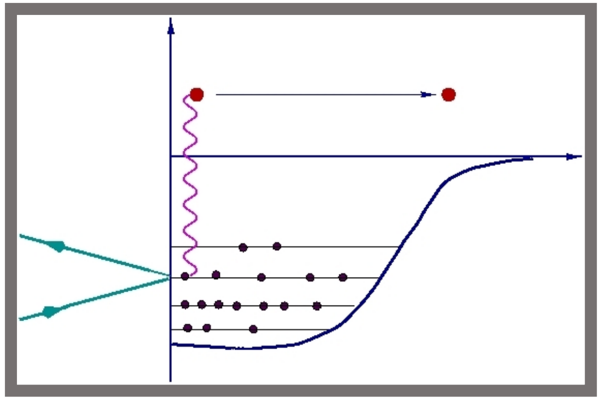
Long-range correlations = probing collective effects

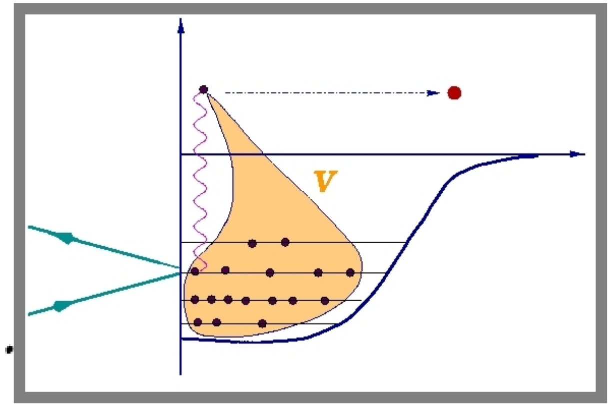


Long-range correlations : Continuum RPA

- Green's function approach
- Same Skyrme SkE2 residual interaction as initial-state
- self-consistent calculations







$$|\Psi_{RPA}\rangle = \sum_{c} \left\{ X_{(\Psi,C)} \left|ph^{-1}\right\rangle - Y_{(\Psi,C)} \left|hp^{-1}\right\rangle \right\}$$

$$\Pi^{(RPA)}(x_1, x_2; \omega) = \Pi^{(0)}(x_1, x_2; \omega) + \frac{1}{\hbar} \int dx \int dx' \; \Pi^{(0)}(x_1, x; \omega) \, \tilde{V}(x, x') \, \Pi^{(RPA)}(x', x_2; \omega)$$

Solving the RPA equations in coordinate space

One gets coupled self-consistent integral equation for the radial transition densities :

$$\langle \Psi_0 || X_{\eta J} || \Psi_C(J;E) \rangle_r = - \langle h || X_{\eta J} || p(\varepsilon_{ph}) \rangle_r + \sum_{\mu,\nu} \int dr_1 \int dr_2 \; U^J_{\mu\nu}(r_1,r_2) \; \mathcal{R} \left(R^{(0)}_{\eta\mu;J}(r,r_1;E) \right) \; \langle \Psi_0 || X_{\nu J} || \Psi_C(J;E) \rangle_{r_2}$$

Solved numerically by discretizing on a mesh in coordinate space
Translates into a matrix inversion for the transition densities:

$$\rho_C^{RPA} = - \frac{1}{1 - R\,U} \; \rho_C^{HF}$$

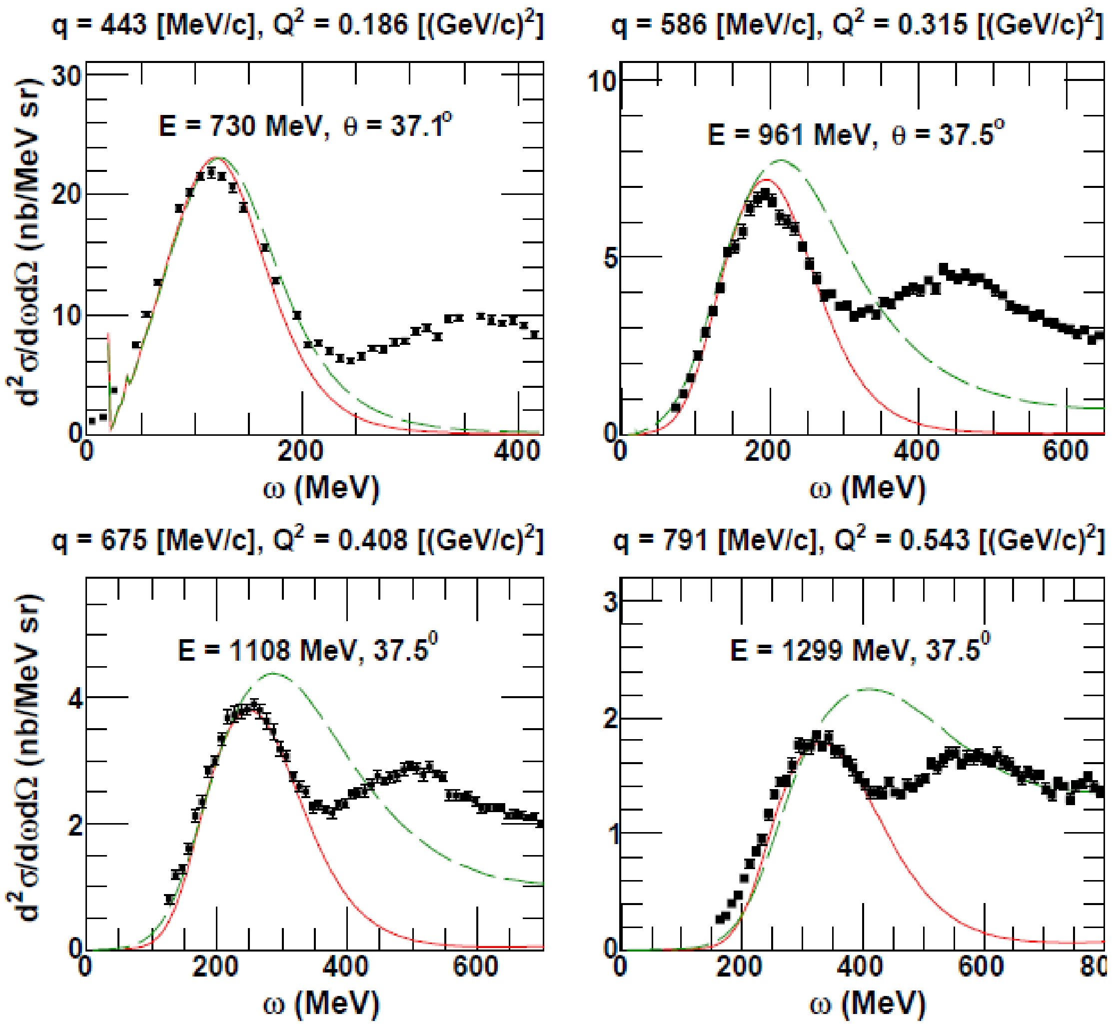
$$|\Psi_{RPA}\rangle = \sum_c \left\{ X_{(\Psi,C)} \left| ph^{-1} \right\rangle - Y_{(\Psi,C)} \left| hp^{-1} \right\rangle \right\}$$

The ‘bare’ transition densities are already dressed at HF level

Additional effects in lepton scattering

Relativistic corrections at high excitation energies

[S. Jeschonnek and T. Donnelly, PRC57, 2438 (1998)]



Shift :

$$\lambda \rightarrow \lambda(\lambda+1) \qquad \lambda = \omega/2M_N$$

Boost :

$$R^{\rm V}_{\rm CC}(q,\omega) \rightarrow \frac{q^2}{q^2-\omega^2} R^{\rm V}_{\rm CC}(q,\omega)\,,$$

$$R^{\rm A}_{\rm LL}(q,\omega) \rightarrow \left(1+\frac{q^2-\omega^2}{4m^2}\right) R^{\rm A}_{\rm LL}(q,\omega)\,,$$

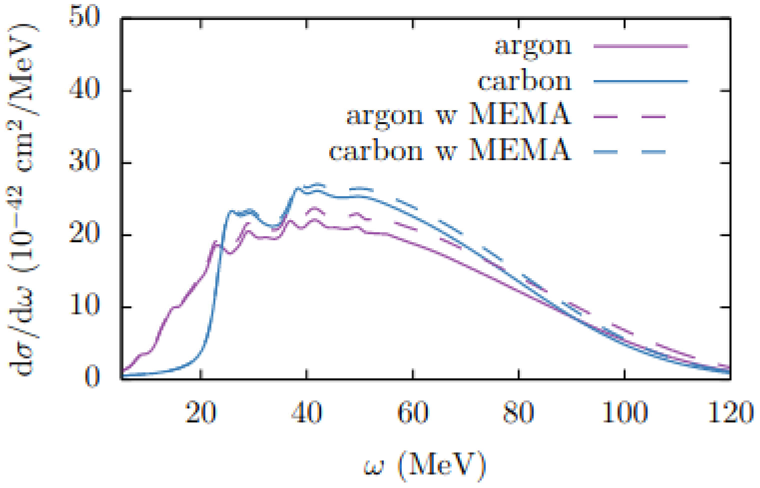
$$R^{\rm V}_{\rm T}(q,\omega) \rightarrow \frac{q^2-\omega^2}{q^2} R^{\rm V}_{\rm T}(q,\omega)\,,$$

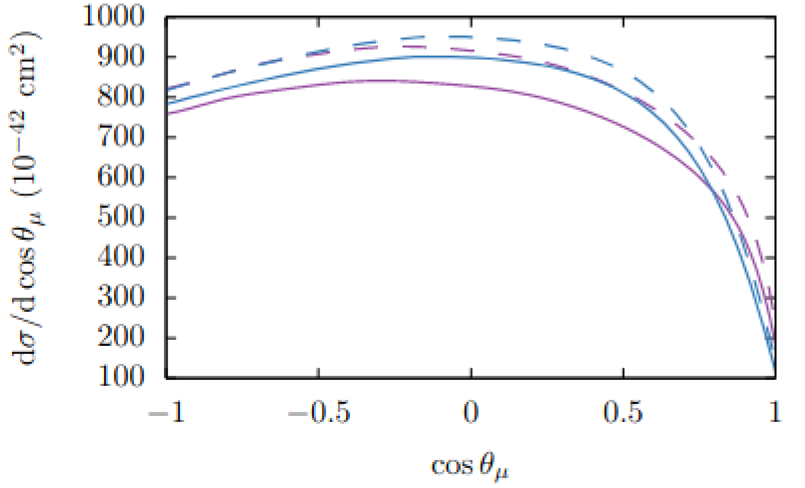
$$R^{\rm A}_{\rm T}(q,\omega) \rightarrow \left(1+\frac{q^2-\omega^2}{4m^2}\right) R^{\rm A}_{\rm T}(q,\omega)\,,$$

$$R^{\rm VA}_{\rm T'}(q,\omega) \rightarrow \sqrt{\frac{q^2-\omega^2}{q^2}}\sqrt{1+\frac{q^2-\omega^2}{4m^2}}\, R^{\rm VA}_{\rm T'}(q,\omega)\,.$$

Additional effects in lepton scattering

Coulomb correction for outgoing/incoming lepton





low energies: Fermi function

= Ratio of plane wave to coulomb-distorted s-wave gives

Multiplicative factor $$2(1+\gamma_0)(2k_f R)^{-2(1-\gamma_0)} \frac{|\Gamma(\gamma_0 + i\eta)|^2}{(\Gamma(2\gamma_0+1))^2}$$

high energies: Modified Effective Momentum Approximation

(MEMA)

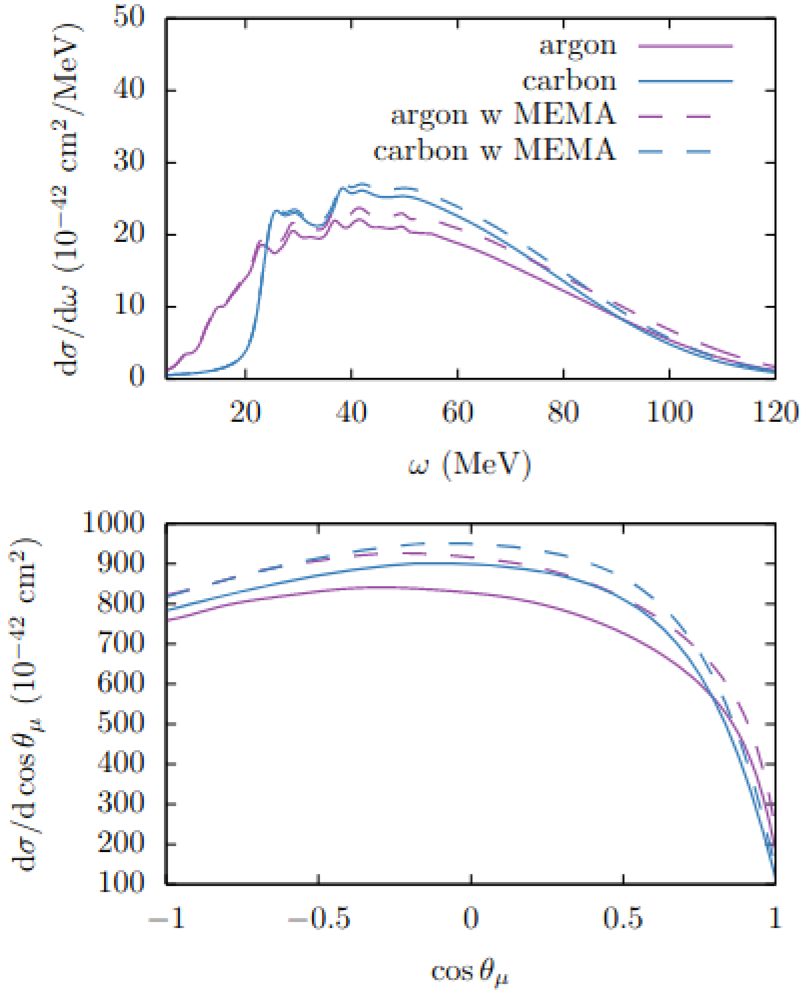
$$e^{i\vec{k}\cdot\vec{r}} \rightarrow \sqrt{\frac{E_{eff}k_{eff}}{Ek}} e^{i\vec{k}_{eff}\cdot\vec{r}}$$

$$k_{eff} = k - V(0)$$

$$q_{eff} = q + 1.5 \left(\frac{Z'\alpha\hbar c}{R}\right),$$

Additional effects in lepton scattering

Coulomb correction for outgoing/incoming lepton



Mostly relevant at low energies and heavy targets

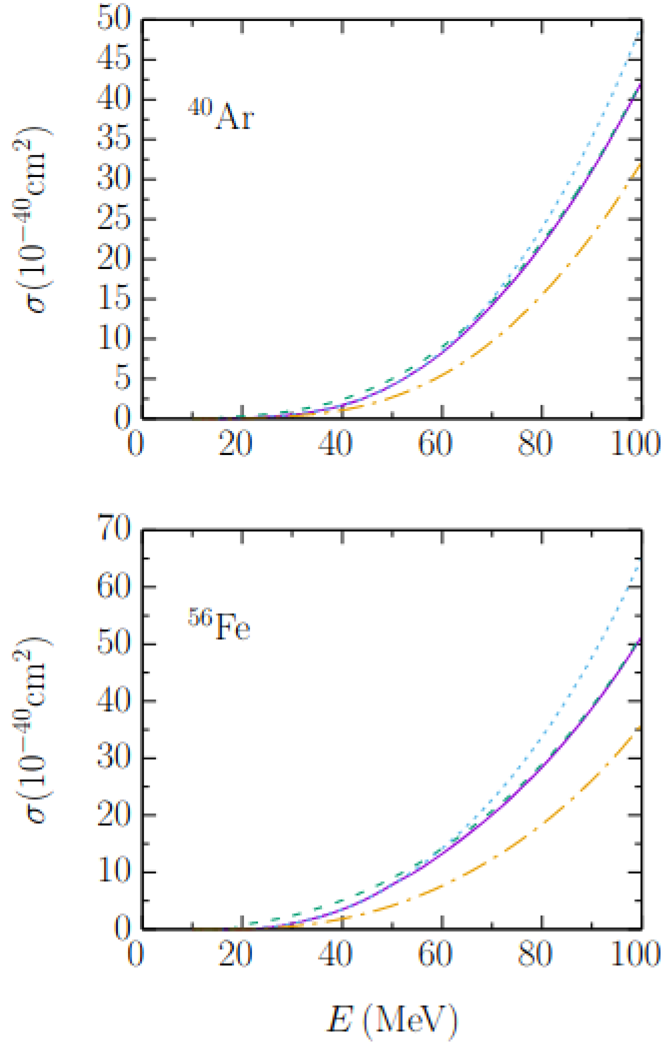
Mono-energetic Kaon-decay at rest neutrinos

E=236 MeV

[Nikolakopoulos et al. PRC102 064603 (2021)]

Additional effects in lepton scattering

Coulomb correction for outgoing/incoming lepton



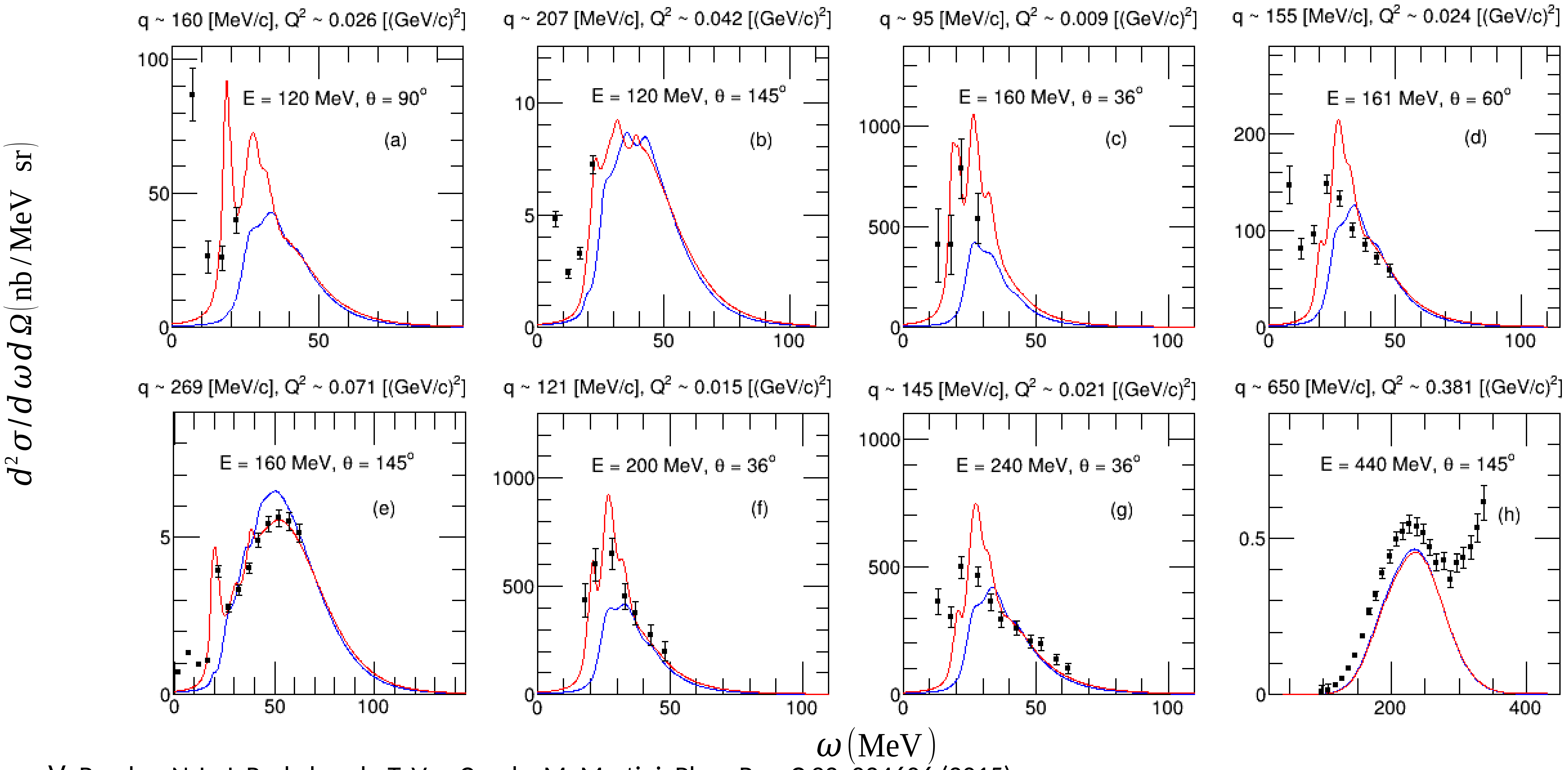
Mostly relevant at low energies and heavy targets

CC interactions with Argon at low incoming energy

[Van Dessel et al. PRC100 055503 (2019)]

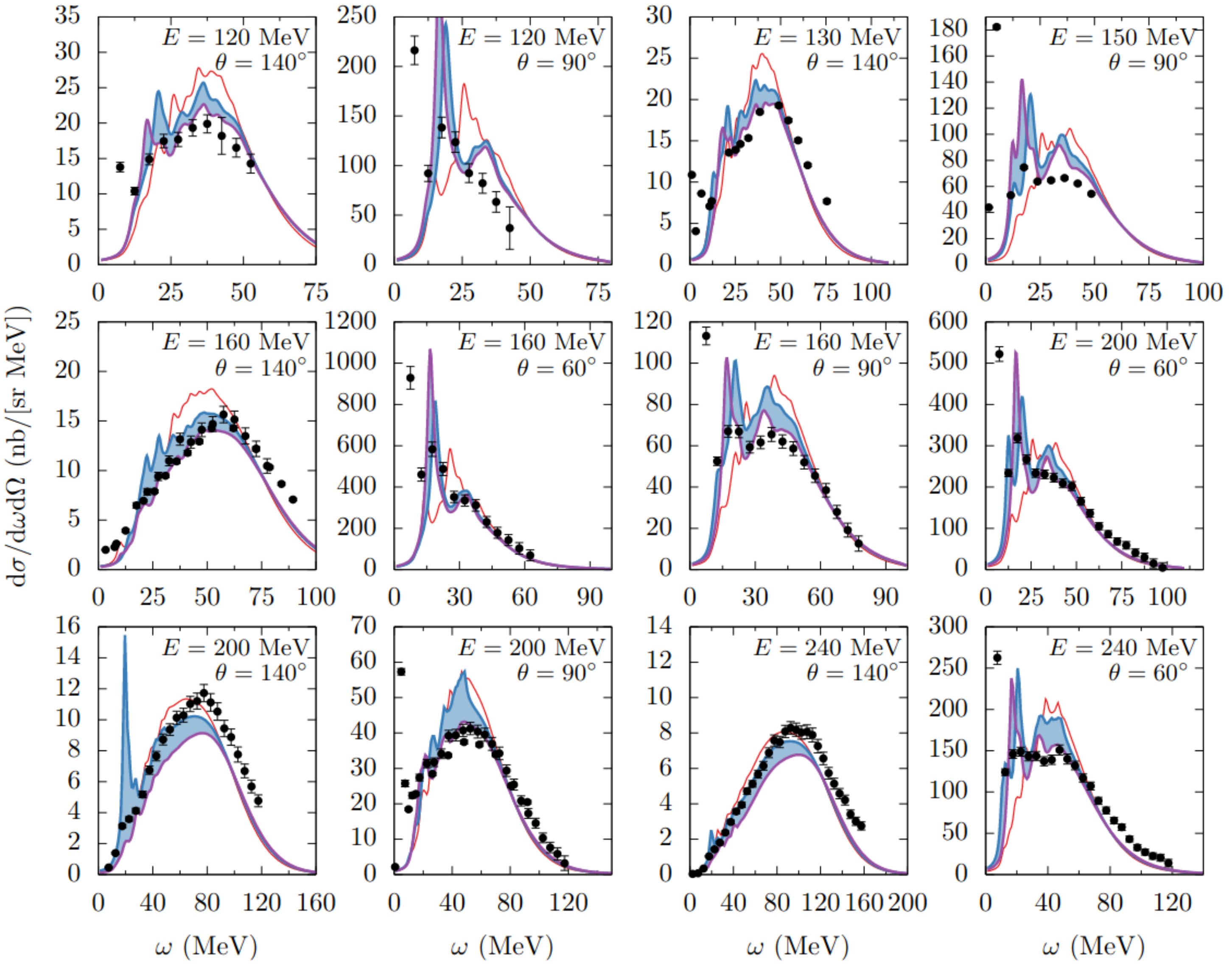
HF-CRPA : comparison with electron scattering data

$^{12}C(e, e')$



V. Pandey, N.J., J. Ryckebusch, T. Van Cuyck , M. Martini, Phys. Rev. C 92, 024606 (2015)

Electron scattering off medium mass nuclei



A. Nikolakopoulos, V. Pandey, J Spitz, N. Jachowicz Phys.Rev.C 103 (2021) 6, 064603

(e,e') off Calcium

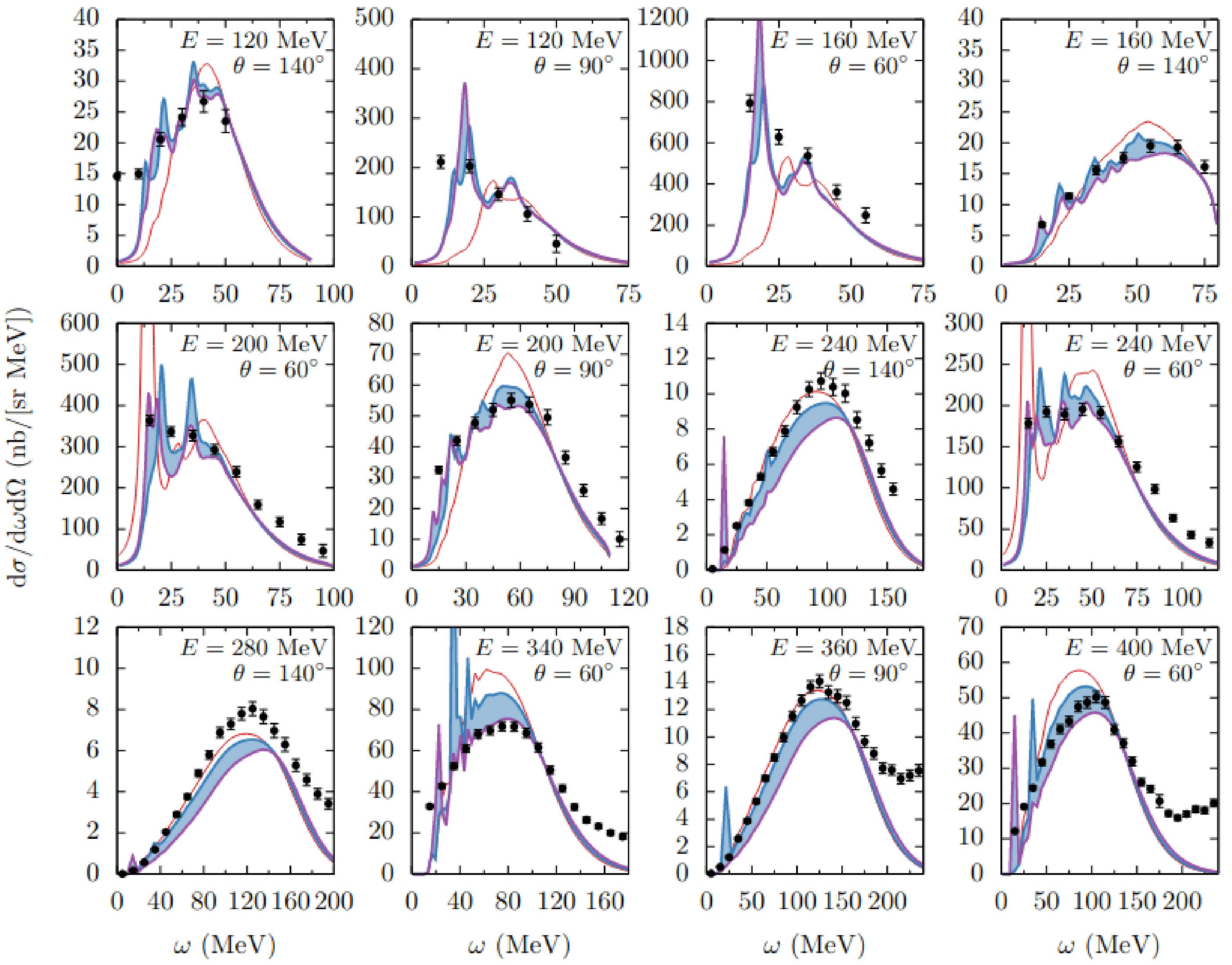
- Blue band uncertainty due to residual interaction in CRPA

$$V \rightarrow \frac{V}{(1+Q^2/\Lambda)^2}$$

- Cut off determined in

[V. Pandey, et al Phys. Rev. C 92, 024606 (2015)]

Electron scattering off medium mass nuclei



(e,e') off Iron

- Blue band uncertainty due to residual interaction in CRPA

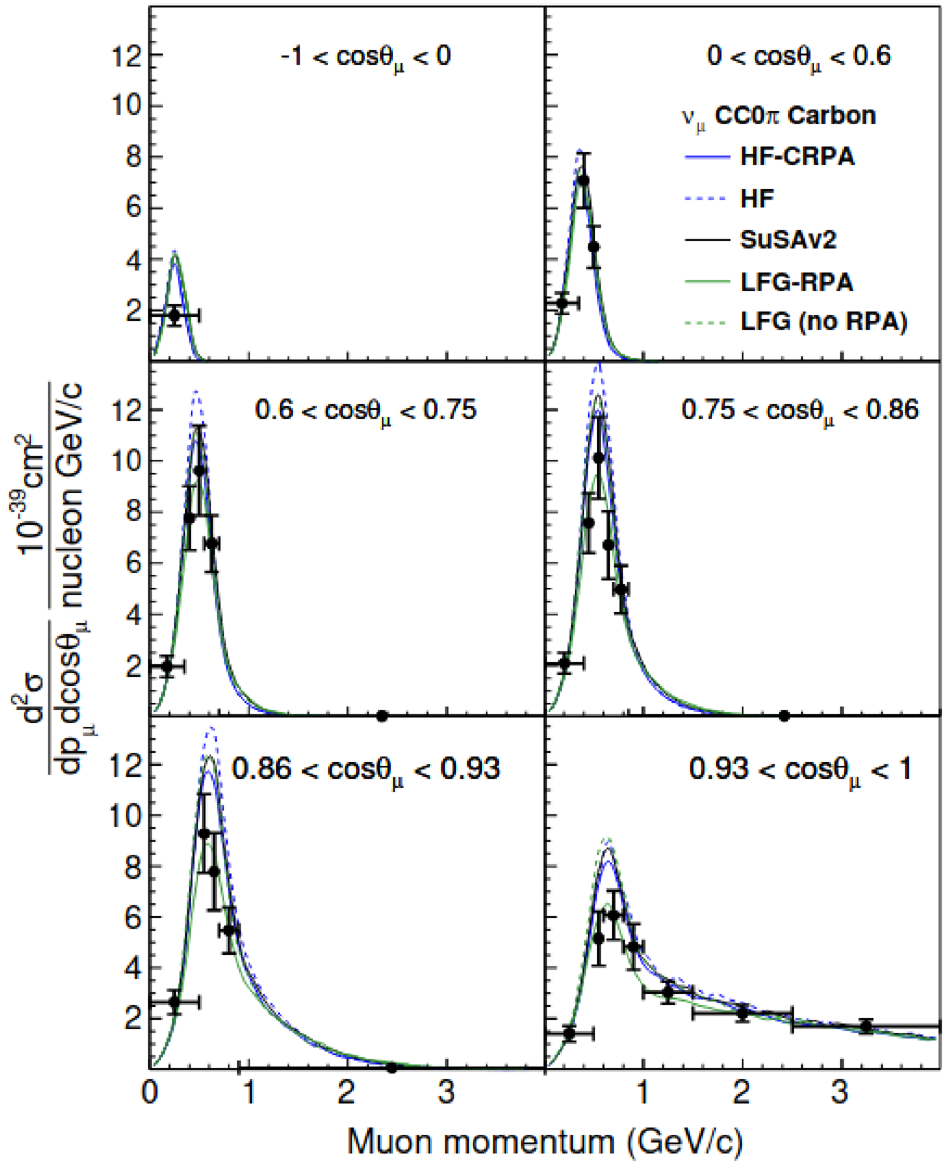
$$V \rightarrow \frac{V}{(1 + Q^2/\Lambda)^2}$$

- Cut off determined in

[V. Pandey, et al Phys. Rev. C 92, 024606 (2015)]

Jachowicz, N., Nikolakopoulos, A. Nuclear medium effects in neutrino- and antineutrino-nucleus scattering. Eur. Phys. J. Spec. Top. (2021)

Neutrino scattering and accelerator-based experiments



Implementation of the CRPA model in the GENIE event generator and analysis of nuclear effects in low-energy transfer neutrino-nucleus interactions

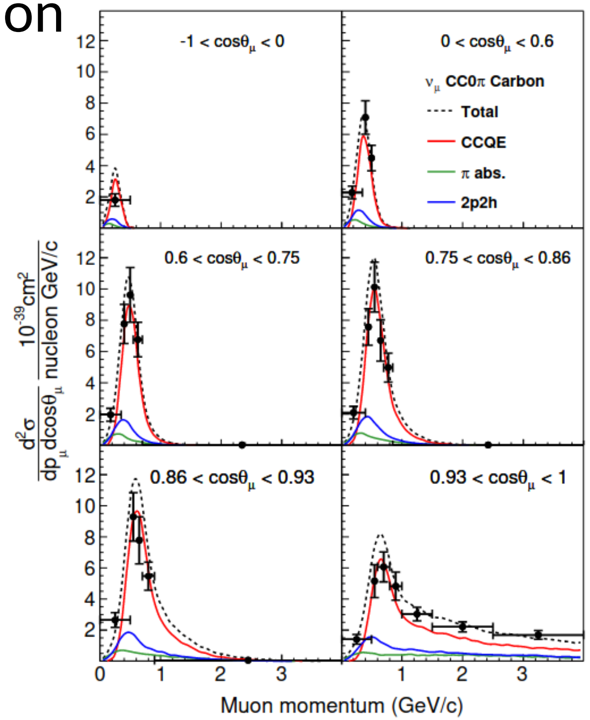
S. Dolan,[1] A. Nikolakopoulos,[2] O. Page,[3] S. Gardiner,[4] N. Jachowicz,[2] and V. Pandey[5]

[1] *CERN, European Organization for Nuclear Research, Geneva, Switzerland**
[2] *Department of Physics and Astronomy, Ghent University, Proeftuinstraat 86, B-9000 Gent, Belgium*†
[3] *School of Physics, University of Bristol, Bristol BS8 1TL, United Kingdom*
[4] *Fermi National Accelerator Laboratory, Batavia, IL 60502, USA*
[5] *Department of Physics, University of Florida, Gainesville, FL 32611, USA*‡

(Dated: November 2, 2021)

Combine **inclusive** cross section
HF-CRPA (for C, O, Ar)
With GENIE ingredients

Model dependence from 'quasielastic'
(but is the separation
Well-defined ?)



Neutrino scattering and accelerator-based experiments

Asymmetry

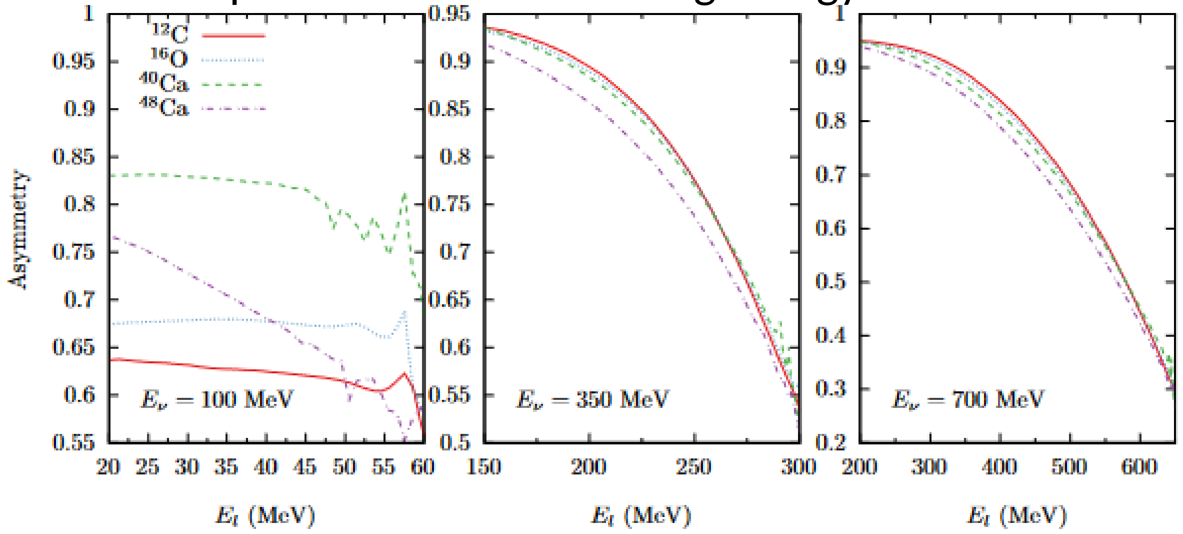
Free nucleon (isospin symmetric):

$$\frac{d\sigma_\nu - d\sigma_{\overline{\nu}}}{d\sigma_\nu + d\sigma_{\overline{\nu}}} = \frac{d\sigma_{VA}}{d\sigma_{VV} + d\sigma_{AA}}$$

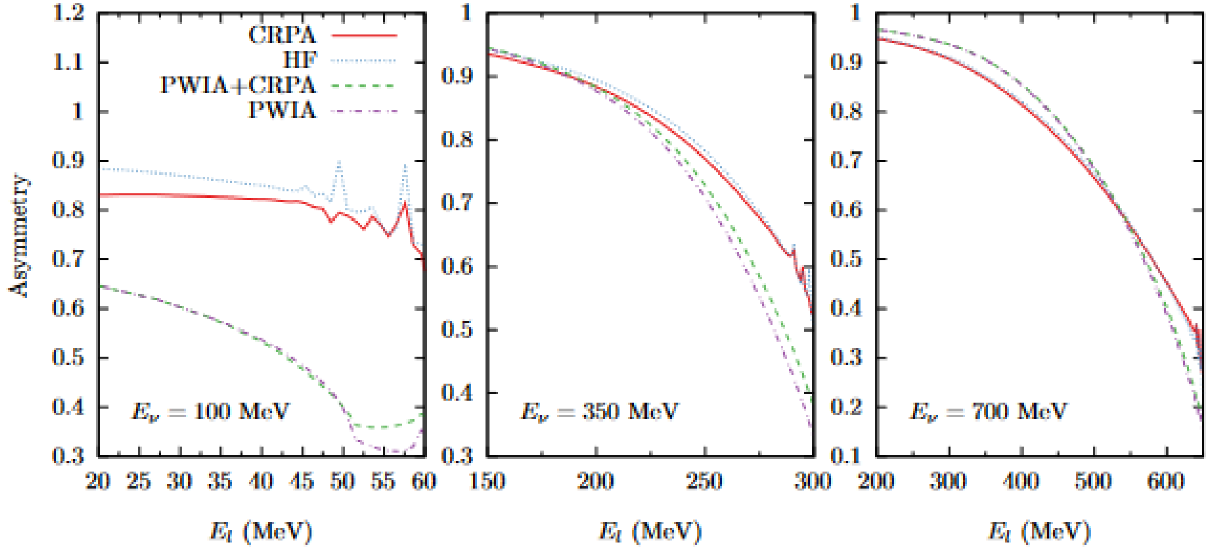
Flux-folded (general L1) + isospin symmetric (L2)

$$A = \frac{\int \Phi_\nu(E_\nu)\sigma_\nu(E_\nu)dE_\nu - \int \Phi_{\overline{\nu}}(E_{\overline{\nu}})\sigma_{\overline{\nu}}(E_{\overline{\nu}})dE_{\overline{\nu}}}{\int \Phi_\nu(E_\nu)\sigma_\nu(E_\nu)dE_\nu + \int \Phi_{\overline{\nu}}(E_{\overline{\nu}})\sigma_{\overline{\nu}}(E_{\overline{\nu}})dE_{\overline{\nu}}} = \frac{\int dE\,(\Phi_\nu - \Phi_{\overline{\nu}})\,\sigma_{VV,AA} + (\Phi_\nu + \Phi_{\overline{\nu}})\,\sigma_{VA}}{\int dE\,(\Phi_\nu + \Phi_{\overline{\nu}})\,\sigma_{VV,AA} + (\Phi_\nu - \Phi_{\overline{\nu}})\,\sigma_{VA}}.$$

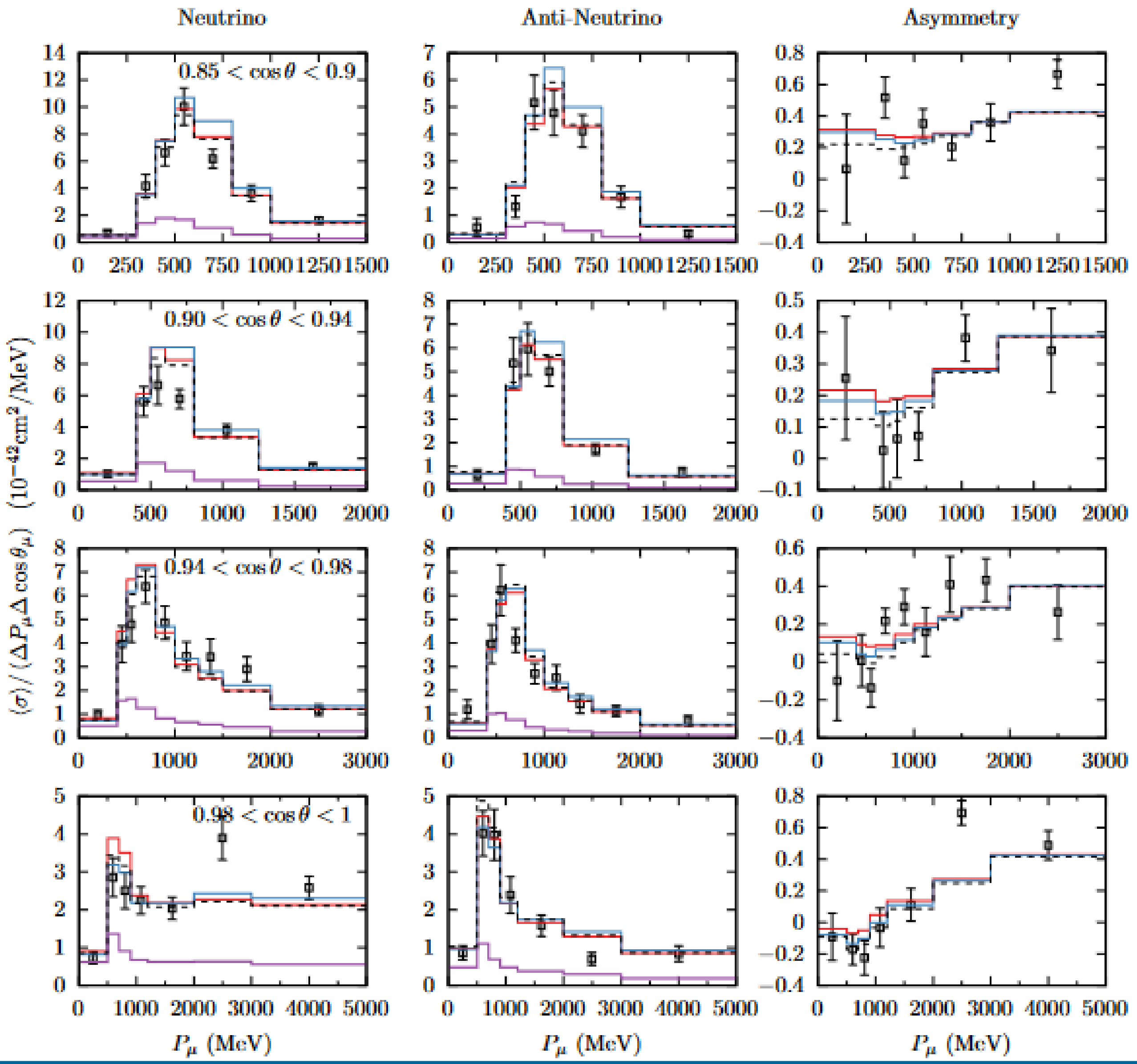
A-dependence fixed incoming energy:



FSI-dependence fixed incoming energy:



Neutrino scattering and accelerator-based experiments



Asymmetry

T2K measurement

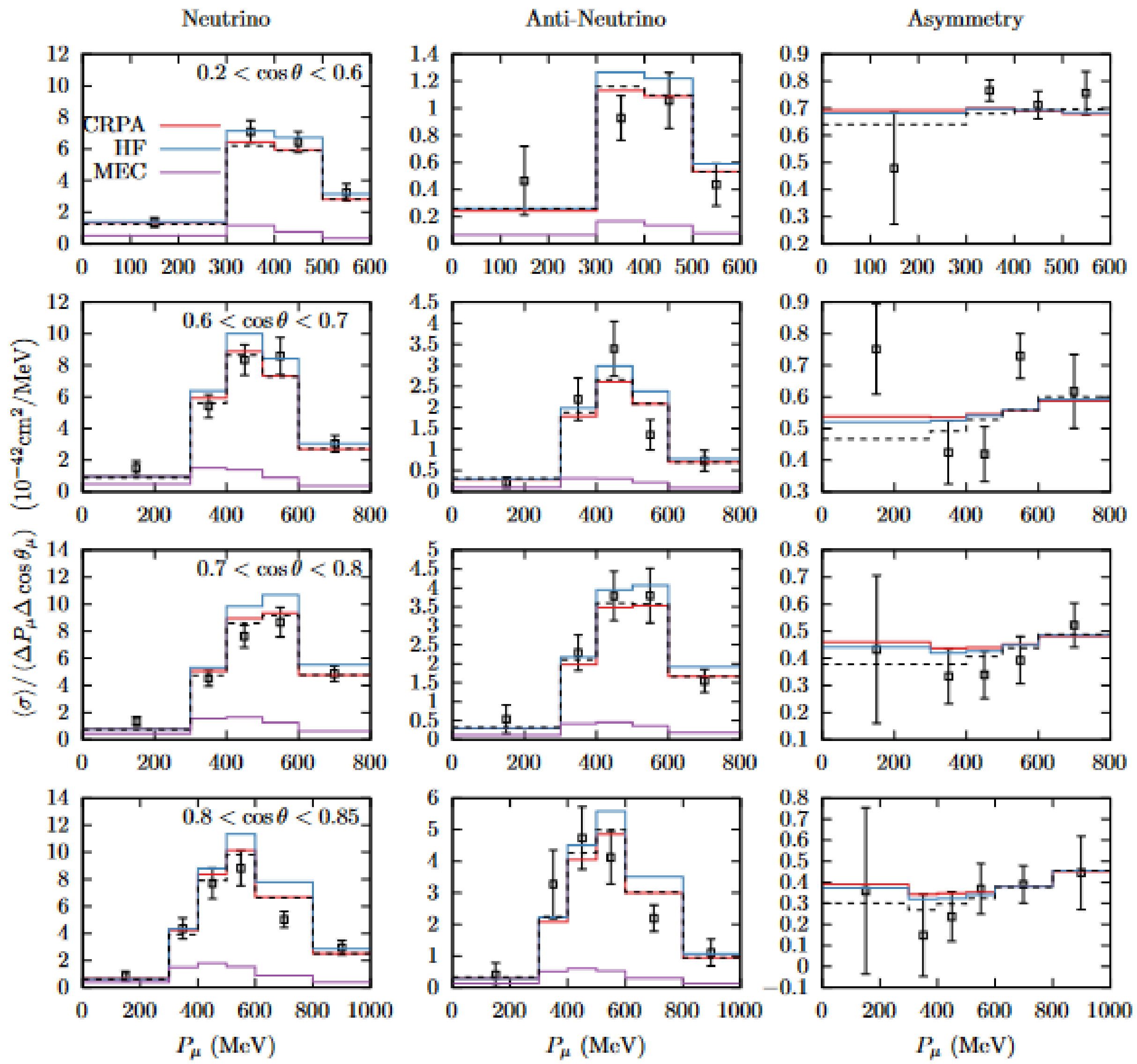
Add SuSAv2 collaboration MEC (RFG calculation)
[G. D. Megias et al. PRD91, 073004 (2015)]

Add Hydrogen in anti-neutrino reactions

Dashed lines: assumption of isospin symmetry
(neglect Coulomb effects)

Asymmetry quite model-independent

Neutrino scattering and accelerator-based experiments



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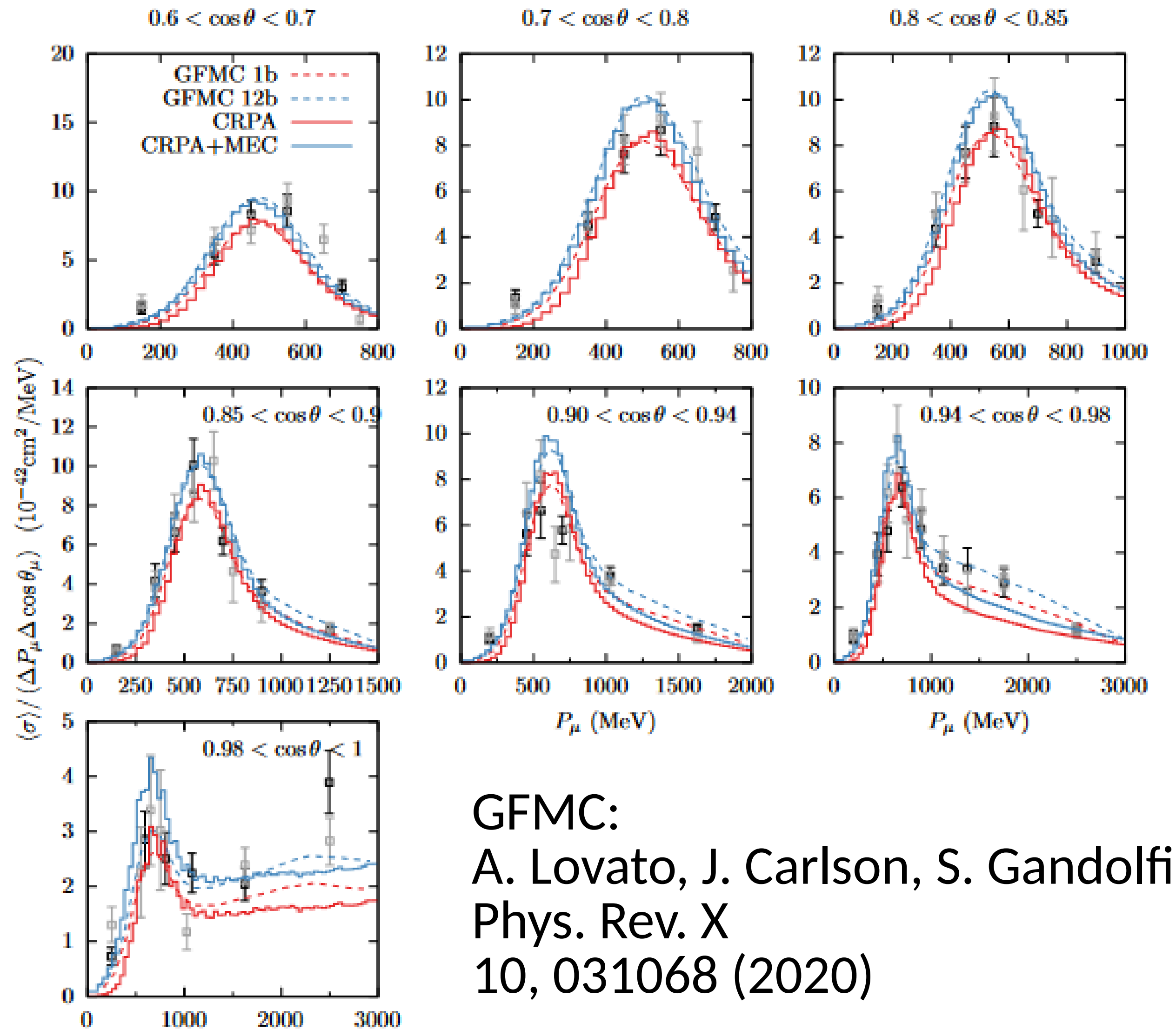


GFMC results

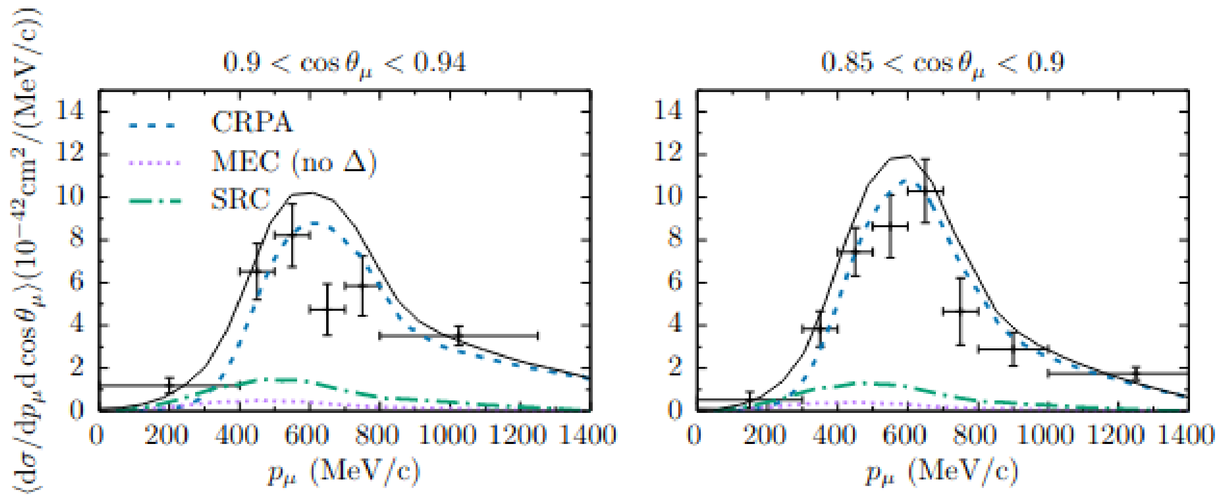
Consistent treatment of one- and two-body Currents!

CRPA & GFMC 1b are similar

CRPA + SuSAv2 MEC & GFMC 1+2b
Similar in backward bins
→ Discrepancies in forward low P region

GFMC:
A. Lovato, J. Carlson, S. Gandolfi, N. Rocco, and R. Schiavilla,
Phys. Rev. X
10, 031068 (2020)

Neutrino scattering and accelerator-based experiments



SRC and MEC in Skyrme-Hartree Fock mean field (T. Van Cuyck 2017)

[T. Van Cuyck, N. Jachowicz, R. González-Jiménez, J. Ryckebusch, and N. Van Dessel Phys. Rev. C 95, 054611]

Is consistency the key ?

LFG+RPA with associated MEC model (talk J. Nieves)

GFMC 1+2b (talk A. Lovato)

Martini LFG+RPA with associated MEC [Phys.Rev.C 81 (2010) 045502]

Lacks Delta currents!

MEC + Delta currents in axial sector in HF mean field [K. Niewczas et al. (in preparation)]

In RMF mean field [talk of T. Franco]

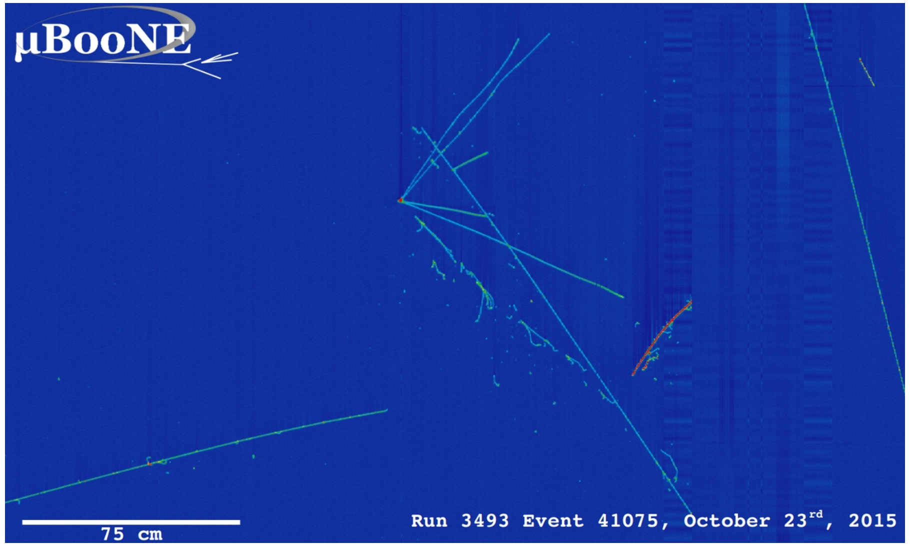
Neutrino scattering and accelerator-based experiments

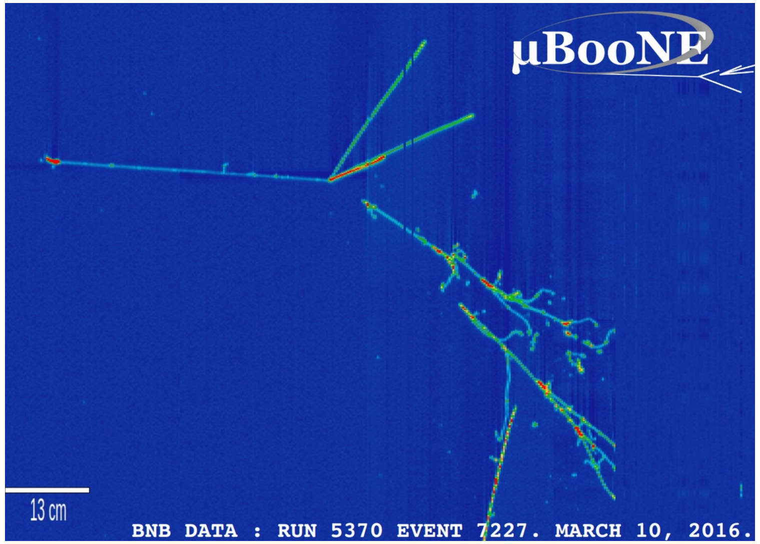
A **'precision era'** because of

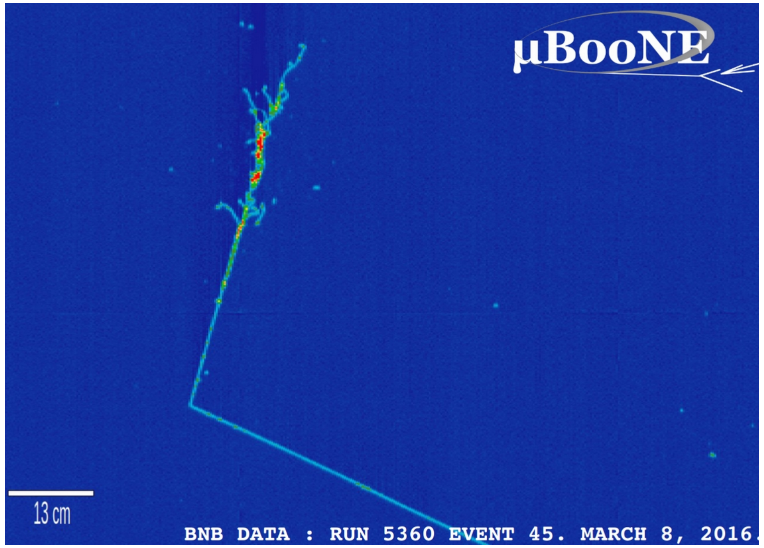
Detector technology (LarTPCs, Gd doping)
Huge detectors, intense fluxes, good statistics

→ Uncertainties projected to come from cross section modeling

An open question: **What do neutrino experiments need ?**







Neutrino scattering and accelerator-based experiments

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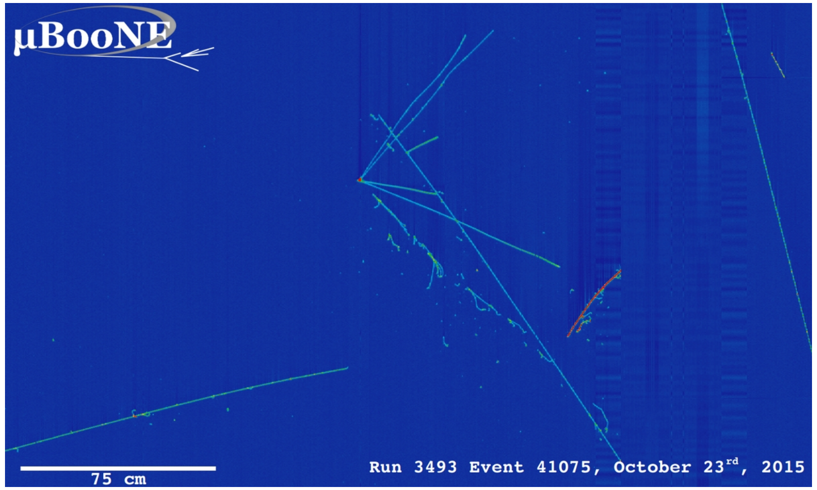
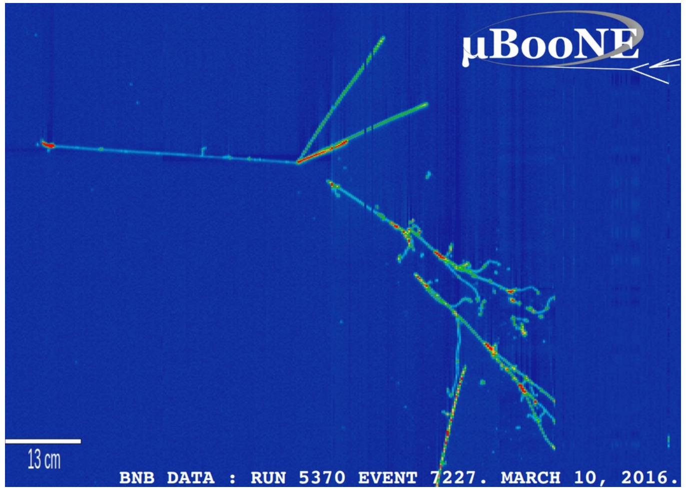
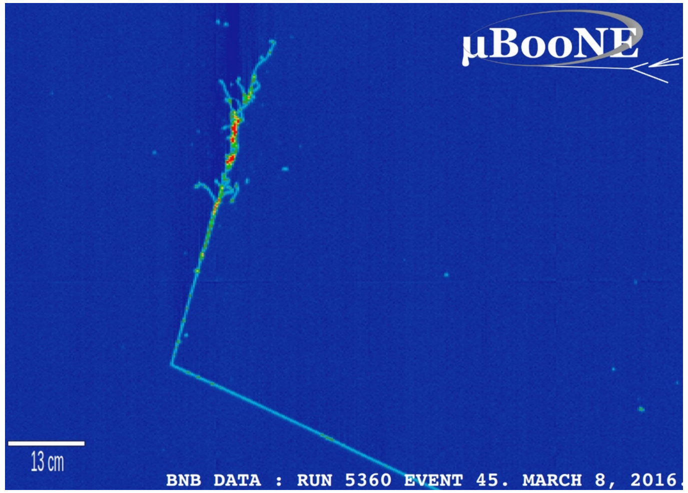






Cross section for all possible semi-inclusive final-states, multiplicities, plus FSI ?
→ Very difficult to combine with ‘precision’

Confidence in a detailed description of a ‘simple’ topology, with error budget, parameters ?
→ Semi-inclusive one-nucleon knockout

Both can co-exist of course

Neutrino scattering and accelerator-based experiments

Neutrino energy reconstruction from semi-inclusive samples

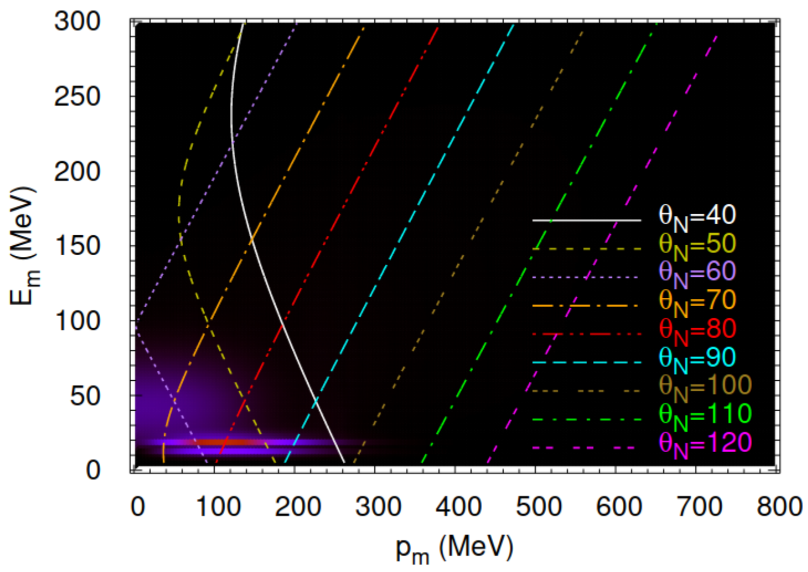
R. González-Jiménez,[1] M. B. Barbaro,[2,3] J. A. Caballero,[4,5] T. W. Donnelly,[6] N. Jachowicz,[7] G. D. Megias,[4,8] K. Niewczas,[7,9] A. Nikolakopoulos,[7] J. W. Van Orden,[10] and J. M. Udías[1]

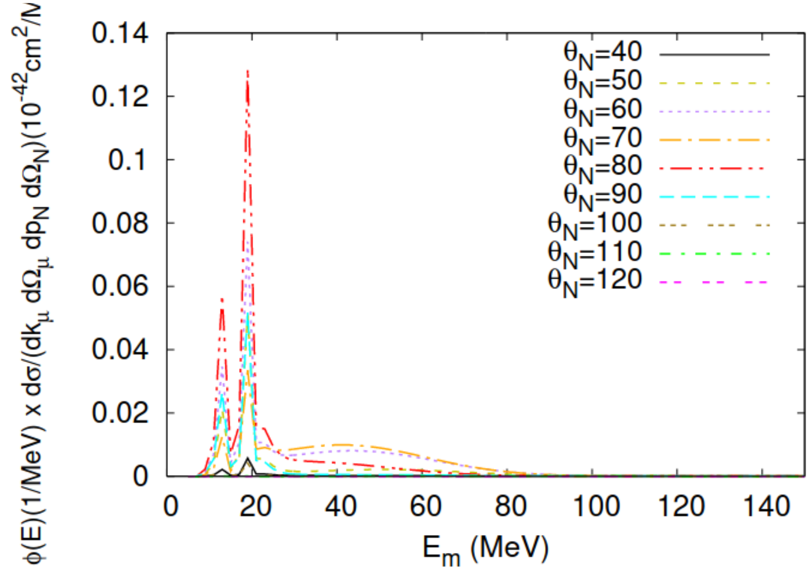
Analysis of 1l1p events
→ A pure signal of single-nucleon knockout minimizes uncertainy on energy reconstruction

$$\left\langle \frac{d^5\sigma}{d|\vec{k}_f|\, d\cos\theta_f\, d|\vec{k}_N|\, d\Omega_N} \right\rangle = \int dE_m \tilde{\Phi}(E_i) \frac{d^5\sigma(E_m)}{d|\vec{k}_f|\, d\cos\theta_f\, d|\vec{k}_N|\, d\Omega_N},$$

$$E_m = E_i - E_f - T_N - T_B = M_B + M_N - M_A.$$

Could be experimentally restricted





Neutrino scattering and accelerator-based experiments

Neutrino energy reconstruction from semi-inclusive samples

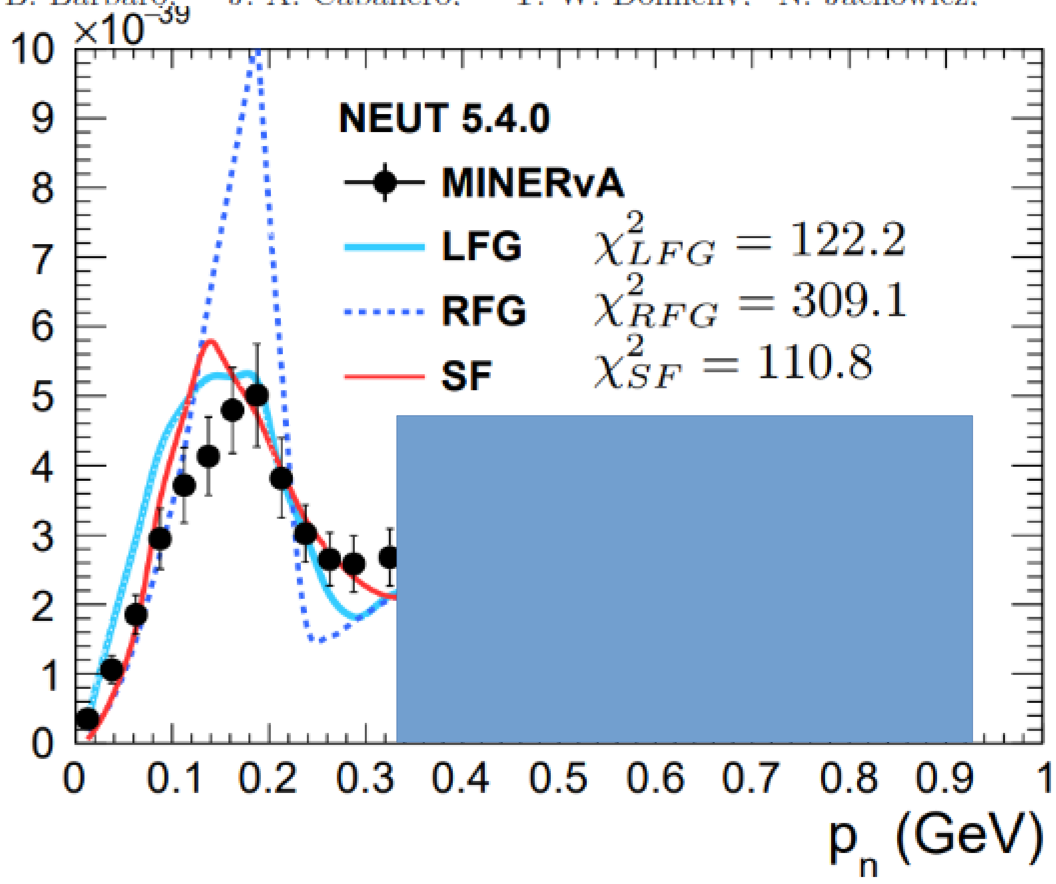
R. González-Jiménez,[1] M. B. Barbaro,[2,3] J. A. Caballero,[4,5] T. W. Donnelly,[6] N. Jachowicz,[7]
G. D. Megias,[4,8] K. Nie

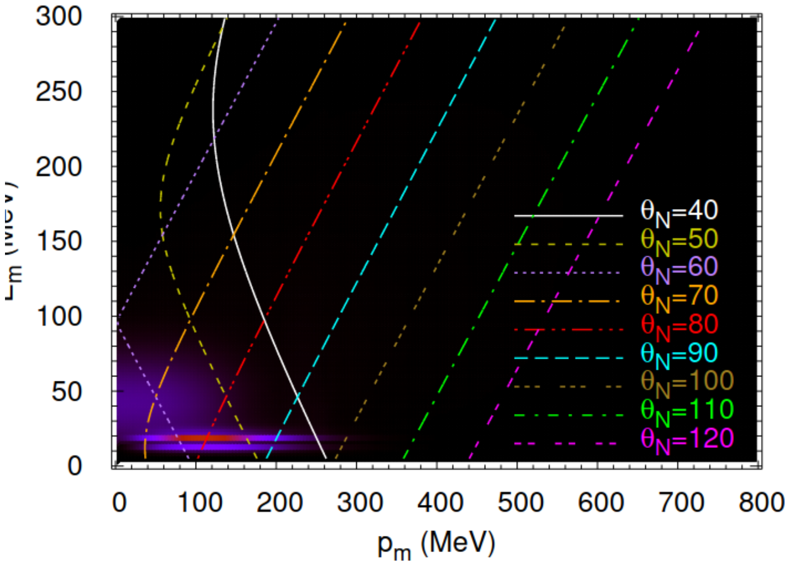
Analysis of 1l1p e
→ A pure signal o
uncertainy on ene

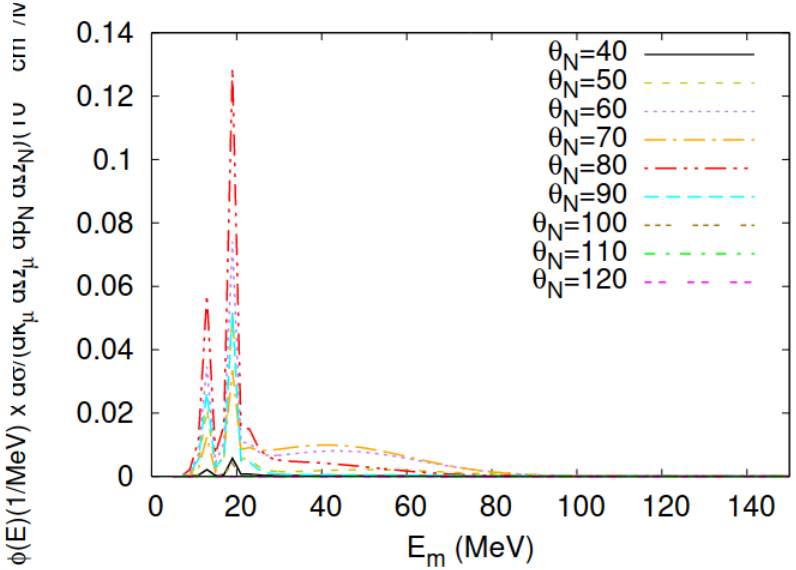
$$\left\langle \frac{d^5\sigma}{d|\vec{k}_f|\, d\cos\theta_f \, \ldots} \right.$$

$$= \int dE_m \tilde{\Phi}(E_i) \ldots$$

$$E_m = E_i - E_f - T \ldots$$







Could be experimentally restricted

Neutrino scattering and accelerator-based experiments

Semi-inclusive 1 nucleon knockout in event generators

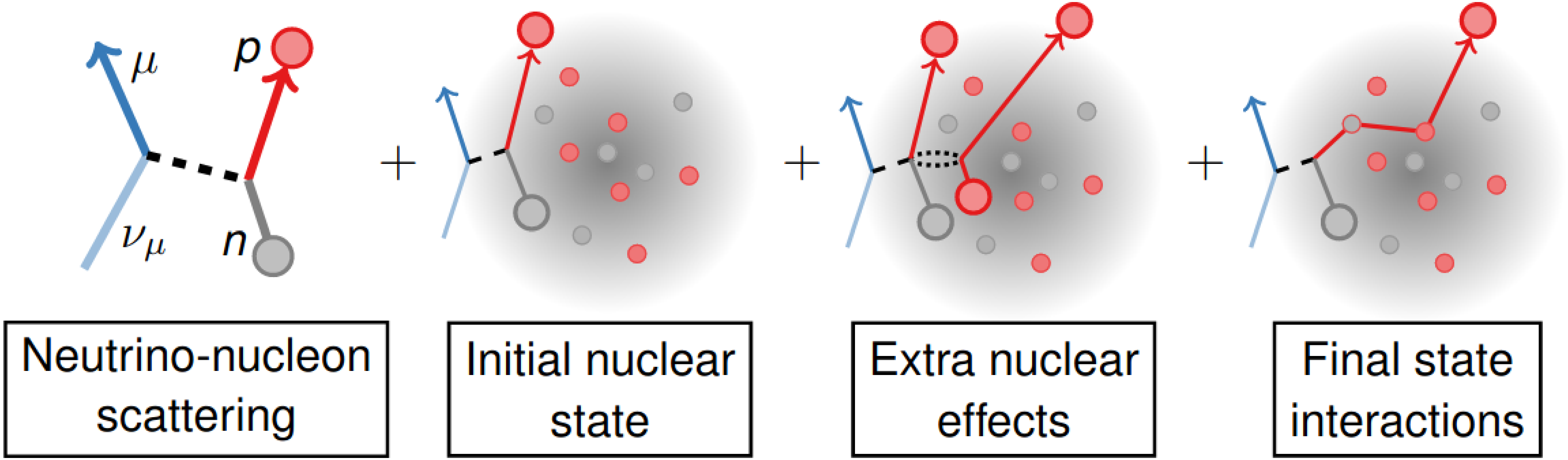
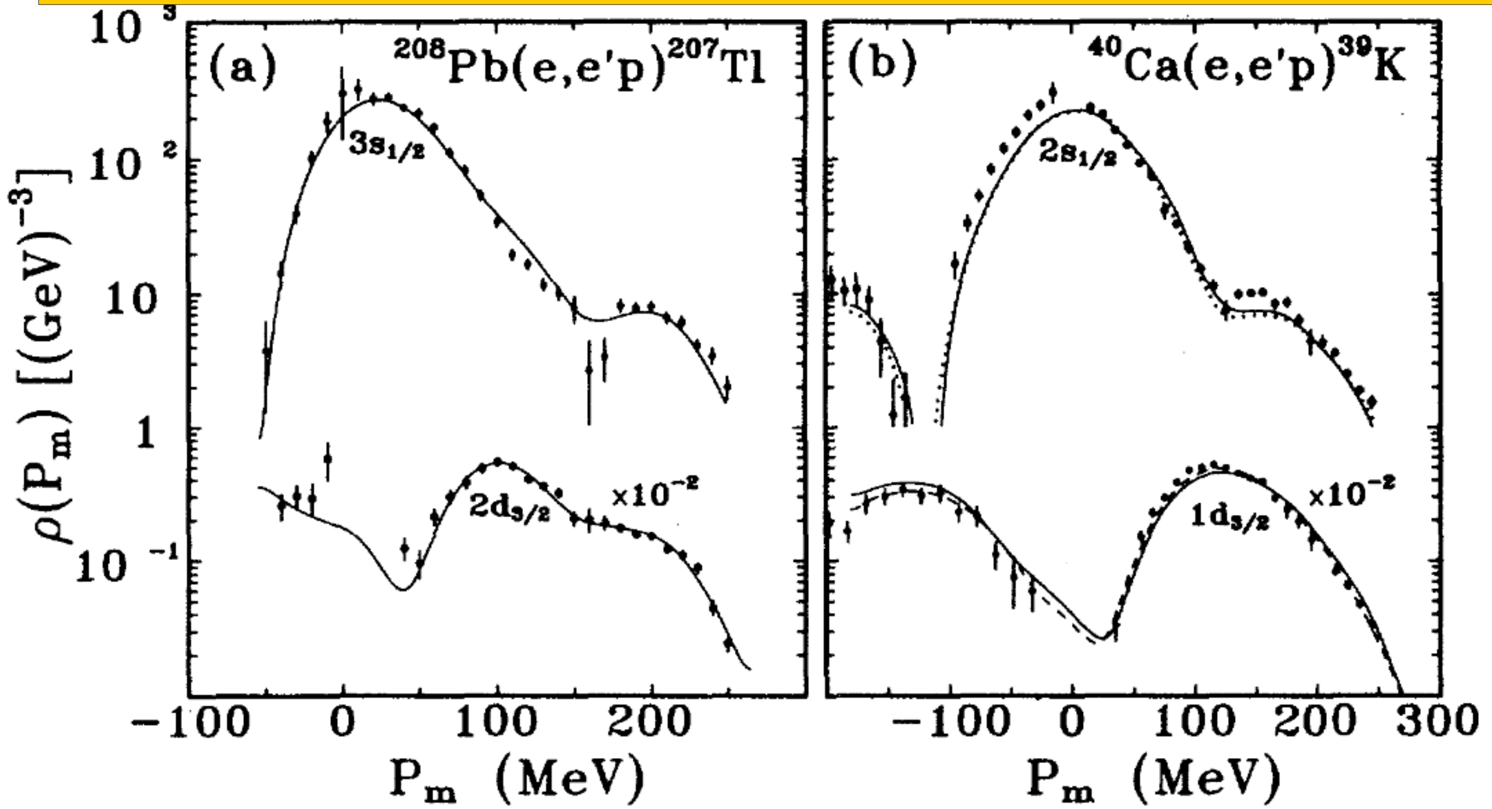


Illustration from K. Niewczas (NuSTEC Workshop on Neutrino-Nucleus Pion Production in the Resonance Region)

‘Factorized’ approach can be consistent for simple initial-state or in the PWIA

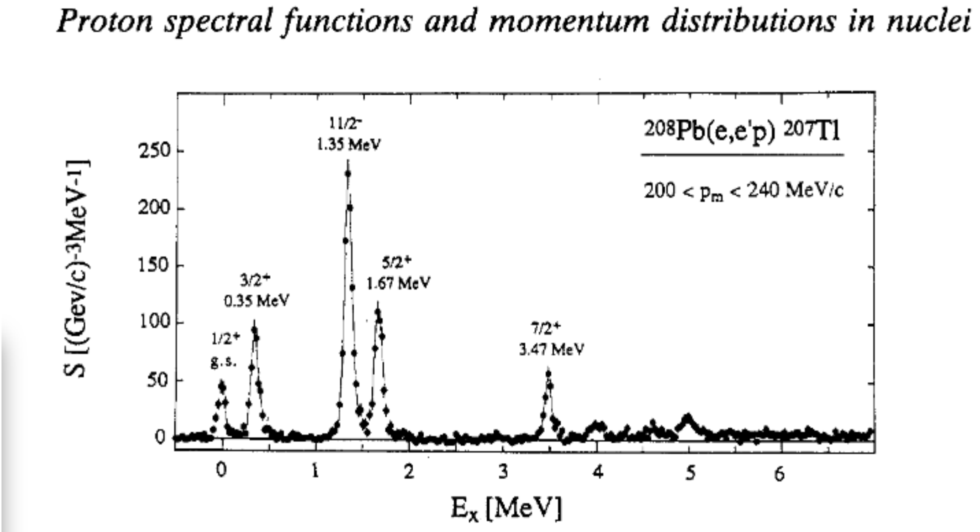
What if the tabularized approach is used ? **No simple relation between inclusive cross section and hadron kinematics** [S. Dolan et al. Phys. Rev. D 101, 033003 (2020)]

FSI in one-nucleon knockout



Spectroscopic factors in ^{40}Ca and ^{208}Pb from (e,e'p): Fully relativistic analysis

J. M. Udías, P. Sarriguren, E. Moya de Guerra, E. Garrido, and J. A. Caballero
Phys. Rev. C **48**, 2731 – Published 1 December 1993

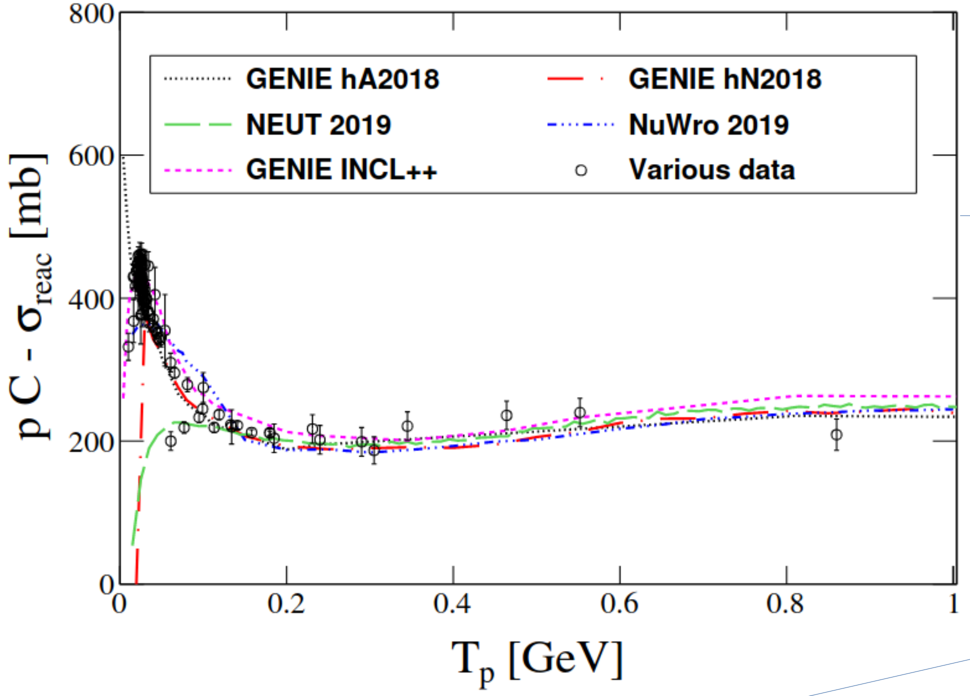


[P K A de Witt Huberts J. Phys. G: 16 507]

Treating the outgoing nucleon wavefunction
In the optical potential can account for FSI
In direct nucleon knockout

Complex potential ‘absorbs’ inelastic interactions

FSI in one-nucleon knockout



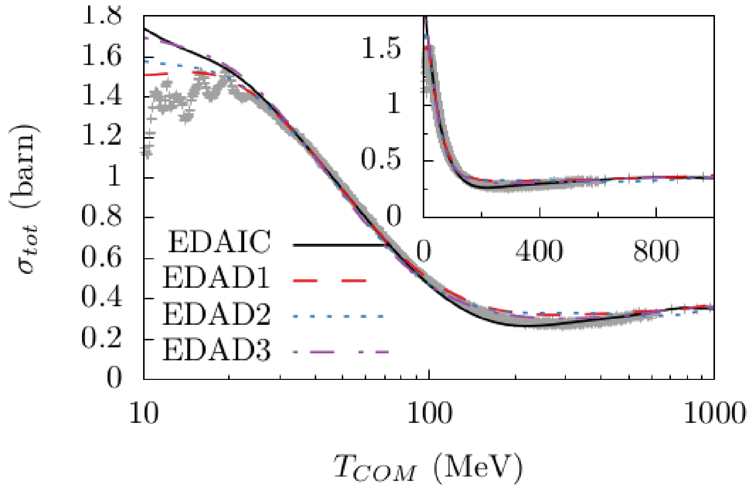
Validation of cascade models
Hadron-nucleus scattering (reaction cross section)

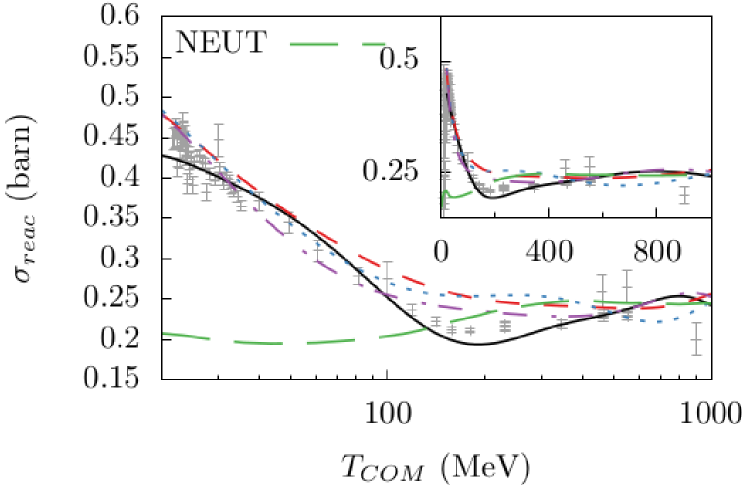
Comparison of validation methods of simulations for final state interactions in hadron production experiments

S. Dytman, Y. Hayato, R. Raboanary, J. T. Sobczyk, J. Tena-Vidal, and N. Vololoniaina
Phys. Rev. D **104**, 053006 – Published 17 September 2021

Global Dirac phenomenology for proton-nucleus elastic scattering

E. D. Cooper, S. Hama, B. C. Clark, and R. L. Mercer
Phys. Rev. C **47**, 297 – Published 1 January 1993





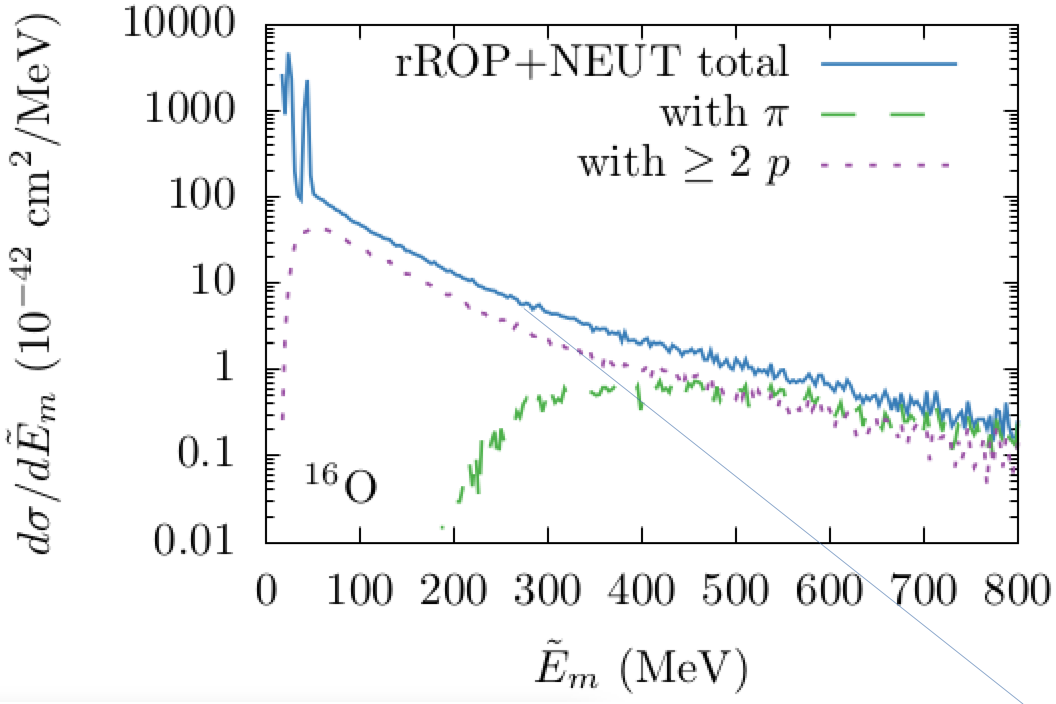
Optical potential

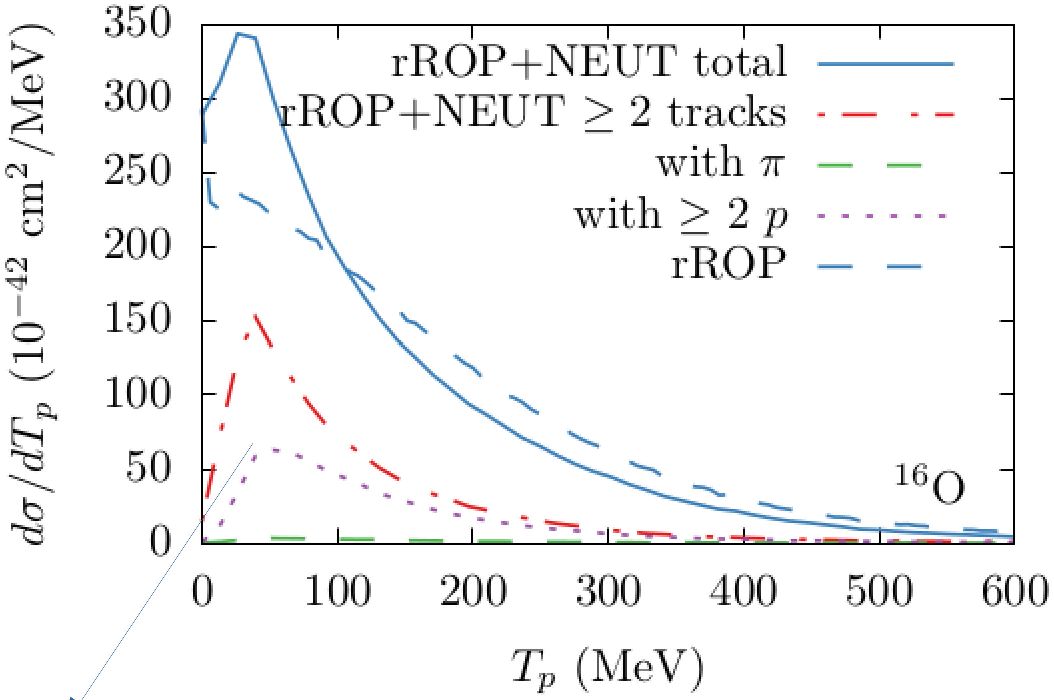
fit to **elastic** proton-nucleus Scattering

total n-C (left)
Reaction p-C (right)

FSI in one-nucleon knockout

Validation of cascade models
Can we bridge between DWIA with optical potential and cascade ?





'Inelastic FSI'

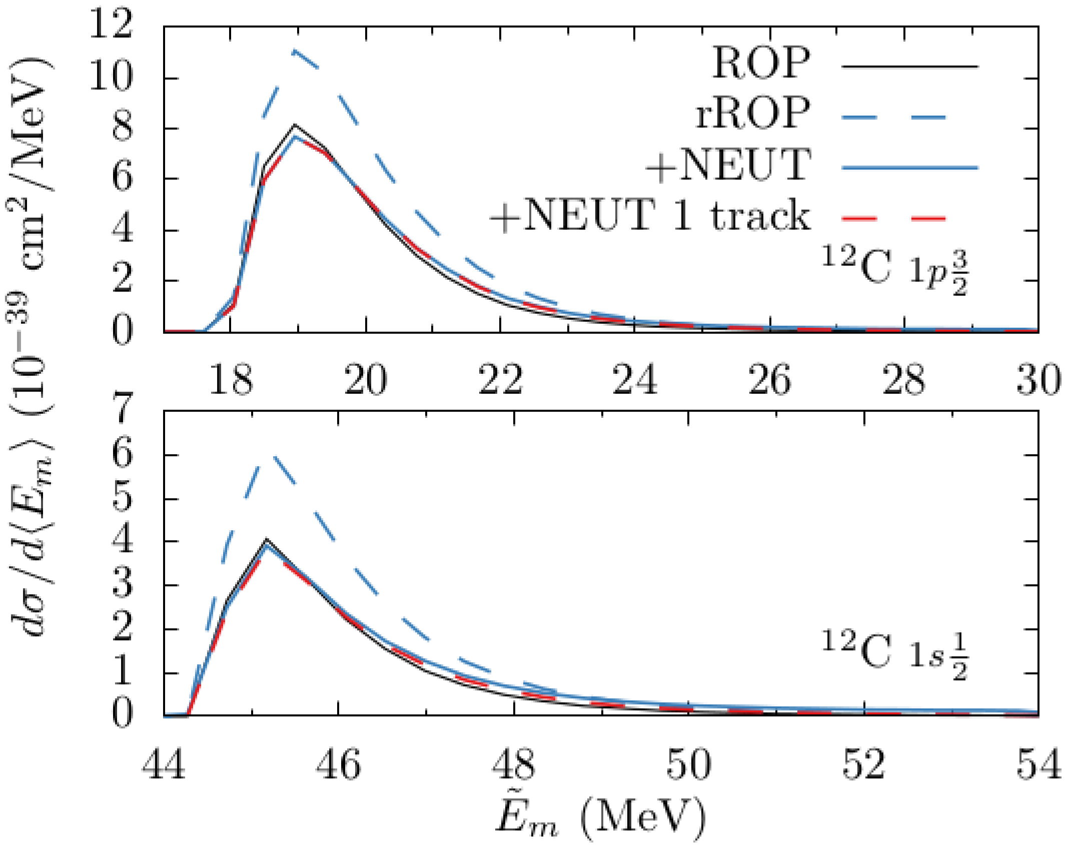
Use unfactorized RDWIA with **real** potential as input to NEUT cascade

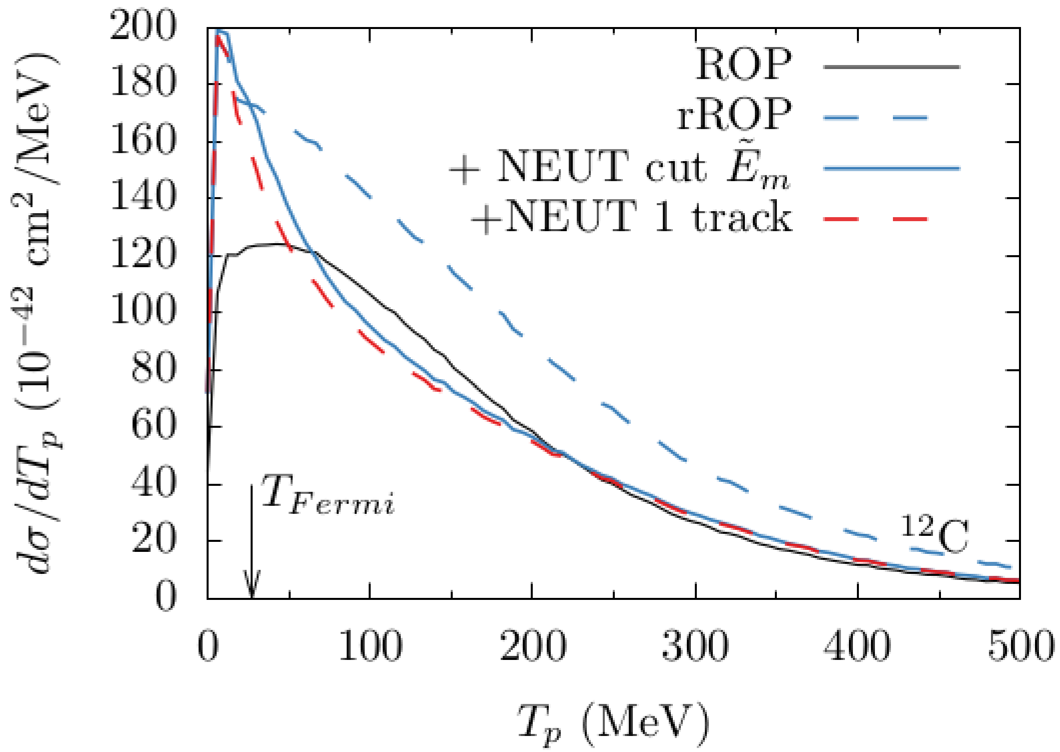
FSI in one-nucleon knockout

Validation of cascade models
Can we bridge between DWIA with optical potential and cascade ?

Use unfactorized RDWIA with **real** potential (rROP) as input to NEUT cascade

Missing energy cut reduces rROP+NEUT to ‘1-track’ results → Can be directly compared to RDWIA with ROP

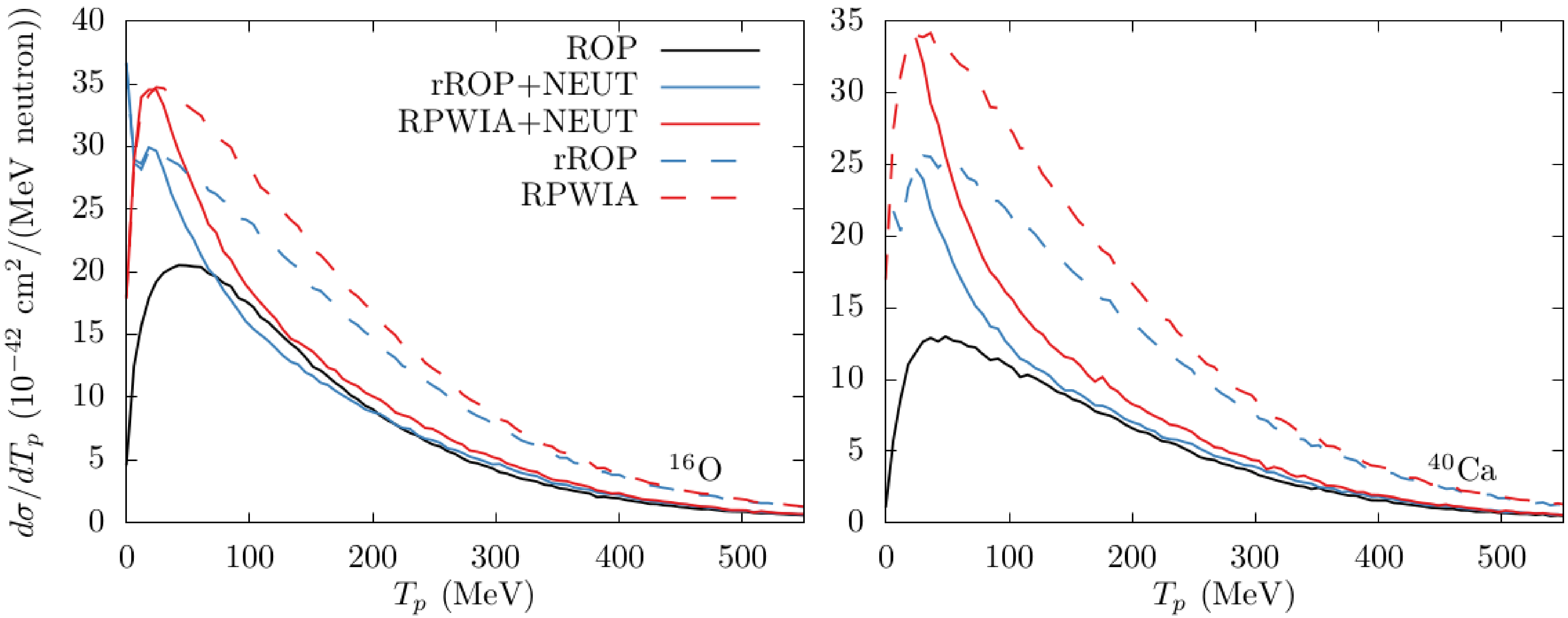




FSI in one-nucleon knockout

Validation of cascade models
Can we bridge between DWIA with optical potential and cascade ?

Robust results for carbon, oxygen, calcium
Elastic channel after FSI in NEUT cascade yields similar results to ROP for T > 100-150 MeV
Discrepancies arise in the low kinetic energy region



Conclusions

Mean-field + CRPA calculations
Robust description of (e,e'), (e,e'p) for a large A-range
Suitable to describe low-energy structure and collective
Excitations in addition to 'direct' interactions

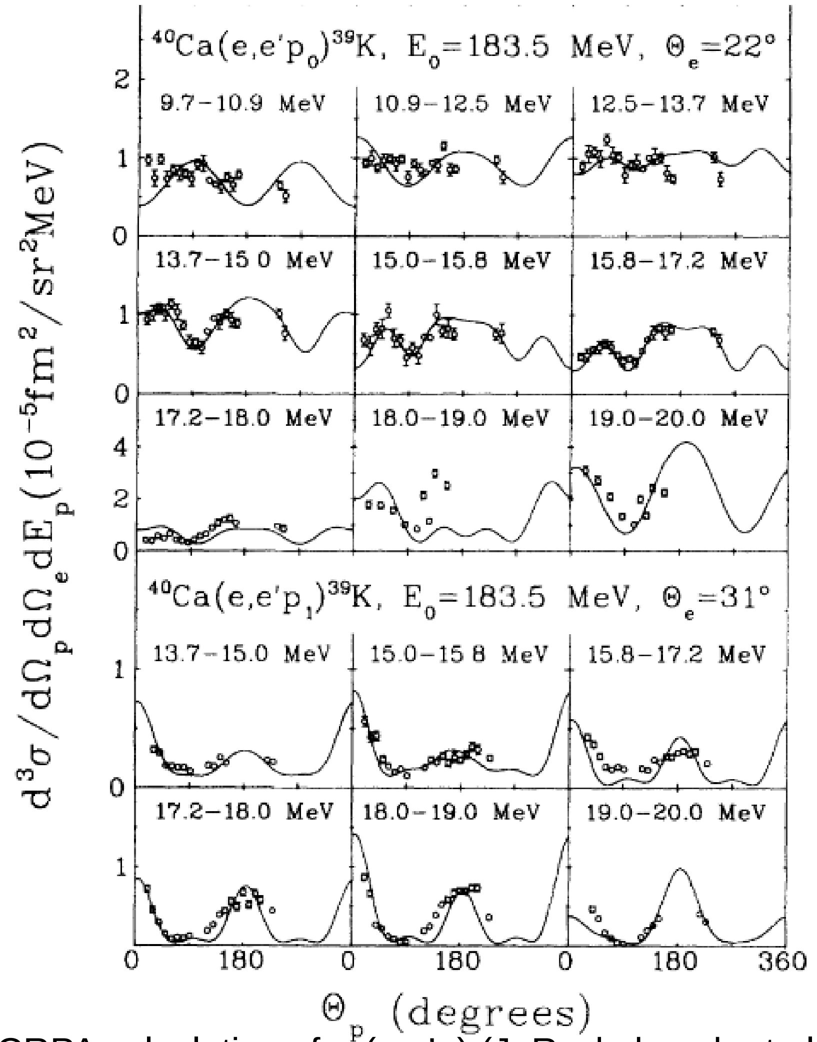
Application to neutrino-data
Mostly succesfull, but not over all kinematics or
Across different experiments

CRPA and model-comparisons for neutrino scattering
Uncertainties for T2K kinematics even in QE scattering
A-dependence can be studied
Difficult to compare model-to-model, 'degeneracy' of
Neutrino data → uncertainty even in 'simplest' mechanism

Validation of cascade models
Straightforward bridge between DWIA with optical potential
and cascade can be used to validate/constrain FSI,
and check the implication of kinematic factorization

Excitation and decay of giant resonances in the ^{40}Ca(e,e'x) reaction

H. Diesener, U. Helm, G. Herbert, V. Huck, P. von Neumann-Cosel, C. Rangacharyulu, A. Richter, G. Schrieder, A. Stascheck, A. Stiller, J. Ryckebusch, and J. Carter
Phys. Rev. Lett. 72, 1994 – Published 28 March 1994



CRPA calculations for (e,e'p) (J. Ryckebusch et al.)